World Meteorological Organization

Mannava V. K. Sivakumar
Raymond P. Motha
Haripada P. Das

Natural Disasters and Extreme Events in Agriculture

Impacts and Mitigation

Mannava V. K. Sivakumar
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(Editors)

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With 93 Figures and 23 Tables

Springer

Dr. Mannava V. K. Sivakumar
Agricultural Meteorology Division
World Meteorological Organization
7 bis, Avenue de la Paix
1211 Geneva 2
Switzerland

Dr. Raymond P. Motha
USDA/OCE/WAOB
1400 Independence Ave. SW
Room 4441, South Building
Washington DC 20250
USA

Dr. Haripada P. Das
Meteorological Office
Division of Agricultural Meteorology
Shivajinagar
Pune 411005
India

Library of Congress Control Number: 2005921509

ISBN-10 3-540-22490-4 Springer Berlin Heidelberg New York
ISBN-13 978-3-540-22490-7 Springer Berlin Heidelberg New York

Springer is a part of Springer Science+Business Media
springeronline.com

Printed in The Netherlands

Cover Design: E. Kirchner, Heidelberg
Production: Almas Schimmel
Typesetting: LE-TEX Jelonek, Schmidt & Vöckler GbR, Leipzig, Germany
Printing: Krips bv, Meppel
Binding: Stürtz AG, Würzburg

Printed on acid free paper 30/3141/as 5 4 3 2 1 0

Foreword

Natural disasters cause heavy loss of life and property, forcing humankind to "learn to live" with these calamities. During the period 1992–2001, floods, droughts, tropical cyclones, hurricanes, typhoons, storm surges, landslides and wild fires and other weather- and climate-related calamities have killed over 622,000 people and affected over 2 billion people. For the same period, losses from natural disasters of hydrometeorological origin were estimated at US$ 446 billion, accounting for about 65% of damages due to all natural disasters.

Natural disasters also affect socio-economic activities. Of these, agricultural production is highly dependent on weather, climate and water availability and is adversely affected by the weather- and climate-related disasters. Failure of rains and occurrences of natural disasters such as floods and tropical cyclones could lead to crop failures, flood insecurity, famine, loss of property and life, mass migration and decline in national economy. The growing concern with the possible impact of natural disasters and extreme events on agriculture and forestry has created new demands for information from, and assessment by agrometeorologists. The need for reorienting and recasting meteorological information, fine-tuning of climatic analysis and presentation in forms suitable for agricultural decision-making and helping marginal farmers cope with the adverse impact of natural disasters and extreme events has become more pressing.

Due to recent advances in science and technology, it is now possible to forecast the occurrence of extreme events and the nature of devastation that they may cause with a greater degree of accuracy and with longer lead time. Availability of such crucial information in advance greatly helps in taking effective measures for prevention and mitigation of loss of life and property and avoid human suffering.

Awareness of the need to give greater attention to disaster mitigation, preparedness and management has been growing among decision-makers. Pre-disaster preparedness now forms an integral part of national development planning in many countries. The Commission for Agricultural Meteorology (CAgM) of WMO at its thirteenth session formed an Expert Team on "Reduction of the Impact of Natural Disasters and Mitigation of Extreme Events in Agriculture, Forestry and Fisheries". The Team was invited to provide guidance on the strategies to reduce the destructive effects of the extreme events by stimulating data acquisition for forecasting and early warning systems, and by making improvements in disaster preparedness.

The China Meteorological Administration (CMA) hosted a meeting of the CAgM Expert Team in Beijing, China from 16 to 20 February 2004. The meeting reviewed and discussed the papers prepared by the members of the expert team and developed appropriate recommendations to reduce the impact of natural disasters and mitigate extreme events in agriculture, forestry and fisheries. I hope that the proceedings of this meeting will serve as a useful source of information to all institutions and agencies interested in this subject.

(M. Jarraud)
Secretary-General
World Meteorological Organization

Preface

Over the past few decades, there is an increasing intensity and frequency of natural disasters around the world with severe socio-economic impacts, especially in the developing world. Agriculture is one of the most important sectors heavily impacted by the natural disasters and the challenge in front of the agrometeorologists around the world is that more than ever before, there is a great need to more effectively integrate and deploy the skills to use climate information and products successfully in natural disaster preparedness strategies. There is also a need to develop locally agrometeorological adaptation strategies to reduce the effect of natural disasters especially in vulnerable regions where food and fibre production is most sensitive and vulnerable to climate fluctuations.

The Commission for Agricultural Meteorology (CAgM) of WMO at its thirteenth session held in Ljubljana, Slovenia established an Expert Team (ET) on Reducing the Impact of Natural Disasters and Mitigation of Extreme Events in Agriculture, Rangelands, Forestry and Fisheries. A meeting of this ET was held in Beijing, China from 16 to 20 February 2004 at the kind invitation of the Chinese Meteorological Administration (CMA). The decision to organize this meeting at this point of time is largely due to the increasing concerns with the impact of natural disasters in recent times as highlighted by Mr M. Jarraud in the Foreword. Fifty-four participants from eight countries, including forty-five from China, attended the meeting. In addition to the experts from CAgM, three experts nominated by the Joint Commission on Marine Meteorology (JCOMM) also participated in the meeting. The specific objectives of the meeting were:

- To review the current status of application of climate and weather information in reducing the impacts of natural disasters and mitigation of extreme events in agriculture, forestry and fisheries.
- To assess the potential for improved disaster reduction strategies and relevant agrometeorological applications in different countries for sustainable agricultural development.
- To identify the shortcomings and limitations of current disaster management and mitigation strategies in reducing the risks associated with natural disasters.
- To discuss the resources and strategies, including education and training, required for promotion of sustained efforts in disaster reduction and mit-

igation of extreme events and research activities to better understand the potential risks to agriculture from natural disasters and extreme events.

Altogether there were 10 sessions (including opening and closing session) in the meeting during which 21 invited papers were presented dealing with various aspects on reducing the impact of natural disasters and mitigation of extreme events in agriculture, rangelands, forestry and fisheries. All the participants in the meeting were engaged in discussions on these papers and developed several useful recommendations for all organizations involved in disaster reduction and mitigation of extreme events, in particular the National Meteorological and Hydrological Services. It should be noted that the recommendations listed reflect the considered opinions of the participants at the meeting and we are aware that these recommendations do not address the totality of the needs. We do hope that these will encourage others to suggest further ways in which the science and applications of agricultural meteorology could contribute to reducing the impacts of natural disasters and extreme events in agriculture.

As Editors of this volume, we would like to thank all the authors for their efforts and for their cooperation in bringing out this volume in time. We are most grateful to the Chinese Meteorological Administration (CMA) for hosting this meeting and to the Secretary-General of WMO for his continuous support and encouragement.

M.V.K. Sivakumar
Agricultural Meteorology Division
World Meteorological Organization
7 bis, Avenue de la Paix
CP 2300
1211 Geneva 2
Switzerland

R.P. Motha
USDA/OCE/WAOB
1400 Independence Ave. SW
Room 4441, South Building
Washington DC 20250
USA

H.P. Das
Meteorological Office
Division of Agricultural Meteorology
Shivajinagar
Pune 411005
India

Contents

List of Contributors

Bi Baogui
Weather Forecast Office, National Meteorological Center
China Meteorological Administration
46 ZhongGuancun South Avenue, 100081, Beijing, P.R. China
E-mail: bibg@cma.gov.cn

Wang Chunyi
Chinese Meteorological Society
No. 46, Zhongguancun Nandajie, 100081, Beijing, China
E-mail: wcy@cms1924.org

Haripada P. Das
Meteorological Office, Division of Agricultural Meteorology
Shavajinagar, Pune, 411005 India
E-mail: hpd_ag@rediffmail.com

Douglas G. Fox
Center for Investigations and Research of the Atmosphere (CIRA)
Colorado State University
Fort Collins, Colorado 80526 USA
E-mail: dfox@cira.colostate.edu

Bernard Gomez
Department of Water Resources
Banjul, Gambia
E-mail: be63gomez@hotmail.com

R.P.R. Guerreiro
Division of Hydrometeorology and Agricultural Meteorology
Department of Climate and Atmospheric Environment
Institute of Meteorology
Lisbon, Portugal
E-mail: rita.guerreiro@meteo.pt

Guo Jianping

Institute of Eco-environment and Agrometeorology
Chinese Academy of Meteorological Sciences
No. 46, Zhongguancun Nandajie, 100081, Beijing, China
E-mail: guojp@cams.cma.gov.cn

Penehuro Lefale

National Institute of Water and Atmospheric Research
P.O. Box 109-695
Newmarket, Auckland, New Zealand

Sanmei Li

National Satellite Meteorological Center of China (NSMC)
46 Zhongguancun Nandajie, Beijing 100081, China
E-mail: sanmeili@nsmc.cma.gov.cn

Jiao Meiyan

National Meteorological Center, China Meteorological Administration
46 ZhongGuancun South Avenue, 100081, Beijing, P.R. China
E-mail: Jiaomy@cma.gov.cn

Raymond P. Motha

U.S. Department of Agriculture, World Agricultural Outlook Board
1400 Independence Avenue, S.W.
Room 4441, South Building, Washington, D.C. 20250
E-mail: rmotha@oce.usda.gov

Liliana Nuñez

Servicio Meteorológico Nacional
C.P. 1002
Buenos Aires, Argentina
E-mail: lnunez@meteofa.mil.ar

John Jianhe Qu

School of Computational Science (SCS)
GeorgeMasonUniversity (GMU)
4400 University Drive, MS 5C3
Fairfax, VA. 220303 USA
E-mail: jqu@gmu.edu

Allen.R. Riebau

USDA Forest Service Research and Development
Wildlife, Fisheries, Watershed and Air Research (WFWAR)
14th and Independence, S.W., RPC-4
Washington, D.C. 20250-1113 USA
E-mail: ariebau@fs.fed.us

M. James Salinger

National Institute of Water and Atmospheric Research
P.O. Box 109-695
Newmarket, Auckland, New Zealand
E-mail: j.salinger@niwa.co.nz

Wang Shili

Institute of Eco-environment and Agrometeorology
Chinese Academy of Meteorological Sciences
No. 46, Zhongguancun Nandajie, 100081, Beijing, China
E-mail: wangsl@cams.cma.gov.cn

Mannava V. K. Sivakumar

World Meteorological Organization
7 bis, Avenue de la Paix
1211 Geneva 2, Switzerland
E-mail: msivakumar@wmo.int

Chang Tao

Weather Forecast Office, National Meteorological Center
China Meteorological Administration
46 ZhongGuancun South Avenue, 100081, Beijing, P.R. China
E-mail: zhangtao@cma.gov.cn

Donald A. Wilhite

National Drought Mitigation Center
and International Drought Information Center
University of Nebraska
Lincoln, Nebraska 68583-0749 U.S.A.
E-mail: dwilhite2@unl.edu

William J. Wright

National Climate Centre, Australian Bureau of Meteorology
GPO Box 1289K, Melbourne, 3001 Australia
E-mail: w.wright@bom.gov.au

Ming Xu

Shanghai Typhoon Institute
166 Puxi Road, Shanghai, China, 200030
E-mail: xum@mail.typhoon.gov.cn

Qiuzhen Yang

Shanghai Typhoon Institute
166 Puxi Road, Shanghai, China, 200030
E-mail: yangqz@mail.typhoon.gov.cn

Du Yaodong
Climatic and Agrometeorological Center
Meteorological Bureau of Guangdong Province
People's Republic of China
E-mail: yddu@grmc.gov.cn

Ming Ying
Shanghai Typhoon Institute
166 Puxi Road, Shanghai, China, 200030
E-mail: yingm@mail.typhoon.gov.cn

Xu Yinglong
National Meteorological Center, CMA
Beijing, China, 100081
E-mail: xuyl@cma.gov.cn /
xuyinong_china@163.com

Yeping Zhang
National Satellite Meteorological Center of China (NSMC)
46 Zhongguancun Nandajie, Beijing 100081, China
E-mail: yepingzhang@nsmc.cma.gov.cn

Yanxia Zhao
Chinese Academy of Meteorological Sciences(CAMS)
46 Zhongguancun Nandajie, Beijing 100081, China
E-mail: zyx@cams.cma.gov.cn

Huo Zhiguo
Institute of Eco-environment and Agrometeorology
Chinese Academy of Meteorological Sciences
No. 46, Zhongguancun Nandajie, 100081, Beijing, China
E-mail: huozhigg@cams.cma.gov.cn

Impacts of Natural Disasters in Agriculture, Rangeland and Forestry: an Overview

Mannava V. K. Sivakumar

Abstract Natural disasters play a major role in agricultural development and the economic cost associated with all natural disasters has increased 14 fold since the 1950s. Natural disasters are classified into hydro-meteorological and geophysical disasters. Definitions of various types of hydrometeorological disasters such as floods, droughts, cyclones, forest fires, heatwaves were presented. Evidence available from different parts of the world showed that there is a rising trend in the occurrence of natural disasters from 1993 to 2002. Impacts of droughts, cyclones, floods, forest and bush fires on agriculture, rangeland and forestry were described with suitable examples. While the predominant impacts from these disasters are negative, there are some positive impacts as well. Environmental degradation is one of the major factors contributing to the vulnerability of agriculture, forestry and rangelands to natural disasters because it directly magnifies the risk of natural disasters. Some methodological issues concerning the characterization of the impacts of natural disasters in agriculture, rangeland and forestry were described. There is an urgent need to mitigate the effects hydro-meteorological disasters through improved use of climate and weather information and forecasts, early warning systems, and appropriate methods of management of land and natural resources.

1.1 Introduction

Throughout human history, natural disasters have played a major role in the economic development and survival of humanity. Historians now believe that an unusually long and severe drought was a primary cause of the disappearance of the Maya civilization (Hodell et al. 1995).

During the past four decades, natural hazards such as droughts, floods, storms and tropical cyclones and wildland fires have caused major loss of human lives and livelihoods, the destruction of economic and social infrastructure, as well as environmental damages. Deaths since the 1950s increased 50 percent each decade, whereas the corresponding population growth rate was only 20 percent (Kreimer and Munasinghe 1991).

The economic cost associated with all natural disasters has increased 14 fold since the 1950s (World Disasters Report 2001). World wide, annual economic costs related to natural disasters have been estimated at about $ 50 to 100 billion. According to China's Ministry of Civil affairs, natural disaster costs have averaged US$ 12 billion or so annually during the past 10 years with an estimated 200 million or so people affected annually. By the year 2050 it is predicted that globally 100,000 lives will be lost each year to natural disasters and the global cost could top $ 300 billion annually (SEI, IUCN, IISD 2001).

The world land use data (FAO 1999) show that 70% of the global land use is for agriculture, rangeland and forestry with 12% of the land used for arable and permanent crops, 31% for forest and woodlands and 27% for permanent pasture. Agriculture is also the essential source of income in most developing countries. For example, agriculture accounts for 70 percent of full-time employment in Africa, 33 percent of total GDP, and 40 percent of total export earnings. Agricultural production is highly dependent on weather, climate and water availability, and is adversely affected by weather- and climate-related disasters.

In order to ensure sustainable agricultural production and assure the livelihood of millions of people, especially in the developing countries, a better understanding of the natural disasters that impact agriculture, forestry and rangelands is essential. This paper provides an overview of the major issues involved.

1.2
Natural Disasters – Definitions and Types

In simple terms, a natural disaster is a natural event with catastrophic consequences for living things in the vicinity. But, different definitions of natural disasters are often used and some of them are based primarily on loss of life.

The emergencies database (EM-DAT) operated by the Centre for Research on the Epidemiology of Disasters (CRED) classifies an event as a disaster if at least "10 people are killed and/or 100 or more are affected and/or an appeal for international assistance is made or a state of emergency declared" (CRED 2000). Clearly, for agricultural purposes only the last part of this definition is applicable.

According to a 1992 disaster training programme, United Nations (UN) defines a disaster as "a serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the capacity of the affected society to cope using only its own resources". With suitable interpretation of some parts, this definition could be used by agriculture.

Anderson (1990) defines natural disasters as temporary events triggered by natural hazards that overwhelm local response capacity and seriously affect the social and economic development of a region.

Susman et al. (1983) describe disasters as the interface between an extreme physical environment and a vulnerable human population. Such definitions emphasize the fact that the socio-economic and political factors are of paramount importance in understanding why populations are vulnerable to the environment and experience disasters.

According to World Disaster Report (2003), natural disasters include hydro-meteorological disasters and geophysical disasters. The hydro-meteorological disasters include landslides/avalanches; droughts/famines; extreme temperatures and heat waves; floods; hurricanes; forest/scrub fires; windstorms; and others (insect infestation and waves/surges). The geophysical disasters include earthquakes and volcanic eruptions. In this paper, only the hydro-meteorological disasters impacting agriculture, rangeland and forestry are dealt with. Definitions of each of these disasters primarily from are given below.

A landslide is a geological phenomenon which includes a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flow. Although gravity acting on an over steepened slope is the primary reason for a landslide, there are other contributing factors. An avalanche is caused when a build up of snow is released down a slope, and is one of the major dangers faced in the mountains in winter. An avalanche is a type of gravity current.

Drought is the consequence of a natural reduction in the amount of precipitation over an extended period of time, usually a season or more in length, often associated with other climatic factors (such as high temperatures, high winds and low relative humidity) that can aggravate the severity of the event. Drought is not a purely physical phenomenon, but instead is an interplay between natural water availability and human demands for water supply. The precise definition of drought is made complex due to political considerations, but there are generally three types of conditions that are referred to as drought.

- Meteorological drought is brought about when there is a prolonged period with below average precipitation.
- Agricultural drought is brought about when there is insufficient moisture for average crop or range production. This condition can arise, even in times of average precipitation, due to soil conditions or agricultural techniques.
- Hydrologic drought is brought about when the water reserves available in sources such as aquifers, lakes, and reservoirs falls below the statistical average. This condition can arise, even in times of average (or above average) precipitation, when increased usage of water diminishes the reserves.

A heat wave is a prolonged period of excessively hot weather, which may be accompanied by excessive humidity. The term is relative to the usual weather in the area, so temperatures that people from a hotter climate find normal can be a heat wave if they are outside the normal pattern for a cooler area. The term is applied both to "ordinary" weather variations and to extraordinary spells of heat which may only occur once a century.

Flood is defined as the condition that occurs when water overflows the natural or artificial confines of a stream of other body of water, or accumulates by drainage over low-lying areas. A flood is a temporary inundation of normally dry land with water, suspended matter and/or rubble caused by overflowing of rivers, precipitation, storm surge, tsunami, waves, mudflow, lahar, failure of water retaining structures, groundwater seepage and water backup in sewer systems.

Forest fire (or bushfire in Australasia) is an uncontrolled fires occurring in vegetation more than 6 feet (1.8 m) in height. These fires often reach the proportions of a major conflagration and are sometimes begun by combustion and heat from surface and ground fires.

Tropical cyclones, hurricanes and typhoons are regional names for what is essentially the same phenomenon. Depressions in the tropics which develop into storms are called tropical cyclones in the south-west Indian Ocean, the Bay of Bengal, and the Arabian Sea, parts of the south Pacific and along the northern coasts of Australia. These storms are called typhoons in the north-west Pacific and are known as hurricanes in the Caribbean, south-east United States and Central America.

Tsunami (in Japanese, big wave in port), often incorrectly called a tidal wave, is a series of massive waves that occur after an earthquake, a seaquake, volcanic activity, slumps or meteorite impacts in or near the sea. Since the constant energy of the tsunami is defined by height and speed, its height increases once its speed is reduced where the wave approaches land. The waves travel at high speed, more or less unnoticed where crossing deep water, but raising to a height of 30 m and more. Tsunamis can cause severe destruction on coasts and islands.

1.3 Natural Disasters – the Rising Trend

Information on natural disasters and trends is basically available from global databases that provide essential information on the occurrence, recurrence and location of disasters and disaster trends over time (World Disasters Report 2003). The emergencies database (EM-DAT), referred to earlier, serves the global community. Other databases such as Sigma and Natcat are operated by insurance companies Swiss Re and Munich Re respectively, but are not always accessible to the public.

There is evidence available from different parts of the world that there is a rising trend of natural disasters from 1993 to 2002 (Fig. 1.1a). Of a grand total of 2,654 disasters during this period, floods and windstorms account for about 70% of the disasters while the remaining 30% of the disasters are accounted for by droughts, landslides, forest fires, heat waves and others (Fig. 1.1b).

At the regional level, in South East Asia and Bangladesh, over the last century, 700 disasters have occurred of which 158 (23%) occurred between 1900 and 1979, and 542 (77%) between 1972 and 1996. For the Latin American and Caribbean region, Charveriat (2000) showed a noticeable trend of increase in the frequency of disasters.

At the national level, Roy et al. (2002) showed that the Orissa state of India has been disaster affected for 90 years; floods have occurred for 49 years, droughts for 30 and cyclones have hit the state for 11 years.

These data together with that of deaths and affected people appear to show that the natural disasters are becoming more frequent and are also causing heavier and heavier consequences.

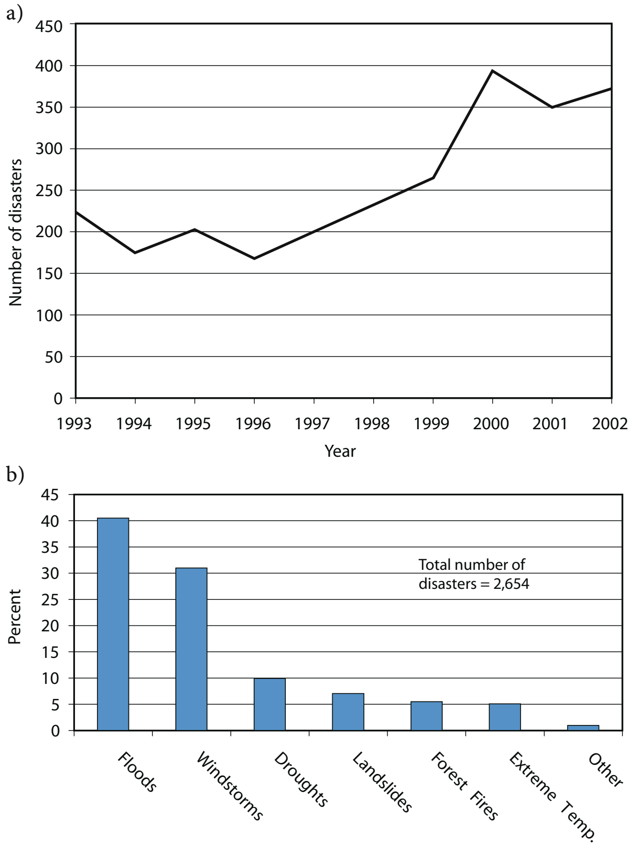

Fig. 1.1. (**a**) Annual variations in the occurrence of hydro-meteorological disasters during 1993–2002 and (**b**) the percentage of different hydro-meteorological disasters as a percent of total number of disasters during 1993–2002

1.4 Impacts of Natural Disasters in Agriculture, Rangeland and Forestry – General Discussion

Impacts from natural disasters on agriculture, rangeland and forestry can be positive or negative. While the impacts are predominantly negative and do affect human society significantly (Joy 1991), there are some positive impacts or benefits that need to be pointed out as well in any discussion on impacts of natural disasters.

As Das (2003a) explained, the impact of natural disasters on agriculture, rangeland and forestry can be direct or indirect in their effect. Direct impacts arise from the direct physical damage on crops, animals and trees caused by the extreme hydro-meteorological event. The impacts may be considered in terms of short-term temporary damage at a particular crop stage to complete crop loss. Within hours of their occurrence, natural disasters produce direct damage to agriculture in terms of total or partial destruction of farm buildings, installations, machinery, equipment, means of transport, storage as well as damage to crop land, irrigation works, dams and destruction of crops ready for harvesting.

Disasters also cause indirect damage which refers to loss of potential production due to disturbed flow of goods and services, lost production capacities, and increased costs of production. Such indirect impacts appear progressively as a result of low incomes, decreases in production, environmental degradation and other factors related to the disaster (Das 2003a).

Anaman (2003) pointed out that the impacts of natural disasters can also be classified as tangible or intangible. Tangible impacts are those that can be easily measured in monetary terms. Intangible impacts are often difficult to measure in monetary terms since they are not purchased or sold in well defined markets and hence direct market values do not exist eg., anxiety or fear of future natural disasters (Oliver 1989), inconvenience and disruption to farm work and stress-induced ill health and human fatalities.

1.4.1 Negative Impacts

Many famines in pre-20th-century Africa, Asia and Europe were triggered by natural disasters – drought, extreme cold, pests and diseases – that devastated crops and livestock (Devereux 2000). According to the EM/DAT data quoted in the World Disasters Report 2003, on average, 246 million people were affected by hydro-meteorological disasters globally each year, between 1993 and 2002. During the same period, these disasters claimed 46,000 lives per year.

Annual variations in the number of people affected by hydro-meteorological disasters during this period (Fig. 1.2a) showed a significant rise in 2002. Data on the percentage of people affected by different hydro-meteorological disasters (Fig. 1.2b) showed that about 56.9% of the 2.46 billion people were affected by floods, 29.8% by droughts, 12.7% by windstorms and 0.6% by the rest of the disasters. On a regional basis (Fig. 1.3), 91% of the people affected were in Asia, due to its huge population. Africa accounted for 6% of the affected people, followed by Americas (2%), Europe (< 1%) and Oceania (< 1%).

During 1993/2002, hydro-meteorological disasters caused an estimated damage of US$ 41.3 billion per year on average. Estimated damage on annual basis during this period (Fig. 1.4a) varied from a high of US$ 67.7 billion in 1995 to a low of US$ 18.1 billion in 2001. Ranking of the different hydro-meteorological disasters according to the percentage of damage caused by them (Fig. 1.4b) is as follows: floods, windstorms, droughts, forest fires, extreme temperatures, landslides and others. On a regional basis (Fig. 1.5), maximum damage occurred in Asia (49%), followed by Americas (29%), Europe (19%), Oceania (2%) and Africa (1%).

Loss of perennial crops such as banana trees or forests has long-term consequences on the ability to generate income. In the case of agricultural income generating assets, the loss might be temporary or permanent (Charveriat 2000).

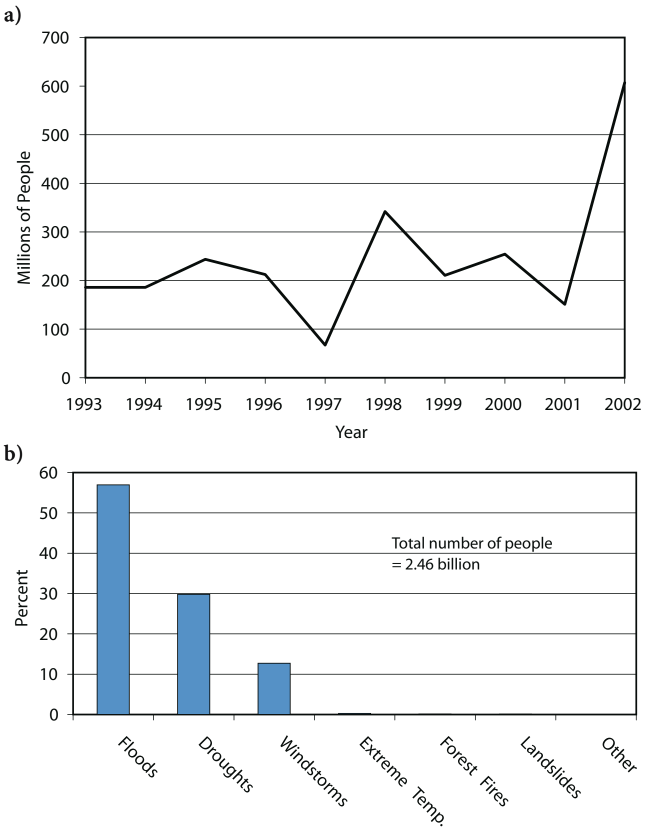

Fig. 1.2. (**a**) Annual variations in the number of people affected by hydro-meteorological disasters during 1993–2002 and (**b**) the percentage of people affected by different hydro-meteorological disasters during 1993–2002

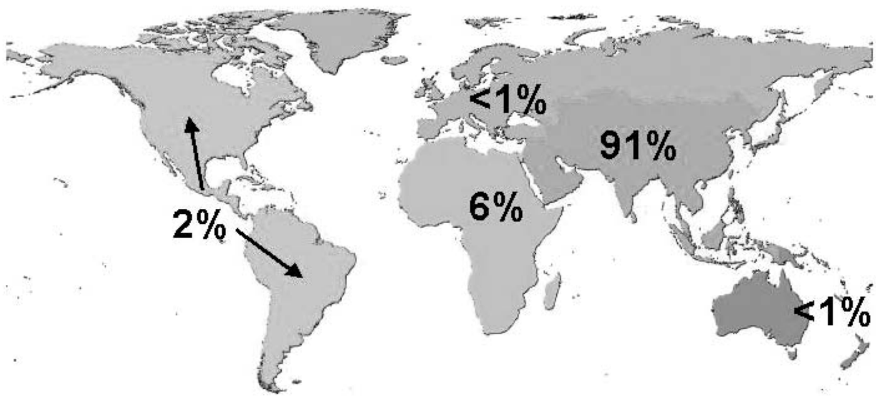

Fig. 1.3. Percentage of total number of people reported affected by hydro-meteorological disasters by region

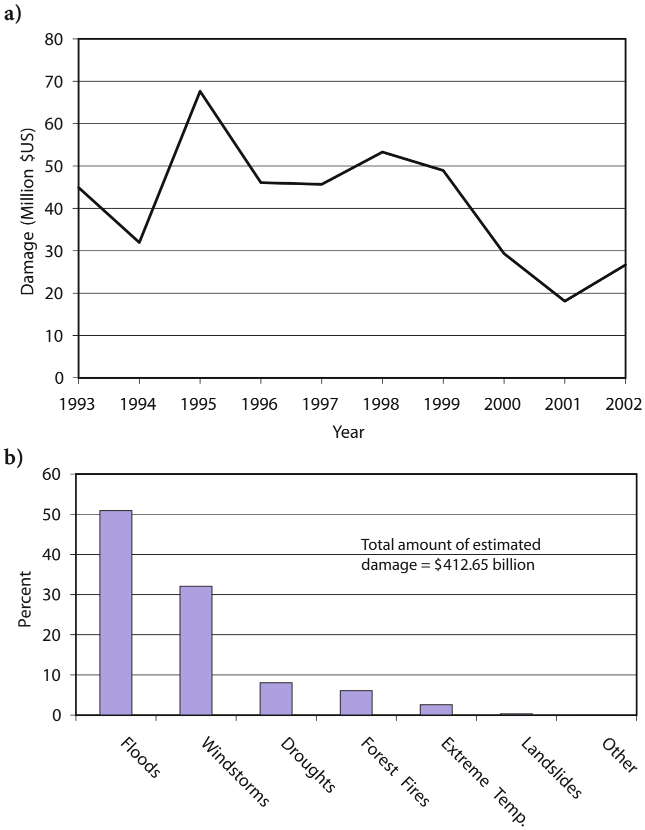

Fig. 1.4. (**a**) Annual variations in the estimated damage due to hydro-meteorological disasters during 1993–2002 and (**b**) the percentage of damage caused by different hydro-meteorological disasters during 1993–2002

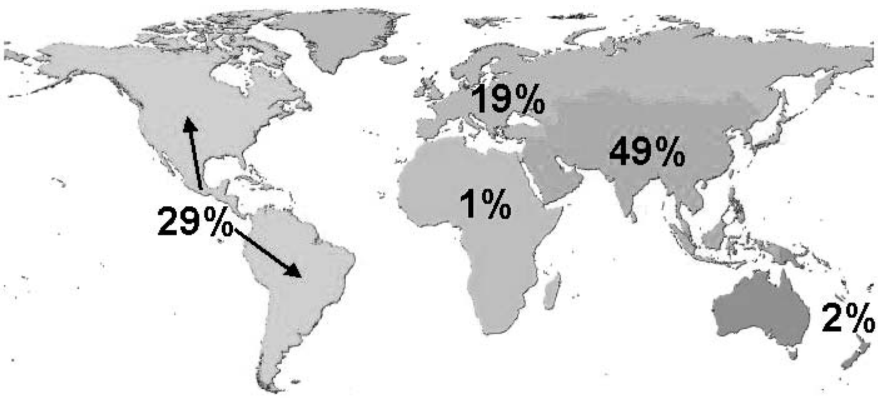

Fig. 1.5. Percentage of total amount of disaster estimated damage by region (2002 prices)

Floods make land unsuitable for agricultural production until waters recede, while hurricanes might wash out arable land or permanently increase its salinity through storm surges and flash floods. Indirect impacts include the evacuation of people in the event of cyclone landfall, disruption to households, stress induced sickness and apprehension (Handmer and Smith 1992; Anaman 1996).

The duration and geographical size of the disaster is an important factor. Localized disasters tend to produce limited aggregate impacts, unlike countrywide natural events such as Hurricane Mitch (Charveriat 2000). Sudden hazards such as storms usually have fewer long/lasting effects than droughts, which are often described as creeping in nature because of the slow rate at which they develop.

Recurrent disasters in the same geographical area might lead to reduced investment due to the perceived risk of asset loss or emigration from stricken areas. Regions repeatedly hit by natural disasters, such as Northeast Brazil, or the coasts of Peru and Ecuador, are usually poorer on average than less hazard-prone areas in a given country.

Poor nations suffer the most from the natural disasters. As Devereux (2000) explained, poor people are more exposed because they tend to live in marginal areas and depend on high-risk, low return livelihood systems such as rainfed agriculture and face many sources of economic vulnerability including little physical infrastructure. Vos et al. (1999) estimated that the poverty incidence in affected municipalities in the coastal province of Ecuador, which already reached 73% before El Niño, rose by 10 percentage points in 1998 due to loss of harvests of poor farmers and rising unemployment among agricultural workers. The UNDP reports that 24 out of 49 least developed nations face a high risk of natural disasters. At least 6 of them have been hit by between 2 to 8 major disasters per year in the last 15 years, with long-term consequences for human development (UNDP 2001).

While damages related with natural disasters are greater in absolute value in developed countries, loss/GDP rates are 20% higher in the developing countries (Funaro 1982). United States experienced more disasters between 1970 and 1999 than any other region, but the impact on national development was not as severe as in some of the developing countries. For example, Hurricane Andrew in 1992 caused a total damage of $ 26.5 billions in the United States, but it was a mere 0.4% of GDP.

Beyond the direct or indirect losses, the economic consequences are of major importance given the repercussions they have on the economic development of the countries (GDP, public finances, foreign trade, price indices). Because of the important role it plays considering the creation of national wealth and the population needs, the agricultural sector appears as a highly vulnerable one. For example, 30.9% of the GNP in Bangladesh was attributed to agricultural activities in Bangladesh while in Cambodia and Laos, it was 44.6 and 54.3% respectively. During the last El Niño in Ecuador, Vos et al. (1999) estimated that around 12,000 workers on banana and sugar cane plantations in the lowlands temporarily lost their jobs. In Honduras, the press reported that the rate of unemployment in the immediate aftermath of Hurricane Mitch had reached an estimated 32%, according to the firm, Asesorias Economicos.

The economic consequences also concern the activities related to international trade, which have become indispensable because of national debt. Export agriculture, tourism, crafts and industrial activities are assumed to bring in foreign currency that is indispensable for the equilibrium of the balance of payments.

The agricultural products hold an even more significant place in exportations. Free zones can be affected by cyclones and floods, with greater probability as they are situated in the coastal plains and on the principal deltas. In Bangladesh, the Chittagong free zone was very seriously affected by the 1991 cyclone (Normand 1991).

1.4.2 Positive Impacts

The positive impacts of natural disasters include increased rainfall to inland areas from tropical cyclones along coastal areas (Ryan 1993), the fixing of atmospheric nitrogen by thunderstorms, the germination of many native plant species as a result of bushfires and the maintenance of fertility of flood-plain soils due to flooding (Blong 1992). The influx of funds into disaster-relief activities after the occurrence of natural disasters can sometimes be positive to local communities, as was shown for the city of Mobile, Alabama after Hurricane Federic (Chang 1984).

1.5 Impacts of Specific Natural Disasters in Agriculture, Rangeland and Forestry

According to Johnson (2003), in a survey of the impacts of extreme weather and climate events on agriculture, the events which were reported by most of the 57 countries around the world which responded included drought (91 per cent), local severe storms (83 per cent), floods (79 per cent), frost (74 per cent) and high winds (72 per cent).

1.5.1 Droughts

Seasonal droughts occur in climates that have well defined annual rainy and dry seasons. Numerous studies have been conducted on the impacts of droughts on crop growth and development at different levels including soil moisture uptake, root growth, shoot growth, various plant processes such as photosynthesis, respiration, plant water uptake and final yield and literature is replete with several good examples. But it is to be understood that the effects of droughts are seriously worsened by human factors such as population growth that forces people into drier and drier regions and inappropriate cropping and herding practices. The impacts of drought are likely to become ever more severe as a result of development processes and population increases (Squires

2001). Droughts often stimulate sequences of actions and reactions leading to long-term land degradation. Droughts may also trigger local food shortages, speculation, hoarding, forced liquidation of livestock at depressed prices, social conflicts and many other disasters associated with famines that may catastrophically affect numerous groups and strata of local populations.

The most prolonged and widespread droughts occurred in 1973 and 1984, when almost all the African countries were affected, and in 1992 when all southern African countries experienced extreme food shortages. In 1973 alone, drought killed 100,000 people in the Sahel (Gommes and Petrassi 1996). It was estimated that hundreds of thousands of people died and nearly half of the entire livestock herds and two million heads of wild animals were killed due to the severe droughts and land desertification at the southern edge of the Sahara Desert. More than six million ecological refugees were forced to emigrate from their homeland to other regions. The whole world was shocked by these disastrous events, and as consequence, the United National Conference on Desertification (UNCD) was sponsored in Nairobi in 1977.

The change in weather patterns during an ENSO event alters regions of high and low pressures around the globe. Descending air of atmospheric circulation cells creates high-pressure centers at the surface. The high surface pressures prevent areas of precipitation from moving into its region. When these abnormal high-pressure patterns persist they lead to drought conditions, depriving the area and its ecosystem of rainfall. Droughts generally occur in the western Pacific during ENSO events, an area normally rich in rainfall. However, droughts in many other regions of the world, including southeastern Africa, India, China and the northeastern region of the South American continent, have been linked to El Niño.

ENSO results in drier conditions in Northeast Brazil during the Northern Hemisphere winter. During the Southern Hemisphere winter, the climatic impact of El Niño is drier conditions in Central America, Colombia and Venezuela. During the 1997–98 El Nino phenomenon, severe droughts and forest fires occurred in northeast Brazil (WMO 1999).

The Committee of Agricultural Organizations in the Union (COPA) and the General Committee for Agricultural Co-operation in the European Union (COGECA) estimate that drought and fires during 2003 have cost European Union farmers €13.5 billion – with Austria, France, Germany, Italy, Portugal and Spain identified as countries most affected.

Currently, South Africa may be heading for a prolonged drought which researchers warn could be among the most severe in decades. It is understood the parts of the country (including KwaZulu-Natal, Limpopo and Mpumalanga provinces) are currently experiencing drought conditions with farmers being forced to sell livestock (recent wildfires have also had a negative impact insofar as they have destroyed large swathes of grazing in KwaZulu-Natal and Mpumalanga provinces). As many as 15 million South Africans could be affected by one of the worst droughts in 10 years. According to Toffee Mokgethi, head of the country's National Disaster Management Centre, "Of those ... at least four million are in need of immediate assistance." Among them are three million communal or subsistence farmers and their dependants. It is claimed that reduced agricultural production in South Africa might impact neighbouring countries since the World Food Programme procures a significant volume of food aid from South Africa for distribution throughout the region.

Benson and Clay (1998) found that the aggregate impacts of droughts could be quite significant in terms of growth. A 50% fall in agricultural GDP would translate into a 10% decrease in GDP for an economy in which agriculture accounted for 20% of total activity in the pre-drought year. Gomes and Vergolino (1995) showed that during 1970, 1983 and 1993, the years of severe drought in Northeast Brazil, when the agricultural GDP decreased between 17.5 and 29.7%, the fluctuations in the region's GDP were explained almost entirely by the occurrence of droughts. For example, the estimated GDP per capita in the Northeast was $ 1,494 in 1993, compared with $ 3,010 in the rest of the country.

One of the major impacts of droughts is regressive distributional effects across communities and across households within communities. Scott and Litchfield (1994) provided evidence of these impacts in the rural regions of Coquimbo in Chile where inequality and poverty at the community level increased significantly in Las Tazas due to the cumulative effects of very low rainfall over the years.

Although drought impacts are primarily negative, it must be mentioned that some times droughts do carry positive impacts. Moderate droughts in the post flowering maturity stage of sugar cane, for instance, helps to increase the sucrose content. Other beneficial impacts include mosquito reduction, reduced cost for snow removal in snowfall regions and other related activities, emergency water conservation leading to permanent and efficient establishment of water use saving patterns etc. (Das 2003a).

1.5.2 Cyclones

Tropical cyclones are among the most destructive of all natural hazards, causing considerable human suffering in about 70 countries around the world. As Das (2003b) described, tropical cyclones are the off-spring of ocean-atmosphere interactions, powered by heat from the sea, driven by the easterly trades and temperate westerlies, the high planetary winds and their fierce energy. An average of 80 tropical cyclones form annually over the tropical oceans, of which, 30 occur in the typhoon region of the western North Pacific (Obasi 1997). The impact of tropical cyclones is greatest over coastal areas that bear the brunt of the strong winds and flooding from rainfall. For example, while the average for the Bay of Bengal and the Arabian Sea is only five, some of the most destructive of these storms have occurred in that region, such as the severe tropical cyclone in Bangladesh in 1970, which claimed 300,000 lives.

El Nino is generally associated with worldwide anomalies in the patterns of precipitation and temperature, as well as with patterns of tropical storms and hurricane activity, the behaviour of subtropical jetstreams, and many other general circulation features over various parts of the world.

The magnitude of hurricanes is assessed with the Saffir-Simpson scale, which takes into account maximum sustained winds and minimum storm pressure. Among the most devastating hurricanes of all times were Hurricane Georges (September 1998) and Hurricane Mitch (October 1998). A category 5 hurricane, Hurricane Mitch was one of the most powerful Atlantic Hurricanes, with 290 km/hr winds and a minimum storm pressure of 906 mb, and had quite a long life span (14.5 days) which explains why it turned out to be the deadliest of the century. It caused loss of life, destruction of property, damage to food production, food reserves and transportation system as well as increased health risks.

The loss to agriculture, rangelands and forests from tropical cyclones can be due to direct destruction of vegetation, crops, orchards and livestock, damage to infrastructure such as canals, wells and tanks and long term loss of soil fertility from saline deposits over land flooded by sea water. Typhoons have been known to inflict severe damage on agriculture: for example, in southern Hainan on 2 October 1999, some 25 million timber and rubber trees were blown down (WMO 1994). A typhoon that struck Thailand on 4 November 1989 wiped out some 150,000 ha of rubber, coconut and oil plantations and other crops (WMO 1997).

Traditionally, small-scale fisheries are also hit by cyclones. In monetary terms, the losses incurred by livestock raising, forestry and fisheries mostly remain below those suffered by crops. But in small islands such as Antigua and Barbuda where fisheries constitute the backbone of the economy, the impact could be quite significant. After Hurricane Hugo in 1989, 47 percent of the losses occurred in fisheries, but crop losses still represented almost 40 percent of the total damage (OSRO 1989).

The loss from a single cyclone may run into millions of dollars. For example, in 1998, El Niño-related weather phenomena caused $ 6.6 billion of damages in Argentina, Peru and Ecuador, while Hurricane Georges caused $ 2.1 billion in damages in the Dominican Republic and Hurricane Mitch produced damages of $ 2.4 billion in Honduras and Nicaragua (Charveriat 2000).

In May 2002, Cyclone Kesiny hit Madagascar affecting more than half a million people, making them homeless or in need of emergency food, shelter and drinking water. Up to 75% of the crops were destroyed, 20 people died and 1,200 were injured (CIDI 2002).

The Orissa cyclones on 17–18 October and again on 29–30 October 1999 in Orissa, India caused devastating damage. The cyclones on 29–30 October with wind speeds of 270–300 km/h for 36 hours were accompanied by torrential rain ranging from 400 to 867 mm over a period of 3 days. The two cyclones together severely affected around 19 million people in 12 districts (Roy et al. 2002). Sea waves reaching 7 metres rushed 15 kms inland. 2.5 million livestock perished and a total of 2.1 million ha of agricultural land was affected.

Not all the impacts of cyclones are negative, some reports cite beneficial effects of tropical cyclones. Ryan (1993) mentioned some important benefits of tropical cyclones in Australia. Increased water availability in water-critical regions makes agricultural production less susceptible to the dry period. Sugg (1968) estimates that nine major hurricanes in the United States since 1932 terminated dry conditions over an area of about 622,000 km^2.

1.5.3 Floods

Floods are among the greatest natural disasters known to mankind. According to historical record, 1092 flood disaster events occurred since 206 BC in China during a period of 2155 years, averaging once in every two years. In China, about 8% of the land area is located in the mid and down-stream parts of the seven major rivers in the eastern and southern parts of the country that are prone to floods. About 50% of the total population of the country lives in these areas (Heng 2004).

The number of people affected by floods during the world during 1991 to 2000 was reported to be around 1.5 billion. According to Roy et al. (2002), the frequency of floods had increased in the Orissa state of India. Between 1834 and 1926, the state experienced floods once in four years, which rose to once in two years after 1926. The state experienced nine bouts of floods within a span of just 15 days in 2001, an all time high, damaging 2.12 million hectares of standing crop.

There are a wide variety of floods from localized flash flood to extensive floods over large areas. There are both positive and negative aspects of floods, which should be factored into land use planning. It is well known that around the world, flood plains are the areas of highest productivity. Some of the most flourishing ancient civilizations were in the flood plains as proximity to rivers enabled them to enhance agricultural productivity. In many areas, annual floods are welcomed by the populations settled in such areas since the increased availability of water resources could be harnessed for greater agricultural output. But such activities are not without risk since they could further increase the risk of flooding hazards.

Floods are a function of the climate (variability in rainfall pattern, occurrence of storms) as well as hydrology (shape of river beds, intensity of drainage, and debit flow of rivers) and soil characteristics (moisture absorption capacity). Flooding occurs primarily when water due to rain from various types of weather phenomena or snowmelt accumulates faster than soils can absorb it or rivers can carry it away. .

More than three quarters of natural disasters in the Americas are high wind and floods. The countries most affected by floods are Brazil (15%), USA (12%), Peru (11%). According to a press release from the European Union, for the period 1980–2002, the greatest number of floods occurred in France (22%), Italy (17%) and the UK (12%) ... the highest number of fatalities occurred in Italy (38%), followed by Spain (20%) and France (17%) ... the greatest economic losses occurred in Germany and Italy (both € 11 billion), followed by Spain and the UK (both around € 6 billion). Floods and high winds represent more than three quarters of the natural disasters in Oceania.

A study of the impact of the 1998 Bangladesh floods revealed that 62% of all micro finance clients had lost their homes, nearly half had lost their every day possessions and over 75% had their ability to generate income at least suspended (Hassan and Hussein 1998). In the same year, many parts of East Africa experienced record rainfall (up to 10 times the usual amount) and disastrous flooding. In Uganda alone, 10,000 people were affected, 40% of the main roads were destroyed and the country became heavily dependent on food imports and aid (NEMA 1999). According to UNEP, the threat of natural disasters is one of the five key environmental issues facing the flood-prone nation that is home to 140 million people.

Johnson (2003) categorized the direct and indirect effects of flooding into those that occur during the non-growing season or fallow period and those that occur during the growing season. Important impacts during the non-growing season include loss of top soil; loss of soil nutrients; soil compaction; soil erosion; permanent damage to perennial crops, trees, livestock, buildings, and machinery; and permanent cessation of farming in floodplains. Impacts during the growing season include waterlogging of crops; lodging of standing crops; loss of soil nutrients; loss of pasture use; soil erosion; greater susceptibility to diseases and insects; interruptions to farm operations; permanent damage to perennial crops, trees, livestock, buildings and machinery etc.,

Johnson (2003) also gave examples of the impacts of flooding on agriculture in the USA. In one example, flooding damage to Californian agriculture from winter rains in 1997 included loss of 24,000 ha of crop with an additional 38,500 ha damaged by rain and flooding with the total losses estimated at $ 245 million.

1.5.4 Forest and Bush Fires

During 1982/83 and 1994/95 El Nino events, South-East Asia experienced severe smoke and haze episodes associated the forest and bush fires due to reduced rainfall and drought conditions. The resulting transboundary pollution compromised the health of downwind populations. Pollution and decreasing air quality caused by the fires contribute to changes in the composition and chemistry of the global atmosphere.

Fires (of which 23% are forest/grassland fire) occur with fairly high frequency especially in Germany (18%), France (15%) and UK (11%). The single largest group in manmade disasters in Oceania are fire (forest/grassland fire as well as building fire) which represent nearly 60 percent of the total in this category. Nearly all of them occur in Australia, the most important in the recent years being the one in January 1994 causing enormous economic losses. Previously fires in Australia have caused damage worth 20 million US$ in 1967, 400 million US$ in 1983 and 215 million US$ in 1985. A mid-July, (Australian) National Association of Forest Industries (NAFI) press release claimed that early-2003 wild fires (bushfires) were "the worst environmental disaster in the history of Australia ... responsible for over three million hectares of destruction, the greatest extent of environmental ruin on record in the nation's history, the bushfire disaster will have long term effects on the environment and the forest estate of this country". According to National Interagency Fire Center (NIFC) published material covering the period January 2003 to early-November 2003 inclusive, around 56,000 United States' wild fires had affected 3.8 million or so acres.

1.6
Environmental Degradation and Impact of Natural Disasters in Agriculture, Forestry and Rangelands

Environmental degradation is one of the major factors contributing to the vulnerability of agriculture, forestry and rangelands to natural disasters because it directly magnifies the risk of natural disasters, or by destroying natural barriers, leaves agriculture, forestry and rangelands more vulnerable to their effects.

Deforestation, land clearing, weed invasion and loss of wetlands could lead to ecosystem alteration, including changes to vegetation cover and composition and the introduction of plant and animal pests. Water erosion, wind erosion, siltation and sedimentation and coastal erosion could result in transport of soil and deposition elsewhere. Soil salinity, degradation of soil structure, soil fertility decline, soil acidification, water logging and soil pollution could lead to soil degradation, involving the alteration of soil properties *in situ*. Clearing of vegetation, rapid abandonment of exhausted cropland, expansion of cropping into more and marginal land set up a vicious cycle that is hard to break.

Poverty and environmental degradation are closely linked, often in a self-perpetuating negative spiral in which poverty accelerates environmental degradation and degradation results in or exacerbates poverty. While poverty is not the only cause of environmental degradation, it does pose the most serious environmental threat in many low-income countries (Pimentel et al. 1994). This problem is compounded because many millions of people, who live near the subsistence minimum, have to exploit natural resources with inappropriate technologies in order to survive. For example, forest fires in Indonesia in 1997–98 were deliberately set, went completely out of control and turned into wildfire surpassing any nation's fire fighting capabilities. They caused hundreds of deaths, devastated some 9 million hectares of forest and cost US$ 10 billion in short term ecological and economic losses. The degree and extent of damage caused by Hurricane Mitch is attributed to the drastic alteration over the years of natural systems that would have provided a buffer effect.

A new report entitled "Outlook for Fish to 2020: Meeting Global Demand" issued by the International Food Policy Research Institute (IFPRI) in October 2003 projects a significant increase in fish consumption during the next 20 years or so – with aquaculture expected to provide more than 40% of all fish consumed by 2020. Expanding aquaculture could also increase pollution and the use of scarce water and land resources, threatening the environment and the poor in developing countries. Substantial increases in fish farming could actually damage already vulnerable wild fisheries, and growth plans for this sector must also consider these potential effects.

1.7
Natural Disasters in Agriculture, Rangeland and Forestry – Some Methodological Issues

One of the major problems in dealing with natural disasters in agriculture, rangelands and forestry is the lack of systematic and standardized data collection from disasters. There is no recognized and acceptable international system for disaster-data gathering, verification and storage.

One good example of the methodological issue is the definition of natural disaster itself. The emergencies database (EM-DAT) of CRED classifies an event as a disaster if at least “10 people are killed and/or 100 or more are affected and/or an appeal for international assistance is made or a state of emergency declared”. The NatCat database of Munich Re classifies an event as a natural disaster if there is any property damage and any person is sincerely affected (injured, dead). The Sigma database of Swiss Re regards an event as a natural disaster if there are > 20 deaths, and/or > 50 injured and/or > 2,000 homeless and/or insured losses exceed a given amount.

The above approach to definition of natural disasters was based on the need to respond to development and humanitarian agenda (Guha/Sapir and Below 2002).

Another problem is that different disasters can be classified as different types by different databases. For example, a flood which was a consequence of severe wind storm, may be recorded as one or the other. The reporting of high wind disasters pose a problem for a database indexed over countries since meteorological organisations report an event as a whole covering all the countries in its path.

Given the complexity of damage assessment, estimating the total impact of disasters in monetary value is quite difficult. It is also complicated by the fact that governments and international agencies use different methodologies. Numerous studies have been made on the assessment and display of specific hazards, but there is no standard method for assessing natural hazards in resource evaluations for development planning. Different methods are a response to specific concerns about individual hazardous phenomena.

Current practices of assessing the economic Impact of natural disasters are inadequate. Many existing estimates of the impacts of disasters are based on damage assessments undertaken in the immediate aftermath of individual disasters. Such assessments are typically undertaken without the use of comprehensive guidelines and by untrained assessors. Moreover, they provide an incomplete account of the impact of a disaster, focusing primarily on areas of particular concern to the assessors, and are completed too rapidly to allow a full assessment of the economic consequences.

Poor assessment practices have important impacts on the effectiveness of disaster management more generally. In particular, they can inhibit the design of timely and appropriate relief and rehabilitation programmes; and result in insufficient attention being paid to disaster prevention and mitigation measures, for example by over- or underestimating the true economic costs of disasters.

Post-disaster damage assessments of the impacts of disasters are generally concerned with the assessment of the economic impacts of sudden-onset rather than slow-onset natural disasters, such as drought or pest outbreaks.

Standard methodologies for estimating economic damage from disasters remains an area where much research is still needed. Governments, insurance companies, or other agencies involved in relief generally estimate economic damage according to varying criteria and standards. This presents serious difficulties, not only in comparisons across countries but also over time. Despite the multiple sources that have generated over 9000 events for the CRED database, only 24% have information on economic losses.

1.8 Mitigating the Impacts of Natural Disasters

The Plan of Implementation of the World Summit on Sustainable Development (WSSD) held in Johannesberg in 2002 highlighted the need to mitigate the effects of droughts and floods through such measures as improved use of climate and weather information and forecasts, early warning systems, land and natural resource management, agricultural practices and ecosystem conservation in order to reverse the current trends and minimize degradation of land and water resources. WSSD noted the need to promote the access and transfer of technology related to early warning systems and to mitigation programmes to developing countries affected by natural disasters.

Over the recent years, new technologies have brought about an accelerated increase in our knowledge of the climate system. Satellites for monitoring aspects of the oceans and sparsely populated parts of the globe, ocean buoys and expendable bathythermographs for monitoring the physical and chemical properties of the oceans, hundreds of specially equipped commercial aircraft, and manned and automatic weather stations on land, are all expanding the volume of data and contributing to knowledge base.

Communities that are most exposed to risk from climate extremes and natural disasters and potentially at risk from climate change, are those with limited access to technological resources and with limited development of infrastructure. Countries, especially the geographically smaller ones, cannot be expected to cope alone because each one needs to have information on the full extent and magnitude of natural disasters. Socio-economic losses cannot be entirely eliminated, but timely and appropriate mitigation measures can certainly reduce the impacts. Planning, early warning and well-prepared response strategies are the major tools for mitigating the losses. The longer in advance a warning can be given about potentially damaging conditions, the easier it will be to mitigate and reduce its impact.

Major advances in technology and notable progress in scientific understanding, the accuracy and timeliness of weather and flood warnings have significantly improved over the last few decades. Today, the accuracy of forecasts of large-scale weather patterns for seven days in advance is the same as those for two days in advance only 25 years ago (Obasi 1998). Now forecasts up to 10 days are showing remarkable accuracy, and there is now capability to provide some skillful information on expected weather patterns several seasons in advance.

For example, early information on El Nino episodes is now allowing advanced national planning, with considerable advantage in many sectors of the economy, such as in water resources management, tourism, and fisheries and agricultural production (Obasi 1996). In the case of the 1997–98 El Nino event, advances in El Nino related science and in monitoring the sea-surface temperatures in the Pacific Ocean, enabled scientists in the NMHSs to predict its formation longer in advance than all the previous events. With recent developments in communication technology, nincluding the use of Internet, information on the El Nino was disseminated in a rapid and timely manner throughout the world. These enabled many governments to take appropriate measures, and stimulated international cooperation and integrated efforts to address the associated impacts.

The accuracy of tropical cyclone track forecasts and the timeliness of warnings have been steadily improving in the past few years. Global efforts, especially within the context of Tropical Cyclone Programme of WMO, have resulted in a noticeable improvement in the warning systems in many parts of the world and resulted in saving a lot of lives and limiting property damage. For example, the decrease in the death toll in Bangladesh, from about 130,000 to 500 caused by similar tropical cyclones in 1991 and 1994 respectively, was attributed in large part, by government sources, to improvements in early warning and evacuation systems (Obasi 1997).

The evolving Internet has proven to be an invaluable tool in facilitating the exchange of global and regional climate monitoring and prediction information. However many users require assistance in the selection, interpretation and application of appropriate information.

Effective early warning systems coupled with community education for protective action has reduced the potential human loss from these events. Floods as a disaster also lend themselves well for preparedness measures both structural and legislative (land use laws, zoning plans and urbanisation). Preparedness of life-saving techniques and evacuation plans should be promoted actively in these high risk zones.

1.9 Conclusions

According to the International Federation of Red Cross and Red Crescent Societies (IFRC), natural disasters are on the rise and they continue to target the world's poorest and least-developed and there must be greater investment in disaster reduction rather than high-profile response efforts. Improved data on past disasters would help inform investment and policy decisions and thus help secure more appropriate levels and forms of disaster prevention, mitigation and preparedness. Historical studies would also help inform the development of appropriate methodologies for the assessment of future disasters.

Despite a long history of disasters affecting agriculture, rangelands and forestry, comprehensive documentation of these disasters at the national, regional and international levels has been weak and it is important to develop mechanisms for more efficient assessment and documentation of natural disaster impacts in agriculture. A comprehensive assessment of impacts of natural disasters on agriculture requires a multi-sectoral and integral approach involving key organisations.

Priority should be given to supporting research with practical applications since research is needed to understand the physical and biological factors that contribute to disasters. Since major impact of the natural disasters is on poor farmers with limited means in developing countries, community-wide awareness and education programs on natural disasters should be a priority. Programs for improving prediction methods and dissemination of warnings should be expanded and intensified. Efforts are also needed to determine the impact of disasters on natural resources.

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CHAPTER 2

The Role of Disaster Preparedness in National Planning with Specific Reference to Droughts

Donald A. Wilhite

Abstract Drought is a slow-onset, insidious natural hazard. Vulnerability to drought is increasing in all drought-prone nations and the traditional crisis management approach to address the impacts of these events has proven to be ineffective, untimely, and poorly coordinated. A more risk-based management approach has been gaining acceptance worldwide because it addresses the underlying cause of impacts – vulnerability. This approach includes development of national policies and mitigation plans directed at identifying the causes of drought impacts and improved early warning systems that provide information to decision makers in a timely manner. This paper discusses the conceptual framework for improved drought preparedness planning with an emphasis on reducing societal vulnerability to future episodes of drought.

2.1 Introduction

Drought is considered by many to be the most complex but least understood of all natural hazards, affecting more people than any other hazard (Hagman 1984). However, there remains much confusion within the scientific and policy communities about its characteristics. It is precisely this confusion that explains, to some extent, the lack of progress in drought preparedness in most parts of the world.

Drought is a slow-onset, creeping natural hazard that is a normal part of climate for virtually all regions of the world; it results in serious economic, social, and environmental impacts. Drought onset and end are often difficult to determine, as is its severity. The impacts of drought are largely nonstructural and spread over a larger geographical area than are damages from other natural hazards. The nonstructural characteristic of drought impacts has certainly hindered the development of accurate, reliable, and timely estimates of severity and, ultimately, the formulation of drought preparedness plans by most governments. The impacts of drought, like those of other hazards, can be reduced through mitigation and preparedness.

Drought preparedness planning should be considered an essential component of integrated water resources management. Increasing society's capacity to cope more effectively with the extremes of climate and water resources variability (i.e., floods and droughts) is a critical aspect of integrated water resources management. Drought preparedness planning will also provide substantial benefit in preparing for potential changes in climate. Historically, more emphasis has been given to flood management than drought management. With increasing pressure on water and other natural resources because of increasing and shifting populations (i.e., regional and rural to urban), it is imperative for all nations to improve their capacity to manage water supplies during water-short years.

Drought risk is a product of a region's exposure to the natural hazard and its vulnerability to extended periods of water shortage (Wilhite 2000). If nations and regions are to make progress in reducing the serious consequences of drought, they must improve their understanding of the hazard and the factors that influence vulnerability. It is critical for drought-prone regions to better understand their drought climatology (i.e., the probability of drought at different levels of intensity and duration) and establish comprehensive and integrated drought EWSs that incorporate climate, soil, and water supply factors such as precipitation, temperature, soil moisture, snow pack, reservoir and lake levels, ground water levels, and stream flow.

Vulnerability to drought is dynamic and influenced by a multitude of factors, including increasing and regional shifts in population, urbanization, technology, government policies, land use and other natural resource management practices, desertification processes, water use trends, and increasing environmental awareness. Therefore, the magnitude of drought impacts may increase in the future as a result of an increased frequency of occurrence of the natural event (i.e., meteorological drought), changes in the factors that affect vulnerability, or a combination of these elements. All drought-prone nations should develop national drought policies and preparedness plans that place emphasis on risk management rather than following the traditional approach of crisis management, where the emphasis is on reactive, emergency response measures. Crisis management decreases self-reliance and increases dependence on government and donors.

In the past decade or so, drought policy and preparedness has received increasing attention from governments, international and regional organizations, and nongovernmental organizations. Simply stated, a national drought policy should establish a clear set of principles or operating guidelines to govern the management of drought and its impacts. The policy should be consistent and equitable for all regions, population groups, and economic sectors and consistent with the goals of sustainable development. The overriding principle of drought policy should be an emphasis on risk management through the application of preparedness and mitigation measures. Preparedness refers to pre-disaster activities designed to increase the level of readiness or improve operational and institutional capabilities for responding to a drought episode. Mitigation is short- and long-term actions, programs, or policies implemented during and in advance of drought that reduce the degree of risk to human life, property, and productive capacity. These actions are most effective if done before the event. Emergency response will always be a part of drought management because it is unlikely that government and others can anticipate, avoid, or reduce all potential impacts through mitigation programs. A future drought event may also exceed the "drought of record" and the capacity of a region to respond. However, emergency response should be used sparingly and only if it is consistent with longer-term drought policy goals and objectives.

A national drought policy should be directed toward reducing risk by developing better awareness and understanding of the drought hazard and the underlying causes of societal vulnerability. The principles of risk management can be promoted by encouraging the improvement and application of seasonal and shorter-term forecasts, developing integrated monitoring and drought EWSs and associated information delivery systems, developing preparedness plans at various levels of government, adopting mitigation actions and programs, and creating a safety net of emergency response programs that ensure timely and targeted relief.

The traditional approach to drought management has been reactive, relying largely on crisis management. This approach has been ineffective because response is untimely, poorly coordinated, and poorly targeted to drought stricken groups or areas. In addition, drought response is post-impact and relief tends to reinforce existing resource management methods. It is precisely these existing resource management practices that have often increased societal vulnerability to drought (i.e., exacerbated drought impacts). The provision of drought relief only serves to reinforce the status quo in terms of resource management. Many governments and others now understand the fallacy of crisis management and are striving to learn how to employ proper risk management techniques to reduce societal vulnerability to drought and, therefore, lessen the impacts associated with future drought events.

Two important trends in drought management are: (1) improved drought monitoring tools and early warning systems and (2) an increased emphasis on drought preparedness and mitigation. Recent trends in each of these areas are discussed below.

2.1.1
Monitoring Drought: Unique Challenges and Recommendations

Effective drought EWSs are an integral part of efforts worldwide to improve drought preparedness. Timely and reliable data and information must be the cornerstone of effective drought policies and plans. Monitoring drought presents some unique challenges because of drought's distinctive characteristics, as previously discussed. In addition, several types of drought exist, and the factors or parameters that define it will differ from one type to another. For example, meteorological drought is principally defined by a deficiency of precipitation from expected or "normal" over an extended period of time, while agricultural drought is best characterized by deficiencies in soil moisture. This parameter is a critical factor in defining crop production potential. Hydrological drought, on the other hand, is best defined by deficiencies in surface and subsurface water supplies (i.e., reservoir and ground water levels, streamflow, and snowpack) and impacts generally lag the occurrence of meteorological and agricultural drought. These types of drought may coexist or may occur separately.

An expert group meeting on early warning systems for drought preparedness sponsored by the World Meteorological Organization (WMO) and others recently documented the status of drought EWSs in several countries, the shortcomings and needs of drought EWSs, and recommendations on how these systems can help in achieving a greater level of drought preparedness (Wilhite et al. 2000). This meeting was organized as part of WMO's contribution to the UNCCD meeting in Bonn, Germany, in December 2000. This report documented recent efforts in drought EWS in countries such as Brazil, China, Hungary, India, Nigeria, South Africa, and the United States, but also noted the activities of regional drought monitoring centers in eastern and southern Africa and efforts in West Asia and North Africa. The shortcomings of current drought EWS were noted in the following areas:

- *Data networks*: inadequate density and data quality of meteorological and hydrological networks and the lack of data networks on all major climate and water supply parameters;
- *Data sharing*: inadequate data sharing between government agencies and the high cost of data limits the application of data in drought preparedness, mitigation, and response;
- *Early warning system products*: data and information products are often not user friendly and users are often not trained in the application of this information to decision making;
- *Drought forecasts*: unreliable seasonal forecasts and the lack of specificity of information provided by forecasts limit the use of this information by farmers and others;
- *Drought monitoring tools*: inadequate indices for detecting the early onset and end of drought, although the Standardized Precipitation Index (SPI) was cited as an important new monitoring tool;
- *Integrated drought/climate monitoring*:
drought monitoring systems should be integrated and based on multiple indicators to fully understand drought magnitude, spatial extent, and impacts;
- *Impact assessment methodology*: lack of impact assessment methodology hinders impact estimates and the activation of mitigation and response programs;
- *Delivery systems*: data and information on emerging drought conditions, seasonal forecasts, and other products are often not delivered to users in a timely manner;
- *Global early warning system*: no historical drought data base exists and lack of a global drought assessment product based on one or two key indicators could be helpful to international organizations, NGOs, and others.

Participants of the expert group meeting on drought EWS made several recommendations. Participants recommended that early warning systems be an integral part of a drought preparedness and mitigation plan and that priority should be given to improving existing observation networks and establishing new meteorological, agricultural, and hydrological networks.

2.1.2 Drought Policy and Preparedness

There are four key components of an effective drought risk reduction strategy (O'Meagher et al. 2000). These include the availability of timely and reliable information on which to base decisions; policies and institutional arrangements that encourage assessment, communication, and application of that information; a suite of appropriate risk management measures for decision makers; and actions by decision makers that are effective and consistent. In 1992, Australia adopted a National Drought Policy that applied these components through three objectives. These objectives were: (1) to encourage primary producers and other sections of rural Australia to adopt self-reliant approaches to managing for climatic variability; (2) to maintain and protect Australia's agricultural and environmental resource base during periods of extreme climate stress; and (3) to ensure early recovery of agricultural and rural industries, consistent with long-term sustainable goals (O'Meagher et al. 2000). Australia's national drought policy is widely known and its philosophy often replicated in other settings.

In the United States, there has been significant progress as well in addressing the impacts of drought through the development of preparedness plans. The most noticeable progress has been at the state level, where the number of states with drought plans has increased dramatically during the past two decades. In 1982, only three states had drought plans in place. In 2004, thirty-seven states have developed plans and four states are at various stages of plan development. The basic goal of state drought plans should be to improve the effectiveness of preparedness and response efforts by enhancing monitoring and early warning, risk and impact assessment, and mitigation and response. Plans should also contain provisions (i.e., an organizational structure) to improve coordination within agencies of state government and between local and federal government. Initially, state drought plans largely focused on response efforts aimed at improved coordination and shortening response time; today the trend is for states to place greater emphasis on mitigation as the fundamental element of a drought plan. Thus, many plans are more pro-active, adopting a more risk management approach to drought management.

The growth in the number of states with drought plans suggests an increased concern at that level about the potential impacts and conflicts associated with extended water shortages and an attempt to address those concerns through planning. Initially, states were slow to develop drought plans because the planning process was unfamiliar. With the development of drought planning models (Wilhite 1991; Wilhite et al. 2000) and the availability of a greater number of drought plans for comparison, drought planning has become a less mysterious process for states. As states initiate the planning process, one of their first actions is to study the drought plans of other states to compare methodology and organizational structure.

The rapid adoption of drought plans by states is also a clear indication of their benefits. Drought plans provide the framework for improved coordination within and between levels of government. Early warning and monitoring systems are more comprehensive and integrated and the delivery of this information to decision makers at all levels is enhanced. Many states are now making full use of the Internet to disseminate information to a diverse set of users and decision makers. Through drought plans, the risks associated with drought can be better defined and addressed with proactive mitigation and response programs. The drought planning process also provides the opportunity to involve numerous stakeholders early and often in plan development, thus increasing the probability that conflicts between water users will be reduced during times of shortage. All of these actions can help to improve public awareness of the importance of water management and the value of protecting our limited water resources.

2.1.3
Drought Mitigation Planning: Examples and Perspectives

Drought mitigation plans have three essential components regardless of whether they are developed at the provincial, national, or regional scale. First, a comprehensive early warning system provides the basis for many of the decisions that must be made by a wide range of decision makers as drought conditions evolve and become more severe. Equally important, early warning systems must be coupled to an effective delivery system that disseminates timely and reliable information. As drought plans incorporate more mitigation actions, it is imperative that these actions be linked to thresholds (e.g., reservoir levels, climate index values) that can serve as triggers for mitigation and emergency response actions. Second, a critical step in the development of a mitigation plan is conduct of a risk assessment (Knutson et al. 1998). The purpose of the risk assessment is to determine who and what is at risk and why. This is successfully accomplished through an analysis of historical and recent impacts associated with drought events. This risk assessment task is accomplished as part of a broader planning process as defined by Wilhite et al. (2000). Third, after impacts have been identified and prioritized, the next step is to identify appropriate mitigation actions that can help to reduce the risk of each impact for future drought events. Mitigation actions currently being employed by some states are referenced later in this paper. In many cases, appropriate response actions are also identified through this process but these actions should not conflict with the basic goal of the drought mitigation plan – to reduce vulnerability to drought events. Some response actions may increase reliance on government and encourage the continuation of inappropriate resource management practices.

One of the current needs is quantifying the advantages of a risk-based drought mitigation planning effort over the current crisis management approach. For those that have been actively involved in drought management, the former holds numerous obvious advantages over crisis management. Still, questions remain in the minds of policy makers that must commit resources up-front to develop and implement mitigation actions versus dealing with impacts during the crisis and in the post-drought period. This field of research is important both in terms of methodology development and conclusions that would emanate from this research. In most cases the costs associated with mitigation actions are minimal when compared with the costs of drought, which often are in the billions of dollars. Clearly, we must improve our estimates of drought impacts, both direct and indirect, in all sectors. It must also be understood that failure to develop mitigation actions aimed at reducing drought impacts will result in a continuation of the spiraling costs of the impacts associated with this natural hazard.

The National Drought Mitigation Center (NDMC) has been promoting the concept of mitigation in its work with state, local, and tribal governments in the United States, as well as to foreign governments and international organizations working in this field. The NDMC has served as a conduit for gathering and disseminating these actions to a broad audience of policy and other decision makers in the United States and elsewhere from the local to national level (Wilhite 1997). These mitigation actions illustrated in Table 2.1 have helped states visualize possible actions to consider in association with the drought plan development process.

Assessment programs adopted by states cover a broad range of actions. Examples include development of improved criteria or triggers for the initiation of specific mitigation actions in response to drought, to the establishment of new data collection networks. Automated weather networks have become commonplace in many states and these networks have significantly improved the capability to monitor climate and water supply conditions in near real time.

Legislative actions have included the passage of measures to protect instream or environmental flows and guarantee low-interest loans to farmers. Low-interest loans, a common federal response to drought in the U.S., are not generally state financed. Many U.S. states have been reexamining aspects of water rights doctrine in response to growing water use and associated conflicts. Some states have formalized state drought plans through legislative actions (e.g., South Carolina and Nebraska). Water banks have been used in some states (e.g., California) as a means of temporarily modifying water allocation procedures (i.e., water rights) during water shortages. MacDonnell et al. (1994) present a review of water banking in the west United States.

Augmentation of water supplies during recent droughts included rehabilitating reservoirs to operate at design capacity and reviewing reservoir operation plans. New reservoirs are being considered in some locations and other cities have expanded current water supply capacity. Cities also worked with self-supplied industrial users on programs to reallocate some water for emergency public water supplies.

One of the key responsibilities of state government during periods of drought is to keep the public aware of the severity of the situation through timely reports. These reports must provide a clear rationale for mitigation actions imposed on either a voluntary or mandatory basis. During recent droughts, states organized informational meetings for the media and the public, implemented water conservation awareness programs, prepared and distributed informational materials, and organized workshops on drought-related topics. Sample ordinances on water conservation were also prepared and distributed to municipalities and rural suppliers.

Table 2.1. Drought-related mitigative actions of state government in response to recent episodes of drought

Category	Specific Action
Assessment programs	Developed criteria or triggers for drought-related actions Developed early warning system, monitoring program Conducted inventories of data availability Established new data collection networks Monitored vulnerable public water suppliers
Legislation/public policy	Prepared position papers for legislature on public policy issues Examined statutes governing water rights for possible modification during water shortages Passed legislation to protect instream flows Passed legislation providing guaranteed low-interest loans to farmers Imposed limits on urban development
Water supply augmentation/ development of new supplies	Issued emergency permits for water use Provided pumps and pipes for distribution Proposed and implemented program to rehabilitate reservoirs to operate at design capacity Undertook water supply vulnerability assessments Inventoried self-supplied industrial water users for possible use of their supplies for emergency public water supplies Inventoried and reviewed reservoir operation plans
Public awareness/ education programs	Organized drought information meetings for the public and the media Implemented water conservation awareness programs Published and distributed pamphlets to individuals, businesses, and municipalities on water conservation techniques and agricultural drought management strategies Organized workshops on special drought-related topics Prepared sample ordinances on water conservation for municipalities and domestic rural supplies Established drought information center as a focal point for activities, information, and assistance
Technical assistance on water conservation and other water-related activities	Provided advice on potential new sources of water Evaluated water quantity and quality from new sources Advised water suppliers on assessing vulnerability of existing supply system Recommended that suppliers adopt water conservation measures
Demand reduction/ water conservation programs	Established stronger economic incentives for private investment in water conservation Encouraged voluntary water conservation Improved water use and conveyance efficiencies Implemented water metering and leak detection programs

Table 2.1. (continued)

Category	Specific Action
Emergency response programs	Established alert procedures for water quality problems Stockpiled supplies of pumps, pipes, water filters, and other equipment Established water hauling programs for livestock from reservoirs and other sources Compiled list of locations for livestock watering Established hay hotline Provided funds for improving water systems, developing new systems, and digging wells Provided funds for recovery programs for drought and other natural disasters Lowered well intakes on reservoirs for rural water supplies Extended boat ramps and docks in recreational areas Issued emergency surface water irrigation permits from state waters Created low-interest loan and aid programs for agricultural sector Created a drought property tax credit program for farmers Established a tuition assistance program to enable farmers to enroll in farm management programs
Water use conflict resolution	Acted to resolve emerging water use conflicts Negotiated with irrigators to gain voluntary restrictions on irrigation in areas where domestic wells were likely to be affected Established a water banking program Clarified state law regarding sale of water Clarified state law on changes in water rights Suspended water use permits in watersheds with low water levels Investigated complaints of irrigation wells interfering with domestic wells
Drought contingency plans	Established statewide contingency plans Recommended to water suppliers the development of drought plans Evaluated worst-case drought scenarios for possible further actions Established natural hazard mitigation council

Most U.S. states lack the financial resources necessary to provide drought relief to individual citizens during times of emergency. However, it is often within the mission and capability of state agencies to provide technical assistance to municipalities and others. During recent droughts, states assisted by providing advice on potential new sources of water and evaluating the quality and quantity of those supplies. Agencies also assisted municipalities in assessing the vulnerability of water supply systems. States encouraged the adoption of voluntary water conservation measures and established stronger economic incentives for water conservation within the private sector. Water metering and leak detection programs were implemented.

Emergency response programs are not considered by some to be mitigation actions. However, if these measures are implemented to reduce immediate impacts or the risk of future impacts as part of a long-term mitigation program, they represent a proactive approach to drought management. State responses included a wide range of measures such as lowering of well intakes on reservoirs for rural water supplies, establishing water hauling programs for livestock, extending boat ramps in recreational areas, and creating a tuition assistance program to enable farmers to participate in farm management classes.

Conflicts between water users increase during water-short periods. Timely intervention to resolve these conflicts will become increasingly necessary as demands on limited water supplies continue to expand in number and complexity. The best approach is to anticipate these conflicts well in advance of drought and initiate appropriate actions to avoid conflict. Many of the actions taken focused on the growing conflicts between municipal and agricultural water use.

The State of Georgia in the U.S. is an excellent example of how mitigation actions can be identified to reflect state-specific needs. Georgia recently developed a drought planning framework and identified a broad range of predrought strategies that could be used to lessen the state's vulnerability to future drought events. These strategies are divided by sector into municipal and industrial, agriculture, and water quality. Selected examples of these actions are provided in Table 2.2. These examples are quite illustrative of the types of actions identified by states that have recently completed the drought mitigation planning process.

With the tremendous advances in drought planning at the state level in the United States in recent years, it should come as no surprise that states have been extremely frustrated and dissatisfied with the lack of progress at the federal level. Early into the 1995–1996 drought that affected a large portion of the southwestern and south-central portions of the country, the lack of leadership and coordination at the federal level quickly became obvious and continued with subsequent drought episodes. Recent initiatives toward development of a national drought policy are the direct result of those frustrations (Wilhite 2001).

The U.S. Congress and the president are currently considering actions that could be taken in response to recommendations issued in May 2000 by the National Drought Policy Commission (NDPC). These recommendations were in response to the National Drought Policy Act, passed by the U.S. Congress in July 1998 and directed at developing a national drought policy that would emphasize preparedness and mitigation in future drought management efforts. One of the NDPC's recommendations strongly endorses drought planning at all levels of government. An interim National Drought Council has been formed, composed of federal and nonfederal members, and legislation was introduced in the U.S. Congress in 2003 that will lead to a more permanent

Table 2.2. Summary of selected pre-drought strategies included in the Georgia Drought Management Plan (Georgia Department of Natural Resources, 2003)

MUNICIPAL AND INDUSTRIAL	AGRICULTURE	WATER QUALITY, FLORA, AND FAUNA
State Actions	***Farmer Irrigation Education***	***State Actions***
Formalize the Drought Response Committee as a means of expediting communications among state, local, and Federal agencies and non-governmental entities.	Recommend that farmers attend classes in best management practices (BMP) and conservation irrigation, prior to (i) receiving a permit, (ii) using a new irrigation system, or (iii) irrigating for a coming announced drought season.	Encourage all responsible agencies to promote voluntary water conservation through a wide range of activities.
Establish a drought communications system between the state and local governments and water systems.	Provide continuing education opportunities for farmers.	Monitor streamflow and precipitation at selected locations on critical streams.
Provide guidance to the local governments and water supply providers on long-term water supply, conservation and drought contingency planning.	Encourage the use of BMPs, conservation irrigation, efficient use of irrigation systems, and the Cooperative Extension Service's water conservation guidelines.	Monitor water quality parameters, such as temperature and dissolved oxygen at selected critical streams.
Review the local governments and water supply providers' conservation and drought contingency plans.	Develop electronic database for communicating with water use permit holders.	Provide the streamflow and water-quality data in real time for use by drought managers and work with drought managers to optimize information delivery and use.
Work with the golf course and turf industry to establish criteria for drought-tolerant golf courses.	Encourage development and distribution of information on water efficient irrigation techniques.	Evaluate the impact of water withdrawals on flow patterns, and the impact of wastewater discharges on water quality during drought.
Encourage water re-use.	***Field/Crop Type Management***	Investigate indicators and develop tools to analyze drought impacts for waterways such as coastal ecosystems, thermal refuges such as the Flint River, and trout streams.
	Encourage the use of more drought resistant crops.	

Table 2.2. (continued)

MUNICIPAL AND INDUSTRIAL	AGRICULTURE	WATER QUALITY, FLORA, AND FAUNA
Provide water efficiency education for industry and business.	Encourage the use of innovative cultivation techniques to reduce crop water use.	Improve the agencies' capabilities and resources to monitor land-disturbing activities that might result in erosion and sedimentation violations.
Conduct voluntary water audits for businesses that use water for production of a product or service.	Conduct crop irrigation efficiency studies.	Identify funding mechanisms and develop rescue and reintroduction protocols for threatened and endangered species during extreme events.
Identify vulnerable water dependent industries, fund research to help determine impacts and improve predictive capabilities.	Provide farmers with normal year, real time irrigation, irrigation scheduling, and crop evaporation/transpiration information.	Develop and execute an effort to identify pollutant load reduction opportunities by wastewater discharge permit holders.
Develop criteria for a voluntary certification program for landscape professionals.	Monitor soil moisture and provide real time data to farmers.	Develop and execute an effort to identify opportunities for industry to decrease water use during drought periods.
Develop and implement a statewide water conservation program to encourage local and regional conservation measures.	***Irrigation Equipment Management*** Encourage the installation of water efficient irrigation technology.	Evaluate the impact of water withdrawals on flow regimes and the impact of wastewater discharges on water quality during drought.
Develop and implement an incentive program to encourage more efficient use of existing water supplies.	Retrofit older irrigation systems with newer and better irrigation technology. Update any system over 10 years old.	Develop and promote implementation of sustainable lawn care programs based on selected BMPs and/or integrated pest management practices.

Table 2.2. (continued)

MUNICIPAL AND INDUSTRIAL	AGRICULTURE	WATER QUALITY, FLORA, AND FAUNA
Local/Regional Actions Develop and implement a drought management and conservation plan.	Encourage farmers to take advantage of available financial incentives for retrofitting and updating older or less efficient systems.	Encourage protection and restoration of vegetated stream buffers, including incentives for property owners to maintain buffers wider than the minimum required by state law.
Assess and classify drought vulnerability of individual water systems.	Recommend irrigation system efficiency audits every 5 to 7 years.	Provide for protection of recharge areas through measures including land purchase or acquisition of easements.
Define pre-determined drought responses, with outdoor watering restrictions being at least as restrictive as the state's minimum requirements.	***Government Programs*** Improve irrigation permit data to create a high degree of confidence in the information on ownership, location, system type, water source, pump capacity, and acres irrigated for all irrigation systems to determine which watersheds and aquifers will be strongly affected by agricultural water use, especially in droughts.	Encourage and explore wildland fire mitigation measures.
Establish a drought communications system from local governments and water supply systems to the public.	Improve on the agriculture irrigation water measurement and accounting statewide.	Enhance programs to assist landowners and farmers with outdoor burning.
	Improve communications and cooperation among farmers and relevant state and Federal agencies regarding available assistance during drought conditions.	
	Support legislation and efforts to enhance the ability of farmers to secure adequate water supplies during drought conditions.	

national drought council and a national drought policy. Key components of this bill include an emphasis on risk management, preparedness planning, and the improvement of the nation's drought monitoring system and forecasting capabilities. A recently completed project, the National Integrated Drought Information System (NIDIS), is intended to provide the foundation for the development of an improved drought monitoring system when the bill is passed by the U.S. Congress.

2.2 Summary and Future Challenges

Drought is an insidious natural hazard that is a normal part of the climate of virtually all regions. It should not be viewed as merely a physical phenomenon. Rather, drought is the result of interplay between a natural event and the demand placed on water supply by human-use systems.

There are many challenges before us if we are to improve our management of droughts. First, drought must be accepted as a natural hazard within the natural hazard community of scientists and policy makers. Because of its slow-onset characteristics and lack of structural impacts, it is often disregarded. A second challenge is to build awareness of drought as a normal part of climate. It is often considered to be a rare and random event, a departure from normal climate; thus the lack of emphasis on preparedness and mitigation. Improved understanding of the different types of drought and the need for multiple definitions and climatic/water supply indicators that are appropriate to various sectors, applications, and regions is a critical part of this awareness-building process. A third challenge is to erase misunderstandings about drought and society's capacity to mitigate its effects. Many people consider drought to be purely a physical phenomenon rather than the result of interplay between the natural event and human activities, i.e., all factors that influence vulnerability. Although it is important to understand the hazard (i.e., the climatology of drought from temporal and spatial perspectives and its causes), it is equally if not more important to understand the factors behind our vulnerabilities and take proper steps to reduce those vulnerabilities. Reducing drought risk is largely about changing behaviors, thus social scientists must play a key role in the drought planning process. A fourth challenge is to convince policy and other decision makers that investments in mitigation are more cost effective than post-impact assistance or relief programs. Evidence from around the world, although sketchy, illustrates that there is an escalating trend of losses associated with drought in both developing and developed countries. Also, the complexity of impacts is increasing. It seems clear that investments in preparedness and mitigation will pay large dividends in reducing the impacts of drought.

A growing number of countries are realizing the potential advantages of drought planning. Governments are formulating policies and plans that address many of the deficiencies noted from previous response efforts – efforts that were largely reactive. Most of the progress made in drought preparedness and mitigation has been accomplished in the past decade or so. Although the road ahead will be difficult and the learning curve steep, the potential rewards are substantial. The crisis management approach of responding to drought has existed for many decades and is ingrained in our culture and reflected in our institutions. Moving from crisis to risk management will certainly require a paradigm shift. The victims of drought have become accustomed to government and donor assistance programs. In many instances, these misguided and misdirected government programs and policies have promoted the nonsustainable use of natural resources. Many governments have now come to realize that drought response in the form of emergency assistance programs only reinforces poor or nonsustainable actions and decreases self-reliance.

Policies that encourage self-reliance and the sustainable use of natural resources will be more effective in the long term and will reduce the need for government and donor intervention. A critical first step is to identify and quantify the sectors and peoples at risk from drought. Once this step is completed, policies, plans, and mitigation programs can be formulated to address these vulnerabilities in a systematic manner. Virtual networks linking the broad range of institutions with interest in drought management at the national, regional, and global scale can greatly accelerate drought preparedness through the sharing of lessons learned.

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CHAPTER 3

The Occurrence and Predictability of Extreme Events over the Southwest Pacific with Particular Reference to ENSO

M. James Salinger, Penehuro Lefale

Abstract Extreme events in the Southwest Pacific (SWP) are widespread and largely centre on tropical cyclones, droughts and floods. These events are directly influenced by the state of the El Niño Southern Oscillation (ENSO). The impacts of climate extremes are dramatic, particularly on Small Island Developing States (SIDS) of the SWP region. They cause destruction and widespread damage to human, socio, economic and development well being of local communities, examples being tropical cyclones Ofa, Val and more recently Heta, Olaf and Percy that devastated Samoa, Niue, Tonga and the Cook Islands and the severe impacts of the 1997–1998 El Niño event on Papua New Guinea and Fiji. Although warming in the SWP region is decreasing, extremes of low temperature, the trend of more El Niño episodes in the 20th century, based on observations, has increased both dry periods and extreme rainfalls in significant parts of the region, especially near the Date Line. The phase of ENSO also significantly affects temperature and rainfall anomalies and extreme across the region, with sharp gradients between contrasting areas of above and below average departures. ENSO also changes tropical cyclone track, density and occurrence, with El Niño events increasing the frequency and displacing tropical cyclones more towards the central South Pacific, and La Niña episodes decreasing the frequency and confining tracks to the west of the Date Line.

Seasonal to Inter-annual (SI) prediction has become a major research area and application tool that offers much promise for early warning and disaster preparedness to extreme events. In the SIDS of the SWP region, the Island Climate Update (ICU), a multinational virtual type regional climate prediction tool, with success hit rates (percentage of prediction being correct after comparing it with what actually happened) greater than 70 percent being achieved in some parts of the region since it was launched in September 1999, provides an extremely useful regional mechanism for preparing and predicting seasonal rainfall departures and other extreme events associated with ENSO for SIDS. The ICU could be used as a model in other regions.

3.1 Introduction

The Southwest Pacific (SWP) region is highly susceptible to climate related extreme events such as droughts, landslides and coastal flooding associated with the El Niño Southern Oscillation (ENSO) and tropical cyclones (Krishna et al., 2001). These extreme events are an integral part of the climate of the region and have dominant influences on the socio, economic and developmental well being of local communities. Experiences from the 1997-1998 El Niño event such as water shortages in Papua New Guinea and an unusual increase in outbreak of diseases such as malaria in some parts of region highlight the vulnerability of the region to extreme events (Shea et al., 2001; Hamnett et al., 2002).

On inter-annual timescales, the ENSO causes much climate variations throughout many areas of the South West Pacific and the globe (Philander, 1990, Kidson and Renwick, 2002). The impacts of ENSO varied considerably from one island to another (Hamnett et al., 2002), including wetter than normal or drier than normal seasons and changes in extreme events.

This chapter briefly assesses the occurrence, impacts and predictability of extreme events in the SWP. A brief overview of the vulnerability of the SWP region to extreme events is provided by assessing the economic costs to selected Small Island Developing States (SIDS) of the region associated with recent extreme events. Trends in extreme daily temperature and rainfall using climate indices for selected areas of the region anre examined, and a review is given of the progress to date of climate prediction (seasonal to interannual (SI)) in the region using knowledge of Sea Surface Temperatures (SSTs) anomalies in the tropical Pacific region (Niño 3.4 region) to predict climate outlooks (temperature, rainfall and tropical cyclones) for the tropical SWP region. This new area of climate science is still in its infancy and developmental phase. The chapter concludes with a brief analysis of a pilot project, the *Island Climate Update* (ICU) implemented in the tropical SWP since September 1999 to provide climate outlooks, including outlooks on occurrence of tropical cyclones, for SIDS in the region.

3.2 Impacts of Extreme Events

Of the extreme events in the Southwest Pacific, tropical cyclones are particularly significant (Krishna et al. 2001). Tropical cyclone Ofa caused an estimated US$ 120 million damages in Samoa in 1990 (or about 25% of its GDP) while tropical cyclone Val caused damages of about US$ 200 millions or 45% of its GDP in 1991. These two cyclones alone set back the development of Samoa by at least twenty years. In Fiji, tropical cyclone Kina in 1993 caused an estimated US$ 120 million damages, about 2.4% of Fiji's GDP. The damage caused by tropical cyclone Heta in January 2004, a category 5 tropical cyclone, is only now being assessed. Property, crops, roads and bridges were destroyed or damaged on Samoa with losses equivalent to US$ 226 million on American Samoa with roads washed away, and other damage to property and infrastructure. In the Cook Islands, 6 metre swells affected the west coast of Rarotonga. However, Heta devastated the tiny island nation of Niue (population 1200). One person died, much property was damaged or destroyed, roads were destroyed, infrastructure cut and crops destroyed because of intense rainfall and high winds (last recorded speed of 150 km/h and gusts to 200 km/h before equipment failure, G. Clarke, pers.comm).

El Niño events produce widespread impacts on communities across the Southwest Pacific, as instanced by the 1997–98 event (Shea et al. 2001). Drought severely affected Fiji, Papua-New Guinea, the Solomon Islands, Tonga and the Marquesas Islands of French Polynesia. In Fiji, by October 1998, 54,000 people were receiving food supplies and 400,000, half the population, were receiving water deliveries (Hamnett et al. 2002, Lightfoot 1999). In contrast Kiribati was wetter than normal. Fisheries were impacted with a general shift of the catch to the east, followed by a shift westwards (Lehodey et al. 1997, Lefale et al. 2003). Catches declined for Papua-New Guinea and the Solomon Islands, and increased for Kiribati. The impacts were severe on eastern regions of New Zealand where there were significant losses in agriculture and water (Basher 1998).

3.3 Trends in Extremes

Trends in daily temperature and rainfall indices for New Zealand have been examined for frequencies and values of daily maximum and minimum temperatures above and below specified percentile levels, as well as frequencies of these above and below fixed temperature thresholds (Salinger and Griffiths 2001). There were no significant trends in maximum temperature extremes ('hot days'), but there was a significant increase in the value, and decrease in frequency, of minimum temperature ('cold nights') extremes over the period 1951–1998. Compared with the 1961–1990 reference period, there was a de-

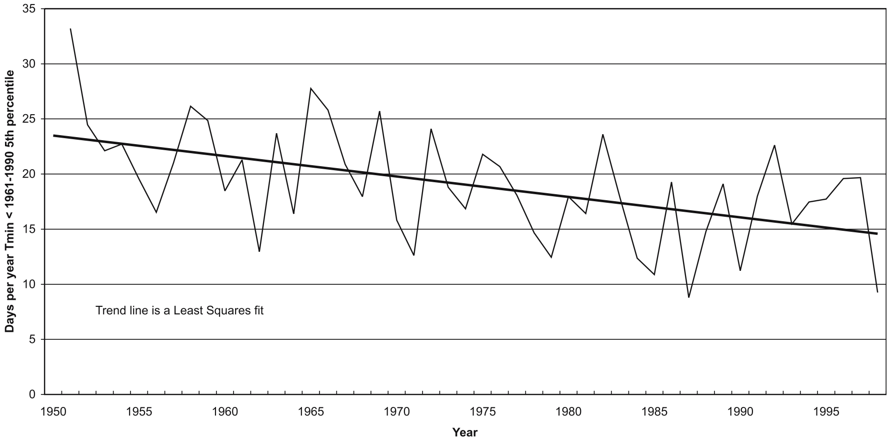

Fig. 3.1. Nationally averaged frequency of days with minimum temperatures below the 1961–1990 mean 5th percentile (*frequency of cold nights*) over the period 1951–1998 for New Zealand (from Salinger and Griffiths, 2001)

cline in frequency of the minimum temperature 5th percentile ('cold nights') of 10 to 20 days a year in many locations (Fig. 3.1). Trends in rainfall indices show a zonal (west-east) pattern of response, with the frequency of 1-day 95th

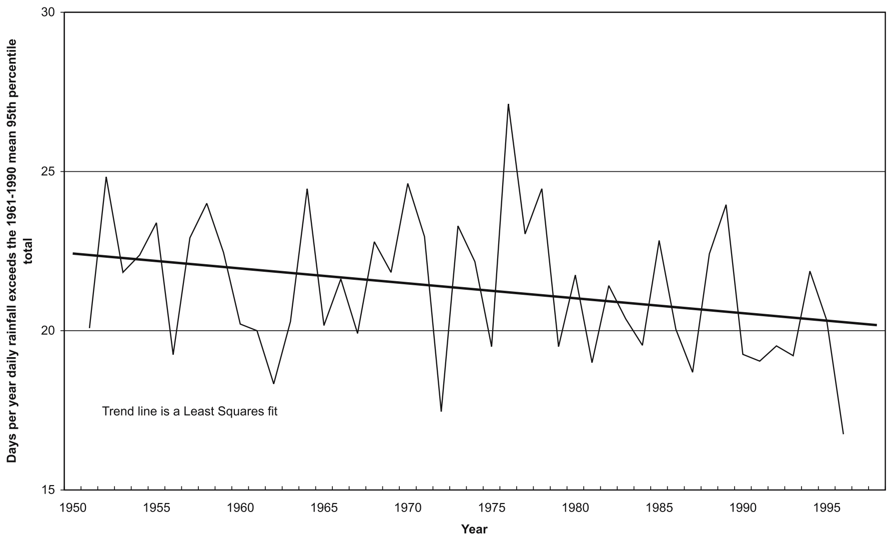

Fig. 3.2. Trend of nationally averaged frequency of daily rainfall exceeding the 1961–1990 mean 95th percentile (*extreme frequency*) for days with rainfall totals of 1 mm or more over the 1951–1996 period for New Zealand (from Salinger and Griffiths, 2001)

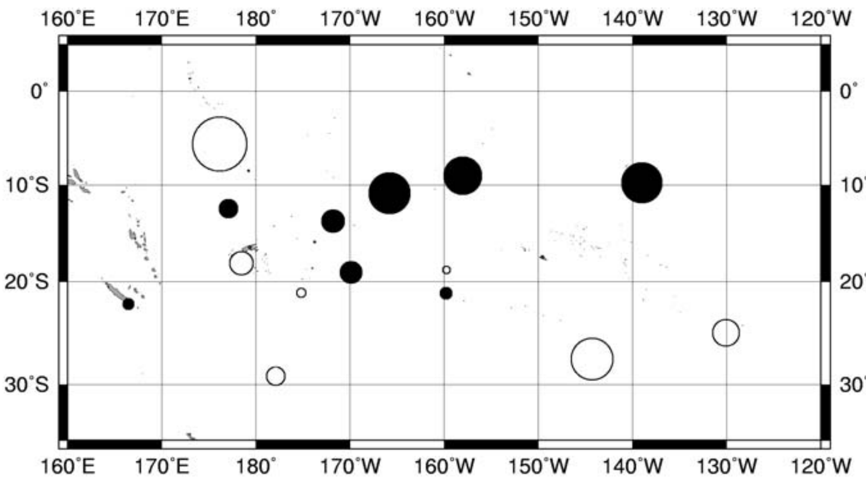

Fig. 3.3. Normalized trends in the extreme intensity of rainfall over 1961–2000. The circle size is proportional to the size of the normalized linear trend per decade. *Black circles* represent positive trends, *white circles* represent negative trends (from Griffiths et al., 2003)

percentile extremes decreasing in the north and east, and increasing in the west over the 1951–1996 period, but decreasing overall when taken nationally (Fig. 3.2). This equates to a higher frequency of ENSO events in the late 20th century. Frost day frequencies decreased between 5 and 15 days a year in many localities, with little change in the west of the South Island, and at higher elevation locations.

For the South Pacific, analyses of daily rainfall records for extremes over the period 1961–2000 have been assessed (Griffiths et al. 2003). Clear spatial patterns emerged in the trends of most indices of extreme rainfall, with a major discontinuity across the South Pacific Convergence Zone (SPCZ). The position of the SPCZ is known to be influenced by ENSO (Folland et al. 2002). Precipitation has become more extreme in the SPCZ zone between 180° and 170°W (Fig. 3.3) over the period 1961–2000, with both dry spell length increasing and daily extreme high rainfalls increasing in magnitude as well as frequency, including extended duration extreme rainfall. The majority show a change in the 1970s or 1980s – coincident with an increase in ENSO episodes.

3.4 ENSO Impacts on Climate in the Southwest Pacific

ENSO is the primary global mode of natural climate variability in the 2–7 year time band defined by sea surface temperature (SST) anomalies in the eastern tropical Pacific. Since the mid-1970s El Niño events have been more frequent than in the previous 30 years, and in each subsequent event global temperature anomalies have been higher (Trenberth and Hoar 1996). Figure 3.4 shows the Southern Oscillation Index (SOI, the Tahiti minus Darwin normalized pressure index) since 1920, which measures whether the climate system is in the El Niño or La Niña state. A significantly negative index indicates the El Niño state, and a positive index the La Niña state.

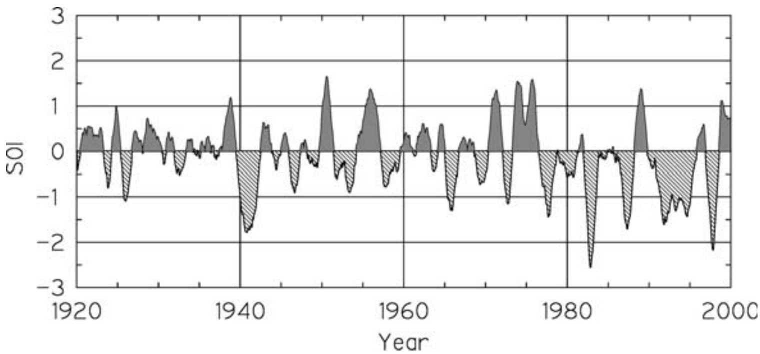

Fig. 3.4. Times series of 12-month running averages of the Southern Oscillation Index, 1920–2000

Relationships between the ENSO state and temperature and rainfall in the Southwest Pacific (Fig. 3.5) using correlations with the SOI (Salinger et al. 1995) are shown. In the El Niño (La Niña) state above average (below average) temperatures occur in the central South Pacific north east of the SPCZ including Samoa, Tokelau, eastern Kiribati, northern Cook Islands and French Polynesia, with below average (above average) temperatures to the south west. Rainfall anomalies are more zonal with all of Kiribati, Tuvalu, Tokelau, northern Cook Islands, the Tuamotu and Marquesas groups of French Polynesia, areas mainly north of 10°S, being wetter (drier) during the El Niño (La Niña) state, and those areas of the Southwest Pacific subtropicals between 15–35°S being drier (wetter).

Tropical cyclones develop in the South Pacific over the wet season, usually from November through to April. Peak cyclone occurrence is usually during January, February and March based on historical tropical cyclone data analysis. Those countries with the highest risk include Vanuatu, New Caledonia, Fiji, Tonga and Niue. Taken over the whole of the South Pacific, on average nine tropical cyclones can occur during the November to April season, but this can range from as few as three in 1994/95, to as many as 17 in 1997/98, during the last very strong El Niño. The mean frequency of tropical cyclones for the 1970–2000 period for El Niño episodes is 11.5, and La Niña events 8.6 per season. The tropical cyclone track densities vary depending on the ENSO state (Fig. 3.6). During El Niño episodes a higher frequency of tropical cyclone tracks occur near Vanuatu and Fiji, and their occurrence spreads further east to 160°W to affect the Cook Islands and most of French Polynesia. In contrast, during La Niña events the maximum occurrence is largely confined to the Coral Sea area of the Southwest Pacific centring on 160°E, 20°S and affecting New Caledonia in particular.

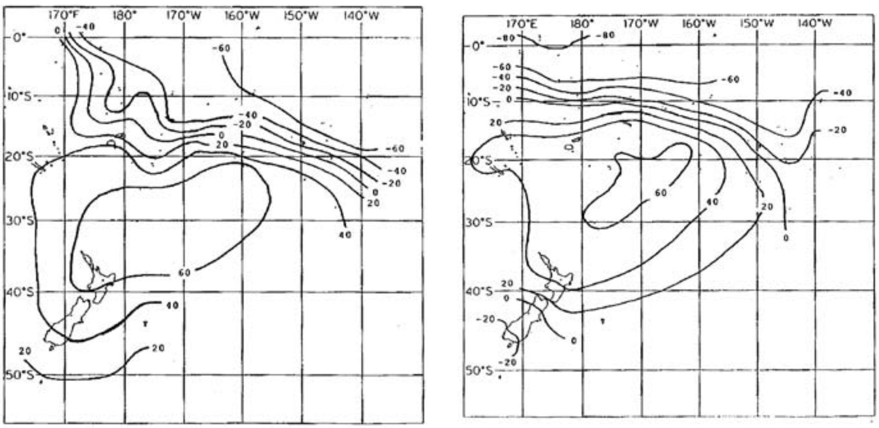

Fig. 3.5. Annual correlation (∗100) between (**a**) temperature and (**b**) rainfall and the Southern Oscillation Index. All isopleths < −35 or > 35 are at least significant at the 95% confidence level

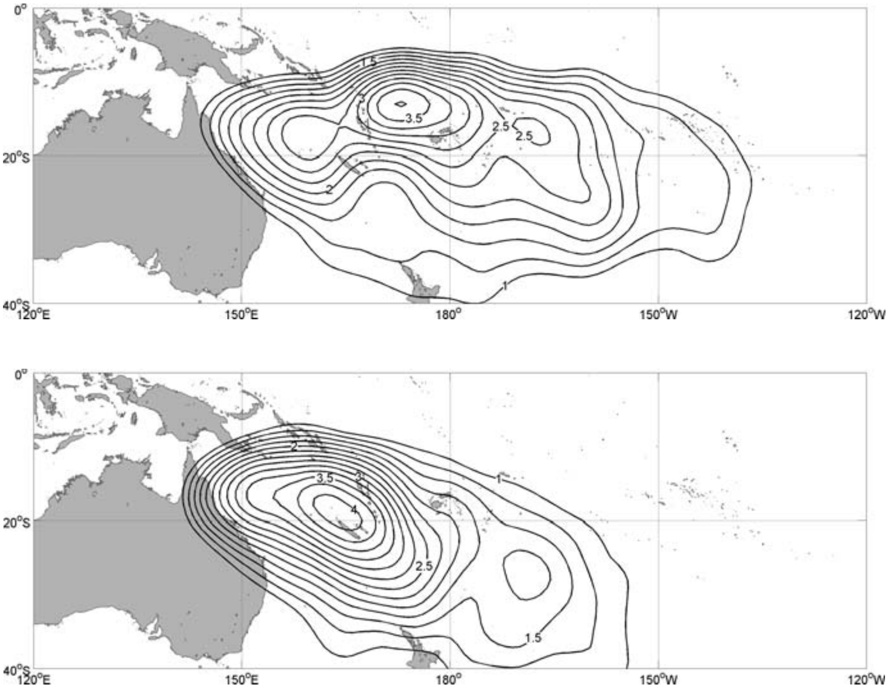

Fig. 3.6. Tropical cyclone track density for (**a**) the 11 strongest El Niño seasons and (**b**) the 11 strongest La Niña seasons (by SOI). Contour interval is 0.25, starting at 1.0

3.5
Predictability of Extreme Events and ENSO

Seasonal to interannual climate forecasting is used to predict ENSO and extreme events related to ENSO (Glantz et al. 1991). Two main groups of models are used (Goddard et al. 2001) – empirical models are developed using historical data and attempt to represent statistical links between one or more predictors, and computer-based dynamical models of the ocean and/or atmosphere, often similar to, or even the same as, the models used for weather or climate change prediction, form the other group. The variety of models targeted on predicting ENSO-related tropical sea surface temperature variations in the Pacific Ocean all have measurable skill out to perhaps nine months to a year, in some case perhaps a little longer. It is these that form the basis of ENSO predictions and the extreme events associated with the ENSO state.

3.6
Predictability of Southwest Pacific Climate

Operational seasonal climate forecasting for this region only commenced in the late 1990s through the Pacific ENSO Applications Center for the North Pacific.

The Australian Bureau of Meteorology produce seasonal outlook reference material for the South Pacific. The National Institute of Water and Atmospheric Research (NIWA) commenced production of the Island Climate Update (ICU) for the Southwest Pacific in September 2000. This is an overview of the climate in the South Pacific, with an outlook for coming months including forecasts of the state of ENSO. It is now a multi-national project with important contributions

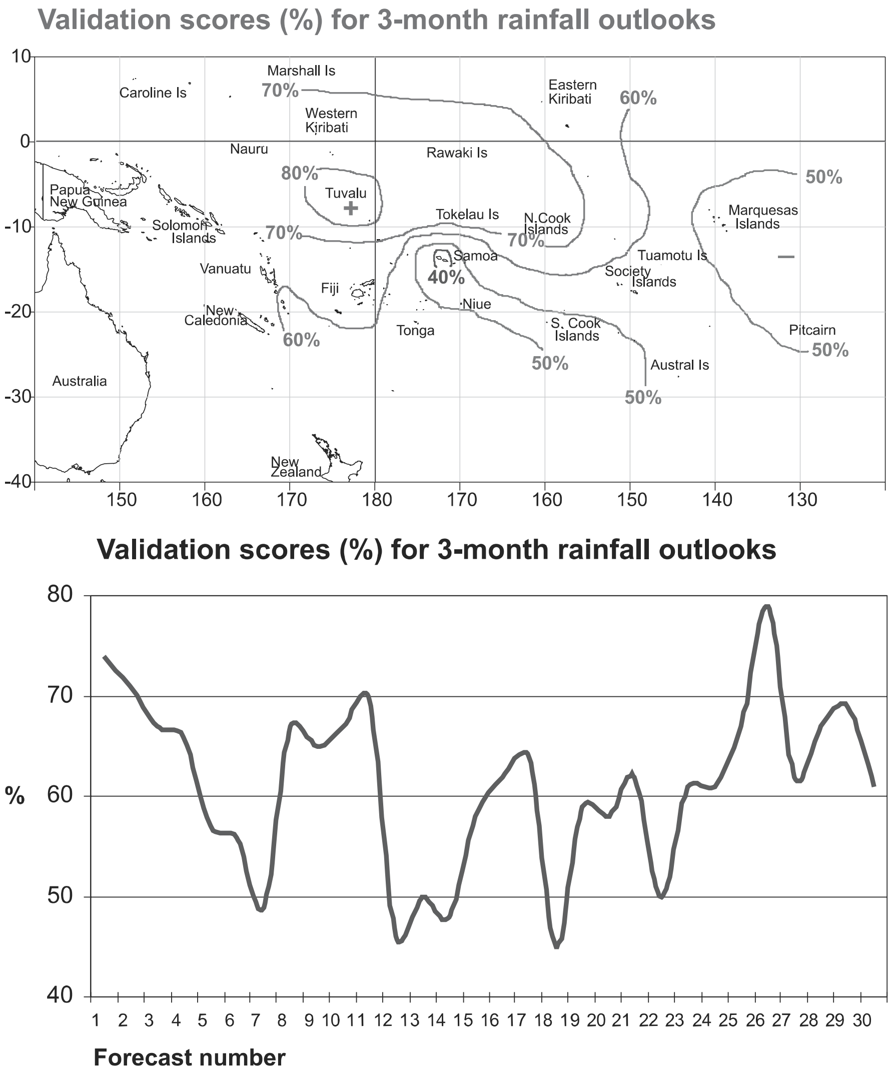

Fig. 3.7. (**a**) Frequency of correct 3-month rainfall outlooks and (**b**) validation score for the 30 (3-month) rainfall outlooks. This shows the percentage correct forecasts. Scores of 60% or more indicate significantly better outcomes than by chance

from the meteorological services of 13 Pacific Island countries, Australia, New Zealand and the United States.

Validation of the first 30 ICU outlooks for the Southwest Pacific (Fig. 3.7a) indicates how often the forecasts have been correct, in a categorical sense. Taking the ICU forecast category (below, average or below, average, average or above, or above average) to be that assigned the highest probability, the contours and numbers show the percent frequency of correct forecasts (or the "hit" rate). The overall hit rate is equivalent to the percentage frequency of correct forecasts. The hit rate has been highest ($> 70\%$) in the 0–10°S latitudes west of about 155°W, in the region from Western Kiribati to the Northern Cook Islands, including Tokelau, and especially over Tuvalu (81%). However, scores have been much lower in areas around and to the south and east of Samoa. For the 30 issue period (Fig. 3.7b), the average hit rate for the whole of the forecast region has ranged between about 45 and 80%. The distribution of forecast success is affected by some extent to the ENSO state and the location of the SPCZ. With much of the period being above 50%, useful skill has been achieved.

3.7 Conclusions

Extreme climatic events produced by tropical cyclones, floods and droughts in the southwest Pacific are particularly devastating and can demolish economies and communities. Those caused by tropical cyclones and ENSO events are particularly significant. There are trends in climate extremes that are detectable throughout the region. Particularly evident is the decrease in cold nights in New Zealand because of general regional warming (Folland et al. 2003). At the same time rainfall extremes in region show a direct response to more ENSO events in the latter part of the 20th century with both dry spells and daily extreme rainfalls increasing near the Date Line in the tropical Pacific, and the latter decreasing in the north east, and increasing in the west of New Zealand.

ENSO, in both the El Niño and La Niña states produces very significant influences on the mean climate, and associated weather and climate extremes of the Southwest Pacific. El Niño events produce the more significant impacts on extreme events. These also affect tropical cyclone tracks and numbers with the El Niño (La Niña) episodes moving the tracks north east (south west) with increases (decreases) in frequency and rainfall distribution.

Seasonal to interannual prediction in the six years during and since the 1997/98 El Niño event, has become a major research and application issue in the Southwest Pacific. The results so far from the ICU work have demonstrated unequivocally that short-range climate prediction is achievable with skill. In the Southwest Pacific with the development of the ICU seasonal climate forecasting project useful skill has been achieved in the seasonal forecasting of seasonal rainfall departures and ENSO events with hit rates greater than 70% being achieved in some parts of the region. This new technology offers much promise for disaster preparedness strategies for all end users in the region.

Acknowledgements

This research was funded by the New Zealand Foundation for Research, Science and Technology (FRST) under contract No. CO1X0202. We would like to thank Dr Jim Renwick and Ms Ashmita Gosai for helpful comments in the preparation of this manuscript.

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Accessibility of Database Information to Facilitate Early Detection of Extreme Events to Help Mitigate Their Impacts on Agriculture, Forestry and Fisheries

R.P.R. Guerreiro

Abstract Extreme events can cause severe damage in several sectors such as agriculture, forests and fisheries. In order to facilitate early detection of these harmful episodes, adequate climate and agrometeorological databases must be ensured. Some observational data and products necessary for early detection are presented in this paper. It briefly reviews the main features of proper databases that provide quality controlled data and products, useful to the end-users, easily accessible and in a timely manner. The data can be accessed through the standardization of database management and electronic accessibility. The main features and importance of data collection, automatic weather stations (AWS), database management and relational database management systems (RDBMS) are described. Examples of agrometeorological databases, database management systems and their applications and accessibility are given. Remote sensing (geostationary satellites, NOAA-Advanced Very High Resolution Radiometer (AVHRR), radar and lighting detectors) offers a valuable source of spatial information and can be complementary or even alternative to ground-based observations. Due to the processing of data from various sources in agrometeorology, and the need to display them in maps, geographical information systems (GIS) are in wider use today. GIS can help to identify the risk, extent and severity of many extreme events. Some examples of applications of remote sensing and GIS are presented. Finally, training, interdisciplinary collaboration and communication between users and developers of products are referred as essential means to achieve these goals.

4.1 Introduction

Extreme events that most affect agriculture, rangelands, forests and fisheries include mainly extreme meteorological events and weather conditions leading to the development of agents such as pests and deseases that affect these systems. Among these events, one can mention droughts, floods, heatwaves, frost, high wind, severe storms, like tropical storms, hailstorms, thunderstorms and duststorms. All of them cause severe damage to agriculture or may even have disastrous effects. Extreme events do less damage when they strike a resilient community; so, it is possible to mitigate their effects with an early detection. To reach this, adequate climate and agrometeorological databases are necessary.

Forest fires, which are considered as indirect effects of extreme meteorological events, constitute an important cause for the loss of forest produce in many countries, next to wind, hail, etc. (Gommes 1997). In Portugal, a heatwave, which took place in August 2003, significantly contributed to the worst forest fires in the last decades. An area of 280,550 ha was destroyed during this month (13th Provisional Report – Forest Fires 2003), similar to the area of Luxemburg. Monitoring of the forest fires is done by using the Canadian Fire Index. The computation and operationality of this Fire Weather Index (FWI) is possible due to the accessibility of databases of daily meteorological observations, as well as an atmospheric mesoscale model. Warnings were issued to the National Fire Brigade and Civil Protection Service, because of the high risk of this situation. However, this did not seems to be adequate. Although this system has proved to give fairly good results, the huge areas were burnt and a few casualties occurred due, among other factors, to some kind of lack of coordination and internal communication between Civil Protection and Fire Brigade, as it was their first year of working in the same organization. Besides this, the access to the information was restricted to official entities and not available to every user. This single example demonstrates the importance of an efficient and automated access to agrometeorological databases, in the prevention and early detection of extreme events, namely forest fires.

One of the main duties of Meteorological and Hydrological Services is to provide public warning of weather conditions conducive to extreme events, which can be dangerous to the population and can cause severe damages in sectors like agriculture, forestry and fisheries. Timely information is essential in the case of extreme events as information is needed at the right time by the users (Anaman 2003). It is indeed very important, since information supplied at the wrong time may be worthless.

Appropriate communication channels for transmitting advice and warnings to users are important. Agrometeorological bulletins transmitted via Internet or web pages dedicated to agromeorological information, with timely warnings of adverse weather conditions are essential to farmers and agricultural authorities. Recent developments in computer technology, database software and telecommunication systems provide the essential tools to facilitate the accessibility to databases and to the development of preparedness measures in the case of extreme events.

Interactions between meteorological conditions, agriculture, forestry and fisheries are complex, as they involve products from different sources. The building of a database of meteorological, phenological, soil and agronomic information is inevitably a major priority (Doraiswamy et al. 2000). The building of these databases depends on the availability of technical personnel and on the necessary hardware and software.

The recent developments in computer technology, communications and database software makes it possible to the users to access large data sets. The World Wide Web (WWW) allows users to access text, images, data or other information that are linked together electronically.

4.2 The Need for Observational Data and Products

The need for observational data necessary for an early detection of extreme events depends on the type of hazard considered. In any case, meteorological observations are always necessary. Some examples are presented below.

4.2.1 Floods

In the case of floods, precipitation is the most important parameter and is used as input for the hydrological models. Real time data collection from an automated raingauges network is an essential condition for flood forecasting improvement (Balint et al. 2001). A suitable communication network is designed in order to exchange the hydrological data in real time. Besides precipitation, other observations such as water level and stream flow are required. The use of radars and remote sensing from satellites are essential for flood forecasting, as they can provide information on areal precipitation and movement of the storms. Hydrological forecasting systems usually contain a database, where data management is necessary to provide standardized formats, quality control, analysis, risk management and dissemination. At the Portuguese Meteorological Institute a model was developed, in connection with precipitation forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF), which processes automatically an Hydrometeorological Bulletin, with observed and forecasted daily rainfall amounts in the main river basins. This information is available to several entities responsible for water resources, environment and civil protection.

4.2.2 Droughts

As far as agricultural droughts are concerned, different indices are often used to quantify them. Percentage of normal and deciles are simple indices based on precipitation amounts. Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI) and Standardized Precipitation Index (SPI) also include data from a water balance model. Geographical Information Systems (GIS) are used to map these indices, in order to monitor their behaviour and provide information about areas experiencing drought and drought severity. Figure 4.1 shows the PDSI distribution in Mainland Portugal, in January 2000, where the whole country was affected by an intense period of drought, with some regions in extreme drought. With these maps, it is possible to monitor the spatial and temporal evolution of droughts across Mainland Portugal (Szalai et al. 2002).

In Portugal, PDSI and SPI were implemented and applications were developed to perform the calculations, archive, analyse the results and make graphs. This quick access to the data and products derived is essential for an early detection of droughts, mainly in drought prone areas. In a near future these

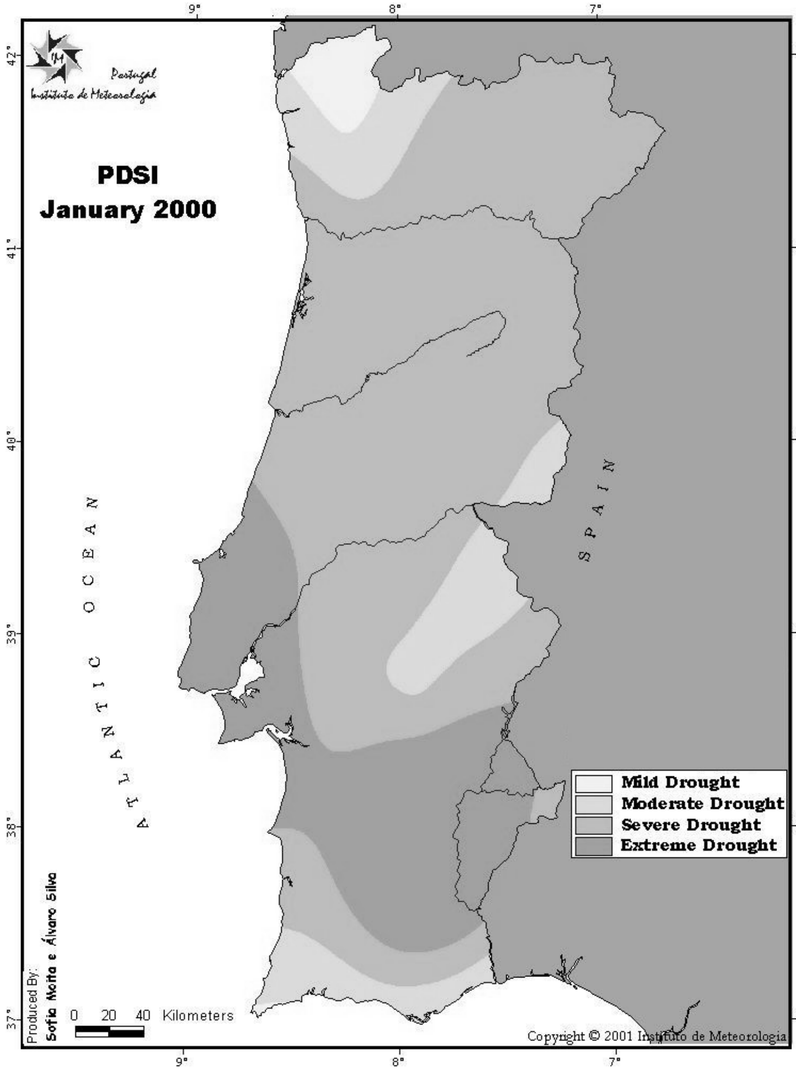

Fig. 4.1. PDSI map for January 2000 in Mainland Portugal (after three months with very short rainfall amounts). *Dark grey* represents extreme drought

products will be available in a web site for direct access by users. It is hoped that, this way, information reaches people in time for them to use it in making decisions (Wilhite and Svoboda 2000).

Besides the indices referred to above, as well as others, one should bear in mind that for agricultural drought assessment, data on soil type, its texture, water holding capacity, slope of the surface, soil bulk density, cultivar characteristics, irrigation and crop management are needed (Das 2003).

4.2.3 Lightning Storms

Lightning storms, due to electric atmospheric discharges in their extreme form, are amongst the most devastating atmospheric phenomena, which can cause loss of lives, hail and heavy rain, causing severe damage on agriculture, forestry and fisheries. Usual methods include meteorological observations, satellite images, data from meteorological radars and results obtained by numeric forecast models. The Portuguese Meteorological Institute has installed four lightning detectors (Fig. 4.2), which measure the variations of the atmospheric electromagnetic field and transmit them to a concentrator and processor. Remote terminals connected to the concentrator make it possible to visualize the information available. These data are automatically introduced in a database, where every detail about the storm is stored. Lightning detection is extremely important to determine the location of the electric discharge and to predict the path of the nebulous system that generates it, highly contributing to early detection of lightning storms.

Fig. 4.2. Lightning detectors installed by the Meteorological Institute in Portugal

4.2.4 Data Needs for Fisheries

As far as fisheries are concerned, the most important observation is water temperature. In the case of inland fisheries and aquaculture, meteorological data that serve for agriculture are also relevant for these fisheries, although the relative importance of parameters and thresholds may be different (Kapetsky 2000). Taylor (2001) refers that besides sea surface temperature, sea surface height, chlorophyll and sediments are of interest to fisheries and aquaculture. These data are available directly from high resolution satellites in real time. If timeliness, resolution and predictive capabilities for agrometeorological data can be improved, considerable benefits will come to fisheries.

4.2.5 Automated Weather Stations

The use of Automated weather stations (AWS) is becoming more and more widespread, as they provide real-time meteorological data from places in agricultural areas with very scarce stations. Data from AWSs have become essential to provide information for the assessment of risk management and for decision making.

During the 90's the Portuguese Meteorological Institute started the installation of a network of AWSs in Mainland and Islands with the following objectives:

- to increase the frequency and to improve the quality of the observations;
- to overcome the lack of non-professional people at the climatological stations;
- to increase data availability during night-time period;
- to allow real-time data availability in digital format at the Institute's central systems.

In total, 93 standard AWSs were installed until 2002. They generate 10 minutes records, for several meteorological and a few agrometeorological parameters, which are collected at the central office by a set of concentrators that automatically call the AWSs to retrieve the data. The transmission of data to the central system is made by using fixed and mobile telecommunications operators . Evaluation of data quality is done in near real-time through the analysis of data graphs and tables and with the application of automatic procedures consisting of algorithms to check and validate the records. The objectives of data processing and validation are to prepare them for long-term archive into a database with compatible format (Nunes et al. 2003). In this system, the degree of automation of the validation procedures still needs to be increased. To achieve this, a new generation system is being prepared, based on more powerful software and better data quality communication system. Another database has been developed and maintained to archive all the features of the AWSs, where detailed metadata have been introduced, including AWSs identification, location, equipment and even the local people contacts. All the changes that occurred at the AWSs are also recorded, including the actions performed by the maintenance company, namely the replacement of sensors and other components. Metadata relating to the operating characteristics and performance of the observational station are an essential part of the data record (Motha 1999).

4.2.6 Agrometeorological Databases

A basic requirement in agrometeorological hazard assessment and mitigation is an adequate agrometeorological database. This should include not only meteorological data, but also agricultural (phenological, crop management, pest and desease cycle), hydrological, land use, soil types, economic and other relevant information. Inclusion of derived data, maps and graphs is a requirement too. With efficient agrometeorological databases, including quality controlled historical data, it is feasible to estimate the risk of extreme events in quantitative terms, which is an important information in risk assessment. According to Weiss et al. (2000), one useful purpose of agrometeorological databases is to transform data into useful information.

Some limitations still exist. For example, detailed phenological information is often sporadic and not very widespread. In Portugal, like in many other countries, such data are generally archived in agronomic research institutes and are not centralized in an agrometeorological database, what makes them not very easily available.

Databases of extreme events, or better, of agricultural disasters resulting from extreme events should also be encouraged. This represents a basic requirement in hazard assessment for extreme events. Such databases should contain the name, type, location, severity, extension and timing of each event.

According to Sinha Ray (2002), the basic components of the databases should have descriptions of the long term effects including recovery, description of extreme factor, impact assessment, production loss, environmental loses, etc. The purpose of a database of extreme agrometeorological events is, of course, to identify patterns of impacts on agriculture with a view to improving impact assessments, including impact forecasting, mitigation, adaptation and emergency operations whenever feasible (Gommes 2003). This kind of database should thus be regarded essentially as an operational tool.

4.3
Database Management

4.3.1
Database Design

The management of climatic and agrometeorological data has become faster and more efficient in the last years. Yet, management of the data is perhaps one of the most critical processes in any design concept (Doraiswamy et al. 2000). A consistent database consists of a complex set of processes involving the collection, transmission, quality control, archiving, processing, analysing and displaying of useful information that can be utilized by users. In fact, large amounts of collected data are essentially useless without a system to manage them and provide analysis (Monnik 2001). When data are processed or transformed into forms useful to people, they become information (Anaman 2003). According to Weiss et al. (2000), information is the result of utilizing a statistical simulation or other type of model, such that the output can be used to make a decision.

Proper database management systems should store, temporally and spatially, data from different instrumentation and sources, including traditional meteorological stations, automated weather stations, radar, satellite imagery, special agricultural and hydrological networks and others (Fig. 4.3).

Database design must provide standardized formats and, preferably, modular structure, since all users do not require or need the same information input (Motha 1999). Moreover, standardized data makes it easier to share and exchange data. Checking the data quality is a necessary step in agrometeorological applications. Databases should store only validated, homogenized long-term datasets and with the smallest possible number of missing data.

Developing homogeneous time series requires complete and accurate station metadata (Murnane et al. 2002). However, known metadata are generally incomplete. The importance of collecting and managing metadata was recognized a few years ago. These data about data must reflect how, where, when and by whom the observational data were collected and what happened between the moment they were observed and the moment they were archived (Plummer et al. 2003). Station metadata should include any kind of changes, not only alterations in the environment around a station, but also instrument upgrades and relocations as well as planned modifications. Metadata relating to the operating characteristics and performance of the observational station are an essential part of the data record (Motha 1999).

Crop growth simulation models are very widely used nowadays to assess the impact of extreme events on crop yields. Mechanistic models simulate crop development from sowing to maturity, based on meteorological conditions, soil type and crop characteristics (Supit and van der Goot 2002). These models are very sensitive to drastic departures from normal conditions (Bedson 1997).

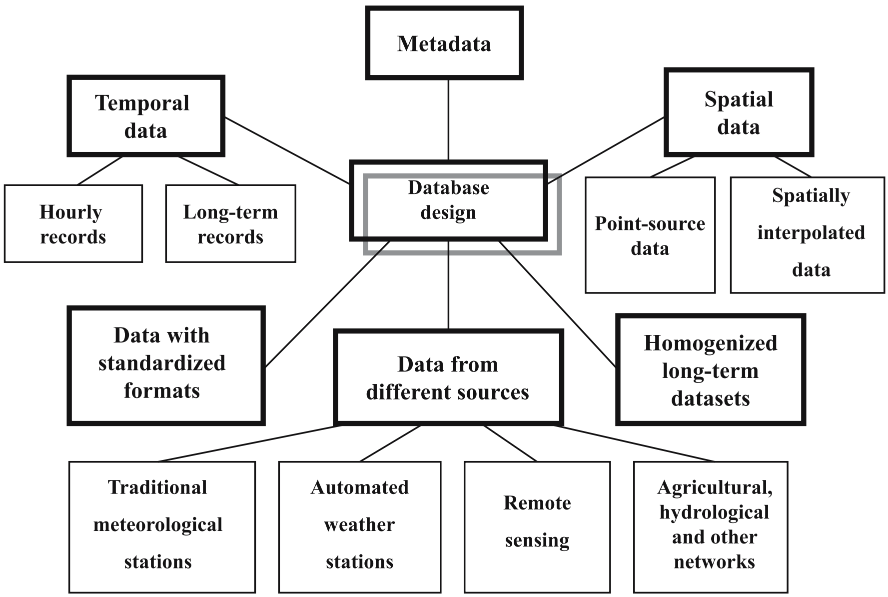

Fig. 4.3. Main components of an agrometeorological database design

Quite often they take advantage of seasonal or inter-annual forecasts in order to estimate crop yields and losses due to extreme events. In Portugal, WOFOST model has been used at the Institute of Meteorology in collaboration with the Faculty of Sciences of Lisbon (Guerreiro and Pires 2004) and DSSAT models at the Faculty of Agronomy in Lisbon (Pinto and Brandão 2002), not only to assess the impacts of extreme events on crops, at a regional scale, but also for climate and climate variability impact assessment and adaptation measures. These actions are included in the CLIVAR project (Santos et al. 2003), which also includes the impact of the use of seasonal forecasts in the process of decision making of crop production. These models usually require daily meteorological data, regional crop parameters and soil data, as inputs. The introduction of meteorological data into the models is still time consuming, due to flaws in the system and also the need to estimate values by means of spatial interpolation of daily data. A database management system (DBMS) , allowing an adequate collecting, analysis, archiving and access to these data can facilitate these tasks.

4.3.2 Real-time Information

It is important to develop the structures and devices for real-time agrometeorological information, in order to face and manage climate hazards, namely extreme events. With the recent advances in the automation technology, information is more and more easily accessible. Internet represents the quickest way to disseminate agrometeorological information to the end-users in a timely manner. Large data volumes and useful information can be transferred quite easily with the File Protocol Transfer (FTP), nowadays. However, the availability of Internet hosts is extremely limited in many developing countries. Information and communication technologies (ICT) offer great scope for innovative dissemination of agrometeorological information to farming communities (Weiss et al. 2000). In these countries, the effectiveness of these tools can be enhanced by linking them to media which are more accessible to farmers, such as rural radio, which allows timely advice to the end-users.

Inclusion of seasonal forecasts in agrometeorological products helps farmers and governments improve their preparedness for extreme events. In fact, an increased demand on climate prediction is greatly due to an increased frequency of extreme events. Meinke et al. (2000) refer that the Australian experience demonstrates that applied seasonal climate forecasts can increase farmer's profits and reduce their production risk. One of the future challenges is to operationalize the forecasts and provide them to the users in a timely and easily understandable manner (Sivakumar 2000).

An example of a good climate information service for rural areas through the Internet was developed in Australia by the Queensland Departments of Natural Resources and Primary Industries. This website offers a range of decision-support information services, tools and training to help clients to better manage climatic risks (Laughlin and Clark 2000). The main themes presented are: seasonal climate outlooks, rainfall and pasture growth, drought monitor and satellite fire monitor (http://www.dnr.qld.gov.au/longpdk).

4.3.3 Relational Database Management Systems

The use of Relational Database Management Systems (RDBMS) by Meteorological Services is increasing and it is quite useful, as the access to reliable and meaningful information becomes much more efficient and user-friendly. It contributes to the development of communication links between users and meteorological and agrometeorological networks, which is specially important in the case of early warning systems of extreme events. The three major RDBMS types are: ORACLE, INFORMIX and EMPRESS (Pérarnaud 2001).

The Meteorological Institute in Portugal has used INFORMIX to create a national relational database, with daily and hourly meteorological and agrometeorological observations and rainfall in short periods. The data were originated from historical archives and from AWSs, since 1920 up to now, and were submitted to quality control. It also includes metadata. Recently, satellite images have been added to this database. Structured Query Language (SQL) was used to create this database, and the access is through a graphical user interface. This database represents a great advance in data access, although it is still disseminated only in Intranet. Before this, the only way to retrieve archives was by means of FORTRAN programs. More derived parameters will be introduced and the transfer of data and other pertinent information to the end-users will be made via Internet in a near future.

An example of an extensive use of data and methods in agrometeorology in Europe is the Crop Growth Monitoring System (CGMS) implemented by the MARS (Monitoring Agriculture with Remote Sensing) project, run by the Agriculture and Regional Information Systems (ARIS), at the Joint Research Centre (JRC), in Ispra, Italy. It is devoted to predict output of the major crops at national level. Every ten days, crop growth conditions, such as occurrences of droughts, excess rain, heat stress, etc., are assessed. The CGMS is based on the deterministic model WOFOST. Input data include daily weather data, topography, regional crop parameters, soil data and historical crop statistics (Supit and van der Goot 2002). Input and output data as well as system definition data are stored in an ORACLE RDBMS, which constitutes the core of the CGMS.

A good example of an up-to-date and efficient database management system is the Unified Climate Access Network (UCAN), derived from US Department of Agriculture. This framework allows climate information users to request information through a unified climate access network that automatically sends requests for specific datasets and climate products to a network of computer systems that maintain the data archives for the requested product (Motha 2000). This system provides users with virtual access via the Internet to several climate datasets. Each participating organization maintains a computer that serves its climate data to the UCAN (Doraiswamy et al. 2000). The various UCAN data servers involved in the processes are coordinated through an efficient catalog of all meteorological stations from which data are archived and disseminated. This system represents a rapid access to quality controlled climate data and products, leading to benefits in several activities. The efficiency of this process is mainly due to the standardization of database management and electronic accessibility.

4.4 Remote Sensing

Remotely sensed data can provide useful information specially in those regions where no ground data are available. Besides, they give a spatial coverage of agrometeorological parameters, contributing to an early detection of droughts, frost, forest fires and other extreme events that affect agriculture, forestry and fisheries.

Geostationary satellites, like METEOSAT and GOES, can be used to monitor severe weather conditions like active frontal systems or tropical depressions and allow real time information about potential storm damage. They collect operational meteorological, hydrological and oceanographic data. Using data from these satellites, several products, such as net radiation, actual evapotranspiration and rainfall estimates are regularly available. They can provide continuous monitoring of the Earth's surface and atmosphere, contributing to an early detection of extreme events.

Advanced Very High Resolution Radiometer (AVHRR) on NOAA polar-orbiting satellites, with a spatial resolution of 1 km, is very useful for estimating vegetation stress, by means of derived indices. They have been used for drought monitoring, detection and impact assessment in agriculture. The Global Vegetation Index (GVI) developed by Kogan (1995) provides information about changes in seasonal land cover by comparing the data with normal dynamics of vegetation. A new numerical method of drought detection and impact assessment from NOAA operational environmental satellites was developed (Kogan 2000). With this new method, drought can be detected several weeks earlier than before, more accurately and in any part of the world. From high resolution satellite data that can track the course of hurricanes, fires, droughts or floods, huge amounts of multidisciplinary observational data can now be fed into computer models and prediction algorithms, or directly into decision processes (Sarewitz and Pielke 2003).

In the MARS project, for the activity on monitoring vegetation conditions and yield indicators NOAA-AVHRR data has been the main source of information. For that purpose, a dedicated software system was implemented (SPACE) to process the data and to derive composite products which were the input for the Advanced Agricultural Information System, namely for the Crop Growth Monitoring System (Perdigão 2000).

Improved access to satellite data is necessary. Several countries have already established databases of information collected by meteorological satellites with high resolution. Monnik (2000) refers that South Africa has been developing an entirely calibrated database of daily NOAA-AVHRR images, including NDVI.

The Portuguese Meteorological Institute is routinely calculating the Normalized Difference Vegetation Index (NDVI) based on NOAA-AVHRR data, in order to quantify vegetation stress and monitor droughts (Fig. 4.4).

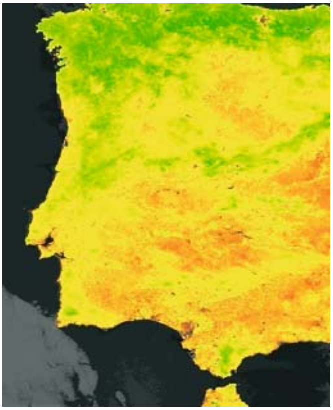

Fig. 4.4. NDVI image for the 18th of June 2000, derived from NOAA-AVHRR sensor, prepared at the Portuguese Meteorological Institute

Satellite Application Facilities (SAFs) are specialized centers within EUMETSAT and are hosted by the European Meteorological Services. The Portuguese Meteorological Institute is responsible for the development of the Land SAF (IM 2003). The main purpose of this SAF is to enhance the benefits of the EUMETSAT new generation of satellite systems, MSG and EPS data related to land,

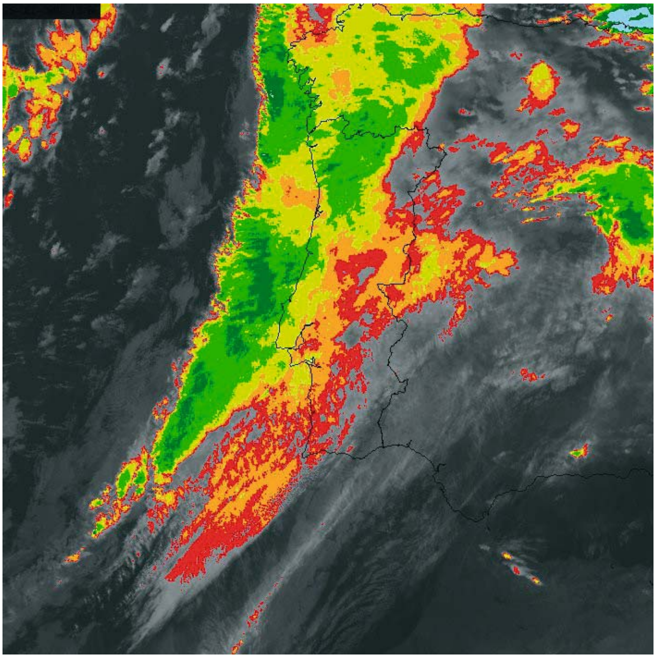

Fig. 4.5. NOAA image showing an active frontal surface crossing Mainland Portugal on 26th December, 2002

land-atmosphere interactions and biophysical applications, by developing the techniques, products and algorithms for more effective use of the satellite data. The Land SAF involves near real-time generation, archiving and distribution of a coherent set of products that may characterize the land surface by surface temperature, scattered radiance and albedo, evapotranspiration, snow/ice cover, soil moisture and vegetation parameters that are specially relevant for vegetation health monitoring and drought management.

Besides meteorological satellites (Fig. 4.5), radar and lightning detectors are remote sensing devices that provide information on storm cells, as mentioned above, contributing significantly to early detection of severe storms. Real-time satellite and radar images are available at the Meteorological Institute web site.

4.5
Geographical Information Systems

In agrometeorology, the processing of data from various sources (meteorology, soil science, topography, etc.) and the need to display them in maps, at regional or national level, led to growing use of geographical information systems. A GIS uses a database management system for the acquision, storage, analysis and display of georeferenced data. It can manipulate information from different sources, like climate and agrometeorogical databases, remote sensing or digital maps, and simulate the behaviour of complex systems. GIS allows datasets to be overlaid over one another, which can help to assess the risk and identify the areas and severity of many extreme events. Besides, this capability enables users to statistically evaluate and quantify relationships, such as the percentage of a corn-producing area that is experiencing severe drought (Shannon and Motha 2002).

The success of any GIS project depends on the data quality, namely accuracy and density of station network, updated time series and ability to manage different types of data and formats. Estimation of values in places where there are no measurement stations is done by interpolation. GISs have several interpolation methods and other statistical applications that combined with other intrinsic capabilities (like data conversion, edition, spatial analysis, modelling and fast corrections or modifications) constitute important tools in climatological and agrometeorological matters (Silva 2002). At the Institute of Meteorology in Portugal, a few interpolation methods are always tested and validated in order to use the model which presents the lowest errors.

Figure 4.6 shows two maps, one for extreme maximum temperatures and one for extreme minimum temperatures for the period 1–14 August 2003, considered of heatwave in Mainland Portugal. Temperature distribution is overlaid with relief, AWSs utilized, districts and main rivers.

The frost risk map and the desertification climatic index are examples of spatial modelling with GIS, produced at the Portuguese Institute of Meteorology. Figure 4.7 represents the overlay of the frost risk and the municipalities in Mainland Portugal and the resulting average risk in each one of them. The frost risk map was elaborated taking in consideration not only the spatial

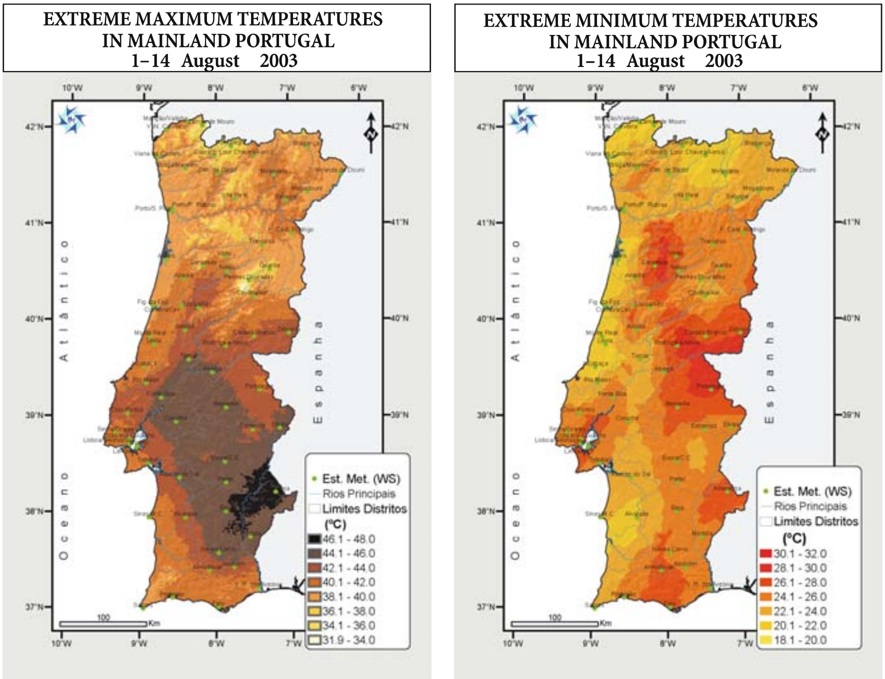

Fig. 4.6. GIS maps with the distribution of extreme maximum and minimum temperatures for the period 1–14 August 2003 in Mainland Portugal

distribution of agroclimatic elements, but also frost physical features that condition frost occurrence (Moita and Silva 2003). To make this map, the following information was necessary:

- Statistical values (1961–1990);
- Digital elevation model GTOPO 30 (USGS);
- Corine Land Cover map.

Remote sensing allows a spatial assessment of crop growth and development and provides important agrometeorological information to GIS. However, in several countries, including European ones, remotely sensed data are not easily accessible yet.

GISs can be extremely useful tools in the analysis of flood-prone areas (Johnson 2003). A GIS in conjunction with digital elevation model (DEM) data can quickly determine slope and aspect of a region and can be used to provide geospatial analysis of multiple spatial layers: elevation, slope, soil characteristics, precipitation, temperature, vegetation and other factors.

A good example of the integration of several information products (soils, crops, meteorology) is the *ISOP* (*Information et Suivi Objectif des Prairies*) project in France, which is operational since January 2000. This project, which

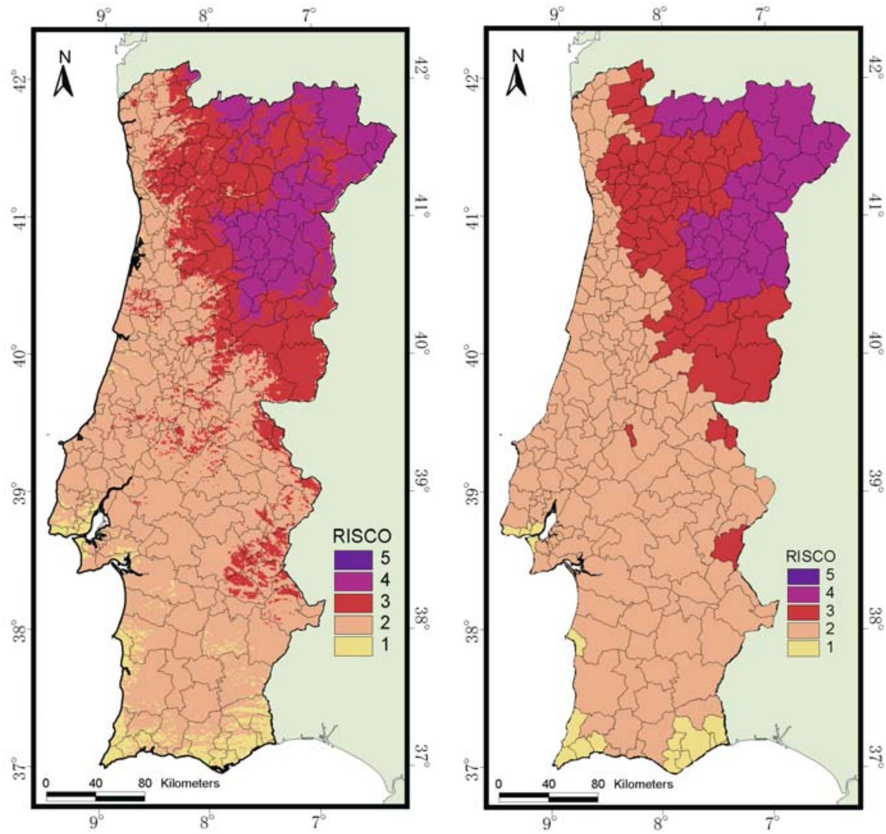

Fig. 4.7. Overlay of the frost risk and the municipalities in Mainland Portugal and the resulting average risk in each one of them (Moita and Silva 2003)

results from a combined effort of *METEO FRANCE*, *INRA* and *Ministère de l'Agriculture*, is an integrated system for real-time assessment of forage production variability over France (Donet et al. 1999). Its objectives are to detect crisis situations, like significantly low productions due to unfavourable soil-climate conditions; moreover, its purpose is also to produce reliable estimates of forage production, in order to objectively estimate real production losses in case of local or global drought (Huard and Pérarnaud 2001). Input data are multiple, including spatialized daily meteorological parameters, percentage of soil types, nitrogen status and amount and frequency of mowing or grazing, estimated from a national survey. The *STICS* crop model, developed by *INRA*, is applied and the results of all GIS operations are stored in a database. This information is synthesized in alert maps and temporal graphs for selected drought-stricken areas. The *ISOP* end-users are several departments of the Ministry of Agriculture and Fishery, namely the bureau for agricultural disasters and the central department for sample survey and statistical studies.

The described examples show the advantages that GIS can provide, namely:

- Fast access and data processing;
- Easy integration of data types and formats;
- Access to error and uncertainty of predictions;
- Spatial queries and analysis;
- Good graphical capabilities;
- Help in fast decision making.

4.6 Conclusions

New technologies in data collection and data management have led to the development of databases where quality controlled data and products from different sources can be displayed in a user-friendly way and electronically accessible. However, the information generated must match (or be adapted to match) the needs and capabilities of the users (Sarewitz and Pielke 2003).

In some countries, phenological, soil, remote-sensed and other types of data are not concentrated in the same database, but scattered in separate ones, quite often belonging to different organizations, which makes their access not very easy. Besides this, these data are not always available to the users.

Improving climate and agrometeorological databases is important to facilitate early detection of extreme events. This initiative includes:

- Developing procedures to identify user needs;
- Taking advantage of the latest technology in database management and standardizing it;
- Creation of databases which include pertinent information besides agrometeorological and climatological;
- Displaying useful products to the end-users, not only for farmers but also government policy makers and other decision makers;
- Dissiminating the products in a user-friendly way and making them readily accessible through the Internet; this will help reach more users;
- Information displayed to the users should include seasonal forecasts in order to help them take the right decisions to reduce or even avoid risks associated with extreme events;
- Strengthening the use of remote sensing and GIS;
- Establishing databases of agricultural disasters, resulting from extreme events, with thorough information about the agrometeorological conditions, including remotely sensed data, and also their economic and social impacts.

To achieve these purposes, the following actions should be undertaken:

- To reinforce training in the new technological applications, such as AWS, DBMS, telecommunication systems, remote sensing and GIS.

- To provide training to information users on the use of agrometeorological and climate information;
- To improve communication between users and developers of products and act according to their feedback;
- To improve collaboration among scientists and managers, to enhance the effectivness of observational networks, monitoring, prediction and information delivery related to extreme events;
- To develop good collaboration links in the exchange of information;
- To promote stronger participation in regional and international programmes, so that partnerships are established and improved interdisciplinary collaboration between NMHSs, Departments of Ministry of Agriculture, Agronomic Research Institutes, Universities and other services is implemented.

Improving the access to high quality information and assuring the usefulness of this information to the users, from farmers to government policy makers, is surely the right way to facilitate early detection and reduce the negative effects and socio-economic impacts of extreme events in agriculture, forestry and fisheries.

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Tools for Forecasting or Warning as well as Hazard Assessment to Reduce Impact of Natural Disasters on Agriculture, Forestry and Fisheries

Liliana Nuñez

Abstract Disasters induced by natural disasters carry significant consequences for agriculture, forestry and fishery sectors. In this paper, an attempt was made to give a brief account of tools available for forecasting or warning of natural disasters including floods, droughts, tropical cyclones, forest fires, and volcanoes. Use of such tools is important to decrease the impact on natural disasters on agriculture and forestry. Amongst the most well known predictions schemes is the El Niño – Southern Oscillation (ENSO). This and other prediction tools have been discussed with suitable examples.

5.1 Introduction

Disasters induced by natural events may deeply affect the social structure of the area struck and causes severe consequences for men and environment, agriculture, forestry, rangelands and fisheries. Mature society may fall apart, places of employment may be destroyed, and infrastructure build up during several decades may break down. The poorer a region, the deeper are the soil effects of disasters.

The prevailing agriculture in a region is largely determined by the climate. This includes temperature (winter minimum, summer means and maximum, ranges, variability), precipitation (total amount, temporal distributions, extremes, variability), wind, solar radiation, humidity and other factors.

Traditional, ground-based observation networks should be spatially dense enough to capture the horizontal dimension of the extreme event. In regions where available, the use of radar and satellite-derived data fields can be extremely useful. The remote sensed data fields are keys to timely and accurate forecasts and warnings. Statistical analysis can be performed on both point and spatial data sets. An ideal database management system would store temporally and spatially congruent data from a variety of instrumentation and sources, including standard weather networks, radar and satellite imagery, special agricultural and hydrological networks and others. It also would be ideal to have forecasts and warnings stored.

Inappropriate management of agroecosystems, compounded by severe climatic events such as recurrent droughts in West Africa, have tended to make the drylands increasingly vulnerable and prone to rapid degradation and hence desertification. Even in the high rainfall areas, increased probability of extreme events can cause increased nutrient losses due to excessive runoff and water logging.

As every farmer knows, the weather next year will do something unexpected. The hope that it might be predicted in advance of planting is hardly new. The longevity of the Farmer's Almanac bears witness to that. But until the last two decades of the 20th century there was no sound scientific basis for believing that such predictions might be possible.

Some of the year-to-year variations in climate are the result of random sequences of events, just as a series of coin flips will occasionally produce a long run of heads. A region may experience a dry spell because no storms happen to pass that way for a time. Prediction of such stochastic events is not possible. We now see, however, that many climatic variations are part of large scale, slowly evolving patterns. Skillful prediction may then be possible, particularly if the patterns are forced by observable changes in surface conditions such as the sea surface temperature (SST). The most dramatic, most energetic, and best-defined pattern of interannual variability is the global set of climatic anomalies referred to as ENSO (El Niño and the Southern Oscillation). The progress in ENSO prediction is built on advances in understanding, advances in coupled ocean-atmospheric modeling, and the development of an ocean observing system. Prospects for improving forecasts of ENSO and its global consequences will then be considered in this paper. We emphasize that modern long-range forecasts have developed from a new understanding of climate variability and from a vastly enhanced ability to monitor the present state of the climate system. In this paper attempts have been made to give a brief account of tools available for forecasting or warning some of the natural disasters for reducing their impacts on agriculture.

5.2 Floods

Inundations cause the great damage worldwide. Disasters are caused by floods resulting from heavy precipitation or snow melt, by storm surges created through the interaction of strong wind and tidal waves, and by the occurrences of tsunamis, caused by the massive displacement of water bodies after submarine earthquake. Storm surges have threatened the inhabitants of low-lying coastal flatlands for centuries, and a sea level rise as a result of climate change will increase the risk in these areas.

The number of people affected by floods from 1991 to 2000 is reported to be around 1.5 billion. Disasters caused by floods have been increasing in the recent past, mainly as a consequence of the expansion of settlements and the growth of investment in flood plains. If the risk of flooding is assessed, and the use of flood plain is well managed, then losses can be reduced significantly. Many lives can also be saved provided adequate warnings of floods are given to those under threat. Here national Hydrological and Meteorological Services work together to ensure that accurate and timely forecasts are provided.

It should not be forgotten that floodwater is also a resource. We should, therefore, learn to live with floods and use them for the benefit of fisheries, wetlands and irrigation. In addition, the potential of the flood plains for socio-economic development cannot be neglected. In fact they are one of the areas with the highest development potential.

5.2.1 Forecasting/Warning of Flood for Reduction of Risk Potential

The application of active warning, protection, and safety measures requires advance-warning systems that permit the forecasting of flood disasters well ahead of time. Because the meteorological factors used to determine runoff are highly stochastic processes, the possibilities for forecasting are quite restricted. In hydrology and water resources planning, however, there are well tested methods to stimulate processes in river basins using mathematical models based on these deterministic rainfall-runoff models, forecasts of future runoff can be made, according to the chosen approach ranging from short-term via medium-to-long-term forecasts. Other than in the geo-sciences, the term "forecast" in the hydro-sciences is used for estimates of the temporal and spatial size of an event that is ongoing or anticipated. In forecasting the progress of an extreme flood event that is already happening, the crucial factor is the determination of the future development of precipitation, together with the modeling of the system in question. For this purpose, stochastic precipitation forecasts, as well as radar and satellite-derived fields of estimated precipitation for large-scale observations may be applied. A flood-forecast system has to work operationally (i.e., present information on the state of the river basin will be transferred on-line to the runoff model, thus providing the basis for a continuously updated forecast). For some regions such a runoff-forecast system already exists. As a measure for reducing damage potential, these systems should be combined with warning systems, which are aimed at launching response activities and the realization of already developed scenarios for action in case of disaster.

Forecast systems must be supplemented by control strategies for existing flood retention basins. Regulating discharge from these basins permits maximum advantage to be taken of the available storage capacity, taking into account the present and forecasted flow. The specification of flood plains and the introduction of restriction in flood prone areas (building and use prohibition) may prevent further increase of existing flood potential.

In the design of flood protection structures, standardized design values are useful (extreme values of precipitation and discharge).

5.2.2 Quantification of Risk Potential and Hazard Assessment

Worldwide, floods have the greatest damage potential. Even comparatively minor natural events may induce major changes because of concentration of property in flood-prone regions. Knowledge of damage potential is fundamental in planning protection measures. Quantification is based on damage functions that provide information depending on use, region, or land-on maximum damage to be expected during an extreme event. For damage assessment, land-use catalogues are needed that allows classification of localised areas of the regions under investigation. The necessary instruments for the assessment of damage potential and the quantification of flood discharge constitute methods of differing complexity. These methods range from simple regression or black-box methods to spatially and temporally high-resolution simulations and forecast models. Damage analysis is aimed at the determination of widely standardized damage functions by investigating as many damage scenarios as possible.

Based on data from historical events, land-use-dependent damage function may be deduced. The final determination of flood damage, as a function of the assumed hydrologic design loads, can be carried out for different regions and varying scenarios through use of computer models.

5.2.3 Forecasting System as a Part of Disaster Management

The establishment of an efficient disaster management system presupposes an optimal exchange of information and communication between the institutions involving disaster management. Deficits are evident worldwide in both communication and the allocation of competence.

Forecasting systems, if operationally available, are regarded as a part of disaster management. Disaster management is characterized by the necessities to make decisions when time is pressing and knowledge of consequent effect is still (at some level) insufficient. Therefore, it is advisable to develop specific disaster scenarios beforehand and to practice them in advance. This can be done by simulation, using the same models as that in water resources management. Possible instruments to meet the demands for an interdisciplinary approach to the respective disaster management are knowledge-based systems in disaster management, it is possible to analyse the system interaction for flood-prone regions and to test the mechanism of different strategies of action during exercises and during a disaster. These techniques can give the people involved (disaster staff) the opportunity to rehearse and realistically simulate different disaster scenarios, especially interaction with the people affected (population). Additionally, such systems provide valuable experience in selecting the best probable approach during a disaster.

5.2.4 Impacts of Flood on Agriculture

Some of the numerous direct and indirect effects that flooding and heavy rainfall can have on agriculture:
Non-growing season or fallow period:

- Loss of top soil
- Loss of soil nutrients

- Soil compactation
- Soil erosion
- Deposition of undesirable materials
- Permanent damage to perennial crops, tress, livestock, buildings and machine
- Displacement of persons
- Breakage of levees and other retention structures
- Anaerobic processes
- Permanent cessation of farming in flood plains
- Permanent diversion/realignment of rivers, streams, other bodies of water and settlements

Growing season:

- Water logging of crops
- Lodging of standing crops
- Loss of soil nutrients
- Loss of pasture use
- Soil erosion
- Greater susceptibility to diseases and insects
- Interruption to tillage, planting, crop management, harvesting
- Permanent damage to perennial crops, trees, livestock, buildings and machines
- Soil temperature reduction and/or retardation
- Necessity of installation of expensive drainage systems
- Loss of livestock and/or habitat
- Transportation interruption
- Grain spoilage, in field and off-site.

5.3 Droughts

Although floods, as a rule, produce a sudden onset of disaster with a clearly defined beginning, a shortage of water develops disastrous effects only over longer periods. In the beginning, the shortage does not cause significant harm, but it may develop to more and more perceptible and finally serious catastrophes.

A drought may thus be called a "silent disaster", and, in this case, it is difficult to determine at what point in time shortages take on the proportions of disaster. Extremely long drought periods, possibly intensified by human activities, may cause the desertification of a region, which, in contrast to drought, will produce irreversible damage.

Drought is undoubtedly the most far-reaching of all natural disasters, it shows their effects mainly through famines. They are of increasing importance to social groups and regions vulnerable to this phenomenon. The fight against drought must issue a high priority and research on the interactions between climate, the hydrological regime and drought in the context of climate variability and change and water resources scarcity must be promoted.

Drought is a regional manifestation of a general atmospheric circulation pattern, which favours subsidence over the region. In some regions, an important tool to predict seasonal drought is El Niño Southern Oscillation (ENSO). The link with ENSO can be formalised by calculating precipitation probability distribution conditional on the estate of ENSO (Ropelewski 1995).

5.3.1 The Nature and Prediction of ENSO

ENSO has two extremes, often referred to as warm (or El Niño) events and cold events. For both pragmatic and historical reasons related to the nature of the impacts of the warm events, discussion of the ENSO phenomenon often centers on the characteristics of El Niño events. Over a very long time, the frequency of warm and cold events is similar. On the average there is an El Niño event about every four years, but the cycle is highly irregular. Sometimes there are only two years between events, sometimes almost a decade. There are great variations in amplitude. Though each warm episode has its own peculiarities, all follow a general pattern. At an early stage, anomalously warm surface waters are found in the western equatorial Pacific. Associated with the warmer surface temperatures is an increase in convective activity, and at a certain stage, a persistent slackening of the normally westward flowing trade winds. Following this is a dramatic and expansive warming of the tropical Pacific Ocean from the dateline to the South American coast, and a further disruption of the trade winds. Very heavy rains fall in the normally arid regions of Peru and Ecuador, while droughts are experienced in Indonesia, Australia and southern Africa, and anomalous tropical cyclones occur in regions such as French Polynesia and Hawaii. Further away, there are often disruptions of the Indian monsoon. The seasonal rains of northeast Brazil, and regional climates over much of East Asia, North America, and Africa are usually affected. Cold events, sometimes referred to as La Nina events, occur with similar spacing and have characteristics that are approximately the inverse of warm episodes.

The first model to successfully simulate ENSO, that of Zebiak and Cane (1987), was based explicitly on the Bjerknes-Wyrtki hypothesis.

One of the most significant results of the model simulations was the recurrence of ENSO at irregular intervals as a result of strictly internal processes; that is, without any imposed perturbations. Analysis of the model helped in developing a now widely accepted theory that treats ENSO as an internal mode of oscillation of the coupled atmosphere-ocean system, perpetuated by a continuous imbalance between the tightly coupled surface winds and temperatures on the one hand, and the more sluggish subsurface heat reservoir on the other.

This theory has a number of implications for the prediction of El Niño events. First, since the essential interactions take place in the tropical Pacific, data from that region alone may be sufficient for forecasting. Second, the memory of the coupled system resides in the ocean. Anomalies in the atmosphere are dissipated far too quickly to persist from one El Niño event to the next. The surface layers of the ocean are also too transitory. Hence the memory must be in the subsurface ocean thermal structure. The crucial set of information for

El Niño forecasts is the spatial variation of the depth of the thermocline in the tropical Pacific Ocean.

In the 1980s the Lamont model was the only physically based forecasting system with moderate level of skill, though there were (and are) comparably skillful statistical schemes. More recently a number of other models have been developed for ENSO forecasting, many of them based on the comprehensive physical models of the atmosphere and the ocean known as general circulation models (GCMs). The GCMs are generally agreed to offer the greatest promise for accurate prediction, because they simulate the climate system with the greatest verisimilitude. In addition, unlike models of the tropical Pacific alone, they make it possible to predict the global impacts of ENSO. Their complexity, however, makes them less forgiving of errors and imperfections than the more simplified models. It was thus a considerable achievement to bring them to the same general skill level as the Lamont model and the statistically based schemes.

5.3.2
Drought and its Forecasts Based on ENSO

This section provides results from the applications to Mozambique in Africa and Argentina Pampas region of Latin America.

5.3.2.1
Application to Mozambique

Drought occurs in Mozambique about once every seven years (Rojas and Amade 1997). As mentioned above, drought events tend to be associated with El Niño events. In drought years, there is a clear link between rainfall and agricultural production. Specifically, crop production declines. In non-drought years, the link between rainfall and agricultural production becomes more tenuous. Above average rainfall years are not necessarily associated with above average production years. Since current prediction technology relies heavily on the presence or absence of El Niño events, it seems less capable of forecasting particularly favorable climate for agricultural production in Mozambique. The main utility appears to come from providing an estimate of the probability of drought. Hence, we focus on drought in this analysis. Table 5.1 shows the simulations presented. Experiment one stimulates an unanticipated drought. In this experiment, resources in agriculture are fixed at their base (expected) levels. We assume that an agricultural production plan is adopted and cannot be modified based on realized climate outcomes. Experiment two illustrates the benefits of a perfectly foreseen drought. In this scenario, farmers are assumed to receive a perfect forecast and react to it. It is important to note that, in this experiment, the forecast is assumed to have no impact on the efficiency of the marketing sector.

In Mozambique, agricultural production is essentially the process of converting labor into agricultural production. The vast majority of production is

Table 5.1. Simulations

Base	Base 1995 Data
Exp. 1	Drought with capital and agricultural labor fixed (no forecast)
Exp. 2	Drought with non-agricultural capital fixed (perfect foresight)

smallholder based using rudimentary technology. Input use is essentially confined to seed, capital use confined to rudimentary tools, and land is generally abundant. In this environment, drought can be adequately simulated by shocking technology. For practical purposes, this implies that the same amount of labor applied to a particular activity yields reduced production in a drought year. The exact declines in technology (production if input use, including labor and capital, does not change) are listed in Table 5.2.

The figures in Table 5.2 reflect existing time series data on production as analyzed by Bacou (1999), the change in technology parameters estimated by Arndt et al. (1999) for agricultural in 1992 from their backcasting work, interviews with experts on Mozambican agriculture, and the judgement of the authors. From a value of forecast perspective, the crucial element is not so much the average productivity decline in agriculture as the dispersion across activities. The figure in Table 5.2 represents a weighted average productivity decline of approximately 20%. If we simply applied a shock of 0.8 to all of the activities shown in the table, we would have roughly the same average productivity decline but no possibility to reallocate resources from drought intolerant to more drought tolerant activities. With the differential figures in Table 5.2, farmers faced with a drought forecast have clear incentives to shift resources from, for example, production of grains to production of cassava (price changes will also influence cropping choice as discussed below).

Table 5.2. Declines in technology used to simulate drought

Grain	0.67
Cassava	0.85
Raw cashew	0.85
Raw cotton	0.85
Other exports	0.67
Basic food exports	0.75
Livestock	0.85
Forestry	1.00

Table 5.3 illustrates the macroeconomic effects of the shock. As expected the drought results in a decline in GDP and absorption. The consumer price index is held fixed at a constant level in the simulations (it is numeraire); consequently, this absorption figure is an appropriate welfare indicator. Recall that the agricultural share in GDP is about 25%. The decline in agricultural

Table 5.3. GDP and welfare

	100 bn Mt Base Run	Percent deviation from base values	
		Exp. 1	Exp. 2
Real GDP	172.1	–5.7	–6.7
Absorption	223.1	–5.6	–6.3

productivity is 20%. This implies a GDP decline is of 5%. The actual GDP decline is only somewhat greater at 5.7%. This is consistent with the work of Benson and Clay (1998) mentioned earlier. Mozambique is a poor country with relatively weak links between primary agriculture and non-agricultural sectors. As a result, the drought-induced decline in agriculture is relatively isolated and does not spill over substantially into other sectors. The overall GDP decline is only slightly greater than the shrinkage of primary agriculture in isolation.

The ability to reallocate crops has a very minor effect on GDP but a discernible impact on absorption (welfare). Aggregate welfare is 0.4% higher in the presence of the forecast. Generally, the complete accounting structures imposed on CGE models limit the welfare gains (or losses) generated by this class of model. For example, in an often cited analysis of the impact of full implementation of the trade policy reforms agreed to under the Uruguay round of the GATT, Harrison et al. (1997) estimate the welfare gains to be on the order of 0.5% or roughly the gains achieved here.

5.3.2.2
Application to Argentinian Pampus Region

Studies conducted in the Argentinian Pampas region indicate that during El Niño years, precipitation tends to be higher than normal between November and January, but in La Nina years rainfall tends to be lower than normal between October and December (Tanco and Berri 1996; Moschini et al. 1996).

Although all these studies indicate the existence of significant spatial variability in southeastern South America, they also reveal a general pattern with positive rainfall anomalies during October-March in El Niño years, and negative rainfall anomalies during the austral late winter and spring months in La Nina years.

The first detailed studies conducted in south-eastern South America reveal the existence of a near symmetry between impacts of El Niño and La Nina on precipitation as well as on crop productivity. Positive rainfall anomalies prevail in El Niño years, and negative rainfall anomalies prevail in La Nina years, during the austral spring and/or summer months. Some research results also suggest that the impact of La Nina are stronger and/or less variable in both, rainfall and crop yields than the impacts of El Niño. Finally, the work conducted by Diaz et al. (1998) suggests the needs to consider the connection between SST anomalies in the Atlantic Ocean and precipitation anomalies in southeastern South America.

5.3.2.3
Observed Impacts of ENSO Phases on Crop Productivity

Often the annual variability observed in crop and pasture productivity is an excellent indicator of the impacts of large scale phenomena (e.g. ENSO) on regional climatic conditions. Crops and pastures are 'integrators' of the general climatic conditions (rainfall, temperatures) during their growing seasons. In addition, most crops present growth stages in which they are specially sensitive to environmental conditions (e.g. flowering, grain filling, etc.). When ENSO phases affect the climatic conditions during those critical crop growth stages, the impacts are very evident. For example, Myneni et al. (1996) found strong negative anomalies in the NDVIs of the rangelands of Uruguay during the 1988/89 La Nina, and much weaker positive NDVI anomalies in that same region during the 1982/83 El Niño.

Baethgen (1998) found stronger negative maize yield anomalies in Uruguay during La Nina years than positive maize yield anomalies during El Niño years. Similarly, Podesta et al. (1998) reported that in Argentina the depression of maize and sorghum yields during La Nina years were larger and less variable than the yield increases during El Niño years. The typical correlation found between maize and sorghum yields and rainfall during the flowering months (December-February) reinforce the findings of positive rainfall anomalies during El Niño years and (possibly stronger) negative anomalies during La Nina years.

More recent studies conducted in the Argentina Pampas revealed that in general, maize and soybean yields tend to be higher (lower) than normal during El Niño (La Nina) years. The same trend was detected in wheat but only in the southern portion of the region, while sunflower response was opposite and weaker (Magrin et al. 1999). Maize yield reductions in La Nina years were associated with negative precipitation anomalies during November, while yield increments in El Niño were positively related to December increments in precipitation (Travasso et al. 1999).

5.3.3
Risk Management

Activities which provide information aimed at helping decision makers apply climate forecasts to minimize negative consequences of climate variability and to take advantage of favorable conditions. In order to benefit from climate forecasts, decision makers must possess flexibility to change their management practices in response to the improved information (Sonka et al. 1986). For that reason, activities in the region aim to specify alternative management options that are feasible and reasonable from the perspective of stakeholders. Research is focused on crop production decisions that are sensitive to future weather conditions. Simulation models are being used to identify optimal management with and without climate forecasts. The selected optimal options allow estimating the efficacy and value of climate forecasts, and identifying options to present to decision makers. Following this approach, a number of activities were carried out to evaluate the acceptance and value of ENSO-based climate forecasts for agricultural decision making. In a preliminary study, Hansen et al. (1996) found that predicted benefits of tailoring soybean planting dates to forecasted ENSO phases ranged from US$ 2.4–32.4, according to location and soybean prices.

Messina (1999) found "optimal crop combinations" for each ENSO phase in different Pampas' locations which depend on location, risk aversion and initial wealth. On the other hand, Margin et al. (1999) concluded that the best management option in La Nina years for both maize and soybean was to delay the sowing date. Inversely, early sowings were more likely to optimize yields and incomes in El Niño years. These researchers also found that nitrogen rates in maize should be higher during El Niño events to maximize expected maize yield and profit. However, due to important intra-phase climate variability (e.g. rainfall during flowering is not always lower in La Nina years), making crop management recommendations based on mean values is still leading to negative results (Magrin et al. 1999).

5.4 Tropical Cyclones

Damage induced by cyclones is a phenomenon primarily of tropical and subtropical coastal regions. These cyclones have relatively large-scale effects and affect about a third of the world population. Damage is caused not only by immediate effects of the wind, but to a high degree is induced by the effects of storm surges and ocean waves directly generated by tropical cyclones.

The tropical cyclone causes irreparable damage to the agriculture, ranches and forest.

The principal causes of the cyclones are:

- strong winds,
- torrential rain and the associated flooding and
- high storm tides (the combined effect of storm surge and astronomical tides) leading to coastal saline inundation.

The loss to an agriculture system is due to direct and indirect effect. The direct effects are:

- destruction of vegetation, crops, orchards and livestock,
- damage to irrigation facilities such as canals, wells and tanks and
- long-term loss of soil fertility from saline deposits over land flooded by the sea.
- disruption of the transportation system
- loss of a portion of the future harvests due to the destruction of standing crops.

- loss of human life
- damage to property
- damage to fishing
- damage of off-shore and on-shore installations
- loss in productivity due to disruption of the work force and to other activities

In addition of the effects of the wind is the damage caused by airborne sea salt, which occurs within a few hundred metres of the coast. Winds, which blow from the coast seas, spray salt on coastal areas, making it impossible to grow crops sensitive to excessive salt.

Fields inundated by the storm surge suffer a loss of fertility due to salt deposition, even after the seawater has receded. The affected land takes few years to regain its original fertility. A rise of sea level would adversely affect a coastal belt, comprising the coastal ecosystem, increasing coastal salinity and reducing crop productivity. Small-scale fisheries are also hit by cyclones. In agriculture, there can be large losses in primary production on account of delay in the recovery of the land.

5.4.1 Cyclone Prediction and Warning

Tropical cyclone (TC) prediction constitutes three aspects viz. cyclone intensity in respect of wind, land-fall in respect of time and space, and associated storm surge in respect of maximum heights of tidal wave. The prediction of cyclone is usually done in 4 time scales – long range (more than 10 days or from the day of formation of low pressure area in the sea), intermediate (3–10 days), short range (1–3 days) and very short range (a few hours-'Now casting'). It may be realised that essentialities of cyclone forecast are timeliness, accuracy of landfall and overall reliability. Essentially in this end is credibility of observation of current atmospheric conditions that are accurate, quality controlled and of high resolution in both space and time, and good and reliable models of cyclones on the scales observed.

Forecasting the movement of Tropical Cyclones is universally considered to be the most important task. A large number of statistical/empirical methods have been developed in the past and, despite the numerical models which have been commissioned in most of TC forecast offices, they are still being used and improved upon. The first step in making a TC task forecast involves fixing its position using all available data resources. Highly accurate positioning is important for accurate short-term forecast.

Some major and near-catastrophic forecast errors have been made by analysis using incorrect positions. Some of the TCs have the presence of small-scale oscillations in their track, which are however generally smoothed to some extent, and biased by the available ad hoc observations. The best positions of TCs are furnished by research aircrafts, which are very expensive and, therefore, not cost effective. There is an imperative need to keep an operational track in the operational scenario, because TC fixes are derived from variety of observing platforms. In the absence of any accurate fix of a TC, the forecast position provides the first guess for this purpose. This is considered good, especially when using satellite data with poorly-defined systems. In the event of better quality observations becoming available, one needs to redraw the track for at least the last 24 hours, using a degree of smoothing appropriate to the situation. Holland and Elsberry (1993) provide an indication of the impact of fitting curves of various orders to cyclone tracks. Such curves can also provide a short-term forecast method.

Dynamical methods have proved successful because of the increase in the power of computing, the development in numerical prediction techniques, the improved understanding of physical processes, improvements in observing systems, and objective analysis and initialization. Considerable success has been achieved using dynamical models (Dastoor and Krishnamurthy 1991).

Recently, a quasi-Lagrangian Model (QLM) for cyclone track prediction in the Indian seas has been implemented in the India Meteorological Department (IMD). The model is an adapted version of the hurricane prediction model of the National Center for Environmental Predictions (NECP – the erstwhile National Meteorological Center) Washington. It is a multi-level primitive equation, a fine-mesh model cast in the sigma coordinate system ($p = p/ps$; pressure divided by surface pressure). The model has a limited area domain using a Cartesian grid. The horizontal grid spacing is 40 km and the integration domain consists of 111×111 grid points in a $4{,}400 \times 4{,}400\,\mathrm{km}^2$ domain that is centered on the initial position of the cyclone. The QLM uses 16 layers in the vertical. The model incorporates physical processes, which include surface frictional effects, sea-air exchange of sensible and latent heat, convective release of latent heat, divergence damping, horizontal diffusion, and isobaric condensation of water vapor. Radiation and turbulent processes, which only have a marginal impact on the development, are currently excluded to minimize computational time. The numerical integration of the model is carried out by using the socalled quasi-Lagrangian method.

Track forecasts based on QLM model were carried out with respect to cyclonic storms that formed during the three-year period from 1998 to 2000 in the Bay of Bengal and the Arabian Sea (Kalsi 2001). A quantitative assessment of the performance of the forecast model can be made by the computation of track prediction errors. Two types of prediction errors have been attempted. Direct position errors (DPE) have been calculated by taking the geographical distance between the predicted position in each case of forecast and the corresponding observed position. The second type of error is the angular deviation between the observed and predicted track vectors, starting from a given initial position of the storm. While the former gives a measure of the absolute error of prediction, the latter provides an indication of the closeness of the predicted direction of movement and the observed direction.

5.4.1.1
Winds, Heavy Rains and Storm Surges Caused by TC

Among all natural disasters, TC-caused events are always the worst both in terms of the death toll and the economic losses. These disasters are mainly caused by strong winds, torrential rains and storm surges. A mature TC may have a wind speed of 60–70 m/s. This is main driving force for the generation of storm surges, which incidentally depend on the offshore bathemetry. Although a TC usually reduces in intensity after the landfall, an enhanced supply of water vapor and interaction with moderately cold air may re-intensify the TC and release heavy rainfall. A TC does not have to be intense to produce heavy rainfall; it all depends on the speed and size of the TC.

Pattern recognition techniques are used not only for the movement of TCs, but also for forecasting their other attributes such as strong winds and heavy rains. Satellite and radar images too go a long way in meeting these requirements. Eye-walls and spiral bands are areas of intense weather and are the most conspicuous features in the satellite and radar images. Attempts are being made to simulate these features and also the severe weather associated with them, using the high-resolution, limited-area model.

The WMO GTS provides the backbone of the telecommunications for the relay of warnings, forecasts, observational data and related information within the meteorological community and to some major external users and, in some instances, supports early warning for non-weather hazards. However, some of the other communication systems cited above are more appropriate for distributing warnings to the local population and external agencies, particularly when speed is essential. In general, the effective dissemination of warnings to the public and lower level administrators requires communication systems which have a very broad public reach, such as radio and television stations and community warning facilities. The dissemination of warnings through these external agents and facilities is, however, carefully coordinated to ensure timeliness and accuracy and, as noted elsewhere, experience confirms that there must be a single official issuing authority for warnings to minimize confusion.

Although tropical cyclone motion forecasts have improved over the years, the intensity forecasts have still a lot to be achieved. Using the frequently (hourly to half-hourly) available satellite imagery, a lot of experience has been gathered in the analysis of tropical storm intensity. Since the launch of modern satellites, the intensity of cyclones has been well-captured. This has enabled cyclone experts to issue realistic storm surge forecasts. However, our knowledge of structural changes in tropical storms on account of land interactions is still in its infancy. The development of localized zones of strong winds, tornadoes and very heavy rains in some pockets continues to be elusive. There has been a vast improvement in forecasting techniques and cyclone warning services in recent years. This helped in considerable reduction of the loss of human lives and damage to agricultural products caused by cyclones.

5.4.1.2
Cyclone Warning System

One of the short-term mitigation measures against tropical cyclone disaster is an efficient cyclone warning system. The requirements for an efficient cyclone warning system (Das 2003) are:

1. Advanced accurate and detailed forecasts of dangerous conditions;
2. A rapid and dependable distribution system for the forecasts, advisories and warnings to all interested parties; and
3. Prompt and effective utilization of warnings by the government and the public.

To have fairly accurate forecast, it is necessary to have (i) maximum high-quality data; (ii) Forecasters with sufficient ability, training, experience, and time for data preparation; and (iii) foolproof techniques for preparing accurate forecasts of the storm's movement, changes in intensity and storm tides. The US Weather Research Program

for Hurricane Landfall (OFCM 1996, Elsberry and Marks 1999) promises improved forecasts of track, intensity, surface wind and rainfall, as well as research on decision-making and the technology transfer necessary to convert advances in science and technology into products useful to society. The communication system for the distribution of advisories and warnings should be one that can dependably deliver the advisory information to all concerned in the shortest possible time, even in cyclonic conditions of strong wind, heavy rain, floods, etc.

An essential element of a warning service is that there should be certainty that the warnings will reach the intended recipients promptly. The supporting communications system, including back-up facilities, should therefore be planned and implemented in full detail. The meteorological warning besides giving precise information about the tropical cyclone itself and the winds and rainfall to be expected, might also serve as a preliminary warning of a flood and storm surge. Such preliminary warnings should be confirmed or amended in due course by the forecast centre, in conjunction with hydrographers in the case of a storm surge warning.

5.5 Forest Fires

Forest fire is one of the main environmental hazards to face at present in many places, and causes injuries and economical losses, with significant impact on ecosystem degradation, soil erosion and flood occurrence. In some countries the problem occurs during the dry season and mainly affects pine forests, bushlands and sometimes cultivated fields.

5.5.1 Fire Danger Ratings

Fire danger rating systems are used as fire management guides such as staffing for fire control, scheduling prescribed fire, and fire prevention. They are also used to track the fire season and allow the comparison of one season to another. Fire danger rating do not predict how a specific fire will behave but measure the potential of fire occurrence. Several fire danger rating systems are being discussed here including application from Russia, Australia, The United States, and Canada.

5.5.1.1
Nesterov Index (Russia)

The most widely used fire danger rating system in Russia is a relatively simple ignition index called Nesterov Index (NI). It provides the general index of ignition potential (Stocks et al. 1996). The daily weather requirements for this index are:

- Dry bulb Temperature
- Dew point Temperature (calculated from relative humidity and temperature)
- Precipitation

The index is initialized at zero and is determined by taking the difference between the daily air (dry bulb) and dew point temperatures, multiplying this difference by the air temperature and then cumulatively summing up the values over the number of days since 3mm of precipitation has fallen. Once 3 mm or more of daily precipitation has fallen, the index returns to zero (Buchholz and Weidemann 2000).

5.5.1.2
Keetch-Byram Drought Index (U.S.)

Keetch and Byram (1968) developed a drought index specially to assess fire potential. It is a continuous index representing the net effect of evapotranspiration and precipitation in cumulative moisture deficiency in deep duff and upper soil layers, as well as the flammability of organic matter. Duff is the humus layer on the forest floor consisting of decomposing litter (needles, leaves and other dead vegetation) and mineral soil (Pyne et al. 1996). The Keeth-Byram Drought Index (KBDI) estimates the amount of precipitation necessary to return the soil to full field capacity. It is scaled from 0 to 800 units to represent 0 to 8 inches of soil moisture. At zero, the KBDI assumes saturation at 8 inches of water and therefore no moisture deficiency. At 800, the KBDI indicates the maximum drought possible.

The KBDI was incorporated into the United States National Fire-Danger Rating System (NFDRS) in 1988 to modify the amount of dead fuel available for consumption (Burgan 1988). A modified KBDI has been used for a Fire Danger Rating System in East Kalimantan on the island of Boreno in Indonesia for five years on an operational basis (Bucholz and Weidemann 2000) and for fire management in Sabah, Malaysia (Solibun and Lagan 1998). The KBDI is also used in the calculations of the Australian McArthur fire danger meters for grasslands and forests.

5.5.1.3
McArthur Fire Danger Meters (Australia)

In Australia, McArthur (1967) developed a widely used fire danger and behavior index. It is based on over 800 experimental fires in a wide variety of fuel types, including eucalypt. The index is calculated by using fire danger meters for forest and grasslands. CSIRO based the forest fire danger index (FFDI) equations from Noble et al. (1980).

The FFDI is based on a scale from 0–100, where a rating of 1 represents a fire that will not burn, or that will burn so slowly that control is very easy, and 100 represents a fire that will burn so fast and so hot that control is virtually impossible. The meter also can be used to determine the rate of forward spread of fire on level and sloping ground, flame height, and the distance of spotting from flame front. The advantage of these meters is that they can be used by fire managers in the field using real-time or hourly weather data.

5.5.1.4
Canadian Forest Fire Danger Rating System (CFFDRS)

This rating system has been under development since 1968 by the Canadian forest Service and consists of two modules: The Canadian Forest fire Weather Index (FWI) System and the Canadian forest fire Behavior Prediction System (FBP) System (Stocks et al. 1989). The FWI System has been used in Canada since 1970 and consists of six detailed moisture and fire behavior codes that account for the effects of fuel moisture and wind on fire behavior in a standardized fuel type (mature pine stand). The following description of the CFFDRS was based from Stocks et al. (1989), Pyne et al. (1996), and Van Wagner (1990).

The FWI system components need the following daily (noon local standard time) weather parameter inputs:

- Dry-bulb Temperature
- Relative humidity (%)
- 10-meter Wind Speed
- 24 hour cumulative precipitation

5.5.2
Fire Behavior Prediction

According to Pyne et al. (1996), fire behavior can be defined as the dynamics of a specific fire event. Three elements of the fire environment triangle influence fire behavior: weather, fuel, and topography. Therefore these elements need to be incorporated into any fire behavior prediction system or model. Fire behavior prediction can be considered a combination of art and science that attempts to estimate the spread and intensity of a specific fire; be it for an ongoing fire or a what-if scenario for planning purposes (Pyne et al. 1996). The key of fire behavior prediction is linking the analytical calculations from the models to judgements bade o experience (i.e. historical analogs). These applications have utility for use in prescribed burning planning and managing unplanning wildfires. The following fire behavior prediction systems can be mentioned here:

5.5.2.1
Behave (U.S.)

Behave is a widely used system for fire behavior prediction in the United States. It consists of models for fire spread, moisture, intensity, and fire size (Pyne et al. 1996). It is ideally suited for real-time predictions of wildfire behavior or unplanned ignition prescribed fires (Andrews 1986).

5.5.2.2
Canadian Forest Fire Behavior Prediction System (FBP)

The Canadian Forest fire Behavior Prediction System (FBP) is the second major subsystem of the CFFDRS. The FBP is based on field data of readily measured variables on over 400 experimental fires and well-documented prescribed and wildland fires (Stocks et al. 1989).

5.5.2.3
Sirofire (Australia)

In Australia, the CSIRO's Bushfire Behavior and Management Group developed a Bushfire Spread Simulator called Sirofire (CSIRO 1997). Sirofire was constructed around the McArthur fire danger rate system meters and the new Grassland Fire Spread Meter. Sirofire, unlike the meters, estimates the rate of spread for the entire perimeter of interest.

In complex terrain areas where meteorological parameters are extremely variable, meteorological conditions derived from neighbouring stations are usually not representative of fire conditions. Then a technique based on NDVI index derived from MOAA/AVHRR satellite data would be applied. There exist some GIS application (Geographic Information System) application for forest fire prediction, that integrates input data on spatial fuel properties, topographic information and temporal weather data to form a computer-animated interactive scenario for fire prediction.

5.6
Volcano

The location of potential volcanic eruptions is usually rather well known, and long-term regional planning near high risk volcanoes may avoid great disasters. Volcanic eruptions often have far-reaching effects on the environment; they incriminate water courses and induce gases specially SO_2, the source of formation of widespread aerosols in the stratosphere that may influence the global climate.

Ashfalls during volcanic eruption may cause considerable damage to agriculture, cattle and industry even at distances up to tens of kilometres from a vent, but eruptions generally do not directly endanger life, although the collapse of roofs and houses under the ash load are not uncommon. The ash can cover the land, then the crops are lost, and the animals can't find nourishment and died.

5.6.1 Prediction of Volcanic Eruptions

The development of methods to predict volcanic eruptions is extremely important to provide for early evacuation of densely populated regions. Hazard and risk potential of volcanoes can be localised reasonably well, unlike some other types of natural disasters (earthquakes, storms). Reliable predictions, to a minimum degree, however, are only possible for volcanoes that are well studied and sufficiently instrumented. A prediction based on the statistics of previous eruptions is too vague for specific and short-term prediction of an eruption. A forecast is a general announcement that a volcano will probably erupt in the near future (e.g., by qualitative signs of unrest). A prediction is a relatively precise statement that describes the part of a volcano that is likely to erupt, the time of the eruption, and the presumable type of eruption. Such predictions must be made public with utmost caution in order to gain credibility within the concerned population, thus enabling adoption of preparedness measures. Our increasing understanding of processes inside volcanoes and their measurable effects put predictions more and more on a deterministic basis.

The careful analysis of the history of a volcano is the most important method in assessing the long-term probability of the occurrence of a specific eruption type and its eruptive energy. Volcanic eruptions are often announced years, months, days, or hours before (e.g., by harmonic tremors in the deeper conduit system). This microseismic activity commonly increases prior to an eruption and is characterised by relatively constant amplitudes and wavelengths that are possibly caused by the turbulent motion of the magma ascending to the surface from a magma chamber.

The relatively slow ascent of viscous magma to the upper crust generates a surface expansion that can be measured with modern geodetic instruments. Temperature increases within a volcano as a result of ascending magma can be detected by infrared signals via satellite. Heat conductivity and the magnetic field are changing. An increase of SO_2, emissions often has been observed before eruptions. The characteristic behaviour of a volcano can be identified with the help of intensive monitoring by satellite.

5.7 Conclusion

Climate variability affects all economic sectors, but agricultural and forestry sectors are perhaps two of the most vulnerable and sensitive activities to such climate fluctuations. Many sectors are currently not optimally managed with respect to today's natural climate variability because of the nature of policies, practices and technologies currently in vogue. Decreasing the vulnerability of agriculture and forestry to natural climate variability through a more informed choice of policies, practices and technologies will, in many cases, reduce the long-term vulnerability of these systems to climate change. For example, the introduction of seasonal climate forecasts into management decisions can reduce the vulnerability of the agriculture to floods and droughts caused by the El Niño – Southern Oscillation (ENSO) phenomena.

Some of year to year variation in climate are the result of random sequences of events, just as a series of a coin flips will occasionally produce a long run of heads. A region may experience a dry spell because no storms happen to pass that way for a time. Prediction of such stochastic events is not possible. We now see, however, that many climatic variations are apart of large scale, slowly evolving patterns. Skillful prediction may then be possible, particularly if the pattern are forced by observable changes in surface conditions such as the sea surface temperature (SST). ENSO events are now predicted well in advance with useful (albeit less than perfect) skill. The progress in ENSO prediction is built on advances in understanding, advances in coupled ocean-atmospheric modeling, and the development of an ocean observing system.

Beyond the changes in the physical climate system one would like to predict impacts on agriculture, health, economic system and so on, and then develop response strategies based on this knowledge.

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CHAPTER 6

Agrometeorological Impact Assessment of Natural Disasters and Extreme Events and Agricultural Strategies Adopted in Areas with High Weather Risks

Haripada P. Das

Abstract Agricultural production is highly dependent on weather, climate and water availability and is adversely affected by the weather and climate related disasters. Impacts of extreme events on the agricultural sector can be positive or negative. While it is easier to contemplate negative impacts of extreme events such as droughts, tropical cyclones and floods, there are several positive impacts or benefits of extreme events. In order to assess the impact of weather disaster on agriculture, one must link two fundamental aspects, first, the disaster proper i.e. the destructive power of the event and secondly, the characteristics of the agricultural system which has been hit. Agricultural planning and practices need to be worked out with consideration to the overall water requirements within an individual agroclimatic zone. Sustainable strategies must be developed to alleviate the impact of natural disasters on crop productivity. All such strategies are location, time, crop, crop stage and socio-economic condition specific. Remote sensing satellite information helps minimise damages e.g. the death of cattle, humans etc. and the damage of agricultural production in time of natural calamities by early warning system.

6.1 Introduction

Agriculture, being a vital source of livelihood, was essentially dependent on the natural seasons. Disasters were believed to be an inseparable part of nature and a series of undesirable fluctuations in climate could endanger food security. People looked upon disasters as a part of rural-agrarian life. And they tried to cope with undesirable climate by offering sacrifices to gods, and by inventing various small-scale devices to ensure the security and their lives, lands and livelihoods. They made their rustic disaster policy, with which they were able to manage the risk, damage and stress of disasters. A majority of the people of the developing countries still depends on agriculture for its livelihood. Agriculture includes farming and also animal husbandry, pastoral activities, fishing and harvesting the forest.

In spite of recent technological developments that have helped to increase agricultural production in many countries, growth of plants and animals continue to depend to a large extent on the weather conditions. Each plant has its own climatic requirements for growth and development and any large-scale deviation from it exert negative influence.

Growth of plants is most sensitive to temperature just above a threshold value and near the maximum value, where growth normally stops. Therefore, periods of extreme temperature i.e. low temperatures below the threshold value and high temperatures above the maxima are hazardous to plant development and growth. Extreme temperature conditions during cold spells cause stress and frost; high temperatures lead to heat stress, and both affect agricultural production. Snow and ice storms in late spring or early autumn are very hazardous to many temperate crops.

Similarly, extremes of moisture conditions caused by dry dessicating winds, drought episodes and low moisture conditions as well as very humid atmospheric conditions including wet spells adversely affect agriculture. High soil moisture in situations of water logging and flooding associated with heavy rainfall and tropical storms have adverse effect on plant growth and development since they influence the rate of transpiration, leaf area expansion and ultimately plant productivity. Drastic changes in rainfall variability can have very significant impact, particularly in climatically marginal zones such as arid, semi-arid and sub-humid areas where incidence of widespread drought is frequent. Dry, dessicating and strong winds reduce agricultural production as a result of very high evapotranspiration rates. It also causes mechanical damage to such plants as sugarcane and bananas with weak stems caused by lodging.

6.2 Agrometeorological Impact of Extreme Events

In the past twenty years, earthquakes, volcanic eruptions, landslides, floods, tropical storms, droughts and other natural calamities have killed over three million people, inflicted injury, disease, homelessness and misery on one billion others, and caused billions of dollars of material damage. Currently, annual global economic costs related to disaster events average US$ 880 billion per year. These figures provide a grim picture. By the year 2025, 80 per cent of the world's population will reside in developing countries, and it has been estimated that up to 60 percent of the people will be highly vulnerable to floods, severe storms and earthquakes. Nearly 90 percent of the natural disasters and 95 percent of the total disaster-related deaths worldwide, occur in the developing countries. Since the 1960s, economic losses caused by disasters have increased at least fivefold. These losses are growing largely because of the increasing concentration of population and investments in vulnerable locations coupled with inadequate investment in measures to reduce risk.

More than any human event, a disaster traumatically brings into focus all the basic problems in a society. It reduces all issues to their most fundamental level and strips away the ancillary issues that obscure or confuse the fundamental questions that must be faced. Critical decisions, previously unaddressed, can no longer be ignored, and choices must be made.

The very face of the land may be altered by a disaster. Droughts have led to famines. Famines have led to migrations. When the people ceased to cultivate the areas that were behind, creeping deserts swallowed the arable land and made it untenable. But positive changes have also been recorded. Better cropping patterns have often followed droughts. Reforestation efforts and better use of contours for hillside agriculture have often followed rain-induced landslides. Where contour planting has been introduced, economic benefits have often followed. For the society, disasters often bring changes in the structure of community leadership. New organizations may be born out of necessity to deal with the disasters and remain to continue the work of bringing economic changes to the community.

The CAgM Working Group of WMO on "Agrometeorology related to extreme events", recently developed a survey of countries regarding extreme weather events and their agricultural impacts. The survey identified a number of extreme events including drought, desertification, cold/frost, floods and heavy rainfall, high winds and severe storms, tropical storms, forest and range fires, etc. throughout the globe. Figure 6.1 provides a graphical representation of these results. Impacts of extreme events on the agricultural sector can be positive or negative.

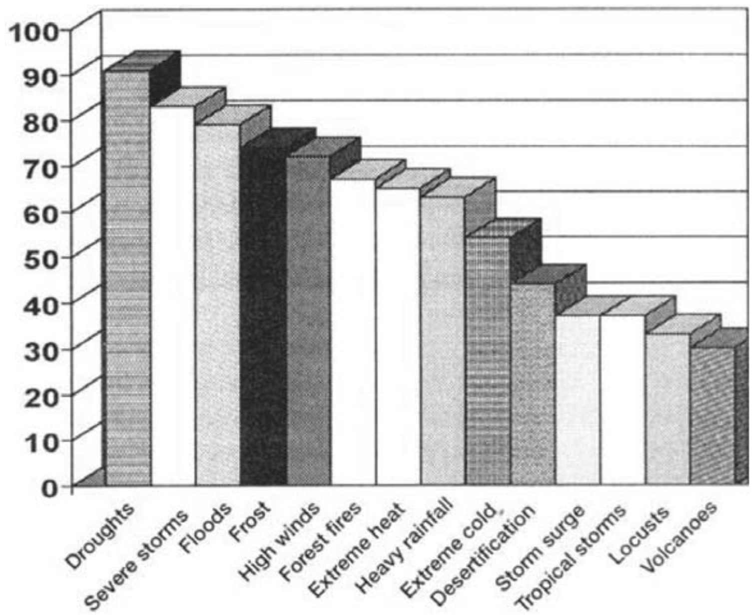

Fig. 6.1. Percentage of countries reporting agricultural impacts from extreme agrometeorological events

6.2.1 Positive Effect on Agriculture of Extreme Events

While it is easier to contemplate negative impacts of extreme events such as droughts, tropical cyclones and floods, there are several positive impacts or benefits of extreme events. Increased rainfall in coastal areas from tropical cyclones, fixing of atmospheric nitrogen by thunderstorms, the germination of many native plant species resulting from bushfires and the maintenance of the fertility of the basin soils due to river flooding are some of the positive impact of extreme meteorological events. There are some advantages of drought at certain times in the development of some crops such as the sugarcane where a brief dry spell is essential during the pre-harvest stage that helps to increase the sucrose content of the cane. Also, there is often a lower incidence of pests and diseases in periods of drought. Transport firms involved in shifting fodder and livestock and tourist organizations do derive benefit from drought.

6.2.2 Negative Effect on Agriculture of Extreme Events

It is, however, the negative or adverse impacts of extreme events referred to as damages or losses which are more pronounced and do affect agricultural operations significantly. Impacts of extreme events can be direct or indirect. Direct impacts arise from direct physical contact of the events with people, their animals and property. Indirect impacts of extreme agrometeorological events are those induced by the events. Indirect impacts often occur away from the scene of the extreme event or after the occurrence of the event. Indirect impacts include evacuation of people in the event of cyclone landfall, disruption to household and leisure activities, stress induced sickness, and apprehension and anxiety of future extreme events like floods or bush fires.

In order to assess the impact of weather disaster on agriculture, one must link two fundamental aspects: the disaster proper (i.e., the destructive power of the event) and, the characteristics of the agricultural system which has been hit. This is illustrated below in the example of Bangladesh (Rahman 1985). Between 1970 and 1984, three major weather disasters struck Bangladesh. In mid-November 1970, one of the worst cyclones in history; in 1978–1979 a severe drought befell the country, followed in 1984, by extended heavy floods lashing from May to September. Each of these disasters resulted in a sharp decrease of the rice production, the staple food of the country (Gommes 1997).

Weather disaster interactions with agriculture are complex and, of course, are likely to involve non-agricultural factors as well. Table 6.1 shows some weather factors that may negatively affect agriculture (Gommes 1997).

As stated earlier, two broad categories of effects on the agricultural sector can be identified: direct and indirect effects. Direct effects to a farmer could be, for example, the loss of his current crop and damage to his irrigation facilities. Indirect effects on agriculture appear progressively, as a result of low income,

Table 6.1. Weather factors that affect agriculture negatively

Weather factor	Negative effects on agriculture of extreme Values (both direct and indirect)
Rainfall	Direct damage to fragile plant organs, like flowers; soil erosion; water logging; drought and floods; land slides; impeded drying of produce; conditions favourable to crop and livestock pest development; negative effect on pollination and pollinators.
Wind	Physical damage to plant organs or whole plants (e.g. defoliation, particularly of shrubs and trees); soil erosion; excessive evaporation. Wind is an aggravating factor in the event of bush or forest fires.
Air moisture	High values create conditions favourable to pest development; low values associated with high evaporation and often one of the most determinant factors in fire outbreaks.
High temperatures	Increased evapotranspiration; induced sterility in certain crops; poor vernalization; survival of pests during winter. High temperatures at night are associated with increased respiration loss. "Heat waves", lengthy spells of abnormally high temperatures are particularly harmful.
Low temperatures	Destruction of cell structure (frost); desiccation; slow growth, particularly during cold waves; cold dews.
High cloudiness	Increased incidence of diseases; poor growth.
Hail	Hail impact is usually rather localized, but the damage to crops-particularly at critical phenological stages- and infrastructure may be significant. Even light hail tends to be followed by pest and disease attacks.
Lightning	Lightning causes damage to buildings and the loss of farm animals. It is also one of the causes of wildfire.
Snow	Heavy snowfall damages woody plants. Unseasonable occurrence particularly affects reproductive organs of plants.
Volcanic eruptions, avalanches and earthquakes	The events listed may disrupt infrastructure and cause the loss of crops and farmland, sometimes permanently. A recent example of carbon dioxide and hydrogen sulphide emissions from a volcanic lake in Cameroon caused significant loss of human life and farm animals.
Air and water pollution	Air pollutants affect life in the immediate surrounding of point sources. Some pollutants, like ozone, are however known to have significant effects on crop yields over wide areas. In combination with fog, some pollutants have a more marked effect on plants and animals. Occurrences of irrigation water pollution have been reported.

decrease in production and other factors related to the weather disaster. The farmer may well have to pay high prices for seeds because of increased demand and disruption of the transportation system. He might also lose a portion of his future harvest because of storm surge-related salinization of soil or the destruction of perennial plantation crops that sometimes take 5 to 10 years to re-establish. Indirect effects are thus difficult to quantify and therefore are often termed "invisible" effects. Conditions conducive to the development of pests and diseases are to be regarded as indirect effects. In fact, the conditions that trigger pest and disease development are rarely directly harmful per se. They are usually a combination of moisture or temperature conditions that do not directly affect crops. Typical examples are desert locust outbreaks or increased disease incidence in sugarcane after hurricanes. Plants weakened by adverse weather are much more susceptible to cryptogamic diseases or pest attacks, such as the explosion of coconut black beetle on wind-damaged coconut trees. A perennial crop needs a number of years before it is restored to its normal situation. For example, it is taking 30 years for certain timber varieties to re establish after hurricane Allen hit Jamaica in August 1980 (FAO 1982). It is frequently from 6 to 12 months for tea and banana plants and 4 to 5 years for coffee and sugarcane. Even for crops that regenerate easily after partial damage, harvesting is usually made difficult by the "abnormal" morphology, thus further reducing yield. In agriculture there can be large losses in primary production on account of delays in the recovery of arable land that has been inundated. For an annual crop, the office of the United Nations Disaster Relief Co-ordinator estimated a global loss (direct and indirect) at 1.5 to 2 times the direct loss (the lost harvest value). For a perennial crop, the global loss was evaluated at 5 to 7 times the value of the lost harvest. The following paragraphs starts with an attempt to list extreme events that can potentially interfere with agricultural productions.

6.2.2.1 Tropical Cyclone and Storm Surge

As regards the impact of cyclones, out of its three accompanying effects of heavy rain, strong wind and storm surge, it is the storm surge of tremendous height and force, which causes most of the damage including loss of human lives and livestock, destruction of property and agricultural and industrial production. Apart from short-term problems, storm surge creates long-term problems because the salt water makes the soil unproductive. The impact of cyclones, with frequent occurrences and substantial magnitude, on the marginal landowners and landless people happens to be tremendous. These affect livelihood assets and seriously challenge the efforts of the country towards self-reliance.

For most developing countries, loss to life, property and the crop represents a bigger part of the damage caused by a cyclone. In monetary terms, the losses incurred by livestock raising, forestry and fisheries mostly remain below those suffered by agriculture. In Madagascar, for instance, according to FAO, a cyclone in 1983–84 caused crop losses of 85% of the total damage to the agricultural sector, whereas the damage to the infrastructure and equipment (drainage, irrigation channels, etc.) barely reach 15%. The traditional small scale fisheries were also hit by the cyclone. The losses incurred by livestock raising, forestry and fisheries mostly remain below those suffered by crops

(OSRO 1984). A rather different impact pattern occurs in small islands like Antigua and Barbuda where fisheries constitute the backbone of the economy. In eastern Caribbean countries affected by Hurricane Hugo in 1989, 47 percent of the losses occurred in fisheries, but crop losses still represented almost 40 percent of the total damage (OSRO 1989).

It is worth mentioning that the losses affecting cash crops, which constitute a major source of export earnings in a number of developing countries is rather high. In Nicaragua, for example, it is reported that direct losses of export crops due to Hurricane "Juana" (Joan) in late 1988 amounted to 21% of the total losses in the agricultural sector (MIDINRA 1988). Coffee and bananas suffered a direct loss of their fruits and mechanical damage to their plants. Nonetheless, food crop losses were estimated to be higher (35%), while the livestock sector was less affected (8%, of which one fifth was poultry).

The effects of strong winds in coastal areas are often stunted and very sculpted trees, providing unmistakable evidence of the direction of the strong winds. In addition to the battering effects of winds, there is the additional damage caused by airborne sea salt that occurs within a few hundred metres of the coast. Winds that blow from coastal seas spray a lot of salt on coastal areas, making it impossible to grow crops sensitive to excessive salt.

Fields inundated by the storm surge suffer a loss of fertility due to salt deposition, even after the sea water has receded. The affected land takes a few years to regain its original fertility. The period of high water can last from 6 hours to several days, if the drainage is poor, and may leave the soil saline and unfit for crops. Saline soils are predominantly observed in the coastal areas of India. A rise in the sea level would adversely affect the 7,000-km coastal belt of India, comprising 20 million ha of coastal ecosystem, increasing coastal salinity and reducing crop productivity.

The effects of cyclonic storms are not entirely bad; benefits focus principally on the precipitation associated with them that may have considerable value to agriculture. The heavy rain associated with cyclonic storms guarantees a longer period of water availability and provides possibilities for off-site extra storage in rivers, lakes and artificial reservoirs (on farms or at the sub-catchment level) giving an improved rural water supply and expanded or more intensive irrigated agriculture and inland fisheries. The extra precipitation due to cyclonic storms on land helps to increase plant growth improving the protection of the land surface and increasing rainfed agricultural production.

6.2.2.2
Drought

Droughts have an immediate effect on the recharge of soil moisture resulting in reductions of streamflow reservoir levels and irrigation potential and even the availability of drinking water from wells.

In the event of a prolonged drought, farmers, either alone or with the entire family, may abandon their land in search of work and food in nearby cities. Fewer and weaker family members remain to till the land, affecting the area under cultivation (McCann 1986). The acreage planted to food crops is also affected by land quality. Due to the uncertainty of rains during the drought, farmers sometimes make several attempts at sowing of seeds leading to a drastic reduction in seed reserves, which in due course are neither sufficient for planting nor for consumption. The farmer is then obliged to borrow offering labour or perhaps a portion of the future harvest as payment for the loan.

Drought not only exposes and accelerates existing land quality problems, it also initiates new ones. The cultivation of lands subject to a high degree of rainfall variability makes them extremely susceptible to wind erosion (and desertification) during prolonged drought episodes, as the bare soil lacks the dense vegetative cover necessary to minimize the effects of aeolian processes. As the fertility of the land and crop yields decline, farmers search for new land to cultivate. Farmers sometimes are forced to cultivate lands considered marginal from the viewpoint of quality, terrain slope and rainfall (Glantz 1994). These newly cultivated lands are high risk areas in the long run for rainfed agriculture.

6.2.2.3
Flooding and Heavy Rainfall

Two of the principal hydrometeorological events that often have deleterious effects on agriculture are heavy rainfall and flooding. It is recognized that in some cases these events can have positive effects. Examples include heavy rainfall from a tropical storm ending a long agricultural drought, or recurring, annual flooding that replenishes topsoil and soil nutrients, as was the historic situation along the lower stretches of both the Nile and Ganges rivers. Soil erosion, disruption to critical agricultural activities, the water-logging of crops, increased moisture leading to increased problems with diseases and insects, soil moisture saturation and runoff, soil temperature reduction, grain and fruit spoilage and transportation interruption are among the more significant agricultural impacts from heavy rainfall.

Direct damage to growing plants from flood is most often caused by depletion of oxygen available to the plant root zones. Flooding creates anaerobic soil conditions that can have significant impacts on vegetation. Root and shoot asphyxia, if prolonged, typically leads to plant death. Chemical reactions in anaerobic soils lead to a reduction in nitrate and the formation of nitrogen gas. The denitrification can be a significant cause of loss of plant vigour and growth following flooding (Foth 1978).

Looking only at temporal characteristics of rain storms and their consequent impact on agriculture, the concept of intensity-duration-frequency (idf) becomes important. If any of these three rain storm characteristics increases, the potential for agricultural impacts increases. Heavy rainfall at a location can thus be defined using the idf convention and is framed by the agroclimatology of a location or region in question. Very intense (extreme) rainfall can result in catastrophic flood damage even though it occurred for a relatively short period of time, and/or at the proper location, at the proper time of year, etc. In general, greater damage to agriculture occurs from rain storms having higher intensities with sufficient duration, compared with low intensity, long duration storms.

6.2.2.4
Sand Storm/Dust Storm

The arid regions are characterised by frequent and strong winds that are due partly to considerable convection during the day. The usually sparse vegetation is not capable of slowing down air movement, so that dust storms and sand storm are frequent concomitant of wind movement. Winds in dry climatic zones also affect growth of the plant mechanically and physiologically. The sand and dust particles carried out by wind damage plant tissues. Emerging seedlings may be completely covered or alternatively, the roots of young plants may be exposed by strong winds. Winds also cause considerable losses by inducing lodging, breaking the stalks and shedding of grains and ultimately decreasing the yield. Many agricultural lands have been lost through wind action by the encroachment of sand, dunes, dust storms and sand storms that carry away the top humus soil, leading to deterioration and degradation of the landscape and desertification.

6.2.2.5
Extreme Cold Weather Including Frost Injury

Long periods of extreme cold weather combined with other meteorological phenomena are detrimental to many sectors of the economy, especially agriculture and can result in the loss of winter crops, fruit crops and vineyards due to frost injury. Frost injury is the most widespread type of cold injury to affect crops. Low soil temperature at the depth of plant roots can cause frost injury. Such reductions in soil temperature occur with strong frosts, in the absence of snow cover and with deep freezing of the soil.

Most frost injury to winter crops takes place in the first half of winter before sufficient snow cover that would afford protection has formed. In the second half of winter frost injury happens in regions with unstable snow cover.

There have been many studies of plant injury caused by extreme cold weather. Under low temperatures, a plant basically dries out and the protoplasm (the living part of cells) dies. This happens because the concentration of cell sap rises, the distance between macromolecules is altered and the process of energy interchange is disrupted. The toxic products of metabolism accumulate within the plant's tissues and it is this that causes the protoplasm to die. The degree of damage depends on the intensity and duration of dangerous frosts as well as the stage of the plant's development. Damage to the part of a plant does not always result in damage or destruction of the whole plant. A determining factor is the degree of frost injury to a tillering node. If it is heavy, the whole plant will perish. The winter crops most frequently destroyed by frost are those grown on upland areas, where snow cover is less and the depth of soil freezing is greater.

The main agrometeorological factor influencing frost damage in winter crops is low soil temperature at the depth of the tillering node. Cooling to the critical temperature of frost injury, even for one day, and especially after a thaw, results in thinning out of crops. Long (three days or more) and intensive cooling causes complete devastation.

6.2.2.6
Forest Fires

Forest fires are considered a potential hazard with physical, biological, ecological and environmental consequences. Forest fires occur frequently in tropical countries particularly in the dry and hot seasons causing serious damage to the forest resources and agricultural production. Since the number of forest fires are increasing every year, continuous monitoring is of great importance, not only to understand present trends but also to devise a model to predict the possibility of fires in future.

6.3
Strategies Adopted in Areas with High Weather Risk

The agrometeorological impacts of natural disasters have a pervasive societal ramification particularly in developing countries. Associated human misery underscores our vulnerability to these natural hazards. A disastrous event does not pose much of the threat and ceases to be a disaster, if suitable and adequate mitigation measures are adopted well in advance. Prevention of the formation of tropical cyclones is not in the realm of possibility, but much of their disastrous potential can be reduced, restricting thereby the loss of human life and loss of property, by adopting appropriate strategies and taking timely precautions on the receipt of weather warnings. Climatological data helps in the advance preparation of long-range policies and programmes for disaster prevention. The following paragraphs list the agricultural strategies to be adopted in the events of some major natural disasters.

6.3.1
Drought Management

In arid, semi-arid, and marginal areas with a probability of drought incidence of say, at least once in ten years, it is important for those responsible for planning of land-use, including agricultural programmes, to seek expert climatological advice regarding rainfall expectations. Drought is the result of the interaction of human pattern of landuse and the rainfall regimes. Thus, there is urgent need for a detailed examination of rainfall records of these regions. In this regards, the development of methods of predicting many weeks or months in advance the occurrence of rainfall deserves high priority.

Since technological inputs quickly reach an optimum level, more emphasis should be placed on drought management policies, especially in dryland farming areas. Agricultural planning and practices need to be worked out with consideration to the overall water requirements within an individual agroclimatic zone. Crops that need a short duration to mature and require relatively little water need to be encouraged in drought prone areas. Irrigation, through canals and groundwater resources, need to be monitored with optimum utilization, avoiding soil salinity and excessive evaporation loss. A food reserve is needed to meet the emergency requirements of up to two consecutive droughts. A variety of policy decisions on farming, human migration, population dynamics, livestock survival, ecology, etc. must be formulated (Das 1999).

Sustainable strategies must be developed to alleviate the impact of drought on crop productivity. In areas of recurring drought, one of the best strategies for alleviating drought is varietal manipulation, through which drought can be avoided or its effects can be minimised by adopting varieties that are drought-resistant at different growth stages.

If drought occurs during the middle of a growing season, corrective measures can be adopted; these vary from reducing plant population to fertilisation or weed management. In high rainfall areas where there are a series of wet and dry spells, rainfall can be harvested in either farm ponds or in village tanks and can be recycled as lifesaving irrigation during a prolonged dry spell. The remaining water can also be used to provide irrigation for a second crop with a lower water requirement, such as chickpea. However, no one strategy can be adopted universally. In fact, all such strategies are location, time, crop, crop stage and (to some extent) socio-economic condition specific. Developing such strategies for each specific factor can help make agriculture sustainable.

6.3.2
Cyclone Preparedness in Agriculture System

Disaster preparedness for impending cyclones, as we know, refers to the plan of action needed to minimize loss to human lives, damage to property and agriculture. The effectiveness of disaster preparedness ultimately depends on the effectiveness of planning and response at a district or local government level (Oakley 1993).

Preparedness for cyclones in the agriculture system can include early harvesting of crops, if matured, safe storage of the harvest, etc. Irrigation canals and embankment of rivers in the risk zone should be repaired to avoid breaching. Beyond this, as the storm approaches the area, nothing can be done, but to secure as much of the property as possible and find safety.

An example of crop diversification may be cited here as a long-term measure to reduce the crop damage during the period of cyclone in coastal districts of Andhra Pradesh of India (Naidu 2001). Paddy is the principal *kharif* crop in coastal districts of Andhra Pradesh. About 50 percent of the paddy-cropped area of the state is situated in the districts of Nellore, Prakasam, Guntur, Krishna, West Godavari and east Godavari. The two traditional varieties of paddy cultivated by nearly 50 percent of the farmers namely 'Akkullu' and 'Massouri' are of five to six month duration. During 1977 and 1996, they were planted in June–July to be harvested in November and December. But unfortunately the cyclone struck at the worst possible time of crop growth, just after the grain had set but before the harvest had commenced. In the cyclone hit areas, the high impact of wind caused majority of the grains to blow away, leaving behind only the stalks. Two reasons could be attributed for the loss of grains. One the traditional varieties are heavy shredders by nature and are susceptible to lodging easily on impact. Secondly, the high winds caused friction among the ear-heads resulting in grain shed again. As a long-term measure, the farmers should be advised to take up the cultivation of those short-duration variety crops which are not easy grain shredders.

Another example of a project "Coastal Environment Preservation" undertaken by Vietnam Red Cross may be illustrated here to show how mitigation programme was useful to the local population living along the seacoast engaged in agricultural and aquaculture. With eight to ten typhoon storms striking the coast of Vietnam annually, tidal flooding often breaches sea dykes causing economic losses to the local population engaged in aquaculture. Under the Environmental Preservation Project, the planting of mangroves were undertaken as mitigation programme to address the suffering of the people living along the sea coast in Thai Thui district of Thai Binh province (Goodyear 2001).

The planting of mangroves serves two important purposes: (a) It acts as a buffer zone in front of the sea dyke system and reduces the water velocity, wave strength and wind energy to protect coastal land, human life and assets invested in development, and (b) it contributes to the production of valuable export products such as shrimps and crabs, high-value marine fish species in cages, mollusk farming and seaweed culture for agar and alginate extraction. By contributing to environmental support to coastal fisheries and aquaculture through the development of 2,000 hectares of mangroves, the Thai Binh Red Cross also helps to provide a livelihood benefit to the vulnerable population through new employment opportunities for their labour.

An evaluation of the project in 1996 indicated that: "By helping to protect the sea dykes, the mangroves were contributing to the economic stability of the communes. All members of the community stand to benefit as their homes, livestock and agricultural land are better protected from the risk of flooding. Poor families with little money to repair or replace material losses from storm damage, are the greatest potential beneficiaries". The project area was struck by the worst typhoon in a decade two month prior to the project evaluation. Lack of any significant damage to the sea dyke and aquaculture pond systems in Thai, provided the best possible indicator of the effectiveness of the mangroves. The perceptions of the local population believed that the mangroves planted would:

- Lessen the frequency of storms, protect flooding of sea dykes and ponds, protect property and the coastal inhabitants;
- Improve aquatic production and the environment, and prevent saline intrusion into agricultural land;
- Expand the land area for the national benefit.

6.3.3 Mitigation of Damage on Agricultural Sector due to Flood and Heavy Rainfall

Preconditioning of an area is very important for determining how significant and damaging a flood will be. Important considerations here are soil, vegetation and water supply factors. Soils that are saturated prior to an extreme weather event will more likely to result in a damaging flood than soils that are relatively dry. Fields that have recently been tilled and are devoid of vegetation are much more susceptible to soil erosion. Vegetation that is able to use much of the water and that can act as a barrier to moving water (horizontally and vertically) can reduce flood severity and impacts. Water storage systems (rivers, lakes, reservoirs, etc.) that are able to capture and hold most of the incoming water will be effective in reducing flood damage. Thus, water supply managers in snow-fed water supply regions of the world typically draw down reservoirs as much as possible prior to the normal beginning of the snowmelt run-off season. In rain-fed agricultural systems, managers typically anticipate rainfall during the growing season sufficient to naturally or artificially irrigate crops. In both situations, however, there is often a balance needed between retaining enough water for agricultural production and environmental health and maintaining enough available storage volume to capture incoming water and prevent floods. Here, analysis of past weather and water data are critical for estimating average conditions and inherent variability. Crops like rice that can function effectively in saturated and even submerged conditions are appropriate for locations that flood regularly and the system becomes dependent upon regular flooding. Many other crops (e.g. corn) would not be adaptable to such conditions and would not be appropriate alternatives to rice.

Geographical Information System (GIS) can be extremely useful tools in the analysis of flood-prone areas. A GIS in conjunction with digital elevation model (DEM) data can quickly determine slope and aspect of region and can be used to provide geospatial analyses of multiple spatial layers (elevation, slope and aspect-all at various scales or resolutions along with soil characteristics, precipitation, temperature, vegetation, and other factors). GIS are being used to develop new floodplain maps (at various frequency and severity levels) and delineate wetlands in many regions and countries, using these types of spatial layers as well as others, including aerial photos. Such information will certainly assist in the best design of agricultural systems, while accounting for reasonable risk.

Floodplain maps with appropriate information about probabilities (return periods) of certain amounts of precipitation and/or depth of flooding water should be developed and used in risk assessments and agricultural planning. Based on these analyses, economic studies can be conducted to determine if certain types of agriculture are appropriate and justified in certain flood regions. For instance, even though analyses indicate a region is subject to significant flooding every five years, it may still be economically advantageous to farm the area, due to its high value of return. Prudent planning would ensure that structures and other items that would be damaged or destroyed by these frequent floods need not be built in the flooded area, but in less vulnerable areas nearby. It is also important that future flood planning looks not only to structural solutions but also to land use planning, zoning and other solutions that encourage agricultural production in less vulnerable areas.

6.3.3.1 Better Land-use and Crop Planning

For development in the floodplains, a careful management of technology so as not to obstruct but to use floods to good purpose through better land-use and crop planning has to be an essential ingredient of any policy. In other words, it is necessary to promote ecologically appropriate policies for human settlements and agriculture in the floodplains.

Suitable short duration strains of paddy and other crops, which can withstand flooding for a few days, have to be developed. Much work has been done in the agricultural universities in India and Bangladesh and it could be utilized to a considerable extent.

People in the eastern floodplains of the Ganga and Brahmaputra in India and those in Bangladesh have a long tradition of living in harmony with floods. The living style, habitations, and crops grown were all evolved taking into consideration the climate and the flood-proneness of the area. Ancient people inhabiting the floodplains took care not to block the natural drains, preserved the natural beds and depressions, and cultivated only those crops that could stand submergence. This tradition is gradually vanishing with changing economic and social conditions. There can be no doubt that the countries of the Ganga-Brahmaputra-Meghna region must adopt ecologically appropriate policies for human settlement, agricultural and industrial development, besides promoting the protection of wetlands for flood moderation (Rangachari 2001).

6.3.3.2 The Application of Nutrients During Flood

Prolonged flooding of soils causes several physical, chemical and biological changes, some of which are not reversible. The application of Nitrogen, Phosphorous and Potassium in appropriate amounts could be especially important to build up soil nutrients for plants weakened by prolonged flooding and especially prone to development of disease problems and provides a perspective on the development of flood mitigation strategies in the future.

6.3.4 Protection of Crop Against Wind

Crop damage by winds may be minimised or prevented by the use of windbreaks (shelterbelts). These are natural (e.g. trees, shrubs, or hedges) or artificial (e.g. walls, fences) barriers to wind flow to shelter animal or crops. Properly oriented and designed shelterbelts are very effective in stabilizing agriculture in regions where strong wind cause mechanical damage and impose severe moisture stress on growing crops. Windbreaks save the loose soil from erosion and increase the supply of moisture to the soil in spring.

6.3.5 Protection of Crops from Dust Storm/Sand Storm

In most countries, field afforestation is the main measure to protect the soil from dust storm. Improving soil resistance to erosion can be achieved by careful selection of cultivation methods, applying mineral and organic fertilizers, sowing grass and spraying various substances that enhance soil structure. It is also important to reduce the areas where a dust can gather, especially in tracts in areas characterized by erosion. One major protection strategy is to establish well-developed plant cover before the dust storms period. This can encourage a reduction in the wind speed in the layer next to the ground by forming an effective buffer.

When assessing the impacts of the dust storm on agricultural crops, it is necessary to take into account the degree of the development of the plants. On well-tilled crops, the deposition of soil moved by airflow is observed more often than soil carried by wind erosion over long distances.

When looking at the conditions in which dust storms developed and data on storm-induced damage, it is evident that measures to reduce the wind speed at the soil surface and to increase the hooking of soil particles are both crucial. Such measures include the establishments of tree belts and wind breaks. Leaving stubble in fields, non-mouldboard ploughing, application of chemical substances promoting the hooking of soil particles, soil-protective crop rotation using perennial grasses and seeding of annual crops are also important.

In regions with intensive wind erosion, especially on wind shock slopes or on light soils, stripe cultivation may be used. On fallow lands bare fallow stripes of 50–100 m can be alternated with stripes of grain crops or perennial grasses; spring crops can be alternated with winter crops.

6.3.6 Protection of Crops from Cold Injury and Frost

A key factor in protection of crops from cold injury is stable air temperatures and snow covers throughout the winter. Thaws, resulting in packing or disappearing snow cover, worsen dormancy conditions and reduce or destroy the protective properties of snow cover. Long thaws can result in the renewal of vegetation, which is accompanied by the consumption of carbohydrates and hence by increase in critical temperature and decrease in winter resistance.

The prevention of crop damage by frost can be controlled by breaking up the inversion that accompanies intense night time radiation. This may be achieved by heating the air by the use of oil burners that are strategically located throughout the agricultural farm. Other methods of frost protection include sprinkling the crops with water, brushing (putting a protective cover of craft paper over plant) and the use of shelterbelts (windbreaks).

6.3.7 Fire Prevention Measures

The use of periodic seasonal data of certain specific forest areas prone to forest fires could be used by the forest managers to enable taking certain fire prevention measures or mounting fire operation measures in advance to mitigate possible damages. On the basis of the weather fire relationship, a system of fire danger rating has been evolved to guide the fire management people in their day to day activity and also to provide a basis for comparing weather and fire behaviour throughout the nation or region. Such system usually include book-keeping schemes for keeping track of the moisture contents from one to three size classes of forest fuels, plus indices of spread rate, fuel quantity consumed and energy output rate of the fire front. Forest fire danger rating system in Canada and universal system of fire danger rating along with fire weather forecasting in USA are providing valuable information to mitigate possible damage due to forest fire.

6.4 Agricultural Strategies for Community Capacity Building

The process of community capacity building for disaster risk reduction starts with community-based risk assessment. Assessment of prevalent hazards and the vulnerabilities and capacities of the community is done with the active involvement of local people. By applying participatory techniques, people are engaged in a process of the analysis of the situation and the risks they face. Imparting awareness to farmers on drought and flood resistant crops is another instance in this line. Some of the agricultural strategies to be adopted are mentioned below (Murshed 2003).

6.4.1 Diversification of Crops According to Different Planting Seasons

Many disaster prone communities depend on only one type of crop, which is harvested only once a year. Due to the occurrence of hazards, this crop is damaged and as a result, they regularly face acute food shortages and people are forced to depend on seasonal out-migration. It is therefore important to identify the potential to harvest other crops in different months of the year. It may involve the assessment of suitability of land for cultivation of other crops, availability of water and orientation and training of farmers to harvest new crops. This can help mitigate the effects of failure of the main crop on farming families due to prevalent hazards; e.g. drought or flood. If the main crop fails, the farmers still can harvest products during the two other seasons. As a result, the number of months people face food shortage could be reduced. Interesting work is being done in this front in Philippines and Vietnam by the agriculture ministries and extensions services.

6.4.2 Propagation of Disaster Resistant Crops

Disasters disrupt farming and damage certain crops, which may result in form of food shortage. In old times in the face of food shortages due to disasters, people depended on wild crops like certain beans, leaves, and root crops. These crops can still be found in many regions although some of them have become scarce and are gradually disappearing. Therefore, it is essential to propagate these, especially among the younger generation, who is hardly aware about the existence of such crops. It is important that the knowledge and skills of old people are tapped regarding these plants for their promotion of mitigation measures. The re-introduction of the already forgotten indigenous crops and the campaign to cultivate them could awaken and remind local residents of the importance of such crops. They are easily grown and do not require a lot of inputs. Their use can be propagated by planting community nurseries/demo-farms and through educational campaigns. Disaster resistant crops and other indigenous crops can serve as a staple food source in times of disasters.

6.4.3 Seed Banks and Nurseries

Establishment of seed banks and nurseries at the community level can ensure a stable supply of seedlings, seeds, cuttings and other plant materials. Seed stocks can be used in times of emergency for rehabilitation of damaged croplands. Most seed banks focus on traditional rice and corn seeds, which are more resistant to pests and less sensitive to changing climatic conditions. These varieties are slowly disappearing because hybrid varieties are promoted in the market. This highlights the importance of community-based seed banks. Nurseries propagate fruit trees, forest trees, forage trees, bamboo, and other plants useful for people in times of crisis. Cultivating utility trees around homes and land, maintaining forest reserves for food, animal feed and cash, improving watersheds, and protecting water sources are long-term interests of vulnerable people. Seed banks and nurseries could strengthen people's existing livelihoods and increase the presence of fallback resources in the community's seed bank and nursery. They should be provided training on seed bank and nursery management, record keeping. They can also formulate policies for the approval of the farmers regarding repayment of seeds, operation and maintenance of the nursery, and the sustainability of the seed bank and the nursery.

6.4.4 Post Harvest Facilities

Marginalised communities cannot always enjoy the benefits of a harvest. After paying the landlord back, they face problems of inaccessible and expensive grain mills, storage problems (attacked by rats and insects, or rotting due to damp conditions), or they have to sell seasonal perishable crops at low price. It is essential to help communities to address post-harvest problems to reduce losses, to reduce expenses for milling, and to maximize the availability of vegetables, fruits and root crops by processing and preserving them for times that they are less abundant. In this way people's coping strategies are strengthened. This can be done by helping construct appropriate storage facilities to avoid rats from entering and eating the rice grains, the main problem in times of drought. Seeds can further be protected from insects and damp conditions by adding charcoal and pinewood splints. Provision of cheap and easily accessible milling facilities could be a strategy. This can improve the availability of food in seasons of disaster.

6.4.5 Encourage Proper Land Use Management and Sustainable Agriculture Practices

The fast deterioration of environment due to outside pressures (logging, mining, multinational plantations, and encroaching settlers) increases the vulnerability of people to various hazards and many times leads towards introduction of new hazards. Therefore, conservation of environment through tree plantation, rehabilitation of watersheds, mitigation of soil erosion, and replenishment of forest reserves is important. It can be done through organizing tree-planting campaigns to raise awareness on environmental issues among a broader public. It is important that people have land use policies which should indicate where remaining forest should not be touched, where 'slash and burn' can still be practised, where permanent farms can be tapped for irrigated farming. In times of crisis, forest products can be used to a limited extent. In this way, local people could try to control and manage their direct surroundings for future generations.

6.4.6 Community Participation for Traditional Rain Water Harvesting

Ever since the beginning of civilization, human beings have adhered to some practices or the other to protect themselves against drought and floods. The traditional rain water harvesting techniques in different parts of the world bear testimony to sincere efforts towards community action and water preservation.

The success story of 'Sukhomajri' (India) is an indicator of the power of traditional wisdom, people's participation and community's deep sensitivity to the environment (Dhameja 2001). A crumbling hillock called Sukhomajri in Haryana state of India is now a farmer's paradise. The ash-ridden saline soil around the area is now yielding fruits, vegetables and even timber. It draws its sustenance from the *catch the rain formula*. The idea behind this is to dig a pit and let the rainwater accumulate. The water can be used to green adjacent tracts. The dried up tank can be used as silted bed for agriculture. Only an inch of deep water penetration is necessary per acre and then the soil can be enriched organically by rotating crops. Sukhomajri today has three earthern dams built across natural gullies, which store rainwater. The water is distributed equitably to each family in return for the commitment to protect the hills (Agarwal et al. 1999). Joint Forest Management, 'Van panchayats' and 'Pani panchayats' are some more examples of effective people's participation and their faith in traditional practices, which, if revived, could strike the right harmony between the human beings and the nature.

6.5
Disaster Risk Reduction Through Livelihood Concerns

Community awareness on disaster preparedness assumes predominance because disaster prevention, preparedness, mitigation and relief are largely dependent on the capability of the communities to withstand disasters. Disaster preparedness needs to be the way of life in such communities if they have to survive the aftermath of different catastrophes. Many studies on droughts, landslides, floods, cyclones, land erosion, etc. conducted in the developing countries found out that disaster-prone communities are living at virtually subsistence levels and very limited livelihood options and opportunities are available to the at-risk communities in these countries.

Most of the disaster-prone population still depends on agriculture as a major source of earning. The continuous onslaught of nature's fury has not only led to the loss of lives but has also led to economic losses. For example, the saltpan workers in Kandla (India) did not have any livelihood option left with them after the Gujarat cyclone. In Kot Murad, a flood prone village in Pakistan where farming is the main livelihood, 87 percent of the total households are landless. Livelihood support measures become more important especially in a disaster scenario. The findings from the case studies in Sri Lanka indicate that the main source of income for 72 percent of the population in Andarawewa and 56 percent of the population in Mahameddawa is from subsistence agriculture during normal years. Off farm income is the major source of income during periods of drought. During such periods people often have to migrate to other places in search of wage labour. Women suffer the most in such situations as they are unable to leave their families in search of employment. Hence, the total income earning opportunity for a family, as a whole is lower in the drought years compared to that of a normal year. Rainfed highland cultivation is the only income source for a majority of the families in villages under study (Bhatti 2003).

Yet, livelihood concerns are practically missing from the disaster policies and plans of many countries. The research argues that besides human lives, livelihood security is the primary concern that comes under severe threat in the case of natural or man-made disasters. This concern becomes graver in the case of communities of developing countries where economic opportunities are generally very few. The limited economic opportunities make disaster-prone communities more vulnerable and they find no way to exit from the burning hell of miseries.

Diversification of livelihood sources can mitigate the effect of disruption of the people's main livelihood. Some livelihoods are extremely vulnerable to particular disaster. To reduce people's vulnerability, support could be provided to these communities with alternative livelihoods that match the people's capacities and that are not sensitive to the existing disaster. This can help them earn an income during the time when their main source of production was down due to the occurrence of disaster (Murshed 2003). One should be conscious of gender roles and responsibilities when selecting an alternative livelihood. Whether the settlement was urban or rural also play an important role in availability and provision of alternative sources of livelihoods.

Some agriculture oriented measures for building more secure livelihoods after the cyclone are mentioned below (Sahni and Dhameja 2003).

6.5.1 Creation of Alternate Livelihood Options

- Measures to improve agricultural production
- More focus on animal husbandry
- Provision of adequate seeds and fertilizers
- Draught animals to be provided to farmers
- Arrangements to be made for providing tractors or power tillers on a hire basis
- Dairy cattle to be produced
- Arrangements for restoring insemination centers for local breeds of cattle have to be made
- Alternative cropping pattern in areas affected by salinity needs to be implemented
- Reclamation and treatment of soils
- Ecological balance needs to be maintained through large-scale plantation
- Wage employment under various Rural Development Schemes

The important sources of livelihood during rehabilitation identified by the community include:

- Supply of seeds
- Supply of fertilizers
- Horticulture plantation
- Livestock rearing
- Food for Work Programme
- Assistance for purchase of tools
- Assistance for repair or construction of work-sheds.

A *Livelihood* and *Employment Restoration Programme* launched by Oxfam in collaboration with the European Union aimed at:

- Restoring the traditional livelihoods of the affected populations through the provision of food/cash for work.
- Facilitating work for community-based rehabilitation and restoration activities, such as reclamation of agricultural land.
- Providing a model for Food-for-Work Programme that is capable of reaching the most vulnerable and marginalized so that other large-scale programmes can integrate vulnerability and equity perspectives.

The support provided by a number of NGOs working in Orissa state of India during rehabilitation and the support extended by the Government of Orissa state has led to the strengthening of the following livelihood options in two major sectors-the farm and non-farm sectors:

Activities in the farm sector:

- Cultivation of paddy, wheat, ragi and groundnut
- Growth of vegetables and potatoes
- Kitchen garden nurseries
- Plantation of mangoes, mangroves, and pipal.

Activities in the non-farm sector for engaging more people in the following occupations: (i) Fishing (ii) Fish drying (iii) Pig rearing (iv) Coir production (v) Rearing of cows, buffaloes, bulls (vi) Bamboo production (vii) Lime making (viii) Poultry (ix) Goat rearing (x) Boat building (xi) Making fishing nets (xii) Shrimp farming (xiii) Basket making (xiv) Mat weaving (xv) Broom making (xvi) Masonry (xvii) Carpentry (xviii) Plumbing (xix) Electrician work (xx) Blacksmith work (xxi) Toy making (xxii) Pottery (xxiii) Applique work (xxiv) Petty trading.

6.5.2
Livelihood Strategies in Disaster Risk Reduction – A Case Study in Bangladesh

Traditionally people have developed different kinds of coping strategies related to their livelihood. Of the indigenous responses to flooding in Bangladesh, a significant number relate to agriculture coping measures including selecting appropriate variety of rice and other crops-depending on the timing-and water level as well as type of soil. People also tend to reduce the magnitude of economic loss through crop loss from flood and erosion by cultivating low cost varieties. Housing techniques are also adapted according to the risks posed by floods and erosion. Houses are built on raised lands or earthen platforms so water cannot reach the plinth during normal floods. Poorer people use thatch, bamboo and corrugated iron sheets as housing material. Plantation of water friendly plats/trees like bamboo, banana, Hoga, Kolmi and others beside the homestead is very common to protect the house from erosion as well as for the use of these plants/trees during floods and after recession of the flood (Khatun 2003). During the dry season, the kitchen is made in the open courtyard, but during floods they make bamboo platforms that can be raised when the water level is increasing and use portable stoves for cooking. Food, household items and crops are stored on raised platforms. Selling animals, grains and other assets like jewelry, sale and lease of land, advance sale of labour and fishing are the common coping mechanism to survive during the crisis period.

6.6 Remote Sensing as a Tool for Disaster Risk Management

Although disasters may be natural phenomena, the damage caused by them is largely due to improper human activity and reckless land exploitation. For instance, the occurrences of floods and landslides can be substantially reduced by proper afforestation of the susceptible region. Thus, accurate mapping of land use and land cover patterns at regular intervals becomes a pre-requisite to effect preventive measure to avoid a disaster and to assess the damages after it has occurred. Remote sensing data at spatial resolutions ranging from 10 m to 100 m available at varied temporal resolutions have been successfully utilised to produce land use land cover maps at a desired accuracy of at least 85% (Arora 2003). Table 6.2 shows the applications of some current satellite sensors for disaster management. The remotely sensed derived land use

Table 6.2. Applications of some current satellite sensors for disaster management

Satellite	Sensor	Spatial resolution	Type of disaster
METEOSAT	VIS	2.5 km, day and night observations	Prediction/monitoring of cyclones, tornadoes and volcanic eruptions, floods, avalanches
NOAA	AVHRR	1.1 km, twice a day	Land cover, detection and monitoring of fires, drought, volcanic eruptions
LANDSAT	MSS TM ETM	30 and 80 m	Land use, flood extent, drought, landslides, fire
SPOT	PAN HRV	10 and 20 m	3-dimensional mapping, flood extent, damage assessment, crop identification, drought, landslide
IRS	PAN LISS WiFs	6, 23 and 188 m	3-dimensional mapping, flood damage assessment, drought, fire, landslide
ERS	SAR	All weather, 25–500 m	3-dimensional mapping, flood extent, damage assessment, night coverage, earthquake, fire, landslide
RADARSAT	SAR	All weather, 10–100 m	3-dimensioanl mapping, flood extent, damage assessment, night coverage, earthquake, fire, landslide
IKONOS	PAN MSS	1 and 4 m	High resolution mapping, infrastructure identification, terrain analysis, property damage assessment

land cover maps are frequently used as input, to a GIS for several disaster related studies, for example landslide hazard zonation and flood risk management.

Now, let's clarify the role of remote sensing and GIS in some commonly occurring hazards.

6.6.1 Cyclones and Tornadoes

The weather satellites (geo-stationary) such as INSAT and GOES provide almost continuous data on day-to-day basis for the prediction of weather and monitoring climate changes. This is beneficial for providing information for issuing early warning and specifying the geographical location of hazards such as severe thunderstorms and tornadoes, thereby assisting the emergency response teams for timely evacuation of the people in the hazard-prone areas.

In an other application, the visual interpretation of SPOT images before and after the cyclone in the Cook Islands sufficiently demonstrated the potential of the remote sensing data sets to identify the large scale changes in coastal and shallow marine areas produced by the cyclones (Loubersac et al. 1991). The large-scale damage due to cyclone visible in SPOT images was helpful in planning emergency aid and reconstruction.

6.6.2 Drought

During drought, physiognomic changes of vegetation may become apparent. Satellite sensors are capable of discerning many such changes through spectral radiance measures and manipulation of such measures into vegetation indices that are sensitive to the rate of plant growth as well as to the amount of growth (Curran 1990). Such indices are also sensitive to the changes in vegetation affected by moisture stress. The visible and near infrared bands on the satellite multi-spectral sensors allow monitoring of the greenness of vegetation. This property is used in the case of monitoring drought, as the stressed vegetation and other bare ground, water, etc. reflect differently.

Reliable drought interpretation requires a geographical information system (GIS) approach, since the topography, soil type, spatial rainfall variability, crop type and variety, irrigation support and management practices are all relevant parameters.

6.6.3 Flood

Remote sensing and GIS tools can be used in flood analysis to determine and delineate the floodplain. Further, these may also assist in mapping and monitoring flood inundated areas, assessing damages due to floods and in flood hazard zoning. The flood plain management and zonation would make for alerting the risk-prone residents and commercial establishments in advance about the areas that are threatened by the floods.

AVHHR images obtained before and after the flood can be classified to generate the flood maps of the region. These maps can be compared to assess the damage due to floods. The data from these maps along with those from other maps (namely soil, geology, land use and contour) can be analysed in GIS to prepare the flood risk map indicating the zones of high to low flood risk (Rahman 1991).

6.6.4 Forest Fires

Forest fires are another natural disaster where remote sensing and GIS can be employed successfully. The detection and monitoring of fires in the quickest possible time helps the emergency management agencies to prevent large-scale damage to life and property. Also, the residents in an area can be notified in advance so that they may have sufficient time to vacate the places.

6.7 Crop Insurance

Insurance is a mechanism for spreading the cost of losses both over time and over a relatively large number of similarly exposed risks. The introduction of disaster linked insurance should be actively pursued and insurance cover should be available not just for life but also for household goods, cattle, structures and crops.

Since insurance premiums are based on the location of a structure within the disaster-prone areas, and are determined primarily by the extent of risk, higher rates may be applied to structures subject to high risks.

In keeping with the impact of natural disasters, disaster insurance could be a critical instrument of development in the field of crop production, providing financial support to the farmers in the event of crop failure. It can encourage farmers to adopt progressive farming practices, better technology in agriculture, besides providing significant benefits not merely to the insured farmers, but to the entire community directly and indirectly through spill over the multiplier effects in terms of maintaining production and employment generation of market fees, taxes etc. and net assertion of economic growth. Crop insurance could also streamline loss assessment procedures and help in building up huge and accurate statistical base for crop production.

One of the difficulties in promoting disaster insurance is that those who are at highest risk have the least capacity to pay the premium. Possibilities of group/community insurance should also be available, particularly for the marginalised communities. The insurance agency may promote a Community Rating System to encourage communities to go beyond the require standards of minimum safety. The incentive can be a reduction in insurance premium for policyholders within communities that take appropriate actions to reduce disaster losses.

6.8
Conclusion

Damage caused by extreme agrometeorological events to the agriculture sector may be significant, sometimes of the order of magnitude of the GNP growth. For many disaster-prone countries, agricultural losses due to exceptional weather events are a real constraint on their global economy. Indirect effects may continue to affect agriculture negatively long after the extreme event took place. The time needed to recover from some extreme agrometeorological events ranges from months to decades.

Environmental planning would be necessary to avoid or mitigate losses from disasters, by using such instruments as land-use planning and disaster management. Natural disaster reduction measures are in place in a significant number of the nations surveyed and ongoing research and development to improve and expand these measures are also a feature of many national strategies to minimize adverse effects of extreme events on agriculture. Steps are being taken to significantly reduce the vulnerability of people and their communities to natural disaster; this can only be done through mitigation.

Acknowledgements

The author expresses his gratefulness to Dr. S.K. Srivastav, Director General of Meteorology, New Delhi for his nomination and participation at this expert meeting.

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CHAPTER 7

Damage Assessment of Agrometeorological Relevance from Natural Disasters: Economic and Social Consequences

Allen R. Riebau, Douglas G. Fox

Abstract Damage from catastrophic events is both social and economic. Perhaps one of the most challenging aspects of modern life is our increasing ability to communicate, especially in the developed countries. This communication has brought an increased sense of connectedness but also made people more aware of the occurrence and consequences of natural disasters. In this paper we explore the potential for changes in frequency and magnitude of weather-related natural disasters and some of their connections to climate change and variability. Although changes in climate may have great consequence, increasing climate variability may become the most immediate challenge for world society. Both observations and simulation models show that as the potential for climate variability increases, natural disasters have become more frequent and of deeper economic impact. In areas of the world where these devastating events appear to occur and then quickly reoccur in a different guise, the sharing of information and resources becomes a pivotal issue for collective security. New technologies can help us understand these events and prepare for them. New social institutions may also be needed to cope with these issues on a global scale.

7.1 Introduction

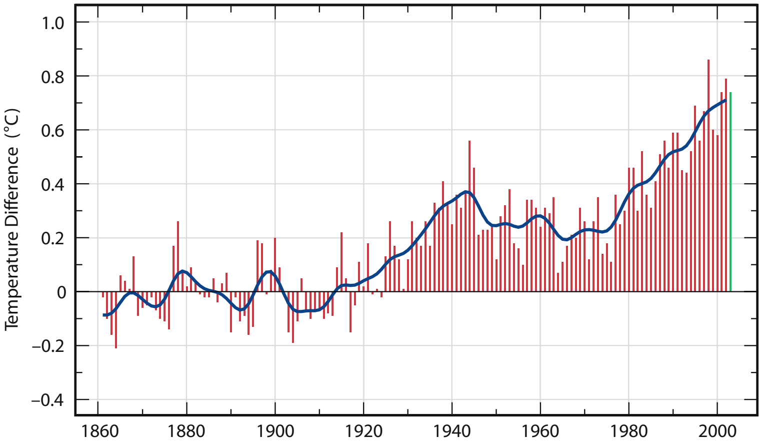
Natural disasters can be classified into those with a climatic component and those without one. But of course, agrometeorologists or climatologists understand that even if a disaster, such as an erupting volcano, has no climatic instigator, weather and climate often influence the magnitude of consequences of the disaster (Jones, 1999). Many have come to believe that climate change is the underpinning of natural disasters that are the result of severe weather or climate variability. In the 21st century, societies must be vigilant about climate change since it is emerging as a reality to be dealt with. A growing sense that the issue is immediate exists within the natural resources management community, but management responses often are bereft of inclusion of climate variability as a factor, with examples in the USA including rangeland management (Fig. 7.1) and forestry.

During the past fifty years data shows an ever-increasing trend towards higher global surface temperatures (Fig. 7.2). These data in records that range

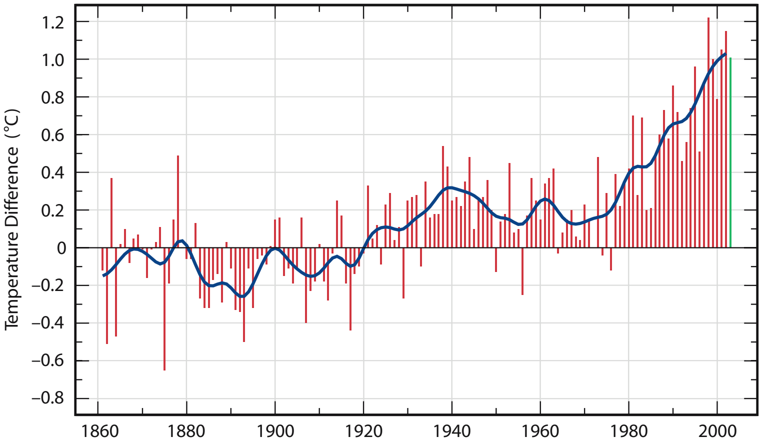
Fig. 7.1. Green Mountain, Common Allotment (Wyoming, USA) showing 2001 forage conditions. Some sources believe rangelands in the USA have reached a disastrously degraded state (Source: rangenet.org)

well beyond the historic direct measurement time scale show a high correlation with increasing concentrations of lower-atmospheric radiatively active trapping gases, especially carbon dioxide, nitrous oxide and methane. The data are not very controversial. There are however many viewpoints on the consequences of these increases, issues such as to how much the earth may warm, what regional differences are likely, how will precipitation dynamics be affected, and how fast it all might occur. An important point of consideration in climate change, in addition to changes in mean or average conditions, is climate variability and the frequency and magnitude of extremes.

The first aspect that can be explored is economic. Although a warmer more carbon-dioxide rich earth could have beneficial aspects for some areas, increases in variability are likely to cause economic stress world-wide. A simple trend in temperatures might be slowly adjusted to by changing agricultural practices. Forestry and grazing land management practices might also be slowly adjusted, even though the adjustments might mean changes in forest structure or grazing carrying capacity. Climate variability has already shown itself to major economic disruptor in developed areas of the world including the eastern United States, Europe's Elbe basin (Fig. 7.3), and central Russia. Although not often stated in the popular press, extreme variation will ultimately be more economically disruptive than a simple warming or precipitation reduction trend. The results of such variations from normal conditions are so



Global near-surface temperatures averaged over the land and ocean. Differences are expressed relative to the end of the 19th century.



Global near-surface temperatures averaged over the land only. Differences are expressed relative to the end of the 19th century.

Fig. 7.2. Global surface temperatures are rising (Source: Hadley Climate Center, UK)

large scale that they can viewed from space and new remote sensing tools are clearing showing the magnitude of these impacts express in vegetative cover (Fig. 7.4).

The second aspect that can be explored is social. Although in the strictest sense economic impacts are social impacts, climate variability and natural disasters have social impacts that are beyond economic. In extreme natural disasters human life is often lost. At a lesser extreme, issues such as health,

Fig. 7.3. One hundred year flood of the Elbe in 2002 inundates the countryside and small villages near Prague (Source: Mlada fronta dnes (MFD)

longevity, sense of wellbeing, family stability, and quality of life are all factors that are influenced by weather extremes. Ultimately, climate variability may influence the stability of political systems through disruptions in energy supply, fresh water, food, and transport of materials. Societies whose foundations rest on their direct use of natural resources, such as some developing nations on the African continent and their endemic ethnic groups, will find climate variability as the major agent of social change. In fact, variability may reshape the agro-ecological setting of entire continents and thus redraw social relationships world-wide. An example of social disruption from climate variability is a response to the year 2000 drought conditions in the United States. Forests, rangelands, and agricultural lands were greatly impacted by the extent of this situation, which was precipitated by ENSO events as a driving factor in climate variability. Wildfire occurrence in the USA is an example of these

Fig. 7.4. This image derived from ASTER data shows the difference between the amount of vegetation in July 2000 and the average July vegetation for North America. Of particular interest are the dry conditions in the western United States, which resulted in one of worst fire seasons in US history (Source: NASA)

social and economic consequences. In that year 8,422,237 acres were burned in wildfires (about twice the yearly average for the last decade). Fire suppression costs reached almost $1.6 billion dollars. As a result the country has been engaged in deep political debate about the future of forests and their management, which has resulted in the passage of the Healthy Forests Act (Public Law No: 108-148). This law proposes to revolutionize the manner in which publicly owned forests are managed and will have wide reaching social implications, even to such activities as energy generation, tourism and recreation, and wildlife management. Other areas have suffered similar fire situations and are considering new laws or policies to avoid the situations repeating, with the fires of Central Russia in 2002 causing the potential for new zoning regulations a prime example (Fig. 7.5).

Fig. 7.5. Drought and elevated air temperature resulted in massive fire smoke events in Moscow, Russian. The smoke caused as yet uncalculated public health impacts, exposing perhaps 20,000,000 people to high concentrations of particulate matter, and resulted in visibility in the city reduced to 300 meters and below. Although smoke or air quality episodes are not often considered natural disaters, the problem is growing and has tremendous economic implecations (Source: N. Chubarova, Moscow State University)

7.2 Climate Change and Climate Variability

The climate change research community has identified sensitivity, adaptability and vulnerability as dimensions for consideration of climate change impacts, including changes in variability and extremes. Sensitivity means the degree to which a system is affected, either negatively or positively by climate related stimuli. Adaptability identifies the capacity of a system to adjust to a changing climate to moderate damage, take advantage of opportunities or otherwise cope with the consequences. Vulnerability identifies the degree to which a system is susceptible or unable to cope with adverse effects of climate. For the purposes of this paper we define a difference between climate change, which is a long term change to a different climate regime through the accretion of small changes of trend and climate variability, which is the swing from one extreme to another along the progression of weather to a new stable set of climate conditions. This type of variability has always been part of the climate record, but during the past several decades it has increased with great social economic consequence (Aber et al., 2001). Climate variability is perhaps the main factor in adaptability and vulnerability of both human and ecological systems under climate change.

The earth system represents a complex set of interacting feedbacks that we are only beginning to understand. Fig. 7.6, originally developed by Dr. Robert Watson, Chief Scientist of the World Bank, illustrates some of the linkages associated with climate change, agriculture, forestry and other renewable natural resource issues. Although this illustrates feedbacks and linkages, it does not address impacts simply resulting from variability and extremes, especially from variability that is beyond the variability we have come to understand is the norm. That there is this omission is not indicative of any deficiencies in the Dr. Watson's reasoning, but it does illustrate that variability is perhaps difficult to portray succulently within the context of climate change.

We have seen increases in variability result in weather changes that range from local to continental scales. The increase in variability has expressed itself in seasons of drought, in severe flooding, in highly energetic tropical storm systems, and even in changes in the balance of solar radiation reaching the earth (Chubarova et. al., 2003). If this sort of variability continues to escalate, its economic consequences will overshadow any that that might occur from

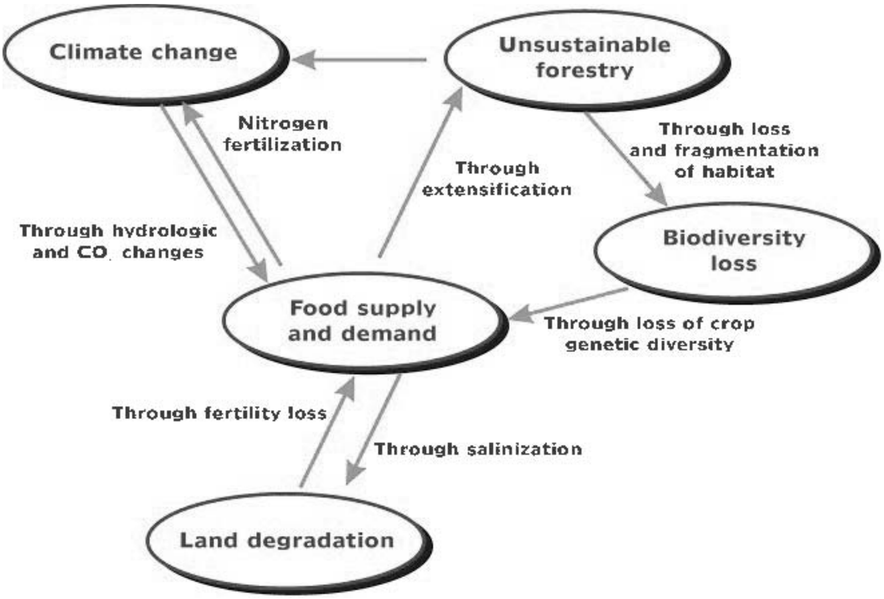


Fig. 7.6. Linkages among food production and environmental issues and climate change (Source: World Bank)

a simple global warming trend (Fig. 7.7). Since nonlinearities of the linked earth system are largely unpredictable, such consequences may be expressed in unanticipated ways.

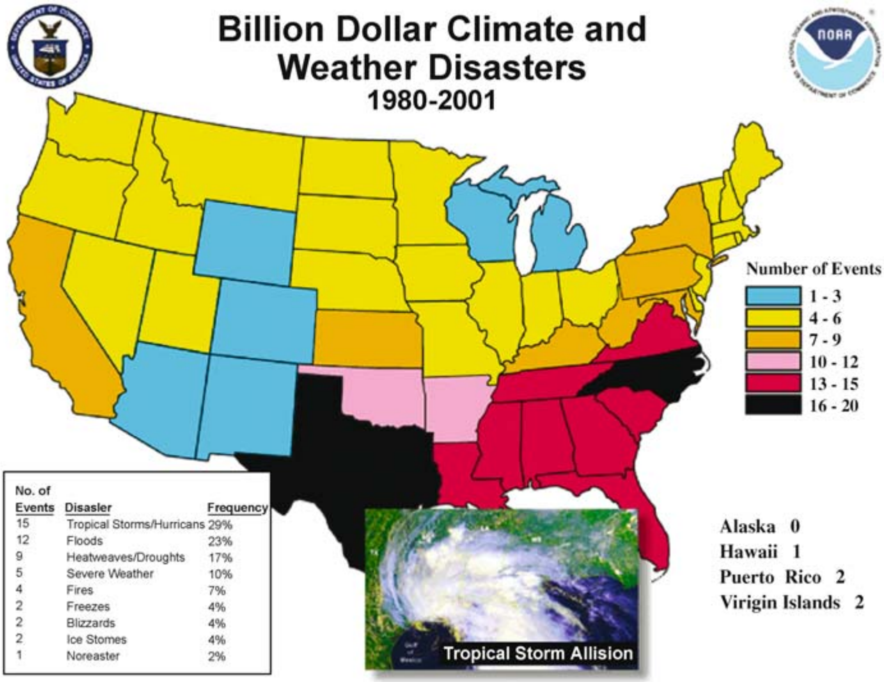
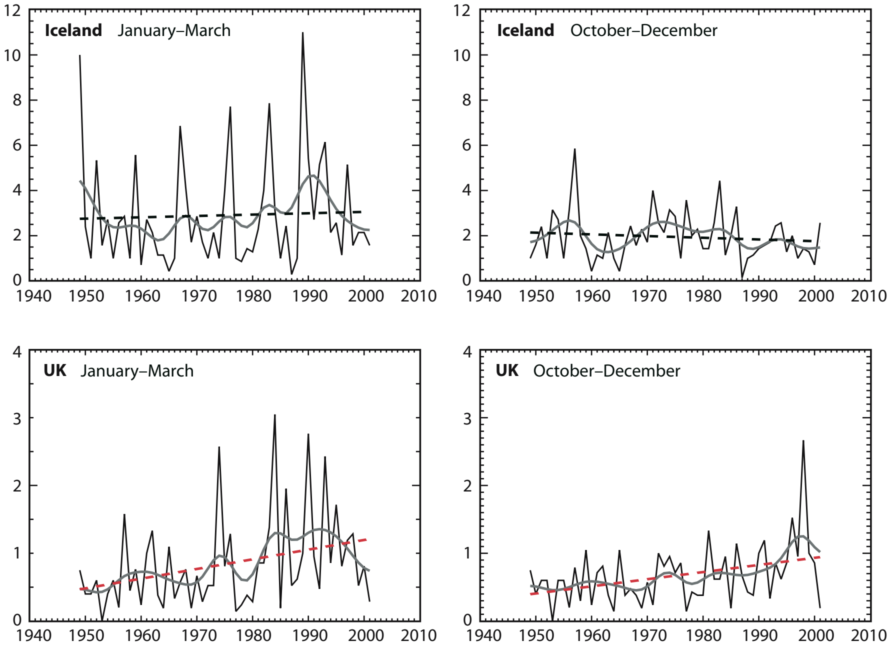


Fig. 7.7. Climate variability resultant weather has caused many natural disaster events in the United States that have resulted in $ 1 billion or more losses per event (Source: NOAA NCDC)

7.3 Variability Shifting Continental Ecosystems

The most severe mid-latitude cyclonic storms have serious impacts on people and property. However, these are fairly rare and small-scale weather events are difficult to detect in historical observations, especially with daily observations that can miss the fastest moving severe storms. In the United Kingdom Hadley Climate Centre scientists have recently studied changes in storm characteristics over the past 50 years or so using three-hourly measurements of surface pressure from the United Kingdom and Iceland. Pressure changes were used instead of winds because the results are less sensitive to observation site moves and instrumentation changes. Observations were available from twenty-one observation sites in the UK and seven in Iceland (Fig. 7.8). The average number of storms (per station) shows a significant increase in the United Kingdom



The number of storms per observation station over Iceland and the United Kingdom during (a) January to March and (b) October to December. A red trend line indicates that the trend cannot be explained by natural variability (as estimated from these records) alone.

Fig. 7.8. Storm frequency has been observed to be increasing along with intensity in many regions, with clear evidence seen from data collected in the United Kingdom (Source: Hadley Climate Center)

winter period (October to March). Regional analysis shows that the largest increases occur over the southern UK. Iceland has experienced a slight reduction in the number of storms (between October and November), although this reduction cannot be separated from natural variability with any degree of certainty. A reduction in storm frequency in the north and an increase in the south is consistent with a southerly movement of the North Atlantic storm track.

A more widely used measure of the storm frequency affecting Western Europe is the North Atlantic Oscillation (NAO) index, which we have compared with the new storm rate analysis. Changes in the NAO index correspond to large-scale changes in the north-south pressure difference across the northeastern Atlantic. Although there is a similar upward trend in the NAO, there is quite a poor correlation between this figure and the storm rate calculated from the 28 pressure measurement sites. This implies that the severe storms over the UK are more related to strong local gradients of pressure than to the large-scale pressure differences over the Atlantic. However, it is likely that the local severe storms are modified by the long-term changes on the large-scale, which are seen in the NAO index. It is also important to place these new results in context. Evidence of storm frequency from daily indices and measurements of wave heights suggest that although it has increased in recent times, the magnitude of storminess at the end of the 20th century was similar to that at the start. This could mean that natural variations in the magnitude of storminess on timescales of several decades or more are responsible for all or part of the trends seen in these new results and that data covering a longer period is needed in order to distinguish a climate change trend from the natural variability. Some of the issues to be considered are:

- It is very likely that precipitation has increased by 0.5 to 1% per decade in the 20th century over most mid- and high latitudes of the Northern Hemisphere continents, and it is likely that rainfall has increased by 0.2 to 0.3% per decade over the tropical (10°N to 10°S) land areas. Increases in the tropics are not evident over the past few decades. It is also likely that rainfall has decreased over much of the Northern Hemisphere sub-tropical (10°N to 30°N) land areas during the 20th century by about 0.3% per decade. In contrast to the Northern Hemisphere, no comparable systematic changes have been detected in broad latitudinal averages over the Southern

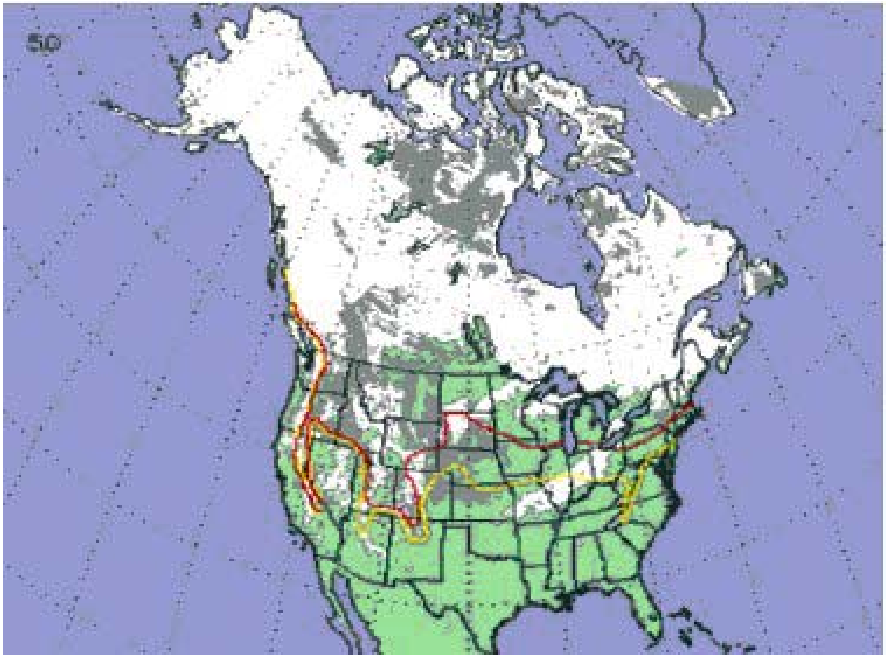


Fig. 7.9. The March 2000 snowline was much farther north than the average March snowline (*red line*) as depicted by the NASA MODIS instrument in a eight day composite image (Source: NASA)

Hemisphere (Holland, 1997). There are insufficient data to establish trends in precipitation over the oceans.

- In the mid- and high latitudes of the Northern Hemisphere over the latter half of the 20th century, it is likely that there has been a 2 to 4% increase in the frequency of heavy precipitation events. This may also be reflected in snowfall and accumulation (Fig. 7.9). Increases in heavy precipitation events can arise from a number of causes, e.g., changes in atmospheric moisture, thunderstorm activity and large-scale storm activity.
- It is likely that there has been a 2% increase in cloud cover over mid- to high latitude land areas during the 20th century. In most areas the trends relate well to the observed decrease in daily temperature range.

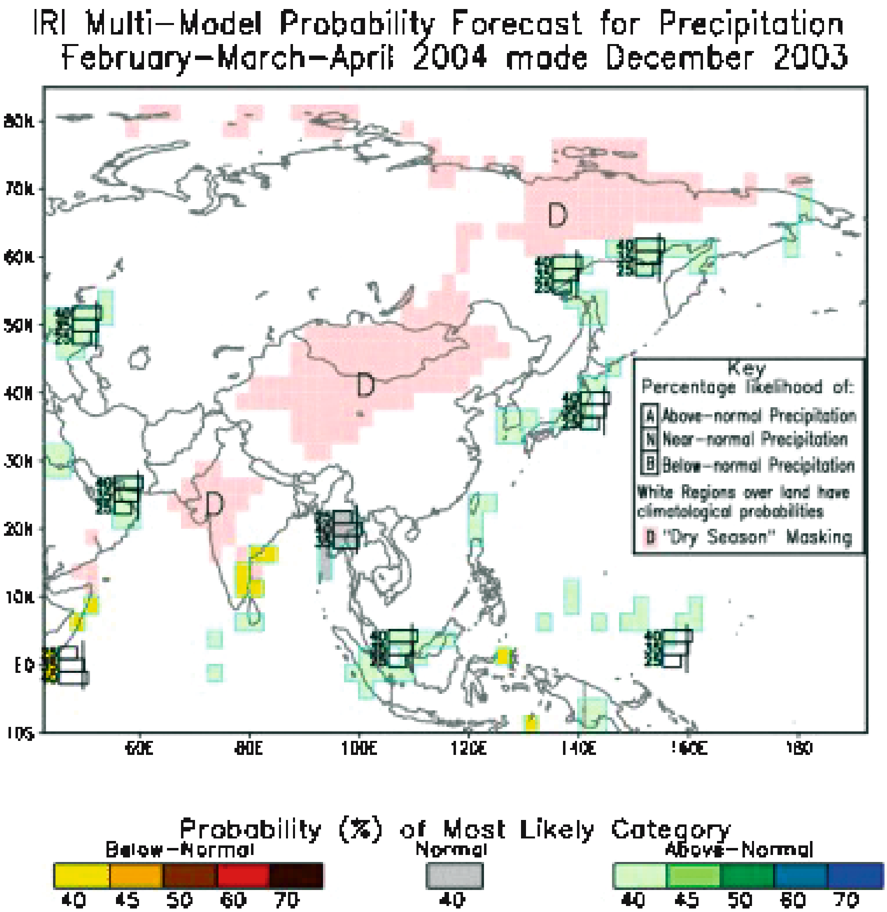


Fig. 7.10. Skill at predictions of seasonal weather has increased, especially utilizing ensemble modeling approaches and incorporating ocean data, as this prediction from Columbia University exemplifies (Source: International Research Institute – IRI)

- Since 1950 it is very likely that there has been a reduction in the frequency of extreme low temperatures, with a smaller increase in the frequency of extreme high temperatures.
- Warm episodes of the El Niño-Southern Oscillation (ENSO) phenomenon (which consistently affects regional variations of precipitation and temperature over much of the tropics, sub-tropics and some mid-latitude areas) have been more frequent, persistent and intense since the mid-1970s, compared with the previous 100 years and skill is increasing in longer-term predictions in many areas (Fig. 7.10).
- Over the 20th century (1900 to 1995), there were relatively small increases in global land areas experiencing severe drought or severe wetness. In many regions, these changes are dominated by inter-decadal and multi-decadal climate variability, such as the shift in ENSO towards more warm events.
- In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts have been observed to increase in recent decades.

7.4 Interdecadal Climate Variability

Changes in climate occur as a result of both internal variability within the climate system and external factors (both natural and anthropogenic). The influence of external factors on climate can be broadly compared using the concept of radiative forcing. A positive radiative forcing, such as that produced by increasing concentrations of greenhouse gases, tends to warm the surface. A negative radiative forcing, which can arise from an increase in some types of aerosols (microscopic airborne particles) tends to cool the surface. Natural factors, such as changes in solar output or explosive volcanic activity, can also cause radiative forcing. Concentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities. This forcing on the larger scale may result in shifts in ocean temperature regimes, which then may be expressed at climate variability episodes.

Figure 7.11 demonstrates the ability of contemporary climate models to simulate the variability of major patterns such as the El Nino Southern Oscillation (ENSO, amplitude and frequency of temperature swings in the equatorial Pacific.) Climate models show conflicting results, varying from a slight decrease (Tett 1995; Knutson et al., 1997; Noda et al., 1999; Collins, 2000b; Washington et al., 2000; Fig. 7.11b) to a small increase in amplitude (Timmermann et al., 1999; Collins, 2000a; Fig. 7.11a). Kitzberger et. al. 2001 have shown that years characterized by widespread fires in the south-western United States (14 events between 1914–1987) and in northern Patagonia (9 events between 1938–1996) are similarly related to ENSO variation indicators. Fire event years are preceded by approximately 1–2 years of El Niño conditions leading to 1 year of La Niña conditions suggesting that major fire years follow a complete El Niño/La Niña cycle in both regions. Simulations of future wildfire areas in the US, eliminating management considerations, suggest that increasing ENSO variability may result in increasing the potential to change vegetation distribution and carbon budgets (Bachelet et. al., 2001).

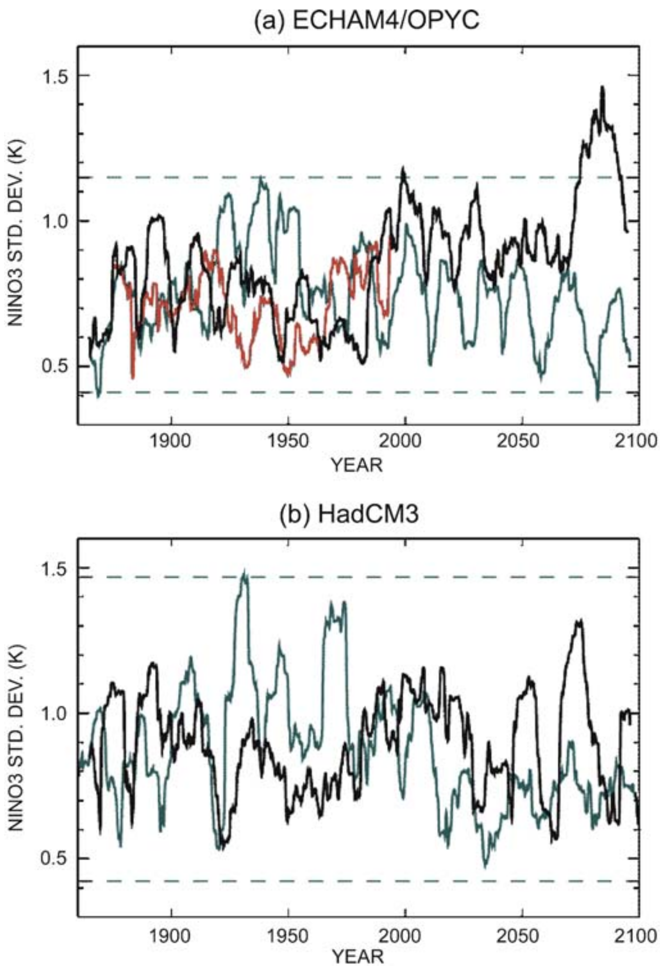


Fig. 7.11. Standard deviations of Niño-3 SST anomalies (Unit: °C) as a function of time during transient greenhouse warming simulations (*black line*) from 1860 to 2100 and for the same period of the control run (*green line*). Minimum and maximum standard deviations derived from the control run are denoted by the *dashed green lines*. A low-pass filter in the form of a sliding window of 10 years width was used to compute the standard deviations. (**a**) ECHAM4/OPYC model. Also shown is the time evolution of the standard deviation of the observed from 1860 to 1990 (*red line*). Both the simulated and observed SST anomalies exhibit trends towards stronger interannual variability, with pronounced inter-decadal variability superimposed, (reproduced from Timmermann et al., 1999), (**b**) HadCM3 (Collins, 2000b). (From IPCC 2001: Figure 9.26)

7.5 Economic and Social Consequences

The costs of extreme weather events have exhibited a rapid upward trend in recent decades. Yearly global economic losses from large events increased from US$ 3.9 billion year in the 1950s to US$ 40 billion year in the 1990s (all 1999 US$, uncorrected for purchasing power parity). Approximately one-quarter of the losses occurred in developing countries. The insured portion of these losses rose from a negligible level to US$ 9.2 billion annually during the same period. Including events of all sizes doubles these loss totals (Fig. 7.12). The costs of weather events have risen rapidly, despite significant and increasing efforts at fortifying infrastructure and enhancing disaster preparedness. These efforts dampen to an unknown degree the observed rise in loss costs, although the literature attempting to separate natural from human driving forces has not quantified this effect. As a measure of increasing insurance industry vulnerability, the ratio of global property/casualty insurance premiums to weather-related losses – an important indicator of adaptive capacity – fell by a factor of three between 1985 and 1999. Part of the observed upward trend in historical disaster losses is linked to socioeconomic factors – such as population growth, increased wealth, and urbanization in vulnerable areas – and part is linked to climatic factors such as observed changes in precipitation, flooding, and drought events. Precise attribution is complex, and there are differences in the balance of these two causes by region and by type of event. Notably, the growth rate in human-induced and non-weather-related losses has been far lower than that of weather-related events.

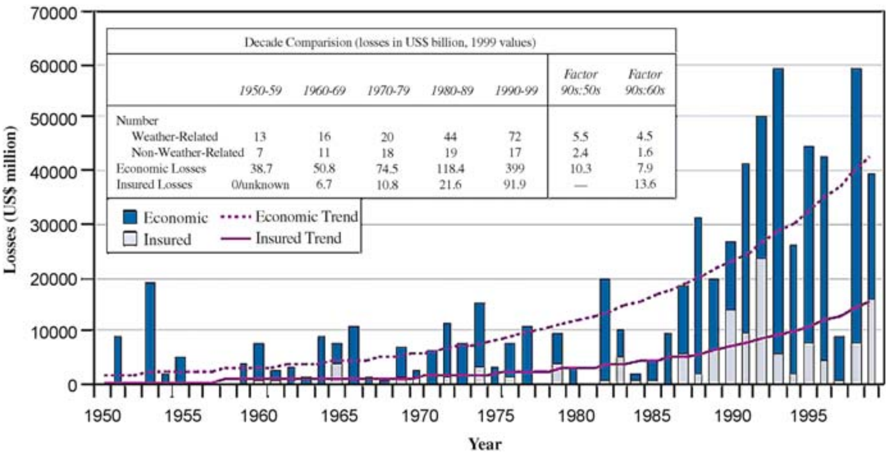


Fig. 7.12. Increases costs of natural disasters are another indication of the complex relationships between climate variability and world society (Source: IPCC)

By 2100 the concentration of carbon dioxide in the atmosphere could be between 90% and 250% higher than in 1750. Increases in temperature over this century without precedent in the last 10,000 years, with the earth's temperature expected to be up to 6 degrees above 1990 levels by 2100. By 2025 up to two thirds of the world's population may experience some form of water stress and also mean ever more extreme rainfall and flooding, and increasingly severe tropical storms.

By 2025 the number of people affected by desertification is expected to double to 1.8 billion, and many will be in Africa. Large parts of Africa and South America could lose their tropical rain forest by 2080. There is likely to be increased flooding, soil erosion, decreased crop yields, increased risk of epidemics. Deserts will grow. Disease will spread. Many species of plant and wildlife are expected to become extinct. Coastal settlements like Senegal, Egypt and Bangladesh are likely to face inundation; in other countries, like Tanzania, rivers will start to run dry. The cost of adapting to these changes is likely to put back development still further.

7.6 Conclusions

When the WWII generation was growing up the world's population was under 3 billion. During the next 60 to 100 years, it is likely to exceed 9 billion. The six warmest years of the twentieth century occurred in the last decade and 25% of the world's land area is affected by soil erosion or other land degradation. Snow and ice cover is estimated to have decreased by 10% since the 1960s according to satellite photography. Since 1980 10% of the forests in the developing world have been lost. 27% of the world's coral reefs have already been lost. This process is accelerating. For some parts of the world, particularly the poorer parts, the effects will be catastrophic. Climate variability, brought on by decal shifts in ocean temperature regimes, often drives the occurrence of weather related natural disasters. As populations increase and agricultural systems are placed under more pressure, events which in stable social systems were historically an annoyance will become increasingly dire.

New techniques, such as remote sensing and sophisticated computer models may give warning of when and where such events are most likely to occur. Information of this sort will not be of greatest value until societies work together on a planet-wide basis to share resources and response to disasters. This will necessitate not only organizations such as the United Nations taking a more active role, but also developed nations viewing world economic stability (with an alleviation of poverty in underdeveloped nations) as the cornerstone of peace and collective security. Although questions remain about climate change and climate variability in the role in the increasing frequency of natural disasters, no question can be allowed to remain as to the every human being's right to clean water, clean air, proper diet, and a sense that world leadership is collectively concerned with the long-term amelioration of the adverse impacts of weather related natural disasters.

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CHAPTER 8

Impacts of Tropical Cyclones on Chinese Lowland Agriculture and Coastal Fisheries

Ming Xu, Qiuzhen Yang, Ming Ying

Abstract Tropical cyclones are perhaps the most devastating of all natural disasters and the vulnerability to tropical cyclones is becoming more pronounced because of high population growth rates in the tropical and subtropical coastal regions. Tropical cyclones cause a range of destruction in the coastal areas. Various features of tropical cyclones affecting China and their impacts on lowland agriculture and coastal fisheries were described.

8.1 Introduction

The natural disaster is a crucial issue in human society nowadays, and tropical cyclones are perhaps the most devastating of natural disasters both because of the loss of human life they cause and the large economic losses they induce. On an average, 80–100 tropical cyclones happen over the world and they cause 20,000 deaths and the economic losses worth 7 billion dollars per year. In November 1970, a tropical cyclone hit Bangladesh and more than 300 thousand people died and made 10 million people homeless. Vulnerability to tropical cyclones is becoming more pronounced because of the fastest population growth in tropical and subtropical coastal regions.

A tropical cyclone is the generic term for a non-frontal synoptic-scale low pressure system originating over tropical or subtropical waters with organized convection and definite cyclonic surface wind circulation. Tropical cyclones with maximum sustained surface winds of less than 17 m/s are generally called "tropical depressions." Once a tropical cyclone achieves surface wind strengths of at least 17 m/s, it is typically called a "tropical storm" or "tropical cyclone" and assigned a name. If the surface winds reach 33 m/s, the storm is called a "typhoon" (the northwest Pacific Ocean), a "hurricane" (the North Atlantic Ocean and the northeast Pacific Ocean), or a "severe tropical cyclone" (the southwest Pacific Ocean and southeast Indian Ocean). Tropical cyclones derive energy primarily from evaporation from the ocean and the associated condensation in convective clouds concentrated near their center, as compared to mid-latitude storms that primarily obtain energy from horizontal temperature gradients in the atmosphere. Additionally, tropical cyclones are characterized by a "warm core” (relatively warmer than the environment at the same pressure level) in the troposphere. It is this unique warm-core structure within a tropical cyclone that produces very strong winds near the surface and causes damage to coastal regions and islands through extreme wind, storm surge, and wave action.

As each attack of tropical cyclone causes huge damages, it is therefore of great significance to study the forecasting and mitigation of tropical cyclone disasters. In this paper, we use the information we have collected to analyze the feature of impacts of tropical cyclones on Chinese lowland agriculture and coastal fisheries.

8.2 Destruction Caused by Tropical Storms in Coastal Areas

The tropical cyclone causes irreparable damage to the agriculture ranches and forests on coastal areas. The loss to an agriculture system can be categorised (Das 2003) as follows:

- Destruction of vegetation, crops, orchards and livestock in coastal areas;
- Damage to irrigation facilities such as canals, wells and tanks; and
- Long-term loss of soil fertility from saline deposits over land flooded by sea water.

The loss caused by a single storm may run into millions of dollars (Holland and Elsberry 1993). This is particularly so in the case of developing countries. Coastal areas in developing countries suffer great loss of life. These areas are also densely populated and are centres of brisk marine activity. Most of the population dwell in temporary thatched houses and the farmers have small land holdings. The lack of cyclone shelters and proper escape routes, the slow mode of transportation and the low elevation of the estuarine area all contribute to the regular catastrophes which occur here.

8.3 Features of TCs Affecting China and TC Disasters

Preferred regions of tropical cyclone formation include the western Atlantic, eastern Pacific, western North Pacific, north Indian Ocean, south Indian Ocean, and Australian–southwest Pacific. Almost 1/3 of all the tropical cyclones around the world are formed in western North Pacific, so this area is visited by tropical cyclones most frequently.

Located on the west coast of western North Pacific Ocean with a 18,000 km coast line, China is greatly affected by tropical cyclones. There are two types of tropical cyclones affecting China, one coming from the western North Pacific ocean and the other forming in the South China Sea region.

Tropical cyclones landing in China always carry grave consequences to the country. From 1949 to 2000, there were altogether 478 tropical cyclones attacking China, with south China and east China being most fragile to tropical cyclones' attacks. Figures 8.1 and 8.2 show the monthly distribution and yearly variation of number of tropical cyclones landing in China. A single peak in August is shown in Fig. 8.1, which means China is easily attacked by tropical cyclones in August. In Fig. 8.2, interannual variation of number of tropical cyclones landing in China is obvious, and a slightly decreasing trend and inter-decadal variation can also be detected. Further analysis shows that, China met less tropical cyclones than normal in the year of El-Niño, while it met more tropical cyclones in the year of La-Niña. So the number of tropical cyclones landing in China varies with the atmospheric circulation and sea condition, which means prediction of number of landing tropical cyclones perhaps can be partly made by analyzing atmosphere and sea condition (Henderson-Sellers et al. 1998).

Tropical cyclone disasters result mainly from huge gales, rainstorms and storm-surges caused by tropical cyclones. Grave disasters are mainly caused

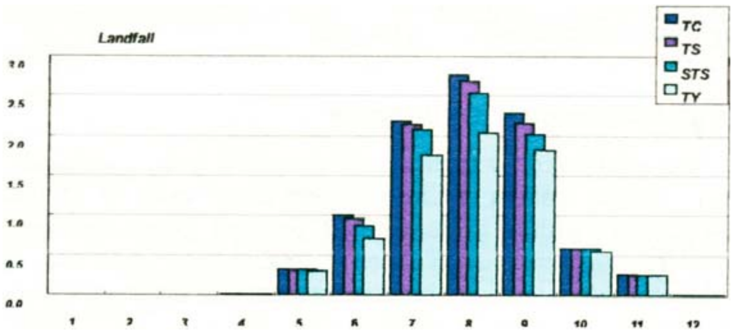

Fig. 8.1. Monthly distribution of number of TCs landing in China

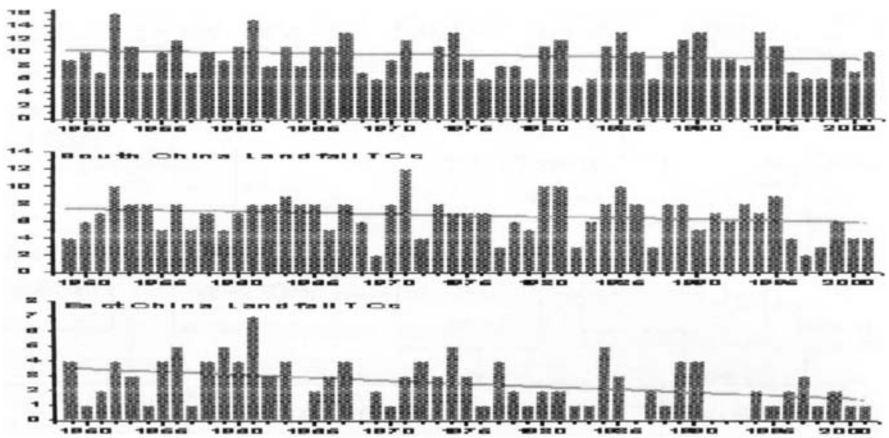

Fig. 8.2. Interannual variation of number of TCs landing in China

by landing tropical cyclones. Tropical cyclone disasters affecting China have the following features:

8.3.1 High Frequency in Occurrence

China is affected by typhoons throughout the whole year. The number of the tropical cyclones landing in China reaches a maximum of 15 and a minimum 4 per year, with an average of 9.2 per year. Grave typhoon disasters occur every year while ordinary typhoon disasters occur with an average of more than 9 times a year. The highest frequency of occurrence is from July to August.

8.3.2 Wide Range of Affecting Areas

From Liaoning province in Northeast China to Hainan province in South China, all the coastal provinces have been affected by tropical cyclones. Moreover, tropical cyclones could invade inland provinces occasionally. Except for six provinces and autonomous municipalities in west China, all the provinces in China have the records of being affected by tropical cyclones (Liang biqi et al. 1994). A tropical cyclone entering inland could bring grave disaster. For instance, No. 7,503 typhoon affected 8 provinces in the country and caused damages to more than 14,933,000 hectares farmland and direct economic losses more than 10 billion RMB *yuan*.

8.3.3 Violent in Sudden Occurence

Typhoon disasters are all caused by the sudden occurrence of typhoons. The disastrous weather, and storm surge brought by typhoons in particular, could often cause severe disasters in several hours. The severe typhoon disasters along the coast are all caused in one or two days, even in several hours. For instance, No. 8,309 typhoon caused disasters on about 134,000 hectares of farmland and turned many villages and towns into a vast expanse of water in only one or two hours after landing in the Pearl River.

8.3.4 Remarkable in Their Chain Effects

Typhoons affecting China not only cause disasters through huge gales, rainstorms, storm-surge and rough sea tides brought by them, but also result in a group of disasters from their chain effects. For example, the typhoon rainstorms can create flood, water-logging as well as mud-rock flow, avalanche and landslides and soil erosion. Moreover, the reverse irrigation of sea water caused by storm surges can form inner water-logging and cause land to be

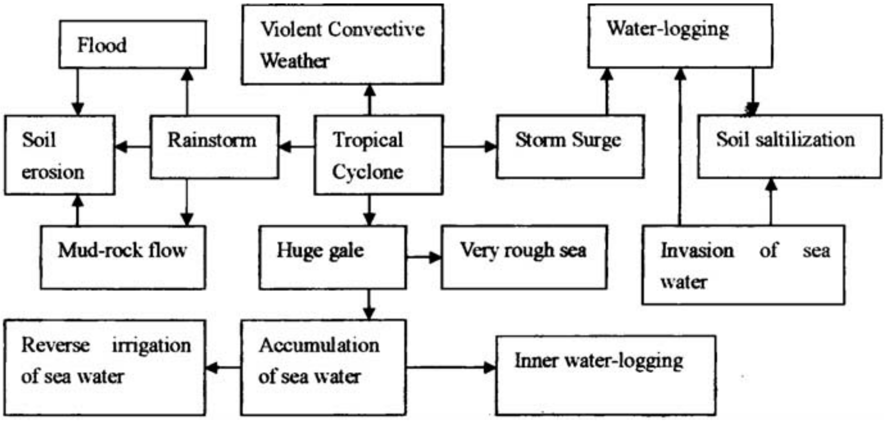

Fig. 8.3. Flow chart showing the chain effects of typhoon disasters

salted. The system of a group of disasters consisting of the chain effects of typhoon disasters can be seen in the flow chart (Fig. 8.3).

Typhoons and their related disasters often cause huge disasters and bring about grave losses in some areas. For instance, No. 8,607 and No. 9,107 typhoons caused great direct economic loss due to their multiple effects.

8.4 Impacts of Tropical Cyclones on Lowland Agriculture and Coastal Fisheries

Tropical cyclone disasters seriously affect lowland agriculture and coastal fisheries in particular. In China, the total area of lowland, swamp and wetland is 25 million hectares, about one quarter of area of arable land of the whole country. And the tropical cyclone prevailing time just meets the key period for crops' growth in coastal area. So every landing tropical cyclone causes disasters on large areas of cropland and decreases output of grains. From 1949 to 2000, the total area of farmland that was drowned by tropical cyclones attained 79,892.4 thousand hectares. Analysis of about 10 typhoons with the most disastrous effects in China showed that on average, every typhoon causes a disaster on more than 1,470,000 hectares of farmland.

Table 8.1 shows the area of damaged farmlands and number of affecting tropical cyclones in China during 52 years (1949–2000). Though the number of tropical cyclones landing in China decreases (Fig. 8.2), the number of tropical cyclones causing damages to agriculture increased quite obviously, while the area of damaged farmland increased too. Especially in 1991–2000, it is very impressing. Considering the quick development of China after 1980, it reflects the social factor of natural disaster influences.

Besides direct effects of tropical cyclones on agriculture, some indirect damages can also be made. These include serious destruction of the installations of water conservancy projects, soil-salanization, increased incidence

Table 8.1. Area of damaged farmlands and number of affecting tropical cyclones

Year	Area of damaged farmlands (Unit thousand hectares)	Number of TCs making agricultural damages
1949–1950	320	1
1951–1960	3,566.4	10
1961–1970	5,566.4	13
1971–1980	17,454.0	7
1981–1990	15,854.1	33
1991–2000	37,131.5	61

of insect pests after tropical cyclone invasion, etc. Because the relevant information is difficult to collect, we cannot provide concrete details on this topic here.

Coastal fisheries in China consist of three parts: off shore fisheries, sea water aquaculture and inland fresh water aquaculture. Tropical cyclones can cause sinking of fishboats, damage to aquafarms, and death of fishermen, thus leading to grave losses of fisheries. Tropical cyclone disasters also cut the piscatorial working time and thus reduce the production. Owing to the limited information we have collected, the fishery damages caused by tropical cyclones are represented by two indices: number of sunk fishboats and area of damaged fishponds.

To solidify the analysis of impacts of tropical cyclones on lowland agriculture and coastal fisheries, we choose Shanghai, Zhejiang province and Jiangsu province in East China to make further studies.

The coastal district of East China is on the delta regions of great rivers and the crossing belt of sea and land and is often invaded by sea tides, and the 70% of arable lands are frequently influenced by floods. Tropical cyclones, rainstorms and tides often bring about floods with severe influence on the agriculture and fisheries.

Table 8.2 shows seasonal distribution of frequency of tropical cyclones causing agricultural and fishery damages. From the third decade of July to the third decade of November, workers of agriculture and fisheries in this area should be cautious about tropical cyclone disasters.

Table 8.2. Seasonal distribution of frequency of tropical cyclones causing agricultural and fishery damages (1949–2000)

	Jun 1D	Jun 2D	Jun 3D	Jul 1D	Jul 2D	Jul 3D	Aug 1D	Aug 2D	Aug 3D	Nov 1D	Nov 2D	Nov 3D	Oct 1D	Total
Zhejiang	0	0	0	1	2	7	8	7	10	7	5	4	1	52
Shang-hai	1	0	1	1	2	7	5	7	8	2	5	3	1	43
Jiangsu	0	0	0	0	0	5	3	4	5	4	3	3	1	28
Total	1	0	1	2	4	19	16	18	23	13	13	10	3	123

Table 8.3 shows frequency of tropical cyclones causing agricultural and fishery damages every ten years. Increasing trend can be seen in this table, it is consistent with the fact exhibited in Table 8.1.

The losses to agriculture and fisheries during 1949 to 2000 are shown in Table 8.4. Zhejiang had heavy damages in fisheries, while agriculture in Jiangsu suffered great losses (Zikang and Weilun 1994).

Description of four particulars cases given below, provides an idea of the nature of damages caused by tropical cyclones.

Case #1: On August 1st, 1956, a severe typhoon landed in Xiangshan in Zhejiang province and 75 counties in Zhejiang encountered great disasters. 400,000 ha farmlands were flooded, more than 3,500 boats were damaged, and 4,925 persons were dead. In Shanghai, 18,000 ha of farmlands were flooded, while 2 million ha of farmlands were flooded in Jiangsu province.

Case #2: During 2–4 August, 1960, Shanghai and Jiangsu were affected by a typhoon. In Shanghai, 33.3 thousand ha of farmlands were flooded, 16.4 million fish were lost, and 67 boats were sunk or damaged. Strong rainstorms attacked east part of Jiangsu and 7.6 million ha of farmlands were flooded.

Case #3: On July 27, 1987, Zhejiang was hit by typhoon no. 8,707 (TY Alex), 619 boats were sunk, and 343 thousand ha of farmlands were flooded. 422 thousand ha of farmlands were flooded in Jiangsu.

Case #4: During 18–19 August, typhoon no. 9,711 (TY Winnie) landed in Wenling, Zhejiang province. 733,000 ha of farmlands were flooded, and 16,000 ha of fishponds were damaged in Zhejiang. In Shanghai, 30,000 ha of farmlands were flooded. In Jiangsu, 667,000 ha of farmlands were flooded.

Table 8.3. Frequency of tropical cyclones causing agricultural and fishery damages every ten years

Year	Zhejiang	Shanghai	Jiangsu
1949–1950	1	1	0
1951–1960	10	9	2
1961–1970	4	8	2
1971–1980	5	6	3
1981–1990	16	12	10
1991–2000	16	7	11

Table 8.4. Losses to agriculture and fisheries (1949–2000)

	Flooded Farmland (1,000 ha)	Damaged Fishponds (1,000 ha)	SunkFish-boats
Zhejiang	864.3	44.4	6,424
Shanghai	546.3	4.7	75
Jiangsu	10,846	7.5	221

Table 8.5. Water requirement of crops and rainfall in summer in Zhejiang

	Jiaxing	Huzhou	Shaoxing	Hangzhou	Ningbo	Wenzhou	Linhai
Total Rainfall [R] (mm)	333.1	355.6	426.5	452.2	431.1	564.5	593.4
Rainfall from Tropical cyclones [r] (mm)	112.3	104.8	154.6	141.6	188.3	275.6	294.8
R – r (mm)	220.8	250.8	271.9	310.6	242.8	288.9	298.6
Water Requirement Q (mm)	354.6	349.5	349.6	337.6	363.2	357.5	351.2
Q – (R – r) (mm)	133.8	98.7	77.7	27.0	120.4	68.6	52.6

The analysis above focused on the damages and losses induced by tropical cyclones. In fact, tropical cyclones also bring some beneficial effects on agriculture. Rainfall brought by tropical cyclones often reduces the drought in summer in Chinese coastal area. In some area the crop's growth depends on tropical cyclones' rainfall intensity. Table 8.5 shows the water requirement of crops and the rainfall in summer in Zhejiang. If there is no rainfall from tropical cyclones, crops would not grow well.

Though the beneficial effects of tropical cyclones on agriculture and fisheries are nontrivial, few studies have been conducted on this aspect. As an important aspect of tropical cyclone impact evaluation, it should be strengthened in the future.

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CHAPTER 9

Frost and High Temperature Injury in China

Du Yaodong

Abstract Frost and high temperature injury are two important agrometeorological disasters in China. In this paper, the concept of frost and its differences from other low temperature injuries are presented. Recent studies on injury mechanism of frost are introduced. Frost-prone areas, crops harmed, and statistical characteristics in China are analyzed and summarized. Frost preventive and preparedness measures in China are discussed. The detrimental impacts of high temperature injury on crops, vegetables, fruit trees, milk yield, livestock, and fish in China are also briefly reviewed.

9.1 Introduction

Frost and high temperature injury are two major agrometeorological disasters. Frost occurs in almost all parts of China and brings significant damage to many crops. Therefore, much attention has been paid to frost in the past in China (Zhang Yangcai, et al. 1991). There were many historical records on frost more than 3,000 years ago, but systematic frost study was not made until after 1949 when many meteorological stations were established and field studies started to carry out the observation and investigation of frost.

In this paper, the concept of frost, and injury mechanism of frost, frost-prone areas, crops harmed, and such statistical characteristics as frequency, distributions and inter-annual changes of autumn frost date, spring frost date, frost-free season, as well as the relationship between climate change and frost in China are analyzed and summarized. Preventive measures and proactive preparedness steps to reduce the impact of frost in China are given. High temperature injury will happen when temperature exceeds the upper limit of optimum temperature range for growth and development of plants and animals. The detrimental impacts of high temperature injury on crops, vegetables, fruit trees, milk yield, livestock and fish are introduced and discussed briefly.

9.2 Frost

9.2.1 Concept and Harmed Mechanism of Frost

In China, frost has different meanings in each of the subjects. Currently, the recognized definition of frost is a phenomenon that temperature on the soil surface or near the plant canopy drops to below 0 °C in a short time, and crops suffer injuries (Zhu Binghai, et al. 1985).

According to a recent study, injury mechanism of frost is concluded as follows (Zhang Yangcai, et al. 1991): frost does not result directly from low temperature, but from icing of plant tissue. The plant temperature below 0 °C is a necessary but not a sufficient condition for icing. Ice nucleation active bacteria (INA bacteria) is an inducement of icing. The density of INA bacteria is closely correlated with the icing temperature of plant tissues. In the past, it was generally considered that the injured degree of crop exposed to frost mainly was controlled by low temperature intensity. In the late 1970's, it was found that INA bacteria played an important role in the occurrence of frost (Lindow, et al. 1978). Recent research has indicated that there are a lot of INA bacteria in many plants of China (Sun Fuzai, et al. 1989). These INA bacteria can induce plants to form ice under the condition of relatively high temperature (Feng Yuxiang, 1990; Liu JiangHua, et al. 1990).

There are three types of icing: cell-to-cell icing, intracellular icing, and, plasmolysis. Only intracellular icing or cell-to-cell icing can cause cell to die thoroughly. If temperature ascends slowly in the course of defrosting, cell-to-cell icing or plasmolysis within the enduring ability does not cause cell to die.

Plant death is not the only result of frost. When some tissues have iced within their enduring ability, the cell is alive, but a film of the cell has been injured to a certain extent. This will adversely affect later growth of the plant.

Table 9.1. Difference among frost, freezing, cool, and chilling injuries

Types	Temperature (°C)	Occurring season	Physiological reaction	Harmed crop	Crop state
Frost	< 0	Comparative warm season (transition)	Dehydration, icing in short time	Winter crop, fruit tree and vegetable	Normal growth
Freezing	< 0	Winter, early spring or late autumn	Dehydration, icing	Winter crop, fruit tree	Wintering season
Cool	10–23	Warm season	Growth and development handicap	Thermophilic crop	Active growth
Chilling	0–10	Winter season	Physiological handicap	Tropical, subtropical crop	Slow growth

Recently, distinction between frost and freezing injury, cool injury, and chilling injury (Cui Duzhang, 1999) has been identified (Table 9.1).

9.2.2
Frost Area

9.2.2.1
Monthly Average Frost Area

Figure 9.1 depicts the monthly average frost area across China. Seen from Fig. 9.1, September, January, and May are the top three months in average frost area (Feng Yuxiang, et al. 1996). September is the mature season for maturity of autumn crops in the north of China and is also a period of sharply dropping temperatures in the continent. Therefore, September is a month that is prone to a larger injury range, higher frequency, and biggest injury area.

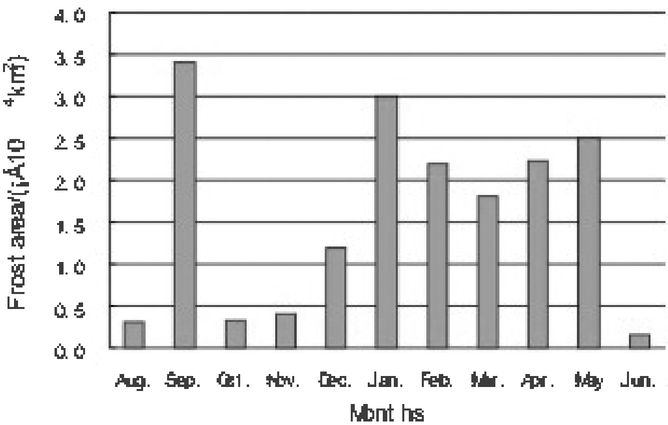

Fig. 9.1. Monthly average frost area across China

In January, because cold air is extremely severe, the range influenced by frost can extend to northern and central Hannan province and southern Yunnan province. Frost brings great damage to such crops as winter wheat, winter rape, and *Vicia faba* during the active growth period, as well as evergreen subtropical and tropical cash plants in the above areas.

In May, because spring-sowed crops have sprouted in northern China, frosts frequently pose severe injury to agriculture, so that average frost are in this month is maximum in the spring season.

9.2.2.2
Inter-annual Change of Frost Area

Annually, average frost area is 181.6×10^4 square kilometers, but there is a great difference from year to year. Frost area is as high as 568×10^4 square kilometers in 1977, but only 48.4×10^4 square kilometers in 1978 (Fig. 9.2) (Feng Yuxiang, et al. 1996).

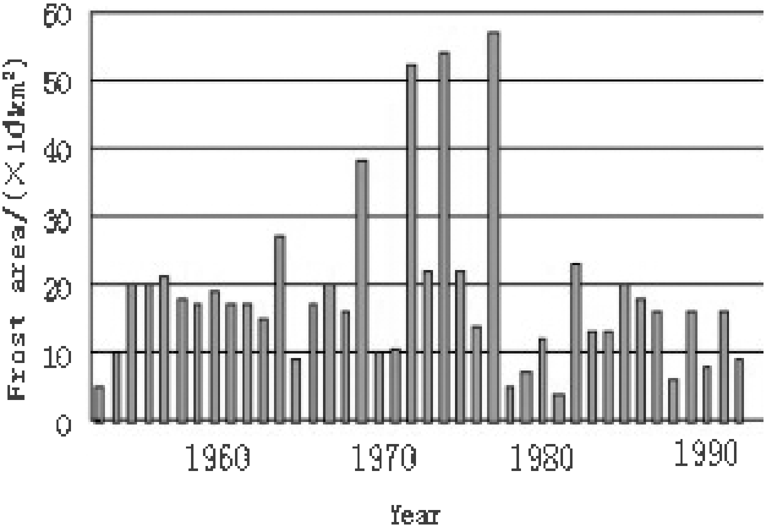

Fig. 9.2. Frost area in different years in China

9.2.3 Crops Harmed by Frost

Grain crops sown in the spring, such as maize, sorghum, millet, soybeans, buckwheat, naked oats, and potatoes, frequently suffer frost hazards in the northeast and northwest parts of China. Generally, frost brings hazards to the above crops during seedling and mature stages. Because of the short distance from the cold air source, the shorter growth season and preferred use of variety for long growth season in northeast and northwest parts of China, serious frost is more frequently seen. For instance, large scale frost between 20–24 May 1974, caused seedlings of more than 6,000 square kilometers to freeze to death only in Heilongjiang province, north China (Feng Yuxiang, et al. 1996). Cryophilic crops such as wheat, rape, *Vicia faba*, planted in cold areas and in the cold season in warm areas, easily suffer more frost hazards.

Wheat is an important grain crop in China and its sowing date is different in the northern and southern parts of the country. In spring wheat areas to the north of the Great Wall, the crop is sown in early spring. Frost during the seedling stage can destroy the leaf but not greatly impact the yield. In winter wheat areas to the south of the Great Wall, the crop is sown in autumn. Generally, wheat does not suffer frost hazards during the seedling stage. But, after stem elongation stages, decreased anti-frost ability of wheat increases risk of spring frost damage to the crop. For instance, ten large-scale frosts took place from 1953 to 1963 in the Huang-Huai-Hai area. Among these, severe frost between 19–20 April 1954, resulted in over 50 percent of wheat freeze in northern Jiangsu and Anhui provinces and yield decrease by more than 50 percent in Henan, Hebei, and Shangdong provinces (Feng Yuxiang, et al. 1996).

Because temperature in the main cotton area of China is unstable in spring and autumn, frost tends to bring hazards to cotton during seedling and ripening stages. Frost frequency during the seedling stage is higher than that during the ripening stage, and the harmed area mainly includes northern Tiangshan Mountain, Hexi Corridor, southern Shanxi, western Liaoning, and northern China plain. Frost during the late growth period of cotton in the boll-forming period greatly decreases both its yield and quality.

Such fruit trees as apple, pear, grape in the north of China and laquat, banana, pineapple, longan in the south of China have suffered frost disaster in the past. Apple trees during the flowering stage have the weakest anti-frost ability. If occurring during flowering stage, frost could make many flowers and young fruits fall off. For example, there were eight frosts in Etuoke county, Inner Mongolia Autonomous Region in the 1970s, with the apple yield decreasing by over 50 percent. Three frosts near Helanshan Mountain, Ningxia Hui Autonomous Region in 1971, 1972, and 1980 made apple yield almost decrease to zero (Feng Yuxiang, et al. 1996).

Because it has lower anti-frost ability than apple flower, pear flower easily suffers from spring frost. Four frosts in Ningxia Hui Autonomous Region from 1969 to 1973 decreased pear yield by over 70 percent.

Young bud and young leaf of grape have low resistance to frost, and the flower is sensitive to low temperature, therefore, frost could bring severe damage to grapes. For example, frost between 20–25 April 1986 caused the buds of grapevines to die by over 70 percent of Shanshan, eastern XinJiang.

Because of lowering anti-frost ability of flower, fruit, and leaf, the banana tree easily can partly and entirely die if it encounters frost. Frost in January 1992 brought about damage of 116 square kilometers in Maoming City and 50.7 square kilometers in Zhanjiang City, Guangdong province, and southern China, respectively.

Because of its low trunk, pineapple would easily be hurt if encountering advection-radiation frost. Frost between 11–13 January 1976, caused most pineapple to freeze to death, with yield decreasing by over 60 percent.

9.2.4
Statistical Characteristics of Frost

9.2.4.1
Frequency of Frost

Frost can occur in almost all parts of China. For spring frost, the highest frequency is recorded in west China, even as high as 64 percent. The frequency of frost is 47 percent in west Shangxi, north Jiangsu and north Anhui. The frequency of 25 percent is observed in southern parts of Jiangsu and Anhui.

For autumn frost, highest frequency of 39–46 percent is recorded in both eastern and western parts of China.

9.2.4.2
Distribution and Inter-annual Change of Autumn Frost Date

The higher the latitude, the earlier is the occurrence of average autumn frost date. The average autumn frost date is about the end of August to the north of Daxinganling mountain in the northeast China, but the average autumn frost date takes place in early January of the following year in the areas of central Taiwan, southern Fujiang, southern Guangdong, and southern Yunnan (Fig. 9.3) (Zhang Yangcai, et al. 1991).

The absolute variability of frost can be computed by equation (9.1):

$$V_a = \frac{1}{N}\sum_{i=1}^{N}|x_i - \overline{x}| \tag{9.1}$$

Where V_a is absolute variability, N, the number of years considered, x_i frost date in i year, $\overline{x}$, average frost date.

Absolute variability of autumn frost date is 4–7 days in northeast China, 6–8 days in north China plain, 8–10 days in middle and lower reaches of the Yangtse River, and 10–14 days in the Yungui plateau, respectively.

Fig. 9.3. Distribution of average autumn frost date in China

The earliest autumn frost date is 15 days ahead of the average autumn frost date in northeast China, about 20 days in the north China plain, and 30–45 days in the Yungui plateau. For areas with a shorter growth season, farmers like to plant late-maturing varieties for full use of frostfree season. If the autumn frost date occurs earlier, crops could suffer damages because they are not fully matured in time. Therefore, much attention must be given to the autumn frost.

9.2.4.3 Distribution and Inter-annual Change of Spring Frost Date

In contrast to the earlier autumn frost, higher latitudes lead to a later average spring frost date. The average spring frost dates occur in early March to the south of latitude 28° and between the end of March and early April to the south of Qinling Mountain, respectively. The average spring frost date does not occur until the middle ten days of June in the north of Daxinganling Mountain, northeastern China (Fig. 9.4) (Zhang Yangcai, et al. 1991).

According to equation (9.1), the absolute variability of spring frost date is 6–9 days in the northeast China plain, 8–13 days in the northern China plain, 6–13 days in the middle and lower reaches of Yangtse River, and 8–23 days in the Yungui plateau, respectively. Absolute variability of spring frost date also decreases with latitude's increase, similar to the distribution of autumn frost date.

Fig. 9.4. Distribution of average latest spring frost date in China

The latest spring frost date is 16–30 days behind average spring frost data in the east China plain, 22–31 days in the north China plain, and 22–36 days in the Yungui plateau. Because the absolute variability of spring frost date and the days of the latest spring frost date beyond the average spring frost date are comparatively large, spring frost is also of significant importance.

9.2.4.4
Distribution and Annual Change of Frostless Season

The average frost-free season is 100–150 days in northeast China, 150–200 days in the north China plain, about 250 days in the middle and lower reaches of Yangtse River, and more than 300 days in the south of Nanling Mountain, respectively. Frost does not occur in the south of Guangdong and Guangxi provinces all the year round (Fig. 9.5) (Zhang Yangcai, et al. 1991).

The absolute variability of frost-free season is 9–13 days in the northeast China plain, 14–16 days from the north China plain to the north of Yangtse River, 14–19 days from the south of Yangtse River to the north of Nanling Mountain, and more than 20 days in the Yungui plateau, respectively. The absolute variability of frost-free season is greater than that of autumn and spring frost date, indicating that frost-free season is more unstable than autumn and spring frost dates.

Fig. 9.5. Distribution of average frostless season in China

Difference of shortest frost-free season from average frost-free season is 20–42 days in the north China plain, 29–44 days in middle and lower reaches of the Yangtse River, and more than 40 days in the Yungui plateau, respectively. Seen from those figures, the shortest frost-free season is over 30 days less than average frost-free season in most parts of China. This issue must be considered in the prevention and preparedness of frost.

9.2.4.5
Climate Change and Frost in China

The climates in north and south China have gradually become warmer since the 1980s. Frost mitigation measures should be considered. In practice, frost still frequently takes place. There are two reasons. First, frost season begins to become more unstable. The second reason is an increased frost possibility with the use of late-maturing varieties and plastic film that is used widely in agriculture.

In order to explore the changing trends in frost areas, the 5-year moving average is computed (Fig. 9.6). Seen from Fig. 9.6, the average value in 1950s is slightly lower than that during 1953–2000. The average value in the 1960s is about equal to that during 1953–2000. The average value in the 1970s is significantly larger than that during 1953–2000. The average value in the 1980s is obviously lower than that during 1953–2000.

Although the 5-year moving average of spring frost date has become earlier since the 1980s, abnormal spring frost still occurs in some years. For example, spring frost on 5 June 1992 was 15–25 days later than average in eastern China. It brought about mass death of crops during seedling or transplanting stages. Spring frost on 2 May 1991, caused the death of 50 percent of cotton seedlings in Yuncheng district, Shanxi province of western China. According to the analysis of results from Beijing, since the 1980s autumn frost dates have become more stable, however, spring frost dates have become more unstable. This shows that there are abnormal spring frosts in obvious warming periods of climate.

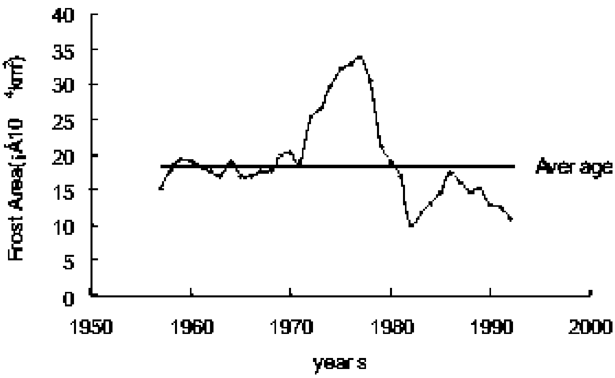

Fig. 9.6. Five-year moving average of frost area in China

9.2.5 Preventive Measures and Preparedness of Frost

Preventive measures and preparedness of frost in China are composed of long-term countermeasures and emergency measures. Long-term countermeasures include selection of favorable topography, breeding of anti-frost varieties, reasonable fertilizer supplies and timely sowing, etc. Emergency measures include artificial clouds of smoke, protective covering, irrigation, sprinkling crop with water and biological agents.

9.3 High Temperature Injury in China

9.3.1 Impact on Crops

Rice, cotton, and maize in the middle and lower reaches of the Yangtse River and the area of southern China and wheat and potato in the north of China frequently suffer from high temperature injury. From July to August, early and middle-season rice are at heading, flowering, milk-filling, or ripening stages in the middle and lower reaches of Yangtse River. Flowering and milk-filling stages for early-season rice also occur during June and July in southern China. It is reported that milk-filling for early-season rice is the fastest at 6–15 days after flowering and the optimum temperature is 25–28 °C in this period of time. If the temperature exceeds 32 °C, the crop has an adverse reaction to excessive heat. If the temperature exceeds 35 °C, the thousand-grain weight of rice can be decreased by as much as 0.42–3.2 grams. As the temperature increases further, the thousand-grain weight also continues to decline. Full-blossom stage of rice is also a stage sensitive to high temperature. At full-blossom stage, seed-setting percentage of rice decreases with the intensity and time of high temperature. According to the study from the Plant Physiological Institute, Chinese Academy of Sciences, seed-setting percentage of rice is 80.9 percent at 28 °C. As temperature ascends to 38 °C, seed-setting percentage of rice declines to zero.

In the middle and lower reaches of Yangtse River and southern China, there are a lot of days when maximum temperatures exceed 35 °C during July to August. For example, days of high temperature over 35 °C are more than 20 in Changsha, capital of Hunan province and Hangzhou, capital of Zhejiang province and 15 in Hefei, capital of Anhui province and Nanjing, capital of Jiangsu province. Longer days of high temperature have greater impact on yield in some years. For example, at milk-filling stage of early-season rice, days of high temperature over 35 °C are 21 in Haizhou, 17 in Nanchang, 16 in Changsha and Hefei, 15 in Wuhan and Nanjing, 13 in Shanghai, respectively. Continuous high temperature causes seed-setting percentage of rice to drop to less than 70 percent.

High temperature injury can shorten milk-filling time of wheat, thus, shortening accumulation of dry matter prematurely. High temperature injury can also accelerate grain's respiration that results in the rapid exhaustion of dry matter and the drop of thousand-grain weight. The harmful effect of high temperature is usually aggravated by the combined effect of low humidity and dry winds. Dry and hot wind is one of the major factors influencing yield of wheat in north and northwest China. High temperature or rapid ascent in temperature after rain can also result in the "green wilt" or death of wheat. Huang-Huai-Hai plain, Hexi corridor and Xinjiang are three severest areas for dry and hot wind in China. Their frequency of occurrence is as high as 30–40 percent.

High temperature is an important reason for the abscission of squares and bolls of cotton. According to research, as the daily mean temperature reaches over 30 °C and maximum temperature is more than 33 °C, abscission of squares and bolls of cotton is aggravated. As the temperature reaches over 36 °C, photosynthesis is close to zero and respiration is enhanced which accelerates the consumption of nutrients. In the cotton area of Yangtse River valley, the high temperature period mainly occurs in the last 10 days of July and first 10 days of August. In the Tulufang basin of Xinjiang cotton area, high temperature in summer often results in serious abscission of squares and bolls of cotton combined with atmospheric drought.

Rapeseed will be prompted to ripen when daily maximum temperature is higher than 30 °C. In China, the daily maximum temperature tends to exceed the optimum 22 °C, sometimes reaching over 30 °C at milk-filling and ripening stage of winter rape. Rapeseeds are frequently being prompted to ripen. The ripening date of spring rape is about 20 days later than winter rape. Therefore, frequency of high temperature is greater and yield is low for spring rape.

9.3.2 Impact on Vegetables

High temperature restrains photosynthesis of vegetable and affects development of budding, flowering, and pollination. With respect to tomatoes, its ability to resist high temperature is the weakest at 8–10 days before flowering. Excessively high temperatures can destroy meiosis preventing normal pollen and gastrula. High temperature at pollination stage can result in the split of the pollen tube and abnormal fertilization. High temperature injury is a significant disaster affecting vegetable production and the main reason for a slack season of vegetable supply in summer in northern China, Yangtse River basin and southern China.

9.3.3 Impact on Other Plants and Animals in Agriculture

High temperatures easily cause forest and fruit trees to scorch. Litchi, evergreens, and fruit trees in southern China need the inducement of relative low temperatures ranging from 0 °C to 10 °C to better flower. Warmer weather in the winter season tends to result in the bad flowering of litchi trees and, consequently low yield. High temperatures not only can accelerate respiration of flowering, but also can make the leaf be discolored and the flowering period be shortened.

High temperature is one of the factors limiting milk yield of dairy cows. As daily mean temperature is higher than 15 °C, milk yield of dairy cows evidently decreases. Under the conditions of excessively high temperatures, the amount of feed uptake and transformation rate of feed for livestock markedly decrease. High temperatures can bring about the shortage of oxygen and the degeneration of water quality that causes fish in pond to uplift head and even to die.

9.4 Conclusions

Frost is a damaging injury resulting from low temperature, generally in the fall and spring season. Frost does not cause injury directly from low temperature, but icing of plant tissue. That plant temperature drops to below 0 °C is a necessary, but not a sufficient condition, for icing. The density of INA bacteria is closely correlated with the icing temperature of plant tissues.

September, January, and May are the top three months in average injury area in China. Annual average frost area in China is 181.6×10^4 square kilometers, but there is a great difference from year to year. Average frost area in the 1970s is greatly larger than that during 1953–2000.

Frost brings injuries to not only thermophilic and cryophilic crops in north but also subtropical and tropical crops in the south.

The highest frequencies of autumn frosts occur in both eastern and western parts of China, while the highest frequency of spring frost occurs in west China. Because of their bigger inter-annual changes, autumn frost date, spring frost date and the frost-free season all must be given close attention to in agriculture. On the background of global climate warming, frost still frequently takes place in China.

High temperature injury has the serious detrimental effects on crops, vegetables, fruit trees, milk yield, livestock, and fish in China. Study of high temperature injury will be strengthened in the future.

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CHAPTER 10

Impacts of Sand Storms/ Dust Storms on Agriculture

Mannava V. K. Sivakumar

Abstract The drylands of the world are affected by moderate to severe land degradation from wind erosion and there is evidence that the frequency of sand storms/dust storms in increasing. Human induced change is by far the most significant factor in the alarming increase of sand storms in some regions. The definition of sand storms and dust storms were presented and the classifications currently in use were discussed. The occurrence of wind erosion at any place is a function of weather events interacting with soil and land management through its effects on soil structure, tilth and vegetation cover. The mechanics of sand and dust storms and their spatial and temporal distribution was described. The impacts of sand and dust storms were described in terms of crop damage, soil productivity losses, economic losses, mass migration, health impacts, and impacts on climate. Not all the impacts are negative and the positive impacts of sand and dust storms were described. Measures to combat sand and dust storms include reduction of the impact of wind speed through the use of live wind breaks or shelterbelts; protection of the loose soil particles through the use of crop residues or plastic sheets or chemical adhesives; and increasing the cohesion of soil particles by mechanical tillage operations or soil mulching. Future strategies for reducing the impacts of sand storms and dust storms must be based on community-based approaches that integrate effective crop and land management strategies as well as policy interventions to promote more effective soil conservation measures at the national and regional scales.

10.1 Introduction

Sand and dust storms are natural events that occur widely around the world, especially in the drylands which occupy half of the world's land surface. According to the measurements of deep-sea lithologic core and glacial cover sediments, sandstorms occurred before the end of the Cretaceous period, dating back 70 million years ago. Local chronicles in China documented sandstorms which had occurred in Wuwei of Gansu province in 351 AD and some collapsed houses and human and animal casualties had been recorded (Wang Shi-gong et al. 2001).

In Russia, the earliest events of wind erosion on sandy soils took place in the 12th to 14th centuries when nomadic tribes moved yearly to the North Caucasus sand lands for the winter period due to the absence of snowpack here from the vast terrain of the steppe zone between the Dnepr and the Volga rivers (Trushkovsky 1959).

It has been estimated that in the arid and semi-arid zones of the world, 24% of the cultivated land and 41% of the pasture land are affected by moderate to severe land degradation from wind erosion (Rozanov 1990). The major sources of present-day dust emissions are the subtropical desert regions and the semi-arid and sub-humid regions, where dry exposed soil is subject to severe winds at certain times of the year. The major world dust producing regions are located in the broad band of arid and semi-arid lands stretching from West Africa to North China, with the majority being in the Northern Hemisphere (Middleton 1986). The Sahara Desert is the world's most important source of dust. The world-wide total annual production of dust by deflation of soils and sediments was estimated to be 61 to 366 million tonnes. For Africa, it is estimated that more than 100 million tonnes of dust per annum is blown westward over the Atlantic (Middleton 1986).

In regions where long dry periods associated with strong seasonal winds occur regularly, the vegetative cover of the land does not sufficiently protect the soil, and the soil surface is disturbed due to inappropriate management practices, wind erosion usually is a serious problem.

In recent years, there is evidence that the frequency of sandstorms is increasing. For example, in China serious wind erosion occurs in the semiarid region, where overgrazing and ploughing of rangeland have dramatically increased since early in the 20th century (Zhu and Wang 1993). Every year desert encroachment caused by wind erosion buries 210,000 hectares of produce land in China (PRC 1994). Ci (1998) showed the annual changes of the frequency of strong and extremely strong sandstorms in China as follows: 5 times in the 1950s, 8 times in the 1960s, 13 times in the 1970s, 14 times in the 1980s, 20 times in the 1990s.

10.2
Anthropogenic Land Disturbances and Wind Erosion

Human-induced change is by far the most significant factor in the alarming increase in some regions in the scourge of dust storms. According to previous studies, wind erosion in the semi-arid regions of America, Africa, Australia, the Near East and many parts of Central Asia could only reach threatening proportions when man disturbed the ecosystem balance. Past policies on land-use and the promotion of farming systems that were unsustainable were the root cause of most disasters.

In the West African Sahel, rapid population growth, at annual rates of 3% during recent decades, has increased demand for food. Instead of intensifying farming systems, for instance by using mineral fertilizers, farmers have tried to enhance production by expanding the cropped area. The previously sustainable fallow system has broken down, yields have declined, and more marginal land, which used to be communal grazing land, is now cropped. Consequently, over-exploitation has resulted in land degradation, or desertification, on a large scale. The amount of dust arising from the Sahel zone has been reported to be around or above 270 million tons per year which corresponds to a loss of 30 mm per m^2 per year or a layer of 20 mm over the entire area (Stahr et al. 1996).

According to Khatteli (1984), the sand encroachment of olive crops in northern Africa resulted from excessive cultivation of soil with disk harrow that pulverised the soil and rendered it more vulnerable to wind erosion. This is manifested by the disappearance of olive crops where the deflation and formation of movable sand dunes occurred or where the sand deposition occurred.

In considerable parts of West Asia and North Africa, large areas of the traditional semi-nomadic rangelands, the steppe, are being opened for barley cultivation. The consequent removal of the natural vegetation cover has exposed the soil surface, leading to the loss of the fertile fine fraction of the shallow soils through wind erosion. This has led to a tremendous decline in soil productivity and quality of life. Hence the Government of Syria has forbidden the conversion of steppe for barley cultivation.

Even in the United States of America, the emergence of effective soil conservation strategies has its background in anthropogenic land disturbances over several decades. From 1850 to 1900, the population of the Great Plains of the United States increased 11 times, from about 700,000 to 8,000,000. Many of these settlers were farmers, who plowed the native grass sod and planted crops using tillage methods developed for more humid regions. The introduction of tractors allowed larger acreages to be farmed. These three events, coupled with the properties of the Great Plains soils, mostly aeolian derived, and the semi-arid climate of the region, set the stage for wind erosion during periods of drought.

Although dry spells are unavoidable in the Great Plains of the US, occurring roughly every 25 years (Warrick et al. 1975; Warrick 1980), it was the combination of drought and the misuse of land that led to the incredible devastation of the Dust Bowl years. Dust storms, known as “Black Blizzards”, rolled across the region and deposited dust on ships at sea off the East Coast of the United States. The maximum number of dust storms occurred from 1935 to 1938. Between 1933 and 1937, the Prairie region of Canada experienced only 60% of its normal rainfall. Thousands of livestock were lost to starvation and suffocation, crops withered and a quarter of a million people across the region abandoned their land to seek better lives elsewhere.

According to Seifert (1936), changes in the climate of Middle Europe were caused mainly by rapid deforestation (from above 40% in the 16th century to 20% in the 19th century) and by intensive land reclamation works done in order to drain wet soils and marshes. New techniques of soil tillage reported in most countries in the 1960’s resulted in the stimulation of the wind erosion process. As mechanization and effectiveness of cultivation increased, the field area expanded, and roadside and field trees were removed, the menace of wind erosion developed (Czarnowski 1956, Sommer 1984).

Since European settlement of New Zealand large areas of the country have been converted from forest and utilised for animal grazing or crop production.

As a result wind erosion became a major concern for soil conservation in New Zealand, and for a long time government subsidies were available to farmers for wind erosion control (Anon 1971; Salter 1984).

Wind erosion in Lithuania, as also the neighbouring Baltic countries, occurred mainly in areas where the natural plant cover has been replaced by agriculture (Racinskas 1997). In the years of Soviet power, the formation of vast continuous tilled fields (up to 1,000 ha) and extinction of agroplantations and individual farmsteads, contributed greatly to intensification of wind erosion.

Dolgilevich (2001) reported that in Ukraine wind erosion has become widespread in the forest zone. Selective soil blowing has caused degradation of light lands. For this reason, about 10% of the arable lands have been transformed into untilled lands.

10.3 Definition of Sand and Dust Storms

The transport, suspension and deposition of dust particles in the atmosphere mainly manifest itself as a dust storm. Squires (2001) presented a good description of the terminology of sand and dust storms. Sand describes soil particles in an approximate size range of 0.6–1 mm, while dust describes particles < 0.6 mm. In practice only those dust particles below 0.1 mm can be carried by suspension and be manifested in a dust storm.

Four definitions of the dust phenomena are the same as used by the Australian Bureau of Meteorology, which conforms to the worldwide standards of the World Meteorological Office (WMO). SYNOP present weather [WW] codes are included:

1. *Dust storms* (SYNOP WW code: 09) are the result of turbulent winds raising large quantities of dust into the air and reducing visibility to less than 1,000 m.

2. *Blowing dust* (SYNOP WW code: 07) is raised by winds to moderate heights above the ground reducing visibility at eye level (1.8 m), but not to less than 1,000 m.

3. *Dust haze* (SYNOP WW code: 06) is produced by dust particles in suspended transport which have been raised from the ground by a dust storm prior to the time of observation.

4. *Dust swirls* (or dust devils) (SYNOP WW code: 08) are whirling columns of dust moving with the wind and usually less than 30 m high (but may extend to 300 m or more). They usually dissipate after travelling a short distance.

At the southern fringe of the Sahara Desert, a special dry and hot wind, locally termed *Harmattan*, occurs. These NE or E winds normally occur in the winter season under a high atmospheric pressure system. When the wind force of

Harmattan is beyond the threshold value, sand particles and dust particles will be blown away from the land surface and transported for several hundreds kilometres to the Atlantic Ocean.

In the Northwest region of India, the convection sand-dust storm that occurs in the season preceding the monsoon is named *Andhi* (Joseph et al. 1980). It is called *Haboob* in Africa and Arabic countries. It is titled *"phantom"* in some regions: namely it means *"devil"* (Wolfson et al. 1986).

In general, two indicators, wind velocity and visibility, are adopted to classify the grade of intensity of sand-dust storms. For instance, Joseph has classified the sand-dust storms occurring in the Northwest part of India into three grades. Namely, the feeble sand-dust storm develops when wind velocity is at force 6 (Beaufort) degree and visibility varies between 500–1,000 m. The secondary strong sand-dust storm will occur when wind velocity is at force 8 and visibility varies 200–500 m. Strong sand-dust storms will take place when wind velocity is at force 9 and visibility is < 200 metres.

In China, a sand-dust storm is defined similarly to the above. The only difference is that the category of strong sand-dust storms is defined again into two grades, namely strong sand-dust storms and serious-strong sand-dust storms. When wind velocity is 50 metres per second (m/s) and visibility is < 200 metres, the sandstorm is called a strong sand-dust storm. When wind velocity is 25 m/s and visibility is 0–50 metres, the sandstorm is termed a serious sand-dust storm (some regions name it Black windstorm or Black Devil) (Xu Guochang et al. 1979).

10.4 Mechanics of Sand and Dust Storms

The occurrence of wind erosion at any place is a function of weather events interacting with soil (intrinsic properties) and land management (past and present practices) through its effects on soil structure, tilth and vegetation cover. As with water erosion, most wind erosion damage comes from relatively rare, severe events.

Wind erosivity is the main factor controlling the broad pattern of wind erosion. It has been defined as "that property of the wind which determines its ability to entrain and move bare, dry soil in fine tilth" (Painter 1978). It can be estimated from daily or hourly records of wind speed above a threshold related to the lowest speed at which soil particles are entrained (Skidmore and Woodruff 1968).

Soil erodibility, defined as "that property of dry, particulate soil which governs its entrainment by wind", determines locally whether erosive winds will entrain soil particles. It can be estimated from soil aggregate size distributions by the percentage of aggregates larger than 0.84 mm (Chepil 1950; Woodruff and Siddoway 1965).

When soil movement is sustained, the quantity of soil that can be transported by the wind varies as the cube of the velocity (Bagnold 1941; Chepil and Woodruff 1963). Soil roughness, soil erodibility, soil wetness, and the quantity and orientation of crop residues are a few of the parameters that impact the transport of eroded soils.

The erodibility of soils, which is an expression of their ability to resist wind erosion, is a result of soil evolution in an environment. For a given soil in a favorable environment, weathering such as wetting and drying and freezing and thawing, disturbs the original soil structure and makes the soil more erodible (Chepil 1954). Disturbing surface soils, by over-grazing that reduces surface coverage, over-cultivation, destruction of soil aggregates by mining, construction, off-road traffic, and military activities, stimulates and accelerates soil wind erosion in dryland regions, leading to land degradation and desertification (Fryrear and Lyles 1977; Gillette et al. 1980; 1982; Dregne, 1988; Saxton et al. 1996). Anthropogenic activities in wind erosion susceptible regions has made the problem more complex.

The most comprehensive summaries on the movement of surface material by wind action have been prepared by Bagnold (1941) for desert sands and by Chepil and Woodruff (1963) for agricultural lands. Wind erosion is possible when the wind velocity at the soil surface exceeds the threshold velocity required to move the least stable soil particle. The detached particle may move a few millimeters before finding a more protected site on the landscape. The wind velocity required to move this least stable particle is called the static threshold (Bagnold 1941). If the wind velocity increases, soil movement begins and if the velocity is sufficient, soil movement is sustained. This velocity is called the dynamic threshold.

When the wind force reaches the threshold value a number of particles will begin to vibrate. Increasing the wind speed still further, a number of particles will be ejected from the surface into the airflow. When these injected particles impact back on the surface, more particles are ejected, thus starting a chain reaction. Once ejected, these particles move in one of three modes of transport depending on particle size, shape and density of the particle. These three modes are designated suspension, saltation and creep. Its size and density determine movement pattern of sand-dust particles.

The suspension mode involving dust particles of less than 0.1 mm in diameter and clay particles of 0.002 mm in diameter are small in size and light in density. These fine dust particles may be transported at altitudes of up to 6 km and move over distances of up to 6,000 km.

Saltating particles (i.e. those between 0.01–0.5 mm in diameter) leave the surface, but are too large to be suspended. The remaining particles (i.e. above 0.5 mm) are transported in the creep mode. These particles are too large to be ejected from the surface and are therefore rolled along by the wind and impacting particles. Due to the nature of this mode the heights carried are rarely more than 30 cm and the distance travelled rarely exceeds a few metres.

During a storm, creep can move particles over distances from a few centimeters to several meters, saltating particles travel from a few meters to a few hundred meters, and suspension transport ranges from several tens of meters to thousands of kilometers. In the sand-dust wall, the up-lifting force produced by the rising air current is powerful. The sand grains at the lower stratum of the sand-dust wall are coarse particles, the sand particles in the middle stratum are the next in size and those in the upper stratum are mainly suspension dusts (Wang Shi-gong et al. 1993).

Sand particles, transported by saltation and by creep will accumulate to form new sand dunes when they are blown out, graded and transported for a distance.

Joseph (1980) studied the convection sandstorm of *"Andhi"* in Northwest India and results show that visibility can be reduced quickly from 1000 metres to 200 metres, and even 100 metres, while a strong sandstorm or dust storm sweeps across. Wind velocity can be increased up to 20 m/s from 4 m/s. Air temperature can be reduced about 5° and relative humidity can increase 10% or more. On May 20th 1976, a sandstorm took place in India and the visibility at New Delhi Airport was reduced to 280 metres from 4000 metres in a span of two minutes. Air temperature declined from 38–25 °C, relative humidity increased rapidly from 31–70% and wind speed was 73–80 km/hr.

10.5
Spatial and Temporal Distribution of Sand and Dust Storms

Sand-dust storms frequently occur in four regions throughout the world: the Sahel, Central Asia, North America, Central Africa, and Australia.

Mattson and Nilsen (1996) indicate that the Sahara region is the main source of aeolian dust in the world. Yaalon (1996) has indicated that North Africa is a source of dust for southern European dust deposition. Franzen et al (1995) made analyzed sand-dust storm processes that occurred in central and southern Europe and the north of Scandinavia in March 1991, which originated from the Sahara Desert, and they concluded that the sand-dust of the Sahara Desert was transported and accumulated in the northern region of Germany. The affected area of the sand-dust storm process of this sand-dust storm in March 1991 was at least $3.2 \times 105\,km^2$.

Several observations of dust from West Africa crossing the Atlantic were reported in the literature (e.g., Prospero et al. 1970; Carlson and Prospero 1972; Westphal et al. 1988). Prospero and Carlson (1972) estimated that between 25 million and 37 million Mg of wind-blown dust cross the Atlantic annually, with even greater amounts presumably deposited in the ocean (Lal 1988).

According to Swap's (1992) research, the sand-dust of the Sahara Desert was transported to the Amazon Plain of Brazil and approximately 4.8×10^5 tonnes of dust particles was brought to the northeastern part of the Amazon Plain during a one-time sand-dust storm that occurred in the Sahara Desert. The annual transport and accumulation was 1.3×10^7 tonnes ie., 190 kg of dust particles accumulated annually on one ha of land.

The Economic and Social Committee of Western Asia (ESCWA 1993) showed that about 18 million ha in Egypt are affected by different levels of wind erosion. Arroug (1995) used the wind prediction equation of Woodruff and Siddaway (1965) to estimate soil loss by wind erosion in El-Omayed area, Northwestern Coast. He showed that soil loss by wind erosion reached 100 mt/ha/yr. In South Sinai, Wassif et al. (1997) used Big Spring Number Eight (BSNE) dust sampler for measuring the amount of soil loss by wind erosion during 83 days from March, 1994. They found that the quantity was 3.07 ton/100 m width.

Pease et al. (1998) suggests that arid and semi-arid regions around the Arabian Sea are one of the principal sources of global dust. India, Pakistan, Iran and the Arabian Peninsular contribute to Arabian Sea dust deposition.

10.6 Impacts of Sand and Dust Storms

Sand and dust storms are hazardous weather and cause major agricultural and environmental problems in many parts of the world. There is a high on-site as well as off-site cost due to the sand and dust storms. They can move forward like an overwhelming tide and strong winds take along drifting sands to bury farmlands, blow out top soil, denude steppe, hurt animals, attack human settlements, reduce the temperature, fill up irrigation canals and road ditches with sediments, cover the railroads and roads, cause household dust damages, affect the quality of water in rivers and streams, affect air quality, pollute the atmosphere and destroy mining and communication facilities. They accelerate the process of land desertification and cause serious environment pollution and huge destruction to ecology and living environment (Wang Shigong et al. 2001). Atmospheric loading of dust caused by wind erosion also affects human health and environmental air quality.

10.6.1 Crop Damage

Wind erosion-induced damage includes direct damage to crops through in the loss of plant tissue and reduced photosynthetic activity as a result of sandblasting, burial of seedlings under sand deposits, and loss of topsoil (Fryrear 1971; Ambrust 1984; Fryrear 1990). The first two types of damage have an immediate effect on crop yields. However, the loss of topsoil is particularly worrying since it potentially affects the soil resource base and hence crop productivity on a long-term basis, by removing the layer of soil that is inherently rich in nutrients and organic matter.

10.6.1.1 Sand Blasting

Since damage to millet strongly depends on plant age, the risk posed by sandblasting and burial will to a large extend depend on the strength and timing of sand storms with respect to the time of sowing. Leaves are more sensitive to sandblast damage than are stems (Armbrust 1982; Fryrear 1971). Michels et al. (1995a) reported on the effect of wind speeds ranging from 8 to 14 m s^{-1} and sand fluxes ranging from 0 to 42 g m^{-1} s^{-1} on millet growth and photosynthetic activity in a wind tunnel experiment. Plants were exposed for 15 min. at 8 days after emergence (DAE), 16 DAE or on both dates. Sandblasted plants saw their viable leaf area reduced by an average of 19% across all treatments at 21 DAE compared to the control. In addition to the loss of viable leaf area, sandblasting affected photosynthesis in the viable parts of the leaves by an average of 55% 1 h after exposure at 8 DAE and was still reduced by 28% 4 days later. Exposure to sandblasting also reduced millet dry weight at the early stages of development. Brenner (1991) similarly reported reduced leaf area and dry matter production of young millet plants as a result of sandblasting during violent storms. However, at 46 days after sowing the crop had entirely recovered from these stresses. Exposure of seedlings to sandblasting prior to burial reduced dry matter production of millet at 70 days after emergence (DAE) by 47% compared to unexposed buried plants (Michels et al. 1995a).

10.6.1.2
Crop Burial

In the traditional sowing techniques of millet cropping systems of West Africa, small depressions are left after sowing the seed and burial of seedlings under deposited wind-blown sand frequently occurs during convective storms, sometimes necessitating partial or total resowing of the crop (Michels et al. 1993, Michels et al. 1995a; Sterk and Stein 1997). Burial of seedlings accentuates the effect of high surface temperatures by bringing the meristems of young seedlings directly into contact with the hot soil surface. Nutrient and water deficiencies at this critical stage may further hamper seedling recovery. In a 1990 field experiment sown in the traditional way, 90% of millet hills were covered by sand 23 DAE, which necessitated re-sowing and therefore increased the risk of exposure of the crop to an end-of-season drought (Michels et al. 1993).

10.6.1.3
Plant Development

In addition to the direct effects of partial burial on yield-determining factors such as number of tillers and panicle length, partially buried plants experience a delayed development compared to unburied plants. This may further increase the risk of an end of season drought stress to millet by extending the crop cycle beyond the usual growing season length. Michels et al. (1993) determined that panicle development was delayed by approximately 2 weeks following partial burial.

10.6.2
Soil Productivity Losses

Studies conducted at large regional scales as well as at field level demonstrated clearly that sand and dust storms result in loss of soil productivity and long-term soil degradation.

Fine airborne particles emitted into the atmosphere represent the loss of the most fertile fraction of the topsoil and can be transported over long distances from their sources of production (Péwé 1981). Calculations based on visibility and wind speed records for 100 km wide dust plumes, centered on eight climate stations around South Australia, indicated that dust transport mass was as high as 10 million tonnes (Butler, Davies and Leys 1995). Thus dust entrainment during dust events leads to long-term soil degradation, which is essentially irreversible (Yaping, Raupuch and Leys 1996). The cost to productivity is difficult to measure but is likely to be quite substantial.

At the field level, following intensive monitoring of sand fluxes in a 40×60 m plot, Sterk and Stein (1997) estimated soil losses from only four sand storms in 1993 at 45.9 t ha^{-1}. These measurements were made on a millet field with a 0.8 t ha^{-1} mulch of millet stover, which reflects on-farm conditions under favorable circumstances. Sterk et al. (1997) reported the only estimates of nutrient losses by wind erosion for Niger. They calculated nutrient fluxes based on the nutrient content of the trapped sediment for the two largest storms. The results reveal a total loss of 57.1 and 6.1 kg ha^{-1} of K and P, respectively. These amounts are roughly equivalent to the quantity of K and P required to produce a millet yield of 2,000 kg straw and 600 kg of grain ha^{-1}. They also correspond to approximately 3% of the nutrients contained in the top 10 cm of the soil.

On the basis of repeated measurements of surface elevation, Michels et al. (1995b) reported a decrease in surface elevation of 33 mm after one year on bare millet plots.

During dust transportation, many young plants are lost to the sand blasting nature of the process at ground level, resulting in a loss of productivity. However, major dust storms have most of their impact within the atmosphere. The most noticeable effect is the reduction of visibility. This is of course dependent on the severity of the dust event. It could range from a slight haze to a major dust cloud. In the worst cases, visibility can be reduced to only a few metres. This loss of visibility can be a major hazard to aircraft and in some cases to motorists.

10.6.3 Economic Losses

Wang Shigong et al. (1995) estimated the direct economic loss caused by the serious-strong sand-dust storm that occurred on May 5th 1993 that threatened 1.1 million km^2 of territory in China at 560 million RMB Yuan. Yang Gengsheng et al. (2001) reported that 373,000 ha of crops were destroyed, 16,300 ha of fruit trees were damaged and thousands of greenhouses and plastic mulching sheds were broken. About 120,000 animals were killed. More than 1,000 km of irrigation channels were buried by sand accumulation. Many water resource back-up facilities, such as reservoirs, dams, catchments, underground canals, and flood control installations were filled up with sand silts. It has brought about critical destruction of desert plants and ecological environment in Northwest China, promoting the desertification process in the affected areas, and its indirect economic loss was hard to assess (Wang Shigong et al. 1995).

Canada is plagued by localized dust storms and drought, especially in the Prairie Provinces of Manitoba, Saskatchewan and Alberta. At least 161 million tonnes of soil is lost each year because of wind erosion, and the annual on-farm costs of wind erosion in the Prairie Provinces are about USD$ 249 million. Sparrow (1984) argued that nearly 58% of the total annual soil loss due to wind and water may be ascribed to wind erosion which would account for a conservative estimate of 161 million t.

10.6.4 Mass Migration

Continued incidence of sand and dust storms over several years can result in total loss of soil productivity and force rural migration. Because of the Dust Bowl in 1930s, millions of hectares of farmland became useless, and hundreds of thousands of people were forced to leave their homes (Hurt 1981; Lee et al. 1999). The Dust Bowl exodus was the largest migration in American history (Bonnefield 1979). By 1940, 2.5 million people had moved out of the Plains states. Of those, 200,000 moved to California.

10.6.5 Health Impacts

Recently published data from South Australia show that wind erosion and dust storms are likely to cost millions of dollars each year. Costs such as house cleaning costs, days lost from work because of illness (or an inability to get to the job), the cost to the aviation industry of diverted flights and so on, are among the costly affects. The most significant cost is that associated with the onset of asthma in susceptible people. South Australia, for example, experiences 8.5 days per year on average when the dust load is sufficient to trigger an asthma attack (Williams and Young 1999). It was concluded that as much as 20% of the Province's asthma problem could be linked to the dust in the air.

10.6.6 Impacts on Climate

The very fine fraction of soil-derived dust has significant forcing effects on the radiative budget. Dust particles are thought to exert a radiative influence on climate directly through reflection and absorption of solar radiation and indirectly through modifying the optical properties and longevity of clouds. Depending on their properties and in what part of the atmosphere they are found, dust particles can reflect sunlight back into space and cause cooling in two ways. Directly, they reflect sunlight back into space, thus reducing the amount of energy reaching the surface. Indirectly, they act as condensation nuclei, resulting in cloud formation (Pease et al. 1998). Clouds act as an *"atmospheric blanket"*, trapping long wave radiation within the atmosphere that is emitted from the earth. Thus, dust storms have local, national and international implications concerning global warming. Climatic changes in turn can modify the location and strength of dust sources.

10.6.7 Positive Impacts

Mineral dust, it has been suggested, has an important role to play in the supply of nutrients and micronutrients to the oceans and to terrestrial ecosystems. Iron in the minerals composing the desert dust is a vital nutrient in oceanic regions that are deficient in iron. Further, more research has shown that the canopy of much of Central and South American rainforest derives much of its nutrient supply from dust transported over the Atlantic from the Sahara region of North Africay. Sahara dust occasionally reaches the State of Florida in the U.S., causing a high-altitude haziness that obscures the sun. Dust from China's deserts is transported to the waters near Hawaii in the south Pacific. As the dust settles in the waters around Hawaii, the primary productivity of the plankton in the water column increases (NOAA 1999). This research suggests that dust transport processes form an integral part of the global ecosystem.

According to Swap et al. (1992), it is indicated that each sand-dust storm in the Sahara Desert can blow up 480,000 tonnes of sand and dust into the Northeast part of the Amazon Valley. The annual sand transport is approximately 13 million tonnes, meaning sand-dust storms have brought about an accumulation of 190 kg of sand and dust particles per ha every year in the region. It was estimated that, along with the accumulation of sand-dust, 1–4 kg of phosphate has been transported and accumulated per ha per year. It can be assumed that the rate of production of the rain forest in the Amazon depends on the phosphorous and other elements transported along with sand-dust storms from the Sahara.

Sand-dust is partially alkali itself and can restrain certain harm from acid rain during its transportation in the affected area. Japanese scientists' research indicated that yellow sands and dust from Northwest China are the major component of coagulation tubercles cooling clouds in the sky of Japan and play an important role in precipitation in Japan. At the same time, ice crystals of yellow sand are alkali and play an active role in the neutralization of emerging of acid rain in Japan (Qu Zhang et al. 1994).

Apart from losses, the Sahel also receives nutrient-rich dust deposits. During the Harmattan season, dust is transported from the Sahara towards the Sahel, where it partly settles. Moreover, during the early rainy season, some of the dust raised by a convective storm is deposited by gravity or rain wash-out. Drees et al. (1993) measured 50% of the total annual dust input in southwest Niger in the early rainy season, whereas the Harmattan season contributed only 15% to the total. Dust deposits are particularly rich in sodium, potassium, magnesium, and calcium, but poor in phosphorus (Herrmann et al., 1996). At the field scale, Sterk et al. (1997) measured nutrient inputs of 2.5 and 0.2 $kg\,ha^{-1}$ of K and P, respectively, from dust deposition.

10.7 Measures to Combat Sand and Dust Storms

Measures to combat sand and dust storms must concentrate on preventing the sand from being picked up in the source area as it may often be cheaper and more effective than to fix the dunes formed in the accumulation area. Basically these measures have concentrated on the following aspects:

- Reducing the impact of wind speed through the use of live windbreaks or shelterbelts
- Protecting the loose soil particles by use of crop residues or plastic sheets or chemical adhesives
- Increasing the cohesion of soil particles by mechanical tillage operations or soil mulching

10.7.1 Use of Wind Breaks or Shelterbelts

A "windbreak" is defined as any structure that reduces wind speed (Rosenberg 1974) and is commonly associated with a natural vegetative barrier against wind. A windbreak can be a single element or a system of elements that through its presence in the airflow reduces the effect of wind speed not only at the system itself but also at a certain windward and leeward distance. Wind barriers can control wind erosion by reducing the travel distance of wind across a field. The wind speed can be reduced by more than 50% at a leeward distance of 20 times barrier height (Skidmore 1986).

Planting and maintaining shelterbelts is an important conservation practice in the Great Plains region of the United States of America. Shelterbelts produce many benefits for farmers such as decreased soil erosion, increased crop yields, reduced livestock stress, control of drifting snow, building maintenance and energy savings, (e.g., Forman & Baudry 1984; Loucks 1984; USDA 1989). Shelterbelts also benefit many wildlife species by providing food, reproductive sites, escape cover and shelter from severe weather (e.g., Cable 1991). In addition, shelterbelts provide important opportunities for recreation, particularly hunting. (Cable and Cook 1990). This recreation in shelterbelts can have important economic impacts (Cook and Cable 1990). Moreover, shelterbelts have been shown to have a positive influence on landscape aesthetics (Cook and Cable 1995).

From meteorological observations, He et al. (1993) showed changes in wind velocity profile over the vegetation, which reduces wind shear at the ground surface and increases the friction velocity. Thus the drag coefficient is bigger compared with that for the shifting dune.

10.7.2
Use of Crop Residues

Surface crop residues help stabilize soils by reducing soil water loss and the erosive force of wind and by shielding the soil from a reduced number of saltating particles. Michels et al. (1995a) showed that covering the soil with 2,000 kg ha^{-1} of millet residues gives sufficient protection from the sand storms. Evaporation reduction by crop residues results from shading and protection from drying winds (Van Doren and Allmaras 1978). Standing stems reduce the wind energy available for momentum transfer at the soil surface (Hagan and Armbrust 1994; Lyles and Allison 1976; Raupach 1992).

The geometry of crop residues alters the surface microclimate, impacting the degree of soil protection and water conservation. Strips of partial mulch cover increased preplant soil warming (Bristow and Abrecht 1989), while standing stems increased crop water use by increasing the transpiration fraction of total evaporation (Lascano et al. 1994). Bilbro and Fryrear (1994) showed that vertical residues are much more effective that flat surface cover in controlling soil loss by wind. Vertical crop stems trapped more snow than horizontal stems (Nielsen and Hinkle 1994). Decomposition of surface residues and the persistence of standing stems change with climate, soil environment, and management conditions (Steiner et al. 1994; Vigil 1995), but impacts on soil water dynamics are less well understood.

Improved crop residue management is also an efficient and cost-effective practice to address land resource issues relating to soil conservation, water quality, sustainability, and enhanced nutrient cycling (Unger 1994; Steiner 1994).

10.7.3
Use of Mechanical Tillage

Increasing the cohesion of soil particles by mechanical tillage operations or soil mulching is an effective strategy, but it must be carried out with considerable care taking into account the weather and soil factors. Special farming implements, such as chisel-type ploughs, which permit the cultivation of vegetated surfaces and maintain a rough, well-textured surface could be used for this purpose.

10.8
Conclusions

As explained in some detail in the previous sections, there is an increasing frequency of occurrence of sand and dust storms in different parts of the world and they carry considerable impacts on agricultural productivity in the near term and on soil productivity losses in the long term. Despite the growing understanding of the problem and the need to counter it on an urgent basis, there are very few examples of comprehensive long-term implementation strategies to combat sand storms and dust storms. Past efforts in this regard have met with limited success because of lack of involvement of affected communities in planning and implementing the strategies to combat wind erosion. Given the complexity of the problem wind erosion control strategies need an integrated participatory and interdisciplinary approach that must be based on maintaining soil fertility; adoption of better crop and land management practices; development of policies to address land carrying capacities, land tenure and soil conservation; increased awareness of farmer perceptions, and a better understanding of local knowledge. Wind erosion is not just a local problem, but has regional and even global implications. Hence information should be collected from national and inter-governmental agencies concerning past successes at the national and regional levels, and the conditions and criteria conducive to ensure the success of future projects should be highlighted.

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Disaster Reduction Planning and Response: The Example of National Drought Policy in USA

Raymond P. Motha

Abstract Severe droughts have occurred frequently in various parts of the United States throughout the 20th Century. These natural disasters caused severe hardship not only on the agriculture sector of society, but also on the entire socio-economic infrastructure. Until recently, governments and relief agencies responded to a drought disaster from a crisis perspective in a purely reactive approach. However, a comprehensive disaster management approach has emerged over the past decade, shifting from reactive relief to proactive risk management. Risk management is based on preparedness and mitigation measures. Interagency collaboration led to the development of a coordinated national drought policy.

11.1 Introduction

Natural hazards are inevitable. Floods, cyclones, wildfires, and droughts are normal occurrences in the natural environment. Disasters, however, result when human activity such as farming and its associated environment intersect with the natural hazards. The growing toll of disasters around the world presents a major challenge for public policy, scientific research, and their interactions. Policy seeks to reduce the human and economic effects of disasters; research seeks to provide the knowledge and tools that can contribute to the effectiveness of the policy. Challenges emerge in the face of societal trends that are converging to increase the likelihood, magnitude, and diversity of disasters. Growing populations, which increase economic and technological interdependence, enhance the increasing threat of disasters.

The severity and nature of the impact of a disaster depend on a range of factors including the type of hazard, the size of the economy and its socio-economic structure, and the sectors affected by the disaster. With respect to hazard types, droughts are often referred to as creeping disasters for their slow development and highly variable impacts on different sectors of society. Their lengthy duration creates significant hardship, especially on the agricultural sector. The loss of crops and livestock, increased wildfire potential, and reduced water supplies caused by drought can have a devastating effect on the economy. In contrast, sudden onset disasters such as tropical cyclones, floods, and blizzards can also have a direct impact on the physical infrastructure and productive resources as well as the socio-economic infrastructure.

Severe droughts have affected various parts of the United States frequently during the 20th Century. In the 1930's, a nearly decade-long drought affected more than 60 percent of the nation, turning millions of hectares of fertile agricultural land into the Dust Bowl across the Great Plains. Hensen et al. (1999) ranked this extreme event as the nation's top weather event of the 20th century. The drought caused a huge migration from the Southern Plains to California and resulted in a major federal agricultural policy. Drought returned to the Plains and the Southwest in the 1950's, claiming millions of cattle. Record drought created severe water shortages in the heavily populated Northeast in the early 1960's. Prolonged drought hit the Pacific Northwest from the mid-1980's to early 1990's, with a severe agricultural drought in the Midwest and the Southeast in 1988.

Drought is perhaps the most obstinate and detrimental of nature's extreme events. It can last much longer and extend across much larger areas than cyclones, tornadoes, floods, and earthquakes. At its most severe, drought creates vast, windblown dust bowls eroding the landscape, damaging terrestrial and aquatic wildlife habitat, contributing to widespread wildfires, and causing hundreds of millions of dollars in economic losses. It brings hardship to all water-dependent enterprises. In many small communities, downturns in farming and ranching have a crippling effect throughout the business and economic community. In large managed river basins and water systems, drought creates or exacerbates water conflicts, notably between agriculture against municipal populations, and water for direct human use against water for ecosystems.

11.2 Disaster Management: Shift from Reactive to Proactive Management

The paradigm in disaster management theory and practice has shifted over the last several decades. Until recent decades, disasters were viewed as on-off events and responded to by governments and relief agencies without taking into account the social and economic implications and causes of these events. It was a purely reactive approach to a crisis in response to a natural disaster.

Over the past few decades, a more comprehensive disaster risk management approach has emerged. Disasters are no longer viewed as extreme events created entirely by natural forces but as complicated unresolved problems of development influenced by physical, social, and economic factors as well. The evolution from reactive relief to proactive risk management has begun to influence the way disaster programs are now being planned and implemented. Risk management is based on preparedness and mitigation measures. Preparedness is designed to increase the level of pre-disaster readiness or improve operational and institutional capabilities for responding to a drought episode. Mitigation refers to both short-term and long-term actions, programs, or policies implemented during or in advance of drought that reduce the risk to life, property, and productive capacity.

Proactive disaster management, focusing on reduction of disaster risks, can contribute significantly toward protecting vulnerable communities, the lives of their inhabitants, the assets and livelihoods. Hazard mitigation, which is defined as sustained actions taken to reduce or eliminate long-term risk from hazards and their effect, is an integral part of a proactive drought management plan.

A significant trend, which has emerged during the shift to risk management, is the focus away from top-down and to a bottom-up approach. Wilhite, et al. (1986) noted that, due to the complex federal bureaucratic structure in the United States, successful drought planning efforts would most likely be initiated at the state level. This has been the emerging and successful trend. Communities are taking on a much stronger role in disaster management to reduce risk. Thus, aid and development agencies are finding new approaches to disaster management that attempt to merge the disaster reduction strategies defined by policymakers with the needs and resources of the local community, where eventually the success or failure of disaster management activities will be tested. Community-based disaster management can be seen as risk reduction programs designed primarily by and for the people in certain disaster-prone areas. The most effective way to ensure that appropriate actions are taken well before the hazardous event occurs is for the preparation and implementation of a comprehensive hazard mitigation plan.

Disaster mitigation using government and institutional interventions alone is insufficient because little attention is addressed to the community-level dynamics, perceptions, or priorities. At the same time, local communities are often either unaware of these formal disaster management interventions or find the interventions inappropriate to their specific needs. In fact, a recent WMO publication (WMO TD No. 201) provides an excellent overview of the agrometeorological aspects of drought and desertification, and addresses some of the latest literature on adaptation issues, drought management, and drought policy. This report notes that the reactive crisis management approach has been criticized by scientists, government officials, and many relief recipients as inefficient, ineffective, and untimely. This approach does not promote self-reliance, and in fact, it may increase vulnerability to drought as well to other natural hazards.

Another reason for implementing community-based approaches is that communities are knowledgeable about the disasters happening in their environment and, in some cases, able to anticipate them. They may not be scientific, but the insight of experience and indigenous knowledge are resources to be recognized and acknowledged. Hazard mitigation planning is, therefore, a collaborative process whereby hazards affecting the community are identified, vulnerability to the hazards is assessed, and consensus reached on how to minimize or eliminate the effects of these hazards.

A number of individual states and local governments include drought in their comprehensive water management, land-use, and long-term planning strategies. It is the local entities that know best how to communicate with their local populations to deal with specific risk management issues.

11.3
Rationale for a Coordinated National Drought Policy

Natural disasters such as droughts, pose severe threats to the social and economic well-being of the nation and their occurrence can cause severe economic hardship for many years after the event. Thus, it is imperative to shift to mitigation approaches to help reduce the impact of droughts. Such mitigation methods are based on scientific knowledge about the hazards and on technical means for countering their effects. Their implementation requires an effective partnership of all stakeholders. Thus, scientists and engineers must join with economists, insurers, politicians, and other decision-makers to make vulnerable communities more disaster resilient.

Disasters generally lead to immediate emergency responses but as time passes, the memory and need for preparedness fades, leaving communities just as unprepared for the next natural disaster. To develop safer, sustainable communities, it is necessary for these communities to become more knowledgeable about dealing with disasters. Given the increasing complexity of community living and the high-consequence risks that these communities are subjected to, the gathering and sharing of relevant disaster-related knowledge needs to be undertaken in a systematic and effective manner. An important role of scientists and natural disaster managers is to develop a culture of knowledge-based management within communities that effectively contributes to risk management and sustainability. The goal should be to help communities become aware of their own specific needs, so they can generate and share knowledge about natural disaster risk management. Equally as important, the community should not develop a dependence on external groups to always undertake this role.

With greater access to data bases, products and information on the Internet and the World Wide Web, a more integrated approach to data base development is needed at the national and regional levels to support risk assessment and natural disaster reduction. Sharing of data, resources, and knowledge-based tools are a cost-effective means of aiding community programs in natural disaster reduction and mitigation of extreme events. Access to these resources can also support the development of a knowledge management framework and standard for natural disaster reduction for communities.

Government agencies must provide these fundamental integrated data management systems as they are beyond the scope of local communities. While these agencies have the ability to manage data sets needed for risk management, to provide the analytical tools for assessment, and to deliver on-line telecommunications infrastructure, effective risk reduction and mitigation requires the active engagement and contribution of the local community. Natural disaster management agencies cannot achieve these results by themselves because the causes of risks are commonly in areas beyond the scope of practice or responsibility of the agencies. Thus, it is essential that a close working relationship is established and maintained for coordination of the disaster management plan between government agencies and local communities.

What is the plan of action for disaster management preparedness? Mitigation embraces all measures taken to reduce both the effect of the natural hazard itself and the vulnerable conditions to it, in order to reduce the scale of future disasters and their impacts. Mitigation also includes measures aimed at reducing physical, economic, and social vulnerability. Mitigation measures can be active or passive. Active measures are those that rely on providing incentives for disaster reduction. They are usually more effective than passive measures that are based on laws, controls, and responses to a disaster. The context within which disaster management and planning operates and is organized is referred to as structural mitigation measures. These decision-making activities include the preparation of preparedness plans, training and education, public awareness, evacuation plans, warning systems, and land use planning. Wilhite (1987) developed a well-coordinated plan of action for integrating various levels of government and various socio-economic and political entities into a drought policy, including management, mitigation, and preparedness strategies.

While drought is a normal part of climate for virtually all regions of the United States, it is of particular concern in the West. Any interruption of the region's already limited water supplies over extended periods of time can produce devastating impacts. Records indicate that drought occurs somewhere in the West almost every year. However, it is the multi-year drought events that are of the greatest concern to water planners, natural resource managers, and government policy makers.

Following initial action of the Western Governors' Association (WGA) in response to the 1995–1996 drought, the Western Drought Coordination Council (WDCC) was formed in February 1997 with federal agencies, the National Association of Counties and the WGA.

The goal of the WDCC was to improve the planning, communication, data, and response with regard to the management of droughts (The Western Drought Experience Report, 1999). Water scarcity continually defines and redefines the West. The steady growth that has been characteristic for much of the West created increased demands for agricultural, municipal, and industrial water supplies. Furthermore, such competing demands as the public's rising concern for meeting "quality of life" and environmental objectives create water supply management challenges in times of normal precipitation. Drought exasperates these challenges.

The WDCC worked to address a range of drought-related issues. It became increasingly clear that to achieve the goals, a national drought policy must be enacted. A comprehensive vision for future drought monitoring, mitigation, and response is essential. In the WDCC report (1999), it outlined a comprehensive, coordinated, and integrated approach that was needed to address future droughts. It included the following critical elements: monitoring/assessment/prediction; preparedness and mitigation; response; and communications. The monitoring/assessment/prediction element provided for the development of a comprehensive system to collect, analyze, and disseminate data, including onset, severity and termination of drought. Preparedness and mitigation provided a framework that assisted all levels of government and water agencies with assessing their vulnerabilities; provided incentives for a variety of preparedness actions, policies and mitigation options that can facilitate improved cooperation among all levels of government and promote individual responsibilities in planning for and mitigating drought impacts; and provided policy to promote drought contingency planning, emphasizing a more proactive, anticipatory approach to drought management. Response enhanced the current capability of the federal agencies, states, localities, and tribes through a variety of appropriate policies and programs to strengthen intergovernmental partnerships, response management, and customer service. Communications encouraged the use of a variety of communication tools to identify and use drought-related information networks to facilitate the exchange and dissemination of drought-related information.

This national framework must utilize risk-based analysis that provides for a greater opportunity to implement cost-effective policies.

The WDCC recognized that it was imperative to establish key partnerships among diverse sectors of society, including research institutions; local, regional, and national public-sector decision-making bodies; and public and private sector organizations. Active involvement, forward thinking policy, and coordinated action by multi-disciplinary partnerships were needed for a sustainable national plan.

11.4 National Drought Policy Commission

The United States has had no national drought policy. Over the years, from a national perspective, it has been a patchwork approach to risk management with the federal government responding to a drought emergency during a crisis. In fact, crisis management, rather than planning and proactive mitigation measures, often characterized the federal role to drought management. However, drought occurs frequently somewhere in the country with severe drought causing major economic hardship nearly every decade or two. Yet, each time drought occurs, many of the same issues are raised. How much damage is inflicted, on whom, and where? The response is to react to the crisis after the event and after evaluating the impact of the event on the economic sector of the nation. The impacts of drought were enormous. For example, the federal government spent $ 3.3 billion responding to the 1953–56 drought. The federal drought response cost at least $ 6.5 billion during the 1976–77 drought. Riebsame et al. (1991) estimated that the 1987–89 drought in the United States caused $ 20 billion in agricultural and forest production losses with an additional $ 10 billion loss associated with increased food costs. Thus, extraordinary federal expenses for drought along over the 1952–88 period averaged over half a billion dollars per year.

These were direct costs. There were other costs involved as documented by Riebsame, Changnon, and Karl (1991). The reductions in crop production and increases in food prices, associated with drought episodes, have a ripple effect across the local and regional economies. Low flows in the major river systems cause barge-shipping prices to substantially increase. Finally, poor crop harvests impact local and state employment, adversely affecting the economy.

Finally, in 1998, after several years of debate on national drought policy, recognition was given to the fact that the United States had no consistent, comprehensive policy driving the federal role to help reduce the impact of drought. The United States Congress passed the National Drought Policy Act in 1998 stating that this nation would benefit from a national drought policy based on preparedness and mitigation to reduce the need for emergency relief.

A national drought policy should be directed toward reducing risk by developing better awareness and understanding of the drought hazard and the underlying causes of society vulnerability. The principles of risk management can be promoted by encouraging the improvement and application of seasonal forecasts, developing integrated monitoring and drought early warning systems and associated information delivery systems, developing preparedness plans at various levels of government, adopting mitigation actions and programs, and creating a safety net of emergency response programs that ensure timely and targeted relief.

The Act created the National Drought Policy Commission, recognizing the need to prepare for and lessen the severe impacts of drought on the American people and the environment. The Commission was to advise Congress on formulation of national drought policy based on preparedness, mitigation, and risk management rather than on crisis management. It also directed the Commission to present a strategy to integrate federal programs with ongoing state, local, and tribal programs into a comprehensive national policy.

The missions of the Commission were: to determine what needs exist on the federal, state, local, and tribal levels to prepare for and respond to drought emergencies; to review all existing federal laws and programs relating to drought; to review pertinent state, local, and tribal laws and programs relating to drought; to determine what differences exist between the needs of those affected by drought nd federal laws and programs designed to mitigate the impacts of and respond to drought; to collaborate with the Western Drought Coordination Council and other appropriate entities to consider regional drought initiatives and the application of such initiatives at the national level; to recommend how federal drought laws and programs can be better integrated with on-going state, local, and tribal programs into a comprehensive national policy to mitigate the impacts of and respond to drought emergencies without diminishing the rights of states to control water through state law and considering the need to protect the environment; to recommend how to improve public awareness of the need for drought mitigation and response by governmental and nongovernmental entities, including academic, private, and nonprofit interests; and, to recommend whether all federal drought preparation and response programs should be consolidated under one existing federal agency and, if so, identify such agency.

The Commission conducted a number of public hearings and meetings to examine the far-reaching impact of drought. What makes this issue even more complex is the very definition of drought, or, more specifically, the lack of a single definition that is applicable to all segment of society. In the Commission's final report (National Drought Policy Commission, 2000), a generic definition states that "drought is a persistent and abnormal moisture efficiency having adverse impacts on vegetation, animals, or people." However, there are meteorological, hydrological, and agricultural definitions of drought that are specifically related to those disciplines. Declarations of drought are often triggered by specific and well-defined conditions, such as specific reservoir levels on a specific date. In some cases, there are well-defined exit points that trigger a resumption of normal activity. These drought triggers become a practical definition of drought for a particular region and for specific sectors of society. Defining these triggers is an inseparable part of planning for and responding to droughts. Once these triggers are defined, a region is much better able to estimate the costs, expected frequency, and risks of drought response.

However, in reality, drought is defined differently in different situations. For example, two months without rainfall during the growing season may result in serious drought conditions in sub-humid climates. This same period of dryness may be normal in semi-arid climates, where water reserves must be used for crops adapted to that region. National drought policy must therefore define drought so that it meets the needs of diverse water users and for diverse functions. It must be flexible enough to include a variety of drought situations. It must also be specific enough to distinguish between those situations that are true drought emergencies and those that are normal cyclical conditions. All of these factors must be accounted for in any definition but it clearly illustrates the need for careful evaluation at the regional level of the most appropriate triggers for a drought declaration and a drought termination.

The Commission reported a number of findings based on its extensive study (Final Report, 2000). Preparedness is a fundamental concept in a national drought policy. Preparedness includes drought planning, plan implementation, proactive mitigation measures, and public education. The Commission found that preparedness may well reduce the social, economic, and environmental impacts of drought and the need for federal emergency relief expenditures in drought-stricken areas. A variety of entities are engaged in some form of drought preparedness, ranging from individuals, citizen organizations, local and state governments, tribes, and regional bodies. This planning is often conducted within the framework of comprehensive water management planning by entities ranging from water districts and large multi-county urban areas to state water resources agencies and regional river basin commissions. The Commission, at the time, found that about 30 of the 50 states in the United States had drought plans, with most on oriented toward relief rather than toward preparedness (that number has now increased to 35). The assessment revealed that in most states, drought responsibilities are normally located in the agencies that are responsible for the functions of agriculture, natural resources, water management, environment, or emergency management. Fewer than five states have independent, designated drought coordinators, while more than 20 states have drought task forces.

Regional entities generally comprise several states with a common geographic boundary or water management jurisdiction such as a river basin. It is clearly evident that regional drought planning or incorporation of drought concerns into comprehensive regional water management plans is essential for any strategy to be successful. For example, in June 1965, during the peak of a serious drought in the northeastern United States, New York City stopped releases from its Delaware River reservoirs to maintain its withdrawal rate. With less fresh water flowing past the city of Philadelphia, there was a risk that salt water would be drawn into that city's water supply system. President Lyndon Johnson convened a special meeting of governors and majors from the Delaware Basin that led to emergency measures for managing the Delaware River.

While larger government entities can address the major issues related to drought, counties, towns, and rural areas must deal with the emergencies and respond to the disasters. These areas are facing suburban growth and development, which are increasing the demand for water and creating greater competition for available water. Local governments must be able to plan for future needs, but they need the technical data, tools, and resources to develop and implement these plans. Local governments must also inform and educate the local population about the need for drought planning, especially when an emergency is not imminent. It is at the local level where the most efficient and direct communication channels can be established to keep the population informed of drought emergencies that may be directly affecting a particular area.

Tribal lands in the western United States have experienced the vagaries of climate for many thousands of years, and the scope of tribal drought issues in current times is immense. There are 306 federally recognized tribes within the conterminous 48 states, with 289 of those west of the Mississippi River, where 95 percent of all tribal trust land is located. A total of six tribes were found to be developing drought contingency plans through cooperative agreements with the federal government. It is within these rural areas that the Commission found the least available information that is critical to basic drought planning. Some tribes lack access to basic weather data that is essential not only for planning but also for triggering emergency response efforts.

The Commission found that, in response to drought challenges over the years, Congress created a number of federal programs to lessen the impacts of drought. In fact, 88 drought-related federal programs were funded from 1988 to 1998 long, and were spread over a number of federal departments and agencies. The programs were classed into four broad program categories: 1) preparedness, including planning and mitigation; 2) information, including monitoring/prediction and research; 3) insurance; and 4) emergency response. Of these programs, 7 provide assistance for drought planning, 42 for drought mitigation, 22 for drought monitoring/prediction and research, and 47 for response. These total more than 88 because some programs cover more than one facet of drought. A major criticism heard at meetings and public hearings was that the federal action was primarily an ad hoc approach to drought. Moreover, limited authorities and funds as well as lack of coordination among and within federal agencies hindered planning efforts.

Based on guidance from the Commission findings, the development of a national drought policy included the following key principles. First, the policy favors preparedness over insurance, insurance over relief, and incentives over regulation. Second, research priorities need to be set based on the potential of the research results to reduce drought impacts. Finally, it is essential that there be coordination of delivery of federal services through collaboration with all non-federal entities.

This policy requires a shift from the traditional emphasis on drought relief following a natural disaster. Preparedness must become the cornerstone of the national drought policy. To achieve this objective, the pooling of non-federal and federal experience and the establishment of non-federal/federal partnerships must be nurtured to develop the tools needed to formulate drought preparedness strategies, including the incorporation of environmental concerns.

The Commission recommended that Congress pass the National Drought Preparedness Act that would establish the non-federal/federal partnerships through a national drought council. The primary function of the council would be to ensure that the goals of the national drought policy are achieved. The five goals are briefly summarized:

Goal 1: Incorporate planning, implementation of plans, and proactive mitigation measures, risk management, resource stewardship, environmental considerations, and public education as the key elements of effective national drought policy.

Goal 2: Improve collaboration among scientists and managers to enhance the effectiveness of observation networks, monitoring, prediction, information delivery, and applied research, and to foster pubic understanding of a preparedness for drought.

Goal 3: Develop and incorporate comprehensive insurance and financial strategies into drought preparedness plans.

Goal 4: Maintain a safety net of emergency relief that emphasizes sound stewardship of natural resources and self-help.

Goal 5: Coordinate drought programs and respond effectively, efficiently, and in customer-oriented manner.

A sound national drought policy can be derived from the development and implementation of these five goals. Testimony and expert analyses presented to the National Drought Policy Commission was convincing that most levels of government and most of the private sector were not adequately prepared for drought. The basic components of the first goal focused on coordinated drought preparedness programs to lessen the need for future emergency financial and other assistance. Basic components of preparedness include long-term planning, implementation of proactive mitigation measures, risk management, resource stewardship, environmental considerations, and public education.

The second goal acknowledged the essential value of observation networks, monitoring, prediction, and information gateways and delivery, and research to drought preparedness. A significant recommendation was the proposal for a drought data monitoring, prediction, and research summit of multidisciplinary, geographically diverse representatives to ascertain the needs and expectations of all concerned. Research priorities should address the impacts of drought non-irrigated systems, aquatic ecosystems, wildlife, and other aspects of the natural environment, including the potential negative impacts of drought mitigation measures.

The third goal promotes a risk management strategy to complement preparedness measures. Prolonged drought episodes cause risks that the best preparedness measures may not adequately address. The federal government offers a crop insurance program for some crops that does promote a financial strategy to cope with drought. However, the program does not cover all crops, nor does it cover livestock. Testimony presented to the Commission also indicted that programs were administered differently across the country. A major recommendation was to evaluate the crop insurance program to ensure that sound insurance and financial strategies will help the country move away from relying on emergency relief in response to widespread drought.

The fourth goal recognizes that over time, efforts at drought preparedness, including risk management, can greatly reduce, but not eliminate, drought-related emergencies. Response measures for drought emergencies can also be useful to respond to water shortages not caused by drought. Thus, the Commission acknowledged that a safety net of responsible emergency relief measures must be incorporated into the national drought plan.

Finally, the fifth goal recognized that federal drought programs are a collection of initiatives managed by different departments and agencies. Every analysis of past responses to major droughts notes that these programs need to be better coordinated and integrated. From this repeated lesson of past history, the Commission urgently recommended the permanent establishment of the National Drought Council that would formally oversee development of the national drought policy.

Several important points are to be emphasized from this major commission report. The enactment of legislation for a national drought policy recognizes the value and importance of observation networks and monitoring and prediction and information delivery systems as fundamental components of a drought preparedness strategy. Applied research that is focused toward operational applications at the regional and local levels must also be part of the strategy. Public education programs for effective drought preparedness at the community level is essential for current awareness and a proper understanding of the effort, scope, and purpose of the undertaking. Throughout the public hearings and meetings it was clear that there must be better coordination between non-federal entities and federal agencies to ensure that the key elements of an effective national drought policy are implemented. The commission endorsed the United States Department of Agriculture as the permanent federal co-chair of the National Drought Council. The fact that the Department of Agriculture was given the lead role recognizes the importance of agriculture in many facets of this natural disaster.

11.5
U.S. Drought Monitor

The National Drought Policy Commission found that about 22 federal programs have some responsibility for drought monitoring, prediction, and research. In relation to monitoring and prediction, these programs focus on weather patterns, climate, soil conditions, and streamflow measurements. Examples of three major networks are the Department of Agriculture's Soil Climate Analysis Network (SCAN)/Snow Telemetry Network (SNOTEL), the National Oceanic and Atmospheric Administration/National Weather Service's Cooperative Observer Network (COOP), and the U.S. Geological Survey's streamgaging and groundwater monitoring network. Federal programs often join with universities, private institutions, and other nonfederal entities to provide additional information. This is especially crucial for agriculture as data observation networks are often sparse in rural agricultural areas. It is well recognized that comprehensive weather, water, soil moisture, mountain snow amount, and climate observations are the foundation of the monitoring and assessment activity that alerts the nation to impending drought.

The vigorous debates and discussions during the National Drought Policy Commission meetings helped to formulate an important new operational drought product. This product was important to develop as it became the first prototype tool to integrate the basic data on current conditions and translate these data into meaningful information to the user community. The emergence of the U.S. Drought Monitor (Svoboda et al., 2002), established in 1999, was a major advancement in drought monitoring products. The Drought Monitor classifies drought severity into five categories. The category thresholds are determined from a number of indicators, or tools, blended with subjective interpretation. The United States Drought Monitor was developed as an operational tool for monitoring drought conditions, including aerial extent, severity, and type, around the country. The Drought Monitor has become a highly successful tool for assessing the development and duration of drought conditions. The U.S. Department of Agriculture, Department of Commerce, and National Drought Mitigation Center publish the map and text weekly and post them on the Internet (http://drought.unl.edu/dm). The product serves as an exemplary case of interagency cooperation. A major strength of the Drought Monitor is its inclusion of input from climate and water experts from around the country.

The Monitor requires a major collaborative effort to pull together the various sources of weather data and compile them in a single, comprehensive, operational, national report. The map not only delineates stages of drought but also specifies drought type when the impacts differ. For example, if severe drought affects wildfire danger and water supplies, but is not in a significant agriculture area, then the map would depict W (water) and F (wildfire danger) only. If drought affected a major crop area, that area would be denoted with "A" for agriculture. The map also reflects forecast trends. If the forecast of drought is expected to intensify, a "+" is depicted in affected area. Similarly, if the forecast calls for rain to diminish drought conditions, a "–" is depicted in the affected area. No change in the drought classification forecast is depicted by no sign. The text of the Monitor provides a detailed discussion of the map.

The Drought Monitor itself is not an index, nor is it based on a single index, but rather is a composite product developed from a rich information stream, including climate indices, numerical models, and the input of regional and local experts around the country. No single definition of drought works in all circumstances (Wilhite, 2000). Water planners and agricultural producers may rely on completely different sets of indicators. The Drought Monitor authors must rely on a number of key and ancillary indicators from different agencies. The map fuses these indicators, using human expertise from across the United States, into an easy-to-read image presenting a current status of drought conditions. The Drought Monitor process is an evolving one as new, or better, indicators and information sources become available.

Lead responsibility for preparing the Drought Monitor rotates among nine authors from four agencies who sequentially take 2 to 3 week shifts as the product's lead author. Nationwide experts respond to the lead author's first draft when it arrives by Internet and through an email list-server every Monday. An interactive process continues until the final product, both map and text, are released on Thursday morning.

Classification of drought magnitude in the Drought Monitor is based on farm levels using a percentile approach. The percentiles are standardized for the year rather than for all times of the year at once. They are not meant to imply an average areal extent value for the United States at any given time. The categories include: D0 (abnormally dry), 21 to 30 percent change of occurring in any given year at a given location; D1 (moderate drought), 11 to 20 percent chance; D2 (severe drought) 6 to 10 percent chance; D3 (extreme drought), 3 to 5 percent change; and D4 (exceptional drought), 2 percent or less change.

The Drought Monitor's severity categories are based on six key physical indicators and many supplementary indicators. The indicators are the Palmer Drought Severity Index (PDSI; Palmer 1965); CPC Soil Moisture Model Percentiles (CPC/SM); Huang et al. 1996); U.S. Geological Survey (USGS) Daily Streamflow Percentiles (http://water.usgs.gov.waterwatch/); Percent of Normal Precipitation (Willeke et al. 1994); Standardized Precipitation Index (SPI; McKee et al. 1993); and remotely sensed Satellite Vegetation Health Index (VT; Kogan 1995).

Ancillary indicators include the Palmer Crop Moisture Index; the Keetch–Byram Drought Index (KBDI; Keetch and Byram 1968); evaporation-related observations, reservoir and lake levels, and ground water levels; USDA field observations of surface soil moisture; and USDA snowpack and snow water equivalent measurements.

Classification of drought impact types is also included in the Drought Monitor. The categories include agriculture (crops, livestock, range, and pastures), water (streamflow, snowpack, groundwater, reservoirs), and fire (wildfire – forest and range fires). Crop stress is often the earliest indicator of a developing drought situation because of the plants need for moisture and moderate temperatures during critical phases of development. On the other hand, hydrological impacts of a major drought often linger for months or even years after agricultural concerns disappear. Thus, it is essential to monitor the evolution of drought types as well as overall conditions.

Finally, as mentioned earlier, a significant key to the outstanding success of the Drought Monitor is the process of gleaning information from many experts located across the country. Their input and verification of impacts at the regional and local levels is critical in both the production of the Drought Monitor and in establishing and maintaining the credibility of the product. These experts include regional and state climatologists, agricultural, and water resource managers, hydrologists, National Weather Service field office employees and others. The list of expert reviewers has grown to nearly 150. A Drought Monitor Workshop is held annually to allow all participants to meet and share ideas for improvement in the process and the product. The Drought Monitor is a dynamic product that is constantly searching for more timely and better indicators to assist the user community. This user community ranges from a farmer to a government policy maker.

11.6 Latest Developments

The Drought Monitor is an important step forward. However, many observations and information products on drought are currently being gathered, developed, and provided by a variety of federal, state, and local entities. The information is not comprehensive, not integrated, not easily accessed, and not readily usable to users. The integration of relevant information is important to customers of water/drought information in order to make proactive decisions on the impact of drought at state, regional, tribal, and local levels. The current Drought Monitor provides information and serves as an excellent prototype in displaying data and information for users but does not include all sources of information and does not provide for an interactive format for users to query data and analyze options for decisions at the regional and watershed scales.

It is envisioned that users will be able to easily access new a set of tools (databases, GIS products, maps, web-based educational material) and be able to use those tools in an interactive query-based process to analyze decision options for proactively responding to drought. This information system will promote scientific information for a variety of decision-makers that will enhance the adaptive capacity for the management of water resources, result in enhanced planning and preparedness for drought, and minimize the economic and ecosystem losses associated with drought. The National Drought Preparedness Act of 2003 includes a proposed National Integrated Drought Information System (NIDIS), which is defined as a comprehensive drought information system that collects and migrates information on the key indicators of drought, including forecasts, in order to make usable, reliable, and timely assessments of drought conditions.

While long overdue, the deliberations of the Commission and the successful implementation of the U.S. Drought Monitor have laid the foundation for active partnerships among key federal and nonfederal institutions involved in drought management. However, a comprehensive national drought policy still awaits congressional enactment.

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CHAPTER 12

Agricultural Drought Policy and Practices in Australia

William J. Wright

Abstract This Chapter describes recent events in the development and application of a national drought policy in Australia. Prior to the 1990s, Government assistance to drought-affected farmers and pastoralists was based on the assumption that drought was an unpredictable natural disaster. A paradigm shift towards the present policy of "self reliance" occurred in the early 1990s. Under this policy, farmers were expected to be able to manage through most droughts, with Government assistance only available in the event of droughts of unusual length or severity – so-called "exceptional circumstances." Details of the policy, and its application in, and following, drought situations, are briefly outlined.

Illustrated by the experience of 2002–03, one of Australia's worst-ever droughts, we show that the development of drought policy in Australia is an ongoing process, in which attempts to apply aspects of the policy in practice generally reveal deficiencies, leading to subsequent modification of the policy. A review of National Drought Policy conducted by the Australian Government after the 2002–03 drought generated a number of recommendations. Among these were: the nearly universal endorsement by stakeholders that proactive drought preparedness measures should be encouraged by Governments; and that improvements were needed to the reliability of seasonal predictions, with calls for better-coordinated research into climate variability, and better presentation of prediction information.

The Chapter also describes changes in water management policy in Australia, which also underwent a fundamental change during the early 1990s. Case studies are provided of certain aspects of the policy, including the application of water entitlements in rural areas, and water restrictions in urban areas.

The Chapter discusses some likely future developments, including discussion of the possible implications for drought policy posed by future climate change.

12.1 Introduction – Past Policy

Australia is fortunate in that, unlike in many other countries, drought does not cause famine or economic collapse. Nevertheless, throughout Australia's history, drought has administered regular and often severe shocks to the country's economy, environment and socio-economic development. During the late 19th Century, and for much of the 20th Century, Australia's economy was dominated by agricultural and pastoral activities. Farm products accounted for approximately 75% of Australia's total export income during the first half of the 20th Century (Australian Bureau of Statistics, 1914 through 1918, and

1941 through 1950), therefore widespread drought exerted a major impact on Australia's economy. Although the relative importance of agricultural exports in the Australian economy has declined, major droughts (such as 1982–83 and 2002–03) still have the capacity to significantly impact on the Australian economy (Fig.12.1), and draw heavily on the resources of Government.

For most of the 20th Century, Australia's Federal (i.e., national) and State/Territory Governments and primary producers took the view that drought was a natural disaster, similar to bushfire, floods, etc, with land managers victims of a capricious climate. The responsibility for responding to natural disasters lay (and still lies) primarily with the various State and Territory Governments (Botterill, 2003), who provided financial support for those affected by drought. When a particular area was declared drought-affected, farmers became eligible for concessional rates on transport for feed and livestock, and for loans at reduced rates of interest. State/Territory Governments would typically provide emergency water supplies, subsidies on fodder for starving stock, and projects to provide employment in drought-affected areas.

Gradually, however, the Federal Government became increasingly involved, until it was contributing substantial sums to drought relief, through Natural Disaster Relief arrangements with the States/Territories (Botterill, 2003). In his history of drought in Queensland, Daly (1994) documented the political and

Fig. 12.1. Denuded earth and dry watercourses during drought near Gunnedah, in the normally well-watered Namoi Valley region of New South Wales, during sustained drought in the early 1990s (photo c/o the *NSW Dept of Land and Water Conservation*)

community factors involved in trying to develop an equitable, compassionate basis for Government support in drought. Relief was largely provided on a subjective and *ad hoc* basis.

There were two main problems with this approach:

1. In a country like Australia, with highly variable rainfall, and where much agriculture takes place in climatically-marginal areas, drought cannot justifiably be regarded as a "natural disaster", but rather, as a natural part of the environment.
2. Although the primary purpose of drought relief was to sustain land managers, by the late 1980s there was an increasing awareness that the existing policy often inadvertently rewarded poor managers, who hadn't adjusted their land use in accord with the limitations imposed by the climate, and whose activities led to serious environmental degradation. On the other hand, land users who had wisely and skilfully managed the drought conditions, and thereby conserved the land resources, were not eligible for support.

12.2 The 1990s – Development of a National Drought Policy

A paradigm shift in Australian Government policy took place in the early 1990s. It became officially accepted that drought was not a natural disaster, but should be viewed as a natural and cyclical part of the Australian environment. Drought came to be regarded as a "business risk" (like, for instance, changes in commodity prices), and subject to sound risk management practices. Under the new policy setting, drought relief for farmers and agricultural communities would be restricted to times of so-called "*Exceptional Circumstances*". In other words, the agricultural sector was expected to cope with the occasional drought, and relief would be available only for droughts of unusual length or severity. It took some time for many farmers, and much of the broader community, to accept this new risk management paradigm.

In July 1992, a National Drought Policy embodying the new paradigm was formally agreed to by the Federal, State and Territory Governments. This Policy had three main objectives:

- To encourage primary producers and other sections of rural Australia to adopt self-reliant approaches to managing the risks stemming from climatic variability;
- To maintain and protect Australia's agricultural and environmental resource base (i.e., to limit damage in these areas) during periods of extreme climate stress; and
- To ensure early recovery of agricultural and rural industries, but in a manner consistent with long-term sustainable levels.

A key part of implementing this policy was to provide farmers with the skills and tools needed to manage with climate variability. To this end the Australian Government, through agencies such as the Bureau of Rural Sciences, the Australian Bureau of Meteorology, the Australian Bureau of Agricultural and Resource Economics, the Department of Agriculture, Fisheries and Forestry (DAFF), and various other Federal and State/Territory agencies, undertook a capacity-building program. Activities included: research into climate variability and prediction, and the application of this knowledge to agriculture; the development of improved "tools" to aid decision-making (such as decision support software packages); and awareness-raising and education programs, with emphasis on the agricultural sector (Fig. 12.2). An important part of the capacity building program was in attempting to teach farmers how to employ seasonal climate predictions as an aid to on-farm decision making. Climate predictions are mainly based on the known and strong link between climate variability – including the occurrence of droughts – over much of Australia, and the state of the El Niño-Southern Oscillation (ENSO) phenomenon (e.g., McBride and Nicholls, 1983; Nicholls, 1985). This capacity-building program is described in more detail in a companion paper (Wright, 2005).

Between 1997 and November 2002 the Federal Government provided more than $ AU 800 million to programs that could be utilised by farmers to improve their general risk management skills, including those for managing drought (Truss, 2002). On top of this amount, payments were provided under Exceptional Circumstances (EC) criteria. A number of other measures were introduced to help manage drought. For instance, to help manage the sharp year to year fluctuations in income associated with climate variability and commodity price variations, a so-called *Farm Management Deposits* scheme was introduced, enabling farmers to put aside earnings from good years to enable them to manage through, and then recover from, subsequent income downturns, including those associated with drought. There are also community support services to help farm families manage through drought.

Fig. 12.2. The 2002–03 drought stimulated public debate about whether the Australian continent could be "drought-proofed." Suggestions such as turning northern Australian rivers inland were proposed. The illustration takes a light-hearted look at the issue (Cartoon copyright: Andrew Weldon)

As noted, for severe droughts, "Exceptional Circumstances" (EC) provisions exist, to support farmers who suffer financially from the drought. In its present form, EC relief consists of interest rate subsidies for two years, and income support for up to two years. To be eligible for EC relief, the following three criteria must be satisfied:

- the event must be rare and severe (a "rare" event is defined as one occurring, on average, once every 20 to 25 years; a "severe" event is one lasting more than 12 months, and of a significant scale);
- the event must produce a severe downturn in farm income over a prolonged period; and
- the event must not be predictable, or part of a process of structural adjustment.

The key point is that a severe income downturn should result from a specific, rare and severe event (usually, but not necessarily, drought) that is beyond normal risk management strategies employed by responsible farmers. "Exceptional Circumstances" can include various events that, in combination, could be considered rare, severe and destructive, such as frost, plagues of vertebrate and invertebrate pests, and drought-followed-by-flood. Many of these occur in combination with, or are exacerbated by, prolonged drought, however by far the greatest number of applications for assistance have been related solely to drought.

The various State/Territory Governments have also continued to provide assistance packages for drought relief (with, of course, different eligibility criteria). Thus, one aspect of the application of drought policy that remains unresolved is the relative contribution of the Federal and State/Territory Governments to drought assistance payments.

12.3 Climate Services in Support of the Drought Policy

A key point in applying National Drought Policy within Australia is in assessing the climatic background to the event. As noted above, the El Niño-Southern Oscillation (ENSO) phenomenon exerts a substantial influence on Australian rainfall, and the majority of serious droughts coincide with that phase when the eastern tropical Pacific is unusually warm (El Niño), and the so-called Southern Oscillation is negative (Nicholls, 1985). An extensive public education campaign by various agencies during the 1990s, targeted especially at the rural sector, has ensured that the link between ENSO and rainfall anomalies in Australia is widely appreciated (Wright, 2005). The Australian Bureau of Meteorology, along with some State Departments of Agriculture, regularly issue seasonal predictions. The Bureau, for instance, has been issuing seasonal climate predictions since 1989, and despite some changes in methodology, the ENSO pattern remains the primary predictor. Currently, the Bureau's seasonal predictions are based on broadscale sea surface temperature (SST) patterns, which exert a strong influence on the overlying atmosphere, yet themselves change only slowly. The dominant SST pattern (Fig. 12.3) reflects the ENSO phenomenon, characterised by strong SST anomalies over the eastern and central tropical Pacific Ocean. A second predictor based on SST patterns in the Indian Ocean is also used. The Bureau has been experimenting with seasonal predictions made by coupled atmosphere-ocean models for several years: it is expected that these dynamical model predictions will become fully operational in coming years. The Queensland Department of Primary Industries also issues seasonal predictions, based on historical links between rainfall and the "phase" of the Southern Oscillation Index (whether positive or negative, combined with whether the Index is rising or falling).

Such predictions have the potential to greatly assist on-farm management. Knowing, for instance, that a dry winter and spring is likely, farmers can take actions to reduce potential losses (such as planting reduced acreages, or more drought-hardy cultivars; or graziers could decide to sell or agist stock, or pre-purchase fodder). Seasonal climate predictions are also an important source of information for Government decision-makers, as they indicate the

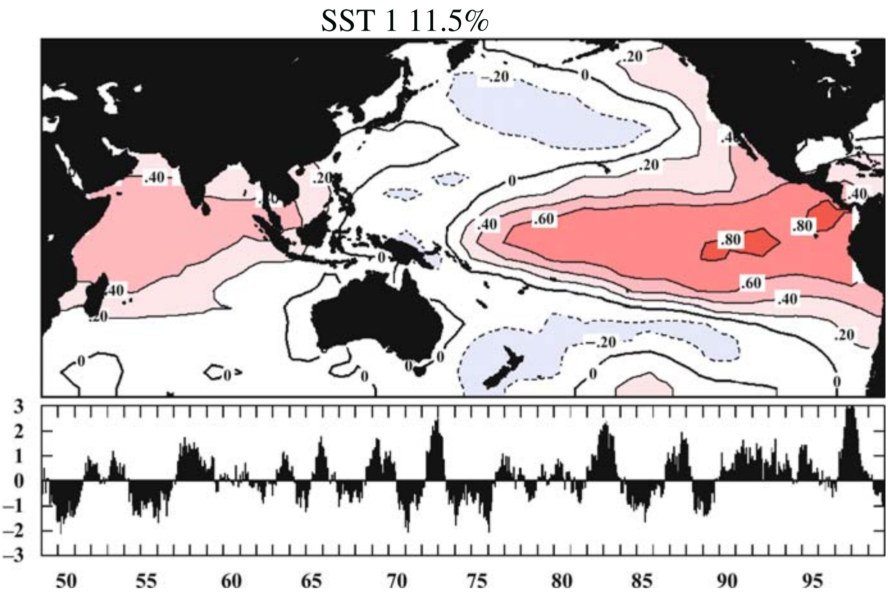


Fig. 12.3. The dominant pattern of sea surface temperature (SST) variability in the Indian-Pacific region. This pattern strongly reflects the so-called El Niño-Southern Oscillation phenomenon, and is closely related to rainfall variations over much of Australia. The time-series at bottom indicates the "strength" of the pattern in each month over the period 1949–2000. Strong positive values, when SSTs in the central and eastern Pacific are well above average (e.g., the early 1990s, and 1997), indicate El Niño conditions; strong negative (e.g., 1988–89) correspond to La Niña

likely duration of a drought, and therefore the probable "draw" on Government funds.

The Bureau also closely monitors recent rainfall patterns, and in times of drought, rainfall deficiency analyses – maps indicating where rainfall over specified periods is in the lowest 10% or 5% of recorded falls – are an important source of information for Government decision-makers. This is discussed in more detail in Sect. 12.5.

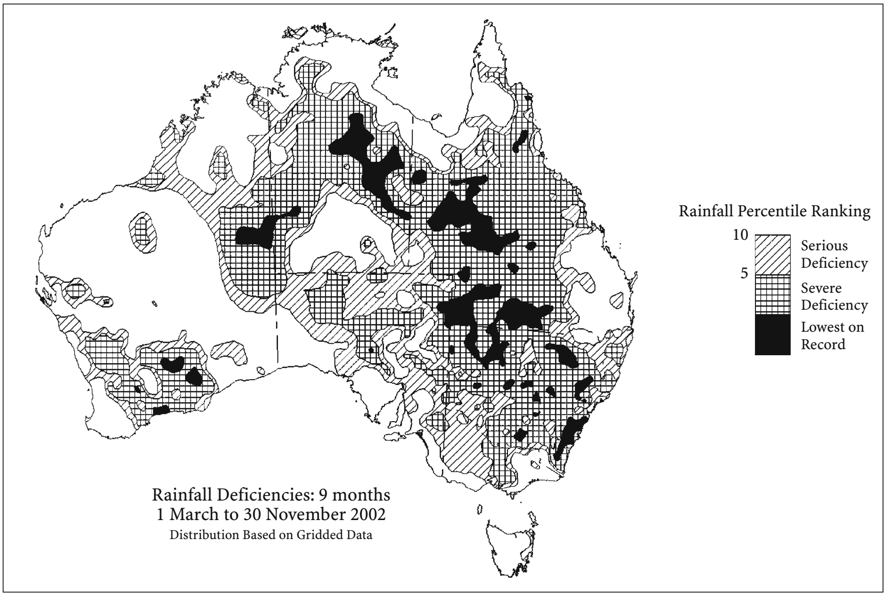
12.4 Application of the Exceptional Circumstances Policy

In applying the EC policy, the process is as follows. Applications are lodged by State/Territory Governments, on behalf of farmers, to the Australian Government. These applications are then assessed against the set of criteria described in Sect. 12.2. The assessment includes scientific and economic analyses, and involves a number of organisations. The coordination of this assessment process is handled by the Australian Government DAFF (see Sect. 12.2). If a *prima facie* case is established, an independent advisory body, the National Rural Advisory Council (NRAC: a group consisting of farmers, agribusiness professionals, and Government officials) is called on to assess the claim for full assistance. This assessment includes further scientific and economic analyses, and includes a visit to the region to assess conditions on the ground. NRAC then makes a recommendation to the Federal Government on the eligibility of the region for EC relief.

As mentioned above, rainfall deficiency maps are a crucial piece of information, as they show directly how rare an event is. It follows from the definition of percentiles that a 1 in 10 year dry spell over a given period is one in which rainfall lies within the lowest 10 percent of recorded falls, i.e., within the 10th percentile. A 1 in 20 year dry spell falls within the 5th percentile. During the 2002–03 drought, rainfall deficiencies over the period March to November 2002 were an important eligibility criterion for interim EC relief (see below). The map (Fig. 12.4) shows rainfall deficiencies over this nine month period, with hatching and cross-hatching indicating areas where rainfall was in the lowest 10th and 5th percentile respectively, and solid shading indicating "lowest on record" rainfall.

It is important to note, however, that in assessing EC claims, other measures that capture the effectiveness of rainfall are also important, such as the timing of the rainfall in relation to the growing seasons, the potential for plant growth, and the availability of water to industries relying on irrigation. The focus of these measures is to capture the impacts on agricultural industries of the rainfall deficiencies, rather than to rely on the rainfall deficiency alone as a suitable measure.

In attempting to apply these EC criteria, various issues and problems came to light, and these have driven ongoing modifications to the policy. A recurrent problem, in the 2002–03 and earlier droughts, has been how to define, fairly and objectively, those areas that qualify for support. Any definition will invariably



 Issued: 09/03/2005

Fig. 12.4. Australian rainfall deficiencies for the 9 month period March–November 2002. Deficiencies are expressed as "Serious" where rainfall for the period is in the lowest 10 percent of recorded falls; "severe" if in the lowest 5 percent of recorded falls; and "lowest on record"

at some point exclude needy farmers whose situation is identical to those on the "right" side of a boundary. This is sometimes prosaically referred to as the "lines on a map" problem. In response, the concept of "buffer" zones was introduced in 2001, in which regions immediately adjacent to the application region could also be included. (Addition of buffer zones to application areas is not, however, automatic). Another problem was financial difficulties caused by delays in processing EC applications (due to the complexity of the process). During the 2002–03 drought, the Federal Government introduced "Commonwealth Interim Income Support" payments, which provided six months of income support, and interest rate relief, to farmers in areas where a *prima facie* case was established. (Even if the application for EC support was subsequently rejected, farmers would still receive a full six months support). Relief payments were also made available to non-farm people who lose their jobs, or suffer serious reduction in income, due to drought. However, various other issues remain unresolved at this stage – for instance, there is as yet no objective means of assessing the relative severity and impacts of long-term drought.

The current situation can be summed up by saying that, in Australia, drought policy and its applications continues to be an evolutionary process, with the assessment of some circumstances (e.g., the situation where a combination of factors lead to an EC application) requiring further development.

12.5 Water Management

12.5.1 Water, Irrigation and the Environment

Soon after the introduction of the National Drought Policy in 1992, a wide-ranging program of national water reform was also introduced. Commencing in 1994, the aim was that each Australian State/Territory Government became responsible for introducing urban and rural water reforms to increase efficiency of water use. (This initiative was broadly similar to a program of reforms that the Victorian State Government had first introduced in the late 1980s). An important aspect of the water reform program was the introduction of a system of water "entitlements" by various user groups. These entitlements – which were tradeable – effectively set limits on how much water was available to an enterprise, organization or other user in any one year, taking into consideration environmental needs.

Probably the most significant of these user groups is the agricultural sector. Much Australian agriculture takes place against a background of limited, and often highly variable rainfall, and therefore access to irrigation water is vital for many Australian farming enterprises. The issue of water entitlements is particularly important in the Murray River system, in Australia's southeast, where the bulk of the nation's agricultural activity takes place. Much of this activity is underpinned by irrigation water from the Murray River in Victoria, New South Wales and South Australia – the States through which the river flows. So important has been the need for irrigation that in the past, water from other rivers, notably the Snowy River, has been diverted into the Murray, causing adverse environmental effects downstream on these "donor" rivers. With the increased value placed on environmental issues, this became a contentious matter within Australian domestic politics.

To address this issue, the three State Governments reached an agreement about appropriate flow levels for the Snowy and Murray Rivers. One agreed outcome was the need to return to the Snowy at least a portion of the once-natural flow levels. The assumption was made that the extra water needed to meet the Snowy River's "environmental" flow levels could be obtained through a program of improved water use efficiency, involving measures such as replacing open water channels (which suffer huge evaporative losses) with enclosed pipelines, and through the sponsoring of research programs aimed at improving water use efficiency in certain key industries, such as viticulture and horticulture. A similar initiative to restore environmental flow levels to the Murray River has also been implemented. Incidentally, environmental and economic issues such as this that cross State boundaries have been a "driver" in the formation in Australia of inter-governmental bodies such as the Murray-Darling Basin Commission, with representation at the Ministerial and head-of-department level.

12.5.2 Urban Water Policy During Droughts

During severe droughts, the water storages supplying urban areas – including those of Australia's major capital cities – can become depleted. This means that care must be taken to protect remaining supplies. A common response to this situation has been for the imposition of mandatory water restrictions – supplemented as necessary by other measures, such as the installation of emergency ground-water bores. Water restrictions are generally imposed on a staged basis, with progressively tougher restrictions as conditions worsen. Lower level stages restrict such activities as washing cars and filling swimming pools. Higher level stages significantly restrict outdoor water use, and even impose limits for household use. (Should these higher level water restrictions not prove sufficient to conserve water supplies, rationing may be imposed: in the severe 1982–83 drought, residents of at least one Victorian country town were restricted to just 60 litres each a day). The development of formal drought response plans has led to changes in the way these restrictions, and other elements of water management policy, have been implemented. The situation in Victoria provides an interesting case-study.

Despite a reputation for generally reliable rainfall, Victoria has experienced many severe droughts. Recent examples including those of 1967–68, 1972–73, 1976–77, 1982–83, 1997 and 2002–03. In the first four cases (prior to 1990), water authorities imposed mandatory water restrictions to domestic and public use. These restrictions were imposed on the basis of subjective estimates of the overall water supply system, and the perceived likelihood of supplies falling to dangerously low levels. Restrictions became progressively tougher as drought continued and water supply levels fell. During the 1972–73 and 1982–83 droughts, restrictions in the Greater Melbourne area reached the point where hand-held hose watering of gardens and lawns could only be carried out between 7 pm and 9 pm three days a week, with odd-numbered and even-numbered properties alternating. Bucket watering – again for just two hours a day – was permissible on days when hose watering was not allowed. The situation attracted considerable media interest, and the popular press ran stories about such topics as "bucket back" (back injuries sustained due to carting water in buckets), "dob in a water cheat" campaigns, and the popular "save water – shower with a friend" bumper stickers, which appeared during the 1972 drought.

A problem with the restriction system was the subjective basis on which various stages were introduced. The situation was often politically charged, with sometimes vigorous exchanges between water supply authorities, State/Territory Governments, and other stakeholders, and pressure from various lobby groups about the need for restrictions (Keating, 1992).

In 1994 this reactive response to drought was replaced with a planned response. Each urban water authority was required to develop Drought Response Plans for the supply systems under their control. A centerpiece was the establishment of objective criteria, or 'trigger points', for restrictions. These were threshold water storage levels, and/or streamflow levels which, when reached, would automatically lead to the imposition of water restrictions and other measures to protect existing supplies. Such a system removed the subjectivity in the imposition of restrictions. 'Trigger points' are specific to each supply region, and were generally established from simulations using long-term records of rainfall and stream-flow. In the case of the Greater Melbourne area, a four stage set of restrictions currently applies.

The other historical response to drought in Victoria was that each water crisis led to the construction of higher capacity dams, mostly to supply the Greater Melbourne area. In 1984 the construction of a large dam on the Thomson River, well east of Melbourne, was completed, with the ambitious aim of "drought proofing" Melbourne (Keating, 1992). With a normal incidence of drought, this aim may well have been achieved. However the seven and a half years between late 1996 and June 2004 saw record low rainfall over most of the catchment area supplying the Greater Melbourne area, leading to a significant decline in storage levels (Fig. 12.5). Level One restrictions were imposed on 1 November 2002, advancing to Level Two restrictions in August 2003, where they remain at the time of writing (May 2004). Many towns in country Victoria, without access to such large water supplies, have suffered water restrictions – severe in some areas – from 1997 onward. This example underlines the need to consider longer-term climate variability and change in framing water (and drought) policy, an issue revisited in Sect. 12.7 below.

It is now accepted in most Australian States/Territories that there are limits to the amount of water that can be harvested from storages. For this reason, current planning emphasizes improving the efficiency of water storage, supply and use. In rural areas, typical measures are as suggested in Sect. 12.5.1 for preserving environmental flows; in urban areas, measures include attempting to develop a water conservation ethic, increased use of recycled water, and changes in pricing.

Fig. 12.5. The height of these two bridges above the dry, baked-mud bottom of Lake Eildon reservoir, in central Victoria, during the late 1990s is testament to the impact on water storages during extreme drought episodes in even relatively well watered areas such as southeastern Australia (photo c/o Catherine Beesley, Australian Bureau of Meteorology)

12.6 The 2002–03 Drought in Australia – a Case Study

The development of El Niño conditions in 2002 was accompanied by one of the worst droughts in recorded history in Australia. In the 11 month period March 2002 to January 2003, 56% of the country recorded rainfall in the lowest decile (i.e., totals were in the lowest 10% of recorded falls for that period). Since 1900, only the droughts of 1901–02 and 1982–83 have had (slightly) higher percentages of the country in decile 1 for a comparable period. The mean percentile in the March 2002–January 2003 period, averaged over the whole country, was 17%, second only to the 1982–83 drought.

The drought had severe impacts on many farmers and rural communities throughout Australia (Fig. 12.6). Farm incomes plummeted by around 70% from the previous (admittedly favorable) year, while agricultural exports fell more than 28%. Statistically this was the worst result in the last 40 years, and perhaps the worst since Federation in 1901 (Eslake, 2003). The price of feed for livestock rose strongly in the second half of 2002, strongly impacting

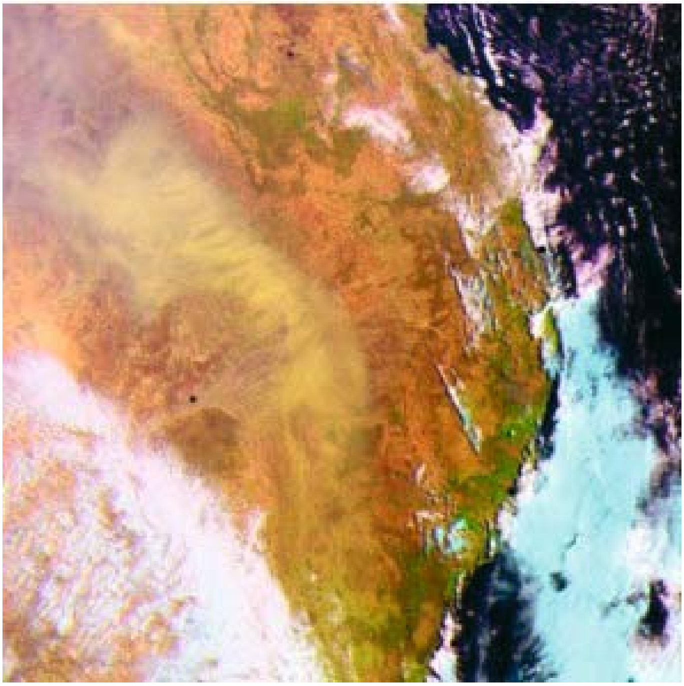


Fig. 12.6. A major dust-storm affects northern New South Wales and southern Queensland on 23 October 2003, as revealed in this satellite image showing the dust-cloud as a diffuse, buff covered area ahead of an eastward-moving frontal cloudband. The image clearly indicates the extensive nature of this dust-storm. Such storms are frequent during severe, and/or extended, drought episodes, and represent major degradation of potentially-arable land

upon the intensive livestock and dairy industries. Water restrictions were imposed in most of Australia's capital cities. The drought was exacerbated by extreme heat, with national average maximum temperatures in each of the austral calendar seasons autumn, winter and spring (March–November) 2002 exceeding by large margins the previous records (from a high quality dataset dating back to 1950). The result was that evaporation was enhanced, exacerbating the effects of the drought. There were severe bushfires: fires encroached close to Sydney, engulfed well over 1 million hectares of forested high country in northeastern and eastern Victoria, while in the nation's capital, Canberra, wildfires on 18 January destroyed 530 homes, with four lives also lost.

Despite the severity of the climatic conditions, the impacts on farmers were less severe than could have been the case, due to good antecedent conditions (i.e., abundant rainfall) over much of the country in preceding La Niña years, an overall sound economy, with low interest and inflation rates, and high export commodity prices. By contrast, some previous droughts in Australia (e.g., in 1914/15 and in the early 1940s) coincided with poor economic conditions (Australian Bureau of Meteorology, 2004). The 1901–02 drought, too, followed several years of dry conditions. Doubtless the impacts in 2002–03 would have been worse but for these inherently favourable mitigating circumstances.

With the drought worsening in the late winter and spring of 2002, the Director of the Bureau of Meteorology was required to provide as-needed briefings to appropriate State/Territory and Federal Government ministers, as well as to the heads of departments of agriculture and natural resources. These briefings consisted of updates on current conditions, including rainfall deficiencies, and the latest seasonal outlooks. This information was used as a guide to Government responses to the drought. The Bureau also provided data and regular briefings to the Bureau of Rural Sciences, whose primary involvement in the implementation of drought policy is to provide scientific advice on whether an EC application region has experienced an exceptional event, and the likely impact of this event on agricultural production. Their scientific advice was in turn provided to the Federal department of Agriculture, Fisheries and Forestry, and to the independent NRAC (see p. 201), who used it as a basis for a recommendation on eligibility to the Federal Government.

By the end of 2002, substantial areas of the country were receiving, or had applications pending, for EC relief. In December the Federal Government introduced its new Commonwealth Interim Income Support scheme (see Sect. 12.4), to support afflicted farmers pending resolution of EC claims. Additionally, in a one-off policy decision, areas suffering a one in 20 year rainfall deficiency over the nine months March–November 2002 were granted interim income support. On the basis that more than 80 per cent of farmers in the State of New South Wales fell into this category, it was decided to declare that entire State eligible for Interim Income Support, with the understanding that similar declarations would be made in other States reaching the 80 per cent "trigger".

While 2003 saw relief in many parts of Australia, drought persisted over much of the eastern States. It was not until late July/early August 2003 that the majority of the serious accumulated rainfall deficiencies finally began to be erased. However, the social, economic and environmental consequences of the drought continued to linger on, highlighting the long recovery period for agricultural activities following the end of a hydrological drought. Even after rainfall and water availability improve, it takes many months, even years, before these conditions translate into production and income, as new crops need to be sown and grown, herds rebuilt, and pasture rehabilitated. Moreover, at the time of writing (June 2004) some areas seemed to be sliding back into hydrological drought, with large areas of inland eastern Australia again experiencing severe water shortages.

Figure 12.7 shows the areas of Australia receiving EC relief as of the end of January 2004, including buffer zones. A small area in far southeastern Victoria was also eligible for Interim Income Support at that time. In February 2004 the Federal Government estimated that the cost of providing EC relief for the 2002–03 drought would amount to more than $ AU 1.2 billion – of this, the Federal Government would contribute around $ AU 1 billion up to 2006, with State/Territory Government assistance amounting to another $ AU 200 million (Australian Government, 2004).

12.6.1 Lessons Learned

The 2002–03 drought provided a stringent test for application of the drought policy, and revealed several areas where modifications were needed. To formalise this process of learning from the 2002–03 experience, the Australian Government established a Drought Review Panel to review national drought policy, taking into account the views of key stakeholders. The review looked at:

- The appropriateness of Australian and State/Territory Government drought assistance measures provided during the drought, viz:
  - the timeliness and accessibility of Australian and State/Territory assistance measures;
  - the role of financial instruments such as Farm Management Deposits and other risk management facilities.
- Key elements of future drought policy, including:
  - whether existing drought assistance arrangements should be retained, modified or replaced;
  - Alternative assistance measures, and/or drought preparedness policies, including preparations for “the next” drought (e.g., providing tax incentives for drought mitigation works, such as improving water and fodder storages);
  - Income-contingent loans for drought relief.

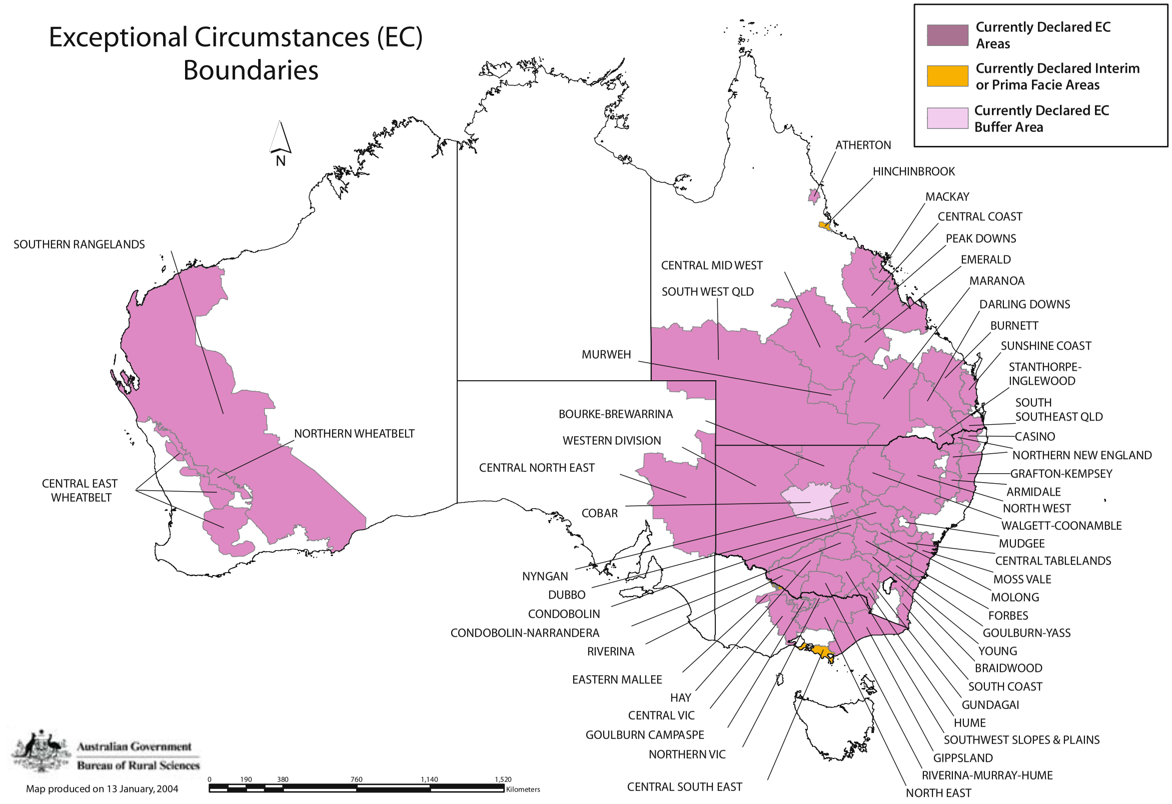


Fig. 12.7. Areas in receipt of Exceptional Circumstances relief, through declarations (*magenta*), buffer zones (*pale purple*), and Interim Income Support (*orange*), in January 2004. Courtesy of Australia's Bureau of Rural Sciences

- The adequacy of research on climate variability and its impacts on agriculture, including how seasonal predictions can be improved.

Some of the outcomes of this consultation process, which spanned the period November 2003–February 2004, are summarised in Box 12.1 (Australian Government, 2004). These reflect a need to emphasize drought preparedness, and when drought bites, for support to be directed towards welfare and community support and away from business support:

Box 12.1. Major issues arising out of a review of the 2002–03 drought in Australia. Adapted from: Australian Government, 2004: *Consultations on National Drought Policy – preparing for the future*

- Overwhelming support from key stakeholders for drought preparedness to be encouraged by Governments, and for appropriate drought preparedness measures to be a focal point of future drought policy;
- The need for clearer information about what drought assistance measures are available, and the eligibility requirements needing to be met (many stakeholders found existing information confusing, and added to tension among people already under stress);
- The need for greater consistency between States in the kinds of assistance measures applied (the measures implemented in some States were actually detrimental to farmers in other States), and also the need for agreement between States on a set of criteria for drought declarations;
- Drought assistance needed to be more timely, although it was emphasised by many that the need for assistance would be greatest during the recovery phase (e.g., for restocking);
- Equity issues, associated with both the “lines on a map” problem, and the equity issue that some industries within EC areas were eligible for assistance, while others were not;
- The need to support non-farm rural businesses and community support services, which were also severely affected by the drought. This reflects the fact that the impacts of drought are felt at all levels within a community, and have the potential to affect the future viability of the entire community (since rapid declines in population, and in access to services such as health and education, often occur in affected rural areas);
- Consideration of the special situations faced by young farmers, who could not be expected to have well-established coping procedures for managing drought, and for older farmers facing succession planning issues; and
- The need to improve the accuracy and usefulness of research into climate variability, and the reliability of seasonal predictions, for this research to be better coordinated, and for climate information to be presented in a form that could be readily understood and applied.

12.7
Relation to Long-term Climate Fluctuations

12.7.1
Cyclical Climate Fluctuations

Drought management, and EC responses to drought, are mostly aimed at managing relatively short-term droughts, associated with interannual climate variability. However Australia occasionally experiences extended periods of below average rainfall over extensive areas, on time-scales upward of five years (Fig. 12.8). Wright (2001) has described some of the more significant climate variations on decadal and multidecadal time-scales over Australia during the 20th Century, and their significant impacts on Australian agriculture and the environment.

Figure 12.9 summarises drought incidence in Australia, and indicates a number of extended episodes, including the so-called Federation drought (1895–1903); a long dry spell that affected much of the country between 1937–45; and more recently (early 1990s), an extended drought in Queensland and northern New South Wales that accompanied extended El Niño conditions in the early to mid-1990s. Each of these impacted severely on Australian agriculture, pastoral activities and the environment.

Climate scientists do not yet know why decadal and longer-term climate fluctuations occur. It may be that such periods arise simply by chance as, for example, when one throws eight heads in ten tosses of a coin. Alternatively, it has been hypothesized (e.g., Power et al., 1999) that such fluctuations could be

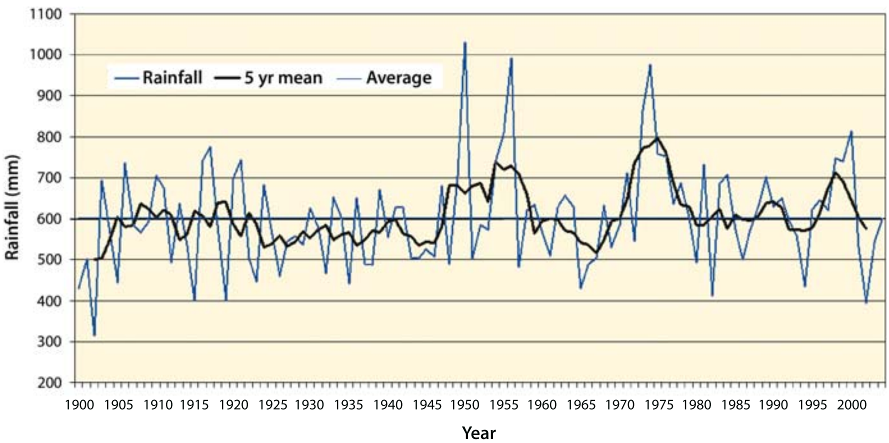


Fig. 12.8. Rainfall averaged over eastern Australia (i.e., land areas east of 130°E), 1900–2004. Rainfall in individual years is shown in *blue*. Also shown are the five-year running mean (to indicate the longer-term fluctuations) in *black*, and the long-term average (*thin blue horizontal line*). Dry conditions prior to 1905 represent the latter stages of the so-called "Federation drought", and other dry spells are evident in the 1920s through 1940s, and in the 1960s. By contrast, wet spells in the 1950s and 1970s stand out clearly

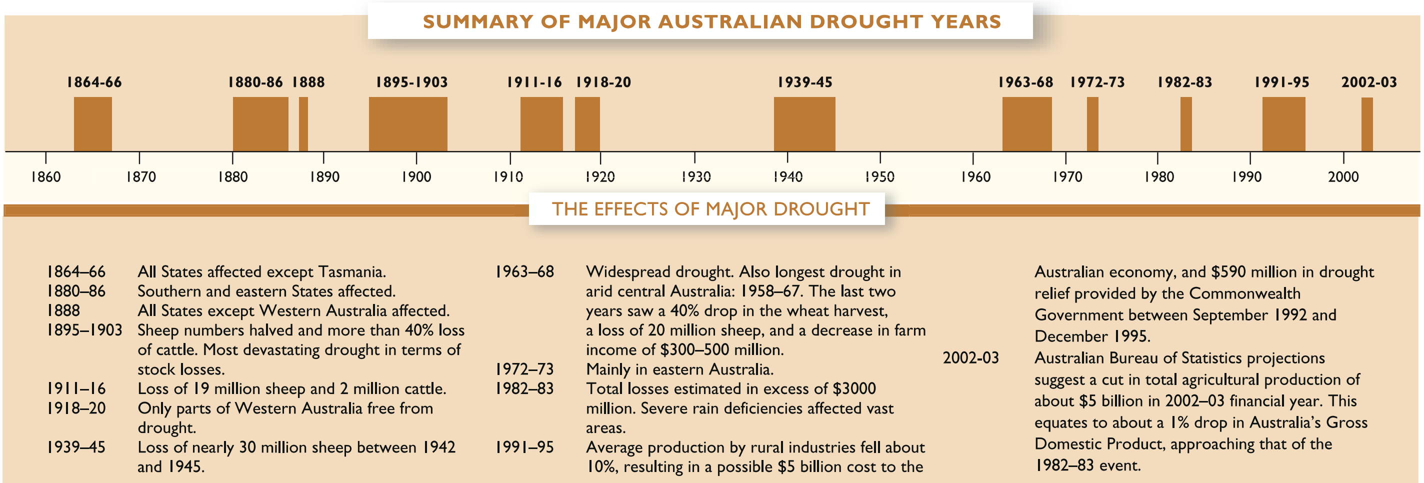


Fig. 12.9. Summary of the major droughts in Australia during the period 1850 to present

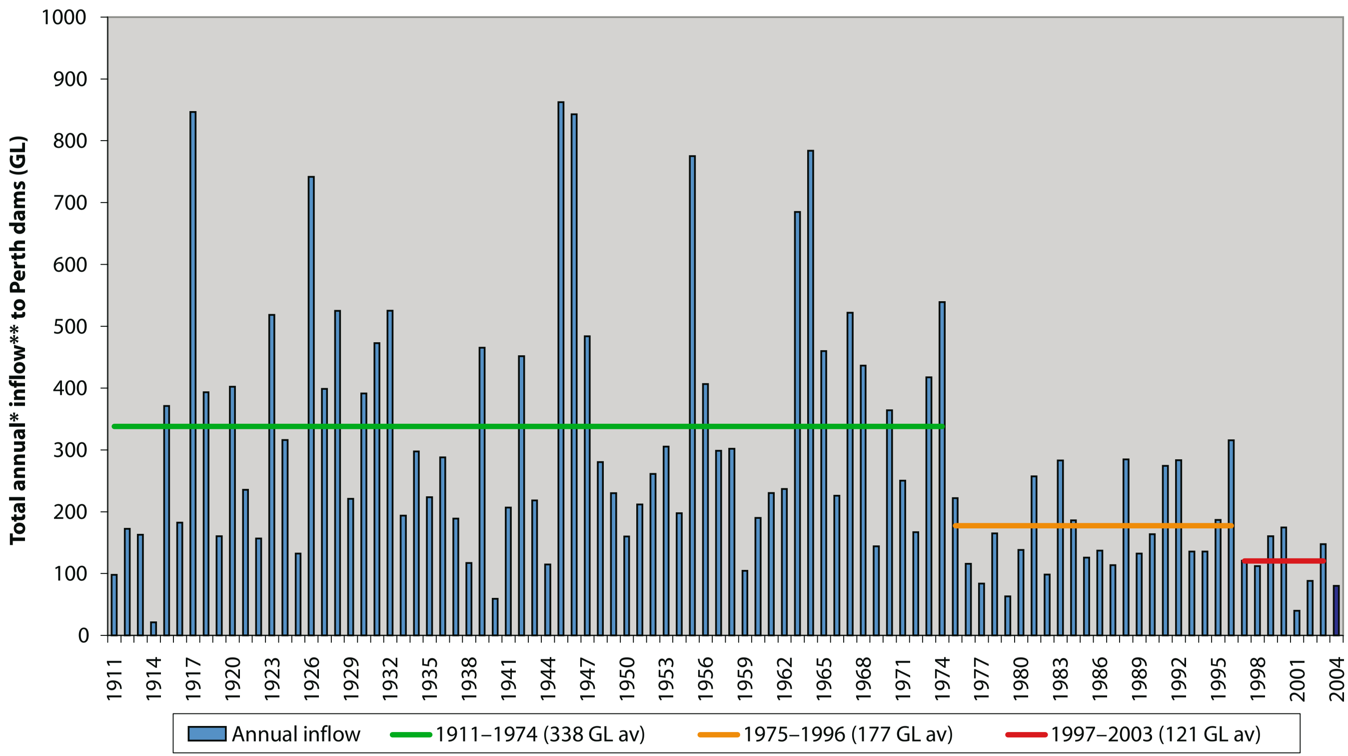
linked to long-term variations in Pacific SST. On decadal time-scales, Pacific Ocean SSTs vary in an essentially similar manner to the year to year fluctuations associated with ENSO. That is, there tend to be periods of around a decade and longer when the Pacific is more "El Niño-like", and other periods when it is more "La Niña-like". Such fluctuations go by the name of the ***Interdecadal Pacific Oscillation (IPO)***. The IPO was in its negative phase during the late 1940s–50s and 1970s, coinciding with wet eras over Australia. On the other hand, extended "warm" phases were evident throughout the late 1920s to early 1940s (a relatively dry era over Australia), weakly so in the 1960s, and again between the 1980s and late 1990s. During these phases – but particularly in the first – Australian rainfall was lower, and droughts more common.

However these phases – the El Niño-like "warm" Pacific phase and La Niña-like "cool" phase – do not follow each other in a systematic way, nor do they last for a consistent period of time. Therefore, predictability of the longer term fluctuations is not yet possible.

12.7.2 Climatic Trends and Discontinuities

Over the past 30 years southwestern Australia, and rather more recently, much of southeastern Australia, have been experiencing the effects of a rather abrupt and sustained drop in rainfall of some 15–20 per cent below their long term normals. Most of this decline has occurred in the normal wet season, in the (southern) winter half of the year, which is critical for agricultural activities and topping up water storages. The declines have been accompanied by substantial changes in Australian region circulation patterns (e.g., Allan and Haylock, 1993), with a tendency for mean sea level pressures to increase across southern Australia, as rain-bearing frontal systems and depressions embedded in the southern westerlies have retreated southwards. The decline in rainfall has had major implications for water resource management in both the southwest and the southeast (IOCI, 2002; Wright and Jones, 2003). For instance, Fig. 12.10 shows that, in southwestern Australia, inflow into storage reservoirs has dropped by approximately 40% since 1975, partly because of the rainfall decline, and also due to increasing temperatures (IOCI, 2002).

In response to the decline in rainfall and water availability over southwestern Australia, a research consortium called the Indian Ocean Climate Initiative, or IOCI, was established. This Initiative represents an excellent example of an effective cross-disciplinary approach to adaptation, essentially formalising collaboration between climate research groups and Western Australian water authorities. IOCI addresses questions such as: what is responsible for the rainfall decline, how likely is it to continue, and what are the likely implications for water management? Their findings to date (IOCI, 2002) indicate the likelihood that both natural variability and the enhanced Greenhouse Effect may have contributed to the decline, and therefore the most likely future scenario is for natural variability to continue against a backdrop of continued rainfall decreases and rising temperatures. Wright and Jones (2003) discussed some of the possible causes of the rainfall decline in southeastern Australia, consider-



Notes: * year is taken as May to April and labelled year is beginning (winter) of year
** inflow is simulated based on Perth dams in 2001 and 2004 is an estimate (as at November 2004)

Fig. 12.10. Estimated inflow into Perth reservoirs, 1911–2000. Note the significant and sustained decline in inflows that commenced in the late 1960s, and accelerated after the mid-1970s, corresponding to the decline in rainfall over southwestern Australia. Source: IOCI (2002)

ing decadal climate variability, and anthropogenic climate change associated with both the enhanced Greenhouse Effect (e.g., CSIRO, 2001) and/or changes to the so-called Southern Annular Mode (see Fig. 12.11), hypothesized to be linked to ozone depletion (e.g., Thompson and Solomon, 2002). Wright and Jones (2003) concluded that the causes of the rainfall declines could not yet be specified categorically, and that well-planned general circulation modelling studies were required to clarify this question. Without such clarification, it is not possible to specify whether the observed decline in rainfall would be maintained.

Such climate shifts and trends potentially pose problems for the application of drought policy in the future. Long-term droughts cannot be "managed through", nor can they be predicted using current techniques. The question must be asked: what implications could this have for the application of National Drought Policy, and in particular, the provision of EC support? These are difficult policy issues, made more difficult by the substantial uncertainty still surrounding climate change scenarios, and the fact that climate science is still far from being able to separate natural climate variability from anthropogenic climate change signals.

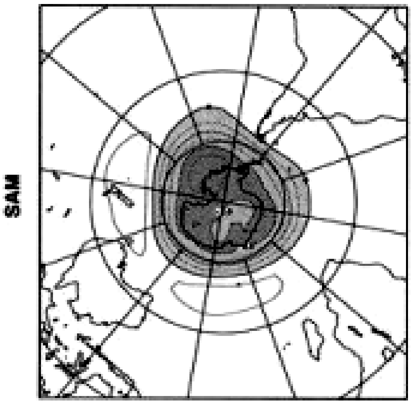


Fig. 12.11. The southern annular mode (SAM), encapsulating a tendency for Mean Sea Level Pressures (MSLPs) at high latitudes (around 60° S) to vary in the opposite sense to those in lower-middle latitudes (including over Australia). The SAM is represented by the so-called Antarctic Oscillation Index. A positive value of this Index implies lower pressures at high latitudes and raised pressures in the lower midlatitudes. A positive trend has been noted since the late 1960s, consistent with the observed circulation and rainfall shifts over Australia. Adapted from Boer et al. (2001)

12.8 Concluding Remarks

In Australia the process of refining drought policy, so that it can be fairly and equitably applied in support of productive and sustainable agriculture, will continue, as illustrated by a recent national Drought Policy review (Australian Government, 2004). In addition, there are other initiatives that could potentially improve the ability of farmers to manage drought. For instance, the Bureau of Meteorology has an internal El Niño alert system, with development work underway in the hope of eventually making it available to the public. And several agencies are collaborating in a bid to establish a Cooperative Research Centre for Climate Risk Technologies, which would ensure a steady funding commitment to drought-related climate research and its application to agriculture and other systems.

On the climatological side, one potential future issue is that, should the current warming trend in Australian temperatures continue (Della-Marta et al., 2004), as predicted by climate change projections (CSIRO, 2001), then future droughts in Australia may have more significant impacts. This is because (as demonstrated in 2002–03) the higher temperatures might be associated with higher levels of evaporation, exacerbating the effects of the rainfall deficiencies (Nicholls, 2004).

This has a number of implications for drought policy in the future. To begin with, if future droughts are indeed more severe, then the viability of at least some types of agricultural activity within Australia may be threatened. This has implications for sustainability, and future policy and planning will need to allow for such potential consequences of long-term climate variability and change.

The way in which monitoring of droughts is conducted will also need to be reviewed. The experience of 2002–03 has illustrated that rainfall deficiencies alone do not necessarily reflect the severity of drought. Therefore it may be desirable for future monitoring to take into account variables such as temperature or evaporation, as well as rainfall, in determining whether EC assistance is justified.

Acknowledgements

I would like to thank my colleagues Bruce Stewart, Neil Plummer, Michael Coughlan, and Scott Power within the Australian Bureau of Meteorology for helpful comments on earlier drafts of this article. The Australian Bureau of Meteorology is only one of a number of agencies which contribute towards drought and water management in Australia, and I would also like to thank Messrs Ashley Leedman, Kate Brinkley, Matthew Koval, and John Sims from the Bureau of Resource Sciences (Australian Government DAFF), and Ms Rae Moran from the Victorian Department of Sustainability and Environment, for their comments and advice.

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CHAPTER 13

Significance of Training, Education and Communication for Awareness of Potential Hazards in Managing Natural Disaster in Australia

William J. Wright

Abstract This Chapter describes the role of public education and training in mitigating the effects of natural disaster in Australia. Emphasis is on weather- and climate-related disasters, which have historically caused heavy economic losses, and sometimes significant loss of life. Three main themes are identified: (a) the continued development of a community-oriented approach to hazard minimisation, in which communities are encouraged and trained to take measures to protect themselves and their property when adverse weather or climate situations threaten; (b) issues involved in educating potential beneficiaries in the effective use of climate information to minimise impacts from climate extremes; (c) underpinning both the foregoing to some extent, the importance of developing a sound communication strategy between authorities responsible for disaster management, the people likely to be affected, and the media.

In describing the community involvement programs (Sect. 13.3), attention is focussed on responses to the threat posed by bushfires in southern Australia, and tropical cyclones in northern Australia. Public education campaigns, designed to minimise adverse effects of severe storms, skin damage due to solar radiation, and heatwaves are also described (the latter two elements are not high profile hazards, but have been responsible for many deaths in Australia). Sect. 13.4 briefly describes capacity-building activities designed to enable the effective use of seasonal climate predictions, a valuable tool in mitigating the effects of drought, both within Australia and over the South Pacific. It is shown that, while extensive educational and awareness campaigns over the past decade have led to increased use of seasonal climate predictions in decision-making by the agricultural sector, a number of barriers remain to more widespread acceptance of this tool. Section 13.5 highlights the importance of good two-way communication between service providers and end users to ensure information is relevant, adequately understood, and effectively applied. The role of the media in communicating information during times of major climate events, such as drought, is also discussed. We conclude with a summary of some promising avenues for improving the effectiveness of managing natural disaster through educational and training activities, along with some thoughts on the implications of future climate change.

13.1 Introduction

Natural disasters are responsible for loss of life, health hazards, loss of agricultural produce, interruption of economic development and creating a lack of confidence in the minds of planners and investors. The results are aggravated in an unprepared community which is unnecessarily exposed and not able to either provide or use warning signals. With the growth of science and technology, it is possible today to minimise these results. For this purpose, it is necessary to have well thought out pre-disaster and post-disaster planning in which training and education are important factors to mitigate the disasters. While Australia is mercifully spared the widespread loss of life from meteorological disasters that can afflict many other countries, events such as drought, fire, flood, cyclone and storm have nevertheless historically inflicted much suffering and heavy economic losses in this country (Australian Bureau of Meteorology, 2004). In the 20th Century, three bushfire events in southeastern Australia have each claimed over 60 lives, while many other fire events have claimed lives and caused enormous property losses. Floods and tropical cyclones have regularly inflicted losses of hundreds of millions of dollars and caused many deaths. Drought has an enduring and well-deserved reputation within Australia for inflicting hardship and loss, especially on farming communities, and has also played a key role in major land degradation episodes over the past century (McKeon et al. 2001).

Fortunately losses have been limited to some extent, especially in the latter half of the 20th century, by the development of robust warning systems, a capacity to respond rapidly to disaster, and improved community education. Each of these is linked to improvements in technology, but also to increasingly effective communication between those likely to be affected and disaster management authorities.

This paper describes some recent developments in awareness raising and community education within the Australian context that have contributed to the reduced losses. It does not attempt to provide a comprehensive review of training and education programs in particular sectors. In any case, there appears to be generally little in the way of formal training arrangements within disaster management organisations in Australia, and most of what there is concentrates on responses to disaster, rather than mitigation. Instead, the Chapter will assess developments in three key areas:

1. developing community awareness and self-management programs in relation to hazard mitigation. The emphasis here is on equipping community groups exposed to a certain type of hazard with the knowledge to manage that hazard;
2. training in the effective use of climate information, specifically climate predictions (which have the potential not only to help minimise heavy losses in "bad" years, but also to maximise returns in good seasons);
3. developing communication strategies between stakeholders, including effective use of the media. Good services and methodologies are ineffective

unless the user understands and applies the information provided. At the same time, it is important that users be able to feed back how the information can be improved.

13.2 Disaster Mitigation Through Education and Training Programmes by Government Agencies

In Australia, primary responsibility for the protection of life and property during most forms of disaster rests with State and Territory Governments, with overall coordination under the Federal (national) Government through the agency *Emergency Management Australia (EMA)*. This organisation promotes a national approach to emergency management, with emphasis on prevention, preparedness, response and post-disaster recovery activities. EMA also provide a wide range of education and training products to those involved in emergency management, and conducts public awareness and education campaigns aimed at advising on preparations for, and coping with, major hazards including severe storms, floods, bushfires, cyclones, earthquakes and heatwaves.

Towards the end of 2002 the Council of Australian Governments (COAG) completed a review of disaster relief arrangements in Australia, aimed at improving disaster mitigation (COAG 2003). Some of its main recommendations may be summarised as: (1) to further a nationally-consistent approach to disaster mitigation among the States, and integrated through local, State and national (Federal) Governments; and (2) to diverge further from the response-oriented approach of the past, by encouraging advance preparations aimed at reducing losses (via measures such as undertaking comprehensive disaster risk assessments, implementing statutory requirements for land use planning and building codes resilient to natural hazards, community awareness programs, and encouraging volunteers). The community awareness and self-reliance programs described in Sect. 13.3 below are a good example of the preparedness strategies mooted in the second of these recommendations.

13.3 Community Awareness and Self-help Programs in Australia

Australians have a long tradition of community involvement to meet the threats posed by natural hazards. For instance, most States and Territories have confronted the bushfire threat by establishing volunteer country fire services, where thousands of volunteers train in fire suppression techniques, and place themselves on standby on potentially hazardous days. The Country Fire Authority in Victoria is, indeed, one of the world's largest volunteer-based emergency services, with (in late 2003) around 59,000 volunteer members supported by over 400 career fire fighters and officers and more than 700 career support and administrative staff. This body was established in 1945, following investigations into major fatal bushfires in Victoria in 1939 and 1944 (Country Fire Authority, 2003).

Emphasis on community awareness and involvement has sharpened somewhat since the late 1980s, as governments and agencies responsible for managing natural disaster move towards imposing a greater sense of self-reliance on those likely to be impacted by severe events. Official government policy for drought and water management has also shifted, with drought now regarded as a natural and inevitable part of Australia's farming environment. The relevant government agencies are now focussing on providing farmers with training on, for instance, how to manage with climate variability. With regard to other forms of natural disaster, community education and training efforts have been best coordinated in areas where significant losses are common. We describe here the community awareness activities conducted in southern Australia in relation to bushfires, and in northern Australia in relation to tropical cyclones.

The essential element of the community-based approach is involving the public, at a local community level, in decision-making. Community members are encouraged to take actions relevant to their own situation, based on a knowledge of the hazard, an acceptance of its likelihood of occurring, and a knowledge of preventive management strategies. This clearly involves an education/training campaign for the communities exposed to risk. Open consultation processes are also critical, since community attitudes and values need to be taken into account in deciding the most appropriate strategies.

Campaigns such as this need to be built around a thorough knowledge of the nature of each type of natural hazard, a process that is more advanced with some kinds of natural hazards than others. Knowledge bases of this type require detailed historical inventories of past disasters, including information on the meteorological and other relevant conditions leading up to and accompanying the event; climatological frequency analyses of certain phenomena (e.g., lightning incidence, tropical cyclone frequency); analysis of broadscale influences (e.g., phase of the El Niño – Southern Oscillation phenomenon) likely to influence variability of the phenomena. These should be supported by statistics on, and analyses of, the impacts of the phenomena (e.g., financial losses, fatalities, etc; assessments of how/why people died). This in turn requires integrated data management systems, for collecting, quality controlling, analysing and presenting data, including metadata. Presentation of information to users (including "intermediaries", such as disaster management agencies) should make use of the best available technology, particularly GIS and the Internet.

13.3.1 Bushfires

As indicated earlier, bushfires are a major hazard in southern Australia during the warmer months, especially in the southeast where, over the years, they have resulted in hundreds of deaths, devastating property losses, and the destruction of large tracts of valuable forests. Fig. 13.1 is a photograph taken during the infamous "Black Friday" fires of January 1939, which claimed 71 lives and destroyed millions of hectares of forest. Much of the loss of life and property

Fig. 13.1. Buildings ablaze during the January 1939 "Black Friday" bushfires in Victoria's forest country, southeastern Australia. (*Courtesy of the Victorian Dept of Sustainability & Environment, Victoria, Australia*)

destruction has occurred in residential areas set among bushland on the fringes of cities. Between 2002 and 2004 major fires have occurred in Canberra (on 18 January 2003, fires destroyed over 500 homes in Canberra's suburbs, and caused four deaths), in outer suburban Sydney, and in eastern Victoria and southeastern New South Wales. Moreover, the forested areas east of Melbourne are regarded as one of the most fire-prone areas on earth. An important part of the strategy for managing bushfires in such fire-prone areas is community education and consultation.

A community-based bushfire risk management program, "*Community Fireguard*", has been initiated in the States of Victoria, South Australia, New South Wales, and Tasmania (essentially the southeastern corner of Australia). This program stands as an excellent example of highly effective risk management in communities regularly exposed to climate-related hazards. In the lead-up to the fire season, fire authorities facilitate community meetings in bushfire-prone areas. In these meetings, the authorities outline the nature of the fire threat, and advise residents on how to protect their property against it. Typical recommended preparatory and preventive measures include: clearance or reduction of flammable vegetation; covering or removing flammable material (e.g. exposed wood); and assembling fire fighting equipment. Homeowners are also encouraged to consider in advance whether on potentially severe fire days they will evacuate early, or prepare to stay and defend their properties. Reports from past severe fires, in Hobart in 1967, and in Victoria/South Australia in 1983, have indicated that well-maintained properties attended by able-bodied people offer a refuge from fire, and are much more likely to be saved than unattended buildings (Ramsay et al. 1986; Packham 1992). It is also argued (Krusel and Petris 1992) that the most effective bushfire safety strategies are developed when communities work together to develop arrangements most appropriate to their specific situation. In some cases, residents are encouraged to operate neighbourhood 'phone trees, so that, in the event of an emergency, residents keep each other informed of their plans (e.g., evacuating, staying and defending, ability to take elderly and infirm to safety).

In the State of Victoria, seasonal climate predictions can provide an indication of the likelihood of severe and less severe fire seasons (Williams and Karoly 1999), and this information can be used by fire authorities and community managers in making decisions on, for example, allocating fire suppression resources, planning personnel deployment, and preparing communities. Specifically, El Niño summers tend to be associated with an increased fire risk in many parts of southeastern Australia (Fig. 13.2). Dangerous conditions, with serious bushfires, are much more likely in southeastern Australia during the summers of El Niño years (negative SOI) than La Niña summers (positive SOI). The association arises because the lead-up to the fire season is likely to have experienced below average rainfall, while there is evidence that extremely hot days and strong winds are more likely in El Niño summers. Prior

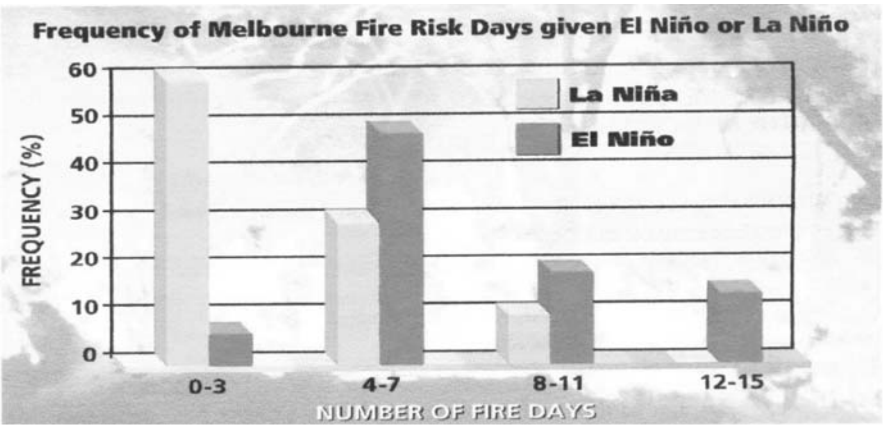

Fig. 13.2. Relationship between El Niño/La Niña and extreme fire danger days in the area around Melbourne, Victoria. *(Courtesy of Harvey Stern & Mark Williams, Australian Commonwealth Bureau of Meteorology, 1989)*

to the severe 2002–03 fire season in Victoria, advice about increasingly severe rainfall deficiencies, and an adverse seasonal climate outlook, led to a greater allocation of fire fighting resources (including fire-bombing aircraft), and public awareness campaigns highlighting the increased risk (Billing 2004). This may have been a factor in the subsequent relatively low level of fatalities and property losses in what was potentially a devastating season, with many large fires.

In some fire-prone regions, local Government bodies enact strict planning regulations, aimed at ensuring that new houses are built in a style that reduces the risk of destruction in wildfire, including provisions for an adequate water supply, and design features aimed at limiting the risk of ignition by airborne burning embers.

13.3.2 Tropical Cyclones

In the lead-up to the tropical cyclone season in northern Australia (normally December-April), the Bureau of Meteorology, in partnership with emergency management and local government authorities, issues detailed information to the public about the risks posed by cyclones, and effective steps to manage this risk. Bureau and emergency management staff also visit communities to inform residents about tropical cyclones, provide general information on cyclone survival preparations, and provide expert advice for specialised users and managers of sensitive infrastructure. Many of these communities are in remote localities, so it is not practicable to visit each community every year. However special arrangements are being made to improve communications through, e.g., improved Internet access and radio.

In the event that a tropical cyclone threatens communities, a comprehensive and regularly-updated series of advices and warnings is provided by the Bureau of Meteorology, to alert communities in areas that may be affected about the likelihood and probable timing of cyclone-related hazards such as destructive winds, flooding and storm tides. The advices also alert residents to the need to activate staged precautionary and defensive measures aimed at reducing losses. An example of such an advice, for residents in northwestern Australia facing an approaching severe tropical cyclone is given below (Box 13.1).

Broader mitigation strategies have also been developed, and supported by legislation and various relevant Codes of Practice. In response to cyclone "Tracy", which devastated Darwin on Christmas Day 1974 (Fig. 13.3), authorities in the Northern Territory imposed strict building regulations for all new buildings. Under these regulations, new buildings must be strong enough structurally to withstand wind-speeds equivalent to a Category 4 cyclone (i.e., with mean wind-speeds up to 211 km/h and gusts to 285 km/h). Elsewhere around northern Australia, similar construction codes have been imposed: buildings along the cyclone-prone Pilbara coast of northwestern Australia are constructed to withstand Category 5 cyclones (wind-gusts in excess of 285 km/h).

Box 13.1. Warning/advice in relation to TC "Fay", a Category 3 cyclone (i.e., with sustained wind-speeds of 64 knots (118 km/h) or more) that affected northwestern Australia in March 2004

SES advises of the following community alerts:

YELLOW ALERT: People in or near coastal communities between Cape Leveque and Bidyadanga including Broome, One Arm Point, Lombadina, Djarandjin, Beagle Bay and Bidyadanga should commence action in readiness for the cyclone's arrival.

People in Broome and Bidyadanga are advised that later this morning they will go on RED ALERT.

BLUE ALERT: People in or near coastal communities between Bidyadanga and Wallal should start taking precautions.

The next warning will be issued at 10 am. Cyclone advices and State Emergency Service Community Alerts are available by dialling 1300 659 210

Rest of message:

TROPICAL CYCLONE ADVICE NUMBER 56

Issued at 7:05 am WST on Thursday, 25 March 2004

BY THE BUREAU OF METEOROLOGY

TROPICAL CYCLONE WARNING CENTRE PERTH

A CYCLONE WARNING for a CATEGORY 3 CYCLONE is now current for coastal communities between Cape Leveque and Pardoo.

A CYCLONE WATCH extends southwest to Roebourne.

At 6 am WST SEVERE TROPICAL CYCLONE FAY was estimated to be

150 kilometres west southwest of Cape Leveque and

110 kilometres north northwest of Broome

and moving south at 8 kilometres per hour.

Severe Tropical Cyclone Fay is moving on a southerly track but is expected to turn towards the south southwest during today. Destructive winds with gusts to 150 kilometres per hour are possible on the Kimberley coast between Cape Leveque and Bidyadanga today, gradually extending to the eastern Pilbara tonight.

Tides between Cape Leveque and Pardoo are likely to rise above the normal high tide mark with very rough seas and flooding of low-lying coastal areas. Residents of Bidyadanga are specifically warned of a dangerous storm tide as the cyclone centre passes to the west. Tides are likely to rise significantly above the normal high tide mark with damaging waves and dangerous flooding.

Fig. 13.3. The near-complete devastation inflicted on Darwin by cyclone "Tracy", which struck early on Christmas Day, 1974. Some 65 people died, and within days, three quarters of the remaining population had been evacuated from the devastated town. *(Photo c/o Australian Department of Foreign Affairs and Trade)*

13.3.3
Public Weather Advice and Alerts

A range of lower-profile climatic threats exist which are increasingly recognised as being responsible for the death of significant numbers of Australians. As such, they are becoming the subject of public safety campaigns, with attendant warnings often carrying advice about preventive actions. Some examples are:

Severe weather advices and warnings, issued through the media, warn of the risk of severe thunderstorms, and provide advice on action to be taken to minimise damage and loss from strong wind squalls, flash flooding and large hail. The Bureau warns graziers of the likely onset of conditions conducive to hypothermia in livestock, and also issues a variety of warnings about conditions likely to cause crop disease or losses.

Australia has a very high incidence of **sunburn and skin cancer**, and for many years now, health authorities have conducted public education campaigns advising the public on how to prevent skin damage, which has potentially fatal consequences. In recent years the Bureau of Meteorology has issued daily Ultraviolet Radiation forecasts, indicating the timing and severity of conditions conducive to skin damage (Fig. 13.4). Index levels higher than 2–3 require preventive actions (e.g., sunscreen, hats, protective clothing) – themselves a subject of an intense community education program – by people facing prolonged sun exposure

It is a fact that **heatwaves** kill more Australians annually than any other meteorological phenomenon (Coates 1996), and this is of increasing concern to health authorities in particular. The elderly and chronically ill are the most likely victims, and the threat appears greatest in areas with otherwise mod-

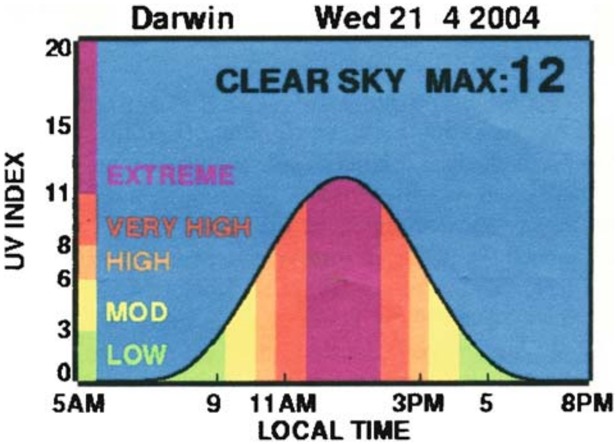

Fig. 13.4. Daily Ultraviolet Radiation forecast for Darwin, Australia, showing variation in intensity of the radiation throughout the day

erate climates subject to occasional hot periods (Kalkstein and Davis 1989). In response, various public authorities are now publishing community information guidelines about avoiding heat stress, and occupational health and safety organisations, and sporting bodies such as Sports Medicine Australia, are providing safety tips for physical activity in hot weather. Increasingly, the Bureau of Meteorology is issuing media releases when unusually hot periods are forecast, and is currently developing the scientific basis for a heat stress warning.[1]

13.4 Droughts and Flooding Rains – the Effective Use of Climate Information in Managing Extremes of Climate Variability

Drought not only causes crop failure and stock losses, but also sets the scene for extreme phenomena such as fires, dust-storms, and general land degradation. This section describes the issues associated with educating potential beneficiaries, particularly farmers, in the effective use of climate information to reduce impacts from drought and other extreme climate events. Broader drought policy issues are described in detail in Botterill and Fisher (2003).

There is a strong link between the incidence of severe drought in Australia and the El Niño-Southern Oscillation (ENSO) phenomenon (Nicholls 1985). Conversely, La Niña events are usually accompanied by above average rainfall, an increased risk of flooding, and reduced frost incidence. Following a series of papers in the 1980s about the impacts of ENSO in Australia, and the potential for seasonal prediction based on indicators of ENSO (McBride and Nicholls 1983; Nicholls 1985), the Australian Bureau of Meteorology com-

[1] As this book went to press, the Bureau had just commenced publicly displaying on the Web heat stress indices for selected locations.

menced issuing seasonal climate predictions in 1989. Predictions were first based on the Southern Oscillation Index, and in recent years, the Bureau has introduced sea surface temperatures (SSTs) as predictors (with the dominant pattern still representing ENSO, and a second predictor based on SST patterns in the Indian Ocean). In addition to these statistical schemes, experimental seasonal predictions are also made using coupled atmosphere-ocean models, and it is expected that dynamical model predictions will become fully operational in coming years. For reasons to be described later, seasonal climate outlooks are expressed in terms of probabilities; however the concept of probabilities has proven a difficult one to describe to potential users.

13.4.1 Seasonal Climate Predictions – Educating the User

Seasonal climate predictions are presented to the users and general public via a number of different media. These include publications such as the Seasonal Climate Outlook (a subscription-based service), on the Internet, via face-to-face briefings, and through the mass media. The information is presented in a variety of different ways, one of which is illustrated via the Table 13.1. In this example, Sydney has an enhanced risk (40%) of being comparatively dry (with seasonal rainfall less than 257 mm), and a reduced chance of being in the upper tercile (377 mm or more; 27%). The "climatological" probability – i.e., in the absence of any climate forcing influence such as ENSO – is 33% in each of the three categories.

Prediction services are only useful if they can be understood, applied, and provide value for decision-making. During the 1990s a huge campaign was mounted to demonstrate to primary producers (farmers, pastoralists, horticulturalists, etc) the links between ENSO and rainfall variations (especially drought) in Australia, and the value of seasonal climate predictions in aiding on-farm decision-making, and minimising losses and environmental degradation during drought periods. Government bodies such as the Bureau of Meteorology, Federal and State Departments of Agriculture and Natural Resource Management (SDAs), and other scientific and research organisations, have collaborated closely in this effort.

Table 13.1. Probabilities of being in the lower and upper terciles (cols 3 and 5 respectively), together with the upper bound of tercile 1 rainfall (col 2), and the lower bound of tercile 3 rainfall (col 4)

Town	33rd Percentile (mm)	Prob. "dry" (%)	67th Percentile (mm)	Prob. "wet" (%)
Perth	21	35	44	32
Melbourne	109	29	177	38
Sydney	257	40	377	27

The Bureau's education/training activities have included:

1. workshops designed to bring together the producers and users of climate information, e.g., the *Cli-Manage* and *DroughtCom* workshops (Australian Bureau of Meteorology 2001; Plummer et al. 2004). During these workshops, the producers of climate information describe what information is available to potential users of the information, while the users provided feedback on their needs for climate information, and the limitations of existing information, especially seasonal predictions;
2. information about ENSO and seasonal prediction via web-sites, educational videos, publications and articles in the media (updates on El Niño and of the seasonal prediction are also routinely provided via the above media); and
3. awareness-raising, via e.g., attendance at agricultural shows, and talks to user groups.

The SDAs are generally in more direct contact with the agricultural sector, and in addition to the above activities (often conducted in collaboration with the Bureau), carry out the following training/awareness-raising activities:

1. workshops/seminars designed for farmers, and usually held in country centres;
2. contact with users via Extension programs (in which Extension officers "package" climate information for farmers in a way that directly assists on-farm decision-making). Extension personnel also provide feedback to research organisations on what information best meets the needs of the end-user;
3. some States run climate education courses designed for farmers at tertiary institutions; and
4. development and demonstration of Decision Support software as an aid in assessing likely outcomes of various management strategies, such as changing planting time, stocking rates, etc. Such programs can be run for a range of possible seasonal conditions (including climate scenarios). For instance, there are packages to simulate growth and potential yield for a range of crops, pasture growth, even economic outcomes.

In addition, while there is no formal coordination of education/training activities between organisations, there is much informal communication and information-sharing at conferences and workshops attended by representatives of SDAs, the Bureau, and other organisations. This has the advantage of encouraging a cross-fertilisation of ideas. Surveys of farmers have led to many improvements in the way information has been presented – for instance, the Australian farming community made it clear that they want information "localised", i.e., what is the prediction for the nearest town?

13.4.2 Responses from Farming Community

In response to these activities, the level of uptake of seasonal predictions (and other climate information) is generally high within stakeholder government agencies, but lower in farming communities. Surveys (White 2001) show that, nationally, about 32% of farmers take seasonal climate predictions into account (with a higher proportion – 44% – in New South Wales and Queensland, where active education campaigns have been in place for many years). However farmers' preparedness to change major decisions is not necessarily influenced by this information. This is true even in extreme situations such as El Niño events, and is despite the fact that, because of the extensive educational efforts in the 1990s, the El Niño – Drought link is now widely known and accepted within the Australian agricultural community.

Feedback from users has indicated a number of factors that have contributed to the limited uptake and use of seasonal climate predictions by farmers:

1. Perceptions of limited accuracy. ENSO-based predictions sometimes suggest an outcome inconsistent with that observed. During the 1997 El Niño, timely rainfall in areas where the El Niño influence on rainfall is normally strong led to some highly critical comments about seasonal outlooks from some sections of the community;
2. Difficulties in understanding, or applying, probabilistic predictions. Because chaos limits the deterministic accuracy of predictions, there are good reasons for expressing seasonal predictions in probabilistic terms. However the communication of probabilistic information remains a serious challenge. Many farmers do not understand or like probabilistic information. The problem is compounded by the fact that, in practice, the probability of rainfall being in a particular tercile range (lower, upper or middle tercile) seldom exceeds 50%. That is, climate prediction input to decision-making often takes the form of relatively minor shifts in probabilities;
3. Farmers' reticence to change traditional strategies/adopt new approaches;
4. Farmers' inability to apply predictions directly in decision-making. However, the development of Decision Support software and ongoing education/training services to farmers by SDAs is reducing this as an issue.
5. Sometimes-conflicting opinions in the media from so-called "experts", including some from outside Australia, leading to confusion and distrust ("if even the experts can't agree ... "); and
6. Inappropriate use of predictions, again leading to a loss of confidence in the system. For instance, using Decision Support software without a clear understanding of the underlying principles, it is possible to generate a whole range of predictions, from which one can then be biased either towards those that appear to give the best results, or to particular outcomes by chance – clearly a scientifically-unsound and misleading practice.

In response to these issues, the means by which seasonal climate information is presented to users in Australia is constantly evolving. For instance, a probability of 70% of above-normal rainfall would now be presented as “in years like the present, 7 out of 10 years would have above average rainfall, and 3 of 10 below”.

Where climate predictions are utilised, they are generally seen to be part of a suite of decision-making tools, and should rarely, if ever, be used in isolation. This is reasonable, because climate is generally only one of several factors that influence farm profitability and sustainability.

13.4.3 Other Climate Extremes

Frost is another serious threat to agriculture. In particular, crops flowering in spring can be seriously damaged by late frosts. In some parts of Australia, notably Queensland, research suggests that late frosts are more likely during El Niño events (Stone et al. 1996). Again, education programs by SDAs have drawn attention to this link, and provided strategies for minimising the risk. Examples of effective responses to increased frost risk include planting cultivars that are more frost-hardy, or which will flower later.

Mitigation of the effects of **flooding** is linked to awareness building within the community, and is also effected through specific projects aimed at reducing impacts in problem areas identified in risk assessment studies (COAG 2003). In Australia, hydrology units within the Bureau of Meteorology oversee a highly effective public warning system for river flooding. These warnings, which include recommended defensive actions agreed by various emergency services, ensure that when warnings of moderate to major flooding along river valleys are issued, action is triggered within communities likely to be affected, as are response strategies by emergency services personnel. In local areas, partnerships have become established between flood warning personnel and vulnerable residents and business owners in flood-prone situations. For instance, the Bureau of Meteorology’s South Australian Regional Office has worked with residents in identified flash-flood-prone areas in urban Adelaide and surrounding areas (Dickins, *pers comm.*, 2004). To date, despite the strong statistical links between La Niña and above average rainfall and flooding over much of Australia, seasonal climate predictions tend not be used, in any direct sense, as indicators of an increased or reduced likelihood of flooding.

As indicated above, specific mitigation activities are carried out to reduce the threat from flooding, under a program supported by all levels of government known as the Flood Mitigation Programme. Of the various natural disaster types, flooding is the only one for which a targetted mitigation program of this sort currently exists (COAG 2003). Typical mitigation activities include: risk assessment studies; the establishment of planning regulations prohibiting development in flood-prone areas; building resilient infrastructure; community awareness, and a number of others. A variety of engineering solutions have also been developed to constrain floods on Australian rivers, including retarding basins and dams, levee banks, and river diversions. For example, after disastrous flooding in Brisbane during January 1974 (in which large sections of the city were inundated and 14 people died), the Wivenhoe dam was built on the Brisbane River in 1985.

Finally, awareness-raising by SDAs and others has also led to an improved understanding of actions (e.g., application of fungicides) for preventing certain wet weather-related crop diseases.

13.4.4
Training in the Application of Seasonal Predictions in the South Pacific

The ENSO phenomenon is a primary influence on the climate of the South Pacific region, as it is in Australia. Building on this fact, the Australian Bureau of Meteorology is undertaking a project aimed at providing Pacific Island Countries' National Meteorological Services (NMSs) with the capacity to provide a seasonal prediction service for people in their countries. The need for such a service was identified in The Pacific Meteorological Services Needs Analysis Project, which in May 2001 reported (South Pacific Regional Environmental Program 2001) that most NMSs in the Pacific region were struggling, and often failing, to provide basic services for the citizens and industries of their countries. The report identified the need for assistance programs in two clear priority areas:

1. improved severe weather warning services; and
2. seasonal and climate prediction services, especially for droughts.

The Project described here tackles the latter issue. It partly involves the provision of computer software, based on the Bureau's operational probability-based seasonal prediction system. Equally important, however, is the planned provision of an extensive training program, aimed at both the National Meteorological Service (NMS) staff who are to provide the service, and the likely users of the predictions. This training program covers topics related to the "prudent" use of climate predictions in supporting decision-making. Some aspects of the project are occurring in collaboration with other countries active in climate service provision in the region, notably New Zealand and the United States. The project has strong parallels with the objectives of WMO's CLIPS program, which has the stated aim of developing the NMSs' abilities to take advantage of recent advances in climate science, with the potential to improve climate services to the user community.

The emphasis in the training program is on providing users with information about how to interpret and apply probability-based seasonal predictions in decision-making, in areas such as agriculture, fisheries, forestry and water management. NMS staff are being trained in how to provide a seasonal prediction service, and potential users are being trained in how to apply probabilistic forecasts in their decision-making. Fig. 13.5 illustrates the use of pie-charts plotted on a map (a feature of the software developed for this project) as an aid in demonstrating probability shifts and how they vary with location.

The above capacity-building exercise is one example of how developed countries in the Asia-Pacific region (including Australia, New Zealand, the US,

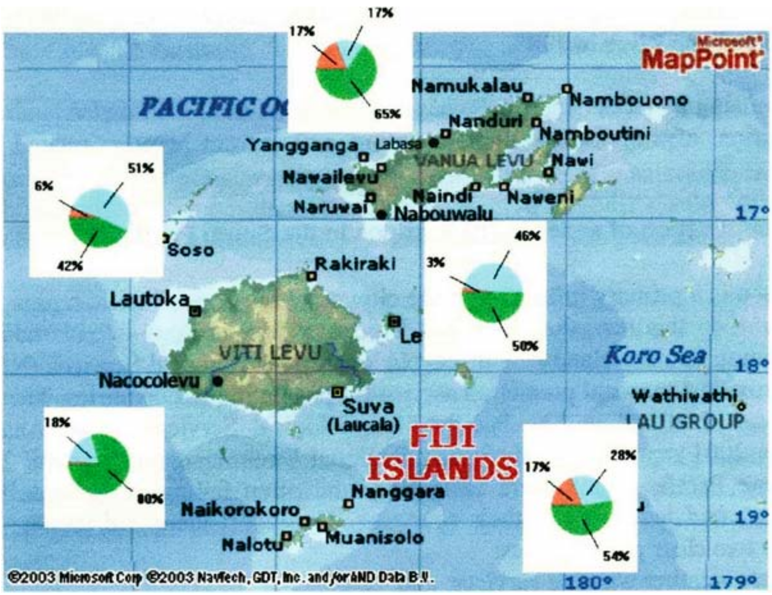

Fig. 13.5. Rainfall tercile probabilities, represented as pie-charts, for the Fiji Island group. Hayman (*pers. comm.*, 2003) has demonstrated that pie-charts are an effective way of presenting probabilistic information

and several other countries) actively participate in aiding the development of meteorological and climate services in developing countries in the region. In addition, in-house meteorological training at the Australian Bureau of Meteorology is regularly provided to staff from Pacific Island NMSs, while Australia and New Zealand have also contributed personnel and resources to train climatologists from the Asia-Pacific region in seasonal outlook development and verification techniques. Workshops on analysing climate extremes have also been held, and some valuable results obtained (Manton et al. 2001). Such assistance is vital in helping these countries minimise the heavy losses associated with weather- and climate-related disasters.

13.5 Towards Improved Lines of Communication

Much of the foregoing illustrates that, at the heart of effective risk management is the need for sound communication between agencies responsible for disaster mitigation and the people potentially affected. Effective information dissemination, carried out via a variety of communication methods, is necessary for educating the public about how they should mitigate, prepare for, and recover from the impacts of hazards, and in providing essential information once an event is underway. At the same time, effective public relations, in this case between agency and public (or user group), is probably best served in the current context through two-way communication in which the "public" have the opportunity to influence the way in which information is conveyed to them.

While communication between the users and producers of climate information has improved substantially in recent years, there is still room for improvement. In an analysis of the communication of climate information during the 2002/03 drought, which drew on a wide variety of stakeholders, Plummer et al. (2004) identified the following areas where increased effort was needed:

1. Better national coordination (so that information is consistent and complementary);
2. Better understanding of user needs;
3. More capacity building (i.e. more information about climate products and their application);
4. More information about products and services;
5. Improved media interactions;
6. Integration and value adding (e.g., combining climate information with other types of information); and
7. More information on current research and its implications.

13.5.1 Role of the Media

Dealing effectively with the media is crucial for any organisation involved in managing natural disasters. Mass media can reach a large audience at minimal cost, and is a popular avenue through which the public receive information. An effective media strategy ensures that information aimed at reducing losses from meteorological hazards reaches the public unambiguously. Also, in reporting on the operational, political and social aspects of events, the media help galvanise national support for victims of adverse events. The latter was emphatically illustrated during the 1994–95 drought, which was the culmination of several very dry years over much of northeastern Australia. The severe drought was causing major hardship in rural communities in the affected areas, with many families, unable to cope any longer from years of adversity and no income, simply abandoning their land. Many in the cities had little knowledge of, or sympathy for, the plight of farmers. However the media drew attention to the farmers' often grave situation, and according to the Federal Primary Industries Minister in the Australian Government (the Honourable Bob Collins), were instrumental in turning around the negative image of farmers (Wahlquist 2003).

It is important to note that the aims of the mass media and service organisations can sometimes be at odds. Media articles in general need to be fairly generalised, timely, brief, and catchy to best capture their audience, whereas scientific organisations (such as meteorological agencies), are more accustomed to dealing with objective information, sometimes with lengthy detail (Mullen, *pers. comm.*, 2004). Add to this the combination of possibly poor explanation by the organisation spokesperson, lack of expertise in the subject area by journalists, and space/time/editorial constraints, and it is not surprising that misrepresentations occur.

Nevertheless, strategies to minimise confusion of the message, as identified in a media analysis study of the 1997/98 drought commissioned by the Bureau of Meteorology's National Climate Centre (Walsh 1998) include:

1. Update, clarify and document clear communication objectives, and specify a consistent message strategy;
2. Train staff in dealing with the media;
3. Direct resources towards the most aware or active "publics" (i.e., particular user groups);
4. Research the information needs of "publics"; and
5. Host education seminars for the media's awareness[2].

13.6 Concluding Remarks

The past 15 or so years have seen considerable advances in the level of coordination between different government agencies responsible for minimising losses due to weather and climate extremes in Australia, and also in the level of coordination between these organisations and community groups likely to be affected by the extremes. Progress in the latter area has been achieved through targeted training and education campaigns, aided by changes in government policy, and better communication strategies.

Drawing on recent experience in Australia, the following policy objectives, from the education/training perspective, appear to hold promise for improving the effectiveness of managing meteorological disasters, and mitigating the impacts of extreme events:

1. Continual fostering, via government agency engagement with community groups, of a sense of self-reliance, extending to the local community level;
2. Further consultation with community groups exposed to natural hazards (e.g., the agricultural sector), resulting in improved awareness of climate information by the users, and better presentation of this information by the producers;

[2] A fine illustration of how this can pay off in times of crisis is provided by the Victorian Country Fire Authority (CFA) who, prior to the 2002–03 fire season, sponsored more than 600 media personnel through a formal course in fire knowledge and safety. They (CFA, 2003) attribute the subsequent "excellent" coverage and timely information dissemination provided by the media during the severe 2003 bushfires in part at least to the training course.

3. Effective communication and media strategies for educating the public and disseminating information;
4. Technological advances in computing and communications, particularly in view of the likely benefits for distance education and the development of Decision Support and other learning tools;
5. Collation and effective management of information about natural disasters, including the meteorological circumstances that precede and accompany an extreme event, and the impacts of the event. The aim of compiling such databases is to better understand the nature of particular types of event, in turn facilitating improved monitoring, assessment, prediction and preparedness. This requires free and unlimited access to such databases, and collaborative links for the exchange of information.

Finally, the development of effective risk management strategies, to which education and training contribute a fundamental role, is likely to assume even greater importance in the future. This is a likely consequence of two parallel trends, which have emerged globally and are reflected to some extent in Australia (Wright et al. 2003). These are:

1. Global warming, which the Intergovernmental Panel on Climate Change argues is at least partially due to an increase in greenhouse gas concentrations in the atmosphere; and
2. A rise in the social, environmental and economic impacts of natural disasters.

With regard to the first of these trends, there has been speculation (e.g., Nicholls, 2004) that the severity of the 2002–03 drought in Australia, and of related phenomena such as bushfires, may be manifestations of global climate change. Moreover, the potential exists for future climate change to further increase the frequency and severity of extreme events like droughts, floods and bushfires.

Given the severe impacts of natural disasters, increased precautionary and defensive planning and action to mitigate known hazards is needed, and National Meteorological Services are likely to play an important role in these activities. Finally, the communication of information and uncertainty about the potential impacts of climate change will pose new challenges for NMSs in the future.

Acknowledgements

The author gratefully acknowledges the assistance of colleagues within the Bureau of Meteorology, including Mr Neil Plummer, Dr Linda Anderson-Berry, Mr Bruce Stewart and Ms Clare Mullen, and Dr Peter Hayman (New South Wales Dept of Agriculture), for providing helpful comments on earlier drafts of this article. Ms Carol Skinner provided the information on heatwaves.

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CHAPTER 14

Agrometeorological Disaster Risk Management in China*

Wang Shili, Huo Zhiguo, Guo Jianping, Wang Chunyi

Abstract Efficient management of risks due to meteorological disasters is very important in China because of their increasing occurrence and limited capability for prevention and preparedness in China. Losses due to meteorological and related disasters account for more than 70% of the natural disaster losses in China. Early warning and prediction of agrometeorological disasters includes improvements in statistical prediction models, predictions based on climate prediction and agrometeorological models, and early warning for agrometeorological disasters using GIS. Risk assessments of agrometeorological disasters are based on identification of risk and use of models to characterize disaster intensity, disaster loss and the capability to combat disasters. Several ways of popularizing the preventive measures of agrometeorological disasters were described with suitable examples.

14.1 Introduction

Agricultural production is highly dependent on weather, climate and water availability, and is adversely affected by the weather and climate related disasters. Abnormality of rains and unfavorable temperature could lead to crop failure, food insecurity, famine, loss of property and life and negative national economic growth. Due to frequent occurrence of disasters and limited capability of prevention and preparedness, meteorological disasters have serious impacts on sustainable development of agricultural production in China, therefore the risk management of meteorological disasters is more important.

China is located in monsoon climate region. Monsoon and its manifestations in terms of onset time, intensity and its impact on various sectors in China are different every year. Some meteorological disasters and extreme climate events such as drought, flood, heavy rain, low temperature damage, frost, hail and heat wave occur frequently. In this situation the meteorological disasters strongly influence national economy, especially agricultural production. According to statistics the losses due to meteorological and related disasters account for more than 70% of natural disasters losses in China. The average damaged acreage of cultivated land caused by natural disasters is 30,660,000 hectares from year 1950 to 1979, and the averaged reduction of crop yield in each

* Supported by national key project "Early warning and control techniques of desease and pest in agriculture and agrometeorological disasters".

year is about 20,000,000 t. In recent years the unfavorable impacts of climate variation and meteorological disasters on agricultural production seem to be increasing, for example, the mean drought-damaged acreage per year from 1950 to 1990 was 20,426,000 hectares, while in 1991–2000 it was 27,147,000 hectares; the flooded areas from 1950 to1990 were 7,982,000 hectares, in recent 10 years it reached to 15,066,000 hectares, nearly doubled. As such, it is very important to strengthen risk management of meteorological disasters so as to mitigate unfavorable impacts on agricultural production and to ensure sustainable development of agriculture. From agrometeorological point of view the major approaches of disasters risk management should be focused on early prediction, assessment and preparedness of agrometeorological disasters and on providing service of disasters information and of practical techniques of disaster-preventing measures.

Chinese meteorologists pay considerable attention to assessing the impacts of meteorological disasters on agricultural production, apart from strengthening and improving the accuracy of weather forecasting and climate prediction. In recent years, agrometeorologists have made good progress in study and service of agrometeorological disasters, which helped in reducing disaster risk, minimizing disaster losses and ensuring stable development of agriculture. In this paper an attempt has been made to highlight the efforts and experience in reducing risk of agrometeorlogical disasters through prediction and extending preventive measures to mitigate agrometeorlogical disasters in China.

14.2 Early Warning and Prediction of Agrometeorological Disasters

Agrometeorological disasters have serious influence on agricultural production due to frequent occurrence of agrometeorlogical disasters and in the absence of capacity building in managing these disasters. Timely and accurate prediction of agrometeorological disasters is very useful for reducing losses of disasters and ensuring sustainable development of agricultural production in China. However, agrometeorological disasters are different from common meteorological disasters, as their occurrence, extent and impacts are determined not only by the variations in weather elements, but also by crop growth status, soil and management level. In recent years keeping in mind the demand of sustainable development of agriculture and mitigating disasters, studies on early warning and prediction of agrometeorological disasters were carried out (Wang Shili 2003).

14.2.1 Improvement in Statistical Prediction Models

Multi-regression analysis, time series analysis, analogue analysis and cadence are often used to develop prediction models for agrometeorological disasters. In multi-regression prediction models the predictors are selected from parameters related to atmospheric circulation, sea surface temperature and other meteorological elements. In the study on prediction of low temperature damage in Northeast China, low temperature damage patterns during the summer period are firstly determined by crop yield index and anomaly of sum of degree-days (daily temperature above 10 °C) during the period from May to September, and subsequently regression analysis, clustering analysis, distinguishing analysis are used to develop cold injury prediction models in which the statistical values of atmospheric circulation are selected as predictors (Zhou Lihong et al. 2001). Some previous signals in atmospheric circulation, along with synoptic and climatic characteristics are revealed to forecast the disasters. As for example sea surface temperature in winter in warm pool of tropical west Pacific is detected as strong signal of low temperature in summer in Northeast China based on EOF (empirical orthogonal function) and, SVD (Singular Value Decomposition) analysis (Zheng Weizhong and Ni Yunqi 1999). SNR (signal noise ratio) is applied to identify previous stronger signal from atmospheric circulation values and sea surface temperature for probable occurrence of drought in North China. It is found out that the abnormal changes in 500 hPa height of Urals and Lake Baikai as well as abnormality in Kuroshio warm pool and Nino 4 are the strong signals of probable severe drought in North China (Wei Fengying and Zhang Jingjiang 2003).

In some models time series analysis is combined with regression analysis. In low temperature prediction during anthesis of rice, the time series of low temperature index are firstly generated as mean generated functions, and then auto-regression prediction models where time periods are independent variables are developed. Other prediction models are multiple regression models with period variation (Na Jiafeng 1998; Xu Bingnan et al.1999). Damaged acreage due to disaster is estimated by GM (1,1) model (Wang Weiming 1998).

Phenological phase reflects past and present weather and climate condition, sometimes which are used to predict abnormality of climate or agrometeorological disasters. In Northeast China the phenological phases of almond tree, poplar tree and willow trees as well as phenological phases of maize crop are used to predict mean temperature of spring and accumulated temperature during growing season. The time of jointing stage of maize is used to forecast the occurrence of crop cold damage in Northeast China (Bi Bojun 2000).

14.2.2
Prediction Models Based on Climate Prediction and Agrometeorological Models

14.2.2.1
Irrigation Scheme for Winter Wheat in North China

In irrigation scheme for winter wheat in North China the regional climate models are connected with soil water model. Based on forecast of daily weather elements from regional climate model and soil water balance model, the soil water contents are forecasted dynamically. The optimal irrigation date and amount are calculated according to the threshold of water requirement of wheat in different development stages (Fig. 14.1). The water deficit and yield

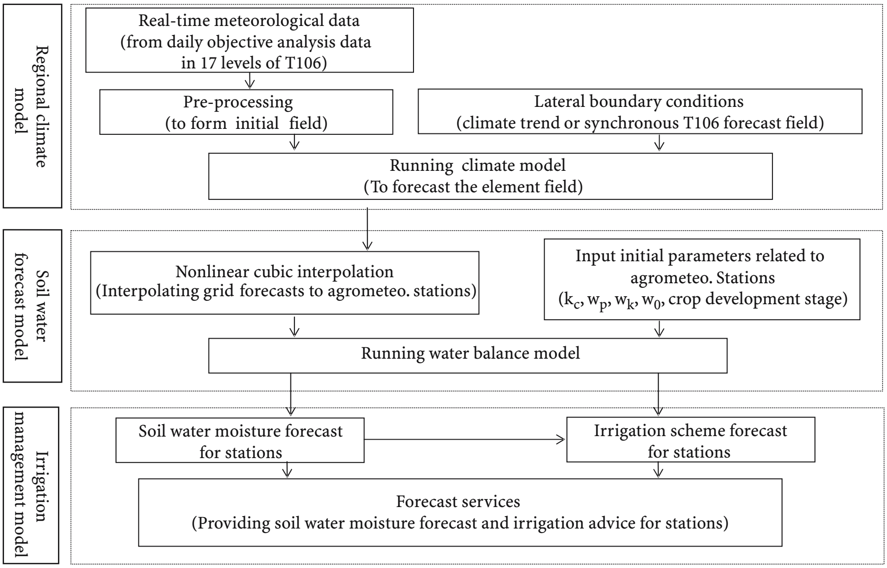


Fig. 14.1. Predicted irrigation scheme for winter wheat in North China

reduction are also estimated. The relative error is found to be 8.6% for soil water content during next 10 days (Zhang Guangzhi et al. 2001). The irrigation scheme information service was shown on China Central Television Station.

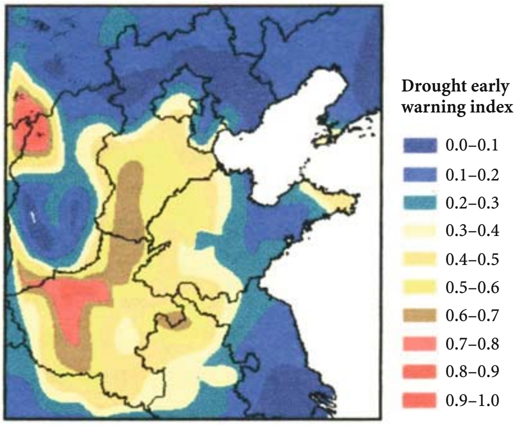
14.2.2.2
Prediction Based on Climate Prediction and Crop Growth Models

Statistical prediction models have their limitation, such as the mechanism is not clear and the predictions are often beyond the record data, and so on. On the other hand, presently the process-based crop growth simulation models have been applied to crop yield estimation, climate risks evaluation and agricultural resources utilization (Gerrit Hoogenboom 1999). Therefore it may be a way of agrometeorological disaster prediction to apply the seasonal climate prediction combined with crop growth simulation model. Some research on this aspect was carried out in recent years.

Wheat Drought Prediction in North China

For identifying and forecasting winter wheat drought, the predicted meteorological elements (decaded values) are put into soil water balance sub-model and the changes in water content and ratio of supply to demand in water are estimated. According to the index expressed with the supply/demand ratio, drought with four grades was identified, assessed and forecasted (Zhao Yanxia et al. 2001). In another study, a winter wheat growth simulation model in North China is developed based on field experiments, where crop parameters such as

Fig. 14.2. Simulated wheat drought in middle of May, 2000 based on crop model (early warning index, higher value denotes severe drought)



maximum photosynthesis rate and initial water use efficiency for local variety in North China under various water conditions are measured and determined, and the cumulated value of relative transpiration ratio is defined in terms of crop drought stress index and drought early warning index. The model was validated for 1998–2000 with satisfactory results. The spatial distribution of simulated drought stress index was drawn using geographic information system (GIS) for historical drought cases (Fig. 14.2) (Liu Jiandong et al. 2003).

Prediction of Low Temperature Damage of Maize in Northeast China

A regional maize growth model was developed and applied to predict low temperature damage in Northeast China. Based on the determination of crop parameters in different regions and the spatial interpolation of daily weather elements, the maize growth status for 12 stations in 1961–2000 and growth processes in grids with $0.25° \times 0.25°$ for the typical low temperature damage year were simulated, respectively (Fig. 14.3). Further-more, experiment of low temperature disaster prediction was made using maize model and regional climate model reGCM-NCC (National Climate Center) by down-scaling from China-GCM (Liu Buchun et al. 2003). It is an attempt to combine the down-scaled climate model with a scaled up crop model.

Prediction of Wet Damage for Wheat in the Middle and Lower Reaches of the Yangtze River

A wheat model for wet damage in middle and lower reaches of Yangtze River has been developed, which includes influences of water-logging days on photosynthesis rate, dry matter allocation and leaf decline. When prediction of regional climate models output or real-time weather forecast is put in, the impact of water-logging on wheat yield can be determined by running wheat water-logging model and the model without water-logging, and by comparing two results, the early warning for water logging can be made (Shi Chunlin and Jin Zhiqing, 2003) .

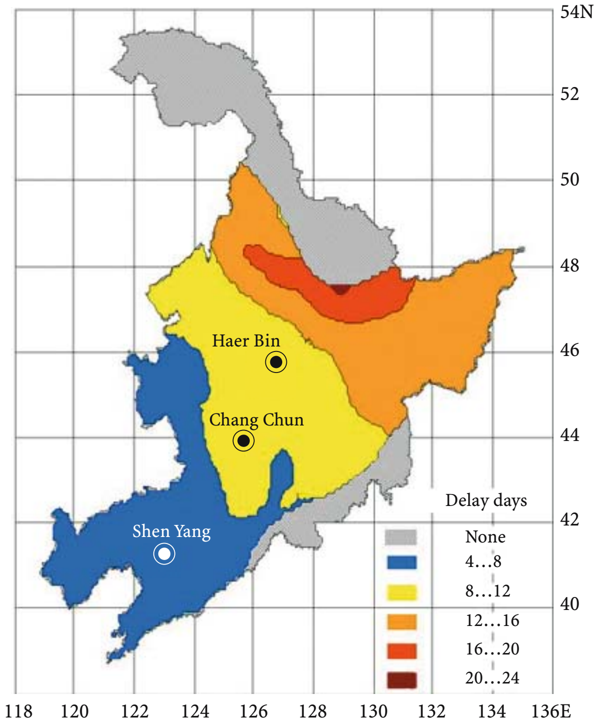


Fig. 14.3. Simulated cold damage in Northeast China in 1969 based on regional maize model (difference of tasseling stage between 1969 and average, unit: d, no cultivation)

It must be pointed out that till now prediction of agrometeorological disasters is not successful due to its particularity and complexity, so it is difficult for any single method or model to get perfect results. The better way is a comprehensive analysis based on various prediction methods and approaches.

14.2.3 Early Warning for Agrometeorological Disasters Using GIS

Due to the great spatial differences in occurrence and impact of meteorological disasters on agricultural production, users often require more specific prediction. It requires application of GIS to prediction of meteorological disasters. Here is a case study of predicting chilling injury of banana and litchi trees using GIS in Gunagdong Province, China (Wang Chunlin et al. 2003).

By using T213 numerical weather forecast products, MOS (model output statistics) prognostic equation is established, and the future 24, 48 and 72 hours temperatures (mean and minimum temperatures) for 86 weather stations are forecasted. Considering that topographic differences will result in different spatial distributions of temperature and impacts on chilling injury, the values of temperature prediction on grids with 0.5° × 0.5° are estimated by GIS, which are corrected by longitude, latitude, elevation, slope gradient, and slope orientation. Furthermore according to the chilling injury index of banana and

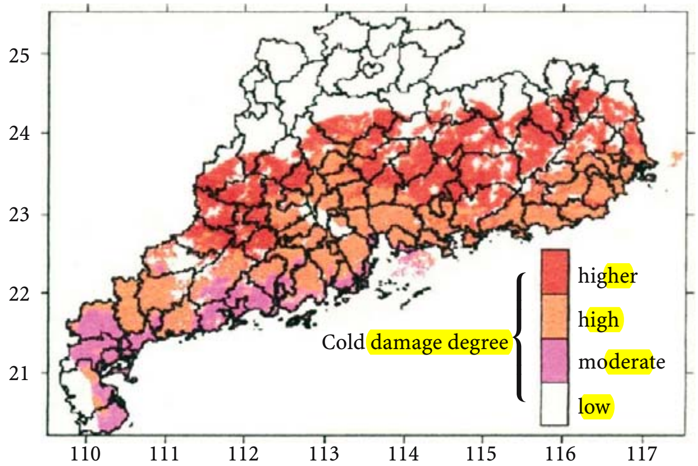


Fig. 14.4. Simulated cold damage degree of litchi in the third-decade, Dec. 1999 in Guangdong Province by GIS

litchi trees and their actual planted distribution, the predicted degree of chilling injury of banana trees or litchi trees on grids could be obtained (Fig. 14.4). The distribution map of early warning and prediction is visual and detailed, which is useful and beneficial to managers and farmers.

14.3 Risk Assessments of Agro-meteorological Disasters

Meteorological disasters risk assessment is helpful for managers of agriculture, government officials and farmers to make decision in agricultural planning, to formulate preventive measures, to rescue and to provide relief after occurrence of disasters, as well as to make insurance so as to minimize the unfavorable impact on agriculture. Up till now it is still lack of quantitative assessment and comprehensive risk analysis of agro-meteorological disasters in China. Studies on risk analysis system including risk identification, risk assessment and types of agro-meteorological disasters were carried out for four major agro-meteorological disasters e.g. winter wheat drought in North China, wet damage of wheat and rape in middle and lower reaches of Yangtze River and Huai River basin, low temperature damage in summer of maize and rice in Northeast China and cold damage of litchi and banana trees in South China (Huo Zhiguo, et al. 2003).

14.3.1 Risk Identification of Major Agro-meteorological Disasters

Risk identification refers to analyzing the locations and seasons of disaster occurrence, characteristics of weather and climate and their effects on agricultural production. For example, drought of wheat in winter and spring in North China is mainly caused by less precipitation in winter and spring and less available water in soil before sowing, which results in severe reduction of wheat yield. The wet damage for winter wheat and rape in middle and lower reaches of Yangtze River and Huai River basin is due to a long period of more precipitation in winter and saturated soil water as well as weak sunshine. Wet damage shortens the duration of grain filling and reduces the crop yield. Low temperature in summer in Northeast China prolongs the crop development stages and crops such as maize and rice are not able to mature before frost in autumn. In some situation, low minimum temperature may damage rice during its productive stage. When a sharp decrease in minimum temperature due to cold wave in winter results in temperatures falling below critical temperatures for sub-tropical fruit trees such as banana and litchi, there will be total damage of these fruit trees (Li Shikui et al. 2004).

14.3.2
Risk Assessment of Major Agro-meteorological Disasters

Risk assessment is the core component of the risk analysis system. Risk assessment of agro-meteorological disasters includes risk assessment models of intensity, losses and capability of combating disasters. Risk assessment models of intensity describe the various grades of intensity and their probabilities while risk assessment models of losses are used to estimate the direct and indirect losses at different intensities. Risk assessment models of capability of combating disasters reflect social and economic level. Risk assessment models of intensity, losses and capability of combating four agro-meteorological disasters mentioned above are established, and spatial distribution are plotted in maps (Wang Suyan et al. 2003; Liu Ronghua et al. 2003a; Xue Changying et al. 2003a; Ma Xiaoqun et al. 2003; Ma Shuqing et al.2003; Liu Jinluan and Du Yaodong 2003).

14.3.2.1
Risk Assessment Models of Disaster Intensity

In the study carried out by Li Shikui et al. 2004 risk index of disaster intensity (I) is a function of different intensity (G) and their probabilities (P) expressed as follows:

$$I = F(G, P) = \sum_{i=1}^{n} G_i P_i \, . \tag{14.1}$$

The risk indices of disaster intensity for different grades of 4 agro-meteorological disasters were determined. For an example, risk indices of water stress under natural water supply during whole growing season in North China (L) consists of 5 grades, which include light drought, moderate drought, drought, severe drought, extreme drought.

$$L = \left(1 - \frac{E_T}{E_{TM}}\right) \times 100\% \tag{14.2}$$

where E_T is soil water available under natural water supply during whole growing season, which is sum of effective precipitation and water available in soil before sowing, E_{TM} represents maximum water requirement of crop during whole growing season, which is calculated by multiplying reference crop evapotranspiration with the crop coefficient (Richard et al.1998).

In order to calculate probabilities of disasters intensities, the probability distribution density functions are fitted using 6 different probability distribution models such as normal distribution based on historical data (Du Yaodong et al. 2003; Huo Zhiguo et al. 2003).

14.3.2.2
Risk Assessment Models of Disaster Loss

The loss due to disasters is expressed by reduction of yield caused by unfavorable meteorological conditions, which is a negative value of the climatic component of the weather-crop yield model. Similarly, risk index of disaster loss is the sum of different yield reduction percentages multiplied by their probabilities.

14.3.2.3
Risk Assessment Models of Capability of Combating Disasters

The capability of combating disasters is related to the resistance of crops and the level of agricultural production. The latter is considered in the study related to agrometeorology. Some models and indices are adopted, such as the ratio of actual yield to maximum yield, the slope of weather yield regression equation, and so on.

14.3.3
Comprehensive Risk Division of Major Agro-meteorological Disasters

Combined with disaster intensity, losses and capability of combating disasters, the comprehensive risk indices are calculated, and risk divisions for four disasters are prepared and plotted. (Liu Ronghua et al. 2003b; Xi Zhuxiang et al.2003; Liu Jinluan 2003 et al.). There is an example of a case study on comprehensive risk division for water stress under natural water supply during growing season. The comprehensive risk index (M) is expressed as:

$$M = \frac{1}{a}\sum_{i=1}^{n}\left(f_i \times P + R_i \times D_i\right) \tag{14.3}$$

were f is water stress, P is its probability, R and D are yield reduction and its probability respectively, a is the coefficient reflecting change trend of capability

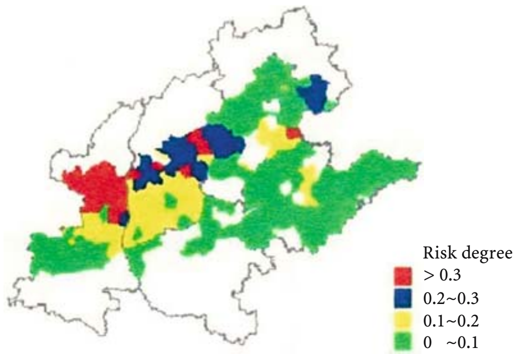


Fig. 14.5. Comprehensive drought risk zoning of wheat in North China

of combating drought and M is normalized as value of 0–1. The division result is shown in Fig. 14.5.

Risk assessment is an effective risk management approach of agro-meteorological disasters. The results of risk assessment are used in guiding management of agricultural production. For example, the drought risk assessment under different irrigation system scheme shows that the drought risk could be effectively reduced under 1–3 times irrigation in North China (traditionally 4–5 irrigation), and the benefit of three-time irrigation in severe drought year is the greatest (Xue Changying et al. 2003b). In 2003 the result was demonstrated in 100,000 hectares farmland in Henan Province. The rational arrangement of tropical fruit trees and adjustment of cropping system are proposed according to the risk division distribution. In 2002–2003, when the results of risk assessment for 4 agro-meteorological disasters were popularized in 4 provinces, the disasters losses were significantly reduced.

14.4 Popularizing Preventive Measures of Agro-meteorological Disasters

It is practical and helpful for farmers to understand and know well the techniques of disasters-preventing measures based on agro-meteorology. Chinese agro-meteorologists carried out studies on techniques of agro-meteorological disasters-preventing measures in the past five years, and popularized the techniques to farmers by various ways.

14.4.1 Rational Use of Agro-climatic Resources to Mitigate Disasters

14.4.1.1 Arranging Proper Crop Varieties According to Climate Conditions

The temperature condition is reflected in a major agro-climatic index determining regional distribution and yield of crops in Northeast China. Because of large variations in climatic conditions in Northeast China and longer growing period and unstable yield for late maturing crop varieties, it is an important counter measure of alleviating low temperature damage to rationally arrange and adjust crop varieties requiring different thermal conditions so as to use thermal resources and avoid yield reduction. It is an objective way to prevent and mitigate low temperature disasters. Yield reduction percent (r) of maize due to lack of thermal adjustments, the relation between yield of different matured varieties and temperature condition is given below:

$$r = 1 - \frac{1}{1 + e^{(a + b\Delta\Sigma T / \Delta\Sigma T_{\max})}} \tag{14.4}$$

where $\Delta\Sigma T$ is difference between the accumulated temperature from sowing date to harvest and the one required from sowing date to complete maturity ($\Delta\Sigma T_{\max}$), a and b are empirical constants. The benefits of each variety in region and the climatic probabilities of each benefit were estimated, and the proper variety which could use thermal resources and get maximum benefit is chosen as the dominant crop variety by probability decision method. In addition, decision-making in matching and adjusting proportions of various varieties under different heat patterns by multi-goal linear program method was made. As a result the spatial distribution of proportion of dominant variety and other varieties under each heat pattern year are determined and plotted. (Liu and Sun 2000).

14.4.1.2 Sowing Crop According to Predicted Proper Sowing Date

Sowing on proper date is one of the effective counter measures to avoid low temperature injury of crops in Northeast China, which could use thermal condition in spring and ensure crop maturity before frost. Normally, indirect and direct prediction methods are adopted (Ma Shuqing et al. 2000).

The numerical weather forecast model and mean function are used to predict mean ten-day temperature of April and May. Based on the relationship between mean temperature in April and sowing date the predicted model of maize sowing date is developed. The accuracy of sowing date prediction is up to 79%. The suitable sowing date for maize in Northeast China is normally determined as starting day of mean daily temperature $\geq 7\,°C$. There is a model to forecast starting date of temperature $\geq 7\,°C$ using co-regression analysis between beginning date and departure field of 500 hPa geopotential height with accuracy of 80%. In routine forecasts, the weighting integration with historical fit accuracy and validation accuracy for different forecast models is adopted.

14.4.2 Adopting Practical Agricultural Measures to Mitigate Disasters

Some practical agricultural measures to mitigate disasters were studied and popularized to farmers.

14.4.2.1
Effect of Plastic Film Mulching and Nursery Transplanting

Film mulching has the significant effect of increasing temperature and preserving soil moisture. Some experimental studies on effects of mulching and nursery transplanting on crop growth in Northeast China were conducted. In Northeast China late maturing varieties could be cultivated by using mulching. Its growing period is 15 days longer than local major variety and gains more than 200 °C of accumulated temperature, and it could be planted at 5 °C of mean daily temperature. When using film mulching the yield could increase 45% (Ma Shuqing et al. 2004). The nursery transplanting prolongs 20 days of maize growing period and increases accumulated temperature up to 220 °C. The yield is enhanced by 40% (Guo Jianping et al. 2003).

Table 14.1. Effect of plastic film mulching and nursery transplanting

Technique treatments	Advanced days of sowing date (d)	Prolonged days of growing period (d)	Increment in sum of temp. during growing period (degree day)	Increment in yield (%)	Increment of weight per 100 grains (%)
Mulching	−5	+15	+200	+45	+40.5
Nursery transplanting	−7 ∼ −10	+20	+220	+40	+6.9

14.4.2.2
Effect of Straw Mulching

With straw mulching, the thermodynamic and dynamic characteristics of soil surface are changed, which results in sensitive heat flux increasing and latent heat flux reducing, more water is stored in soil. It is favorable for soil water accumulation in early growing period and promotes transpiration and dry matter accumulation in later growing period (after jointing stage). The results indicate that straw mulching is an effective measure for preserving soil water and raising crop yield. Different amount of straw, different mulching time and different soil water content have different influences on the dry matter weight, leaf area, intensity of transpiration, yield and water use efficiency of winter wheat. The optimum mulching date in North China plain is the end of December when winter wheat stops growing. The optimum straw amount used for mulching is about 4,500–6,000 kg/hm^2, and the optimum soil water content is 55%–70% of relative soil humidity. Under the combination of above conditions, the yield of winter wheat increased by 18.5% and water use efficiency raised by 22.2% (Zhu Zixi et al.2000; An Shunqing et al.2001).

14.4.3 Preparing and Applying Reagents to Mitigate Agrometeorological Disasters

14.4.3.1 Low Temperature-resistant Growth Promoting Regulator

A new low temperature-resistant growth promoting regulator without pollution and hormone was prepared for combating low temperature damage in Northeast China. It consists of various nutrients required by crops, improves chlorophyll content of leaf and promotes photosynthesis and anti-adversity performance. The results of field experiments and demonstration on farm land show that spraying growth promoting regulators on leaf surface of crops twice during vegetative growth stage and spraying again when low temperatures occurs, helps in advancing the crop maturity by 5–6 days and increasing seed weight by 9%–10% and in production increases of 6%–11% under normal climatic conditions, and 10% in low temperature years. The ratio of input to output is about 1:20 (Wang Chunyi, et al. 2000).

14.4.3.2 Growth- and Tiller-promoting Regulators of Rice

In order to mitigate low temperature injury during sowing period of rice in Northeast China, a new regulator of promoting growth and tillers of rice seedlings was prepared. It consists of multi-organic and mineral substances. The results show that by using the regulators in seedling period, the time of tillering shifts earlier. Effective tiller percent is 25%–27% compared with contrast of 2.2%–6.7%, proline content increases 10%–46% and electrical conductivity decreases 23%, which reflects the feature of low temperature resistance (in the year 2001). The rice yield raises 2.5%–6.7% in four site experiments (in 2002), and 8%–12% in farmland with 7,500 hectares (in 2003) and the ratio of input to output is 1:10 (Wang Chunyan et al. 2003).

14.4.3.3 Drought-preventing Reagent

A multi-functional drought-preventing reagent restraining evaporation and promoting crop growth was prepared in laboratory and tested in field in North China. It plays a role in combating drought and saving water. Its use may enhance stomatal resistance of leaf by 24%–51%, depress plant transpiration by 2%–9%, thus reduce water consumption by 27.0–28.1 mm during the stage of ear formation and 10.2–11.3 mm in grain-filling stage, and improve water use efficiency by 2%–10%. At the same time the multi-functional drought preventing reagent may retard the senescence of green leaves and therefore prolong the wheat grain-filling process. The leaf area index increased by 0.24–1.12, the rate of grain filling increased 22%–44%, and photosynthetic intensity was enhanced by 18%–28%, as compared with increase in 1,000-grain weight by 1.6%–3.3%, and yield increased by 6.7%–8.4% (Zhao Guoqiang et al. 2000).

14.4.4
Popularizing Agrometeorological Disaster-preventing Techniques

In order to make more farmers learn and operate the techniques of meteorological disaster preventing so as to reduce disaster risk, Chinese agrometeorologists actively popularize agro-meteorological disaster preventing techniques through demonstration, education and training. The handbooks of countermeasures against low temperature damage in Northeast China and drought in North China were published and issued to farmers. The training courses on agro-meteorological disaster-reduction techniques are held in disaster prone regions. In some areas the agro-meteorological disaster preventing techniques are shown on TV station. During the past 2–3 years the growth and tiller promoting regulators of rice were popularized in 7,500 hectares and average increase in yield was 8%–12% while the increase in net rice production was 2,400 tons. The comprehensive techniques of preventing drought of winter wheat has been popularized on about 50,000 hectares.

14.5
Agrometeorological Information Services

Timely information on crop growth status, agro-meteorological conditions as well as occurrence and effects of agro-meteorological disasters is important and necessary for decision-makers, managers of agricultural production and farmers as it helps them to manage agricultural production and avoid or mitigate adverse impacts of meteorological disasters on agricultural production. In China Meteorological Administration (CMA) there are various levels of operational agro-meteorological information service.

14.5.1
National Level

There is a huge and effective agrometeorological information service system in CMA, it relies on an agrometeorological observation network with 584 stations and advanced communication network. It consists of data collection and their transmission, processing and analysis, and subsequent product preparation as well as delivery system. The agrometeorological information bulletins are issued every ten-days to users by mail, e-mail, internet, and the daily agrometeorological conditions along with review and assessment is also broadcasted on the agricultural channel of China Central TV. Drought and flood are monitored by using remote sensing techniques and provided to the public. When the meteorological disasters occur or are predicted, the possible unfavorable effects and practical counter measures are proposed and suggested through bulletin or TV channel. The yield forecasting for major crops all over the China is provided to governments in advance.

14.5.2 Provincial Level

In all the Provincial Meteorological Bureaus, agrometeorological information services are carried out routinely. Many information services are integrated systems including prediction and assessment of agrometeorological disasters followed by decision-making, crop yield forecasting and consultation on agricultural production management. The service products are issued by bulletin, Internet, TV program, radio and newspaper. There are also some professional information service systems, such as special information service for cotton crop. (Wei Li and Lu Shuming 1997; Ge Huiyan and Zhang Yong-hong 2001). The role of guidance and consultation in provincial level is more detailed and directive, and benefits obtained are also more pronounced.

14.6 Conclusions

With increasing incidence of natural disasters around the world, timely and accurate prediction of disasters, comprehensive assessment of their impacts on agriculture, forestry, and fisheries as well as relevant strategies for mitigation of natural disasters are critical for sustainable development, especially in the developing countries. It may not be possible to prevent the occurrence of these natural disasters, but effects of the resultant disasters and vulnerability associated with the hazards of natural disasters could be reduced considerably through proper planning and effective preparedness and also can be controlled to some extent by accurate and timely prediction and by taking counter-measures.

It is very important to strengthen and to improve risk management of natural disasters. Disasters should not be viewed as extreme events created only by natural forces but complicated unsolved problems influenced by physical, social, and economic forces as well. An effective approach for risk management is to put forward timely and accurate prediction of agrometeorological disasters, comprehensive risk assessment and practical disasters preventing measures. At the same time transferring agrometeorological disaster information to users and popularizing disasters counter-measures to farmers have the desired effects on sustainable development of agricultural production in China.

In order to better make disaster risk management, mitigate extreme events and reduce loss due to agrometeorological disasters, it is necessary to further strengthen monitoring of agrometeorological information, establish a comprehensive database in accordance with the users needs, including adequate collection, quality control and presentation of data specific to certain kinds of disaster, and make good use of modern available technology, e.g., remote sensing, geographic information system and Internet. There is an urgent need to improve the forecasting skills for agrometeorological disasters. Lack of good forecast skill is a constraint to improved adaptation, management, and mitigation. Prediction models based on improved statistical models and combination between seasonal climate prediction and crop growth simulation models should be integrated. Agrometeorological disasters risk zoning is an essential component of disaster mitigation and preparedness strategies. The study on models for disaster loss assessment should be further promoted. More practical and useful techniques of preventing or reducing loss of disasters on agricultural production should be extended and popularized to farmers by imparting education and training. Agrometeorological information service system should be established with more capabilities to deliver information of agrometeorological disasters to public and users more easy and faster.

It is essential to promote and foster the use of international and regional programs to enhance collaboration and building of partnerships on issues related to improved management of and preparedness for meteorological disasters. In addition, the cooperation between agrometeorologists and users, institutes and government agencies is important.

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Degradation of Vegetation and Agricultural Productivity due to Natural Disasters and Land Use Strategies to Mitigate Their Impacts on Agriculture, Rangelands and Forestry

Bernard Gomez

Abstract Natural disasters are known to cause severe economic losses and in many developing countries in the form of decline in agricultural production, destruction of food reserves, damage to water supplies, etc. This report focuses on land use strategies to mitigate natural disasters including tropical storms, floods, droughts, dust storms and sand storms, frosts, volcanoes, landslides, bush, and forest fires. It is important that disaster preparedness and prevention projects are built into a wider development strategy. Mitigation efforts need an integrated and concerted action by all the agencies concerned. Long term disaster reduction efforts should aim at promoting appropriate land-use in the disaster-prone areas, by harmonizing land suitability with agricultural development strategies.

15.1 Introduction

Natural disasters affect human society and cause suffering, damage to infrastructure worth billions of dollars each year, loss of life and deterioration of the environment, substantially exceeding normal expectations. In recent decades, people throughout the world have become increasingly concerned by extreme meteorological and hydrological events, which are becoming more frequent and more destructive. Natural disasters that affect agriculture are mainly those that are related to weather and climate such as drought, floods, frost, excessive rainfall, tropical cyclones, storm surges, high winds, hailstorms, forest fires etc.

In the developing world, some of the impacts that can accompany natural disasters include the decline in agricultural production and destruction of food reserves and damage to or loss of water supplies through drought or through pollution of traditional water sources during floods. The extension of cultivation into less suitable climates also increases the risk of damage.

A major attempt has been made to focus this work on land use strategies to mitigate natural disasters. With this case studies an attempt to analyse the strengths and weakness of the strategies, would have been most useful, as we firmly believe that the ultimate objective of this work is to define effective and efficient ways of mitigating the negative effects of natural disasters. We also recognise that the types of extreme events have not been fully exhausted.

15.2
Definitions of Terminologies

Unless stated otherwise in this study, the following terms are construed to have the following meanings:

- degradation – reduce to a lower organic type or a simpler structure
- vegetation – plants collectively
- agricultural productivity – efficiency in producing agricultural goods
- natural disasters – a serious disruption in the functioning of a society, causing widespread human, material, or environmental losses which exceed the ability of the affected society to cope using their own resources.
- land use strategies – plan(s) or policy(ies) to achieve the purpose an area of the Earth is put to (e.g., agriculture, forestry, urban dwellings, or transportation corridors) or its character (e.g., swamp, grassland, or desert)
- mitigate – the process of taking action in advance to minimize the effects of future hazards.
- impacts – the detrimental and beneficial consequences of a phenomenon on natural and human systems.
- agriculture – the process of cultivating land and rearing livestock.
- rangelands – Unimproved grasslands, shrublands, savannas, and tundra.
- forestry – the science or practice of planting and caring for forests.

15.3
Natural Disasters

To combat the situation arising from natural disasters and take effective measures and draw up appropriate plans to minimise the loss particularly in agricultural sector, it is essential to know about them. Some of these major natural disasters in the context of agricultural activities are outlined as follows:

15.3.1
Tropical Storms (Cyclones, Hurricanes, Typhoons)

Tropical cyclones are amongst the most destructive natural disasters to affect many regions of the globe, causing tremendous loss of life, property, agriculture etc. the impact of tropical cyclones is greatest over coastal areas, which bear the brunt of the strong surface winds and flooding from rainfall at the time of landfall. Apart from the strong winds and heavy rainfall, cyclones are also associated with devastating storm surges, which inundate vast areas of coastlines.

15.3.1.1
Process of Damage

The principal causes of destruction by tropical storms are:

1. Fierce winds;
2. Torrential rain and associated flooding;
3. High storm tides.

Most casualties are caused by coastal inundation from the resulting storm tides. The collapse of buildings, the falling of trees, flying debris, electrocution and disease from contaminated food and water in the post-cyclone period contribute substantially to loss of life and destruction of property (Das 2003).

The effects of strong winds in coastal areas are seen in stunted and often very sculpted trees providing unmistakable evidence of the direction of the strong winds. In addition to the battering effects of winds, there is the additional damage caused by airborne sea salt which occurs within a few hundred meters of the coast. Winds which blow from the coastal seas spray a lot of salt on coastal areas, making it impossible to grow crops sensitive to excessive salt.

Moreover, a rise in the ecstatic sea level results in the territorial extension of coastal salinity under the direct or indirect influence of sea water. Fields inundated by the storm surge suffer a loss of fertility due to salt deposition, even after the sea water has receded. The affected land takes a few years to regain its original fertility. The period of high water can last from 6 hours to several days, if the drainage is poor, and may leave the soil saline and unfit for crops. Saline soils are predominantly observed in the coastal areas of India. A rise in the sea level would adversely affect the 7,000 km coastal belt of India, comprising 20 million ha of coastal ecosystem, increasing coastal salinity and reducing crop productivity.

15.3.1.2
Impacts on Vegetation and Livestock

Impacts of tropical storms to agriculture, rangelands and forests can be characterised as follows:

1. Physical destruction of vegetation and livestock;
2. Damage to irrigation infrastructure such as canals, wells and tanks; and
3. Long-term loss of soil fertility from saline deposits over land flooded by sea water.

15.3.1.3
Mitigation Measures

In any effective tropical storm mitigation measure, public awareness plays the most important role. People in affected areas must understand the physical nature of the threat and its disastrous potential. Aside from early warning actions aimed at saving lives and property from impending danger, the following land-use strategies could be very useful:

- Hazard-prone areas should be subject to land reform. Harvests should be phased such that they coincide with the safe period or periods of low risk.
- Protective forests (mangrove) should be encouraged, both to reduce the frequency of inundation and to initiate reclamation.
- Risk zone mapping and analysis of land use pattern should be undertaken to guide growth and development away from hazard-prone areas.
- Land-use legislation and building regulations should be established and strictly enforced in hazard-prone areas.
- Raised platforms for livestock, emergency food grain storage facilities, drinking water storage and wells with covers to avoid pollution and silting during inundation should be built in storm-risk areas and properly maintained.

15.3.2 Floods

Floods are produced by tropical cyclone, severe thunderstorm or prolonged heavy (including monsoonal) rainfall. These floods occur mainly in areas where the soil is not well drained or are clayey and hence non-drainable. Heavy rains and floods result in certain constraints in agricultural activities but their impacts may vary greatly from one area to the other depending on the rate of drainage seepage and drying. Examples of negative effect, either direct or indirect of heavy rain and flood on agriculture are the damage to fragile plant organs like flowers and buds, soil erosion, water logging and conditions favourable to crop and livestock pest development as well as on pollution and pollinators.

In monsoon area such as southern Asia and coastal areas of West Africa, flashfloods are common, often caused by heavy rains associated with the monsoons. These heavy rains, apart from causing damage to economic structures such as roads, dams and bridges, affect agricultural products in the areas.

Flooding caused by flash floods is not always linked to bodies of water. On sloping terrain the water masses can turn the smallest of channels into raging watercourses; on even terrain the water does not run off fast enough and accumulates on the surface. Flash floods are a great danger to life and limb. It also causes landslides with resultant damage to life, property, loss of soil etc.

15.3.2.1 Impacts on Vegetation and Livestock

Flooding often has significant, deleterious effects on agricultural production, rangelands and forestry. The impacts can be wide ranging, both temporally and spatially. Its economical and political impacts are also far reaching. The following effects can be observed:

Erosion: The movement of water at considerable speed, in some parts of a flooded area, particularly during flash floods causes erosion of the topsoil, resulting in the loss of the soil nutrients.

Sediment transport: Flowing water carries sediments along with it. The amount of sediment that can be transported depends on the flow velocity and the size of the sediment particles. Sediments enhance the fertility of the soil and beneficial for agriculture.

Deposits and debris: Sediments are often deposited outside the course of a river. Debris and refuse (trees, structural components, cars, ice floes, etc) may become wedged at bridge passages and cause backwater which can lead to very high water levels even when there is only a small increase in discharge. Backwater can be used for aquaculture.

Debris flows: This is usually associated with torrential rain. They are a mix of water and solids that advance at high speeds of 15 m/s and over and carry almost everything along which get in their way.

Contamination: Flowing water transports impurities, which can lead to very unpleasant pollution. Leaking oil tanks and flooded sewage plants in particular, generate significant hazard to natural systems. Freshwater fisheries are also affected by contamination of water

Landslides: It is usually triggered by torrential rain. The infiltrating water activates slip planes and at the same time increases the weight of the upper soil layer by filling up the pores in the soil. Road transportation can be interrupted significantly.

Waterlogging: Crops, nurseries, pastures can be completely destroyed due to asphyxiation, if flood waters stay for a significant period of time. Flood water causes interruption to tillage, planting, crop management and harvesting. It also causes permanent damage to perennial crops, trees, livestock, building and machinery. Soil temperature reduction and retardation due to flood is harmful for agricultural production. Stagnant water due to flood could be favourable breeding ground for insects and diseases.

15.3.2.2
Protection Against Flood

Various devices may be employed in order to control an excess flow of water so that a flow may be prevented, or at least, the worst effect reduced. These devices include engineering works, embankments, detention reservoirs, the adaptation of river channels and facilities for flood diversion. Short- and long-term protective measures, which can be classified as conventional, and non-conventional methods of flood control are as follows:

1. Conventional Methods

Depending on the cause of flooding, two conventional approaches to flood control can be distinguished. When the cause is excessive rainfall over the basin, then levees and floodwalls along the river are used to confine the water to the river channel and thus accelerate the floodwater flow to the sea or storage reservoir. When the cause of flooding includes tidal influence, then control gates at the river mouth are used to regulate the tidal effect.

2. Non-conventional Methods

Other possibilities for minimising flood include the following:

- On-farm storage in lowland ricefields: Practised in ASEAN (Association of South East Asian Nations) countries, this involves the storage of excessive waters in ricefields, especially during the vegetative phase of the crop. With properly maintained ricefield bund spillways, the amount of rainfall that can be trapped as on-farm storage is equal to the height of the bund. This practice can also be conducted in upland farms or fairly flat areas, with 2- to 3-m deep dug-out farm reservoirs, can also trap some runoff which would otherwise flow immediately to the river.
- Low earth dams: The construction of a series of low earth dams (up to 3 high) on shallow waterways or gullies leading to the rivers, can be done by farmers with technical assistance from the appropriate national agency.
- Reforestation and terracing of hilly lands constitute long term approaches to minimising flash flooding.
- In urban areas, flooding can be minimised by constructing appropriate drainage channels based on the estimated peak floods. Allowance should be made to cater for clogging of drainage systems by garbage, particularly non-bio-degradable materials.

15.3.3 Drought

Dryness and the more serious drought conditions occur in a regional climate system when the supply of water, that is available for plants, humans and livestock cannot satisfy the demand adequately. Demand may differ significantly from one region to another and thus as a rule adjusts to the long-term supply, which, in turn, is determined in essence by the average annual precipitation and the local evaporation rates. Regions in which the availability of moisture is more or less constant may be severely affected by a short dry period, whereas arid and semi-arid regions, have no major problems enduring relatively long periods without any precipitation at all.

Dryness and drought differ from the majority of natural hazards in that it is not possible to pinpoint inception date, at least not at the time. The last precipitation event observed is not synonymous with the beginning of a drought because the important role played by the amount of antecedent precipitation and the ground moisture. Therefore, the transition from a dry period to a drought is gradual.

In addition to precipitation and evaporation, such factors as temperature, wind, type of soil and its capacity to store water, depth and availability of groundwater, vegetation growth, and a few other factors play a role in the making of a drought. On account of this complexity it is extremely difficult to predict a drought and to react in good time. It is usually not recognisable until it is already well-advanced.

The vulnerability of a region to drought is a function of the social, political, and economic conditions there. A drought event can quickly change a basic vulnerability due to an unstable supply system into a famine if external assistance is not provided on time.

15.3.3.1
Response of Plants to Drought Conditions

Not all parts of a plant react to drought in the same way. According to Molga (1962) the upper leaves of the plant maintain their physiological activity the longest by drawing water from lower leaves. The latter are first to wilt or dry up during a drought.

It is not unusual for plants under such conditions to develop short lateral shoots with tiny leaves from the axils of the dropped old leaves. These new small thickish leaves can be kept alive and turgid even with a much reduced water supply from the roots. If the drought occurs during the seed formation in grain the seed will be small, deprived of adequate amounts of nutrient substances, its size being inversely proportional to the area of the assimilating surface of the plant.

Drying out of the tilled layer of the soil at any time during the vegetative period has an adverse effect upon yields. However, with respect to grains , the greatest yield reduction takes place when drought occurs during or immediately after the stem elongation stage, i.e. at the beginning of the heading stage.

The increased sensitivity of grains to droughts during the period from rooting to heading stage is well known. The development of spikelets coincides most frequently with appearance of the fourth leaf. If the tilled layer dries out during this period the number of spikelets is greatly reduced. Particularly adverse in this respect is the combination of drought and high temperature. These conditions also reduce the number of heads which are formed at this time. This leads to the reduction of yield even though moisture conditions improve during later stages of development (Kulik 1957).

Prolonged dry periods coupled with the absence of effective water in the one-metre soil layer reduce yields to zero. If there is some effective water in the 20–100 cm soil layer, dry periods reduce the yields but do not ruin them completely. Any additional water accumulated during the fallow period prior to seeding becomes highly significant under these conditions.

15.3.3.2
Impacts on Vegetation and Livestock

Drought may result in the following phenomena:

Subsidence: Certain types of soil (clays in particular) shrink tremendously when they dry out. Subsidence occurs especially when these types of soil are subjected to stress (e.g. by a building).

Desertification: In prolonged or repeated periods of drought, the ground and the flora are so badly damaged that their resilience, is impaired or even destroyed permanently. Die-back of forests occurs due to drop in water tables. Mangrove forests are threatened by increased level of salinity.

Famine: When a drought is prolonged, the entire food supply system in a region for both human and livestock may break down. International aid is usually required to restore it.

Forest, bush, brush, and grass fires: Vegetation that is dry or parched is extremely combustible. A fire may be caused by a stroke of lightning, a spark, or even an object that just needs to act as a burning glass (e.g. a piece of broken glass).

Conflicts: Shortage of fodder and drinking water for cattle may lead to hostile confrontations between farmers and pastoralists, or between neighbouring states sharing common water resources.

15.3.3.3 Mitigation Measures

Drought is a recurring phenomenon and its occurrence cannot be avoided. Furthermore, the consequences of future drought events may be considerably aggravated, because the progressive evolution of the ecosystems tends to worsen the imbalance between population and resources. Generally, there are always some areas which are not affected by drought while some other areas may be reeling under drought. Therefore, there is a need to develop infrastructure for mitigation of drought (Das 1995). The impacts of drought can be minimised through the application of science and technology in developing suitable drought management plans as mentioned below:

1. Current or Short-term plans

The availability of accurate agricultural, meteorological, hydrological and/or other environmental monitoring data/information on the occurrence of drought in any area cannot be over emphasized. Since the onset and cessation of a drought is generally difficult to determine, continuous monitoring of the environmental variables is the only way to track the occurrence of the phenomenon.

A recently introduced technique in the CILSS (Permanent Interstate Committee for the Control of Drought in the Sahel – French acronym) member countries of the West African Sahel, is that in addition to monitoring the environmental variables during the crop growing season, Geographical Information System techniques are used to locate “zones-at-risk” of drought (famine).

Although the technique is not operational yet in most of the countries, it goes without saying that given the least developed status of the countries of the Sahel, timely information on the risk of famine/water scarcity in any area is a major achievement, if not the most important tool to withstand the negative impacts of drought. Using the information generated from this planning tool, policy/decision-makers can intervene (either shift national priorities or appeal for external support) on time to alleviate a catastrophe.

2. Medium-term plan

- Water control: During drought periods, the water factor becomes of primary importance and often constitutes an element of survival. Availability of sufficient potable water supply for both humans and livestock therefore becomes urgent. This can be achieved through the use of ground water (deepening of old wells, digging of new wells, drilling of boreholes, etc.) resources, where advantageous and the creation of water reservoirs as appropriate in order to maximise the use of surface water resources.
- Moisture Conservation: In fragmented and/or sand soils, the ability to retain moisture for proper crop growth is not always guaranteed, especially during low rainfall periods. This is all the more pronounced in sloppy terrain and where rainfall intensities are significant, e.g., most parts of the West African Sahel. Upland vegetation does not benefit much from the incoming rainfall, which drains as runoff to the lower lands. Placing obstacles (stones in general) on waterways in farms encourages infiltration of the water into the soil for use by crops.
- Contour Bunding: In areas receiving seasonal rainfall, another device of water conservation is to build small bunds on the small perennial rivulets. During period of rainfall water gets stored in such check-dams which can be used by the village folks during dry periods. It also recharges the adjoining soils. In some areas of rural India, this technique has found wide acceptability.

3. Long-term plan

One of the objectives of long-term planning to enhance resilience to drought is to organize and equip vulnerable countries/regions in a way as to make their economies less vulnerable to drought.

Irrigation: Since water is the major limiting factor in drought environments, the possibility of irrigating crops should be explored. This will certainly need the assessment of various factors such as topography, availability of water, costs and benefits analysis, etc. In food insecure regions, this option should be examined seriously, as drought is a recurrent phenomenon and self-sufficiency in food production is more secure than reaching out for imports or food aid.

Drought planning and water crisis management need to be proactive. The overall policy, legislation and specific mitigation strategies should be in place well before a drought or water crisis affects the regular supply of the country's water resources.

15.3.4
Dust Storms and Sandstorms

Dust storms occur all over the world but have large frequency over arid and semi-arid lands. Their spatial extent varies markedly from several hundred meters to thousands of kilometers horizontally and from several meters to several kilometers vertically.

The largest dust storms occur in sandy deserts. Here they are responsible for putting large volumes of dust into the atmosphere and moving great masses of sand on the earth's surface. As a result of selective blowing, soil with a high sand particle content is created and the organic element (the main source of nutrients for plants) decreases. Thus in these places the dust storms cause loss of soil fertility and alter the chemical structure of the soil. The physical properties of the soil are changed also with changes in soil structure. In dry areas, steppes and deserts, dust storms are observed usually in spring and early autumn in connection with dry soil.

Soil structure, moisture conditions, presence of snow cover and relief are important factors in the formation of dust storms. The drying of the upper soil horizon, absence of crop and vegetation cover, low relative air humidity (below 30 percent) in winter as well as a poor cementation of soil, etc. increases the probability of dust storms. Dust storms mostly occur in spring and summer, when the wind strengthens, and fields are in a ploughed state or contain poorly developed vegetation.

When the soil moisture content in the ploughed layer is 25 mm or less, dust storms may be formed at wind speeds above 15 m/s. When this content is below 10 mm, dust storms occur even at wind speeds of 8–10 m/s. In stable air conditions particles of sand and dust may be lifted up to great heights under the influence of convective mixing. The light soil particles move as dust in great distances; the relatively heavier particles fall out and dislodge other soil particles, which are then taken up by wind. Thus, there is a chain reaction.

The intensity of the blowing of soil is proportional to the speed of the wind raised to a third power. For example, when the wind speed changes from 12 to 15 m/s, the intensity of the blowing of soil is increased approximately twofold (Adamenko 2003).

15.3.4.1
Impact on Agriculture and Rangeland

Dust storms cause great damage to agriculture and vegetation cover, if any. They destroy and damage crops. High winds may remove significant volumes of earth, leading to reduced soil fertility. Dust storms are often associated with droughts. Such a combination causes major losses to a national economy. Crops are ruined and poor developed seedling being blown away; fields, roads, canals, water reservoirs, irrigation systems are covered by sand and dust; all kinds of infrastructure and communication networks are adversely affected.

15.3.4.2
Prevention/Mitigation Measures

In most countries, field afforestation is the main measure to protect the soil from dust storms. Improving soil resistance to erosion can be achieved by careful selection of cultivation methods, applying mineral and organic fertilizers, sowing grasses and spraying various substances, which enhance soil structure. It is important to reduce the areas where dust can gather, especially in tracts in areas characterized by erosion. One major protection strategy is to establish well-developed plant cover before the dust storms period. This can encourage a reduction in the wind speed in the layer next to the ground by forming an effective buffer.

When looking at the conditions in which dust storms develop and data on storm-induced damage it is evident that measures to reduce the wind speed at the soil surface and to increase the hooking of soil particles are both crucial. Such measures include the establishment of tree belts and windbreaks. Leaving stubble in field, non mouldboard ploughing application of chemical substances promoting the hooking of soil particles, soil protective crop rotation using perennial grasses and seed of annual crops are also important (Adamenko 2003).

In planning and implementing protection measures it is necessary to take into account the direction of prevailing winds, relief, microclimatic details and soil properties.

In regions with intensive wind erosion, especially on wind shock slopes or on light soils, strip cultivation may be used. On fallow lands bare fallow strips of 50–100 m can be alternated with strips of grain crops or perennial grasses; spring crops can be alternated with winter crops. The direction of strips should be perpendicular to the damaging winds.

Cultivating without turning over furrow and retaining a cover of stubble from previous crops are two important measures to reduce the oscillations of soil temperature and protect soil from wind erosion during the winter–spring period.

Barriers, such as tree belts and buildings, cause a slackening of the wind and the heavier particles to fall out, forming land-drifts. The lightest particles of soil can remain suspended in the atmosphere for a long time. And so, during a dust storm visibility and light penetration worsen.

15.3.5
Frost

Frost is a condition in which the temperature of the air close to the ground surface is below 0 °C. An important role is also played by regional circulation systems in the oceans (e.g. Gulf Stream) and in the atmosphere (e.g. monsoons). A second decisive factor is the elevation, as the mean temperature decreases by 0.6 °C on average per 100 m of elevation, although this rate is influenced by the humidity. The frost risk is not synonymous with the level and duration of the minus temperatures recorded.

During the winter, there is a constant decrease in the temperature of both the ground and ocean surfaces in higher latitudes and of the air above these areas. Since cold air streams into areas which would not cool down to below freezing on account of the reduced radiation alone, the cooling effect can also be "transported" into these areas.

On clear nights there is increased radiation from the warmer surface of the earth to the colder atmosphere, as a result of which the earth's surface cools (as well as objects, vegetation, etc.). For this reason ground frost may occur even at air temperatures above freezing.

15.3.5.1
Impact of Frosts on Vegetation

Losses due to frost are primarily to be found in the agricultural sector. At temperatures below 0 °C the water contained in plant cells freezes. On account of the expansion of the ice, the cells burst and are destroyed. Although some plants have adjusted to low temperatures, others, are extremely susceptible to frost and cannot even survive short periods at temperatures slightly below freezing without being damaged; sometimes they are injured even at temperatures above freezing. Damage may also occur if the blossom period is too cold for insects to fly and pollinate the flowers. Although this does not lead to direct plant damage, yields may be reduced or the crop may even fail altogether. Freezing rain is a special case in which the temperature is not the critical parameter but the extreme weight of the ice under which the branches break and entire trees collapse.

Damage to crops by frost and freezing temperatures causes serious loss to farmers in many parts of the world. In the middle-latitude, the incidence of killing forest determines the length of the growing season, which is practically limited to the time-interval between the last killing frost of spring and the first killing of autumn. The shorter this period is, the earlier maturing will be the varieties that can be grown and lower their potential yielding ability. In warmer regions occasional and exceptional frosts may do considerable damage because the crops grown in such regions are usually very susceptible to low temperature. Frosts are, on the other hand, common in the temperate region and in the subtropical areas which suffer occasional incursions of cold air masses.

15.3.5.2
Mitigation Measures

Water pipes and other installations exposed to frost must be adequately protected against the cold. Pipes in the open freeze more quickly if the water in them does not move. Insulation is a good alternative. This can be done by covering the pipes (with earth) or wrapping them with a thermal insulating material. Water pipes in the open must be laid at a sufficient depth.

Standing water and consequently ice too are almost as poor thermal conductors as air and are thus good insulating materials. Wine-growers often exploit this property by watering vines when there is a risk of frost.

Precautions can be taken against radiation frost by covering the objects that require protecting. In most cases, canvas sheet stretched out like a tent will do the job. Another possibility is to churn up the often shallow layer of cold air with the warmer air above it using fans.

15.3.6 Volcanic Eruption

Major volcanic eruptions may be even more destructive than earthquakes, but their occurrence probability is much lower than that of strong earthquakes. The ash that is thrown out in large eruptions may reach into the earth's upper atmosphere, where it may stay for a relatively long time (months to even years) and affect the global climate by blocking out the sun's rays. The mean global temperature in the year after the eruption of Pinatubo in the Philippines in 1991 was reduced by approx. 0.6 °C.

15.3.6.1 Impact of Volcanic Eruption on Vegetation and Livestock

The hazard derives from various features of volcanic eruption, in particular, ash fall, tsunamis, lava flows and lahars, gases, glowing clouds and volcanic earthquakes.

Volcanic gases (sulphur oxides and nitrous oxide) threaten the entire living world in the surroundings. Plant life could be poisoned by volcanic gases, resulting in the loss of rangeland, and death of livestock. Property is also threatened by the corrosive effect of volcanic gases. Volcanoes as natural springs of new rock have many advantages. It contains numerous minerals formed at high temperatures, which quickly break down when attacked by water, providing essential nutrients for plants. In the aftermath of a major eruption of volcanic ash, farmers (at a distance) often enjoy greatly improved harvests.

15.3.6.2 Mitigation Measures

For many volcanoes throughout the world there are hazard maps that represent a good basis for land use regulations, engineering measures, and emergency response planning with a view to minimization or prevention of loss. Engineering measures are viable in the case of lahars and even at short notice in the case of lava flows due to their slow speeds. Barriers may be erected either to check or to channel the progress of the flows, as is the practice in connection with the Mount Etna eruptions.

15.3.7 Landslides

Landslides involve the movement of the topmost portion of the earth caused by internal earth forces (relief and exogenic geological processes) and external actions (climatic and human activities). They constitute a major problem during the rainy season along roads with steep embankments, on mountain slopes and on hillsides. The manifestation of these processes is often catastrophic, causing destruction and havoc over large areas, transforming lush valleys and agricultural lands into lifeless wastes, and maiming and killing human beings.

Exogenic geological processes can occur independently of human activity. In denuded mountain slopes, some soils crack in the dry season due to excessive drying. These cracks can be as wide as 10 cm or more, and run to a few metres in depth. With the arrival of rains, landslides of these cracked soils, often occur.

At the zone of occurrence, landslides displace objects sitting on the earth to a lower hypsometric level, therefore making them loose their grip and thus tumble and fall.

15.3.7.1
Impacts on Vegetation and Frost

Losses due to the negative impacts of landslides include both direct and indirect losses. Direct costs involve the replacement, repair, or maintenance due to damage to installations or property (industrial plant, houses, buildings, and equipment, including tractors, automobiles, agricultural machinery, etc), whilst indirect costs related to this work include:

1. Loss of productivity of agricultural or forest lands;
2. Temporary closure of industrial plants due to interruption of transport systems;
3. Loss of agricultural productivity due to the destruction of irrigation systems, etc.

15.3.7.2
Control of Landslides

There exists a general consensus that the incidence of landslides has gone up due to hydrological problems arising from widespread denudation of hill slopes. Majority of slope stability problems in the Western Himalayan areas have their origin in a cumulative erosion of hill slopes. Effective system of surface drainage is needed to intercept the surface runoff, to minimise percolation of water into the slope material and to establish a stable moisture regime. Drainage enables a reduction in the weight of the mass tending to slide, as well as, leads to increase in the strength of the slope forming material. Plantation of grasses and shrubs to restore the vegetation cover has been found to be successful in arresting this type of mass movement. Since a high proportion of landslides are of erosional type, the need for providing a vegetation cover on denuded slopes is an urgent task.

15.3.8
Bush/Forest Fires

The extensive forest fires of the late nineties, not only in Latin America and the Caribbean, but also in the rest of the world, have moved this issue off the back burner to the forefront of the world's attention. Fires are changing in their frequency, intensity and pattern. For example, if fire incidence stays at current levels or increases in frequency, then many rain forests will be replaced with vegetation that is less diverse and more combustible, contributing further to the trend. People are now concerned not only with the disappearance of the forest, but also the extensive and widespread impacts of fires on human health and the economy.

Weather plays a significant role in the fire environment (Pyne et al. 1996). Federal fire mangers in the United States recommend that fire danger rating indices, based in part on weather data, be considered part of a comprehensive set of criteria used to decide whether to control naturally occurring forest fires or to let them burn as part of a management strategy for reducing fuel load and/or ecological purposes (Andrews and Bradshaw 1995).

15.3.8.1
Favorable Conditions for Fire

Prevailing weather conditions, fuel composition and structure of forest cover and topography are highly influential to fire behavior. In dry and hot weather conditions, especially over an extended period, there will be more fuel available across the landscape. Fires spread when adjacent fuel catches alight before fuel that are already burning go out; this can continue until all fuel is used up. Some favourable conditions have been mentioned below:

- Both heat and dryness serve to reduce the required amount of heat to cause ignition.
- Wind aerates a fire and increases oxygen availability, enhancing the rate and intensity of the combustion and fire spread.
- Chemical composition affects the temperature of ignition and also the energy release from combustion.
- Fuel structure determines the availability of oxygen and effectiveness of heat transfer.
- Topography affects the relative geometry of a fire's flames, thereby affecting the efficiency of heat transfer from the fire to adjacent fuels, and hence, the likelihood and rate of fire spread.

15.3.8.2
Impacts of Forest Fire

Forest fires have seriously affected human health, the economy and the environment. The extent of the damage to human health from smoke inhalation depends on the constituents of the smoke, its concentration, and exposure time. Smoke from fires causes thousands of respiratory, cardiovascular and eye problems (e.g. conjunctivitis). In addition to numerous cases of constrictive or obstructive lung disorders, the number of cases of asthma, pneumonia bronchitis, acute laryngitis, and bronchiectasis rise dramatically. It also can kill, as in 1998, when 70 Mexican firefighters were killed, and there were 700 smoke-related deaths in the Brazilian Amazon.

The environmental impacts from forest/bush fires ranges from local to global. Local impacts include soil degradation, increased risks of wet-season flooding and dry-season drought, reduced number of animals and plants, and increased risk of recurrent fires. Global effects of these fires include the release of large amounts of various greenhouse gases, reduced rainfall and increased dry lightning as well as contributing to the reduction of world biodiversity through the extinction of populations or species.

15.3.8.3
Prevention/Mitigation Measures

These can be considered at several levels: fire prevention, fire management, fire prediction, fire detection and monitoring and fire fighting.

1. The importance of fire prevention in any fire management strategy cannot be over-emphasized. Prevention is less expensive than suppression and obviously has the benefit of reducing fire damage.
   Fire prevention methods are quite straightforward and well-known. They include:
   - The creation of firebreaks, by clearing the ground of all fuels, around any area that is to be burned
   - The use of back or perimeter fires so that firebreaks are created by burning towards the centre instead of toward an edge
   - The cutting of dead trees which could span firebreaks as they fall and burn
   - Consulting with neighbours before burning lands

   Mopping-up operations to prevent fires in tropical/subtropical forests are particularly necessary and time-consuming. Falling foliage from trees destroyed in a fire can begin to blanket the ground with a new fuel layer within a few days. This process has resulted in as many fires in a single area within a given year. To prevent this, a detailed search of the entire affected area is necessary to extinguish anything still smoldering. If a fire is rapidly contained, the mop-up operation will be minimal, but if it is allowed to burn over substantial areas of forest, time and manpower needed to deal with this increase substantially. Monitoring the progression and spread of fires or all these fire prevention efforts can be expensive for local owners.
   Zoning of land use across tropical landscapes can be effective. For example, the disassociation of fire-maintained agricultural area from selectively-logged forest would reduce the probability of forest fires and the severity

of fire damage from accidental fires. Easily-flammable fuel sources should not be exposed to frequent ignition events (e.g. pasture maintenance or new slash fires). Land use intensification has been cited as a way to increase land values and possibly decrease deforestation. This would also help the fire problem because greater productivity and value of property would make fire prevention and protection efforts more cost-effective.

2. Fire management at a national level involves the establishment of the necessary infrastructure, equipment and trained personnel to be able to detect, monitor and respond to forest/bush fires. Special emphasis needs to be placed on international cooperation, since very few nations have the human, material, or financial resources to cope alone with severe fire situations. Interaction between nations and personnel exchange/training programmes should be encouraged and fostered by international agencies.
   Many different strategies can be adopted to tackle the fire problem, from better education and fire management to economic incentives and land use planning. But these will not be successful without the support and involvement of local people.
3. Fire prediction or early warning systems need to integrate information about weather, vegetation dryness, fire detection and fire spread to provide a simple measure of the fire situation. It is therefore important to know the status and distribution of land cover. Reasonably accurate and current maps of the changing landscape are therefore needed. Local populations must be involved in supportive efforts against fire.
4. Patrols, towers and aircraft are integral parts of the fire detection and monitoring process but satellite detection is a necessity. Trade-offs exist for using various satellite platforms for fire detection and monitoring and mapping. New satellite sensors will enhance capability but aerial detection and suppression of fire in tropical forests, although critical, can still be problematic. The forest canopy disperses smoke and obscures vision, making it difficult to locate fire lines. It intercepts much of the water and fire-suppression agents that are dumped on fires, making them much less effective.
5. Fire fighting should make use of aerial and ground suppression forces. They should be well trained, equipped and coordinated through a well-defined command structure.

15.4
Conclusion

The recent spurt in the periodicity and intensity of disasters calls for a systematic mitigation strategy, which is comprehensive as well as contextual. More so, because the ever changing countenance of disaster cannot be totally attributed to nature's wrath. Vulnerability to natural disasters is also increasing because of unmindful human actions and insensitivity. We are completely out of tune with our surroundings. The heedless pace of development has left us ecologically barren. Developing countries face the most debilitating consequences in the form of economic and social disruption caused by disasters. Only when disaster preparedness and prevention projects are built into a wider development strategy or when mitigation efforts go beyond the individual action of a single department, can there be any lasting impact on the lives of the affected. Long-term disaster reduction efforts should aim at promoting appropriate land-use in the disaster-prone areas, by harmonizing land suitability with agricultural development strategies. The measures to promote proper land-use should include both legislative and economic inducements and creation of public awareness of proper land practices. Formulation of land-use policies for long-term sustainable development is, therefore, imperative.

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Agricultural Drought Mitigation and Management of Sustained Agricultural Development in India

Haripada P. Das

Abstract Drought is a many faceted natural disaster that leads to serious socio-economic impacts particularly affecting agricultural production and water supplies. There are two distinct phases in which the application of the knowledge of weather and climate can reduce the impact of drought on the communities. The first is the long term planning in which strategies can be devised, and precautions taken to reduce impact. The second phase is the action taken during the onset of the event to reduce adverse effect. Efforts were made to stabilize dryland agriculture by evolving contingent crop production strategies in rainfed areas of India. Drought management policies included agricultural planning and practices with consideration of overall water requirement within the individual agroclimatic zones.

The ill effects of drought, to a considerable extent, can be alleviated by adopting proper crop management strategies. These strategies may vary from moisture conservation to manipulation of plant population, and even mid-season corrections. Rainfall also can be harvested in either farm ponds or in village tanks and can be recycled. In case of drought mitigation, it was recommended that economies diversify to include agro-industry or various tertiary products, which could create new forms of income. The focus in mitigation should be on measures like improvement in agriculture, management of rangeland, development of water resource and animal husbandry. There is an urgent need to develop appropriate policies and strengthen institutional mechanisms for drought preparedness and mitigation accompanied by concrete programs.

16.1 Introduction

Among the various hazards of nature, drought is one of the most disastrous because it brings innumerable miseries to mankind. Few areas of the world can boast of not having faced this calamity one time or the other in their history. A few thousand years ago people were aware of how adverse weather conditions affected food production and water supplies. The idea of a genesis strategy was suggested in biblical times, i.e., to store surplus grain produced in the good rainfall years for use in the years of poor rainfall. This idea reminded societies that droughts do recur and that the people must learn from history, or they will repeat their mistakes.

Drought and famines have occurred in India for centuries and have even been mentioned in folklore. No precise data of these events are available,

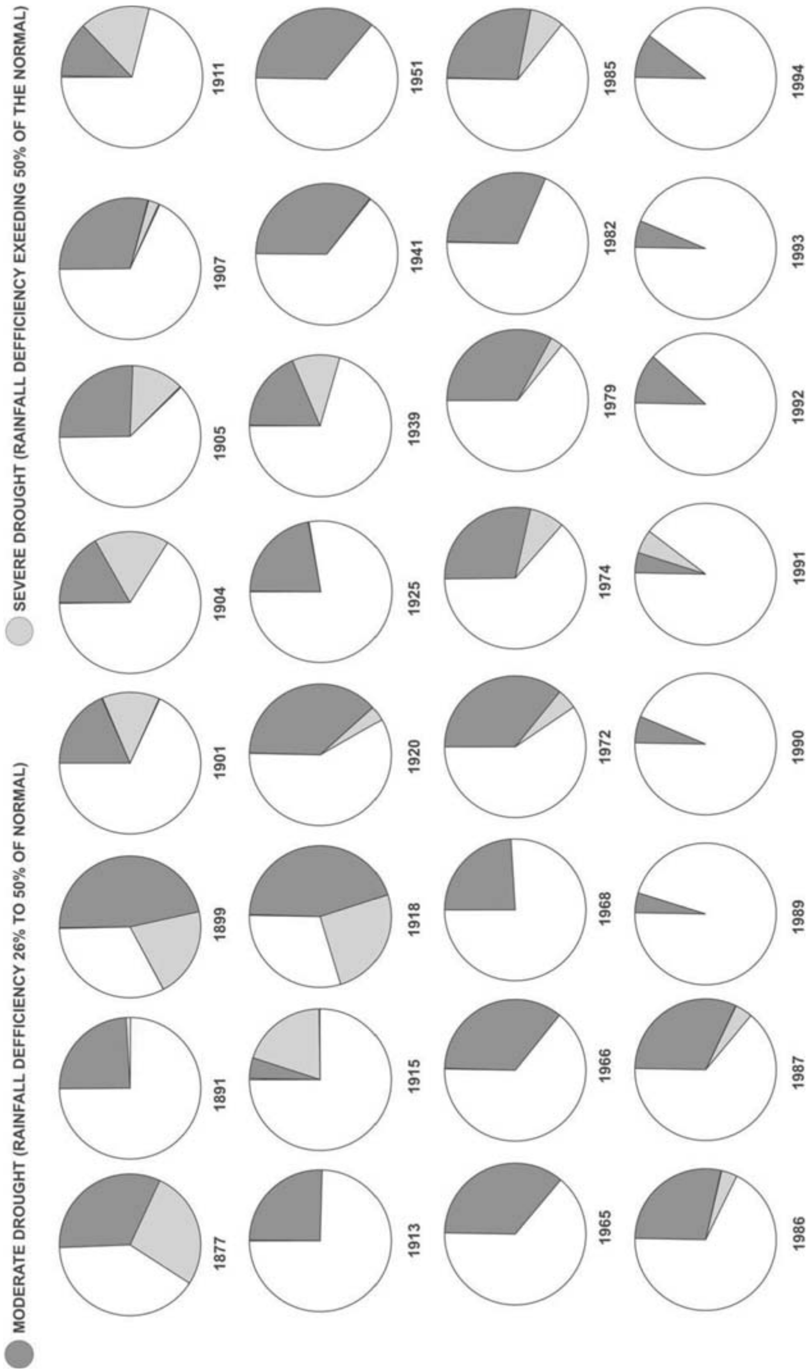

Fig. 16.1. Drought years in India, with percentage of the area affected since 1875

however. Since the establishment of the India Meteorological Department in 1875 and systematic data generation, it has been possible to demarcate areas affected by droughts in each year. Some typical cases of significant droughts in India are depicted in Fig. 16.1. While drought by itself may not appear to be a major cause of societal dislocation, it can combine with underlying societal problems to initiate new changes that are already under-way. Often, the impacts of droughts linger long after a drought has ended, thereby dissociating the drought itself from many of its impacts (Das 1995).

Poor people living in drought-prone environments are consummate risk managers. They often have successful track records in managing drought, even though the effectiveness of indigenous coping strategies to protect food and livelihood security has been undermined by successive droughts and impoverishment. Although crops and cropping patterns are adjusted to given climate and physiographic conditions, intermittent drought spells or recurring drought conditions in a given area can be managed with the help of different strategies. A range of policy tools has been developed to mitigate the effects of drought, but their effective implementation has proved elusive. National organisations to manage and plan for drought relief have proliferated in sub-Saharan Africa (SSA) often in alliance with donor agencies, and have met with varying degrees of success. Many have drafted drought contingency plans, but these tend to remain at the level of theory. Wilhite (1993) outlined in considerable detail a generic process with meteorological steps that may be adopted by governments to develop comprehensive drought planning and management.

The basic objective of drought risk management is to minimise possible adverse outcomes within the constraints of the costs involved. Given the certainty that drought will occur but the uncertainty about the timing of such events, the management task encompasses anticipation of and preparation for the drought, and management of the various phases of the drought event, including drought onset, occurrence, and recovery.

The effective management of drought risk is therefore a matter of concern not only to those countries subject to significant climate uncertainty, but to the international community as a whole.

16.2 Drought Management

Drought is indeed a many faceted natural disaster that leads to serious socio-economic impacts, which have long-term implications. Associated human misery underscores our vulnerability to this natural hazard and makes it imperative to improve our knowledge of the nature and causes of drought and to innovate strategies for reducing its adverse impacts.

It is important to note that drought does not descend all of a sudden. It results from a set of weather sequences that require an extended period to develop. Thus it takes a good period of time for a drought situation to begin, expand and decay. This allows us some times to adopt contingency plans to reduce the adverse effects of drought. There are two distinct phases in which the application of the knowledge of weather and climate can reduce the impact of drought on the communities. The first is the long term planning in which strategies can be devised, and precautions taken to reduce impact. The second phase is the action that is taken during the onset of the event to reduce adverse effect. It is in this context that development of appropriate drought management strategy is of great importance, for individual countries as well as through internationally initiatives. Drought management is currently addressed by the following mechanisms and sectors:

Governmental

- Policy issues at national, regional and district level
- Rural development infrastructure
- Input supply, marketing and farm advisory services

Non-governmental

- NGOs
- Rural institutions, local self-governments
- Private sector
- Philanthropic organizations
- Community codes (tribes, herders)
- International aid agencies
- Alternate land use systems

Research and development institutions

- Best practices for rainwater and soil management through linking on-station and on-farm research
- Weather forecasts
- Contingency crop planning/mid season corrections

16.2.1 Risk Management

Risk is the probability of loss due to drought event. The probability is the likelihood of occurrence of an event assessment based on the historic data. For the purpose of decision making, it is adjusted to take into account currently available information and referred mainly as subjective probability. Risk aversion refers to an individual's attitude towards risk. Risk assessment takes into account the consequences of event and the likelihood of its occurrence. Risk management refers to actions taken to reduce the consequences or probability of unfavourable event. It provides the basis for an effective warning system at any level of responsibility. It identifies potential threats from hazards and establishes the degree of local exposure or vulnerability to hazardous conditions. This knowledge is essential for policy decisions that translate warning information into effective preventive action.

16.2.2 Drought Management Strategy

Research and development initiatives especially in areas like understanding the monsoon behaviour, agrometeorology, arid/dryland farming systems and hydrology have since contributed substantially to the knowledge base on drought management. These advancements have contributed in the development of useful technological outputs and also infused dynamism in agricultural production strategies and development of appropriate farming systems. These efforts thus enable the farmers to tide over difficulties created by the drought situations. However, the technology adoption by small holders who constitute the bulk of stakeholders in drought prone areas has not been to the desired extent. This shortfall is not only due to inherent difficulties in developing appropriate technologies for extremely complex rainfed-drought prone environment, but also due to the poor socio-economic conditions of the farmers and lack of adequate development infrastructure. Of-late, the drought management approach has shifted significantly in the region from crisis response to risk management through early warning systems, advance planning for emergency response and better preparedness. This paradigm shift in research and development strategy has since made some impact, but the sustainability in rainfed areas is yet to be achieved (Singh and Sharma 2002). The quality of life of small holders in rainfed areas therefore is yet to attain the minimum level of the desirable standards of living to reduce the gap with high productivity zones i.e. the irrigated areas. This is a national priority.

In India, having gone through the unnerving experience of suffering widespread droughts due to high variability of rainfall in time and space, a fairly organized drought management system has evolved in last 150 years. The problems caused by drought were faced with fair amount of competence and dedication. However, the approach was essentially that of starting adhoc relief works, as per famine code, to provide employment to the distressed population rather than having the long-term perspective for improving the conditions in the region and to reduce the probability of drought. The approach did not prove effective in mitigating the drought conditions. It was only since 1970s, with the launch of Drought Prone Area Programme (DPAP), that a long-term view was taken for evolving technological and organizational innovations, which were accepted as the strategy for integrated development of drought prone areas. This policy improvement has paid rich dividends while dealing with the infamous droughts of 1987 and 1999–2000. At present, the main objectives of drought management strategy are (Anonymous 1994):

- Distribution of essential commodities such as water, fodder, and food at subsidized rates, sometimes under Food for Work Programmes;
- Optimum utilization of resources in the affected areas with emphasis on primary resources viz. soil, water, vegetation, livestock, manpower, etc. Relief works undertaken for providing employment to drought stricken population are mainly for drought proofing; and,
- Improvement in terms of living conditions of the rural poor who suffer most due to scarcity and drought in particular, and the community in general by creating direct and indirect wage employment and taking up short gestation programmes of development.

In India, major research efforts on improving the productivity of rainfed areas with focus on reducing the adverse effects of drought have been underway for the last 2–3 decades. Packages of practices involving appropriate crops, improved varieties, tillage and seedling practices, soil and rainwater conservation/harvesting, use of fertilizers, weed control, alternate land use systems and plant protection have been developed through intensive and location specific research efforts. However, except for improved crop varieties, other components of the technology-particularly those aimed at conservation of natural resources (soil and water) have not been adopted by the farmers, more so the small holders who dominate the agriculture sector in rainfed areas. The integrated watershed management programme which forms the central strategy for the national programme of development of drought prone areas in India, initiated in mid-seventies has not made the desired impact in terms of replicability of pilot project despite the huge investment of public funds. Among other reasons, inadequate rural infrastructure and lack of efforts in rain water harvesting and water shade management may be attributed to this set back.

In arid, semi-arid and marginal areas with a probability of droughts incidence of say, at least once in ten years, it is important for those responsible for planning of land use, including agricultural programmes, to seek expert climatological advice regarding rainfall expectations. Drought is the result of the interaction of human pattern of land use and the rainfall regimes. There is thus an urgent need for a detailed examination of rainfall records of these regions. In this regard, the development of methods of predicting many weeks/months in advance, the occurrence of rainfall deserves high priority.

Since the technological impacts quickly reach an optimum level, more emphasis should be placed on the drought management policies, i.e., land and water management policies to minimize the food grain loss. This is especially important in dry-land farming areas. The agricultural planning and practices need to be worked out with consideration of overall water requirement within the individual agroclimatic zones. Crops that need shorter duration to mature and require less water need to be encouraged in the drought prone areas. Irrigation through canal and ground water resources needs to be monitored with optimum utilization avoiding soil salinity and excessive evaporation loss. Food reserves to meet the emergency of maximum up to two consecutive droughts must be planned. A variety of policy decisions on farming, human migration, population dynamics, livestock survival, ecology, etc. must be formulated.

16.2.2.1
Crop Adjustment for Alleviation of Drought

Efforts were made to stabilize dryland agriculture by evolving contingent crop production strategies in rain-fed areas of India. One of the best methods evolved was the adjustment of a suitable crop to the rainfall quantum and distribution in a given area. Using years of experience, crops have been chosen to suit the zones, based on rainfall and physiographic features. However, certain crops often are grown more for convenience, by convention, or for family needs. With more and more commercialization of agriculture, the attitude of the farmers is changing. As for example in Madhya Pradesh state of India, during the last decade, soybean area has increased from a mere thousand ha to more than 1 million ha. This is one of the best examples of crop choice to suit the rainfall pattern. Thus selection of a crop suitable for the rainfall quantum and distribution can contribute to sustainable agriculture.

In attempts to deal more effectively with problems of complex, marginal, diverse, risk prone agriculture and disadvantaged farmers operating in harsh environment, the farming system, as a whole should be regarded as a part of the larger system, such as the rural livelihood situations and administrative domains. The dryland farming system comprises several subsystems such as natural resources, the commodities, external inputs, internal inputs and marketing.

Small scale farming in upland areas of India is generally rainfed and on marginal lands and thus risks are high. Rather than depending on annual crops alone, it would be desirable to adopt the strategy of spreading the risks by using as wide a range of options as possible, including tree crops and livestock. The use of perennial tree crops in upland areas has a long history in India. Major types of trees grown include fruit (as inter cropping), paulowni, and white mulberry. Agroforestry is being practiced on a large scale in the region only for the past 20 years. In drought prone eastern areas, growing period of rice is shortened for late transplanting due to delayed onset of rain. Further, in jute-rice cropping pattern, harvest of jute extends to planting time of rice. The risk of water stress during the grain filling stage of rice is thus increased. As a cropping strategy, farmers use older seedlings in many situations. Changes in cropping patterns, varieties and input uses, reduction in rice area by replacement with other remunerative crops, are the major components of the recommended strategies when drought is of milder intensity and occurs early in the growing season (Pandey et al. 1999). Most of these innovations based on decades of research and largely adopted by farmers are centered to crops and cropping systems. Some of these are also based on the indigenous technical knowledge. Growing trees, and raising livestock, fish and poultry could be the important components of drought proofing strategies in the low land drought prone areas, and hence need concerted research efforts. There have been success stories to amply demonstrate that the more diverse the production system, lesser is the risk of failure of farm level economic security, inherent to rainfed drought prone regions.

16.2.2.2
Drought Resistance Varieties of Crop

Drought resistant plants are those varieties that are able to grow and yield satisfactorily in areas liable to periodic drought (Hounam et al. 1975). May and Milthorpe (1962) identified three types of drought resistance. They are:

- drought 'escapability' – the ability of a plant to complete its life cycle before being subjected to serious water stress,
- drought endurance with high internal water content, enabling a plant to survive drought by virtue of a deep root system or reduced transpiration; and
- drought endurance with low internal water content during the period of drought but the ability to recover and grow when soil water is replenished.

In India, the third type of drought tolerance is needed in the rice variety at the seedling stage because the root has not penetrated to deeper layers, the first type (drought-escaping) is needed in the rice variety, which completes its reproductive stage by the end of August.

In the areas where prolonged dry spells occur, varieties of the second type of drought tolerance are needed. For example, sorghum is more drought resistant than corn because of differences of root concentration. Greater drought resistance is shown by these plants with deeper and more extensively branched root systems. Root extension virtually ceases in most species during flowering and podding stages and hence the plants with faster maturity can survive during a drought spell.

16.2.2.3
Crop Management to Alleviate Drought Conditions

In the case of drought incidence during the growing season, the ill effects of drought, to a considerable extent, can be alleviated by adopting proper crop management strategies. These strategies may vary from moisture conservation to manipulation of plant population, fertilization, and even some midseason corrections. For example, recurring drought conditions can be managed primarily by crop variety adjustments, either by planting early maturing varieties that can escape drought or by planting drought resistant varieties. If drought occurs during the crop growing season, it can be alleviated with either soil water conservation techniques or supplemental irrigation. In high rainfall areas where there are a series of wet and dry spells, rainfall can be harvested in either farm ponds or in village tanks and can be recycled as lifesaving irrigation during a prolonged dry spell. The remaining water can also be used to provide irrigation for second crop with a lower water requirement, like chickpea. There have also been significant improvements in the ability to predict the consequences of drought on people's access to food, through the establishment of famine early warning systems (EWS). Much less progress has been made in using this information to improve preparedness and to trigger timely and appropriate responses, at either national government or donor level. Some of the strategies that can be adopted are discussed below. However, one point to be noted is that no one strategy can be applied to every situation. In fact, every strategy is specific to a given location, crop, time, and socioeconomic conditions.

16.2.2.4
Plant Population Management

If water stress conditions occur at the time of or immediately after germination, it would be best to resow the crop, preferably with some early-maturing variety. On the other hand, if water stress occurs around forty to fifty days after crop emergence, ratooning and thinning need to be considered. According to Venkateswarulu (1992), ratooning of a drought-affected sorghum crop with a subsequent rain resulted in a grain yield of 0.8 t/ha, compared to 0.2 t/ha for the same crop without ratooning. Similarly, pearl millet had a yield of 2.51 t/ha with ratooning, whereas the non-ratooned crop yielded 1.6 t/ha. Thinning the plant population by removing every third row at the time of drought increased the productivity of sorghum from 1.55 t/ha to 2.11 t/ha at Bellary in south India. When the plants started to recover after the return of rainfall, a 2–3 per cent urea spray was also found to be beneficial.

16.2.2.5
Rainfall Distribution Modeling and Contingency Planning

The corrective measures that can be taken in the event of moisture stress depend on the period during which drought occurs. If the rain falls immediately after sowing, resulting in a heavy mortality of seedlings, resowing has to be done. Mid season droughts usually occur when the crop is 40–50 days old with maximum leaf area which results in fast depletion of soil moisture. Therefore, reduction of leaf area either by water rationing or thinning can mitigate the drought effects to some extent. Weed control and mulching are other short-term measures that can mitigate drought by conserving the scarce moisture. Long-term measures for improving the soil moisture storage through appropriate land configurations also contribute to minimise the mid-season drought effect. However, these measures are to be planned well in advance at least in areas vulnerable to recurring droughts, as stated earlier. In short, the main strategy of mid-season correction revolves around extending the moisture availability period in soil. Such contingency plans can be prepared only if rainfall distribution models are prepared for different situations and are made available.

16.2.2.6
Weed Management

During a dry spell or water stress conditions, weed competition is a problem for crops because weeds also use the little moisture that is available. It was found that when a prolonged dry spell occurs immediately after the germination of the crop under rain-fed conditions, weeds infest the entire field. Bushening, one of the traditional practices of weed control and a means of creating semi-puddled conditions (a condition of partially pulverized soils), cannot be done under dry conditions.

Under such conditions, at thirty or thirty-five days after sowing, harvesting the entire field (weeds and rice together) can economically reduce the weed problem (Sastri et al.1990). Even in dryland crops sown in line, weed control through interculture operations was found to be beneficial under water stress conditions.

16.2.2.7
Management of Pastures and Range Lands

Among the different land use units in the rainfed agro-ecosystem, the permanent pastures are the most degraded and neglected. In many instances these are devoid of even the basal vegetation cover. Since the land does not belong to any individual, there is no concern for it. Overgrazing and other forms of destruction of natural vegetation, as well as encroachment, have increased so much that other poor communities have largely replaced the original plant communities. In order to reverse the process, a serious and sustained effort (perhaps even legislation) is warranted. In the arid areas, pelletted seeds of grasses such as *Lasiurus sindicus, Cenchrus ciliaris and Cenchrus setigerus* may be planted. Such simple interventions can increase the carrying capacity of an average permanent pasture from 2.5 sheep ha^{-1} to as much as 4.5–6.9 ha^{-1} sheep in sandy and 9.0–13.8 ha^{-1} sheep in loamy sand soils (Abrol and Venkateswarlu 1995). Multipurpose trees and shrubs such as *Prosopis cineraria, Ziziphus nummularia, Capparis decidua, and Acacia nilotica* are suitable for silvipasture. The areas marked for development need to be protected from grazing for at least two years. The controlled rotational grazing can then be introduced. Community mobilisation is thus the central issue. Farmers may be encouraged to establish pastures on part of their holdings (short and long term/degraded fallow lands) to decrease the pressure on village commons. The size of pasture may depend on the individual requirement and holding size. The approach, however, should be integrated with research and development in complimentary sectors. This may include replacing the large herds of poor quality animals with improved quality livestock of smaller number, which can be sustained in arid and semi-arid rainfed environments, improving grazing land management/stall feeding, improving the fuel energy situation, people's willing participation, and even legislation, if absolutely required and practical. Dynamic models need to be developed that help to identify the appropriate balance between the resilience of vegetation to short-term overgrazing, the variability in the weather, the indebtedness of herdsmen and their attitude to risk. Mention may be made here of an outstanding example of efforts made by community participation to involve the people in the management of their land in 'Banaskantha', a poor tribal district of Gujarat state of India. Banaskantha is one of the 18 districts in the North of Gujarat state of India, which is a drought prone and arid area. The main problem here has been lack of water and unpredictability of the rainfall, with the result that there has been a drought in the district in almost every other year. Livestock forms an essential part of the farming system. Droughts led to migration, fall in agricultural production, food scarcity, and so on.

An initiative of the Self-Employed Women's Association (SEWA), the National Dairy Development Board (NDDB), and the Disaster Mitigation institute (DMI) evolved into a Fodder Security System. This was aimed at increasing the ability of the people and the environment to cope with the adverse impacts of drought. Its immediate objective was to provide fodders to the members of the local dairy cooperatives in times of scarcity so that their animals would continue to be fed, the milk yield stabilized and their income sustained. The fodder was purchased at the lowest prices by the local cooperatives by pooling their resources during the earliest periods. Then, the fodder was stored at convenient locations and distributed at the right time in required quantities, thereby minimizing wastage. The final aim of the Food Security System was gaining access to ownership, production and distribution of fodder. It was felt that too much money was being spent on purchase of fodder and if they could collectively grow the fodder, the amount of fodder that needed to be purchased would be reduced (Bhatt 1997).

Wastelands are common property resources that are individually used but owned by the village community. These are important sources of fuelwood and fodder. The village community including the Panchayat was convinced by SEWA about the acquisition of wasteland for a fodder farm. Fodder was grown collectively and the yields were distributed among the members according to the number of cattle they owned and quantity of milk they produced. The Fodder Security System had a good impact on the community. It prevented death of cattle to a great extent caused by drought conditions, enabled continuous milk supply to cooperatives, decreased migration levels and produced positive ecological consequences. This initiative made the people realize as to how an organized effort could help them cope with the drought (Bhatt 1987).

16.2.2.8
Water Conservation Practices

The water conservation practices require improved irrigation (reduce conveyance loss, trickle irrigation), reduced evaporation from water surface, conservation of water in soil, reduced transpiration and evapotranspiration, increased underground recharge, conjunctive use of surface and sub-surface ware, etc. The storage of scanty rainfall through simple as well as extensive types of surface and ground water has been an important source of water in arid and semi-arid regions. These practices have often saved the drought-affected regions from water famine. One among the reasons of large-scale drought in the country is due to higher consumption of water and discontinued use of traditional water harvesting practices.

Monsoon dependent regions require sustainable surface and sub-surface water conservation practices. Such conservation practices should have social binding/responsibility in maintaining it. Conservation practices that were followed in the past are irrespective of rainfall amount in the region. In arid regions, precipitation is a basic element responsible for the water resources influencing development of the area. There is need of rain water conservation systems like Nadir (pond) harvesting catchment system of harnessing precipitation for human and livestock consumption; Tank – a covered underground tank for collection and storage of surface run-off (rainwater); Toba (pond catchment system of water harvesting) for human and livestock uses and Khadins (a water harvesting method where run-off water is stored) for irrigation. Conservation of both surface and ground water has been an integral part in most of the drought-affected areas of India. Ponds and tanks represent an important community resource for drinking water in rural India (Narain et al. 2000). The main attributes to their success are the sound scientific knowledge and methods on which they were built (Barah 1996). Destruction of the catchment area has resulted in excess water runoff away from the ponds leading to water storage. The boring of the large number of tube wells mainly by rich farmers has resulted in the steady decline in the level of ground water in these areas. The modern lift technology withdraws water exceeding the recharge rate and pushes the water table below the natural depth of water. Large-scale lift technology had left 30 to 40% of wells dry up annually in Anantapur district. In the coastal alluvial plains of Kutch and Saurashtra regions of Gujarat, high pumping of potable ground water along the sea has resulted in intrusion of saline water into freshwater aquifers. The water shortage is also due to the misuse of traditional water systems that could partially cope with the problem to meet the needs of cattle and irrigation. Increase in the population of livestock and humans and their fodder and fuel requirements have led to depletion of natural resources.

16.2.2.9
Lifesaving Irrigation

Drought prone areas suffer from inadequacy of soil moisture resulting into partial or total failure of crops. One life saving irrigation can transform the situation from failure to productivity. The concept of life saving irrigation received greater impetus with the concept of water harvesting. It is already reported that 15–20% rainfall goes as run off from the cultivated areas. The run off can be stored into farm pond and used at the critical stages. Generally for cereals, grain formation stage is critical. However, in dryland, the stage is decided by the soil moisture content. Under normal situations, one irrigation at the critical stage would boost yield by 50–60 per cent (Randhwa and Venkateswarlu 1979). One presoaking irrigation may make difference between crop versus no crop. When taken as a second crop, there may not be enough moisture below seeding zone due to which crop can not be established on the seed zone. Irrigation of 6 cm depth can saturate seed zone to establish the crop stand. Whatever may be the situation; the life saving irrigation is important. Use of available water judiciously for such kind of situation would be the best way to manage the drought. Even under certain situations life saving irrigations can be managed from regular irrigation projects.

In drought-prone areas of India, although there are no irrigation facilities, technological developments have been made to harvest, conserve, and recycle excess rainwater for use during water stress period. Such techniques are in vogue in almost every dryland area of the world. However, in recommending a particular practice of harvesting rainwater for providing lifesaving irrigation, care should be taken to match the practice to the available natural resources. Land, soil types, physiography, rainfall quantum, rainfall distribution and intensity, and cropping patterns must all be considered in this process.

16.2.2.10
Fertilizer Management

The crops in drought prone region suffer two kinds of stresses viz. moisture stress and nutrients stress. Nutrient stress is more pronounced due to low nitrogen content of soils. By providing moderate fertilizer the crop growth can be enhanced and drought can be escaped. It is, therefore, rightly said that 'beat the drought by fertilizer application'. Numerous large-scale trials have been conducted on farmers' fields to prove the worth of fertilizer use in dry farming.

Use of fertilizer, particularly nitrogen accelerates the growth and develops profuse root system thus making plants more capable to face the drought. The time and method of application are important. Placing the fertilizer 10 cm below the soil surface in the vicinity of moist soil at seeding is the most effective. Usually 25 to 50 kg N/ha dose is recommended. For kharif sorghum the level can be increased by 25% more due to alternate wetting caused by intermittent rains.

16.2.2.11
Contingency Crop Planning

Under rainfed conditions, the farmers have learned to keep their cropping practices flexible so that corrective measures can be introduced, depending on the type of weather aberrations (Subbiah 2000). Normally, the following kinds of aberrations are observed under rain-fed conditions:

- delayed onset of monsoon rains;
- long break in rainfall during the middle of the rainy season;
- lack of rainfall during the post-rainy season; and
- high soil temperature at sowing time (in case of post-rainy season crops).

In response to late onset of rainfall conditions, farmers change from long-duration high-yielding crop varieties to short-duration low-yielding varieties. The mid-season correction for each aberration varies from place to place, depending on the rainfall pattern, soil type, choice of crop, and so forth. Corrective measures include reducing the plant population by thinning crops to reduce crop competition for available moisture and providing supplemental irrigation in case there is a long break in rainfall during the crop season. However there are very few options to manage terminal droughts due to early withdrawal of monsoon. Harvesting the crop for fodder is the only way to slightly reduce the damage. Nevertheless, most of the drought management strategies need to be adopted from the beginning of the season in order to be effective. In other words, “one has to plan for drought management, before planting the crops even if the forecast is for a good year”. Therefore, the farmers sow a mixture of crops and thin out the cropstand as the intensity and duration of rainfall becomes clearer over the passage of time.

16.2.2.12
Drought Watch System

There is a need to have a Drought Watch System at district and state levels, which should be developed, implemented, and managed by experts in meteorology, agriculture, irrigation, public health, food supplies etc. (Das 2000).

The pre-requisites for the operation of such a drought watch system are:

- a network of rainfall stations, with reliable records of good quality, that are homogeneous and extend over a period of at least 20 and preferably more than 50 years;
- weekly/monthly rainfall records that are in computer compatible form;
- weekly/monthly rainfall totals that are available at the drought watch center within two or three days at the end of the week/month; and,
- the drought watch centers should have the capability of issuing weekly/monthly drought watch statements whenever rainfall situation demands.

16.2.2.13
Climate Forecast for Drought Management

As drought is a phenomena associated with scarcity of water, the period during which the scarcity of water is likely to be experienced, the extent of scarcity of water and the areas/regions that are likely to be affected by drought have to be known in advance. Information about the onset of drought conditions in a timely and reliable manner is useful in many ways to organize corrective steps in mitigating droughts for farmers. The information will facilitate:

- decisions at the time of sowing about the choice of crops/varieties;

- adoption of management practices related to soil moisture conservation, fertilizer application and manipulation of plant population during the crop growing period;
- Improved long range forecasts would diminish uncertainty in long-term planning and facilitate;
- development and sectoral planning – especially for water, an increasingly scarce regional resource;
- drought preparedness and mitigation strategies – governments need justification and confidence to embark on long-term approaches; and
- capital investment projects – through a more certain environment for investors throughout the economy.

Reliable long-term forecasts would also enable improvements in a larger number of strategic planning decisions in the public and private agricultural support services. For example, the availability of reliable seasonal forecasts should vastly extend the scope of response farming, allowing researchers to develop a limited range of different agronomic packages; in any particular year, the most appropriate extension packages could be promoted in accordance with the actual forecast for the area (Williams 2000). In India, demand for water – urban, rural, industrial, agricultural, and ecological – is increasingly outstripping supply. Options to satisfy future requirements increasingly demand international collaboration. Potential benefits from better regional water resource planning and management would justify major investment in improving the reliability and precision of long-lead forecasts.

The meteorological community in India has been contributing its experience to manage the drought in the following manner:

- Provision of improved long-range forecast of the seasonal rainfall before the beginning of the season. This provides time to the planners to adopt different strategies;
- Close monitoring of the rainfall over different parts of the country on daily, weekly and monthly scales within the rainy season;
- Delineation of different agro-climatological zones which helps in specific measures for agricultural planning on climatological basis; and,
- Continued research efforts to enhance our capabilities of forecasting monsoon rain over local, regional, and all India based on different temporal scales.

16.3 Drought Planning in Relation to Climate Change

Drought planners should also take steps to plan for the possibility of climate change or climate variability. They must plan for the change, since they are already considering changes in population and technology that will affect the demand. To address climatic uncertainty, drought planners should assess the sensitivity of water resource systems to climatic change. One could conduct a simple analysis by examining for example how a 2 °C or 4 °C increase in temperature and a 10% increase or decrease in rainfall affects a system's vulnerability to drought. Alternatively, one could use a more sophisticated scenario based on climate models. The sensitivity of the system to these kinds of changes could be compared to the impacts of other factors such as population growth and technological change. Drought planners in sensitive regions can take steps to improve the ability of water resource systems to recover from drought (Das 1999). Among the steps that can be taken are:

Water conservation promotion

- Water conservation can be encouraged by reducing or eliminating wastage. Agriculture is the greatest user of water in the country and has the greatest potential for conservation.

System optimization

- Better use of existing infrastructure would reduce vulnerability to regional droughts. Water resource managers should explore ways to transfer water between neighbouring systems during droughts.

Water quality protection

- Water pollution, control and abatement programs can increase the amount of water available for consumption during droughts. States and river basins should have comprehensive drought contingency plans that will reduce the impacts of drought quickly, such as automatic short-term water rationing.

All of these measures should have benefits even if climate does change or does not change.

16.4 Mitigation of Drought

Drought is a recurring phenomena and its relatively frequent occurrence cannot be avoided. However, its impact can be minimised through application of science and technology in developing suitable drought management plans. Generally there are always some areas that are not affected by drought while some other areas may be reeling under drought. Therefore, there is a need to develop an infrastructure for drought mitigation. Mitigation measures specific to drought can be defined as short and long term actions programmes or policies implemented in advance of drought that reduce the degree of risk to people, property, and productive capacity (Das 1999).

16.4.1 Drought Mitigation Strategies

Droughts are caused not merely by failure of rains but also due to lack of proper dispersal. Some areas get scanty rainfall, and therefore the strategy has to be built around water conservation and a cropping pattern, which should be supported by a judicious cropping pattern. Only those crops should be permitted which can be supported by the rain water. This should be worked out on the basis of the recorded rainfall data and its dispersal. There should be a proper regulation of ground water use. Apart from proper geographical dispersal of shallow and deep tube wells and dug wells through an appropriate legislation, sinking of tube wells should not be permitted beyond a certain depth. This would ensure availability of ground water in times of water scarcity. The legislation should also provide for regulation of flowing water in the rivers, streams and rivulets so that it is not used for irrigation in the years of scanty rainfall and water scarcity. Restoration of village ponds, tanks, streams and rivulets should be undertaken after village-wide survey. The work of survey and restoration should be completed in a period of three years. Fodder is a big problem at the time of droughts. A combination of pasture development and afforestation programme will provide not only the fodder during normal and drought years but also lead to soil and water conservation, and employment generation on a sustainable basis. Funding of these programmes can be done from the funds under the rural development and employment generation programmes under the various centrally sponsored schemes.

Some of the measures that would help in effective response and mitigate the hardship of the people are as under:

- Arrangement for reasonable buffer stock of food grain and fodder;
- Ensure supply of good drinking water in rural areas for human and livestock in drought affected areas;
- Assess fodder requirements in drought affected districts and locate areas where shortage are likely to occur and arrange supplies from outside;
- Fodder cultivation to be encouraged wherever feasible;
- Rejuvenation of traditional rainwater systems viz., Nadis, Tankas, Khadins, etc;
- Rainwater harvesting for both the drinking and cropping purposes;
- Management of human livestock population to reduce pressure on fragile arid ecosystem;
- Timely availability of credit, postponement of revenue collection, and repayment of short-term agricultural loans;
- Appropriate land-use planning (Inter-cropping system), discouraging the cultivation of water-intensive crops, and encouraging sprinkler and drip irrigation systems;

- Creation of local task force in each district to initiate relief measures immediately after the drought takes place;
- Implementation of crop and livestock insurance schemes;
- Provisions for cattle camp in drought affected areas; and,
- Early warning and drought monitoring should be carried out on the basis of long, medium and short term forecasts.

Typically, rural communities in drought-prone areas have managed their vulnerability by storing harvests and diversifying their livelihoods (e.g., crops, cattle, and off-farm employment). Population growth and the sometimes resulting degradation of natural resources are circumstances that can undermine the ability of communities to cope with drought. This is particularly true in dryland areas. It is often recommended that economies diversify to include agro-industry or various tertiary products, which could move some of the population out of direct farm employment and create new forms of income.

16.4.2 Government Action to Combat Drought

People of India from ancient times, have been concerned about the occurrence of this natural calamity. Governments from the historical past to the present, have tried methods to combat drought situations in different parts of the country so as to mitigate the sufferings of the people and reduce losses to the country's economy. These measures included: the reduction/waiver of the land revenue; distribution of free food from the government stock/granaries; provision of employment to the poor, marginal agriculturists, and landless labour force to provide purchasing power; migration of labour from the part of the country under drought to another part where rainfall is more normal, and food and employment are available; and, digging of water reservoirs in the form of tanks, wells and canals to provide irrigation facilities to avoid or reduce drought impacts in future events, etc.

The government also initiated the policy of maintaining adequate food reserves. Grain storage facilities have been improved and enhanced and a network of fair-price shops have been established in different parts of the country under a Public Distribution System. This has helped to instill confidence in the people and avoid panic purchase by the affluent section of the society. Agricultural research and other inputs like, the use of fertilizers, provision of power for tapping underground resources for irrigation and additional irrigation resources have also contributed to the 'green revolution' in the country. Different types of 'food for work' programmes have been initiated by the central and state governments to augment purchasing power to the poor. Loans granted under the Land Improvements Act have stimulated the construction of wells and other minor irrigation works.

The commonly adopted drought mitigation strategies (Sahni 2003) in India include: (i) Construction of check dams (ii) Water rationing (iii) Cattle management (iv) Proper selection of crop for drought affected areas (v) Levelling, soil conservation techniques (vi) Reducing deforestation and fire wood cutting in the affected areas (vii) Checking of migration and providing alternate employment for people in government sponsored relief schemes (viii) Education and training to the people (ix) Participation in community programmes.

16.4.3 Development of New Agronomic Practices and Modern Technology

Attempts to induce drought resistance by various pre-sowing hardening treatments of seeds, such as pre-sowing exposure to radiation, are being made. Attempts have also been made to evolve drought resistant cultivars and shorter duration crop varieties. Agronomic practices are being developed so that the active growth of the crop, during peak water demand, does not coincide with rainless period.

The focus in mitigation should be on the following measures:

- Improvement in agriculture through modifying cropping patterns and introducing drought-resistant varieties of crops;
- Management of rangelands with improvement of grazing lands, improved grazing patterns, introduction of feed and protection of shrubs and trees;
- Development of water resource system with improved irrigation, development of improved storage facilities, protection of surface water from evaporation, and introduction of drip irrigation system; and,
- Animal husbandry activities helping in mitigation with the use of improved and scientific methods, increasing outputs without destroying the eco-system.

What we need today is change over from traditional farming methods to more modern dynamic, flexible practices, making greater use of modern technology. This is necessary for farmers to respond rapidly to the changing demand for agricultural produce, replacing and adjusting varieties, crops and technologies to cope with new situations. What is needed is that the farmer is actually able to apply the new technologies. This calls for intensive training for all those connected with agricultural production and planning. An efficient agrometeorological training service consisting of professional scientists of high caliber is needed. This entails advanced level of training both in theory and practice.

16.4.4 Education and Training Programmes for Mitigation of Drought

Educational and training programmes should concentrate on several points. First, a greater level of understanding must be established to heighten public awareness of drought and water conservation and the ways in which individual citizen and the public and private sectors can help to mitigate impacts in the short and long term. The educational process might begin with the development of a media awareness programme. This programme would include provisions to improve the media's understanding of the drought problem and the complexity of the management issue involved, as well as a mechanism to ensure the timely and reliable flow of information to all members of the media (e.g., via news conferences). Second, the drought planner should initiate an information programme aimed at educating the general population about drought and water management and what they can do as individuals to conserve water in the short run. Educational programmes must be long-term in design, concentrating on achieving a better understanding of water conservation issues among all age groups and economic sectors. If such programmes are not developed, governmental and public interest in and support for drought planning and water conservation will wane during periods of non-drought conditions.

16.4.5
Farming Systems Approach for Drought Mitigation

As discussed earlier, extension and development programmes have failed to inspire farmers to adopt technologies in drought prone areas. Besides lacking a farmer participatory approach, these failures partly stem from the inherent difficulty of the task. Of late, it has been increasingly recognized how difficult it is to develop a sustainable technology for heterogeneous agro-ecological and socio-economic conditions of small holders in drought prone areas, unlike that for irrigated areas. The problems are complex, characterized by a host of environmental and socio-economic issues. Addressing not only a component of the farming system, e.g. crop variety, fertilizer use, or even crop husbandry per se, does not generally result in a dramatic increase in productivity as witnessed in irrigated areas. Mixed farming, consisting of crop production and animal husbandry for risk aversion, has been the mainstay of subsistence for such farmers. The farming systems perspective, therefore, can only be the proper management strategy for such regions.

Planning on-farm farming system research requires an understanding of what farmers are already doing. Four sets of information are needed to initiate farming system research in real field situations (i) socioeconomic conditions of people, their perceptions, priorities, requirements, and indigenous technical knowledge; (ii) natural resource conditions; (iii) technology (research information) developed at the research stations; and (iv) infrastructure (market and input issues) (Singh 2001). These data are collected and then carefully analyzed to balance resource conditions and farmers requirements for selecting technologies to apply and test as treatments. To begin with, more emphasis should be placed in refining indigenous technical knowledge. Strict prescriptions of component technologies developed at the research stations should be avoided. Required adjustments can be incorporated to offer baskets of options that suit the client's requirements and priorities.

Sustainability of rainfed agriculture is anticipated to be one of the most crucial problems of the next two decades. In this context sustainable agriculture refers to a farming system, which on a continuous basis enhances the productivity and economic returns, protects the environment, conserves the natural resources, and finally leads to an improved quality of life of people. The burgeoning human and livestock population regime in the region demands a continuous increase in productivity to meet the increasing requirements. Economic growth associated with development further adds to it. The fragile resource base in these regions is, therefore, required to be balanced with production activities in such a way that it continuously responds to the increased requirements without compromising its quality.

In irrigated areas the synergy among components of the recommended production technology (viz. high yielding variety, water management, fertilizer use and plant protection) resulted in a quantum jump in productivity. Farmers got impressed and readily accepted the technology, which led to the green revolution. However, in rainfed region, such synergy could at best operate at a very low level. Water, the most important input is uncertain. Moreover, farmers are poor and cannot cope with the risk factor. Inputs such as fertilizer are thus seldom used. In this setting, it is difficult to get farmers interested in improved technology as willing participants. We cannot do so until productivity substantially increases. For this reason farmers in rainfed areas have not accepted technologies (in isolation) despite vigorous extension efforts during the past two decades. Crops alone cannot meet the formidable task of sustainable dryland farming. We therefore, have to look into the whole production/farming system for synergy among its components, e.g., arable cropping, livestock management, alternative land use systems, and management of village commons/degraded lands. With such a synergistic integration the farming systems approach can meet the objective of productivity increase to the desired extent in the rainfed areas.

16.4.6
Strategy to Induce Farmer's Participation

Technology development for rainfed areas in the past has by and large ignored the farmer. It is known that people's participation is hard to come by unless some tangible benefits come through in the immediate future.

The following methodology may hitherto be appropriate to obtain interactive participation of farmers in drought mitigation efforts:

- Participatory resource appraisal (PRA);
- Demonstration of land degradation processes and water and soil losses with tools such as portable rainfall simulator;
- Focus group interactions to clearly obtain farmer's perceptions on: (i) drought prone issues; (ii) watershed and its relevance; (iii) sustainability of rainfed farming; and,
- Identification/listing of indigenous technical knowledge aimed at its utilization for on-farm assessment and refinement.

The success in interactive participation if focused in a mission-mode may eventually lead to voluntary participation or self-mobilization, which must be the national strategy for technology transfer in rainfed areas in the next decade. This methodology should invariably be adopted for planning on-farm drought prone research in a farming systems perspective.

16.5 Strategic Planning for On-farm Research

Strategic planning for developing best agricultural practices and farming systems is crucial and central to attain the goal of sustainable management of drought prone areas. In this context it would be permitted to divide the on-farm program into short-term (5 years), medium-term (10 years) and long-term (20 years) technological interventions (Singh and Sharma 2002).

16.5.1 Short-term Measures

Technologies to address the problems on a short-term basis aim at immediate benefit to farmers. An ideal approach would be to start from refinements in indigenous technical knowledge based practices. These interventions would not need much monetary inputs, but at the same time may lead to tangible benefits from improved crop productivity, thus in resulting in indigenous capacity building. This would build the confidence of the farmer in the programme and motivate them to adopt medium and long-term measures in due course, which will obviously need more of his contribution both in terms of labour and cash input. These consist of 'doable' technologies, which the farmers can adopt at their farm level (irrespective of farm size) and of course, as far as possible on a watershed basis with a little or no help from external agencies. Drought tolerant varieties, inter-bund treatments like key-line and appropriate tillage, summer tillage, ploughing/sowing across the slope, green-loppings-land cover-cum-manure treatment, vegetative barriers, ridge furrow configuration for planting, opening of conservation furrows, etc. are some of the examples for short-term measures. These technologies aim at creating an impact within a short span of 2–5 years. Nevertheless, such technologies act as "starters" or "stepping stones" for the longer-term task of managing water stress by developing sustainable water resources. These interventions aim at ensuring utilization of the in situ conserved moisture integrated with improved crop management for enhancing the crop yield under erratic and uncertain water supply.

16.5.2 Medium-term Measures

Once the farmers begin to realize the benefits of adopting technologies (through short-term measures), they can better understand the goals for control of drought and respond to participate in the adoption of medium and long-term measures. The medium-term measures address the problems in a time frame of 5–10 years. Integrated watershed management for development of farming systems and best practices is central to the medium-term measures. Regularization of runoff and storage in medium size reservoirs, renovation of existing tanks, adoption of alternate land uses systems and improvement of common pool resources are examples of medium-term interventions. Construction of such structures needs major initiative from the farmer with support from the government. Best practices are those which are appropriate both from biophysical and socio-economic angles.

16.5.3 Long-term Measures

These measures have a time frame of 10–20 years. Besides generation of large-scale surface and groundwater resources, development of wastelands that have gone out of cultivation should receive special attention in such interventions to reduce pressure on existing arable land resources for ease in drought mitigation. The emphasis on rehabilitation of wastelands should be to develop alternate land use systems with silvi-pasture integrated to livestock production as the main production enterprise. Extremely degraded and rocky terrains can be utilized as catchments for generation of surface water resource for utilization in adjoining areas. Such long-term measures thus can restore the land back to the production chain.

Long-term measures also include structures, which are erected to regulate overland flow and reduce peak flow. These structures, aim at improvement of relief, physiography and drainage of watersheds on macro scale, say 2,000–5,000 ha.

16.6 Drought Management and Remote Sensing

By virtue of a synoptic and repetitive coverage at regular intervals, space-borne measurements offer immense potential for early warning of and addressing most of the issues related to drought management on a near-real time basis. India has developed a space-based strategy for all the three phases of drought management, namely the preparedness phase, the prevention phase and the relief phase. Since 1989, the National Agricultural Drought Assessment and Monitoring system (NADAMS) has been providing biweekly drought bulletins which describe prevalence, relative severity level, and persistence through the crop growing season in most of the peninsular and northern India. The drought interpretation takes into account rainfall and aridity anomaly trends (Fig. 16.2). Plans are afoot for a comprehensive assessment of drought by accounting for variations in rainfall, surface water availability and soil moisture, in addition to vegetation condition. Apart from general crop condition assessment, crop-specific damage assessment is also contemplated using high spatial resolution

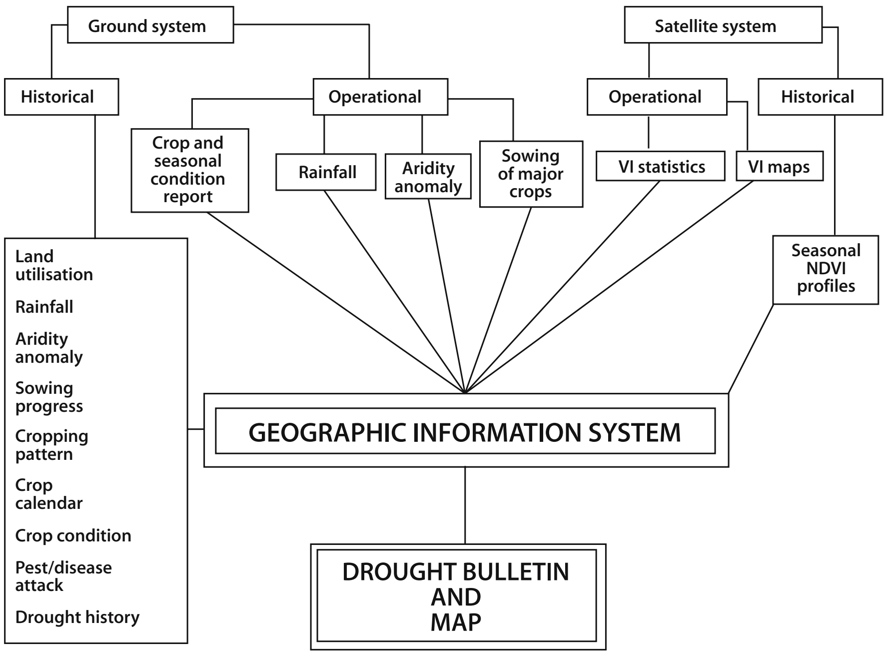

Fig. 16.2. National Agricultural Drought Assessment and Monitoring System (NADAMS)

satellite data. Future earth observation missions with improved spatial spectral and temporal resolution may enable the realization of our goals especially in the relief phase of drought management, by way of enabling the refinement of the locale-specific action plan for land and water resources development aimed at providing long-term relief.

16.7 Risk Transfer Through Insurance

In keeping with the impact of natural disasters, especially drought in India, disaster insurance could be a critical instrument of development in the field of crop production, providing financial support to the farmers in the event of crop failure. It can encourage farmers to adopt progressive farming practices, better technology in agriculture, besides providing significant benefits not merely to the insured farmers, but to the entire community directly and indirectly through spill over and multiplier effects in terms of maintaining production and employment generation of market fees, taxes, etc., and net assertion of economic growth. Crop insurance could also streamline loss assessment procedures and help in building up huge and accurate statistical base for crop production (Sahni 2003).

It envisages coverage of all the food crops (cereals, millets and pulses), oil seeds and annual commercial/horticultural crops.

The basic objectives of the crop insurance are to:

- Provide insurance coverage and financial support to the farmers in the event of failure of any of the notified crop as a result of natural calamities, pests and diseases;
- Encourage the farmers to adopt progressive farming practices, high value inputs and higher technology in agriculture; and,
- Help stabilise farm incomes, particularly in disaster years. Comprehensive risk insurance is provided to cover yield losses due to non-preventable risks namely natural fire and lightening, storm, hailstorm, cyclone, flood, inundation, drought, dry spells, pests, diseases, etc.

16.8 Conclusion

Drought inflicts considerable pain and hardship on society. The impacts of contemporary droughts have demonstrated this fact again and again over the past several decades. Drought illustrates in innumerable ways the vulnerability of economic, social, political, and environmental systems to a variable climate. It also illustrates the dependencies that exist between systems, reinforcing the need for improved coordination within and between levels of government.

Extended periods of normal or benign weather conceal the vulnerability of societies to climate variability, while drought exposes these sensitivities. Projected changes in climate because of increased concentrations of CO_2 and other atmospheric trace gases suggest a possible increase in the frequency and intensity of severe drought in the future. Any increase in the incidence of drought will aggravate drought management problems further. Coupled with increasing population and the associated rise in demand for water and other shared natural resources, there is a sense of urgency for reducing the personal hardships and economic and environmental impacts of drought.

The task of reducing the impacts of drought in developing countries poses tremendous challenges in regions where large segments of the population are poor and food-insecure and poverty levels are expected to increase in the future. The development of appropriate policies and strengthening of institutional mechanisms for drought preparedness and mitigation need to be accompanied by concrete programmes to promote sustainable livelihoods, as well as safety net to protect lives and livelihoods in the event of major drought episodes. Ultimately, development strategies for dryland areas need to help create increased opportunities for the populations and reduce marginalisation in order to contribute significantly to reducing vulnerabilities to drought.

Acknowledgement

The author expresses his gratefulness to Dr. S.K. Srivastav, Director General of Meteorology, New Delhi for his nomination and participation at this expert meeting.

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CHAPTER 17

Early Detection and Monitoring of Drought and Flood in China Using Remote Sensing and GIS

Yanxia Zhao, Sanmei Li, Yeping Zhang

Abstract Drought and flood are the most frequent and severe natural disaster. With the development of remote sensing and GIS technology, early detection and monitoring of drought and flood using remote sensing and GIS has become a reality in China. The paper summaries the status of the field including the methods and data used. It especially presents the methods and products for early detection and monitoring of drought and flood developed by National Satellite Meteorological Center (NSMC), and gives an example of Flood monitoring.

17.1 Introduction

Drought and flood are worldwide problems, causing enormous destruction and creating human suffering and producing negative impacts on national economies. Due to geo-climatic condition, China is one of the world's most disaster prone countries (Li, et al. 1996, 2000). Statistics show that among all the natural disasters that country faces, drought and river floods are the most frequent and often devastating (see Fig. 17.1, Fig. 17.2). They averagely account for 80 percent in terms of the area struck by disasters, drought is simply responsible even for 55 percent. Especially in the North China Plain, drought is the most serious natural disaster to winter wheat, and it usually accounts for half of the total agricultural loss. The east part of China is under the influence of the continental monsoon climate, and the rainfall is high in intensity and concentration in time. The flood season in the east region starts from June through September. During the flood season the maximum rainfall in one month can make up 25 percent to 50 percent of the total annual rainfall. Based on analysis of climate data (see Fig. 17.3 and Fig. 17.4), we can see that temperature generally increases and rainfall decreases. Drought becomes very severe. Meantime, due to rainfall distribution unevenly in China in recent decades, devastating floods frequently hit China, especially in 1990s. Many of them were the most severe in the last century (i.e. the 1998 flood in China).

Drought/flood affects few million hectares of crop area, take to a heavy toll of human and animal lives, and have damaged millions of houses annually during the last decade. Drought and flood early warning and monitoring are

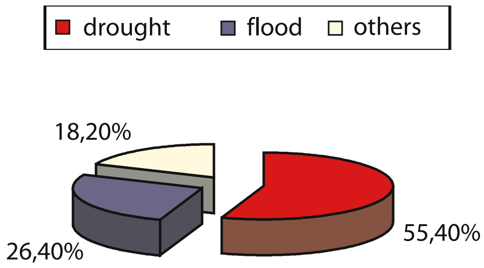

Fig. 17.1. Percent of drought and flood area in the total area suffering from natural disasters (based on statistics during 1951–2000)

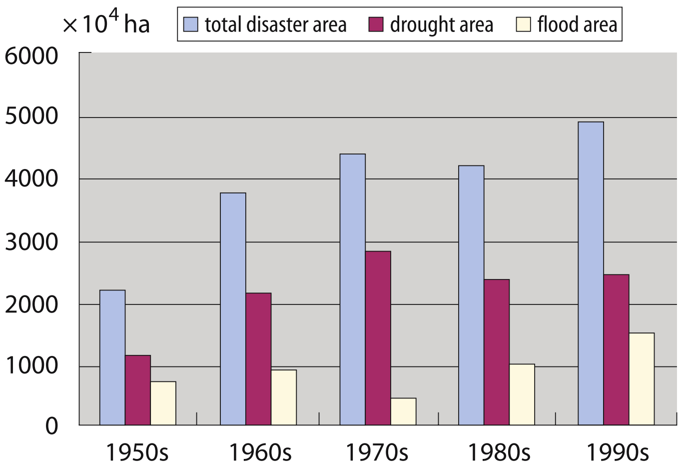

Fig. 17.2. Area affected by drought and flood in the total area suffering from natural disasters (based on statistics during 1951–2000)

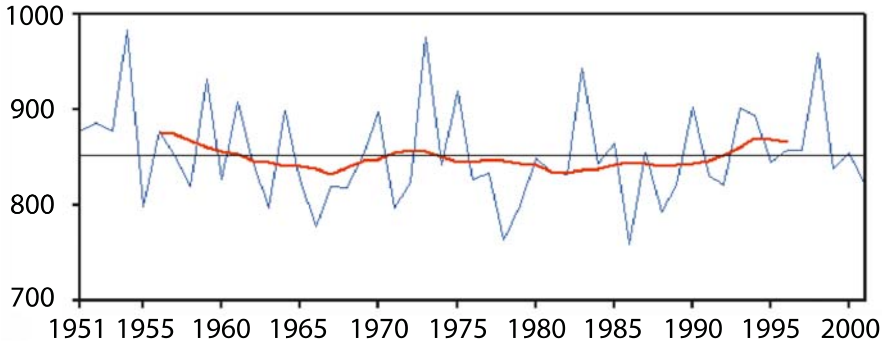

Fig. 17.3. Annual-mean precipitation series based on data of 160 stations (1951–2001) (unit: mm)

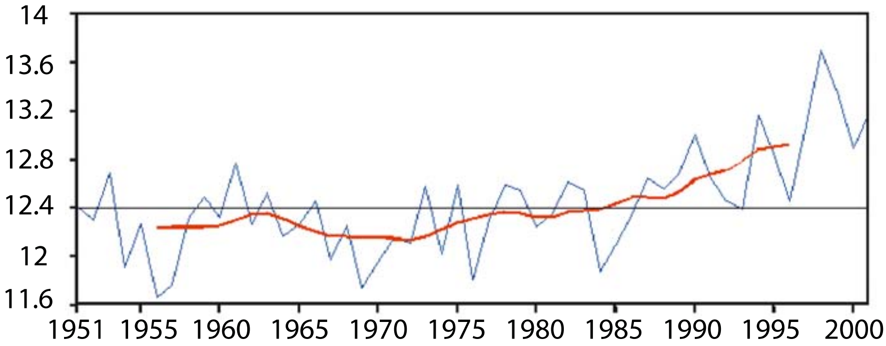

Fig. 17.4. Annual-mean temperature series based on data of 160 stations (1951–2001) (unit: °C)

crucial components of drought preparedness and mitigation plans. Recent advances in operational space technology have improved our ability to address many issues of early drought warning and efficient monitoring. With help from satellites, drought, for instance, can be detected 4–6 weeks earlier than before and delineated more accurately, and its impact on agriculture can be diagnosed far in advance of harvest. Though it is not possible to completely avoid the disasters, but the sufferings can be minimized by creating proper warning system, disaster preparedness and management of disasters through application of information technology tools such as GIS and remote sensing. The emergence of China as an advanced country in the area of remote sensing with its own satellite in orbit has led to better management of drought/flood.

17.2 Status of Drought and Flood Early Detection and Monitoring in China

Remote sensing and Earth Observation System (EOS) are available to disaster management professionals today, which make the effective preparedness very much possible and more accurate now than ever before. Although none of the existing satellites and their sensors has been designed solely for the purpose of observing natural hazards, the variety of spectral bands in VIS (visible), NIR (near infrared), IR (infrared), SWIR (short wave infrared), TIR (thermal infrared) and SAR (Synthetic Aperture Radar) provide adequate spectral coverage and allow computer enhancement of the data for this purpose. Repetitive or multi-temporal coverage is justified on the basis of the need to study various dynamic phenomena whose changes can be identified over time. Typical polar orbiting satellites are the NOAA-AVHRR, the French SPOT, the US LANDSAT, TM and FY-1 series. The data received from polar-orbiting satellites is very useful in understanding and monitoring the natural hazards. Also, the effect of the space and time distribution of water accompanied by phase changes on the water and energy budget at the earth surface from the point of view of understanding and control of the mechanism of environmental changes can be better evaluated with satellite data.

GIS are computer-based systems that efficiently store, retrieve, manipulate, analyze and display spatial data according to user specifications. It is used as a decision support system. When it is integrated with remote sensing systems that collect vast amounts of biological and physical data, it can realize the full potential of both systems, thus monitoring of the environment.

Drought and flood monitoring using remote sensing and GIS began in the middle of 1980's in China. Several sectors such as National Satellite Meteorological Center (NSMC) of China Meteorological Administration (CMA) and provincial meteorological bureaus, Ministry of Water Resource, Ministry of Agriculture, some research institutions in Chinese Academy of Science (i.e. Institute of Remote Sensing Application, Institute of Geographical and Natural Resources Research) and some research institutions in the universities have been engaged in this work and provide services for government and public. So far, many methods and products suitable to different regions and different seasons have been developed and some of them have been put into practice, providing service. In terms of scientific research, many kinds of satellite remote sensing are used to develop the methods of early detection and monitoring of drought and flood (Tian 1993, Xiao 1994, Tian et al. 1998). However, for the operational systems, such as those developed by NSMC, FY-1 series and NOAA series satellite data are mainly source of information. This paper will take National Satellite Meteorological Center (NSMC) of China Meteorological Administration (CMA) as an example to detail operational early detection and monitoring system of drought and floods in China using remote sensing and GIS (NSMC, 2003).

17.2.1 Drought

One of the missions of NSMC is to employ satellite data to monitor the natural disaster and environment, including drought/flood monitoring. Based on the two types (polar-orbiting and geostationary) of satellite data receiving and processing system, NSMC has been carrying out drought/flood monitoring since the middle of 1980s. In order to monitor the occurrence and development of droughts efficiently and provide information on the strength and range of drought, several operational systems for drought monitoring were developed. National Satellite Meteorological Center (NSMC) of China Meteorological Administration (CMA) has developed practical products of drought monitoring suitable for different seasons using weather satellite data and GIS. They can dynamically monitor the occurrence and evolution of droughts over the whole country and provide early warning of droughts. NSMC and some of provincial meteorological bureau usually distribute monitoring information once every ten days. But once the drought occurs, they are needed to provide their products as soon as possible in unfixed time manner.

Table 17.1 lists the features of some drought monitoring operational products. An improved thermal-inertia model has been developed for monitoring

Table 17.1. Main features of methods

Models	Data source	Condition	Period	Quantitative	Resolution
Thermal inertial	NOAA	Bare soil; less vegetated	Spring, Autumn	Soil moisture	1.1 km
WSVI	FY-1, NOAA	Fully vegetated	Summer	Relative drought level	1.1 km
Energy and water balance	GMS	Bare soil; vegetated	All seasons	Relative drought level	5.0 km

soil moisture in areas without vegetation cover. For vegetated areas, Water Supplying Vegetation Index (WSVI) is adopted. In addition, a method based on energy and water balance was developed to estimate evapotranspiration (ET) and soil moisture (SM), thus monitoring drought.

17.2.1.1 Thermal Inertial

Thermal inertial is defined as:

$$I = (k\varrho C)^{1/2} \quad \left[\mathrm{Jm^{-2}K^{-1}s}\right] \tag{17.1}$$

K: bulk thermal conductivity $[\mathrm{Wm^{-1}\,K^{-1}}]$
ϱ: bulk density $[\mathrm{kg\,m^{-3}}]$
C: specific heat capacity $[\mathrm{J\,kg^{-1}\,K^{-1}}]$.

Thermal inertia represents the ability of a material to conduct and store heat.

$$I = C \cdot (1 - A) / \left(T_{\text{day}} - T_{\text{night}}\right) \tag{17.2}$$

A : albedo
$T_{\text{day}}, T_{\text{night}}$: temperature of day and night

$$SM = f(I) \tag{17.3}$$

SM: soil moisture

One of the limitations of the method is to need two images one day with cloud free; the other is just applicable to bare soil or less vegetated.

17.2.1.2 Water Supplying Vegetation Index (WSVI)

The Water Supplying Vegetation Index (WSVI) is a newer method to detect drought information by using meteorological satellite data.

$$\mathrm{WSVI} = \mathrm{NDVI}/T_s \tag{17.4}$$

NDVI: normalized difference vegetation index
T_s : surface temperature derived from AVHRR channel 4.

When vegetation suffers from drought, the NDVI decreases and the temperature of the canopy increases, WSVI decreases. Therefore, WSVI can reflect drought effectively. Using this method, vegetation growth can be monitored timely and the regional effects of summer drought detected quickly. The method is adopted when ground is completely covered by vegetation.

17.2.1.3 Energy and Water Balance

Figure 17.5 is the chart of elements of energy and water balance.
The above can be expressed by the following equations:

$$\text{Energy balance:} \quad In = H + LE + G \tag{17.5}$$

$$\text{Water balance:} \quad P = E + I + R \tag{17.6}$$

LE: latent heat flux ($\mathrm{J/m^2\,s} = W/\mathrm{m^2}$)
E : evapotranspiration, moisture flux ($\mathrm{kg/m^2\,s}$)
L : heat of evaporation (J/kg).

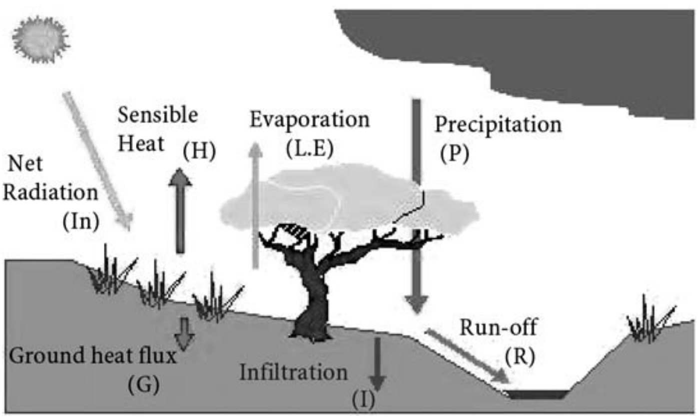

Fig. 17.5. Elements of energy and water balance

17.2.2
Flood

In the summer, from May to September, NSMC uses FY-1 series and NOAA series satellite data for daily water body monitoring of seven major rivers' basins in China including NenJiang, LiaoHe, HaiHe, Yellow River, HuaiHe River, HanShui River, Dongting Lake, Poyang Lake, Taihu Lake, Zhujiang River, Yongjiang River, and North of Xinjiang (See Fig. 17.6). The monitored area is divided into several regions, and each region has a range of $5° \times 5°$. In recent two year, EOS/MODIS data has been extensively used in water body monitoring and played an important role for its higher resolution. Generally, three types of efforts should be made in monitoring flood: water body identification, determination floodwater body and flood area mapping. Fig. 17.7 is the flow chart of NSMC monitoring flood.

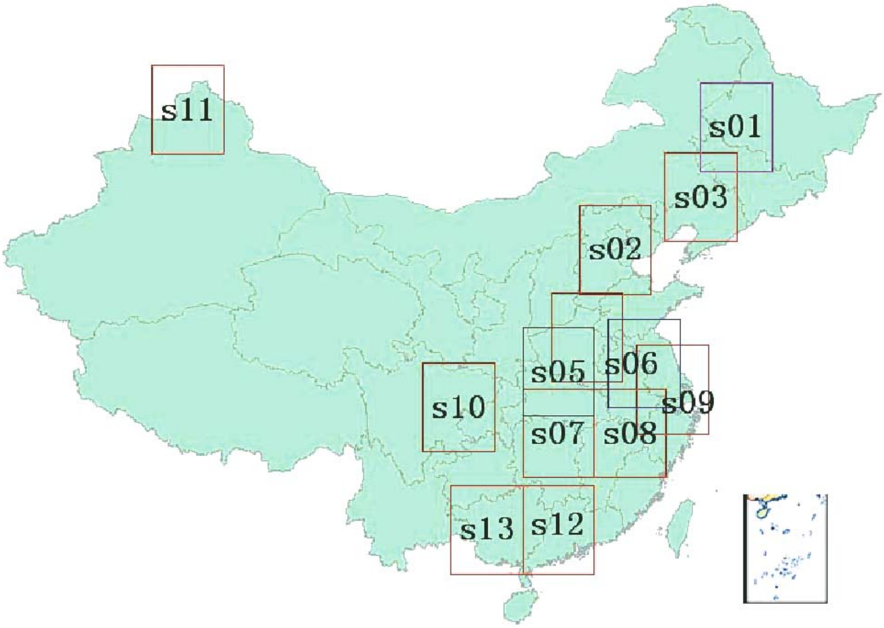

Fig. 17.6. The sketch of water body monitoring regions in China

17.2.2.1
Water body identification

Water body identification is the base of water monitoring. In visible and near infrared channels, the reflectance of water body, vegetation and bare soil are quite different. Water body has a strong absorption in near infrared channel, leading to a very low reflectance in this channel and a lower reflectance than

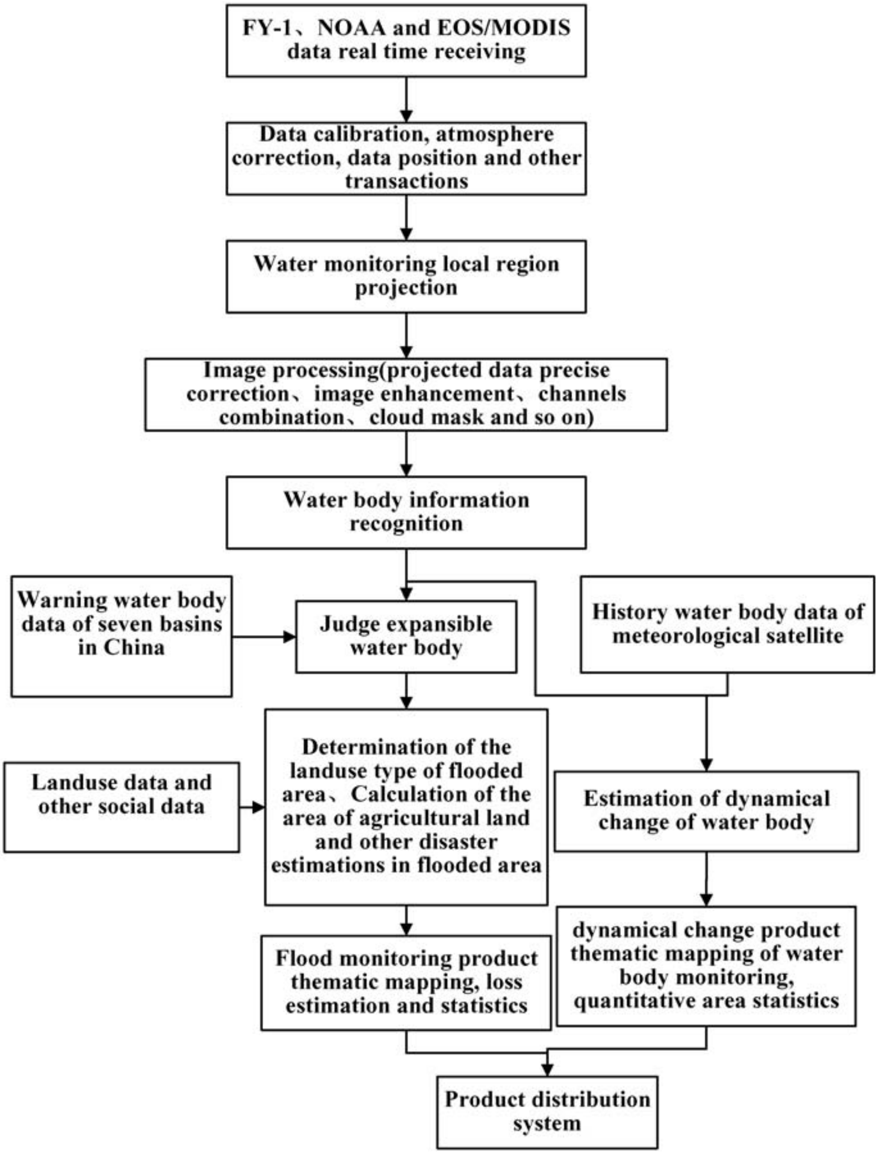

Fig. 17.7. Flow chart of flood monitoring by NSMC

in visible channel. On the contrary, vegetation has a low reflectance in visible channel but a much higher reflectance in near infrared channel. The reflectance of bare soil in visible channel is much higher than both water body and vegetation, and in near infrared channel, the reflectance is higher than water body but lower than vegetation. So based on the difference of the ratio of reflectance in near infrared channel and visible channel for the three objects,

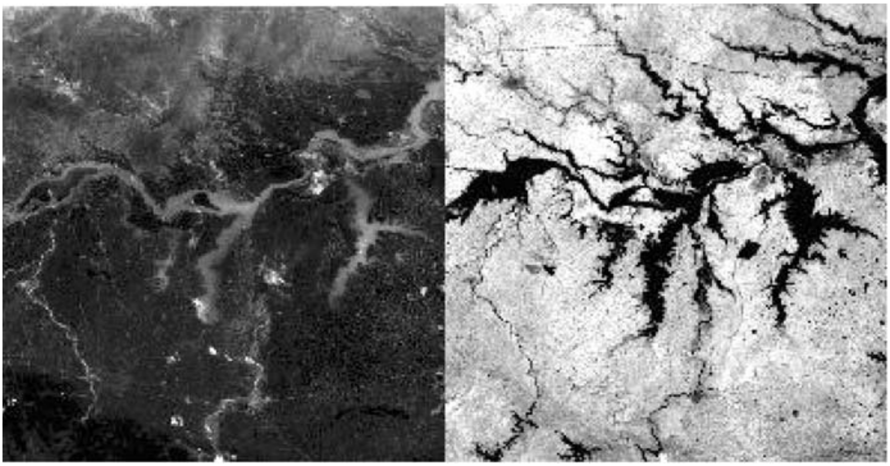

Fig. 17.8. Ch.1 and Ch.2 of EOS/MODIS is sensitive to water body (*left* is Ch.1 (visible) image, *right* is Ch.2 (near infrared) image)

it is possible to recognize water body by using FY-1, NOAA and EOS/MODIS satellite data (see Fig. 17.8)

In cloud free area, water body recognition can be processed based on the feature of the clear boundary between water and land in near infrared channel data, using threshold by interactive mode in a limited area.

In the area covered by thin cloud, the reflectance observed by satellite includes cloud and land surface.

$$V_{\mathrm{si}} = V_{\mathrm{ci}} + V_{\mathrm{gi}} \tag{17.7}$$

V_{si}: reflectance from channel I,
V_{ci}: reflectance from cloud,
V_{gi}: reflectance from land.

The ratio of Ch.2 and Ch.1 is:

$$R_{21} = \left(Vc_2 + Vg_2\right) / \left(Vc_1 + Vg_1\right) . \tag{17.8}$$

For water body,

$$R_{21}(W) = \left(Vc_2 + Vg_2(W)\right) / \left(Vc_1 + Vg_1(W)\right) . \tag{17.9}$$

For land surface:

$$R_{21}(L) = \left(Vc_2 + Vg_2(L)\right) / \left(Vc_1 + Vg_1(L)\right) . \tag{17.10}$$

According to the characteristics of water body and land surface:

$$Vg_1(L) < Vg_1(W), \; Vg_2(W) < Vg_2(L) . \tag{17.11}$$

Therefore,

$$R_{21}(L) > R_{21}(W) \ . \tag{17.12}$$

By selecting proper threshold, the water body covered by thin cloud can be calculated, then the influence of thin cloud can be deleted.

17.2.2.2
Determination of Unusual Expanding Water Body

Unusual expanding water body is the water body beyond the normal, namely floodwater body. In China, the water body area of most of lakes and rivers is changed constantly with seasons and precipitation. In certain period, the relative expansion of water body is not always floodwater body. So it is necessary to build up warning water body data to discern the expanding water body. Warning water body data can be obtained by extracting lakes and rivers water body information when the water surface is on the warning level. Compared with warning water body, the expanding part of water body is the flood area. Similarly, compared with the maximum water body in flood period, the reduction area is the shrunk water body.

17.2.2.3
Flood Mapping

Flood mapping is by overlaying a pre-flood image and a peak flood image to delineate the inundated area. Damages, in terms of properties and crops, are assessed with the help of existing land use map and GIS. Post-flood image could be an effective tool to evaluate impact of flood on environmental concerns, under the support of GIS, of course.

17.3
Examples of Flood Monitoring by NMSC in 2003

In the summer of 2003, a severe flood happened in Huaihe River. NSMC monitored its evolution. Fig. 17.9 is a product of flood monitoring in Huaihe River Basin on July 18,2003, using EOS/MODIS data. From it, we can learn the evolution of the flood.

The following is an example of flood product for a county's loss evaluation (Fig. 17.10, Fig. 17.11, Table 17.2). Land use data and other social data are extensively used by the support of GIS technique to estimate the area of the flood. Here flooded size, non-irrigated farmland inundated size, irrigated land inundated size and percentage of flooded size to the county size was precisely calculated for quantitative loss estimation.

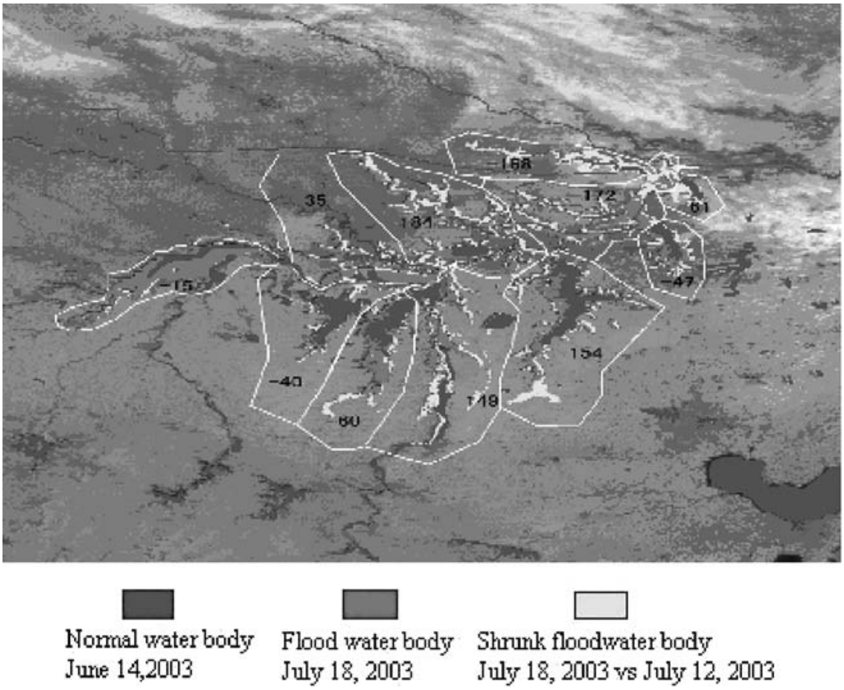

Fig. 17.9. The evolution of flood in Huihe River in 2003

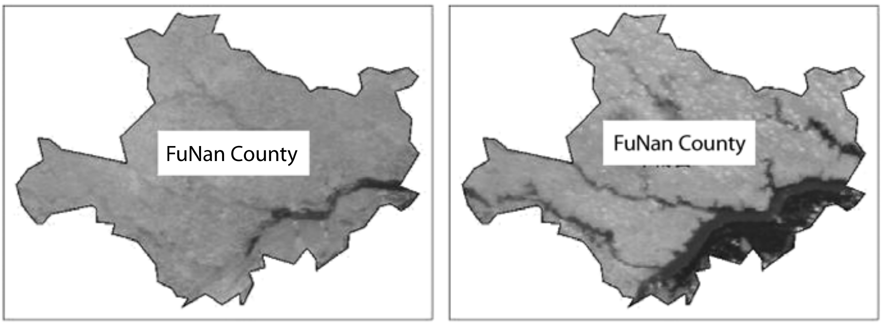

Fig. 17.10. Water conditions before and after flood (left is before flood, June 28, 2003; right is after flood, July 23, 2003

17.4 Conclusions

(1) Drought and flood are China's severest natural disaster. Early detection and monitoring of drought and flood are particularly useful for drought planning and mitigation.

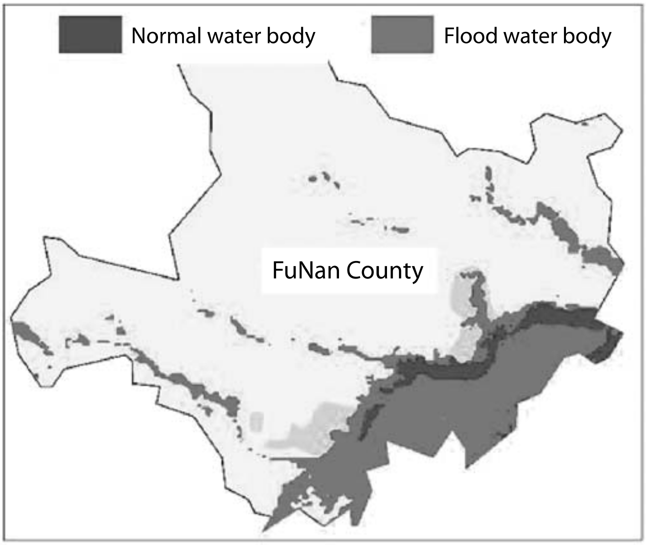

Fig. 17.11. Output by comparison of before and after flood images

Table 17.2. Assessment of the flood area for Funan county

County name	Funan
Total size	1,927 km^2
Water body size (June 28)	50 km^2
Water body size (July 23)	370 km^2
Flooded size	320 km^2
Nonirrigated farmland inundated size	271 km^2
Irrigated farmland undated size	27 km^2
Percentage of flooded size to the county size	16.6%

(2) NSMC and other organizations provide the central government, all national economic sectors and public with real time information through letter, internet, and other applicable way.

(3) Substantial progress in both academic and operational aspects of the subject has been achieved in China. But we have to see remote sensing and GIS are not perfect for disaster monitoring. There are a variety of limitations.
   a) Monitoring methodology: techniques for processing remotely sensed data, i. e. geometric and radiometric calibration; development of models and algorithms to extract the physical variables that are needed for disaster monitoring;
   b) Database: inadequate observation stations in a so large territory and inadequate data sharing between different sectors; lack of geographical, economic and social data, especially in less developed regions.

(4) Anyway, natural disasters monitoring by remote sensing technology was one of the main contributions in last century. Integration of remote sensing with GIS and web technology makes it a powerful tool to identify indicators of potential disasters. The future is promising with the new generation of very high-resolution satellites. They will provide high spatial and temporal resolution images of the world to track natural and human-made disasters.

Acknowledgements

Many thanks to Professor Cheng Liu at the National Satellite Meteorological Center, China Meteorological Administration, for providing many of the figures and giving helpful advice.

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The Decision of the Center of a Tropical Cyclone over China Coastal Waters Using a Doppler Radar

Xu Yinglong, Jiao Meiyan, Bi Baogui, Chang Tao

Abstract Using the Doppler radar radial velocity data simulated by Rankine combined vortex and observed by a Doppler radar and typhoon yearbooks, the applied study about the objective positioning methods of a typhoon was made. Two methods had been established. A series of simulated and actual tests were made for the two methods. The results show that the errors of the two methods in simulated tests are below $0.5 \sim 1$ km and those of radial maximum wind are below 0.12 km. Compared to the best operational track data, the errors of the two algorithms in actual tests are below $3 \sim 13$ km, sometimes those are below 3 km. So it is feasible to decide the center of a tropical cyclone with the data of a single Doppler radar radial velocity in operational tropical cyclone positioning. The positioning results of the two methods are of important reference and guidance in operational tropical cyclone forecasting and warning.

18.1 Introduction

As we know, China is one of the most severely countries which suffers from tropical cyclones. There are about 7 tropical cyclones make landfalls over China every year and a slight increasing trend in the number of landing tropical cyclones (Fig. 18.1). Tropical cyclones are the most important disastrous weather system over Southeast China coastal area from summer to autumn every year and often bring great casualties and damages. In total there are US$ 33.528 billion economic losses resulting from tropical cyclones since 1993 and US$ 335.28 million every year (Fig. 18.2). In total 7,158 persons were killed by tropical cyclones since 1988 and 477 persons were killed every year (Fig. 18.3). Because of the effective forecasting and warning service, economic and life losses have some decreasing trends in the past.

In August 1994, Typhoon Fred (9417) hit Zhejiang province which killed 1,126 persons and economic loses were estimated over US$ 2,167 million.

In August 1996, Typhoon Herb (9608) landed over Fujian province, over 700 persons were killed and economic loses were estimated over US$ 8,025 million.

In June 2001, Typhoon Chebi (0102) hit Fujian province (Fig. 18.4a), 122 persons were killed and economic loses were estimated over US$ 547 million.

In September 2002, Typhoon Sinlaku (0216) made landfall over Zhejiang province (Figs. 18.4b–d), 29 persons were killed and economic loses were estimated over US$ 984 million.

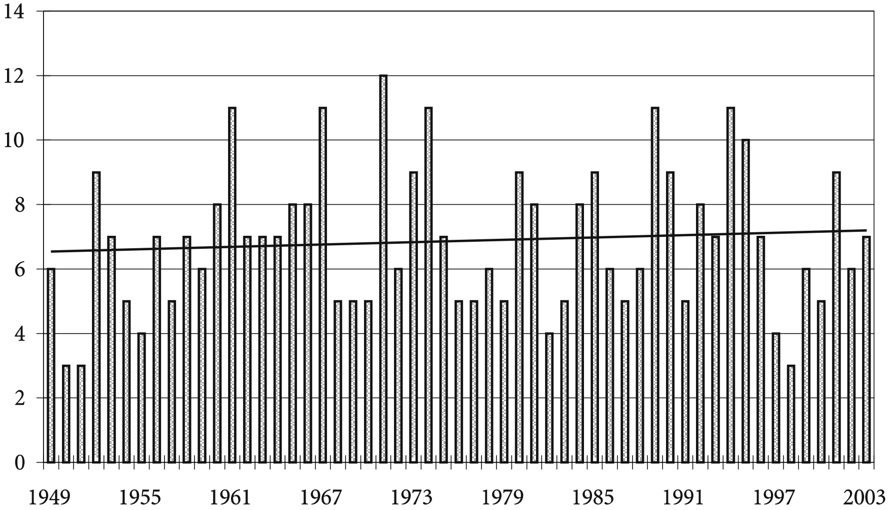


Fig. 18.1. The number of tropical cyclones landing over China since 1949

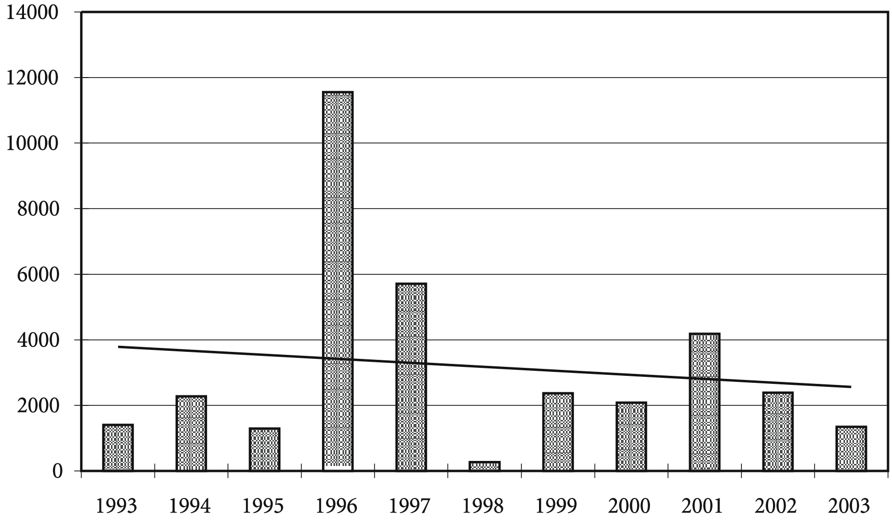


Fig. 18.2. Economic loss of tropical cyclone disaster since 1993 (unit: million US$)

Therefore, the operational tropical cyclone forecasting and warning is of crucial importance in all operational forecasting and warning of CMA. In the course of actual operational forecasting, exact positioning is the basis for successful forecasting, timely and effective prevention and fight against tropical cyclones.

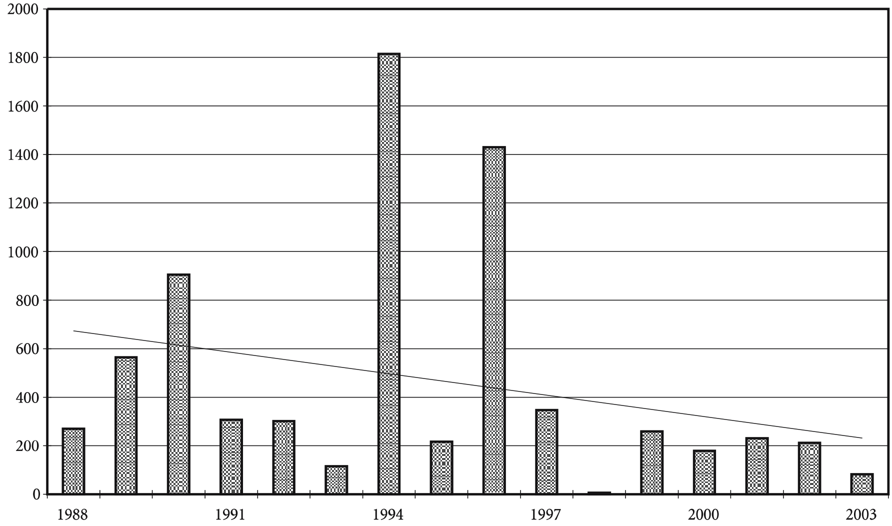


Fig. 18.3. Life loss of tropical cyclone disaster statistics since 1988

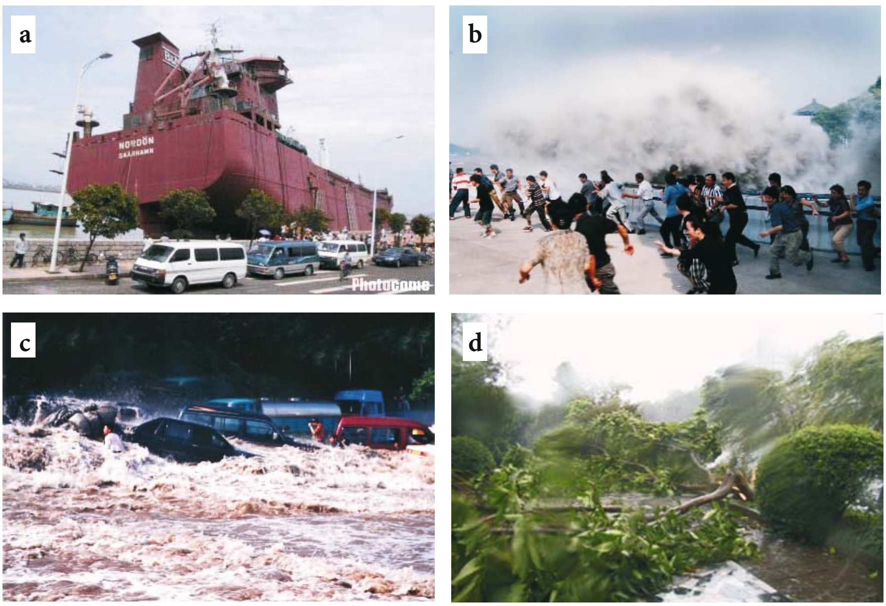


Fig. 18.4. A large ship was pulled up to the sea bank by Typhoon Chebi in 2001 (**a**). The storm surge in the Qiantang River (**b**), the flooded area in Zhijiang Street in Hangzhou City (**c**) and the big trees fell to the ground in Cangnan County (**d**) during the period of Typhoon Sinlaku in Zhejiang province in 2002

In the past, the tropical cyclone center was commonly decided by satellite images. However, when tropical cyclones approach land, their structures became more complicated in the influence of islands and continental terrain. So, it is hard to get exactly centers of tropical cyclones only by satellite images. At present, the radar is the best detecting tool. The positioning ways using radar echo include spiral rain belt (Senn and Hiser, 1959; Anthes, 1982), geometric center of eye wall (Griffin, 1992), etc. But its positioning accuracy is poor when the spiral rain belt is not evident, or when the structure of radar echo is in disorder, or when spiral rain belt or eye wall rain belt is not observed in the influence of terrain after landing, etc. The reconnaissance mission observations show that the center position of radar echo is same as the center position of typhoon circulation, and the circulation center often slants to the side of the most intensive radar echo region (Marks, 1992).

With the development of Weather Surveillance Radar-1988 Doppler (WSR-88D) during the 1990s, it is possible to detect tropical cyclone center using the pattern distribution of Doppler radar velocity. The research of Wood and Brown (1983) and Chang Paoliang (2000) indicated that Doppler radar velocity of the circulation near tropical cyclone center, which is characteristic of approximately axisymmetric distribution or Rankine vortex, has a particular dipole pattern distribution feature. A lot of methods were designed to decide a tropical cyclone center on the basis of the distribution feature and the hypothesis about the radius maximum wind (RMW). Wood and Brown (1992) first developed the Geometric Axisymmetric Center Positioning Method (WB92) to decide a tropical cyclone center using Doppler radar radial velocity and its operational positioning accuracy is below 4 km compared to aircraft reconnaissance. Ben Jong-Dao Jou et al. (1996) advanced the Velocity Distance Azimuth Display Positioning Method (VDAD) to detect a tropical cyclone center using the product ($V_r \times D$) of the Doppler radar radial velocity value (V_r) and the distance from observation site to radar center (D) and obtained better results. However, when the asymmetric component or environmental mean flow is evident, big errors are introduced.

18.2 Pattern Recognition Technique

Because Doppler radar only can observe radial velocity along the radar beam direction and can't get the structure of real three-dimensional flow, the analysis and the research about the flow structure observed by Doppler radar are made by the particular pattern distribution of Doppler radial velocity according to the early research about the aspect by Donaldson (1970), Wilson and Wilk (1982) and Wood and Brown (1986). Pattern recognition technique mainly is an analytical technique with which the real circulation of atmospheric system (e.g. the thunderstorm mesoscale cyclone and typhoon circulation etc.) can be identified by the particular pattern distribution of Doppler radial velocity.

For a run of increasing velocities in any radial direction, a shear segment is defined as the beginning and ending velocity data points of the run. It consists

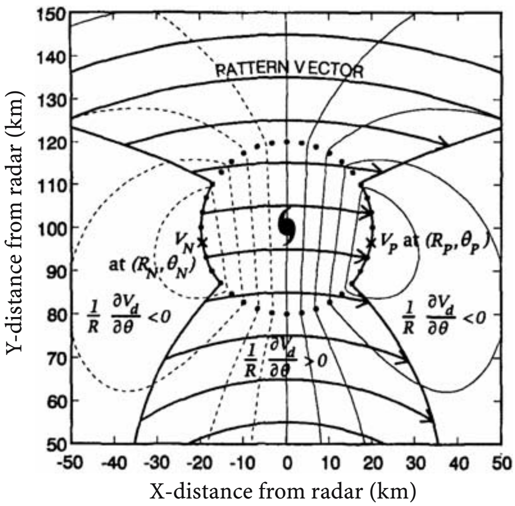


Fig. 18.5. The single Doppler velocity pattern an axisymmetric Typhoon Votex. (Source: Vincent T. Wood, 1994 RSSL of NOAA)

of the slant range (R), the beginning and ending azimuth angles (θ_b, θ_e), the beginning and ending Doppler velocity values (V_b, V_e), and the beginning and ending times (t_b, t_e) at both ends of the shear segment (Fig. 18.5).

Here, for identifying the tropical cyclone vortex, the azimuthal shear is defined as the shear of Doppler velocities in the azimuthal direction for a pattern vector, and is given by

$$S = \frac{\Delta V}{R\left(\theta_e - \theta_b\right)} \ .$$

Where $\Delta V = V_e - V_b$ is the velocity difference and $R(\theta_e - \theta_b)$ is the azimuthal distance across the shear segment.

If there is $S > 0$ in any pattern vector, a cyclonic shear will be identified. The shape of the region of the pattern vectors of all cyclonic shears will be detected by a cyclonic circulation of a real atmospheric system.

18.3 The Geometric Axisymmetric Center Positioning Method

18.3.1 The Detection of a Tropical Cyclone Vortex

1. Searching for Cyclonic Shear (i.e., $S > 0$).
2. The Determination of Detection Thresholds. In order to prevent the influence of non-typhoon circulation, some detection thresholds will be given in advance. And these thresholds will be given on the base of the intensity of the typhoon. In the following typhoon case, the detection thresholds are

given as:

$$\Delta V = V_\mathrm{e} - V_\mathrm{b} = 60 \sim 70\,\mathrm{m\,s^{-1}}$$
$$S = \Delta V / R\left(\theta_\mathrm{e} - \theta_\mathrm{b}\right) = 1\,\mathrm{m\,s^{-1}\,km^{-1}}\ .$$

18.3.2 The Determination of the Locations of Extreme Doppler Velocity

1. The determination of the extreme negative Doppler velocity value (V_N) and its range (R_N) and azimuth (θ_N) are given as:

$$\begin{aligned} V_\mathrm{N} &= \frac{\sum_k \left(V_\mathrm{b}\right)_k \left(W_\mathrm{b}\right)_k}{\sum_k \left(W_\mathrm{b}\right)_k}\ , \\ R_\mathrm{N} &= \frac{\sum_k \left(R_\mathrm{b}\right)_k \left(W_\mathrm{b}\right)_k}{\sum_k \left(W_\mathrm{b}\right)_k}\ , \\ \theta_\mathrm{N} &= \frac{\sum_k \left(\theta_\mathrm{b}\right)_k \left(W_\mathrm{b}\right)_k}{\sum_k \left(W_\mathrm{b}\right)_k}\ . \end{aligned} \tag{18.1}$$

2. The determination of the extreme positive Doppler velocity value (V_P) and its range (R_P) and azimuth (θ_P) are given as:

$$\begin{aligned} V_\mathrm{P} &= \frac{\sum_k \left(V_\mathrm{e}\right)_k \left(W_\mathrm{e}\right)_k}{\sum_k \left(W_\mathrm{e}\right)_k}\ , \\ R_\mathrm{P} &= \frac{\sum_k \left(R_\mathrm{e}\right)_k \left(W_\mathrm{e}\right)_k}{\sum_k \left(W_\mathrm{e}\right)_k}\ , \\ \theta_\mathrm{P} &= \frac{\sum_k \left(\theta_\mathrm{e}\right)_k \left(W_\mathrm{e}\right)_k}{\sum_k \left(W_\mathrm{e}\right)_k}\ . \end{aligned} \tag{18.2}$$

3. The determination of the weight $(W_\mathrm{b})_k$ and $(W_\mathrm{e})_k$.

Here the weight $(W_\mathrm{b})_k$ and $(W_\mathrm{e})_k$ are decided with the technique of Desrochers and Donaldson (1992), and $(W_\mathrm{b})_k$ and $(W_\mathrm{e})_k$ are confined to $0 < (W_\mathrm{b})_k \leq \Delta W$ and $0 < (W_\mathrm{e})_k \leq \Delta W$, and ΔW is given as:

$$\Delta W = 3\,\mathrm{m\,s^{-1}}\ , \quad \Delta\overline{V} < 35\,\mathrm{m\,s^{-1}}$$
$$\Delta W = 5\,\mathrm{m\,s^{-1}}\ , \quad \Delta\overline{V} \geq 35\,\mathrm{m\,s^{-1}}\ .$$

Where $\Delta\overline{V} = (V_\mathrm{max} - V_\mathrm{min})/2$ is the average of peak Doppler velocity values obtained readily from all the pattern vectors. Then the $(W_\mathrm{b})_k$ and $(W_\mathrm{e})_k$ are given as:

$$\left(W_\mathrm{b}\right)_k = \Delta W - \left|\left(V_\mathrm{b}\right)_k - V_\mathrm{min}\right|\ ,$$
$$\left(W_\mathrm{e}\right)_k = \Delta W - \left|\left(V_\mathrm{e}\right)_k - V_\mathrm{max}\right|\ .$$

18.3.3
The Decision of the Center of a Tropical Cyclone

After (18.1) and (18.2) are computed, the estimated range (R_E) and azimuthal (θ_E) of the tropical cyclone center are given by the following:

$$R_E = F\left(\frac{R_N + R_P}{2}\right) ,$$
$$\theta_E = \left(\theta_N + \theta_P\right)/2 .$$

Where R_E is the range of the center; θ_E is the azimuth of center; F is the correction factor and is given by

$$F = \sec\left(\frac{\Delta\theta}{2}\right)$$
$$\Delta\theta = \theta_P - \theta_N ,$$
$$0^\circ \geq |\Delta\theta| < 180^\circ .$$

Where the correction factor F is made to avoid the large difference between the estimated and real range from typhoon center to radar while the maximum wind region of typhoon circulation is approaching the radar.

18.3.4
The Decision of the Radius Maximum Wind (RMW)

After the locations of the extreme negative and positive Doppler velocity have been computed, we can use a half of the distance between the two points as the radius maximum wind. Supposing (X_{min}, Y_{min}), (X_{max}, Y_{max}) are the locations in the Cartesian coordinate of the extreme negative and positive Doppler velocity, RMW is given as:

$$X_{min} = R_N \sin\theta_N ,$$
$$Y_{min} = R_N \cos\theta_N ,$$
$$X_{max} = R_P \sin\theta_P ,$$
$$Y_{max} = R_P \cos\theta_P ,$$
$$\mathrm{RMW} = \frac{1}{2}\sqrt{\left(X_{max} - X_{min}\right)^2 + \left(Y_{max} - Y_{min}\right)^2} .$$

18.4
The Velocity Distance Azimuth Display Positioning Method

When a tropical cyclone is very close to the radar, Doppler radial velocity observed by radar will become deformed and the big errors of estimated center will occur by directly using Doppler radial velocity. Ben Jong-Dao Jou etc. (1996) developed a method to detect a tropical cyclone center using the product ($V_r \times D$) of the Doppler radar radial velocity value (V_r) and the distance from observation site to radar center (D). The flow of detecting the center of a tropical cyclone is given as:

1. Compute $V_r \times D$ in constant level and get its space distribution chart.
2. Compute the values and locations of the extreme negative and positive of $(V_r \times D)/D_{CR}$. In the course of computing, the handling way is the same as the Geometric Axisymmetric Center Positioning Method. D_{CR} is the distance from a reference center of a tropical cyclone to radar, so the value of $(V_r \times D)/D_{CR}$ will be eaqual to the Doppler radial velocity value (V_r). The formula are given by:

$$V_N = \frac{\sum\limits_k \left[\left(\frac{V_r \times D}{D_{CR}}\right)_b\right]_k (W_b)_k}{\sum\limits_k (W_b)_k},$$

$$R_N = \frac{\sum\limits_k (R_b)_k (W_b)_k}{\sum\limits_k (W_b)_k},$$

$$\theta_N = \frac{\sum\limits_k (\theta_b)_k (W_b)_k}{\sum\limits_k (W_b)_k},$$

$$V_P = \frac{\sum\limits_k \left[\left(\frac{V_r \times D}{D_{CR}}\right)_e\right]_k (W_e)_k}{\sum\limits_k (W_e)_k},$$

$$R_P = \frac{\sum\limits_k (R_e)_k (W_e)_k}{\sum\limits_k (W_e)_k},$$

$$\theta_P = \frac{\sum\limits_k (\theta_e)_k (W_e)_k}{\sum\limits_k (W_e)_k},$$

$$(W_b)_k = \Delta W - \left| \left[\left(\frac{V_r \times D}{D_{CR}}\right)_b\right]_k - \left(\frac{V_r \times D}{D_{CR}}\right)_{min} \right|$$

$$(W_e)_k = \Delta W - \left| \left[\left(\frac{V_r \times D}{D_{CR}}\right)_e\right]_k - \left(\frac{V_r \times D}{D_{CR}}\right)_{max} \right|$$

$$0 < \left(W_{\mathrm{b}}\right)_k \le \Delta W$$

$$0 < \left(W_{\mathrm{e}}\right)_k \le \Delta W$$

$$\Delta W = 3\,\mathrm{m\,s^{-1}}\,, \quad \Delta\overline{V} < 35\,\mathrm{m\,s^{-1}}$$

$$\Delta W = 5\,\mathrm{m\,s^{-1}}\,, \quad \Delta\overline{V} \ge 35\,\mathrm{m\,s^{-1}}$$

$$\Delta\overline{V} = \frac{\left[\left(\frac{V_{\mathrm{r}}\times D}{D_{\mathrm{CR}}}\right)_{\max} - \left(\frac{V_{\mathrm{r}}\times D}{D_{\mathrm{CR}}}\right)_{\min}\right]}{2}\,.$$

3. After computing the coordinate of the extreme negative and positive of $(V_{\mathrm{r}} \times D)/D_{\mathrm{CR}}$, the center of a tropical cyclone and the radius maximum wind of typhoon circulation are given by

$$X_{\mathrm{C}} = \frac{X_{\min} + X_{\max}}{2} \qquad Y_{\mathrm{C}} = \frac{Y_{\min} + Y_{\max}}{2}$$

$$\mathrm{RMW} = \frac{1}{2}\sqrt{\left(X_{\max} - X_{\min}\right)^2 + \left(Y_{\max} - Y_{\min}\right)^2}\,.$$

Where $(X_{\mathrm{C}}, Y_{\mathrm{C}})$ is the coordinate of a tropical cyclone center, $(X_{\max}, Y_{\max})$ is the coordinate of the maximum extreme value of $(V_{\mathrm{r}} \times D)/D_{\mathrm{CR}}$, $(X_{\min}, Y_{\min})$ is the coordinate of the minimum extreme value of $(V_{\mathrm{r}} \times D)/D_{\mathrm{CR}}$, and RMW is the radius maximum wind of a tropical cyclone circulation.

18.5 Simulated Test

18.5.1 The Building of the Simulated Doppler Radial Velocity

The analytic dataset is based on a single-level, idealized Rankine combined vortex at sea level. The rotational and convergence/divergence flows are constructed as

$$V(R) = V_{\max}\left(R/R_{\max}\right) \quad R \le R_{\max}\,,$$

$$V(R) = V_{\max}\left(R_{\max}/R\right) \quad R > R_{\max}\,.$$

Where $V_{\max} = 40$ m/s, $R_{\max} = 10$ km, the Cartesian coordinate of the vortex center is (100 km, 100 km).

The environmental horizontal mean flow added in a vortex is constructed as

$$\vec{V}_{\mathrm{M}} = -V_{\mathrm{M}}\sin\left(\theta - \theta_{\mathrm{M}}\right) + V_{\mathrm{M}}\cos\left(\theta - \theta_{\mathrm{M}}\right)\,.$$

Where V_{M} is the mean velocity of environmental horizontal flow, θ_{M} is the included angle between mean flow and eastward.

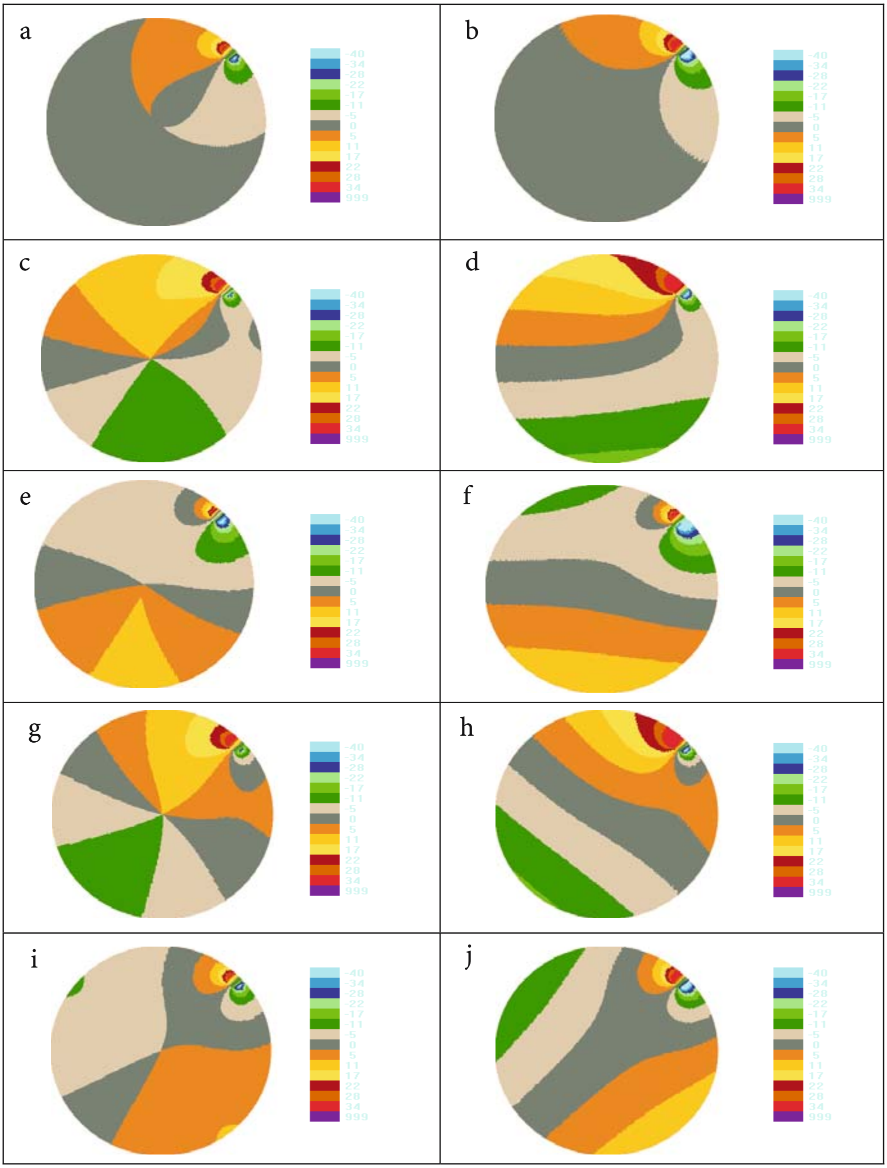


Fig. 18.6. The simulated Doppler radial velocity V_r (**a**,**c**,**e**,**g**,**i**) and $V_r \times D$ (**b**,**d**,**f**,**h**,**j**); **a** and **b** are under no environmental mean flow, **c** and **d** are under westward environmental mean flow ($V_M = 10$ m/s, $\theta_M = 180°$), **e** and **f** are under eastward environmental mean flow ($V_M = 10$ m/s, $\theta_M = 0°$), **g** and **h** are under southwestward environmental mean flow ($V_M = 10$ m/s, $\theta_M = 135°$), **i** and **j** are under southeastward environmental mean flow ($V_M = 10$ m/s, $\theta_M = 45°$)

18.5.2 The Result of Simulated Test

For a Rankine combined vortex, with vortex center located at (100, 100), maximum wind is 40 m/s and the radius maximum wind is 10 km, its Doppler radial velocities are simulated in five environmental horizontal mean flows (Fig. 18.6). Under no environmental mean flow, eastward and southeastward environmental mean flow, the distributions of the simulated radial velocities (V_r) and the product ($V_r \times D$) of the radar radial velocity value (V_r) and the distance from observation site to radar center (D) are characteristic of approximately axisymmetric feature. Meanwhile, under westward and southwestward environmental mean flow, their distributions are of very asymmetric feature.

Table 18.1. The position and the radius maximum wind (RMW) errors of Simulated Test with Geometric Axisymmetric Center Positioning Method (GACPM) (km)

Scheme	Real position of center and RMW			Estimated result					
	X_{C0}	Y_{C0}	RMW_0	X_C	Y_C	RMW	ΔX_C	ΔY_C	ΔRMW
$V_M = 0$ m/s	100.0	100.0	10.0	100.26	100.26	9.88	0.26	0.26	0.12
$V_M = 10$ m/s, $\theta_M = 180°$	100.0	100.0	10.0	100.01	100.01	9.88	0.01	0.01	0.12
$V_M = 10$ m/s, $\theta_M = 0°$	100.0	100.0	10.0	99.72	99.73	9.88	−0.28	−0.27	0.12
$V_M = 10$ m/s, $\theta_M = 45°$	100.0	100.0	10.0	99.88	99.53	9.88	−0.12	−0.47	0.12
$V_M = 10$ m/s, $\theta_M = 135°$	100.0	100.0	10.0	100.32	100.32	9.88	0.32	0.32	0.12

Table 18.2. The Position and the radius maximum wind (RMW) errors of Simulated Test with Velocity Distance Azimuth Display Positioning Method (VADAPM) (km)

Scheme	Real position of center and RMW			Estimated result					
	X_{C0}	Y_{C0}	RMW_0	X_C	Y_C	RMW	ΔX_C	ΔY_C	ΔRMW
$V_M = 0$ m/s	100.0	100.0	10.0	100.11	100.11	9.90	0.11	0.11	0.10
$V_M = 10$ m/s, $\theta_M = 180°$	100.0	100.0	10.0	100.13	100.15	9.90	0.13	0.15	0.10
$V_M = 10$ m/s, $\theta_M = 0°$	100.0	100.0	10.0	100.14	100.09	9.92	0.14	0.09	0.08
$V_M = 10$ m/s, $\theta_M = 45°$	100.0	100.0	10.0	100.11	100.11	9.90	0.11	0.11	0.10
$V_M = 10$ m/s, $\theta_M = 135°$	100.0	100.0	10.0	100.12	100.20	9.94	0.12	0.20	0.06

But it also is evident that their distributions are of a particular dipole pattern feature. After using the Geometric Axisymmetric Center Positioning Method (GACPM) and Velocity Distance Azimuth Display Positioning Method (VADAPM) respectively with simulated data, the center and the radius maximum wind of vortex are estimated. The results of simulated tests show that the center position errors of GACPM are less than 0.5 km, the radius maximum wind errors of GACPM are less than 0.12 km; the center position errors of VDADPM are less than 0.2 km, and the radius maximum wind (RMW) errors of VADAPM are less than 0.10 km (Table 18.1 and Table 18.2).

18.6 Actual Test of Typhoon Case

The simulated test results show that the Geometric Axisymmetric Center Positioning Method and the Velocity Distance Azimuth Display Positioning Method are two better tools in detecting the center and the radius maximum wind of vortex, even for these vortexes with asymmetric distribution under westward and southwestward environmental mean flow. The following tests will be made with actual radial velocity data to certificate the capability of these two methods.

18.6.1 The Data of a Typhoon Case

1. Typhoon Case: Typhoon Nari (No. 0116).
2. Radar location: WSR-88D in Wufengshan Mountain in Taiwan.
3. Scan Time: From 0000UTC to 1300UTC 16 September 2001.
4. Scan Time Interval: One hour.
5. Angle of Elevation: 0.5°.
6. Grid Length in Radial Direction: 250 m.

18.6.2 The Result of Actual Test for a Typhoon Case

Figure 18.7 gives the distribution charts of the observed Doppler radial velocities (V_r) and ($V_r \times D$) when Typhoon Nari (0116) was approaching the northeast of Taiwan province in September 2001. It is evident that their distributions of (V_r) and ($V_r \times D$) are characteristic of approximately axisymmetric feature and show a particular dipole pattern feature.

Using the Geometric Axisymmetric Center Positioning Method and Velocity Distance Azimuth Display Positioning Method respectively with real observed Doppler radar radial velocity data of Typhoon Nari (0116), its center and the radius maximum wind are estimated. The results show that Typhoon Nari had the trend to move west-south-westward. It is identical with the real motion direction. In the course of estimating the center position, the best track is

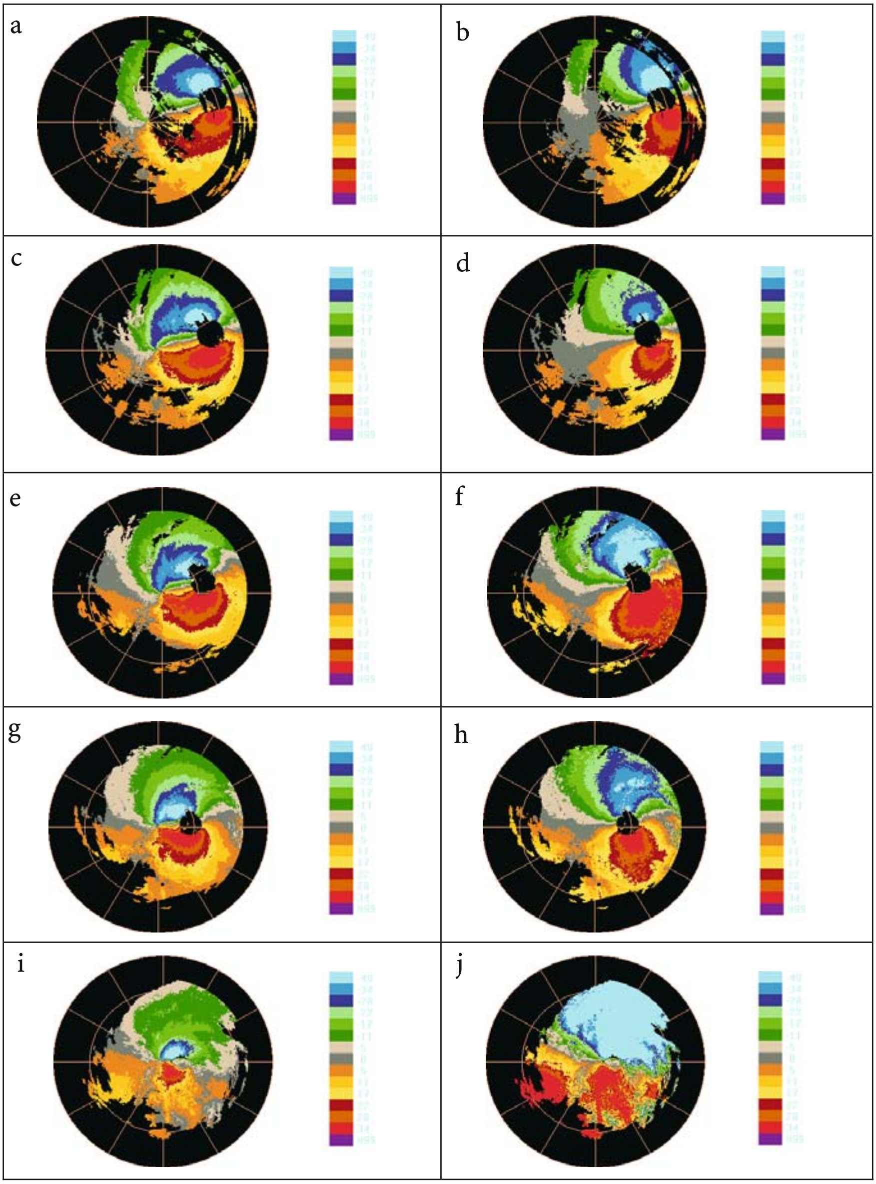


Fig. 18.7. The observed Doppler radial velocity V_r (**a,c,e,g,i**) and $V_r \times D$ (**b,d,f,h,j**), **a** and **b** are at 0000UTC, **c** and **d** are at 0300UTC, **e** and **f** are at 0600UTC, **g** and **h** are at 0900UTC, **i** and **j** are at 1200UTC

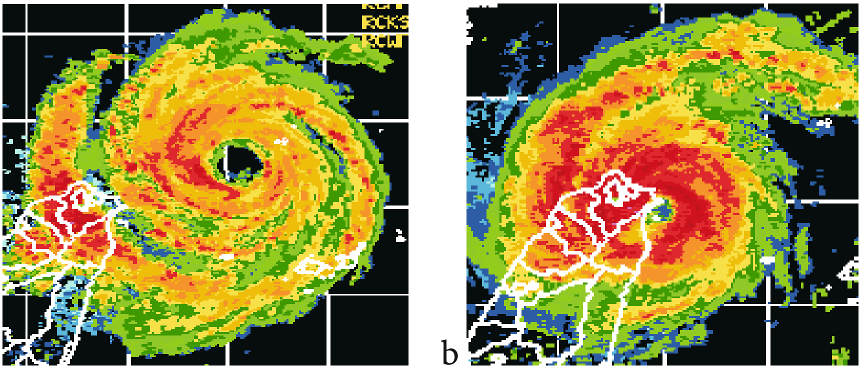
served as the real-time center position. Test results also show that the center position errors of GACPM and VADAPM are from 3 to 13 km and sometime the errors are less than 3 km (Table 18.3, Table 18.4).

Table 18.3. The position and the Radius Maximum Wind (RMW) errors of Actual Test with Geometric Axisymmetric Center Positioning Method (GACPM)

Real-time Center			The Geometric Axisymmetric Center Positioning Method (GACPM)				
			Result of Test		Error		RMW (km)
Time (UTC)	Lat. (°N)	Long. (°E)	Lat. (°N)	Long. (°E)	Lat. (°N)	Long. (°E)	
00	25.5	123.1	25.52	123.10	0.02	0.00	32.74
01	–	–	25.48	123.00	–	–	33.99
02	–	–	25.42	122.91	–	–	30.62
03	25.5	122.8	25.38	122.87	0.12	0.07	36.20
04	–	–	25.38	122.76	–	–	31.41
05	–	–	25.37	122.68	–	–	31.96
06	25.4	122.6	25.35	122.57	0.05	0.03	33.15
07	–	–	25.25	122.50	–	–	30.79
08	–	–	25.24	122.47	–	–	34.02
09	25.2	122.4	25.13	122.44	0.07	0.04	28.43
10	–	–	25.06	122.33	–	–	24.17
11	–	–	25.04	122.20	–	–	19.31
12	25.0	122.2	24.99	122.17	0.01	0.03	14.18
13	–	–	24.99	121.93	–	–	8.17

Table 18.4. The position and the Radius Maximum Wind (RMW) errors of Actual Test with Velocity Distance Azimuth Display Positioning Method (VADAPM)

Real-time Center			The Velocity Distance Azimuth Display Positioning Method (VADAPM)				
			Result of Test		Error		RMW (km)
Time (UTC)	Lat. (°N)	Long. (°E)	Lat. (°N)	Long. (°E)	Lat. (°N)	Long. (°E)	
00	25.5	123.1	25.53	123.13	0.03	0.03	33.69
01	–	–	25.52	123.03	–	–	32.45
02	–	–	25.47	122.98	–	–	30.76
03	25.5	122.8	25.38	122.84	0.12	0.04	36.48
04	–	–	25.38	122.75	–	–	38.82
05	–	–	25.33	122.67	–	–	31.22
06	25.4	122.6	25.32	122.59	0.08	0.01	33.37
07	–	–	25.31	122.53	–	–	34.83
08	–	–	25.23	122.47	–	–	39.83
09	25.2	122.4	25.12	122.47	0.08	0.08	29.58
10	–	–	25.09	122.34	–	–	28.94
11	–	–	25.06	122.27	–	–	22.63
12	25.0	122.2	25.04	122.12	0.04	0.08	24.31
13	–	–	24.91	121.98	–	–	22.32



a b

Fig. 18.8. The Radar Echo Images of Typhoon Nari on 16 September 2001. (**a**) 0000UTC, (**b**) 1300UTC (Source: Taiwan Province Meteorological Bureau)

From the result of actual test, it is evident that the radiuses maximum wind gradually reduced when Typhoon Nari was approaching toward and was making landfall over Taiwan. It is consistent with the lessening of the radiuses of eye wall echo (Fig. 18.8). The reason may be that its low-level circulation converges toward the typhoon center with orographic forcing effect when Nari was approaching the land. And the radiuses maximum winds estimated by the two methods are about the same from 00 to 09 UTC. But after 09 UTC the difference between the radiuses maximum winds estimated by GACPM and the radiuses by VADAPM are increasing. These reasons maybe that asymmetric component of typhoon circulation was increasing by orographic effect or radial velocity observed by radar would become greatly deformed when Typhoon Nari was very close to the radar.

18.7 Conclusions and Discussion

1. The Geometric Axisymmetric Center Positioning Method (*GACPM*) and the Velocity Distance Azimuth Display Positioning Method (*VDADPM*) give a good position of a typhoon for operational typhoon forecasting. In this case, their accuracy of positioning is less than 13 km, sometimes less than 3 km.
2. The results also show that the radius maximum wind gradually reduced when Typhoon Nari approached towards and was making landfall over Taiwan. It is consistent with the lessening of the radius of eye wall echo.
3. Because *GACPM* and *VDADPM* are based on the hypotheses in which the typhoon circulation is axisymmetric and there is the radius maximum wind (RMW) in the typhoon circulation, a big error will occur when the asymmetric component or environmental mean flow is evident.
4. Because of the velocity ambiguity in observed Doppler radial velocity field, the technique of velocity unfolding (dealiasing) directly influences the accuracy of the center position.

Acknowledgements

Many thanks to Mr. Paoliang Chang at Taiwan Province Meteorological Bureau for providing a lot of Doppler radar data and for many beneficial discussions about some technical details.

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CHAPTER 19

Application of Remote Sensing and GIS for Analysis of Forest Fire Risk and Assessment of Forest Degradation

Allen R. Riebau, John Jianhe Qu

Abstract Forest, shrub-steppe, and grassland fires have come under the inclusive terminology of wildland fire. In the past decade, fire occurrence and area of surface burned has increased dramatically. This increase in wildland fire frequency and intensity has been driven by climate variability and in some countries, worsened by fuel management policies. Many areas that have been burned are in remote areas of the world where collection of information on fires is either difficult or impossible on the ground. Satellite remote sensing has been applied to this problem with some remarkable successes in locating large fires, mapping the areas burned, and tracking smoke plumes. For smaller fires, pixel size limitations have led to use of aircraft based sensor development. To understand fire ecological consequences, parameters such as fire intensity, fuel consumed, and heat release rate to atmosphere must be understood. In parts of the Southwest Pacific Region, the potential for fire occurrence is exacerbated by lack of infrastructure common to more developed areas. The use of remote sensing, geographic information systems, and computer models will allow fires to manage to lower risks.

19.1 Introduction

During the past decade wildland fire occurrence in the United States has increased dramatically. The consequences of these increasing wildland fires have been devastating and include loss of life and structures. Increasingly, it has become recognized that fires are becoming more intense and more difficult to control. This has resulted from a number of issues including fire management policies that have resulted in even forest canopies and extreme fuel build-up. Another exacerbating factor has been droughts and overly warm winter seasons increasing the spread of forest pests. Rangeland systems are also suffering from drought events, with increasing fire severity. Although the United States is a developed and wealthy country, the sheer volume of fires has stretched its resources to detect fires by traditional means beyond the breaking point. Additionally, fire smoke is causing increasing concern in the United States with the size of plumes reaching beyond regional scales (Fig. 19.1; Fox and Riebau, 2000). During the period from 1991 to 2000 there were an average

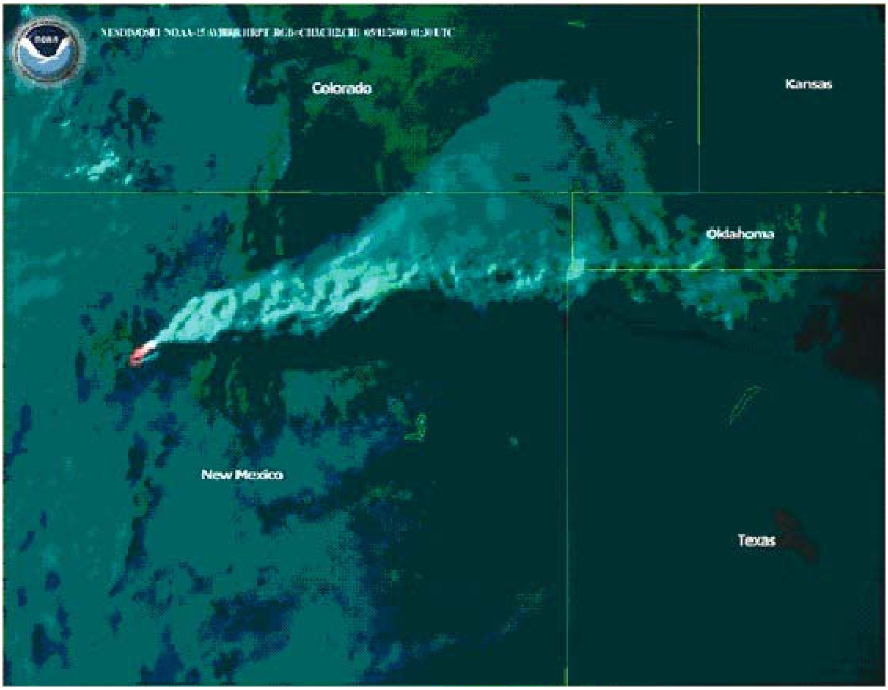

Fig. 19.1. Smoke Plume from the New Mexico El Centro Wildfire as imaged by GOES Satellite covers a large region (Source: NOAA NESDIS)

of 80,303 wildfires in the U.S each year burning an average of 3.7 million acres (Fig. 19.2). In 2002 there were 88,458 fires in the United States burning 6,937,584 acres costing an estimated $ 1.6 billion for fire suppression (source: US National Interagency Fire Center). In addition, more than 1.4 million acres of forests and rangelands were deliberately burned on average in each of the last six years in prescribed burns to reduce the danger of wildfires (in 1999 2,240,104 acres and in 2000 1,077,314 acres, for example; Source: U.S. National Interagency Fire Center). To address this growing problem, the United States has increased its investment to manage fire beginning in 2001 by approximately $ 1.8 billion per year under an initiative named the National Fire Plan (USDA, 2001).

To understand wildland fire one must understand fire fuels. Fuels have a number of characteristics that influence fire behavior and emissions to the atmosphere. The first is fuel loading, or the amount of fuel that is available to burn. Fuel loading is also closely related to fuel type, which in natural vegetation incorporates such issues as the amount of oils and volatile compounds in fuels that affect the combustion process. Another factor that must be considered is the structure of the fuel bed itself, which includes issues such as the occurrence of "ladder fuels" or those forest fuels that allow fire to spread upwards into the

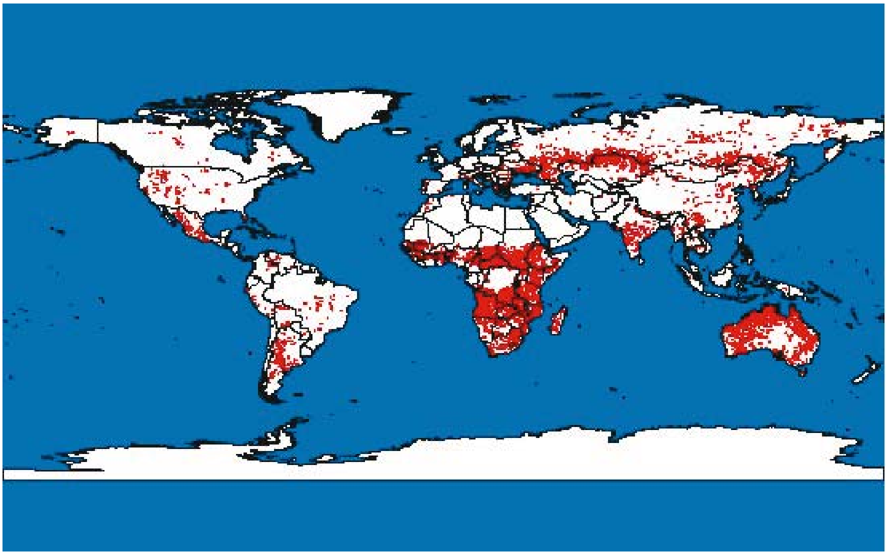

Fig. 19.2. Planetary area of wildland fire (in *red*) for the severe fire occurrence year 2000 (Source: FireGlobe)

forest canopy. Finally, there are very important ephemeral physical properties of fuels such as fuel temperature and moisture, which change with weather.

For mapping all fuels parameters, geographic information system (GIS) technology has been applied, often with the GIS capabilities being joined with descriptive and predictive models. Newer satellite sensors are also allowing direct detection of fuels characteristics on meaningful scales that can be displayed using GIS technologies.

Fire itself is controlled by the atmosphere in a complex reciprocal series of events. First, the risk of fire is a function of both current weather and weather over the past several days or weeks. Although most wildland fires are human ignited, the occurrence of dry lightening is also of paramount importance for fire ignition in areas that are remote. Fire behavior, which includes such measures as fire line intensity, heat release rates, and rate of spread, is also a function of the state of the atmosphere.

Finally, smoke emissions are controlled by the atmosphere's influence on fuel conditions and the combustion process itself. Fire also influences the atmosphere in return, with large intense fire often creating weather anomalies at the fire front. From a practical standpoint, wildland fire managers often combine weather, fuels, and fire information in simple indices to help them estimate how severe or dangerous fires are likely to be (Tables 19.1 and 19.2).

Fire emissions to the atmosphere are becoming of increasing importance. At several sets of temporal and spatial scales, fires are a major concern in the global carbon cycle. Inventories of fires and fire emissions in large areas of the world

Table 19.1. Fire Behavior, Controllability, and Fireline Intensity (Source: USDOI Bureau of Land Management)

Burning Index	Fireline Intensity BTU/S/Ft	Flame Length FT	Narrative
0–28	0–50	2.8	Most prescribed burns are conducted in this range.
38	100	3.8	Generally represents the limit of control for manual attack methods.
78	500	7.8	The prospects of control by any means are poor above this intensity.
96	700	9.6	The heat load on people within 30 feet of the fire is dangerous.
108	1,000	10.8	Ave this intensity, spotting, fire whirls, and crowning should be expected.

Table 19.2. Severe Fire Behavior Potential Related to Relative Humidity and Fuel Moisture Content (Source USDOI Bureau of Land Management)

RH%	1-HR F.M. %	10 HR F.M. %	Relative ease of change ignition and spotting, general burning conditions
> 60	> 20	> 15	Very little ignition; some spotting may occur with winds above 9 mph.
60	15–19	12–15	Low ignition hazard - campfires become dangerous; glowing brands cause ignition when RH is < 50%.
30–45	11–14	10–12	Medium ignitability - matches become dangerous; "easy".
26–40	8–10	8–9	High ignition hazard - matches always dangerous; occasional crowning, spotting caused by gusty winds; "moderate" burning conditions.
15–30	5–7	5–7	Quick ignition, rapid buildup, extensive crowning; any increase in wind causes increased spotting and crowning, loss of control; fire moves up the bark of trees igniting aerial fuels; long distance spotting in pine stands; dangerous burning conditions.
< 15	< 5	< 5	All sources of ignition dangerous; aggressive burning, spot fires occur often and spread rapidly, extreme fire behavior probable; critical burning conditions.

were almost completely unreliable until the application of remote sensing in the 1970s (Qu and Omi, 1993). On a local scale, cities have had extreme smoke events that have endangered public health and welfare (Chubarova et al., 2003). In the United States, fire smoke has become highly regulated under air

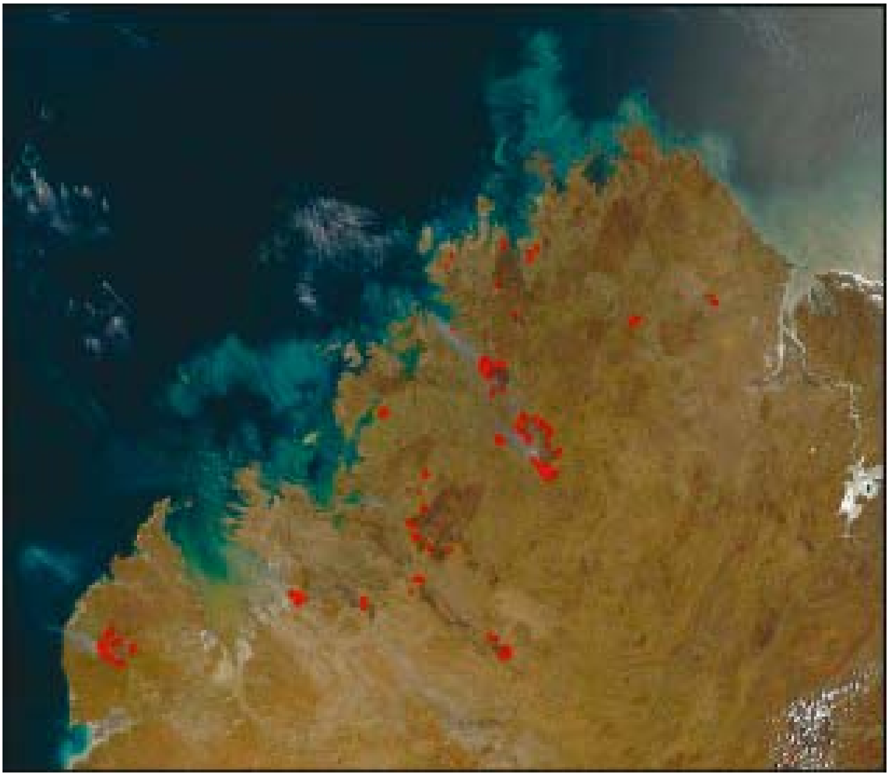

Fig. 19.3. MODIS image of wildfires in Western Australia's Kimberly Range (Source: NASA)

quality law (Fox and Riebau, 2000). Remote sensing of smoke has become common practice for many of these issues and the relatively new Moderate Resolution Imaging Spectroradiometer (MODIS) (Fig. 19.3) instrument has proven very useful both for location of fires (Fig. 19.4) and smoke plume trajectories (Fig. 19.5).

The use of simulation models is also increasing in fire management. First several systems of models for fire risk have been developed and applied. Additionally, new modeling tools for fire behavior are being developed and applied. Perhaps one of the newest approaches to fire management in the United States has been the application of mesoscale meteorological models to fire management, allowing predictive capability of important fire weather parameters with high terrain definition, temporal resolution and projection, and linkage with more traditional fire models. Finally, these new models have been applied to predict the impacts of fire smoke (Riebau et al., 2003).

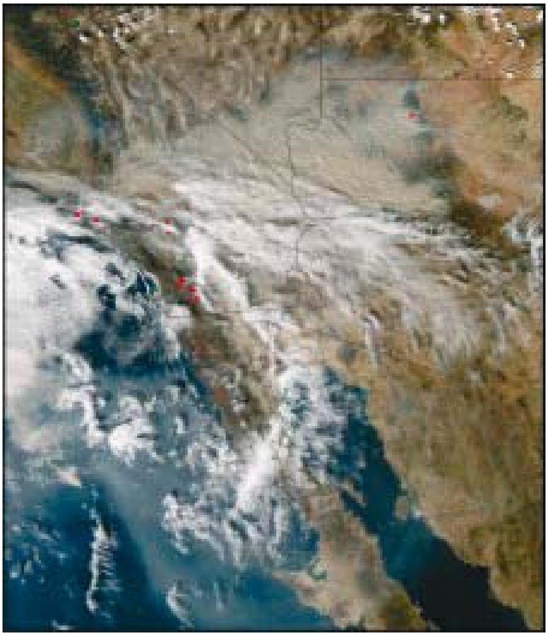

Fig. 19.4. MODIS images of Southern California smoke plumes from fires in the fall of 2003, showing how fires in mountains areas can be transported into urban centers (Source: NASA)

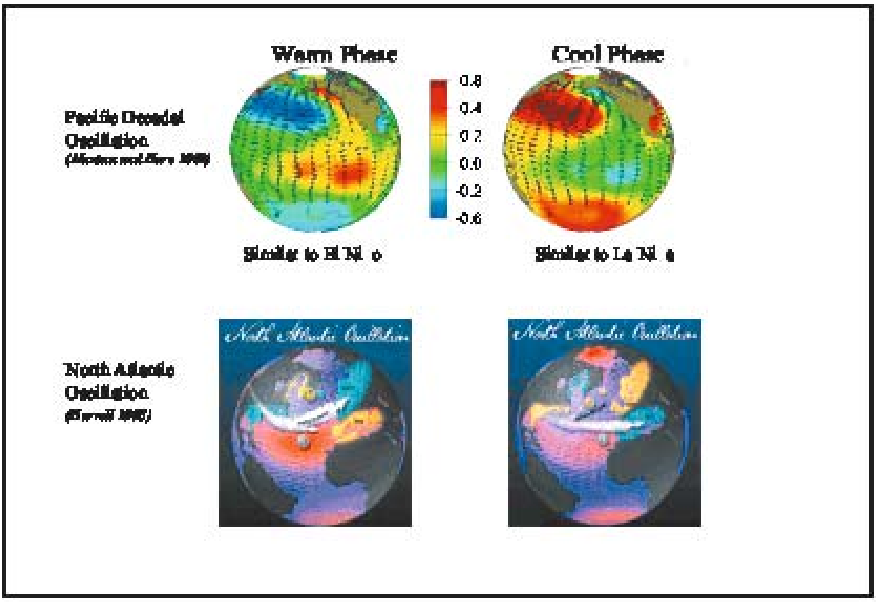

Fig. 19.5. Ocean surface temperature phenomena influence the temperature regimes of the atmosphere and are strong predictors of fire occurrence and severity. In these graphics red is warmer and blue corresponds to colder regions (Source: Ron Nielson, USDA Forest Service)

19.2
Climate Change, Climate Variability, and Fire Danger

Atmospheric conditions and forest fuel properties (especially, fuel moisture) are two major factors in potential wild fire severity. Because of the significant inter-annual variability in atmospheric conditions, fire severity may change dramatically from one year to another. The El Niño and Southern Oscillation (ENSO), for example, can result in increased chances of droughts in some regions of the U.S. and floods in other regions and, as a result, affect wild fires (Qu et al., 1994, and Qu and Wolf, 2003). The USDA Forest Service reported the lowest rangeland fire occurrence and area burned since record-keeping began in 1906 during the 1982–83 strong ENSO event. Fire activity is statistically weak in the southern hemisphere during ENSO events. The influence of climate on fire regimes was apparent in the regional synchrony of large fires with reduced fire activity with low ENSO indexes (Aber et al., 2001). ENSO can also contribute to the inter-annual variability of vegetation in the North America (Bachelet et al., 2001). It is critical to these events when assessing the potential severity of the forthcoming fire season to enable fire management to respond under the expected conditions (Fig. 19.5).

A large number of efforts have been made toward developing such capacity using traditional techniques mainly based on calculation and analysis of meteorological data. Monthly fire potential and burning index (e.g., Fosberg Burning Index, Fosberg 1978) were estimated in monthly fire weather prediction. Global and regional climate models have been used to obtain high-resolution distribution of seasonal trend of precipitation and temperature, which then are used to predict fire risk using statistical techniques (Fox and Riebau, 2000). Some comprehensive fire danger tools, for example, the U.S. National Fire-Danger Rating System (NFDRS, Deeming et al. 1978, Burgan et al., 1998) and the Canadian Forest Fire Danger Rating System, issue a fire occurrence index or fire weather index for estimating the possibility of potential wildland fires. These systems include calculations of indices (e.g., Keetch-Byram Drought Index (KBDI)) and the Canadian Drought Index, which are useful for long-term fire potential assessment.

19.3
Remote Sensing Applications of Fire Fuels Monitoring

Satellite remote sensing is a new technique for wild fire monitoring and fire danger assessment. Satellite instruments like the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS) provide global high-resolution products like the Normalized Difference Vegetation Index (NDVI) and Surface Temperature (ST), which have shown close relationships with fuel moisture status. Thus, remote sensing can overcome some problems facing the traditional techniques, including low spatial resolution and unavailability of meteorological data over part of forest regions.

Remote sensing mapping and characterization of vegetation and fire fuels parameters and datasets were clearly defined as technology goals in strategic documents such as the US National Fire Plan and have been required by international fire management and science communities. Applications of satellite remote sensing have been made during many large wild fire areas, including monitoring fires lines and total fire smoke (Hao et al., 2003). The Wildland Fire Assessment System (WFWAS) developed by the USDA Forest Service, became operational in middle 1990s, and has been providing useful information such as a "greenness" map using AVHRR-NDVI since (Burgan et al. 1998).

Satellite remote sensing also has great potential to provide information for calculation of seasonal fire danger. The fuel moisture detected by satellite remote sensing is mostly the moisture of live fuel, which predominately represents long-lag moisture (e.g., 1,000 hour fuel moisture), a determining factor of seasonal fire danger. Thus, it is possible to develop a capacity to assess the seasonal fire danger using remote sensing of fuel moisture and other products. These products are limited by spatial resolution of 1 km or more and thus are generally only representative at meso or synoptic scales.

The estimation of forest fire danger from satellite remote sensing data is an important research area, with potential for great practical application. Fuel moisture is an important index for fire potential. Over the past decade, research on fire danger estimation from remote sensing data has been concentrating on determining fuel moisture. The accurate estimation of fuel moisture using remote sensing data is very difficult, most of the approaches use proxy variables as indices of fuel moisture, and most available techniques can be placed into two categories: 1) methods based on the relationship of Land Surface Temperature (LSTs) and Normalized Difference Vegetation Index (NDVI); and, 2) methods based on regression analysis of vegetation indices directly.

As a key research instrument of the NASA Earth Observing System (EOS) missions, the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument was launched onboard the NASA Terra and Aqua satellites. Because the MODIS instrument senses the earth's entire surface in 36 spectral bands, it spans the visible (0.415 μm) to infrared (14.235 μm) spectrum at nadir, with spatial resolutions of 1 km, 500 m and 250 m, respectively. One significant strength of MODIS, especially important to fuel property estimation, is that strong absorbance of water in the middle infrared region (1.3 to 2.5 μm) makes this band most suitable for the estimation of forest fuel moisture content. This band is not included in most satellite systems, suggesting that MODIS should be useful for improving the capacity of applying satellite remote sensing data to more accurately estimating fuel moisture content and fire danger indices.

Qu et al. (2003) computed fuel moisture leveraged on Burgan's algorithm using both MODIS vegetation index measurements. MODIS provides two VI products, NDVI ad EVI (enhanced vegetation index) globally over land with 250 m and 500 m spatial resolution. EVI was developed to improve vegetation signal sensitivity in high biomass regions and reduce the influences of canopy background signals and atmosphere.

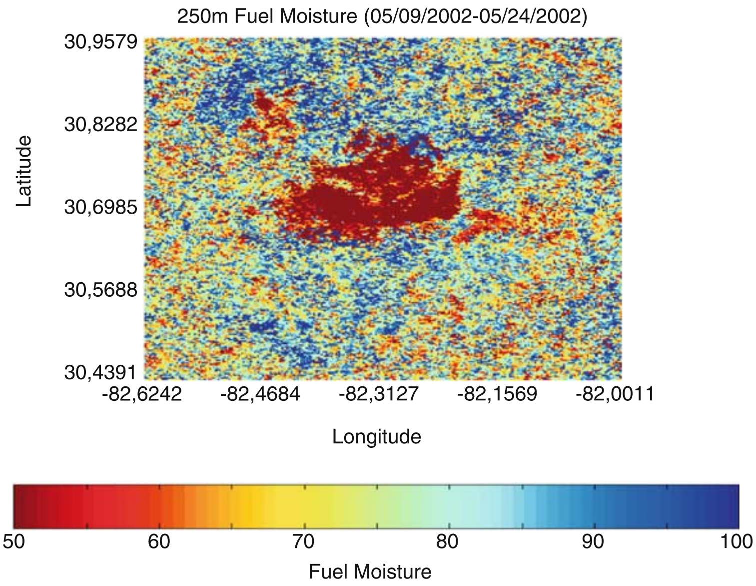

Fig. 19.6. Fuel moisture measurement in Okefenokee National Wildlife Refuge using the MODIS instrument depicts areas where fire is likely to consume vegetation (Source: Qu and Lui)

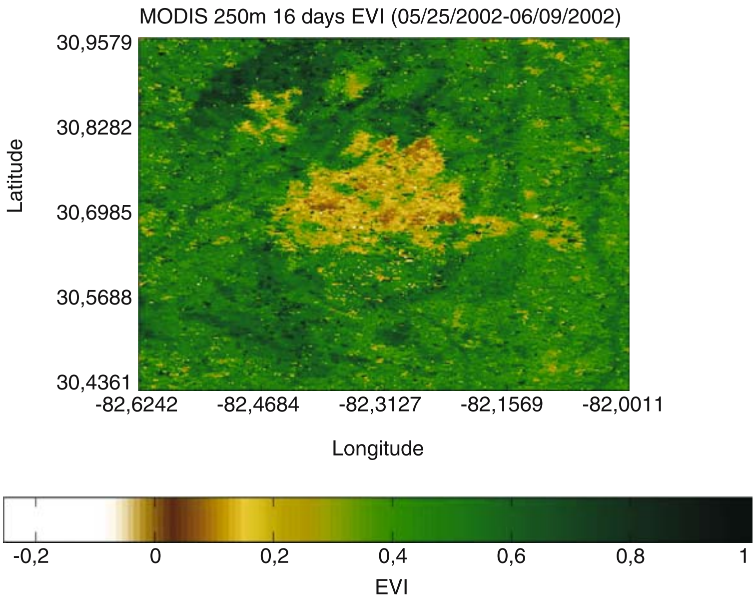

Fig. 19.7. NVDI/EVI measurement in Okefenokee National Wildlife Refuge using the MODIS instrument shows where fire burned, corresponding well with MODIS derived fuel moisture (Source: Qu and Lui)

A swamp wildfire in the Okefenokee National Wildlife Refuge (Georgia, USA) spread over 11,000 acres during May 2002. Figure 19.6 shows fuel moisture before this large fire during May 2002. The 16-day-composited 250 m NDVI image shows the vegetation change after the fire (Fig. 19.7). A good agreement between the fuel moisture and burn areas can was demonstrated in this study.

19.4 GIS Applications and Fire Information Mapping

The GIS as a tool can provide the functions of spatial and temporal geographic classification, analysis, and result mapping to support wildland fire management. GIS is an important tool to integrate the information of risk conditions, fuel conditions, forest value, NDVI, land quality, weather patterns, topographic data and other fire risk related factors. GIS can thus compute and generate fire danger maps based on the knowledge base of traditional and state-of-the-art remote-sensing fire-risk model.

A new major program, LANDFIRE, will use GIS technology to map all wildland fire fuels across the USA at 30-meter spatial resolution. LANDFIRE will develop a comprehensive package of spatial data layers, models, and tools in support of analyses for prioritization and planning to initiate the implementation of the National Fire Plan, both at the national and local level. LANDFIRE is a mid-scale project targeting map accuracies of 60 to 80 percent for the sub-watershed level (10,000 to 40,000 acres). The spatial datasets for LANDFIRE will be maintained at a 30-meter pixel size. LANDFIRE is intended to be the safety net for land management agencies that do not have local-scale information, and the project is not a substitute for finer scale, local mapping efforts. It is intended to be scalable from sub-watersheds to a national level. While LANDFIRE will develop many layers that will be key for mapping the wildland/urban interface, LANDFIRE will not create a wildland/urban interface map (US DOI, 2002).

19.5 Fire Smoke and Air Quality

Emissions from fires are lofted high into the atmosphere and can significantly impact air quality on local, regional, and even global scales. These emissions can cause problems with air quality regulatory programs for particulates, ozone, and visibility. The smoke produced is the most obvious air quality impact, but certainly not the only one. Forest fire plumes Forest fire plumes are known to contain a highly variable mix of gaseous and particulate pollution and are difficult to inventory (Sestak et al., 2002). This mix is farther modified by atmospheric reactions and surface deposition as the plume drifts downwind.

In September 2000, the USDA Forest Service's Deputy Chief for Research and Development issued a request for NFP research proposals to the Research branch of the Forest Service. In response to this request and these research needs, scientists within the atmospheric research program of the USDA Forest Service developed a research and product development strategy built around the concept of regional modeling consortia. Scientists at five USDA Forest Service research stations are developing five regional Fire Consortia for the Advanced Modeling of Meteorology and Smoke (FCAMMS), as shown in Fig. 19.8. Each regional Consortium has been established as a multi-agency coalition of researchers, fire managers, air-quality managers, and natural resource managers at the federal, state, and local levels.

The missions of the consortia are to:

- Increase understanding of fire-weather, fire danger, fire behavior, and the transport, diffusion and impact of smoke from fire;
- Develop and implement new technologies related to regional fire-weather and air-quality;
- Enhance our ability to use fire for land management purposes; and,
- Improve tools for fire fighters by better predicting the dangers of wildfire.

In order to deliver this mission, the FCAMMS are developing and maintaining contemporary computational and data processing resources for US fire fighting and smoke management use. The computer requirements needed to simulate high-resolution meteorology include very large data processing and

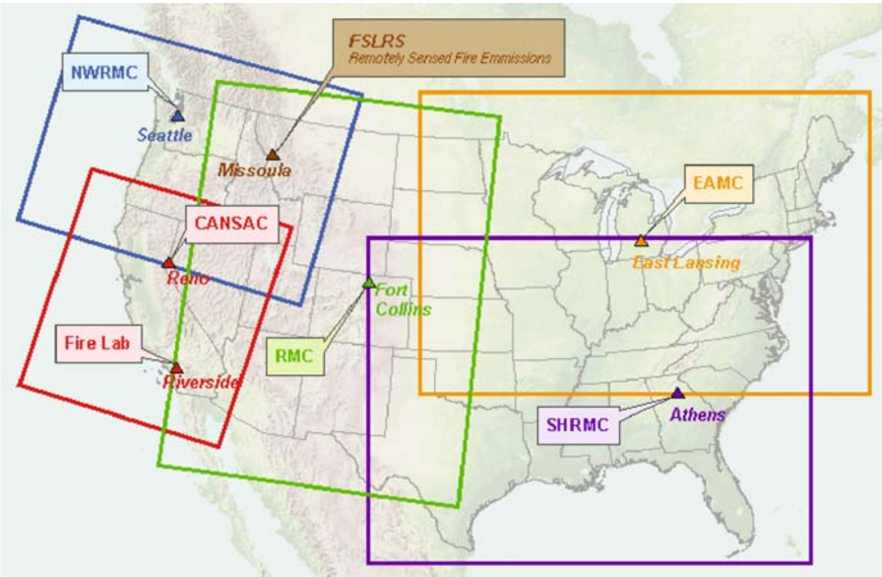

Fig. 19.8. Locations of the five Fire Consortia for Advanced Modeling of Meteorology and Smoke (FCAMMS) established under the United States of America National Fire Plan and the 12 km spatial grid weather modeling domains covered by the individual consortia (Source: USDA Forest Service)

storage capacities, high-speed calculation capabilities, broadband communications facilities and web-based, map-based graphical displays (Fig. 19.9). In general, these capabilities are being provided through the use of clusters of multiple PC processors operating under LINUX systems, utilizing large RAID disk array data stores and relying on the World Wide Web for communication. To a large extent these represent new and different ways for Forest Service to do business that have increased the challenge to consortium members. FCAMMS have also led to significant improvements in the internal capacity of the USDA Forest Service Research and Development through hiring scientists and technicians with modern computer and atmospheric sciences skills.

A major justification for the FCAMMS is to provide intelligence for managing smoke from forest burning. Smoke management has strategic planning, tactical planning and operational aspects. For the purpose of strategic

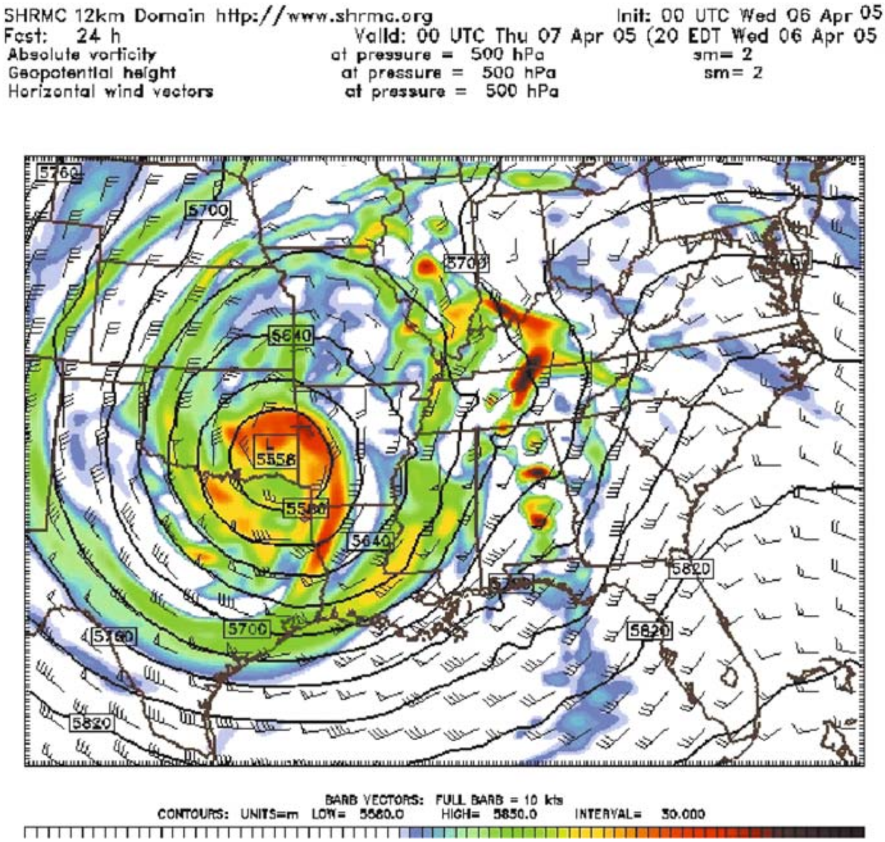

Fig. 19.9. The Southern High Resolution Modeling Center (SHRMC) produces fire weather and fire indices forecast up to 48 hours into the future (Source: USDA Forest Service)

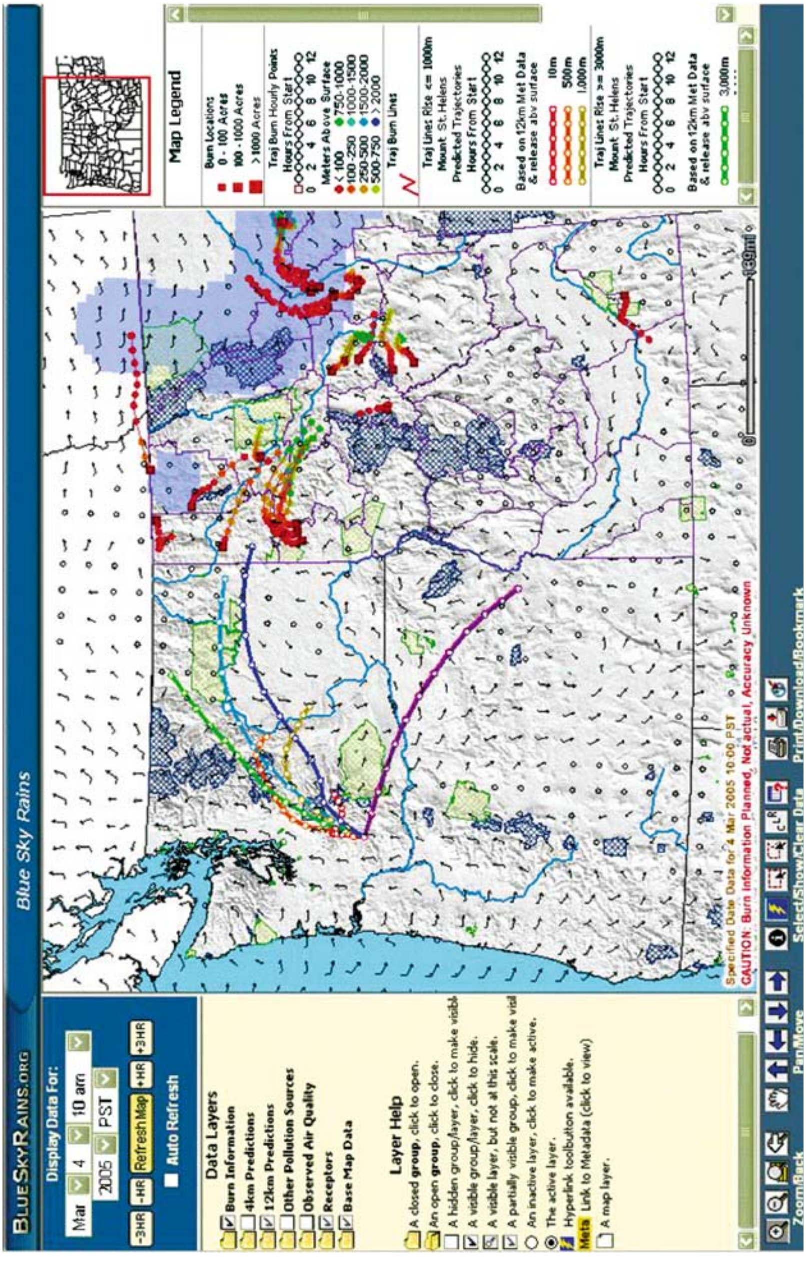

Fig. 19.10. The BlueSkyRAINS combines fire modeling, mesoscale meteorology modeling, and smoke dispersion modeling within a web-based GIS framework. The new system is planned to be implemented across the USA by 2006 (Source: USDA Forest Service)

planning applications are needed that can consider regional scale impacts on issues such as the contribution to regional haze and ozone. For tactical planning, there is a need for a permitting tool; one that allows some indication of where smoke is likely to go once a fire is ignited. Finally, for the operational application, there is a need for real-time forecasts of smoke impacts from individual and groups of potential and actual fires. Although the FCAMMS will address all of these applications the latter, operational application is currently well developed through the BlueSky modeling framework. The BlueSky smoke-modeling framework is a flexible framework for obtaining smoke impacts by combining fire location information, forest fuels, outputs from MM5 (Greel et al., 1988) meteorological simulations and air quality dispersion models (e.g., the US EPA CALPUFF model) to illustrate where smoke will go and how much of it will get there. BlueSkyRAINS links the BlueSky smoke modeling framework with the US EPA Rapid Access INformation System (RAINS) based web serving technology. RAINS utilizes the ArcIMS / geographic information system to allow for data overlays from a variety of geographical data. The capability of the BlueSkyRAINS to provide information about the likely trajectories and ground level concentration impacts from prescribed fires is a major advance of FCAMMS (Fig. 19.10).

19.6 Summary and Conclusions

The use of remote sensing for wildland fire is rapidly growing. Notable successes have been made in detecting fires and mapping fire areas, especially for large fires. To understand the ecological consequences of fire and fire emissions effects to the global carbon cycle, remote sensing tools will need further development for measuring fire intensity and actual fuel consumed. Also needed are tools that can give fuel loading and condition parameters such as fuel moisture content and temperature in near real-time (every five to 10 hours). Higher spatial resolution is also needed, with high-resolution detectors such as the MODIS and its 250-meter resolution perhaps still not fine-scale enough for agricultural and other small fires. Fire smoke is also an issue of high concern. Remote sensing and GIS can be used for fire smoke, with remote sensing of fire location and emissions parameters being tied to weather and dispersion models for display of ground-level concentrations on the earth's surface.

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Conclusions and Recommendations

Conclusions

Participants in the meeting concluded that:

1. With increasing incidence of natural disasters around the world, a comprehensive assessment of their impacts on agriculture, forestry, and fisheries and strategies for mitigation of natural disasters is critical for sustainable development, especially in the developing countries.
2. Progress in impact assessment has been made. The impact assessment of natural disasters is extended from agriculture to social and economy, local to regional, and national and global level.
3. Natural disasters are affected by various modes of climate. Strategies for adaptation and preparedness are required for these modes. This will have extremely profound implications for natural resources managers and agriculturalists as they attempt to adapt to and mitigate the effects of natural disasters.
   - A. Climate Change. We have much evidence that the climate is changing. The IPCC TAR has concluded that most of the warming in the last half of the 20th Century is due to human activities.
   - B. Climate Variability. Variability is most important in the near-term from a natural disaster viewpoint. These include both short term [ENSO] and longer-term variability forced by the oceans, including the PDO/IPO, NAO, and other such oscillations.
   - C. A New State of Climate. The climate may be moving, and perhaps rather rapidly, to a new systematic state. A new systematic state may be inherently more variable (having more extremes) due to a warmer and thus more energetic atmosphere.
4. Variability of climate, if encompassing more intense and frequent extremes, will result in the occurrence of natural disasters that are beyond our socio-economic planning levels. This will stretch national response capabilities beyond their capacity and will require new adaptation and preparedness strategies.

5. Ecosystems, at least parts of them may be relics. This idea has not caught on with natural resource managers and perhaps not agriculturalist, but it certainly is difficult for policymakers.
6. We have no excuse for non-cooperation. Consortia approaches are a key feature in changing and adapting along the potential path to a new systematic climate state: International – Regional – Local – Community.
7. Each type of extreme event has its own particular climate, cultural, and environmental setting, and mitigation activities must use these settings as a foundation for proactive management.

Recommendations

1. Current definitions of natural disasters are primarily meant to address socio-economic management issues related to natural disasters. It is important to develop a more comprehensive definition of natural disasters for applications in agriculture, rangelands, forestry, and fishery sectors.
2. Assessment of the impact of natural disasters on agriculture, rangelands, forestry, and fisheries requires the design of a comprehensive data base in accordance with the users needs. There is a need for an integrated data management system, from adequate collection to quality control, analysis, presentation and also metadata not just meteorological data, but data specific to certain kinds of disaster, e.g., lightning incidence, soil moisture, and fire danger indices. Presentation should make use of best available technology, e.g., GIS and Internet.
3. Effective management of, and preparedness for, natural disasters requires free and unlimited access to relevant databases that will allow monitoring, assessment, and prediction. It is recommended that all agencies responsible for these databases develop good collaborating links for the exchange of information included in these databases.
4. There is an urgent need to assess the forecasting skills for natural disasters to determine those where greater research is needed. Lack of good forecast skill in drought, for example, is a constraint to improved adaptation, management, and mitigation.
5. There is a need to recognize the importance of understanding glacial lake outburst floods (GLOFS) as a new natural disaster and develop appropriate assessment and preparedness strategies.
6. Given the growing incidence of dust and sand storms around the world, it is essential to include measurements of aeolian sedimentation loads in the standard agrometeorological stations of NMHSs. It is also essential to include a routine and comprehensive analysis of wind speed and direction data and disseminate this information to the users. These data should be applied to analyze the impact of sand storms on agriculture. Use of air

quality networks to aid in data collection on dust and sand storms may also be examined.

7. Current natural disaster management is largely crisis driven. There is an urgent need for a more risk-based management approach to natural disaster planning in agriculture, rangelands, forestry, and fisheries. An effective risk management approach would include a timely and user-oriented early warning system with rapid dissemination of information to users.

8. Recognizing that early warning is an important component of preparedness, it is recommended that:
   A. The concept of the drought monitor map product be promoted as a tool for all drought-prone countries to better understand drought severity using multiple indicators.

   B. A white paper on the methodology for preparation of a drought monitor map be developed with recommendations for minimum, maximum, and optimum data layers needed to successfully accomplish this task. Recommendations on the importance of inter-agency collaboration should be included to accomplish this task.

   C. The feasibility of organizing joint training workshops on national and regional drought monitor products under the auspices of WMO and the NDMC should be examined. Indices used in China in their agrometeorological bulletin could be effective training tools. The first of these workshops should be organized in China.

9. Given the importance of storm surges to coastal lowlands, it is essential that WMO, in collaboration with other international and regional agencies, develop an integrated coastal management approach in reducing the impacts of natural disaster on agriculture, rangelands, forestry, and fisheries.

10. The issue of distinguishing long-term climate variability (e.g., IPO) and long-term climate change is important, as is the need to consider the impacts of both on agriculture, water resource management, and disasters such as bushfires. This is important because there are implications for long-term sustainability of certain types of activities, especially agriculture. There is modeling work at some overseas institutions (e.g., the Hadley Centre) that would be of relevance here. These issues need to be drawn to the attention of national policymakers.

11. Agricultural risk zoning is an essential component of natural disaster mitigation and preparedness strategies. Given the complex nature of databases, GIS and remote sensing should be employed to facilitate strategic and tactical applications at the farm and policy levels.

12. A number of modern tools and methodologies for the monitoring and prediction of natural disasters, such as storm surges, tropical cyclones, drought, floods, etc., are now available. It is recommended that an integration of GIS, remote sensing, simulation models, and other computational

techniques be used to develop more effective early warning alerts of natural disasters.

13. It is recommended that countries develop policies aimed at effective natural disaster management. Such policies should emphasis preparedness and incentives over insurance, insurance over relief, and relief over regulation.
14. Education and training is an important component of natural disaster management in agriculture, forestry and fisheries. It is recommended that strategies for education and training address the needs at national, regional, and international levels in order to exploit the synergies and share experiences.
15. Best practice strategies for developing and implementing education and training programs in support of drought preparedness policies should be documented from the experiences of countries such as Australia, China, India, and the United States. Elements of this include consulting the users; developing skills in an influential "target group," user-producer workshops; and adequate feedback channels.
16. Community involvement and education is essential in preparedness and mitigation. The "Community Fireguard" example for bushfire-prone areas in Australia is a good example.
17. The growing frequency of natural disasters requires effective use of the media to better inform and educate the general public and policymakers about the potential impacts of natural disaster and the need to adopt preparedness strategies.
18. Given the need for guidance in natural disaster management, case studies of China and other countries in agriculture, rangelands, forestry, and fisheries and the application of storm surge forecasting at the local level must be documented.
19. Given the regional and global nature of natural disasters, it is essential to promote and foster collaboration between agencies and between international and regional programs and build partnerships.
20. Given the complexity of issues involved in natural disaster management, it will be necessary to develop virtual networks with distributed functions to enhance cooperation on issues related to improved management of and preparedness for natural disasters.
21. More attention should be given to the impacts of potentially increasing frequency and severity of extreme events associated with global change and appropriate mitigation strategies.
22. Attention needs to be given to minimizing damage due to extreme events of infrastructure underpinning agriculture, rangelands, fishery and forestry.
23. The WMO Technical note on drought and agriculture published in 1975 should be updated to include the major advancements in understanding

these complex interrelationships. This revision should emphasize early warning, monitoring, and prediction techniques; vulnerability and impact assessment tools; preparedness and mitigation strategies. Case studies of China and India should be included in the revision. The publication could be published in hard copy, CD-ROM, and made internet accessible.

24. The IPCC Assessment Report 4 should examine whether or not climate extremes are becoming more frequent and, if so, for which natural hazards and climate extremes.
25. There should be more research into the physical behavior of crop growth and moisture regimes to develop better agricultural mitigation strategies.
26. There is a need and opportunity for agrometeorologists to supply design requirements for new satellite sensors. This applies in particular to drought and rangeland and forest fires from a disaster mitigation viewpoint.
27. Effective feedback mechanisms between affected parties (farmers, pastoralists, foresters, and fishermen) and those responsible agencies for mitigation and relief should be developed.

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