PREDICTING DROUGHT ON SEASONAL-TO-DECADAL TIME SCALES

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Drought, especially prolonged multiyear drought, has tremendous societal and economic impacts on the United States and many other countries throughout the world. Estimates of the costs of drought to the United States alone range from $6 to $8 billion annually, with major droughts costing substantially more (e.g., $39 billion in 1988). In April 2003 the Western Governors' Association, in partnership with the National Oceanic and Atmospheric Administration (NOAA) wrote a report titled "Creating a drought early warning system for the 21st century: The National Integrated Drought Information System" (NIDIS 2004). The basic idea behind the National Integrated Drought Information System (NIDIS) is that it should take a proactive approach to reducing or mitigating the impacts of drought. Fundamental to this objective is improved monitoring and forecasting capabilities. The NIDIS report is available online (www.westgov.org/wga/publicat/nidis.pdf).

OBSERVATIONAL AND MODELING REQUIREMENTS FOR PREDICTING DROUGHT ON SEASONAL-TO-DECADAL TIME SCALES

WHAT: More than 100 drought researchers and others from multiple nations met to accelerate programs on drought prediction, and to facilitate water management and agricultural applications for the Americas.
WHEN: 17–19 May 2005
WHERE: University of Maryland

NOAA has been designated as the lead federal agency for coordinating the implementation of NIDIS, a task that involves coordination among all of the relevant federal and nonfederal partners, scientists, water users, and policy makers. In that regard, a key recommendation of NIDIS is that it must "facilitate the coordination and program delivery

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A supplement to this article is available online (DOI:10.1175/BAMS-88-10-Schubert)

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DOI:10.1175/BAMS-88-10-1625

In final form 21 June 2007

across interagency, intergovernmental and private sector science and research programs by establishing an integrated federal drought research program." The report specifically recommends improving capabilities to monitor, understand, and forecast drought, and encourages all relevant federal agencies, in cooperation with the NIDIS Implementation Team, to expand their drought research portfolios by undertaking an analysis of existing research and identifying gaps that would guide funding and priorities for future drought research. Additionally, federal agencies participating in the coordinated research program under NIDIS should commit a percentage (no less than 5%) of their research budgets to drought issues.

NOAA has recently completed the development of an implementation plan for NIDIS. The National Aeronautics and Space Administration (NASA), in coordination with NOAA, is also engaged in planning for NIDIS as part of an overall strategy to implement key aspects of the international Global Earth Observation System of Systems (GEOSS) strategic plans. In fact, the U.S. Integrated Earth Observing System Strategic Plan (IEOS 2005), as this nation's contribution to the GEOSS 10-Year Implementation Plan, has embraced NIDIS as one of six high-priority near-term opportunities (NTOs).

It is during this early phase of NIDIS that both NOAA and NASA are looking to the research community for specific guidance on research priorities for improving drought prediction and monitoring tools.

The planning for this workshop originated as a grassroots effort to bring together researchers and members of the applications communities to help determine what is needed to accelerate progress on drought prediction. The timing of the workshop was largely a reflection of recent successes in improving our understanding of the causes of long-term drought, and as such was aimed at building on this momentum to help foster drought research and ensure that research addressed the most pressing needs of the various applications communities. While not specifically geared to NIDIS planning, the workshop has set goals that very much coincide with those of NIDIS, and the recommendations coming out of this workshop should help the agencies' needs for guidance.

WORKSHOP FINDINGS. Drought is a natural disaster that, within the United States, is dealt with through crisis management at a cost to the U.S. Treasury of tens of billions of dollars. A key message that came out of the workshop was the following: With increasing vulnerability to drought, a shift is needed to a risk-based approach aimed at better monitoring, early warning, and prediction of drought. A risk-based approach will encourage wiser stewardship of our agricultural lands, forests, and water resources.

Progress toward a risk-based approach will require improved coordination between the climate research and applications communities, as well as prioritizing research that is most likely to improve risk management. Results presented at the workshop indicate that a shift to risk management based on climate prediction is now feasible because climate research has advanced to the point that 1) probabilistic forecasts of precipitation and soil moisture can be performed on seasonal-to-interannual time scales, 2) the causes of multiyear droughts are being unraveled, and 3) because this work has shown that tropical SSTs are important for forcing the circulation anomalies that create drought, there is real hope that drought conditions (potentials) can be predicted (nowcasted) with useful lead times on interannual and longer time scales.

Drought monitoring and early warning. Currently, the online U.S. and North American drought monitors are the main vehicles for communicating the past and current status of drought to users. These have been successful and popular, partly because of their simplicity; but, they could be improved by becoming more quantitative and expanding into the presentation of different maps for agricultural and hydrological drought, and specialized maps for different users, and the incorporation of future soil moisture measurements, among others. Going beyond the drought monitors to the establishment of a drought early warning system will require soil moisture estimates either from direct measurements or from land data assimilation systems (LDAS). LDAS are currently in an experimental stage and efforts must be accelerated to develop accurate systems that have also been validated against historical records. Drought monitoring is currently constrained by a lack of high-spatial-resolution soil moisture measurements, satellite data of insufficient vertical depth, and poor knowledge of the snowpack that melts each spring into the summer water supply. Further, monitoring drought needs to be integrated with real-time attribution studies that can assess the causes of a drought and the probability of its continuation or termination.

Drought prediction. Modeling work has now attributed the major North American droughts of the last century-and-a-half to global circulation anomalies forced by tropical SSTs, with the tropical oceans playing an important, and probably dominant, role. On the seasonal and longer time scales, successful drought prediction will require the following several steps: 1) a successful SST prediction, 2) a successful simulation of the global circulation response to the SST anomalies, and 3) a proper account of the land–atmosphere interaction that converts a precipitation anomaly into a meteorological or hydrological drought. Current climate prediction capacities are limited to those associated with ENSO, a capacity developed two decades ago. Now, there is a need for efforts to examine the predictability beyond the interannual time scale and in other ocean basins. In this regard it is important to realize that, for multiyear droughts, the observed precipitation reduction averaged over the drought can be simulated by climate models forced by only the small change in mean SSTs during the drought interval (e.g., the 1930s); knowledge of the detailed ENSO variability and variance that make up a drought period is not required. Such forecasts, if successful, could be used to, for example, assess the likelihood of a drought continuing for a few more years as a result of a persisting La Niña–like state.

Drought prediction—or drought hindcasts—require land–atmosphere reanalyses against which forecasts and hindcasts can be validated. Significant errors persist in the atmospheric moisture budgets of the current atmospheric reanalyses, which make them of limited use for the task of validating hindcasts. It needs to be determined where the problems lie and whether improved models, improved observations, or improved data assimilation offer solutions.

Climate prediction models have their greatest skill at large spatial and temporal scales. It needs to be determined what information users need. If models used in crop and water management require information not just on long-term and large-scale means, but also on weather variability and extreme events, then it needs to be determined whether either prediction models can provide this information or downscaling methods can fill the gaps.

Improving the past record of drought and the future of drought in a changing climate. As we move into the current century we will be dealing with a climate increasingly influenced by man. On time scales from years to decades, climate forcing scenarios will be used to project future climate using coupled models. For those projections to be trusted, long integrations of the unforced coupled models need to be examined to see if they produce droughts akin to those observed. Future projections of hydroclimate need to be examined in light of this and the changes in the accompanying global atmosphere–ocean state as a means of assigning confidence levels to the projections. A better understanding of forced changes in hydroclimate will be aided by a better knowledge of past changes. Tree ring records of an even more arid climate than today that prevailed in the West for centuries during the Medieval period have raised considerable interest among users concerned by the likelihood of a man-induced return to such levels of aridity that would threaten much of the water use in the region.

User needs. As a drought prediction program gets underway it is important to develop a good understanding of the needs of the potential users of the forecasts. What are the desired spatial and temporal scales? What are the key quantities of interest? How do needs differ by region and application? The range of users is large and includes agriculture, energy production, transportation, tourism, forest and wildland management, urban water districts, and health care. Systems need to tailor forecasts to the needs of these users. For example, climate model forecast information could be integrated with high-resolution remote sensing and soil information as input to crop models that could be used to assess the feasibility of crop production. Forecasts must be provided to users, together with estimates of their uncertainty. Users need to know how uncertainties in forecast precipitation and temperature propagate into uncertainties in the quantities they need to know—soil moisture, streamflow, reservoir levels, ground water, and snowpack.

Determination of drought costs and forecast value. Although drought costs the U.S. government tens of billions of dollars a year (during a drought) there is no systematic effort to determine drought impacts. Methods need to be developed that measure the different impacts, including both primary and secondary impacts. This is required as a precursor to measuring the value of forecasts. Forecasts can be of value if their use leads to fewer government costs, as well as less loss to water users, less social disruption, equity of access to water, and protection of new users.

To facilitate drought-related decision making, scientists and users need to begin using a common language and tools that relate historical data and forecasts to a water manager's perspective. Managers also need tools with which to present climate information to stakeholders. This will best be accomplished through interactions that are maintained over time, whereby scientists are involved in the drought-planning process and water managers are involved in the climate research and prediction process. It is important to have forums that will bring the different communities together to share varying perspectives and to develop communication.

SPECIFIC NEEDS. Progress on the overall drought problem will require tight coordination and strong support for three elements of ongoing and new drought research. We have attempted to prioritize the research, modeling, observational, and other needs (with the highest-priority items listed first) of each element.

1) The short-term drought problem will require a coordinated effort in drought monitoring, prediction, and early warning, in support of NIDIS. It is proposed that a "National Drought Attribution and Prediction Consortium" (see the online supplement at doi:10.1175/BAMS-88-10-schubert) be created that uses multiple models and analysis techniques to address drought problems in coordination with stakeholders (as outlined in element 3, below).

   This problem's resolution will also require the establishment of long-term (multidecade) climate records that are adequate for retrospective studies and, as required, for initialization, calibration, and validation. These include global and regional atmosphere–land reanalyses, which focus on the improved representation of the hydrological cycle.

   Improving (real time) observation/assimilation of key surface variables will be required for monitoring, model initialization of, and/or validating (with uncertainty estimates) short-term drought. Such variables include soil moisture profiles (e.g., a monitoring system focused on "sensitive" regions, such as a pilot effort focused on the Great Plains), snowpack, forcing data (precipitation, radiation, etc.) for land data assimilation, vegetation properties [e.g., from the Normalized Difference Vegetation Index (NDVI), Emissivity Difference Vegetation Index (EDVI) Moderate Resolution Imaging Spectroradiometer (MODIS) data], surface temperature, and streamflow.

   Improving the coupled (atmosphere–ocean–land) model prediction system will require a focus for development on teleconnections between SST variations and continental precipitation, on weather statistics (particularly extreme events), on land–atmosphere interaction, and on surface/subsurface water reservoirs (including estimates of recovery time).

   Understanding the roles of local and remote processes on drought variability and predictability, as a function of time scale, can be improved through a better understanding of the role/predictability of a) drought-related SST variations (including ENSO), b) subsurface land water, and c) short-term atmospheric variability [e.g., weather, Madden–Jullian oscillation (MJO)].

2) The long-term drought problem will require fostering research on the mechanisms that control the land surface branch of the hydrological cycle at multiyear (decadal) time scales. Such research areas include

   - decadal ocean variability in the context of regional drought,
   - connecting ENSO and other shorter-term SST variability to the initiation and demise of long-term drought,
   - deep soil moisture variability (drought unforced by SSTs),
   - aerosol feedbacks (i.e., the Dust Bowl),
   - decadal vegetation feedback,
   - global change, and
   - drought migration.

   A research effort focusing on the causes of historical droughts will also be required. This includes the production of multiyear-to-decadal hindcasts of past droughts, and studies to characterize drought duration, seasonality, and spatial extent. It also includes the development and improved use of paleodata for estimating decadal- and longer-term drought variations, including megadroughts.

   Improving simulations of hydrological variability on decadal time scales will require development focused on simulating realistic decadal SST variability and teleconnections to regional drought, as well as realistic simulation of subsurface water on decadal time scales.

   To foster research on the predictability of multiyear-to-decadal drought, the focus needs to be on assessing the predictability of SST variability related to long-term drought, as well as the predictability of both the onset and demise of drought. Additional research will need to focus on experimental forecasting of droughts on a multiyear time scale.

OVERARCHING RECOMMENDATIONS

The key recommendation of the workshop is that an interagency [NASA, NOAA, National Science Foundation (NSF), Department of Energy (DOE)] drought research program should be initiated that would focus ongoing and new drought-related research on the definition, predictability, and prediction of drought, and on the utilization of this information by stakeholders. It is further recommended that the program be established within the next three years as a central part of the agencies planning activities for the NIDIS. A drought prediction consortium (see action 1 below; described further in the online supplement at doi:10.1175/BAMS-88-10-Schubert) is recommended as a high-priority initial coordinating and focusing activity of the program. The program would consist of the following three elements:

Short-term drought: Improve definition, attribution, and prediction on subseasonal-to-interannual time scales.

Action 1: Form a national consortium of prediction centers and drought researchers that would use existing tools, models, and observing systems (monitoring) to assess the quality of monthly to interannual forecasts of precipitation and other hydrological quantities. This consortium would also investigate the impact of new observations and the utility of new forecasting techniques (such as multimodel ensembles), perform observing system sensitivity studies related to hydrological variables, and make recommendations for the improvement of observing systems and modeling–assimilation systems.

Long-term drought: Improve understanding of the mechanisms of decadal drought and its predictability, including the impacts of SST variability, deep soil moisture variability, and the impact of global warming.

Action 2: Consolidate multiagency research efforts into a program that will address the mechanisms that control the land surface branch of the hydrological cycle at decadal time scales. The program would include basic research on the causes of historical droughts and would assess the usefulness of coupled climate models for drought-related diagnostic and predictability studies. The program would also support the use of paleodata for improved estimates of current drought risk and would assess potential effects and implications of long-term drought predictions for policy/planning/etc.

Utilization of drought predictions: Transition improved monitoring–prediction–attribution tools to operations; bridge the gap between hydrological forecasts and stakeholders (utilization of probabilistic forecasts, education, forecast interpretation for different sectors, assessment of uncertainties for different sectors, etc.).

Action 3: Provide a focal point among agencies with drought research interests that will facilitate transition of research advances into operations. It should support interaction with the user community (e.g., NIDIS) to define aspects of drought that are most useful to predict and improve how drought information is conveyed, and it should foster collaboration/coordination with neighboring countries (e.g., the Canadian Drought Research Initiative).

3) Utilizing and conveying drought information will require coordinating the development of new drought indices to link assessment, monitoring, and prediction efforts. Work with stakeholders and the drought monitor community to develop objective indices useful for validation of drought predictions is of primary importance. Facilitating the incorporation of new land surface monitoring tools (outlined under the short-term drought problem element above) into new drought indices is also important.

Improvements in the conveyance of drought predictions to stakeholders will require improved definition(s) of the onset and demise of drought, the development of more objective and applications-specific drought indicators, and improved predictions of variables (beyond basic hydroclimatic variables) that are directly linked to user needs (e.g., vegetation stress, quantities affecting rangeland and forest health, dust transport, etc.). Work with stakeholders to revise traditional drought response strategies, taking into account the probabilistic nature of forecasts, will also be needed.

Additional requirements to utilize and convey drought information include interagency support for the transfer of research results into operations (e.g., collaboration in efforts such as the NOAA Climate Test Bed), and an improved collaboration/coordination with neighboring countries (e.g., the Canadian Drought Research Initiative).

ACKNOWLEDGMENTS. Funding for the workshop was provided by the NASA Programs on Modeling, Analysis and Prediction, and Terrestrial Hydrology, and NOAA's Climate Prediction Program for the Americas. Additional support was provided by NASA's Global Modeling and Assimilation Office. Max Suarez made substantial contributions to the formulation of the recommendations and provided editorial assistance.

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