Applying Climate Information in Africa

An Assessment of Current Knowledge

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Contents

Acknowledgments 7

List of Acronyms 8

Executive Summary 11

Introduction 15

Chapter 1: Vulnerability to Climate Variability and Change in Africa 19
  Climate and climate vulnerability in Africa
  Sectors affected by seasonal climate variability
  Using climate information to reduce vulnerability

Chapter 2: Predicting Seasonal Climate in Africa 37
  Statistical methods of climate prediction
  Analog year forecasts
  Dynamical climate models
  Presentation of uncertainty
  Predicting seasonal climate variability and climate change
  Conclusions

Chapter 3: Organizations and programs contributing to the application of climate information 51
  World Meteorological Organization
  Regional applications centers
  National level organizations
  Climate Outlook Forums
  Major forecasting and modeling centers
  Early warning and response organizations
  World Health Organization
  Donor organizations
  International research programs
  Challenges

Chapter 4—Results from applications research: food security 67
What types of information could add value?
Given institutional and political constraints, is value there?
Institutional architecture
Conclusions

Chapter 5—Results from applications research: agriculture and livestock management 73
Effects of predictable climate variability on harvests and incomes
What are farmers' information needs?
How can climate information be best communicated to farmers?
Factors limiting farmers' use of climate information
Farmers' use of traditional forecasts and modern climate information
Benefits to farmers of using climate information
Conclusions

Chapter 6—Results from applications research: water resources and flood response 95
Dam management
Emergency flood preparation and response
Conclusions

Chapter 7—Results from applications research: public health 101
Epidemiological research on malaria
Malaria early detection and early warning
Using climate information to reduce the incidence of other infectious diseases
Conclusions

Chapter 8: Conclusion: lessons learned from research and practice 109
What we know and do not know
Major accomplishments and shortcomings

References 115

Annex: Studies Cited by Region and Sector 125

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List of Acronyms

ACMAD	African Centre for Meteorological Applications for Development
AIACC	Assessments of Impacts and Adaptations to Climate Change
AIDS	Acquired Immune Deficiency Syndrome
AMMA	African Monsoon Multidisciplinary Analysis
AR4	Fourth Assessment Report of the IPCC
CCAA	Climate Change Adaptation in Africa
CDF	Cumulative Density Function
CFU	Commercial Farmers' Union
CGE	Computable General Equilibrium
CILSS	Permanent Interstate Committee for Drought Control in the Sahel
CLIPS	Climate Information and Prediction Services
COF	Climate Outlook Forum
CPC	Climate Prediction Center
CPT	Climate Prediction Tool
CSAG	Climate System Analysis Group
DMCH	Drought Monitoring Centre Harare
ECMWF	European Centre for Medium-Range Weather Forecasting
EDS	Early Detection System
ENSO	El Niño / Southen Oscillation
EWS	Early Warning System
FAO	Food and Agriculture Organization
FEWS NET	Famine Early Warning System Network
GCM	Global Climate Model
GCOS	Global Climate Observation System
GDP	Gross Domestic Product
GHACOF	Greater Horn of Africa Climate Outlook Forum
GIEWS	Global Information and Early Warning System
GIS	Geographical Information System
GL - CRSP	Global Livestock Collaborative Research Support Program
GNI	Gross National Income
GTZ	Gesellschaft für Technische Zusammenarbeit
HDI	Human Development Index
HIV	Human Immunodeficiency Virus
ICPAC	IGAD Climate Prediction and Applications Centre
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
IDRC	International Development Research Centre
IGAD	Intergovernmental Authority on Development

IISD	International Institute for Sustainable Development
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
IRS	Indoor Residual Spraying
ITCZ	Intertropical Convergence Zone
ITN	Insecticide Treated Net
MCA	Multiple Correspondence Analysis
MDG	Millennium Development Goal
MEWS	Malaria Early Warning System
NASA	National Aeronautic and Space Administration
NCEP	National Center for Environmental Prediction
NDVI	Normalized Difference Vegetation Index
NGO	Non Governmental Organization
NMHS	National Meteorological and Hydrological Service
NOAA	National Oceanic and Atmospheric Administration
PDF	Probability Density Function
PEAC	Pacific ENSO Applications Center
PIREM	Plate-Forme des Institutions Regionales pour l’Environnement et la Météorologie
PRA	Participatory Rural Appraisal
PRESAO	Previsions Saisonnieres pour l’Afrique de l’Ouest
RANET	Radio and Internet
SADC	Southern African Development Community
SARCOF	Southern African Regional Climate Outlook Forum
SMS	Short Message Service
SOI	Southern Oscillation Index
SST	Sea Surface Temperatures
THORPEX	The Observing System Research and Predictability Experiment
TOGA	Tropical Oceans and Global Atmosphere
UCT	University of Cape Town
UKMO	United Kingdom Met Office
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
US	United States
USAID	United States Agency for International Development
VAM	Vulnerability Assessment Mapping
WCP	World Climate Programme
WFP	World Food Programme
WHO	World Health Organization
WMO	World Meteorological Organization

Executive Summary

The past twelve years have seen a major international effort to make climate information useful for sustainable development in Africa. One of the drivers has been the growing skill with which climatologists can predict seasonal climate, such as total rainfall, based on a combination of climate and ocean models, and a better understanding of global climate cycles, such as the El Niño Southern Oscillation (ENSO).

Africa is one of the most, if not *the* most, vulnerable continents to the effects of climate change and variability. This has not just to do with climatic and physical features of the continent, but also with social and political features. Vulnerability is linked not only to a community's exposure to climatic disruptions, but also to its sensitivity to those disruptions, and its capacity to adapt to the changes. The economies of most African countries are highly dependent on agriculture, the economic sector that is arguably most sensitive to climate variability and change. Malaria and other tropical diseases—outbreaks of which are linked to climate factors—negatively affect the health of millions of Africans, and hinder wider development efforts. But the dominant factor influencing Africa's vulnerability is poverty. This poverty indicates that many people are at the edge of survival, and will suffer not just lost of income but also loss of health, or even life, as a result of climate disruptions. It also means that fewer resources are available to adapt to climatic factors.

Given the vulnerability of so many sectors in Africa to climate variability, efforts to improve the management of that vulnerability, and the lessening of its consequences on society and the economy, appear to be vital. Access to climate information of three types could contribute to this effort. First, it is important to build management practices around a sound understanding of climatological conditions, taking into account the links between these conditions and social, economic, and demographic factors. One may assume that planners have access to such information, but is not always the case. Climatological data itself is often not available to all planners, either because it doesn't exist, or because it is proprietary, and too expensive for them to purchase. Baseline data on infectious disease, local-level agricultural yields, and soil hydrology is often absent, and often proprietary. Second, it is essential for many people to have rapid and reliable access to real-time meteorological data, such as rainfall, temperature, and wind. Obviously, if one knows that heavy rains have fallen high in a watershed, it makes it possible to predict some chance of flooding downstream. But data like this often takes weeks or months to be reported, undercutting its value significantly. Satellite data can partly correct for such problems, but many Africans lack the technical capacity, the computing power, and the bandwidth to access and analyze this type of data. Third, it is often useful to develop, and use, forecasts of future conditions. Short-term forecasts range from hours to days. Medium-term forecasts extend up to about ten days. Seasonal forecasts can project departures from climatological means months in advance. Finally, long-term projections of climate change can anticipate the effects both of decadal scale variability and of changing greenhouse gas concentrations. These can guide multi-decadal planning decisions.

There are a number of different ways to make predictions of seasonal climate. None of these is foolproof, and often which method is appropriate depends on what climate variables (e.g. total precipitation, temperature) are being predicted, and the geographic region for which the prediction is being made. The most commonly used techniques are statistical modeling, and dynamical modeling. For each method, it is crucial to represent the uncertainty inherent in the future climate, and to communicate that uncertainty to potential users in an effective manner. This report identifies five areas where forecasting efforts could be improved: regional modeling, integrated use of earth observation systems, development of additional forecast products, forecast verification, and communication of uncertainty.

The institutional and organizational landscape within which climate forecasting and weather data application takes place is complicated. Many of the organizations, such as the National Meteorological and Hydrological Services (NMHS's) within each country, were originally conceived as serving particular segments of society; in many countries, the primary beneficiary of the NMHS was the aviation sector. Coordinating the activities of NMHS's globally and through its regional offices is the World Meteorological Organization (WMO), and regionally within Africa three different organizations, based in Niger (ACMAD), Kenya (ICPAC), and Zimbabwe/Botswana (DMC). Supplementing these is a number of specialty forecasting agencies, and international partners. This report identifies four areas where the organizations currently involved in developing and applying climate information products could improve: making climate data more widely available, conducting user-driven analysis, designing communication efforts around the need to enhance the credibility and legitimacy of the information, and engaging in greater and more rapid organizational learning. All of these goals can be achieved, one way or another, through enhancing the partnerships and collaborative agreements that already exist, and by forming new, strategic ones.

Within four general sectors of application, NOAA and other organizations have sponsored research projects, in order to advance the state-of-the-art of climate information application. Through a review of the results of that research, it is possible to identify which questions have been answered in an authoritative manner, and which remain, so far, unanswered.

The first area of application that this report reviewed is food security. Early warning organizations, founded in the 1970s in response to a series of famines in the Sahel and East Africa, had the mission of providing advance warning of crises, as they were developing, so that international assistance could be mobilized in time. Early warning organizations monitor not just projected and actual harvests, but also economic indicators that determine whether people will be able to purchase enough food to avoid harm. Within the area of food security, applications research has demonstrated the following:

- Global and regional climate forcing factors such as ENSO can have a strong influence on national level yields in some countries, and this in turn can affect such a country's national level food security and its balance of trade.
- It is possible to use global and regional forcing factors to predict local level yields, but the explanatory power is less than for national level yields.
- At the local level, weather and climate patterns, as captured through indicators such as NDVI, have an impact on local yields, and on other factors that contribute to food security or insecurity, such as market prices.
- Depending on how seasonal climate forecasts are used, they can either have little influence on national level food security, or have a posi-

tive influence through stimulating advance contingency planning.

- Pre-existing institutional interlinkages can improve the likelihood that forecasts will have a positive influence on planning.

The second area this report examines is agriculture and livestock management. In this sector, research has examined a number factors that determine whether farmers will use, and benefit from, seasonal climate forecasts. While most of the attention has been on the growing of staple crops such as maize, there have been some studies addressing livestock management as well. Applications research has demonstrated the following points:

- Farmers across Africa make use of traditional indicators to forecast local weather and climate conditions.
- In countries that have made an effort to communicate seasonal climate forecasts to farmers, many farmers are aware of the forecasts, and many report that they use the forecasts to guide their decisions.
- Farmers would like to receive more detailed and downscaled climate forecasts, including statements about the likely onset and cessation of the rainy season, and the likelihood and timing of significant dry spells.
- Under modeled growing conditions, seasonal climate forecast can provide economic value by influencing the choice of crop, application of fertilizer, and other farming practices. Local factors and farmers' risk aversion dictate whether these benefits are greater in years with higher predicted likelihood of heavy rains, normal rains, or light rains.
- In pilot studies in Mali and Zimbabwe, farmers in the field were observed to derive significant economic benefits from applying climate information to their decisions.

The third area this report examines is water resource management, which includes the issues of dam management and emergency flood preparation and response. Applications research has demonstrated the following points:

- In several river systems in Africa, climate forecasting could be incorporated into dam management models to improve seasonal planning and daily operations.
- Dam managers, and other water resource managers, have many reasons not to use climate forecasts to guide their decisions. These include a lack of confidence in the forecasts, and a lack of technical capacity either to downscale existing forecasts to their own site, or to incorporate existing forecasts into their operations.
- There is anecdotal evidence that many dam managers use climate information to modify their decisions in informal ways, which may be quite beneficial.
- A pilot project in West Africa, with close assistant from Météo France, appears to be the only instance in Africa of dam managers formally incorporating forecasts into their planning and operations.
- Disaster planners in Mozambique have increasingly paid attention to seasonal and medium term climate forecasts to guide their contingency planning efforts, and that this practice has reduced the damage and loss of life from flooding.

The final sector this report examines is public health. There are a number of tropical diseases, the transmission and spread of which scientists have suspected are strongly influenced by climate. Of these, the one that has received the greatest amount of research in relation to climate factors is malaria. Efforts are currently underway to develop information systems for applying climate information to malaria planning. Applications research in this area has demonstrated the following points:

- Climatic factors, and climate variability, influence the prevalence and spread of several tropical diseases, including malaria, Rift Valley fever, and meningitis.
- It is possible to predict the climatic factors that influence the prevalence and spread of these tropical diseases.
- For some parts of Southern and East Africa, carefully tailored and downscaled climate forecasts can predict a large proportion of the variance in epidemic malaria.
- Recent efforts that have been made so far to develop a Malaria Early Warning System in Southern Africa appears to have delivered impressive results, in terms of reductions in mortality and morbidity.

Finally, this report has reviewed the results of a number of studies that have examined the cross-cutting issue of communication. This is applicable to all sectors. This applications research has demonstrated the following points:

- Except in the case of highly trained specialists, most people lack the ability to understand and use a tercile probability seasonal climate forecast without substantial additional explanation and assistance.
- Journalists themselves require training in how to interpret a probabilistic seasonal climate forecast, before they can adequately and correctly explain it to their audience.
- Most people have the capacity to learn how to understand and use a probabilistic forecast.
- Participatory methods of forecast communication, while primarily aimed at helping people to understand and use a forecast, also improve a forecast's credibility and legitimacy, and provide a forum for identifying what types of information might be most valuable for decision-makers.

Introduction

The past twelve years have seen a major international effort to make climate information useful for sustainable development in Africa. One of the drivers has been the growing skill with which climatologists can predict seasonal climate, such as total rainfall, based on a combination of climate and ocean models, and a better understanding of global climate cycles, such as the El Niño Southern Oscillation (ENSO).

One of the primary sponsors of this effort worldwide has been the United State National Oceanographic and Atmospheric Administration (NOAA), often working hand-in-hand with the United States Agency for International Development (USAID). While other countries such as the United Kingdom, Germany, and France, and international organizations such as the World Meteorological Organization (WMO), have contributed substantially to the effort, it is safe to say that NOAA's multi-pronged contribution has been unique. First, NOAA has sponsored much of the basic climatological research on ENSO and other phenomena that has raised the skill of climate forecasting. Second, through its Climate Prediction Center (CPC) and the International Research Institute for Climate and Society (IRI), which it largely funds, NOAA has made a special effort to bring climate information and climate prediction online and freely accessible to a variety of users. Third, NOAA has provided consistent funding for users' meetings and workshops, such as the Climate Outlook Forums (COFs) that take place annually or biannually in several regions of the globe. Fourth, NOAA has funded a great deal of social science research on the application of climate information to decision-making.

This last element is especially important, because to the extent the results of such research are discussed and acted upon, they can lead to the improvement of the first three elements of NOAA's approach, and of the efforts that other countries and international organizations have made. In order for that to happen, however, it is essential for relevant decision-makers to know what those results actually are. To date, this has not always happened. Many of the results have been incorporated into reports filed with NOAA and elsewhere. Others have appeared in the published literature. Others have largely vanished in piles of papers and CD-ROMs. To correct this problem for Africa, where the issue of development is most urgent, NOAA commissioned this current assessment. The purpose of this assessment is to gather the results of past research on forecast applications in Africa, summarize the findings in such a way that their usefulness for practice can be evaluated, supplement these findings with additional insights gained from our stakeholder interaction, and present them in a single document that will be easily accessible to decision and policy-makers.

Added value of this report

Scientists affiliated with the IRI have conducted much of the research on forecast applications. Moreover, in the last two years, the IRI has produced three important publications on the use of climate information in Africa, and it is important to distinguish this report from them. In 2005, the IRI published “Sustainable development in Africa: is the climate right?” (IRI, 2005). The report outlined the need for a better appreciation of climate variability on sustainable development in Africa, with a particular focus on the Millennium Development Goals. In 2006, the IRI published a “gap analysis” of climate forecast applications in Africa (IRI, 2006). It highlighted the major informational and institutional barriers to forecast adoption in Africa, in order to suggest to the United Kingdom Department for International Development (DFID) how best to promote the use of climate information in their development agenda. In 2007, the IRI published a report on best practices in climate risk management in Africa, as the first in their Climate and Society Publication Series (Hellmuth et al., 2007). This report focused a series of case studies, highlighting the value that appropriate use of climate information could have.

Given the three relative recent and extremely valuable IRI publications, what new value does this present report add? We see it as useful in two ways. First, we aim to provide the reader with an overview of some of the current issues in climate information development and application, including a rough guide to the institutional context within which this is occurring. We mean this overview to help people unfamiliar with this field to understand the type of information that is reaching stakeholders, who is producing that information, and how they are producing and communicating it. Second, we want to distinguish quite carefully between how climate information could be used in Africa, and how it has already been used. Where has the information proven useful, and where has it not? What have been identified as the major challenges to forecast applications? In many cases, we dig even deeper, and describe the methods that researchers have used to make their findings. We do this not only to help the readers better understand how that research was conducted, but also to help future researchers to design their own studies.

Intended audience

There are two different audiences for this report. The first is NOAA. NOAA needs to understand how the research that they have sponsored has generated insight. For this reason, we have made every effort to assess applications research that NOAA has directly sponsored. We draw off of not only published findings, but also the project reports that researchers have submitted to NOAA. The second audience is the wider community of stakeholders and scholars who are concerned with how to make climate information more useful in the future. For this reason, we have not limited ourselves to NOAA-funded research, but rather have attempted to conduct a more comprehensive review of the literature. For research results that were not NOAA funded, however, we have been slightly more selective, including those that offer important insights based on empirical research and modeling. Furthermore, it is for the benefit of this wider community that we include the extensive background section on climate over Africa, forecasting methods, and institutions. For the person attending a Climate Outlook Forum for the first time, we hope this report to be useful.

Report structure

We have structured the report first to provide background information about the application of climate information in Africa, second to present the results of applications oriented research, and third to suggest the most important lessons to be learned, which in turn suggest areas for future work.

We divide the background material into three chapters. Chapter 1 covers the African climate and climate vulnerability. It provides a very general overview of the African climate, and the climate vulnerability literature. It then examines the different sectors that are especially vulnerable to climate variability and change. It then presents a theoretical framework for applying climate information to decisions, and determining whether they add value to those decisions. Chapter 2 presents the different methods of predicting seasonal climate. We explore how uncertainty in predicted climate is dealt with by different modeling and communication approaches. We also summarize some of the important linkages between the effort to predict seasonal climate and longer term climate change. Chapter 3 describes the institutional and organizational landscape for climate forecasting and forecast applications.

We present the results of applications oriented research in four sections, each covering a different applications sector. Chapter 4 focuses on food security and famine, which provided the major motivation for seasonal forecast application. Chapter 5 covers agriculture and livestock management, which is where the majority of applications research has taken place. Chapter 6 covers water resources and flood management, which are linked by the need to conduct analysis on a watershed basis. Chapter 7 covers public health, with the majority of work having been directed at malaria control. In each of these sections, we summarize the applications research that has been conducted, identify how far advanced applications efforts have become, and identify the important next steps for improving on the current system. We have tried to include the important studies from all across Africa, but the reader will notice that we have reviewed many more studies from Southern Africa, and fewer from West and Central Africa, as the Annex to this report indicates. That we may have missed important findings, especially ones from West and Central Africa, is a potential weakness of this report.

Chapter 8, the conclusion of the report, is brief, and is also the most editorial. We pull together the different findings that we have summarized, and offer what we believe to be the most important lessons learned.

1

Vulnerability to climate variability and change in Africa

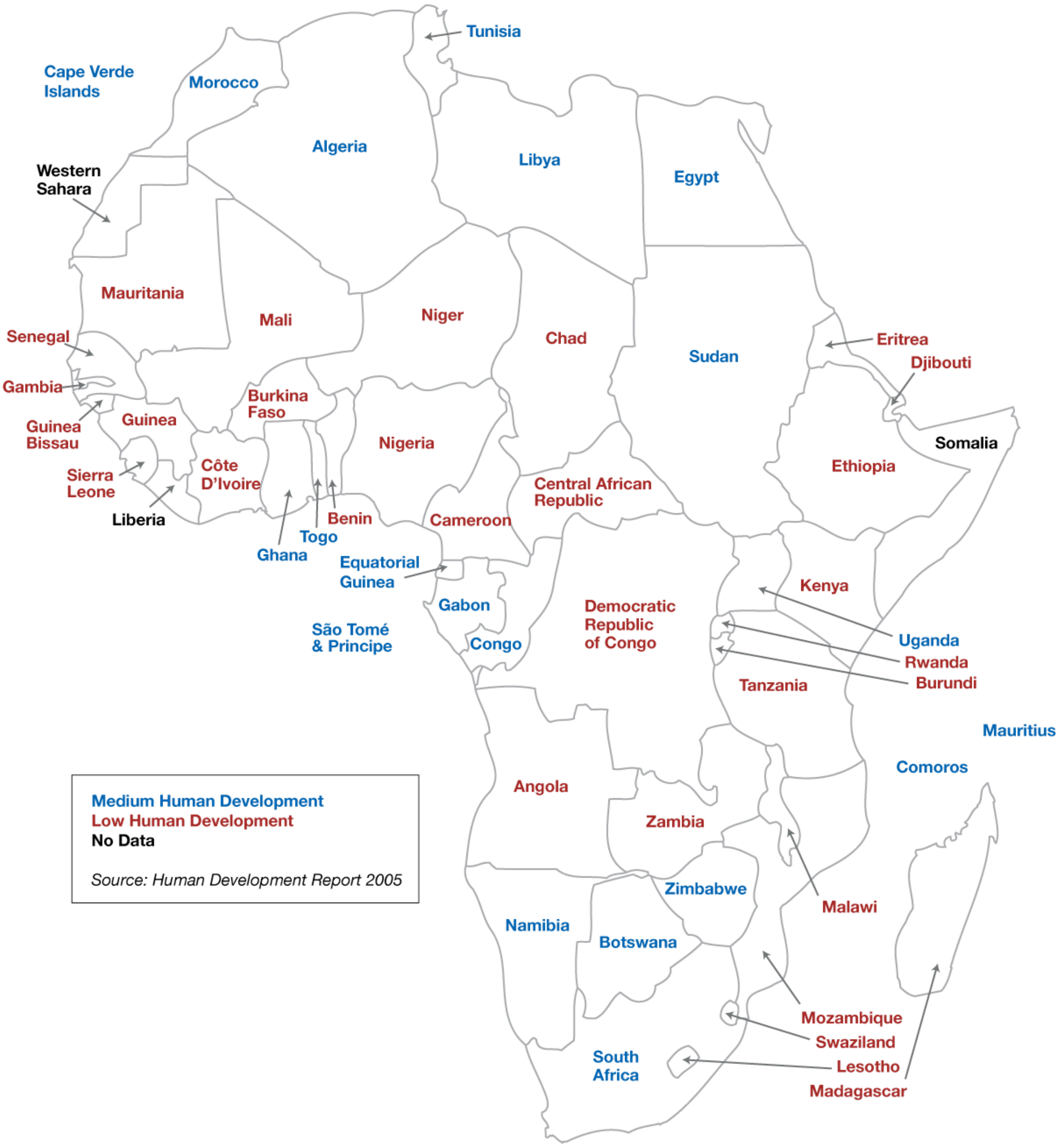
There has been growing attention to the use of seasonal climate forecasts to inform decision-making across many economic sectors, beginning in the early 1990s (Golnaraghi and Kaul, 1995). One of the landmark papers in this area was published in 1994, and highlighted the connection between an important economic sector—maize farming—and ENSO (Cane et al., 1994), for which predictive skill already existed (Cane et al., 1986; Latif et al., 1994; Zebiak and Cane, 1987). Interest in ENSO intensified when the 1997-98 El Niño occurred, with tremendous consequences around the globe (Glantz, 2001). Since then there have been a growing number of pilot projects and studies examining how to make forecasts not only accurate but also useful for decision-makers; a large number of these have been in Africa, not only because of the links between African climate and sea surface temperatures (SST) (Glantz, 2000), but also because of the continent's vulnerability to rainfall excess and deficit (NOAA, 1999).

Climate and climate vulnerability in Africa

Africa is one of the most, if not *the* most, vulnerable continents to the effects of climate change and variability (McCarthy et al., 2001). This has not just to do with climatic and physical features of the continent, but also with social and political features. Vulnerability is linked not only to a community's exposure to climatic disruptions, but also to its sensitivity to those disruptions, and its capacity to adapt to the changes. The economies of most African countries are highly dependent on agriculture, the economic sector that is arguably most sensitive to climate variability and change (Antle, 1995). Malaria and other tropical diseases—outbreaks of which are linked to climate factors (Martens et al., 1997)—negatively affect the health of millions of Africans, and hinder wider development efforts. But the dominant factor influencing Africa's vulnerability is poverty. As Figure 1.1 shows, the majority of African countries are in the lowest group in the United Nations Human Development Index rankings (Watkins, 2005). This poverty indicates that many people are at the edge of survival, and will suffer not just lost of income but also loss of health, or even life, as a result of climate disruptions (Brooks and Adger, 2004; Yohe and Tol, 2002). It also means that fewer resources are available to adapt to climatic factors (Adger et al., 2003).

Overview of the African climate

The two dominant climatic factors of concern in Africa are rainfall and temperature, and this is for several reasons. Most importantly, African agriculture is predominantly rain-fed, meaning that if sufficient rainfall does not fall with the growing season, there will be a loss of harvest, and the potential for both loss of income but basic livelihood disruption, including food insecurity. Because most of the continent is in the tropics and subtropics, extreme cold weather is simply not a concern, except in a few highland areas. However, temperature can affect the rate of evapotranspiration, and thus indexes of water satisfac-

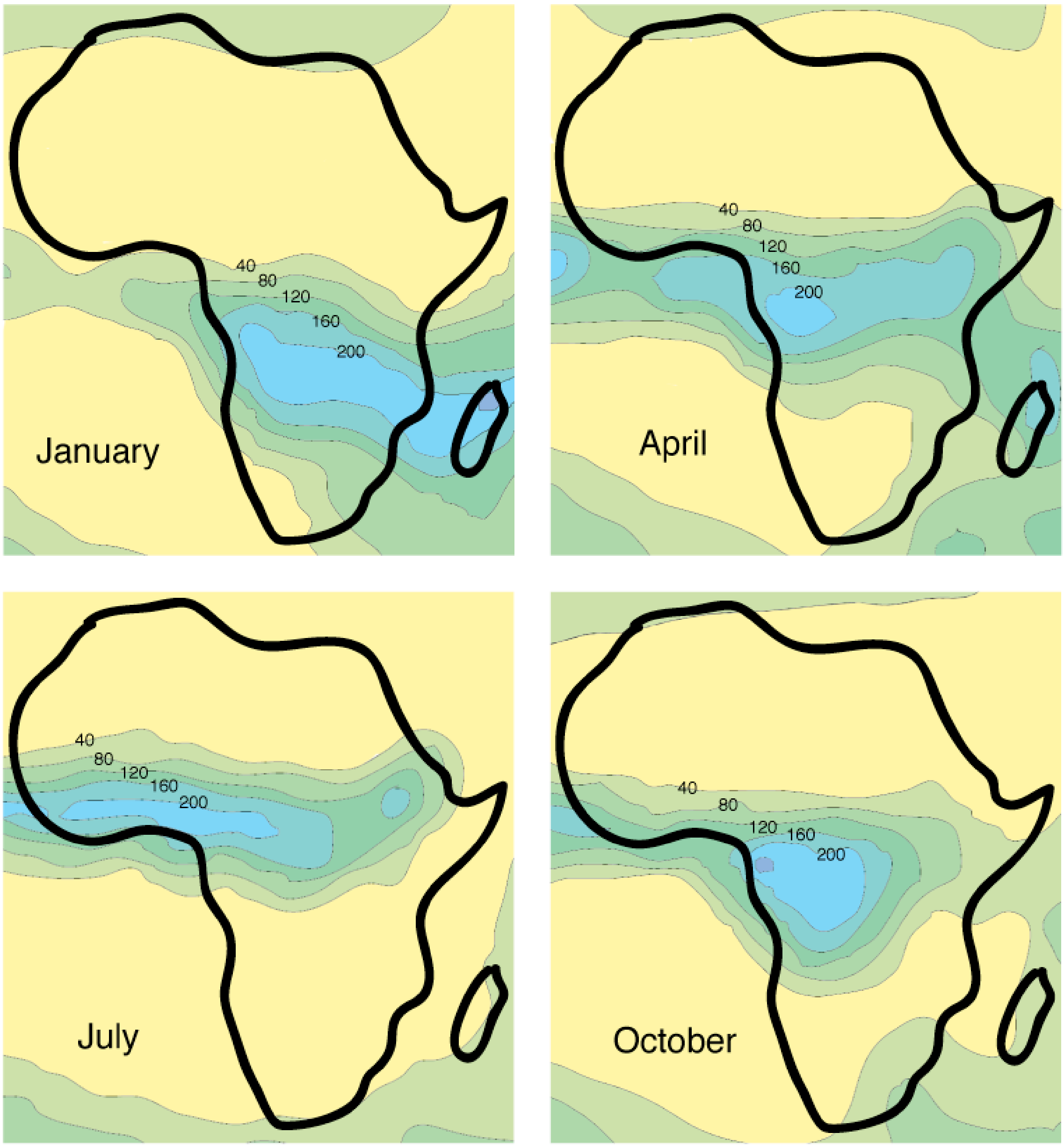


Source: Human Development Report 2005

Figure 1.1—African Countries' Human Development Index (HDI). The HDI measures the average achievements of countries across three dimensions: life expectancy and level of health, average educational attainment, and standard of living.

tion for crop growing. Moreover, especially in highland areas, temperature can affect the prevalence of disease vectors.

Precipitation in Africa is influenced by both large- and small-scale phenomena. At the large scale, the latitude of different areas plays an important role. The African continent stretches from about 35 °South to 35 °North. At the southern and northern extremes, the climate can be described as Mediterranean, and precipitation is primarily in



Source of data: NOAA NCEP

Figure 1.2—Average Monthly Rainfall Totals. This shows rainfall totals in mm during the two seasonal extremes of the intertropical convergence zone (ITCZ), January and July, as well as the two intermediary periods, April and October.

the winter, associated with passing frontal systems. The summers in these areas—the Mediterranean coast in the north and the Cape of Good Hope in the south—tend to be hot and dry. Equatorward are areas dominated by year-round high-pressure zones, with subsiding air inhibiting rainfall. These are the Sahara and Kalahari deserts. A band of low pressure, the Intertropical Convergence Zone (ITCZ), influences rainfall over the majority of the continent. The ITCZ is an area marked by high convective activity (thunderstorms) and larger low-pressure systems, and occurs roughly at the area where the midday sun is highest overhead. This area moves, naturally, according to the seasons, and is furthest north during the months of July and August, and furthest south during January and February. At the poleward edge of the ITCZ is the Intertropical Front (ITF) or Intertropical Discontinuity (ITD), which marks the boundary between dry, hot air towards the pole, and warm, moist air towards the equator. Meteorological events typically take place 1 – 2° equatorward of the ITD, especially in West and Central Africa.

Areas at the edge of the tropics, such as Botswana and Zimbabwe, experience the ITCZ at the height of their summer season, and hence tend to have a single rainy season. Areas closer to the equator, such as Kenya, tend to have a bimodal rainy season, with peaks centered around September-October and March-April, partly because the ITCZ passes twice each year. There are other reasons for bimodal rainfall patterns, such as in the southern part of the Gulf of Guinea countries (Nigeria to Sierra Leone), where changes in the monsoonal flow play a critical role. While the ITCZ moves north and south in seasonal cycles, its location is also affected by other large-scale phenomena, such as the differences in temperature between landmasses and the oceans, and even differences in relative SST. Hence, the ITCZ does not cut an east west line across the continent, but responds somewhat to Africa's shape.

There are also many smaller scale factors that influence rainfall across Africa. Elevation plays a major role, as highland areas are cooler and tend to receive greater rainfall. Highland areas stretch down the entire length of the eastern side of the continent, from Ethiopia to South Africa. In mountainous areas micro-climates can exist, in which distances of only a few kilometers separate areas that receive hundreds of millimeters more or less rainfall per year. Bodies of water can also play an important local role in influencing convection, and hence rainfall.

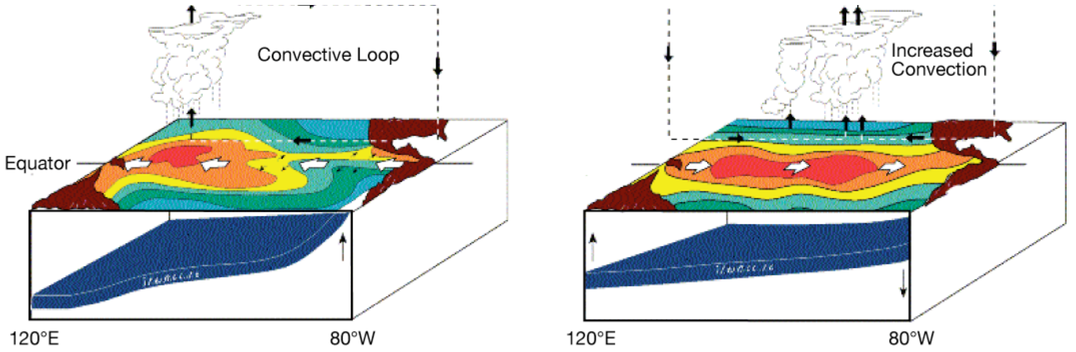
ENSO and SST influences on seasonal variability

Beginning in the 1980s, climatologists began to study the effects of sea surface temperatures (SST) on global climate. Much of this work revolved around understanding the phenomenon known as El Niño / Southern Oscillation (ENSO), a cyclical pattern of changes to SST and atmospheric pressure across the tropical Pacific Ocean.

The name El Niño derives from the observations of people living on the Pacific coast of South America. At times, the water off the coast would become warmer, and the trade winds would weaken. The weakening trade winds would lead to a narrowing of the band of coastal upwelling, meaning that pelagic fish stocks would first concentrate closer to shore, as upwelling dependent plankton stocks further out to sea began to die. The greater concentration of fish close to shore created short-lived booms for fisheries, but then often led to collapse, as the upwelling would grow weak even close to shore. At the same time, the warmer SST would result in greater rainfall along the coast. This was sometimes a boon for agriculture, but could also lead to flooding and landslides. Because these phenomena often occurred in the months leading up to Christmas, the residents named them El Niño (the Boy), after the Christ child.

In fact, El Niño is one element and one phase of variable ocean atmosphere conditions taking place across the entire tropical Pacific. Under so-called “normal” conditions, there are strong easterly trade winds across the Pacific, associated with low pressure in the west, and high pressure in the east. This results in warm surface waters (about 30° C) pooling in the area of Indonesia, and colder water (about 22° C), resulting from strong coastal upwelling, near South America. The entire circulation pattern is known as a Walker cell. Figure 1.3A shows the Walker cell under these normal conditions.

The pattern seen in Figure 1.3A is self-reinforcing, to a point. Warm water in the west leads to vertical convection and lower atmospheric pressure, and the colder water in the east leads to subsidence and higher atmospheric pressure. When these conditions are most strongly developed—the water in the east is particular cold, and the atmospheric pressure is lowest in the west and highest in the east—climatologists say that a La Niña (the opposite of El Niño) has developed. However, La Niña conditions also appear to lead to changes that cause the entire system to reverse. The water pooling in the west is not only warmer, but also about a half a meter higher, than the water in the east. This appears to cause a wave to propagate eastward across the Pacific, disrupting the thermocline (the depth at which warm surface water is differentiated from much colder deep water). When this wave reaches the coast of South America, a resulting rise in SST reduces the high atmospheric pressure typically found there, and slows down the trade winds. Reduced trade winds lead to less coastal upwelling off of South America (and hence even warmer water there), and less pooling of warm water in the west (and reduced convection and higher atmospheric pressure there). This is the El Niño phase, shown in Figure 1.3B. El Niño conditions, however, also contain the seeds of their own destruction. A second wave begins to propagate back to the west, eventually hitting and reflecting off of the coast of Asia. This wave again affects

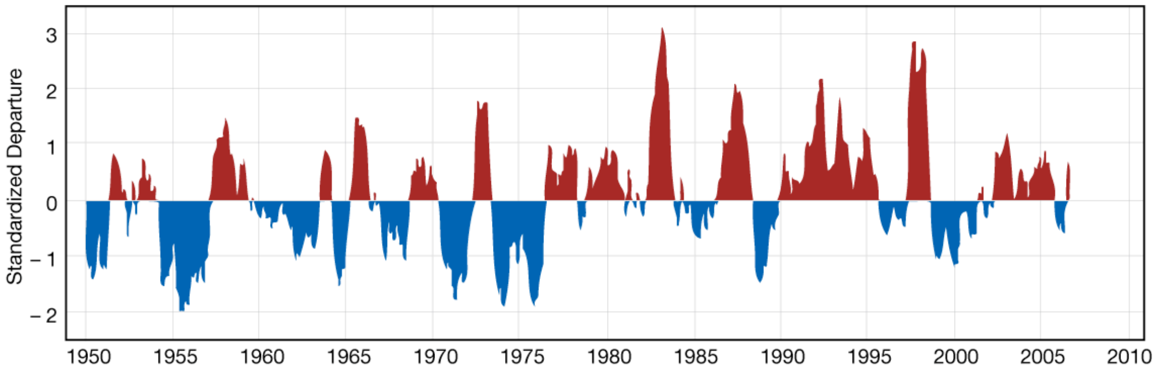


A. Normal Conditions

B. El Niño Conditions

Source: NOAA/PMEL/TAO

Figure 1.3—Walker Cell. The Walker Cell is the convective pattern over the tropical Pacific Ocean. So-called “normal” conditions are dominated by strong easterly trade winds, warm water and low atmospheric pressure in the western Pacific, and a shallow thermocline in the eastern Pacific. El Niño conditions are marked by weaker tradewinds, warmer water extending to the eastern Pacific, and the area of low atmospheric pressure being shifted to the east.

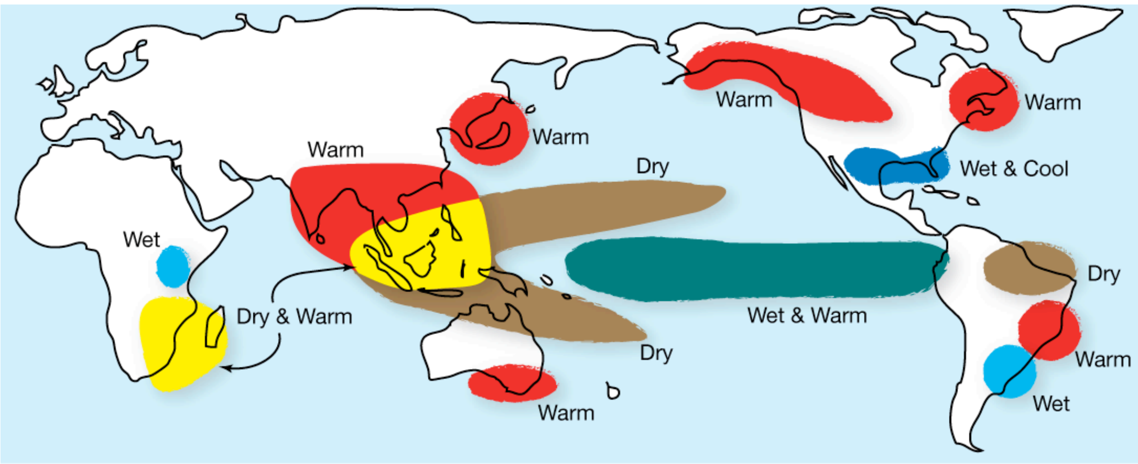


Source: NOAA CIRES Climate Diagnostics Center Multivariate ENSO Index

Figure 1.4—ENSO Cycle. The areas of red show warmer than normal temperatures in the eastern Pacific, characteristic of El Niño, while the blue areas show the reverse condition. The departures from normal are in °C. ENSO follows a cycle of 3 – 7 years.

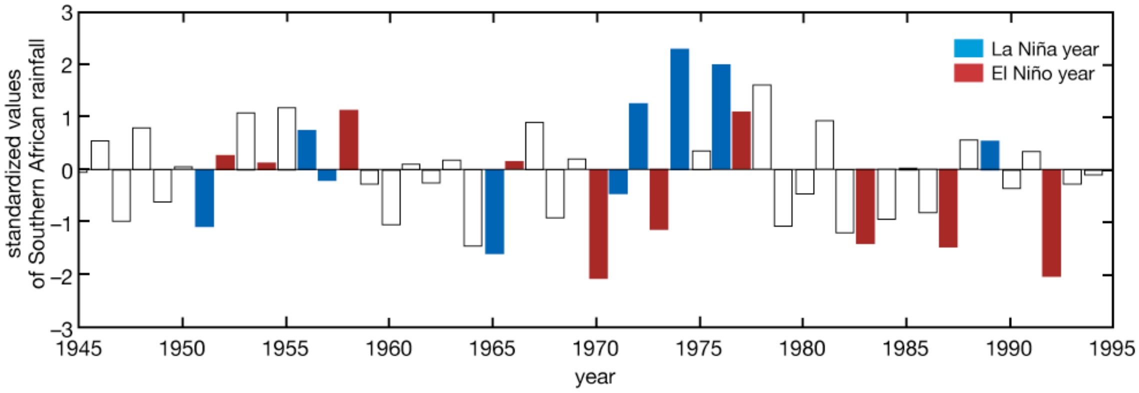
the depth of the thermocline, and leads to a re-warming of western SST, and the end of El Niño conditions.

El Niño, then refers to conditions where SST in the eastern tropical Pacific is warmer than usual, and La Niña to conditions when that water is colder than usual. Neutral conditions exist when the water is neither unusually warm nor cold. Climatologists measure this by an array of buoys, taking the average of their readings across a geographically defined space. The most common averages used are for the Nino3 (5°S – 5°N, 150°W – 90° W) and Nino3.4 (5°S – 5°N, 170°W – 120° W) regions. Related to this is the Southern Oscillation Index (SOI). This refers to the difference in atmospheric pressure between the island of Fiji, in the middle of the Pacific Ocean, and Darwin, Australia. A positive SOI anomaly—when the pressure in Fiji is much greater than that in Darwin—typically occurs during La Niña conditions. A negative SOI anomaly typically occurs during El Niño conditions. The entire system is



Source: IRI

Figure 1.5—El Niño Teleconnections. The colored areas show typical climate anomalies during El Niño years. Many of the anomalies are the opposite during La Niña years.



Source: Richard et al. (2000), p. 887

Figure 1.6—Southern African Rainfall Anomalies. Each bar shows the anomaly from mean rainfall, averaged over Southern Africa. As can be seen, the anomaly is usually positive during La Niña years, and usually negative during El Niño years. This is especially so since 1970.

thus known as El Niño / Southern Oscillation, or ENSO.

ENSO typically follows a cycle of three to seven years, as can be seen in Figure 1.4. Because reliable measurement of SST only goes back a few decades, it is difficult to reach a firm conclusion about whether the ENSO cycle is changing as a result of recent climate change. Nevertheless, there is some evidence that some features of the Pacific Ocean have changed in the last thirty years in ways that are consistent with a trend towards more frequent, or more intense, El Niño conditions (Guilderson and Schrag, 1998). Supporting this conclusion are also paleo-climatic studies that show that El Niño was a more dominant state at times when average global temperatures were warmer (Wara et al., 2005). Some coupled ocean-atmosphere general circulation models (CGCMs) also suggest that El Niño may become more pronounced as the climate continues to change due to anthropogenic factors (Collins et al., 2005). The shroud of uncertainty, however, is great.

Whether or not it is changing, ENSO is important because it influences climate patterns around the world on a regular basis. Figure 1.5 shows the identified influences, or teleconnections, associated with El Niño conditions. Around the Pacific basin, these changes are not difficult to understand, since El Niño has a direct connection to local changes in atmospheric pressure, and hence local weather. Further away, however, the connections are less strong, and subject to influence by other factors, such as SST in the Atlantic and Indian oceans.

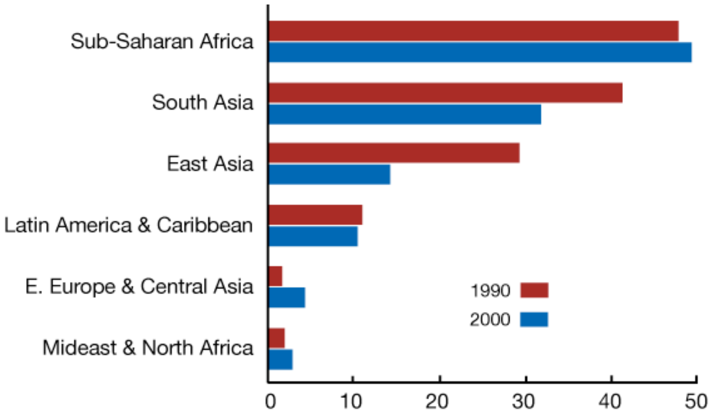
In Africa, the effect of El Niño conditions is to often to prevent the ITCZ from pushing as far to the south, especially over the eastern half of the continent, during the austral summer. What this means is that areas in Southern Africa typically receiving their heaviest precipitation when the ITCZ is at its southernmost limit, are deprived of some of that rainfall, since the ITCZ remains to the north. Likewise, those areas further to the north receive greater rainfall. Figure 1.6 shows the relationship between El Niño events and rainfall in Southern Africa. The red bars indicate years in which an El Niño occurred, the blue bars represent years in which a La Niña occurred, and the white bars represent years in which conditions in the tropical Pacific were neutral (Richard et al., 2000). As can be seen in the figure, especially since the late 1960s, there is a high correspondence between El Niño years with below average rainfall, and La Niña years with above average rainfall.

Rainfall patterns in East Africa, which lies across the Equator, are also influenced by the same basic shifts in the ITCZ. Much of East Africa has two rainy seasons: a long season in March – May, and a short season in October – December. Indeje et al. (2000) identified eight homogenous rainfall regions in East Africa, and for each region were able to identify a slightly different mix of effects associated with El Niño. In general, however, rainfall is heavier in both rainy seasons over most of East Africa during El Niño years, and lighter than usual the year after an El Niño has ended. Rainfall patterns in West Africa appear to be much less linked to ENSO.

Ocean temperatures other than ENSO, including other multi-annual oscillations, also matter for much of Africa. Temperatures in the Atlantic play an important role in determining summer rainfall over West Africa. Warmer SST, especially within the Gulf of Guinea, favors heavier rainfall close to the coast (such as over Liberia, Côte d'Ivoire, and Ghana), and lighter rainfall further to the north (such as over Mali and Niger). Similarly, warmer SST in the Indian Ocean favors heavier rainfall over the eastern side of the continent. There are temperature and pressure oscillations in both basins—the North Atlantic Oscillation and the Indian Ocean Dipole—and although neither of these is as important a driver of global climate as is ENSO, each can have important local and regional effects on African climate. The Indian Ocean can affect East and Southern African climate, especially close to the coast. The Atlantic Meridional Dipole affects the Sahel of West Africa. When the dipole is warm in the northern part and cold in the south, Sahelian rainfall is typically enhanced. The reverse situation in the dipole is associated with diminished Sahelian rainfall.

Sectors affected by seasonal climate variability

As Figure 1.7 shows, Africa is the continent with the highest proportion of people living in absolute poverty, and one where little progress has been made to change this. In sub-Saharan Africa, 200 million people go hungry in years of poor rainfall (IRI, 2005). Climate variability in Africa is an impediment to human development, and to progress



Source: World Bank & IRI

Figure 1.7—Proportion in Absolute Poverty. The bars show the percentage of people living on less than US$ 1 per day. As can be seen, Sub-Saharan Africa is the region with the highest proportion of people living in absolute poverty, and one the regions where this did not improve during the 1990s.

towards the Millennium Development Goals (MDGs) (IRI, 2005). One of the factors that makes Africa unique, and its vulnerability to climate variability so great, is the relatively high number of people living in rural areas, and dependent upon rainfed agriculture for a living. Seventy percent of people in sub-Saharan rely on agriculture for their livelihood.

Agriculture and food security

Agriculture and food security are two related areas of concern. Through the practice of agriculture, people grow the crops necessary to sustain high-density populations. When people do not have steady access or entitlement to enough of these crops, they become food insecure (Sen, 1981).

Agriculture requires enough water to be in the soil at the right time. In most of Africa, agriculture exists without access to irrigation, and hence is entirely rain fed; over 95% of the crop-land is devoted to rain-fed agriculture, and over 90% of the population depends on rain-fed agriculture for their basic food requirements. Rain-fed agriculture generates roughly 35% of GDP. In addition, the agricultural sector accounts for 70% of total employment, and roughly 40% of exports (FAO, 2000). Clearly, the viability of rain-fed agriculture depends on water falling in predictable quantities, in predictable places.

Variability can interfere with agriculture for in three ways. First, the crops that farmers plant have a restricted window of time within which they mature, and during which they need adequate moisture. Because of climate variability, there is a good chance that the climate in any given year will not be suitable for the crops that farmers have planted, and those crops will die. Second, the presence of uncertainty can lead farmers to plant lower yielding crops. As a general rule of thumb, the crops that require more water, over longer periods of time, also produce greater yields. But with few exceptions (Osgood and Warren, 2007), African farmers do not have access to insurance mechanisms, and so rely on some minimal harvest every year. This makes them risk averse, and leads them (for good reason) to plant safer crops with much lower average yields than is possible within their climate region. Third, the presence of climate variability, and in particular climate variability that may be changing, means that many farmers simply do not know what is "normal" rainfall for their region. The signal to noise ratio is too high. In the absence of good historical records, and living in societies with a great deal of social change, some farmers may simply not know what crops are ideal for their location, and may be planting crops that are ill suited on average.

Compared to agriculture, the relationship between climate variability and food security is in some ways more complicated, and in some ways simpler. It is more complicated because food security results not just from crop failure, but more importantly from an inability of people to gain access to adequate food, whether it is locally grown or imported into the region, as well as to utilize the food they eat. Food access is a typically a function of economic conditions, the presence of social safety nets, and other government policies. Climate effects influence many of these, over long periods of time. Given that rain-fed agriculture generates roughly 35% of GDP, and 40% of exports, in most parts of Africa, a poor harvest one year can have a significant impact on economic and social conditions within a country the following year. Effects on the balance of trade mean that the costs of many farming inputs, such as spare parts for tractors, can rise significantly as a result of poor harvests. In a region with intermittent droughts, the resilience of society may be diminished, making the people more vulnerable to food insecurity. Poverty can lead to poor health, reducing people's utilization of the food they eat.

On the other hand, the opportunities to avoid food insecurity in the face of climate variability are greater than the opportunities to avoid a simple bad harvest, because the range of potential options is much wider. Farmers must decide what crop to plant before the rainy season begins, and except for small adjustments to fertilizer use or, in some locations, irrigation, there is often very little they can do over the coming months to avoid a poor harvest. But food insecurity is a slow onset disaster, something that builds often over several years. There are many interventions that can be taken over a longer period of time, and at a wider variety of spatial scales, all of which can serve to diminish risk. Avoiding food insecurity requires decisions that can be made not just at the household scale, but also at the national, regional, or global level. There are economies of scale: the people making these decisions can invest in training, computing and analytical power, and access to data, to an extent that most farmers cannot. The opportunity to make good decisions based on the best available data and analysis are much greater.

One way to represent strategies for coping with climate variability was captured in a US National Research Council report in the late 1990s (Stern and Easterling, 1999). They suggested the matrix seen in Table 1.1, which divides the coping mechanisms according to whether they affect consumption or production, and whether they are *ex ante* or *ex post*. Coping mechanisms aimed at consumption are those that preserve the food security of rural households, while those aimed at production are those that seek to mitigate the effects of climate variability on harvest quantities. Clearly, the usefulness of climate forecasts is in the *ex ante* category. *Ex post* climate information—rainfall and NDVI measurements, for example—are less useful to farmers, although they too could guide some decisions such irrigation or fertilizer application. They are certainly useful to government decision-makers, however, who must decide what potential disaster relief may be

Table 1.1—Strategies for coping with climatic variations in agriculture (Stern and Easterling, 1999, p. 41)

	Temporal Relationship to Resolution of Uncertainty	
Consumption versus Production	Ex Ante (Based on Expectation)	Ex Post (Based on event realization)
Consumption: reduce impact of fluctuations in output on access to consumer goods and services	Accumulate assets Purchase crop or weather insurance Make a sharecropping contract Arrange to share with family, community Diversify income sources	Buy or sell assets Receive or provide transfers Seen nonagricultural employment Cash insurance check Accept government disaster payments
Production: reduce adverse impact of climate event on agricultural output and profits; exploit opportunities	Diversify crops, livestock Select climatically robust seeds, animals Invest or disinvest in irrigation, fertilizer, etc.	Reduce or intensify inputs Change crops Move production Irrigate fields

needed. At the government and NGO level, avoiding food insecurity requires a ongoing set of decisions, making use of a constant stream of information.

Water resources and electricity

Farmers use water that is present in the top few meters, and even centimeters, of the soil. Water stored in natural aquifers, behind dams, and running in rivers, by contrast, serves a wide variety of users. It provides water for irrigation, industry, and residential use, as well as electricity. Climate variability has a strong influence on all of these.

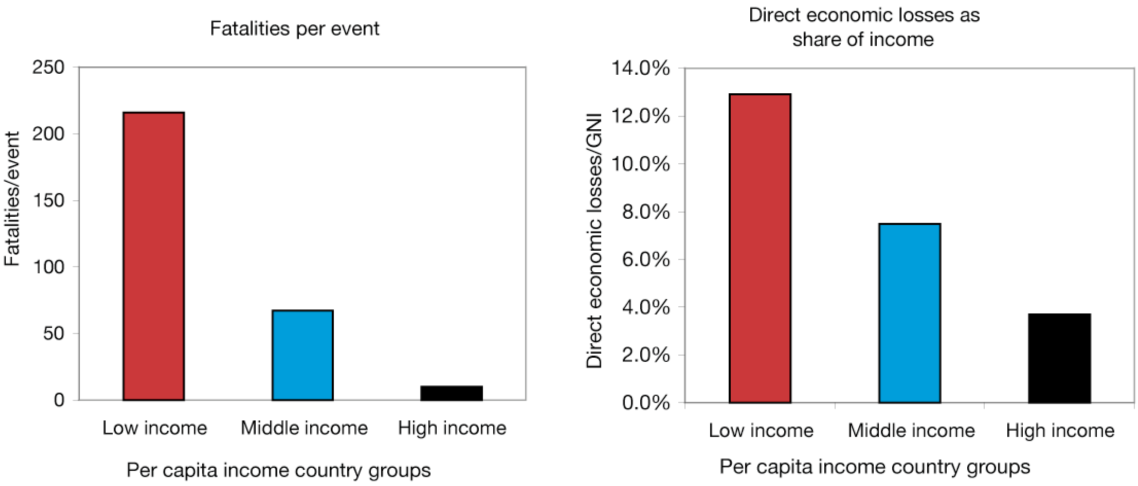
There are 1,272 large dams in Africa (World Commission on Dams, 2007). The highest of these is the Cahora Bassa dam in Mozambique, at 171 meters, and the largest in terms of reservoir capacity, just upstream on the Zambezi River, is the Kariba Dam between Zambia and Zimbabwe, which holds 180 billion cubic meters of water. While some dams, such as Cahora Bassa and Kariba, serve multiple purposes, multipurpose dams constitute only 19% of the large dams in Africa, and the remaining 81% of the large dams in Africa are single purpose. Of the single purpose dams, 66% are for irrigation, 25% are for public water supply, and the remainder are for other purposes, including power generation (World Commission on Dams, 2007). Dams clearly serve an important function of smoothing water supply over time: by storing water, it is possible to avoid the worst implications of climate variability, providing water for public use and for irrigation even in years of low rainfall. But the need for dam managers to ration water wisely is especially pronounced in Africa, where competing water rights are often not fairly addressed in the legal system and through regulation (World Commission on Dams, 1999).

One important function of dams that are properly managed is flood control. Along rivers that are not dammed, or are poorly managed, residents face an ever-present risk of flooding. In the floodplain of the Limpopo River in southern Mozambique, for example, heavy rains in February, 2000, caused the river to rise as much as 8 meters in a matter of hours. Over 100,000 people needed to be evacuated, over 90% of the irrigation systems were destroyed, and 60,000 head of cattle were lost (Government of Mozambique, 2000). Dam managers and disaster planners often need to work together to avoid and resolve crisis situations.

Public health

Climate variability has a profound effect on public health, perhaps most acutely with respect to malaria, but also through infection rates for meningococcal meningitis, Rift Valley fever, trypanosomiasis, yellow fever, and visceral leishmaniasis (WHO, 2005).

The malaria parasite, genus *plasmodium*, infects an estimated 300-500 million people each year, causing 1.5 to 2.7 million deaths. Over 90% of the cases are in Africa, and over 90% of the deaths are in African children under the age of five. Malaria symptoms are flu-like, with fever, headache, weakness, and chills, leaving people unable to engage in much physical activity. Untreated infections last from several months to several years, and severe cases can lead to failure of vital organs. Left untreated, as many as 25% of the people who are infected with *P. falciparum* can die from it, with a higher percentage among pregnant women and young children. Those who do not die, and who continue to be exposed to the parasite, develop temporary immunity. People lose their immunity within a few years if they are not continually exposed to it, in part because the parasites are continually evolving, and new strains progressively overcome the immunity developed to older strains. Thus, in regions where malaria is



Source: IIASA, Höppe (2005)

Figure 1.9—Global Disaster Losses. The bars in the left-hand graph show the fatalities per event, for large natural disasters. As can be seen, low income countries, which include almost all African countries, suffer more than ten times the loss of life per event, compared to high income countries. The right-hand graph shows the direct financial losses, as a percentage of Gross National Income (GNI). Low income countries suffer much higher proportionate losses: although their total losses are less, as a share of GNI they are much greater. The graph does not show indirect losses to the economy, which can often be several times the level of direct losses.

endemic, there is both a high rate of malaria incidence and a high rate of immunity, whereas there is little or no immunity in areas where malaria outbreaks occur sporadically or not at all. The areas that are most at risk of epidemics—temporary sharp increases in the number of malaria cases—are those that border the regions where malaria is endemic. In these areas, the intermittency of conditions favorable to malaria transmission can interfere with people's acquired immunity, and magnify the severity of epidemics and loss of life.

HIV/AIDS intersects a great many sectors, and is intimately tied to climate vulnerability in Africa, via a number of different causal pathways. Climate variability can affect patterns of seasonal or longer-term migration, and this can affect the spread of the virus, as well as people's access to antiretroviral treatment. People who are suffering from poor nutrition and health, partly as a result of food insecurity, are more likely to develop AIDS symptoms. People suffering from AIDS symptoms, likewise, are more vulnerable to other diseases and stresses associated with climate variability.

Others sectors affected

Just as the concerns of agriculture and food security intersect, so do several other economic and government sectors overlap with those just discussed. Because of African countries' large reliance on agriculture, and in particular rain-fed agriculture, aggregate economic conditions are heavily influenced by climate and climate variability. Beyond the effects of agriculture, economic growth can also be heavily influenced by natural disasters, which are increasingly seen as an important concern for development. As Figure 1.9 shows, natural disasters have a profoundly differential impact on countries depending on their level of income. Low income countries suffer many more fatalities per event, and while their overall economic losses are less than in high income countries (because the value of built infrastructure is simply less), their losses as a percentage of gross national income are much higher (Höppe, 2005). Climate variability obviously plays an important role in this, as many of these disasters are climate related. Sea surface temperature can influence the strength of tropical cyclones over a given season, and El Niño or La Niña conditions can cause the conditions for extensive flooding over large areas of East or Southern Africa. Thus, disasters often tend to occur grouped in time and spaced, with their patterns closely connected to basic variability in climate, which in turn makes it difficult to develop local insurance systems.

Climate factors affect biodiversity, from the complex soil food webs upon which most terrestrial life depends, to the large mammals, birds, and trees that are symbols of the African landscape. In many parts of Africa there are efforts to manage the ranges and numbers of these large animals and plants, often with tourism in mind. In theory these decisions, as with those described for the previous sectors, could be improved by the use of climate information.

Using climate information to reduce vulnerability

Given the vulnerability of so many sectors in Africa to climate variability, efforts to improve the management of that vulnerability, and the lessening of its consequences on society and the economy, appear to be vital. Access to climate information of three types could contribute to this effort. First, it is important to build management practices around a sound understanding of climatological conditions, taking into account the links between these conditions and social, economic, and demographic factors. One may assume that planners have access to such information, but is not always the case. Climatological data itself is often not available to all planners, either because it doesn't exist, or because it is proprietary, and too expensive for them to purchase. Baseline data on infectious disease, local-level agricultural yields, and soil hydrology is often absent, and often proprietary. Second, it is essential for many people to have rapid and reliable access to real-time meteorological data, such as rainfall, temperature, and wind. Obviously, if one knows that heavy rains have fallen high in a watershed, it makes it possible to predict some chance of flooding downstream. But data like this often takes weeks or months to be reported, undercutting its value significantly. Satellite data can partly correct for such problems, but many Africans lack the technical capacity, the computing power, and the bandwidth to access and analyze this type of data. Third, it is often useful to develop, and use, forecasts of future conditions. Short-term forecasts range from hours to days. Medium-term forecasts extend up to about ten days. Seasonal forecasts can project departures from climatological means months in advance. Finally, long-term projections of climate change can anticipate the effects both of decadal scale variability and of changing greenhouse gas concentrations. These can guide multi-decadal planning decisions.

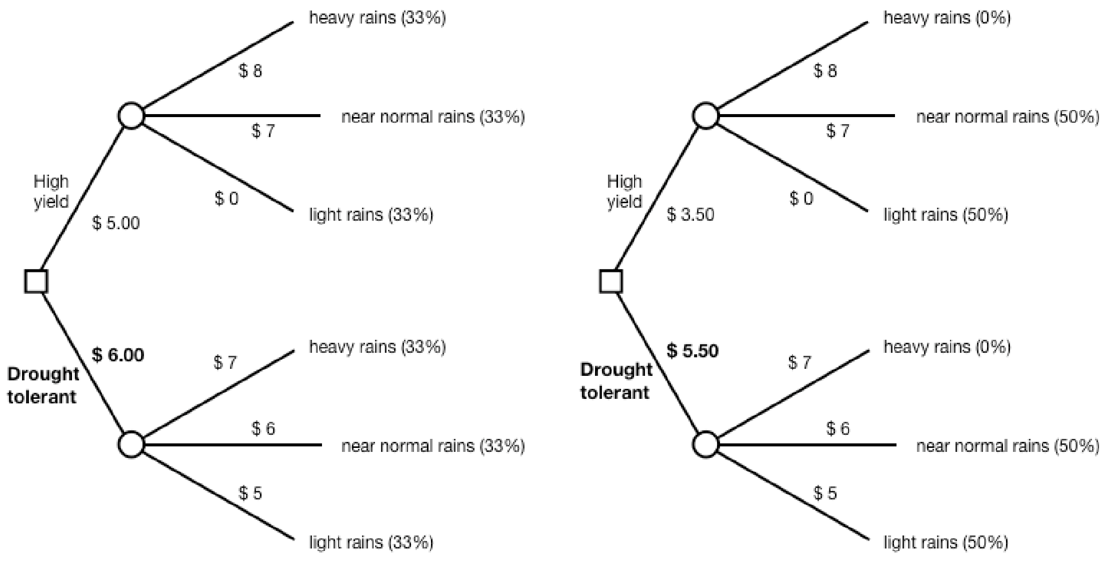
Most of the work so far on climate information applications in Africa has focused on the use of seasonal climate forecasts. This was driven by the growing ability to predict seasonal patterns, based on an improved understanding of ENSO and other sources of inter-annual climate variability. Many stakeholders, especially those in the public health sector, agree that greater emphasis needs to be placed on historical and real-time data.

Seasonal forecasts can be valuable. They could help in the reduction of vulnerability and poverty, and hence progress towards the MDGs, by allowing ex ante adaptation to inter-annual variability (Thornton, 2006). Ex ante adaptation means that people make decisions not in response to the average climate for their location, but rather for the climate as it is predicted to be in the coming months. In most cases, such prediction can reduce the uncertainty associated with climate, by narrowing the range of uncertainty concerning one or more critical climate parameters, such as rainfall. In some cases, the decisions that would deliver the highest expected value under the narrower distribution will be different than those that would deliver the highest expected value under the more general climatology distribution. When this occurs, the value of the forecast is the difference between the expected value of the two decisions that would have been made—one with the forecast, the other without—given the narrower distribution of climate parameters.

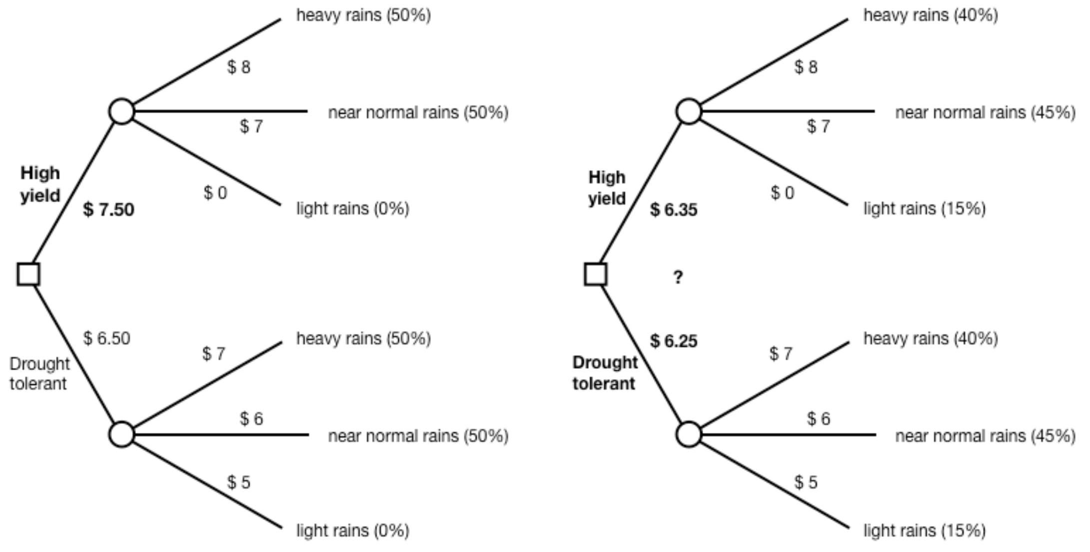
Value of information model

Figure 1.10 illustrates, via a simplified example, how forecasts may or may not add value, and is based on the cost-loss model of information value (Katz and Murphy, 1997). It depicts a farmer who faces a choice of whether to plant one of two different crops in her small house garden, although its core features are equally applicable to other types of decisions in other sectors. The choice between a high yield and a drought tolerant crop is represented in each decision tree by a square. Regardless of which crop the farmer plants, the circle represents the random chance that rainfall will be heavy, near normal, or light. Each crop produces a different yield, and hence a different payoff, contingent on rainfall. When rainfall is normal to heavy, the higher yield crop slightly outperforms the drought tolerant crop, but when rainfall is light, the drought tolerant crop outperforms the higher yield one.

Under climatological conditions, shown in Figure 1.10A, the expected payoff of the high yield crop is $5.00, which is the equally weighted average of $8, $7, and $0. The expected value of the drought tolerant crop is $6.00, and this is what a yield-maximizing farmer would choose to plant. Figure 1.10B shows the case of a forecast of decreased rains. The expected values reflect the different probability weights, and in this case the drought tolerant crop outperforms the high yield crop by an even greater margin—$5.50 to $3.50—than under climatological conditions. It is important to note that in this case, the forecast does not add any value to the decision, since the farmer will do what she would have done anyway, in the absence of the forecast. Figure 1.10C shows the case of a strong, or high skill, forecast of increased rains. If the farmer plants the high yield crop, she will earn $8 or $7 with equal likelihood, for an expected value of $7.50. If she plants the drought tolerant crop she will earn $7 or $6 with equal likelihood, for an expected value of $6.50. If she is trying to maximize her expected yield, she would plant the high yield crop, which is different than what she would have done without the forecast. In this case, the forecast has a value of $1, which is the difference in expected value between what she would do with the forecast and what she would have done without the forecast. Finally, Figure 1.10D shows the case of a weaker, or lower skill, forecast of increased rains. In this case, the expected value of the high yield crop is just slightly higher than that of the drought tolerant crop, but is also riskier. A purely yield-maximizing farmer would plant the high yield crop, and the forecast would have a value of $0.10, the difference between $6.35 and $6.25. However, a risk averse farmer might be fearful of the possibility of earning no payoff at all, which could happen if she plants the high yield crop and the rains turn out to be light, predicted to happen with a 15% probability. She may decide to forego the extra $0.10 in expected value associated with high yield crop in order to guarantee a payoff of at least $5.00, by planting the drought tolerant crop. If this is what



A. Climatology **B. Forecast of decreased rains**



C. Strong forecast of increased rains **D. Weak forecast of increased rains**

Figure 1.10—Decision Trees and the Value of Information. Each picture shows a decision-tree resulting from a different climate forecast. The payoffs for each choice—planting a high yield or a drought tolerant crop—remain the same for each quantity of rainfall, but the relative likelihoods of different rainfall quantities vary from year to year, and are described by the forecast. The forecast has value to the farmer if it induces the farmer to make a different decision from the baseline decision under conditions of climatology. Under the conditions of the simple example shown here, this does not occur when the forecast is of decreased rains, but might occur when the forecast is of increased rains. In the final case, D, it is necessary to know the farmer's level of risk aversion in order to determine whether the forecast has value.

she does, then the forecast would have no value to her. Across many years, the value of the forecast is the weighted average of the values it has in the different years.

The last case, Figure 1.10D, shows that the value of the forecast can depend on factors other than expected payoffs. Different farmers may have very different risk attitudes, for very good reasons. One farmer, who has stockpiled food or has other assets that she can sell, may be willing to take the risk associated with the high yield crop. Another farmer, with no food stockpiles or other assets to sell, may decide that planting the high yield crop is a risk he cannot afford to take if he is to be certain to feed his family.

Research approaches

The fastest way to predict whether people will use a forecast, and how much value they will receive from it, is through modeling. One starts with a production model of the sector in concern, such as a crop model for the agricultural sector, and examines both the sensitivity of production to climate variability, and the management options that can be employed. Such modeling efforts can offer important insights. In the case depicted by Figure 1.10, for example, a model would show that farmers, even risk neutral farmers, would plant drought tolerant crops as their baseline choice, and hence the only forecasts that could potentially offer value are those showing an increased likelihood of normal to above normal rainfall. But the figure also shows how difficult it can be to make finer order predictions, distinguishing which among those potentially valuable forecasts actual add value for any given farmer. In order to do so, one has to identify the different climate-sensitive decisions that can be made in a particular sector, the outcomes each of those decisions under the range of possible climatic conditions, how a forecast modifies the distribution of those climatic conditions, and objectives of the individual decision-maker. The objectives of the decision-maker can be the most difficult to ascertain, because it may involve not only maximizing economic output, but also minimizing risk or effort, and other factors that may be even harder to identify. For example, farmers may want to minimize their travel distance to purchase seeds, and this could be important if the closer seed stores have a limited selection of seeds, compared to larger stores further away, restricting their set of choice options.

Another important factor is whether farmers completely trust the forecasts. The case represented in Figure 1.10D, for example, was one where the forecast indicated no chance at all of light rains, and because of this, risk aversion did not matter (since there was no chance at all of the high yield crop failing). A farmer might not completely trust such a forecast, and may decide to plant the drought tolerant crop anyway, in order to minimize risk, just in case the forecast is wrong. Because of different risk preferences and other user-specific factors, combined with a lack of data in Africa about these factors, it may not be possible to predict forecast use or value through modeling studies alone, but may require field observation of how real actors, facing real risks, decide to use the information. But because of the need to collect data from users over multiple years, this second means of identifying forecast value is far more time consuming and expensive. However, except in the simplest and clearest of decision-making contexts, it is the only reliable way to identify finer details of forecast value and use.

Application approaches

The example above also illustrates an important issue in forecast application: what exactly the forecasters should tell the users. There are three possible approaches. The first of these is to deliver only the basic forecast information, and to let the user decide how best to make use of it. This has been labeled the “loading dock” approach: like a truck or train delivering a shipment, the forecaster drops the information off on the loading dock, and from there it is the user’s property and the user’s responsibility (Cash et al., 2006). The loading dock approach counts on the user to understand what to do with the information. The second approach is for the forecaster, or an analyst within the same organization or collaborative institution, to analyze the information, and to advise the user what decisions to make. For example, the forecaster might advise farmers to plant drought tolerant crops in one year, and high yield crops in another. Compared to the loading dock approach, the advisory approach requires greater time and effort on the part of the forecaster—since it will be necessary to analyze the information, incorporating it into a user-specific production model to identify optimal decisions—but may lead to dramatic increases in the extent to which the information is used. The third approach is in between the other two: the users assume responsibility for deciding what decisions are appropriate given the information, but the forecaster assumes the responsibility of giving the user the capacity to make such decisions. This necessitates some sort of participatory dialogue between forecasters and users, in which the forecaster guides the users through the process of incorporating the information into their decisions, which in turn requires users to make explicit their full set of objectives. This participatory approach, while lying between the loading dock and advisory approaches in terms of shared responsibility, is by far the most time consuming and expensive, since it requires forecasters to spend a lot of time interacting with different users, or groups of users.

Which approach is preferable? There is little question that the loading dock approach is the least effective (Cash et al., 2006). At the same time, the loading dock approach allows the forecasters to focus on their core area of expertise and to remain independent. By contrast, the advisory approach requires forecasting organizations to build their own capacity in modeling users’ production systems, while the participatory approach would require them to engage in partnerships with users (Cash and Buizer, 2005). There is considerable debate, however, about whether the advisory approach or the participatory approach is preferable. The advisory approach is an efficient way of informing users what they ought to do, as long as the analysis is insensitive to differences between users’ objectives and production models. The participatory approach, by contrast, is far more expensive and time consuming, and yet takes into account each user’s objectives and production model separately.

An additional factor to be considered is trust. There is evidence that the participatory approach is better at building and maintaining trust between forecasters and users, while the advisory approach may see that trust fall, especially when users suffer negative consequences as a result of following the advice, which is bound to happen some of the time (Lemos et al., 2000; Orlove and Tosteson, 1999). This can be especially so when users perceive that the forecasters do not have an economic or political incentive to give them the best possible advice (Patt et al., 2006). We believe that the participatory approach is the standard to which forecasting organizations should aspire. At the same time, it can be prohibitively expensive, and so given budgetary constraints, may not always be possible. It is necessary, on a sector-by-sector and case-by-case basis, to explore whether the benefits of the participatory approach justify the added costs, compared to the advisory approach.

2

Predicting seasonal climate in Africa

There are a number of different ways to make predictions of seasonal climate. None of these is foolproof, and often which method is appropriate depends on what climate variables (e.g. total precipitation, temperature) are being predicted, and the geographic region for which the prediction is being made. One concern is that methods that rely on historical observation to generate statistical models may be less appropriate today than they were in the past, because today's global climate is changing. Hence, the statistical relationships that existed in the past may no longer be the same in the present and future.

An important distinction must be made between weather prediction versus climate forecasting. Through weather prediction it is possible to say where, when, and how much rain will fall, as well as various other statements, such as how warm it will be. It is only possible to be very accurate with weather forecasting for a few days into the future; the evolution of weather systems is very sensitive to small differences in initial conditions, and without data showing the exact value of key parameters at every point in space, all specifications of starting conditions will have some degree of error. Climate forecasting, by contrast, does not give any information about particular weather events, such as rainstorms. Rather, it is the practice of making statements about seasonally averaged parameters, such as cumulative rainfall. While the timing of rainfall will remain unknown, one can say whether slowly changing features of the climate-ocean system increase or decrease the propensity for heavy and frequent rainfall.

One of the most important of these features is is sea surface temperature (SST). The oceans change in temperature quite slowly, in part because of the water's high thermal mass, and it is often possible to predict whether SST will be above or below normal for a given location many months in advance. At the same time, SST has a large impact on the climate system, because of its constant interaction with the air above it, influencing both its temperature and relative humidity. That in turn often dictates the location of areas of high or low atmospheric pressure, which can in turn extend their influence to regions over land. Hence, by predicting SST months in advance, one can make statements about the propensity for different weather events to develop at particular times and places. This is the art of seasonal climate forecasting.

Statistical methods of climate prediction

The easiest type of prediction to understand relies on statistical models, which describe the observed relationships between different climate data. As a simple qualitative example, suppose that in most of the years when SST in the eastern tropical Pacific Ocean is high in August (i.e. there is an El Niño forming), rainfall over much of Southern Africa is below average the following summer, i.e. December – March. Based on this observed relationship, it would be then possible in late August of any given year to issue a forecast for Southern Africa for the coming summer, simply by noting whether SST in the tropical eastern Pacific Ocean were high or not. Such a forecast makes use of historical data to build a model, and then applies that model to the current year.

Fundamentally, this is exactly what climatologists do, but the statistical methods that they use are more complicated, and follow several successive stages.

- *Identify regions of covariation*. First, the modelers examine the historical record in their geographic area of concern (i.e., the country for which they are trying to make a prediction). They attempt to identify those geographic areas where deviations from historical averages follow similar patterns. In Mozambique, for example, the northern part of the country often experiences wet conditions in precisely those years when the southern part of the country experiences dry conditions, and vice versa, because of the effects of the ITCZ and how far south it progresses in the summer months. A similar situation is found in Nigeria, although this is related more to water temperatures in the Gulf of Guinea. In both countries, one would thus want to divide the area into the northern and southern parts. Exactly where the division should fall requires careful analysis of rainfall data from the monitoring stations, and can vary depending on the particular month or quarter (e.g. October – December, January – March) for which the forecast is being made.
- *Identify the predictor variables*. For each of the homogenous regions (e.g. northern Mozambique), it is necessary to identify which predictor variables have the greatest effect for which months of the year. For Mozambique, these likely include SST in the tropical eastern Pacific Ocean (the so-called Niño 3 or Niño 3.4 regions), as well particular regions of the Indian Ocean. For Nigeria, there may be some influence from the Pacific Ocean, but also a strong influence from the Atlantic Ocean. For each of these ocean regions, of course, data exists for each month of the year, and some added predictability can often be gained from including several months' data. Including too many predictor variables, however, reduces the level of confidence in the model results, and so it is important to identify which variables to leave out. It is also important to identify which predictor variables (e.g. Niño 3.4) can themselves be predicted several months in advance.
- *Establish a functional relationship between the predictor variables and the forecast region*. Using multivariate regression techniques, it is now possible to express the variable to be forecast as a mathematical function of the predictor variables. The simplest of the techniques predicts a quantity of rainfall for a particular place, as a linear function of the predictor variable values. A slightly more complicated technique predicts the likelihood that rainfall in a particular place will fall within a particular range, as a particular non-linear function of the predictor variables. An even more complicated

technique predicts the distribution, or probability density function (PDF), for rainfall, rather than either a point value or a probability, again as more complicated function of the predictor variables. These functional relationships constitute the statistical model.

- *Use the statistical model to forecast the current season*. Once the statistical relationships are established, it is then possible to make a prediction for the current year, by using the current year's data within the model.

Statistical forecasting requires access to a lot of data, both in the predictor regions and in the area to be forecast. Predictor region data, such as SST or the SOI, are collected by a network of ocean buoys, atmospheric measurement stations, and satellites, and are available from the countries that collect them, such as the United States, Europe, and Australia. More problematic in Africa are in-country monitoring data. While many African countries established extensive monitoring networks during the much of the 20th century, in order to support daily weather forecasting, economic difficulties in the region, not to mention civil wars, have led to the deterioration of these networks in recent years. There are fewer rainfall monitoring stations in many African countries now than there were 20 or 30 years ago. To some extent it is possible to use remotely sensed data (i.e. satellite observations of reflected light and radiation) as a proxy for on the ground measurement, but this adds to the complexity of developing sound statistical models. Ultimately, the lack of good historical data makes it more difficult to build a robust statistical model.

Data needs aside, statistical forecasting has advantages and disadvantages relative to the other methods of forecasting, in particular dynamic modeling. A distinct advantage is that the computing power required for statistical forecasting is modest. All desktop PCs can run the basic statistical software at sufficiently high speeds to be useful. A second advantage is that the level of training necessary to run these models is relatively modest. Statistical forecasting does require expert judgment, especially at the stage of deciding on homogenous regions of covariance, and identifying the right mix of predictor variables, since these choices entail some tradeoffs between apparent and actual forecast skill. Current capacity building efforts, such as the weeklong training sessions that take place each year in West, East, and Southern Africa, seek to provide the skill and judgment to run statistical models, and the national meteorological and hydrological services (NMHSs) within Africa currently engage in the process of issuing statistical forecasts, contributing to and sometimes duplicating statistical modeling taking place at the regional and global level.

There are two important disadvantages of statistical forecasting. The first relates to the fact that statistical models do not capture the actual dynamics of climate, or explain how it actually operates, and for this reason it is possible to develop a statistical model that does not capture conditions for the present year, if there is something highly unusual about the present year. The second is that the climate is changing, and this could disrupt the relationships between SST and African rainfall that have existed in the past. All the data in the world will not deliver an accurate forecast if the relationships between different places and times are now different than they were at the time that the data were collected, as result of intervening climate change.

Analog year forecasts

Closely related to statistical forecasts are analog year forecasts. These are often used to give people an indicator for climate variables for which statistical models have very little skill. For example, it has not been possible to issue a forecast of the date of onset of rains, or of dry spells within a rainy season. Yet these are very important pieces of information for farmers. What an analog year forecast can do is to identify some past years when the predictors of climate variation, such as El Niño and other SST, were similar to the current year. By looking at the variable of concern for these years, it may be possible to identify some qualitative trends or patterns. For example, it may appear that in these analog years the date of rainfall onset was quite erratic; that would tell a farmers to prepare for the possibility the rains will begin either very early of very late this coming year. There are statistical techniques to select the best possible analog years, or collections of years.

One organization that uses analog year forecasting predict rainfall is the Institute of Biometeorology in Florence, Italy (http://www.ibimet.cnr.it), preparing a forecast for the Sahel region of Africa. They use an algorithm that relies on SST and rate of change of SST in three locations (Niño 3, Gulf of Guinea, and the Indian Ocean), and which chooses the past year that minimizes the difference across these six variables from the present year. From that past year, then, they project a deviation from climatological means for the coming season, across the Sahel. They claim that this technique works quite well for the Sahel, although it is unclear exactly how it compares with more traditional statistical methods. One danger with analog year forecasting is that it is possible to read too much into what the analog years are saying.

Dynamical climate models

The most complicated means of forecasting seasonal climate is through the use of dynamical climate models. Dynamical models forecast the future not by starting with statistical relationships, but rather with an understanding of the basic physics that govern atmospheric and ocean processes. Hence, these models represent the actual dynamics of the ocean – atmosphere system, and attempt to predict how state variables will develop in the future. These models break up the world atmosphere and oceans into a 3 dimensional grid. Within each grid cell, a number of variables take into account relevant features, such as temperature, pressure, and humidity. The models progress in incremental time steps, with the state variables for each grid cell in one period influencing the state variables in that grid cell and its neighbors in the next period. If one can predict the occurrence of high and low pressure areas in the atmosphere, or some of the major forcing factors such as SST, then it is possible to make a general prediction about the likelihood of rain.

There are several variants of dynamical climate models, serving different purposes. Global climate models (GCMs) predict global trends over many years, and are used by the main modeling centers to predict the consequences of climate change. These operate on a fairly coarse spatial resolution, such as 200km grid cells. The current state of the art is to operate on a 30 minute time step for the atmosphere, and then couple the atmosphere and oceans once or twice daily. They also omit some of the more complicated features, such as cloud dynamics, that operate on much finer scales. Operational models that are used to predict several days into the future work on a finer spatial and temporal scales, and take into account more detailed physical relationships. In between are regional climate models, which operate over long time scales, but consider a smaller region of the globe on a relatively fine (e.g. 10 km) spatial scale. These are run in coordination with GCMs, in order to generate the boundary conditions for the region. Another way to generate a local picture is to run a GCM, but then use a statistical model to downscale to predict weather events at the sub-grid scale using established statistical relationships (Landman and Goddard, 2002). These use historically observed relationships to forecast local conditions based on the average properties of the larger grid cell. This is thought to be a robust method for making fine scale seasonal forecasting, although perhaps less valid for longer-term study, where even local statistical relationships may change.

Dynamical models are improving, for three reasons. First, scientists' understanding of the basic physical processes is improving, based on continuing geophysical research. This means that there is less uncertainty as to whether the model is an accurate representation of reality. Second, later generation models incorporate more interaction between different systems, which can often include important feedbacks. For example, early models contained no dynamical representation of the biosphere, even though evapo-transpiration from plants is determined by and is an important determinant of local climate. The most recent models do include such components, and can thus capture important feedbacks more accurately. Third, computing power is improving, and this means that models can be programmed at finer resolutions, capturing more physical relationships, and still generate results in an acceptable amount of time. The result of these improvements is that dynamical models are now beginning to outperform statistical models of seasonal climate over many parts of Africa.

Despite these changes, dynamic models are expensive to run, for two reasons. First, programming them is exceedingly time consuming, and requires a great deal of expertise. There are only a few modeling centers in the world that have developed full GCMs and the set of downscaled regional models that go with them. Second, dynamical models need to run on super computers, which are also very expensive. One mini super computer on the African continent, powerful enough to run a regional model, is at the IGAD Climate Prediction and Applications Centre (ICPAC) in Nairobi. ICPAC is currently running a regional climate model for the Greater Horn, the Regional Spectral Model. To obtain boundary conditions, they take the results from the ECHAM 4.5 model, which was developed at the Max Planck Institute in Hamburg, Germany, and which is being run for ICPAC on a super computer at the IRI. A second center of excellence in dynamical modeling is in Morocco.

The Climate Systems Analysis Group (CSAG) at the University of Cape Town (UCT) is another place in Africa where dynamical modeling is taking place. The UCT group is developing their own set of regional models for the southern Africa region, downscaled from GCMs using both statistical and dynamical methods, and the only group in Africa developing broad-based and tailored regional projections of climate change. The team has a 15-year track record in this field, has been intimately involved in methodological development, and currently produces and disseminates downscaled scenarios, based on the latest Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) data, to a broad range of users across Africa. Prof. Bruce Hewitson, who leads the CSAG, was the IPCC coordinating lead author for the regional projections chapter in the IPCC AR4.

Presentation of uncertainty

All seasonal forecasts are probabilistic, at best. What this means is that they can provide the likelihoods of a given place receiving rainfall within a given quantity range over a given period of time, but can never say exactly how much rain will fall. Some statistical models provide probabilistic information about rainfall as their primary output. Dynamical models present specific forecasts, but it is possible to obtain probabilistic information by

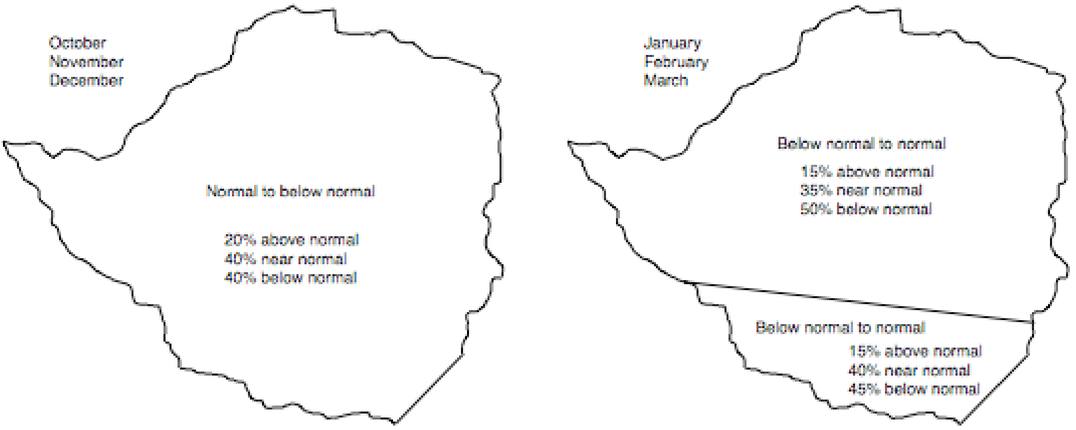


Figure 2.1—Tercile Forecasts. The two maps are each of Zimbabwe, and show the tercile forecasts for the first and second halves of the rainy season for 1997–98. This was a year with a strong El Niño, and hence a forecast of a high likelihood of below normal rainfall.

running an ensemble of models. This can mean running the same model over and over again, using different starting conditions within the range of uncertainty about those conditions, running several different models (which contain slightly different assumptions about the physical behavior of the system), or a combination of both.

Presenting this information in a form that people can understand it can be a challenge, for several reasons. First, many people have a difficult time understanding the concept of uncertainty and probability in the first place. Second, a given forecast may cover a region of covariation that is itself quite heterogeneous in terms of how much rainfall it actually receives. For example, the Eastern Highlands of Zimbabwe typically fall into one zone, meaning that the entire area tends to respond in similar ways to the basic climate drivers: if there is an El Niño, the whole Eastern Highlands area is typically drier than usual. But within the Eastern Highlands, there is a tremendous amount of heterogeneity in terms of how much rain actually falls. Along the mountainous ridge, many places usually receive in excess of 1,200 mm of rain in a year. A few kilometers to the west, in their wind shadow, communities may receive only 700 mm of rain. The important problem is how to represent a probabilistic forecast for an area that responds similarly to global climate drivers, and yet covers a wide range of climatic zones. The forecast makes a statement about the anomaly that is expected, but that anomaly must be viewed in relation to very different local mean values.

Tercile forecasts

The traditional answer to this problem within the seasonal forecasting community has been to develop tercile forecasts. A tercile forecast expresses the likelihood, in a given period of time, of rainfall that is above normal, near normal, or below normal for that period of time. Figure 2.1 shows a tercile forecast for Zimbabwe for the periods October-December 1997, and January – March 1998. In the first time period, all of Zimbabwe fell into a single zone, whereas in the second time period, the country was split into two zones. Inside each zone, the numbers express the probabilities of each tercile, and summarized qualitatively by expressions such as “Below normal to normal.”

One obvious question is what each tercile, such as “near normal,” means. The answer is quite simple. For any given place where there is a weather monitoring station, climatologists look at the last 30 years of rainfall data, aggregated over the relevant time period (e.g. October – December). They then order those years, from lowest total rainfall to highest total rainfall, and divide them into three groups of ten years, finding the cutoff amounts of rainfall between the groups. For example, suppose that the ten driest years for a particular monitoring station all had rainfall during October – December below 185 mm, while the ten wettest years all had rainfall of more than 348 mm. For this monitoring station, then, “below normal” means rainfall that is less than 185 mm, “near normal” means rainfall between 185 and 348 mm, and “above normal” means rainfall in excess of 348 mm. If you had no information about the coming year, a reasonable conclusion would be that each of these rainfall ranges would be equally likely (since they have occurred with equal frequency in the past), and you would have to issue a forecast of “climatology.” That means there is a 33% chance of each category occurring. If you know more about the coming year, from a climate model, you can issue a forecast that is somewhat different, and has higher probabilities for one or more of the three categories, and lower probabilities for the others, such that the three numbers still add up to 100%. A single forecast may cover a wide geographical area, and so it is important to take into account the fact that in each community there may a different set of ranges for “below normal”, “near normal”, and “above normal”, even if the probabilities of those different ranges are the same in the entire forecast area.

Tercile forecasts are attractive because they convey a good amount of information over a wide geographical area. To interpret what they mean for actual rainfall amounts, however, one has to have access to historical rainfall data. In theory an agricultural extension service office ought to have such data; they would be able to translate the forecast into likelihoods of specific rainfall quantities for their local area. This is the information that would be useful to local decision-makers. Communicating a tercile forecast directly to a farmer, by contrast, may be less useful. The farmer may not understand what the terciles represent, and may not have an accurate picture of the actual historical distribution of rainfall in her community.

Methods relying on probability density functions

A second means of representing uncertainty, which promises to be more useful, ties more closely to actual probability density functions, and closely related to that, cumulative density functions. Figure 2.2 illustrates how this might work, for a hypothetical location. The upper graph shows the probability density function, with the blue curve representing historical data, and the red curve representing a probabilistic forecast for the coming season. Note that the blue curve captures the relative frequency of different quantities of total rainfall that has fallen in the past, while the red curve shows the relative likelihoods that are predicted. The fact that the red curve is to the left of the blue curve indicates that this coming year is likely to be on the dry side. Indeed, the blue curve has a mean (and median) of about 500 mm of rainfall, while the red curve has a mean of a little less than 400 mm. The lower graph translates these same hypothetical data into cumulative density functions. For the blue curve, this means 500 mm corresponds to the 0.50 probability level, indicating that half of the time this location receives less than 500 mm of rain.

The cumulative density functions are useful, because they allow one to answer specific questions. For example, suppose that a particular crop

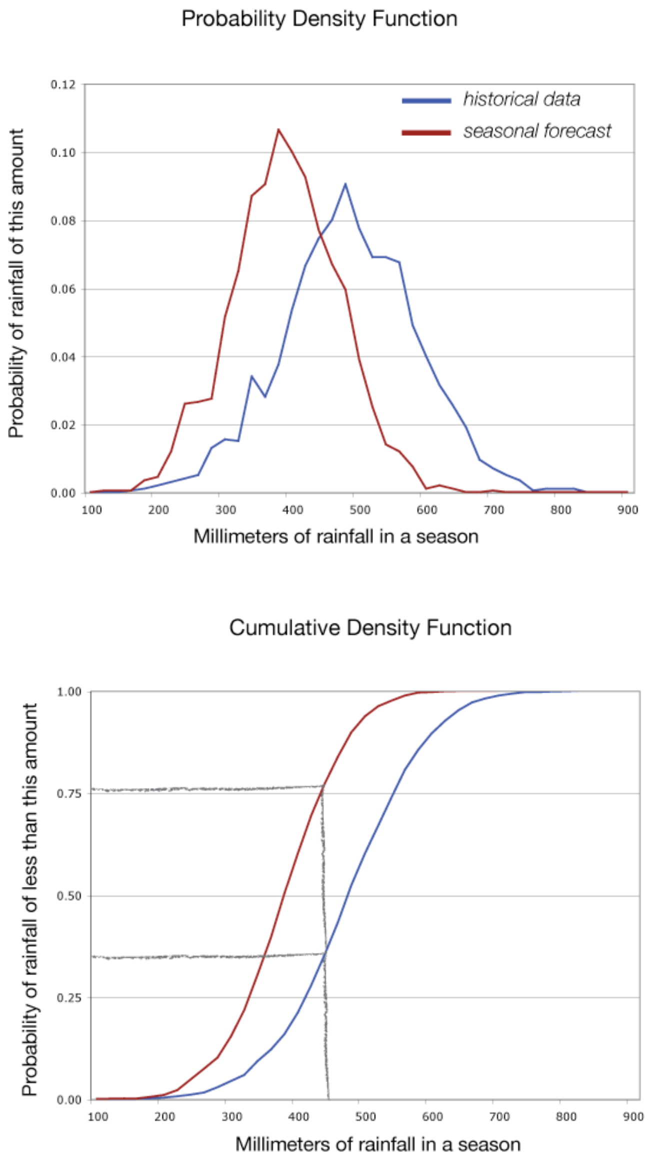
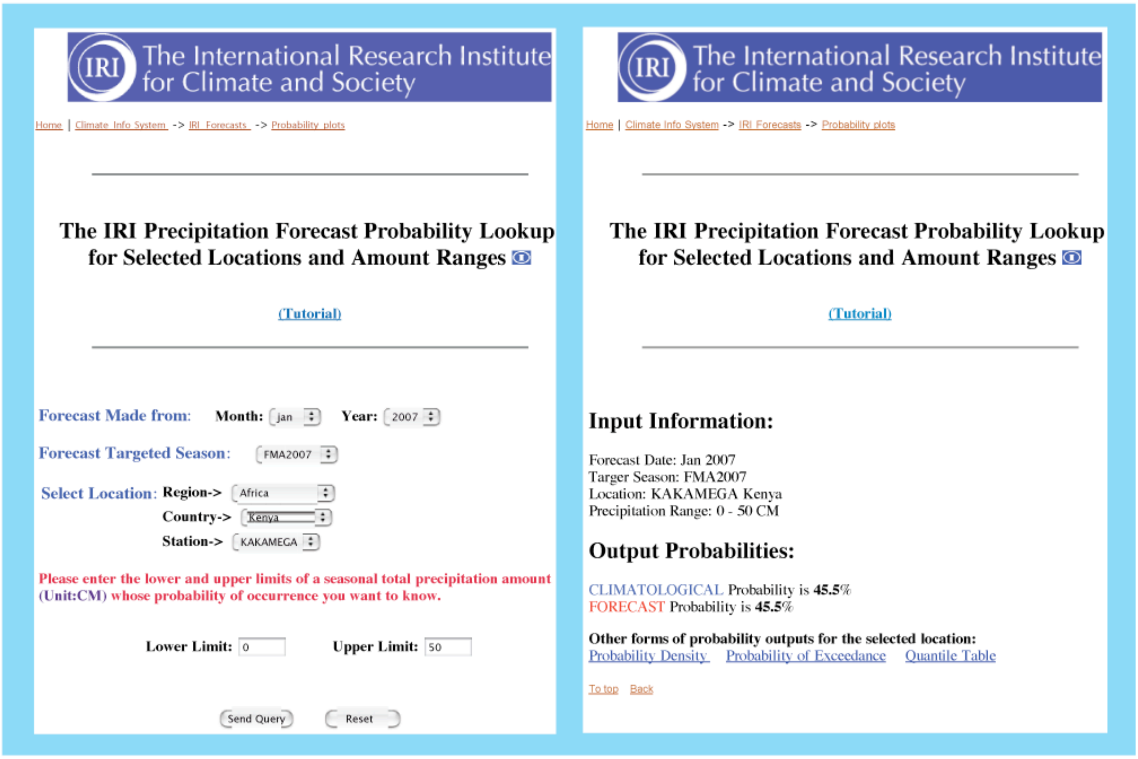


Figure 2.2—Rainfall Distributions. The upper graph shows a probability density function, or PDF, which shows the relative likelihood of rainfall within particular ranges. Given the seasonal forecast for light rains, the center of the distribution is shifted somewhat to the left. The lower graph shows a cumulative density function (CDF). In this case, the y-axis represents the probability of rainfall falling below some given quantity. Given historical data, there is a 35% chance that rainfall will be below 450 mm. Given this year's seasonal forecast, the probability is more like 75%.

requires 450 mm of rainfall in order to survive. An important question is thus: "What is the probability of rainfall less than 450 mm?" Because of where the grey pencil line intersects the blue curve, one can see that this location only failed to attain 450 mm of rainfall about 35% of the time in past years. By contrast, for the coming season, there is about a 75% chance that this region will receive less than 450 mm of rainfall. That certainly makes it less attractive to plant this particular crop!

Unlike tercile forecasts, the communication of probability density functions has to be very locally specific: it relies on having precise historical data for the specific location. There have been two different efforts to develop forecasting communication tools that make use of probability density functions. The first has been developed by the Famine Early Warning Systems Network (FEWS-NET), in coordination with the United States Geological Service and the University of California, Santa Barbara (FEWS-NET, 2003). Their FEWS-NET Agroclimatological Toolkit, or FACT, takes the tercile forecast for a region, and the historical CDF, as the two pieces of input data. It “warps” the historical CDF—shifting it left or right, and making it more or less vertical, in order to make it fit the tercile forecast for the coming season. From this new CDF, then, it is possible to answer the types of question illustrated above. The results of this effort are particular valuable, because they have gone an additional step of linking this model with a model to compute the Water Requirement Satisfaction Index (WRSI). The WRSI is an index developed by the Food and Agriculture Organization (FAO) of the United Nations, and is based not only on precipitation, but also variables such as soil type, rainy season duration, and potential evapotranspiration. The FACT model thus allows an agricultural user in a particular place to learn the probability that a particular crop will succeed or fail, based on a number of locally specific variables and the tercile forecast.

The second tool has been developed at the IRI, and is known as the Climate Prediction Tool


Input Screen

The IRI Precipitation Forecast Probability Lookup for Selected Locations and Amount Ranges

Forecast Made from: Month: jan Year: 2007

Forecast Targeted Season: FMA2007

Select Location: Region-> Africa
Country-> Kenya
Station-> KAKAMEGA

Please enter the lower and upper limits of a seasonal total precipitation amount (Unit:CM) whose probability of occurrence you want to know.

Lower Limit: 0 Upper Limit: 50

Output Screen

The IRI Precipitation Forecast Probability Lookup for Selected Locations and Amount Ranges

Input Information:

Forecast Date: Jan 2007
Targer Season: FMA2007
Location: KAKAMEGA Kenya
Precipitation Range: 0 - 50 CM

Output Probabilities:

CLIMATOLOGICAL Probability is **45.5%**
FORECAST Probability is **45.5%**

Other forms of probability outputs for the selected location:

Figure 2.3—The IRI’s Climate Prediction Tool (CPT). This is the user interface on the internet for the CPT. The input screen allows the user to specify the time and location for which the forecast is desired, the lower and upper limits for which a probability estimate is desired, and the time at which the forecast is made, i.e. the data that is available. This latter feature allows the user to validate the CPT by issuing forecasts for prior seasons. The output screen shows the probability of rainfall falling within the specified range according to climatological conditions, and according to the forecast made at the particular time.

(CPT). It is a software package that can be downloaded from the IRI's website at http://iri.columbia.edu/outreach/software. It was developed in order to address several shortfalls in current forecasting techniques, especially in Africa, only one of which is the reliance on tercile forecasts. The CPT allows the user to specify whether to rely on statistical models including relationships between SST and observed rainfall, or on dynamical models. For the GCM-based predictions, the CPT engages in statistical downscaling. The CPT then allows the user to ask specific questions, such as the probability that seasonal rainfall in a particular location will fall within a specified range. In addition to providing answers to these questions, the CPT provides measures of forecast skill. Perhaps most importantly, the CPT allows the user to generate a reliable forecast quickly. The time consuming part of forecasting is gathering data for the predictor variables; at the Climate Outlook Forums (COFs), this process can take several days. As with a similar effort that was made at ACMAD in 2003 to provide a standard data set of NMHS forecasters, the CPT prepackages data for the predictor variables, and allows the forecast to be made within a matter of hours. This would leave much more time available at these international meetings and workshops for interpreting the forecasts. While the full CPT can be downloaded and run on a Windows PC, there is a more limited version of it that is currently available online, at http://pred.ldeo.columbia.edu/forecast/poe/. The online tool allows the user to input the question in the form of a range of rainfall (in centimeters), a range of time over which the rain will fall, the time at which the forecast has been made. The left hand frame in Figure 2.3 shows this input screen. The tool then outputs the probability estimate, as seen in the right hand frame of Figure 2.3. At present, the online tool is only available for two stations in Kenya, eight stations in South Africa, and one in Tunisia.

Predicting seasonal climate variability and climate change

As already noted, climate change may be lessening the reliability of statically based forecasts. There are two additional reasons to be concerned about climate change in the context of considering climate variability. First, climate change is likely to be felt as an increase in climate variability, at least at some time scales. Second, efforts to help people and societies better to cope with climate variability, a key purpose in the application of climate information, may also be the most effective immediate action to help people adapt to longer term climate change.

First is the question of whether climate change will bring greater climate variability to Africa, which would in turn increase the value of seasonal climate forecasts and climate information in general, as well as those institutions and organizations that develop and disseminate forecasts. At interannual time scales the answer appears to be "maybe". The Intergovernmental Panel on Climate Change (IPCC) examined historical El Niño reconstructions, as seen in Figure 2.4. They noted that recent large El Niño events, such as those in 1982/83 and 1997/98, were outside the range of variability of the past few centuries. This could signify that ENSO is changing, and towards a state in which there are stronger El Niños, but the IPCC did not issue a firm conclusion on this (IPCC, 2001). The IPCC also summarizes research to suggest that the climate response in some places to El Niño and La Niña events could become more pronounced: "for tropical Pacific Ocean and Indian Ocean regions, anomalous wet areas could become wetter and anomalous dry areas become drier during future ENSO events" (IPCC, 2001, § 9.3.5.2). More recently, an ensem-

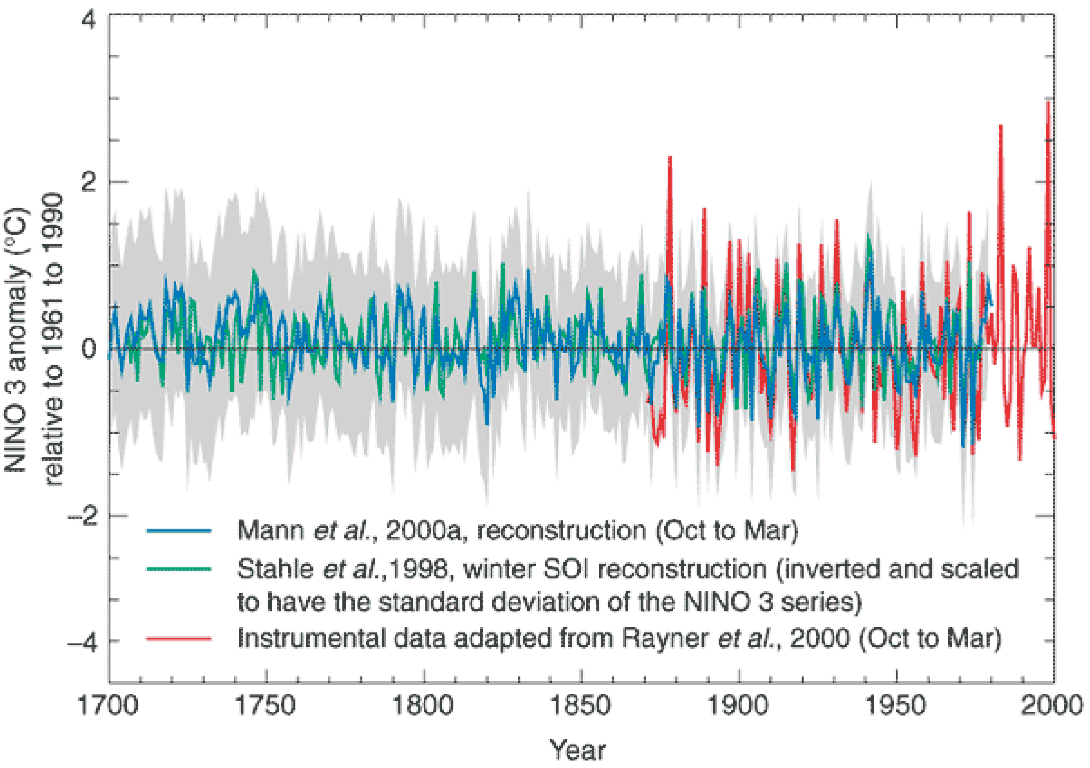


Figure 2.4—Niño 3 Proxy Record. This graph shows a longer time series of ENSO anomalies, making use of instrumental records (i.e. thermometers) and climate proxies, such as tree rings. One conclusion is that El Niño may be becoming more intense. Source: IPCC (2001)

ble of dynamical models has suggested that if there is a shift in ENSO, it is towards more El Niño-like conditions; again, however, the evidence for this is limited, and the range of uncertainty remains wide (Collins et al., 2005). A similar story emerges from examination of longer-term paleoclimatic evidence; at times when the earth was significantly warmer than it is today, El Niño was also more prevalent (Wara et al., 2005). At sub-annual time scales the answer appears somewhat clearer. Most dynamical models suggest that under warming conditions, precipitation patterns shift towards fewer but more intense rainfall events (IPCC, 2001). What this means for Africa is that there may be longer dry spells in between rainfalls, even if the overall amount of rain does not change significantly.

The second reason for concern about climate change is the question of whether adaptation to climate variability is useful for promoting adapting to climate change. Here, a growing number of researchers are arguing that the answer is “yes” (Klein, 2002), although to-date there has been little empirical research demonstrating this to be so. The basis for this belief is that the institutions that promote adaptation to climate variability are the very ones that will allow people to incorporate expectations of future climate conditions into their everyday decisions. Mainstreaming is mainstreaming, and there is crossover in value between time scales. Thus, even if the main concerns about climate change are in terms of changes in mean state, rather than variability, people’s efforts to cope with variability today will help them cope with mean state changes in the future. This increases the long-term payoff from current efforts to help the use of climate information, and thus provides an additional reason for investing resources in this direction.

Conclusions

The ability to predict seasonal climate over Africa has improved dramatically over the last 20 years. Much of this progress has gone hand in hand with two related efforts. The first of these has been the effort to model and predict ENSO, and this has been made possible by better SST data, in turn allowing for better statistical analysis The second has been the effort to develop projections and scenarios of longer-term climate change, which has spurred the development of GCMs. Stakeholder discussions suggest that there are five areas where more work is needed

- *Regional modeling*: Regional climate modeling is essential to capture the level of detail necessary to forecast weather and climate patterns at the scale that matters to stakeholders. The level of skill captured by GCMs rarely surpasses that of statistical models for most of Africa, and this is because their scale of spatial resolution is so low. The work that has gone into downscaling GCMs into regional models has been limited, arguably lagging behind efforts for North American and Europe. To improve forecasting skill, it is essential to engage in more development of regional models for Africa, through statistical and dynamical downscaling.
- *Integrated use of earth observation systems*: One of the biggest problems associated with predicting African climate, and the effects of climate on different sectors, is the lack of data. Both the density and reliability of weather monitoring stations across most of Africa is far lower than for industrialized countries. Civil wars and economic crises have led to years of missing data. Data is also fragmented. Many organizations maintain their own data sets, supplementing data measured by government organizations with private sources, and yet these data sets are not necessarily widely available. Given this, it is important to make full use of remotely sensed data to supplement ground-based measurement. Work is currently underway to bring multiple sets of satellite information, from different countries' space programs, together into a common database. Further work is also necessary to develop the means of analyzing remote sensing data to develop meaningful indicators.
- *Additional forecast products*. Until now, the most visible forecast product has been the maps showing tercile rainfall probabilities for three-month intervals. Forecasts are needed for more than monthly probabilities of rainfall patterns. For many users, it is important to know the date of the onset and cessation of the rainy season, and the likelihood of dry spells within the region. Temperature, humidity and wind can also be key climate parameters. More work is needed to develop forecast skill for these parameters, and to draw off of the skill that currently exists to develop and test forecasts now.
- *Verification*. It is essential to build trust in forecast products, and this does not happen unless there is consistent effort at verification. In any given year, a probabilistic forecast will often appear to have major errors: the pattern of actual rainfall rarely matches the most likely outcome in the forecast. In some years, the forecast may appear to be entirely wrong. It is essential to do the quantitative analysis over multiple years' data to identify whether the forecasts are in fact correctly stating spatial

and probabilistic distributions. In addition to building trust in the forecasts, verification is essential to answer fundamental questions about whether previously observed statistical relationships still are valid.

- *Communication of uncertainty*. Forecast users have specific problems they face, and the way that uncertainty is presented has to match their own type of decisions. For many years, most users have complained that tercile probability forecasts are difficult to interpret and use. While they are efficient ways of presenting information on a printed page, they fail to answer specific questions about actual rainfall quantities. Approaches such as that of the CPT are probably superior, and yet there has been little work at actually making these communication approaches operational.

3

Organizations and programs contributing to the application of climate information

The institutional and organizational landscape within which climate forecasting and weather data application takes place is complicated. Many of the organizations, such as the National Meteorological and Hydrological Services (NMHS's) within each country, were originally conceived as serving particular segments of society; in many countries, the primary beneficiary of the NMHS was the aviation sector. Coordinating the activities of NMHS's globally and through its regional offices is the World Meteorological Organization (WMO), and regionally within Africa three different organizations, based in Niger (ACMAD), Kenya (ICPAC), and Zimbabwe/Botswana (DMC). Supplementing these is a number of specialty forecasting agencies, and international partners.

World Meteorological Organization

The World Meteorological Organization (WMO) grew out of the International Meteorological Organization (IMO), and since 1951 has been a specialist agency of the United Nations (UN) focusing on meteorology and operational hydrology, operating within the UN Economic and Social Council. The WMO has 181 members, from Afghanistan to Zimbabwe. Based in Geneva, it is charged with fulfilling six purposes:

- To facilitate worldwide cooperation in the establishment of networks of stations for the making of meteorological observations as well as hydrological and other geophysical observations related to meteorology, and to promote the establishment and maintenance of centres charged with the provision of meteorological and related services;
- To promote the establishment and maintenance of systems for the rapid exchange of meteorological and related information;
- To promote standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics;
- To further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities;
- To promote activities in operational hydrology and to further close cooperation between Meteorological and Hydrological Services; and

- To encourage research and training in meteorology and, as appropriate, in related fields and to assist in coordinating the international aspects of such research and training (WMO, 2003, pp. 9 - 10).

As of 2004, the WMO had 244 permanent staff members, of whom 36 were African (WMO, 2005). The WMO operates on an annual budget of about $500 million, of which slightly more than half goes to support its eight scientific programmes (WMO, 2005). In 2004 it provided $20.5 million in technical assistance.

The second largest (in terms of operating budget) of the WMO's eight scientific programs is the World Climate Programme (WCP), overseen by the WMO's Commission for Climatology. The current director of the WCP is Dr. Buruhani Nyenzi. The WCP coordinates research around the globe to improve the basic understanding of the climate system, its variability, and its changes, and promotes the application of that knowledge to economic sectors. Within the WCP are three subprograms: the Agricultural Meteorology Programme, the World Climate Data and Monitoring Programme, and the World Climate Applications and Services Programme (WCASP). Within the WCASP is the Climate Information and Predictions Services (CLIPS) project.

The CLIPS project is of particular importance for Africa and seasonal climate forecasting, because its mission is to help member states develop operational products describing climate on a time scale of up to a few years, i.e. shorter than the time scale of long term climate change. CLIPS, working together with the World Bank, NOAA, the IRI, the European Commission, and the NMHS's, was a driving force for developing seasonal climate prediction in Africa. The first main product of this effort was the establishment of the Climate Outlook Forums (COFs), the first of which took place in 1997. Within each NMHS is an employee who serves as a CLIPS Focal Point. CLIPS then supports training programs for the Focal Points, as part of its capacity-building remit. The current Chief of CLIPS is Rupa Kumar Kolli.

Regional applications centers

Within Africa, there are three regional climate centers, each receiving some of their original support from the WMO, and playing an important role in coordinating and supporting the activities of NMHS in their respective region. All three of these centers are trying to address some of the problems that NMHS's and other national level ministries are facing. At the same time, the regional centers face their own challenges of obtaining adequate funding. This has been especially the case in Southern Africa.

Drought Monitoring Centre Harare

The Southern African Development Community (SADC) Drought Monitoring Centre Harare (DMCH) was conceived of during WMO sponsored meetings in 1983, and created, along with a sister center in Nairobi, in 1991. The original core funding came from the United Nations Development Programme (UNDP), with technical assistance from WMO in the form of 2 technical staff and 6 support staff. When the original funding ran out, the DMCH operated on a combination of UNDP stopgap funding and support from the government of Zimbabwe. In addition, the Zimbabwe NMHS lent technical support by seconding the two technical staff members. Beginning in 1997, funding came from the Belgian government, and negotiations began to turn the DMCH into a SADC institution. The DMCH currently operates with a staff of six people. Brad Garanganga has served as both the coordinator and the climate expert. There are three people conducting data entry and analysis, an administrative secretary, and a driver. The

DMCH also received visiting scientists sent from NMHSs.

The primary mission of the DMCH is to develop the regional capacity to use climate data, to develop operational forecasts to assist in early warning activities, and to coordinate the network of NMHS's in the SADC region, including assisting in the organization of workshops and training sessions, and maintaining a network of national focal points to assist in the sharing of data. Since 1997, the DMCH has worked to organize the annual SARCOF meetings, where it oversees the preparation of seasonal forecasts. The DMCH also issues ten-day (dekadal) bulletins throughout the year. The DMCH organizes a climate forecasting training session each year prior to the Southern African Regional Climate Outlook Forum (SARCOF), and in recent years has taken a leading role in coordinating a Malaria Outlook Forum.

The DMCH has in the past hosted pilot applications research, but the most recent of their reports is from 2002, reflecting a diminished capacity of the DMCH to engage in new activities and research projects, the malaria programme being a prominent exception. Primarily this is related to a lack of core funding coming from SADC and donor countries. The location of the DMCH in Harare, the capital of Zimbabwe, has been both an asset and a liability in this regard. It has been an asset because many of the regional early warning institutions, such as FEWS-NET and the Regional Remote Sensing System, are based in the Harare. More recently, however, there have been problems associated with the political and economic situation in Zimbabwe. There are currently sanctions in place against the Government of Zimbabwe, and this makes it difficult for donor organizations to provide support to the DMCH. At time of writing, the DMCH is in the process of moving from Harare to Gaborone, Botswana, and is also experiencing a change in staffing.

African Centre of Meteorological Applications for Development

The African Centre of Meteorological Applications for Development (ACMAD) is based in Niamey, Niger, and unlike the two sub-regional centers, has a remit to provide services to the entire African continent. The 53 African countries are thus member states of ACMAD. Like the DMCH, ACMAD became operational in 1992, having been created by the United Nations Economic Commission for Africa and the WMO. ACMAD operates with a limited core staff, most of whom are there on detachment from the NMHS's of member states.

The essential mission and functions of ACMAD are to:

- provide training in weather and climate for capacity-building in African meteorological institutions,
- serve as a center of information production for the implementation of policies for vulnerability reduction and adaptation to climate variability and change
- serve as a vehicle for knowledge transfer and exchange amongst sustainable development actors

For West, Central and North Africa where there are no sub-regional centers, ACMAD also plays the role of a sub-regional center. It organizes the PRESAO Forum (Previsions Saisonnieres pour l'Afrique de l'Ouest), the PRESAC forum for central Africa and PRESANOR for North Africa. These are equivalent to the COFs in East and Southern Africa.

ACMAD also has hosted pilot applications research and training activities, and continues to do so. At a global level, it is an active participant in two large research projects, THORPEX and AMMA, which are described in greater detail below. The French funded initiative RIPIECSA (Recherche Interdisciplinaire et Participative sur les Interactions entre les Ecosystemes, le Climat, et les Sociétés d'Afrique de l'Ouest) is to conduct interdisciplinary research on the interactions between ecosystems, climate, and society in West Africa. ACMAD has devoted considerable effort to implementing the RANET system in Niger. Perhaps most importantly, ACMAD has an active agenda conducting training programs for capacity-building for NMHSs. Since 2005-06, ACMAD has organized its On-the-Job training programme into 9 different training modules of 1 – 3 month duration.

ACMAD has been aggressive in pursuing funding options, and initiating new programs. Its resources are constituted by financial and human expertise contributions of its 53 Member States. ACMAD currently benefits from the synergy and assistance of the French cooperation, the UK Meteorological Office, the Instituto Nacional de Meteorologia of Spain, and the United States National Weather Service.

IGAD Climate Prediction and Applications Centre

The third regional center in Africa is the Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Centre (ICPAC), located in Nairobi and serving the East Africa / Greater Horn of Africa region. ICPAC was originally the DMC–Nairobi (DMCN), formed alongside the DMCH in the late 1980s by UNDP and WMO. Beginning in 1998, at the end of UNDP core funding, the DMCN and DMCH began operating independently. In 2003, DMCN was absorbed as an "autonomous specialized institution" of IGAD, and became ICPAC. With financial assistance from the United States Agency for International Development (USAID) Regional Economic Development Services Office for East and Southern Africa (REDSO), ICPAD developed its expanded mission and set of objectives. These go beyond those of the DMCH, in the direction of informing decision-makers concerning a variety of weather- and climate-related phenomena, instead of just droughts. Thus, ICPAC's current stated objectives are:

- To improve the technical capacity of producers and users of climatic information, in order to enhance the input to and use of climate monitoring and forecasting products;
- To develop an improved, proactive, timely, broad-based system of information and product dissemination and feedback, at both the sub-regional and national scales through national partners;
- To expand the knowledge base within the sub-region in order to facilitate informed decision making, through a clearer understanding of climatic and climate-related processes, enhanced research and development, and a well managed reference archive of data and information products (ICPAC, 2007).

IGAD itself is comprised of seven countries: Djibouti, Eritrea, Ethiopia, Kenya, Sudan, Somalia, and Uganda. ICPAC serves these, but also involves Rwanda, Burundi, and Tanzania in its activities. As with DMCH and ACMAD, a major activity of ICPAC is organizing the COFs. Because of the bimodal pattern of rainfall in East Africa, ICPAC organizes two Greater Horn of Africa COFs (GHACOFs) per year, one in September preceding the October – December rainy season, and one on March preceding the May – June rainy season. Also, like ACMAD and DMCH, ICPAC coordinates training sessions.

Of the three regional centers, it is fair to say that ICPAC is currently playing the most dynamic role. There are several reasons for this. First, it appears possible to predict seasonal climate in East African region (at least the October – December rainy season) with a higher degree of skill than in either Southern Africa or West Africa. As a result of more skillful predictions, which are greater departures from climatology, there may be a higher likelihood of economic value in the seasonal forecasts, and a more engaged user community. Second, ICPAC benefits from close linkages with the University of Nairobi—outside of South Africa, home of the continent's one Department of Meteorology—and the WMO regional office. The Director of ICPAC, Prof. Laban Ogallo, is Chair of the department of Meteorology at the University of Nairobi, and there is a constant flow of talent between the two organizations. ICPAC shares its building with the WMO regional office, which helps to establish close linkages between ICPAC and the international community. Third, the director of ICPAC, Prof. Ogallo, is an exceptionally good leader, who has consistently pursued international partnerships, and innovative areas of research. For all of these reasons, ICPAC is a beehive of activity. They have recently acquired their first super-computer, and are developing the capacity to run a regional dynamical prediction model. They are currently engaged in a review of their key organization mission and set of strategies, and should emerge from this review even stronger.

National level organizations

National level organizations throughout Africa, in particular the NMHS's, play an instrumental role in the process of climate information application. The NMHS's are usually located within ministries of commerce or transportation, reflecting their historical and still important role in providing weather forecasts to aid air traffic and trade routes. They maintain the weather and climate data monitoring stations within each country, develop and downscale forecasts on daily, dekadal (ten-day), and seasonal timescales, and communicate those forecasts to users, which means other government ministries, and the general public.

Cataloguing the specific capacities of each county's NMHS is beyond the scope of this report. Many studies have suggested, however, that the NMHS's in Africa are under-funded and poorly equipped to do their job. As the WMO reports:

> *Many African National Meteorological and Hydrological Services (NMHS's) in Africa suffer from limited economic, technical and scientific resources, which, often, do not enable them to manage good, useful and usable historical databases, to develop their own numerical models, to set up relevant and dense enough observational networks, to recruit and train people, and even sometimes to access forecast data supplied by other African or foreign centres (Roehrig, 2006, p. 10).*

Problems aside, however, the NMHS's have been active in helping to develop seasonal climate forecasting products. They send representatives to the COFs in each of the three regions, and typically receive the seasonal forecast from the COF, and broadcast it within their own country. The receivers of their forecasts are then the general public, through the media, and other government ministries, usually by direct interaction.

A variety of ministries then make use of forecasts nationally, in particular agriculture, energy, and health. Each of these ministries, however, often faces the same type of budget constraints found within the NMHSs, and there have been criticisms of the degree to which they have been able to take the information supplied to them from the NMHS and make it useful for end users, such as farmers, dam managers, and local malaria control workers. Better linkages are necessary between these ministries and the NMHS; the fault may lie not with funding limitations, but rather with the fact that the NMHS people and the ministry people speak very different technical languages, and are simply not used to cooperating (IRI, 2006).

Climate Outlook Forums

Much of the work of the three regional centers concentrates around the annual or bi-annual Climate Outlook Forums (COFs). The idea for the COFs traced back to the mid-1990s, as a vehicle for developing a consensus forecast for each region. It was hoped that such a forecast would avoid much of the confusion on the part of users that had existed up until that point, as they were confronted with a number of different, often conflicting forecasts. For example, commercial farmers in Zimbabwe had become accustomed to reading the on-line forecast issued by a climatologist at the University of Zululand, in South Africa, a forecast that had at times disagreed substantially with the forecast prepared by the Zimbabwe NMHS (Patt, 2006). The COF was designed to change that by producing an authoritative forecast for the region, based on input from the NMHSs and an international team of climatologists. At the same time, the COF would be a forum for exploring the uses and implications of the forecast with a variety of users, including ministries of agriculture, public health, and water resources, as well as early warning organizations. Planning for the first COF, the Southern African Regional Climate Outlook Forum (SARCOF) took place at a workshop in Victoria Falls, Zimbabwe, in October 1996 (Stewart et al., 1996). SARCOF 1 was held in September, 1997, in Kadoma, Zimbabwe. A meeting devoted to issuing a mid-season correction took place the following December, and a third devoted to evaluation of the first year's results was held in mid-1998.

Since then, COFs have been held each August or September in Southern Africa, each May in West Africa, and bi-annually (September and March) in East Africa, where the rainfall pattern is bimodal. An additional meeting takes place in central Africa, as a follow up to the West African COF. Originally, a significant period of time within the COF was devoted to negotiating the regional forecast from the national forecasts prepared by each NMHS. Now, agreement on the regional forecast takes place behind the scenes, and the duration of the COFs has shrunk accordingly, from five days in the late 1990s, to two or three days now.

Preceding each COF are a series of capacity building events, usually lasting a week or more. At the core of these is a set of sessions to help representatives from each participating NMHS to prepare a statistically derived national seasonal forecast. There are currently informal discussions occurring about whether this training session could be better devoted to using a more automated forecasting system, such as the IRI's CPT or a similar system developed at MéteoFrance and tested at the West African COF at ACMAD, combined with more advanced topical training, such as downscaling, applications, and communication. Other training events also take place, especially preceding the East and West African COFs, on issues such as economic modeling of forecast benefits, and specific sectoral applications of forecasts.

Major forecasting and modeling centers

There are several major modeling and forecasting centers that provide data, which NMHSs and other decision-makers in Africa often access. We briefly describe who these are, and what products they offer.

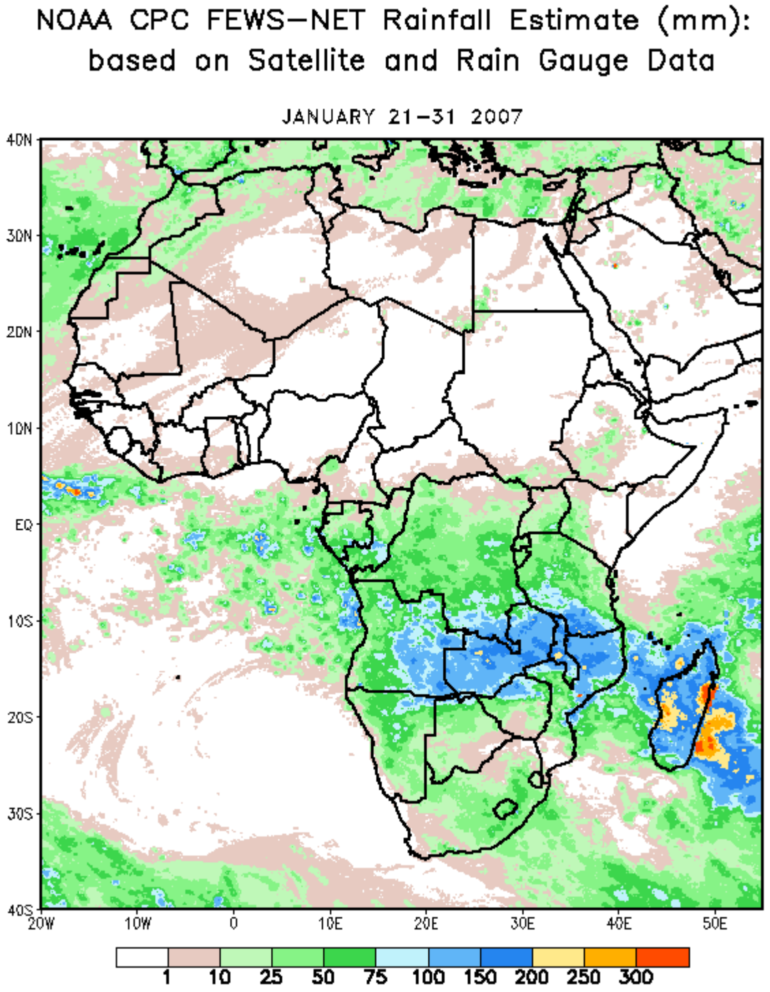


Figure 3.1—NOAA / NCEP online rainfall summary for Africa, for the previous week. Source: NOAA

United States

The United States National Oceanic Administration (NOAA) is part of the Department of Commerce, and manages the National Weather Service, the United States' NMHS. The National Centers for Environmental Prediction (NCEP) are an arm of the National Weather Service, and is the starting point for weather prediction within the United States. It is made up of nine centers, each of which serves a different prediction mission, such as the Aviation Weather Center, the Ocean Prediction Center, and the Storm Prediction Center. One of these is the Climate Prediction Center (CPC), which monitors and forecasts climate conditions over a range of time-scales.

The CPC maintains a public online database that is especially useful, in the form of a set of climate data and maps for the entire world. The CPC maintains a special African Desk, which aims to develop partnerships with African NMHSs, and produces precipitation maps, as well ones showing weekly SST anomalies. It issues seasonal forecasts, and the dekadal forecasts that are used by FEWS-NET (described below). The CPC has a new demonstration project, with which they forecast severe weather events for Southern Africa.

Their products can all be accessed online. For example, Figure 3.1 shows an online map estimating rainfall across Africa, which was accessed seven days after the period depicted.

The International Research Institute for Climate and Society (IRI) was created with core funding from NOAA in the mid-1990s. The IRI's mission is "to enhance society's capability to understand, anticipate and manage the impacts of seasonal climate fluctuations, in order to improve human welfare and the environment, especially in developing countries" (IRI, 2007). Probably more than any other institute, the IRI is engaged not only in developing useful forecasting products, but also in conducting the basic and applied scientific research on how best to make those forecasts relevant for decision-makers. Of greatest benefit to end users and the NMHSs in Africa is the IRI's set of forecast products. These include seasonal forecasts, probabilistic ENSO forecasts, and the CPT forecasts described earlier. There are also some novel applications-oriented forecasts, such as the beginnings of a Malaria early warning system.

USAID awarded the Texas A&M University system funding in the 1990's to develop a livestock early warning system for East Africa. This represented a collaborative effort between United States and East African scientists. They successfully integrated remote sensing indicators, crop, grazing, and market models into a geographical information system (GIS) framework, to be able to publish up-to-date maps on the internet of predicted forage sufficiency and market conditions. This has led to the Livestock Information Network and Knowledge System (LINKS), now run out of the University of California, Davis, which has further developed a set of decision-support tools for livestock management in East Africa. In the last several years there has been endorsement of their products within the East Africa region.

NOAA also has contributed to the development and operation of the Radio and Internet (RANET) program. RANET is a system whereby detailed climate information, including downscaled forecasts and other important operational alerts, are broadcast via satellite to African countries. It is possible for community radio stations to link to this satellite via a simple antenna, plugging into a desktop computer. The computer automatically and continuously downloads the data files from the satellite, some of which are quite large. At any time, the computer operator can look at these data via an ordinary internet browser, and use the information to issue local advisories. The RANET system overcomes the lack of internet connectivity in rural Africa. RANET pilots have been operational in several countries throughout Africa.

Europe

Like NOAA and the IRI, European forecasting centers such as the UK Met Office (UKMO) and the European centre for Medium Range Forecasting (ECMWF) also provide publicly available forecasting products available online, with monthly updates. These European centers also engage in capacity building and training efforts.

The UK Met Office's Hadley Centre is one of the leading climate research centers in the world, and runs a variety of GCM and regional models on its group of supercomputers. Through cooperation with the Hadley Centre staff, it is possible to obtain historical data sets derived from a combination of observation and model results, as well as long-term future projections. Hadley Centre models can provide the boundary conditions for regional climate models being used for Africa. Climate modelers from the Hadley Centre and the rest of the UK Met Office have assisted in training and capacity building programs within Africa. Météo France, as with the UKMO, has lent a tremendous amount of capacity building and training support to Africa, particularly within West and Central Africa.

There are several European consortia involved in weather prediction. The European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) is the consortium that develops, launches, and receives data from the European weather monitoring satellites. The most recent of these satellites, Meteosat 9, is in geostationary orbit above the Gulf of Guinea, south of West Africa, being there, it can monitor conditions not only over Europe, but a great deal of Africa. The European Centre for Medium-Range Weather Forecasts (ECMWF) is based in Reading, England. It has existed since 1975, and has been producing operational medium-term (a week to ten days in advance) forecasts since 1979. It has a cooperative agreement with ACMAD to produce forecasts for the West African region. The ECMWF also produces seasonal forecasts for Africa based on ensembles of dynamical models, which are used in the development of consensus forecasts at the COFs. In coordination with the UKMO and Météo France, the ECMWF provides a monthly multi-model forecast, the Euro Sip.

Early warning and response organizations

There are a variety of organizations—non-governmental, UN-affiliated, and multilaterally funded—whose job it is to produce and use specialty forecast products. The United States Agency for International Development (USAID) launched the Famine Early Warning System (FEWS) in 1986, partly in response to the terrible famine that had hit Ethiopia in 1985, in which more than 1 million people died. FEWS' mission was "to lower the incidence of drought-induced famine by providing timely and accurate information regarding the potential famine conditions to decision makers" (FEWSNET, 2007). In 2000, FEWS transformed into the Famine Early Warning Systems Network (FEWS NET), it remains a US government funded program, but is now operated by USAID in cooperation with NOAA, the United States Geological Survey EROS Data Center, the National Aeronautics and Space Administration (NASA), and Chemonics International (a private contractor). Since the involvement of NASA and NOAA, FEWS NET relies to a great extent on the use of remote sensing data and data products, such as the normalized differential vegetation index (NDVI). The USGS EROS Data Center incorporates these data into GIS formats, making them useful for on-the-ground decision-making. Chemonics International operates the field offices in 22 African host countries.

FEWS NET provides monthly reports for each of the three regions of Africa (as well as for the Caribbean, Central America, and Central Asia). These reports summarize the food security situation in each of the countries in each region, presenting not only the results of satellite data monitoring, but also estimated yields and supplies of food on hand, local market conditions (including commodities prices), and government and NGO actions (such as emergency distribution programs). FEWS NET responds to some pre-season forecasts by issuing alerts. FEWS NET also provides a Weekly African Hazards Assessment bulletin, which is based on the previous week's observed weather and the predicted weather for the coming week.

Two of the three United Nations organizations based in Rome work on avoiding and responding to climate-related food insecurity. The World Food Programme (WFP) plays an important role in post-disaster recovery efforts. Their Vulnerability Assessment Mapping (VAM) unit is especially important in providing GIS data about growing conditions. The Food and Agriculture Organization (FAO) has a primary mission of ending hunger: "to make sure people have regular access to enough high-quality food to lead active, healthy lives" (FAO, 2007). FAO maintains a regional office in Accra, and a sub-regional office in Harare. FAO operates the Global Information and Early Warning System (GIEWS), which was set up in the 1970s, to provide information relevant to developing food emergencies to governments and relief organizations. While in many ways GIEWS does similar work to that of FEWS NET, being part of the UN system means that there is a greater emphasis on cooperation with other UN organizations, such as the High Commission for Refugees (UNHCR), the WMO, and the Children's Fund (UNICEF). While FEWS NET issues monthly bulletins, GIEWS has a number of separate publications that come out at different intervals: "Food Outlook" (5 times annually), "Foodcrops and Shortages" (5 times annually), "Food Supply Situation and Crop Prospects in Sub-Saharan Africa" (3 times annually), and the "Sahel Report" (monthly during the growing season). At the same time, GIEWS maintains databases, such as the Africa Real Time Environmental Monitoring Information System (ARTEMIS), which rely on remote sensing and other sources of data. GIEWS maintains a web portal, Geoweb, for Internet users to gain immediate access to databases and tools.

Nine countries of the West African Sahel (Chad, Niger, Mali, Burkina Faso, Mauritania, Senegal, Gambia, Guinea Bissau, and Cape Verde) are part of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS). A number of organizations, in addition to ACMAD, are also located in Niamey, and are members of the Plate-Forme des Institutions Regionales pour l'Environnement et la Météorologie (PIREM), through which they coordinate their activities. These include the Niger Basin Authority, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) regional office, the African School of Meteorology and Civil Aviation (EAMAC), and the AGRHYMET Regional Centre. The latter was created in 1974 as a location of analysis and technical expertise. The objective of AGRHYMET is to assist in food security efforts and natural resource management in the Sahel, through the provision of training and information provision, integrating climatology, hydrology, and agricultural sciences. It cooperates closely with FEWS NET, ACMAD, and other organizations already discussed. Its special expertise, complementing these other organizations, is in agricultural sciences.

World Health Organization

The World Health Organization (WHO) maintains a regional office for Southern Africa in Harare, which has become a center of excellence in efforts to control epidemic malaria. The WHO office has devoted a full-time staff member to this work, which is the beginning of establishing an operational Malaria Early Warning System (MEWS), to parallel the famine early warning systems such as FEWS NET and GIEWS. The regional office has cooperated closely with IRI, DMCH, NMHSs in the region, and ministries of health, to develop the Malaria Outlook Forum (MALOF). The first MALOF took place in 2004, and has now been repeated annually. WHO country representatives are especially active in Botswana and Madagascar, where collaborative agreements have already been signed between the ministries of health and the NMHSs.

Three departments within WHO—Communicable Disease Surveillance and Response (CSR), Protection of the Human Environment (PHE), and Roll Back Malaria—have teamed up to promote the development of early warning systems for tropical diseases, including malaria, using climate information (WHO, 2005). As part of this effort, they have entered into a partnership with the

WMO, the Climate Health Partnership. This is managed out of the WHO's Multi-Disease Monitoring Centre in Ouagadougou, Burkina Faso, and has led to a number of joint training activities and workshops.

Donor organizations

Several national donor organizations are involved in efforts to minimize the adverse effects of climate variability, and their activities are increasing. USAID has had a long commitment in this area, as evidence not only by its support of FEWS NET, but also it funding of specific projects, often relying on NOAA to select and oversee such work. Recently the UK Department for International Development (DFID) has become quite interested and involved in climate variability. DFID funded an analysis recently completed by IRI, which identified important gaps in the use of climate information in Africa (IRI, 2006). This has served as a starting point for a DFID commitment to fund projects in Africa to cope with climate variability. DFID and the International Development Research Centre (IDRC) based in Canada are funding a major climate change programme, Climate Change Adaptation in Africa, that aims at enhancing the capacity of Africans to carry out research to support adaptation that benefits the poorest segment of the society the most. Within DFID, the newly organized Disaster Risk Reduction (DRR) team has started to pay special attention to climate-related natural disasters, such as flood and famine; this could also signal an increased role of DFID in promoting the use of climate information. The German organization for technical cooperation (Gesellschaft für Technische Zusammenarbeit, or GTZ) has also funded some limited projects, such as the PRODER project in Mozambique, the purpose of which is to help farmers respond better to warnings of coming natural disasters, and to improve their livelihoods, through better use of climate information. There are many other examples of donor efforts to fund climate change adaptation efforts, many of which are connected with climate variability, too numerous to list here.

International research programs

The fields of climatology and meteorology have a history of benefiting from large, often international, research projects. These range from efforts primarily designed to improve the understanding of the climate system, such as the TOGA program, to efforts primarily aimed at sustainable development incorporating climate information (e.g. ClimDev), as well as several efforts incorporating both aspects (e.g. THORPEX).

TOGA

Much of what is now possible in terms of El Niño forecasting is a result of the Tropical Oceans and Global Atmosphere (TOGA) program, which ran from 1985 until 1994. NOAA's Office of Global Programs provided more than 50% of the funding to TOGA, but had partners across multiple United States federal agencies, and eighteen international partners. The TOGA program established an observation system of buoys across the tropical Pacific Ocean, funded a peer-reviewed grants program to make use of the data coming from those observations, and ultimately developed coupled ocean-atmosphere dynamical models that could make one-year ENSO predictions (NOAA, 1996).

AMMA

The African Monsoon Multidisciplinary Analyses (AMMA) project is of particular relevance for West Africa. The African monsoon is the progression of rains that occurs each year from the Gulf of Guinea into the Sahel. While the monsoon provided reliable and abundant rainfall during the 1950s and 1960s, there was a major drying trend over the period from the 1970s to 1990s. Associated with this trend were major droughts in the region, leading to widespread famine, along the southern edge of Saharan desert.

The French government initiated the AMMA project in 2002 to be able to understand what had caused this shift, and what could happen to the monsoon in the future. But in the process, AMMA has attempted to address the very lack of predictability of West African weather and climate in the first place: to do for the region what the TOGA project had done for the understanding of ENSO cycles and impacts. AMMA has augmented the existing network of monitoring stations throughout West Africa, has developed modeling capacity, and has established an international network of meteorologists working and meeting together. The AMMA project is now funded by the French, US, UK, and several African governments, and has received extensive additional funding from the European Union's Sixth Framework Programme. The AMMA project has taken on increased relevance for the United States, as growing understanding of the Atlantic basin has shown that climatic events in West Africa are instrumental in the processes leading to Atlantic hurricanes. A recent AMMA-affiliated research effort is a collaborative effort by French and US researchers to understand the genesis of hurricanes. It involves floating weather balloons from the ground in Niger, and dropping instrument packages over a wide area of West Africa and the Atlantic Ocean.

The AMMA project is highly relevant for developing the ability to predict seasonal climate in West Africa, and has led to a large community of climatologists having the funding to be able to study the West African climate in great detail, for the first time. ACMAD is heavily involved in the AMMA process, as Niamey, Niger is one of AMMA's main research locations. ACMAD has hosted AMMA meetings and AMMA sponsored training sessions.

THORPEX

Another important international research project is The Observing System Research and Predictability Experiment (THORPEX) project. It was established in 2003 as a ten-year research and development program, overseen by the WMO's Commission for Atmospheric Sciences. The goals of THORPEX are to improve the skill and usability of short-term forecasts (1 – 14 day) of extreme weather events, in order to help reduce the losses from weather-related natural disasters. As such, THORPEX is planned to be an important contributor to the UN's International Strategy for Disaster Reduction (ISDR) and the WMO's Natural Disaster Prevention and Mitigation Programme. Discussions with WMO staff indicate that THORPEX, despite its stated focus on short-term forecasts, is also examining the application of forecasts up to seasonal duration.

THORPEX has a strong African component, which is cooperating with all three African regional centers. The goals within Africa are to increase the understanding and predictability of high-impact weather events, improve the weather observing system in Africa, foster improved research about African weather, develop socio-economic applications, carry out demonstration projects, and build a bridge between weather predication and climate forecasting (Roehrig, 2006). THORPEX Africa had its first meeting in Ouagadougou in February 2007, and is currently revising its scientific and implementation plan in preparation for its second meeting, scheduled for November 2007. Work within THORPEX Africa is currently built around three working groups: Observing Systems / Data Assimilation and Observing Strategies (OS/DAS), Predictability and Dynamical Processes, and Societal and Economic Research and Applications (SERA). The SERA work will be the most relevant in the area of climate information applications.

AIACC

Assessments of Impacts and Adaptations to Climate Change (AIACC) is a global initiative developed in collaboration with the UNEP/WMO Intergovernmental Panel on Climate Change (IPCC) and funded by the Global Environment Facility, USAID, the Canadian International Development Agency, the United States Environmental Protection Agency, and the World Bank to advance scientific understanding of climate change vulnerabilities and adaptation options in developing countries. The project lasted between 2000 and 2007. The aim of AIACC was to enhance the scientific capacity of developing countries to assess climate change vulnerabilities and adaptations, and generate and communicate information useful for adaptation planning and action. The AIACC project launched 24 regional assessments of climate change vulnerability and adaptation in 2002, covering 46 countries in Africa, Asia, Latin America and Small Island States. Seventeen of the countries are in Africa. The project provided training, technical support and mentoring to the regional assessment teams. Nearly 300 scientists and students in developing countries, plus another 40 scientists from developed countries, participated in the AIACC regional assessments.

CCAA

The Climate Change Adaptation in Africa (CCAA) Programme, a joint initiative of Canada's International Development Research Centre (IDRC) and the United Kingdom's Department for International Development (DFID), aims to significantly improve the capacity of African people and organizations to adapt to climate change in ways that benefit the most vulnerable members of society.

This main goal can be dissected across four strategic objectives:

- To strengthen the capacity of African scientists, organizations, decision-makers and others to contribute to adaptation to climate change.
- To support adaptation by rural and urban people, particularly the most vulnerable, through action research.
- To generate a better shared understanding of the findings of scientists and research institutes on climate variability and change.
- To inform policy processes with good quality science-based knowledge.

Building on existing initiatives and past experience, the CCAA program is working to establish a self-sustaining, skilled body of expertise in Africa. CCAA seeks to promote African leadership in finding solutions to support both the science and practice of climate change adaptation. The programme is currently launching its first supported projects, while commissioning a number of scoping activities, and getting its first set of "core" capacity development activities underway. The programme is also working closely with existing initiatives to develop training and fellowship programmes that will help train a cadre of African experts whose skills in climate risk analysis can help build a critical mass of trained individuals, able to evaluate, analyze and assess adaptation relations, strategies and policies. Plans are also in development for efforts to support knowledge sharing within and beyond the CCAA program partnership base, to ensure research findings and program learning reach those who most stand to benefit from them. Efforts are being made to set up a viable community of practice that would share knowledge and experience to develop collective responses at national, regional and international level in the fight against climate change.

ClimDev Africa

The most recent large research program for Africa is Climate Information for Development Needs (ClimDev Africa), a program sponsored by the Global Climate Observation System (GCOS), the United Nations Economic Commission for Africa, and the African Union Commission. ClimDev Africa has its root in the G8 summit that took place in Glen Eagles, Scotland, in 2005, where the UK pledged to make development-oriented funds available to help Africa cope with climate change and climate variability. ClimDev Africa is currently a plan of action to make better use of climate information in order to achieve the Millennium Development Goals (MDGs). The plan of action was initiated at a meeting in Addis Adaba, Ethiopia, in April 2006, where the results of a “Gap Analysis” sponsored by the UK Department for International Development (DFID) and conducted by the IRI were considered. Following the April 2006 meeting, a steering committee set out a specific plan, in terms of initiating a call for proposals, which DFID would consider funding. The general plan is to fund three stages of work. The first stage, over three years, would be devoted to demonstration and planning projects, with a budget of $50 million. The second phase, over 3 – 5 years, would involve testing successful stage 1 projects up to a level consistent with achieving the MDGs, in selected countries. This would also involve a budget of %50 million. The third stage, over 3 – 5 years, would involve a continent wide implementation of the successful scaled-up projects. This would entail a budget of at least $100 million (GCOS, 2006). This plan was presented at the Eighth Summit of the African Union in Addis Adaba in January 2007, where it was officially endorsed (IISD, 2007). The results of this endorsement are still forthcoming, though it is expected that funding for projects will commence by or during 2008.

Challenges

Based on interactions with stakeholders, we believe that the most important challenge to overcome is in forging partnerships and collaborative agreements between the different agencies that are involved in the process of collecting, managing, analyzing, communicating, and using climate data. These partnerships need to serve four main goals:

- *Greater data availability*. As already mentioned in the previous section, African climate data is dispersed among a large number of organizations and agencies. Much of it is proprietary, especially as NMHSs have been forced to become cost-sustaining. This can hinder useful analysis and creative research. It is important that the users of climate information have access to all information that could benefit them, or at least to know what information exists. The three regional centers are working towards this, in coordination with the WMO and its partner institutions. These efforts need to be supported, both in terms of encouragement and in terms of financial support.
- *User-driven analysis*. As will become evident in the remainder of the report, effective use of seasonal climate forecasts and other climate information requires user-specific analysis. Most users lack the capacity to work with raw climate information, or general forecasts, and incorporate them into their decisions. To overcome this, it is necessary for scientists and users to work together, in a sustained fashion, to develop user specific models that make the best use of climate information. This is time consuming, hence expensive, and best occurs when there are formal agreements for cooperation laying out specific responsibilities, with adequate funding over a long enough period of time to iron out the inevitable first wrinkles.

- *Credibility and legitimacy of climate information*. There is a growing literature showing that the path by which information travels from scientists to users, and the nature of the organizations through which communication takes place, can have a great impact on whether users trust the information (credibility), and whether they see it as empowering, rather than disempowering, them (legitimacy) (Mitchell et al., 2007). One of the most important elements is that users receive information from organizations that are accountable to them, and not just to the scientific community or to foreign governments or donors (Cash and Buizer, 2005; Cash et al., 2003; Patt et al., 2006). Such organizations can often be ad-hoc groups specially charged with climate forecast analysis and communication, including users and information providers as equal partners (Cash et al., 2006).
- *Organizational learning*. Organizations learn differently than individuals. They take on information not simply by observation and by trial and error, but also by incorporating individuals and other organizations that have the requisite knowledge already (Simon, 1991; Social Learning Group, 2001). Partnerships are thus a vital part of this organizational and social learning process. Learning is, in turn, vital for making climate information more useful, as published examples from Ethiopia (Erkineh, 2007) and Mozambique demonstrate (Lucio et al., 2007), and which successful efforts in Mozambique to combat flooding in 2007 continue to demonstrate.

Achieving these four objectives takes leadership, financial commitment, willingness to share authority, and perseverance. The African regional centers are in a position to accomplish this, but in some cases their resources and their capacities are stretched. This is especially so in Southern Africa, where the DMC is in a state of transition.

4

Results from applications research: food security

There is a dense network of organizations in Africa working to avoid situations of food insecurity and hunger. While national governments traditionally had ministries that were charged with responding to crises after they had developed, these were often unable to prevent tremendous loss of life. Early warning organizations, founded in the 1970s in response to a series of famines in the Sahel and East Africa, had the mission of providing advance warning of crises, as they were developing, so that international assistance could be mobilized in time. Recognizing that famines develop as a result not just of inadequate harvests, but also a lack of entitlement to basic food requirements, early warning organizations monitor not just projected and actual harvests, but also economic indicators that determine whether people will be able to purchase enough food to avoid harm. Combining all of this information, it becomes possible to identify where people may neither be able to produce nor purchase the food they need.

Climate information—both monitoring and forecasting—can contribute to the ability to project where harvests will be insufficient to meet local food needs. The attempt to use climate information as part of early warning raises three critical questions suitable for scientific research:

- What types of climate information might add value to early warning?
- Given institutional and political constraints, does climate information actually add value?
- What type of institutional framework is best suited to using climate information for food security early warning?

There have been several studies and scholarly papers addressing each of these issues, which we now summarize.

What types of information could add value?

It is commonly assumed that climate information of a variety of types might potentially add value to early warning (Sutherland et al., 1999). These include rainfall monitoring from ground stations, remote sensing of climate related indexes (such as the Normalized Differential Vegetation Index, NDVI), monitoring to identify particular agriculture threats (such as locust swarms), and probabilistic forecasts of seasonal rainfall, as Dilley (2000) categorizes. We describe results for each in turn.

Monitoring and remote sensing data

Rainfall monitoring data has been traditionally strong throughout Africa, but interviews suggest a growing frustration with the decrease in the reliability and coverage, especially in countries experience civil strife or severe economic difficulties. To fill this gap, there has been research in the use of remote sensing data, and the extent to which it correlates with conditions of growing food insecurity. Brown and her co-authors have conducted a series of innovative studies.

The first of these established a correlation between food aid needs and remotely sensed information, in particular NDVI (Brown and Funk, 2006; Funk and Brown, 2006). The objective was to create a simple and effective method for quantifying the effects of current environmental conditions on future effects by examining the lagged relationship between rainfall and NDVI. The first step was to determine if NDVI had significant ability to predict food shortages. Using May through June NDVI readings in Ethiopia from 1981 to 2005 and FEWS NET estimates of people needing food from 1996 to 2004 the ability of NDVI to predict food aid needs was tested. NDVI values were able to explain 72% of the annual variance in food aid needs. It is clear from this result that NDVI has a strong potential for predicting food aid needs; however, in order to create a tool for policy makers there must be sufficient lag time on the prediction—therefore NDVI values must be predicted in advance. Utilizing remotely sensed information on precipitation, relative humidity, and current NDVI state, Brown and Funk were able to project NDVI up to four months in advance.

The second study established the link between remotely sensed data and specific challenges that farmers faced, which could lead to low aggregate production (Brown, 2006). She combined information gleaned from participatory rural appraisals (PRA) with remotely sensed data, analyzing one hundred PRA reports from Senegal and The Gambia in an effort to correlate the socioeconomic and natural resource management problems with environmental factors. Net primary production (NPP), the net difference between annual carbon dioxide uptake from the atmosphere through photosynthesis and that lost through respiration, was used to determine agro-ecological potential, while rainfall estimates were taken from NOAA's Africa Rainfall Estimate product. She used two techniques—multiple correspondence analysis (MCA) and averaging of environmental variables—to analyze the relationship between the environmental variables with the information derived from the PRA reports. MCA allows for a visual interpretation of the relationships between categorical variables in a scatter plot or map in order to determine relationship between variables. Averaging of environmental variables gives the average of communities with similar problems. Utilizing NPP as a predictor the MCA analysis found that bush fires, credit problems, and lack of veterinary services were associated with both high rainfall and highly productive/low variability environments. Reduced precipitation, lack of revenue, and plant and animal sickness are problems most closely associated with low levels of primary productivity. Problems relating more directly to agricultural processes—soil infertility, declining yields, increased migration, and diminishing groundwater—fall between medium and low NPP variables. Using rainfall as a predictor the MCA found that problems of education, labor, land scarcity, migration, and yields are associated with areas with low rainfall variability and areas with moderate rainfall. The problems of grain storage, insufficient labor, health and bad roads are associated with medium productivity and both low and high variability. This combination of remote sensing data and social science data creates more meaningful results, and also allows one to verify the use of PRAs as accurate tools. This concept can extend to the tailoring and scale-down efforts of seasonal forecasts. Regions with long-term reduction of rainfall, high inter-annual rainfall and vegetation variability, and large spatial and temporal variations in rainfall events can be identified and targeted for PRAs. Remotely sensed information can be transformed into information about causes and consequences, and ultimately aid in the communication and delivery of forecasts.

The third study attempted to predict volatile market prices—an important economic variable that early warning organizations need to track—using remotely sensed information (Brown et al., 2006). Growing season vegetation production is related to the price of grain at both the annual and seasonal time scales—erratic and sparse rainfall seasons result in higher market prices. The researchers analyzed monthly millet prices from 445 markets in Niger, Mali, and Burkina Faso, and used NDVI to indicate areas where food price and food stability coincide, creating a new tool for understanding the spatial dependence of market prices on production. They point to the utility of transforming spatially explicitly databases such as NDVI into tools for decision makers. Mapping out these databases brings attention to areas of high instability where forecasting efforts can be focused or may be potentially dangerous.

Seasonal forecasting

The belief that climate forecasting products could add value to early warning was a driving force behind the establishment of the COFs (Farmer, 1997). Presentations at COFs since then have suggested the potential value of forecasts for early warning, yet there has been little quantitative analysis. A study focusing on Zimbabwe did examine the potential to build forecast information into a risk-mapping framework in order to identify localized areas of growing food insecurity (Boudreau, 1997). The "Risk Map" software contains database on livelihood patterns of rural households, and predicts how given inputs (crop shortages, grazing, etc) effect given locations based on their known behaviors. An early warning system, in order to be effective, needs to indicate the likelihood of a problem, the severity of the problem, and the probable effects of the problem on different geographic areas and for different economic groups. Risk Map provides a way of accomplishing the latter. While climate scientists have highly organized models and institution for creating forecasts, there is little organization in specifying accompanying economic problems, or monitoring past problems. Yields and total production needs to be monitored based on local food economy zones and income groups, this information is critical for hindcasts, which inform forecasts by providing the parameters of realistic prediction in terms of food, cash and wild food crops as well as for forecasting consequences of particular problems. Influencing factors need to be monitored, such as labor constraints, area cultivated, seeds and tools, pest damage, timing of planting, and rainfall plans. Milk yields and livestock health should be monitored to determine weather other sources of food will be needed to compensate for losses. This project attempted to validate a modeling program, but brought to light the need to connect cause and effect when dealing with seasonal climate forecasts. This model had the capability of giving some direction when considering where to send food aid if a drought is impending. Such efforts could reduce bottlenecks in transportation, and ultimately reduce the costs of drought relief.

Given institutional and political constraints, is value there?

In a series of reports, Glantz and co-authors assessed with his co-authors the 1991-1992 drought in southern Africa, focusing on whether a credible, accurate, and readily available ENSO forecast would have changed the outcome, ultimately saving lives and money (Betsill et al., 1997; Betsill et al., 1998; Glantz et al., 1997). Countries in the region could have placed orders for grain imports earlier in 1991 and have obtained food supplies at a cheaper price. An earlier response would also have enabled governments to take advantage of cheaper transportation alternatives and avoid expensive transport bottlenecks. Zimbabwe could have reduced or halted its maize export program much earlier, using those supplies to increase its domestic reserves, saving approximately US $41 million. Although ENSO information, including a forecast, existed throughout most of 1991, few decision makers within the SADC region had access to this information. Few people were familiar with ENSO and its link to regional drought: only 20 individuals in Southern African, 8 of them in then isolated South Africa, directly received publications that included the ENSO bulletins. ENSO information did not play a significant role in the regional and national responses to the drought situation and the relatively slow build up of events does suggest that even an earlier credible and accurate ENSO drought forecast would not necessarily have altered the SADC region's precarious food supply position. The World Bank failed to include the probability of drought within the structural adjustment framework. In reality an earlier forecasts in 1991 would not have made a great deal of difference because potential users and uses of an ENSO forecast had not been identified in advance of the drought situation At the time of the drought, there was no formal structure or process in place for disseminating ENSO information. The authors conclude that the demonstration of an ENSO forecast's accuracy and reliability over time is crucial if forecasts are to be useful for decision makers.

Broad and Agrawala (2000) analyzed the case of the Ethiopian food crisis in 2000. By that point, climate forecasts were being used by the early warning community, and could have helped to avert the crisis. Indeed, the climate forecast that year predicted a high likelihood of drought, at a time when other indicators already suggested that the country was food insecure. The authors showed how a set of political factors led the necessary decision-makers not to head the forecast. On the one hand, the study suggests that more attention needs to be devoted to making the forecasts credible to decision-makers. On the other hand, the authors suggest that expectations about the use of forecasts for food security need to be tempered.

Clay (2005) reached a similar finding, studying the failure of early warning to prevent a famine in Niger five years later. He states: “Both government and donors, it seems, are unprepared to act on the warnings the systems deliver, until there are clear signs of distress amongst the population.” One should not expect too much from early warning. At the same time, he suggests that a greater willingness to trust the forecasts is necessary, and if that occurs, then they can begin to make more of difference.

There is hope for change. A case study of Ethiopia in 2002-03 reveals a very different outcome from what occurred in 2000 (Erkineh, 2007). By this point, the institutional framework in Ethiopia had changed, such that people were prepared to use the information. When, at a time when the country was already food insecure, a forecast suggested a high likelihood of drought due to ENSO cycles. Within weeks, an emergency response committee had begun to meet, and had developed a contingency plan. This then was followed with an appeal for international support, which in this case was forthcoming. Food was successfully brought into the country and distributed, and the effects of the drought that did occur were mitigated.

Institutional architecture

Marsland (2004) provided lessons from experience for managers and technicians concerned with food security and vulnerability information systems, particularly systems which involve several countries within a region. The history of regional early warning in Southern Africa indicates that a self–sustaining (i.e. fully government financed) regional food security system is possible. Integrating it into existing early warning systems may be difficult if those systems are already under strain. In order to avoid confusion and duplication at country level and encourage consistency at regional level, there is need for strong interagency collaboration. This may be best achieved by formation of a regional technical hub, in which methodologies can be agreed and consistent messages can be passed to agency country offices and national governments. Indeed, the formation of a regional multi-agency body, including and chaired by regional technical institutions, lends credibility to regional leadership and builds consensus amongst participating institutions. The Southern African experience demonstrated the need to move quickly when opportunities arise for influencing decision- making, particularly at the start of a food crisis. In 2001, results of a rapid assessment of food insecurity in Malawi gave an entry point to NGOs to lobby at the international level. The Regional Vulnerability Assessment Committee (RVAC) targeted a regional UN humanitarian conference as a key event to present the assessment findings. By making a strong presentation at the conference, the RVAC was able to promote the coordinating and facilitating of National level Vulnerability Assessment Committees (NVACs) in six countries. Those involved in development of information systems need to seize upon opportunities for partnerships with influential agencies. In Southern Africa, a partnership between WFP, the RVAC and DFID started because it appeared beneficial to all parties. The strong links formed between the RVAC and these two influential stakeholders was of enormous benefit to the development of food security and vulnerability information systems at national and regional levels.

Tefft et al. (2006) provide a synthesis of findings and recommendations from an assessment of early warning systems (EWS) in sub Saharan Africa. Most EWS use a food production model for monitoring, relying heavily on a national cereal balance. The most effective systems use an ensemble of methods based on a livelihoods orientation, allowing for a better understanding of the food and nutritional situation. The way that information is collected, analyzed, and disseminated is critical to the success of its use in decision-making. Participatory and transparent processes help actors to reach consensus on the food situation and facilitates prompt action. The institutional setting or home of an EWS has a major influence on its ability to carry out its mission. Several factors appear to exert a positive influence on system performance:

- positioning that is conducive to a reciprocal flow of information with the primary decision-making bodies involved in emergency actions and food security programming;
- administrative ease to access primary and secondary data from the decentralized offices and line ministries;
- managerial independence and analytical autonomy that allows EWS to independently carry out its mission with minimal bureaucratic obstruction or political interference;

- the ability to recruit and train a diverse group of food security analysts who can address the evolving nature of EWS work, particularly in terms of a multi-sector orientation; and
- the opportunity to procure sustainable sources of funding from the national budget.

A demand-based system should be initialized. Too many decisions are made on assumptions of what is needed rather than on a clear articulation of what users want and need. One core recommendation emerging from this assessment is that countries, regional organizations, development partners and the African Union focus their collaborative efforts on creating or strengthening institutional mechanisms that guide the development of the EWS and enable them to evolve in a dynamic and sustainable manner, responsive to their principal users. This synthesis also presents the core elements of an improved strategy for EWS that focuses on developing the mechanisms, institutions and national capacity needed for future work. The hallmarks of this improved strategy include national ownership and development partner commitment to a national process, partnerships for improved analysis, accountability and responsiveness to user needs, use of the most cost-effective methods, consensus-building in analysis of the food situation and appropriate response options, linkages to long-term development programming, strengthened national and regional capacity, and financial sustainability.

Conclusions

There has a great deal of enthusiasm towards the use of climate information in early warning, in order to prevent food emergencies. While there have been few quantitative studies, early modeling work suggested that the information could add value, when coordinated with other types of information, such as economic indicators. More recent statistical analyses suggest that other climate-related information, from remote sensing, could complement the use of ground based monitoring.

The evidence of how climate forecasts have helped avert food crises in practice are more mixed. In Zimbabwe in 1992, Ethiopia in 2000, and Niger in 2005, the presence of climate forecasts appears to have made little difference. The problem was the systems were not in place to use that information, and decision-makers were unwilling to act on it. But a case study of Ethiopia in 2002-03 shows how these factors can change. After the problems of 2000, the country developed the systems to put the information to use in a credible way, convincing international donors to take the necessary actions. Clearly, there is a learning process that appears to have occurred in Ethiopia. Ideally, counties can learn from the successes and failures that have already occurred, so that the benefits of forecasts to avert crisis can be realized more quickly in other countries in the future. Given that climate change may be leading to changes in regional food security (Adejuwon, 2006), learning from successes and failures needs to occur not just once, but on a repetitive basis. The literature on institutional architecture is encouraging, because it suggests that efforts underway at the regional level are headed in the right direction, although it is unclear whether this is duplicated in all cases at the national level.

5

Results from applications research: agriculture and livestock management

The use of climate information for agriculture poses a different set of challenges than for food security, because both the scale and timing of decision-making is quite different. Use of climate information to avoid food insecurity is primarily at the national and international level, in order to take steps to avoid a crisis situation as problems begin to arise. For this reason, a constant stream of information—from underlying economic conditions, to seasonal forecasts, to climate monitoring, to crop monitoring, to commodity price data—is needed in order to direct resources to where they are needed when they are needed. The emphasis needs to be on supplying this information to a relatively small set of policy-makers. Using climate information to improve harvests, by contrasts, requires a small wet of information, used by a larger number of people. Farmers need first to decide what crops to plant, a decision that must be made months before the rains begin to fall. For this reason, a seasonal climate forecast is likely to be the most important piece of information. There are other decisions, such exactly when to plant, apply fertilizer, and harvest, that depend on medium-term forecasts. Getting this information to farmers in a form that they understand and trust is itself a challenge. Applications research, for all of these reasons, has focused on a different set of issues in the area of agriculture, compared with food security.

- What are the effects of climate variability on harvests and incomes?
- What are farmers' information needs?
- How should forecasts be communicated to farmers?
- What contextual factors limit farmers' use of forecasts?
- What is the actual use of traditional forecasts, compared to modern forecasts?
- What are the economic benefits of farmers' using forecasts?

We summarize the results of research in each of these areas, and draw attention to questions that still remain.

Effects of predictable climate variability on harvests and incomes

That predictable climate variability has an effect on harvests has been recognized ever since the ability to predict that variability has increased. The first important result was to correlate maize yields in Zimbabwe with El Niño, recognizing that El Niño could be forecast (Cane et al., 1994). That study found that Pacific SST explained the majority of the variance in yields. Indeed, there was a closer correlation between SST and maize yields than between SST and actual rainfall, pointing to the fact that El Niño can affect the timing of rainfall (and thus yields), in addition to the overall quantities.

This latter point was highlighted in a second study of rainfall and maize yields in Zimbabwe and South Africa (Martin et al., 2000). Martin et al. used an agroclimatological model to create an historical record of maize water stress as a function of evapotranspiration. Annual water-stress time series were created and related to SOI and Niño 3 indexes. Correlations between water stress time series and ENSO were highest at a 4-month lead with respect to a May harvest. The results suggested that water stress forecasts relate more strongly to ENSO than seasonal rainfall alone, and the teleconnection is best captured by incorporating several climatological variables. The authors caution that the success in these models is highly dependent upon ENSO; changes in intensity may decrease forecasting skill. This paper is particularly interesting because it provides an example of a tailored forecast product, one that stays away from the probabilistic rainfall estimates. Of importance is their consideration of the many factors influencing evapotranspiration, most notably the changes in solar insolation that accompany rainfall events. The authors note that in some areas the limiting factors to successful harvests may be nutrient limitation. However, while this work finds strong statistical correlations between SST and water stress, it does not assess the use of this information by any end users.

A study by Phillips and McIntyre began to make this link, focusing on the implications of predictable variability for farm management in Uganda (Phillips and McIntyre, 2000). They addressed unimodal and bimodal rainfall modes (in the northern and southern parts of the country, respectively), comparing monthly mean rainfall records (1931-1960) for 33 stations in Uganda with Pacific sea surface temperature anomalies. In the bimodal zone El Niño events strengthen the November and December short season rainfall peaks. In La Niña years, maximum rainfall is shifted to August-October with a reduction in total precipitation. This suggests the early sowing of a short duration crop (beans) and a late sowing of late maturing grains in an El Niño year, and early sowing of grains in an La Niña year. In the unimodal zone, rainfall is depressed in August and continues into November during an El Niño year, providing a strong advantage for late-maturing varieties, whereas in a La Niña year the potential for a strong August maximum and a steep decline to January are enhanced. These results suggested that in order for local level decision makers to make use of seasonal ENSO forecasts they must be tailored down at least to the sub-regional scale. Often papers that make the broad suggestion that "forecasts must be tailored to end users specific needs" fail to provide any examples of what these needs may be or how to tailor a forecast. The strength in this paper is that it bases this call in the analysis of a country that has two distinct rainfall modes that are correlated differently to ENSO events. In the presence of El Niño, the management practices need to be modified in different ways in the two different zones. It should be noted that while giving farmers statements regarding potential planting strategies for the season eliminates the possibility of misinterpreting forecasts, it will be of limited effectiveness if it is not accompanied by a rationale for the decision. This paper provides clear rationale, and serves as an example of a potentially useful product that could be delivered to farmers.

Hansen and Indeje (2004) conducted a modeling study of maize yields in test sites in Kenya. Their goal was to examine whether downscaled dynamical models could generate forecasts that would accurately predict local rainfall and local yields. They used the ECHAM GCM, developed at the Max Plank Institute Hamburg, downscaled using a statistical technique, to generate predictions of monthly rainfall. They then used several different methods to predict yields, based on the prediction of monthly rainfall totals. Two of their methods were statistical: a non-linear regression, and a k-nearest neighbor approach based on analog years, using either one or two principal components. The final method was based on simulation, first of daily weather parameters, and then of crop yields. A stochastic weather generator—a modeling tool that would generate a possible pattern of daily rainfall, temperature, and sunshine—translated the downscaled GCM monthly predictions into the daily weather parameters that were the input into a crop model (the CERES Maize v. 3.5 model). They generated daily weather both with and without explicit consideration of the frequency and duration of rain events and dry spells. The crop model predicted yields, assuming other parameters such as fertilizer input, crop density, and soil type. They had three main findings. First, all of the methods were able to predict some measure—between 28 and 33%—of the variance in yields. Second, they found that the downscaled GCM better predicted rainfall than crop yield, unlike the findings of Cane et al. (1994). This was consistent with the findings of Phillips et al. (1998), discussed later, which explained this discrepancy by noting that local level yields correlate less well than national level yields with large scale climate phenomena such as ENSO. Third, they found that incorporating the predictability of the frequency and duration or rain events and dry spells did not improve their yield predictions. The study is one of the more technical modeling studies to have been undertaken in Africa, and is useful because it quantifies the extent to which climate prediction can predict yields at the local level. The study did not address how farmers themselves can use the forecast information, since it did not contain any decision-making model.

The Global Livestock Collaborative Research Support Program (GL-CRSP) based at the University of California Davis and the Texas A&M University, which has implemented the Global Livestock Early Warning System, has published a series of technical reports on the role of predictable seasonal climate variability on livestock management in East Africa. Kaitho et al. (2006) analyzed the accuracy of forage forecasts produced via the decision support tool developed as part of the Livestock Early Warning System. They found the 90 day forecast to have predicted 87% of the variance in observed forage quantities, the 60 day forecast to have predicted 92% of the variance, and the 30 day forecast to have predicted 97% of the variance. It is not clear from the study whether the same would hold for successive year forecasts for a single location, rather than a single forecast for a large number of locations representing a great deal of natural variance in forage quantities. Assuming the forecast to be a good predictor, however, the study makes clear that such a forage outlook could be used to develop an advance indication of market price data, and assist herders with their marketing strategies. Next, Ochieng et al. (2006) analyzed market prices for goats in three market locations in East Africa. They found that prices were correlated between the different locations, but responded to an evolving drought at different times. This suggests that herders could take advantage of predictions of market prices by moving their animals to different markets, in order to be able to sell them for a higher price. It is not clear what would happen, however, if all herders were to do so: whether this would affect the market price, and negate the benefits received of using the climate information.

What are farmers' information needs?

The need for information is tied closely to the decisions that such information can affect. Research on farmers' information needs has thus been grounded in the analysis of farmers' decisions (Ziervogel, 2004; Ziervogel and Calder, 2003).

Considering farmers' information needs has been an important element of many COFs, and implicit element of a large number of research projects going beyond this question, and the direct subject of only a few projects. UNDP (2000) conducted a project that focused on information needs in Ethiopia, Kenya, Mali, Mozambique, Senegal and Zimbabwe. Their aim was to improve farmer accessibility and use of climate forecasts involving a literature review, survey, and workshops aimed at identifying farmers needs for information. Their results showed that farmers rely mostly on geographically specific traditional indicators to make decisions on farm operations. The largest limitations to use of official forecasts were found to be: inaccessibility, timing, and poor reliability. It was recommended that research projects should be undertaken on the value of climate information in farmer decision-making as well as the integration of traditional indicators into official forecasts. The authors also suggested that further work be undertaken to create communication systems between end users and forecasts to provide feedback, as well as proper training for extension workers and farming communities on the use of forecasts (UNDP, 2000). This project presented a good consensus of data from multiple countries and underscores the issues of communication and the need for feedback mechanisms.

Mwinamo (2002) researched what kinds of information would be most useful to farmers by asking the farmers themselves. This project was designed to determine what meteorological information farmers in the Kwale district of Kenya require for successful farming and fishing activities, and aimed to determine the problems farmers encounter accessing this information. Researchers verbally questioned workshop participants on farming and meteorology. Farmers were either illiterate or only attained primary education. Climate information should therefore be translated into the local language, disseminated in community forums. Farmers asserted that they rely heavily on meteorological parameters to assist in fishing including wind, temperatures, sunny periods, and cloudiness. Preseason forecasts should be more detailed, and include information on onset, duration, mid-dry spell and cessation of the season. Many farmers rely on traditional methods of forecasting. Over 96% of the farmers were aware of traditional forecasts, 57% believed these forecasts to be "very accurate", while the remainder believed they were "fairly" accurate. Nevertheless, 67% reported that they believed the government forecast to be more reliable. To increase confidence in the modern forecast even more, they said here is need to increase the rainfall network in the district for the Kenya NMHS to effectively monitor conditions. The most valuable aspect of this paper is the suggestion of localized forums for dissemination of climate information translated into the local languages and explained in terms that relate specifically to farmers needs.

Archer (2003), working in southern Africa, presented problems relating to the dissemination and interpretation of climate information in the SADC region This paper discusses the application of climate information by the agricultural sector, using a targeted multi-stakeholder analysis to identify gaps and present recommendations. Stakeholders were interviewed assigning the extent to which the climate information system currently served the agricultural sector in their countries. All SADC countries asked that measure of intra-seasonal rainfall distribution be predicted. However, there needs to be more emphasis on tailoring climate forecasts to specific sectors together with the development of training workshops for extension officers; the forecasts are too general to be of use to the agricultural sector. Countries requested further parameters to be forecast, such as relative humidity and temperature. Angola, Botswana, Namibia, Swaziland and Zambia all described problems with their numbers of reporting meteorological stations. Ten of out eleven countries found communication as a key weakness. This paper is quite useful because it compares the stated needs of farmers, and those suggested by policy-makers. Importantly, the results suggest a close correspondence in needs: an accurate forecast, giving more than just rainfall total, communicated in a form that is useful.

There have been several studies of the ability to forecast the onset and cessation of the rainy season, and these demonstrate how little is known about this yet. In West Africa there have been attempts as far back as 1992 to forecast onset and cessation of rainfall (Omotosho, 1992), including methods for predicting the onset and cessation, and monthly and seasonal amounts of rainfall in the West African Sahel (Omotosho et al., 2000). The advantage of this methodology is that the data required are readily available at many stations in most countries. Looking at Tanzania, Mhita (2003) sought to identify trends in onset and cessation dates of rainy seasons and variability with respect to El Niño and La Niña phenomena. Rainfall and temperature data from 67 stations in the country were used, grouped into 10 homogeneous zones. These data were compared with SOI data from Bureau of Meteorology, Australia. There was a systematic and gradual temperature increase before onset of seasonal rains, by as much as 2°C. There is a temperature decay at the end of rainy season, dropping as much as 3°C. In general there is an inverse relationship between SOI and temperature and precipitation. Though March-April-May (MAM) rains are normally greater than October-November-December (OND), during El Niño the OND rains are greater than MAM. During a La Niña event the OND rains are at a deficit. OND rains are very systematic during an El Niño. During warm El Niño events the onset of OND is generally earlier by two or three weeks in the north. This paper presents a useful, albeit preliminary, analysis of ENSO connections with rainfall for a small region. Mark Tadross at UCT in South Africa has conducted similar research for southern Africa.

At the COFs, there have been numerous presentations from ministries of agriculture and agricultural extension services (Ogallo, 2006). In general, these have focused on the need to go beyond a tercile forecast, in order to serve farmers' actual needs. Many farmers state that they need information about the onset of the rainy season, and the timing of dry spells, something that current seasonal forecasts do not (and are unable to) provide. More importantly, however, the presentations have highlighted the need for communicating the forecasts in language that they can understand, and in a form that is useful. The next subsection will consider the findings specific to this.

How can climate information be best communicated to farmers?

Communication is a central issue for agriculture because the group of people using climate information is so diverse and dispersed. Because of the diversity, it is important to pay attention to the form of the information: is it in a form that farmers can use? Because of the dispersion, there needs to be attention to the information delivery system: is it reaching farmers? Research projects have examined each of these issues.

Communication and information form

Patrick Luganda is a professional journalist who founded the Network of Climate Journalists in the Greater Horn of Africa, based in Kampala, Uganda. He has conducted a number of studies, focusing on the potential to train journalists to improve the content of their reporting better to reflect the actual forecast, while avoiding common misinterpretations (Luganda, 2004). For example, at the first Southern African Regional COF that he attended, in 2002, the journalists present were asked to write a newspaper story describing the forecast. When the meteorologists at the COF reviewed this story, they found that it fundamentally mis-communicated the substance of the forecast, in terms of confusing issues of probability, the meaning of normal rains, and the geographical coverage. The aim of the network in the Greater Horn of Africa, and of a network for southern Africa established following the 2002 COF in Lusaka, is to help journalists get their stories right. Luganda argues that communicating weather forecasts and other climate information to the general public is quite problematic in all parts of the world. Even where the audience is extremely literate, it is not automatic that the recipients will grasp the important elements of the message that is being disseminated. Climate scientists often speak in a language that only they understand best. The ordinary recipient of information will discard anything that is difficult to understand. An abundance of alternatives makes it easy to ignore any single choice, regardless of sophistication of audience. Educating the journalists about the inner working of the climate community has brought a turn around in attitudes, understanding, and created an atmosphere of mutual trust. Luganda provides a good analysis about the inherent difficulties in communication technical forecast information. Forecasts must be approachable so that recipients can engage in an open dialogue regarding the content in order to realize the full benefit of the information.

There is a growing trend around the world to prepare climate and weather forecast information in probabilistic terms, since it is now recognized that this better helps users to optimize their decisions (National Research Council, 2006). Additionally, research has suggested that the credibility of a probabilistic forecast remains higher following an outcome that was not predicted to occur with high likelihood. In such cases, a deterministic forecast will simply be wrong (since it will have predicted something else to occur), while a probabilistic forecast will have included the possibility of that event occurring, albeit a small one (Patt, 2006). Nevertheless, it is commonly assumed that farmers, especially relatively uneducated subsistence farmers in Africa, lack the background to use a probabilistic forecast, and instead ought to be given one that is deterministic, since they will find such a forecast easier to use. To test this assumption, Patt (2001) conducted an empirical study of subsistence farmers in Zimbabwe. A set of simple betting games was constructed to assess both the farmers' ability to grasp probability and the associated risk, as well as the ability to learn these concepts over time. The results indicate that farmers' have an understanding of probability that is qualitatively similar to that of residents in industrialized countries. In the final game, which was a repeat of the first game, subjects showed more consistent strategies than the first, indicating that learning took place. The results do not significantly differ on the basis of education or gender, with one exception: women learned faster than men to adopt the optimal better strategy. This project demonstrates that farmers may currently have the ability to understand more complex forecasts, and also have the potential to increase their understanding over time. Also this project marks a departure from much of the literature in this area, in that it assesses the validity of a simple assumption that most of the forecasting procedures are based on. This methodology also suggests that forecasts should be approached with a so-called "bottom-up" mindset, addressing the specific needs of the end users before disseminating information.

Suarez and Patt (2004) carried this analysis one step further, by considering farmers' ability to consider issues such as joint probability. This concept is crucial to understanding why a forecast may change over time. For example, a seasonal forecast issued in September may be based on an estimated likelihood that El Niño will grow stronger over the coming months, and the distribution of rainfall expected should this occur, or fail to occur. The first of these estimates will be resolved over time, as more up-to-date SST become available, while the second set of estimates will not change. Using an analogy based on betting on a football game, considering the possibility that a star player will become injured before the start of the game (analogous to El Niño occurring or not) and the underlying odds with and without that player, the researchers were able to help farmers participating in a workshop to understand the issue as applied to climate. They administered a survey of the participating farmers, and found that they were able to grasp the concept. This in turn made them receptive to the idea of using a seasonal forecast, but also waiting for updates to occur. The authors argued that forecast communicators ought to describe the underlying factors that give rise the probabilistic forecast, giving farmers a better idea of when a forecast is likely to change significantly over time, and thus when it might make sense to delay important decisions until an updated forecast is available.

Sue Walker from South Africa conducted an extensive project, in which communication was one element. Her findings were somewhat more pessimistic than those of Patt and Suarez, although she did not take learning into account, and instead focused on baseline comprehension of complicated information (Walker et al., 2001). Walker's specific focus was on whether farmers receive and use forecasts, understand forecasts, the role of media in disseminating the forecasts, the most widely used media, and the influence of farmers' understanding of the forecast on their output. She found that jargon and technical terms create misunderstanding amongst farmers. Among the large commercial farmers surveyed, 93 % believed that they understood the technical terms (such as "near normal rainfall") used in the forecast, but that when asked to define those terms, 54% of them could not do so correctly. Two thirds of small-scale farmers thought that they understand the technical terms, while only 22% could successfully define them when asked. Those with larger farms believed that the forecasts were more important (relative to smaller farmers), yet were not better at understanding the forecasts; they demonstrated the greatest overconfidence in their ability to understand the technical terms. More than 59% of the farmers surveyed could had not received a seasonal forecast, or could not identify where they had received it from, indicating that they do not receive them. Walker concludes that training programs for scientists and extension officers should be required to improve communication skills. There should be further involvement of agrometeorologists, as they can successfully bridge the gap between forecasters and users. Training programs for farmers, to accompany the forecasts, could not only teach farmers how to decipher forecasts, but also serve as an opportunity for scientists to become more familiar with the comprehension level of your average farmer.

Communication systems to reach farmers

Researchers have examined alternative means of reaching farmers. Not surprisingly, each of them has found excellent opportunities associated with the medium that they happened to be studying. Perhaps the common element is that those opportunities can be best realized when the users are helped to understand what they are hearing.

Unganai (1998) examined the opportunities for agricultural extension workers to communicate forecasts to farmers, and his results support Walker's (2001) findings. In a training session of extension workers, he gathered their own specific insights. First, farmers have ideas on how to improve farm management if they had access to a reliable forecast. Second, radio broadcasts are likely to be the best means of getting the forecast information out to rural areas, but the broadcasts need to be done by authoritative figures on climate. Third, primary constraints which may inhibit the use of seasonal climate forecast information were identified to be lack of draught power at time of planting, lack of access to technical advice, lack of faith in the forecast, poor access to credit, lack of alternative cultivars and lack of convergence between the traditional forecast and the conventional one. The extension workers participating in the workshops wanted to know how seasonal climate forecasts were derived, and expected clarification of some of the commonly used terms in forecasting and ideas on how to disseminate the information thereafter to users. Only 34 of the 75 participants regularly received season climate forecast information, 50 of them reported problems with interpreting forecasts, and 73 of them said the workshop improved their ability. Many of the extension officers were not able to interpret the probabilities in the forecasts correctly. The results of this exercise demonstrate the need to train extension workers before they communicate with farmers.

The findings of Patt et al. (2005) provide hard evidence that also supports the recommendation of Walker et al. (2001), in terms for participatory training workshops for farmers themselves. The researchers conducted training workshops in four communities of subsistence farmers in Zimbabwe, from 2000 to 2004. They attempted to attract a random sample of approximately 50 farmers to each workshop, where they presented the probabilistic forecast, and worked with farmers on interpreting them. As part of these workshops, they sought farmer input on local conditions that could affect forecast use. After the growing season, they surveyed the farmers who had attended the workshops, as well as a random sample from the community of farmers who had not attended the workshops, in order to find out whether workshop attendance increased the used of the forecasts. Among those farmers who had heard the forecasts but had not attended a workshop, fewer than 10% could identify specific changes they made in their management practices in response to the forecasts. Among those farmers who had attended a workshop, more than 50% of them could identify specific changes they made. These results strongly suggest that participatory workshops can enhance forecast use, beyond what is already achieved through more traditional media.

Participatory communication methods are potentially costly, and one suggestion is to leverage their benefit using existing stakeholder networks. Ziervogel and Downing (2004) conducted workshops to provide stakeholders with a forum for expressing their views about forecast utility, and then conducted semi-structured interviews to gain feedback. From these data, the authors mapped out patterns of information flow between farmers. They found that networks did already exist for other purposes, and could be utilized to spread climate information. Policies would need to address this issue, since in their study they found that climate information was not effectively communicated through the networks they identified.

Several studies have examined the use of radio to communicate climate information to farmers, such as Mumbi's (2003) report on experience in Zambia, incorporating survey results from the Zambian Agricultural Extension and Information Survey. The author notes that over most of sub-Sahara Africa at present the information communication infrastructure is mainly tailored for the urban areas, while the vast rural areas are left in the information void. In order for rural communities to manage their development effectively, information must be available to different target groups, in different locations, and at appropriate times. In Zambia poverty inhibits access to information. The Zambian government formed 1,000 Radio Farm Forums (RFF) throughout Zambia and supported them with radio sets, batteries, and stationery. During the period of 1968-2001 a total of 31 radio programs were broadcast weekly in all the seven local languages and English. The purpose of the RFF was to use mass media in order for the rural communities to benefit from the transmitted ideas on radio. The arrangement has been to assemble a group of 15 to 20 farmers and introduce a problem by radio and then give listeners time to talk it over and decide on how and what to do about the problem. The farmers listen to the programs through the radio sets, discuss the idea/problem, and seek clarification through subsequent program broadcasts, thus creating a two-way communication system. Another attempt to provide information to rural communities was made in 1987, through the NMHS and the agricultural extension service. Twice a week ten to fifteen farmers would assemble at each met station and use radio transceivers installed at each of the 36 stations and talk to the experts at the Meteorological Headquarters and the National Agricultural information services. Questions were asked at the end of the first day sessions and answers were given at the follow session, two days later. In 2001, a survey was given on the rural community listenership to radio agricultural information, to analyze the use of mass media by extension works as well as the rural communities, particularly small-scale farmers. Extension officers reported that other farmers were their first important source of agricultural information, while farmers reported that extension officers were the first important information source. For both parties, radio programs were the second, and other sources such as printed material, newspapers, and television programs were not regarded as important because of their low availability. Radio set ownership among extension officers was more than 85%, which was much higher than that of other rural dwellers. Radio set ownership among farmers was estimated at 20% to 30% on average although fluctuations could be observed from community to community. While about 70 to 75% of the radio listener farmers had own radio sets and listened at home, there was a good number who did not have radio sets but could listen to it somewhere else such as a friend or relative's house. Therefore, radio listenership among farmers was considered much higher than the radio ownership in most of rural communities. Extension officers preferred listening to the agricultural radio programs in English, whereas farmers preferred listening to the local language. Over 70% of farmers reported that they had never read any print materials including newspapers for the last one year. The low level of formal education among farming communities has raised the question as to whether written material was an important channel of information. This study is important because it shows that farmers are appreciative of the climate forecasts, and understand the limitations. It also provides good examples of two-way communication, which allows the farmers to question the forecasts.

The combination of radio and listening groups was also used in a study by Phillips, Orlove, and Luganda in Uganda, and reported in Phillips (Phillips, 2003b). They also conducted a pilot project in which the formed radio listening groups, in order to discuss and provide feedback on the broadcasts. Their findings were similar: farmers showed a great willingness to participate, and stated that the forecasts were valuable.

A clear question coming out of these studies of radio is whether it can be as effective in the absence of listening groups. As part of their study reported earlier, Suarez and Patt (2004) found that the credibility and usefulness of radio broadcast forecast rose, when farmers had other opportunities to learn about the forecast. Farmers participating in their workshops stated that they had less confidence in the forecasts they heard over the radio than they did in the forecasts they heard at the workshops. This changed, however, for farmers who had already attended at least one workshop. After having had the opportunity to ask questions about the forecast, even in a forum not tied to the radio broadcast, their understanding and confidence in the radio forecasts rose. This study compliments the other studies focusing on radio by suggesting that radio broadcasts of forecasts can be highly effective, but that farmers need help, through a listening group or training workshop, to be able to start to understand and use the forecast they hear on the radio.

One implication is that the RANET approach (Boulahya et al., 2005) may be especially effective. RANET is unique in that it relies on community radio stations to broadcast the climate information, providing it to them via a dedicated satellite receiver tied into their Internet browser. Even if remote communities do not have access to the internet, they can thus access climate information via satellite, downloading relevant information and articles from a large set of choices. Unfortunately, there have been very few results analyzing the success of the RANET system. Such a study would, ideally, rely on surveys of RANET community broadcasters and users.

As part of the GL-CRSP Livestock Early Warning Sysytem, Kariuku and Kaitho (2006a) reported on the development of a system to bring market information to pastoralists and livestock traders, via radio, internet, and mobile phone short message services (SMSs). A great many stakeholders attended the various training sessions that they organized. In a second paper, they report that the government of Kenya adopted the proposed information system, in particular its use of SMS technology to alert herders and marketers (Kariuki and Kaitho, 2006b). It is not clear from either paper, however, the extent to which the information was used, although it may be still premature to tell.

Three related studies examine how information dissemination institutions can and should be structured. Cash et al. (2006) examined the effectiveness of forecast communication organizations, tied to the types of information they produced. They compared the communication strategies of the DMCH and the Pacific Islands Application Center (PEAC). They found that PEAC had done a better job tailoring their products to users' specific needs than had the DMCH. One explanation for this, the authors suggested, is that the PEAC had involved information users at a much more fundamental level: while DMCH is an organization of meteorologists charged with helping users, PEAC is an organization made up of both meteorologists and users, with both groups working together to plan PEAC activities. Patt (2006) compared the effectiveness of the Commercial Farmers' Union (CFU, which served large commercial farmers) and the agricultural extension service (AGRITEX, serving small subsistence farmers) at communicating the seasonal climate forecast in Zimbabwe during the 1997/98 El Niño. He found that the CFU was far more effective than AGRITEX, for reasons similar to the story of DMCH and PEAC: the CFU was made up of and financed by commercial farmers, which engaged the NMHS to provide them with useful information about the coming El Niño, and to help them to analyze it. The CFU then provided their members with probabilistic information specifically tailored to meet their needs. AGRITEX, by contrast, was provided the forecast by the NMHS, but did not work to further analyze it, except to the extent they were engaged to do so by the NMHS itself. As a result, the commercial farmers used the information more extensively and effectively, without being as swayed by the exaggerated reports of El Niño that were appearing in the media.

Both of these studies suggested that the organizations that were visibly controlled by information users, or their representatives, enjoyed higher credibility than did the organizations that had less user involvement. What remained unclear was whether this credibility resulted directly from the visible accountability to users, or indirectly, because that accountability led to a more carefully tailored forecast, which in turn was more credible. To test this, Patt et al. (2006) conducted an empirical study in Zimbabwe, making use of a decision-making game, and observing the behavior of participants randomly assigned to treatment and control groups. The decision-making game included the opportunity to use accurate advice about the optimal game strategy; because the game itself contained an element of chance, the advice was inherently probabilistic in character, much like a seasonal climate forecast. The results showed that when the person providing the advice had a clear connection to the player of the game, either because the player had paid the advisor for the advice, or because they would share in any winnings, the use of the advice increased. The latter form of connection was especially effective following plays of the game where the advice was counterproductive, analogous to a forecast of a high likelihood of drought followed by above normal rains. This study shows that the known accountability of communicators to the users can influence the credibility of their advice.

Vogel and O'Brien (2006) examined the role and value of current climate information systems, the overall institutional design, and the factors enhancing or constraining the sustained longevity of these efforts. Through a meta-analysis of projects the authors found that a more flexible and varied communication strategy between a range of actors and users would be more successful. This requires rethinking the current institutional framework of the climate-risk management environment. Currently there is a preoccupation with dissemination of forecasts, as well as end users' ability to understand the information within the forecast. This diverts the focus from the contextual situation in which the forecasts are used. Climate information should be coupled to other development and management tasks through collaborative models, especially where resources are strained and where development needs are already being addressed by existing platforms. There is an implicit understanding that as technical constraints (jargon, spatial and temporal scale) are removed the forecast is improved. However the environment and context in which many agricultural decisions are made is not well understood. End users operate in an environmental of considerable uncertainty reacting to risks whose impacts are not always clear. Climate variability is only one factor in production decisions. It is necessary to understand the factors that may limit the ability for farmers to respond to information they are given.

Factors limiting farmers' use of climate information

Several studies have examined the factors that limit farmers' use of climate information. The most extensive of these has been in Burkina Faso, using a workshop approach to communicate the forecasts with farmers, and to gain feedback from them (Roncoli et al., 2001). The researchers documented how household resource access profiles and livelihood portfolios shape food procurement and farm management practices. Access to labor saving technologies that accelerate land preparation and planting and timely availability of adapted seed varieties are key to adaptation. Access to credit that is not tied to specific crops or inputs and improved market access increased the flexibility of farmers' responses and facilitated livelihood diversification. The research also focused on how farmers can use the forecasts to safeguard their own food security. Farmers' observations of climatic and agronomic interactions during planting time helped to predict harvest failure and food insecurity long before their occurrence, and can be included into seasonal rainfall forecasting and famine early warning systems. This requires more micro-level research and closer integration of meteorological, agricultural and social sciences.

Table 5.1—Constraints facing farmers in using forecasts (source: Patt and Gwata, 2002)

	Causes	Effects	Corrective Action
Credibility	Previous forecasts perceived as being wrong; communicator not generally trusted	Users will ignore the forecast	Give probabilistic forecasts; rely on trusted communicators
Legitimacy	Forecasts perceived as superceding local knowledge or hurting farmers	Users will ignore the forecast and reject any concomitant advice	Incorporate local knowledge into forecast; involve users in developing advice
Scale	Forecast tells users nothing about events in their local community	Users will not incorporate forecast into decision-making	Work with users to analyze implications for the local areas
Cognition	Forecast is new, different, and confusing	Users will either not incorporate forecast, or will do so in a way that is counter-productive	Work repetitively with users to decipher the meaning of forecasts for their local area and to correct mistakes
Procedures	Forecast arrives at the wrong time, to the wrong people, or is unexpected	Users will not incorporate forecast	Repeat communication to resolve time, relevant actors, and consistency
Choices	Forecast does not contain enough new information to alter specific decisions	Users will not change decisions in response to forecast	Improve forecast skill; encourage users to make incremental decisions

The research points to the need for closer integration of drought preparedness efforts, farmers' understanding of climate-crop interactions and interventions that bolster the capacity of resource-limited households to respond. A workshop held in Burkina Faso capital of Ougadougou, as part of the West African COF, also indicated that farmers' use of the forecast was limited by their capacity take on risk. A state of food insecurity, combined with the lack of risk transfer mechanisms such as crop insurance made it difficult for farmers to use the forecast (Céron, 2007). As a follow up, Roncoli (2006) reviewed a number of separate studies to summarize the role that ethnographic and participatory methods have played in climate application efforts. Her study concludes that that there is a need to expand application efforts away from a model of adapting new technology to a focus towards the socio-political aspects of application. To accomplish this researchers must employ a multidisciplinary approach to their research, using many different approaches and tools. Continual interaction with farmers is necessary to gain insight onto how they perceive and respond to climate information. Roncoli suggests shifting the focus from the "uptake" of climate forecasts to understanding how climate information can interact with other resources to help enable rural producers to make decisions that reduce their vulnerability to climate risk.

Based on a study in Zimbabwe, Patt and Gwata (2002) identified six factors that limit or enhance farmers' use of climate forecasts. For each of the constraints, the authors identified the causes, the effects, and the actions that could be taken to correct them. These are shown in Table 6.1. Based on the same study in Zimbabwe, and also drawing in a case study of residents' responses to flood warnings in Germany, Grothmann and Patt (2005) identified an additional factor: individual motivation. Basing their analysis on protection motivation theory (Prentice-Dunn and Rogers, 1986) from the field of psychology, they analyzed people's self-protective behavior in response to new information, as a function of socio-economic variables (such as income) on the one hand, and socio-psychological variables (such as social status) on the other. They found that the model based on socio-psychological variables explained a higher proportion of the variance in behavior than that based on socio-economic ones. This work suggests that it is not income constraints, but psychological ones, that limit people's use of forecasts. An implication is that the forecast communication strategy ought to address those, supporting people's feelings of individual empowerment, and ability to use new information to improve their own well being.

Farmers' use of traditional forecasts and modern climate information

Given the systems for forecast applications already in place in many countries, a critical question is whether farmers are using them to change their decisions. If they are, then this is a good sign that the forecasts are useful, and that the communications systems are to some extent adequate. Closely related to the issue of forecast use is the use of traditional forecasts. Initially, it was thought that farmers would be reluctant to use modern forecasts if they conflicted with their traditional indicators; studies have shown, however, that by relating the forecasts to the traditional indicators, it is possible to build upon farmers' habitual use of information. Several studies have examined these issues, and have also set about identifying what those indicators are, and in the spirit of Orlove et al. (2000) to figure out whether the indicators are in fact accurate.

Roncoli and Ingram (2002) described how farmers in Burkina Faso utilize traditional methods in predicting seasonal rainfall, how these methods relate to those produced by meteorological scientists, and how the two can be combined for maximum effectiveness. The results suggested that farmers are interested in receiving scientific forecasts as they perceive local forecasts as becoming less reliable as a result of increasing climate variability. Indicators on which farmers relied most were fruit production on certain trees at the onset of the rainy season and temperatures during the dry season. Farmers stated that in their lifetime climate variability has increased: it rains less than before, rains begin late or end prematurely, and dry spells during the season are more frequent. The authors suggested that local understanding of the relationships between temperature and precipitation relate to technical aspects of sea surface temperature affects on precipitation. Scientific forecasts must be presented in ways that do not devalue local expertise but build on it. A clear implication of this study, consistent with Patt and Gwata (2002), is that the potential for forecast use hinges on the farmers' trust of the information. Given that farmers are constantly monitoring their environment in order to predict the rains, it must be recognized that farmers have prior knowledge when the forecasts are received. This knowledge may not agree with the forecasts being received, in which case the farmer is faced with a decision to either accept the traditional methods and reject the scientific consensus (or vice versa), with no way of questioning what was considered in the forecasts. This speaks to two points: farmers need to be able to question forecasters on the contents of the forecast, and the forecasts need to be described in a way that includes traditional methods to increase trustworthiness.

Nyakwada et al. (2003) conducted a study to identify the traditional indicators used in Kenya, and their effectiveness. The authors found that traditional indicators—plants, birds, insects (bees, butterfly, red ants, termites), stars, hill shadows, moon, winds, clouds, lightning, springs and swamps, amphibians, and cyclones—are widely used amongst the communities. The indicators, however, are local: they vary from community to community, both in terms of which indicators are used, and in terms of the relative importance and prominence within the set of indicators. Many farming communities relied more heavily on headsman and "rainmakers" for climate information than district meteorologists. Although the authors found evidence that the local indicators appear to correlate with modern forecasts, farmers find scientific climate forecasts inaccurate and untrustworthy, especially when they live far away from a meteorological station. This study points to the further potential to evaluate the indicators' accuracy and performance, and quantitative correlation. This paper could be extremely useful in directing future studies in both the areas of effectively communicating scientific forecasts to local farmers, and better understanding the local climate aptitude. It is very clear that while the scientific understanding of weather phenomena may be limited, there is a highly trusted dependence on visible environmental factors to predict weather. Although many of these environmental indicators have been listed, the scientific explanations are lacking. Successfully integrating these indicators into the dissemination of forecast information is paramount. The need for forecasters to be more involved in the communities that they predict for is also apparent. Another interesting point was the locals' distrust of the forecasts based on geographic location, which further suggests the need for localized broadcast of climate information. If headsmen met with met offices and dispersed the forecasts orally in community forums there may be more incentive to heed the advice.

A study based at the Sokoine University of Agriculture (2002) in Tanzania used a participatory methodology to integrate indigenous knowledge on season climate forecasts into formal predictive functions to enhance the predictive capability of probabilistic forecasts. Districts in Tanzania were chose to represent arid and semi-arid areas of the country. Group discussions and surveys were administered to village elders. Participants' recollection of past climate aligned with statistical findings for the areas. Over 80% of the respondents received climate forecasts, the most common source being radio. Over 90% acknowledged the existence of indigenous indicators that provide warning of climate anomaly. Indicators based on the appearance of plants and ambient temperatures were found to be the most important. The majority of the indicators were seen between August and November each year. Attempts were made to quantify traditional indicators for input into statistical regression models by using temperature, humidity, and rain variables as proxies. While the model for one location had a predictive skill of 60%, this must be viewed with caution, given a lack of detail about the statistical methods used, and whether assumptions of independence and temporal correlation were violated. It should be noted that the farmers in this study stated government assistance as their more important mitigation technique for a drought, and second most important for a flood, indicating a great deal of trust and expectation in government institutions. This level of trust and expectation suggests that if improved forecasts were effectively disseminated they would most likely be used.

After the 1997-98 rainfall season a study was conducted in South Africa to determine who the users of forecasts were and where the information comes from (Klopper, 1999). The South African Weather Bureau (SAWB) has been developing and releasing climate predictions since 1994 and had released a warning of a developing El Niño event nine months prior to the 1997 rainfall season. Seventy five percent of the respondents had changed their decisions or strategies as the result of the forecasted El Niño event. The actions taken in response to the forecast included changing crop varieties, changing planting time, or reduced seeding. An important question also raised by Klopper regarded the end-users perception of the rainfall that season. Users were asked if they experienced a "normal" season or not, thus seeking to determine the variation in end users expectations. Two thirds of the respondents considered the weather in their region to be "not normal," with explanations ranging from "extremely dry and warm" to "poor distribution" and "above-normal rainfall during an El Niño season" depending on the region. When asked if they had received contradicting forecasts, 25% of the respondents claimed that they had. The media may have lent to the confusion, as well as individuals trust in a given source. Radio, television, and newspaper were all seen as the most reliable source of information.

Phillips et al. (2001) examined forecast use as part of a project to identify opportunities and constraints related to the use of climate forecasts through field surveys over a 3 year period in Zimbabwe. This study assessed the current use of indigenous seasonal forecasts, access to and belief in official forecasts, and degree of flexibility in management at the communal farm level. Surveys were completed pre- and post-harvest. Ninety percent of farmers said they had "some degree of belief in an expected seasonal outcome," based on traditional forecasts. However, most farmers did not take specific action based on either the traditional or modern forecasts. They stated that the information was not accurate enough. The authors also noted that the expectation of external food aid in a drought situation may alter perceptions of risk, and that this in turn could influence forecast use. The findings of Phillips et al. (2001) are consistent with those of Patt and

Gwata (2002). They found that while most farmers believed the traditional forecasts to be somewhat accurate, they used these forecasts to develop an expectation for the coming season, and very rarely based specific farming decisions on them. Likewise, the farmers in the Patt and Gwata study expressed a reluctance to base decisions on the modern forecasts, unless they had a good understanding of how accurate those forecasts were.

A second paper by Jennifer Phillips examined the factors that correlated with forecast use by subsistence farmers. In particular, the research aimed at identifying whether socio-economic factors were a significant limitation (Phillips, 2003a). Over 90% of households that had heard a seasonal forecast from sources outside the village put it to some use, however minor. Importantly, neither the level of household assets nor the biogeographical location significantly influenced whether the information was used (although location influenced *how* the information was used), if they had access to it. However, access to climate information was positively correlated with level of assets, as wealthier households were more likely to have working radios. Households headed by women had a larger source of information from discussions.

Luseno et al. (2003) examined whether pastoralists in East Africa use forecasts. Using survey methods the authors found that pastoralists readily understand and can themselves communicate probabilistic season climate forecasts. Those who hear external forecasts are roughly the same proportion of the population as those who own radios, and access to and confidence in external forecasts is strongly and positively associated with market access and education. The majority of those who report receiving modern forecasts find them at least somewhat useful, have some confidence in them, and update their subjective beliefs in response to the forecasts they receive. This suggests that building confidence in forecasting is less a priority than promoting the economic advancement needed.

There have only been two large studies in West Africa of forecast use. One of these is the Climate Forecast Applications Research (CFAR) project of Roncoli, Kirshen, and Ingram, results of which have already been discussed. The other was a survey of 566 farmers in 13 communities conducted from October to December 2001 in Mali, Burkina Faso, Niger, and Nigeria, and reported by Tarhule and Lamb (2003). The primary goal of this study was to see whether farmers had access to climate information, and the results were disappointing. Only 43% of the respondents were aware that forecasts existed, and only 33% had received them personally. However, these results were biased, because several of the communities were participating in a Mali pilot program to disseminate forecasts (discussed below); omitting these communities, only 20% of the farmers were aware of the forecasts. At the same time, most farmers had some access to climate information, including information about developing droughts, and traditional forecasts, and 70% of the respondents used such outside information to some extent. Of those who did receive the modern forecasts, between 70% and 85% rated the forecasts as satisfactory to excellent across a range of criteria. Over 90% of the respondents stated that they would use the seasonal forecasts if they were to have access to them. They would change their planting time, their choice of crops, their grazing methods, their heard size, and their heard location. As a follow up to this study, Tarhule (2005) proposed specific measures to increase the use of climate information in West Africa. Tarhule calls for the establishment of a new agency charged with monitoring emerging research findings that might have relevance or applications to African situations. This agency would maintain an archive and database of such results that could be assessed and queried by researchers, policy makers, media organizations, and funding agencies. This would facilitate more rapid propagation of best practices and minimize duplication of efforts. In lieu of entirely new agencies, existing organizations, such as ACMAD, could take on this additional responsibility.

Benefits to farmers of using climate information

To the extent that forecasts are being used by farmers, as the studies indicate that they are, one can infer that farmers derive value from them. Such an inference in turn would be based on the assumption that farmers are acting rationally, and that if the forecasts were not actually helping them, they would not use them. Several studies have addressed this issue head on: how much benefit do the forecasts actually confer? The first approach to this question is through modeling, attempting to simulate the actions that farmers would take with and without the forecasts, and measuring the difference. The second approach is empirical: measuring the actual difference in yields that farmers achieve when they use the forecasts.

Phillips et al. (1998) conducted one of the important early modeling studies of forecast benefit. The researchers used an agricultural model to simulate maize yields in Zimbabwe under a variety of growing conditions. They identified specific adaptation strategies that farmers could adopt based on the forecast that they received. An important element of the model was the incorporation of risk aversion into the behavior of farmers, and indeed this drove an important outcome. Without access to information, risk-averse farmers would adopt conservative planting strategies, making use of short season varieties that would generate a dependable, if small, harvest. When farmers learned that a coming season would likely have low rainfall, there would be little they could do to modify their strategy. By contrast, in years when farmers learned that the coming season would likely have good rains, they might be able to take advantage of longer season varieties that produce greater yield. Hence, and important finding of this paper was that forecasts have value in all years, but that the value is greatest in years of high predicted, and actual rainfall. The study also provided a word of caution. Cane et al. (1994) had shown a high correlation between ENSO phases and national level maize yields in Zimbabwe. Phillips et al. (1998) noted that this national level correlation does not necessarily translate into correlation at the local scale. Indeed, to forecast local level maize yields, climate prediction may need to incorporate causal factors other than ENSO that may influence fine-scale rainfall patterns.

Ziervogel et al. (2005) used an agent-based model to infer the value of forecast use among farmers in Lesotho, with a focus on the pay-offs of using the forecast as a function of accuracy, how trust in the forecast grows or declines as a function of accuracy, and what the benefits of using the forecast might be in terms of yield, with and without interactions among farmer agents and for different wealth profiles. In their model, people, households, or larger institutions were represented by a set of logical rules that determine uniquely for each agent how they will act in a given environment. Rainfall data from 1960-2000 were utilized and classified as above, below, or normal. Crop yield for maize and sorghum was considered as a function of rainfall and planting density. Following forecasts of high rainfall is a much higher risk strategy than following those for low rainfall, unless the forecast in wet years is better than dry. On the other hand following the forecast in dry years confers only a small benefit over behaving as for normal weather. The forecast must be correct more than about 60–70% of the time to benefit these household-agents and when the forecast fails, it must be very poor no more than about 10% of the time. The model also showed that the level of forecast accuracy determines the level of trust, and that there is a threshold of accuracy below which trust will be lost significantly. If the forecast is accurate 60% of the time and very poor not more than 10% of the time, then trust saturates at 30 years. For some household-agents, the mean trust level saturates at the point where using the forecast begins to become economically advantageous. Many household-agents, if acting in isolation, may give up using forecasts earlier because of short-term losses, even though in the longer term using forecasts may be to their benefit. Finally, the model indicated that social processes have an impact on the effect of the forecast, both from the point of view of individual response and that of interaction between individuals. Poor farmer-agents benefit the most in the sense of reducing the likelihood of food shortage conditions, but yield enhancement is better for the wealthier household classes. This study is important because it identified potentially unforeseen consequences of poor forecasting skill. Often with agent-based models, however, the specific non-linear properties are quite sensitive to small changes in the model structure, and in cases where a model cannot be validated, one should view the precise results with caution.

Most of the studies have examined the needs of farmers conducting rain fed agriculture. One exception to this was a study of livestock management in South Africa (Boone et al., 2004). This project assessed the utility of a climate forecast in refining drought coping strategies in the livestock sector by including ecosystem responses. To evaluate these responses, the researchers adapted the SAVANNA modeling system to five commercial farms and five communal grazing areas. Model runs were completed with dry and wet rain years and demonstrated that seasonal forecasts may help improve range condition and livestock production for owners. Rangeland condition was improved if livestock stocking was reduced prior to a forecasted drought. A single culling event prior to a drought led to increased population more than a decade following the event. When forecasts were ignored, range and animal condition declined, and populations failed to recover for many years. If excess animals were sold range was not degraded, and populations increased when rains returned. The results point to the utility of destocking overstocked grazing lands prior to a forecasted drought. Indeed, even the use of an incorrect forecast would result in benefit to farmers from animal sale, and improved livestock production due to density-limited resources, thus minimizing the cost of an incorrect forecast of drought. While this study identified options for livestock management, it did not address the market effects that would occur with large amounts of cattle entering the market. Economic theory would suggest that the price would drop both as the supply of cattle increased, and as the demand for cattle fell in response to a widespread forecast of drought. This limitation does not negate the value of this study, but rather points to the need for further research that includes the effect of market forces. It must also be noted that these are modeled results, and do not take into account issues of forecast credibility. Farmers may be reluctant to listen to forecasters when it comes to selling or culling livestock. As mentioned briefly by the workshop results, this communal livestock farmers would not be likely to sell livestock as protection from a drought, therefore this strategy would apply only to large scale farmers. Workshop attendants in South Africa doubted that communal livestock owners would be willing to sell animals in response to a forecast.

Arndt and Bacou (2000) and Arndt et al. (2003) employed a computable general equilibrium (CGE) model to simulate the potential implications of climate forecast information for Mozambique. The CGE approach allows one to predict the impacts on all economic sectors in an economy of a change in production in one of the sectors. Experiments simulated both anticipated and unanticipated droughts, with various amounts of information sharing and reaction. From a value-of-forecast perspective the crucial element was not production decline but the dispersion of resources from drought intolerant to drought tolerant activities. The ability to reallocate crops was shown to have a very minor effect on GDP when only farmers are involved in the reallocation. Inclusion of marketing sector actors created significant gains in GDP and welfare. The simulations indicated that the marketing sector is a priority target for extension of forecast information. This project provided an example of how a simple theoretical modeling exercise can provide substantial insight on forecast use. It should be recognize that many assumptions are made here, the most obvious being that a farmer has enough knowledge of market forces and the factors that enter their own utility function to utilize information as a rational actor. This also suggests that when aggregate production is considered within a region it is more important to address the market institutions rather than the farmers. This conflicts with suggestions of tailoring forecasts specifically for farmers and may represent a more realistic goal; the transaction costs of disseminating forecasts to uneducated farmers will be much higher than providing the information to marketing institutions.

Phillips et al. (2002) conducted a study that involved both empirical and modeling components to identify economy wide effects of forecast use, investigating the implications in aggregate of a widespread response to climate forecast information using the case of Zimbabwe in the 1997-1998 El Niño, and the following year's La Niña. The researchers administered a questionnaire on baseline farming methods, access to climate information, actual use of the modern forecast, and belief in traditional forecasts. Within the study area, 95% of the population had heard the forecast and 84% found it to be credible. While farmers can respond to a forecast by changing crop variety, changing planting date, and changing the area planted, it appeared to be the latter adaptation that was most widely used. An important finding was that even in the absence of climate information, there were large inter-temporal variations in the areas that farmers planted, but that these variations increased in the presence of climate information. Given a forecast of drought conditions, farmers decreased their crop area, and this would decrease national-level production below that which would have occurred in the absence of a forecast. Likewise, production could potentially increase in years when the forecast is for greater than average rainfall. Assuming that the observed changes were in response to climate forecasts, and using historical data to project yields from the areas planted and cultivars used, they found that production volatility might increase with the use of forecasts. Where market infrastructure is poor and transaction costs high, there would likely be price volatility associated with production fluctuations as well. To help reduce the effect of a warning of poor rainfall leading to reduced production, farmers who switch to drought tolerant crops rather than reducing area might be given price guaranties for crops they do produce, or insurance payments in case of failure.

Two studies of the benefits from forecast use have been purely empirical. Patt et al. (2005) reported on a study in Zimbabwe taking place in four subsistence farming villages, from 2000 to 2004. In each village, the researchers raised awareness of the forecasts among a random group of farmers by holding a pre-season forecast workshop. At the workshop, farmers discussed with their agricultural extension agent specific changes that they could make in response to the forecast, and taking other constraints such as seed availability into account. After the 2002-03 and 2003-04 growing seasons, the researchers conducted a household survey, including both those who had attended the workshops, and a roughly equal number of farmers who had not. The questionnaires asked farmers for their historical yield data for each of the crops they planted, their yields in the current year, and whether they had made specific changes to their farm management decisions on the basis of the forecasts. To analyze the data, the researchers constructed an index that compared the farmers' current year harvests with their historical range, in order to see how each farmers had performed in the current year relative to what was possible for his or her plot of land. Across the two years of the study, the farmers who reported using the forecast outperformed those who had not by 9%. Providing empirical support to the modeling results of Phillips et al. (1998), the gains from forecast use were higher in the 2003-04 season, the year with a forecast and outcome of good rains; in that year, farmers using the forecast outperformed those who had not by 17%. During the 2002-03 season, when rains were both forecasted and turned out to be poor, farmers using the forecasts outperformed their peers by only 3%, a result that was not statistically significant. Adding credibility to these results is the attention to the

Table 5.2—Crop yields and farm incomes for farmers taking management decisions with and without agrometeorological information, in the 2003-2004 season in Mali.
Source: Diarra and Kangah (2007)

Zone	Crop	Field Type	Area (ha)	Average yield (kg/ha)	Gross income (US$/ha)	Income gain in agromet fields (%)
1	Pearl Millet	Agromet	2,600	1,204	175	26
		Non-Agromet	67,168	957	129	
	Sorghum	Agromet	5,375	1,427	193	42
		Non-Agromet	470,996	1,005	136	
	Maize	Agromet	6,075	1,984	249	80
		Non-Agromet	27,079	1,105	139	
2	Pearl Millet	Agromet	750	757	110	10
		Non-Agromet	45,790	690	100	
	Sorghum	Agromet	28,275	955	129	10
		Non-Agromet	222,662	871	118	
	Groundnut	Agromet	6,060	874	237	25
		Non-Agromet	102,113	702	190	
3	Pearl Millet	Agromet	10,400	1,247	181	48
		Non-Agromet	461,915	840	122	
	Sorghum	Agromet	2,850	1,562	212	56
		Non-Agromet	179,853	1,002	136	

statistical robustness of their conclusions that the authors engaged in.

The most extensive test of forecast value has been conducted since 1982 in Mali and reported on by Diarra and Kangah (2007). The project was started by the Swiss Agency for Development and Cooperation with a core group of 16 farmers, helping them to make better use of climatological data and traditional forecasts in planning their planting decisions, with continuous and close communication between the farmers and the agricultural extension service. The farmers managed two plots, one on which they based their action on modern agrometeorological information, and the other on which they based their actions on traditional indicators. At that time, seasonal forecasts were not available, but farmers were provided with short- and medium-term weather forecasts. By the end of the first year, the plots utilizing the agrometeorological data significantly outperformed the others, and demand from neighboring farmers to participate in the program grew, to 80 farmers by 1990, and eventually to over 2000 farmers living in five districts. Today, the farmers receive forecasts from short-term to seasonal, and the training to understand and use those forecasts. Table 5.2 shows results from the 2003-04 season, showing that plots making use of climate information outperformed the others by between 10% and 80%, depending on the crop variety that they were planting. These numbers are remarkable, yet there are limitations: it is unclear whether all of the benefits observed can be attributed to the agrometeorological information, since the farmers who participated in the program were self-selected, and hence may have represented the better farmers to begin with. Alternatively, farmers with two fields may have decided to devote their field with better soils to the use of agrometeorological information. This is in contrast to the more modest results observed in Patt et al. (2005), where the farmers who participated in both the workshops and the surveys were randomly selected.

Conclusions

Research in the agricultural applications across Africa has covered a spectrum of issues, and has taken place to some extent in all regions, if not in all countries. Studies in South Africa, Zimbabwe, and Uganda have all shown that predictable climate variability has a negative impact on crop yields, which in turn suggests that farm management could benefit from using information about that variability. Exactly what management techniques might be appropriate, the Uganda study showed, depends on the specific meteorological patterns. The information that farmers need is not just forecasts of seasonal rainfall, but also guidance about the onset of the rainy season, the timing and extent of dry spells, and the cessation of the season, downscaled to their local community. Unfortunately, many of these parameters are not ones that can be forecasted on a seasonal basis. With respect to onset and cessation of rains, farmers may benefit from dekadal forecasts, although this is unclear. It is hard to imagine them benefiting from dekadal forecasts showing dry spells, since there is little they can do at that point to react.

A large number of studies have examined communication of forecasts. It seems clear that the communicators of climate information—agricultural extension agents, the media, and NGO representatives—need to be trained in how to interpret and describe the information, and without training they are likely to make statements that are not accurate. Experimental findings suggest that there is a benefit of communicating forecasts to farmers in their full probabilistic version, including an identification of the physical factors that give rise to those probabilities. At the same time, since understanding a probabilistic forecast is a challenge, there is a need for training programs for farmers to be able to interpret such forecast, and the technical terminology contained within them, correctly. Perhaps the best way to reach a large number of farmers quickly is via radio, but radio suffers from the problem of being a one-way communication medium. To supplement radio broadcasts, farmers ought to be able to participate in training workshops or listening groups. Findings from Zimbabwe showed that the use of forecasts rose by a factor of five, when farmers had an opportunity to discuss them and ask question. The RANET program may also be an effective platform for participation centered around radio broadcasts, since it facilitates broadcasts at the community level. Finally, several studies point to the need for the communicators of climate information to have some sort of accountability to their listeners, in order to increase their credibility. Community broadcasters might have this.

A variety of factors limit farmers' use of forecasts. One might assume that economic factors are especially important, since farmers without the necessary resources will be unable to take actions on the basis of the information. Several studies, however, undercut this assumption, and show that economic factors only constrain forecast use to the extent they block people's access to the information. Other factors may play an important role, from the reliability of the information flow (so that farmers can plan their decisions around the arrival of the information), to the factors that influence farmers' motivation for using the information.

Farmers rely on a great deal of traditional forecast information in their planning. The extent to which farmers actually trust their own traditional indicators enough to base planting decisions on them, several studies suggest that they listen to them primarily to develop an expectation of the season's yields (which may influence non-farming behavior, such as financial planning). It also remains unclear whether the traditional forecasting methods used in Africa have a scientific basis; testing this is made difficult by the very local character of all of the indicators used. What is clear is that the credibility and use of modern forecasts can be improved when communicators respect the traditional forecasts, and discuss them alongside the modern forecasts. Just as it is difficult to quantify the extent to which farmers actually use the traditional forecasts, it is also difficult to identify exactly how they use modern forecasts. Farmers say that they will use them if they had access to them, and yet in surveys of farmers who have had the opportunity to use them, it is difficult to identify specific actions that they have taken on the basis of the information. It is unclear whether telling farmers exactly how to use the forecasts is beneficial: on the one hand, it makes the use of forecasts easier. On the other hand, it could lead to resentment against the forecast should the suggested strategies prove to be counterproductive, as can often be the case.

The studies that have looked for benefits of forecast use have all found them at the level of the individual farmer, though not necessarily at a macro-economic level. Modeling studies in Zimbabwe and Mozambique have both found that when farmers react to the forecasts, they do benefit, but that these action lead to minor variations at the level of national GDP, and can even increase price volatility, creating stress for other people. The two empirical studies have found benefits in both Mali and Zimbabwe. The Mali study found benefits in one year of between 10% and 80%, depending on crop, but it is not clear whether all of this is attributable to the climate information. The Zimbabwe study showed benefits of between 3% and 17%, depending on the year (lower benefits in the drier year).

6

Results from applications research: water resources and flood response

Some rainfall is utilized directly by vegetation, but most ends up as surface runoff or groundwater. That, in turn, ends up in rivers, where it has the potential both to be used, and to cause damage through flooding. Information ought to be able to help people attempting to manage and respond to changes in river flow, both through optimizing dam management, and through preparing for and responding to floods.

Dam management

Electricity generation from hydropower dams requires decisions on various time scales. For the long term, the power generator must agree on selling prices for electricity in futures contracts. If enough electricity cannot be produced to satisfy demand the distributor, often operating separately from the producer, must purchase electricity from outside sources. This may include purchasing electricity directly from neighboring countries, or purchasing it from fossil fuel sources. On a shorter time scale the generating company needs to make decisions regarding the amount of water to hold within the dam. There is a risk of flooding if an unexpected precipitation event occurs while there is too much water behind the dam. On the other hand, running a dam too low will adversely affect electricity production if there is an unexpected drought. The shortest time scale decisions are how much water to spill from the dam if the dam is approaching capacity. Depending on the hydrological features downstream of the dam, spilling too much water may result in flooding. Furthermore, the dam has a limited capacity at which it can produce electricity, such that past a certain flow rate of water there is no gain in electricity production. Each of these decisions is tied into each other, with each decision affecting multiple time scales.

Each of these decisions is based on the amount of water available—for the long-term decisions it is the amount of water that will eventually reach the dam, while for the medium to short term decisions it's the amount of water that is currently in the dam. The amount of water that is in the dam is a function of the water flowing into the dam. That amount of water is dependant on the amount of precipitation falling in the catchments of the river, combined with the hydrological features of the basin. This dependence on precipitation falling over a large area opens up the potential to benefit from seasonal climate forecasts. If probabilistic forecasts can be tailored to fit models of stream flow then it is possible to have information on drought or flooding events in advance to assist in decision-making. This information can be utilized to minimize the economic costs associated with power rationing and brownouts, as well as prevent the devastation that can accompany severe flooding. Despite the potential very few studies have been carried out on the benefits of forecasting for the hydro sector.

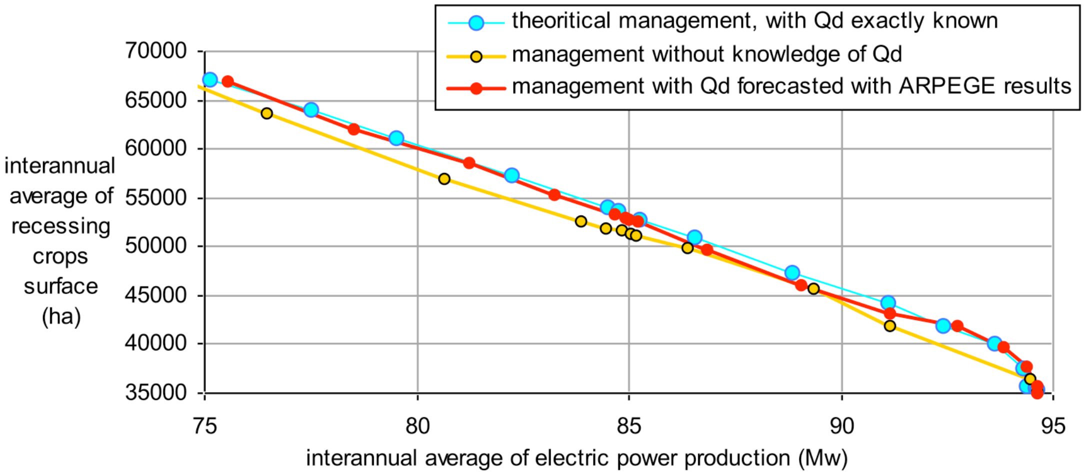
In 2001 a pilot project was completed in Ethiopia by Babu et al. (2001) to assess the economic impact of rainfall variability on hydropower production. Specifically the project aimed to assess the spatial and temporal variability of rainfall in the region and establish the relationship between seasonal rainfall and stream flow in Awash River and its tributaries through statistical relationships with regional and global ocean data sets. Time series of monthly rainfall amounts from 14 meteorological stations and average monthly flow of Awash and Majoro rivers from 1961-1990 were used to generate seasonal water inflow to the reservoir. Monthly average values of SST data at a 1° resolution were taken using the CLIMLAB2000 software. Principal component analysis was utilized to identify homogenous zones of the river—areas that have similar temporal and spatial variability—into two zones corresponding to the highlands and lower plains. A significant correlation between the summer rains and SST was established, which allowed for statistical empirical models of rainfall and pre-seasonal SST. Predictions in the June through September rainy season were better than the February through May season, with more variance explained in the lower plains than the highlands. The SST derived model shows potential, but the authors note that seasonal to inter-annual forecasts of hydrological variables should be added to the models to increase their accuracy. Given the course spatial scale of hydrometric stations along the Awash it is very difficult to detect such changes. It is also noted that since the strength and extent of ENSO episodes vary from year to year, simply using ENSO alone to forecast the season is not sufficient.

The next section of the project assessed the economic impact of rainfall variability on the power industry. In 2001 hydropower generation made up 97% of Ethiopia's total energy production. Utilization of mid- to long-range forecasting has a significant importance in reducing the risk of energy shortages during the dry season and minimizing spillage and flooding during high water periods. During times of rainfall deficit it is common practice to cut power supply. This occurred in 1996, 1998, and 2000. The total revenue loss in these years of the power supplier is estimated at US$ 7 million. Babu et al. (2001) concluded that to ensure power supply security, the Ethiopian Electric Power Corporation must incorporate seasonal meteorological forecasts in its long-term plan.

A group at the University of Nairobi studied power generation and seasonal forecasting in Kenya, and attempted to build awareness and capacity of the staff in the power sector in the use of integrating climate information and prediction products in planning and management. During the drought of 1999-2000 the Kenyan government was forced to require strict power rationing measures. Power was cut from residential and industrial sectors from sunrise to sunset, and the GDP dropped by 0.3%. Oludhe et al. (2001) sought to assess the impacts of the 1999 – 2000 drought on hydropower generation along the Tana River. The researchers sought to determine the overall losses from power rationing to the Kenyan economy,the benefits that might have been derived from the use of the COF forecast products, and the level of usage of climate forecasts in power generation decision-making and the associated benefits. They utilized data sets of power generation and consumption, rainfall, river discharges, dam levels, and socio economic information. Socioeconomic development hinges on the availability of adequate and reliable power supplies, and the power shortages that resulted from the 1999 – 2000 drought were estimated at US$ 2 million per day. The Kenyan Power and Lighting Company (KPLC) lost US$ 20.5 million in six months from a combination of power rationing and purchase of power from independent producers. The total cost incurred by KPLC totaled at US$ 141 million. The business sector reported huge losses, with many plants resorting to massive lay-offs. While it is unlikely that even the most accurate forecast could have entirely prevented these losses, a well-developed and tailored forecast could have minimized the impact. To assess forecast use, they administered questionnaires to workers at KenGen, the national hydroelectric authority. The seasonal forecasts appear to have assisted in the decision to institute power cutbacks in 2000. However, KenGen employees stated that the forecasts were not user friendly as they employ scientific jargon, rainfall forecasts are not as useful as river flow forecasts, and ultimately it is very difficult to predict flows from the probabilistic forecast.

By comparing climatic variables such as SST and ENSO events, Oludhe (2003) attempted to determine if a statistical model could be created to accurately predict river flow at the Masinga and Kamburu dams along the Tana River in Kenya to minimize the costs associated with rainfall variability. Data and information covered rainfall in the Tana River catchments, river inflows into Masinga and Kamburu dams, total power demand over a ten year period, net power shortfall over a ten year period, and the usage of climate information by the KenGen Corporation. The research utilized SST anomalies from the Pacific, Atlantic, and Indian Oceans in a multiple regression model and utilized ordinary least squares to make its predictions. Specific areas of SST were determined utilizing a stepwise regression process in the CLIMLAB2000 software. The simple models were shown to capture over 80 percent of the variance in river inflows, as determined by an R^2 value. According to the surveys given to KenGen climate information and prediction products were very useful: both the short- and long-term forecasts were being used for planning and management of hydropower production and in particular for reservoir operations and water management. However, the study did not address the question of how such information is precisely used, and hence there is no discussion of what lead-time is needed in order to minimize the losses from floods or drought, and whether a model based on actual rainfall, rather than SST, could deliver as much value. A further limitation of the study may be in the statistical methodology, which made use of least squares regression, which is often inappropriate to model spatial data. The lack of independence between data points, based on heir spatial correlation, violates assumptions of the least squares regression model.

Apparently the only case where climate forecasts have been incorporated into formal decision-making models in Africa was reported for the Manantali dam serving Senegal, Mali, and Mauritania (Céron, 2006). The Manantali Dam was built in 1987, and supplies 800 Gwh/year of power, and also controls about 50% of downstream flow, in an area where recessional agriculture (flooding, followed by planting) is practiced. The rainy season is from June to October, recessional agriculture begins in November, and there is no rain from November until May. The challenge, therefore, is to maintain electricity production throughout the year, while allowing for downstream flooding during the period of peak flow, as well as maintaining river heights for navigation, and supporting irriga-



Source: Céron (2006)

Figure 6.1—Pre-Operational Results of Forecast Applications for the Manantali Dam. The variable Qd represents rainfall. The dam managers have to optimize along two dimensions: releasing enough water for downstream recessional crops, and generating power. For the study period, the yellow curve shows the combinations that dam managers could achieve, without knowing the amount of rain they will receive in the coming season. The red curve shows what they could achieve, using the ARPEGE seasonal climate forecast. The blue curve shows what they could achieve with perfect knowledge of the coming season. Interestingly, their decisions are not very sensitive to the difference between the ARPEGE results and perfect knowledge.

tion, and flood management. Decisions must be made by August as to electricity generation. The project involves collaboration between Météo France and OMVS, the local dam management authority. Beginning in 2001, and continuing through 2004, Météo France supplied downscaled climate forecasts to OMVS, for the pre-operational mode of the project. Beginning in 2005, and with an agreement to continue to 2015, the forecasts will contribute to dam management operations. Figure 6.1 shows the results from the pilot stage of the project. Points along the yellow line show the combination of power generation and recessional agriculture area that could be achieved on average, given an absence of climate information, with each point representing a different decision about prioritizing agriculture and generation. The points on the blue line show what combination could be achieved, if inflows to the dam were known with certainty. The points along the red line show what can be achieved in practice with the forecasting system that is in place. Interestingly, the blue and red lines are quite close together, and both represent an improvement in the production frontier over the yellow line.

Why isn't there more extensive formal use of climate information by water resource managers? Johnston et al. (2007) examined this issue in the Western Cape of South Africa, with case studies of the city of Cape Town and a rural area approximately 100 km to the east. They interviewed stakeholders, including those involved in storage, purification, reticulation and disposal, stormwater, natural biodiversity management, agriculture, forestry and disaster management, and then conducted a set of stakeholder workshops and focus groups, where additional information was gathered. Even though the stakeholders identified a great number of ways in which they could use the forecasts, their actual use of climate information was quite limited. In the rural location, for example, the only forecasting product regularly used was the three-day weather forecast seen on television. There were several reasons for such limited use. First, the stakeholders lacked the technical expertise to understand and gauge the reliability of the forecasts. Second, the forecast information that they received was in too raw a form – it did not address the specific issues they faced. Third, they needed more interaction with the forecasters themselves, in order to be able to ask questions and have some of their basic concerns addressed. This study demonstrates that these stakeholders face many of the same constraints to the use of information as do farmers, as shown in many of the studies cited here. Even though water managers are trained professionals, that training does not extend to meteorology, and they are reluctant to take on board information that they do not completely understand.

Emergency flood preparation and response

At the COFs, there are frequent presentations about the use of climate information in the disaster management sector, specifically to prepare for and respond to floods. Nyoni (2006), for example, described how short-term weather forecasts are essential to help the Zimbabwe disaster management agency respond. It is less clear whether there are benefits of using *seasonal* climate forecasts for disaster management and flood preparation purposes.

Lucio et al. (2007) suggested that it is possible. They described the Mozambique floods of 2000, which are remembered as a terrible disaster in which 700 people loss their life and millions were affected, and suggested that it would have been even worse in the absence of the seasonal forecast. At the SARCOF meeting in September 1999, the predictions did not call for particularly high risks of above normal rainfall, but the NMHS in Mozambique suspected that this projection was inaccurate, and projected a 50% probability of above normal rainfall over much of the country. The national disaster committee began to meet, and issued a contingency plan for excessive rains and cyclones in late November. They attempted to mobilize resources, such as boats, but in the absence of hard evidence that flooding would occur, were not very successful (of the 20 boats requested, only 1 was obtained). Holiday leave was cancelled for key planners during the December-January holiday season. Rains started heavy in December, and flood warnings were issued, though were largely ignored by the local population. Disaster struck in early February when a series of cyclones hit the coast, with heavy rains falling on saturated soils. The floods that occurred, most notably in the Chókwe and Xai Xai districts along the Limpopo River, were the worst in 100 years, and overwhelmed all preparations. International aid was mobilized, and 50,000 people were rescued. Lucio et al. (2007) argued that this relief was as successful as it was because of the advance planning, which had already developed the contingency plans to cope. Even though the floods were worst than anything planned for, the necessary framework for coordinating international assistance was already in place. There is evidence to suggest that the response to flooding in 2007 was much more successful, in part because of the lessons learned following the 2000 floods (FEWS-NET, 2007).

Conclusions

The hydropower sector has the potential to utilize seasonal forecasting products with relatively less communication infrastructure than other sectors. Unlike the agricultural sector, which relies on distributing information to thousands of uneducated rural farmers, a relatively few individuals make the decisions on dam management. While in some cases channels of communication already exist, and users are receiving the forecasts, it would appear that in most countries, both the content the form of the information is not sufficient. Anecdotal evidence suggests that water managers use the forecasts informally, in terms of making marginal adjustments to their practices on the expectation of heavy or light rainfall, but that such actions are not systematized. The example of Céron (2006) stands out as a notable exception, and points to the need to have a close and ongoing involvement between NMHS and the dam managers in order to develop an operational system. One issue that is not resolved is whether use of real-time climate monitoring data can also be useful. On many rivers, such as the Tana in Kenya, the lag between rainfall in the upper reaches of the catchment and inflow to the dam can be over a month, and this may be a long enough lead-time for decision-making.

The example of using seasonal climate forecasts to prepare for the 2000 Mozambique floods demonstrates many of the same issues that arise in the area of food security. The floods developed over time, as heavy rains continued, and short- to medium-term weather forecasts were as important as the seasonal forecast. But the seasonal forecast provided a basis for developing contingency plans, and securing the necessary resources. As in Ethiopia in 2000 (Broad and Agrawala, 2000), government agencies were not willing to devote significant resources to preparation while the floods were merely a probability. The money was made available to buy only 1 of the 20 boats requested. This points to the need to take efforts to evaluate, and hopefully demonstrate, the credibility of the forecasts, so that the necessary policy-makers will be willing to make decisions on their basis.

7

Results from applications research: public health

It has been recognized for over a decade that there is a strong relationship between climate variability and transmission rates of several tropical diseases, such as malaria, meningitis, and Rift Valley fever. Unlike the other sectors, however, understanding the exact form of that relationship is problematic. For example, malaria transmission rates depend on temperature, humidity, and precipitation, but until recently it has been unclear which of these factors is most important in particular places and times. There is not general agreement on a single quantitative model of malaria transmission, and how climatic factors influence that transmission (WHO, 2005). Given this lack of agreement, there is a valid concern about using climate information in ways that are simply ineffective; the consequences of doing so could cost people their lives, because it would divert resources from other public health programs with proven track records. Until very recently, then, most of the research on the links between public health and climate variability was centered around understanding these basic issues—quantifying the relationship between climate factors and disease transmission—as a prerequisite to applying climate information to try to mitigate the effects of variability. It is only in the last three years that the first application of climate information has taken place in Africa, to fight malaria epidemics in the SADC region.

Epidemiological research on malaria

Both climate variability and climate change are important factors in malaria transmission (Martens et al., 1997). In Zimbabwe, for example, Ebi et al. (2005) found that by 2100 the transmission of malaria will increase in the highlands, while there will be varying rates of change in the lowlands, as a result of climate change.

At least in theory, malaria control efforts need to take account of the life cycles of both the parasite and its mosquito vector. The parasite's life cycle begins when a female *anopheles* mosquito acquires two gametocytes (sexually differentiated *plasmodium* parasites) by biting an infected person; the gametocytes come together within the mosquito to form an egg. Over the course of roughly five to ten days, and depending on temperature, the egg develops within the mosquito to the point where it releases sporozoites, which make their way into the mosquito's saliva. This constitutes the *extrinsic* phase of the life cycle. If a mosquito carrying sporozoites in her saliva bites a person, she injects these into the blood. They migrate to the liver, where they reproduce to form merozoites, which then move back into the blood. There, the merozoites multiple within red blood cells, eventually bursting the cells. This releases toxins, and causes illness. Some of the merozoites differentiate into gametocytes, which can be acquired by another mosquito, leading to another cycle. The time between being bitten by the mosquito and experiencing a fever depends on the plasmodium species, but for *falciparum* averages about 11 days.

There are roughly 430 species of *anopheles* mosquito, existing worldwide except for Antarctica, of which 30 – 40 transmit malaria. They have a four-stage life cycle. Eggs are laid in water, and hatch within 2- 3 days, although it can take several weeks in colder climates. The eggs hatch into larvae, which grow in the water over the course of one to two weeks, feeding on pollen and other organic matter, before turning into pupae. After one to four days in the water, the pupae split open, releasing an adult mosquito. Both the larvae and pupae need to breathe air, and hence need to live in still water, where they can stay near the surface. The female adult mosquito typically survives for one to two weeks, although she can live for over a month. In colder climates, females with fertilized eggs can spend the winter in cool damp places, and the lay their eggs in spring before dying. The female needs to take a blood meal after mating with a male and before laying her eggs. She can lay eggs several times during her life. At higher temperature and humidity she is more active, and hence will bite and lay eggs more frequently.

Climatic factors influence the extrinsic life cycle of the parasite, and the life cycle of the mosquito vector. *P. falciparum* develops in the mosquito most quickly at ambient temperatures around 26°C. Below about 20°C and above 40°C the parasite is not able to develop. Given the short life span of the female *anopheles*, the faster the extrinsic life cycle of the malaria parasite, the higher the likelihood of transmission. At higher

Table 7.1—Timing in the malaria transmission cycle

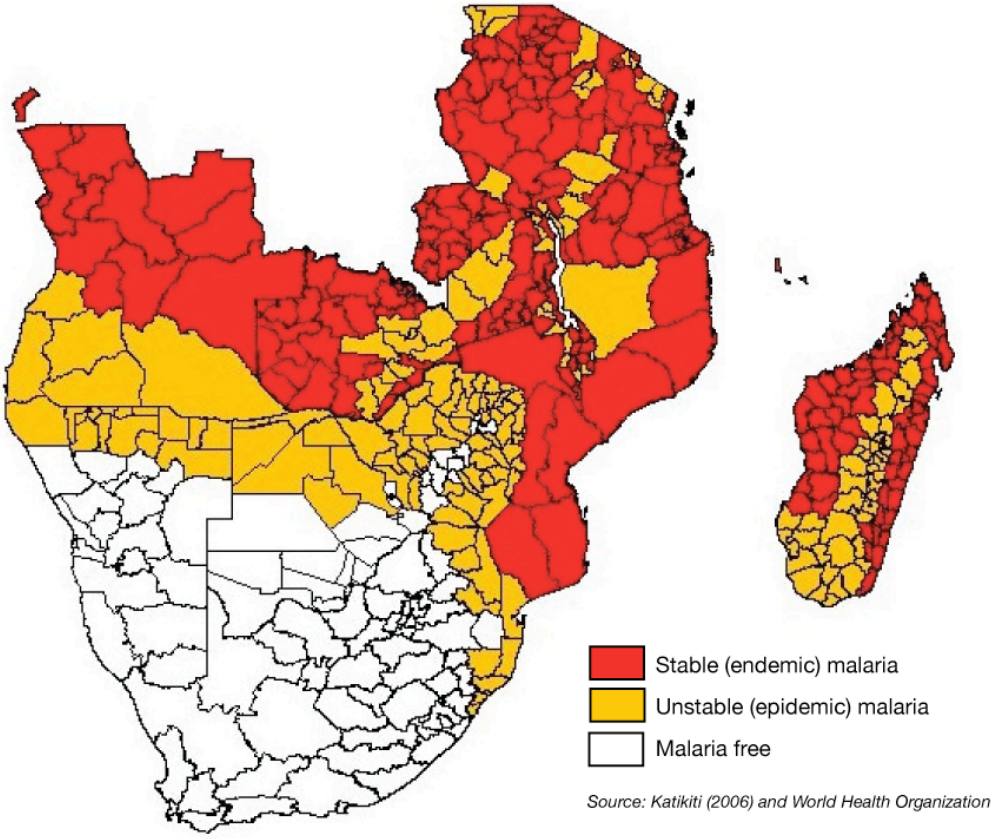
Event	Time (days)	Climatic Sensitivity
Time for anopheles eggs in water to hatch into larvae	2 – 3	Requires standing water
Development of mosquito larvae into pupae	7 – 14	Requires standing water
Development of mosquito pupae into adults	1 –4	Requires standing water, occurs more slowly at low temperatures
Lifespan of adult female anopheles mosquito	7 – 14	High humidity increases mosquitoes' rate of activity, and lengthens their lifespan
Plasmodium parasite egg matures to release sporozoites	5 – 10	Requires temperatures between 20°C and 40°C, most quickly at 26°C
Onset of fever in humans after being infected	~ 11	Not sensitive

temperatures, adult mosquitoes also feed earlier in their life cycle. Both factors increase the chances that the mosquito will transmit the parasite before the vector dies. Malaria cases begin to increase within two to three weeks of high temperatures in these areas, since the high temperatures increase the transmission rate among the existing vector population. In addition to temperature, rainfall and humidity have been shown to be important factors across all of Africa (Thomson et al., 1996). High rainfall, leading to puddles of standing water, can increase the rate at which mosquitoes reproduce. Malaria cases thus begin to increase within four to eight weeks of heavy rains, given the time needed for the development of the mosquito eggs, larvae, and pupae, and the extrinsic life cycle of the parasite within the adult mosquito. Finally, high humidity can increase mosquitoes' activity, and lengthens their lifespan: when relative humidity is consistently below 60%, few mosquitoes live long enough for the parasite to complete its extrinsic life cycle. As with high temperature in East Africa, high humidity can lead an increase of malaria cases by several weeks (Thomson et al., 1996).

Climate variability shifts the location, on a year-to-year basis, of areas where malaria transmission is highest (Zhou et al., 2004). As is evident from Table 7.1, which summarizes the time required for various events in the malaria transmission cycle, several climatic factors need to be present for any transmission to occur: there needs to be standing water for mosquitoes to reproduce, the temperature needs to be close to 26°C for the parasite to develop in the mosquito before the mosquito dies, and the humidity has to be high enough for the mosquito to be consistently active and able to outlive the parasite's extrinsic lifecycle. It is thus frequently the case for areas on the fringe of an endemic malaria region to experience low humidity, rainfall, or temperature such that transmission ceases altogether for one or more years. In this case, immunity within the human population will be lost. Such an area would then be vulnerable to a malaria epidemic, should it experience a season of heavy rainfall and high humidity. This often occurs precisely when people need to be healthy to engage in demanding agricultural activities (Worrall et al., 2004). Figure 7.1 shows the areas in southern Africa where malaria is endemic (stable), epidemic (unstable), and absent; as can be seen the epidemic areas fall on the fringes of the endemic areas (Katikiti, 2006).

Recent research has shown that in the highlands of East Africa, temperature is the major factor limiting the spread of malaria, with higher maximum temperatures leading to an increase in the transmission rate. For example, Githeko and Ndegwa (2001) examined three years of hospital admittance data and rainfall data from the Kakamega district of Kenya, finding that maximum temperatures, rather than mean temperatures, are the necessary indicator of malaria transmission. The data indicated that when the maximum temperatures were rising and minimum temperatures were falling, resulting mean temperature values concealed the epidemic related signal seen in the maximum temperature. The model was able to predict both El Niño and non El Niño malaria outbreaks, with no false predictions. Zhou et al. (2004) used a mixed-model regression to examine the link between climate factors and epidemic malaria in East African highlands. Including not just climate factors, but also seasonality and autoregression (the number of malaria cases in the previous period, their model predicted between 65% and 81% of the variance in malaria outpatients. There was, however, a great deal of geographic heterogeneity in terms of the interaction between the different variables.

In many parts of Southern Africa, by contrast, the major limiting climatic factor is rainfall, al-



Source: Katikiti (2006) and World Health Organization

Figure 7.1—Malaria in Southern Africa. This map shows all districts within SADC member countries, and for each district whether it is an area of endemic malaria, or subject to periodic epidemics. The epidemic areas lie on the fringe of the endemic areas, and suffer epidemics when climatic conditions are especially favorable for malaria transmission. For most of Southern Africa, this corresponds to years of high rainfall. For the highlands of Madagascar, it also correlates with years of high maximum temperatures.

though there have been debates about the specific relationship between rainfall and transmission. One would suspect that high rainfall leads to greater transmission. Some have argued, however, that low rainfall turns rivers into pools of standing water that are perfect for mosquito breeding, while high rainfall tends to flush those rivers out. Thomson et al. (2005) examined this for Botswana, and found a quadratic relationship between rainfall and epidemic, a relationship that remained significant even after controlling for recent developments in malaria control. They used a stepwise regression with log malaria incidence as the dependent variable and rainfall estimates, year, and policy intervention as the independent variables. The regression coefficients for policy intervention and year were used to eliminate the impact of these factors from the time series. The mean of this data set was subtracted from each year creating a malaria incidence anomaly. This anomaly was correlated with both estimated national averaged rainfall anomalies and SST. Rainfall accumulations from December onwards were found to be significant predicts of log-confirmed malaria. A quadratic model of malaria anomaly was found to predict more variance than the linear model. The variables from the quadratic model were used to calculate a variability index, which was subtracted from the standardized set, resulting in a time series that removed the effects of trends in vulnerability and policy intervention. More than 70% of the residual variance in malaria incidence was correlated with a quadratic model of nationally averaged seasonal rainfall. Lastly anomalously high and low standardized malaria incidence anomalies were defined using the higher and lower quartiles of the dataset. The quadratic model using rainfall estimates successfully predicted the low and high malaria anomaly years.

Thomson et al. (2006) took this analysis a step further by explicitly considering whether it would be possible to predict, using a dynamic climate model, malaria incidence. They utilized a forecast system developed out of the DEMETER (Development of a European Multi-model Ensemble Forecast System for Seasonal to Interannual Climate Prediction) project. The DEMETER model is an ensemble forecast system that predicts a probability distribution of climate scenarios. The researchers found that the same quadratic relationships that held with the CMAP dataset in Thomson et al. (2005) could be utilized with the DEMETER forecast. Most importantly, the malaria incidence anomalies were shown to be fairly accurate when predicted with DEMETER four months earlier than with rainfall monitoring alone. This significant gain in lead time with a small loss in prediction skill suggests that probabilistic seasonal climate forecasts can be used to predict malaria incidence in Botswana, as well as in neighboring epidemic areas. The two Thompson et al. papers, taken together, provide a good basis for using climate information for malaria early warning (Cox and Abeku, 2007).

Malaria early detection and early warning

There are two related approaches to targeting malaria control efforts in places where an epidemic is about to occur, or is in its early stages. The first of these is an early detection system (EDS), which “aims to detect the early stages of an epidemic by measuring changes in the incidence of malaria cases” (Guintran et al., 2006, at 1). An EDS relies on three levels of activity: a group of peripheral health offices that collect local data and act as “sentinel sites”, an intermediate location where the information from 2 – 3 sentinel sites in a district can be analyzed and responded to, and a central coordination site that can develop policy, planning, and coordination at the provincial or national level. An essential element of an EDS is accelerating the rate at which reporting is made. In some East African countries, there is evidence of poor reporting procedures leading to delays of up to 20 weeks in the data that is needed for early detection (Checchi et al., 2006). Weekly reporting is essential (Guintran et al., 2006), and requires the developing of standard operating procedures in order to ensure that reporting takes place, and that decisions are made quickly and systematically on the basis of the analyzed information (Cox et al., 2007). Another essential feature of an EDS is the availability of detailed baseline data, which allows for the detection of anomalies. As Abeku et al. (2004) describe, an EDS may provide enough lead time (days to over a week) to deliver malaria control drugs to the affected region, and thereby minimize the morbidity and mortality associated with the outbreaks, and to conduct additional vector control measures—indoor residual spraying (IRS) and distributing insecticide treated nets (ITNs)—in order to keep the outbreak from spreading. The World Health Organization has been taking steps to implement EDSs in East and Southern Africa since 1998, predominantly in highland areas. Currently, many countries in Africa, including all of the East African countries, do incorporate an EDS into their malaria control efforts.

The other approach to targeting malaria response activities is a malaria early warning system (MEWS). A MEWS makes use of climate information, primarily timely-delivered monitoring data and satellite imagery, in order to identify places where the conditions are right for an epidemic to develop (Connor, 2003; Rogers et al., 2002). A MEWS can also incorporate seasonal climate forecasts, although this can also be referred to not as early warning, but as long-range epidemic forecasting (Abeku et al., 2004). The MEWS approach, especially utilizing pre-season forecasts, may be most useful in semi-arid areas where rainfall and humidity are the limiting factors for malaria transmission, rather than temperature (Guintran et al., 2006). The primary benefit of a MEWS, compared to an EDS, is the longer lead-time that climate data affords: enough time to engage in vector control and medication stockpiling to prevent a significant outbreak from starting in the first place. A more advanced MEWS would take advantage of seasonal climate forecasting to predict, with an additional three or four months' lead-time, whether climatic conditions are likely to require responding to an imminent outbreak. Although the skill is lower, and the spatial and temporal resolution is course, this can allow for stockpiling at the national level the supplies that may be needed effectively to respond.

The MEWS approach builds on the EDS, since it adds climatic factors to monitoring of cases in sentinel sites. Whether the attention to climate, in particular seasonal climate forecasts, is appropriate is a question that has generated some debate. Hay et al. (2003) did a retrospective study of four study sites in the Kenyan highlands for the April – June 2002 rainy season. The seasonal forecast for the region was of a 35% chance of *above normal* rainfall, a 40% chance of *near normal* rainfall, and a 25% chance of *below normal* rainfall. The rain that fell was in the *above normal* range, leading to epidemics across the study sites in May, June, and July. The authors claimed that the forecast was not accurate enough in predicting the heavy May rains to have been useful for guiding preparation for the coming epidemic, and the remote sensing data were useful for predicting epidemics in only two of the sites. Unfortunately, the EDS was also not very effective, as the early outbreak data from the sentinel sites was not reported in a timely manner. The authors concluded that it is important to improve basic planning based on the analysis of historical data, supplemented by an effective EDS, but not necessarily a MEWS. In a response to this article, Thomson et al. (2003) suggested that it may be premature to rule out the effectiveness of a MEWS in the East African highlands, and certainly inappropriate to do so for Africa as a whole. They suggested first that seasonal climate forecasting is evolving, and second that the usefulness of a forecast is highly contingent on local factors, most importantly the forecasting skill that can be obtained, combined with the sensitivity of local places to deviations in rainfall and temperature. It may be necessary to pay more attention to highly local factors, and not simply the general pre-season COF tercile forecast, as Hay et al. had done.

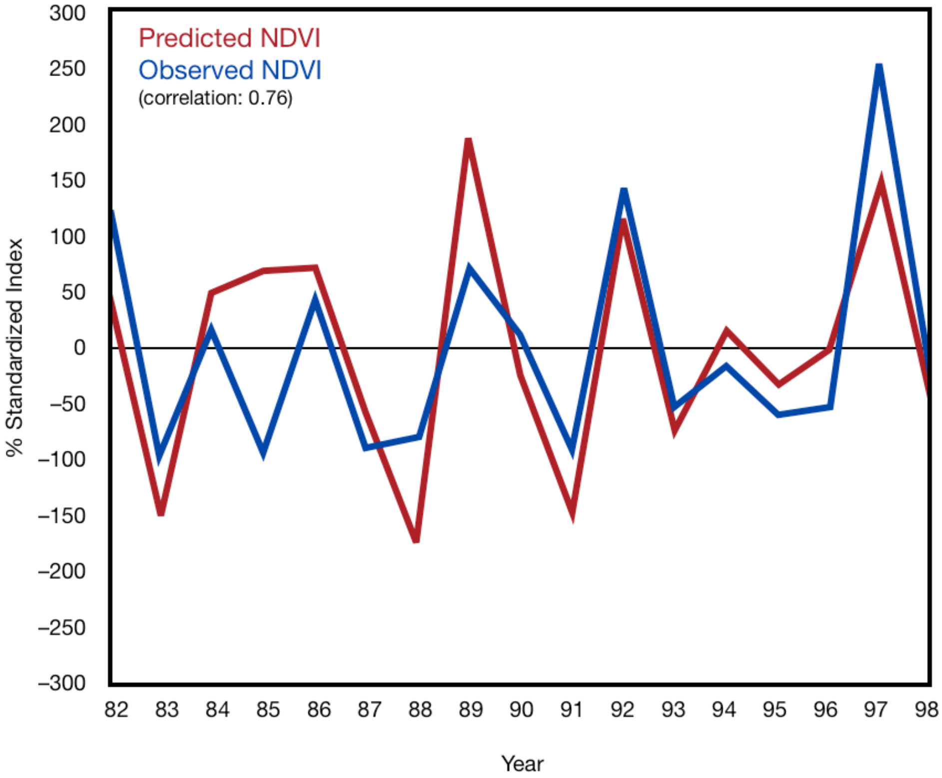
The efforts to develop a MEWS, by incorporating these local factors and moving beyond a tercile forecast, have increased in recent years. Since 2004, the DMCH, WHO Africa Office, and IRI have worked with SADC NMHSs and Ministries of Health to conduct a pre-season Malaria Outlook Forum (MALOF), which has taken place in addition to the SARCOF meeting (DaSilva et al., 2004). The MALOF meeting, which has now been held three times in the SADC region and, for the first time in March 2007 in the IGAD region, has been the cornerstone for beginning to implement a MEWS. Connor et al. (2007) report on the results of the nascent MEWS in the SADC region, with a focus on Botswana, where the system has been the best implemented. Following the MALOF meeting, climate-monitoring data from ground stations and satellite indexes were made available to national malaria control programs on ten day intervals. In Botswana, the 2005-06 rainy season was especially wet, comparable to that of 1996-97. However, while the wetness did appear to have led to some incidence of malaria, the number of cases was ten times lower in 2005-06 than in 1996-97. It is unclear what fraction of this is due to improvements in malaria control independent of the MEWS—in Botswana this has been steady improving—and what fraction can be attributed to MEWS. But it is an encouraging sign that not only in Botswana, but in all of the SADC countries participating in the MEWS, the number of malaria cases in 2005-06 was far below the number in 1996-97.

There has also been work to explore a MEWS in the East African highlands, as part of the Highland Malaria Project (HIMAL) operating in Kenya and Uganda. The project has relied extensively on remote sensing data, which can estimate maximum and minimum land surface temperatures, dekadal rainfall, and the normalized difference vegetation index (NDVI), which represents foliage development and thus, indirectly, humidity (Abeku et al., 2004). The first East African MALOF took place in March of 2007. East Africa lags Southern Africa in the implementation of a MEWS, in part because the climate variables that need to be monitored are more numerous, but it is likely that an operational East African MEWS is imminent.

Using climate information to reduce the incidence of other infectious diseases

Despite the fact that malaria has gained the most attention within Africa, there are several other diseases for which the links to climate, and the potential for using climate information to assist control efforts, are becoming clearer. Other diseases for which climate appears to play an important role in Africa include meningococcal meningitis, Rift Valley fever, trypanosomiasis, yellow fever,and visceral leishmaniasis (WHO, 2005). Perhaps the best example is meningococcal meningitis, which occurs primarily in West Africa. Molesworth et al. (2003) showed that meningitis epidemics are poorly understood: population susceptibility, introduction of new strains, poor living conditions, and concurrent infections have all been implicated. However, the fact that epidemics occur in the dry season, coinciding with periods of very low humidity and dusty conditions, and disappear with the onset of rains, suggests that these environmental factors may play an important role in the disease. They developed a model that to predict the probability of an area experiencing an outbreak, based on environmental information. After inputting binary data (had suffered an epidemic of any size, or had not) on 3,281 districts in Africa into a GIS program, and creating a single surface by principal component analysis and clustering techniques, they utilized a logistic regression to determine the association between a given district having ever had an outbreak and environmental variables. All investigated variables were found to be independently associated with the location of epidemics, however absolute humidity and land cover were chosen as the best predictors in the final model. Areas without distinction between wet and dry seasons were less likely to have had epidemics than those with contrasting seasons. Accounting for humidity, areas with sparse vegetation were less likely than others to have an epidemic.

Indeje et al. (2006) studied the potential to predict outbreaks of Rift Valley Fever in East Africa. Prior work had shown a link between the normalized difference vegetation index (NDVI), a measure of greenness, to outbreaks of Rift Valley Fever. The authors showed that it is possible to predict NDVI using a statistically downscaled



Source: Indeje et al. (2006)

Figure 7.2—Predicted and Observed Normalized Difference Vegetation Index (NDVI) for East Africa. This shows the high predictive skill that forecasts allow, which could be beneficial in forecasting areas of Rift Valley fever, which correlate with NDVI.

GCM. As Figure 7.2 shows, they obtained a correlation of 0.76 between the predicted NDVI and the observed values. This suggests a usefulness of climate forecasts for predicting Rift Valley Fever outbreaks. The authors noted, however, that a quantified statistical correlation between NDVI and Rift Valley Fever is still necessary in order to make accurate Rift Valley Fever predictions. This is probably going to be difficult, given the lack of reliable data on Rift Valley Fever itself, compared to the NDVI data.

Conclusions

For many years here has been a great deal of hope that the use of climate information could help to target interventions against disease outbreaks. Doing so, however, would run the risk of diverting resources from existing public health programs, and potentially do more harm than good. At the same time, both the nature of disease transmission and the ethics of treatment decisions make it impossible to conduct small-scale pilot projects. Hence, there has been a need to establish clear quantitative linkages between climate and disease epidemics, prior to making any use of climate information operational. Nearly all of the research to date has been of this character. For malaria, the first MEWS has now been developed, in the SADC region, and the first results are promising. The use of climate information for other diseases has been proposed, but efforts at application lag far behind those for malaria. It is thus too early to assess the efforts at applying information for these diseases.

8

Conclusion: lessons learned from research and practice

There are two sets of lessons that can be drawn out of the studies that we have cited in this report. First, one can identify what basic applications questions the various research projects have answered, and what questions they have failed to answer. Second, one can point to some of the major accomplishments and shortcomings in the application of climate information.

What we know and do not know

Most of the research studies on applications have focused on the particular sectors that we have used to structure this report, while other have looked at cross cutting themes, in particular communication form and content. We address each in turn.

Food security and famine

What we know

- Global and regional climate forcing factors such as ENSO can have a strong influence on national level yields in some countries, and this in turn can affect such a country's national level food security and its balance of trade.
- It is possible to use global and regional forcing factors to predict local level yields, but the explanatory power is less than for national level yields.
- At the local level, weather and climate patterns, as captured through indicators such as NDVI, have an impact on local yields, and on other factors that contribute to food security or insecurity, such as market prices.
- Depending on how seasonal climate forecasts are used, they can either have little influence on national level food security, or have a positive influence through stimulating advance contingency planning.
- Pre-existing institutional interlinkages can improve the likelihood that forecasts will have a positive influence on planning.

What we do not know

- We cannot quantify the added benefits to an early warning system, either economically or in terms of decreased risk of famine, from greater use of seasonal climate forecasts, above and beyond continuous monitoring of weather data (both through ground measurement and remote sensing) and monitoring of actual yields.

Agriculture

What we know

- Farmers across Africa make use of traditional indicators to forecast local weather and climate conditions.
- In countries that have made an effort to communicate seasonal climate forecasts to farmers, many farmers are aware of the forecasts, and many report that they use the forecasts to guide their decisions.
- Farmers would like to receive more detailed and downscaled climate forecasts, including statements about the likely onset and cessation of the rainy season, and the likelihood and timing of significant dry spells.
- Under modeled growing conditions, seasonal climate forecast can provide economic value by influencing the choice of crop, application of fertilizer, and other farming practices. Local factors and farmers' risk aversion dictate whether these benefits are greater in years with higher predicted likelihood of heavy rains, normal rains, or light rains.
- Farmers face a number of economic, social, and cultural constraints that may limit their ability to use forecasts.
- In a randomized controlled field study in Zimbabwe, farmers obtained value from using forecasts to guide their decisions. The value was equal to approximately 17% of their average yields in a year of forecast and actual normal rainfall, and not significantly different from zero in a year of forecast and actual poor rainfall.
- In a large study in Mali, farmers obtained much greater value from using climate information—with income gains as much as 80%—although this study was not a randomized controlled study, and so it is possible that selection bias could have inflated the results.

What we do not know

- We do not know the economic value of traditional indicators, both because we do not know how reliable they are, and because we do not know the extent to which farmers use traditional indicators to modify their actual farming decisions.
- We do not know whether the results in Zimbabwe and Mali can be generalized to other places in Africa, under conditions to be found outside of a pilot project environment with enhanced attention to communication.
- Because we cannot generalize the results from Zimbabwe or Mali, and in the absence of other empirical studies of forecast value, we cannot yet calculate the economic value to farmers across Africa of access to seasonal climate forecasts.
- We do not know what practical benefit livestock managers receive from forecasts of forage or market conditions, or the extent to which they use these forecasts.

Water resources and flood response

What we know

- In several river systems in Africa, climate forecasting could be incorporated into dam management models to improve seasonal planning and daily operations.
- Dam managers, and other water resource managers, have many reasons not to use climate forecasts to guide their decisions. These

include a lack of confidence in the forecasts, and a lack of technical capacity either to downscale existing forecasts to their own site, or to incorporate existing forecasts into their operations.

- There is anecdotal evidence that many dam managers use climate information to modify their decisions in informal ways, which may be quite beneficial.
- A pilot project in West Africa, with close assistant from Météo France, appears to be the only instance in Africa of dam managers formally incorporating forecasts into their planning and operations.
- Disaster planners in Mozambique have increasingly paid attention to seasonal and medium term climate forecasts to guide their contingency planning efforts, and that this practice has reduced the damage and loss of life from flooding.

What we do not know

- We do not know whether tercile probability rainfall forecasts produced at COFs, not downscaled to the watershed or local level, provide any benefit to dam and other water resource managers.
- We do not know what the total economic benefits to dam and other water resource managers could be of using short-term, medium-term, and seasonal climate forecasts.
- We do not know the added value to disaster planners of using seasonal climate forecasts, above and beyond the value obtained from using short and medium-term forecasts, and having access to climate and weather monitoring data.

Public health

What we know

- Climatic factors, and climate variability, influence the prevalence and spread of several tropical diseases, including malaria, Rift Valley fever, and meningitis.
- It is possible to predict the climatic factors that influence the prevalence and spread of these tropical diseases.
- For some parts of Southern and East Africa, carefully tailored and downscaled climate forecasts can predict a large proportion of the variance in epidemic malaria.

What we do not know

- We do not know the extent to which seasonal climate forecasts can predict the variance in tropical diseases other than malaria.
- We cannot yet quantify the added value that climate forecasts provide to malaria early warning, above and beyond the rapid use of short- and medium-term forecasts and monitoring data, or the added value of an early warning system above and beyond an early detection system.
- Recent efforts to develop a MEWS in Southern Africa appear to have led to reductions in mortality and morbidity.

Communication

What we know

- Except in the case of highly trained specialists, most people lack the ability to understand and use a tercile probability seasonal climate forecast without substantial additional explanation and assistance.
- Journalists themselves require training in how to interpret a probabilistic seasonal climate

forecast, before they can adequately and correctly explain it to their audience.

- Most people have the capacity to learn how to understand and use a probabilistic forecast.
- Participatory methods of forecast communication, while primarily aimed at helping people to understand and use a forecast, also improve a forecast's credibility and legitimacy, and provide a forum for identifying what types of information might be most valuable for decision-makers.

What we do not know

- We do not know whether the value of seasonal climate forecasts is high enough to enough users to justify the high cost of participatory forecast communication systems.
- We do not know the best way to communicate probabilistic information to a diverse group of decision-makers via radio and other media.

Major accomplishments and shortcomings

The prior subsection identified the results, and lack of results, of applications-oriented research projects, namely how the applications process works. In addition to this, it is also important to identify the important successes and failures at actual forecast application: where the application process has worked. Since establishing the practical value of forecasts and climate information is most likely a prerequisite to governments' and donors' committing high levels of funding to applications, we also include in this section the success or failure of applications research to establish that practical value. By its very nature, this subsection is more subjective than the last, since it is based not on a process of summarizing existing research findings, but rather on interactions with key stakeholders in the region.

Food security and famine

Major accomplishments

- Across Africa, early warning organizations have been at the forefront of incorporating climate information into their operations.
- Linkages between forecasters, early warning organizations, donors, and NGOs have slowly but consistently developed, increasing the likelihood that climate information will improve efforts to avoid famine and food insecurity.

Major shortcomings

- There is reason to believe that seasonal climate forecasts could be used for national level economic planning, and yet this has failed to take place.
- There has been very little progress using climate information to improve local and household level food security planning.
- There has been too little research identifying the practical value of seasonal climate forecasts for food security planning at any scale.

Agriculture

Major accomplishments

- Numerous modeling studies, and a small number of field-based pilot projects, have established the economic value of seasonal climate forecasts for commercial and smallholder farmers.
- In several countries, there have been substantial efforts to communicate forecasts to farmers through the public media, the agricultural extension service, and other community organizations, with some evidence that this has made a difference.

Major shortcomings

- In most countries, the efforts to communicate seasonal climate forecasts to farmers have fallen far short of what is possible. This includes a failure to engage farmers in the communication process, a failure to train extension workers in understanding the forecast, a failure to downscale the forecast to local areas, and a failure to communicate the forecast in a non-technical language that farmers can understand. In some cases, it has also included a failure to describe the probabilistic nature of the forecast, which has led to lower credibility.
- There has been little effort to develop additional forecasting and climate information products that would be useful to farmers, such as a consensus forecast of the onset or cessation of the rainy season.
- Tied to the generalized failure to make progress towards the MDGs, there has been little progress in overcoming many of the constraints that farmers face in using climate information. This is especially so in the case of the absence in Africa of micro-insurance systems, which would allow farmers to take on greater amounts of risk and expand their range of practical options.

Water resources and flood response

Major accomplishments

- Modeling in several countries has demonstrated that seasonal climate forecasts could add value to dam planning and operations and water resource management.
- In West Africa, there have been successful efforts to bring water resource and watershed managers, such as the Niger River Basin Authority, into the network of forecasting organizations.
- In Mozambique, the country in Africa that is perhaps most at risk of flooding, there has been substantial progress at incorporating climate information into disaster planning and management operations.

Major shortcoming

- Outside of West Africa, there have been no collaborative efforts between forecasters and dam managers to develop operational models that include climate forecasts. As a result of this, there have been no other cases where dam and water resource management formally relies on climate information.

Public health

Major accomplishments

- There has been a steady stream of research establishing the scientific link between climatic factors and tropical diseases, and this has laid the foundation for early warning systems that incorporate climate information to target resources to those places where they will be most effective.
- Institutional linkages have been established between public health and meteorological organizations, at a variety of scales. Some forecasting and application organizations that are active in Africa, such as the IRI, have made a deliberate effort to foster linkages by hiring public health experts, who can work closely within the organization with meteorologists and climatologists.
- In Southern and East Africa, the establishment of the MALOF has addressed the particular needs of the public health community, and has

been a forum for strengthening institutional linkages.

Major shortcomings

- Existing EDSs have suffered from delays caused by a failure of timely reporting of data from sentinel sites. A similar problem threatens a MEWS, as well as current delays in reporting of rainfall monitoring data.
- It still needs to be established where the added benefit of incorporating a seasonal climate forecast into a MEWS, or of using a MEWS rather than a EDS, justifies the added expense.

Communication

Major accomplishments

- There has been steady progress at developing decision-support tools, such as the CPT, that can help convey probabilistic climate information to decision-makers in a clear and efficient manner.
- In East Africa, there has been progress developing a communication system to benefit herders and livestock traders, making use of SMS technology, which is rapidly becoming an established tool for development.
- There have been successful efforts in East Africa to train journalists in how to communicate climate forecasts effectively.

Major shortcomings

- There has been almost no progress moving beyond the tercile probability forecast as the primary piece of information communicated by seasonal forecasters, despite widespread evidence that most users find these difficult to understand and use.
- With the exception of the MALOF, there have been very few recent efforts to mainstream climate information into sector-specific planning efforts, or to develop participatory communication systems to help people use climate information more effectively.
- RANET technology has never moved far beyond the pilot project phase. There has not been a similar cross-cutting push making use of mobile telephones and SMS technology, which has gained ground in providing market and other information, including even banking and remittance services, to rural residents across Africa.

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