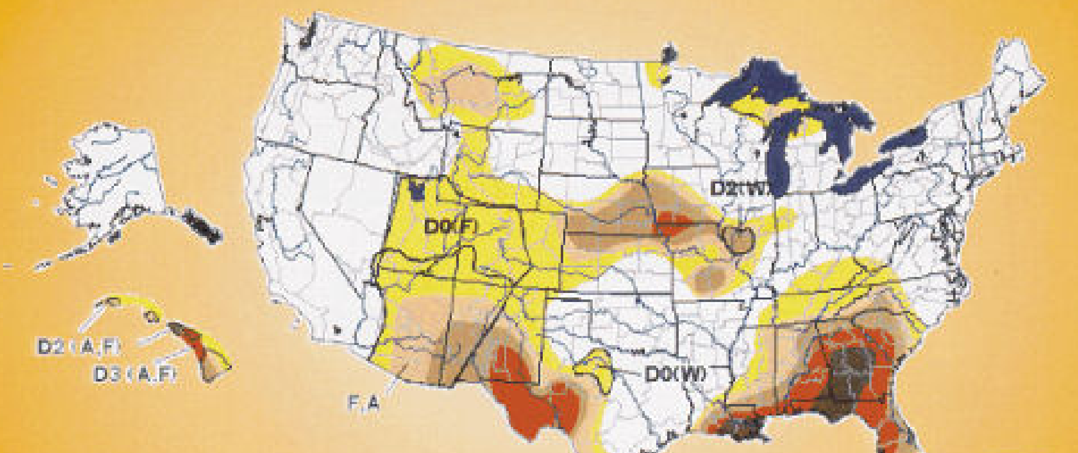
Early Warning Systems for Drought Preparedness and Drought Management



World Meteorological Organization

Early Warning Systems for Drought Preparedness and Drought Management

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Editors:

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Drought Early Warning Systems in the Context of Drought Preparedness and Mitigation

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Abstract

Drought is a normal part of climate and occurs in virtually all regions of the world. Recent droughts have illustrated the vulnerability of all parts of the United States to extended periods of precipitation deficiency. Drought preparedness planning has become a widely accepted tool for governments at all levels to apply to reduce the risks to future events. In the United States, planning has been employed by local, state, regional, and tribal governments. In 1982, for example, only 3 states had developed drought plans. Today, 30 states have prepared drought plans and other states are at various stages of plan development.

Drought plans should contain three basic components: monitoring and early warning, risk assessment, and mitigation and response. A 10-step drought planning process illustrates how these components of a plan are addressed during plan development. Because of drought's slow-onset characteristics, monitoring and early warning systems provide the foundation for an effective drought mitigation plan. A plan must rely on accurate and timely assessments to trigger mitigation and emergency response programs. The monitoring committee's functions are discussed as an integral part of the drought planning process. An example of a new climate monitoring product, the Drought Monitor, is presented to illustrate how climate parameters and indices are being used in the United States to produce a weekly comprehensive assessment of drought conditions and severity levels.

Introduction

The economic, social, and environmental costs and losses associated with drought in the United States are significant. In 1995, the U.S. Federal Emergency Management Agency (FEMA) estimated annual losses attributable to drought at US$6-8 billion. Drought occurs somewhere in the United States each year, with an average of 12% of the nation (excluding Alaska and Hawaii) in the severe to extreme drought category. The maximum spatial extent of severe and extreme drought occurred in 1934, when 65% of the nation was affected.

Widespread and severe drought conditions in 1996 in the southwest and south central states, the recurrence of drought in 1998 in this same region and its expansion into the southeast, and the return of drought in 1999 to the southwest, southeast, and south central states and its expansion into the mid-Atlantic and northeast states have raised serious concerns about our nation's continuing vulnerability to extended periods of drought-induced water shortages. In 2000, drought again was widespread in the spring and summer months. It has resulted in severe impacts in three regions of the country: southeast and Gulf Coast, southwest and south central, and central and western Corn Belt states.

Our vulnerability to drought is quite different from that of many developing countries, where the primary concerns are centered largely on issues of food security and meeting the nutritional needs of the population, environmental degradation, and a retardation of the development process. In the United States, the economic, environmental, and social impacts of drought are substantial. Drought in 1996 resulted in serious losses in crop and livestock production and increased the incidence of forest fires and wildfires. Decreases in surface and ground water supplies affected public water supplies and water-based tourism and recreational activities. Energy demand also increased markedly in response to searing heat. These losses were estimated at nearly $5 billion in Texas alone (Boyd 1996); substantial losses also occurred in Kansas, Oklahoma, New Mexico, Arizona, Utah, Nevada, and Colorado. The rapid emergence of drought in 1998 following the strong El Niño event resulted in drought-induced wildfires in Florida and acute agricultural losses in Texas, Oklahoma, Louisiana, South Carolina, Georgia, and other southern states. Losses in Texas and Oklahoma were estimated at $5 billion (Chenault and Parsons 1998) and $2 billion (Thurman 1998), respectively.

Drought conditions that returned in 1999 in the southwest, south central, and southeast states have had a cumulative effect on economic and social systems and the environment. Drought in the mid-Atlantic and northeast states also had devastating effects in some areas. The economic impacts of the 1999 drought are likely to be several billion dollars. Drought events in 2000 have resulted in serious impacts on agriculture and municipal water supplies, especially in the southeast region, where drought has occurred in each of the past three years over most of Georgia and portions of Florida, Alabama, and South Carolina. It is too soon to know the extent of agricultural losses associated with this drought in the central and western Corn Belt. A dry fall, winter, and spring season over this area resulted in poor soil moisture conditions at planting, placing agriculture in a high-risk situation.

A critical component of planning for drought is the provision of timely and reliable climate information, including seasonal forecasts, that aids decision makers at all levels in making critical management decisions. This information, if properly applied, can reduce the impacts of drought and other extreme climate events. A comprehensive, integrated national climate monitoring or drought early warning system has been under discussion for some time in the United States (Wilhite et al. 1986; Riebsame et al. 1991; Wilhite and Wood 1994; Wilhite 1997a), but little action on these recommendations has taken place until recently. The wide range of data and information that is readily accessible to users via the Internet has made the development of an integrated climate monitoring system a more executable task.

The purpose of this paper is to discuss the current status of drought planning in the United States and illustrate the key role that drought early warning systems play in drought plans. This chapter will begin with a brief overview of some of the concepts of drought, how it differs from other natural hazards, and its characteristics. Understanding the unique characteristics of drought is crucial to establishing an effective and comprehensive monitoring and early warning system as one component of an effective drought preparedness plan. A planning methodology that has been applied in numerous settings in the United States and elsewhere and at various levels of government will be discussed. This methodology represents a step-by-step approach to developing a drought plan, including the creation of a drought monitoring or early warning system. A new national monitoring tool developed in 1999, the Drought Monitor, will be discussed because this approach integrates multiple indices and parameters in the assessment process and relies heavily on the Internet in product development and dissemination. The Drought Monitor has been widely accepted by decision makers and the media in the United States and is being used in drought assessment at the state and national level.

Drought: The Concept

Drought is a normal, recurring feature of climate; it occurs in virtually all climatic regimes (Wilhite 1992a). It occurs in high as well as low rainfall areas. It is a temporary aberration, in contrast to aridity, which is a permanent feature of the climate and is restricted to low rainfall areas. Drought is the consequence of a natural reduction in the amount of precipitation received over an extended period of time, usually a season or more in length, although other climatic factors (such as high temperatures, high winds, and low relative humidity) are often associated with it in many regions of the world and can significantly aggravate the severity of the event. Drought is also related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness of the rains (i.e., rainfall intensity, number of rainfall events). Thus, each drought year is unique in its climatic characteristics and impacts.

Drought differs from other natural hazards in several ways. First, since the effects of drought often accumulate slowly over a considerable period of time and may linger for years after the termination of the event, the onset and end of drought is difficult to determine. Because of this, drought is often referred to as a creeping phenomenon (Tannehill 1947). Although Tannehill first used this terminology more than fifty years ago, climatologists continue to struggle with recognizing the onset of drought and scientists and policy makers continue to debate the basis (i.e., criteria) for declaring an end to a drought.

Second, the absence of a precise and universally accepted definition of drought adds to the confusion about whether or not a drought exists and, if it does, its degree of severity. Realistically, definitions of drought must be region and application (or impact) specific. This is one explanation for the scores of definitions that have been developed. Wilhite and Glantz (1985) analyzed more than 150 definitions in their classification study, and many more exist. Although the definitions are numerous, many do not adequately define drought in meaningful terms for scientists and policy makers. The thresholds for declaring drought are arbitrary in most cases (i.e., they are not linked to specific impacts in key economic sectors). These types of problems are the result of a misunderstanding of the concept by those formulating definitions and the lack of consideration given to how other scientists or disciplines will eventually need to apply the definition in actual drought situations (e.g., assessments of impact in multiple economic sectors, drought declarations or revocations for eligibility to relief programs).

Third, drought impacts are nonstructural, in contrast to, the impacts of floods, hurricanes, and most other natural hazards. Its impacts are spread over a larger geographical area than are damages that result from other natural hazards. For these reasons, the quantification of impacts and the provision of disaster relief are far more difficult tasks for drought than they are for other natural hazards. Emergency managers, for example, are more accustomed to dealing with impacts that are structural and localized, responding to these events by restoring communication and transportation channels, providing emergency medical supplies, ensuring safe drinking water, and so forth. These characteristics of drought have hindered the development of accurate, reliable, and timely estimates of severity and impacts and, ultimately, the formulation of drought contingency plans by most governments.

Drought severity is dependent not only on the duration, intensity, and spatial extent of a specific drought episode, but also on the demands made by human activities and vegetation on a region's water supplies. The characteristics of drought, along with its far-reaching impacts, make its effects on society, economy, and environment difficult to identify and quantify. This continues to represent a formidable challenge to those scientists involved in operational climate assessments.

Many persons consider drought to be largely a natural event. In reality, the risk associated with drought for any region is a product of both the region's exposure to the event (i.e., probability of occurrence at various severity levels) and the vulnerability of society to the event. The natural event (i.e., meteorological drought) is a result of the occurrence of persistent large-scale disruptions or anomalies in the global circulation pattern of the atmosphere. Exposure to drought varies spatially and there is little, if anything, that we can do to alter drought occurrence. Vulnerability, on the other hand, is determined by social factors such as population, demographic characteristics, technology, policy, social behavior, land use patterns, water use, economic development, diversity of economic base, and cultural composition. These factors change over time, so vulnerability will change in response to these changes. Subsequent droughts in the same region will have different effects, even if they are identical in intensity, duration, and spatial characteristics, because societal characteristics will have changed. However, much can be done to lessen societal vulnerability to drought. Improved understanding of a region's drought climatology will provide critical information on the frequency and intensity of historical events. Identifying the factors that explain who and what is at risk and why (i.e., the underlying factors behind the vulnerability) can lead to the development and implementation of a wide variety of mitigation actions and programs to reduce impacts from future drought events.

Drought Characteristics and Severity

Droughts differ from one another in three essential characteristics: intensity, duration, and spatial coverage. Intensity refers to the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall. It is generally measured by the departure of some climatic index from normal and is closely linked to duration in the determination of impact. Many indices of drought are in widespread use today, such as the decile approach (Gibbs and Maher 1967; Lee 1979; Coughlan 1987) used in Australia, the Palmer Drought Severity Index and Crop Moisture Index (Palmer 1965, 1968; Alley 1984) in the United States, and the Yield Moisture Index (Jose et al. 1991) in the Philippines and elsewhere. A relatively new index that is gaining increasing popularity in the United States and worldwide is the Standardized Precipitation Index (SPI), developed by McKee et al. (1993, 1995). The SPI will be discussed in greater detail in later sections of this chapter.

Another distinguishing feature of drought is its duration. Droughts usually require a minimum of two to three months to become established but then can continue for months or years. The magnitude of drought impacts is closely related to the timing of the onset of the precipitation shortage, its intensity, and the duration of the event.

Droughts also differ in terms of their spatial characteristics. The areas affected by severe drought evolve gradually, and regions of maximum intensity shift from season to season. During the drought of 1934 in the United States, the area affected was approximately 65% of the country (see Figure 1). In the United States, it is unusual for drought not to exist in a portion of the country each year. A recent analysis of drought occurrence by the U.S. National Drought Mitigation Center (NDMC) for the 48 contiguous states in the United States demonstrated that severe and extreme drought affected more than 25% of the country in one out of four years.

Methodology for Drought Preparedness Planning

Drought planning in the United States has gained considerable momentum in the past two decades. Since 1982, there has been a rapid development of drought plans by state governments in the United States. In 1982, only 3 states (Colorado, New York, and South Dakota) had completed drought plans. Today, 30 states have drought plans in place and Texas, Georgia,

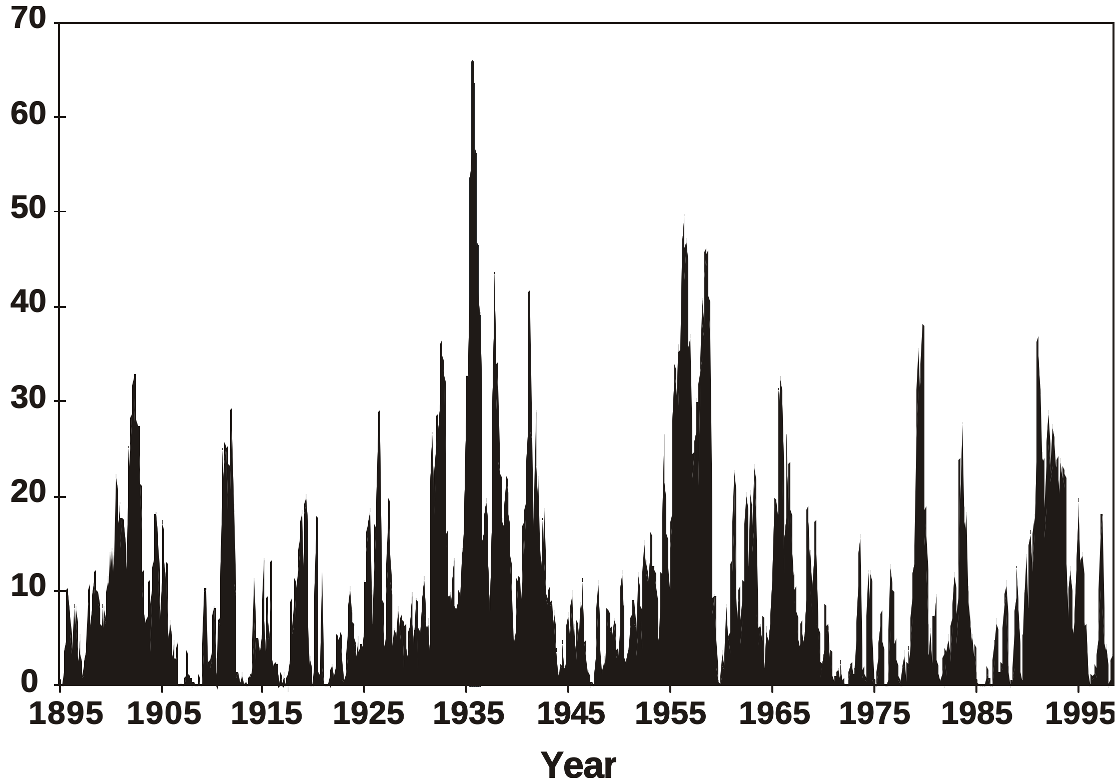

Figure 1. Percent area affected by drought.

Arizona, and Hawaii are in various stages of plan development. Most state drought plans are largely response oriented since they were first developed in the mid to late 1980s or early to mid 1990s. The exceptions are the plans of New Mexico, Utah, Nebraska, and Texas, in which greater emphasis is now being placed on mitigation. These four states will likely serve as models for other states. In the early years of state-level drought planning, Colorado's drought plan served as a model for others to emulate, and many states borrowed heavily from its organizational structure and operating procedures.

In 1991, a 10-step planning process for states in the United States was published as a methodology for plan development (Wilhite 1991). This process was intended to be generic and adaptable to the needs of any level of government in any drought-prone region. It has been widely disseminated at workshops and conferences in the United States and internationally as well as through the literature (Wilhite 1992b, 1996; Wilhite et al. 2000; UNDP/UNSO 2000). The influence of the planning process is clearly evident in plans that have been or are being developed at various levels of government in every drought-prone region. The original version of the planning process (Wilhite 1991), although recognizing the need for developing mitigation tools to reduce the impacts of drought, did not place as much attention on mitigation as is warranted today, given the growing emphasis on risk management in addressing the impacts associated with natural hazards. When first published, this planning process focused more attention on improving governmental response to drought emergencies through development of greater institutional capacity directed at creating an appropriate organizational structure, improving monitoring capability, defining a more explicit decision-making authority for implementing response measures, and improving information flow and coordination between and within levels of government.

As vulnerability to drought has increased globally, greater attention has been directed to reducing risks associated with its occurrence through the introduction of planning to improve operational capabilities (i.e., climate and water supply monitoring, building institutional capacity) and mitigation measures that are aimed at reducing drought impacts. This change in emphasis is long overdue. Mitigating the effects of drought requires the use of all components of the cycle of disaster management (Figure 2), rather than only the crisis management portion of this cycle. In the past, when a natural hazard event and resultant disaster has occurred, governments have followed with impact assessment, response, recovery, and reconstruction activities to return the region or locality to its pre-disaster state. Little attention has been given to preparedness, mitigation, and prediction/early warning actions (i.e., risk management) that could reduce future impacts and lessen the need for government intervention in the future. Because of this emphasis on crisis management, society has generally moved from one disaster to another with little, if any, reduction in risk. In fact, many response measures instituted by governments, international organizations, and donors have actually increased vulnerability by increasing dependency on internal or external assistance. All components of the cycle of disaster management should be addressed in a comprehensive hazards mitigation plan, but greater attention needs to be placed on pre-disaster activities than has occurred in the past.

The goal of the 10-step planning process (Figure 3) is to derive a plan that is dynamic, reflecting changing government policies, technologies, natural resources management practices, and so forth. It is intended to serve as a checklist to identify the issues that should be addressed in plan development, with appropriate modifications. An overview of the steps included in the planning process follows.

In brief, Steps 1-4 (see Figure 3) of the planning process focus on making sure the right people are brought together and that they have a clear understanding of the process and what the drought plan must accomplish and are supplied with adequate data to make fair and equitable decisions when formulating and writing the actual drought plan. Steps 1 and 2 focus on the creation a drought task force (DTF) to supervise and coordinate plan development. When the plan is activated, the DTF will coordinate actions, implement mitigation and response programs, and make policy recommendations to the appropriate person or elected official and legislative body. A generic statement of purpose for a drought plan is to provide government with an effective and systematic means of assessing drought conditions, developing mitigation actions and programs to reduce risk in advance of drought, and developing response options that minimize economic stress, environmental losses, and social hardships during drought. The DTF should define the scope of the plan, the most drought-prone areas and most vulnerable economic and social sectors, the role of the plan in resolving conflict between water users and other vulnerable population groups, current trends (e.g., land and water use, population growth) that may increase/decrease vulnerability and conflicts in the future, and principal environmental

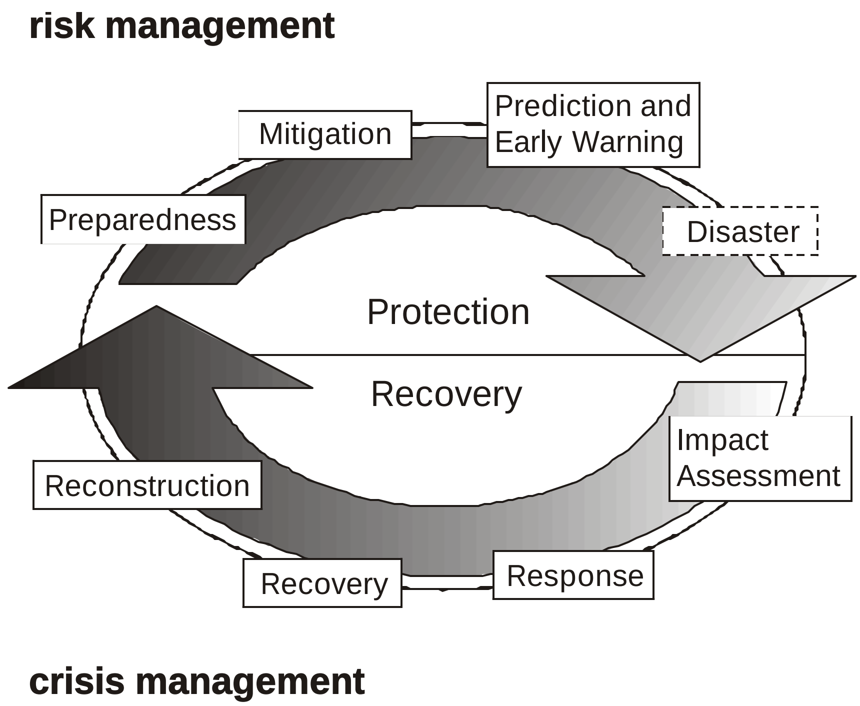

Figure 2. The cycle of disaster management.

concerns caused by drought. The DTF should identify the specific objectives of the plan, which will vary between countries and should reflect unique physical, environmental, socioeconomic, and political characteristics.

Step 1 *Appoint* a drought task force

Step 2 *State* the purpose and objectives of the drought preparedness plan

Step 3 *Seek* stakeholder participation and resolve conflict

Step 4 *Inventory* resources and *identify* groups at risk

Step 5 *Develop* organizational structure and *prepare* the drought plan

Step 6 *Identify* research needs and fill institutional gaps

Step 7 *Integrate* science and policy

Step 8 *Publicize* the drought preparedness plan, *build* public awareness

Step 9 *Teach* people about drought

Step 10 *Evaluate and revise* drought preparedness plan

Figure 3. The 10-Step planning process.

Steps 3 and 4 are directed at involving stakeholders in the planning process, resolving conflict, and conducting an inventory of resources available to the planning process. One of the goals of Step 4 is to complete a preliminary identification of primary groups or areas most at risk because of drought. In drought preparedness planning, making the transition from crisis to risk management is difficult because, historically, little has been done to understand and address the risks associated with drought. To solve this problem, areas of high risk should be identified, as should actions that can be taken before a drought occurs to reduce those risks. Risk is defined by both the exposure of a location to the drought hazard and the vulnerability of that location to periods of drought-induced water shortages (Blaikie et al. 1994).

Step 5 describes the process of developing an organizational structure for completion of the tasks necessary for preparing the plan. Since the focus of this meeting is on drought early warning systems, this step of the planning process will be discussed in greater detail because the establishment of a monitoring or early warning system is critical to the success of the planning process. Steps 6 and 7 detail the need for ongoing research and coordination between scientists and policy makers. Steps 8 and 9 stress the importance of promoting and testing the plan before drought occurs. Step 10 emphasizes revising the plan to keep it current and making an evaluation of the plan's effectiveness in the post-drought period. Although the steps are sequential, many of these tasks are addressed simultaneously under leadership of the DTF and its complement of committees and working groups. The steps in the planning process are part of an integrated planning process rather than a list of discrete tasks. These steps represent a "checklist" of tasks that should be considered and completed as part of the planning process.

Drought Plan Development

Step 5 describes the establishment of an organizational structure for the drought preparedness plan. The drought plan should have three primary components: monitoring and early warning, risk and impact assessment, and mitigation and response. It is recommended that a committee be established to focus on the first two needs; the mitigation and response function can in most instances be carried out by the DTF after receiving input from the other committees. These committees will have their own tasks and goals, but well-established communication and information flow between committees is still a necessity to ensure effective planning.

Monitoring/Early Warning Committee

A reliable assessment of water availability and its outlook for the near and long term is valuable information in both dry and wet periods. During a drought, the value of this information increases. The monitoring committee should include representatives from agencies with responsibilities for monitoring climate and water supply, traditionally meteorological, hydrological, and agricultural services. It is recommended that data and information on each of the relevant indicators (e.g., precipitation, temperature, evapotranspiration, seasonal weather forecasts, soil moisture, streamflow, ground water, reservoir and lake levels, and snowpack) be considered in the committee's evaluation of the water situation and outlook for the country. The agencies responsible for collecting, analyzing, and disseminating data and information will vary according to each country's infrastructure. The monitoring committee should meet regularly, especially in advance of the peak demand season.

The primary objectives of the monitoring committee are:

1. Adopt a workable definition of drought that could be used to phase in and phase out levels of state and federal actions in response to drought. It may be necessary to adopt more than one definition of drought in identifying impacts in various economic, social, and environmental sectors. Several indices are available (Hayes 1998), including the Standardized Precipitation Index (McKee et al. 1993, 1995), which is gaining widespread acceptance (Guttman 1998; Hayes et al. 1999). The commonly used Palmer Drought Severity Index (Palmer 1965) is being replaced or supplemented as a monitoring tool in many states. The trend is for states to rely on multiple drought indices to trigger responses, which are calibrated to various intensities of drought. No single index of drought is adequate to measure the complex interrelationships between the various components of the hydrological cycle and impacts.

It is helpful to establish a sequence of descriptive terms for water supply alert levels, such as “advisory,” “alert,” “emergency,” and “rationing” (as opposed to more generic terms such as “phase 1” and “phase 2,” or sensational terms such as “disaster”). The monitoring committee should review the terminology used by other entities (i.e., local utilities, states, river basin commissions) and choose terms that are consistent for areas where there may be authorities with overlapping regional responsibilities. These alert levels should be defined in discussions with both the Risk Assessment Committee and the Drought Task Force.

In considering emergency measures such as rationing, it is important to remember that the impacts of drought may vary significantly from one area to the next, depending on the sources and uses of water and the degree of planning previously implemented. For example, some cities may have recently expanded their water supply capacity while other adjacent communities may have an inadequate water supply capacity during periods of drought. Imposing general emergency measures on people or communities without regard for their existing vulnerability may result in considerable political repercussions. A related consideration is that some municipal water systems may be out of date or in poor operating condition, so that even moderate drought strains a community’s ability to supply customers with water. Identifying inadequate (i.e., vulnerable) water supply systems and upgrading those systems should be part of a long-term drought mitigation program.

2. Establish drought management areas (i.e., subdivide the state or region into more conveniently sized districts by political boundaries, shared hydrological characteristics, climatological characteristics, or other means such as drought probability or risk). These subdivisions may be useful in drought management since they may allow drought stages and mitigation and response options to be regionalized. Climatic divisions are the most commonly used subdivisions at the state level, but they may not be the most appropriate, given topographic features, land use patterns, or water use characteristics.

3. Develop a drought monitoring system. Most states already have a good data collection system for monitoring climate and water supplies and identifying potential shortfalls. Responsibility for collecting, analyzing, and disseminating the data is divided between many state and federal agencies. The monitoring committee’s challenge is to coordinate and integrate the analysis so decision makers and the public receive early warning of emerging drought conditions. On a national basis, much of this information has been compiled under the Drought Watch section of the NDMC’s web site (http://enso.unl.edu/ndmc/). Two new products, the Drought Monitor and Current Droughts Affecting the U.S., should be noted. This section is also linked to specific state web sites that illustrate how others are organizing information on drought conditions.

   Many states (e.g., Nebraska, Oklahoma, California) and other regions have developed automated weather data networks that provide rapid access to climate data. These networks can be invaluable in monitoring emerging and ongoing drought conditions.

These data can be coupled with data available from federal agencies to provide a comprehensive monitoring of climate and water systems. Data and data products should be disseminated on a timely basis in printed form and via the World Wide Web.

4. Inventory data quantity and quality from current observation networks. Many networks exist that monitor key elements of the hydrologic system. Most of these networks are operated by federal or state agencies, but other networks also exist and may provide critical information for a portion of a state or region. Meteorological data are important but represent only one part of a comprehensive monitoring system. Other physical indicators (e.g., groundwater and streamflow) must be monitored to reflect impacts of drought on agriculture, households, industry, energy production, and other water users. Helpful technology includes soil moisture sensors, automated weather stations, and satellite data such as digital data obtained from the Advanced Very High Resolution Radiometer (AVHRR), transmitted from a National Oceanic and Atmospheric Administration satellite. Satellite data is useful in detecting areas where moisture deficiencies are affecting vegetation growth.

5. Determine the data needs of primary users. Developing new systems for collecting and analyzing data is most effective when the people who will be using the data are consulted early and often. Soliciting input on expected new products or obtaining feedback on existing products is critical to ensuring that products meet the needs of primary users and will be used in decision making. Training on how to use or apply products in routine decision making is also essential.

6. Develop and/or modify current data and information delivery systems. People need to be warned of drought as soon as it is detected, but often are not. Information needs to reach people in time for them to use it in making decisions. In establishing information channels, the monitoring committee needs to consider when people need various kinds of information. These decision points can determine whether the information provided is used or ignored.

   A growing number of states have created web sites that contain current climate and drought-related information, including the state's drought plan and the responsibilities of key agencies. Some of these web sites are listed in Table 1.

Table 1. Drought-related web sites for various states in the United States.

State	Web Site Address
Montana	http://nris.state.mt.us/wis/Swsi/MTDrought2000.html
Nebraska	http://linux1.nrc.state.ne.us/carcunl
New Mexico	http://weather.nmsu.edu/drought
Oklahoma	http://www.state.ok.us/~owrb/features/drought.html
Pennsylvania	http://www.dep.state.pa.us/dep/subject/hotopics/drought/drought.htm
South Carolina	http://water.dnr.state.sc.us/climate/sco/drought.html
Texas	http://www.twdb.state.tx.us/DATA/DROUGHT/drought_toc.htm

Risk Assessment Committee

Drought impacts cut across many sectors and across normal divisions of responsibility for government ministries. These impacts have been classified by Wilhite and Vanyarkho (2000). Impacts are the result of exposure to the drought hazard (i.e., probability of occurrence) and a combination of economic, environmental, and social factors. Therefore, to reduce vulnerability to drought, it is essential to identify relevant impacts and assess their underlying causes.

Information on drought impacts and their causes is crucial for reducing risk before drought occurs and for appropriate response during drought. The membership of the risk assessment committee should represent economic sectors, social groups, and ecosystems most at risk from drought. The committee's chairperson should be a member of the DTF.

The most effective approach to follow in determining vulnerability to and impacts of drought is to create a series of working groups under the aegis of the risk assessment committee. The responsibility of the committee and working groups is to assess sectors, population groups, and ecosystems most at risk and identify appropriate and reasonable mitigation measures to address these risks. Working groups would be composed of technical specialists representing each of the sectors, groups, or ecosystems at risk. The chair of each working group, as a member of the risk assessment committee, would report directly to it. The responsibility of the committee is to direct the activities of each of the working groups and make recommendations to the drought task force on mitigation actions. The number of working groups will vary considerably, reflecting important impact sectors.

A methodology for assessing and reducing the risks associated with drought has recently been completed by the National Drought Mitigation Center (NDMC) (Knutson et al. 1998) and is available on the NDMC's web site at http://enso.unl.edu/ndmc/handbook/risk.pdf. The guide focuses on identifying and assigning priorities to drought impacts, determining their underlying causes, and choosing actions to address the underlying causes. This methodology can be employed by each of the working groups. This effort requires an interdisciplinary analysis of impacts and management options available.

The choice of specific actions to deal with the underlying causes of the drought impacts will depend on the economic resources available and related social values. Typical concerns are associated with cost and technical feasibility, effectiveness, equity, and cultural perspectives. This process has the potential to lead to the identification of effective and appropriate drought risk reduction activities that will reduce long-term drought impacts, rather than ad hoc responses or untested mitigation actions that may not effectively reduce the impact of future droughts.

Mitigation and Response Committee

Mitigation and response actions could be under the responsibility of the drought task force or could be assigned to a separate committee. The task force, working in cooperation with the monitoring/early warning and risk assessment committees, should have the knowledge and experience to understand drought mitigation techniques, risk analysis (economic, environmental, and social aspects), and drought-related decision-making processes at all levels of government. The task force, as originally defined, is composed of senior policy makers from various ministries and, possibly, representatives from NGOs. Therefore, they are in an excellent position to recommend and/or implement mitigation actions, request assistance through various programs, or make policy recommendations to the legislative body or the prime minister/president. Mitigation and response actions must be determined for each of the principal impact sectors identified by the risk assessment committee. Wilhite (1997b) recently completed an assessment of drought mitigation technologies implemented by states in the United States in response to drought conditions during the late 1980s and early 1990s. However, the transferability of these technologies to specific situations in other locations needs to be evaluated.

The U.S. Drought Monitor: An Example of Integrated Climate Monitoring

The need for a national drought early warning system has been acknowledged for some time in the literature as part of a more comprehensive approach to drought assessment and management. Following the creation of the NDMC, one of our first goals was to create a "one-stop shopping" section of our web site that would provide users with access to all of the information necessary to develop a timely and reliable climate and water supply assessment for their state or region. The development of the Drought Watch section was undertaken because no routine national or regional assessment was available. However, all of the components necessary to assess current climate and water supply conditions and the long-range outlook were becoming readily available on the World Wide Web. The goal of the Drought Watch section of the NDMC's web site (http://enso.unl.edu/ndmc/watch) is to provide users with first-hand climate and water supply assessments through products such as the Standardized Precipitation Index (SPI) and also to link to other sites that provide information on snow pack, soil/crop moisture conditions, ground water and reservoir levels, streamflow, fire danger, and seasonal forecasts. In the absence of a national assessment product, the NDMC sought to encourage users to examine products and resources available on the Internet. From these web sites, users could assemble the necessary data and information to assess current climate conditions and longer-range climate and water supply outlooks. The popularity of this type of information has been reinforced over the past 5 years, as the Drought Watch section is the most-often visited of the NDMC web site.

The series of drought years that have occurred since the NDMC was established in 1995 has continued to raise the level of interest in drought planning and, consequently, the importance of effectively monitoring drought and delivering useful and timely information to a diverse set of users. To further that goal, the NDMC, U.S. Department of Agriculture's Joint Agricultural Weather Facility (USDA/JAWF), and the National Oceanic and Atmospheric Administration's Climate Prediction Center (NOAA/CPC) created a joint drought monitoring facility in 1999. The purpose of this partnership was to develop new products collaboratively and bring together existing products under a new web site to provide users with "one-stop shopping." The intent of this new web site was to improve user accessibility to that information and, through the collaborative product development process and user feedback, to improve the quality (i.e., information content and ease of understanding) of climate-related products.

What has evolved from this collaborative effort has been a series of accomplishments that have significantly advanced the information available, its utility, and its resultant application by users to decisions that are climate sensitive. First, the Drought Monitor map integrates information from numerous indices and parameters in the determination of areas experiencing drought and the severity of that drought. A classification system for levels of drought severity has been developed that is similar to that available for hurricanes, tornadoes, and earthquakes. Drought levels are identified as first stage, severe, extreme, and exceptional. Areas that have experienced abnormally dry conditions over a period of time but have not yet reached a "drought" stage are also identified. These areas represent regions of concern or "watch" areas for future reference. An interpretive summary of each week's map is included.

Second, this assessment effort has successfully incorporated local and regional experts in a formal review of the draft map before release. This review group receives the map via an email exploder on Tuesday afternoon each week. This review group is made up of state climatologists, regional representatives of the National Weather Service and other federal agencies, regional climatologists from regional climate centers, hydrologists, and agricultural specialists. The advance review of this product by this group has helped to ensure the validity of the product by providing some ground truth for data analysis and interpretation, as well as for assessments of current impacts.

Third, the Drought Monitor web site also includes links to other web products. Products used in the preparation of the Drought Monitor map are linked, as well as forecast products. In addition, the web site includes information on how the map is developed and an archive of previous maps. The NDMC plans to animate these maps in the near future to help depict the changing nature of intensity and spatial extent over time.

Fourth, user demand for this information and the collaborative nature of product development have helped to spawn additional products in support of the development of this product. For example, the U.S. Geological Survey created a daily streamflow map that illustrates the status of streamflow. This clickable map allows users to interpret streamflow conditions daily at the national, state, or local (stream gauge) level. This product has been extremely valuable in assessing the severity of drought conditions at the local and regional scale since streamflow is one of the first elements of the hydrological system to be affected by prolonged dry conditions. Below-normal streamflow is an excellent indicator of potential impacts on navigation, irrigated agriculture, municipal water supply, recreation, and fish and wildlife.

The first Drought Monitor maps were produced on an experimental basis in May 1999. Because of the severe drought that was affecting the eastern United States in August 1999, the Drought Monitor map quickly became an operational product. The product was released officially at a White House press conference in August and has continued to receive considerable publicity. Not only does it appear weekly in many local, regional, and national newspapers, it is also shown regularly on The Weather Channel. Although the product simplifies a very complex issue, it still seems to capture enough information in an easy-to-interpret format for a diverse audience. At release, it is widely used by commodity brokers in the United States and elsewhere. Since its unveiling, the Drought Monitor has been well received by people from a wide variety of backgrounds and trades. The media has been especially quick to pick up on and use the new product to inform their readers and listeners of current and changing drought patterns. Producers, commodity brokers, congressional delegations, and federal/state agencies also are using this product. Users like the simplicity and ease of use of the product (see Figure 4).

The Monitor consists of a color map (converted to black and white for this publication) showing which parts of the United States are suffering from various degrees of drought, and accompanying text. The text describes the current impacts, future threats, and predicted prospects for improvement. The Monitor is a synthesis of several scientific drought indices. It is by far the most user-friendly national drought monitoring product available. The Monitor is particularly well suited for use by mainstream media because it represents state-of-the-art scientific expertise, packaged as a timely, colorful, unambiguous map. Currently, the World Wide Web is the main means of distributing the Monitor. NOAA also distributes the Monitor through internal channels. The obvious advantages to using the web are that there are no distribution costs, and the information is instantly available, always current, and free. The obvious disadvantage is that not everyone has access to the web. Our focus to this point has been how to best disseminate the product in the most timely manner.

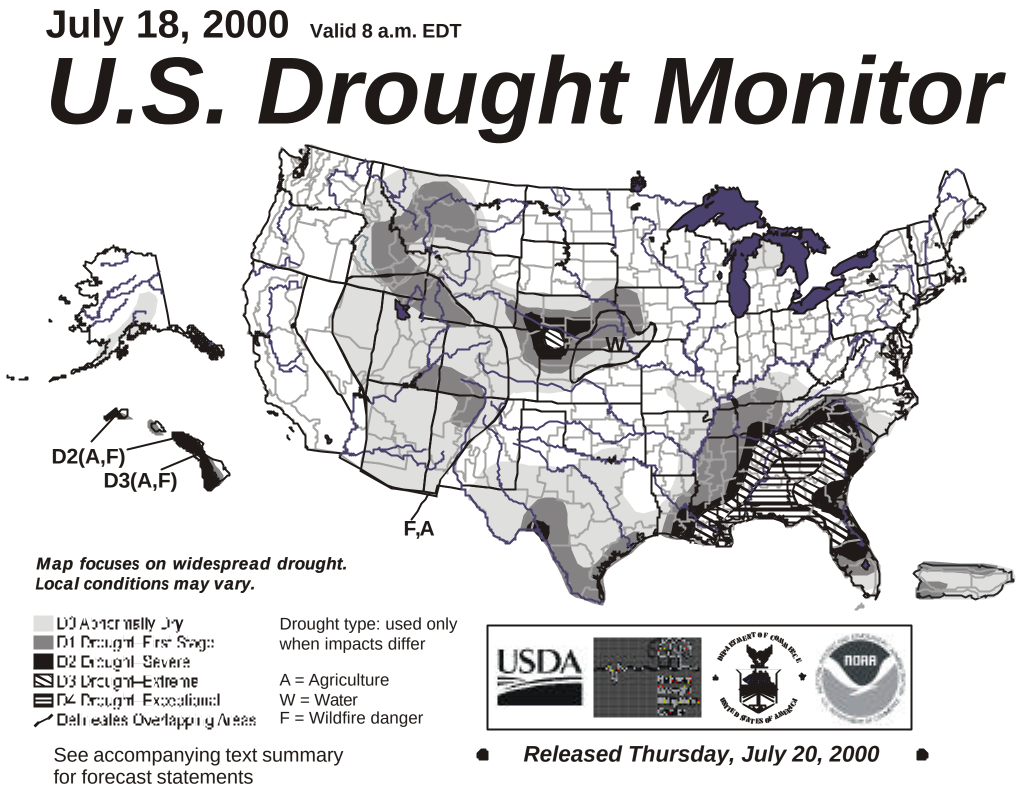

Figure 4. U.S. Drought Monitor.

No single definition of drought works in all circumstances, so water planners rely on indices or data that are most often depicted in map or graphic form to recognize droughts. The Drought Monitor relies on input from several key indices and ancillary indicators from different agencies. The final map is posted each Thursday morning at http://enso.unl.edu/monitor/monitor.html. The seven key parameters making up the current scheme are: Palmer Drought Index, Crop Moisture Index, CPC Soil Moisture Model (percentiles), USGS Daily Streamflow (percentiles), Percent of Normal Precipitation, USDA/NASS Topsoil Moisture (percent short and very short), and the remotely sensed Satellite Vegetation Health Index. The final color map summarizes all of this information in an easy-to-read format that captures where drought is emerging, lingering, and subsiding.

For the Drought Monitor, droughts are classified on a scale from zero to four (D0-D4), with zero indicating an abnormally dry area and four reflecting a region experiencing an exceptional drought event (i.e., comparable to the drought of record). The drought intensity categories are based on the six key indicators mentioned above as well as many supplementary indicators. The Drought Monitor summary map and narrative identify general drought areas, labeling droughts by intensity from least to most intense. D0 areas (abnormally dry) are either (1) drying out and possibly heading into drought or (2) recovering from drought but still experiencing lingering impacts or not yet back to normal or wet conditions.

The Drought Monitor also shows which sectors are presently seeing drought-related impacts. This is accomplished by assigning a label of A, W, or F. The "A" represents observed agricultural impacts on crops, forests, livestock, and range/pasture. Water (W), or hydrological, impacts are meant to show that the region is experiencing an impact on one or more components of the hydrologic or water supply system (i.e., streamflow, snowpack, ground water and reservoirs). "F" is used when abnormally high risks of fire danger are observed.

Two-week forecasts (5-day and 6-10 day) are used to determine which areas may see improvement or a worsening of conditions. Seasonal forecasts are also used in an informal way to identify areas that may see drought develop. These forecasts can generally illustrate what the trend looks like months into the future, especially when an El Niño or La Niña is occurring. Many teleconnections are found within certain regions of the United States depending on the ENSO phase. Some strong correlations do exist between dryness or drought in certain parts of the United States, depending on the season and whether or not we are in an El Niño or La Niña phase. The relationship is not nearly as strong, however, in the primary grain-producing regions that make up our corn and wheat belts. Another problem is addressing the non-phase year, especially in the summer. In fact, the summer months are the toughest to predict, regardless of whether an ENSO event is taking place. Models have improved and will continue to improve as computing power increases and the complex relationships that exist between our oceans, continents, and atmosphere are better understood.

The drought severity classification system that is currently being used in the preparation of the Drought Monitor map can be found at http://enso.unl.edu/monitor/archive/99/classify.htm. The system was intended to be flexible, allowing it to continually evolve by responding to and incorporating the latest technologies and data available.

Conclusions and Future Challenges

Reducing the risks and therefore the impacts associated with drought in the future requires that much greater emphasis be placed on preparedness and mitigation. Preparedness leads to greater institutional capacity to cope with drought events through the creation of an organizational structure that improves information flow and coordination between and within levels of government. Improving our level of readiness or preparedness for drought is about building institutional capacity at all levels of government, as well as improving coordination between levels of government. It is also about increasing the coping capacity of individuals, communities, and governments to handle drought events. Drought preparedness, coupled with appropriate mitigation actions and programs, can reduce and, in some cases, eliminate many of the impacts associated with drought.

This chapter described a drought planning process than can be followed in the development of a drought preparedness plan. A drought plan has three components: monitoring and early warning; risk assessment; and mitigation and response. The monitoring and early warning component of a drought plan is essential because it provides the foundation on which timely decisions can be made by decision makers at all levels (i.e., farmers to national policy makers). Given drought's slow onset or creeping characteristics, monitoring all components of the hydrological system is the only mechanism we have for detecting drought's early onset and its potential impacts on sectors, regions, and population groups. This information serves as the basis for management decisions during both the developing and receding phases of drought, including the timing for the start-up and shut-down of mitigation and emergency response programs that are part of the drought preparedness plan.

Drought early warning systems face numerous challenges. First, data and information on climate and water supply, including seasonal forecasts, must be integrated to provide decision makers with a comprehensive picture or representation of current conditions and future outlooks. This will require much greater coordination between meteorological, hydrological, and agricultural services. Second, improved delivery systems must be developed to get information in the hands of decision makers in a timely manner. This will require a better understanding of user needs and their preferences on how this information is displayed or presented. The World Wide Web provides the most cost-effective and timely mechanism for information delivery, but this technology is not widely available in many countries. Appropriate delivery systems need to be employed. Third, potential users of climate information must be educated on how that information can be applied to reduce the risks associated with extreme climatic events such as drought. Improved communication between the developers and users of products must be established so that products are better suited to user needs and users understand how this information can be applied in the decision process. Currently, many products are not user-friendly and the value of this information is not fully appreciated.

References

Alley, W.M. 1984. The Palmer Drought Severity Index: Limitations and assumptions. *Journal of Climate and Applied Meteorology* 23:1,100-1,109.

Blaikie, P., T. Cannon, I. Davis, and B. Wisner. 1994. At Risk: Natural Hazards, People's Vulnerability, and Disasters. Routledge Publishers, London, England.

Boyd, J. 1996. Southwest farmers battle record drought. United Press International.

Chenault, E. A. and G. Parsons. 1998. Drought worse than 96; cotton crop's one of worst ever. http://agnews.tamu.edu/stories/AGEC/Aug1998a.htm.

Coughlan, M.J. 1987. Monitoring drought in Australia. Pages 131-144 *in* Planning for Drought: Toward a Reduction of Societal Vulnerability (D. A. Wilhite and W. E. Easterling, ed.). Westview Press, Boulder, Colorado.

Gibbs, W. J. and J. V. Maher. 1967. Rainfall deciles as drought indicators. Bureau of Meteorology Bulletin No. 48. Bureau of Meteorology, Melbourne, Australia.

Guttman, N. B. 1998. Comparing the Palmer Drought Index and the Standardized Precipitation Index. *Journal of the American Water Resources Association* 34(1):113-121.

Hayes, M. 1998. Drought indices. National Drought Mitigation Center, Lincoln, Nebraska.

Hayes, M. J., M. Svoboda, D. A. Wilhite, and O. Vanyarkho. 1999. Monitoring the 1996 drought using the SPI. *Bulletin of the American Meteorological Society* 80:429-438.

Jose, A. M., F. O. Magnayon, and F. D. Hilario. 1991. Climate impact assessment for agriculture in the Philippines. Unpublished paper, National Workshop on Drought Planning and Management in the Philippines, Quezon City.

Knutson, C., M. Hayes, and T. Phillips. 1998. How to Reduce Drought Risk. A guide prepared by the Preparedness and Mitigation Working Group of the Western Drought Coordination Council. National Drought Mitigation Center, Lincoln, Nebraska.

Lee, D. M. 1979. Australian drought watch system. Pages 173-187 *in* Botswana Drought Symposium (M. T. Hinchey, ed.). Botswana Society , Gaborone, Botswana.

McKee, T. B., N. J. Doesken, and J. Kleist. 1993. The relationship of drought frequency and duration to time scales. Eighth Conference on Applied Climatology. American Meteorological Society, Boston.

McKee, T. B., N. J. Doesken, and J. Kleist. 1995. Drought monitoring with multiple time scales. Ninth Conference on Applied Climatology. American Meteorological Society, Boston.

Palmer, W. C. 1965. Meteorological drought. Research Paper No. 45. U. S. Weather Bureau, Washington, D.C.

Palmer, W. C. 1968. Keeping track of crop moisture conditions, nationwide: The new crop moisture index. *Weatherwise* 21(4):156-161.

Riebsame, W. E., S. A. Changnon, Jr., and T. R. Karl. 1991. Drought and Natural Resources Management in the United States: Impacts and Implications of the 1987-89 Drought. Westview Press, Boulder, Colorado.

Tannehill, I. R. 1947. Drought: Its Causes and Effects. Princeton University Press, Princeton, New Jersey.

Thurman, J. N. 1998. Oklahoma in grip of new Dust Bowl. *Christian Science Monitor*, 24 August. http://www.csmonitor.com/durable/1998/08/24/pls3.htm.

UNDP/UNSO. 2000. Drought Preparedness and Mitigation in Sub-Saharan Africa. United Nations Office to Combat Desertification and Drought, New York.

Wilhite, D. A. and M. H. Glantz. 1985. Understanding the drought phenomenon: The role of definitions. *Water International* 10:111-120.

Wilhite, D. A., N. J. Rosenberg, and M. H. Glantz. 1986. Improving federal response to drought. *Journal of Climate and Applied Meteorology* 25:332-342.

Wilhite, D. A. 1991. Drought planning: A process for state government. *Water Resources Bulletin* 27(1):29-38.

Wilhite, D. A. 1992a. Drought. Pages 81-92 *in* Encyclopedia of Earth System Science, Vol. 2. Academic Press, San Diego, California.

Wilhite, D. A. 1992b. Preparing for drought: A guidebook for developing countries. Climate Unit, United Nations Environment Program, Nairobi, Kenya.

Wilhite, D. A. and D. A. Wood (ed.). 1994. Drought Management in a Changing West: New Directions for Water Policy. IDIC Technical Report Series 94-1. International Drought Information Center, University of Nebraska, Lincoln, Nebraska.

Wilhite, D. A. 1996. A methodology for drought preparedness. *Natural Hazards* 13:229-252.

Wilhite, D. A. 1997a. Responding to drought: Common threads from the past, visions for the future. *Journal of the American Water Resources Association* 33(5):951-957.

Wilhite, D. A. 1997b. State actions to mitigate drought: Lessons learned. *Journal of the American Water Resources Association* 33(5):961-968.

Wilhite, D.A., M. Hayes, C. Knutson, and K. H. Smith. 2000. Planning for drought: Moving from crisis to risk management. *Journal of the American Water Resources Association* 36(4), in press.

Wilhite, D.A. and O. Vanyarkho. 2000. Drought: Pervasive impacts of a creeping phenomenon. Pages 245-255 *in* Drought: A Global Assessment, Volume 1, (D. A. Wilhite, ed.). Routledge Publishers, London, England.

Role of Early Warning Systems in Decision Making Processes

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Introduction

An early warning system (EWS) can be defined as a system of data collection to monitor people's access to food, in order to provide timely notice when a food crisis threatens and thus to elicit an appropriate response (Davies et al. 1991). Whether it succeeds in its goal of eliciting an appropriate response is dependent on numerous factors, most of which are beyond the control of the EWS. How key decision makers *use* early warning (EW) information is one of the most important factors.

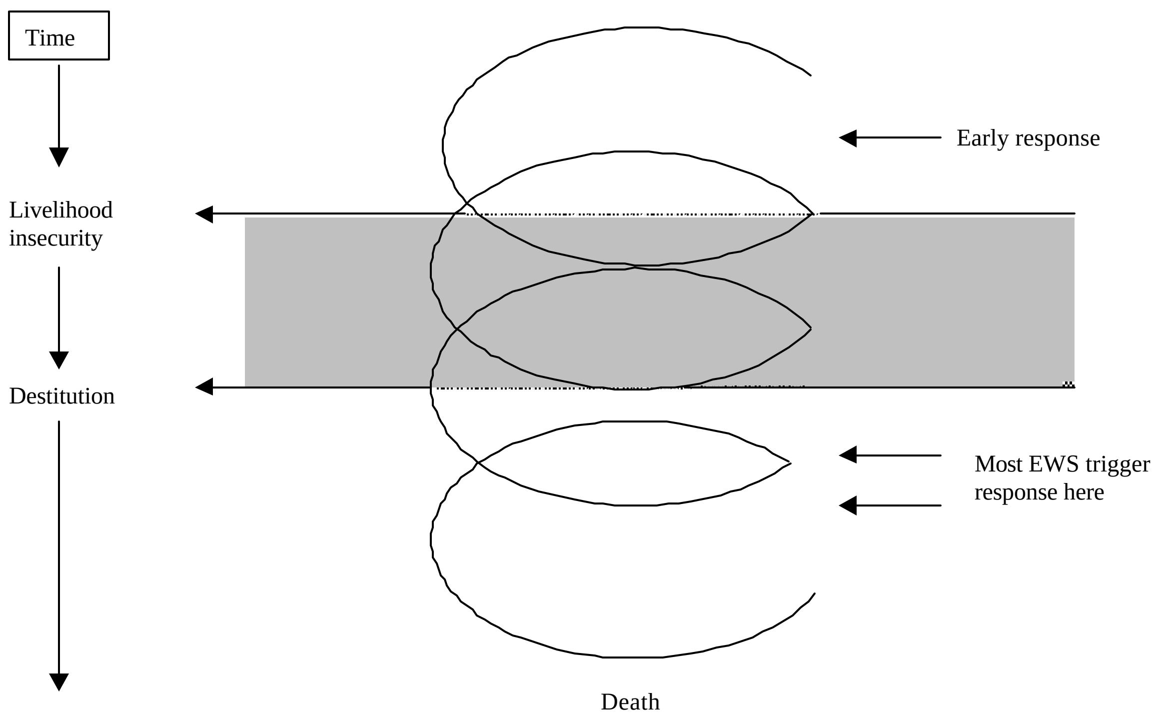
This chapter focuses principally on decision making within donor aid agencies, with brief reference to decision making within the government of the country/area affected. In the most drought-prone and food-insecure countries in the world, a swift and effective response tends to be highly dependent on donor governments. Of course there are numerous other decision makers for whom EW information is useful and important: nongovernmental organizations (NGOs), commercial traders, and farmers. However, EWS in the most drought-prone countries are rarely geared to commercial traders and farmers, although this is beginning to change in countries in southern Africa. NGOs are often dependent on donor governments for the relief resources they need to respond to an impending crisis.

This chapter is based on evidence of how EW information has been used in some of the most food-insecure countries of Africa. This topic was researched in depth in four countries in the Sahel region in the early 1990s (Ethiopia, Sudan, Chad, and Mali) and in Turkana, one of the northern drought-prone districts of Kenya (Buchanan-Smith and Davies 1995). The chapter also draws on a study of response to the 1997 El Niño event in five countries in sub-Saharan Africa (Thomson et al. 1998). And it reflects on the current drought and food crisis in Ethiopia.

What is an Efficient and Effective EW/Response System?

It is of little use to look at an EWS in isolation. To be effective, it must be able to trigger a timely response, intervening *before* the point of destitution is reached, to protect livelihoods before lives are threatened (see Figure 1). In other words, the EW/response system must be geared to protect future capacity to subsist as well as able to ensure current consumption. Thus, the EWS must be sensitive to changes in food security status before famine threatens and able to detect localized pockets of acute food stress.

Figure 1. The timing of response in the downward spiral of famine.



Source: Buchanan-Smith and Davies 1995

To achieve this implies a number of assumptions about the EWS and how it is used. It assumes that EW information is reliable, timely, and consistent; that there are clear processes for feeding the information into decisions about how and when to respond; and that there are clear and rapid response mechanisms in place. In reality, this is rarely the case. The rest of this chapter explores how EW feeds into decision making in practice, factors that determine whether EW information is heeded by decision makers, and why it is not always used to its full potential. The chapter concludes by identifying a number of ways in which the impact of an EWS can be strengthened and a timely response launched.

Factors Affecting the Take-up of Early Warning Information

Ownership of Early Warning Information

Research shows that who "owns" EW information is critical to how it is used. In other words, the source/provider must be known and trusted. Donor agencies have frequently been skeptical of EW information provided by national government EWS, particularly where relations are strained and motives suspected. This was the case in the late 1980s and early 1990s in Ethiopia, under the Mengistu government. In effect, donors set up their own parallel EWS, only trusting the assessments carried out by the Food and Agriculture Organisation (FAO) and the World Food Programme (WFP), even though, in some years, this merely confirmed the figures of the national EWS.

This has since changed in Ethiopia, with the new political regime. It is now common practice for NGOs and the WFP to participate with the government in the teams that carry out the final round of assessments, in order to minimize distrust over figures. Joint assessments involving government, the United Nations, and bilateral donors appear to be increasingly common in countries in sub-Saharan Africa. For example, a joint assessment was launched in Kenya to assess needs in the drought-stricken northeast of the country in late 1996/early 1997, and again to assess the impact of the El Niño floods in 1998. This is an important and positive development in terms of increasing the sense of ownership, and hence acceptance by international donor agencies of needs assessments.

In situations where senior donor representatives have carried out a field trip to the drought-affected area, and have first-hand evidence of an impending food crisis, this has sometimes proved to be the critical trigger to launch (or give much-needed impetus to) the international response. In Chad in 1991, the Systeme d'Alerte Precoce (SAP) organized a field mission of high-ranking donor and government representatives to five of the six Sahelian prefectures. As a result, the more doubtful were convinced of the severity of the food crisis, impressions were conveyed back to agency headquarters, and the response was treated with more urgency than before. Similarly, in Ethiopia last year, an ambassadorial mission to the north of the country in April was important in convincing donors that there was an immediate food crisis. The U.S. Embassy declared an emergency in Wollo two months later, in June. Facilitating this kind of field mission may be an important way of triggering a major response when written EW bulletins have failed to generate a sense of urgency.

A Clear and Consistent Early Warning Message

In the last 10 to 15 years there has been substantial investment in EWS. This has been very important in terms of improving the art of early warning, and developing and refining new methodologies and approaches. However, it has also meant a certain amount of duplication. Although most drought-prone countries will have their own national EWS, it is quite common to find a number of NGO-operated EWS, usually operating on a much smaller scale--for example, covering the particular district/location where the NGO is working. There are also examples of donor-operated EWS, of which the U.S. Agency for International Development's (USAID) Famine Early Warning System (FEWS) is the most developed and best known.

Although it might be argued that this proliferation of EWS enables cross-checking in the interests of greater accuracy, there is also a danger that different EWS generate contradictory information, confusing decision makers and delaying a response. In Ethiopia in 1997, the National Meteorological Services Agency (NMSA) was warning of a higher probability of drought in the main rainy season of 1998 because of El Niño, which FEWS contradicted, saying that the probability of abnormal rainfall was only slightly changed from normal years. More influential in delaying the donor response in 1997 was the lack of consistency of the early warning message over time. Thus, highly publicized figures predicting national food self-sufficiency at the end of 1996 proved to be an inaccurate reflection of reduced relief needs, or of the potential for local purchase to meet food aid requirements. The donor response was "unusually poor and late," delivering less than 15% of estimated relief requirements by December 1, 1997, long after the main hungry season (Thomson et al. 1998:101).

In Kenya, responsibility for EW has been split between a number of different departments at the national level. The absence of a single EW bulletin providing a clear and consistent message is a hindrance to timely decision making, by government and donors alike.

Interpreting Early Warning Information

The predominant response to drought-induced food crisis continues to be food aid, however unimaginative and blunt this may be as an instrument. The challenge is how to translate early warning data into food aid requirements. There are a number of crude and broadly accepted methods around, of which the food balance sheet is the most traditional and widely used. However, some more recent efforts have attempted to refine the calculations, paying more attention to vulnerability and access to food--for example, the Food Economy Approach pioneered by Save the Children (UK), and FEWS vulnerability assessment work. Translating EW indicators into data the decision maker needs may prove critical to triggering a timely response. For this reason, it may be particularly difficult for an EWS to recommend more appropriate nonfood aid means of supporting livelihoods, because this is not the kind of information that donors are geared to respond to.

The study on how El Niño information was used in 1997 shows that interpreting EW information based on probabilities was particularly difficult for decision makers who need to relate it to their own perceptions of risk. By early 1998, some were claiming that the El Niño event had been overblown in southern Africa because of misunderstandings about what the forecasts meant, although ex-post verification shows that the forecast was mostly correct. The problem lay in how the information was interpreted, leaving the researchers to conclude that much has to be done at the national level to customize forecasts and to provide appropriate interpretations (Thomson et al. 1998).

In Kenya, the EWS model pioneered by the Turkana Drought Contingency Planning Unit (TDCPU), which has now been scaled up to cover 10 districts in the north of the country, provides an interesting example of how EW data can be translated and communicated clearly to decision makers. Although monitoring at least 18 indicators, covering the environment, the rural economy, and human welfare, the EWS delivers a simple message to decision makers. By using a predefined sequence of warning stages, from "normal" to "alert" to "alarm" to "emergency," it presents an easily understood summary analysis, directly linked to response interventions (see below).

Donor Bureaucracies and the Use of Early Warning Information

The Quest for Certainty and Quantitative Information

Early warning is an art, not a science. An EWS makes predictions based on analysis of available information, inevitably tinged with an element of judgment. The data are never as comprehensive and accurate as the EW practitioners would like, and the earlier the warning, the less certain it will be.

This feature of EW sits uneasily with the culture of decision making within many donor bureaucracies. This culture is usually risk-averse, seeking quantifiable proof that an emergency is imminent or already exists. Thus, there is a tendency for donor decision making to be driven by downstream rather than upstream events, to be motivated by hard evidence rather than by predictions. How many times have those advocating an emergency response found that the most influential indicators are indicators of human stress, usually expressed as high rates of malnutrition and increased mortality? This can be a fundamental flaw in the EW/response process–waiting for signs of the outcome of *failure* to respond in time.

In early 2000, officials in some donor agencies appeared to be waiting for evidence of increasing and high malnutrition to convince them of the need to respond to the food crisis in parts of Ethiopia. In the politically fraught context of drought in Sudan in 1990-91, indicators had to be "catastrophic," in the words of one agency representative, to be taken seriously and treated with urgency. Even the well-publicized and very early warning provided of the 1997 El Niño event encountered the attitude that "we'll wait until something actually happens" (Thomson et al. 1998).

This wait-and-see attitude is most acute in situations where political relations are least conducive to an early response. It is also accentuated when there is strong competition for relief resources from a number of major emergencies around the world.

The danger of this scenario is that it encourages EW practitioners to bid up the severity of the crisis to attract attention, which may eventually backfire if the situation does not deteriorate to the catastrophic levels predicted. This can undermine the credibility of the EWS.

Bureaucratic Rigidities

Related to this tendency to delay relief decisions until there is clear evidence of a food crisis, most donor agencies do not pledge relief aid to countries in the Sahel and Horn of Africa early until early in the calendar year. However, this pre-supposes that the time lag between decisions being taken and food reaching intended beneficiaries before the start of the hungry season (in June/July – sometimes earlier) is less than six months. Evidence shows that the time lag is often longer, particularly when transport and distribution within the country is taken into account, to reach those affected by the emergency in remote rural areas.

In Ethiopia in 1999, food aid pledges had almost met the government's appeal by May, but by the end of September 1999, at least 3 months after the start of the hungry season, only 281,000t had arrived out of 400,000t that had been pledged.[1] Similarly, WFP's internal procedures for accessing relief resources are protracted, and only triggered once the government concerned has launched its appeal. Then approval for a WFP appeal must be sought in Rome, before being sent out to donors. Eventually food is pledged and dispatched. This whole process can take a number of months. Thus, in 1998 in Kenya, WFP food aid did not reach the drought-stricken northeast of the country until May, some 9 months after the relief operation had begun and 4 months after the government of Kenya had declared an emergency.[2]

The findings of the El Niño study revealed a different type of institutional rigidity, which hampered preparedness and contingency measures. One of the most common responses of national governments to the predictions of an El Niño impact was to set up ad hoc committees, which were most active in pursuing an ongoing dialogue and monitoring, and less successful in modifying existing programs and budgets to take account of the El Niño predictions. Indeed, a number of donors found it hard even to access funds for short-term preparedness initiatives. This applied to the Commission of the European Union (EU) and to the U.S. Office of Foreign Disaster Assistance (OFDA).

In Ethiopia, the study concluded that the "annual relief operation has become so ritualised that it is even difficult for donors to respond quickly to emergency situations that occur outside the 'normal' timeframe" (Thomson et al. 1998:51). This appeared to be a factor contributing to the late response of donors to the food crisis in 2000. The timing of need in pastoralist areas in the south and southeast of the country was not adequately taken into account in the "usual" food relief planning process.

Political Factors Influencing Decision Making

Political Will

Perhaps the single most important factor that positively affects the use of EW information in decision making is the political will to respond, both nationally and internationally. This is something that EW practitioners can do little to influence.

Experience in Turkana district in the early 1990s illustrates this particularly well. There were two episodes of drought: in 1990-91, and a year later, in 1992. In the first episode, the EWS generated reliable information and recommended a response. The District Commissioner was supportive, and donor/government relations were good at the district level. Thus, the political will to respond early was present, resources were made available, and measures were taken to protect livelihoods before lives were threatened. Just over a year later, the context was very different, although the EWS was still firmly in place. At the national level, the government was trying to play down the scale of the drought-induced food crisis, and was more concerned with preparations for the forthcoming multiparty elections. International donors were less well disposed to the Kenyan government, pushing for the transition to multipartyism and for the government to improve its human rights record. The District Commissioner in Turkana was not supportive of a rapid response, and as a result the decision-making body in the district–the District Drought Management Committee–was paralyzed. The relief operation started too late. Although full-scale famine was averted, there was acute food insecurity and human suffering (Buchanan-Smith and Davies 1995).

The relationship between donor governments and the recipient government is usually the key determinant of international political will to respond. Although humanitarian aid is supposed to be exempt from political conditionality, political differences can seriously delay a relief operation if it becomes a pawn in political controversy and negotiation.

This has been the case for North Sudan during much of the 1990s. Antagonistic and distrustful relations between the Sudanese government and western donor governments have meant that the government-held North has received proportionately fewer relief resources than rebel-held parts of the south, despite high levels of need, especially among the displaced population. In 1991, when the Sudanese government was supporting Iraq in the Gulf War, the standoff between donors and government was particularly acute. The new government, which was actively pursuing a policy of food self-sufficiency, was reluctant to acknowledge publicly the severity of the food crisis. Meanwhile, donors insisted that the government admit that there was a humanitarian emergency before they were prepared to launch a major response. This symbolic wrangling over language shows just how political early warning information can become.
In Ethiopia this year, the Emergency Food Security Reserve (EFSR) has been allowed to drop to dangerously low levels. This has been a major factor behind the slow response to food crisis in the south and other parts of the country, partly because some donors were slow to honor pledges to replenish the EFSR after heavy drawdowns the previous year. Although there are a number of reasons for this, some suspect that continuation of the war between Ethiopia and Eritrea, affecting relations between the Ethiopian government and international donor agencies, was a key influence.

Influence of the Media

Dreze and Sen (1989) argue that a free press, which is usually associated with a democratically elected government, is one of the best protections against famine. This, they claim, has been a major positive influence in preventing famine in India.

There are numerous examples of how the international media has triggered an international response. The best-known, and perhaps the best-documented, case was the 1984 famine in Ethiopia, when a famous BBC television documentary exposed to the world the horrific famine that was unfolding, and the international community’s failure to respond in time. On a much lesser scale, international media coverage of the current food crisis in Ethiopia helped to trigger a more energetic and increased response from many western donors earlier this year.

However, acute food insecurity only becomes newsworthy when famine is imminent or already present and the pictures are guaranteed to shock. It is of little use for publicizing genuine *early* warning, with the possible exception of the widely broadcast forecasts associated with El Niño in 1997. In most cases, the media is a last resort for exasperated EW practitioners and others, desperate to trigger a response before famine becomes full-blown.

This relates closely to the issue of accountability. Where lines of accountability between those affected by food crisis and those with the necessary resources to prevent it are clear and effective, there is a much greater chance that early warning signals will be heeded by decision makers. In Kenya, the introduction of multipartyism and an increasingly robust and critical free press have been positive influences in speeding up the response to emergencies of all kinds during the 1990s.

When it comes to international donors, the accountability link to famine victims is extremely tenuous. The latter are far removed from decision making in agency headquarters in Europe or America. The accountability of western donors is usually limited to western public opinion, which may be mobilized by the media to act on behalf of those threatened by famine elsewhere in the world. But, as argued above, this rarely works in favor of *early* warning being heeded. It is most likely to trigger a late response.

Improving the Use of Early Warning Information in Decision Making

Although there is still scope to improve early warning methodology, the greatest challenge facing many EWS is how to ensure that their information is taken seriously by decision makers and acted on to ensure a timely relief response. There are a number of ways of strengthening this link.

1. First and foremost, the EWS must make its information accessible and easy to interpret, and they must deliver a clear, consistent message to decision makers so that they can act on this information. Although this seems obvious, it can be hard to achieve in practice, if information is patchy and methodologies of different EWS conflict.

2. Early warning information is most likely to be used if it is trusted. And it is most likely to be trusted if the decision makers have a stake in the system and really understand it. For this reason, in countries that are dependent on international humanitarian aid to relieve food crisis, it often makes sense for EWS to be jointly funded by donors and by government. In these circumstances, it is more likely that the political influences an EWS is subject to can be negotiated over. And the problem of a purely national EWS being bypassed by the international community insisting on its own assessments is less likely to arise.

3. To counteract the decision makers' tendency to delay a response until there is hard evidence of a crisis, ignoring genuine *early* warning, a phased response could be promoted by the EWS. This particularly applies to donor agencies, where there are long time lags involved in mobilizing, shipping, and transporting relief in-country to the final beneficiaries. Thus, for Sahelian countries, for example, rather than wait for harvest assessments to be complete, which leaves six months or less to mobilize and deliver relief resources, the pledging process

could begin much earlier, in September/October, in response to preliminary estimates of the *minimum* amount of relief that is likely to be required. Although this would require re-programming of donor bureaucracies, and early indicative assessments by the EWS, it could make a substantial difference in the timely provision of relief resources.

4. Where drought is a frequent occurrence, the more that can be done in advance the better, in terms of contingency planning and identifying clear institutional and decision-making responsibility for an emergency response. As far as possible, contingency measures should be integrated into development plans and the development process, so that an appropriate response is expected, indeed is automatic, when drought hits, rather than having to be argued for every time. In other words, bureaucratic inertia works in favor of a response rather than against it.[3]

5. Finally, the pre-positioning of relief resources is one of the best options for ensuring a timely response where international aid is depended on. It can substantially reduce the time lag between early warning information being made available and the necessary relief resources reaching those affected. This may be feasible and cost-effective only for the most drought-prone countries, where emergency relief operations are a frequent requirement. Ethiopia was an obvious candidate, and now has an Emergency Food Security Reserve. Supported financially by international donors, the reserve is managed by a joint committee of donors and government, and is designed to cover the bridging period while relief aid is being imported. The potential of the EFSR to improve the timeliness of the relief response is substantial. However, as described above, even this more long-term facility can be affected by donor/government relations.

Although political will is a key ingredient to ensure that EW information is heeded by decision makers, the above measures should help to ensure that the information is used by decision makers and that the right mechanisms are in place to facilitate a timely response.

Footnotes

[1] Fortunately the EFSR could be drawn on for relief food-see below.

[2] Fortunately for the drought-stricken district of Wajir, OXFAM filled the breach until the WFP food arrived, distributing food aid purchased locally with funds from the UK's Department for International Development (DFID) (Buchanan-Smith and Barton, 1999).

[3] This was a key feature of the innovative EW and response system designed for Turkana district in the late 1980s. Each of the four warning stages, described above, was linked to a pre-determined set of responses that was supposed to be triggered automatically, although the "how" of implementation has sometimes proved problematic.

References

Buchanan-Smith, M. and S. Davies. 1995. Famine Early Warning and Response – The Missing Link. Intermediate Technology Publications, London.

Buchanan-Smith, M. and D. Barton. 1999. Evaluation of the Wajir Relief Programme: 1996-1998. For OXFAM. ODI, London.

Davies, S., M. Buchanan-Smith, and R. Lambert. 1991. Early warning in the Sahel and Horn of Africa: The state of the art. A review of the literature. Volume 1 of 3, Research Report No. 20. IDS, Brighton, U.K.

Dreze, J. and A. Sen. 1989. Hunger and Public Action. Clarendon Press, Oxford.

Save the Children (UK). 1999 and 2000. Various documents related to the current food crisis.

Thomson, A., P. Jenden, and E. Clay. 1998. Information, risk and disaster preparedness: Responses to the 1997 El Niño event. Research Report DFID ESCOR No.AG1215. SOS Sahel, London.

Drought Science and Drought Policy in Australia: A Risk Management Perspective

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Abstract

This paper describes Australian science about, and policies to deal with, drought from a risk management perspective. Coverage includes a review of recent policies, the role that the Bureau of Rural Sciences (BRS) plays within the Commonwealth Department of Agriculture, Fisheries and Forestry-Australia in relation to drought, and Australian examples of seasonal forecasting tools and services.

Background: Australia's Drought Policies in the 1990s

The National Drought Policy (1992)

Australians farm an island continent where production agriculture operates in a highly unreliable climate. Up to 80% of Australia's agricultural products are destined for the international marketplace, where prices fluctuate in an increasingly open and competitive economy. These two sources of risk—the recurring cycles of drought and changing economic values for commodities—are two very significant drivers of risk in Australian agriculture.

Policies that provided direct subsidies and other forms of support to underwrite drought risk were phased out in 1992 with the inception of the National Drought Policy, developed by Australia's Commonwealth and state governments through the policy development process at ARMCANZ (Agriculture and Resource Management Council of Australia and New Zealand). The three principles of the policy are to

1. encourage primary producers and other sections of rural Australia to adopt self-reliant approaches to managing climatic variability;
2. maintain and protect Australia's agricultural and environmental resource base during periods of extreme climatic stress; and
3. ensure early recovery of agricultural and rural industries, consistent with long-term sustainable levels.

The core principle, *self-reliance*, maintained that farmers and regional professionals were in the best position to develop the agronomic systems, practices, and business strategies that would manage frequent agronomic droughts in Australia. This moved Australia's drought policy away from a subsidy-based, reactionary or "crisis driven" approach. The setting was created in which drought is considered a normal part of the Australian farming environment. State and

Commonwealth governments negotiated the staged removal of subsidy-based support for drought, including transaction-based business support particularly for transport, water, and livestock provided by state and territory governments. The framework focused rural Australia on developing risk management strategies to manage climate and market variability.

Following our (BRS) experience with evaluating drought in the 1990s, the concept of self-reliance is one of the key principles for understanding Australia's approach to managing drought. In the long run, it is hoped that through continued improvement of risk management strategies, future meteorological (i.e., deficiency in rainfall) droughts will have decreased impact on agricultural production.

Drought Exceptional Circumstances (DEC, 1995)

In 1994-95, much of eastern Australia was gripped by a severe meteorological drought. Analyses demonstrated that rainfall during this period was in the lowest 5% of historical observations for some locations. In some subregions, pasture availability and crop yields were the lowest or second lowest in the 100-year record. At that time, the government developed the policy of Drought Exceptional Circumstances (DEC), allowing the Commonwealth Minister for Agriculture to allocate business and welfare support for affected producers.

After consulting the states and territories, a national framework for assessing DEC was established (ARMCANZ resolution 1F, August 18, 1995). While acknowledging the principles of the National Drought Policy, the framework noted circumstances that warranted direct government intervention. These were defined as rare and severe events: rare being a 1 in 20 year event, and severe being either more than 12 months or at least 3 consecutive failed seasons, depending on the nature of the production system being considered. The framework revolved around the assessment of 6 criteria:

1. meteorological conditions;
2. agronomic and stock conditions;
3. water supplies;
4. environmental impacts;
5. farm income levels, and
6. scale of the event.

The agreement stated that DEC would be indicated when the combined impact on farmers of the six criteria was a rare and severe occurrence, and that meteorological conditions would be the threshold or primary condition. Drought support continued until it could be demonstrated that climatic and agronomic conditions had returned to a level that was considered normal.

The Rural Adjustment Scheme Advisory Council (RASAC), with representatives from government, rural industry, and the farming community, was the key advisory body, reporting to the Commonwealth Minister for Agriculture, while the final decision rested with the Commonwealth government's Cabinet of Ministers. The assessment was based on a formal application from the state government in which the affected region was located. RASAC also sought independent information, including scientific analysis from the Bureau of Rural Sciences.

Exceptional Circumstances (1999)

The use of rainfall as the trigger or core criterion attracted considerable controversy, with debates between state and Commonwealth analysts regarding the effectiveness of rainfall and its use in the DEC decision-making process. Notwithstanding the validity of either perspective, the government formally broadened the concept of DEC to Exceptional Circumstances (EC) in 1997. This acknowledged that other risks—outside or relating to rainfall variability—such as pests, disease, frosts, and waterlogging—would be formally considered in an assessment. Assessments of "multiple peril" created challenges, particularly in the integration of different events with meteorological drought.

The Commonwealth Government's *Agriculture—Advancing Australia* package recognized that there are exceptional circumstances beyond the scope of normal risk management, and in these exceptions the government should provide assistance. In 1999, new criteria were agreed to by the Commonwealth and states (ARMCANZ Resolution 3D, March 5, 1999), specifically:

1. the event, or events, must be rare and severe;
2. the effects of the event, or events, must result in a severe downturn in farm income over a prolonged period; and
3. the event must not be predictable or part of a process of structural adjustment.

The key indicator, a severe income downturn, should be tied to a specific rare and severe event, and be beyond normal risk management strategies employed by responsible farmers.

The ARMCANZ criteria define rare events as those that occur, on average, once every 20 to 25 years. The event is severe if it lasts for a prolonged period, or more than 12 months, and is of a scale to affect a significant proportion of farm businesses in a region.

The Role of the Bureau of Rural Sciences in Drought Assessment

Risk Assessment Framework

Risk assessment involves the application of analytical tools to decision making, as well as the development of communication and management strategies that appropriately deal with uncertainty and the perception of risk. In Australia, generic approaches to risk assessment, like the Australian Standard in Risk Management (Australian Standard 1999), have been refined and applied to climate risk assessment for implementation of drought policies like EC. There are a number of key lessons, discussed briefly below, from our experience with the application of these approaches to drought risk assessment.

Risk analysis is a decision-making tool and needs to be distinguished from research science (Morgan and Henrion 1990). Described as a trans-science (Jacob and Hellström 1998), analysis for decision makers is driven by a policy problem, in this case the diagnosis of a rare and severe drought event. This contrasts with research science, where the problems and approaches are fundamentally driven by the research paradigm.

The application of analysis methods from scientific research to a policy problem is not always seamless and there may need to be substantial revision to refine these into risk analysis tools. Correspondingly, the routine application of risk analysis tools will not provide the perfect scientific analysis for every policy problem. The risk analyst must decide if it is appropriate to undertake analysis with the existing techniques or to return to scientific theory for a more adequate solution. Our approach has been to maintain an ongoing dialogue with decision makers and the research community, allowing continued innovation in the development of risk analysis tools and methods.

Ultimately, it is the responsibility of the risk analyst to form a defensible judgment for decision makers addressing uncertainty. The judgment is focused on addressing the policy problem, allowing the analysis to drive the answer, and is based on the best available scientific evidence. (Interestingly, this evidence usually evolves and sometimes improves over time.) There are usually no single answers, models, or solutions to these types of problems, and model selection in risk analysis is important in forming the final judgment.

Because of the direct linkages between analysis and a policy problem, risk analysis is not (or should not be) a "black box" or a linear process. Risk analysis is iterative and will be refined through a number stages. Both the analysis and the policy question can be refined throughout these iterations. One approach to ensuring the objectivity and independence of a risk analysis is to clearly frame the policy problem, defining how far the objective analysis can be taken and where the value judgments of decision makers will influence decisions.

Uncertainty is a component in all analyses, judgments, and decisions, including those relating to drought in Australia. A common approach to dealing with uncertainty in decision making has been to ignore it. However, when uncertainties are important, this can create an "erosion of trust" in the final outcome and lead to the eventual rejection of objective analysis from future decisions. There is opportunity for risk analysts to identify and communicate, in plain English, the important uncertainties throughout the iterations of a risk analysis.

There have been few attempts to systematically analyze uncertainty in climate risk assessment. We have developed the *Integrated Toolset* (discussed in the section on evaluation) to allow uncertainty to be estimated and tracked in the analysis of future regional-scale droughts in Australia using rigorous statistical techniques. This risk analysis tool will also provide flexibility in the geographic scale of analysis, allowing greater precision to be achieved through each iteration of climate risk analysis. Importantly, the modeling approach allows tracking of model and measurement errors throughout these iterations.

Most failures of risk assessment point toward a loss of trust between the stakeholders, the analysts, and the "expert judgments" on which the decisions are ultimately based (Slovic 1997). This can impede the flow of pertinent information between these players, creating inefficiencies and leading to more uncertainty in final decisions and inevitably more publicly controversial outcomes. This is certainly the case in the DEC process in Australia, where there were reported attempts of state and territory governments and farmer organizations to exploit perceived shortcomings in information and analytical systems, in an effort to have more Commonwealth funding channeled to local communities (White and Karrises 1998).

Strategies involving rural communities, states, and the Commonwealth exist in Australia to improve the communication of drought policy rationale, its implementation, and analysis; these have been beneficial in some evaluations. Communication is a major problem with the current EC assessment processes. Some stakeholders don't understand or accept the rationale or methods used in the process. Many see the objective analysis undertaken in the review process as a "black box" and do not trust the results of the scientific modeling undertaken by BRS and others. Those affected by decisions often question the long-term historical perspective that is taken to define rare and severe events.

Although there are no easy answers, communication is one area where we are looking to improve future evaluations of drought and other events that affect agriculture. However, risk theorists suggest that communication alone will not lead to a more equitable risk assessment process, and that there may be benefits in the development of mechanisms that do not, or only partially, rely on trust. There may be opportunities to develop approaches that manage trust with appropriate checks and balances (Slovic 1997). Moves toward a more participatory drought response strategy and a full partnership between the states and Commonwealth are being considered as possible future directions in Australia.

General Approach to Assessing Drought Applications

(see also: http://www.affa.gov.au/csg/rpc/excirc/handbook/contents.html)
As part of the EC assessment process, the BRS is called on by NRAC (the National Rural Advisory Council, the successor to the Rural Adjustment Scheme Advisory Council, or RASAC), to integrate available scientific evidence and provide interpretation with the aid of models and expert opinion (ARMCANZ Resolution 3D, March 5, 1999). NRAC advises the Commonwealth Minister on matters relating to Exceptional Circumstances and other agricultural issues, providing balanced judgment in a decision-making environment that is subject to uncertainty. The level of expertise provided by NRAC is crucial to the review process, particularly in cases that are marginal. In formulating its decision, NRAC also draws on advice from the Australian Bureau of Agricultural and Resource Economics (ABARE) for analyses of income and financial data.

In addition, a selection of NRAC members visits the application area during the process of assessment, providing opportunity for producers to individually or collectively state their case for assistance. The field visits are an important phase of the assessment process. They provide opportunity for NRAC to consult with a wide range of stakeholders, gain on-ground reports of conditions, and collect the information necessary to make informed judgements. The BRS is generally invited to accompany NRAC on these visits and uses these opportunities to collect additional data and information from local agricultural professionals.

The formal assessment methodology used by the BRS in its assessment can be characterized as a two-stage process.

The first stage establishes the context in which agriculture operates in a given region, whereby climatic, production, and natural resource variability are described. The risk characterization is achieved in part by analysis of Commonwealth Bureau of Meteorology climate records, application of production data from the Australian Bureau of Statistics, (in some cases) grass growth and production simulation studies, monitoring from satellite (remote-sensed data), and sourcing published agronomic research. Information, usually published material that is also available to producers, is collected to provide a preliminary appraisal of risk management strategies in the region. A high level of consultation is maintained with independent industry professionals and recognized experts.

The second stage is the formal risk analysis in which the event—be it climatic or otherwise—is analyzed to determine its historical frequency and its agronomic impact. Analysis methods, described in further detail below, generally involve assessment of climate records, application of crop or pasture simulations, production monitoring from field trials, and the interrogation of remote-sensed data. The risk analysis determines, on balance, if the objective indicators provide evidence of a 1 in 20-25 year event that can be linked to a severe decline in producers' income, as is required for declaration of Exceptional Circumstances (ARMCANZ, 1999).

Evaluation

The BRS receives a range of evidence relating to an EC case in the form of a submission or case provided by the state or territory concerned, as described earlier. In addition, it may undertake additional analysis as described below.

Climate data are analyzed to determine background temporal rainfall distribution and variability—based on approximately 100 years of records—as well as to characterize the specific event against this 100-year background. Analyses are carried out using point and spatially continuous data.

Point Data (Climate)

Point-based analyses might include simple presentations of specific events and their long-term historical context; the former is usually expressed in both millimeter and percentile terms while the latter is usually in millimeters only. This kind of analysis is usually performed using a commercial spreadsheet program and assists in establishing prima facie whether an event is near the 1:20 (or 5th percentile) level. A series of moving averages, ranging from 1-month to 36-month moving windows, can be used at this stage to determine the temporal scale of the drought event (Smith and McKeon 1998). Figure 1 shows an analysis of rainfall in millimeters for a site in southern Australia using four different averaging "windows" (similar analyses are performed on rainfall expressed as percentiles).

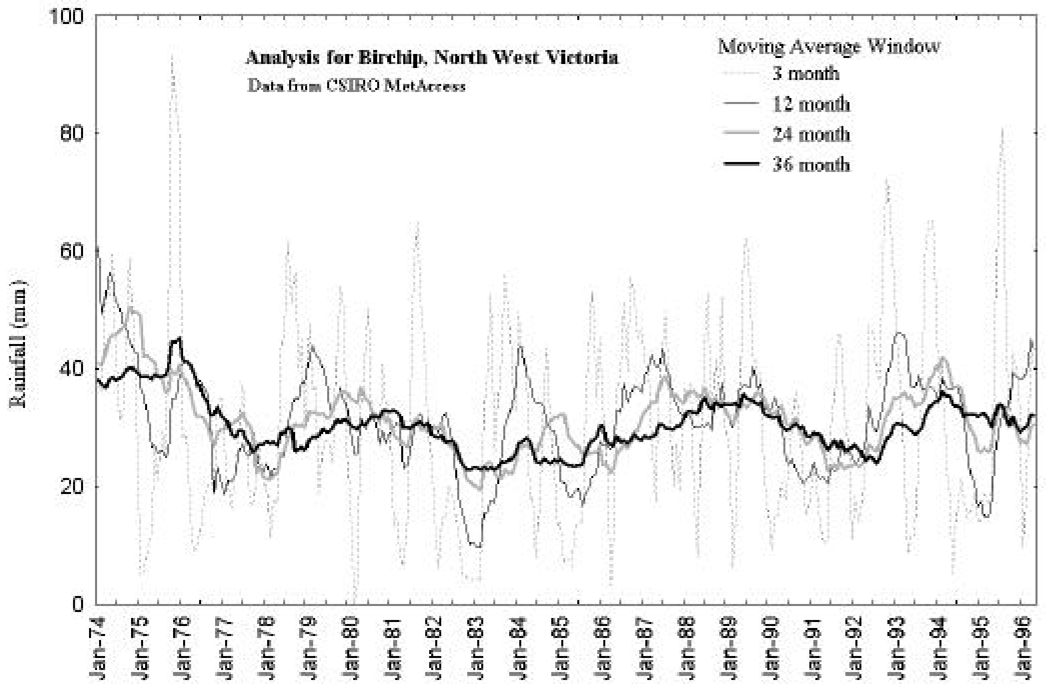

Figure 1. An example of the use of moving averages to determine the temporal scale of drought events using different averaging windows and applied to 20 years of observed rainfall at a site in southern Australia.

It is important to note that this is not the final indicator of an exceptional drought; for example, there have been instances in which a 5th percentile drought was apparent at an 18-month time scale while the important agronomic production season (spring) within this 18-month period was at the 60th percentile. Generally, periods greater than 12 months having rainfall at the 5th percentile, with failed production seasons within this period, are considered for further analysis. If one or more sites (points) appear to be close to this threshold, the BRS usually proceeds to produce maps (i.e., as continuous surfaces) derived from these points, since conditions between the points are equally important, if not more so, than those experienced at the measuring sites.

Spatial Analysis

Other sources of information, particularly useful in broader regional contexts, are maps of both long-term and specific events based on gridded rainfall data from the Commonwealth Bureau of Meteorology. The grids are computer generated using the Barnes successive correction technique. This technique applies a weighted average to data reported within set grids across Australia (Jones and Weymouth 1997). On most maps, each grid represents a square area with sides of approximately 25 km. The size of the grids is limited by the relative sparsity of rainfall measur ing stations in some areas of Australia.

Data from individual stations can be variable in length and continuity, whereas the gridded data provides a continuous record of rainfall for at least 100 years across all of Australia. Thus the gridded data, in particular, lends itself to a diverse range of statistical analyses that can be based on continuous periods of time—for example, months, seasons or years—or on repeated periods of time such as sequential production periods.

It is important to note that the BRS also independently analyzes rainfall records from non-official stations, where these are available. This enables a cross-check of the gridded data, and addresses any queries with regard to smoothing that can be inherent in some of the more data-rich areas when using the Barnes successive correction technique. This is particularly the case in regions of marked spatial climate variability.

This sort of analysis is useful for determining broad-scale climatic features where broad-scale topographic features and mesoscale climatic processes influence rainfall patterns. Alternatively, maps of rainfall reliability may be produced, meaning maps of the probability of receiving the seasonal average in a predetermined way. Such maps are useful for determining whether rainfall is likely to be distributed through a season or more likely to be the consequence of a few large-volume rainfall events, based on the analysis of historical records. This latter technique has been made a relatively simple task through the development of the BRS Rainfall Reliability Wizard (see, for example, http://www.brs.gov.au/agrifood/reliability.html).

Experience in applying this model framework has shown that the 25 km spatial resolution can be deficient in some cases, particularly where small application regions are defined by the states, or when the application boundaries bisect one or more of the grid cells. It was also difficult in some cases to explain the interpretation of this output at this scale to local producers, decision makers, and agricultural professionals who were not climate scientists. There was a need to develop a more flexible and robust modeling framework that could be applied within the timeframe of the assessment process and improve the communication of factors that influence rainfall at local scales.

To achieve this, the BRS's *Integrated Toolset* project has enabled sophisticated surface fitting and contouring routines as described in Hutchinson (1998a, 1998b), and known as ANUSPLIN, in a desktop Geographic Information System (GIS). The model framework is currently being coupled with a data warehouse called SILO (http://www.dnr.qld.gov.au/longpdk/) to provide a real-time operational tool for drought risk analysis. This system has the following features and capacities:

- ANUSPLIN surface-fitting and contouring routines for creating grid or raster "surfaces" from point features that may be irregularly spaced, noisy sample points (e.g., fitting a continuous surface to point rainfall data).
- The capacity to perform statistical interpolation as well as three-dimensional modeling of rainfall processes, allowing finer, "local scale" spatial resolution in model output.
- The capacity to interpolate existing grid surfaces to a user-defined extent and cell size.
- Explicit spatial error diagnostics.
- The capacity to query grids, points, lines, and polygons in a similar manner (e.g., produce spatial statistics for grids underlying user-defined areas like pasture trail paddocks or EC application areas).
- The capacity to accept user-defined and spatial coordinate inputs (e.g., keyboard entry of latitude and longitude of the location of a "weather station" or sample point).

Remote Sensing

Reflective remote sensing is used operationally in the assessment of drought in Australia (McVicar and Jupp 1998). Generally, two standard sources of data are used: reflectance data from the NOAA Advanced Very High Resolution Radiometer (AVHRR) and Thematic Mapper (TM) data from the LANDSAT earth resources satellite system (LANDSAT 6). In the assessments of frost impact on cereal production in 1998, NOAA thermal remote sensing was employed. To assess widespread flooding in the same year, an integration of LANDSAT, SPOT (Systeme Probatporie d'Observation de la Terre), and RadarSat data was commissioned.

For assessment of the impact of drought on vegetation in an application region, a standard multispectral transformation is applied to two-week composite AVHRR data: the Normalized Difference Vegetation Index (NDVI). At 1.1 km^2 resolution, imagery from this approach provides a spatial estimate of plant greenness across an application area.

Temporal analysis can also be carried out on constrained sets of pixels, usually chosen to be representative of the application area, and if possible free from significant tree cover. The NDVI time sequences allow between-year comparison of vegetation flushes, as well as estimation of the rates of senescence and vegetation decay in landscapes. Examples of these types of analyses are available at the Environment and Resources Information Network (Environment Australia) website at http://www.environment.gov.au/psg/erin/satellite/.

When an application area is spatially small, risk characterization can be assisted by the classification of LANDSAT TM data. At 30-meter resolution, this enables maps of land uses, such as pasture communities, irrigation areas, and the spatial extent of cropping infrastructure, to be generated. Our techniques include the following: standard image analysis; unsupervised classification using clustering algorithms; supervised classification using maximum likelihood rules; radiometric image enhancements like density slicing and convolution filtering.

In assessing regional droughts, there can be considerable advantage in integrating LANDSAT TM and AVHRR data with each other and with other data sources, including cadastral layers, appropriately scaled climate surfaces, and, importantly, verification from field-based assessment. The *Integrated Toolset* provides the software platform to achieve this level of integration on a portable computer. Field-based verification can range from spatially referenced pasture trials to observations of pest population density to photographs spatially and temporally referenced by producers in a region. Portable Global Positioning System (GPS) technology has been tested on field visits to application areas and has aided in the internal analysis of data by BRS, but has not been presented in formal reports to decision makers.

It is important to note that the NDVI is a measure of plant greenness, and there are limitations in applying the index to assessment of agricultural production. There can be discrepancies between the level of green "flush" monitored by the NDVI and plant growth: "green droughts" and false autumn breaks occur frequently in southeastern Australia, while trees in woodland areas can affect the index.

The enhanced NDVI or eNDVI refers to a research project (in progress) being conducted by the BRS and its collaborators (CSIRO Divisions of Land and Water and Atmospheric Research).

The research is investigating approaches to take the current measure to one of direct assessment of biomass. The basic methods here include the "un-mixing" of satellite pixels to separate tree, annual, and perennial grass components and linking the grass components to biomass estimates via deterministic pasture models, including that of Kumar and Monteith (1981). This project is due for completion in June 2001.

Pasture and Crop Simulation

Debates regarding the effectiveness of rainfall for crop or pasture production led to considerable research and application of simulation studies in many of the original DEC reviews, and similar studies have been applied tactically in the assessment of EC. Generally, simulation involves the computer generation of historical production data (output) from daily climate record (input), given the modifiers of soil moisture balance, varietal differences in plant growth represented by mathematical functions, and (in some models) simulated management tactics. Once the historical production record is simulated, frequency and impact risk analyses are conducted on the data set. This approach offers the advantage of a longer-term production record, but (usually) only as far back as 1956 because of constraints in Australia's recording of daily temperature.

Caution should be adopted when applying simulation studies to decision making. It is important to ensure that the models have been well calibrated for a given production system and regional setting, and that an independent validation has been included in the study. Without considerable work to achieve a high level of precision, many simulation studies will not have the sensitivity to depict the difference between a 1 in 10-15 and a 1 in 20-25 year event.

A number of research groups produce real time output or provide the modeling frameworks to simulate the influence of climate variability for most of Australia's agricultural regions. We cannot hope to provide a full directory of all of these groups, but we refer you to the work carried out by a number of researchers:

- The construction of the National Drought Alert Strategic Information System by the Queensland Centre for Climate Applications (Queensland Department of Natural Resources). This project delivers national-scale simulation using the GRASP modeling framework, and involves ongoing work with other state government agricultural departments to validate and calibrate the model (see http://www.dnr.qld.gov.au/longpdk/). It has improved the level of drought preparedness for many of Australia's regions. Similar work, applying the APSIM model to wheat production, is also being conducted.
- The temperate production system models GRAZFEED and GRASSGRO have been developed by the CSIRO Division of Plant Industry and in collaboration with state governments from southern Australia (Donelly et al. 1998). This type of model has been applied as a decision support tool to facilitate tactical on-farm decision making and provide information for benchmarking climate risk management practices, and as a tool in farm group facilitation. There are many success stories in which farm groups and extension officers have integrated the model into existing research and extension activities.

- The wheat production system simulator STIN, produced by Agriculture Western Australia, provides regular within-season output, providing information to assist producers and grain traders in making within-crop decisions relating to drought (Stephens 1998).

Australian Examples of Seasonal Forecasting Tools and Services

It is important to note that seasonal forecasting or "outlooks" per se are not part of routine *assessments* of DEC and EC submissions, although they may be used in consideration of revoking areas from DEC; for example, a number of months in the growing season at or above the 40th percentile rainfall—in combination with a favorable seasonal outlook—may be sufficient to revoke an area from DEC assistance. Having said that, seasonal forecasting is an increasingly important aspect of drought management at the farm and policy level, as it has proved to be a valuable early warning tool. Through the strategic use of seasonal forecasting, Australia is in a position to significantly improve some aspects of drought preparedness.

Under the Commonwealth's *Agriculture—Advancing Australia* package, funding is administered by the Land and Water Research and Development Corporation to the Climate Variability in Agriculture Program (CVAP). An important focus of CVAP is the continuing development of Australia's capacity to forecast the seasons ahead. Australia has a considerable climate and seasonal forecasting community, which is linked to similar efforts all around the world. The following are examples only. Approaches include Global Circulation Models (GCM), with and without coupled oceans; use of analogue seasons and years; and Southern Oscillation Index (SOI)-based statistical approaches. A wide range of point-based and spatial outputs is available with various lead times, for various seasonal lengths, and based on different models and approaches.

Commonwealth Bureau of Meteorology

The Commonwealth Bureau of Meteorology offers a range of products and services (see http://www.bom.gov.au/climate/ahead/). For example, at this writing, they have made available continental-scale maps that show the probability of exceeding the median rainfall, August 2000 to October 2000. Similar maps are provided for maximum and minimum temperatures, along with explanatory text. The Bureau also provides a wide range of other climate and weather products online.

Queensland Departments of Primary Industry and Natural Resources

In recent years the Queensland Departments of Natural Resources and Primary Industries have undertaken significant research, development and extension aimed at improving management for climatic variability. As shown in their web site (http://www.dnr.qld.gov.au/longpdk/), they offer a range of decision-support information services, tools, and training developed to help clients to better manage climatic risks and opportunities. Importantly, this service is aimed very much at agriculture and agricultural prediction. For example, tropical and sub-tropical grasses are simulated on a 5 km grid and have been calibrated for a broad range of pasture communities, soil types, and climatic conditions, and when linked to seasonal outlooks can provide agronomically relevant risk management information.

References

ARMCANZ. 1999. Exceptional Circumstances Guidelines, Resolution 3D. Commonwealth of Australia.

Australian Standard. 1999. Risk Management. AS/NZS 4360:1999, rev. ed. Standards Australia, Sydney, NSW, Australia.

Australian Standard. Risk Management (AS/NZS 4360:1999). Standards Australia ™, Revised Edition 1999.

Donnelly, J.R., M. Freer, and A.D. Moore. 1998. Using the GrassGro decision support tool to evaluate some objective criteria for the definition of exceptional drought. *Agricultural Systems* 57(3): 301-313.

Hutchinson, M.F. 1998a. Interpolation of rainfall data with thin plate smoothing splines: I. Two dimensional smoothing of data with short range correlation. *Journal of Geographic Information and Decision Analysis* 2(2): 152-167. http://publish.uwo.ca/~jmalczew/gida_4.htm

Hutchinson, M.F. 1998b. Interpolation of rainfall data with thin plate smoothing splines: II. Analysis of topographic dependence. *Journal of Geographic Information and Decision Analysis* 2(2): 168-185. http://publish.uwo.ca/~jmalczew/gida_4.htm

Jacob, M. and T. Hellström. 1998. Reviewing the science-policy relationship: The policy as theory alternative (PAST). *Science and Public Policy* 25(4): 218-226.

Jones, D. and G. Weymouth. 1997. An Australian monthly rainfall dataset. *Technical Report 70*. Bureau of Meteorology, Melbourne, Australia.

Kumar, K. and J.L. Monteith. 1981. Remote sensing of crop growth. Pages 133-144 *in* Plants in The Daylight Spectrum (H. Smith, ed.). Academic Press, London.

McVicar, T.R. and D.L.B. Jupp. 1998. The current and potential operational uses of remote sensing to aid decisions on drought and Exceptional Circumstances in Australia: a review. *Agricultural Systems* 57(3):399-468.

Morgan, G.M. and M. Henrion. 1990. Uncertainty: *A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*. Cambridge University Press, Cambridge.

Slovic, P. 1997. Risk perception and trust. Chapter III.1 *in* Fundamentals of Risk Analysis and Risk Management (V. Molak, ed.). CRC Press LLC, Boca Raton, Florida.

Smith, D.M.S and G. McKeon. 1998. Assessing the historical frequency of drought events on grazing properties in the rangelands. *Agricultural Systems* 57(3):271-299.

Stephens, D.J. 1998. Objective criteria for estimating the severity of drought in the wheat cropping areas of Australia. *Agricultural Systems* 57(3):333-350.

White, D.W. and L. Karrisses. 1998. Australia's National Drought Policy: Aims, analysis and implementation. *Water International* 24(1):2-9. (Originally presented to the World Water Congress, September 1-6, 1997. Montreal, Canada.)

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Recommendations on Drought Monitoring by the U.S. National Drought Policy Commission

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Abstract

In 1998, the U.S. Congress passed the National Drought Policy Act, stating that the nation would benefit from a national drought policy based on preparedness and mitigation to reduce the need for emergency relief. The Act acknowledged that there was no consistent, comprehensive policy driving the federal role to help reduce the impacts of drought. It also created the National Drought Policy Commission to advise Congress on how to develop such a comprehensive national policy to mitigate the impacts of drought, to improve public awareness, and to achieve federal/nonfederal partnerships for better coordination and response to drought. Preparedness is the foundation for such a policy. A major recommendation focused on improved collaboration among scientists and managers to enhance the effectiveness of observation networks, monitoring, prediction, information delivery, and applied research and to foster public understanding of and preparedness for drought.

Introduction

Drought has often been referred to as a creeping disaster because the lack of sufficient moisture can lead to profound implications for the environment and all segments of society. However, drought may affect each segment differently and be highly variable in its severity and magnitude on each segment. One of the basic reasons for this variability is the lack of a clear and concise definition of drought that is applicable to all disciplines. There are four main types of drought. Meteorological drought is based on a specified time period with precipitation averaging below a critical threshold. Agricultural drought refers to the lack of sufficient moisture available for crops, forests, rangelands, and livestock. Hydrological drought is associated with water supply systems such as river drainage basins and aquifers. A fourth definition of drought has been referred to as societal or economic drought. The latter definition is a complex interaction of the natural phenomenon, environmental degradation, and human impact. This lack of a uniform definition of drought points to one of the most serious problems related to the issue of drought. The response to this naturally occurring event is usually reactive (coming after the drought event has occurred) rather than proactive (i.e., mitigation measures as part of drought preparedness). The challenge is to develop a national drought policy with preparedness as its foundation. This chapter reviews the report of the National Drought Policy Commission, which takes aim at this challenge.

Background

Drought can have a major impact on society. Two notable drought events of the last century had tremendous environmental and societal implications. The drought years of the 1930s in the U.S. Great Plains ranked as the nation's top weather event of the 20th century, according to Hensen et al. (1999). These Dust Bowl years caused a legendary and influential migration from the southern Great Plains to California, revolutionized agricultural policy on the Plains, and synchronized with the Great Depression to compound the event=s misery for millions of people. Hundreds of heat records from the 1930s still stand across the Plains. No other drought of the century encompassed nearly two-thirds of the nation in severe to extreme drought conditions as was the case in July 1934. In all, the decade-long drought turned 50 million acres into dust across the Plains. Across the Atlantic Ocean, recurring droughts in the West African Sahel between 1968 and 1973 directly affected 6 million of the region=s inhabitants and 25 million cattle (Glantz 1977; Grainger 1990). The extremely delicate balance of nature can be irreversibly upset by the combination of natural climate variability and mismanagement of the land. In the case of Sahel desertification, excessive overgrazing denuded a dwindling vegetation resource during the drought years. In an effort to overcome the loss of water supplies, the construction of deep wells to tap water inadvertently aggravated the situation by maintaining an excessive carrying capacity of the land. The devastating results are well documented.

While these case studies highlight the disastrous consequences of two major drought episodes of the past century, it must be noted that drought conditions of varying severity and magnitude occur around the world in almost any given year. Few areas are spared the natural occurrence of drought and many areas have suffered from its impact. Although a better understanding of atmospheric phenomena and oceanic interactions is improving our ability to predict conditions conducive to drought, nations must have a proactive strategy to prepare for drought and to react in time to mitigate the effects of drought, with the goal of reducing the vulnerability of people and resources to the consequences of this natural event.

The U.S. National Drought Policy Commission (NDPC)

In the United States, drought has occurred in various parts of the country on a routine basis. After the 1930s, major drought episodes occurred in the southern Plains during the early 1950s, in the Northeast in the early 1960s, in the far West during the mid 1970s and again in the early 1980s, in the Midwest and parts of the Southeast in 1988, and in Hawaii and the East in the late 1990s. In July 1998, the U.S. Congress enacted Public Law 105-199, the National Drought Policy Act. This law created the National Drought Policy Commission (hereafter referred to as NDPC) to advise Congress on the formulation of a national drought policy based on preparedness, mitigation, and risk management rather than on crisis management. The law directed the Commission to conduct a thorough study of ongoing drought programs, to present a strategy that shifts from ad hoc federal action toward a systematic process similar to those for other natural disasters, and to integrate federal programs with state, local, and tribal programs to ensure a coordinated approach to drought response. This chapter will focus on the findings and recommendations of the final report that was submitted to the president and the Congress in May 2000.

Although drought frequently occurs in any given area of the United States, there is no national drought policy that focuses on reducing the impacts of this natural disaster. Many states and local governments include drought in their comprehensive water management, land use, and long-term planning strategies. Some have devised separate drought plans. Other private entrepreneurs and nonprofit groups with an interest in water management and environmental issues work with governments to carry out drought education projects and water conservation initiatives. State, local, and tribal governments must deal individually with each federal agency involved with drought assistance. Although the federal government plays a major role in responding to drought events, there is no single federal agency in a lead or coordinating position regarding drought. Therefore, crisis management, rather than planning and proactive mitigation measures, often characterizes the federal response to drought emergencies.

The consequences of drought are immense. At its most severe, drought creates vast, windblown dust bowls, eroding landscape, damaging terrestrial and aquatic wildlife habitat, contributing to widespread wildfire, and causing significant monetary losses. Drought may cause economic ruin to farmers and ranchers. It brings hardship to water-dependent enterprises such as commercial fishing. In many small towns and villages, downturns in farming have a rippling effect to other local businesses. Drought can have a devastating impact on agricultural workers and lead to difficult decisions regarding allocation of water and stringent water-use limitations. Drought puts drinking water supplies at risk and may hamper rural fire-fighting efforts. Drought creates or exacerbates conflicts over access to river basins and water systems. Thus, drought's impact is far-reaching and damage to the ecosystem may be irreversible.

Drought Triggers

What makes this issue even more complex is the very definition of drought, or, more specifically, the lack of a single definition that is applicable to all segments of society. In the Commission's final report, a generic definition states that "drought is a persistent and abnormal moisture deficiency having adverse impacts on vegetation, animals, or people." Declarations of droughts are often triggered by specific and well-defined conditions, such as specific reservoir level on a specific date. In some cases, there are well-defined exit points that trigger a resumption of normal activity. These drought triggers become the practical definition of drought for a particular region and for specific issues. Defining these triggers is an inseparable part of planning for and responding to droughts. Once these triggers are defined, a region is much better able to estimate the costs, expected frequency, and risks of drought response. However, in reality, drought is defined differently in different situations. For example, two months without rainfall during the growing season may result in serious drought conditions in subhumid climates. This same period may be normal in semiarid climates, where water reserves may be used for crops adapted to that region. National drought policy must therefore define drought so that it meets the needs of diverse water users and for diverse functions. It must be flexible enough to include a variety of drought situations. It must also be specific enough to distinguish between those situations that are true drought emergencies and those that are normal cyclical conditions. All of these factors must be accounted for in any definition, but it clearly illustrates the need for careful evaluation at the regional level of the most appropriate “triggers” for a drought declaration and a drought termination.

A suite of objective drought thresholds could be supply-type triggers or demand-type triggers. Examples of supply-type triggers include precipitation less than a specified threshold for a season or a water year; the Palmer Drought Index -2.0 or less; and consolidated drought indices at the 20th percentile or less, such as used by the Drought Monitor. Examples of demand (impact) based triggers include water supply less than a threshold percent of normal and various crop loss thresholds. The United States experiences two types of drought. “Stored water” droughts occur when large stores of water in manmade reservoirs, natural lakes, and ground water aquifers are depleted by very long, unusually low periods of precipitation. “Natural water” droughts happen quickly and fairly frequently after just a few weeks or months of below-normal rainfall. Thus, numerous situations arise when those who share stored water are not affected by a natural water drought. However, as the demand for stored water increases with population and with more diverse uses of water, the vulnerability to more severe drought episodes also increases. From this discussion, it can be seen that the issue of drought is very complex and drought=s impact on various sectors of the economy is highly diverse. With this recognition of complexity and diversity, the next section will summarize some of the significant findings of the report.

Report Findings

Preparedness is a fundamental concept in a national drought policy. Preparedness includes drought planning, plan implementation, proactive mitigation measures, and public education. The Commission report found that preparedness may well reduce the social, economic, and environmental impacts of drought and the need for federal emergency relief expenditures in drought-stricken areas. A variety of entities are engaged in some form of drought preparedness. These include individuals, citizen organizations, local and state governments, tribes, and regional bodies. Often, this planning is conducted within the framework of comprehensive water management planning by entities ranging from water districts and large multicounty urban areas to state water resources agencies and regional river basin compacts and commissions. In a survey conducted for the final report, the NDPC found that 30 of the 50 states in the United States had drought plans, with most oriented toward relief rather than preparedness. The assessment revealed that in most states, drought responsibilities are normally located in the agencies that are responsible for the functions of agriculture, natural resources, water management, environment, or emergency management. Fewer than five states have independent, designated drought coordinators, while more than 20 states have drought task forces.

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

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

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

In response to individual challenges over the years, Congress has created federal programs to lessen the impacts of drought. The NDPC found that 88 drought-related federal programs were funded within the past ten years and were spread over a number of federal departments and agencies. The programs were classed into four broad program categories: (1) preparedness, including planning and mitigation; (2) information, including monitoring/prediction and research; (3) insurance; and (4) emergency response. Of these programs, 7 provide assistance for drought planning; 42, drought mitigation; 22, drought-related monitoring/prediction and research; and 47, response. These numbers total more than 88 because some programs cover more than one facet of drought. For example, some of the mitigation programs also contain drought planning and response elements. Although these numbers seem large, a major criticism that was repeatedly heard at meetings and public hearings of the NDPC was that the federal action was an ad hoc approach to drought. Moreover, limited authorities and funds as well as lack of coordination among and within federal agencies hinder planning efforts.

To succeed in the development of national drought policy, the guiding principles should be:

1. Favor preparedness over insurance, insurance over relief, and incentives over regulation.
2. Set research priorities based on the potential of the research results to reduce drought impacts.
3. Coordinate the delivery of federal services through collaboration with nonfederal entities.

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

Report Recommendations

The NDPC recommended that Congress pass the National Drought Preparedness Act, which would establish a nonfederal/federal partnership through a national drought council. The primary function of the council would be to ensure that the goals of national drought policy are achieved. The five goals are briefly summarized before a more detailed discussion of drought monitoring efforts.

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

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

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

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

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

Drought Monitoring Networks

The NDPC emphasized the value and importance of observation networks, monitoring, prediction, information gateways and delivery, and research for effective drought preparedness. One of the first major tasks of the newly formed National Drought Council will be to convene a drought data monitoring, prediction, and research "summit" of multidisciplinary, geographically diverse representatives to ascertain the needs and expectations of all interested parties. Research priorities should address the impacts of drought on nonirrigated systems, aquatic ecosystems, wildlife, and other aspects of the natural environment, including the potential negative impacts of drought mitigation measures. Better coordination of governments and private entities in international drought monitoring, prediction, research, education, water conservation, and technology transfer is essential. Specific recommendations to meet the desired objectives are next discussed.

One of the five major goals (Goal #2 above) of the final report is the recommendation for the development of a viable plan to maintain, modernize, expand, and coordinate a system of observation networks that meets the needs of the public at large. The plan should include cooperation with states, development and improvement of baseline historical data sets, and recognition of the Council recommendations. Priority should be given to filling the gaps on tribal lands and in rural America. To provide a measure of the complexity of this problem, an extensive network of weather observation sites is operated by various federal agencies in the United States. In fact, the NDPC reported that about 20 federal programs have some responsibility for drought monitoring/prediction and research. The National Weather Service manages a cooperative observer network that has been in existence for more than 100 years. The U.S. Department of Agriculture operates an automated weather observing network, mostly in the mountainous West, called the Snowpack Telemetry (SNOTEL) network, and a much less dense network, the Soil Climate Analysis Network (SCAN), in agricultural areas. The U.S. Forest Service operates its own Remote Automated Weather Stations (RAWS) network in the federally managed forest lands. The U.S. Geological Survey manages a stream gauging and ground water network for flood monitoring. These federal networks do not provide uniform coverage that is acceptable at the state or regional level.

Consequently, the number of nonfederal automated weather networks has increased over the past 20 years to fill some of the state and local needs. Brusberg and Hubbard (2000) reported the findings of a survey of nonfederal networks in the United States and Canada. Their preliminary results show 39 networks, with 33 in operation for less than 20 years and 15 in existence for less than 10 years. One interesting result was that nearly all of these networks have some type of partnership with private industry or universities. Many have some type of relationship with the public sector as well. Of the 39 networks offering responses, 12 indicated some type of arrangement at the federal or national level, and 15 have some form of partnership with state, provincial, or municipal levels of government. The survey found that quality assurance and quality control are practiced by a majority of these networks, but meta-datasets are highly variable, as would be expected with the wide range of purposes and inception dates. The authors recommended that a national registry for mesoscale networks be established for the purpose of information exchange, and the development of reasonable operational standards should be encouraged.

Although there is sharing of instrument and information technology, the greatest concerns regard quality control issues and industry (or community) standards for both data formats and equipment. The survey results also showed that user outreach was a significant concern, with a number of respondents (networks) wishing to discern the true utility of their products to the general public and expand their outreach. Another encouraging sign was the willingness expressed by the network managers to work together on mutually beneficial projects.

The NDPC found that federal monitoring/prediction programs often join with universities, private institutions, and nonfederal entities to provide information needed for effective drought preparedness and mitigation. For example, federal programs provide the basic data used by private weather services and other enterprises that play a vital role in transferring appropriate information at the farm level. The private weather services use the federally supplied data in developing tailored products for crop and irrigation management. However, it was also found that there was a strong need for an accessible "gateway," or point of contact, where high-quality, standardized, comprehensible current information and historical data are managed. Although there is a tremendous storehouse of drought-related scientific and technical research, the NDPC also found that the results of research are not always disseminated in a timely manner or through easily accessible modes. A consensus was that research results as well as technology transfers are key to effective drought planning, proactive mitigation, emergency response, and drought-related technical assistance and training. Therefore, these results must be made readily and widely available for planners and decision makers.

Conclusion

To establish an effective national drought information delivery system, a coordinated effort must be undertaken to bring more systematic data networks to rural and tribal areas. These networks must be integrated into a national program through partnerships between federal and nonfederal entities. A comprehensive information gateway must be established to provide users with free and open access to observational network data and drought monitoring, prediction, impact, assessment, preparedness, and mitigation measures. Links among federal and nonfederal sources are critical to ensure a comprehensive and collaborative system of data information. These drought products can then be used by planners and decision makers in a vast array of measures to cope with this natural disaster. The key elements of an effective national drought policy include planning, proactive mitigation, risk management, resource stewardship, and public education. All of these elements require detailed knowledge of observational data and research products that form the foundation for efforts to reduce drought impacts on society.

References

Brusberg, M.D. and K.G. Hubbard. 2000. Preliminary findings of the 1999 survey of (non-federal) automated weather stations in the U.S. and Canada. Proceedings of the WMO Workshop on Automated Weather Stations for Applications in Agriculture and Water Resources Management: Current Use and Future Perspectives, March 6-10, 2000, Lincoln, Nebraska (in press).

Glantz, M. 1977. The U.N. and desertification: Dealing with a global problem. Pages 1-13 *in* Desertification (M. Glantz, ed.) Westview Press, Boulder, Colorado.

Grainger, A. 1990. The Threatening Desert. Earthscan Publications Ltd., London, England.

Hensen, R., S. Horstmeyer, B. Rippey, P. Kocin, and E. Pinder. 1999. The 20th century's top ten U.S. weather and climate events. *Weatherwise* 52(6):14-19.

Role of Drought Early Warning Systems in South Africa's Evolving Drought Policy

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Abstract

During the last two decades in South Africa, two of the severest droughts of the century have been experienced. The policy framework has also undergone a tremendous change, and continues to be dynamic. Traditionally, drought early warning systems have primarily comprised physical indicators of the recent meteorological conditions. Several such products are available in South Africa, focusing on both meteorological and biological aspects. As further responsibility is placed on farmers to plan for and survive droughts with minimum intervention from the state, greater emphasis on locally relevant early warning systems is required. Early warning systems (EWS) currently used include decile rainfall, the water satisfaction index, the NOAA Normalized Difference Vegetation Index (NDVI), and other crop- and rangeland-based models. As the face of agriculture changes, EWS will have to change to cope with the greater variety of crops, the greater scale at which the information is available, and a greater focus on accurately reflecting the needs of small-scale farmers.

Introduction and background

The 1982-83 and 1991-92 droughts were the most severe meteorological droughts of the 20th century over southern Africa. In the 1991-92 drought, 70% of the crops failed. It was estimated that half of the population in the affected area was at risk of malnutrition, other related health problems, and even starvation (Anonymous 1994).

Buckland (1994) stated that the introduction of hybrids, although raising average yields, has also resulted in increasing the amplitude of the fluctuations in yield for maize. In good years, the hybrids yield better, but generally in poor years, yields are worse. On the positive side, yields for sorghum, although still dependant on rainfall, have generally increased over the last two decades (Buckland 1994). Together with greater sensitivity to rainfall fluctuations, the likelihood of droughts may increase with increasing carbon dioxide (Joubert and Mason 1996).

Overview of Drought Warning Systems

In one sense, droughts are particularly well suited to early warning systems because the disasters have a slow onset. On the other hand, the start of a drought is difficult to define, even when a variety of data is available.

A composite early warning system should ideally consist of:

1. meteorological information,
2. agricultural information,
3. production estimates,
4. price trends of food and feed,
5. availability of drinking water, and
6. household vulnerability.

The better EWSs are those that attempt to monitor a variety of indices related to production, exchange, and consumption (Ayalew 1994). This chapter will focus on meteorological and agricultural information, as these issues are generally common internationally.

According to Wilhite (1990), a monitoring/early warning system to provide decision makers at all levels with information about the onset, continuation, and termination of drought conditions is an integral part of drought planning. However, an early warning system should not be a process of data collection and analysis that is regarded as an end in itself, but it should be part of a larger system that is designed to mitigate and respond to the crisis (Buchanan-Smith 1994).

Most drought early warning systems focus on the hazard of the impending disaster, and not on the vulnerability of farming systems and rural communities. Information on vulnerability is required to provide a focus for drought interventions (Anonymous 1994).

A vulnerability profile of the area complements an EWS and gives direction to decision makers on how and where to respond for maximum effectiveness. A vulnerability profile should include, inter alia, trends in recent rainfall, production, prices, and nutritional status, environmental status, soil fertility, and household status (Ayalew 1994).

The physical aspects of an EWS should be able to provide information on:

- spatial extent of drought,
- duration of drought,
- time of occurrence of drought in relation to the crop calendar, and
- severity of drought.

An EWS is a system of data collection that facilitates the detection and monitoring of disasters in order that action can be taken to reduce the effects of the disaster in some way. The existence of an EWS suggests that mitigation and disaster reduction strategies have been incorporated. The intention of the information is to provide those with power and ability to respond in a way that will ameliorate the effects of the disaster.

Changes in Drought policy

Pre-1990 drought policy in South Africa was directed primarily at stock farmers (Walters 1993). Stock farming was considered to be best adapted to the highly variable rainfall conditions in these areas. However, relief aid tended to favor the poorer managers and climatically marginal areas (Smith 1993).

During the early 1990s, drought policy was changed in order to place greater obligations on farmers to reciprocate for state aid by committing themselves to practices aimed at promoting resource conservation and the long-term sustainability of economic production (Walters 1993). Only farmers who submitted stocking rates quarterly to their local Department of Agriculture office, and who reduced stock when drought warnings were issued, were eligible for state aid. Critics of this policy stated that insufficient consideration was given to the protection of the rural poor from threats posed by insufficient water, food, and employment (Walters 1993). In addition, definitions of disaster drought conditions tended to favor the western portions of the country, where the coefficient of variation of rainfall was greater. In fact, Bruwer (1990) noted that certain magisterial districts had been declared disaster drought for 70% of a 30-year review period, while some eastern portions of the country had never been declared.

Australian drought policy places considerable emphasis on encouraging primary producers to adopt self-reliant approaches to coping with drought and farm management (White 1992). The South African minister for Agriculture noted that a prolonged drought would affect everyone in the country, and that drought aid (Hanekom 1997):

- encouraged bad practice;
- was inequitable in the past; and
- creates expectations that government will bail out farmers in all disasters.

Recent draft legislation on agriculture recommended that government enhance access by the agricultural sector to meteorological and financial information that could forewarn a farmer of upcoming natural disasters, particularly drought. With the recent floods during February 2000, drought issues have receded from the agenda.

Primary data and information products

Physical indicators of drought are still the primary constituents of drought early warning systems in South Africa. These indicators can be divided between meteorological and biological systems. The primary data used to for these information products are:

- daily rainfall (point measurements and radar rainfall estimates),
- daily maximum temperature (point measurements), and
- NOAA AVHRR.

These data are generally easily available in near real-time.

The following drought monitoring products are available:

1. Decile rainfall

Decile rainfall analysis is valuable because it is normalized over time and is therefore spatially comparable. This allows the index to be used to compare areas that have very different rainfall climatologies, as in South Africa. In addition, sequences of months have been used in much the same way as the Standardized Precipitation Index (SPI). A significant criticism of the index is its lack of sensitivity to the distribution of rainfall within the period considered.

2. Water Saisfaction Index (WSI)

This method was developed by Frere and Popov (1979) and used by Vossen (1990) in Botswana. The index has been applied spatially across South Africa using WindDisp and ArcView software (Figure 1). Images are available historically for 1960-1999. Systems to operate this in real-time are under development by ARC-Institute for Soil, Climate and Water. The WindDisp version of the product has been developed to provide additional useful information such as planting date, soil moisture status, and irrigation requirements (Figure 2). Among the weaknesses of the WSI is that for ease of calculation, assumptions are made concerning a specific crop, replanting, evaporation, and soil water holding capacity. du Pisani (1990) noted that:

- WSI does not consider crop- or stage-specific sensitivity to drought stress;
- it only takes account of cumulative moisture deficits, not consecutive deficits;
- it can only partly accommodate actual evapotranspiration; and
- the model assumes equal soil moisture availability over the entire range between field capacity and wilting point.

3. NOAA NDVI

Since 1984, South Africa has been developing a data base of daily NOAA AVHRR images for southern Africa. Until recently the data was uncalibrated because part of the header information was lacking. However, recent work and collaboration with the University of Maryland and other institutions has resulted in a revamping of the information, and an entire calibrated data base including the Normalized Difference Vegetation Index (NDVI) and active fires will soon be complete. In the interim, NDVI values were accessed by a percentile approach that allowed the identification of below- and above-normal areas (Figure 3, Figure 4). The NDVI allows near-real-time analysis of vegetation status in South Africa.

4. ZA Model

Venter (1992) developed a simple mathematical model (ZA model) using monthly precipitation to characterize Karoo shrub land (semiarid vegetation). This model provides an effective representation of shrub water status (Figure 5). The application of the model is limited to the dry western portions of the country.

5. PUTU Veld Production model

Fouché and de Jager, from the ARC-Range and Forage Institute and the University of the Free State, developed the PUTU crop production model. The rangeland component of the model has been used, together with a rainfall outlook based on the SOI index, to create images of expected rangeland conditions for the Free State province (Figure 6).

6. Long-lead forecasts

The South African Weather Bureau provides long-lead forecasts and ENSO advisories (http://www.weathersa.co.za/rgscs/products/seasonal.htm) for use in southern Africa. These forecasts are widely accessed, although practical application of the information is still limited. An example of a rainfall outlook is provided (Figure 7).

7. Free State Agricultural Conditions

Agricultural conditions are provided for the Free State province (http://miniwebs.agri24.com/OVSWeer/defaultframe.asp). Recent rainfall, expected rainfall (based on SOI), rangeland conditions, crop estimates, and agricultural produce price trends are included. In addition to the web access, about 200 individuals and organizations receive the information via e-mail.

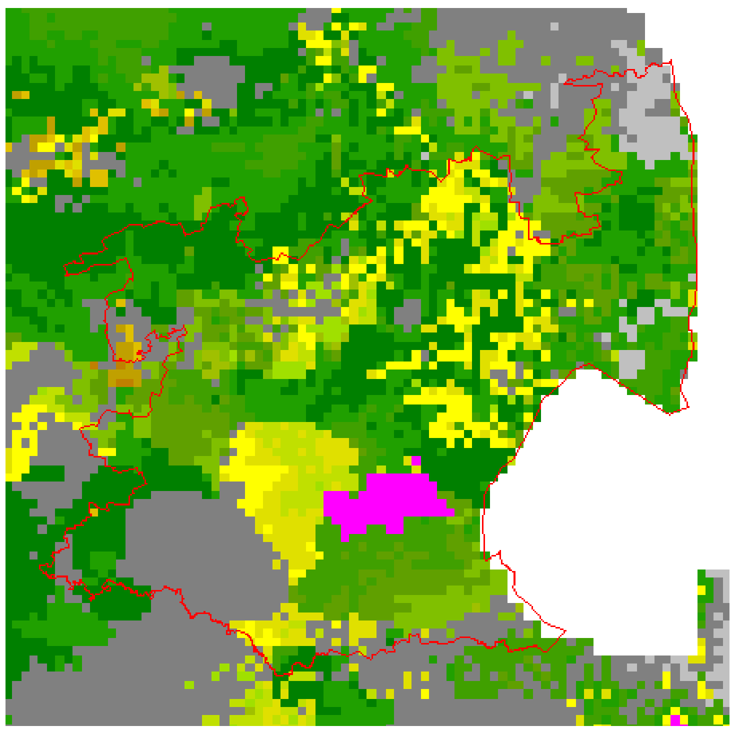

Figure 1. WSI image for Mpumulanga province in South Africa for the third decadal in January 1983.

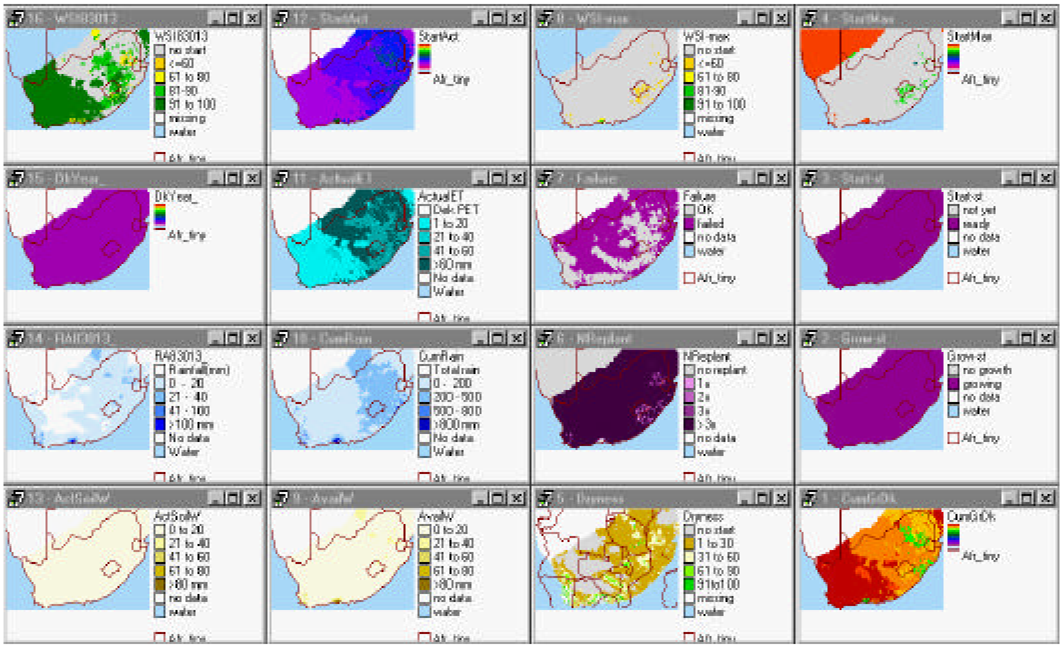

Figure 2. Comprehensive WSI information available using the WinDisp program.

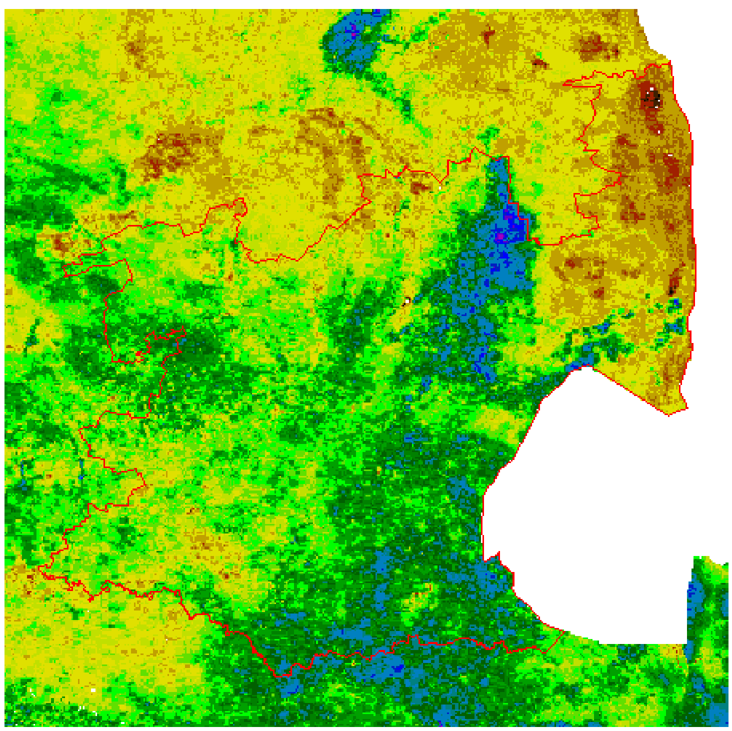

Figure 3. Uncalibrated NDVI image for Mpumulanga province in South Africa for November 1991.

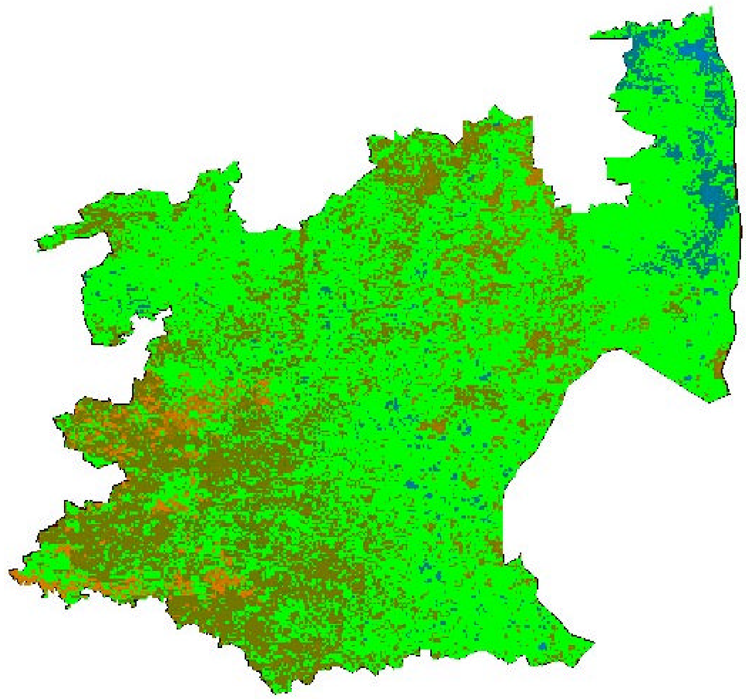

Figure 4. NDVI image for Mpumulanga, showing areas where NDVI value is greater than 1 standard deviation different from the long-term.

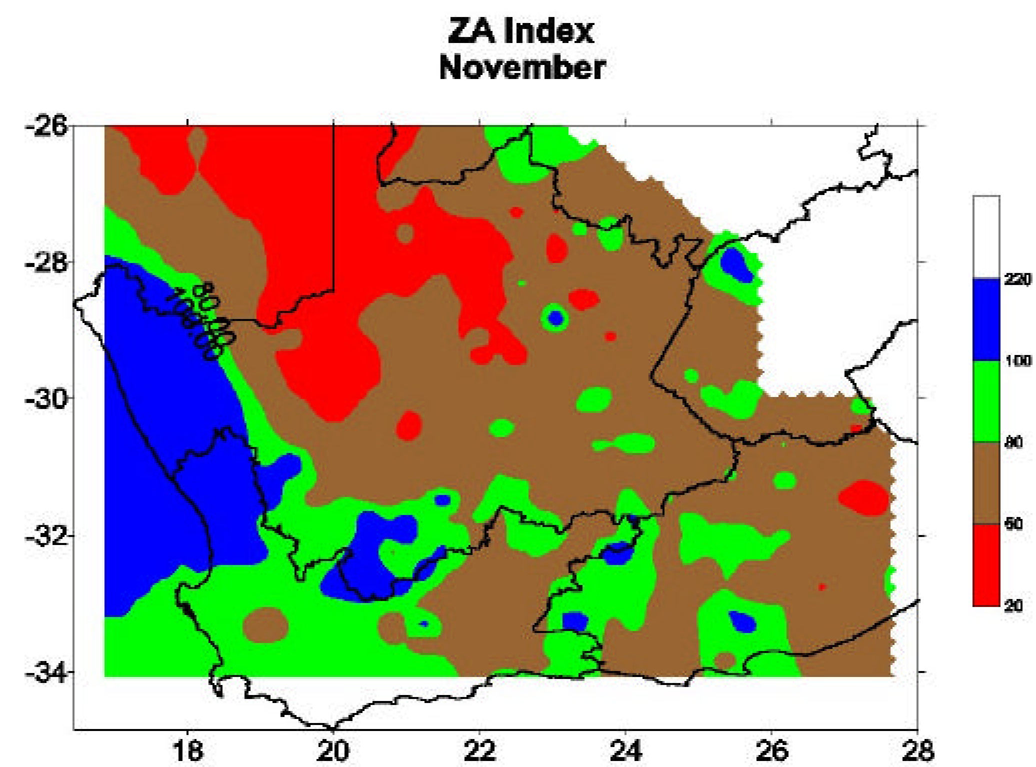

Figure 5. ZA index for western South Africa.

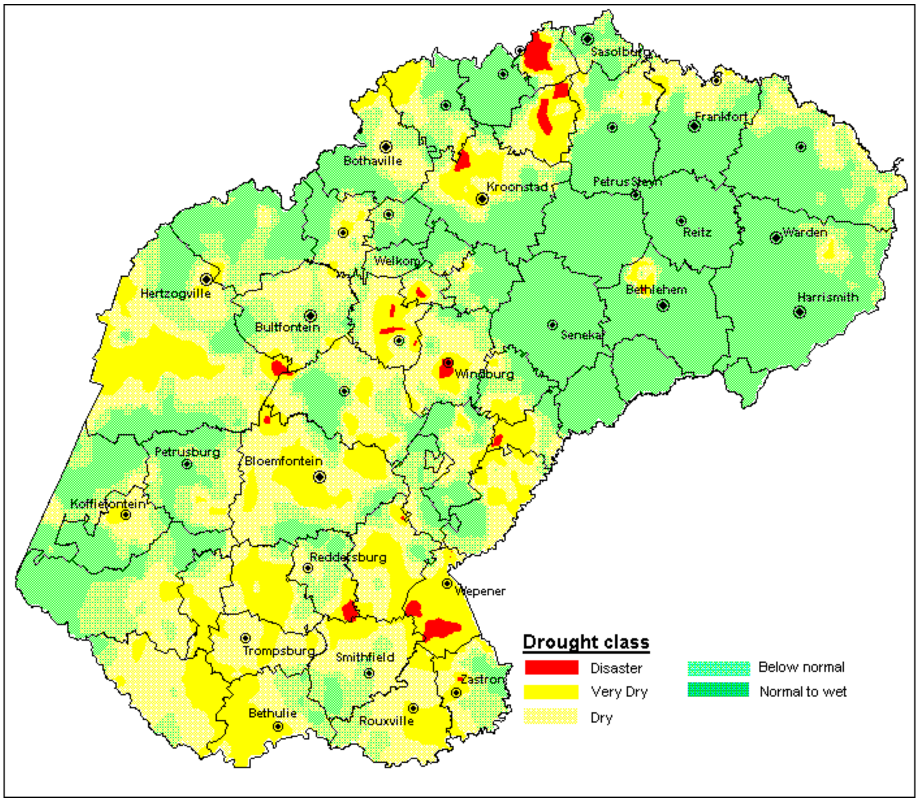

Figure 6. Rangeland production outlook for November 1998 for the Free State province of South Africa.

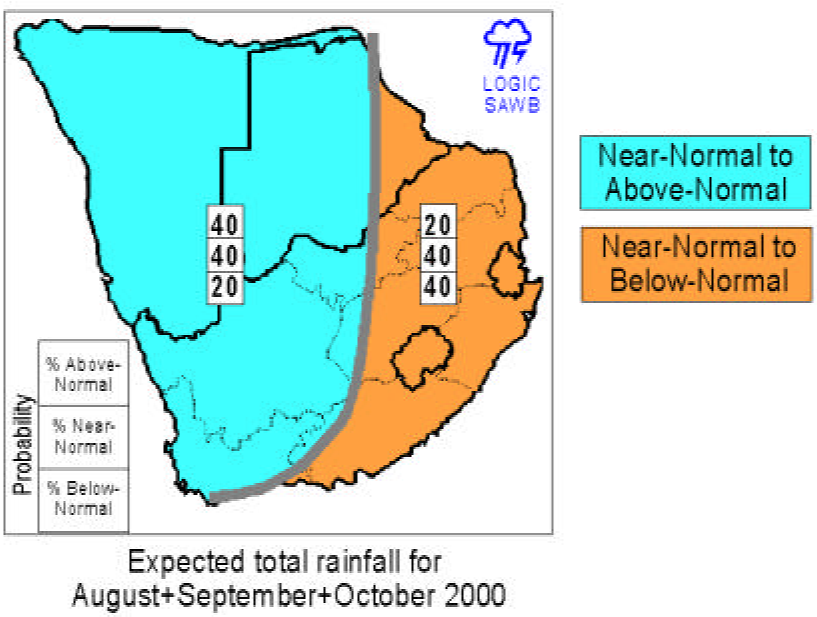

Figure 7. South African rainfall outlook for early rainfall.

Identification of Primary Users

Primary users of early warning information are government departments and the agri-industry organizations. Commercial farmers also access the information.

If legislation comes into effect that the government will not be responsible for natural disasters, but will simply create an enabling environment for farmers to manage the risks, increased emphasis will have to be placed on providing early warning products to those affected.

Use of Triggers

In the past, state aid required magisterial districts (counties) to be declared as drought disaster status. This legal requirement necessitated a quantitative index that could be uniformly applied. This index was broadly defined as two consecutive seasons experiencing 70% or less rainfall (Bruwer 1990). Normal drought, for which a farmer was expected to be self-reliant, was of a period of one year and less.

As pointed out earlier, certain parts of South Africa were declared drought affected for more than 70% of the time over a 30-year period, while other areas had never been declared. This indicates that the quantitative index is not optimal. In fact, since it is dependent on a deviation from mean annual rainfall, and the skewed distribution of annual rainfall totals in the drier areas, the index is biased.

Status of Delivery Systems

The status of early warning information in South Africa is shown in Table 1. Several of the systems remain dormant until a need arises. The reason for this is the limited resources available to keep systems running when the demand is low.

Because media attention has focused on the ENSO phenomenon, high status has been given to these forecasts. Particularly during 1997, when there was an expectation of a large El Niño event, response from the private sector was noticeable. It was reported that McCarthy Motor Holdings sold no light delivery vehicles from their Hoopstad agency since the first press release on a possible El Niño. In addition, tractor sales for October 1997 were 20% lower than the corresponding period the previous year. The sales of haymaking equipment increased by 50% for the same period (Redelinghuys 1997).

The impact of this ENSO event on South African rainfall did not materialize as predicted, which caused many people to lose faith in these forecasts. However, economists state that the financial discipline exerted by farmers resulted in them being in a much healthier state at the end of the season than they would have been had they ignored the forecast from the beginning.

Table 1. Status of drought information systems in South Africa.

Drought Monitoring System	Status
Decile rainfall	On demand
Water Satisfaction Index (WSI)	Under development
NOAA NDVI	Under development
ZA model	On demand
PUTU Veld Production model	On demand
Long-lead forecasts	Routine
Free State Agriculture Outlook	Routine

Constraints or Limitations of Current Systems

The main constraints to future development and access of drought early warning systems are:

- lack of a completed drought policy framework,
- lack of coordination between institutions that do provide some type of drought early warning,
- lack of vulnerability data bases, and
- lack of social indicators to form part of a holistic early warning system.

A clear policy framework would provide the foundation on which further systems development and integration between institutions could occur.

Future Needs

Farmers and agricultural organizations are increasingly being required to manage themselves. They will require systems to enable them to anticipate drought so that they can effectively respond.

National Early Warning Systems may have been sufficient for the needs of the state in the past, but EWS that are locally based and focused on the systems used by farmers are now required. For example, although maize is the staple crop, many commercial farmers are planting higher-value crops that are generally more vulnerable to drought. For small-scale farmers and rural communities, many other social and economic factors interact. Thus a more comprehensive suite of indicators is required.

Conclusions

South Africa will continue to experience droughts, and the likelihood of serious droughts is greater with increasing CO_2. Together with the changing policy framework and governments' commitment to reduce direct assistance to farmers in times of disaster, the challenge to provide effective drought warning to farmers and rural communities increases.

These users cannot depend on vague warnings, and will soon discard systems that prove unreliable. Early warning systems that can be used across a range of agricultural production systems are needed.

References

Anonymous. 1994. National Report of the Republic of South Africa. Prepared for the IDNDR Mid-term Review and the 1994 World conference on Natural Disaster Reduction. Yokohama, Japan, May 1994.

Ayalew, M. 1994. What is food security and famine and hunger? *In* (Glanz, M.H., ed.). Usable Science: Food Security, Early Warning, and El Niño, Proceedings of the Workshop on ENSO/FEWS, Budapest, Hungary, October 25-28, 1993. NCAR, Boulder, Colorado.

Bruwer, J.J. 1990. Drought policy in the Republic of South Africa. *In* Proceedings of the SARCCUS Workshop on Drought, (du Pisani, A.L., ed.). Southern African Regional Commission for the Conservation and Utilisation of the Soil, Pretoria, South Africa.

Buchanan-Smith, M., 1994. What is a famine early warning system? Can it prevent famine? *In* Usable Science: Food Security, Early Warning, and El Niño (M.H. Glanz, ed.). Proceedings of the Workshop on ENSO/FEWS, Budapest, Hungary, October 25-28, 1993. NCAR, Boulder, Colorado.

Buckland. R. 1994. Implications of climatic variability for food security in the Southern African Development Community. *In* Usable Science: Food Security, Early Warning, and El Niño. (M.H. Glanz, ed.). Proceedings of the Workshop on ENSO/FEWS, Budapest, Hungary, October 25-28, 1993. NCAR, Boulder, Colorado.

du Pisani, A.L. 1990. Drought detection, monitoring and early warning. *In* Proceedings of the SARCCUS Workshop on Drought. (du Pisani, A.L., ed.). Southern African Regional Commission for the Conservation and Utilisation of the Soil, Pretoria, South Africa.

Frere, M. and G.F. Popov. 1979. Agrometeorological crop monitoring and forecasting: Plant production and protection. FAO Paper 17. FAO, Rome.

Hanekom, D., 1997. Agriculture's response to El Nino and Drought subsidies to farmers. Media statement from Derek Hanekom, Minister for Agriculture and Land Affairs, 18 September 1997.

Joubert, A. and S. Mason. 1996. Droughts over South Africa in a double-CO_2 climate. *International Journal of Climatology* 16:1,149-1,156.

Redelinghuys, J. 1997. The economic implications of El Niño. National Workshop on the El Niño phenomenon, National Department of Agriculture, Pretoria, South Africa, 3 December 1997.

Smith, D.I. 1993. Drought policy and sustainability: Lessons from South Africa. *Search* 24(10):292-295.

Venter, J.C. 1992. Drought characterization based on Karoo shrubland productivity. *South African Journal of Science* 88(3):154-157.

Vossen, P. 1990. Comparative statistical validation of two ten-day water-use models and of three yield-reduction hypotheses for yield assessment in Botswana. *Agricultural and Forest Meteorology* 51:177-195.

Walters, M.C. 1993. Present state drought policy in the RSA and possible areas of adaptation. Presented at Planning for Drought as a Natural Phenomenon, Mmabatho, South Africa, January 28, 1993.

White, D.H. 1992. Analysing and improving agricultural systems – Identifying opportunities and minimizing risks. Proceedings of the New Zealand Institute of Agricultural Science and the New Zealand Society for Horticultural Science Annual Convention, Lincoln University, August 25-28, 1992.

Wilhite, D.A. 1990. Planning for drought: A process for state government. IDIC Technical Report Series 90-1. International Drought Information Center, University of Nebraska–Lincoln.

Drought Early Warning Systems in West Asia and North Africa

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Abstract

The North Africa/West Asia region is characterized by considerable diversity in climatic conditions. Most countries of the region have a high degree of aridity and pronounced rainfall variability in large parts of their territories and are therefore highly vulnerable to drought. Drought is an inherent characteristic of climates with pronounced rainfall variability. In the last few decennia, there has been a marked increase, or at least a perception of increase, in the number of droughts in the region, particularly in North Africa.

Drought early warning systems, as they have been set up in many other countries of the world, are virtually nonexistent in the North Africa/West Asia region. Drought early warning systems of the region function at two levels, international and national.

The international level is the FAO-coordinated GIEWS, which is, strictly speaking, an information network for early warning of food shortages. One of the key characteristics of the international food security monitoring system is that it is integrated, draws on all possible alert indicators (economic, meteorological, agronomic, social, nutritional) and uses extrapolation tools (GIS and remote sensing) to assess the food security outlook.

National-level integrated drought monitoring systems are not operational in the region. In general, there has been limited coordination of information from sources, such as water supply or irrigation authorities, agricultural extension services, meteorological departments, and NGOs, about the extent and impact of drought.

In most countries of the region, meteorological networks are adequate, being well equipped and well sited, representative for major agroecologies and agricultural production areas. Notwithstanding these advantages, the meteorological departments of the region are at the moment poorly prepared to function effectively in drought early warning systems because of inadequate analytical tools for drought monitoring, unsuitable information products, and insufficient data sharing.

The region has an overwhelming need for modern and effective drought early warning systems. To develop such systems, challenges have to be met, as related to the reliability of long-range forecasts, selection of appropriate drought indicators, spatialization tools, agroecological characterization, and institutional arrangements.

In the North Africa/West Asia region, no significant relationships have been confirmed between droughts and ENSO events. For this reason, long-term forecasts for a whole season or longer are not considered reliable.

Different types of drought require different drought indicators. Some indicators are more suited to monitor agricultural drought, others to assess hydrological or meteorological drought. The assessment of socioeconomic drought requires socioeconomic and nutrition-based indicators.

The choice of drought indicators should also be guided by the goal of the drought assessment, which can be to assess intensity, exceptionality, or impact of drought. To assess agricultural drought, indicators based on the water balance are preferred.

Institutional arrangements may determine success or failure of drought early warning systems. The key characteristic of well-functioning early warning systems, whether for drought or food security, is that they are small but multidisciplinary and tightly integrated units. Of critical importance for the success of all early warning units is the free flow of information.

Importance of Drought in the North Africa/West Asia Region

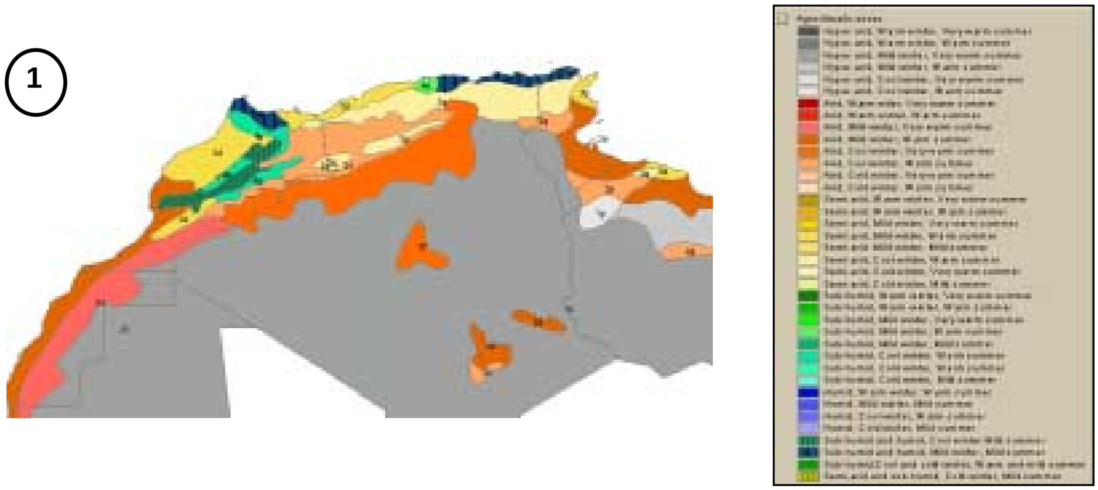
The regions of West Asia and North Africa are characterized by considerable diversity in climatic conditions. This is evidenced by the map in Figure 1, which shows the agroclimatic zones according to the UNESCO classification for the arid zones (UNESCO 1979). As the map indicates, the region contains widely different moisture regimes ranging from humid to subhumid, semiarid, arid, and hyperarid. In addition, temperature regimes vary considerably, particularly as a result of differences in altitude and, to a lesser extent, oceanic/continental influences. With the exception of Turkey, the countries of the region have a high degree of aridity in large parts of their territories (Table 1) and are therefore highly vulnerable to drought.

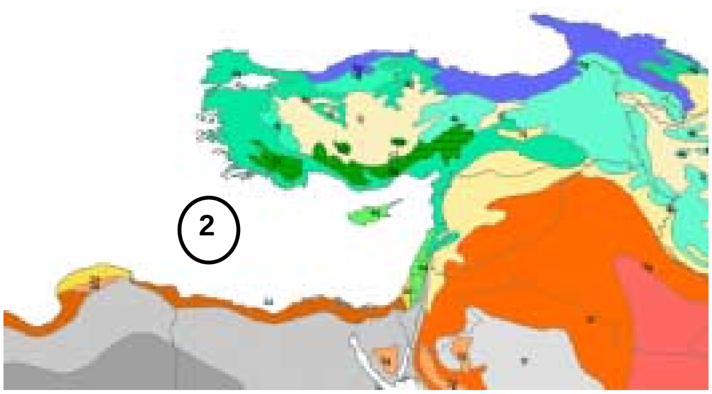
Drought is mainly the result of deficient rainfall. One of the many definitions of drought is “a deficiency of precipitation from expected or ‘normal’ that, when extended over a season or longer period of time, is insufficient to meet demands” (Knutson et al. 1998). From this definition it is clear that drought is an inherent characteristic of climates with pronounced rainfall variability.

Rainfall variability is considerable in the North Africa/West Asia region, irrespective of the moisture regime (Figure 2). Figure 2 shows the annual rainfall variations for 4 stations in different agroclimatic zones. It is evident that rainfall variability is not confined to the low rainfall areas of the region. The large amplitude of the variations is typical for the region as a whole.

One of the major characteristics of drought in the region is that it is essentially not predictable. As will be discussed later in this chapter, no significant correlations with any particular weather anomalies have been confirmed.

Another feature of drought in the region is that it can strike any time of the season and varies with location. Early-season, mid-season, and late-season droughts are all possible. In addition,





EXPLANATORY	
Moisture	**Annual**
Hyperarid	< 0.03
Arid	< 0.2
Semiarid	< 0.5
Subhumid	< 0.75
Humid	>=
Winter	**Average temp. winter**
Warm	> 20
Mild	> 10
Cool	> 0 °C
Cold	<= 0
Summer	**Average temp. summer**
Very	> 30
Warm	> 20
Mild	> 10
Cool	<= 0

Figure 1. Agroclimatic zones of North Africa (1) and West Asia (2) (after UNESCO 1979, with modifications).

Table 1. Countries of the region with arid zones.

Country	Degree of Aridity					Very Dry Areas	
	HA	A	SA	SH	H	Sq. km	%
Algeria	do	as	As		In	1,245,000	53.8
Egypt	do	in				508,000	50.9
Libya	do	as	in		In	1,162,000	71.9
Mauritania	as	as	in			733,000	69.8
Morocco		as	as	in	In	110,000	26.9
Tunisia		do	as		In	72,000	46.9
Israel	as	as	as			6,000	29.9
Jordan	in	do	in			50,000	55.6
Lebanon			do			1,000	11.4
Syria		as	as	in		115,000	61.4

Explanatory notes:

(a) degree of aridity:
HA: hyper-arid; A: arid; SA: semiarid; SH: semihumid; H: humid

(b) The symbols used refer to relative importance within the country:
in: inclusion (< 5% of country)
as: associated (at least 5-10% of country)
do: dominant (> 50% of country)

(b) The category 'very dry areas' is derived from the FAO Soil Map of the World as areas where Xerosols and Yermosols occur. This is a valid approach since the latter soils are defined in terms of their soil moisture regime, which is arid (Xerosols) or very arid (Yermosols).

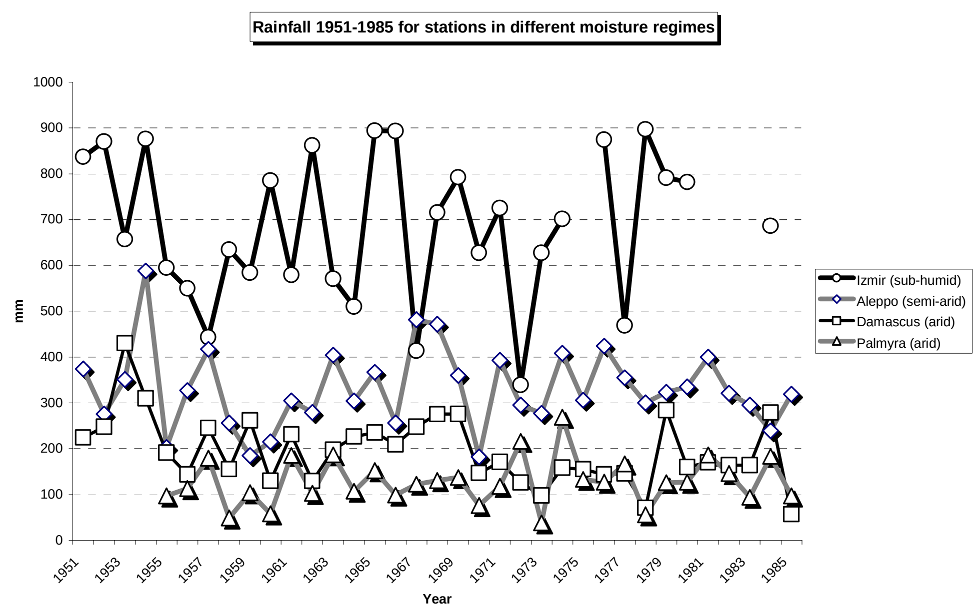


Figure 2. Rainfall variability in different agroclimatic zones.

they can be very localized. This local confinement of drought is illustrated in Figure 3, which shows the cumulative rainfall deviations for Aleppo, Damascus, and Palmyra in Syria, three locations a few hundred kilometers apart, but with different patterns of longer-term positive or negative anomalies.

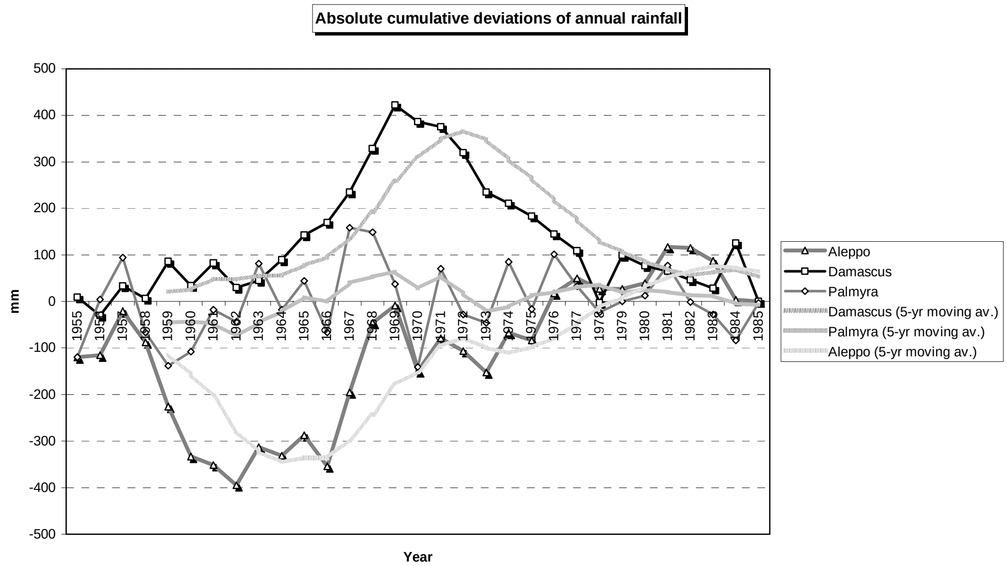


Figure 3. Patterns of positive and negative precipitation anomalies for 3 locations in Syria.

Droughts in the region are complex in pattern, effects, and impact. Droughts express themselves by reduced rainfall, which is directly used by rainfed crops and rangelands; reduced runoff, which fills small dams or recharges ground water tables; reduced streamflow; and lowered water reservoir levels. Assessing the impact on these various natural resources therefore requires different indicators.

The main effect of drought is a reduction in agricultural productivity, which ripples through society via the linkages of agriculture with other economic sectors. If severe or persistent enough, droughts put added pressure on urban resources through increased migration of vulnerable rural people from drought-stricken areas. In marginal areas where opportunistic cropping has occurred in years of above-normal rainfall, a subsequent return to normal or below-normal conditions can initiate wind erosion and accelerate existing processes of desertification. This has been the case, among others, in the Syrian steppe (Debaine and Jaubert 1998).

The impact of drought depends on its timing and duration, particularly in relation to growth stages of particular crops and the tolerance of individual crops or cultivars to drought. Land use change may also affect the impact of drought. Vulnerability to drought may increase, as the above example of expansion of rainfed cropping into marginal areas demonstrates. However, land use intensification may also decrease vulnerability to drought, through the transition from rainfed to either partially or fully irrigated cropping systems.

In the last few decennia, there has been a marked increase, or at least a perception of increase, in the number of droughts in the region, particularly in North Africa. Although no clear trends of declining rainfall have been identified (Yacoubi et al. 1998), the apparent increase in drought events raises the possibility of increasing rainfall deficits in the region as a result of climate change.

As a matter of fact, the Intergovernmental Panel on Climate Change projects small increases in precipitation for the region, but these increases are likely to be countered by increased temperature and evaporation (Watson et al. 1997). According to the Panel, drought is therefore likely to increase and will have the greatest impact on the grasslands, livestock, and water resources of the marginal areas. Water shortage, already a problem in many countries of this arid region, is unlikely to be reduced, and may be amplified by climate change. In addition, drought may exacerbate existing land degradation problems and, through the added stress on limited water supplies, threaten the food security of some countries.

It is particularly in this context of climate change that drought issues are gaining interest in the region. Planning for drought becomes an unavoidable policy issue for governments of the region. Drought planning implies effective early warning systems, tactical planning for mitigation of drought impact, and long-term strategies for drought adaptation, particularly land use policies and technologies for drought-prone areas. The importance of drought planning is well recognized and governments of the region are fully cooperating with international organizations, such as FAO,[1] in the mitigation of food shortages, which are often related to drought. Nevertheless there are no integrated government structures that can deal with all aspects of drought planning. As a result, drought early warning systems, as they have been set up in many other countries of the world, are virtually nonexistent in the North Africa/West Asia region.

In the next sections, the situation will be described in more detail and suggestions for improvement will be made.

Status of Drought Early Warning Systems in the Region

Drought early warning systems of the region function at two levels, international and national. The international level is the FAO-coordinated GIEWS,[2] which is, strictly speaking, an information network for early warning of food shortages.

International Level

In many countries, particularly in Africa, FAO has helped governments establish specialized units, “Early Warning and Food Information Systems” (EWFIS), for food security monitoring. These units act as focal points within governments for collecting, processing, and communicating information on all the key variables that influence food security. The EWFIS use a well-established methodology of food security assessment, which is based on crop condition monitoring at regional and national levels and monitoring of food security at global, national, and subnational levels.

The crop condition monitoring relies on agrometeorological models, fed by data from meteorological networks, and supplemented, in data-sparse areas by low-resolution satellite imagery products, particularly cold cloud duration (CCD), as a proxy for rainfall, obtained from

Meteosat, and the Normalized Difference Vegetation Index (NDVI), as an indicator of crop stage and condition, obtained from NOAA.

At the global level, GIEWS monitors world food prices and estimates global food supply and demand.

At the national level, GIEWS monitors in particular a group of some 80 “Low-Income Food-Deficit Countries” (LIFDCs), in which food security is particularly vulnerable to crop failure or high international cereal prices. The standard instrument is the National Food Balance sheet, a regularly updated accounting system that monitors commercial imports and food aid deliveries and estimates the quantities of imports, including food assistance, which will be required to maintain consumption at normal levels. The main focus of this analysis is on cereals because up-to-date information on other types of food is often weak in many countries.

At the subnational level, the system focuses on vulnerable population segments and monitors indicators of food crisis such as local market food supplies, retail price rises, and evidence of individual and community responses to food insecurity. Such responses are sometimes referred to as “coping strategies” and include unusual sales of livestock or other assets, migration in search of food, consumption of wild foods that are not part of the normal diet, and a reduction in the number and size of meals. When they are available, data on malnutrition indicators are also monitored.

The GIEWS produces a wide range of regular reports, which cover global and national food security outlooks and are frequently updated. Some of these reports focus on particular regions, such as sub-Saharan Africa and the Sahel. Special reports and alerts are issued when food security emergencies arise in particular countries. More information about GIEWS, including reports, can be found on the relevant web page.[3]

The EWFIS are basically an international mechanism to avoid famine situations, and are therefore mainly situated in sub-Saharan Africa, where food insecurity is endemic. Within the North Africa/West Asia region, where drought but not food security has been a major problem, EWFIS have not been established. However, through FAO’s regional and national offices, information is compiled, from governments and intergovernmental authorities, that allows the GIEWS to assess the food security situation in individual countries that do not have EWFIS.

In cases of abnormal drought that may cause major production shortfalls and create exceptional food emergencies, GIEWS mounts rapid assessment missions, usually jointly with the World Food Programme, to the affected countries. On the basis of these visits, and with the inputs of government experts, ad hoc situation assessment reports to governments and the international community are prepared with suggestions on how to deal with the food emergency caused by drought. In the last few years, such assessment missions and reports, prompted by drought-induced food insecurity, have been prepared for most governments in the region.

National Level

One of the key characteristics of the international food security monitoring system is that it is an integrated one. It draws on all possible indicators (economic, meteorological, agronomic, social, nutritional) as well as extrapolation tools (GIS and remote sensing) to assess the food security outlook.

The main goal of the international monitoring system in the North Africa/West Asia region, as in other parts of the world, is to assess food security, not drought. Since the countries of the region have the financial means to import food in case of a production shortfall, drought has rarely been a threat to national food security, and has therefore not been the subject of a monitoring system in its own right.

National-level integrated drought monitoring systems are not operational in the region. Although drought affects major segments of society in the region, in general there has been limited coordination of information from sources, such as water supply or irrigation authorities, agricultural extension services, meteorological departments, and NGOs, about the extent and impact of drought.

In any drought monitoring system, meteorological services of the region have a critical role. Without meteorological data, and analytical tools that transform meteorological data into relevant drought indicators, droughts cannot be adequately monitored. In most countries of the region, meteorological networks are adequate, being well equipped and well sited, representative for major agroecologies and agricultural production areas. Obviously improvements are always possible, especially in servicing the more arid zones.

Nevertheless, at the moment, meteorological departments of the region are poorly prepared to function effectively in drought early warning systems. Major shortcomings are related to:

- inadequate analytical tools for drought monitoring;
- unsuitable information products;
- insufficient data sharing.

Most services still define drought as a negative anomaly from normal precipitation, in terms of absolute or percentile deviations. An example of an output of this type of analysis is provided in Figure 4, which has been obtained from the Turkish State Organization for Meteorology.[4]

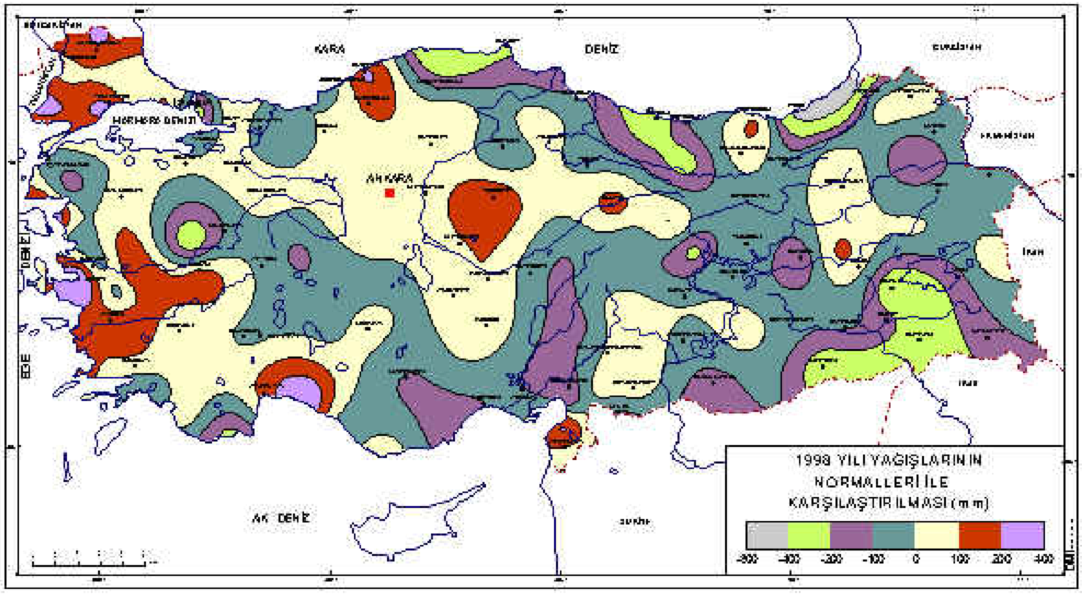


Figure 4. Deviations of 1998 annual rainfall from normal.

Well-established drought indicators such as the Palmer Drought Severity Index (PDSI), the Standardized Precipitation Index (SPI), or deciles are not used. Work on developing suitable drought indicators has started only recently in Morocco (e.g., Yacoubi et al. 1998) and Syria, and is not yet incorporated in operational drought monitoring.

In addition, the information is not used to monitor drought, but rather to characterize the climate during the ongoing year, month, part of the year, or agricultural year. There are no regular bulletins that target the agricultural user community or other stakeholders in drought mitigation, through interpretation of the available raw data and communication in terms of impact and seasonal outlook.

It can be argued with some justification that the production of such derived products exceeds the in-house expertise of most meteorological services, and should therefore not be their sole responsibility. However, the inter-institutional partnerships that are required to produce specialized drought information bulletins are much hampered by the common practice of meteorological services of the region to charge for meteorological data, even to other government departments. With exceptions (e.g., Turkey), the charges are often prohibitive and make no economic sense. As a result, the meteorological data bases, which are indispensable for basic analyses, such as drought risk assessment, cannot be accessed by the agricultural user and research community, which has the highest data requirements but the lowest financial resources of all potential users of meteorological data. In return, agricultural research institutes are not sharing their growing in-house expertise in agricultural applications with meteorological services. The exorbitant charging by meteorological services for data is one of the major handicaps to be overcome in order to set up effective early warning systems.

Conspicuously missing in this region are integrated spatial frameworks, such as agroecological zones, for relating anomalous weather conditions to static physical regions that are more or less homogeneous in land and water resources and land use, and for which drought conditions need to be assessed separately. Such spatial frameworks are highly relevant to the region given its great agroecological diversity.

Future Needs

The region has an overwhelming need for modern and effective drought early warning systems. All countries of the region have experienced, and continue to experience, very high population increases and increasing pressure on land and water resources, which threatens the sustainability of current land uses and exacerbates the impact of drought on rural populations.

Increasing awareness that droughts have mounting economic, social, and environmental costs, and may particularly hit vulnerable population segments is changing government's perception about the need for drought early warning systems. As a matter of fact, some countries have opted for a *comprehensive* approach, working toward integrated systems for drought management, rather than drought monitoring.

The key principles of drought management are:

- the approach is multidisciplinary and integrated;
- drought planning must cover different time scales and include, apart from short-term solutions to mitigate drought impact, long-term land use strategies ;
- consideration is given to both the biophysical and socioeconomic dimensions of drought;
- drought management is a key component of sustainable land use in drought-prone areas.

The main strategies for effective short-term and long-term drought mitigation are (ICARDA 1998):

- seasonal climate forecasts and early warning systems;
- better targeting of crops and cultivars to specific agroecological environments;
- natural resource management adapted to the limitations of drought-prone areas, in particular, crop breeding and crop management to increase water use efficiency; soil and water conservation, including water harvesting; and sustainable use of irrigation water;
- policy and institutional measures to facilitate implementation of drought mitigation practices, in particular, the conservation and harvesting of water, shifts to more adapted crops, etc.

The major challenges facing integrated drought management systems are:

- *Drought monitoring*: developing reliable indicators and forecasts and accurate spatialization of drought extent and intensity;
- *Drought impact assessment*: assessing sensitivity to drought of different agroecological land use systems and identification of vulnerable population groups;
- *Institutional arrangements*: creating effective multidisciplinary, multi-institutional focal points to coordinate national drought management plans.

In the following paragraphs, some of these issues will be discussed in more detail.

Feasibility of Seasonal Forecasts

Weather patterns in many parts of the world appear to be related to different phases of the El Niño-Southern Oscillation (ENSO) cycle. The existence of such linkages is now being used in operational early warning systems, such as FEWS, [5] to forecast rainfall patterns for the coming crop growing season. The basis for forecasting is that a particularly strong linkage exists between the warm-ocean phase of the ENSO and drought in southern Africa. Such correlations have proved to be useful in tropical areas and there is confidence it may soon be possible to predict, for southern and eastern Africa, certain climatic conditions associated with ENSO events more than a year in advance.[6]

In the North Africa/West Asia region, no significant relationships have been confirmed between droughts and ENSO events. This is probably because the effects of this global ocean-weather linkage, and therefore the weather, are substantially modified by more localized weather phenomena (e.g., the North Atlantic Oscillation), but also by very site-specific factors, such as topography, antecedent soil moisture and vegetation condition, and the nearness of large desert land masses. As a result, the countries of the region, or even parts of countries, have highly contrasting rainfall-generating mechanisms. For this reason, long-term forecasts for a whole season or longer are not considered reliable.

The current practice is to forecast the remainder of an ongoing season on the basis of statistical or empirical relationships between meteorological events, such as precipitation, in the beginning and at the end of the season. This practice is adopted, among others, by the Office National de la Météorologie of Algeria, which uses for the purpose the numerical climate model ARPEGE[7] of the Centre National de Recherches Météorologiques. The value of this approach for drought planning is doubtful. Some authors (e.g., El Mourid and Watts 1989) found no correlation in Morocco between autumn and spring rainfall, which is a critical period for crops, given the common occurrence of end-season drought.

Even where the correlations are highly significant, as is the case in the linkage between ENSO and East African rainfall, the forecasts usually retain a few highly likely rainfall patterns, each one with significant probabilities but different effects on crop condition. Because the probabilities for occurrence of each rainfall pattern are usually not negligible, they all need to be considered, which diminishes considerably the value of the forecasts for very early planning purposes.

This problem is illustrated in Figure 5, which provides for southern Africa the outlook for rainfall during the period January-March 2000, the most important months of the growing season. The forecast made in September 1999 (SADCC 1999) is expressed in terms of probabilities of different rainfall patterns according to climatic regions. The top figure for each climatic region represents the probability of above-normal rainfall, the middle figure the probability of normal rainfall, and the bottom figure the probability of below-normal rainfall. It is clear that only in a few cases can a scenario be dismissed as highly unlikely.

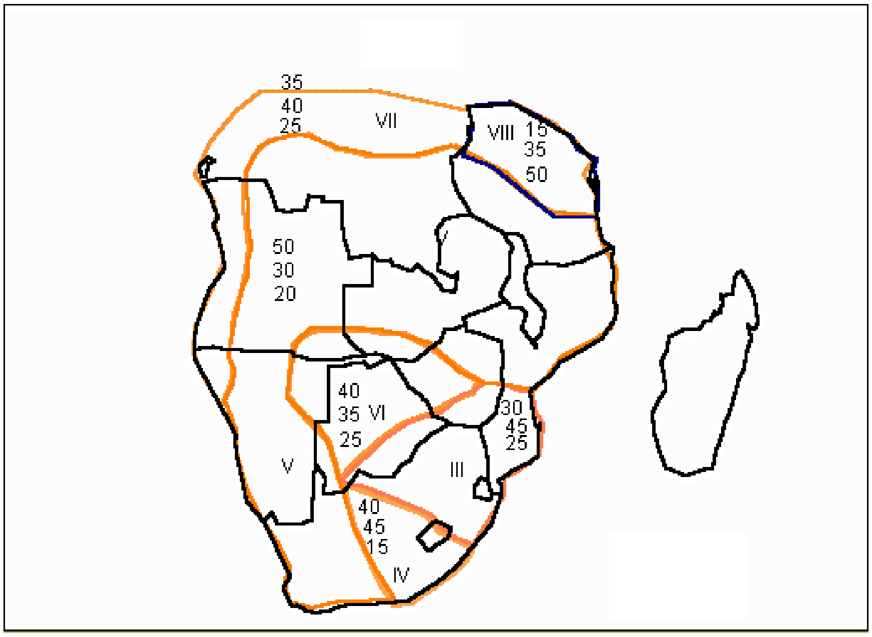


Figure 5. Probabilities of seasonal rainfall patterns for southern Africa (SADCC 1999).

Drought Indicators

The main criteria for early warning indicators of drought is that they are accurate, are responsive to changes in the moisture supply situation, are comparable across space and time, and aid decision making for drought mitigation at a sufficiently early stage and in individual regions.

Different types of drought require different drought indicators. Some indicators are more suited to monitor agricultural drought, others to assess hydrological or meteorological drought. The assessment of socioeconomic drought requires socioeconomic and nutrition-based indicators.

An exhaustive comparison of relative merits and disadvantages of different drought indicators is beyond the scope of this chapter. A review of commonly used drought indices, to assess agricultural, meteorological, or hydrological drought, has been prepared by Dr. M. Hayes of the National Drought Mitigation Center.[8] The best-known indices internationally are the Palmer Drought Severity Index (PDSI), Standardized Precipitation Index (SPI) and decile method. Some of these methods have been tested, with varying results, in the region.

The choice of drought indicators should also be guided by the goal of the drought assessment, which can be to assess intensity, exceptionality, or impact of drought. Indicators showing absolute deviations are better suited to assess drought intensity and are comparable across space, which may allow the production of drought intensity maps. An example of an intensity indicator is given in Figure 6, which shows within a growing season the cumulative deviations from normal of the actual evapotranspiration, a water balance-based indicator, for 3 years with different rainfall patterns.

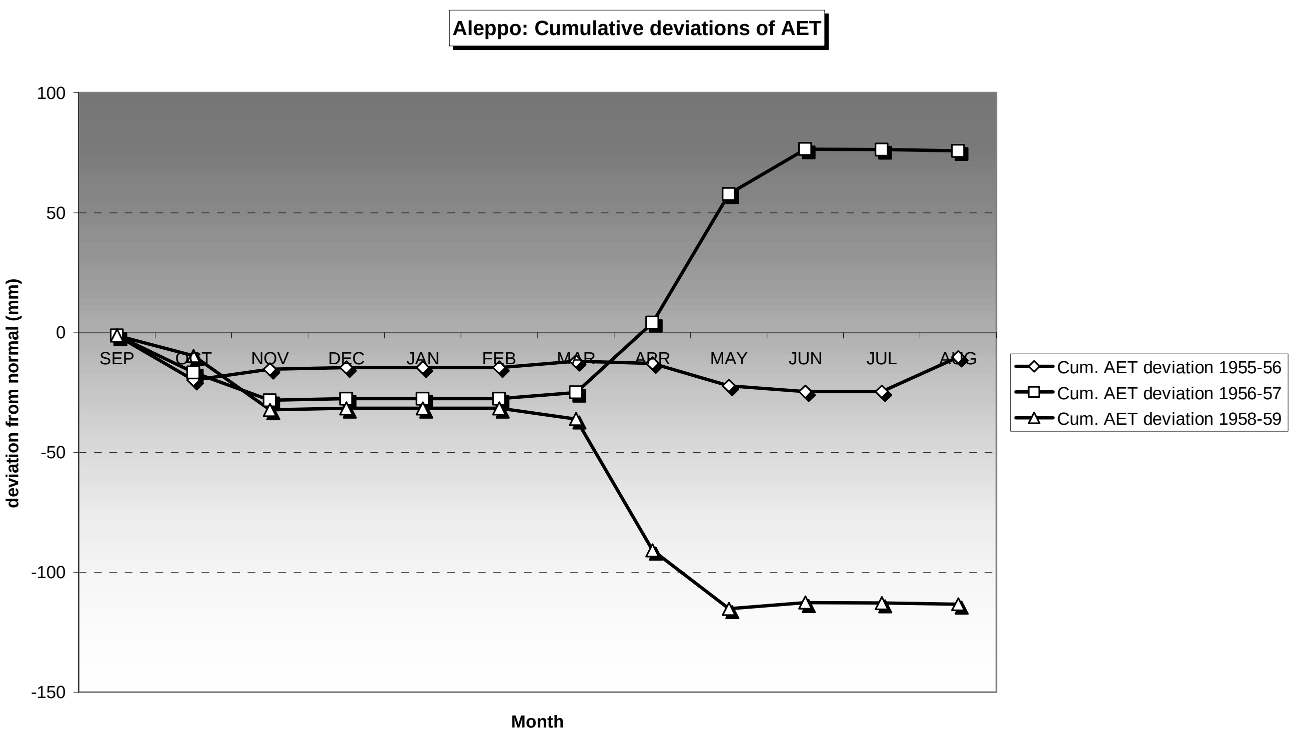


Figure 6. Example of the cumulative deviation of AET, an indicator of drought intensity, for Aleppo, Syria.

Indicators such as the SPI or deciles, which are based on fitting meteorological parameters to probability distributions, are more suitable for deciding on the exceptionality of drought events and may be a basis for providing aid such as emergency assistance and crop insurance.

Indicators to assess drought impact are much more complex and diverse, and need to be used with great caution, especially for forecasting purposes. Early warning systems for crop yield and production forecasting, such as those of FAO or the European Commission, use sophisticated crop yield models, based on a combination of crop growth simulation and production trend functions with remote sensing and GIS for spatialization. The information requirements of these systems, especially the European one, are very high, making them very expensive to operate and maintain.

It must also be noted that drought indicators have a useful "lifetime." A typical example is the SPI, which needs to be calculated for different periods (e.g., 1 month, 3 months, 6 months, etc.). For each period, the interpretation associated with the index is different; for example, the 3-month SPI has a different meaning from the 1-month SPI.[9]

Agricultural Drought Indicators

To monitor agricultural drought, the most suitable indicators are those that are responsive to soil moisture status and are therefore based on the soil water balance. The reason is that the timing of soil moisture deficits in relation to crop water requirements and sensitivity to moisture stress is of major importance to assess the impact of drought on crops. At the same time, the indicators should be simple enough to allow straightforward interpretation.

In the course of a collaboration between the Syrian Meteorological Department and ICARDA, the feasibility of using a soil water balance-based indicator, the PDSI, as a drought index for Syria was evaluated. The main conclusion was that, although the PDSI is sufficiently responsive to assess agricultural drought, it is unsuitable for Syrian conditions because of the difficulty in obtaining the empirical weighting factors for each month and area. The index scale of the PDSI has apparently been calibrated on the basis of data available from the U.S. state of Kansas and has little meaning in terms of assessing the rarity of drought events under Syrian conditions. One reason for this is that potential evapotranspiration, an input to the water balance, is calculated by the Thornthwaite method (Thornthwaite 1948), which significantly underestimates potential evapotranspiration under arid conditions (Smith 1990; Choisnel et al. 1992). In addition, the calculation procedure appears unnecessarily complex, and the output is difficult to interpret in terms of drought impact or to assess the exceptionality of drought events, one of the key criteria for deciding emergency aid or compensation to farmers.

A simple but effective agricultural drought indicator, which can be derived from a generic water balance approach (Thornthwaite and Mather 1955), is the deviation of actual evapotranspiration (ETa) from expected under average climatic conditions. Because the ceiling for actual evapotranspiration is the potential evapotranspiration (ET0), differences between the two will indicate water stress with possible reduction of the potential yield. Cumulative water stress is indicated by the cumulative deviations of ETa from normal for different stages of the growing period.

The cumulative deviations of ETa are a measure of drought intensity, and to some extent drought impact. In addition, they can be carried over from one year to another, showing patterns of water deficit or surplus that may occur over longer time spans (Figure 7).

ETa-based indicators are useful for rapid identification of areas with severe drought problems. They can be easily spatialized where meteorological networks are adequate. In addition, in view of the strong correlations between NDVI and ETa, there have been successful attempts to derive ETa directly through remote sensing (e.g., Bastiaanssen 1995). Most important, in areas where

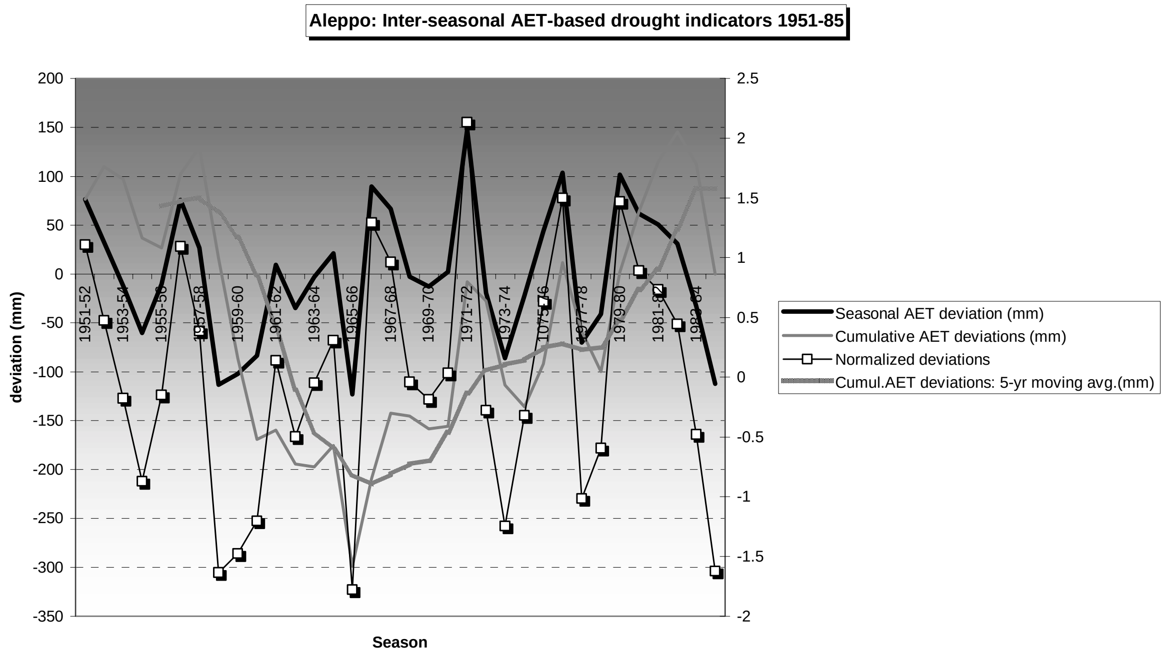


Figure 7. An example of the interseasonal drought indicator based on seasonally accumulated ETa deviations at Aleppo, Syria.

yields are mainly conditioned by limited water supply, as is the case--by definition--in most semiarid areas of the world, ETa is strongly correlated with crop yield (Figure 8).

For the purpose of crop yield monitoring and forecasting, the indicators obviously have to be crop specific. The best-known systems are the National Early Warning and Food Information Systems established with FAO assistance in many countries of Africa (FAO 1990). These systems use an agrometeorological forecasting model, based on the water balance, which calculates for each station of the network, on a 10-daily basis, a crop-specific water satisfaction index (WSI), which is responsive to the sensitivity of crops to water stress at different growth stages.

The WSI is a weighted measure of ETa, which can then be correlated with crop yield, as in Figure 8.

A more sophisticated approach is used by the MARS[10] Project of the Joint Research Center of the European Commission for monitoring agrometeorological conditions and forecasting yields of the major cereal, oil seed, and root or tuber crops of the European Union. The engine is the crop growth simulation model WOFOST (Supit et al. 1994), which includes a water balance submodel and is supplied with daily meteorological data obtained from all national meteorological services. It uses national soil maps and pedo-transfer functions to convert measured soil attributes, such as texture and structure, into water holding capacity, an essential parameter for site-specific water balances. The crop phenology and yield forecasts obtained from

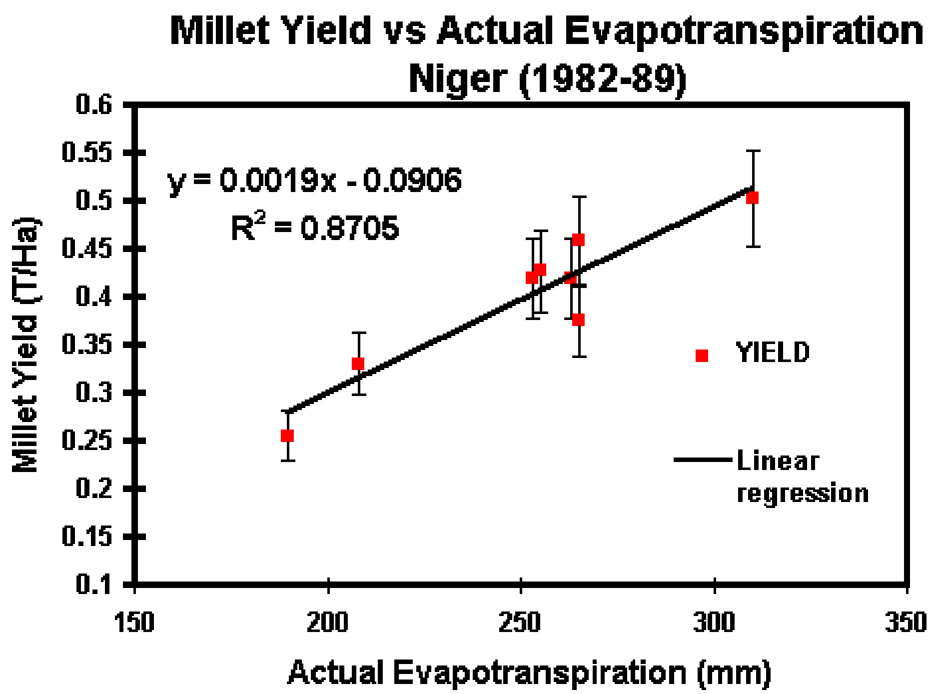


Figure 8. Example of relationship between crop yield and ETa (from Gommes et al. 1998).

the physically based simulation model are validated through NDVI imagery and corrected with a yield trend function representing technology-related productivity increases. Validation of the final yield and production forecasts is through a network of statistical sampling sites (de Koning et al. 1993). To improve the estimates of crop areas, the feasibility of rapid assessment of crop area changes through high-resolution satellite imagery from a scattered sample of 100 mini-sites, which represent different agroecological and land use situations, is currently investigated. This system is currently being extended toward Eastern Europe and North Africa. For more details on the MARS project and project bulletins, see the relevant web pages.[11]

Spatialization

In most countries of the region, the network for monitoring rainfall is adequate. Assessing the extent of drought on the basis of rainfall only is therefore not a problem. For other weather parameters, particularly temperature, sunshine, humidity, and wind, the number of measuring stations is insufficient. Since many countries are quite diverse in terms of landscapes and topography, temperature regimes will not be uniform and, in view of their effect on crop water demand, have to be taken into consideration when using water balance-based drought indicators.

Several statistical techniques are now available that make use of digital elevation models (DEM) in order to improve the spatialization of climatic parameters. In view of the strong linkages between climatic variables (especially temperature, but also rainfall, humidity, and sunshine) and topography, the most promising techniques for spatialization in climatology are multivariate approaches, since the latter permit the use of terrain variables as auxiliary variables in the interpolation process. In contrast to the climatic target variables themselves, which are only known for a limited number of sample points, terrain variables have the advantage of being known for all locations in between, which increases the precision of the interpolated climatic variables significantly. Co-kriging (e.g., Bogaert et al. 1995) and co-splining (e.g., Hutchinson and Corbett 1995) are methods that in most cases lead to excellent interpolations.

Another important tool for spatialization is remote sensing. Remote sensing has become a standard tool in most food security early warning systems, such as FEWS, GIEWS, and MARS. This is mostly the result of decreasing costs of satellite data products and image analysis tools, large-area coverage, and significant correlations between soil moisture status or biomass productivity and some parameters derived from spectral analysis (e.g., NDVI). The major role for remote sensing in these systems is to monitor changes in the edaphic factors. By its synoptic view and rapid refresh capability, remote sensing offers a unique ability to integrate the effects of changing weather, vegetation, soil, and land use. These changes can be monitored over different spatial and time scales. Especially the use of AVHRR imagery, with low spatial but high temporal resolution, in combination with higher-resolution imagery such as Landsat or SPOT, in representative sample areas, offers cost-effective prospects for monitoring drought and associated agricultural production deficits. A successor of AVHRR, the MODIS instrument on the Terra satellite launched in December 1999, will soon produce imagery with NDVI at 250 m resolution and other vegetation indices at 500 m or 1 km resolution.

Agroecological characterization is a very important support activity for drought early warning systems and is needed for both short-term and long-term drought management. The delineation of zones that are relatively homogeneous in terms of climatic conditions, soils, landscapes, water resources, and land use systems is required for establishing drought vulnerability profiles and drawing drought risk maps. These studies also allow to target new crops or cultivars to match climatic conditions where either drought evasion is possible or drought tolerance is required.

Agroecological zones are developed in a GIS approach, developing individual thematic layers, which are merged into gradually more integrated layers. The zones are then further characterized by overlaying new themes. The principle is illustrated in Figure 9.

Institutional Arrangements

Institutional arrangements may determine success or failure of drought early warning systems. The key characteristic of well-functioning early warning systems, whether for drought or food security, is that they are small but multidisciplinary and tightly integrated units. Of critical importance for the success of all early warning units is the free flow of information. This should send a strong signal to all institutions, which, by the very nature of droughts, have a key role in drought monitoring and management. In particular, meteorological services of the region are likely to come under public scrutiny if they appear to hamper the joint efforts required to combat drought through constraints on the provision of meteorological data.

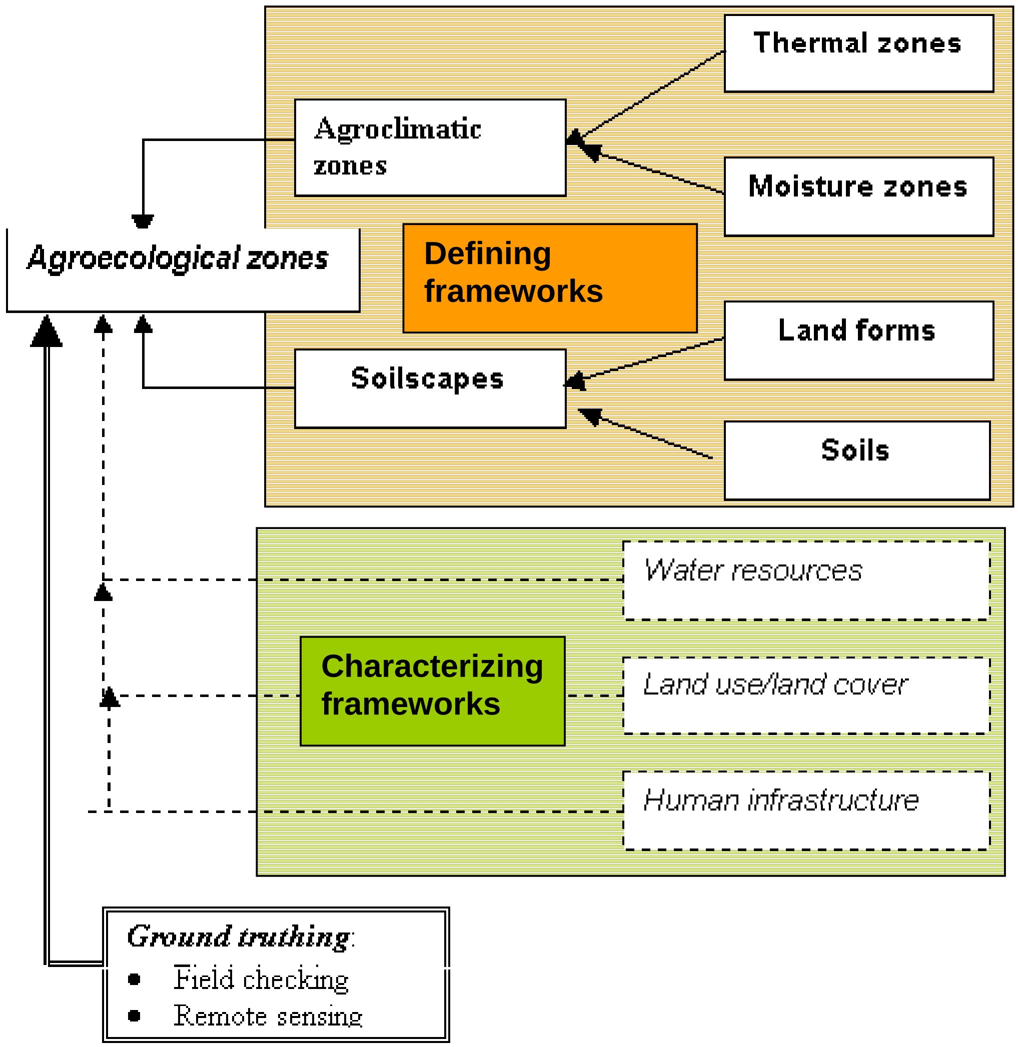


Figure 9. Integration of thematic layers into agroecological zones.

In drought-prone countries, a central drought management unit needs to be established, with a legal status and mandate and a small multidisciplinary core staff. This structure would be most effective if housed in a coordinating ministry, such as a prime minister's or president's office, or a planning ministry, rather than a line ministry. This way the drought coordinating body would have access to the multidisciplinary manpower and information sources in other ministries, to deal with any emergency, as droughts get worse, or for developing drought management plans. Such a unit would also hold responsibility for developing policy to facilitate drought mitigation both in the short term and long term.

Under the general supervision of the central drought management unit, but not necessarily in the same ministry, a drought early warning unit needs to be established with a more technical character. This unit will compile and interpret all data sources to monitor drought extent and impact, and report through regular or special bulletins to the central drought management unit. The experience of the described food security information systems, although not fully transferable in a drought and different economic context, may be useful to develop the specifications for national drought early warning systems in the North Africa/West Asia region.

It is encouraging that the government of Morocco has recently established an entity for drought monitoring, very much in line with the above principles. The "Observatoire pour le Suivi de la Sécheresse"[12] is a permanent coordinating body with a legal status and mandate, and with a small multidisciplinary core staff, drawn from different ministries. Drawing inspiration from the international monitoring system, which successfully integrates multiscale, multi-institutional and multidisciplinary data sources, this coordinating unit is at the apex of a "virtual" structure composed of technical experts from different government administrations, dealing with different aspects of drought management through technical committees and working groups. The technical committees are responsible for monitoring and prediction of harvests, monitoring and impact evaluation of drought alleviation programs, and strategy development for long-term drought mitigation. One of the major tasks for the Monitoring Committee will be to set up a drought early warning system, which, on the basis of multiscale and multidisciplinary indicators, will monitor the evolution of agricultural, meteorological, hydrological, and socioeconomic drought.[13]

The idea of the *Observatoire* as an integrated system for *drought management*, rather than drought monitoring, is a useful model for the other countries of the region and, if successful, is likely to be reproduced.

Footnotes

[1] Food and Agriculture Organization of the United Nations.
[2] Global Information and Early Warning System on Food and Agriculture.
[3] URL: http://www.fao.org/WAICENT/faoinfo/economic/giews/english/giewse.htm.
[4] Source: http://www.meteor.gov.tr/webler/hidro/hidromaster.htm.
[5] USAID Famine Early Warning System. See http://www.info.usaid.gov/fews.
[6] See "Predicting drought," on the NDMC website at http://enso.unl.edu/ndmc/enigma/predict.htm.
[7] For details, see http://www-pcmdi.llnl.gov/modeldoc/amip/13cnrm_b.html.
[8] For details, see http://enso.unl.edu/ndmc/enigma/indices.htm.
[9] An in-depth analysis of the SPI can be found at http://enso.unl.edu/ndmc/watch/spicurnt.htm.
[10] Monitoring Agriculture with Remote Sensing.
[11] See http://mars.aris.sai.jrc.it/stats/bulletin/.
[12] Observatory for Drought Monitoring.
[13] Personal communication by Dr. T. Ameziane, Institut Agronomique et Vétérinaire, Hassan II, Morocco.

References

Bastiaanssen, W.G.M. 1995. Regionalization of surface flux densities and moisture indicators in composite terrain: A remote sensing approach under clear skies in Mediterranean climates. Ph.D. thesis. Landbouwuniversiteit Wageningen, The Netherlands.

Bogaert, P., P. Mahau, and F. Beckers. 1995. The spatial interpolation of agro-climatic data. Cokriging software and source data. User's manual. FAO Agrometeorology Series 12. FAO, Rome, Italy.

Choisnel, E., O. de Villele, and F. Lacroze. 1992. Une approche uniformisée du calcul de l'évapotranspiration potentielle pour l'ensemble des pays de la Communauté Européenne Centre Commun de Recherche, Commission des Communautés Européennes, EUR 14223.

Debaine, F., and R. Jaubert. 1998. Les marges arides de Syrie: La "frontière" des 200 mm. Planification agricole et occupation du territoire. *Sécheresse* 9(1):43-50.

de Koning, G.H.J., M.J.W. Jansen, E.R. Boons-Prins, and C.A. van Diepen. 1993. Crop growth simulation and statistical validation for regional yield forecasting across the European Communities. El Mourid (p.32) Joint Research Centre of the European Commission (JRC), Ispra, Italy.

El Mourid, M. and D.G. Watts. 1989. Rainfall patterns and probabilities in the semi-arid cereal production region of Morocco. Pages 59-80 *in* The Agrometeorology of Rainfed Barley-based Farming Systems (Jones, M., G. Mathys, and D. Rijks, eds.). ICARDA, Aleppo, Syria.

FAO. 1990. Report of the FAO Workshop on strengthening National Early Warning and Food Information Systems in Africa, Accra, Ghana, October 23-26, 1989. FAO, Rome.

Gommes, R., M. Bernardi, and F. Petrassi. 1998. Agrometeorological crop forecasting. FAO Research, Extension and Training Division, FAO, Rome Available online at http://www.fao.org/sd/EIdirect/AGROMET/FORECAST.htm.

Hutchinson, M.F. and J.D. Corbett. 1995. Spatial interpolation of climatic data using thin plate smoothing splines. Pages 211-224 *in* Co-ordination and Harmonisation of Databases and Software for Agroclimatic Applications (FAO). Agrometeorology Series Number 13. FAO, Rome, Italy.

ICARDA. 1998. Drought preparedness and mitigation of drought effects. Paper presented at the International Expert Group Meeting for the Preparation of a Sub-Regional Action Programme on Combating Desertification and Drought in Western Asia. Muscat, Oman, September 14-16, 1998. ICARDA, Aleppo, Syria.

Knutson C., M. Hayes, and T. Phillips. 1998. How to Reduce Drought Risk. A guide prepared by the Preparedness and Mitigation Working Group of the Western Drought Coordination Council. National Drought Mitigation Center, Lincoln, Nebraska. Document available online at http://enso.unl.edu/ndmc/handbook/handbook.htm.

SADCC. 1999. Statement from the Southern African Regional Climate Outlook Forum, September 13-17, 1999, Maputo, Mozambique. Available online at http://www.usaid.gov/fews/imagery/fc9909s.html.

Smith, M.1990. Expert consultation on revision of FAO methodologies for crop water requirements. Land and Water Development Division. FAO, Rome.

Supit, I., A.A. Hooijer, and C.A. van Diepen (eds.). 1994. System description of the WOFOST 6.0 crop simulation model implemented in CGMS. EUR 15956, Agriculture Series, European Commission. Joint Research Centre of the European Commission (JRC), Ispra, Italy.

Thornthwaite, C.W. 1948. An approach towards a rational classification of climate. *Geographical Review*. 38:55-94.

Thornthwaite, C.W. and J.R. Mather. 1955. The Water Balance. Publications in Climatology, Vol. 8, No.1. Drexel Institute of Technology, Laboratory of Climatology, Centerton, New Jersey.

UNESCO. 1979. Map of the world distribution of arid regions: Explanatory note. UNESCO, Paris.

Watson, R.T., M.C. Zinyawere, R.H. Moss, and E. Dokken (eds.). The regional impacts of climate change. An assessment of vulnerability. Special report of IPCC Working Group II. Cambridge University Press, Cambridge.

Yacoubi, M., M. El Mourid, N. Chbouki, and C.O. Stöckle. 1998. Typologie de la sécheresse et recherché d’indicateurs d’alerte en climat semi-aride marocain. *Sécheresse* 9:269-76.

Contribution of Remote Sensing to Drought Early Warning

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Abstract

The main goal of global agriculture is to feed 6 billion people, a number likely to double by 2050. Frequent droughts causing food shortages, economic disturbances, famine, and losses of life limit ability to fulfill this goal. NOAA/NESDIS has recently developed a new numerical method of drought detection and impact assessment from NOAA operational environmental satellites. This is the first globally universal technique to deal with such a complex phenomenon as drought. The method was tested and adjusted based on users' response; validated against conventional data in 25 countries, including all major agricultural producers; and accepted as a tool for monitoring grain production potential. Now, drought can be detected 4-6 weeks earlier than before and delineated more accurately, and its impact on grain production can be diagnosed far in advance of harvest, which is the most vital need for global food security and trade.

Introduction

The main goal of global agriculture is to feed 6 billion people, a number likely to double by 2050. Although the Green Revolution of the last 50 years led to an intensive increase in agricultural production, frequent droughts offset the gains from enormous technological efforts and spending in satisfying the growing world demand for food and feed. In just the last ten years of the 20th century (declared by the United Nations as the International Decade for Natural Disaster Reduction), widespread intensive droughts claimed 50-150 million tons of grain (the main source of food for world population) (Figure 1, FAO 2000). In developing countries, the economic, physical, and social effects of drought could be detrimental, resulting in famine, human suffering, death, and abandonment of whole geographic regions (Riebsame et al. 1990; Changnon 1999).

Drought early warning and monitoring are crucial components of drought preparedness and mitigation plans (Wilhite and Glantz 1993). Recent advances in operational space technology have improved our ability to address many issues of early drought warning and efficient monitoring. With help from environmental satellites, drought can be detected 4-6 weeks earlier than before and delineated more accurately, and its impact on agriculture can be diagnosed far in advance of harvest, which is the most vital need for global food security and trade. This chapter describes how the new operational space technology can help agriculture detect drought early enough to assess and mitigate its impacts on grain production.

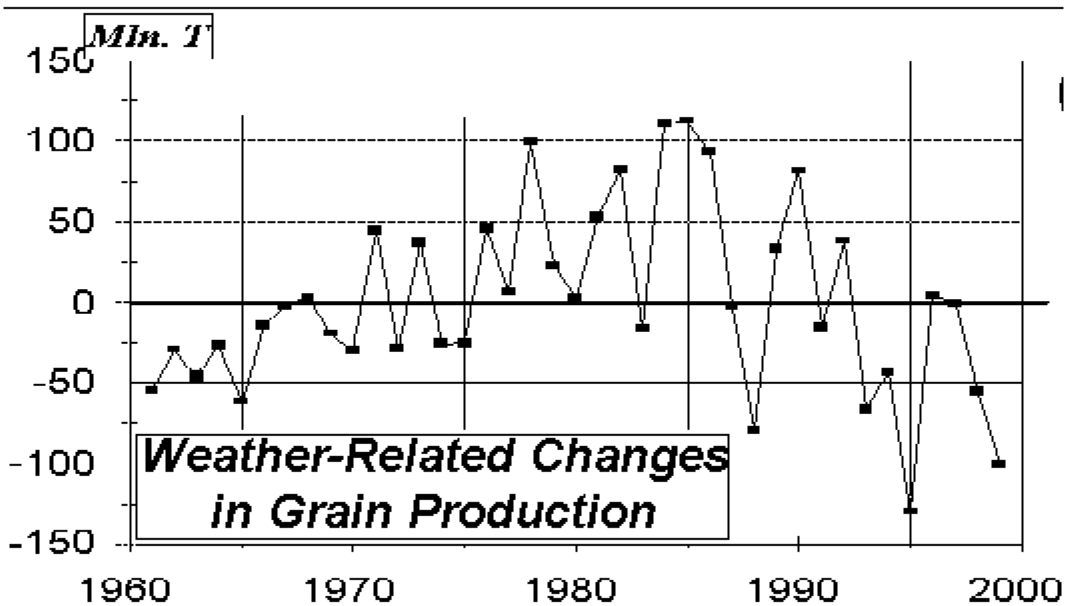

Figure 1. Weather-related variation in world grain production.

Drought as a Natural Disaster

Drought is a part of the earth's climate. It occurs every year with no warning, without recognizing borders or economic and political differences. Of all natural disasters, drought affects the largest number of people. During 1967–91, drought affected 51% of the 2.8 billion people who were affected by natural disasters (Obassi 1994). During the same period, 3.5 million people perished, 45% of them from drought. It has been said that "drought follows the plough" (Glantz 1994), a statement which has proved true. Very productive land is extremely vulnerable to drought. In addition, drought has unique features. Unlike other natural disasters, it starts unnoticed and develops cumulatively. Furthermore, its impact is cumulative and not immediately observable by eye or ground data. By the time the results are evident, it is too late.

Operational Weather Satellites

Operational weather satellite measurements help us cope with these problems. Weather satellites, first launched 40 years ago, were designed to help weather forecasters, but were found to be useful for addressing vegetation issues. Since the late 1980s, they have also been used for drought detection, monitoring, and impact assessment in agriculture (Kogan 1995, 1997, 2000; Hayas and Decker 1996; Unganai and Kogan 1998; Liu and Kogan 1996).

Radiances measured by the space sensors, especially by the Advanced Very High Resolution Radiometer (AVHRR) on NOAA polar-orbiting satellites, respond closely to changes in leaf chlorophyll, moisture content, and thermal conditions (Gates 1970; Myers 1970). Over the last 20 years, the AVHRR data has been used extensively, continuously monitoring earth surface changes, and it is widely recognized around the world. AVHRR-based spectral radiances have been combined into indices and used as proxies for estimation of the entire spectrum of vegetation health (condition) from excellent to stressed (Kogan 1997, 2000).

Moreover, AVHRR-based multiyear daily observations from space provide cost effectiveness, free access, and a repetitive view of nearly all of the earth's surfaces. They are indispensable sources of information versus in situ data, whose measurements and delivery are affected by telecommunication problems and difficult access to environmentally marginal areas, places of economic disturbances, and areas of political and military conflicts. Furthermore, they are preferable to in situ data in spatial and temporal coverage and in quick data availability. Finally, they characterize an area rather than a point location, which is typical for agricultural and weather observations.

New Method and Data

A new method for early drought detection, monitoring, and impact assessment is based on estimation of vegetation stress from AVHRR-derived indices designed to monitor vegetation health, moisture, and thermal conditions (Kogan 1997). Unlike the two spectral channel approach routinely applied to vegetation monitoring, the new numerical method, introduced in the late 1980s, is based on a three spectral channel combination: visible (VIS, ch1), near infrared (NIR, ch2), and 10.3-11.3 μm infrared (IR, ch4). The new method is built on three basic environmental laws: law-of-minimum (LOM), law of tolerance (LOT), and the principal of carrying capacity (CC).

LOM postulates that primary production is proportional to the amount of the most limiting growth resource and becomes the lowest when one of the factors is at the extreme minimum. LOT states that each environmental factor that an organism or ecosystem depends on has maximum and minimum limiting effects, wherein lies a range that is called the limits of tolerance. With regard to these laws, the CC is defined as the maximal population size of a given species that resources of a habitat can support (Reinign 1974; Ehrlich et al. 1977; Orians 1990).

The new method was applied to the NOAA Global Vegetation Index (GVI) data set issued routinely since 1985 (Kidwell 1995). The GVI is produced by sampling the AVHRR-based 4-km (global area coverage format, GAC) daily radiances in the VIS (0.58-0.68 μm), NIR (0.72-1.1 μm), and IR (10.3-11.3 and 11.5-12.5 μm), which were truncated to 8-bit precision and mapped to a $(16\ km)^2$ latitude/longitude grid. To minimize cloud effects, these maps were composited over a 7-day period by saving radiances for the day that had the largest difference between NIR and VIS.

Since AVHRR-based radiances have both inter-annual and intra-annual noise (variable illumination and viewing, sensor degradation, satellite navigation and orbital drift, atmospheric and surface conditions, methods of data sampling and processing, communication and random errors), its removal is crucial for the new method. The initial processing included post-launch calibration of VIS and NIR, calculation of the Normalized Difference Vegetation Index (NDVI=[NIR-VIS]/[NIR+VIS]), and converting IR radiance to brightness temperature (BT), which was corrected for nonlinear behavior of the sensor (Rao and Chen 1995, 1999; Winereb et al. 1990).

The three-channel algorithm routines also included complete removal of temporal high frequency noise from NDVI and BT values, stratification of world ecosystems, and detection of medium-to-low frequency fluctuations in vegetation condition associated with weather variations (Kogan 1997). These steps are crucial in order to use AVHRR-based indices as a proxy for temporal and spatial analysis and interpretation of weather-related vegetation condition and health.

Finally, three indices characterizing moisture (VCI), thermal (TCI), and vegetation health (VT) conditions were constructed following the principle of comparing a particular year's NDVI and BT with the entire range of their variation during the extreme (favorable/unfavorable) conditions. Based on the LOM, LOT, and CC, the extreme conditions were derived by calculating the maximum and minimum (MAX--MIN) NDVI and BT values from 14-year satellite data. The (MAX--MIN) criteria were used to classify "carrying capacity" of ecosystems in response to climate and weather variations. The VCI, TCI, and VT were formalized as:

$$VCI = (NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min})*100$$

$$TCI = (BT_{max} - BT) / (BT_{max} - BT_{min}) * 100$$

$$VT = a*VCI + b*TCI$$

where NDVI, $NDVI_{max}$, and $NDVI_{min}$ are the smoothed weekly NDVI and its multiyear absolute maximum and minimum, respectively; BT, BT_{max}, and BT_{min} are similar values for brightness temperature; and *a* and *b* are coefficients quantifying a share of VCI and TCI contribution in the combined condition. For example, if other conditions are near normal, vegetation is more sensitive to moisture during canopy formation (leaf appearance) and to temperature during flowering. Therefore, the share of moisture contribution into the total vegetation condition (health) is higher than temperature during leaf canopy formation and lower during flowering. Since moisture and temperature contribution during a vegetation cycle is currently not known, we assume that the share of weekly VCI and TCI is equal.

Major Droughts

United States. The United States is the world's largest producer and leading exporter of agricultural products. Drought is a very common phenomenon in the North American climate. It occurs almost every year somewhere in the nation, and agriculture is often seriously affected. A classic example of devastation occurred in 1988, when drought caused around $40 billion in damage to the U.S. economy in terms of human health, environment, and wildlife (compared to $15 billion in damages for the 1989 San Francisco earthquake). Grain production fell below domestic consumption probably for the first time in the last half century (Reibsame et al. 1990; Kogan 1995).

The AVHRR-based estimate in Figure 2 shows that by the end of June 1988, vegetation experienced stress in the most productive areas of the Great Plains, the breadbasket of the United States. The effect of the drought was exacerbated by the time of its occurrence (during a critical period of crop growth) and the worst combination of moisture (VCI) and thermal (TCI) stress.

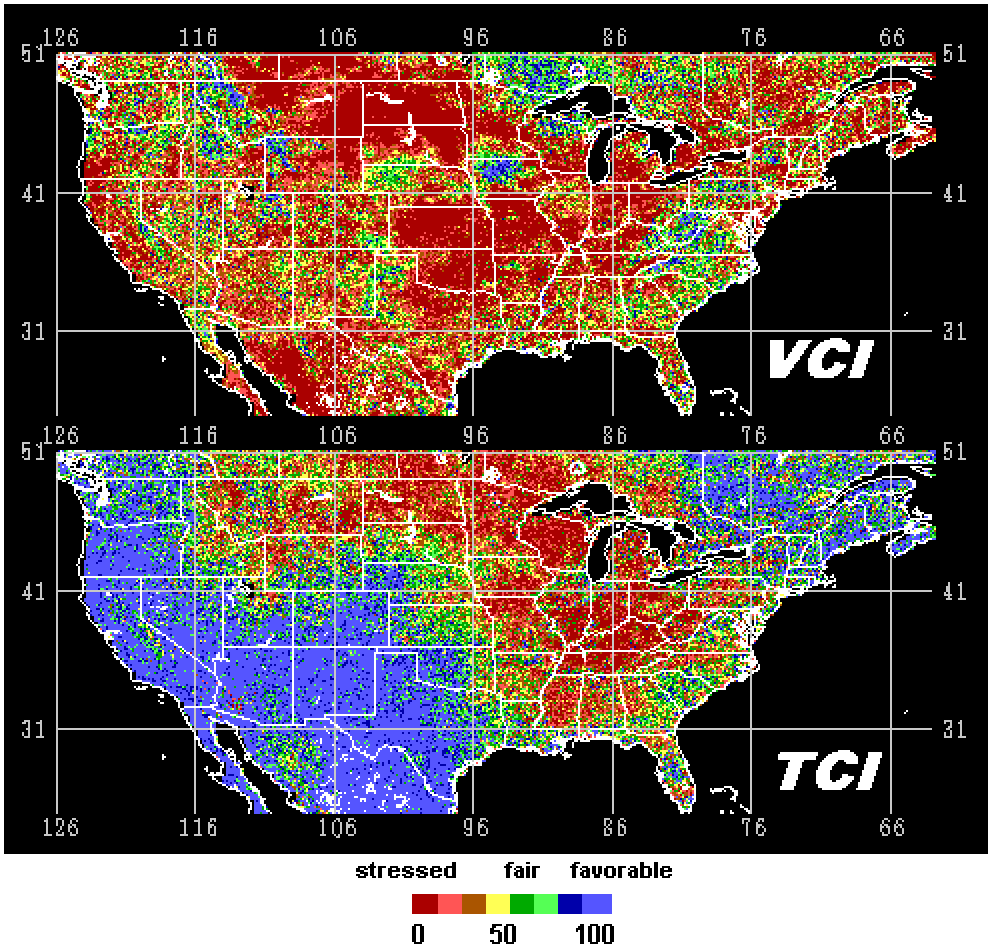

Figure 2. Moisture (VCI) and thermal (TCI) stress (black), end of June 1988, USA, NOAA-9.

Total U.S. corn production dropped by nearly 30% (other grain crops also had considerable losses), and the most affected states were in a zone that was experiencing a three-month shortage of rains (Kogan 1995). The economic effect of this drought was felt globally because the 1988 total world corn production was 50 million tons less than in 1987 and 75 million tons less than in 1989. Total world grain production in 1988 dropped 3% (FAO 2000).

Other major U.S. droughts of the last 15 years occurred in 1989 and 1996. These droughts were quite similar. Both started very early and affected the primary winter wheat areas by the end of April (Figure 3, left). Compared to them, the 1988 vegetation stress (shown in black) did not

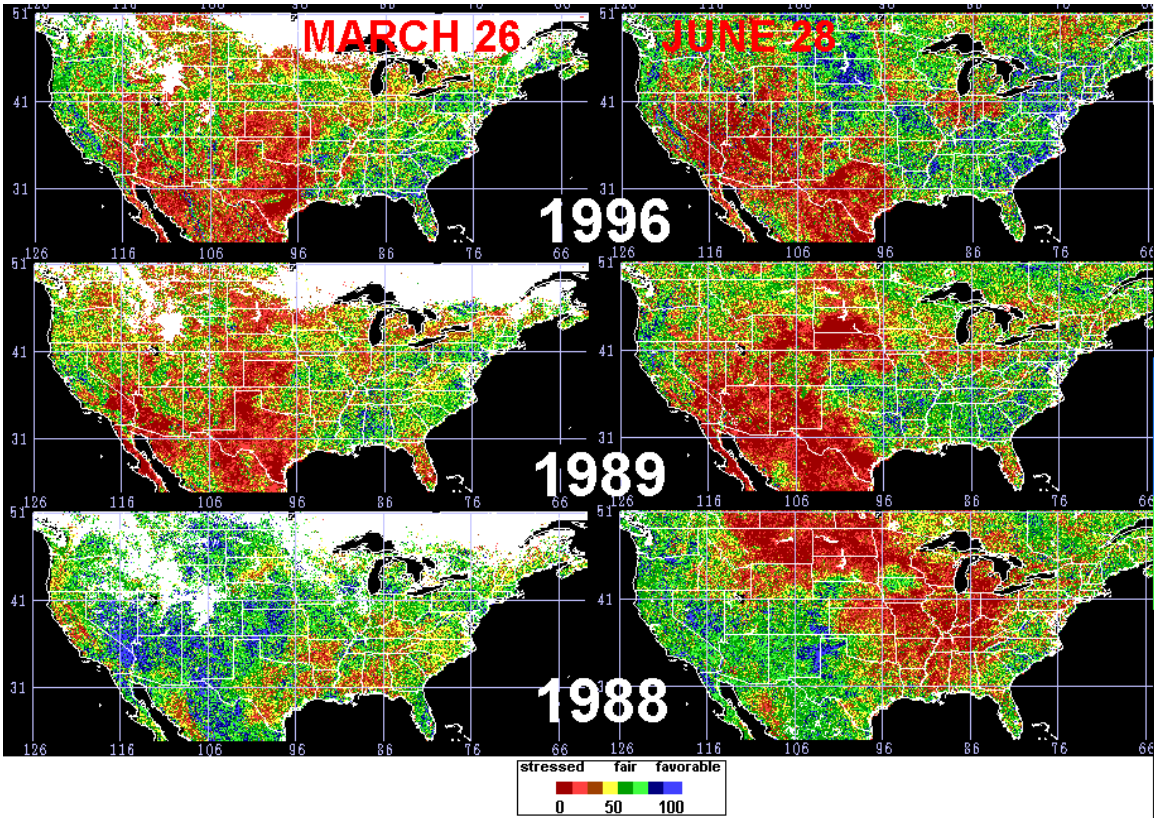

Figure 3. Vegetation stress (black), USA, NOAA-9, -11, and –14 polar-orbiting satellites data.

appear as early. Three months later, the 1988 drought turned into a national disaster, affecting vegetation during the most critical mid-season period (Figure 3, right). The 1989 and 1996 vegetation stress persisted into the summer, although in 1989, only spring crops were affected. Luckily, crop production was reduced in only a few states of the central and northern Great Plains and the total 1989 U.S. spring crop production did not shrink much (Kogan 1995).

Former Soviet Union (FSU). If the United States is the largest seller of grain, the FSU has been and will likely be the largest buyer of U.S. grain. Climate and weather are key factors constraining agriculture and grain production. Since the breakup of the Soviet Union in 1991, grain yields have stagnated because of limited introduction of new technology. This factor, in combination with frequent droughts, led to serious grain shortages. Therefore, monitoring FSU grain production and possible purchases is very important for U.S. grain growers and traders.

Since 1991, four major (every other year) and two minor droughts have been identified by the AVHRR-based indices (Figure 4). Some of them occur two years in a row (e.g., 1995 and 1996). The major droughts of the last decade covered 100-150 million acres of crops and rangeland and reduced the total FSU grain production 10-15% (20-30 million metric tons). The individual countries incurred grain losses up to 30%. The worst economic problems occur when major drought affects both winter (mostly Ukraine and southern Russia) and spring grain crops (eastern regions in 1991, 1996, 1998).

Argentina. Argentina is the world's second largest exporter (after the United States) of corn and coarse grains, and the third largest exporter of wheat (FOA 2000). Droughts do not bypass Argentina since the climate provides considerably less precipitation than thermal resources can potentially evaporate; droughts and dry spells are frequent and devastating. In the last 15 years, Argentina experienced two major and several minor droughts. By all standards, the most damaging droughts occurred during the 1988/89 and 1989/90 crop seasons (Figure 5), when the country lost 15-20% of the total volume of grain. The minor droughts were less intensive and affected smaller areas and/or only a part of the growing season, leading to a 5-10% reduction in crop yields.

China. China is the world's leading agricultural country, producing the largest portion of global grain and cotton, most of which is consumed domestically. From time to time, China also imports small amounts of agricultural commodities. However, in 1994, China unexpectedly purchased a huge volume of cotton, almost double the amount of their previous largest purchase. These imports were preceded by a cotton yield reduction three years in a row: 22% in 1992/93, 11% in 1993/94, and 7% in 1994/95 (the estimates were relative to the average yield in the very productive 1990/91 and 1991/92 seasons [Kogan 1997; USDA 1994]). Our investigation indicates that this reduction can be attributed to unfavorable growing conditions, which caused vegetation stress in the main cotton-growing areas (Figure 6). The most severe vegetation stress (both moisture and thermal) occurred in 1992, which also showed the largest yield reduction. Some deterioration of vegetation conditions was also observed in 1994, but the drought-related stress was partially offset by near-normal summer rainfall. Unlike the other two drought years, 1993 AVHRR-derived vegetation stress in the cotton-growing area was due to excessive moisture.

Technology Transfer

The objective of NESDIS is to interact with the global community and provide early drought (and related environmental calamities) warnings and impacts on agriculture; validate and calibrate satellite-based products; and develop new applications. These goals are reached in several ways: distributing the products through NOAA's web site, scientific cooperation, training, and public outreach.

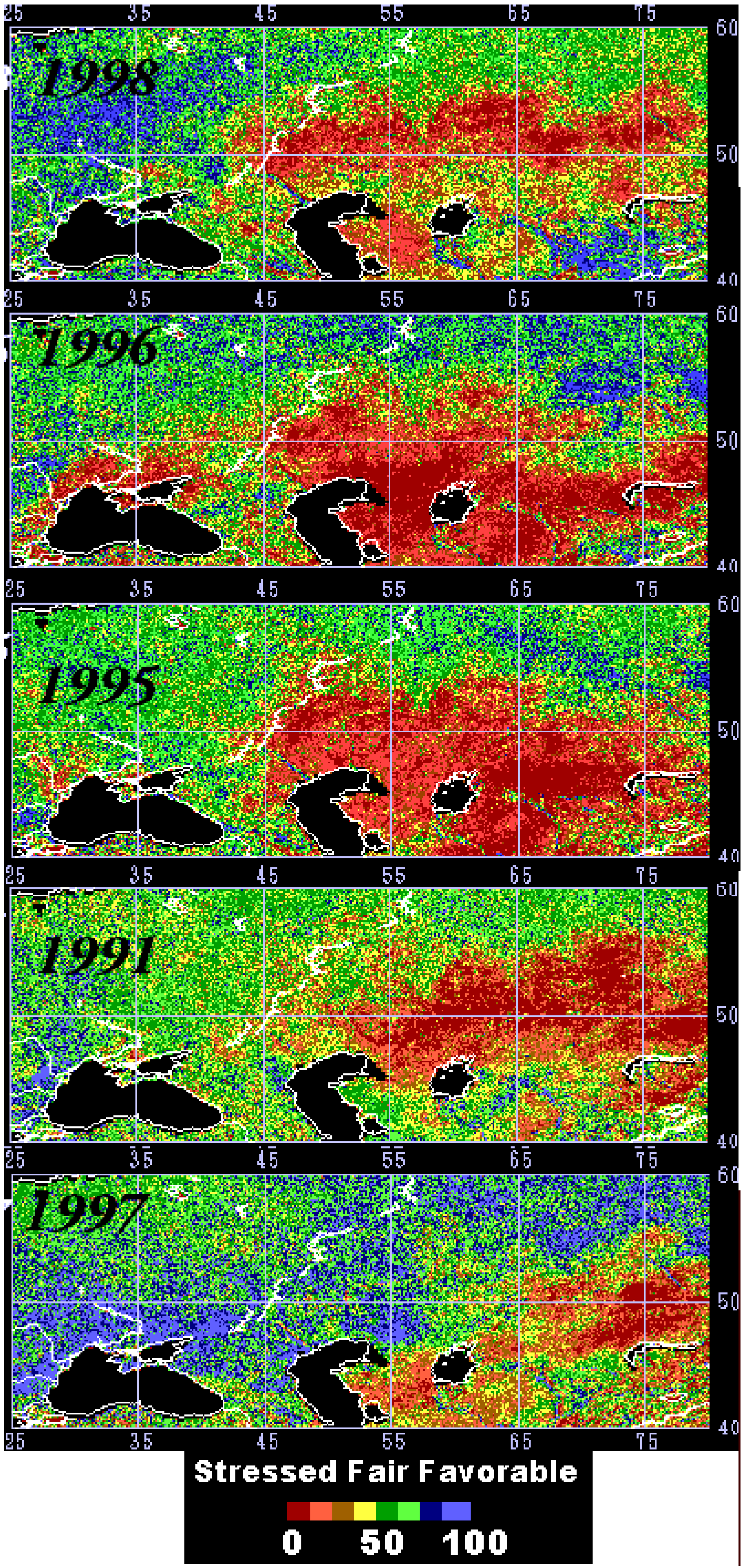

Figure 4. Vegetation stress (black), FSU, NOAA-11, and –14 polar-orbiting satellites data.

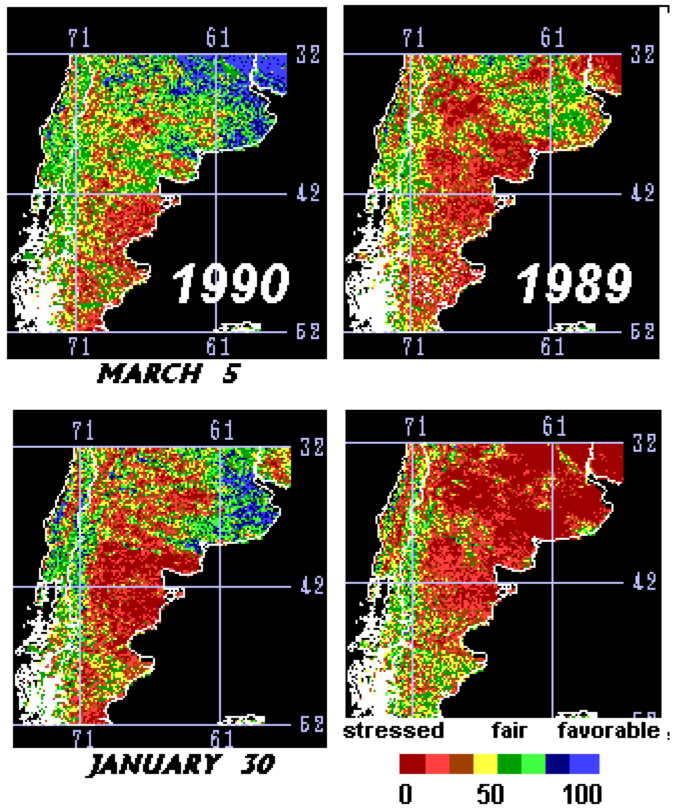

Figure 5. Vegetation stress (black), Argentina, NOAA-11 and –14 polar-orbiting satellites data.

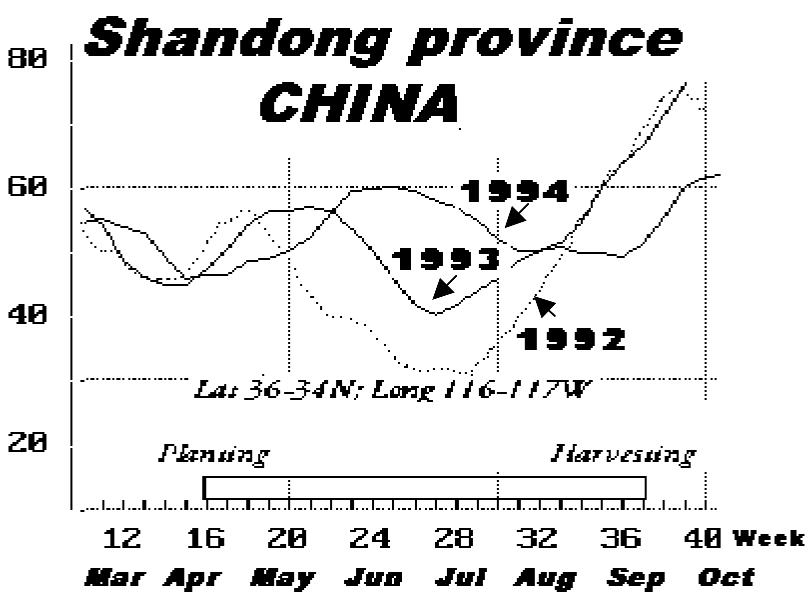

Figure 6. Vegetation health dynamics in Shandong province (25% of China's total cotton production, USDA 1994); the strongest and longest vegetation stress (VT below 40) was in 1992.

The products and data discussed in this paper are delivered in real time (every Monday) to the following web site address: http://orbit-net.nesdi.noaa.gov/crad/sat/vci. They show global and regional vegetation health, moisture and thermal conditions, and fire risk potential. An important part of this process is close cooperation with users, taking into account their suggestions and comments on how the products perform versus available ground data. Some of the comments are quite inspiring. For example: “I am using your images of USA, China and Argentina for the world grain stock analysis” (Dr. Seiler, University of Rio Quarto, Argentina, 1999); “your information on drought is going to Mexico’s Minister of Agriculture to make important decisions on implementing the Alternative Crop Program to the farmers of Central Mexico; in November 1998 the Minister met with the President and showed the images to explain how drought affected rural areas” (Mr. Cuevas, adviser to the Minister of Agriculture, Mexico, 1999); “I use your images as a background for my 10-day agricultural and climate conditions assessments” (Mr. Themaat, Disaster Management Center, Republic of South Africa, 1999); “I look at your fire monitoring web site and find it useful for us in Brazil” (Dr. de Silveira, National Meteorological Institute, Brazil, 2000).

We also provide 2-4 month one-on-one (on-site) training for users of the new technology. This includes access to satellite data, hardware, and software. The users are required to match their country’s conventional data with satellite-based products to validate existing products and to develop new applications based on joint interests. Another way of interacting with users is a long-term cooperation program. Among recent projects, the most successful (which led to the development of a new PC-based data processing system and AVHRR-based crop yield models) were with China, Kazakhstan/Israel (supported by the U.S. Agency for International Development), and Poland (U.S.–Poland bi-national fund).

AVHRR-based Crop Yield Prediction

Crop yield modeling has been a very successful program, specifically in the area of limiting ground data. The background for this task was done in the mid 1990s and was confirmed in the U.S. Midwest and in Zimbabwe (Hayas and Decker 1996; Kogan 1997; Unganai and Kogan 1998). It has been shown that vegetation health indices highly correlate with yield during the critical period of crop development and might be used for modeling and diagnosis of crop yield. Currently, satellite-based crop yield models have been developed for Argentina, Brazil, the Republic of South Africa, Morocco, Poland, Hungary, Kazakhstan, India, and China. In Poland, this program was so successful that the AVHRR-based drought detection and watch method and its models were accepted by the government as an official tool for cereal yield diagnostics. An example of independent evaluation in Morocco (Figure 7) shows that regional wheat yield estimates (line) follow closely the official statistics (bar), especially in the main regions of wheat production.

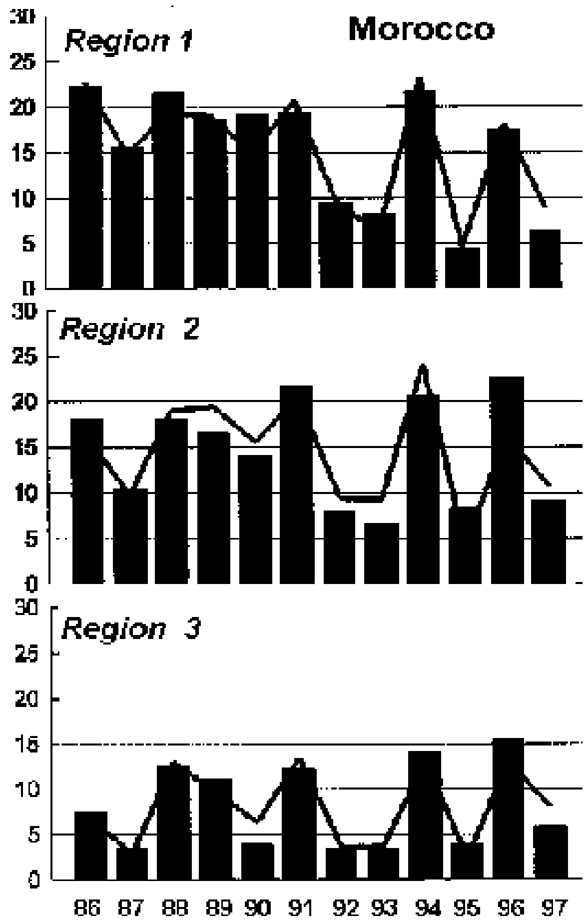

Figure 7. Independent evaluation of wheat yield estimated from satellite (line) and ground (bars) data, Morocco, major regions, 1985-1998.

Vegetation Health 2000

Although the 21st century has just started, drought has already claimed its toll. Huge areas in central Africa, the Middle East, Southeast Asia, central South America, and the central United States had vegetation stress (Figure 8). Compared to fair and favorable vegetation conditions in 1999, a quarter of the world is suffering from dryness in 2000. The most severely affected areas are in the Horn of Africa, where vegetation stress started in January (Figure 9). In a four-month period, the stress intensified and expanded to new areas. By the end of April, this drought turned into natural disaster, affecting 90% of Kenya, Somalia, and Uganda and almost all agricultural lands of Ethiopia. The minor ("belg") crop season in Ethiopia (March–May), which normally provides food and feed before the start of the main growing season, almost completely failed. Moreover, a huge area of the entire Horn of Africa region is under the threat of fire. It is estimated that nearly 15 million people in the Horn of Africa are affected. Agriculture was also affected in Afghanistan, Pakistan, India, Mongolia, and China (Figure 8). The new space-based

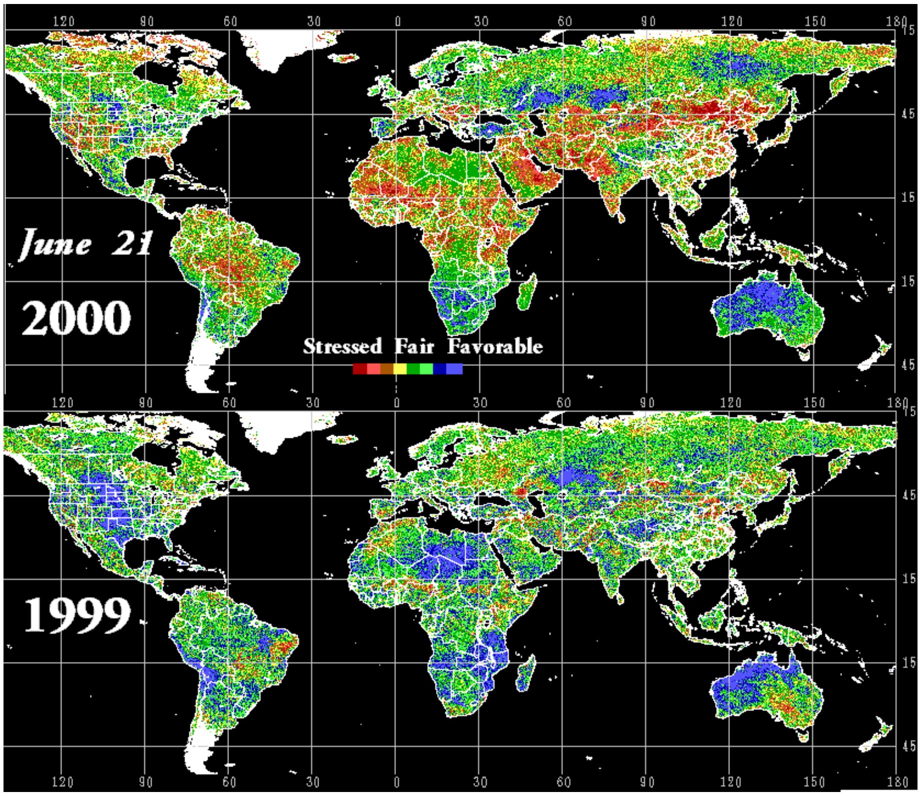

Figure 8. World vegetation health (stressed=black, fair=grey, favorable=white).

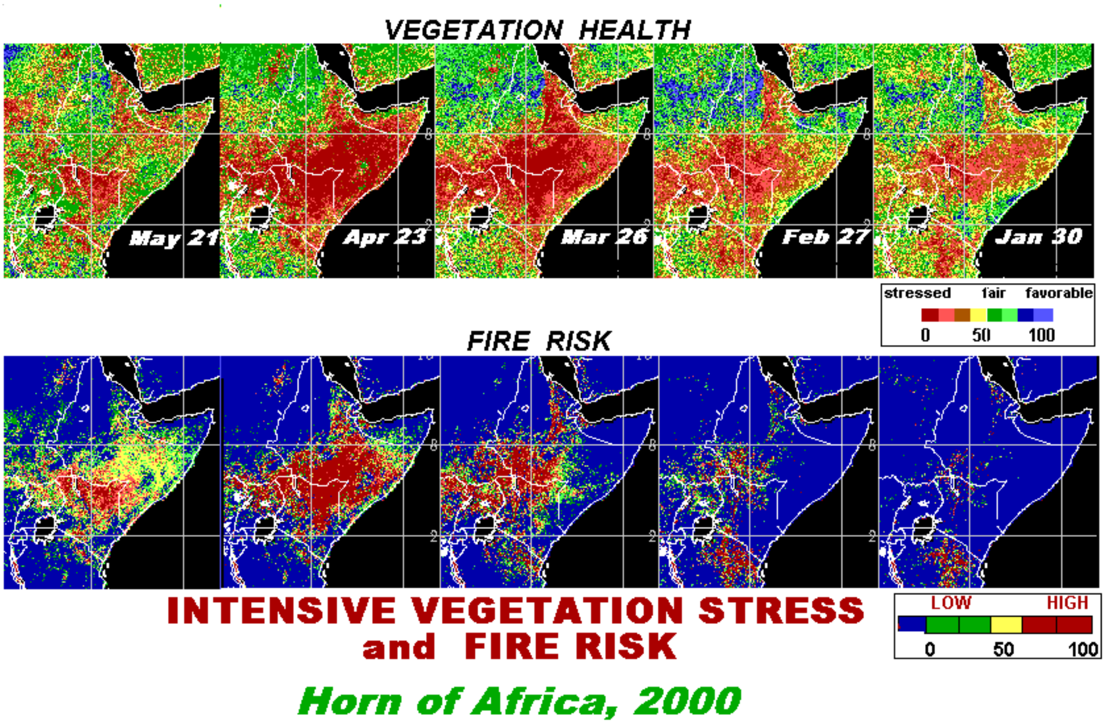

Figure 9. Dynamics of vegetation stress in the Horn of Africa, 2000, NOAA-14.

technique is useful not only for early drought detection and diagnosis of impacts, but also for assessment of the size of the affected area. As seen in Figure 10, in Afghanistan and Kenya, the area of vegetation stress in 2000 is the largest since 1991 in both categories (severe and extreme).

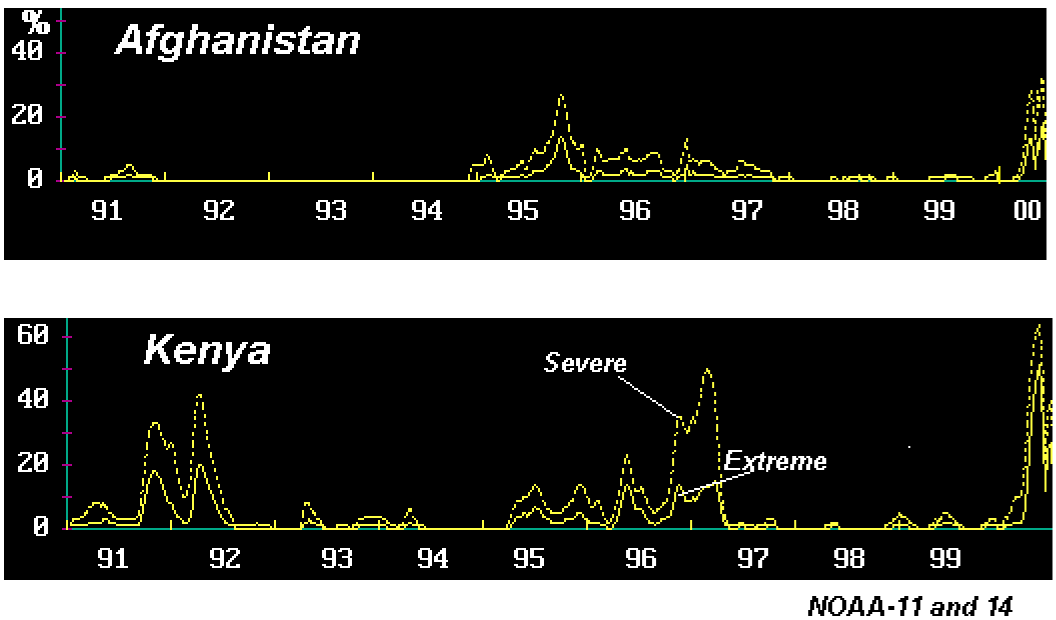

Figure 10. Percent area in Kenya with severe and extreme droughts.

Conclusions

The results of this chapter show that we begin the 21st century with exciting prospects for the application of operational meteorological satellites in agriculture. With the introduction of the new method, which was tested around the world, including all principal agricultural producers, drought can be detected 4-6 weeks earlier than before in any corner of the globe and delineated more accurately, and its impact on grain production can be diagnosed long before harvest. This is the most vital step for global food security and trade.

The current developments in satellite technology and sensor design, along with great achievements in numerical methods, speed and capacity of computers, and available hardware and software, will bring more progress in the application of operational and research satellites. With the accumulation of satellite data we will continue to enhance the accuracy of hazard detection, monitor the environment, increase the lead time of estimates, and better diagnose impacts. New products geared to diagnose epidemics, human health problems, and insect development will be more aggressively pursued. New sensors will widen our abilities to detect problems earlier and with higher spatial accuracy. New high-resolution capabilities of satellite sensors will help with precision agriculture and the ability to move from problem detection to mitigation. A new era of satellites will provide the ability to estimate economic effectiveness of applied technologies in order to optimize profit.

References

Changnon, S.A. 1999. Impacts of 1997-98 El Niño-generated weather in the United States. *Bulletin of the American Meteorological Society* 80:1,819-1,827.

Ehrlich, P.R., A.H. Ehrlich, and J.P. Holdren. 1977. Ecoscience: Population, Resources, Environment. W.H. Freeman, San Francisco.

FAO. 2000. Crop production statistics. http://www.fao.org.

Gates, D.M. 1970. Physical and physiological properties of plants. Pages 224-252 *in* Remote Sensing with Special Reference to Agriculture and Forestry (National Research Council Committee on Remote Sensing for Agricultural Purposes). National Academy of Sciences, Washington, D.C.

Glantz, M.H. 1994. Drought, desertification, and food production. Pages 9-30 *in* Drought Follows the Plow (M.H. Glantz, ed.). Cambridge University Press, Cambridge.

Hayas, M.J. and W.L. Decker. 1996. Using NOAA AVHRR data to estimate maize production in the United States Corn Belt. *International Journal of Remote Sensing* 17:3,189-3,200.

Kogan, F.N. 2000. Global drought detection and impact assessment form space. Pages 196-210 *in* Drought: A Global Assessment, Vol. 1 (D.A. Wilhite, ed.). Routledge, London.

Kidwell, K.B. (ed.). 1995. NOAA Polar Orbiter Data Users Guide. National Oceanic and Atmospheric Administration, NESDIS/NCDC, Satellite Data Services Division, Washington, D.C.

Kogan, F.N. 1997. Global drought watch from space. *Bulletin of the American Meteorological Society* 78:621-636.

Kogan, F.N. 1995. Droughts of the late 1980s in the United States as derived from NOAA polar orbiting satellite data. *Bulletin of the American Meteorological Society* 76:655-668.

Liu, W.T. and F.N. Kogan. 1996. Monitoring regional drought using the Vegetation Condition Index. *International Journal of Remote Sensing* 17:2,761-2,782.

Myers, V.I. 1970. Soil, water, and plant relations. Pages 253-267 *in* Remote Sensing with Special Reference to Agriculture and Forestry (National Research Council Committee on Remote Sensing for Agricultural Purposes). National Academy of Sciences, Washington, D.C.

Obasi, G.O.P. 1994. WMO's role in the International Decade for Natural Disaster Reduction. *Bulletin of the American Meteorological Society* 75:1,655-1,661.

Orians, G.H. 1990. Ecological sustainability. *Environment* 32(9):10-15, 34-39.

Rao, C.R.N. and J. Chen. 1995. Inter-satellite calibration linkages for the visible and near-infrared channels of the Advanced Very High Resolution Radiometer on the NOAA-7, -9, and -11 spacecrafts. *International Journal of Remote Sensing* 16:1,931-1,942.

Rao, C.R.N. and J. Chen. 1999. Revised post-launch calibration of the visible and near-infrared channels of the Advanced Very High Resolution Radiometer on the NOAA-14 spacecraft. *International Journal of Remote Sensing* 20:3,485-3,491.

Reinign, P. 1974. The use of ERTS-1 data in carrying capacity estimates for sites in Upper Volta and Niger. Pages 176-180 *in* Proceedings of the Annual Meeting of the American Anthropological Association (Mexico City, Mexico). American Anthropological Association, Arlington, Virginia.

Riebsame, W.E., S.A. Changnon, and T.R. Karl. 1990. Drought and Natural Resource Management in the United States: Impacts and Implications of the 1987-1989 Drought. Westview Press, Boulder, Colorado.

Unganai, L.S. and F.N. Kogan. 1998. Drought monitoring and corn yield estimation in Southern Africa from AVHRR data. *Remote Sensing Environment* 63:219-232.

USDA. 1994. Major World Crop Areas and Climatic Profiles. Agricultural Handbook No. 664: 157-170. World Agricultural Outlook Board, U.S. Department of Agriculture.

Weinreb, M. P., G. Hamilton, and S. Brown. 1990. Nonlinearity correction in calibration of the Advanced Very High Resolution Radiometer infrared channels. *Journal of Geophysical Research* 95:7,381-7,388.

Wilhite, D.A. and M.H. Glantz. 1993. Planning for drought: A methodology. Pages 87-109 *in* Drought Assessment, Management, and Planning: Theory and Case Studies (D.A. Wilhite, ed.). Kluwer Academic Publishers, Dordrecht, The Netherlands.

Drought Quantification and Preparedness in Brazil - The Example of São Paulo State

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Abstract

Drought in Brazil is a very important phenomenon that affects not only agricultural production but also society. The magnitude and large-scale variation of drought are analyzed specifically for São Paulo State. The quantification and monitoring of drought, rainfall distribution, and agricultural management are discussed. Daily climatological data from 114 localities are used to determine drought indices. These indices take into account soil type and crop characteristics; they are derived from the relationship between ETR/ETP and soil water availability obtained by the water balance. Crop response to drought, soil management, and agricultural practices are also analyzed. Meteorological variability and weather forecast parameters are used to give support to the warning system.

The indices used to quantify and monitor drought are the ratio ETR/ETP, soil water surplus, soil water deficiency, rainfall frequency and distribution, crop water requirement, dry spell frequency, probability of stored water in the soil, rainfall anomaly, and agricultural dryness.

Agrometeorological bulletins are issued twice a week and distributed to farmers, extension service, and media. All information related to crop planting and harvesting, drought intensity, rainfall anomaly, agricultural practices, and crop weather requirements are considered in the preparation of the agrometeorological bulletins. Aspects of climatic risks zoning are used to determine the best planting time to avoid or reduce drought risks during crop development.

Recently the Standardized Precipitation Index (SPI) concept has been incorporated into the bulletins. A specific analysis was made for the 1999–2000 drought period in São Paulo State. The results demonstrated that the SPI was useful for monitoring and quantifying drought regimes and their effects on crops.

Introduction

Drought concepts vary widely in Brazil, depending on soil characteristics and crops. For instance, 6-7 days without rainfall may characterize a severe drought period for shallow-rooted crops, whereas for crops with deep rooting systems this may not be considered drought. Another important aspect is the water storage capacity of the soil. Soils with a deep profile and good water retention capability provide a good water reservoir and also facilitate root expansion. Shallow soils enhance drought because of the smaller volume of stored water in the soil layer, but on the other hand, precipitation values may not have to be very high to return the soil moisture to field capacity.

The large variability in climatic conditions and topography have led to great differences in agro-ecological zones and agricultural production in Brazil. Although the northeastern region is more prone to drought, other regions of the country also may be affected by drought, particularly during the main crop growing season.

According to Repelli and Alves (1996), northeast Brazil is located between 1° S and 18° S latitude and from 35° W to 47° W longitude. The semiarid region is a subregion of this whole area; it is defined mostly by a rainfall regime with a great interannual variability. If drought is a normal climatological feature of northeastern Brazil, it is important to determine the probability of above- and below-normal rainy seasons.

Several studies of rainfall regime or dry spell frequency have been carried out for the region (Silva and Rao 1994; Andrade and Bastos 1997). Liu and Liu (1983) determined the probability of drought during the growing season for maize using the frequency distribution over 15 levels of soil water deficit obtained through the soil water balance (Thornthwaite and Mather 1955).

Silva et al. (1985) determined with 80% probability the occurrence of rainfall after March 19 for Paraiba State. In this case, the crop growing season lasted from September 22 to September 21 (next year), and the probabilities of rainfall for the first (Q1) and fourth (Q4) periods were very different. The last period (Q4) had a higher probability of rainfall deficits.

Nitzche et al. (1985) developed criteria to define the tendency of the rainy season. They defined the years as rainy (wet), dry, or normal. This study was based on the mean (X) and standard deviation (S) of the total rainfall observed for each year, and the limits are:

Dry Year $X_i < (\overline{X} - S)$

Normal $\overline{X} - S \leq X_i \leq \overline{X} + S$

Wet (rainy) $X_i > X + S$

($X \equiv$ expected rainfall)

Winter in southern Brazil is relatively humid, with a good rainfall distribution. Summer months receive a good amount of rainfall, except for some areas in Rio Grande do Sul, where the normal climatic values indicate water deficits, particularly for December and January. Although precipitation is not the limiting factor, there are often periods with severe dry spells or even drought periods which may reduce agricultural production substantially.

Mota (1979; 1987) presents a methodology to quantify drought effects on crops. His methodology is based on the ratio ETR/ETP, determined by the daily soil water balance. He proposed the use of the dry index as indicated by Shaw (cited in Mota 1979), which is given by:

$$DI = 1 – ETR/ETP$$

He used this index to estimate crop yield reductions in functions of drought for specific years, and the results he obtained were very reliable.

Rainfall characteristics are very well defined in the central and southeastern (S/C) regions. Summer months are humid and hot, and winter months are very dry, but not so cold, with occasional frost. Nevertheless, for some specific years, dry spells may seriously affect crop yield, and drought may last for up to 6-8 months, substantially decreasing the water stored in the reservoirs and causing problems for agriculture, human needs, and irrigation scheduling.

Crops cultivated in the S/C regions have their growing period during the summer (rainy) season, which lasts from October until April, but some crops can be grown during the dry or winter months, and the major crops cultivated during this period are maize, wheat, sorghum, sunflower, oat, and rye. These crops can be cultivated only by integrating suitable agronomic technologies and irrigation techniques and by choosing the best or correct planting date. Although irrigation practices are very important for dry-season agriculture, during the humid season (summer), dry spells occur often and crop water requirements can only be achieved by supplementary irrigation. For this reason, many studies have dealt with the probability of drought or dry spell periods during critical phenological stages (flowering, pod formation, fruitification) of crops. Those studies are intended to reinforce the importance of crop calendar aspects and crop zoning (Arruda et al. 1979).

Large-scale phenomena, like El Niño (ENSO) or La Niña, affect rainfall distribution markedly (Bergamaschi 1999), but their effects are more pronounced on the southern and northeastern regions of the country (Brunini and Pinto 1997).

Fontana and Berlato (1996) have observed that the El Niño phenomenon affects rainfall distribution in Rio Grande do Sul State, increasing the amount of rain particularly in October and November. On the other hand, Mota et al. (1996) have pointed out that drought and dry spells are very well correlated to La Niña in such regions.

Drought Monitoring in São Paulo State

Agrometeorological parameters and agricultural production are closely related in São Paulo State, and the most important climatic factors that may substantially reduce crop development or yield are frost, drought, and dry spells. For this reason, an agrometeorological monitoring system is being carried out to give support to drought forecasting, preparedness, and mitigation. This agrometeorological system is supported by previous work and studies that attempted to correlate crop development and weather parameters. These studies and their results are incorporated into agrometeorological bulletins that are prepared twice a week, enhancing the agrometeorological conditions (actual and future) that affect crop development. Irrigation demands and the climatic risks (drought, for instance) during the crop growing period are also analyzed and evaluated.

The studies try to incorporate the variability of climatic elements and more specific rainfall data, crop weather requirements, and soil type. The results are transferred to farmers and governmental agencies as technical or scientific papers; in some cases, they are summarized in state policy to support agricultural production and farmers' decisions. The studies and research are based on soil, plant, and climate interactions as described below.

Stored Soil Water

Most of the agricultural processes in São Paulo State are carried on under a rainfed regime. For this reason, knowledge of the stored water in the soil and its variation during the year or from year to year helps farmers choose the best planting date to avoid drought risks during critical crop stages.

Stored soil water has been determined in two ways: (1) continuous measurements over a reasonable number of years and (2) an estimate through the soil water balance on a 5-, 10-, 15-, or 30-day basis, using long-term weather parameters for at least 20 to 30 years of recorded data. Based on this, the probability of the stored water in the soil or the water deficiency for each type of soil can be predicted (Figure 1).

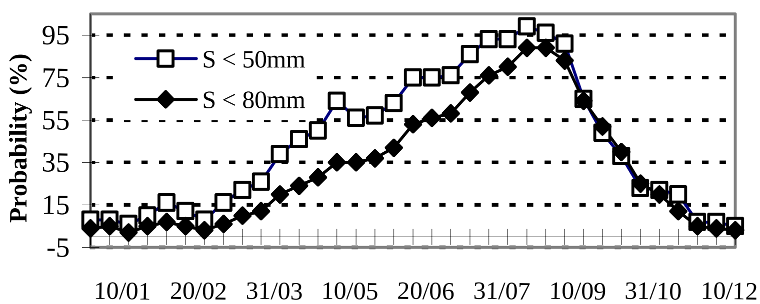


Figure 1. Probability of soil water deficiency in a 10-day analysis, considering critical levels of 50 mm and 80 mm of soil holding capacity.

Dry Spell Probability

In this case, all the studies try to determine the risks of severe drought or dry spell periods during critical phenological stages of crops. Arruda et al. (1979) and Alfonsi et al. (1979) used the moving average method (step 1) and calculated the total rainfall for every 10 days, then compared this to the crop water requirements. Crop water demand was estimated as a function of potential evapotranspiration and crop stage. An example is presented for the first 20 days of

January (Table 1) for rice cultivars, considering that this crop has a minimum water requirement of 40 mm in a 10-day period.

Table 1. Relative frequency of total rainfall less than 40 mm in a 10-day period for several localities in São Paulo State.

Period	Mococa	Campinas	Pindorama	Ribeirão Preto	Jaú	Ataliba Leonel	Presidente Prudente	Pindamo-Nhangaba
01-10	0.10	0.37	0.43	0.20	0.26	0.47	0.36	0.32
02-11	0.10	0.28	0.38	0.10	0.17	0.35	0.36	0.32
03-12	0.10	0.28	0.33	0.15	0.26	0.29	0.40	0.28
04-13	0.20	0.28	0.38	0.20	0.22	0.35	0.30	0.32
05-14	0.20	0.25	0.38	0.20	0.22	0.35	0.30	0.36
06-15	0.20	0.25	0.29	0.20	0.22	0.35	0.33	0.40
07-16	0.25	0.23	0.24	0.20	0.26	0.35	0.24	0.24
08-17	0.30	0.18	0.24	0.20	0.35	0.35	0.27	0.28
09-18	0.30	0.23	0.19	0.25	0.39	0.41	0.27	0.36
10-19	0.25	0.25	0.24	0.25	0.35	0.47	0.36	0.32
11-20	0.30	0.28	0.24	0.15	0.35	0.41	0.36	0.32

Crop Water Requirements

Camargo et al. (1985) and Alfonsi et al. (1989) defined the best sowing date for different crops based on crop water requirements and rainfall distribution for each critical phenological stage. First of all, the water requirement was determined for each crop for the planting dates. Potential evapotranspiration (ETP) was estimated according to Thornthwaite (1948) using the simplified "T index" as proposed by Camargo (1962). Instead of using the total rainfall for every ten days, the authors determined the probability of attaining the crop water requirement using the Gamma distribution concept:

$$f(x) = \frac{x^{\gamma-1} e^{-x/B}}{B^{\gamma} \gamma(F)}$$

γ was determined previously by Arruda and Pinto (1980).

$$f(x) = \exp(-\bar{X} / \bar{X}) / \bar{X}$$

The distribution function (F(x)) is:

$$F(X) = \int_{o}^{x} f(x) dx \qquad F(X) = 1 - \exp(-\bar{x} / \bar{X})$$

and the probability of (p(x)) of the crop water requirement for each period is:

$$p(x) = 1 - F(x)$$

These results are transferred to farmers and extension services to enable them to choose the best planting dates for crop sowing and emergence (Figures 2, 3, 4, 5).

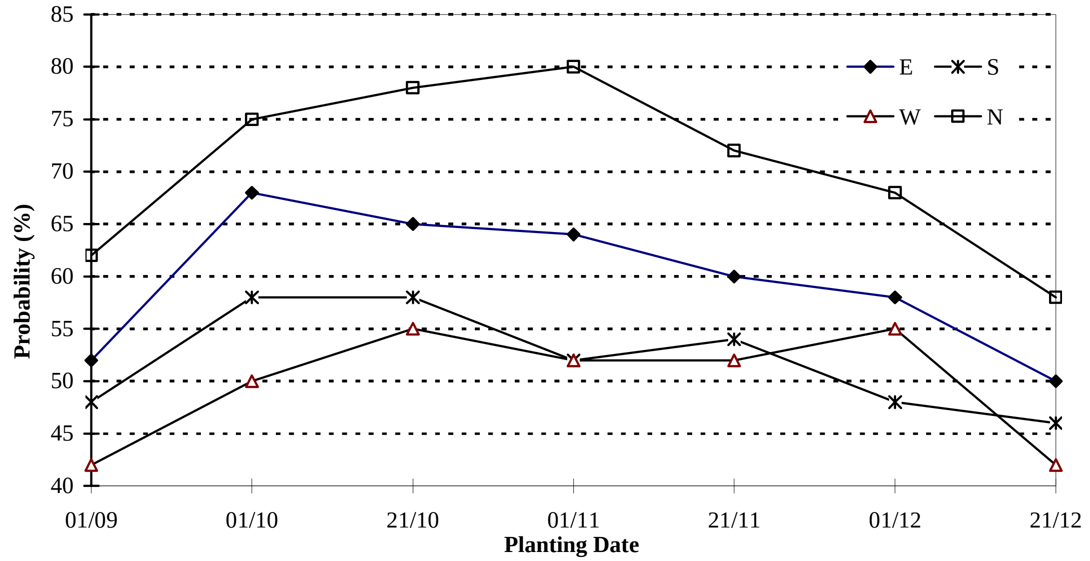


Figure 2. Probability of attaining soybean water requirements at flowering stage and pod formation as function of the planting date, for different regions in São Paulo State (N-North; S-South; E-East; W-West).

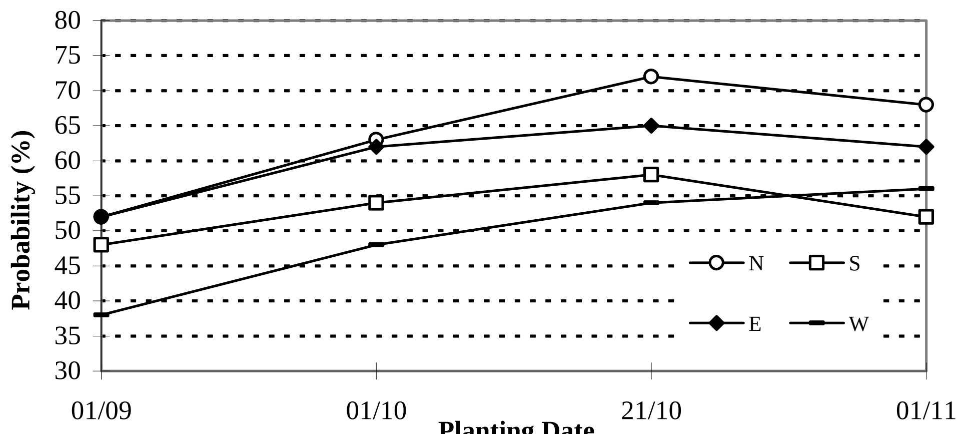


Figure 3. Probability of attaining upland rice water requirements at flowering stage as function of the planting date for different regions in São Paulo State (N-North; S-South; E-East; W-West).

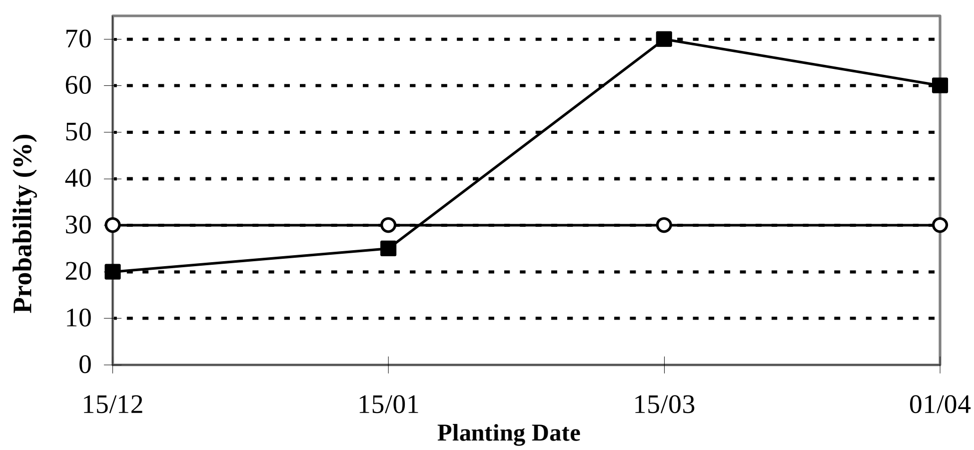


Figure 4. Probability of soil water deficits during the maize growing period as a function of the planting date for northern (N) and southeastern regions (S) of São Paulo State.

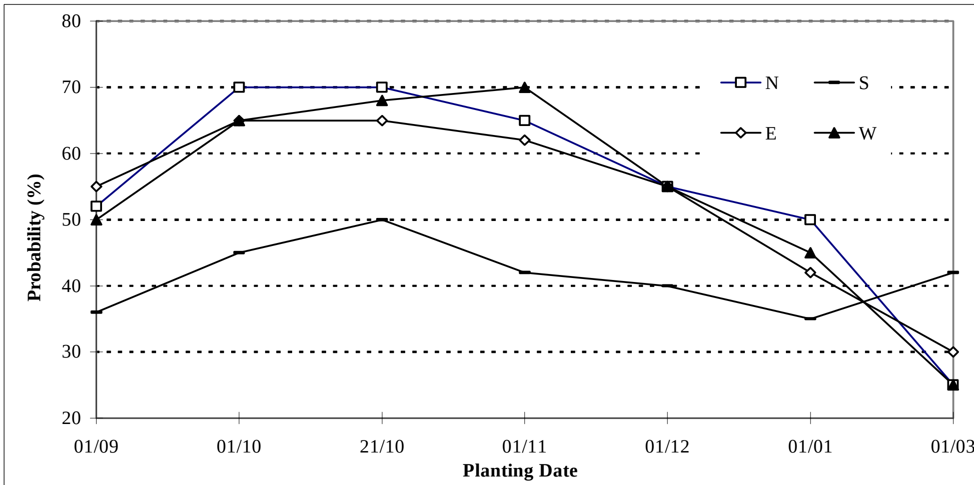


Figure 5. Probability of attaining the maize crop water requirement during flowering and silk stage as a function of the planting date for northern (N) and southern (S) regions of São Paulo State.

Climatic Risks Zoning

Because climatic risks are a normal feature of any region in the world, and because agricultural production in São Paulo State is affected every year by drought, several studies are being carried out to determine the probability of climatic hazards during the crop growing period.

The actual crop zoning studies determine the potential suitability of a specific crop for a given region and the probability of climatic risks, particularly drought and frost, during the crop growing period.

The agroclimatic indices used in climatic risks zoning are:

1. main factors affecting crop development (frost, drought);
2. phenological stage most susceptible to drought/frost;

3. cropping aspects (rainfed, lowland, irrigation); and
4. available meteorological data.

First of all, the ISNA (Water Requirement Index—Zullo and Pinto 1997) is determined for each crop at each phenological stage:

$$ISNA = (ETR)/(ETM)$$

ETR , ETM = actual and maximum crop evapotranspiration

The study was carried out considering long-term values of daily precipitation data for 390 localities (Figure 6). Crop development stages were determined using a heat unit concept or growing degree days. Base temperature (tb) and the total number of degree days required to reach a specific phase were previously determined (Brunini et al. 1995). It should be noted that water balances and the ISNA were performed in a 10-day analysis considering 3 types of soil (clay, sand, silt-loam).

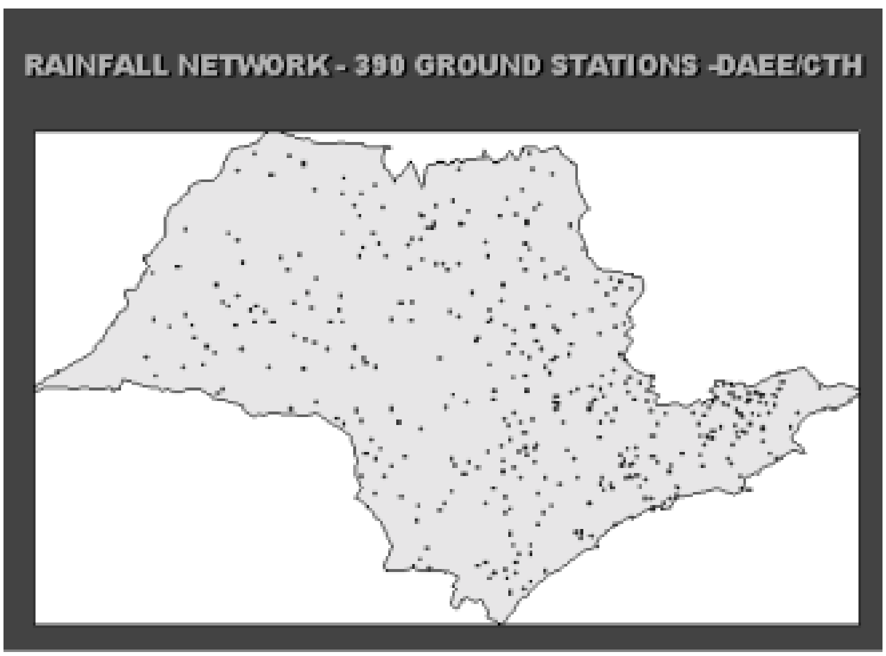


Figure 6. Map of São Paulo State with the 390 rainfall ground stations used in this work.

The steps used to determine ISNA and the climatic risks are indicated in Figure 7. A suitable planting date is adopted when the corresponding ISNA value is greater than or equal to 0.55 during critical crop phenological phases. Maps 1 and 2 present the climatic risks to maize and wheat cultivar development for specific planting dates. It should be noted that risks of high temperature and frost were also evaluated in this analysis.

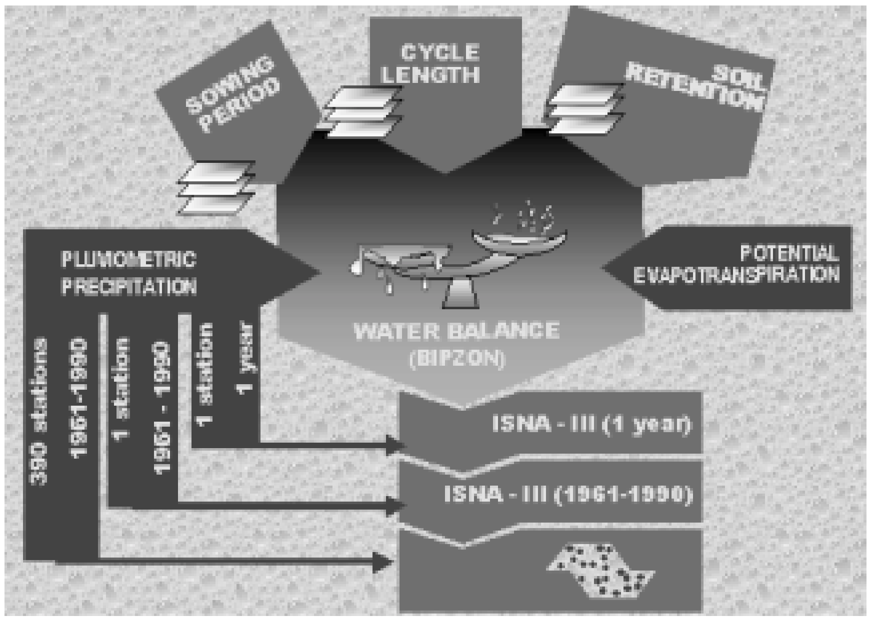
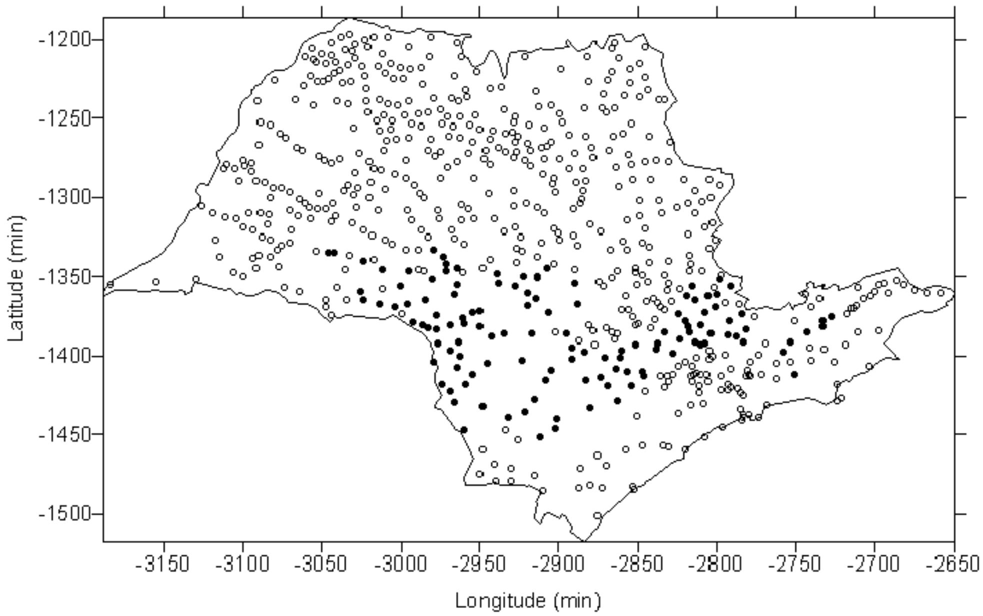
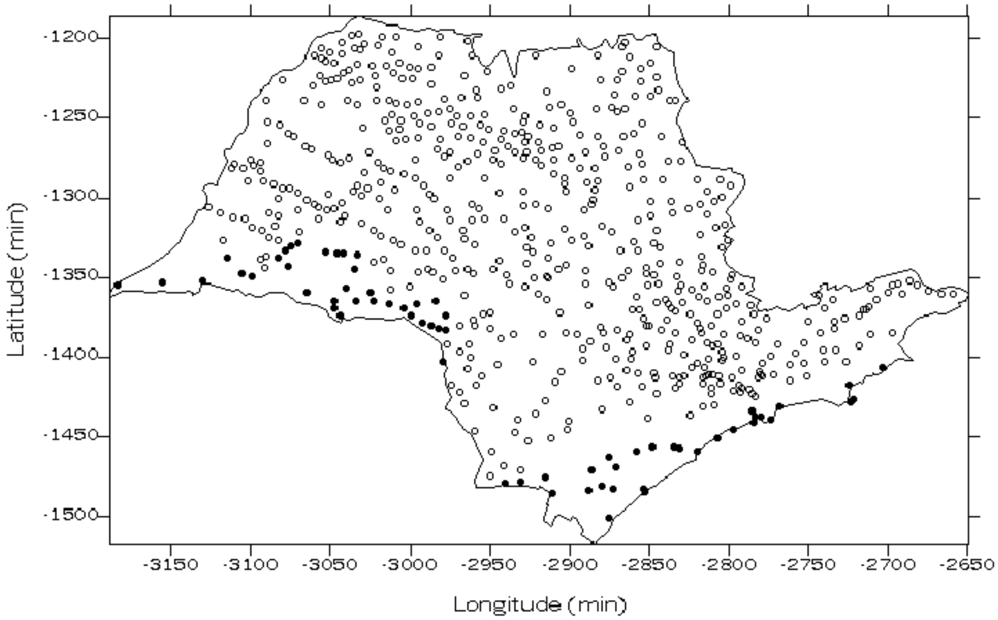


Figure 7. Definition of planting periods according to water supply restrictions.



Map 1. Climatic risks zoning for dryland wheat. Planting date: April 10-20. Full dots indicate probability of 80% of attaining crop water requirements.



Map 2. Climatic risks zoning for maize. Planting date: February 10-20. Full dots indicate probability of 80% of attaining crop water requirements.

Agrometeorology Warning System (AgWS)

In 1988, the Agrometeorology Information Center (CIIAGRO) started an agrometeorology warning system (AgWS), which gives support to agricultural production and crop development in São Paulo State (Brunini et al. 1996; 1998; 1999). It is an operational framework that provides agrometeorological information to farmers and extension services regarding the type of soil, crop development, agricultural practices, pest management, irrigation requirements, climatic risks (frost, drought, dry spell), stored water in the soil, water balance, crop yield, and weather forecast.

The AgWS is based on a network of 114 weather stations. Among these, 30 are automatic weather stations (AWS) and the others are First or Second Class Weather Stations. There is now a proposal to have an operational system based on at least 120 AWS. The basic concept of the AgWS is that all information related to weather, climatic variability, crop climate requirements, and pest management is integrated in a routine analysis to give support to farmers and governmental policies. Figure 8 describes the processes involved in the AgWS network.

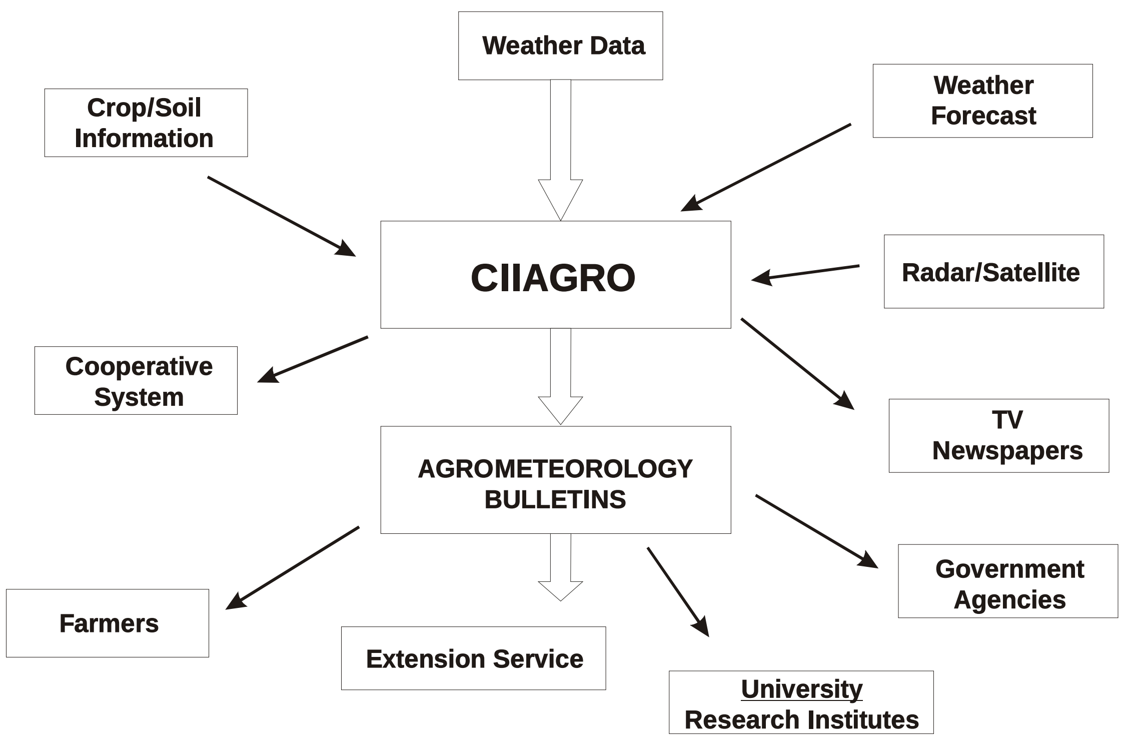


Figure 8. Processes involved in the AgWS procedure.

Most of the drought indexes are derived from an estimate of the actual water stored in the soil. For this it is assumed that the critical level of water in the soil is 60% of the maximum holding (field capacity) capacity of the soil.

Potential evapotranspiration is estimated according to Camargo's formula (Camargo and Camargo 1983). Comments are made regarding crop growing season, crop calendar, pest and disease management, soil management, planting and harvesting, and irrigation requirement.

Drought frequency and assessment are regularly analyzed. The indices used to monitor drought are ratio ETR/ETP, available soil water, dry spell duration, and rainfall anomaly. All information is included in agrometeorological bulletins that are prepared and issued twice a week. The major users are governmental agencies, newspapers, farmers, and extension services. The information is also transformed into agroclimatic maps to better explain the spatial variability of the climatic elements in the State (Maps 3, 4).

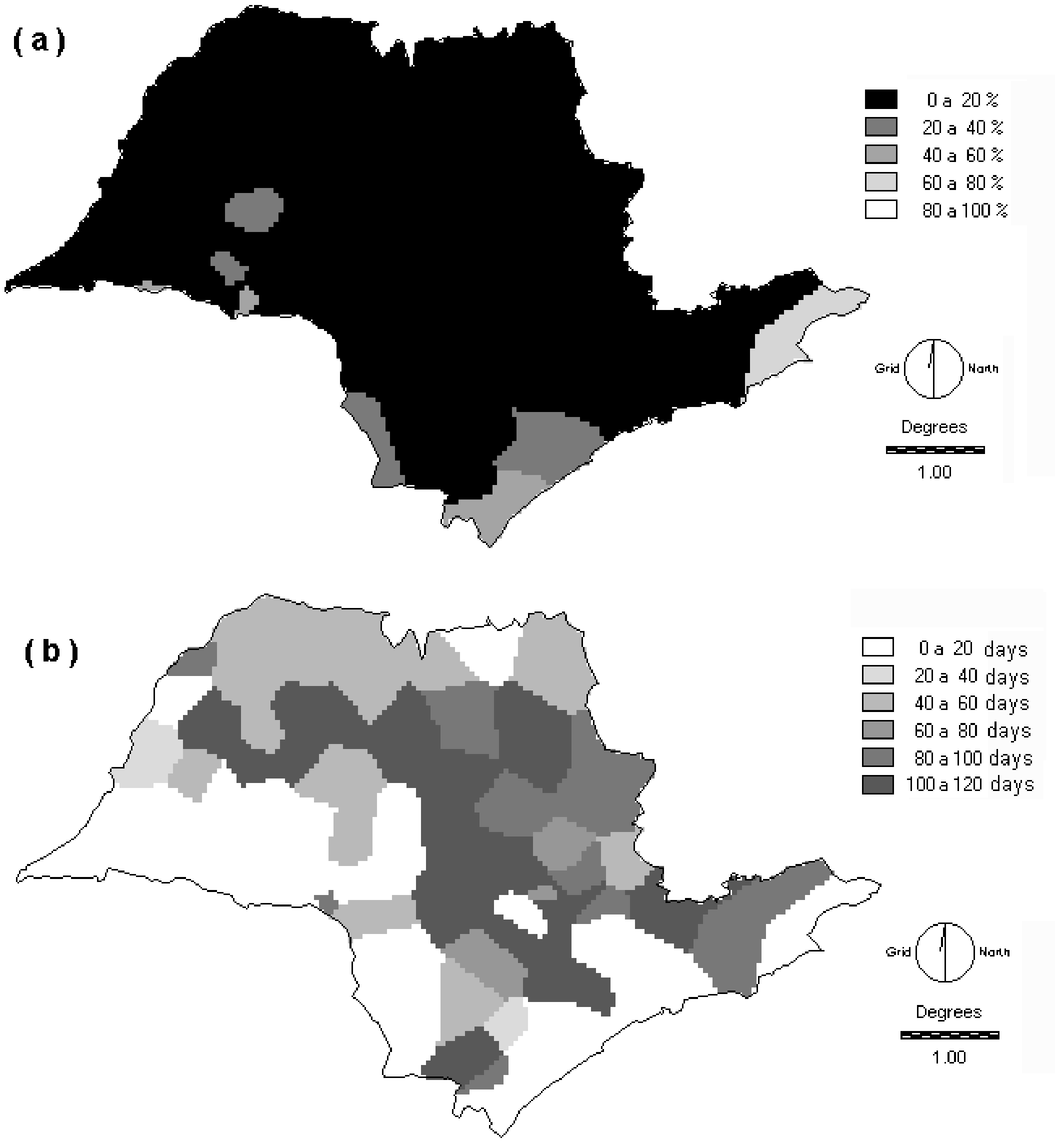
Drought Monitoring and Standardized Precipitation Index

The SPI was recently introduced to quantify and monitor drought in São Paulo State. Discussion related to the methodology and background of the SPI can be found elsewhere (Hayes et al. 1999). The SPI has never been used in a routine procedure in Brazil. For this reason, analyses were made to compare water balance parameters and the SPI.

The water balance was performed on a monthly basis, considering soil water holding capacity of 125 mm, and the parameters used in the analysis were soil water surplus and soil water deficiency. No specific parameters related to crop effects were evaluated at this time.

The drought years analyzed and compared to the SPI were 1963, 1969, 1979, and 1994, but only 2 are discussed in this chapter. There is a tendency for the SPI to follow the soil water regime (Figures 9, 10). All drought periods are clearly indicated by the SPI and water balance parameters. On the other hand, very humid periods, like 1982-83, are very well indicated by the SPI and water balance parameters.

Based on this, a prediction was made for the 1999-2000 drought. The results are very good (Figure 11a and 11b). Such an analysis was very important in quantifying the drought for specific crops (coffee, sugar cane, maize) and for supporting government policies to help farmers and to avoid price speculation. It is important to point out that the SPI indicates that from August to December 2000, São Paulo State will have a relatively humid period. This finding is corroborated by a climatic analysis projection made by INPE (Dr. Sattyamurthi, personal communication). Specific information related to soils and crop water demand will improve drought prediction.



Maps 3 and 4. Estimated available water in the soil (a), up to a depth of 40 cm, and days with rainfall below 10 mm (b).

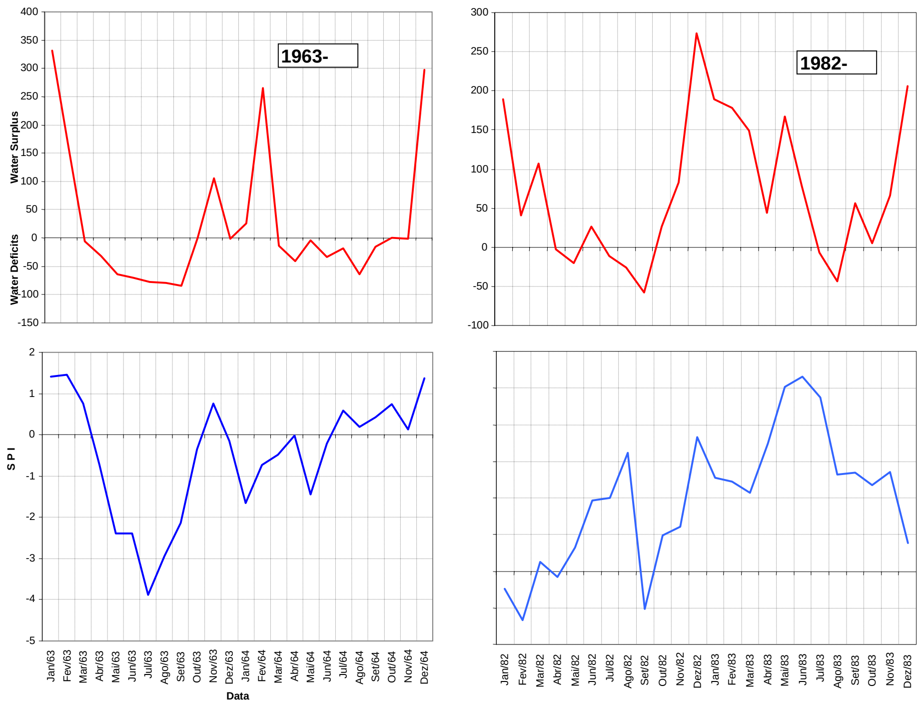


Figure 9. Variation of the SPI and soil water balance parameters for Campinas-SP-Brazil, during two constrasting rainfall regimes.

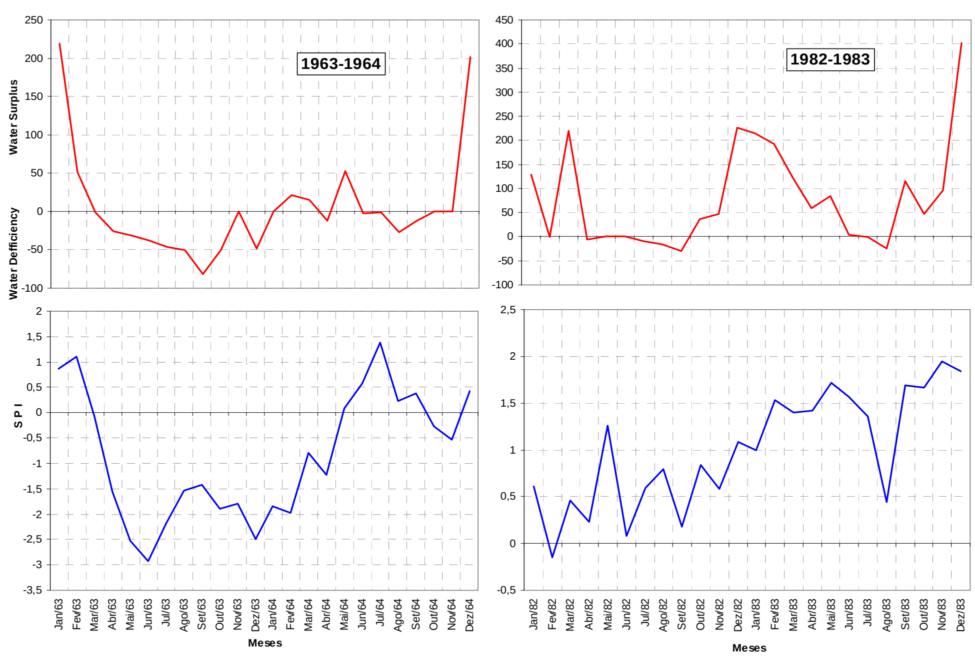


Figure 10. Variation of the SPI and soil water balance parameters for Mococa-SP-Brazil for two contrasting rainfall regimes.

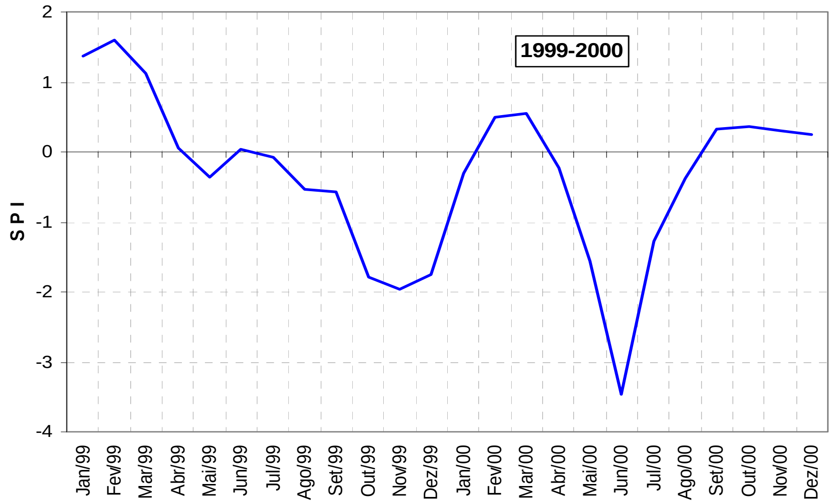


Figure 11a. Observed and estimated SPI values for Campinas-SP-Brazil during the 1999–2000 drought period.

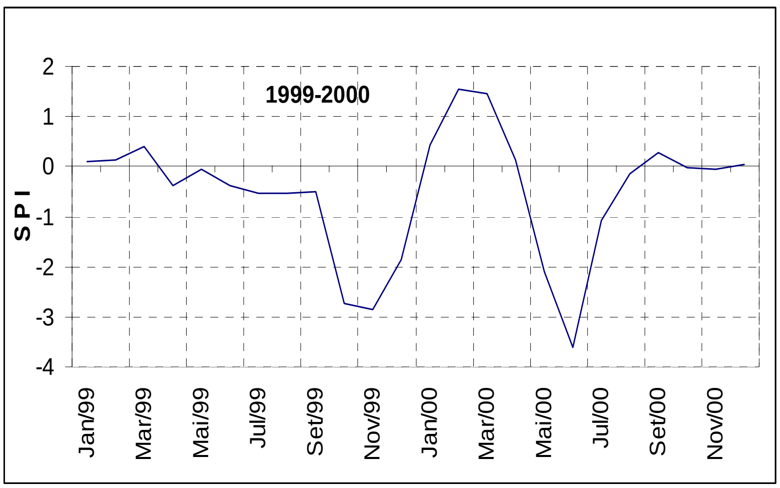


Figure 11b. Observed and estimated SPI values for Mococa-SP-Brazil for the 1999–2000 drought period.

References

Alfonsi, R.R., M.B.P. Camargo, O.M.D.P. Chiavegatto, M.J. Pedro Jr., A.A. Ortolani, and O. Brunini. 1989. Níveis de probabilidade de seca como subsídios à irrigação para o Estado de São Paulo. Pages 39-42 *in* Proceedings Sociedade Brasileira de Agrometeorologia. Maceió-AL, Brasil.

Alfonsi, R.R., H.S. Pinto, and H.V. Arruda. 1979. Freqüência de veranicos (dry spell) em regiões rizícolas do Estado de São Paulo. Pages 147-151 *in* Proceedings, RETERIESP.

Andrade, A.S. and E.A. Bastos. 1997. Precipitação provável para o município de Uruçui, no Cerrado Pianiense utilizando a função de distribuição Gama. Pages 110-112 *in* Anais X Congresso Brasileiro de Agrometeorologia. Piracicaba, 13 a 18 de julho de 1997.

Arruda, H.V. and H.S. Pinto. 1980. A simplified gamma probability model for analysis of the frequency distribution of rainfall in the region of Campinas, SP - Brazil. *Agricultural and Forest Meteorology* 22(2):101-108.

Arruda, H.V., H.S. Pinto, and R.R. Alfonsi. 1979. Probabilidade de estiagem nos meses de janeiro e fevereiro na região de Campinas (SP). Pages 143-146 *in* Proceedings, RETERIESP.

Bergamaschi, H. 1999. Estratégias para reduzir riscos por estiagens. Seminário apresentado no DPFA/UFRGS - 13/05/1999. Mimeo.

Brunini, O. and H.S. Pinto. 1997. As oscilações climáticas e agricultura. Laranja & Cia No. 47, pp. 6-7.

Brunini, O., N. Bortoletto, A.L.M. Martins, M.G. de A. Landell, J.C.V.N.A. Pereira, G. de Sordi, P.B. Gallo, O.V. Villela, J.L. de Castro, A.P. Duarte, R.A.D. Kantack, E.M. Paulo, E. Sawazaki, W.H. Merege, L.E.C. Miranda, L.T. Miranda, F.B. Arruda, and M. Fujiwara. 1995. Determinação das exigências térmicas e hídricas de cultivares de milho. Pages 141-145 *in* Seminário Sobre A Cultura Do Milho “Safrinha”, 3. Assis, 1995. Resumos. Campinas, IAC/CDV.

Brunini, O., H.S. Pinto, J. Zullo, M.T. Barbosa, M.V. Fontaneti, A.P.C. Brunini, A.B. Belluzo, E. Caputi, and R.D. Gonçalves. 1999. Probabilidade de cultivo da cultura do milho no Estado de São Paulo. Pages 7-14 *in* “Anais V Seminário sobre a cultura do milho Safrinha”. 03 a 05 de fevereiro de 1999. Barretos - SP.

Brunini, O., H.S. Pinto, J. Zullo, G.Q. Pellegrino, F.B. Arruda, M. Fujiwara, E. Sakai, and R.C.M. Pires. 1998. Sistema de Aconselhamento Agrometeorológico. Pages 15-37 *in* Anais II. Congresso Brasileiro de Biometeorologia. Goiânia-GO.

Brunini, O., M.A. Santos, R.V. Calheiros, E. Caputi, J.M. Santos, A.G. Picini, and H.S. Pinto. 1996. Centro Integrado de Informações Agrometeorológicas. Pages 133-134 *in* Anais VIII Congresso Argentino de Meteorologia e VII Congresso Latinoamericano Ibérico de Meteorologia. Buenos Aires, AR.

Camargo, A.P. 1962. Contribuição para a determinação da evapotranspiração potencial no Estado de São Paulo. Bragantia, Campinas 21:163-203.

Camargo, A.P. and M.B.P. Camargo. 1983. Teste de uma equação simples para estimativa da Evapotranspiração Potencial baseada na radiação solar extraterrestre e na temperatura média do ar. Pages 229-244 *in* Proceeding - Sociedade Brasileira de Agrometeorologia. Campinas - SP - Brasil.

Camargo, M.B.P., H.V. Arruda, M.J. Pedro Jr., O. Brunini, and R.R. Alfonsi. 1985. Melhores épocas de plantio do trigo no Estado de São Paulo baseadas na probabilidade de atendimento hídrico. Bragantia, Campinas 44(1):255-261.

Fontana, D.C. and M.A. Berlato. 1996. Relação entre El-Niño oscilação sul (ENOS) precipitação e rendimento de milho no Estado do Rio Grande do Sul - Pesquisa Agropecuária Gaúcha. *Porto Alegre* 2(1):39-45.

Hayes, M.J., M.D. Svoboda, D.A. Wilhite, and O.V. Vanyarkho. 1999. Monitoring the 1996 drought using the Standardized Precipitation Index. *Bulletin of the American Meteorological Society* 80(3):429-438.

Liu, W.T.H. and B.W.Y. Liu. 1983. Seleção das melhores épocas de plantio de milho e sorgo na região do Alto São Francisco. Pages 69-76 *in* Proceedings, Sociedade Brasileira de Agrometeorologia. Campinas-SP, Brasil.

Mota, F.S. 1979. Metodologia para caracterização da seca agronômica no Brasil. *Interciência* 4(6):344-350.

Mota, F.S. 1987. Estratégias e tecnologias para minimizar os efeitos da Seca sobre a produção de alimentos no Brasil. Technical Bulletin No. 7. Sociedade Brasileira de Agrometeorologia.

Mota, F.S., M.O.O. Agendes, E.G.P. Alves, and E. Signorini. 1996. Análise agroclimática da necessidade de irrigação da soja no Rio Grande do Sul. *Revista Brasileira de Agrometeorologia, Santa Maria* 4(1):133-138.

Nitzche, M.H., B.B. Silva, and A.S. Martinez. 1985. Indicativo de ano Seco e Chuvoso. Pages 307-314 *in* Proceedings, Sociedade Brasileira de Agrometeorologia. Londrina-PR, Brazil.

Repelli, C.A. and J.M. Alves. 1996. Uso de análise de correlações canônicas para prognosticar a variabilidade espacial da precipitação sazonal sobre o Nordeste do Brasil. *Revista Brasileira de Meteorologia* 11(1/2):67-75.

Silva, B.B., M.H. Nitzche, and F.A. Souza. 1985. Estimativa da chuva esperada após o dia de São José. Pages 195-200 *in* Proceedings Sociedade Brasileira de Agrometeorologia. Londrina-PR, Brazil.

Silva, F.A.S. and T.V.R. Rao. 1994. Regionalização referente à pluviosidade anual e sua distribuição intra anual no Estado da Paraiba. *Rev. Bras. Agrometeorologia* 2:93-97.

Thornthwaite, C.W. and J.R. Mather. 1955. The Water Balance. Drexel Institute of Technology, Centerton, New Jersey.

Zullo, J. Jr. and H.S. Pinto. 1997. Redução dos riscos climáticos na agricultura: Cultura do milho no Estado de São Paulo. Zoneamento Agrícola. Ministério da Agricultura e Abastecimento.

Drought Early Warning and Impact Assessment in China

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Abstract

In this chapter, progress on drought early warning and assessment in China is discussed. Soil moisture and drought monitoring have been achieved using satellite remote sensing and station observation data. A drought monitoring system, climate impact assessment system, and short-term climate prediction system were developed in China. This Operational System currently produces 14 products. The problems and limitations of existing systems are also discussed.

Introduction and Background

Drought is China's greatest natural disaster. Among all natural disasters, droughts occur the most frequently, have the longest duration, cover the largest area, and cause the greatest losses in agricultural production. In addition to its direct influence on grain yields, drought also has a potential long-term effect on the environment, desertification, and other disasters. Especially when drought effects are combined with human activities, the environment is at great risk; its survival, and ability to support mankind, becomes more complicated (Li and Lin 1993; Li et al. 2000).

Wilhite (2000) noted that drought is a normal part of climate. Because of its insidious nature, it is difficult to determine its onset, development, and end. This fact emphasizes the importance of developing comprehensive monitoring or early warning systems. Satellite- and station-derived data are also proving to be of significant value in drought monitoring. Drought prediction (monthly, seasonal, or yearly trends) is particularly useful for the drought planning and mitigation.

The China National Climate Center (CNCC) was founded in January 1995. CNCC is assigned major missions of climate (including drought) prediction and studying climate change and its associated impacts. Its focus is placed on short-term (monthly, seasonal, and interannual scale) climate prediction and studies of climate change induced by anthropogenic activities. During 1996-2000, CNCC is establishing the first integrated operational system, based on the implementation of a national study of China's short-term climate prediction system. Figure 1 is the operational flow chart of CNCC.

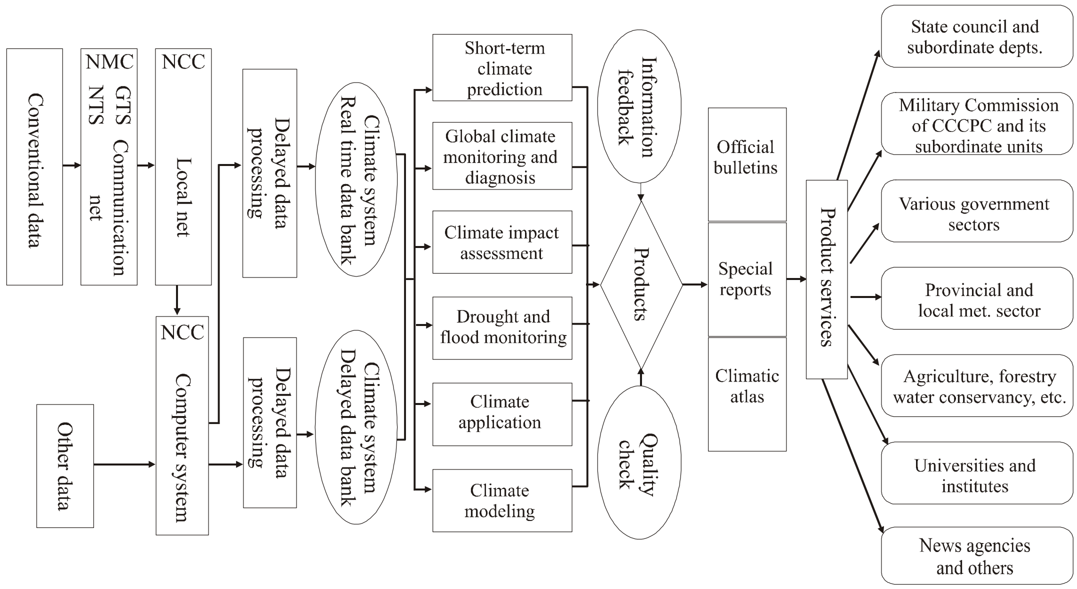

Figure 1. The operational flow chart of the CNCC.

Overview of Drought Early Warning Systems in China

Drought Monitoring

Drought is a creeping phenomenon, the extent of which appears gradually, thus offering the possibility for monitoring and early warning of drought. There are two ways to monitor droughts: one is based on a network system of stations, and another is by remote sensing, which offers fast, objective, economic, and large-range characteristics.

Through remote sensing, station networks, and modern communications, including geographical information systems (GIS), a variety of information about climate and water supply conditions can be provided continuously before drought occurs. This information is useful for defining the possible range, period, and risk degree of drought, and it will help in the adoption of drought mitigation measures. During drought, the processes and status of drought can be monitored constantly to provide information to all drought response agencies. Drought losses can be determined quickly and precisely for large areas, and this information will facilitate response and recovery operations. The remote sensing method of drought monitoring will primarily track crop growth, status of soil moisture, evapotranspiration, status of the hydrological system, and precipitation. This technology, combined with station observations, can monitor the formation and development of drought objectively, quickly, and economically for large areas.

Soil Moisture and Drought Monitoring Using Remote Sensing in China

Monitoring by satellite remote sensing techniques is most appropriate for detecting the status of soil moisture, evapotranspiration, crop growth, land cover type and drought. The Institute of Remote Sensing Application and the Institute of Geography, both part of the Chinese Academy of Sciences, have done considerable work in this area. An improved thermal-inertia model has been developed for monitoring soil moisture in areas without vegetative cover. For vegetated areas, crop water deficit models have been improved. Substantial progress has also been achieved in the dynamic monitoring of soil moisture and drought in China.

Using a surface observation station network and remote sensing techniques, the development and spread of drought conditions can be monitored in a routine and cost-effective manner. Tian (1993) and Tian et al. (1998) have done considerable work in this area. It provides an excellent strategic monitoring tool for assessing drought stress and the need for response at a regional scale.

A method based on energy balance was developed to estimate evapotranspiration (ET) and soil moisture (SM) to monitor drought in north China using NOAA-AVHRR digital images and meteorological data by Tian (1993). The NOAA-AVHRR data were used to compute reflectance and temperature after atmospheric correction. ET was estimated by combining remotely sensed reflected solar radiation and surface temperature with ground station meteorological data to calculate net radiation and sensible flux. SM was estimated from the relationship between the Crop Water Stress Index (CWSI) and soil water content. Spatial distribution of drought was obtained from the Surface Water Supply Index (SWSI) model. The scheme for estimation of ET, SM, and drought is shown in Figure 2 (from Tian). The other models for monitoring soil moisture and drought using remote sensing are shown in Figures 2-5, and comparisons of the precision of the models are given in Table 1 (from Tian 1993).

The Drought Monitoring System

Before the drought monitoring and early warning systems are run, at least one objective and practical drought index should be provided. Then certain thresholds, also called the initial point, can be determined so that certain activities are adopted when the drought index exceeds the threshold. In the United States, the Palmer Drought Severity Index (PDSI) is often adopted, while the SWSI is also used.

Since no single index is adequate to evaluate meteorological, agricultural, or hydrological droughts, a variety of indexes should be used. The difference between the various regions and economic departments should also be considered.

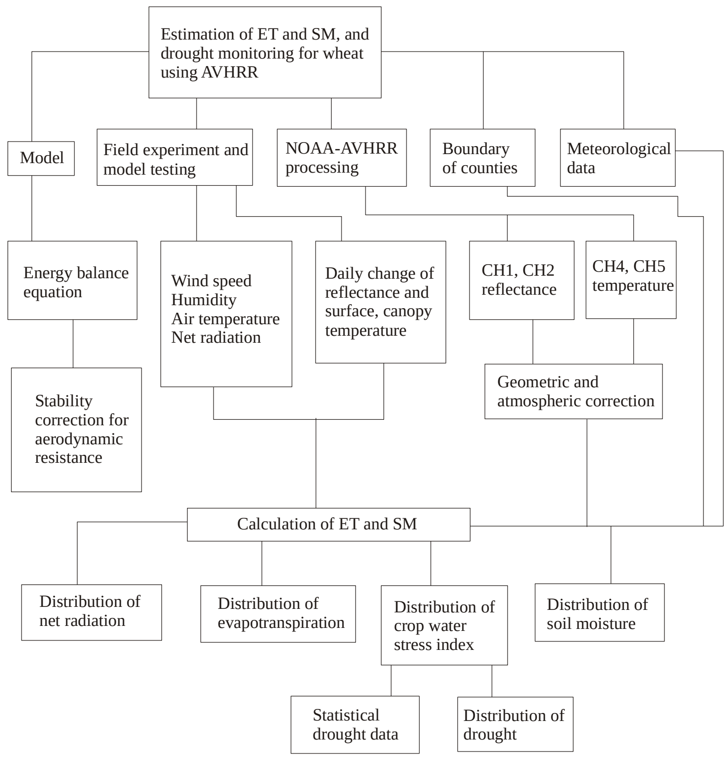

Figure 2. Estimating ET and SM and monitoring drought using NOAA-AVHRR data (Tian 1993).

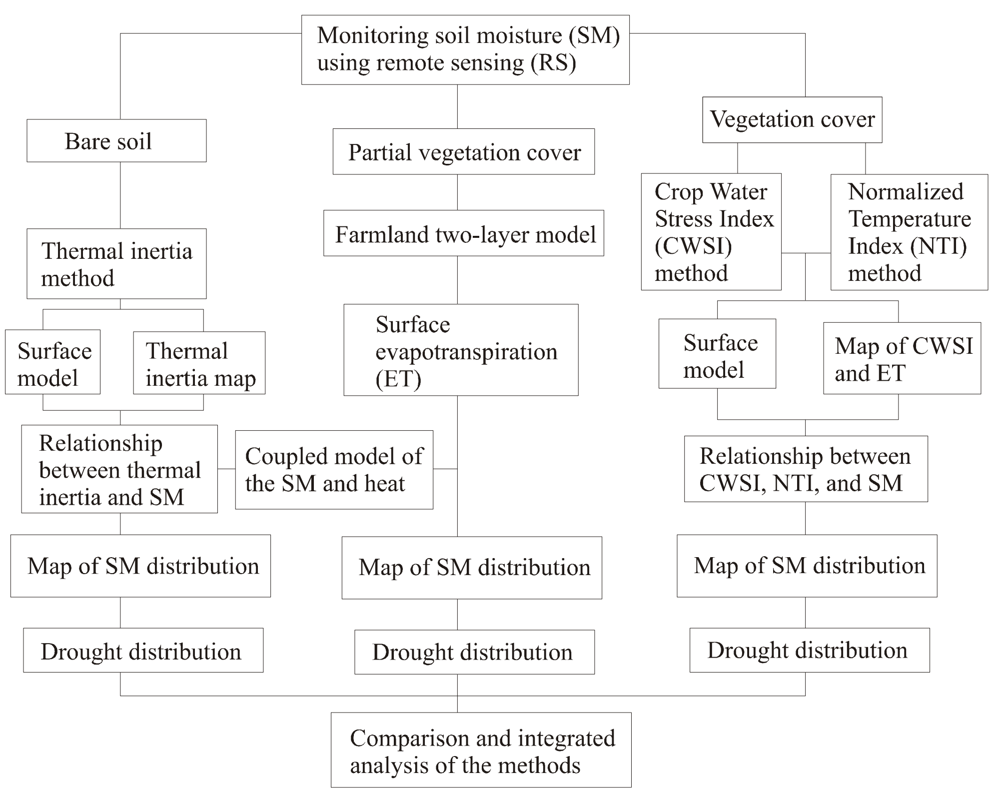

Figure 3. Soil moisture and drought monitoring models using remote sensing.

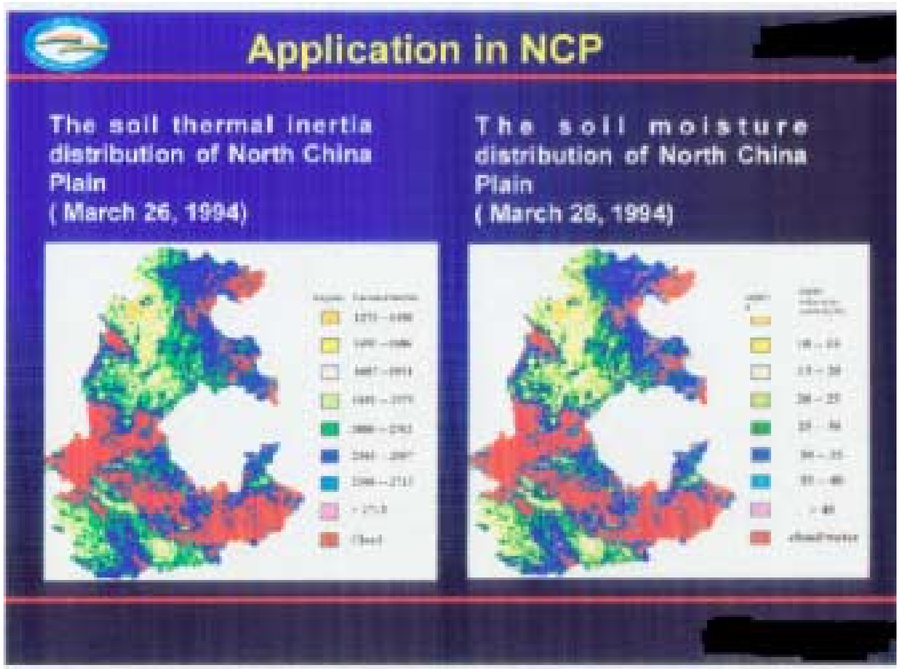

Figure 4. The soil thermal inertia (a) and soil moisture (b) distribution of north China (March 26, 1994).

(a) (b)

Figure 5. The distribution map of soil moisture in north China with one layer (a) and two layer (b) models.

Table 1. Comparison of precision of soil moisture estimates using different models.

Area	County Number	Simple	Precision of Two-Layer Model (%)	Precision of One-Layer Model (%)
Beijing	6	5	87.1	75.2
Tianjin	5	4	89.2	76.1
Hebei	20	14	85.6	73.5
Henan	30	20	87.1	76.1
Shandong	11	8	86.3	72.2
An hui	12	7	82.7	72.6
Jiangsu	10	6	87.2	75.7
Total Precision			86.5	74.3

A drought monitoring and early warning system should be established to provide timely information on the formation, development, persistence, alleviation, and end of drought to those responsible for drought response/recovery. To this end, the following steps should be taken: building a system that can capture, analyze, and transfer drought information in a timely fashion; setting up criteria to confirm drought-affected zones; monitoring the status of and estimating future available water and soil moisture; and establishing a special department to enforce the criteria and issue/cancel drought warnings.

In order to monitor the occurrence and development of droughts efficiently and provide information on the strength and range of drought (and flood), the China Drought-Flood Monitoring System was developed by CNCC. This system can dynamically monitor the occurrence and evolution of droughts (or floods) over the whole country and provide early warning of droughts. It distributes climate information on droughts (or floods) in real time by the network and publishes some written products for decision making and public welfare.

Methodologies

The methodologies used include qualitative analysis (description, analog analysis, and expert reviews) and quantitative analysis (statistics models, dynamic models, integrated assessment).

The intensity of meteorological drought in China generally can be classified on the basis of departure from normal precipitation. The meteorological drought index (D) is given as:

$$D = [(P - \overline{P}) / \overline{P}] \times 100\%$$

where P is actual month precipitation and $\overline{P}$ is multiyear mean precipitation for the same month. D can be used to determine the occurrence of drought and its severity. Drought standards are listed in Table 2.

Table 2. Drought standards by D index.

Duration of Drought	Moderate Drought (%)	Severe Drought (%)	Extreme Drought (%)
One month	<-80		
Two months	-51—-80	<-80	
Three months	-26—-50	-51—-80	<-80
Four months	-1—-25	-26—-50	-51—-80
Five months		-1—-25	-26—-50
More than six months			-1—-25

Source: Li et al 1996.

The Function of the Drought-Flood Monitoring System in China

The Drought-Flood Monitoring System is responsible for:

- Monitoring the nature of droughts and floods at any station and the evolution of other meteorological elements by using histograms and curve diagrams;
- Consecutively monitoring drought-flood development at the regional and national scale, displaying clearly the characteristics of droughts and floods at various time periods;
- Displaying drought-flood distributions over the country, and determining as soon as possible the geographical positions (longitude and latitude) and station names where droughts or floods are occurring.
- Comparing and ranking the severity, duration, and extent of drought and flood disasters;
- Monitoring precipitation over the country automatically and continuously, giving early warning when or before droughts or floods occur;
- Printing drought and flood monitoring figures and tables.

Operational System of Climate (Including Drought) Impact Assessment in China

Climate impact assessment primarily aims at assessing climate (including drought) impacts on the national economy and society, especially on agriculture. The drought impact assessment system (DIAS) includes a database, statistics analysis software, methodology for impact assessment and appropriate models, graphics software, a disaster search system, and an expert system to assess drought impacts.

Information is the basis of DIAS. In the processes of drought impact assessment, a wide variety of information, such as meteorological, agricultural, satellite remotely sensed, and social and economic, must be collected. An information network must also be developed to analyze and deliver data and information.

Operational System of Short-term Climate Prediction in China

Short-term climate prediction (long-term forecast) has been carried out for many years in China. The laboratory of climate prediction of CNCC periodically publishes climate trend predictions on various time scales, ranging from one month to one year, over the country. Short-term climate prediction has been focused on significant disasters such as drought and floods. Figure 6 is the Operational System of Short-Term Climate Prediction at CNCC.

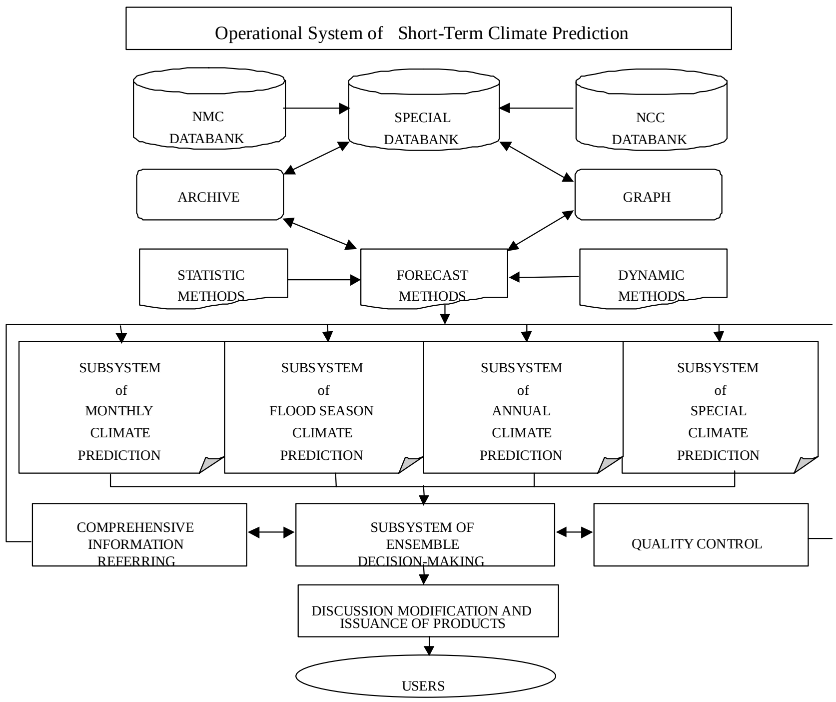

Figure 6. The Operational System of Short-Term Climate Prediction at CNCC.

Data and Prediction Methods:

Data

- General circulation data: geopotential height of pressure levels 1000, 500, 100, 50 hPa
- SST, ice-snow cover, ground temperature, OLR
- Temperature and precipitation over China: 160 stations
- Various physical parameters

Methods

- Monthly prediction methods

    Statistical method

Dynamic method

- Seasonal prediction methods

  Physical factor analysis methods: SST, ground temperature, snow cover, monsoon, subtropical height over north and east Pacific, etc.

  Statistical method: time series analysis, multivariate analysis, correlation and analogue analysis

  Dynamic method (CCM, OSU)

Common methods include correlation and analogue analysis, statistical methods, physical factor analysis, and dynamical numerical forecast, with a special emphasis on analyzing the relationship between the circulation system of the east Asian monsoon, atmospheric active centers, underlying surface thermodynamic anomaly, and Chinese climate. Figure 7 shows the major physical factors influencing China's climate during summer.

Primary Data and Information Products

Short-term Climate Prediction Products

- Monthly Climate Prediction (25th of each month)
- Flood Season Prediction (mid-Apr.)
- Annual Climate Prediction (mid-Nov.)
- Significant Climate Report (periodically)
- Review on Climate Prediction (end of May)

Drought and Flood Monitoring Products

- Monthly Drought and Flood Bulletin
- Annual Drought and Flood Bulletin
- Brief Report on Drought and Flood Monitoring
- Advisory Report on Climate and Service Report on Drought and Flood Disasters

Climate Impact Assessment Products

- Monthly Climate Impact Assessment
- Yearly Climate Impact Assessment
- China Climate Bulletin
- Annals of China'a Major Climate Disasters

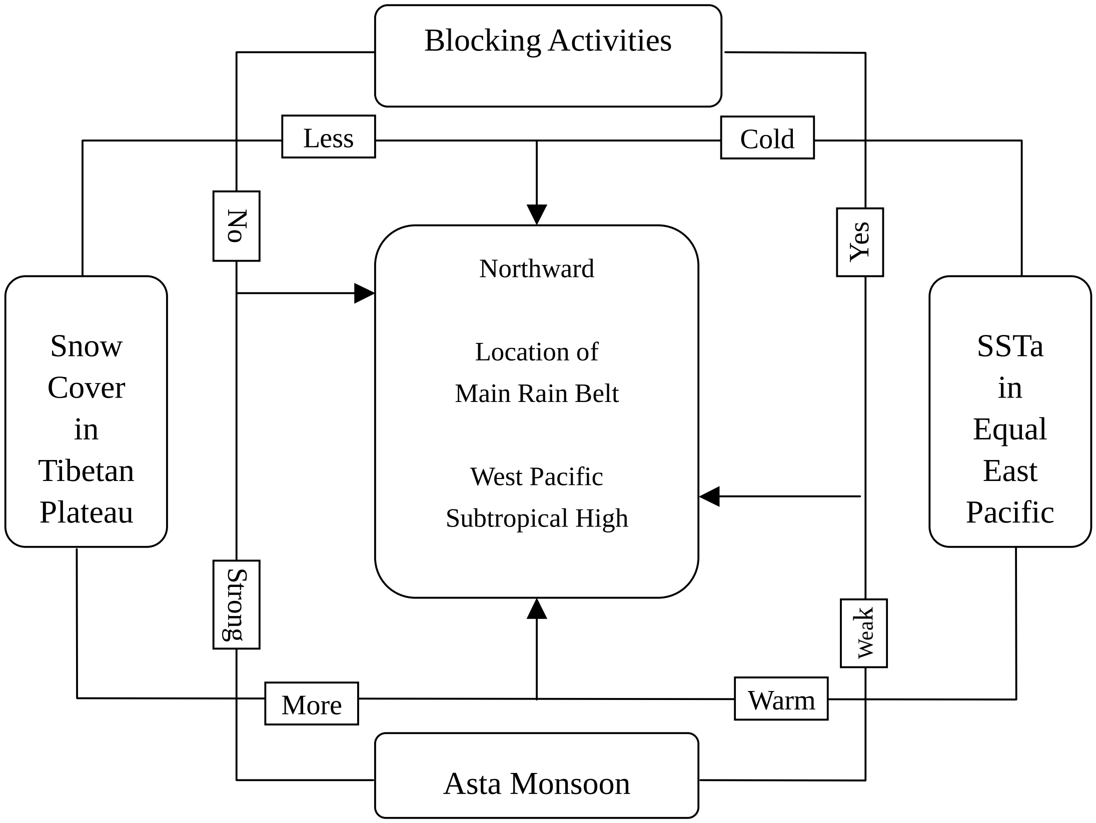

Figure 7. The major physical factors influencing China's climate during summer.

Status of Delivery Systems and Identification of Primary Users

The CNCC operational system currently prepares 14 products. These products provide the Chinese government and all national economic sectors with real time information and published information for decision making and public welfare. The Drought-Flood Monitoring System and the climate impact assessment system provide climate information on drought and floods, early warning of possible droughts, and advisory service for various users (from government sectors to agriculture, forestry, and water conservancy), enabling them to make good use of climate resources and disaster information.

The ongoing climate operational system can ensure the improved quality of climate service through both equipment and technology. CNCC has provided significant climate information for making decisions, planning national economic strategies, determining policies, conducting important construction projects and participating in relevant international activities.

Figure 8 shows the rainfall anomaly percentage observation (a) and forecast (b) for the summer of 1994. Figure 9 shows the accuracy curve of rainfall prediction for the flood season.

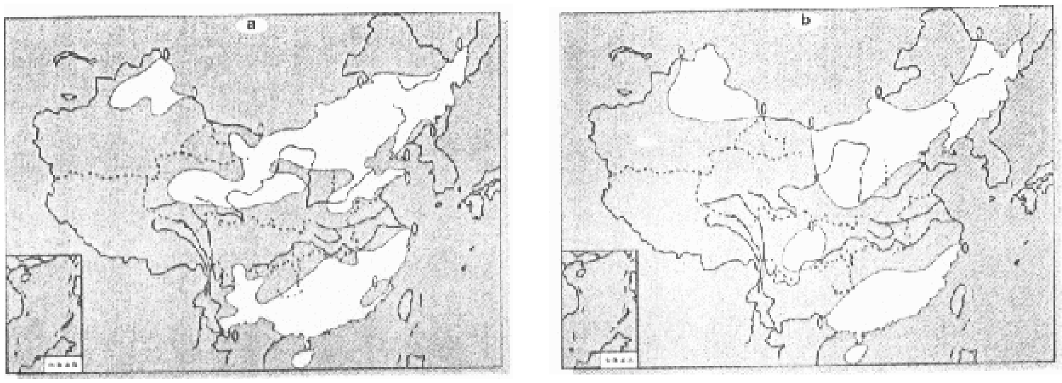

Figure 8. The rainfall anomaly percentage observation (a) and forecast (b) for summer 1994.

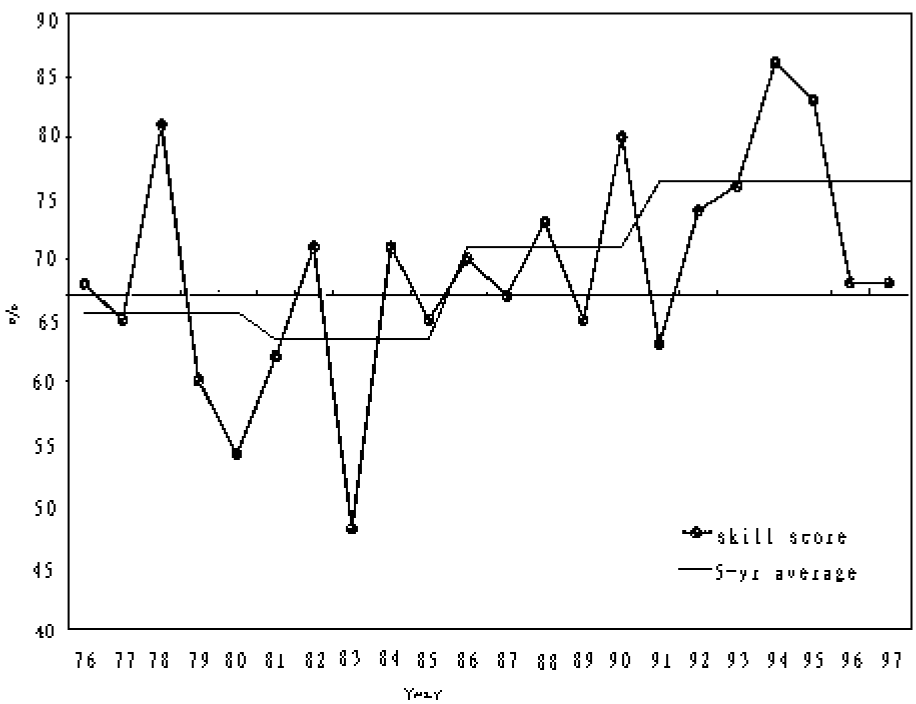

Figure 9. The prediction skill score of summer rainfall.

Limitations of Current Systems and Future Needs

China's technological equipment in this field is relatively less advanced than that of developed countries. China has a limited number of stations in Qinghai-Xizang Plateau, high mountain areas, immense deserts, and seas. The climatic system cannot be monitored adequately with so few stations.

Although large quantities of data are available in China, the basic data are kept in many units in various formats. The data quality and the length of record need to be quality controlled. Inadequate data archiving and automatic data processing is one of the limitations.

Numerical climatic models were developed and applied in China later than in some other countries. Dynamic climatology and climate prediction research needs to be reinforced.

A large part of the land in China is located in so-called climatically vulnerable areas, which are susceptible to climate variability and drought. Therefore, understanding the causes and formation mechanisms of short-term climate change and drought leading to strong prediction signals has become an important task in drought early warning and prediction. For example, the large-scale persistent climate anomaly usually demonstrates strong signals. It has been found that tropical low-frequency oscillation and ENSO are strong signals that are considerably beyond the noise background, and these should be applied in monthly, seasonal, and interannual scale predictions.

Monitoring drought and variations in the characteristics of the earth's surface using remote sensing techniques is an important subject. We should improve the inversion model and establish a data bank for information collected by meteorological satellites with high resolution. Other important needs are:

- to study inversion methods and monitoring techniques for assessing land surface physical characteristics (e.g., soil moisture, albedo) using satellite remote sensing techniques,
- to conduct a comparative analysis of remote sensing data and ground-based data
- to study correction methods for atmospheric attenuation, and
- to establish data sets for land cover with high resolution.

Conclusion

Drought is China's greatest natural disaster. Drought monitoring and prediction are particularly useful for drought planning and mitigation. Using satellite remote sensing techniques and surface observation stations, substantial progress has been achieved in the dynamic monitoring of soil moisture and drought in China.

The Drought-Flood Monitoring System and Operational System for Climate Impact Assessment and for Short-term Climate Prediction was developed at CNCC in China. The CNCC Operational System currently prepares 14 products, which provide the Chinese government and all national economic sectors with real time information and also published informational products.

The problems and limitations of the system include limited number of stations, data quality problems, short length of record, relatively weak qualitative analyses and modeling studies, and a late initiation of a study of remote sensing monitoring.

Acknowledgements

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References

Li, K. and X. Lin. 1993. Drought in China: Present Impacts and Future Needs. Pages 263-289, *in* Drought Assessment, Management, and Planning: Theory and Case Studies (D.A. Wilhite, ed.). Kluwer Academic Publishers, Dondrecht, The Netherlands.

Li K., S. Yin, and W. Sha. 1996. Characters of time-space of recent drought in China. *Geographical Research* 15(3):6-14.

Li K., Y. Chen, and C. Huang. 2000. The Impact of Drought in China: Recent Experiences. Pages 331-347 *in* Drought: A Global Assessment, Vol. 1 (D.A.Wilhite, ed.). Routledge, London.

Tian, G .1993. Estimation of evapotranspiration and soil moisture and drought monitoring using remote sensing in North China Plain. Pages 23-31 *in* Space and Environment, Special Plenary Session, 44th lnternational Astronautical Federation, IAF Congress, Graz, Austria.

Tian G., D.L.B. Jupp, Y. Qin, T.R. McVicar, and F. Li.1998. Monitoring Soil Moisture and Drought Using AVHRR Satellite Data II: Applications. CSIRO Earth Observation Centre, Canberra, ACT.

Wilhite, D.A. 2000. Drought as a natural hazard: Concepts and definitions. Pages 3-18 *in* Drought: A Global Assessment, Vol. 1 (D.A. Wilhite, ed.). Routledge, London.

Role of Drought Early Warning Systems for Sustainable Agricultural Research in India

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Abstract

Agricultural drought is a complex phenomenon. Its impacts vary greatly since they depend not only on the magnitude, timing, duration, and frequency of rainfall deficits but also on the differing responses of various soils, plants, and animals to water stress. The essence of good drought management is to use this range of responses to best advantage.

In recent years, because of growing human population, soil degradation, decreases in water resources, and future projected climate change scenarios, sustainable agriculture has become an important area of research. Agriculture is probably the most weather-dependent activity. Thus, an early warning system for sustainable agriculture is very important. Although early warning for weather parameters other than precipitation has improved considerably, precipitation forecasts on a medium-range scale of 3 to 10 days and long-range forecasts on a smaller spatial scale are still unreliable. The government of India and its various agencies have taken steps for drought management, but drought forecasting has not been developed for various growth stages of the crop. The advisories regularly issued by the India Meteorological Department (IMD) and the National Centre for Medium Range Weather Forecasting (NCMRWF) can be made more user-oriented and a better feedback mechanism may evolve. Proper validation of remotely sensed data in coordination with IMD scientists, scientists from other agencies, and policy makers for proper and timely monitoring of drought in smaller areas has been emphasized. Better communication between farmers, policy makers, and researchers to improve the nature and quality of information provided to the users also has been stressed.

This chapter provides an overview of drought early warning systems in India, including various feedback mechanisms presently in vogue. A brief description of related drought research and management options is included. Future action regarding sustainable agriculture in India has also been highlighted.

Introduction and Background

Drought is universally acknowledged as a phenomenon associated with scarcity of water. Although droughts are still largely unpredictable, they are a recurring feature of the climate.

Drought varies with regard to the time of occurrence, duration, intensity, and extent of the area affected from year to year. It is broadly classified into three categories.

Meteorological drought indicates the deficiency of rainfall compared to normal rainfall in a given region. Hydrological drought indicates the scarcity of water in surface and underground resources. Agricultural drought occurs when the rainfall and soil moisture are inadequate to meet the water requirements of crops.

According to the India Meteorological Department (IMD), meteorological drought is defined as occurring when the seasonal rainfall received over an area is less than 75% of its long-term average value. It is further classified as moderate drought if the rainfall deficit is 26-50% and severe drought when the deficit exceeds 50% of normal. A year is considered to be a drought year for the country if the area affected by drought is more than 20% of the total area of the country.

In dryland areas where irrigation facilities are almost nonexistent, rainfall is the main source of water for various crops. It is well known that the supply of water through rainfall in drylands cannot be as regular as it can be through irrigation. The major challenge in dryland agriculture is to establish ways to minimize reductions in agricultural production through efficient soil, water, and crop management practices during the drought years. Thus, research in dryland agriculture should be aimed at generating management skills required for adjusting cropping patterns and cultivation practices as the situation demands, depending on the occurrence of rain/drought. In India, almost 20% of the total area of the country lies in the dry farming tract where annual rainfall is between 40 and 100 cm without any irrigation support. Thus even after full exploitation of irrigation potential in the country, it is estimated that in India about 70 million ha of cultivable land will be under rainfed agriculture, spread over some parts of Haryana, Rajasthan, Uttar Pradesh, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, and Tamil Nadu.

In the places where long-term average rainfall is less, year-to-year variability is greater and so the likelihood of drought is greater. However, because the farming options in the driest region are limited, the major impact of drought is felt in semiarid and subhumid regions, where the incidence of drought years is fairly high, but intensive, diversified farming is profitable in years of good rainfall. However, such years are usually few.

There have been many attempts to link drought to sunspot number, meteor showers, volcanic activity, changes in composition of the atmosphere, and other possible causes, but their effect, if any, is masked by the pronounced spatial and temporal variability in drought duration, intensity and extent. Droughts result from anomalies in large-scale circulation of the atmosphere and oceans. The El Niño phenomenon in the Pacific Ocean may provide fairly short-term prediction of drought in certain areas, but cannot account for all droughts worldwide, and the basic question of what causes the El Niño phenomenon is still controversial. Even if accurate long-term forecasts of drought materialize, they will not do away with droughts, and the need for skilled drought management for sustainable agriculture will remain.

Drought has multidimensional effects in dry farming areas. The drought conditions may lead to (1) shortages in food production due to failure of crops; (2) shortages of fodder and drinking water for cattle, migration of livestock populations, and even a decrease in the animal population; (3) shortages of resources for agricultural operations during the subsequent year as a result of decreases in the animal population; and (4) deforestation to meet the fuel shortage for cooking in rural areas because of nonavailability of agricultural wastes and crop residues. The other socioeconomic implications of droughts include increases in prices of essential commodities, import of foodgrains, distress sales of cattle, rural unemployment, malnutrition, health hazards, and depletion of assets at the farmers' level. Drought impacts are long lasting, at times lingering for many years. Human and social factors aggravate the effect of drought, as it takes several years for small and marginal farmers in dryland areas to recoup the losses.

In the vast semiarid and arid regions of the world, years of below-average rain are more frequent compared to the years of normal/excess rainfall. Every farmer in these areas should recognize the inevitability of drought and prepare for it by equipping himself with coping strategies.

Moreover, drought management should be an integral component of sustainable agriculture. Thus the threat of instability inherent in recurring drought must be counteracted as far as possible.

As the basic requirement for managing drought in dryland agriculture is to generate the management skills required to adjust crop cultivation plans/practices depending on the time of occurrence of rain/drought, it is necessary to characterize the different types of droughts likely to be encountered in drylands.

Five distinct categories of drought affecting crop production in the drylands were clearly distinguished in India, depending on the time of occurrence of drought and general climatic conditions of the region.

Early season drought

The early season droughts occur in association with the delay in commencement of sowing rains.

Characterization of early season droughts in any agroclimatic region requires precise information on (1) optimum sowing periods for the different crops and their varieties grown in the region under rainfed conditions, (2) amount of rainfall needed to complete the sowing in a given region, and (3) the initial amount of rainfall required for safe germination and establishment of the crop stand to minimize the adverse effect of dry spells immediately after sowing.

Mid-season drought

Mid-season droughts occur in association with the breaks in the southwest monsoon. If the drought conditions occur during the vegetative phase of crop growth, it might result in stunted growth, low leaf area development, and even reduced plant population. Mid-season droughts for crops grown under rainfed conditions can be characterized by (1) the relationship between leaf area index and water use of the crop, depending on the water availability to the crop, and (2) the relationship between the actual leaf area index and effective leaf area index of the crop under moisture stress conditions.

Late season or terminal drought

If the crop encounters moisture stress during the reproductive stage because of early cessation of the rainy season, there may be an increase in temperature, hastening the process of crop development to forced maturity. Therefore, late-season droughts have to be characterized on the basis of the relationship between water availability to the crop during the reproductive stage of crop growth and grain yield.

Apparent drought

Rainfall in the region may be adequate for one crop but not for others. Therefore, apparent drought conditions are encountered because of mismatching of the cropping patterns to the rainfall/moisture availability patterns in some of the regions.

Permanent drought

Drought is a recurring feature in arid regions, as it is in virtually all climate regimes. Even the drought-resistant crops grown in these regions are likely to be subjected to moisture stress, even during years with above-normal rainfall. Alternate land use systems have to be introduced in these regions for sustainable agriculture.

Overview of the Drought Early Warning System in India

Breaks in the monsoon rains can be of different durations. Breaks of shorter duration, like 5 to 10 days, may not be of serious concern. But prolonged breaks of more than 2 weeks can create plant water stress, leading to low productivity of crops. These breaks cannot be predicted in advance. The agricultural droughts resulting from prolonged breaks in the monsoon rains can be of different magnitudes and severity and affect different crops in varying degrees. Meteorological information, in terms of the frequency and probability of these breaks, can be used to select a combination of crops of different durations in such a way that there is a time lag in the occurrence of their growth for appropriate intercropping systems.

Long-range seasonal forecast of the India Meteorological Department

The Indian economy is basically an agro-based economy. The nation’s agricultural planning is primarily dependent on the reasonable accurate prediction of the total amount of rainfall from the beginning of June to the end of September. This kind of prediction comes under the category of long-range forecast (LRFs). The first operational LRF for seasonal monsoon rainfall was issued on June 4, 1886. This was based on antecedent Himalayan snow cover (Blanford 1884). Over the last hundred years, there have been many refinements in the LRF techniques, including the multiple regression technique introduced by Sir Gilbert Walker (1910). Presently, IMD issues LRFs based on statistical techniques. In the last 12 years (1988-99), all the monsoon rainfall forecasts have proved to be fairly accurate.

On the basis of LRFs, various precautionary measures can be planned and adopted. For example, if an LRF indicates below-normal rainfall, then food grains could be purchased from the international market well in advance. Also, adequate arrangements could be made for the transport, storage, and distribution of the food grains. The government authorities can work out various plans and schemes to counter the adverse situation well in advance, and the strategies can be used at various levels, such as states, districts, talukas, villages, and so on.

At present, LRFs pertain to the seasonal total rainfall for the entire country. Scientific research is required for the development of LRF techniques for a smaller spatial and temporal scale.

Service rendered by the Agrimet division of IMD

A scientific study of the influence of weather on crops is of vital importance. Any abnormalities in the weather during the season, such as delay in the outbreak of rains, untimely or excessive rains, droughts, or spells of too-high or too-low temperatures, would very seriously affect the growth and final yield of the crops. Analysis of the existing data indicates that at least 50% of the variability of crop yields is related to weather.

Realizing the importance of meteorology in better understanding the crop-weather relationship and thereby increasing the food production in the country, the Agricultural Meteorology Division (Division of Agricultural Meteorology) was started in August 1932 in Pune. After the formation of the division at Pune, the problems connected with the application of meteorology to agriculture began to receive specialized attention. Close and very fruitful contacts have been established with all the central and state agricultural departments.

The Division of Agricultural Meteorology has a wide network of agrometeorological observatories, which generate various kinds of data on agrometeorological parameters. In tune with the changing agricultural scenario in the country, the Division has taken up more specific research problems like water requirement of crops, pests and diseases, rainfall probabilities in the dry farming tracts, crop-weather relationship, and application of remote sensing techniques in agricultural meteorology.

Agrometeorological Advisory Services Unit (AASU)

The Division of Agricultural Meteorology, in coordination with the respective state agricultural departments, is issuing weekly/bi-weekly Agromet. Advisory Bulletins from 17 AAS units located at State Meteorological Centres (MCs)/ Regional Meteorological Centres (RMCs). The scheme was first launched in 1977 from the state of Tamil Nadu. The Advisory Bulletins contain specific agricultural advisories tailored to the needs of the farming community.

The first and foremost aim of the service is to render timely advice on the actual and expected weather and its likely impact on the various day-to-day farming operations. Short-range forecasts valid for 12 to 24 hours and then extended to the following 2 to 3 days are used extensively to provide this advice. Secondly, agrometeorological forecasts extending over a week or 10 days (medium range) are very important from the users' point of view as well as for planning for various agricultural operations and strategies.

The advisories are prepared by taking into account the stage of the crops, agricultural operations in progress, prevalence of pests and diseases, and the immediate impact of weather on crops. They are prepared in consultation with the experts of the State Department of Agriculture and broadcast over All India Radio (AIR) stations in the state and Doordarshan Kendra as special programs for the benefit of the farmers in the state. These bulletins are also sent to various agricultural authorities in the state.

The bulletins contain specific advice for farmers for protecting their field crops from adverse weather or to make best use of prevailing favorable weather to increase production. These bulletins are broadcast in the regional languages from radio stations of the concerned region. They are also telecast over some of the national TV network stations of the specific region. Newspapers, particularly those in regional languages, are also used for the dissemination of weather information.

In addition to this bulletin, the Farmers' Weather Bulletin (FWB) is also regularly issued from all MCs/RMCs. Weather services for the farmers in India were started by the India Meteorological Department in 1945. FWBs indicate the onset of rains, probable rainfall – intensity and duration, weak or a break in monsoon conditions, occurrence of frost, hail, squalls, and other conditions. The bulletins also contain daily district forecasts of weather, including warnings of conditions (such as heavy rainfall and low temperature) that are injurious to plants.

Farmers' Weather Bulletins are issued throughout the year for broadcast in different regional languages through AIR stations. Initially there was only one broadcast a day, in the evening. A second bulletin was then issued in the morning during the rainy season. Since 1990, FWBs have been issued throughout the year twice a day. These bulletins and the daily weather reports prepared by the centers are also published in the newspapers. At present, 70 radio stations broadcast FWBs in India. The validity of these forecasts is for 48 hours, with an outlook for the subsequent two days. Figure 1 shows the network of Agromet Advisory Services Centres and AIR stations broadcasting FWBs. Contents of the Bulletin are (1) a summary of past weather, (2) a district forecast of weather during the next 48 hours and special weather warnings for cyclonic storms, etc., and (3) an outlook for the subsequent two days.

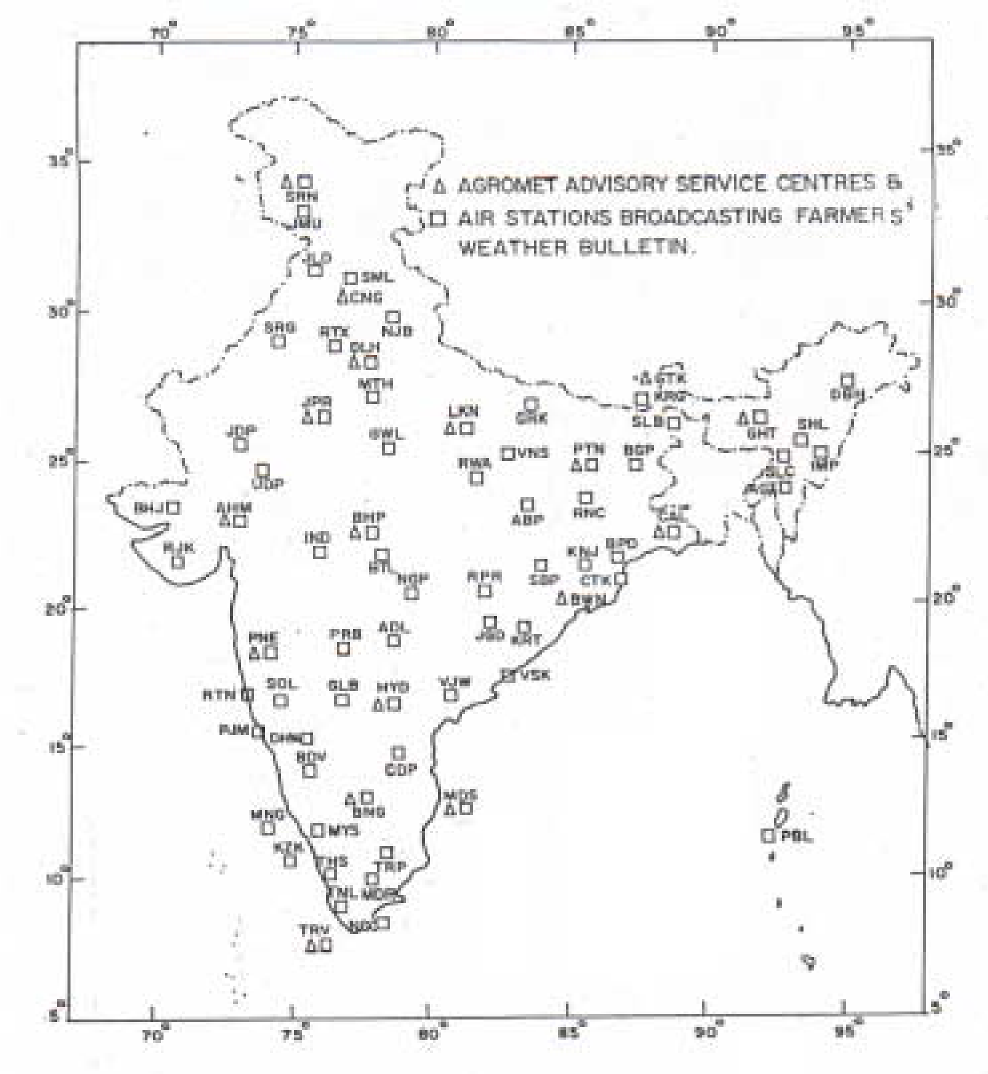

Figure 1. Map indicating - Agromet Advisory Service Centres (△) and Air Stations Broadcasting Farmers' Weather Bulletin (□)

Feedback

To assess the utility and impact of operational weather services to farmers, feedback can be obtained through conferences, workshops of forecasters, agrometeorologists, agriculturists, extension workers, and farmers. Feedback is obtained by various means, such as questionnaires. The questionnaires usually include (1) general information (e.g., name of unit, main crops, and main cultural operations), (2) information regarding farmers' awareness of meteorological forecasts and agromet advisories, and (3) information regarding the language of advisories (e.g., whether the language is easy or difficult to follow), reliability of forecasts, and usefulness of warnings. Regular surveys for this feedback information are essential for the improvement of our forecasting at such a level, so that the user community can correctly interpret the advisories to their best advantage. The feedback information reveals that the use of modern techniques in agrometeorological analysis has increased the credibility of forecasts among the user community. Now with the development of information technology, the feedback may be obtained from farmers and user agencies through the Internet.

Drought Research Unit of the India Meteorological Department

The Drought Research Unit was set up at IMD in Pune under the instruction of the Planning Commission of the government of India in June 1967.

IMD identifies meteorological drought for subdivisions every year based on rainfall analysis. During the last 125 years (1875-1999), IMD has identified meteorological droughts (moderate or severe) over meteorological subdivisions of the country using IMD criteria and also drought years for the country as a whole. Similarly, drought-prone areas and the probability of occurrence of drought were also identified.

IMD monitors agricultural drought once every two weeks on a real-time basis during the main crop seasons (kharif and rabi) of India. For this, an aridity anomaly index (AI) developed on the lines of Thornthwaite's concept is used to monitor the incidence, spread, intensification, and recession of drought. AI is given as

$$AI = \frac{PE - AE}{PE} \times 100$$

where PE is potential evapotranspiration calculated with the help of Penman's formula, which takes into account mean temperature, incoming solar radiation, relative humidity, and wind speed. AE is actual evapotranspiration calculated according to Thornthwaite's water balance technique, taking into account PE, actual rainfall, and field capacity of the soil.

The aridity anomaly is calculated by using the normal Aridity Index for 210 well-distributed stations over the country. The arid areas are demarcated as follows:

Aridity Anomaly	Areas
0 or negative	Non-arid
1 – 25	Mild arid
26-50	Moderate arid
> 50	Severe arid

With the help of aridity anomalies, crop stress conditions in various parts of the country can be monitored during the monsoon season. These anomalies can be used for crop planning and in the early warning system during drought/desertification.

It should be mentioned that aridity is different from drought. Aridity is a permanent climatic situation of a region, while drought may occur at any place and on any time scale. Thus aridity anomaly reports used by the India Meteorological Department do not indicate arid regions; on the contrary, they give an indication of the moisture stress in any region on the time scale of one or two weeks, and they are useful early warning indicators of agricultural drought.

Biweekly aridity anomaly reports are prepared for the country as a whole during the southwest monsoon season and over 5 subdivisions (Coastal Andhra Pradesh, Rayalaseema, South Interior Karnataka, Tamil Nadu, and Pondicherry and Kerala) during the northeast monsoon season. These anomaly reports are widely circulated to various users such as Agromet Advisory Services, the agricultural departments of state governments, agricultural universities, and the National Remote Sensing Agency in Hyderabad. The system is being further refined by supplementing remote sensing data.

The Drought Research Unit also provides Crop Yield Forecasts (CYFs). This unit has developed pre-harvest crop yield forecasting models and issues of monthly statewise crop yield and countrywide total production forecasts for the major crops of kharif (rice) and rabi (wheat), based on the agrometeorological models. Weather parameters like rainfall, temperature, relative humidity, cloud amounts, and improved technology influence crop growth and yield. Based on a long series of past crop yield data and meteorological data of the corresponding period, pre-harvest crop yield forecasting models have been developed using the multiple regression technique. Pre-harvest crop yield forecasts are issued for 15 states comprising 26 meteorological subdivisions for kharif (rice) and 12 states comprising 16 meteorological subdivisions for rabi (wheat) and also for the total rice/wheat production of the country. The forecasts are supplied to India's Directorate of Economics and Statistics, Ministry of Agriculture. The first interim forecast for kharif rice is issued in August and the final forecast is given in November/December. For wheat, the first interim forecast is issued in January and the final in March/April/May.

Rainfall Climatology for the Agricultural Planning Unit in IMD

One of the most important pieces of agrometeorological information required by agriculturists is the suitable time for starting the sowing operations in their fields. Sowing dates for the states of Karnataka, Rajasthan, Gujarat, Madhya Pradesh, Uttar Pradesh, and Maharashtra, based on the climatology of daily rainfall data, soil type, and cropping pattern, have been prepared by the India Meteorological Department. Based on such studies, it is also possible to identify areas that may need supplementary irrigation to sustain crop growth. By superimposing results of the analysis on the soil map of the state, areas experiencing different degrees of drought proneness have also been demarcated.

The National Centre for Medium Range Weather Forecasting (NCMRWF)

In January 1988, the government of India approved the establishment of NCMRWF as a constituent unit of the Department of Science and Technology (DST) to help develop suitable numerical weather prediction (NWP) models for medium-range weather forecasts (3–10 days in advance) and prepare agrometeorological advisories for the farming community in 127 agroclimatic zones of India. The main objectives of NCMRWF are (1) to develop location-specific medium-range (3 to 10 days) weather forecasts, (2) develop weather-based agro-advisory services for the farming community, and (3) promote and coordinate research in related areas of meteorology and agrometeorology.

The project has received continued support from IMD since its inception. An exclusive coordination cell, the Agrometeorological Co-ordination Cell, was established in November 1988 in IMD for coordinating activities related to the project. NCMRWF, in collaboration with the India Meteorological Department, Indian Council of Agricultural Research (ICAR), and state agricultural universities (SAUs), is providing Agrometeorological Advisory Service (AAS) at the scale of agroclimatic zones to the farming community, based on location-specific medium-range weather forecasts.

To provide numerical weather prediction (NWP) based AAS to farmers, NCMRWF opened an agrometeorological field unit (AMFU) in each of the 127 agroclimatic zones of the country. These AMFUs are co-located with the National Agriculture Research Program (NARP) Centres of ICAR and the SAUs so that research output can be used effectively in formulating the agro-advisories. At present, NCMRWF has established AAS units in 83 agroclimatic zones (Figure 2). The remaining zones may be covered in a phased manner. Agromet Advisory Bulletins, with expert advice on crop, soil, and weather, are made available to the farming community.

Dissemination and feedback mechanism

NCMRWF's weather forecast bulletin is disseminated biweekly to AAS units every Tuesday and Friday over a telephone, telegram, or satellite-linked Very Small Aperture Terminal (VSAT) communication system. In addition to these bulletins, weather charts are also sent to AAS units. The VSAT has the capability for reliable data transmission, interactive data communication voice transmission, and picture transmission. The same communication system is also being used to collect observational data from AAS.

Periodic feedback on the worthiness of forecasts and usefulness of advisories is also obtained by NCMRWF. Feedback from selected farmers and SAUs indicates whether they have adjusted their day-to-day farming operations in response to the advice provided by AAS; it also highlights their additional requirements.

Central Research Institute for Dryland Agriculture (CRIDA)

CRIDA is maintaining six agrometeorological observatories in their regional research stations at Jodhpur, Jaisalmer, Chandan, Bikaner, Pali, and Bhopalgarh. Data collected at these observatories are also used for drought assessment, which is disseminated to the public and other agencies through the media.

Figure 2. Agromet Advisory Services units of NCMRWF

Remote sensing for drought monitoring

During periods of drought conditions, physiognomic changes within vegetation may become apparent. Satellite sensors are capable of discerning many such changes through spectral radiance measures and manipulation of such measures into vegetation indices, which are sensitive to the rate of plant growth as well as to the amount of growth. Such indices are also sensitive to the changes in vegetation affected by moisture stress. The vegetation index maps are prepared by the National Remote Sensing Agency (NRSA) of the Department of Space and distributed to users for monitoring agricultural drought.

Drought Research in India

Many studies have dealt with monsoon variability and the impact of global- and regional-scale parameters on summer monsoon rainfall. There are also many studies on the prediction of summer monsoon rainfall through numerical models. Studies by Smith and Sikka (1987), Singh and Kriplani (1985), Chowdhury et al. (1988), Singh et al. (1992), and Vernekar et al. (1993) have shown that the 30-50 day mode has strong interannual variability, which may in turn affect the variability of the monsoon season rainfall through active-break monsoon episodes. Bhalme and Mooley (1981) prepared a time series of the drought area index. They defined the moisture index as the ratio of departure of rainfall from the monthly mean and standard deviation of monthly rainfall.

The epochal behavior of drought has been discussed by Joseph (1978), Sikka (1980), and Mooley and Parthasarathy (1984).

Appa Rao (1991) classified the drought-prone areas and chronically drought-affected areas. Most of the drought-prone areas identified above are in either arid or semiarid regions where droughts occur more frequently. Sen and Sinha Ray (1997) have shown a decreasing trend in the area affected by drought in India. Gore and Sinha Ray (1999) made a detailed study of the variability of drought incidence over districts of Maharashtra. Sinha Ray and Shewale (2000) have determined the probability of occurrence of drought on the basis of summer monsoon rainfall data for the period 1875-1999. Figure 3 indicates the probability of occurrence of moderate and severe drought over various subdivisions in India. Probability of occurrence of severe drought was found to be greatest in Saurashtra and Kutch, followed by Gujarat and West Rajasthan. Sinha Ray and Shewale (2000) also studied the effects of El Niño on summer monsoon rainfall of various subdivisions of India.

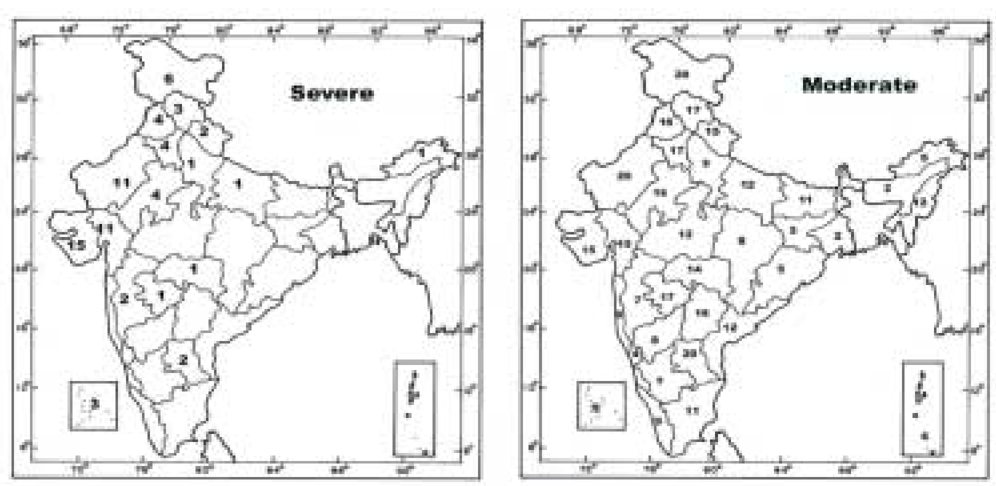

Figure 3. Occasions of moderate and severe drought during 1875 - 1999

Government Efforts

The National Natural Resource Management System (NNRMS) has been set up to monitor the progress of remote sensing applications to natural resources management in the country. To pursue and guide remote sensing application development in the agriculture sector, the Standing Committee on Agriculture and Soils (SC-AS) has been created. The SC-AS is entrusted with the responsibility of examining the role of remote sensing technology in addressing various issues related to management of agricultural resources. They are assessing the present and future capabilities of that technology to develop procedures to retrieve agromet parameters from space-borne systems and disseminate agromet information for farmers' advisory services.

Recent efforts to combat drought through policies formulated by governmental agencies include:

- crop weather watch groups at the national and state level,
- food security through buffer stocks,
- priority to the most seriously affected areas for "food for work"/National Rural Employment Project and other programs,
- high priority to food production in the most favorable/irrigated areas as compensatory programs,
- optimum input use,
- rural godowns to avoid crash sales, and
- crop insurance schemes.

Most recently, serious attempts have been made to develop areas on the basis of watersheds. The Watershed Development Programmes have brought out the possibility of holistic development of an area. They include:

- soil and water conservation programs,
- choosing production systems based on land use capability classification,
- increased cropping intensity either through harvesting excess rainwater through surface runoff or by improving the ground water recharge through percolation tanks, and
- good crop husbandry.

The space-based National Agricultural Drought Assessment and Monitoring System (NADAMS), which has been operational since 1989 under India's Department of Agriculture, provides scientific information at the district level for most of the states and subdistrict levels in a few states. The NADAMS program needs to be strengthened with interdepartmental support. The Drought Prone Area Development Programme (DPAP) and Desert Development Programme (DDP) should use the action plans prepared on the basis of integrated resource estimation from remote sensing data.

Premier government institutions like the Central Arid Zone Research Institute (CAZRI), Jodhpur; Indian Grassland and Fodder Research Institute (IGFRI), Jhansi; Central Soil Salinity Research Institute (CSSRI), Karnal; and research stations of the Ministry of Agriculture in various states have developed some ameliorative measures. These practices are region specific, and after proper implementation, they have the potential of bringing forth productive green cover on otherwise marginal degraded lands.

Forecasting agricultural output using space agrometeorology and land-based observation (FASAL) is under active consideration at the Ministry of Agriculture for administrative approval and implementation. The pilot FASAL project in Orissa (1999-2000) has demonstrated the combined use of various sources of data in making kharif rice multiple forecasts.

Drought Management

Drought management should not be treated as an isolated problem but as an integral and key factor in sustainable agriculture. Farmers should be encouraged to develop a range of flexible contingency plans that protect the soil, climate, and vegetation. By having numerous contingency plans, farmers can resist the temptation of overextracting these resources. Drought management procedures include:

- community nurseries at points where water is available,
- transplantation,
- sowing of alternate crops/varieties,
- ratooning or thinning of crops,
- soil mulching if the break in the monsoon is very brief,
- weed control,
- in situ water harvesting and/or run-off recycling,
- broad beds and furrows,
- graded border strips,
- inter-row and inter-plot water harvesting systems,
- intercropping systems for areas where the growing season is generally 20 to 30 weeks,
- alternate land use systems,
- development of agriculture on the basis of the watershed approach,
- alley cropping,
- agro-horticultural systems,
- watershed approaches for resource improvement and use,
- water resources development,
- treatment of lands with soil conservation measures,
- alternate land use systems, and
- forage production.

Future Needs

- IMD’s long-range forecasts should be available on a smaller spatial and temporal scale, which will be helpful for sustainable agriculture.
- Agromet parameters estimated from remote sensing data need to be validated with ground-based observation and turned into a usable product.

- The Department of Agriculture and All India Co-ordinated Research Project on Agrometeorology of ICAR and IMD should have a linkage with the NADAMS project of the Department of Space to provide periodic crop/pest/disease information at subdistrict to national levels.
- The Agromet advisory service issued from NCMRWF and AGRIMET of IMD should coordinate the space-based program on NADAMS and use the spatial maps for strengthening the present advisory services on crop pest/disease monitoring.
- The Drought Prone Area Programme (DPAP) and the Desert Development Programme (DDP) require improved management of land and water resources to avoid land degradation like salinity, alkalinity, and waterlogging.

Each state should be equipped with a drought management system, linking district administration with state and national departments that provide services.

Agromet information for farmers' advisory services should be made more user-oriented, and frequent feedback may be obtained from farmers for further improvement. Use of the Internet may be exploited for more efficient feedback.

References

Appa Rao, G. 1991. Drought and southwest monsoon. Training course on Monsoon Meteorology. 3rd WMO Asian/African Monsoon Workshop, Pune, India.

Bhalme, H.N. and D.A. Mooley. 1981. Cyclic fluctuations in the flood/drought area and relationship with the double (Hale) sun spot cycle. *Journal of Applied Meteorology* 20:1,041-1,048.

Blanford, H.F. 1884. On the connection of the Himalayan snowfall with dry winds and seasons of droughts in India. *Proceedings of the Royal Society*, London 37:3-22.

Chowdhury, A., R.K. Mukhopadhyay, and K.C. Sinha Ray. 1988. Low frequency oscillation in summer monsoon rainfall over India. *Mausam* 39:375-382.

Gore, P.G. and K.C. Sinha Ray. 1999. Variability in drought incidence over districts of Maharashtra. Accepted for publication in *Vayu Mandal*.

Joseph, P.V. 1978. Sub-tropical westerlies in relation to large scale failure of Indian monsoon. *Indian Journal of Meteorology, Hydrology and Geophysics* 29:412-416.

Mooely, D.A. and B. Parthasarathy. 1984. Fluctution in All-India summer monsoon rainfall during 1871-1985. *Climate Change* 6:287-301.

Sen, A.K. and K.C. Sinha Ray. 1997. Recent trends in drought affected areas in India. Presented at International Symposium on Tropical Meteorology, INTROPMET-1997 at IIT, New Delhi.

Sikka, D.R. 1980. Some aspects of the large scale fluctuations of summer monsoon rainfall over India in relation to fluctuations on planetary and regional scale circulation parameters. *Proceedings of the Indian Academy of Sciences, Earth and Planetary Sciences* 89:179-195.

Singh, S.V. and R.H. Kriplani. 1985. The south to north propogation of rainfall anomalies across India during the summer monsoon season. *Pure and Applied Geophysics* 123:624-637.

Singh, S.V., R.H. Kriplani, and D.R. Sikka. 1992. Nature of Madden-Julian Oscillation in Indian Summer monsoon rainfall. *Journal of Climate* 5:973-978.

Sinha Ray, K.C. and M.P. Shewale. 2000. Probability of occurrence of drought in various subdivisions of India. Submitted to *Mausam.*

Smith, E.A. and D.R. Sikka. 1987. The coherence of satellite intra red temperature with monsoon rainfall at preferred frequencies and the triplex behaviour of the Indian summer monsoon. *Meteorology and Atmospheric Physics* 37:219-236.

Vernekar, A.D., V. Thapliyal, R.H. Kriplani, S.V. Singh, and B. Kirtman. 1993. Global structure of the Madden Julian oscillation during two recent contrasting summer monsoon seasons over India. *Meteorology and Atmospheric Physics* 52:37-47.

Walker, G.T. 1910. Correlation in seasonal variation of Weather II. IMD Mem. XXI Part II, 22-25.

Regional Drought Monitoring Centres – The Case of Eastern and Southern Africa

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Abstract

Eastern Africa is prone to extreme climate events such as droughts and floods. In the past, these events have had severe negative impacts on key socioeconomic sectors of the economies of most countries in the subregion. In the late seventies and eighties, droughts caused widespread famine and economic hardships in many countries. For this reason and at the request of 24 countries in the eastern and southern Africa subregion, WMO established two drought monitoring centers (DMCs), in Nairobi, Kenya, and Harare, Zimbabwe, in 1989 with financial support from UNDP. The main objective of the centers was to contribute to early warning systems and mitigation of adverse impacts of extreme climatic events on agricultural production, the mainstay of economic activities in the subregion. Since their establishment in 1989, the centers have played an important and useful role in providing the subregion with weather and climate advisories and, more importantly, advance warnings on droughts, floods, and other extreme weather events, on the basis of which appropriate actions have been taken to mitigate the adverse impacts.

Because of the enhanced need for drought-related products, the two centers have split into the Drought Monitoring Centre, Nairobi (DMCN), and the Drought Monitoring Centre, Harare (DMCH). DMCN caters to countries in the Greater Horn of Africa region while DMCH is responsible for countries in southern Africa. Whereas DMCH has been integrated into the SADC, the DMCN is still a project and would need an institutional framework to ensure its long-term operation.

Introduction and Background

The frequent and widespread droughts of the 1980s and their attendant problems of famine and economic hardships provided a strong incentive for the establishment of monitoring capabilities within eastern and southern Africa. The establishment of the Nairobi and Harare operational drought monitoring centers under the UNDP/WMO project “Drought Monitoring for Eastern and Southern Africa” arose out of the realization that mitigating the effects of drought in this subregion could not be effectively tackled in isolation, but only through well-coordinated regional collaboration. The project had 24 participating countries: Angola, Botswana, Burundi, Comoros, Djibouti, Ethiopia, Eritrea, Kenya, Lesotho, Malagasy, Malawi, Mauritius, Mozambique, Namibia, Rwanda, Seychelles, Somalia, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia, and Zimbabwe.

The two operational centers were charged with timely monitoring of drought, with respect to its intensity, geographical extent, duration, and impact on agricultural production; and giving early warning to enable the formulation of appropriate strategies to combat its adverse effects. This was to be achieved through improved application of meteorological and hydrological data and products.

Extreme climate events like drought, floods, cyclones, cold/hot spells, and severe storms are common in the subregion. Whenever they occur, they have devastating effects on agricultural activities and food security, water availability and quality, energy demand and supply, safety of transportation systems, human health, and many other socioeconomic activities. Many water-use activities in the eastern African countries heavily depend on rainfall. Because of the complex nature of rainfall patterns in the subregion, there is no year or season in which the whole region receives normal rainfall and is devoid of extreme climate anomalies. *The best strategy to minimize negative impacts associated with climatic extremes is timely availability of weather and climate information and prediction products, coupled with effective disaster preparedness policies.*

The extreme climate events have been associated with the El Niño/Southern Oscillation (ENSO) phenomenon, tropical cyclone activity, and anomalies in monsoon wind systems, among many other regional systems. Monitoring such anomalies is a core activity of the DMCs, global climate centers, and WMO.

ENSO events have a strong influence on the intertropical convergence zone (ITCZ), regional monsoon wind circulation, and patterns of rainfall anomalies over many parts of the subregion. The impacts, however, vary significantly from season to season and location to location. For example, El Niño episodes are often associated with above-normal rainfall conditions over the equatorial parts of eastern Africa during October to December and below-normal rainfall over much of the Horn of Africa during the June to September rainfall season. On the other hand, La Niña events often give rise to below-normal rainfall over much of the Greater Horn of Africa during October to December and March to May and above-normal rainfall during the June to September rainfall season.

Warm phase ENSO episodes have been more frequent in recent years than episodes of the cold phase (La Niña). This might have led to the recent recurrences of floods and droughts in regions with strong ENSO signals such as eastern Africa**.** *It should be noted that El Niño episodes at times change to La Niña. In such cases, many locations with strong ENSOs signal have observed severe floods that are followed by severe droughts, and vice versa.* These have had devastating socioeconomic impacts in such locations. For example, in equatorial eastern Africa, heavy rains associated with the 1997-98 El Niño event preceded the current dry conditions, which are the result of the 1998-1999-2000 La Niña conditions.

It should also be noted that ENSO is not the only cause of floods and droughts in the subregion. There is therefore a need for more regional research to understand other causes of climate anomalies in the region. ENSO can, however, account for more than 80% of the rainfall anomalies in some seasons and locations. This signifies the importance of ENSO, SSTs, and other general circulation information for purposes of early warning in the subregion. Another major factor that often affects regional circulation is the tropical cyclone activity over southern and northwestern Indian ocean regions. Cyclones are associated with intensive rainfall over the region of occurrence. However, they can cause drought in the regions outside the cyclone activity by dragging the normal winds to the cyclone region. This is one of the factors that caused the failure of the March-May 2000 rainfall season in the tropical eastern African region. The cyclone activity in the southwest Indian ocean region was associated with floods in Mozambique and other countries of southern Africa. Enhancement of regional/national meteorological and hydrological early warning systems is essential in order to enable them to take maximum advantage of new technology to produce useful climate and prediction information for decision making.

Overview of Drought Early Warning Systems in Eastern Africa

Drought is a natural component of the climatic system. Droughts have occurred in Africa throughout the historical period for which rainfall records are available (Ogallo and Nassib 1984; LeComte 1985; Winstanley 1985). Because of the varied nature of water use, drought assumes a variety of definitions, each of which is dependent on the water-use activity. However, it can be regarded as "*lack of sufficient water to meet essential needs*." It is a supply-and-demand phenomenon in which the demand exceeds the supply from all sources. In the eastern African region, many economic activities heavily depend on agricultural production. Rainfall fluctuations therefore play a significant role in determining the national economies.

Drought can be monitored through the application of various statistical techniques. This requires the availability of long-term series of historical data. The statistical techniques for monitoring drought range from highly sophisticated models like the Palmer Drought Index to simple procedures such as the use of percentiles, deciles, and quartiles.

Assessment of drought severity in the subregion is based on the quartile index as depicted in Table 1. Participating countries are charged with timely provision of near real time data to the operational centers. This computational assessment is supplemented by satellite remotely sensed data in the form of the NDVI and CCD.

Table 1. **Drought severity index based on the quartile range.**

Range	**Comments**
< Min	Driest on record
Q1-Min	Dry
Q1-Q3	Near normal
Q3- Max	Wet
>Max	Wettest on record

Q1: 1st quartile Q3: 3rd quartile

Cumulative rainfall information is also used to assess cumulative impacts of rainfall anomalies. The temporal evolutions of rainfall anomalies over the last several months for some selected stations over the Greater Horn of Africa are given in Figure 1. The cumulative curves indicate that some of the locations have recorded their worst drought since 1961.

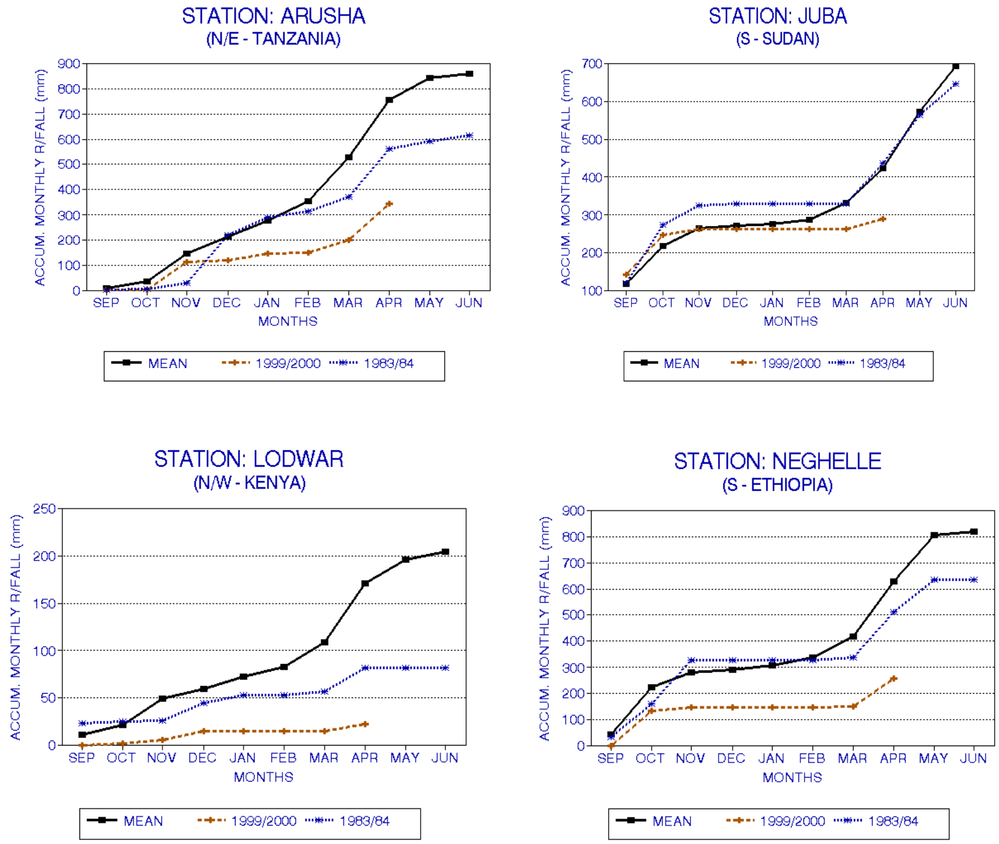

Figure 1. Time series plots of cumulative monthly rainfall for selected stations.

In recent years, new developments in early warning and climate prediction services have made it possible to predict ENSO with lead times of a few months. This has provided new prediction and early warning systems of ENSO-related extreme weather/climate events in many regions with strong ENSO signals, like eastern Africa. Formulation of seasonal (three months) weather outlooks is therefore based on ENSO conditions and sea surface temperature anomalies (SSTAs) as well as cyclone activity in the tropical oceans. On the basis of these indicators, the DMCs have been able to regularly forewarn the target groups of the possibilities of anomalous rainfall behavior in the subregion. Some of the countries in the affected sectors have used this timely information to institute strategies to minimize drought impacts.

Primary Data and Information Products

The DMCs prepare, publish, and disseminate to users the following products:

1. Ten-day weather advisories for the subregion, which include:

- decadal climatological summary (drought severity);
- decadal agrometerorological conditions and impacts; and

- decadal synoptic review and weather outlook.

2. Monthly Drought Monitoring Bulletin for the subregion, which includes:

   - monthly and three-monthly climatological summaries (drought severity);
   - dominant synoptic systems and three-month weather outlook;
   - agrometeorological conditions and their impacts on agricultural activities and water resources; and
   - monthly and three-monthly actual meteorological data.

In addition, special advisories are prepared and disseminated to users when the need arises.

The effectiveness of the products is evaluated through a feedback mechanism that has been established with the users. Climate outlook fora that take place before the beginning of the major rainfall seasons were initiated recently in the subregion. These bring together scientists from within and outside the subregion and users of climate information to participate in two activities. The first activity is a 2-day users' workshop that is meant to enhance the application of the climate information and products and to foster interactions between the producers and users of climate information. The second activity is normally a climate outlook forum at which a consensus climate outlook is developed and the potential impacts of the expected rainfall conditions are determined for the following rainfall season. The participation of users of DMC climate information in the climate outlook fora has facilitated the evaluation of the usefulness of the outlooks in diverse sectors of the economies. The users assess the past climate outlook products in terms of how closely the actual weather matched the forecasts. It has been noted that the past forecasts have been in broad agreement with observations made by users on the ground.

Identification of Primary Users

Because of the heavy dependence of many activities on water, users of the early warning information generated by the DMCs are quite diverse. They include policy makers, agriculturalists, water resources scientists, health officials, and environmentalists. Policy makers institute actions that can enable nations to absorb the shocks associated with climate extremes. A recent example is the timely appeal by a number of nations in the Greater Horn of Africa for donor intervention in the wake of the impending drought. Some countries waived duty on certain commodities to allow for sufficient importation.

The users also put in place actions that assist in reducing the impacts of extreme events. Workshops are organized at the grassroots level to educate the end users on strategies to adopt. An illustrative example is the case of Kenya Breweries, which made a profit of Kenya Shillings 130 million, or approximately US$2 million, on account of having judiciously used the forecast for July to September 1999.

Use of Triggers

The media is a very important avenue of disseminating information to the end users. It was on this basis that the 4th Climate Outlook Forum for the Greater Horn of Africa, held in September 1999, addressed the theme, “The role of the media in disseminating climate information.” The users who attend such fora and subsequent national workshops determine potential impacts of the outlook for diverse socioeconomic sectors of the economy.

Status of Delivery Systems

The DMC products are disseminated through the following modes:

- high-frequency radio facsimile broadcasting,
- the meteorological data distribution (MDD) system,
- ordinary mail through the post office,
- ordinary fax, and
- the Internet on the DMC website.

After the inception of the climate outlook fora, additional approaches have been adopted to disseminate climate information to users. Immediately following the conclusion of the fora, the national meteorological services are given the task of organizing national workshops to disseminate the forecast information to the end users. It is in these workshops that details at the national level are included in the forecast information. The DMCN also posts the forecast information on its website immediately after the fora. The users who attend the fora normally formulate effective ways of disseminating the forecast information to the very grassroots level. In some cases, translation of the information into local languages has been adopted to ensure that it reaches as wide an audience as possible.

Major roles played by users include giving feedback to climate scientists during the users’ capacity-building workshops. The feedback covers various issues aimed at increasing the quality of climate outlook products. Users emphasize what needs to be included in the climate outlook products to add value and make them more useful. They also emphasize the importance of providing climate outlooks in a simple and easily understandable language to enable end users to use it more effectively. For example, users have always stressed that expected rainfall amounts need to be included in the climate outlook products.

Constraints or Limitations of Current Systems

Data quality is not a major constraint as far as the current monitoring is concerned. The data used normally comes from synoptic stations, which are manned by well-trained meteorological personnel. However, before the data is used in any drought-related products, the spatial and temporal consistency of the data is ascertained. Any doubtful values are referred back to the source for verification. Station density is a problem, especially in the low potential rainfall areas, but the use of remotely sensed data supplements the data sparsity in such areas. Lack of a reliable and efficient communication system for data and products exchange was a major problem at the inception of the DMCs. However, this has greatly improved with the installation of Internet and e-mail services in most meteorological services of the subregion. In some countries, the interaction between the producers and users of climate information is still limited. This is a serious impediment to the dissemination and use of climate information, but the gap is being gradually closed through the users' workshops during the climate outlook fora.

Future Needs

- There is a need to increase the number of stations, especially in the marginal areas of the subregion. The use of remotely sensed data is being encouraged to supplement the conventional data.
- Users have proposed ways of packaging information for easier comprehension and dissemination. Some of these proposals have already been implemented. The interaction between the users and climate scientists, however, should be strengthened to facilitate effective implementation of some of these recommendations.
- There are initiatives to explore other modes of delivering climate information. The use of radio networks is being encouraged. The African Learning Channel is also another avenue of disseminating early warning information.
- Only a limited number of users have benefited from the users' capacity-building workshops that have been conducted so far. There is a need to train more users on the use of climate information. This will be achieved through national workshops that are planned within the current DMCN project. In addition, pilot application projects that are meant to demonstrate the value of using climate information are in the process of being implemented.

References

Drought Monitoring Bulletins Nos. 3/91-7/00.

LeComte, D. 1985. The year of the Africa drought. *Weatherwise* 38(1):8-15.

Ogallo, L.J. and I.R. Nassib. 1984. Drought patterns in East Africa during 1922-1983. Extended Abstracts of papers presented at the Second WMO Symposium on Meteorological Aspects of Tropical Droughts. Fortaleza, Brazil, September 24-26, 1984.

Winstanley, D. 1985. Africa in drought. A changing climate. *Weatherwise* 38(2):75-81.

Meteorological Early Warning Systems (EWS) for Drought Preparedness and Drought Management in Nigeria

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Abstract

The Nigerian Department of Meteorological Services (NDMS) is currently implementing a meteorological early warning system (EWS) as part of its effort to combat the effects of drought in Nigeria. Knowledge of the onset of drought and other hazardous meteorological conditions is important for drought preparedness and management. Presently, the basic users of EWS products are government, media, and the agricultural industry. The EWS forecasts are prepared using state-of-the-art equipment and models that were developed by NDMS staff or other researchers and scientists. These models include: (1) the Standardized Precipitation Index (SPI), (2) NDMS Prediction Schemes, and (3) Sea Surface Temperature (SST) Prediction Schemes. We used the SPI model to study incidences of drought in Nigeria, and conducted two studies to evaluate the skill of the NDMS and SST Prediction Scheme models. The results indicate that the north has the highest incidence of drought years, in comparison to the south. The skill of both the NDMS and SST Prediction Schemes is low, but these models were found to be appropriate for planning purposes. Some of the limitations we identified as being responsible for the lower skill level of these models include data quality, station density, delivery systems, and identification of the predictable components of climate. As a result, we are proposing, as part of our future needs, the development of a robust modeling technique to identify and predict band-limited cyclic components of climate that will be based on a nonlinear model of the earth/ocean/atmosphere system.

Introduction

"The Lord does whatever it pleases him in the heavens and on earth, He sends lightning with flooding, and brings whirlwinds from His storehouses." (Psalm 135: verses 6, 7).

Drought is a creeping phenomenon, characterized by extended periods with rainfall far below average, prolonged periods of dryness, high temperatures and evapotranspiration, very low humidity, and reduced streamflow and reservoir water levels (and in some cases completely dried-up water sources). It usually lasts 2-4 years, and if it is not well managed, it could precipitate another drought condition. It is for this reason that the need for drought planning and management in Nigeria cannot be overemphasized.

Extending northeast from the gulf of Guinea Coast in West Africa, Nigeria is located within latitudes 2^{o}–14^{o} N and longitudes 2^{o} 41°-14^{o} 42° E. It shares borders with Benin Republic to the west, Niger Republic to the north, Chad to the northeast, and Cameroon to the east. The country has an area of 923,766 km^2, with an average population density of 124/km^2; 180,000 km^2 are under cultivation and 9,000 km^2 are under irrigation (FGN 1997).

The total land area of Nigeria is delineated into 36 states (see Figure 1) that make up eight broad agro-ecological or land resource zones. The climate characteristics are summarized in Table 1. Climatologically and historically, it has been shown that major drought episodes associated with those of the Sudan-Sahelian drought occurred in Nigeria in locations north of latitude 11^{o} N in 1882-86, 1913-16, 1942-45, and 1971-73 (FGN 1998). These drought episodes caused massive famines. Indications from various studies show that with the present global warming, some hydrometeorological conditions could be reached that could trigger a major drought situation within this decade.

Each time drought occurs in Nigeria, the area that usually receives very severe impacts includes all areas north of 11^{o} N parallel (Kebbi, Sokoto, Katsina, Kano, Jigawa, Borno, Gombe, Adamawa and Niger states). The effects of the 1971-73 severe drought and the 1983-84 localized droughts on agricultural production prompted the federal government through its various relevant agencies to put in place institutional arrangements and schemes to minimize drought impacts.

With the present awareness of the effects of ongoing climate change and global warning, the importance of a meteorological early warning system becomes more apparent. It was from this background that the Nigerian Department of Meteorological Services (NDMS) put in place its EWS a few years ago. The development of the EWS therefore resulted in the setting up of various methods and services for the provision of weather forecasts, especially to warn the public of hazardous weather and hence minimize loss of life and property damage.

So far, the EWS project has benefited from an appreciable allocation of government funds, more so than any other meteorological project. About 50% of the total annual and 3-year rolling plan allocations to the department come under the EWS project. This funding has enabled the department to achieve 20-25% of the optimal level of implementation of other related projects. Also important is the fact that for drought projects, annual rainfall is one of the primary determinants for allocation of annual budgets and other funds, such as the “Ecological Fund,” to states, local governments, and national organizations and research institutions such as Ministries of Agriculture, Water Resources and Environment.

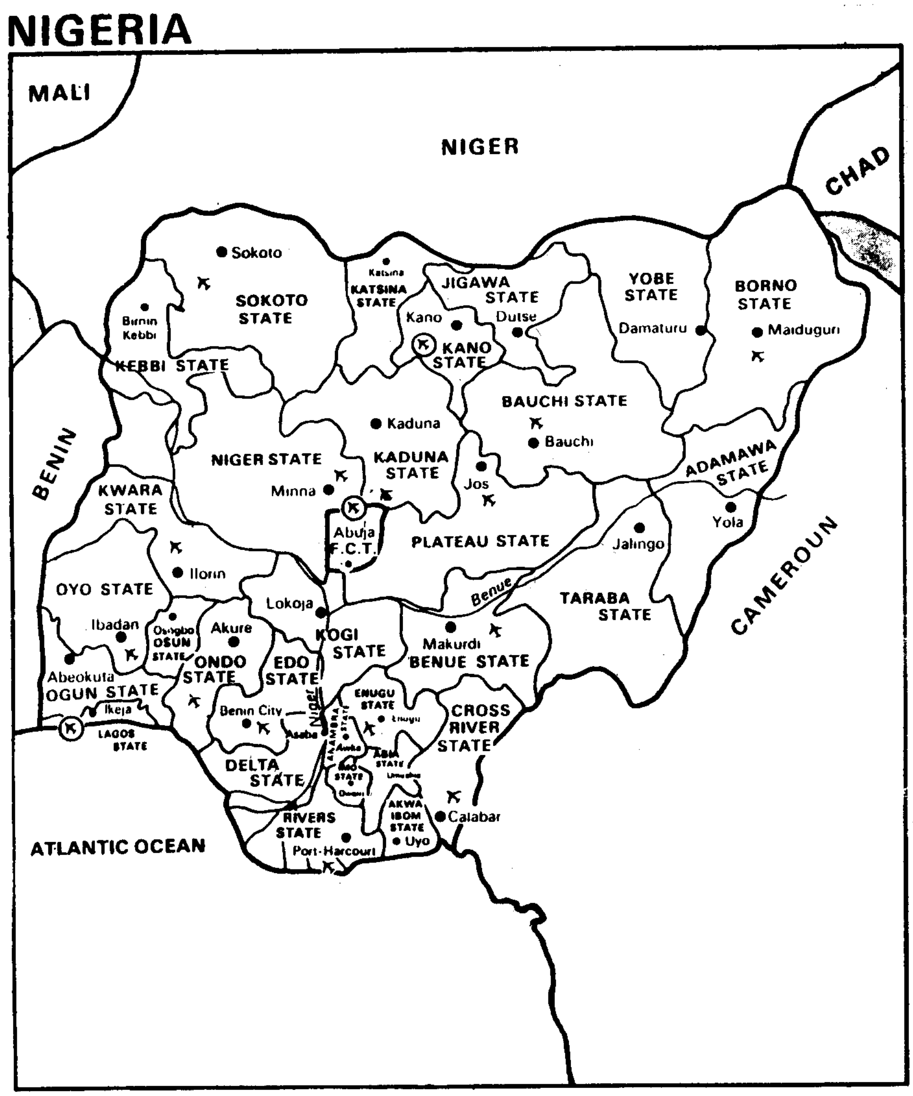

Figure 1. Map showing locations of the 36 states that make up Nigeria, and the adjoining countries.

Table 1. Agro-ecological zones of Nigeria (after FGN 1997).

Zone	Area %	Wet Seasons (s)			Mean Monthly Temperature(s) ^oC		
		Rainfall (mm p.a)	Kind	Length (Days)	Max	Normal	Minimum
Ultra Humid	2	2000+	Extended	300-360	32	28 –25	23
Very Humid	14	1200-2000	Bimodal	250-300	33	28-24	21
Humid	21	1100-1400	Bimodal	200-250	37	30-26	18
Sub Humid	26	1000-1300	Unimodal	150-200	37	30-23	14
Plateau	2	1400-1500	Unimodal	200	31	24-20	14
Mountain	4	1400-2000	Bimodal	200-300	36	29-14	5
Dry Sub Humid	27	600-1000	Unimodal	90-150	39	31-21	12
Semi Arid	4	400-600	Unimodal	90	40	32-33	13

In the process of implementing EWS, the acquisition of state-of-the-art equipment for strengthening the national meteorological network of observing stations became necessary. Presently NDMS has 50 synoptic (i.e., full-time) stations, 500 rainfall and agrometeorological stations, 20 automated weather stations, 3 weather surveillance radars, 1 total ozone station, 1 global atmospheric watch (GAW) station, and 10 global surface climate stations. In addition, we have 6 upper air and 6 marine stations that are evenly distributed over all climatic zones of the country.

The synoptic stations are equipped with basic conventional operational instruments and equipment. Automated weather stations are established alongside the conventional ones, with a view to upgrading our level of data acquisition. In addition, high-tech instruments employing both computer- and satellite-based technology such as Meteorological Data Distribution (MDD), Primary Data User System (PDUS), and Analysis, Forecasting, Data Processing and Operational System (AFDOS) have been acquired and installed. However, our major constraints or limitations include data quality and station density. Most of our synoptic stations are located in urban centers and at airports. These locations are known to generate local heat that is capable of influencing measured data. The lack of sufficient stations to adequately cover the length and breadth of the country has led to the use of extrapolation techniques in order to prepare certain EWS products.

However, despite our constraints, we have begun intensive monitoring and forecasting of weather and climate systems in Nigeria with the newly acquired equipment. So far, we have been able to contribute to national socioeconomic development and sustainable management of natural resources and the environment in Nigeria. The following are some of the information products obtained from the use of EWS models:

1. Short-, medium-, and long-range weather forecasts.
2. Prediction of onset and cessation of the rainy season.
3. Prediction of wet and dry spells.
4. Seasonal climate forecast.
5. Fog forecasting.

6. Seasonal agrometeorological forecasts.
7. Dust haze forecasting.
8. Outlook for onset of drought (SPI).
9. Soil moisture monitoring (FAO method).
10. Storm surges and coastal erosion forecasting, etc.

Currently, telecommunication between the stations is achieved by use of single side band (SSB) radio, high-frequency radio, and satellite-linked communication instruments. International linkage is achieved through the Global Telecommunications System (GTS), a component of which is presently partially installed at the Meteorological Forecast Office, Muritala Muhammed Airport, Ikeja, Lagos. Very Small Aperture Terminal (VSAT) technology has been acquired to enable the Department to link with products of World Area Forecast System (WAFS) centers of ICAO and WMO. In addition, the Digi-cora upper air equipment is being upgraded to link with the WMO's Global Positioning System (GPS) for the acquisition of upper air data, especially the upper air winds. Other telecommunication equipment recently acquired to further facilitate data collection and dissemination includes:

- MESSIR-VISION: Meteorological weather forecasts workstation for improving the accuracy of weather forecasts with sufficiently long lead-times.
- MESSIR-COMM: An automatic message system used as an interface engine between the Meteorological Service and the World Meteorological Organization GTS.
- MESSIR-SADIS: Satellite-based workstation for providing real-time aeronautical weather forecasting information, particularly to pilots.

The most important primary user of EWS products is the Nigerian government, but there are other users, including sectors such as the media, farmers, schools, and the public (see Table 2). In terms of measuring user reactions to and comments on EWS products, we found that the general public is becoming more aware of our services, judging by the comments, complaints, and criticism either received directly or reported in the media. We now receive more requests for press interviews on current weather and its effects on human activities and agricultural production. Moreover, there is an increased awareness of weather forecasts by the public, judging by complaints received by media houses when the weather forecasts are not aired.

The objective of this chapter is to present an overview of the EWS project that includes an evaluation of the EWS models and their effectiveness for drought preparedness and management in Nigeria. We will present information on our current progress as well as future goals aimed at sustaining or improving our current level of combating drought.

Table 2. Primary users of EWS products and how the products are used.

	User	How Products Are Used
1	Government	Determine policies on resources (human and revenue) allocation
2	Farmers, unions, cooperative societies, forestry, wildlife and environmental practitioners	Adapted and used in a package with other information by extension workers for effective application (e.g., translating into local languages when passing agronomic and other information packages to farmers)
3	Schools, colleges, universities, research institutes	Most primary data and indices used for research and training
4	Public engineering construction	Adapted and used in a package with other information to design structures
5	Media (print, radio, electronics, etc.), NGOs, CBOs, etc.	Adapted and used in a package with other information for public awareness and education programs

Monitoring Drought Using the SPI over Nigeria

Materials and Methods

The SPI is used to study the relationships between drought duration, frequency, and time scale, as described by Agnew (1999). For the most part, the daily, monthly, and annual rainfall values for the period 1960-90 were used for this study, but the SPI was also determined for other years beyond 1990 when data was available. A general homogenization procedure based on running averages was used to extrapolate data that was lost for most southern stations during the civil disturbances period of 1966-70. The whole data sets were obtained from NDMS, and they belonged to the existing 40 synoptic stations.

The SPI for each station was determined using the equation below:

$$SPI = (X_{ik} - X_i) / \sigma_i$$

where σ_i = standardized deviation for the ith station, X_{ik} = rainfall for the ith station and kth observation, and X_i = mean rainfall for the ith station. All negative SPI values are taken to indicate the occurrence of drought, while all positive values show no drought.

To determine drought intensity, SPI values of equal to or less than -0.50 were used. The frequency of occurrence of drought years within each decade was determined on a station-by-station basis by simple statistical means, and the result was then summed over the 40-year period.

Results and Discussion

Results of the SPI analyses indicate that all the climatic zones within Nigeria had experienced drought at one time or another during the study period (Table 3). However, the extreme northern zone of Nigeria has the highest number of occurrences of drought years during the study period.

In this zone, the number of drought years ranged between 12 and 18. This result did not come as a surprise because of the awareness that the north is more prone to drier conditions than the south.

The frequency of drought occurrence per decade-year varies greatly between decades and among stations, but ranged between 1 and 8. The third decade-year (1980-89) has the most severe and highest number of drought occurrences for the period studied. On climatic zone analysis, the dry, semiarid north zone, which lies within latitude 10^o N and 12^o N, had the highest frequency of drought incidences, while the middle-belt zone had the lowest frequency. The southwest and southeast zones have almost the same number of drought years, ranging between 5 and 14 years.

It is noteworthy that the most severe drought years (1973, 1983, and 1987) coincided with the global droughts widely believed to be the result of El Niño's effect.

Prediction of the Dates of Onset and Cessation of Rainy Season and Monthly and Annual Amounts of Rainfall Using Surface Data

Materials and Methods

The NDMS prediction schemes developed for this work use surface data from the 40 synoptic stations in Nigeria. In these schemes, the predictors are the equivalent and saturated equivalent potential temperatures:

$$\theta_e = \Theta \exp (Lq/C_pT_v)$$
$$\theta_{es} = \Theta \exp (Lq_s/C_pT)$$

where Θ = potential temperature, Θ_e = equivalent potential temperature, Θ_{es} = saturated equivalent potential temperature, L = latent heat of condensation, q = specific humidity, C_p = specific heat for dry air at constant pressure, and T_v = virtual temperature of the air.

The predictants are the dates of onset and cessation of the rainy season and monthly and annual amounts of rainfall. The schemes make use of only surface data (pressure, temperature, and relative humidity) on a daily basis for about 30 years for their development and about 10 years for testing and validation.

The calculation of equivalent and saturated equivalent potential temperatures involved a prior calculation of saturation vapor pressure from the Clausius-Clapeyron equation. The saturation vapour pressure is given as:

$$E_s = E_{so} \exp \{M_vL(T-T_o)/(R^*T_oT)\}$$

where e_{so} = 6.11 hpa, T_o = 273.06, R* = universal gas constant, p = pressure, k = R/CP, and R is the specific gas constant for dry air = 287 $Jkg^{-1}k^{-1}$.

Table 3. Number of occurrences of drought years.

S/No.	Stations	1960-69	1970-79	1980-89	1990-99	Total
1	Maiduguri	1	3	7	5	16
2	Sokoto	1	5	8	3	17
3	Katsina	2	3	5	8	18
4	Nguru	-	2	7	3	12
5	Gusau	-	3	3	3	9
6	Kano	1	2	5	1	9
7	Potiskum	1	2	4	1	8
8	Yelwa	-	1	3	2	6
9	Kaduna	2	3	3	5	13
10	Bauchi	-	4	6	2	12
11	Yola	2	2	1	3	8
12	Minna	-	1	4	-	5
13	Bida	1	3	2	4	10
14	Lokoja	-	2	3	1	6
15	Ibadan	3	4	3	2	12
16	Ikeja	1	5	4	2	12
17	Benin	1	2	5	1	9
18	Enugu	2	3	5	2	12
19	Calabar	1	2	1	1	5
20	Lagos	-	3	5	1	9
21	Ondo	4	5	3	2	14

The dates of onset of the rainy season are estimated from the date when the anomalies of equivalent potential temperature are positive for at least 15 days. This is considered as the beginning of abundant moisture supply. The mean number of days between this date and the mean onset date for each station is added to this date of positive equivalent potential temperature anomaly to obtain the onset date for the station for the year.

The dates of cessation are estimated from the date of maximum difference between the anomalies of the equivalent and the saturated equivalent potential temperatures. This maximum difference between equivalent and saturated equivalent potential temperature is considered the “maximum moisture deficit” of an unsaturated atmosphere. The mean number of days between this date and the mean cessation date is added to this date of maximum difference between equivalent, and saturated equivalent potential temperatures to obtain the cessation date for the station for the year (Omotosho 1999).

The annual rainfall is predicted from two approaches. The first is from the graph of annual rainfall against the sum of the anomalies of the equivalent potential temperature plotted with about 30 years of data. The sum of the anomalies of equivalent potential temperature is considered as accumulated excess moisture. The second is from the graph of annual rainfall against the sum of the differences between the equivalent and the saturated potential temperatures, plotted with about 30 years of data. The annual rainfall prediction is made after the summation of each of these two predictors used independently within 3 or 4 months preceding the date of onset of rains for the station for the year.

The same approach is applied for the prediction of monthly rainfall. However, a slight difference is that the summation of the predictors is made for the two months preceding the month for which the rainfall prediction is to be made.

Results and Discussion

The model gave a good prediction of the onset Julian day of the rainy season for stations north of 8^o N but gave late dates for stations south of 8^o N. Generally, the prediction was very good in only 66% of the stations analyzed.

The residual between predicted and observed cessation Julian day appears minimal and is not statistically significant. The model gave a good prediction of the length of the rainy season in both northern and southern stations but was inconsistent in its level of accuracy across the studied stations.

Predictions of the annual rainfall amounts were lower than those observed in more than 90% of the stations under study (Figure 2). The departures from observed are, however, random and cannot be thought of as a constant error term that could be inherent in the model. The prediction models' performance could be an indication of an absence of a certain factor or factors that directly influence rainfall.

The monthly rainfall prediction was limited to only 11 northern stations because of their proneness to drought conditions. With the exception of a few stations, the general sense of the prediction closely approximates the observed values.

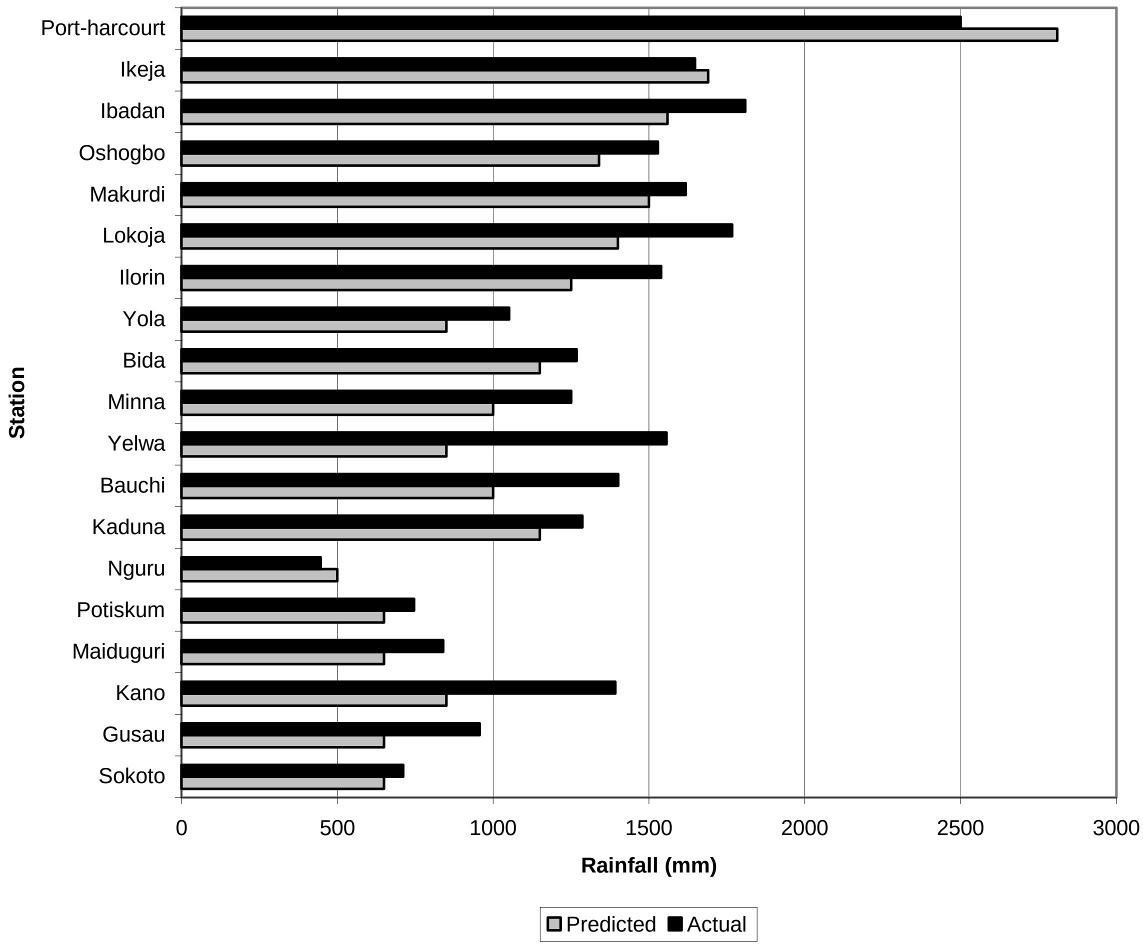

Figure 2. Observed versus predicted 1999 annual rainfall in some selected Nigerian stations.

Prediction and Evaluation of Seasonal Rainfall Based on Sea Surface Temperature for the Period 1998-2000 in Nigeria

Materials and Methods

Standardized anomaly series of rainfall were derived from monthly data obtained from NDMS. Thirty stations evenly distributed across Nigeria with complete historical data for the period 1961-99 were considered. SST data for the corresponding period were obtained from the U.K. Met. Office (through the African Center of Meteorological Applications for Development, ACMAD), and the Equatorial Atlantic (EQATL), East and Central Pacific (N1N03), and North Atlantic (NATL) regimes were considered.

To determine correlations between SST anomalies (SSTA), the regions, and the stations, the stations were divided into three zones, and standardized rainfall anomalies were calculated for each zone. Two-month running averages were calculated. The regression model:

$$Y = \text{Constant} + A(\text{SSTA})$$

was employed after obtaining correlations between SSTA in the regions and each of the 30 stations. Thereafter, the zonal data were substituted in the model and matched with SSTA in the various sea domains. Empirical orthogonal functions (EOF) analysis was also applied. The above methods were used for 1998 and 2000 data sets, while another method, the ENSO composite/rainfall percentile method, was adopted in 1999. The second method gave an indication of whether rainfall will be below normal ($P<45$), normal ($45<P<55$), or above normal ($P>55$).

Results and Discussion

Generally, results for individual stations show good positive correlations between rainfall for stations in the southwest, up to latitude 10^o N, and equatorial Atlantic SSTA. The best forecast skill was obtained with April-May and May-June SSTA, giving a lead time of 1-2 months. Stations to the southeast up to latitude 10^o N had weak correlations with all predictions. Those to the north of latitude 10^o N showed some moderate correlations with July-August-September SSTA in Nino 3 and March-April EOF (see Table 4).

Although the efforts made so far to predict seasonal rainfall for the country using the SST have had some success, the limitation of the scheme is its inability to predict the onset, cessation, and amount of rainfall for the benefit of the farmers. However, the scheme in its present form is ideal for national planning. Since the ENSO composite/percentile method can be used as early as October of the preceding year, one can say that the SST prediction scheme is still very useful for the country's seasonal outlook.

Recent Progress: Remote Sensing/Geographic Information System (GIS)

One objective of the Nigerian Department of Meteorological Services' Information Technology Unit is the operational application of remote sensing to create information products. In view of the perceived advantages of remote sensing applications, the NDMS has acquired and is installing the following information technology equipment:

- personal computers, one of which is the server, an HP Vectra 6/233 MT series 6 with 128MB, a 6GB hard disk, 4 MB RAM, 1 HP T400es tape drive (external), and 1 HP Sure Store CD writer (internal);
- an HP Vectra 5/200 MHz computer with an HP Design Jet 750 Plus plotter and a Digitizer Calcomp Drawing Board III (12"x18");
- a PC/SAT-HRPT weather satellite system; and
- Image Analyst, Erdas Image Pro, Spatial Analyst, ArcView, and MS Office 2000 software.

Table 4. Skill and evaluation of seasonal rainfall forecast based on sea surface temperature (SST).

Year	Zone	Skill (%)	Forecast	Observed
1998	North	40	BN to N	N
	SW	20	N	N
	SE	40	N to ABN	ABN
1999	North	30	N	ABN
	SW	30	BN to N	N
	SE	40	AB	AB
2000	North	40	N	
	SW	20	BN to N	
	SE	40	N to ABN	

The use of this system, when operational, is expected to lead to an improvement in drought and environmental monitoring in the country. Remote sensing will be applied to monitor weather elements, measure components of the hydrologic cycle, and estimate crop yields. The system will produce regular products to support weather forecasting and hydrologic resources. Agricultural monitoring will also be supported by the system. These products will be produced on a regular basis and distributed to users.

Future Program on Long-Range Forecasting of Nino 3 and Associated Predictability of Nigerian Temperature and Rainfall

Objectives

We propose to use a robust modeling technique to identify and predict band limited cyclic components in a limited set of monthly SST and Nigerian rainfall and air temperature data. These data are available on the U.S. National Oceanic and Atmospheric Administration (NOAA) website and from NDMS. The correlation between SST and Nigerian temperature and rainfall will be determined for approximately 40 stations. For the Nigerian climatological stations, teleconnections between SST and monthly temperature and rainfall would indicate the usefulness of the former as a predictor.

The project products will include:

1. a written report summarizing the methodology,
2. predictability performance for the 3-year period (1999-2001), and
3. prediction for the period 2001-2003.

Methods and Procedure

If daily data for climatic variables such as air temperature and rainfall are averaged over a calendar month and the results plotted over many years, the plots will show interesting tendencies. Generally, temperature data will show a somewhat regular yearly cyclic pattern, while the rainfall data will be much more irregular in form, with a weaker cyclic pattern. When these seasonal cyclic patterns are estimated and removed from the data, all variables will show a random characteristic over the years, with no pattern immediately discernible. It is the purpose of this project to identify whatever cyclic patterns exist in the SST and Nigerian temperature and rainfall data.

Trends in cycles of climatic variables are difficult to understand, let alone predict. If the model to be developed can relate these trends to underlying physical processes in the atmosphere and ocean, then the understanding of this process will allow us to identify the predictable components of climate. A purely statistical model that excludes a priori knowledge of the physics of the problem is of limited value in identifying the predictable components of climate change. The model to be developed relies on an underlying physical climatic model, based on a nonlinear model of the earth/ocean/atmosphere system.

Although a portion of the spectrum of climatic data is band limited and quasi-cyclic, the problem of signal extraction and prediction in the presence of noise remains formidable. The problem is the nature of the noise. To extract a cyclic signal in the presence of these nonlinear noise components, a robust norm criteria will be adopted. Analysis of this type has been successfully applied in fields as disparate as seismic data analysis (Claerbout and Muir 1973) and medicine (Frome and Yakatan 1980).

As an example of the application of this type of robust prediction, we show both the observed and prediction set for Kano rainfall, based on data through December 1999. The prediction can be compared with the actual data from January 1999 to December 1999 (Figure 3). For the current year, 2000, the rainfall prediction calls for reduced, but not significantly different from normal, rainfall for Kano.

Justification

Multiple-year rainfall and temperature foresight capability is critical in developing a viable long-range early warning system. Drought and crop yields are functions of many variables, but are particularly dependent on certain key climatic factors. Drought or rainfall projections, however, have always been subject to uncertainty because of the difficulty in predicting specific climatic behavior. This project seeks to remedy this uncertainty by developing a climatic foresight model that can estimate trends of the associated climatic variables in a monthly time-step for upwards of 2-3 years into the future.

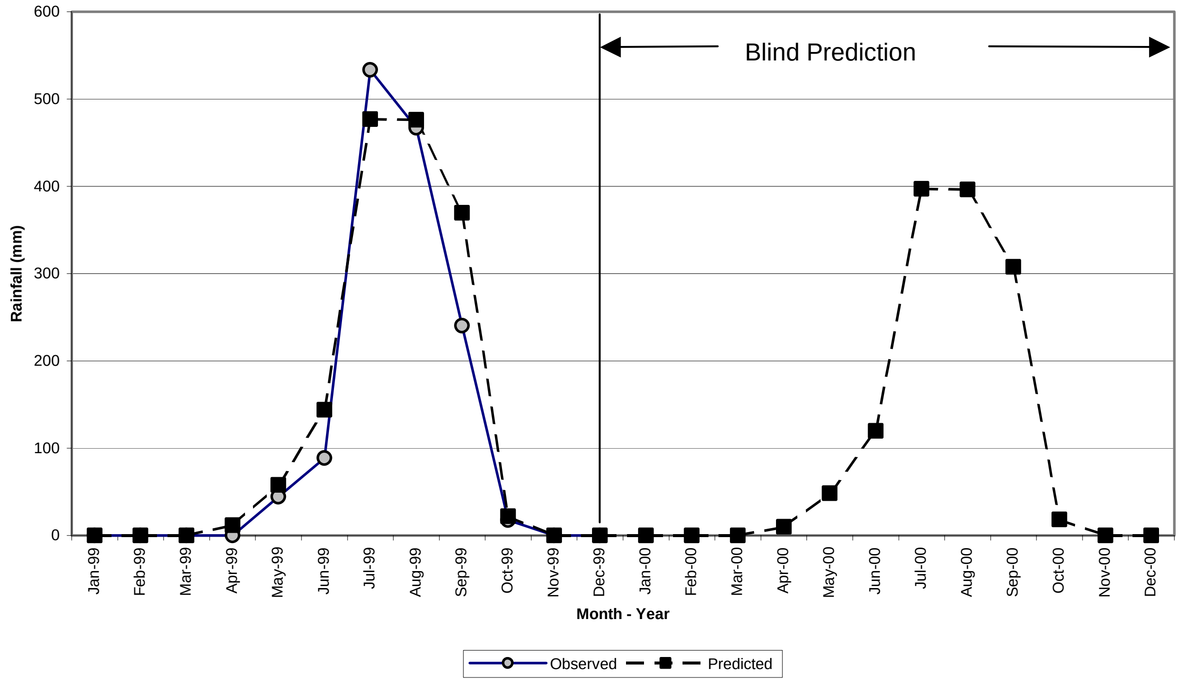

Figure 3. Observed versus predicted rainfall for Kano, Nigeria.

Conclusion

The users of EWS products include governmental organizations, media, agricultural industry, and the general public. There is evidence that these users believe that EWS products are relevant and useful in their work. For this reason, we are encouraged to continue finding the optimal level of implementing and improving EWS products in Nigeria.

Through this study we have now identified areas that are most prone to drought in Nigeria. These areas, located between latitude 10^{o} and 12^{o} N, experienced drought incidents in more than 15 of the last 40 years. The monitoring and prediction of drought in these areas is therefore necessary for preparedness and drought management.

Although predictions of onset, distribution, and cessation of the rainy season based on the NDMS prediction schemes described earlier were lower than observed in most cases, these predictions nevertheless proved useful as a planning tool. When used in combination with predictions based on SST, it is possible to increase the skill and usefulness of the predictions. We currently have and are acquiring equipment necessary for the smooth running of additional EWS models and operations. However, the major constraints we face are data quality and problems of station density.

References

Agnew, C.T. 1999. Using the SPI to identify drought. *Drought Network News* 12(1):6-11.

Claerbout, J. and F. Muir. 1973. Robust modeling with erratic data. *Geophysics* 38:826-844.

FGN, 1997. Drought management in Nigeria: What can people do to minimize its impact? Abuja, Nigeria.

FGN, 1998. Sustainable watershed management: An awareness publication of Federal Ministry of Water Resources & Rural Development, Abuja, Nigeria.

Frome, E. L. and G.J. Yakatan. 1980. Statistical estimation of the pharmokinetic parameters in the one compartment open model: Commun. Statis.-Simula. Computa.

Omotosho, J. A. 1999. Predicting monthly and seasonal rainfall, the onset and cessation of the rainy season in West Africa using only surface data. Accepted for publication in *International Journal of Climatology*.

Drought Tendencies in Mainland Portugal

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Abstract

Drought in Portugal is a phenomenon that affects some regions every year, with serious consequences to the economy. Any contribution to the understanding and prediction of drought conditions will be a step toward minimization of drought impacts. The purpose of this study is to characterize drought by using long time series of the Palmer Drought Severity Index (PDSI) in some stations of Portugal and short time series for the whole country. The time series are examined by means of graphic analyses and through a statistical test based on Szinell et al. (1998), with the main objective of featuring changes in drought occurrences: frequency, persistence, and severity in Portugal over the 20th century. With this test it can be shown whether drought events will tend to concentrate at the beginning or the end of the time series. For the stations in the southern part of Portugal, the results indicate that moderate, severe, and extreme droughts tend to concentrate near the end of the time series, therefore occurring with an increased frequency in the latest years.

Introduction

Drought is a natural phenomenon that usually is associated with a deficiency of rainfall from normal or expected amounts over an extended period of time. It occurs in many regions of the world every year, with serious damage to national economic structures, especially water resource, agriculture, and cattle breeding sectors. In extreme situations, it can also cause loss of human lives. This phenomenon is becoming more and more important at local, regional, and global scales, leading to increasing awareness at both scientific and political levels.

Long drought spells have already occurred in Portugal, with consequent damages to agriculture and water resources, especially in the southern part of Portugal. Gonçalves (1983) carried out a climatological analysis to determine the existence of drought spells and their duration and intensity, for a period of 29 years or more at 27 stations in Portugal, and detected the existence of 8 country-wide drought spells. Almeida (1981) describes a procedure to detect the occurrence of drought at some stations in the Portuguese mainland by means of the monthly rainfall amounts for the period 1857-1977.

Drought can be quantified by different indices, the Palmer Drought Severity Index (PDSI) developed by Palmer (1965) being one of the most commonly used. It was originally conceived as a meteorological index, expressing regional moisture supply, standardized in relation to local climatological norms (Briffa et al. 1994). It can detect the existence of drought spells (or wet spells) in time series, allowing the quantification of a full range of moisture conditions, from extremely wet to extremely dry. In spite of some limitations of the PDSI (Alley 1984), this method is implemented over all of the United States (Palmer 1965; Karl 1983), and more recently in Europe (Briffa et al. 1994).

In this study, the Palmer Drought Severity Index is computed in order to feature some changes in drought tendencies, subsequently analyzing the persistence and severity of drought in mainland Portugal.

Climate Profile in Mainland Portugal

The climate over mainland Portugal is temperate, and variation in climate factors is small, although it is still sufficient to explain significant variations in the elements that are most characteristic of the climate (i.e., air temperature and precipitation amount).

Air Temperature

The lowest values of the mean annual air temperature (based on observations between 1961 and 1990) are in the northern part of the country, with a minimum around 7º C over the highlands of central Portugal, and the highest values are in the southern part, with a maximum of 18º C in the southern coastal region. This distribution shows a significant difference between northern and southern Portugal.

A statistical analysis of long-term climatological series of air temperature over mainland Portugal for the period 1931-99 can be seen in Figure 1. It shows the variability of the regional average of the mean annual temperature. For the last 30 years, there has been a trend toward an increase in the mean annual temperature, 1997 being the hottest year recorded since 1931, with 1.58º C above the 1961–90 normal.

The mean temperature anomalies with respect to 1961–90 for the last 20 years (Figure 2) show that the 6 hottest years ever recorded occurred in the last 11 years.

The mean annual maximum and minimum temperature (Figures 3a and 3b) show an increasing trend over the last 20-30 years. In fact, 1999 is the last of 13 consecutive years in which the minimum temperature reveals positive anomalies with respect to the 1961–90 mean. The year 1997 presents the highest maximum temperature since 1931, with 1.67º C above the 1961–90 normal.

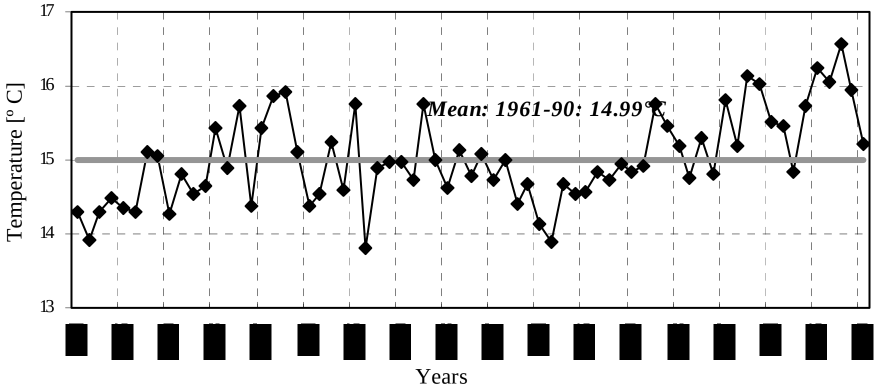


Figure 1. Variability of the regional average of the mean annual temperature in mainland Portugal for the period 1931-99.

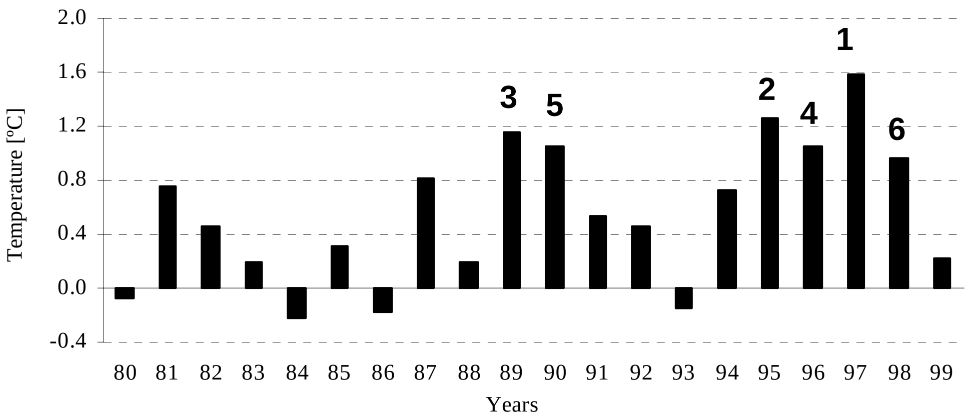
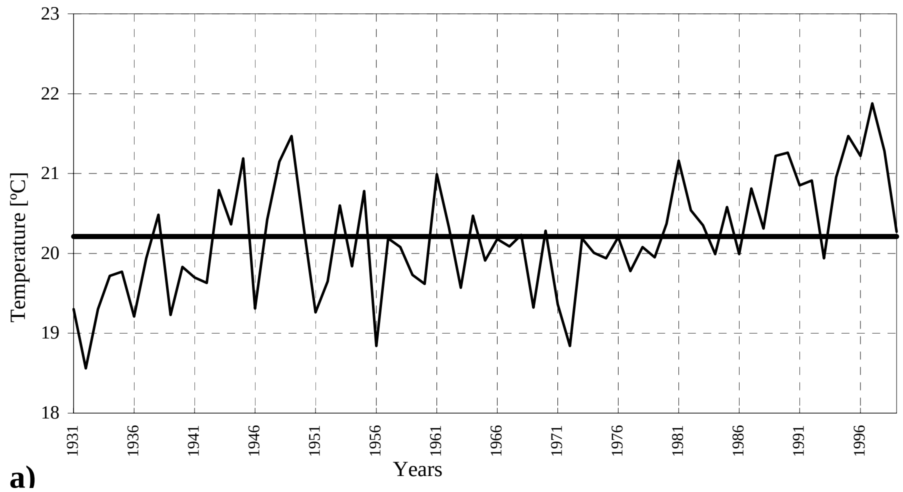


Figure 2. Mean annual temperature anomalies with respect to 1961-90 for the last 20 years.

Precipitation

The mean annual precipitation on mainland Portugal is around 900 mm, with the highest values (around 3,000 mm) in the highlands of the northwestern region, and the lowest values (around 500 mm) in the inner regions of the south. Also in this distribution, a significant difference can be seen between northern and southern Portugal.

The variability of the regional amount of annual precipitation (Figure 4) shows that in only 5 of the last 20 years, the precipitation values were above the mean for 1961-90. It can be observed that, in the last 20 years, precipitation values were abnormally below the mean between 1990 and 1994.



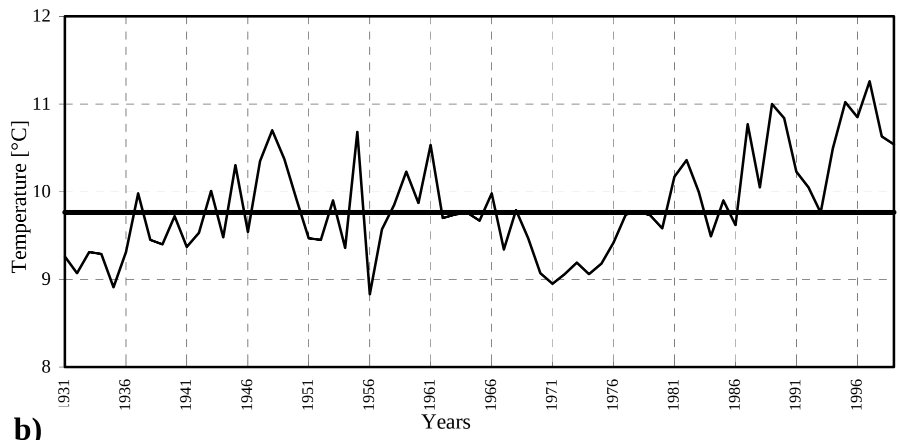


Figure 3. Variability of the regional average of the mean annual maximum (a) and minimum (b) temperatures in mainland Portugal for the period 1931-99.

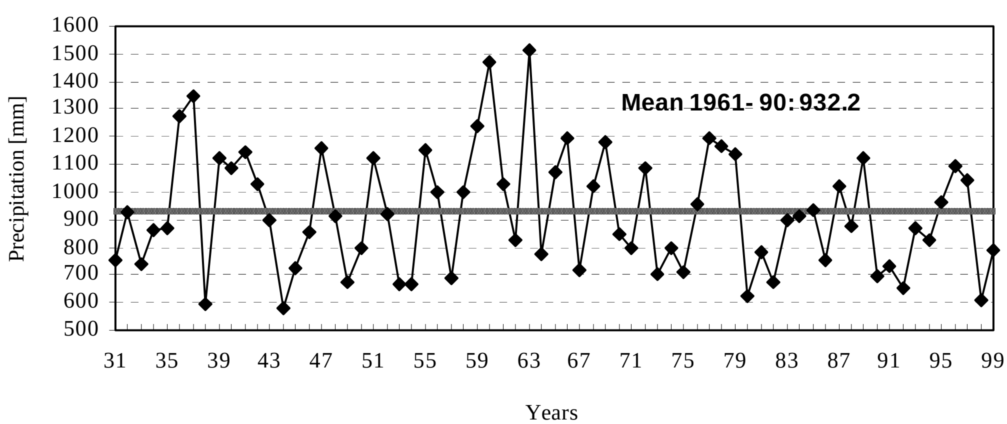


Figure 4. Variability of the regional average of annual precipitation in mainland Portugal for the period 1931–99. The mean for 1961–90 is 932.2 mm.

An analysis of Figure 5 for the period of 1931–99 shows a significant decrease in the precipitation amount in spring during the last 30 years. This decrease is essentially because of lower precipitation in March (Figure 6).

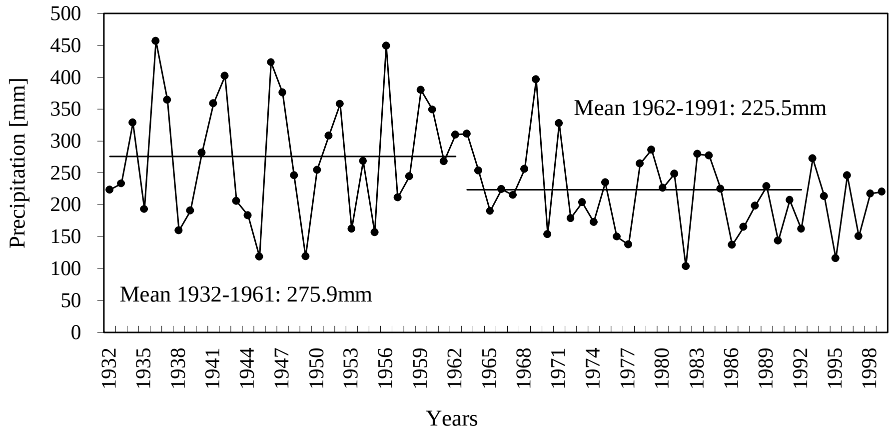


Figure 5. Variability of the regional average of annual precipitation in spring, 1932-99.

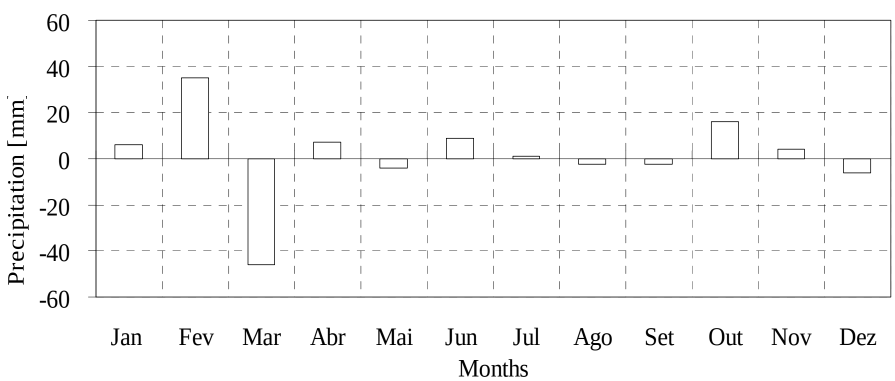


Figure 6. Variation of average monthly values for the 1961-90 period in comparison with the 1931-60 period.

Synoptic Situation

Mainland Portugal is located in the transitional region between the subpolar depression zone, which affects mainly the northern regions of the country, and the subtropical anticyclone, which affects mainly the southern regions (Figure 7). Under these conditions, it can be stated that in general there is a trend for droughts to occur more frequently in the southern part of mainland Portugal than in the north.

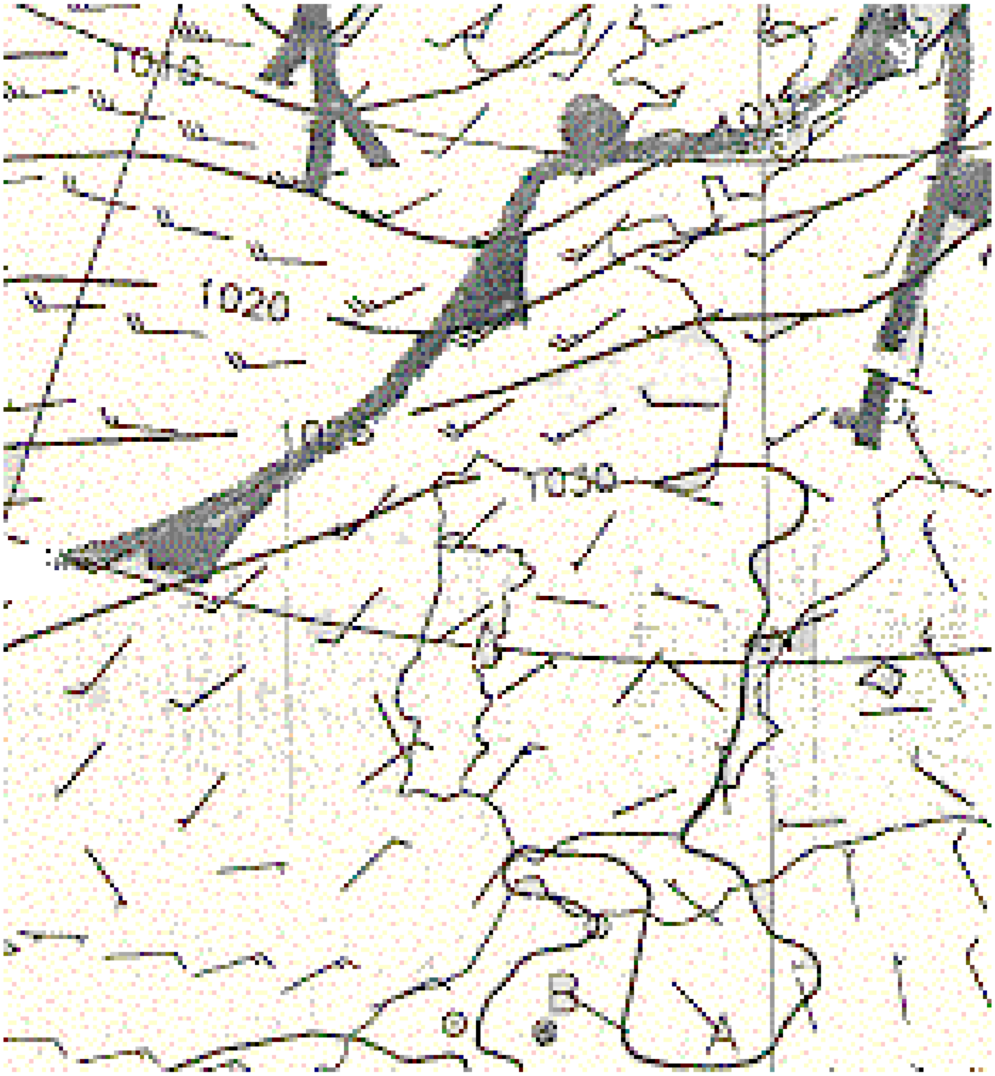


Figure 7. Synoptic conditions that frequently occur in mainland Portugal: a cold front affecting the northern regions and a ridge affecting the southern regions.

Data and Methods

The PDSI is a meteorological index that represents a range of climate conditions from "abnormally dry" to "abnormally wet" (I.C.I.D. Guide 1998). In the calculation procedure, a hydrological accounting is used, which compares the soil moisture content with the climatological mean, based on the supply-and-demand concept of the water balance equation. For the calculation of the monthly PDSI values, monthly temperature means and precipitation sums are needed. Another parameter that is needed is the available soil water capacity, which varies from region to region, depending on the characteristics of the soil.

The calculation procedure of the Palmer Drought Severity Index is well described in papers by Palmer (1965), Alley (1984), and Briffa et al. (1994). Palmer (1965) defined threshold values of PDSI for drought spells, given as follows: PDSI values between -2.0 and -3.0 refer to a moderate drought; between -3.0 and -4.0, a severe drought; and below -4.0, an extreme drought. In the case of wet spells, the range values are 2.0-3.0, 3.0-4.0, and above 4.0 for moderate, severe, and extreme wet conditions, respectively. To calculate the PDSI, historical time series of monthly temperature means and precipitation sums were used for the stations listed in Table 1. The temperature and precipitation data for the long time series from those stations were examined and showed no inhomogeneities.

Table 1. Stations of Portugal with the long time series. *The series contain values up to April 2000.

	Latitude (N)	Longitude (W)	Height (m)	Period
Oporto	41º 08'	8º 36'	93	1922–2000*
Lisbon	38º 43'	9º 09'	77	1883–2000*
Evora	38º 34'	7º 54'	309	1888–2000*
Beja	38º 01'	7º 52'	246	1901–2000*

The PDSI was also calculated for the whole country, by using monthly temperature means and rainfall amount sums measured at stations all over the country for the period 1931-99.

A statistical test was applied to the PDSI time series, with the purpose of finding changes in drought tendencies, especially in the temporal distribution through the time series. This test is based on the test used in Szinell et al. (1998), which was applied to PDSI series of Hungarian stations. It was developed to study normal and extreme climatic features through the thresholds established by Palmer (1965) for moderate, severe, and extreme droughts. The test is suitable for detecting an increase in the frequency of threshold events: if there is a trend in the occurrence, drought events will concentrate at one end of the time series (Szinell et al. 1998).

Analysis of the Results

Analysis of PDSI Values

Long Time Series

Monthly PDSI values have been calculated from 1871 (for the longest time series) to April 2000. The number of occurrences for moderate, severe, and extreme drought was obtained (Figure 8), as well as the corresponding percentage relative to the total number of months. Figure 8a shows the values for the complete time series and Figure 8b shows the values only for 1922-2000 (Oporto), allowing comparison of the 4 stations in that period. Oporto has the smallest percentage of droughts in all the categories, showing a difference in climate conditions relative to the other 3 stations.

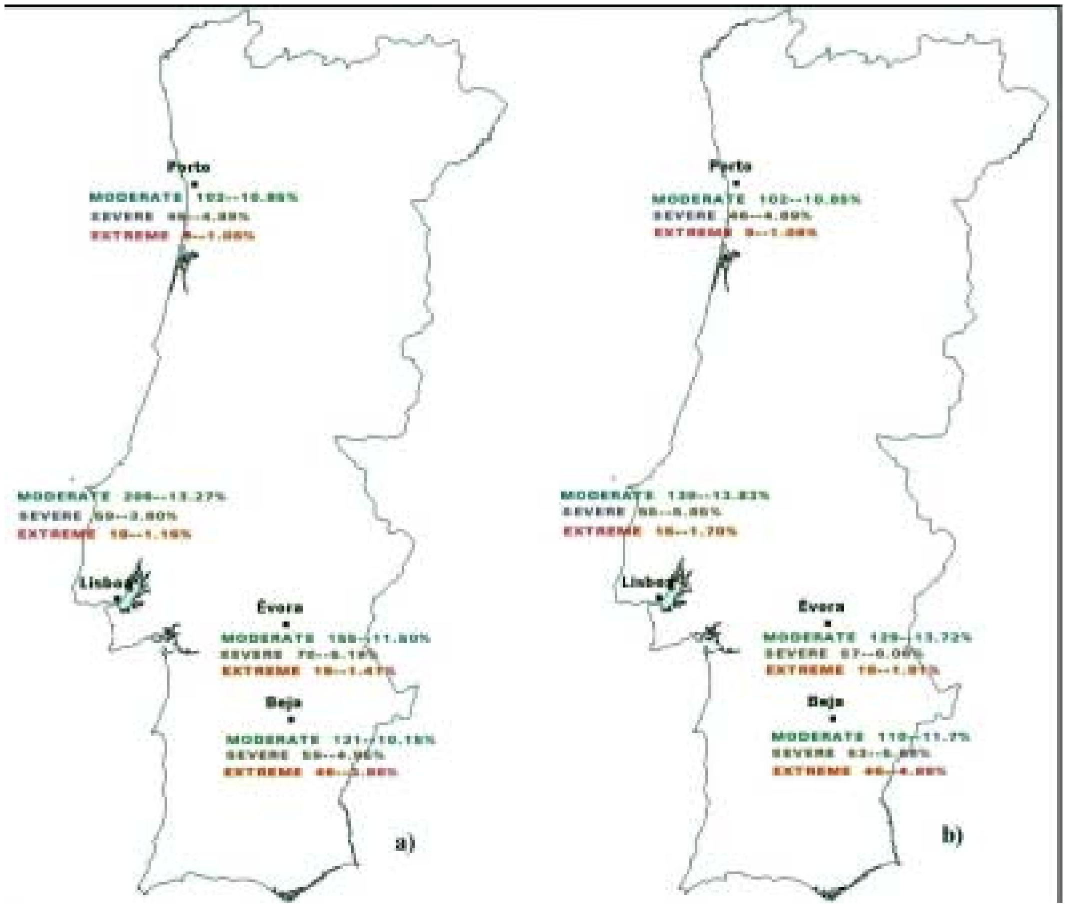


Figure 8. Number of occurrences and percentage of moderate, severe and extreme droughts in Beja, Evora, Lisbon, and Oporto (a) for the complete time series and (b) for the period of the smallest time series (Oporto 1922-2000).

Figure 9 shows the normalized cumulative PDSI for the longest time series, in which we can observe the evolution of the PDSI over the years, allowing us to detect periods of continuous drought as well as wet spells. For example, starting with Beja it can be seen that, until 1930, no long drought periods occur, only short ones, revealing a tendency for normal conditions. After 1930, cumulative PDSI values decrease considerably, indicating a long drought spell. This period continues until about 1960, only interrupted by a wet spell between 1940 and 1943 and some annual wet spells. A long period of drought can be seen in the 1930s, followed by the wet spell mentioned before. After that and until 1960, the cumulative PDSI continuously decreases, with some annual wet spells. Between 1960 and 1980, no long drought spells are observed, with a small exception in the mid 1970s. After 1980, the cumulative PDSI values continuously decrease, indicating a tendency for an increase in drought spells, but with a short duration. A drought spell of almost 3 years just after 1980 is the exception.

For the station of Lisbon in the first years, until about 1900, no long periods of drought occur and the cumulative PDSI values increase slightly, which shows a small prevalence of wet spells.

After 1901, a resemblance between the data for Beja and Lisbon can be observed. The long drought spells occur near the same years. Around 1930 the cumulative PDSI values decrease sharply, being interrupted by a long wet spell after 1940. It can also be noticed that, in Lisbon, after the strong increase in cumulative wet spells between 1960 and 1980, the trend toward a continuous decrease in cumulative PDSI values, associated with drought spells, is also present.

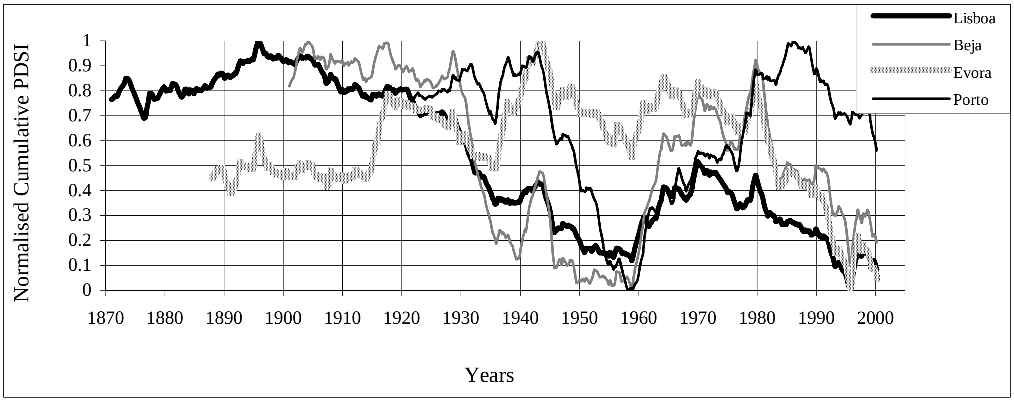


Figure 9. Normalized cumulative PDSI values for Beja, Lisbon, Evora, and Oporto.

The cumulative PDSI in Evora is different from that of Lisbon and Beja, but the main features are easily identified: a period between 1918 and 1935 where the cumulative PDSI decrease (high frequency of drought spells), followed by a wet spell, longer than in Beja and Lisbon. After 1980, a strong decrease in cumulative PDSI can be observed, with a small wet spell near the end, in the same position as in the time series for Beja and Lisbon.

The cumulative PDSI in Oporto is completely different from the other stations. A period of drought in the 1930s is followed by a wet spell and a stable period until 1944; then a long period of drought, interrupted only by small wet spells, can be observed until 1960. An inversion of the cumulative PDSI values (wet spells) lasts until the end of the 1980s, where a small increase in drought spells is registered until the end of the series.

In general, it can be seen that although some differences exist, the shape of the curves reveals the same pattern.

The Entire Country

The data series for the entire country (Figure 10) is shorter (1931-99), but some of the main features shown by the cumulative PDSI values in Lisbon, Evora, and Beja can be seen (Figure 9): the increase in cumulative PDSI values just before 1940 (wet spells) and a change in the trend in 1943 (drought spells); the increase in cumulative PDSI values around 1978 (wet spells) and a change in the trend in 1980 (drought spells); a similar annual cumulative PDSI value variation from 1980 to the end of the time series.

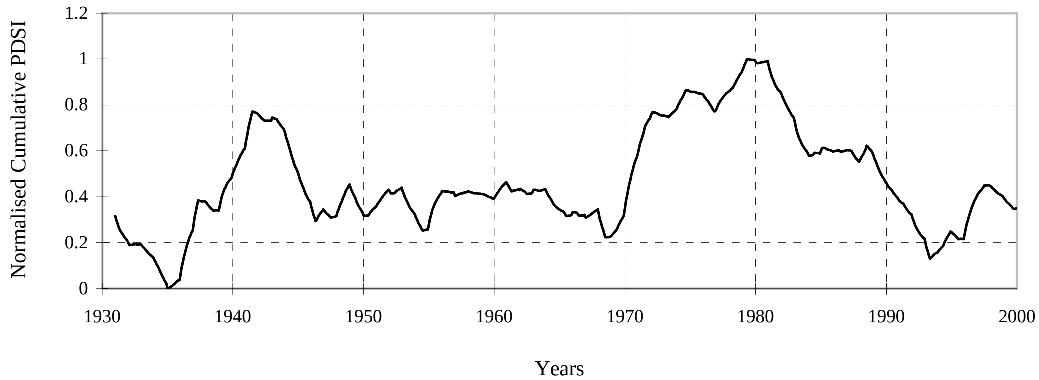


Figure 10. Cumulative PDSI values for Portugal for the period 1931-99.

Statistical Test

The statistical test is based on the Wilcoxon test (Szinell et al. 1998). It was applied to monthly PDSI series from the four stations of Portugal with the longest series and to the whole country on a monthly basis. The results are presented in Table 2, where the N column contains the number of months in which drought of that category occurred and the Test column represents the results of the statistical test.

Table 2. Results of the statistical test applied to the longest time series for four stations in Portugal and to a time series for the whole country.

	Moderate		**Severe**		**Extreme**	
	N	Test	N	Test	N	Test
Oporto	175	0.803	57	0.889	9	1.118
Lisbon	283	2.842	77	6.316	18	2.497
Evora	244	6.968	89	5.287	19	4.024
Beja	229	3.037	105	3.929	46	4.586

The statistical test implemented by Szinell et al. (1998) indicates whether the occurrence of drought in the given category tends to concentrate at the beginning or the end of the time series. Positive numbers correspond to a greater frequency in later years; a greater value (positive) means a larger number of drought spell occurrences near the end of the time series. Tests made for different periods of the PDSI series in which the drought trends were different confirmed these results.

In evaluating the tendencies of moderate, severe, and extreme droughts in the four stations, it can be observed that in Beja, Evora, and Lisbon, the results indicate that, generally, in some of the categories the droughts occurred more frequently just near the end of the time series. In Oporto, a station in northern Portugal, where drought does not occur as frequently as in the south (Figure 8), no well-defined tendency can be observed in moderate and severe droughts.

In Beja it can be seen that, although only extreme drought occurred more frequently in the second part of the series, there is also a trend for moderate and severe droughts to occur near the end of the series rather than at the beginning.

These statistics for extreme droughts are significant at the 1% level (Mann-Kendall test), except in Oporto, where the limited number of extreme droughts provides little information.

Figure 11 shows the percentage of monthly cumulative PDSI values below the three categories of drought for Beja, Lisbon, Evora, and Oporto. This figure shows the evolution of the PDSI for the different drought categories over the years. On this percentage scale, we can detect periods where the different categories of drought were more intense and periods were no droughts have occurred. In Beja (Figure 11a), 50% of the extreme droughts occur after 1980 (i.e., in the last 20 years of the 100-year series). For moderate and severe droughts, only about 10% of the occurrences were recorded in the first 20 years, while more than 20% occurred in the last 20 years. The long period of droughts in the intermediate region of the series (1930s and 1940s) does not allow us to conclude whether this is abnormal behavior for moderate and severe droughts. However, in the case of extreme droughts, it can be concluded that there is a trend for droughts to be more severe.

In Lisbon (Figure 11b), moderate drought events do not appear to show any special trend over the whole time series, except for a small increase in the 1930s and 1940s. The distribution of the drought events in both halves of the series is approximately equal, causing the test to provide a small value. In the 1930s and 1940s, a sudden increase in severe and extreme droughts was also detected. After a period of more than 30 years, between 1945 and 1978, with almost no severe and extreme drought events, a sudden increase in these events was detected in the last 20 years of the 130-year series, causing the test to provide high values. At the end of the time series, the increase in the drought trend is thus mainly due to severe and extreme droughts.

In Evora (Figure 11c) for all the drought categories, the 50% threshold is achieved in the second part of the time series, with special evidence of an increase in severe and extreme drought.

In Oporto (Figure 11d) for all the drought categories, two distinct periods can be observed: the first half of the time series contains a large percentage of droughts, and the last 10 years show a strong increase in severe and extreme droughts, balancing the test values and causing the test to provide small positive values. However, for extreme drought, the result provides little information, because there is a limited number (9) of droughts in that category.

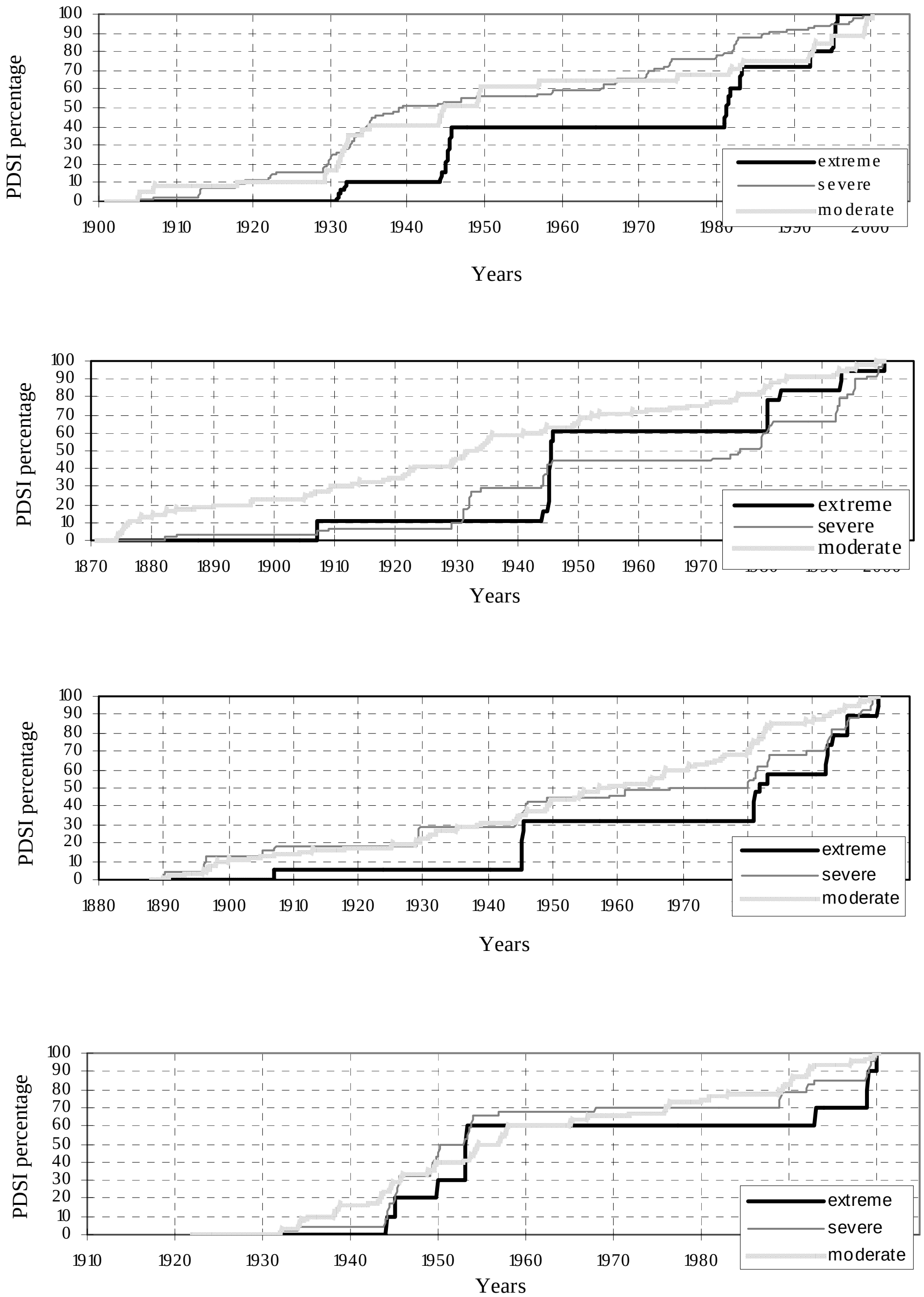


Figure 11. Cumulative percentage of PDSI values for moderate, severe, and extreme droughts: (a) Beja; (b) Lisbon; (c) Evora; (d) Oporto.

Conclusions

This chapter presents an analysis of the PDSI values for the longest time series of some stations in mainland Portugal as well as for the entire country. A statistical test was applied to the PDSI values to characterize the different categories of drought severity (moderate, severe, and extreme). This allows us to identify a trend in the frequency of those different categories along the time series. Of all the drought spells that occurred in Portugal, the percentage of those recorded in Oporto (northern Portugal) was lower than the percentages in Lisbon, Beja, and Evora (southern Portugal).

In the longest time series (without Oporto), two different periods of high occurrence of drought spells are detected: the 1930s and 1940s, and the last 20-year period. The statistical test shows an increase in severe and extreme drought spells at the end of the time series (the last 20 years), indicating that there is a trend for droughts to become more severe in Beja, Lisbon, and Evora. In Oporto, the droughts become more severe only in the last 10 years. For the analysis of mainland Portugal, the time series is shorter (1931-99), and the two different periods of high occurrence of drought spells mentioned above were also detected.

A larger number of stations covering the entire country by administrative regions must be analyzed using the PDSI series as well as other indexes, in order to confirm the different climate conditions in the various Portuguese regions, namely the difference between northern and southern Portugal, and also to confirm that in the last two decades there is a trend toward the occurrence of severe drought spells.

References

Alley, W.M. 1984. The Palmer Drought Severity Index: Limitations and assumptions. *Journal of Climate and Applied Meteorology* 23:1,110-1,109.

Almeida, M.R. 1981. Períodos de seca em Portugal Continental. *Revista do Instituto Nacional de Meteorologia e Geofísica* 4:27-56.

Briffa, K.R., P.D. Jones, and M. Hulme. 1994. Summer moisture variability across Europe, 1892-1991: An analysis based on the Palmer Drought Severity Index. *International Journal of Climatology* 14:475-506.

Gonçalves, M.Z. 1982. Contribuição para o estudo das secas em Portugal. *Revista do Instituto Nacional de Meteorologia e Geofísica* 5:35-118.

I.C.I.D. Guide. 1998. How to work out a drought mitigation strategy by Laszló Vermes. *ICID* Guidelines 309. DVWK, Bonn, Germany.

Karl, T.R. 1983. Some spatial characteristics of drought duration in the United States. *Journal of Climate and Applied Meteorology* 22:1,356-1,366.

Palmer, W.C. 1965. Meteorological drought. U.S. Weather Bureau Research Paper No. 45. U.S. Weather Bureau,Washington, D.C.

Szinell, C.S., A. Bussay, and T. Szentimrey. 1998. Drought tendencies in Hungary. *International Journal of Climatol*ogy 18:1,479-1,491.

Drought Monitoring in Hungary

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Abstract

The tools of the drought monitoring system used at the Hungarian Meteorological Service (HMS) are discussed in this chapter. A short description of the climate of Hungary is given. The status of seasonal forecasting is discussed in more detail, and a verification case study is presented. The mapping technique applied at HMS is examined. Research on drought indices, their trends, and the combined use of meteorological and hydrological indices is described. Recommendations for future work and cooperation are also presented.

Introduction

We do not mention Europe among the areas of the world most damaged by drought. However, drought is a quite frequent natural disaster in the Mediterranean region and the Balkan peninsula, and it does occur in different parts of the continent--for example, in the northern part in 1999, and in central Europe in 2000.

Hungary is situated in the Carpathian Basin. Its climate is determined mainly by the large-scale circulation patterns of maritime, continental, and Mediterranean air masses, modified by the topography of the basin. This is expressed in increased sunshine, less precipitation, diminished winds, greater amplitude of daily and yearly temperature variation range, and great spatial variability of precipitation (annual mean maximum is 879 mm, minimum is 453 mm). The mean annual temperature is about 10°C and exhibits a zonal pattern modified by the altitude. The distribution of precipitation over Hungary is uneven, as is apparent from Figure 1. The most humid parts of the country, in the west, receive somewhat less than 900 mm of rain per year, about twice the precipitation of the driest areas in the Hungarian Plain, which is the most important agricultural area of the country. In the Hungarian Plain, climate is characterized by a tendency for dryness and insufficient rain for agriculture during summer months. The highest monthly precipitation values are recorded in June (60-90 mm), and February is the driest month. Although monthly precipitation can exceed 100 mm or sometimes even 200 mm in any month, it is also possible that no monthly precipitation may be recorded at any given time of the year. The growing season (April-September) exhibits even larger variations in monthly precipitation sums.

Drought is a recurrent feature of Hungary's climate and can cause substantial damages to the nation's agriculture. Dunay and Czakó (1987) note that 36% of all agricultural losses are caused by drought, followed by hail, floods, and frosts, in order of importance. In the period from 1983 to 1995, every year, with the exception of 1987, 1988, and 1991, was a drought

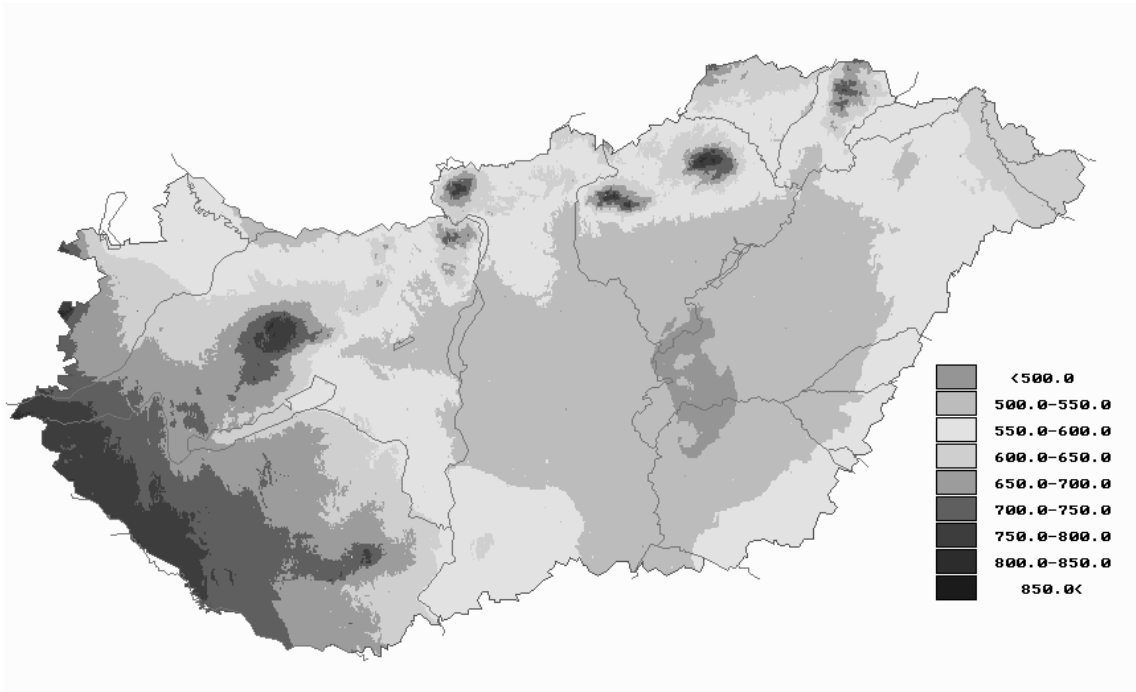

Figure 1. Mean annual precipitation in Hungary.

year. This long drought series was unprecedented in the 20th century in the region and comparable in length only to the 10-year period from 1943 to 1952 or in severity to the 1779-94 drought event (Gunst 1993). Because 8 of the 12 years were disastrous drought years, this eries of dry years has increased scientific and political interest in climate variability and climate change and the importance of drought as an extreme meteorological event.

Measuring Network

The largest national meteorological observing networks in Europe are operated by (hydro)meteorological services. Providing general data access is difficult, because of the combined financing systems of these institutes; budgets are partly governmental, partly commercial.

The national meteorological observing networks operate according to WMO recommendations. Another benefit of this system is that the hardware (sensors, data loggers, etc.) are the same throughout the network. This ensures that the data is measured, managed, and quality controlled in the same way. Here we have to point out the importance of quality control: different methods could lead to different results, even in the case of similarly measured data.

HMS's automated weather stations make measurements every 10 minutes, and most of the data are collected from the stations hourly. Therefore, most of the information is available in quasi-real time. HMS operates about 100 automated weather stations and more than 500 precipitation gauges throughout Hungary's 93,000 km^2. Figure 2 shows that these stations are evenly

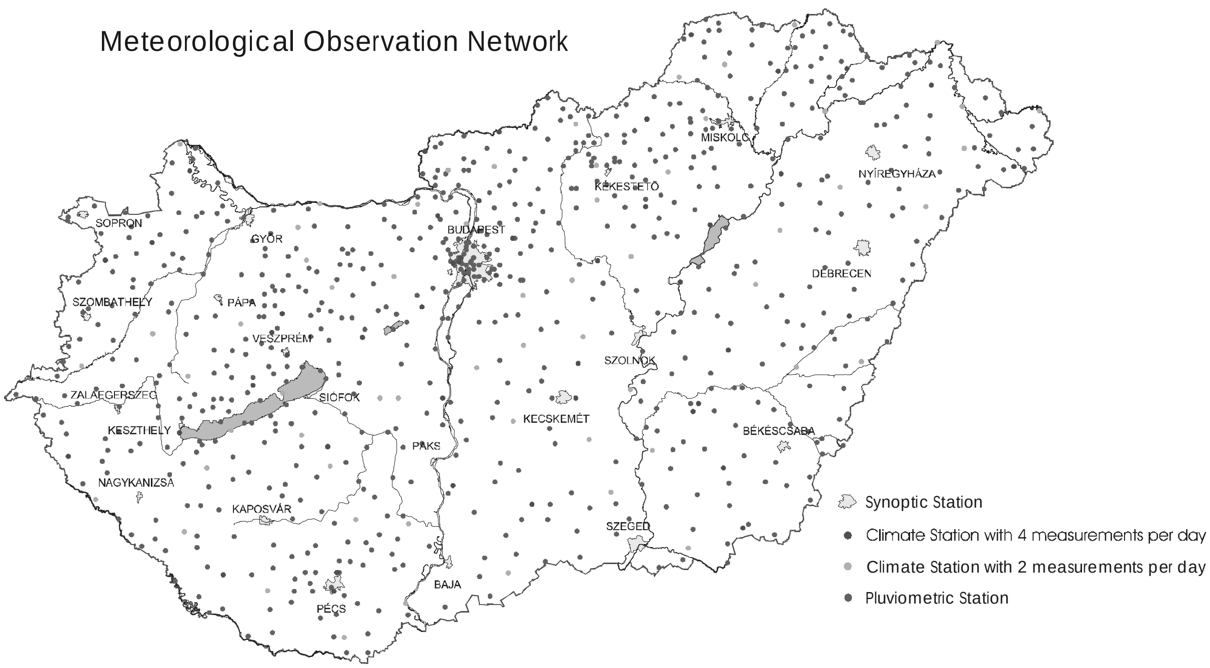

Figure 2. Meteorological Observation Network of HMS.

distributed. The main problem in the distribution of stations is that the mountainous areas have significantly fewer stations.

Long-Range and Seasonal Forecasts

One-month to one-year forecasts are based mostly on El Niño throughout the world. The investigations in this field do not support the existence of a simple teleconnection system of ENSO for Europe.

At the Hungarian Meteorological Service, an operational statistical (analogue) technique for long-range forecasting was developed and has been used for 20 years. The forecasts are generated for 6 months ahead. Temperature and precipitation forecasts are produced as one-month average values for 10 Hungarian towns. These forecasts have been issued on a monthly basis.

In 1998, we started to investigate the applicability of the European Centre for Medium Range Weather Forecasting's (ECMWF) dynamical seasonal forecasts for the Hungarian territory. These forecasts are available on the ECMWF's website for three overlapping 3-month periods, and they have been generated in every month. Forecasts of precipitation, surface air temperature, and mean sea level pressure are available both as ensemble mean anomalies and as probability plots. Sea surface temperature fields are available as ensemble mean anomalies only. We are developing programs for automatic data-reading from the forecasted fields, automatic data processing, and verification.

Verification Procedures

Ten Hungarian synoptic stations (Budapest, Győr, Sopron, Szombathely, Siófok, Pécs, Szeged, Békéscsaba, Debrecen, Miskolc) are evenly distributed over the country (Figure 3). We investigated surface air temperature and precipitation predictions, and we verified both ensemble mean anomalies and probability fields.

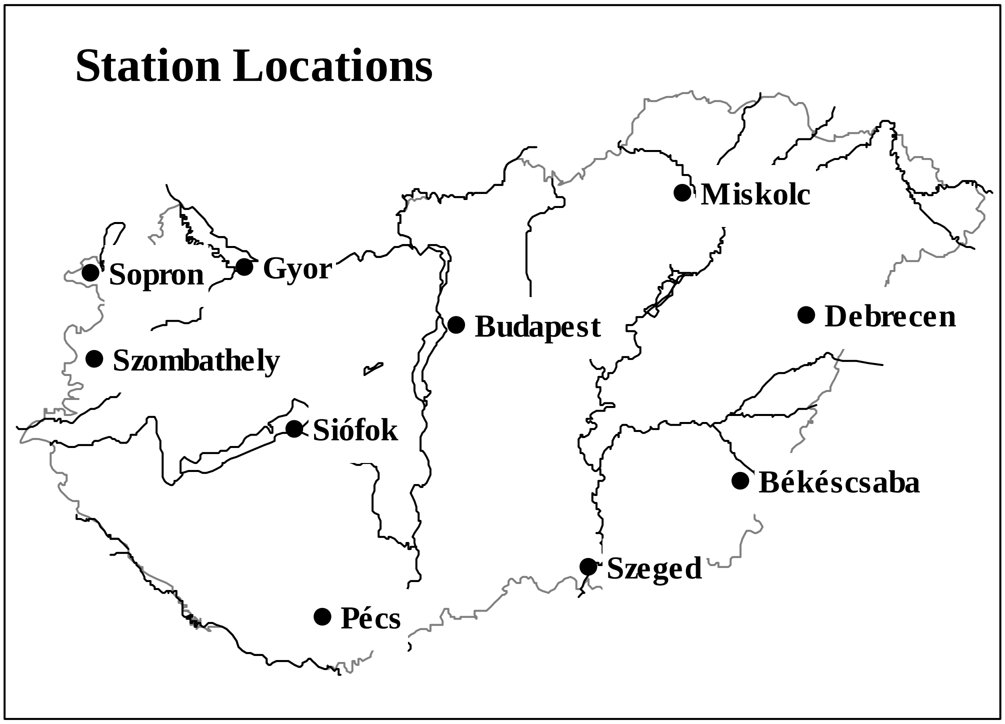

Figure 3. Stations used for the verification of ECMWF seasonal forecasts.

In the case of verification of ensemble mean plots, we used three categories (Table 1).

Table 1. Categories used in verification of ensemble mean plots.

Below normal	$\Delta T<-1K$	$\Delta P<-50mm$
Normal	$-1K<\Delta T<1K$	$-50mm<\Delta P<50mm$
Above normal	$1K<\Delta T$	$50mm<\Delta P$

The results of the verification for the period March 1998–December 1999 are shown in Table 2.

Table 2. Temperature/precipitation forecast verification for March 1998-December 1999.

	2-4 Months	**3-5 Months**	**4-6 Months**
Temperature forecasts	71%	65%	68%
Precipitation forecasts	52%	52%	52%

Probabilistic skill has been assessed by the use of the Relative Operating Characteristic (ROC). ROC values are suited to the comparison of the two different forecasts. The ROC scores were obtained at all 10 stations for the temperature and precipitation events that are above normal. The ROC values for the 10 stations are shown in Tables 3 and 4. The value 1 corresponds to a perfect forecast; values below 0.5 mean no skill. Climatological forecasts offer no skill. It can be seen that the skills of temperature forecasts, especially in the western part of Hungary, are promising.

Table 3. Skills of probabilistic temperature forecasts for the period March 1998-December 1999.

	2-4 Months	**3-5 Months**	**4-6 Months**
Sopron	0.74	0.51	0.43
Szombathely	0.74	0.52	0.43
Győr	0.73	0.57	0.50
Siófok	0.50	0.38	0.34
Pécs	0.58	0.43	0.54
Budapest	0.51	0.43	0.39
Miskolc	0.60	0.44	0.34
Szeged	0.63	0.55	0.52
Debrecen	0.47	0.44	0.36
Békéscsaba	0.57	0.45	0.50
Country wide mean	**0.61**	**0.48**	**0.44**

Table 4. Skills of probabilistic precipitation forecasts for the period March 1998-December 1999.

	2-4 Months	**3-5 Months**	**4-6 Months**
Sopron	0.56	0.56	0.38
Szombathely	0.59	0.55	0.43
Győr	0.57	0.57	0.38
Siófok	0.57	0.50	0.60
Pécs	0.61	0.50	0.57
Budapest	0.61	0.54	0.57
Miskolc	0.55	0.55	0.53
Szeged	0.47	0.43	0.43
Debrecen	0.53	0.56	0.56
Békéscsaba	0.56	0.56	0.53
Country wide mean	**0.56**	**0.53**	**0.48**

Drought Prediction

Another method of drought prediction used in Hungary was developed by Pálfai (Pálfai et al. 1998). This method calculates the possible situations until the end of the year under given conditions. A scenario-like calculation of drought is based on springtime conditions and three climatologically calculated scenarios (wet, normal, and dry) for the whole year. For a more effective calculation, the so-called Pálfai drought index was developed.

Yield Estimation

Two institutes develop yield estimation systems in Hungary. One system is based on the use of the NDVI index. The other is based on surface meteorological elements. Both systems are operational, but they are still primarily in the testing phase.

Climatological Scenarios

Climate Changes in the 20th Century in Europe

Many studies have investigated the current trends of climate variability. Herewith, we mention the study of the European Climate Support Network (ECSN 1995) for the climate of Europe. Data up to 1990 were used. The results show that almost all European stations experienced warming during the 20th century in what may be partly an urbanization effect. In the first part of the century, to around 1940, a warming trend occurred, followed by a cooling trend to the present. Relative cooling is found over the eastern Mediterranean, with another cold anomaly over the North Atlantic and Greenland. Long-records show that, at least in central and northern Europe, the temperature distribution in Europe around 1990 was at about the same level as it was 200 years ago.

Over the last century, an overall increase in precipitation can be observed over northern Europe, except Finland, where conditions are relatively unchanged, and southern and central Europe, where precipitation is decreasing or unchanged.

The last decade (1981-90), compared to 1951-80, shows general drying over much of southern Europe and large parts of northern Europe, with Scandinavia in contrast, becoming relatively wetter.

Climate Change Predictions

The following discussion of climate change prediction is based on the recent study of the Hadley Center.

With unmitigated emissions, global average temperature is predicted to increase by 3° C by the 2080s. Under this scenario, land areas would warm twice as fast as oceans, and winter high latitudes are also expected to warm more quickly than the global average, as are areas of northern South America, India, and southern Africa. Large changes in precipitation, both positive and negative, would be seen, largely in the Tropics. Large changes are also predicted in the availability of water from rivers. Substantial decreases would be seen in Australia, India, southern Africa, most of South America and Europe, and the Middle East. Increases would be seen across North America, Asia (particularly central Asia), and central eastern Africa.

Water resource stress due to climate change by the 2080s is predicted to worsen in many countries (for example, in northern Africa, the Middle East, and the Indian subcontinent), but will improve elsewhere (for example, in China and the United States). Overall, about 3 billion people will suffer from this increased water stress. Reductions in emissions leading to stabilization at concentrations of 550 ppm CO_2 would reduce this number to about 1 billion. Stabilization at 750 ppm has little effect on the total.

By the 2080s, climate change and CO_2 increases due to unmitigated emissions are estimated to increase cereal yields at high and mid latitudes, such as North America, China, Argentina, and much of Europe. At the same time, cereal yields in Africa, the Middle East, and, particularly, India are expected to decrease.

Spatial Interpolation

The AUREHLY method is the most frequently used method at HMS. This method was developed at the French Meteorological Service by Benichou and Le Breton (1987). This two-step method first describes the meteorological field as a function of the land surface via multiple linear regression equations. Second, the resulting surface of differences between the calculated and measured meteorological values is smoothed by ordinary kriging.

Simple regression is normally applied for site elevation. Therefore it is beneficial to apply multiple regression, since it can also account for other surface characteristics, provided that the given surface is depicted by principal component analysis.

The product surface S(x,y,T) is determined by the following formula:

$$S(x,y,T) = S(T) + ß(x,y),$$

where S(T) is determined by the orography via multilinear regression and ß(x,y) is the residual smoothed by kriging.

For calculations, a digital map of Hungary has been used with about 1 km x 1 km resolution. Each grid point was characterized by its elevation and the elevation differences between the central point and 120 neighboring points (on an 11 x 11 grid section). Therefore each grid was assigned 121 data values. This immense amount of information has been condensed by principal component analysis; thus the grid points are represented by their elevation and the appropriate values of the first 15 principal components, which account for about 90% of the orography variance, preserving sufficient accuracy.

The first five principal components (PC) can easily be interpreted geometrically:

PC1 indicates peaks (positive values) and valleys (negative values)

PC2 indicates east-west slopes
PC3 indicates north-south slopes
PC4 indicates north-south saddle
PC5 indicates northeast-southwest saddle

The next step is to develop relationships between the surface structures and meteorological fields. In determining the multilinear regression, the observation locations and the nearest grid points formed data pairs. Five principal components revealing the strongest simple linear regressions with observations were chosen and included in developing the multilinear regression equation.

After determining S(T), this function was applied to estimate the value of the meteorological element at the observation location, and the differences between estimated and measured values were calculated. These discrepancies were interpolated by kriging. The calculations are made by a program prepared by FAO (Bogaert, Mahau, and Beckers 1995).

The accuracy of the kriging method depends largely on the selection of variograms, which describe spatial dependence existing between variables at different locations. In our experience, the linear variogram was found to be the most appropriate for mean temperature; for precipitation, a combination of nugget and linear variograms was the most suitable (Dittmann 1999).

Drought History and Indicators

To consider drought severity on a country-wide scale, both the index values and their spatial extent are important. The following categories were used to evaluate drought severity: drought is *moderate* if PDSI values of <-2.0 extend over more than 50% of Hungary, *severe* if PDSI values of <-3.0 extend over 33% of the country, and *extreme* if PDSI values of <-4.0 cover at least 20% of the nation. These categories, while somewhat arbitrary, were selected because more severe droughts have a lower probability of affecting larger areas. Moderate and severe droughts have occurred almost continuously during the period 1983-95 (Figure 4).

Trends of Drought Events

General trends of PDSI series were tested by regression analysis and by the Mann-Kendall test. In general, both tests resulted in the same figures. Results of the Mann-Kendall test are presented in Table 5. The consistent results of the regression analysis and the Mann-Kendall test support the assumption of a drying tendency and lower PDSI values in the later years. A decrease in PDSI values for different stations and months was in the range of -1.3 to -2.4 PDSI/100 years.

The majority of the values fulfill the criteria of a 1% significance level. Moreover, for more than one-third of the stations, the test statistics showed a decrease in PDSI in all the months at the 1% level. Eleven of the fifteen PDSI station series in all the months have experienced a significant decrease (1-10%). Only two stations revealed no significant change in the PDSI series in the majority of the months. The index series of May, October, and November at all stations decreased significantly (i.e., at least 10%). Moreover, for October a significant decrease was found at fourteen of the fifteen stations on a 1% level and at one station on a 5% level. In July, three series did not indicate statistically significant change. Test statistics exceeding 4 refer to an exceptionally strong trend, which was found at Buda (in three months), Nyíregyháza (five months), Sopron (three), Szeged (three), Szombathely (ten), Túrkeve (one), and Pécs (ten), but in the latter case, four series even exceeded 5 (Figures 5, 6) (Bussay et al. 1999).

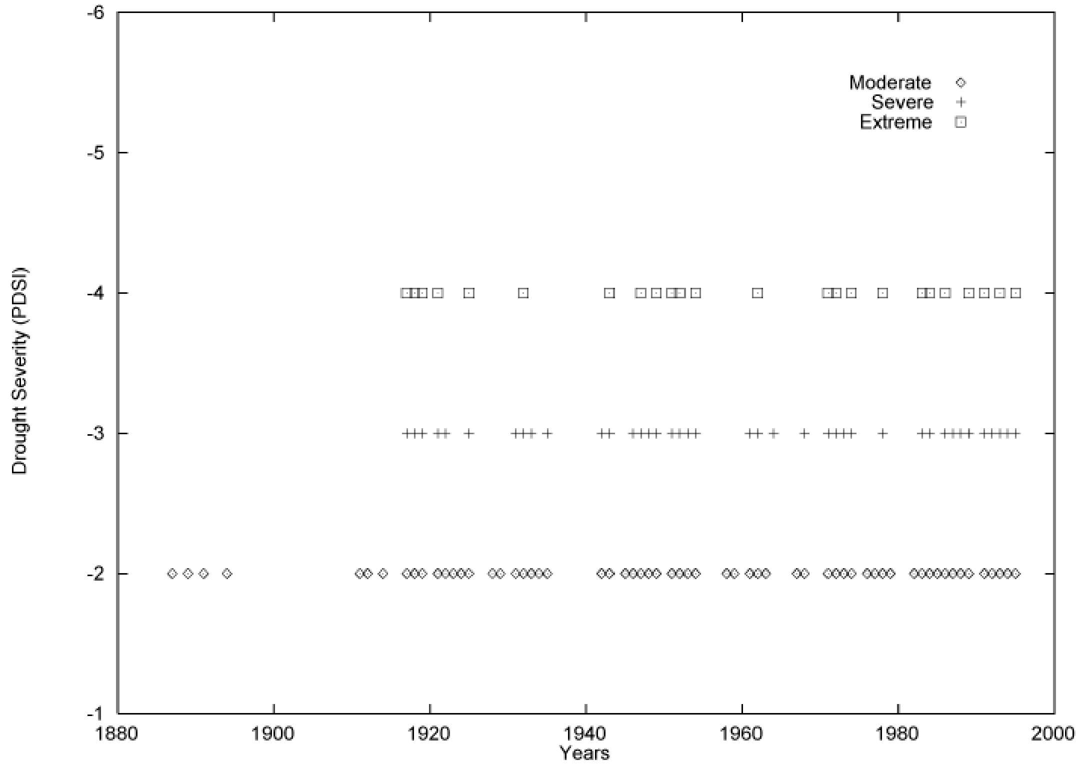

Figure 4. Occurrence of moderate, severe, and extreme droughts, 1880-2000.

Table 5. Results of the Mann-Kendall test. Sign of significancy levels: 10% italic, 5% bold, 1% bold italic.

Baja	***-2.835***	***-2.705***	***-3.285***	***-3.063***	***-3.309***	***-2.710***	**-2.429**	**-2.284**	**-2.366**	***-3.295***	***-2.589***	**-2.115**
Buda	***-3.614***	***-2.951***	***-3.546***	***-4.479***	***-4.904***	***-3.899***	***-3.764***	***-3.198***	***-3.793***	***-4.764***	***-3.938***	***-3.570***
Debrecen	**-2.299**	**-1.999**	**-2.526**	**-2.033**	**-2.076**	**-2.159**	**-2.260**	**-2.183**	***-2.671***	***-3.077***	***-3.024***	***-2.816***
Kalocsa	**-2.347**	**-2.018**	**-2.540**	**-2.497**	***-2.618***	**-2.072**	-1.448	*-1.665*	**-2.139**	***-2.821***	**-2.139**	*-1.632*
Kecskemét	**-2.802**	***-2.163***	**-3.092**	**-3.295**	**-3.261**	**-2.632**	*-1.951*	***-2.966***	***-3.183***	***-3.831***	***-3.208***	***-2.719***
Keszthely	-0.906	-0.742	-1.438	-1.443	**-2.018**	-0.960	-1.240	*-1.810*	**-1.994**	***-2.627***	*-1.873*	-1.404
M.óvár	**-2.323**	-1.491	*-1.757*	***-2.922***	***-3.145***	***-2.758***	***-2.729***	***-1.970***	***-2.623***	***-3.179***	***-2.627***	***-2.420***
Nyíregyháza	***-3.971***	***-3.657***	***-4.005***	***-4.266***	***-3.894***	***-3.826***	***-3.967***	***-3.121***	***-3.560***	***-4.435***	***-4.150***	***-4.295***
Pécs	***-4.750***	***-5.219***	***-5.349***	***-5.586***	***-5.852***	***-4.624***	***-4.213***	***-3.913***	***-3.817***	***-4.987***	***-4.426***	***-4.421***
Sopron	***-2.714***	*-1.651*	*-1.815*	***-2.632***	***-2.792***	**-2.463**	***-3.256***	***-4.639***	***-4.576***	***-4.537***	***-3.739***	***-3.667***
Szarvas	***-3.502***	***-3.391***	***-3.478***	***-3.967***	***-3.971***	***-3.541***	***-3.270***	***-3.425***	***-3.696***	***-4.363***	***-4.121***	***-3.817***
Szeged	***-3.672***	***-3.938***	***-4.155***	***-4.179***	***-4.165***	***-2.937***	***-2.681***	***-2.197***	***-2.743***	***-3.851***	***-3.657***	***-3.217***
Szombathely	***-4.083***	***-3.710***	***-4.286***	***-4.972***	***-4.228***	***-3.735***	***-4.170***	***-4.450***	***-4.721***	***-4.817***	***-4.489***	***-4.411***
Túrkeve	***-3.101***	***-2.884***	***-3.174***	***-3.478***	***-2.714***	***-3.314***	***-2.951***	***-2.850***	**-2.555**	***-4.141***	***-3.764***	***-3.517***
Zalaegerszeg	-1.385	-1.665	-1.960	-2.603	-1.777	-1.593	-1.409	-1.303	-1.661	-2.110	-1.293	-1.245

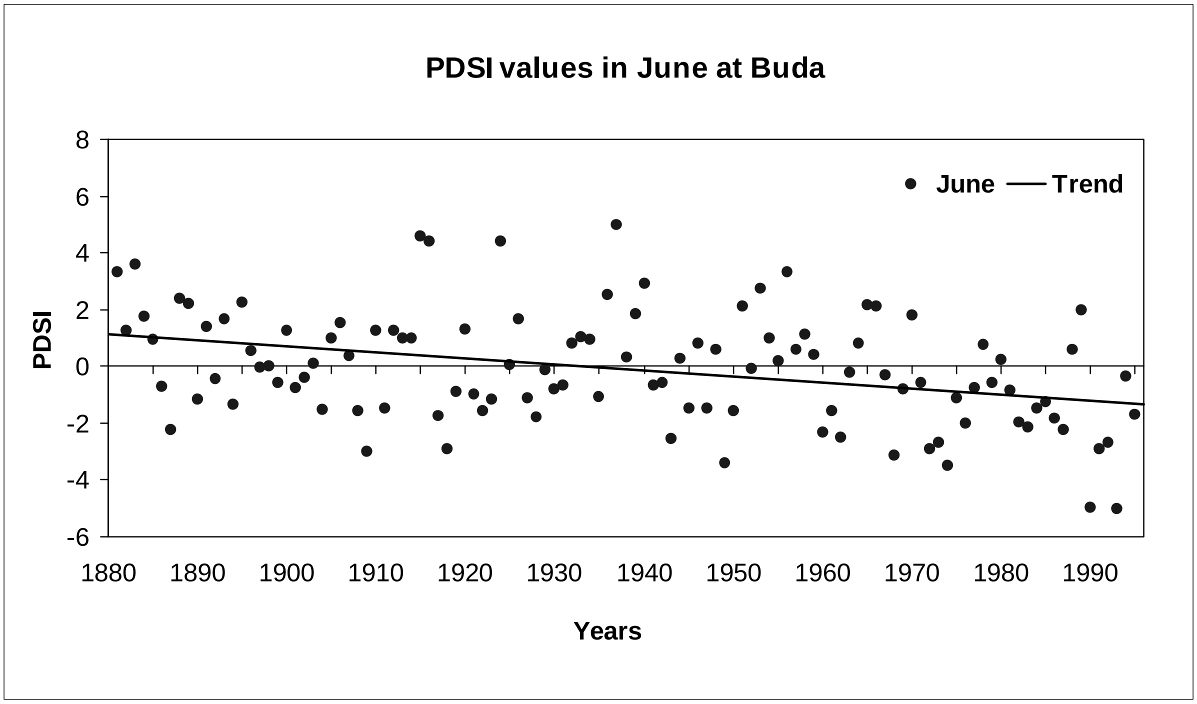

Figure 5. PDSI values in June at Buda.

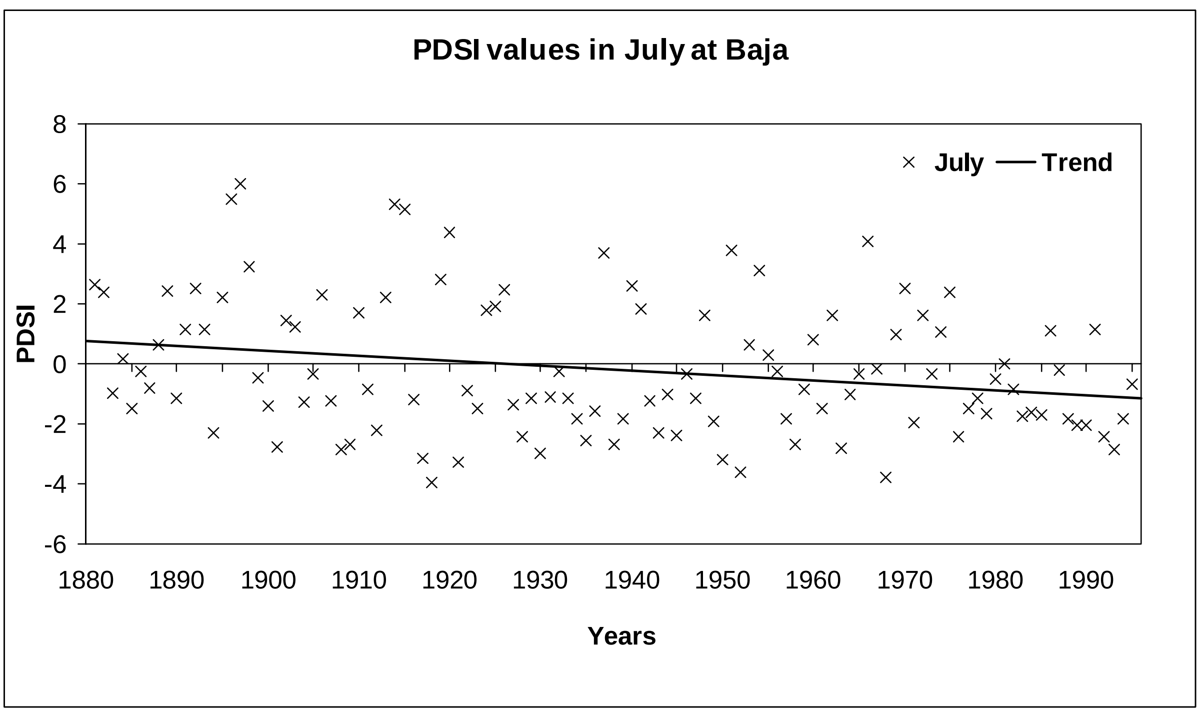

Figure 6. PDSI values in July at Baja.

Drought Frequency Investigations

Two statistical tests were used to detect changes in drought frequency. The first test is based on the Wilcoxon test, and it addresses the question of whether drought occurrence in a specific intensity category has systematically changed or not. If there is a trend in the occurrence, it is that drought events concentrate at one end of the time series. The limiting distribution of the test statistics is normal, so its values can be easily checked for significance. The second test investigates whether occurrence of droughts in a particular category reveals periodicity over the years. For this, the number of threshold crossings are counted when two subsequent elements of the time series are on different sides of a certain threshold—e.g., when the PDSI falls from -2.8 to -3.2 and the threshold is -3. This test statistic has binomial distribution, and therefore the significance of the results should be compared to a table. Both tests are described in detail by Szinell et al. (1998).

Results of the Tests

The two tests were first applied to the PDSI and SPI index series ending in 1995, then to the series ending in 1999. For the PDSI, the tests indicated significant (1% to 5%) increasing drought frequency at a number of stations, mostly on the Hungarian Plains. The second test indicated that droughts tend to occur in spells of years even when the first test failed to indicate a drying tendency. This result suggests that successive years in which PDSI values under certain thresholds recur are more probable than individual occurrences. Tests 1 and 2 when applied to the PDSI series ending in 1999 resulted in a similar outcome. In accordance with the expected behavior, the test statistics are smaller and their significance is sometimes less than in the previous case because of the recent spell of wet years. However, the general characteristics remained the same (Figure 7).

SPI index series of 3-, 6-, 9-, and 18-month time scales have been calculated. SPIs of shorter time scales can characterize water supply changes for short time periods. One advantage of using the SPI is its explicit time scale in contrast to the PDSI, which responds to moisture anomalies on the scale of 6-12 months (e.g., Guttman 1998).

The 3-month SPI revealed different patterns from those of the PDSI discussed above. They also indicated existing drying tendencies, but at more defined periods of the year. According to these series, drying occurs mostly in the late spring and early summer months and during late autumn. Both periods play a very important role in agriculture, as the first is the time of germination and sprouting and the second is after harvest, when soils should fill up with moisture for the next vegetative period. Therefore drying during these important phases can have crucial effects on agricultural production. Tests on longer SPI series also indicated that the recent period has been drier, but, similar to the PDSI results, the significant results occurred at longer time scales within the year.

Test 2 when applied to the SPI series resulted in far fewer significant test statistics than when applied to the PDSI series. This suggests that the clustering feature found earlier could be associated with the PDSI characteristic, that it has a tendency to be stuck at negative or positive values (e.g., Guttman 1998; Bussay et al. 2000).

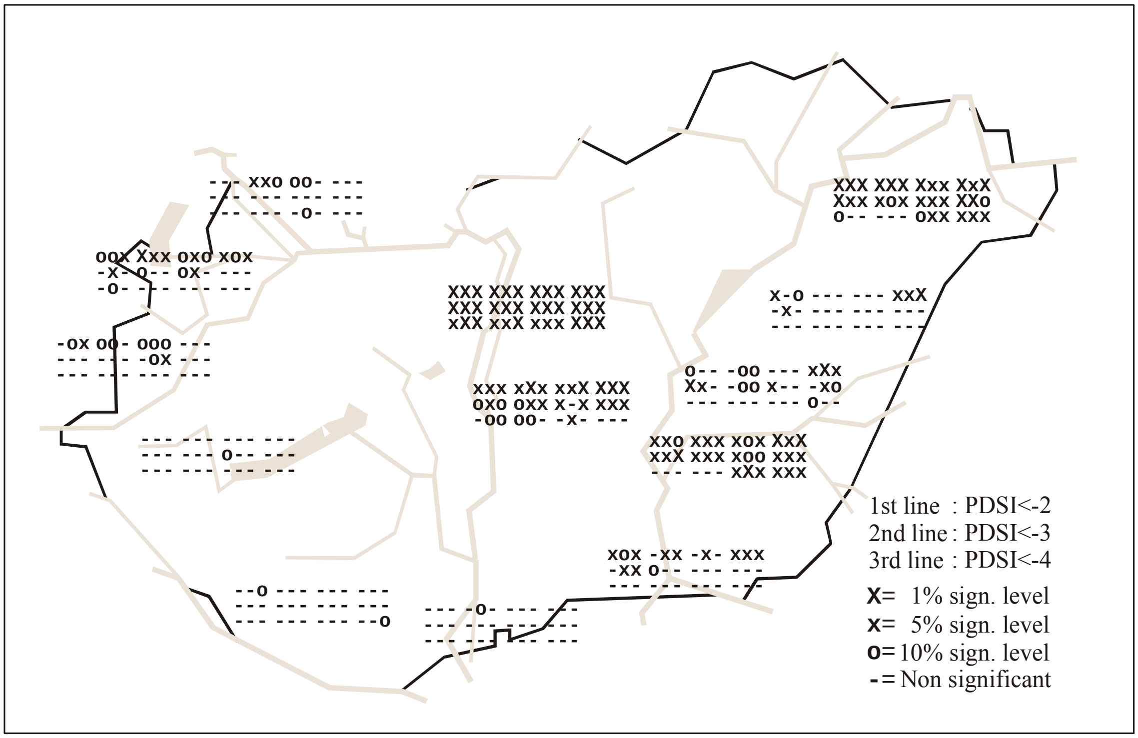

Figure 7. Significance of Test 1 for PDSI through 1999 for 13 locations in Hungary.

Combination of Different Drought Indices (Bussay et al. 2000)

SPI and Hydrological Droughts

Because the SPI is based on precipitation amounts, it is a natural for examining meteorological droughts. The flexibility of the multiple time scale component of the index means that it may be useful for hydrological applications as well. Several questions need to be addressed: Can the SPI identify and characterize hydrological droughts? How strong is the connection of the SPI with hydrological features such as streamflow and ground water levels? What is the appropriate SPI time scale for these features? Finally, what are the limitations of using the SPI for hydrological applications? Very few studies have examined the capability of the SPI to monitor hydrological drought conditions.

SPI Relationship with Streamflows

The first hydrological relationship examined will be between SPI and streamflows. Rainfall certainly has an impact on streamflows through runoff, based on the distribution in space and the intensity of the rainfall. Runoff, however, is influenced by many additional factors, such as the size and topography of the catchment area, soil characteristics, and frozen ground and snow cover. All of these factors affect the relationship between the SPI and streamflow.

Figure 8 shows the relationship between the 2-month SPI and streamflows in the southwest. Although the scatter is quite large, an exponential relationship identifying low streamflows with negative SPI values and high streamflows with positive SPI values is evident. The fitted curve is convergent at the large negative SPIs with minimal runoff, while large runoff values are scattered along an extended SPI range. Additional examination reveals that all of the very high streamflow values occurred during the late winter and early spring and were associated with the quick melting of a thick snow cover. To find the appropriate SPI time scale, regression coefficients (*r*) were calculated for the relationships between streamflows and the series of SPI time scales for the four river basins (Table 6). As in Figure 8, an exponential relationship was used. Results were similar in each basin, with the short time scales having the highest correlation values. The 2-month SPI had the highest relationship for the Black-Körös, Kapos, and Zala rivers, while the relationship was best with the 6-month SPI for the Zagyva River. The PDSI was also included in Table 6, and the regression coefficients between the PDSI and streamflow were lower, in general, compared to the SPI, except for the Zagyva River. Several factors could be affecting these relationships, but it does appear that for these small Hungarian basins, the 2-month or 3-month SPI values could provide the best information about streamflow levels.

SPI Relationship with Ground Water

Relationships can also be examined between the SPI and ground water levels measured at the well sites. Figure 9 shows the relationship between the 5-month SPI and the depth to the water table at Keszthely in western Hungary.

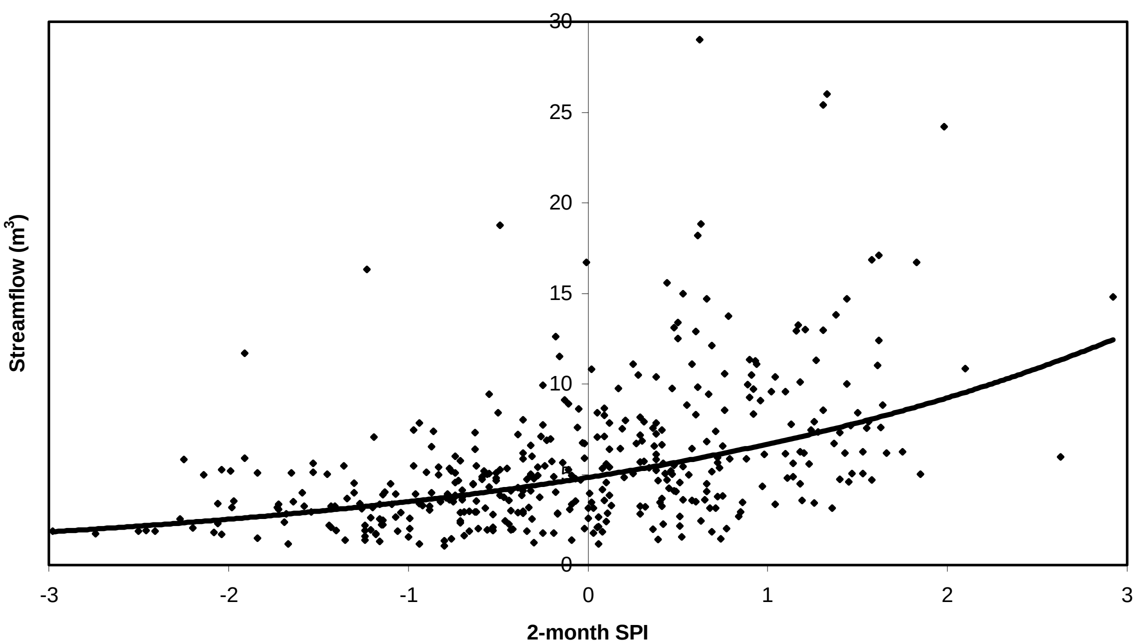

Figure 8. Relationship between the 2-month SPI and streamflows in the southwest.

Table 6. Relationships between streamflow and SPI for several time scales. Underlined values are the maximums. Test statistics of 5% significance are in italic; 1%, bold.

	Correlation Coefficient (r)							
River	SPI1	SPI2	SPI3	SPI6	SPI12	SPI18	SPI24	PDSI
Black-Körös	**0.3324**	**<u>0.4493</u>**	**0.4418**	**0.3274**	**0.2062**	**0.3531**	**0.3681**	**0.3463**
Kapos	**0.4471**	**<u>0.5139</u>**	**0.5093**	**0.4591**	**0.4441**	**0.4363**	**0.3912**	**0.4810**
Zagyva	**0.3471**	**0.4639**	**0.4894**	**<u>0.5133</u>**	**0.4607**	**0.2278**	**0.1783**	**0.5226**
Zala	**0.4232**	**<u>0.4573</u>**	**0.4127**	**0.2728**	**0.2590**	**0.1606**	**0.1280**	**0.3233**

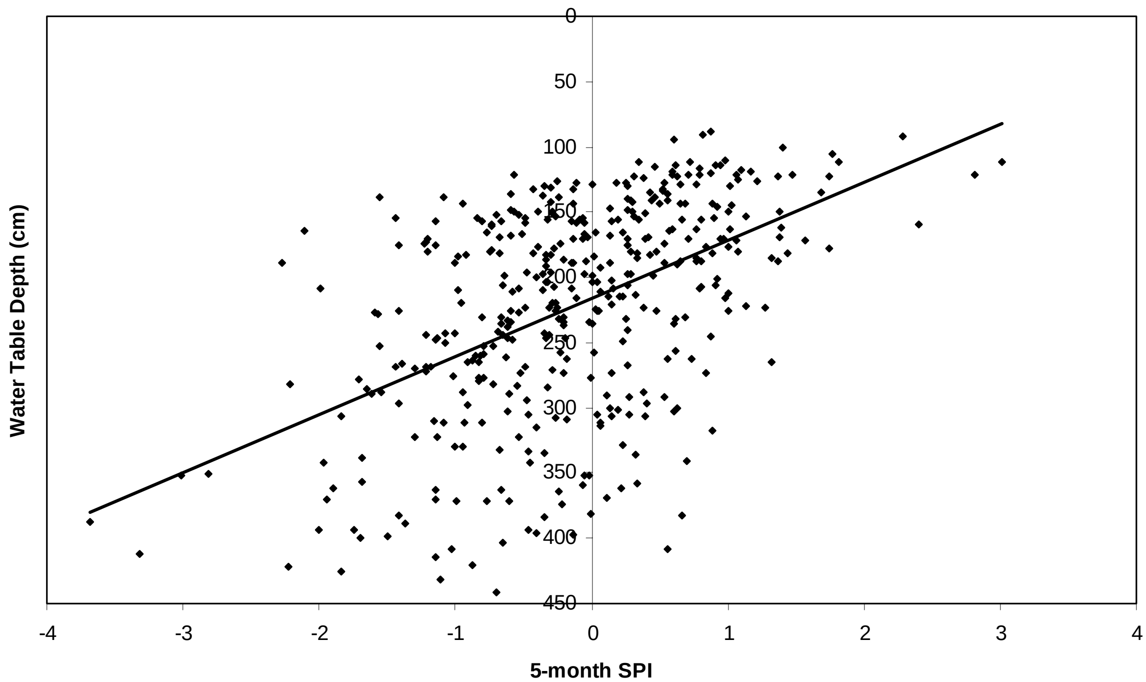

Figure 9. Relationship between the 5-month SPI and the depth to the water table at Keszthely.

The SPI and the Ground Water Table

Generally, the most positive SPI values occur at the same time that the ground water table is closest to the surface, and SPI values are below zero when the ground water table is farther below the surface. As for streamflows, a table of the regression coefficients (r) was constructed showing the relationship between ground water measured by well levels at the four locations and the SPI for various time periods (Table 7). The strongest relationships are at longer time scales: 5, 12, 18, and 24 months for the different areas. Some of the differences in time may be accounted for by the distance between the well and the station. They are close at Keszthely and farther apart at Kaposvár. The PDSI is also included in the table, but those relationships are not as strong as the particular SPI relationships.

Table 7. Relationships between the depth of the ground water table and SPI for several time scales. Underlined values are the maximums. Test statistics of 5% significance are in italic; 1%, bold.

	Correlation Coefficient (r)						
Well Location	SPI3	SPI5	SPI6	SPI12	SPI18	SPI24	PDSI
Southeast	*0.1200*	**0.1612**	**0.1688**	**0.1895**	**<u>0.2404</u>**	**0.2387**	**0.1470**
Southwest	**0.1356**	*0.1204*	*0.1225*	0.0574	**0.3079**	**<u>0.3877</u>**	**0.1411**
Central	**0.2938**	**0.3895**	**0.4297**	**<u>0.5265</u>**	**0.5083**	**0.5148**	**0.4596**
West	**0.4613**	**<u>0.5249</u>**	**0.5135**	**0.4972**	**0.4163**	**0.3471**	**0.4719**

Figures 8 and 9 appear to indicate that the SPI can be used qualitatively to identify hydrological drought. Correlations of the SPI with streamflows were similar, while for ground water levels the best correlations were found at widely different time scales. This behavior can be the result of other factors, since hydrological parameters, such as streamflow or ground water, depend on several different soil and ground characteristics. Therefore, one meteorological parameter (rainfall) and its derivative (SPI) can only be used as a tool for identifying tendencies in the evolution of these hydrological variables.

SPI and Agricultural Droughts

To determine the usefulness of the SPI for detecting and monitoring agricultural drought, the soil moisture component was investigated. Soil moisture is one of the most important limiting factors of plant production in Hungary.

For this investigation, the winter half of the year (October to March) was excluded. Generally there is very little evaporation from the soil, and soils are usually saturated at the end of winter regardless of the amount of winter precipitation. Monthly soil moisture data were used for April through September at a depth of 0.5 m. Table 8 shows the regression coefficients (r) between the monthly soil moisture from April through September and four SPI time periods. Table 9 shows the same, except that only soil moisture is considered for the main summer months of June, July, and August. The r values show the strongest relationships to be with the 2-month SPI. The relationships between soil moisture and PDSI are also shown in both tables, and the relationships are poor. Figure 8 shows the relationship between soil moisture in June, July, and August and the 2-month SPI at Szolnok. There is a large scatter of soil moisture values around the relationship, indicating that nonmeteorological factors (e.g., agronomic factors) also play a role in determining soil moisture.

Table 8. Relationships between April through September soil moisture (0.5 m) and SPI for several time scales. Underlined values are the maximums. Test statistics of 5% significance are italic; 1%, bold.

	Correlation Coefficient (r)				
Station	SPI1	SPI2	SPI3	SPI6	PDSI
Southeast	**0.3587**	**<u>0.4880</u>**	**0.4390**	**0.3763**	0.1217
Southwest	**0.3752**	**0.5173**	**<u>0.5217</u>**	**0.4384**	**0.4770**
Central	**0.4152**	**<u>0.5352</u>**	**0.4873**	**0.4507**	0.0663
West	**0.5383**	**<u>0.5877</u>**	**0.5532**	**0.3575**	0.1100

Table 9. Relationships of June, July, and August soil moisture (0.5 m) and SPI for several time scales. Underlined values are the maximums. Test statistics of 5% significance are italic; 1%, bold.

	Correlation Coefficient (r)				
Station	SPI1	SPI2	SPI3	SPI6	PDSI
Southeast	**0.4465**	**<u>0.5960</u>**	**0.5479**	**0.4691**	0.1616
Southwest	**0.3697**	**<u>0.5842</u>**	**0.5585**	**0.5095**	0.0300
Central	**0.5223**	**<u>0.6938</u>**	**0.5799**	**0.5253**	0.1652
West	**0.5348**	**<u>0.6788</u>**	**0.5912**	**0.4592**	0.1334

Irrigation Advisory System

It is clear from the above investigation that different types of information about precipitation in Hungary are necessary. Therefore, an automated irrigation advisory system was developed with the financial support of the Ministry for Agriculture and Rural Development.

The system calculates daily evapotranspiration (Penman-Monteith formula) and uses these results and precipitation measurements to derive the accumulated actual daily water shortage. From the water shortage we can calculate the water demand of different plants.

This system is the first automated, interactive, and freely accessible system on the Internet in Hungary. As a next step, we would like to expand this system, with more detailed calculations of water demand, a mapping system, and more information about the situation of the atmosphere and pedosphere.

International Cooperation

Many international activities are connected with drought. The International Commission on Irrigation and Drainage has a special working group investigating this question, and the south European division of this group published a paper on the drought mitigation issue, in English and Hungarian.

The network of European climatological services (ECSN) has a special project on drought. The tasks of this project are more practical than theoretical. The participants of the project use the same software, which is very important, especially for the PDSI index. The value of this cooperation is shown by the growing number of participants.

The first meeting involving regional cooperation was held in Hungary in spring 2000. The participating countries agreed to strengthen their common activity for the better management of drought on the regional level (National Drought Mitigation Center 2000).

Conclusions

1. There is a growing frequency of drought in Hungary, even if we calculate the recent wet years.
2. Hungary has a relatively small area, but drought tendencies differ significantly in the various regions of the country.
3. Comparable data are necessary for drought monitoring. This means standardizing the networks of different authorities and countries.
4. In the case of surface measurements, a good mapping procedure is necessary.
5. The SPI index describes the evolution of drought events quite well, and it shows good correlations (but on different time scales) with parameters of different types of drought (other than meteorological).

Therefore, it is beneficial

1. to use common data management systems,
2. to use combinations of different drought indices,
3. to have international cooperation, especially within one geographical unit, and
4. to use a unified methodology for calculation of the cost/benefit ratio of drought management.

References

Benichou, P. and O. Le Breton. 1987. Prise en compte de la topographie pour la cartographie des champs pluviometriques statistiques. *La Météorologie*, 7e serie, No. 19.

Bogaert, P., P. Mahau, and F. Beckers. 1995. The spatial interpolation of agro-climatic data. FAO Agrometeorology Series, Working Paper No. 12. FAO, Rome, Italy.

Bussay, A., M. Hayes, Cs. Szinell, and M. Svoboda. 2000. Monitoring drought in Hungary with the Standardized Precipitation Index. Submitted to *Water International*.

Bussay, A., Cs. Szinell, and T. Szentimrey. 1999. Investigation and measurements of droughts in Hungary. Climatological & Agrometeorological Papers, 7. Hungarian Meteorological Service, Budapest.

Dittmann, E. 1999. Spatial Interpolation of Climatological Parameters. Arbeitsergebnisse Nr. 57. Deutscher Wetterdienst, Offenbach, Germany.

Dunay, S. and F. Czakó. 1987. Use of meteorological information in the agricultural production. Pages 193-209 *in* Reports on Scientific Research of the Hungarian Meteorological Service (HMS). Hungarian Meteorological Service, Budapest. (In Hungarian.)

European Climate Support Network. 1995. Climate of Europe. Executive summary, First European Climate Assessment. http://aire.inm_es/summary.html.

Gunst, P. 1993. The droughts and the Hungarian state. Pages 131-159 *in* Drought 1983 (Baráth, C., ed.). University for Horticultural Science, Budapest. (In Hungarian.)

Guttman, N.B. 1998. Comparing the Palmer Drought Index and Standardized Precipitation Index. *Journal of the American Water Resources Association* 34:113-121.

National Drought Mitigation Center. 2000. Conclusions and recommendations from the Central and Eastern European Workshop on Drought Mitigation. *Drought Network News* 12(2):11-12.
Pálfai, I., Gy. Szilárd, and L.M. Tóth. 1998. Drought forecasting as an aid to irrigation water management. Pages 422-429 *in* Water and the Environment: Innovative Issues in Irrigation and Drainage (Pereira, L.S. and J.W. Gowing, eds.). E&FN Spon, New York.
Szinell, Cs., A. Bussay, and T. Szentimrey. 1998. Drought tendencies in Hungary. *International Journal of Climatology* 18:1,479-1,491.

Improving Drought Early Warning Systems in the Context of Drought Preparedness and Mitigation

Summary of Breakout Sessions

Introduction

Effective drought early warning systems are an integral part of efforts worldwide to improve drought preparedness. Timely and reliable data and information must be the cornerstone of effective drought policies and plans. In pursuit of the goal of improving the effectiveness of drought early warning systems, participants of the experts meeting were asked to address three fundamental questions:

1. What is your assessment of the current status of drought early warning systems?
2. What are the shortcomings, limitations, and needs for drought early warning systems?
3. How can drought early warning systems be improved to better support drought preparedness and mitigation efforts at the local, national, and international level?

Participants identified the primary users of data and information derived from drought early warning systems as a first step in evaluating the status of early warning systems. Users were diverse, including government agencies, farmers, extension services, insurance companies, media, donors, NGOs, and the general public. Leadership for drought early warning systems is provided principally by meteorological or agricultural services. In general, where meteorological services were the lead agency, the information tended to be more meteorologically based. In contrast, leadership for drought early warning systems that were more agriculturally based tended to take a more multidisciplinary or integrated approach to monitoring. An integrated approach is considered preferable because information from all elements of the hydrologic system must be considered to obtain a comprehensive assessment of climate and water supply conditions. Although forecasting and monitoring are considered critical components of all early warning systems, there appeared to be little evidence of the beneficial use of that information by farmers.

It was noted that few countries currently have a national drought policy in place. Australia is an exception and progress in South Africa and the United States was noted. It was apparent that other countries were moving in the direction of a national drought policy. In some instances, subnational policies were in existence. Comprehensive early warning systems should be the foundation on which national drought policies and plans are constructed. Although many countries have some type of drought early warning system in place, these systems are not comprehensive and have very limited financial and human resource inputs.

Shortcomings and Needs of Drought Early Warning Systems

Participants noted the following shortcomings and needs of existing drought early warning systems:

Data Networks. In many countries, the density of meteorological and hydrological stations is insufficient to provide adequate coverage for drought monitoring. A wide range of data is necessary to adequately monitor climate and water supply status (i.e., precipitation, temperature, streamflow, ground water and reservoir levels, soil moisture, snow pack). These data are often not available at the density required for accurate assessments. Data quality (i.e., missing data) and length of record also represent critical deficiencies in data networks for many locations. Existing data networks need to be maintained and expanded in coverage and data reporting needs to be automated wherever possible to ensure timely receipt of data.

Data Sharing. Meteorological and hydrological data often are not widely shared between agencies of government. This restricts early assessment of drought and other climate conditions and retards its use in drought preparedness, mitigation, and response. In some countries, the high cost of data acquisition from meteorological services restricts the flow of information for timely assessments and for use in research. Memoranda of Understanding (MOUs) between government agencies would facilitate data sharing and use and could bring tremendous societal benefits.

Early Warning System Products. Data and information products produced by early warning systems often are not user friendly. Many products are too complicated and do not provide the type of information needed by users for making decisions. Users are seldom trained on how to apply this information in the decision-making process or consulted before product development. Many products are not evaluated for their utility in decision making. User needs should be assessed and products evaluated through permanent feedback mechanisms.

Drought Forecasts. Long-term drought forecasts (a season or more in advance) are not reliable in most instances. Drought forecasts often do not provide the specificity of information needed by farmers and others (e.g., the beginning and end of the rainy season, distribution of rainfall within the growing season) to be useful for operational decisions. Greater investments in research to improve the reliability of seasonal forecasts would provide significant economic benefits to society if these forecasts were expressed in user-friendly terms and users were trained in how these forecasts can be applied to reduce climate risks.

Drought Monitoring Tools. Tools for detecting the early onset (and end) of drought are inadequate. The Standardized Precipitation Index (SPI) was noted as an important new tool that is receiving widespread acceptance in many countries. The SPI needs to be tested and applied in more drought-prone areas, and the results should be shared. Triggers for specific mitigation and response actions are often unreliable because of the inadequacy of detection tools and inadequate linkages between indices and impacts. Integrated assessment products are preferred, but few attempts have been made to integrate meteorological and hydrological information into a single product for purposes of detecting and tracking drought conditions and development. The Drought Monitor product recently developed in the United States could serve as a model. More research is needed on climate indices such as the SPI as an early warning tool and the relationship between SPI values and impacts in specific sectors to form the basis for triggers for mitigation and response actions. Also, drought should be monitored on weekly rather than monthly time intervals in order to more accurately evaluate changes in severity and spatial characteristics. Satellite-derived remote sensing data (AVHRR) offers considerable advantages and should be an integral part of drought early warning systems.

Integrated Drought/Climate Monitoring. It is critical that an integrated approach to climate monitoring be employed to obtain a comprehensive assessment of the status of climate and water supply. Too often, drought severity is expressed only in terms of precipitation departures from normal, neglecting information about soil moisture, reservoir and ground water levels, streamflow, snow pack, and vegetation health. Seasonal climate forecasts may also provide valuable information regarding whether conditions are likely to improve or deteriorate in the coming months. Use of multiple climate indices and parameters provides monitoring specialists with an assortment of tools, each with its own strengths and weaknesses. Understanding these strengths and weaknesses will provide a scientific basis for accepting or rejecting indicators. By comparing multiple drought indicators, the relationships between these indices/tools will be better understood. The experiences in the United States with the integrated drought assessment tool, the Drought Monitor, during 1999–2000 is potentially a good model to follow in future assessment efforts for some countries. This product integrates six different indicators/parameters, including vegetation health, in its assessment of drought severity in the United States.

Impact Assessment Methodology. One of the missing links in early warning systems is the connection between climate/drought indices and impacts. The lack of effective impact assessment methodologies has hindered the activation of mitigation and response programs and reliable assessments of drought-related impacts. Impact assessment methodologies need to be improved in order to help document the magnitude of drought impacts and the benefits of mitigation over response. Significant investment in interdisciplinary research on impact assessment methodologies could result in considerable progress in addressing this problem. Social scientists should be an integral part of the research team necessary to address this issue.

Delivery systems. Data and information on emerging drought conditions, seasonal forecasts, and other products often are not delivered to users in a timely manner. This characteristic significantly limits the usefulness of these products for most users. It is critical that delivery systems be improved and that they be location appropriate. For example, the Internet provides the most timely and cost-effective method of information delivery in many settings but is inappropriate in most developing countries. Electronic and print media, as well as local extension networks, need to be used more fully as part of a comprehensive delivery system to diverse user groups.

Global Early Warning System. Because of the many definitions and characteristics of drought, no historical drought data base exists. Similarly, no global drought assessment product illustrating current and emerging drought conditions is available to governments, international organizations, donors, and NGOs. A global drought assessment product that relies on one or two key variables (e.g., precipitation, vegetation health) would be a valuable tool to provide early warning of areas of potential concern.

Recommendations

Considerations:

$ Recognizing that drought is a natural hazard that is quite distinct from other natural hazards in terms of its slow onset, spatial extent, and nonstructural impacts, the participants of the meeting recommend that countries develop national drought policies and preparedness plans that address the unique features of drought.

$ Acknowledging that significant diversity exists within each country, the participants of the meeting emphasized the need to conduct risk assessments to identify and address the most vulnerable people and sectors at the national and subnational level. It is also essential to identify the information needs of all users at the local level.

$ Recognizing that drought is a complex phenomenon, a comprehensive drought early warning system must be at the foundation of a national drought policy and preparedness plan.

In the light of the above considerations, the participants of the meeting propose the following:

Recommendation 1:

A drought preparedness and mitigation plan should be integrative, proactive, and incorporate the following elements:

$ Drought monitoring and early warning system;

$ Drought risk and impact assessment; and

$ Institutional arrangements, including mitigation and response actions and programs.

All of the above elements must be underpinned by research.

Recommendation 2:

As a first step, a vulnerability profile should be completed to capture the socioeconomic conditions of diverse population groups.

Recommendation 3:

Priority should be given to improving existing observation networks and establishing new meteorological, agricultural, and hydrological networks, as well as associated analytical and predictive tools and models. This effort would include:

$ identifying weaknesses in the current observation system, including the critical needs of marginal areas and the most drought-prone areas;

$ drought monitoring products that are prepared in collaboration with decision makers and presented in an easy-to-understand format; and

$ periodic user evaluation of drought monitoring products.

Recommendation 4:

Social, economic, and environmental assessments of drought impacts must be addressed by:

$ identifying appropriate and relevant physical and social indicators;
$ developing triggers that link indicators of drought severity to impacts during the onset and termination of drought conditions; and
$ appropriate interpretation of information and clearly expressing that assessment to decision makers in a timely manner.

Recommendation 5:

Develop institutional capacity for national drought policy and planning that includes the creation of a drought task force or commission composed of government agencies with principal responsibility for drought preparedness, monitoring and assessment, mitigation, and response. This task force could also include key stakeholder/citizen groups, NGOs, and donors.

The objectives of a national drought policy should be broadly stated and

$ establish a clear set of principles or operating guidelines to govern drought management;
$ be consistent and equitable for all regions, population groups, and economic/social sectors;
$ be consistent with the goals of sustainable development;
$ reflect regional differences in drought characteristics, vulnerability, and impacts;
$ promote principles of risk management by encouraging development of
    - reliable forecasts
    - comprehensive early warning systems
    - preparedness plans at all government levels
    - mitigation policies and programs that reduce drought impacts
    - a coordinated emergency response program that ensures timely and targeted relief during drought emergencies.

Drought plan objectives are more specific and will vary between countries, reflecting the unique physical, environmental, socioeconomic, and political characteristics of the country. A national drought preparedness plan should include the following:

1. Collection and analysis of drought-related information in a timely and systematic manner.
2. Criteria for declaring drought emergencies and triggering various mitigation and response activities.
3. An organizational structure and a delivery system that assures information flow between and within levels of government.
4. Definition of the duties and responsibilities of all agencies with respect to drought.
5. Maintenance of a current inventory of mitigation and response programs used in assessing and responding to drought conditions.
6. Identification of drought-prone areas and vulnerable economic sectors, individuals, or environments.

7. Identification of mitigation actions that can be taken to address vulnerabilities and reduce drought impacts.
8. A mechanism to ensure timely and accurate assessment of drought's impacts on agriculture, industry, municipalities, wildlife, tourism and recreation, health, and other areas.
9. Provision of accurate, timely information to media in print and electronic form (e.g., via TV, radio, and the World Wide Web) to keep the public informed of current conditions and response actions.
10. A strategy to remove obstacles to the equitable allocation of water during shortages and requirements or incentives to encourage water conservation.
11. A set of procedures to continually evaluate and exercise the plan and provisions to periodically revise the plan so it will stay responsive to the needs of the country.

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