AFRICAN DROUGHT: MONITORING AND PREDICTION

A Report of a Workshop

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A Workshop Report

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African Drought: Monitoring and Prediction

ABSTRACT

Substantial advances have been made in understanding short-term climate variability, particularly in the tropics. Empirical relationships have been identified which provide a reason for optimism in improving prediction of major tropical rainfall perturbations on seasonal time scales, and perhaps longer in some regions. This report recommends exploiting these advances in science through a program of research applied specifically to monitoring, predicting, and responding to African drought. The report recommends making use of relevant national and international programs now under way to stretch the new resources required.

EXECUTIVE SUMMARY

This is the report of a workshop organized by the U.S. National Climate Program Office (NCPO) under the auspices and financial support of the U.S. Agency for International Development (USAID). The purposes of the workshop were to:

(1) review the status of research on climate change in Africa;

(2) assess the basis for determining the causes, trends, and recurrence of African drought;

(3) assess prospects for drought prediction and the potential for a research program at this time to produce results useful in guiding U.S. and international policies toward Africa; and

(4) outline a research agenda to evaluate the extent and significance of climate change in Africa, including desertification and the continuing climatic effects of large-scale regional land-use practices.

Addressing these points, workshop participants concluded:

- African drought episodes will recur. An investment in African climate research is likely to yield great dividends. It is time to exploit modern capabilities in numerical modeling and diagnostic analyses, to go beyond mere assembly and analysis of historical data in striving for physical understanding of African drought.

- Occurrence of drought in Africa can be related to global climate fluctuations. While unique causes cannot be identified, drought events appear to be influenced from well beyond the African continent. The extent to which internal changes in African land surface prolong or enhance drought is not well understood, but can be tested by analysis of improved observations and climate modeling.

- Prospects for useful seasonal to interannual lead time forecasts of likely precipitation variations in southern Africa appear especially promising. Forecasts for the Sahel and East African regions are more problematical. Yet there is optimism that current research strategies that are applied elsewhere may be applied successfully to Africa.

- The proposed research agenda is focused on a diagnostic and experimental forecast program supported by and crucially dependent on an expanded observational system that includes application of remote sensing for real-time assessment and diagnostic studies. It is also noted that closer coordination and prescribed expansion of existing national and international programs would draw considerable additional resources to fill many needs of African researchers.

Workshop participants recognize that any actions resulting from advances in physical science must be integrated into a broader socioeconomic and political program that requires international action. While problems of African drought and technical development are being addressed by many international organizations and agencies, current efforts are largely independent and narrowly focused. Close planning and coordination are absent. Workshop participants underscored the need to develop a long-term international program and strategy for Africa. Such a program would address fundamental problems of African infrastructure, technical development, and application of scientific information in light of climate variability.

Accordingly, workshop participants recommended:

- A U.S. government review of commitment and strategy toward African development, with the aim of maximizing resources to build internal communication systems and technical centers. Such improvements would provide training and education in emerging forecast capabilities and create local centers which would use climate data and information effectively.

- A U.S. government proposal, through the World Meteorological Organization (WMO), for an international meeting of all countries and agencies involved in African aid and development to review existing programs and to assess these programs' collective ability to address long-term African needs.

In summary, workshop participants call for development of an international strategy to address fundamental problems of African development of which drought is and will likely continue to be the major environmental problem. Now is the time to organize the research agenda recommended here to improve our understanding of the causes of drought and our ability to predict them. To obtain the most long-lasting value, this research must be accompanied by improved observations, data processing, and communications in Africa. (See Appendix A for a list of workshop participants.)

AFRICAN DROUGHT: MONITORING AND PREDICTION

INTRODUCTION

This report recommends a ten-year project in research and applications under the National Climate Program. It is a proposal for a trial union between an agency (USAID) that has to respond to life-threatening situations around the world using the best information current technology allows, and agencies (NOAA, NASA, and NSF) that are able to assemble and improve upon that knowledge.

This union is important. Unless research supporting development of new information is coordinated closely with the programs it is intended to help, it risks being irrelevant, misunderstood, too cumbersome, too costly to apply, or duplicative.

For the United States, the focus for federal assistance to Africa is in the U.S. Agency for International Development (USAID). Within this agency, programs such as the Sahel Development Program, offices such as the Office of Foreign Disaster Assistance, and support groups such as the Africa Bureau, monitor world-wide environmental conditions for signs of potential problems, provide emergency relief where such problems occur, and help nations help themselves to develop long-term strategies and in-country capabilities to meet or obviate possible environmental problems. These and other efforts are substantial.

From 1975 to 1983 the United States contributed over $1 billion in official development assistance to the Sahel countries alone in response to drought. In 1984, the United States contributed $274 million to relief in the Sahel, 14 percent of the total contributed by all nations. Government assistance and private contributions throughout Africa have been impressive. On March 10, 1986, the Washington Post, for example, reported that "U.S.A. for Africa," producers of the "We Are The World" record album, earned $44.6 million; of this, $19 million went for immediate relief efforts, with $24.5 million ear-marked for "long-term recovery and development" projects.

Because governments and volunteer relief organizations were late to sense the magnitude of worsening drought conditions in 1984, direct food aid became the only viable option for response. Even for much of this, the relief efforts were, of necessity, hastily prepared. Early monitoring and identification of drought conditions permits a greater number of technical options to be considered. An awareness of expected climate conditions provides a firmer base upon which to form long-term strategies for in-country development. Only through testing and evaluation within a user agency can the value of this information be determined. This report recommends a means to develop, test, and evaluate new information and guidance for an important set of applications.

1. RESEARCH STRATEGY AND PROPOSED ACTIONS

The roots of African drought episodes are buried in a complex climate system, and the means to cope with drought are not simple. Because of this, actions needed to confront problems of forecasting and responding to drought are broad, indeed. Thus, workshop participants recommended a program ranging from improved weather observations to prediction research and applications studies.

The recommended overall strategy is an integrated program to:

- o improve the historical research data base
- o implement a new observation system
- o begin experiments with emerging forecast methods
- o test application in long-range planning

Full implementation requires national and international cooperation. The United States, however, can play a significant leadership role by (a) reinforcing national efforts in data analysis and climate prediction research, and (b) promoting international cooperation to share in the development of new observation and communication systems.

Information for decision making comes from data collecting, analysis, information generation and dissemination, and application. Immediate attention can be given to the data problem. The United States can promote:

1. development of a complete data inventory and expansion of the assembly and analyses of historical data; and

2. modernization of existing observing systems, data processing facilities, and establishment of a satellite-based real time communication and climate assessment system.

1.1 Data and Observation Systems

Studies of climate fluctuations in Africa are hindered by a scarcity of modern and historical data. Outside of Algeria and South Africa, for example, few meteorological records are as long as a century. A number of meteorological stations were established in the 1890s, but they generally discontinued observations after a few decades. Most countries first established reasonable station networks in the 1940s or 1950s, but even today large areas of the continent are data sparse (Figures 1 and 2). This contrasts sharply with Europe, and to a lesser extent, the United States, where dense observing networks have been in operation for a century or more.

Thus, to look at African climate over a period of decades or centuries, one must rely on a variety of heterogeneous and often imprecise data derived from several disciplines. For the more distant past, the best sources of information are historical records and geographical descriptions of drought and famine or floods, agriculture, harvest quality, landscape, lakes and rivers, and climate and weather. Among the great variety of available sources are archives, local chronicles, the ancient works of Arab

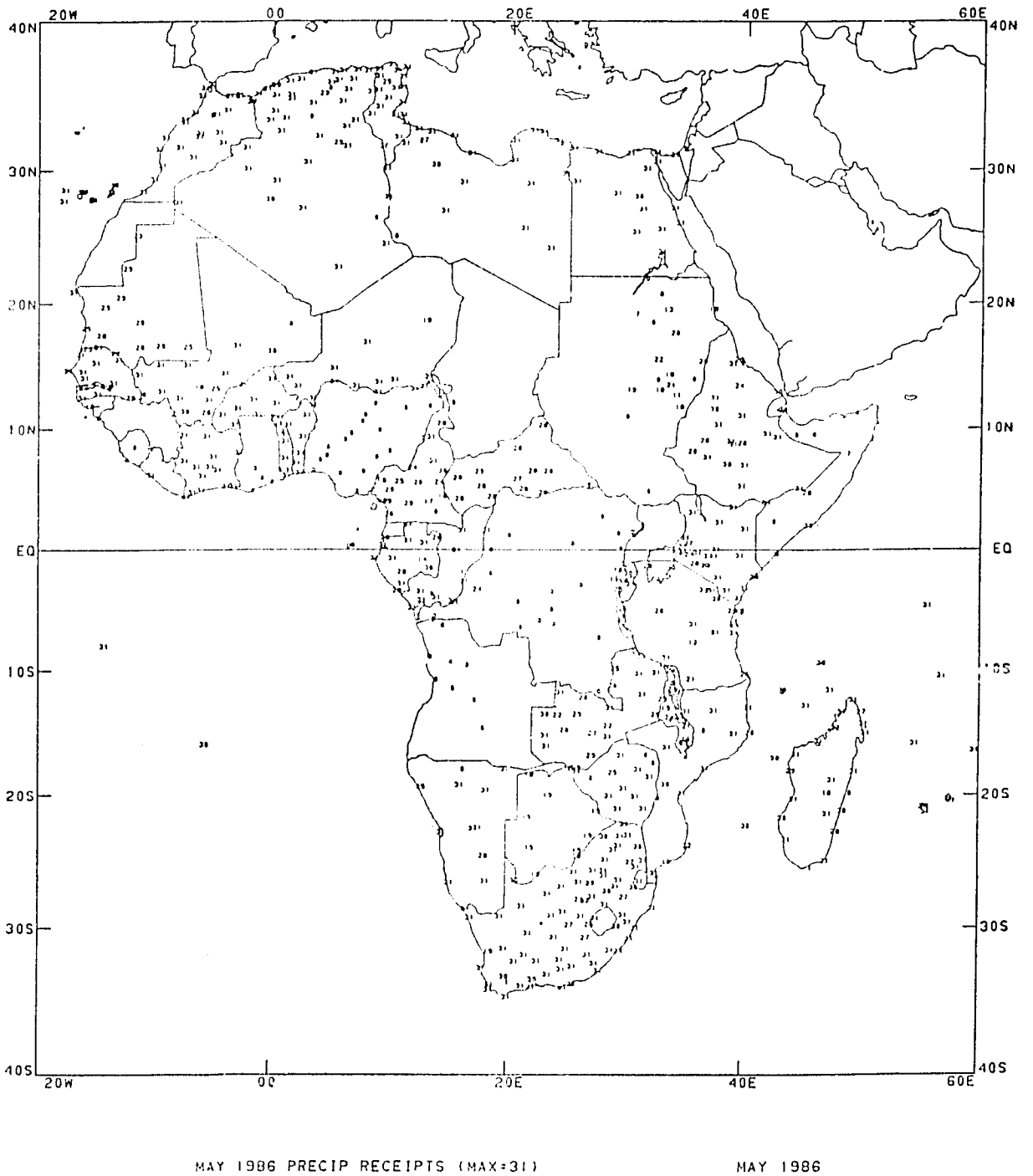

Figure 1 The number of days during May 1986 when reports to the world meteorological centers were received from African weather stations that measure precipitation. It is difficult to obtain many long-term records of precipitation from such a loose network--far more difficult, in fact impossible, to ascertain accurate, long-term, large scale rain distribution patterns useful to most climate research applications. Each station should score a "31," representing a report received in the World Weather Watch of the WMO for each day of the month. (Source: NOAA, National Weather Service)

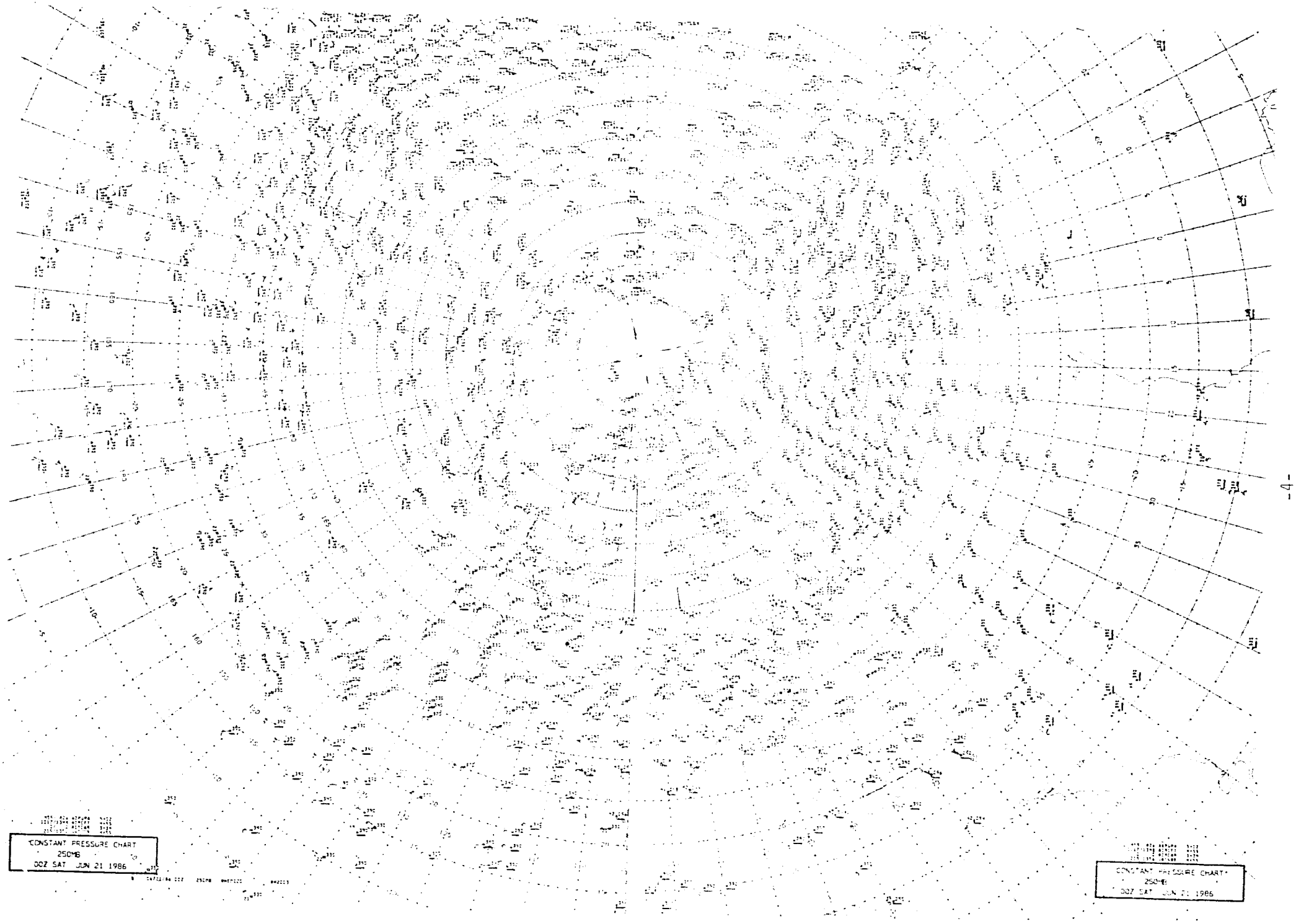

Figure 2

Figure 2 (Opposite) The distribution of Northern Hemisphere upper-air observation for one global standard reporting time (midnight GMT, June 21, 1986). Reports include balloon-borne instruments, aircraft reports, and applicable satellite soundings. Africa is in the upper right of the figure. Observations critical to determining wind, pressure, and moisture fields are less dense over Africa north to the equator than observations over much of the open oceans. (Source: NOAA, National Weather Service)

geographers, the journals of travelers and settlers, ships' logs, maps, early geographical journals, colonial reports, newspapers, and information derived from lake sediments and, in a few areas, tree rings. Only a fraction of these records have been studied. The best long-term, continuous record now available is that of Lake Chad; it provides a quantitative "calibration" of many of the other indicators. For direct measurements, Lamb et al (1986), using rain/gauge data beginning in 1941 from twenty stations just south of the Sahara Desert, show the startling downward trend in rainfall from the early 1950s (Figure 3).

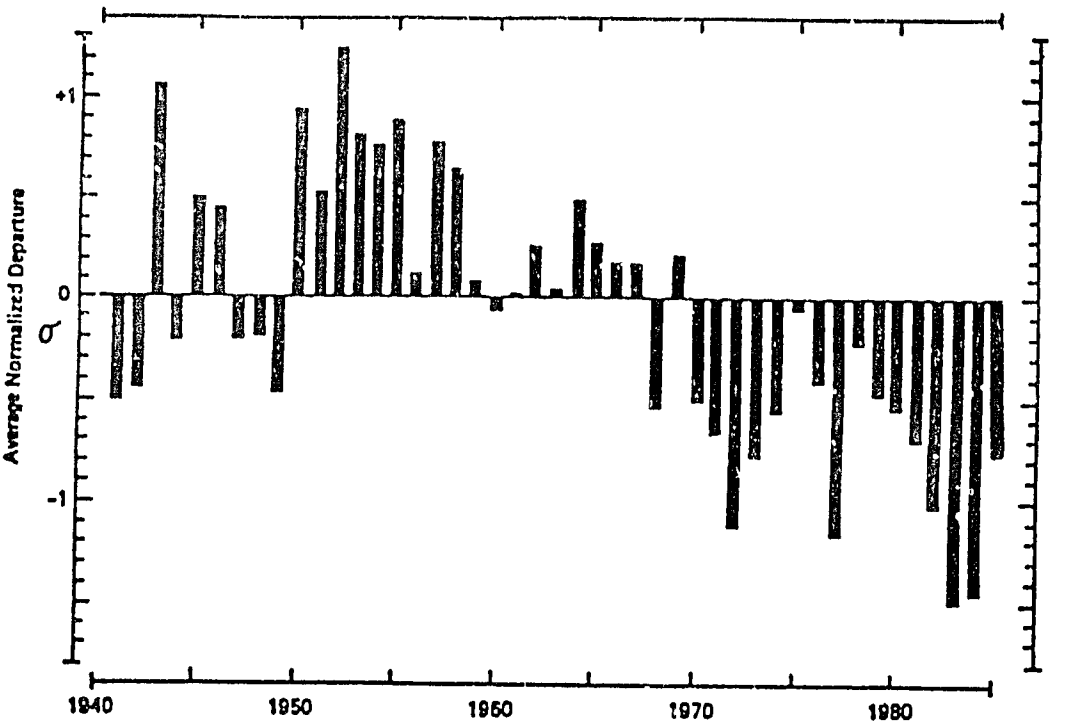

Figure 3. A rainfall index from 1941 through 1985, computed by averaging rainfall departures from normal for 20 stations in the West African Sahel. Note the downward trend in rainfall from the early and mid-1950s to the present. (Source: P. Lamb et al, 1986)

Because of the paucity of modern observational data, the WMO is committed to upgrading the existing meteorological network. This is an essential step in providing real time assessment capability for Africa and for providing necessary data for global climate models. Workshop participants suggested several specific data improvements to the African network and encourage the United States through the WMO to consider their implementation. One principal recommendation includes development of a greater number of upper air stations. Pilot balloon (PIBAL) observations of low-level winds would provide a wealth of information necessary to determine moisture and heat flux into precipitation systems. These observations are simple and inexpensive compared with radiosondes,

where complex payloads are carried to greater heights, tracked electronically, and require a more highly trained team of operators. From such a beginning could evolve, from the best of the PIBAL stations, a smaller network of radiosonde sites. The combination of many low-level wind observing sites with a few sites from which wind, temperature, humidity, and pressure profiles are taken through most of the troposphere is ideal for the problem at hand. Establishing such a network, with a plan for acquisition of expendable supplies, and with appropriate communication links and centers for analysis, would be a major step in establishing cooperation among nations, developing an indigenous technical capability, and providing data necessary to meet the long-term goals of African weather and climate research and services.

In addition to modernizing and expanding the current observational network, an inventory of historical climate data is needed. Workshop participants identified significant untapped data sets which include the U.S. Air Force 1945-1970 collection of global data.

Although few stations measured vertical profiles of wind, temperature, and humidity before the late 1950s, wind profiles were routine in many African countries in the 1930s and 1940s. Upper air data can be located for select years (e.g., the locust project of 1954-55, the IGY project of 1957-58, the Global Atmospheric Research Program (GARP) projects, and the West African Monsoon Experiment in 1978-79). Data available at the National Center for Atmospheric Research, National Climatic Data Center, and Florida State University can be combined with recent aircraft and satellite data to create more complete views of African climatology.

Climate data for 546 African stations gathered under a WMO project have been published by NCDC. This file has recently been extended, largely through the efforts of Dr. Sharon Nicholson, to include 1,087 African stations. The expanded file of station data usually begins between the late 1800s and 1920, and extends to 1973. A full description of these data is being prepared as an NCAR Technical Note by Nicholson et al (1986). Archiving and compiling historical data is a crucial international task because, in many cases, data are in imminent danger of being irretrievably lost (in fact, this happened during the recent war in Chad). Similarly, much information is archived outside Africa (preserved in such countries as the U.S.A., France, Belgium, Portugal, West Germany, and Great Britain), but is in bits and pieces not amenable to research.

Fortunately, data preservation efforts are under way. These include projects supported by ASECNA and ORSTOM in France, by WMO in Belgium, and by the AGRHYMET centers operated or planned in several African countries. More assistance must be given to national meteorological services to preserve data, with closer cooperation between African meteorological services, WMO, and other countries. This assistance and cooperation can be combined with upgrading of local meteorological services recommended in the next section.

1.1.1 Other Data Sources

Information on river flow, vegetative cover, desertification, and other land surface characteristics is important in climate model development;

forecasting these variables may also be desired. Ocean data, particularly from the adjacent Atlantic and Indian oceans are important also. Assessing the causes and nature of future drought will require these and more data collected worldwide by many nations under the World Climate Program (WCP). Substantial efforts by the WCP are underway to routinely assemble and analyze such data.

1.1.2 Development of Satellite Products

Satellite data have been used successfully to estimate precipitation amounts, and NASA is investigating the possibilities of measuring precipitation rates from satellite-borne sensors in a project called TRMM (the Tropical Rainfall Measuring Mission). While existing and planned satellite systems will fill most needs, ambiguity and uncertainty are inherent in retrieval and interpretation of the observations. Care and rigorous study are essential to avoid misinterpretations. For example, the potential of a vegetation index as an indicator of surface latent heat flux or rainfall has yet to be fully explored or validated; similarly, the use of a number of different satellite-based techniques for the estimation of evapotranspiration and soil moisture and components of the surface radiation budget have only recently been the subject of precise scientific study.

Three satellite-dependent research projects are directly relevant to investigation of African climate: the International Satellite Land Surface Climatology Project (ISLSCP); the International Satellite Cloud Climatology Project (ISCCP); and TRMM. Workshop participants recommend the strengthening of these ongoing efforts to tailor some applications to African studies.

1.2 An Infrastructure for Observations and Communication

Experience shows that isolated collections of data cannot easily be assembled into coherent sets for larger scale analysis. A major weakness in the existing infrastructure for Africa is the absence of diagnostic or forecast centers where data sets can be combined and used for climate prediction. It is necessary to develop this capability. Such centers, admittedly a long-term objective, could be tied to training activities for technical personnel from participating countries. By the year 2000, three or four such centers spanning the global tropics could become an integrated system for tropical forecasting. These centers would require satellite links to receive and disseminate information. The cost of developing such centers is high and their development must be part of an overall plan for data observation and dissemination.

The need for such an infrastructure and its composition can be defined, but appropriate international mechanisms to accomplish the act also must be defined and implemented. Workshop participants recommended that the United States take the lead in organizing a conference of interested parties to explore needs and options for developing this infrastructure. Existing organizational frameworks should be urged to join in the planning, such as the CILSS/Club du Sahel, the nine riparian countries of the River Nile, FAO, UNDP, the World Bank, and WMO.

The workshop participants encourage AID to initiate this collaboration effort with NOAA.

1.3 Causes and Trends of African Drought

Spatial correlation and time series, and analyses of worldwide rainfall data have shown that, on year-to-year time scale, periods of high and low rainfall affect wide areas of the tropics simultaneously. This simultaneity sometimes encompasses tropical regions of both hemispheres, even though Southern and Northern Hemisphere rainy seasons are six months out of phase. Although there can be links or correlations in the latitudinal direction, the strongest relationships are often in the longitudinal direction. A prime example is in the sub-Sahara Sahel belt, where rainfall anomalies are often coherent across 40° of longitude. The most recent drought of the 1980s also affected Sudan and Ethiopia, although rainfall in Ethiopia does not always vary in phase with the Sahel to the west.

Strong interannual variability is the dominant characteristic of rainfall in the arid and semiarid regions of Africa. In addition, West African rainfall data show a strong tendency for longer drought and wet regimes that persist for a number of years. For the Sahel-Sudan zone, the 1950s were wetter than the long-term average (Figure 3). Since 1965, every year has been drier than the long-term average. This persistence is also characteristic of the coastal West African zone and just south of the Sahel, albeit less marked (Lamb, 1976). For all other regions of Africa, persistence is no more or less than pure chance would indicate. Runs of more than three consecutive dry years are, therefore, rare. Rainfall time series for different regions show some weak periodical features, but these account for little of the overall variability. The strongest periodicities occur in southeastern Africa where they seem to be related primarily to the El Nino-Southern Oscillation (ENSO) phenomenon (Figures 4 and 5). Possible physical links with ENSO are being explored.

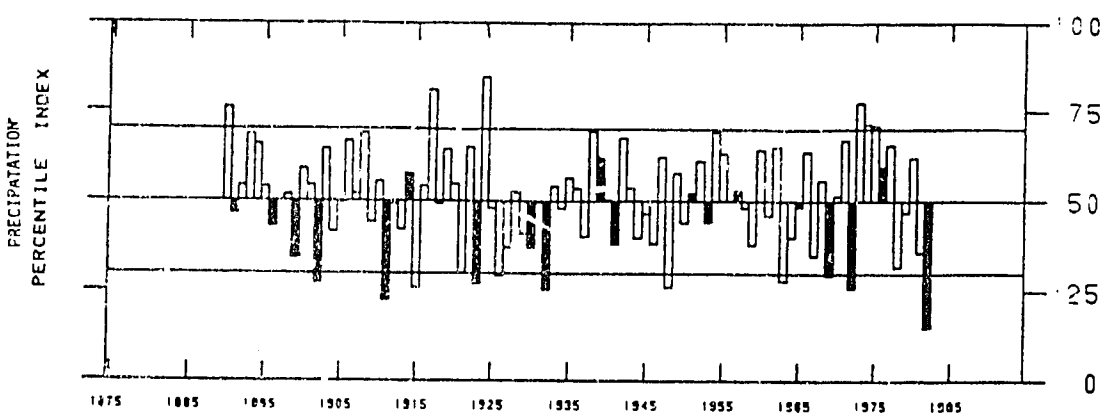

Figure 4. A time series of seasonally averaged precipitation for southeastern Africa. Solid bars indicate years where El Nino-Southern Oscillation (ENSO) events have occurred. Precipitation most frequently is below normal following initiation of an ENSO event. (Source: C.F. Ropelewski and M.S. Halpert, 1986)

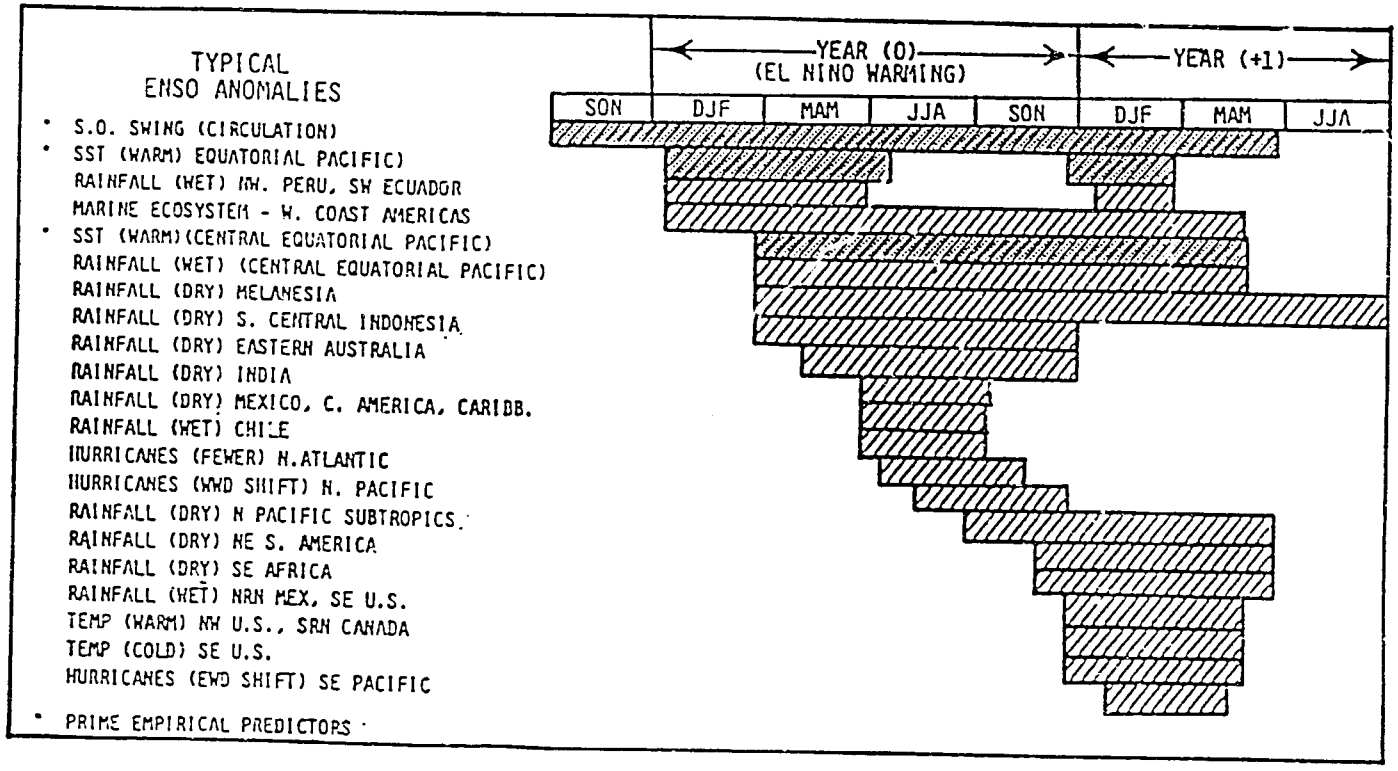

Figure 5. This diagram shows the sequence of major anomalies during a typical El Nino-Southern Oscillation episode. The pattern of lag relationships offers the potential for long lead time (several seasons) for dry conditions over southeastern Africa (Source: E.M. Rasmusson, 1986)

Improving our understanding of African rainfall fluctuations requires consideration of both global and regional-scale climatic processes. Knowledge of African meteorology and climatic systems is inadequate for explaining and modeling these fluctuations. In particular, links between global-scale fluctuations, (for example sea surface temperature and tropical wind fields) and African weather variability, are not adequately described and understood. The relationships between continental scale and rain-bearing weather disturbances are likewise poorly understood. These links must be identified through diagnostic studies and statistical analyses of observational data. This includes evaluation of the role of global teleconnections, surface heating fields, sea-surface temperatures, and planetary-scale phenomena such as the Quasi-Biennial Oscillation (QBO), El Nino-Southern Oscillation (ENSO) events and the 30- to 60-day atmospheric pressure wave. Midlatitude influences must also be considered, notably north of the Sahara and throughout much of southern Africa. Long-term (i.e., decadal) persistence of drought in the Sahel must be viewed in the context of long-term changes of general circulation features, atmospheric centers of action, hemispheric temperature gradients, sea-surface temperature, wind fields, and land surfaces.

Diagnostic studies are needed to understand the factors that initiate a dry or wet episode and to determine the factors promoting persistence of such episodes. While the former is likely to be connected to general atmospheric circulation and/or oceanic influences, the latter may be associated with surface forcing, requiring further analysis of the dynamic interaction between the land surface and atmospheric circulation patterns. These studies will contribute to an understanding of drought in general.

A final area of diagnostic analysis is the potential influence of African weather on the global tropics. Three aspects in particular warrant further study. The first is dust, produced over the Sahara and carried into the western Atlantic and Caribbean. This Saharan dust, and associated stable layers in the atmosphere, is often detected in southern Florida; potential effects on rainfall are not yet known. Second, Atlantic hurricanes can be traced to African easterly waves; hence, a relationship with Sahelian weather is possible. Finally, changes of surface influences on the atmosphere above and latent heat release associated with continental-scale patterns of drier or wetter conditions over Africa may influence circulation on a much broader scale. Central equatorial Africa is one of the major heat source areas of the world. Yet, to date, the degree to which Africa influences global climate has received very little attention. The extent to which these research questions can be addressed is assessed in the section on proposed research.

1.4 Determining the Predictability of African Drought

The theoretical limit to prediction of daily weather events is about two weeks. A characterization of climate, a statistical blend of weather events over a time period of two weeks or more, however, may be predictable in some cases over several seasons.

The ultimate predictability of African drought, in principle, can be estimated by empirical and modeling studies. For example, weather data can be analyzed and the high frequency, unpredictable daily weather events

can be separated as "noise" from the longer term climatic "signal," which may be predictable over much longer periods. Systematic examination of model experiments can address similar objectives in model atmospheres.

Realistic physical models of the coupled atmosphere-ocean-land system will be needed to clarify the causes of variability over Africa, and determine its predictability. These models will be complex because of the inherent nonlinearity of atmospheric dynamics, and because of complex interactions between atmosphere, land, and ocean. Such models will be used first to simulate the average climate (including the annual cycle) of the atmosphere and then to carry out controlled sensitivity and predictability studies. They must be backed by improved observational data. These studies may reveal various physical mechanisms responsible for interannual variability of atmospheric circulation over Africa.

Some complex models (general circulation models, GCM) have already shown great promise in simulating planetary scale circulation and its variability. However, special effort is required to improve treatment of land-surface processes, particularly for the African drought problem. For example, in current GCMs, sunlight reflectance of the earth's surface (albedo) and surface roughness are arbitrarily prescribed, but more realistic models must calculate these characteristics based upon the true nature of the surface, including vegetation.

Although current GCMs have several deficiencies, they have provided useful insights into the mechanisms through which land surface processes might influence local climate. For example, several experiments suggest that an increase in albedo and a decrease in soil moisture promote further reductions in rainfall. Likewise, in model experiments, a reduction in surface roughness diminishes rainfall over the Sahel, and overgrazing and deforestation are speculated to affect moisture recycling and consequently rainfall. These results suggest that observed changes in land-surface properties over the Sahel and/or the possibility of adjoining regions may contribute to observed rainfall fluctuations. Precise evaluation of these effects must await observations of greater detail and modeling experiments with more realistic (and detailed) treatment of land-surface processes. However, useful hints and insight into the possible causes of African drought, and possible mitigating actions that might be taken, can be derived from controlled modeling experiments. Some of these estimates could be available during the next five years as observations, analyses, and complex models continue to improve.

1.5 Forecasting Precipitation over Africa

It is useful to distinguish three different time scales for predicting drought. On the shortest time scales, up to one month, guidance from high-resolution numerical weather prediction (NWP) models will likely prove valuable. Although at an early stage of development, such models have provided deterministic forecasts of rainfall from specific sets of initial conditions. Several modeling groups have successfully experimented with forecasts over this time range. It is fair to say, however, that the skill and limits of NWP models have been assessed more reliably in the extratropics than in the tropics. A search for predictability over this short time range must investigate land and ocean boundary forcing variables. For example,

experiments with general circulation models have demonstrated that use of observed SST anomalies considerably improves predictions of monthly mean rainfall and circulation for the tropics. Other important variables might include local soil moisture content and albedo. There is evidence, for example, that effects of initial anomalies in soil moisture can persist long enough to influence an entire season.

On seasonal and interannual time scales, ocean surface temperature is a particularly important variable for studying predictability. For example, observations strongly suggest that ocean warming in the equatorial Pacific, characteristic of the El Nino event, influences rainfall over southern Africa. Hence, knowledge of development of an El Nino event could be used to predict African rainfall in certain areas.

A sequence of empirical relationships has been developed which identifies the connections and likely timing for climatic events following the initiation of an El Nino event. Figure 5 shows that drought in Southern Africa is associated with ocean warming nearly 1-year earlier. A major research objective is to quantify and model the physical relationships leading to this association.

While initial studies show some correlation of Pacific Ocean warming and drying conditions in southern africa, other studies are investigating links between changes in Atlantic and Indian ocean temperatures and drought in areas just south of the Sahara.

Recent work at the Illinois State Water Survey, the University of East Anglia, and the British Meteorological Office shows promise in the use of tropical Atlantic sea surface temperature in northern spring for predicting Sahel rainfall in summer. General circulation experiments indicate dynamic links between variations in Atlantic and Indian ocean temperatures and the strength and position of the rain-bearing intertropical convergence zone. This is particularly evident over South America; dedicated studies may demonstrate that the same is true for Africa.

There is much optimism for developing empirical climate prediction methods on seasonal to annual time scales, using global atmosphere, ocean, and land surface parameters as predictors of rainfall. The importance of these parameters could be tested in sensitivity experiments with general circulation models.

On decadal time scales, our ability to predict the onset or demise of a long period of drought is certainly limited by a very poor understanding of local land surface feedbacks and interaction with the large-scale planetary circulation. If decadal time scale variability is strongly coupled with ocean variability, for which there is some evidence (Folland et al, 1985), then prediction on these time scales depends on empirical and numerical models that can predict key processes associated with the coupled ocean and atmosphere system. In this respect, it is encouraging that simple equatorial models of the atmosphere and Pacific Ocean apparently show some skill in predicting El Nino events a year and perhaps more in advance (Cane et al, 1986). Such models are being extended to the Atlantic Ocean.

An experiment in climate analyses, forecasting, and applications is proposed as a collaborative effort among the AID Africa Bureau, the AID Office of Foreign Disaster Assistance, and the NOAA Climate Analysis Center (CAC). The five-year experiment would link climate information networks and prediction research with AID programs in emergency relief and foreign development assistance.

It is the prerogative of the user to determine what climate or weather information is most relevant, and to judge when such information has been improved. Two AID programs could form the applications component (1) the famine early-warning system, and (2) developing strategies for conservation of natural resources in Africa , setting program goals, and testing relevancy and applicability of climate information.

The forecast subprogram would draw upon existing resources now in the U.S. National Climate Program and the World Climate Program (WCP). A cross-cut of these programs reveals relevant ongoing activities which, given the proper platform, coordination mechanism, and seed money, would fill most of the important African program resource requirements. Drawing upon these, and filling gaps with new resources would form a strong climate monitoring and forecast component.

The experiment will:

- Describe and monitor current precipitation characteristics and distributions

- Examine and describe the most prominent rainfall characteristics of the past

- Study and report on observed and reconstructed precipitation and related climate characteristics to attempt to determine (diagnose) the causes of African drought and the potential human impacts on Africa's climate

- Examine and report on the value to development and assistance issues of more accurate and timely precipitation analyses, and of drought and precipitation long-range forecasts

- Determine the predictability of African drought episodes and regional precipitation variability over monthly, seasonal, and interannual time scales

- Where theory and data permit, conduct precipitation forecast and projection experiments for time scales of months to decades

- Recommend follow-on collaboration necessary to improve climate-related information for AID programs in general and the Famine Early Warning System program in particular.

2. FUNDING REQUIREMENTS

By exploiting existing climate-related programs (national and international) costs associated with the African program predescribed in this report would be far less than an effort launched on its own. Activities that would benefit from additional funds are described below.

DATA COLLECTION AND ANALYSIS

Historical data[1]
Satellite systems[2]

INFRASTRUCTURE FOR OBSERVATIONS & COMMUNICATIONS[3]

EXPERIMENT IN FORECASTING AND APPLICATIONS

Describing & monitoring climate[4]
Diagnosing cause of drought[5]
Testing information value[6]
Drought predictability and forecasting[7]

[1]Search, inventory, assembly, formatting, analysis and archiving of historical data; proxy data collection and analysis; includes upper air, land, and ocean surface networks and historical and proxy records.

[2]Satellite data collection and analysis, interpretation of remote sensing for surface moisture, roughness, temperature, and other weather/climate parameters. Establish access to analyses and install peripheral data transmission equipment for surface truth systems.

[3]Observation system improvement; an infrastructure for real-time data transmission, assembly, analysis, access, and archiving; training and education; establish data processing and access systems to enable African countries to supply needed data.

[4]Search, inventory, assembly and routine collection of data for real-time monitoring and description of African climate, past and present; design and make accessible information products.

[5]Data analysis; statistical, empirical and numerical model studies of the causes and characteristics of African drought and the climate processes assumed associated with it.

[6]Assemble and assess climate information products; advise and guide researchers in product needs and program goals.

[7]Empirical, statistical, numerical model studies of African drought predictability; long-range forecast experiments using statistical, synoptic, and dynamic modeling methods, in real-time and in retrospect for test and evaluation by user.

3. SUMMARY

What is the status of research on African climate?

Substantial advances have been made in understanding short-term climate variability, particularly in the tropics. Empirical relationships have been identified which provide a reason for optimism in improving prediction of major tropical rainfall perturbations on seasonal time scales, and perhaps longer in some regions.

It is time to go beyond the mere assembly and analysis of data on past African climates and major drought events to reach for a physical understanding of the climate processes responsible, using diagnostic and numerical modeling capabilities.

What are the bases for determining causes, trends, and recurrence of African drought?

Combining information from many sources, significant variability in African climate (precipitation) can be documented on time scales of decades to centuries, albeit with rapidly decreasing precision as more distant periods are approached. Data sets on atmospheric conditions have become sufficient for rather detailed analyses of global climate dynamics, and the major systems influencing Africa's climate.

Recent rapid growth in fundamental understanding and modeling capability has created a very favorable environment for advances in diagnostic and forecasting techniques.

What are the prospects for drought prediction, and is it time to establish a prediction research program to support policy decisions on Africa?

A scientific breakthrough has been made in understanding interannual variability of the tropical climate and its global connections. This breakthrough is related to a capacity of major tropical rainfall anomaly patterns to lock in anomalous states of circulation in the tropics, interacting with oceanic and land surface conditions in the process.

The notion that an experimental forecast activity could at this time be expected to yield usable information within a reasonably short time from startup was a basic premise for this workshop. This premise has been upheld by the workshop proceedings.

What is the recommended research agenda?

A strong effort toward experimental forecasts puts almost the same demand on model development as does a push toward deeper understanding through diagnostic studies. The main difference is that forecasts need current observations. The first payoff in the effort is an improved assessment of the potential for making forecasts; forecast experiments will follow closely.

The research agenda has three core areas:

1. Data base improvement. Mining the resources of past records may still lead to some important advances, but the buildup of an observation and data processing infrastructure in Africa (under current consideration) is essential. Even present efforts at WMO to help modernize African weather services should be encouraged.

2. Physical model implementation. Principal interest is in rainfall prediction. This is where the main development effort is needed. One is not dealing with an independent effort here, but rather with an augmentation of ongoing development work in extended range forecasting and global climate modeling. A modest group of researchers, with access to existing computer facilities, could make a major impact. Diagnostic studies and numerically based forecast experiments will point the way for more scientifically satisfying numerical model representations of African climate as part of the global climate system.

3. Remote sensing development. Encourage remote sensing studies that may permit space-based observation of rainfall rate (as in the proposed NASA Tropical Rainfall Measuring Mission) and amounts (based on cloud reflectivity matched with surface ranges). Further development of remotely sensed vegetation indices from satellite platforms is highly recommended. This research will have three significant objectives: (i) an indication of rainfall and moisture distributions to augment insitu methods; (2) a vegetation, earth-surface observation system for real-time input for boundary conditions in numerical model forecast experiments, and (3) comparisions of indices of surface conditions with outputs from physical models, which will lead to experimental predictions of surface conditions.

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Appendix A

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Appendix B

ACRONYMS

AGRHYMET	An organization for training in agro- and hydro-meteorology
AID	Agency for International Development
ASENCA	Agence pour la securite de la navigation aerienne en Afrique et a Madagascar (mainly forecasting for aircraft)
CAC	Climate Analysis Center
CILSS	Comite Interetats pour la Lutte contre la Secheresse au Sahel (Permanent Interstate Committee for Drought Control in the Sahel)
ENSO	El Nino - Southern Oscillation
FAO	Food and Agricultural Organization
FEWS	Famine Early Warning System
GARP	Global Atmospheric Research Program
GCM	General Circulation Model
IGY	International Geophysical Year
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land-Surface Climatology Project
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center
NCPO	National Climate Program Office
NOAA	National Oceanic & Atmospheric Administration
NMC	National Meteorological Center
NSF	National Science Foundation
NWP	National Weather Prediction

ORSTOM	Office de la Recherche Scientifique et Technique Outre - Mer
PIBAL	Pilot Balloon
QBO	Quasi-biennial Oscillation
SST	Sea Surface Temperature
TRMM	Tropical Rainfall Measuring Mission
USAID	United States Agency for International Development
UNDP	United Nations Development Program
WCP	World Climate Program
WMO	World Meteorological Organization