Developing Seasonal Predictive Capability for Drought Mitigation Decision Support System

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Drought Monitoring Decision Support System

The Drought Monitor Decision Support System (DM-DSS), in response to the need for accurate, centralized drought information, provides a weekly overview of where drought in the United States is emerging, lingering, or subsiding. The Drought Monitor (DM) (http://drought.unl.edu/dm/monitor.html) is produced jointly by the National Oceanic and Atmospheric Administration's (NOAA) Climate Prediction Center and National Climatic Data Center, the United States Department of Agriculture (USDA), and the National Drought Mitigation Center (NDMC) at the University of Nebraska-Lincoln.

The Monitor presents a single, easy-to-read color map that summarizes current information from numerous drought indices and indicators. The map uses a new classification system based on a ranking percentile approach to show drought intensity, similar to the schemes currently in use for hurricanes and tornadoes (i.e., D0-D4, ranging from abnormally dry to exceptional drought). The map also delineates regions experiencing longer-term hydrologic drought and shorter-term agricultural drought.

In related efforts, a limited number of forecast tools are being used to indicate whether drought will strengthen or weaken significantly over the coming three months. The forecast tools include the Seasonal Drought Outlook (SDO), developed by NOAA's Climate Prediction Center (CPC). The SDO is a blend of art and science, combining short- and long-term seasonal forecasts, which are still under development.

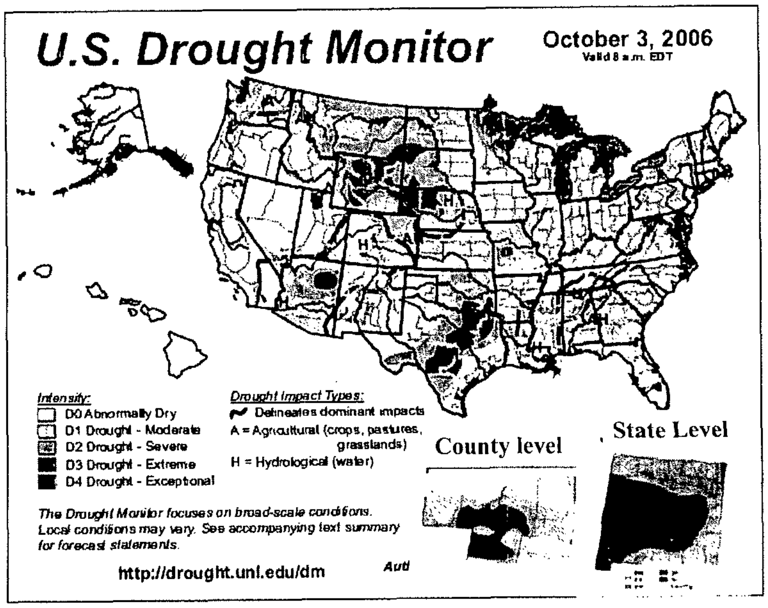

Figure 1: A drought map produced by DM-DSS. The degrees of drought (D0-D4, abnormally dry to exceptional drought) are characterized jointly by several drought indicators, including the Palmer Drought Index (PDI), Standardized Precipitation Index (SPI), CPC Soil Moisture, and USGS Weekly Streamflow. The final outputs also incorporate expert judgments. Recently, an enhanced version of the DSS was released with state-level breakdowns that include county lines, enabling decision makers to more readily identify drought levels in their locale (NDMC, 2006).

The DM-DSS has grown in importance since its inception and is now used as one of the determining factors to grant emergency assistance to agricultural producers and small businesses. It provides the general public, media, government officials, and others a common starting point for decision making. Since it was established in 1999, numerous users have benefited from the DM-DSS (Svoboda et al., 2002), which has taken advantage of significant advances in computing power and internet access to combine data from a wide variety of sources and quickly disseminate the product to end users. Table 1 represents a partial list of DM-DSS user groups that utilize the information provided by the DM-DSS. Numerous user organizations link their websites to the online DM-DSS, as a convenient way of obtaining timely information about drought conditions.

Table 1: Incomplete list of end-users of the DM-DSS

End Users	Decision-making issues related to drought
Farmers	Irrigation scheduling, crop insurance, planting provisions
Ranchers	Pasture, grassland health maintenance
Water managers	Drought mitigation plan, including water conservation, allocation, regulation, etc.
Policy makers	Drought response projects at federal, state, and local levels; contingency planning
Emergency agencies	Fire prevention, water shortage reduction, preparation of equipment
Health agencies	Hygiene, sanitation, and disease control
Environmental groups	Environmental quality monitoring (e.g., water quality, ecological habitats)
Economists	Drought damage, cost, and other socioeconomic losses
Insurance companies	Collaboration with federal crop insurance agency, and refinement of insurance premiums and level of coverage
Recreational businesses	Adjustment of schedules and collaboration with health and emergency agencies
Citizens	Water conservation, health and safety enhancement, vacation plan changes
Media	Information dissemination, warning, and new reports on drought events
Education agencies	School and community enhancements of water conservation, health protection, and safety, as well as natural disaster knowledge and mitigation methods

One of the urgent needs in regard to improving drought monitoring and outlook is to develop and incorporate the latest state-of-the-art forecast tools so that the DM-DSS can be used to indicate whether drought will strengthen or weaken significantly over weeks and even months into the future. Given the growing extent, intensity, and impacts of drought today, such improvements in forecasting will allow for significant national savings in economic damages.

With better short-term forecast and prediction capability, decision support information using probability-based outputs will be needed by the end users of the DM-DSS. Such information will be related to their particular drought management targets. For example, irrigation farmers will need to update their irrigation scheduling, and reservoir managers will need to update the storage operation rules. A decision analysis component that translates the drought prediction into specific decision making information for various users will make the DM-DSS and SDO more valuable to end users and strengthen the role of earth science research for more effective drought mitigation in the United States. The enhanced DM-DSS is expected to serve users with real-time decision support information regarding “what to do now”.

Earth Science Research Result

The DM-DSS is scientifically based on features such as climate, hydrology, and geography, and enhancing the DSS by using earth science research results is one of the goals of the DM-DSS developers (Svoboda et al., 2002).

Earth Science Models - GMAO, CFS, and NARR

Currently, NASA carries out experimental climate forecasts using the GMAO (Global Modeling and Assimilation Office) coupled atmosphere-ocean general circulation model (GCM) and its variations (http://gmao.gsfc.nasa.gov/cgibin/products/ climateforecasts/index.cgi), while the National Center for Environmental Prediction (NCEP) issues operational seasonal outlooks based on the composite of the CFS (Climate Forecast System, Saha et al., 2006) dynamic predictions and other statistical forecasts (http://www.cpc.ncep.noaa.gov/ products/predictions/90day/). GMAO and CFS predict, at a 10-month lead, global variations of daily sea-surface temperature (SST). These daily SST data will be used to drive the Community Atmosphere Model (CAM, Collins et al., 2006) to simulate the 6-hourly planetary circulation responses, which provide the lateral boundary conditions (LBCs). The GMAO Reanalysis (Rienecker, 2006) and the North American Regional Reanalysis (NARR) and its near-real time counterpart, the Regional Climate Data Assimilation System (R-CDAS)—all maintained by NCEP (Mesinger et al., 2004)—will be used to form the initial conditions (ICs) of atmospheric and land surface states for CAM and Climate extension of the Weather and Research Forecasting model (CWRF).

In summary, we propose to downscale and improve the NASA GMAO and NCEP CFS prediction of U.S. seasonal-interannual climate variations at regional to local scales, focusing on precipitation and hydrology, which are crucial for effective drought forecasting and mitigation. The interfaces between CFS, CAM, and CWRF are being developed under the support of the ISWS (Illinois State Water Survey) pilot study on seasonal-interannual climate prediction. Similar interfaces for GMAO are planned to be developed in collaboration with Dr. Siegfried Schubert at NASA GSFC.

Earth Science Data – MODIS and GRACE

MODIS will be assimilated into the coupled hydro-climatic model to improve the prediction of soil-moisture levels, a critical element for the improved hydro-climatological forecast using the CWRF. An effective scheme to accomplish this using the SEBS (Surface Energy Balance System, Su et al., 2002) framework has been developed by Chintalapati and Kumar (2007), using the land surface state variables (land surface temperature, vegetation properties, albedo, and emmissivity) from MODIS. MODIS will also be used to estimate actual crop evapotranspiration (ETA) in a hydrologic-agronomic simulation at the crop field scale, which will support irrigation scheduling decisions in this study. Wang and Cai (2007b) implemented the surface energy balance algorithm for land (SEBAL) (Bastiaanssen et. al, 1998) for estimating ETA from crop fields using MODIS data at the Terra platform.

The Gravity Recovery and Climate Experiment (GRACE) satellite mission is now providing data on terrestrial water storage variations at regional scales (> 160,000 km2). In this project, GRACE will be used to verify water storage simulated by the Common Land Model (CLM). GRACE will also be the data assimilation targets for the hydroclimate modeling. Moreover, by combining the GRACE data with auxiliary information on soil moisture and snow water storage, it is now possible to estimate changes in groundwater storage (Rodell and

Familglietti, 2002; Becker, 2006). For drought events occurring in larger regions over a longer period of time, groundwater storage prediction will be important for water supply, irrigation, and ecosystems related to aquifers.

Technical and Scientific Plan

Research objectives

The goal of this project is to develop the seasonal predictive capacity of the Drought Monitor Decision Support System (DM-DSS) using earth science models and satellite products. Such an enhanced DM-DSS will assist society's response to drought from a traditional "crisis management" scenario, which emphasizes emergency response, to a "risk management" approach, which places greater emphasis on preparedness planning and mitigation actions (Wilhite, 2002). We hypothesize that the DM-DSS improvement will be achieved through a systematic integration of earth science research results and PIs' previous and ongoing research in hydroclimate prediction and drought monitoring, forecasting, and management. We further hypothesize that a decision analysis component that translates the drought prediction into particular guidelines for **risk-based** decision making will make the DM-DSS more valuable to end users and strengthen the role of earth science research for more effective drought mitigation in the United States. Research objectives are to:

1. Incorporate into the existing DM-DSS the seasonal climate predictions from a state-of-the-art CWRF (Climate extension of Weather Research and Forecast model) coupled with an advanced terrestrial hydrologic model CLM-VAST (Common Land Model enhanced by 3D Volume Averaged Subsurface Transport with conjunctive dynamic upland and channel routing) to develop seasonal predictive capability within the DM-DSS, using various satellite products and models provided by NASA and NOAA.
2. Add a decision analysis component to the predictive DM-DSS that will help end users make appropriate decisions using probability-based drought information provided at a lead time of up to one season. Additional remote sensing data will be used to enhance decision models, such as using MODIS, to estimate crop evapotranspiration.
3. Assess the quantitative and qualitative enhancements within NASA's earth science model and remote sensing products by evaluating and comparing the baseline and benchmark levels of the predictive DM-DSS and relating them to stakeholders' perceived benefits.

An **integrated system solution (ISS)** will be designed to incorporate the NASA earth science model, Global Modeling and Assimilation Office (GMAO), climate and hydrologic prediction models (CWRF and CLM-VAST), and decision analysis modules into the DM-DSS. The ISS provided here is justified by the need to extend the coupled land-ocean-atmosphere models such as NASA's GMAO and NCEP's CFS so that the outputs from those models can be translated into decision support information. The forecasts or outlooks from the current version of those models are very general in nature and only provide probabilistic information about seasonal total precipitation and average temperature; there is no specific information that can be directly related to most impacts of climate. Although they have demonstrated certain skills in depicting large-sale signals identified with planetary circulation anomalies such as the most prominent El Niño-Southern Oscillation (ENSO), their practical applications are highly limited by insufficient spatial resolution and incomplete representation of regional surface boundary conditions (SBCs) and physical processes that are keenly important for climate prediction. Such regional phenomena are likely unpredictable by GCMs such as GMAO and CFS. On the other hand, regional climate models (RCMs) have been established as a valuable dynamic downscaling approach to bridge the gap between GCM simulations at global coarse resolutions and impact assessment applications at regional scales (Giorgi et al., 2001; Leung et al., 2003a,b; Roads et al., 2003; Han and Roads, 2004; Pan et al., 2004; Liang et al., 2004a,b, 2006a; Zhu and Liang, 2005, 2007). This success results primarily from the fact that RCMs resolve key physical processes (particularly surface-atmosphere and convection-cloud-radiation interactions) more realistically than GCMs. It is thus a natural step to apply advanced RCMs to downscale the GMAO and CFS products to provide fine-resolution, and likely improved, seasonal climate predictions. Objective 1 is to achieve the success of this critical step.

The objectives of this project are also justified by the need to assist end users of the DM-DSS in adopting a risk management approach to dealing with drought. As mentioned before, the current DM-DSS can only provide some qualitative messages about future drought trends and it mainly summarizes the current or nowcast drought conditions. Thus it supports "crisis management," i.e., supporting users to make tactical decisions in drought mitigation. The enhanced DM-DSS with prediction capability will provide future probability-based drought outlooks with qualified uncertainty (probability density function), which will facilitate proactive "risk management" (Objective 2). It will therefore support the users' switch from crisis management to risk management (Objective 3).

The DM-DSS **multidisciplinary research team** of PIs and Co-PIs includes researchers from the NDMC at the University of Nebraska-Lincoln, CWRF and CLM-VAST from the University of Illinois at Urbana-Champaign, and the Illinois State Water Survey. The team from the NDMC is involved in the prototype DM-DSS development and its inclusion in the National Integrated Drought Information System (NIDIS), which will directly connect this project to NIDIS. Co-PIs X. Liang and P. Kumar, who both have long-term collaborations with NASA, will be responsible for CWRF/ CLM-VAST development with GMAO and real-time earth science results assimilation. PI X. Cai and Co-PI J. Ryu, who both have expertise in systems analysis and drought management, will coordinate the system integration. **Collaboration with NASA** research staff has already been initialized for this project with Dr. Siegfried Schubert and his group at NASA GSFC, who are developing a sample data set of seasonal-interannual predictions based on GMAO. **Collaboration with end users** of the DM-DSS will be achieved by utilizing the NDMC's established connections with national and regional stakeholders to solicit interaction and feedback through the use of electronic and/or mail surveys (as described in later sections of this proposal). Additionally, two national associations (National Irrigation Association and National Corn Growers Association) and three state or local associations (Central Illinois Irrigated Growers Association coordinated by Mason County Farm Bureau, and Chicago Metropolitan Agency for Planning) have contributed letters of support for the proposed project's objectives (attached). The project will adopt a shared-vision approach based on interactions between end users and researchers in order to assess quantitative and qualitative enhancements to the DM-DSS and socio-economic benefits from the improved decision making enabled by the enhanced DM-DSS.

Methodology Overview – Integrated Systems Solution (ISS)

The diagram of Figure 2 shows the ISS "architecture" to integrate different components targeted for the final DM-DSS prediction. The solution is designed with a national perspective, given that the GMAO, CWRF, CLM-VAST and DM-DSS all serve at the national level, while the benchmark of the DM-DSS improvement will be conducted with soil moisture and streamflow forecasts in a focus area (Midwest) through the nested CWRF/CLM-VAST coupled with decision analysis at the local watershed level. The added decision analysis model that is specific to the application area of interest will be available at the start of the project and can be connected to the DM-DSS. Therefore, the system solution to be investigated in this project will be suitable in enhancing the DM-DSS that is currently used for drought monitoring across the entire country. Note that the CWRF and CLM-VAST represent cutting-edge science and techniques for hydro-climatic prediction studies (Liang et al., 2006; Choi et al., 2007), which are ready to integrate NASA NSIPP modeled products. The CLM is also built with a new land (bare and vegetated) surface albedo parameterization developed from MODIS and thus will assimilate the MODIS measurements (Liang et al., 2005).

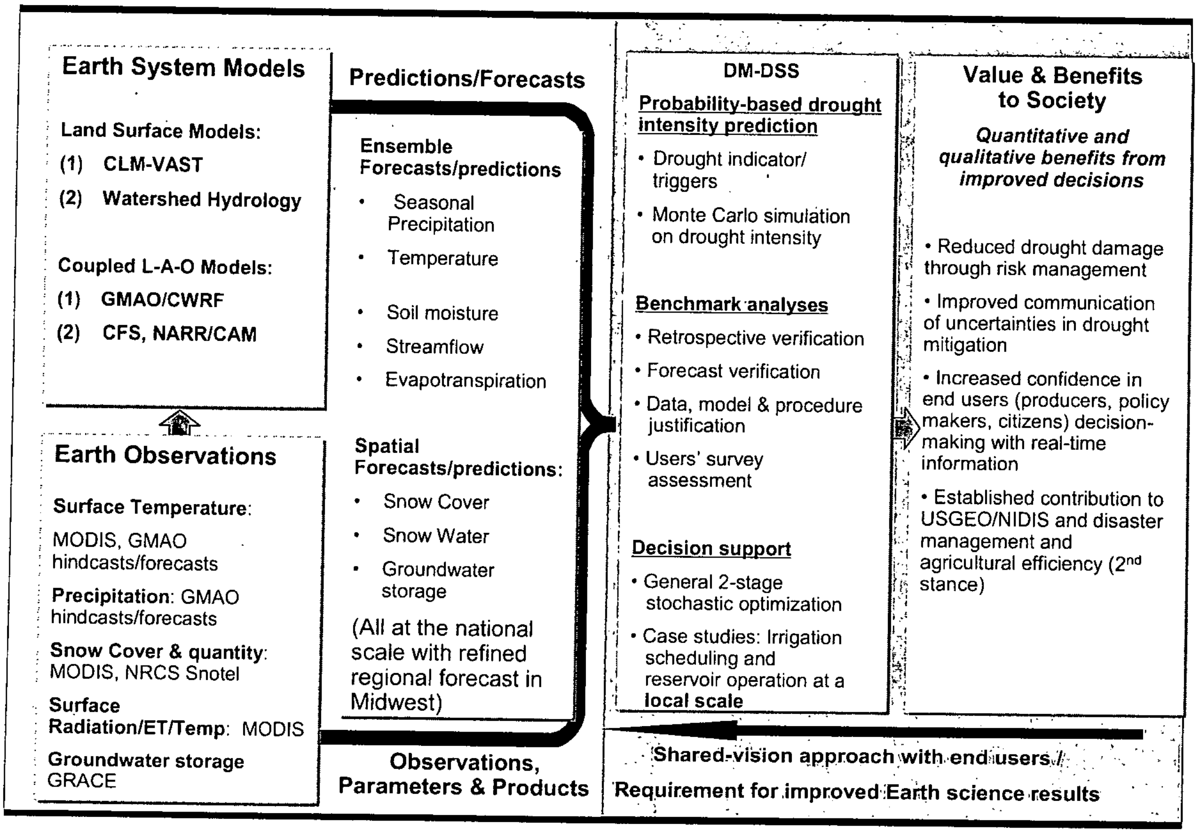

Figure 2: The architecture of the ISS using remote sensing data and models crossing multiple scales such as global, national, regional, and local.

The methods involved in the ISS architecture are briefly discussed in the following section. The technical details for each of the components are described in the description of research tasks.

Ensemble climatic and hydrologic prediction

The enhanced DM-DSS will have a more effective capability of assessing uncertainty involved in hydroclimate predictions and evaluating the impact of the uncertainty on drought mitigation decision making. The prediction tools (CWRF, CLM-VAST) include methods to characterize uncertainty in climatic and hydrologic forecasts. An ensemble prediction of precipitation, soil moisture, and streamflow will be conducted.

Probability-based drought forecast/prediction

The DM-DSS will receive ensemble predictions from the hydroclimate models and provide a probability-based drought forecast and seasonal drought prediction, as well as the monitoring of current drought levels over the country. This procedure will first derive the probability distributions of the key drought indicators using the ensemble hydroclimate results. Drought intensity is a function of the key drought indictors, and a standard Monte Carlo method will then be used to derive the probability distribution of the drought intensity.

Stochastic decision making analysis

To assist users in becoming more familiar with drought probability and risk assessment and utilizing these in their decision making, this project will add a real-time decision analysis component, which receives the ensemble drought prediction from the DM-DSS, and conduct a stochastic decision analysis. The decision problem can be understood as a two-stage process – "what to do now" and a "wait and see"component, based on the current and future predicted drought status. This process can be formulated as a probability-based two-stage stochastic programming model, which supports the immediate decision while providing a number of "wait and see" solutions dependent on which scenario unfolds (Birge and Louveaux, 1997). The decision variables will be a set of tactical and strategic drought mitigation measures, which could include irrigation scheduling, reservoir operation, and other engineering and financial (e.g., crop insurance) measures.

Although the stochastic decision procedure will be generic for any area, the model implementation will depend on local management problems and infrastructure conditions. During this project, the decision analysis component will be applied to two agricultural areas - the Republican River Basin in Nebraska and the Fox River Basin that includes a major part of the greater Chicago area. If this project is successful, a decision model for any area in the United States can be added to the DM-DSS.as one agent in the DM-DSS model base, provided that data are presented and decision objectives are defined for those areas. Therefore, the added decision analysis capability will be applicable to various region-specific drought management problems in the country.

Shared-vision modeling approach

This project will adopt the shared-vision modeling (SVM) concept. The terminology of SVM was introduced by the Corps of Engineers more than twenty-five years ago to describe the combination of systems-based planning, advanced public involvement, and stakeholder-driven models. Since that time, the approach has been adapted for use in drought preparedness (Loucks and van Beek, 2005). The purpose of SVM is to have stakeholders and other DSS users be involved in the project so that they learn about drought mitigation and institutional change options and may reach both a better understanding of other stakeholders' concerns and a common vision of system operation. Meanwhile the participants also provide feedback on project outcomes, which will help researchers to improve the technical development of the project.

In this project, end users of DM-DSS will participate in the project at two levels.

1) Nationwide users will be invited to respond to electronic surveys periodically throughout the development of the DM-DSS. The survey population will be composed of individuals who receive or provide periodic information from the NDMC through enrollment on list serves housed with the NDMC. The questions on the survey will ask the nationwide users about their perceptions of the DM-DSS, potential uses of the tool, and any changes they would like to see made to the functionality or content of the DM-DSS. Questions will be a combination of open-ended and Likert scale format.

2) Additional electronic and/or mail surveys will be distributed to agricultural producers and water managers within the Republican River Basin of Nebraska and the Fox River Basin in Illinois at the mid-development point of the project. The combination of the two river basins will provide a comparison of primarily rural water managers and agricultural producers (Republican River Basin) and primarily urban water managers (Fox River Basin). Survey questions will again focus on their perceptions of the tool, necessary changes, and uses of the tool for management decisions under different drought scenarios. Questions will again be in a Likert scale or open-ended format.

Benchmark the use of the improved DM-DSS

The improvement of the DM-DSS will be benchmarked from both scientific testing and verification and drought management practices. The scientific testing will use both a retrospective and forecast verification by comparing the DSS forecast or prediction to the actual occurrence of drought events. The former will use the historical climatic records and the latter will compare the real-time predictions during the late period of the project to the actual occurrences after a week, month, or season. The benchmark through drought management practices will be based on the results of the nationwide and regional surveys. It is hypothesized that the degree of user satisfaction with the DM-DSS will be improved over the project.

Research Tasks

Task 1: Ensemble hydroclimate forecast/prediction

It is well understood that predictable climate signals are memorized in global oceans, mainly sea-surface temperature (SST) anomalies and terrestrial storages (especially soil moisture, snow cover, and vegetation). Actual predictive skill depends on not only the degree of climate anomalies that are predictable (versus natural variability) but also the ability of forecast systems that capture reality (versus model biases). No single model, GCM or RCM, fully represents the observed climate system. Each model contains substantial climate biases and inherits unique climate sensitivities, both of which mask the correct prediction of regional climate responses to imposed anomalous forcings. Even for the same model, results may greatly differ because of the choice of alternative physics schemes, like cumulus and planetary boundary layer (PBL) parameterizations. Thus, consensus weather and climate predictions based on the ensemble of multiple models or multiple physical configurations of a model have recently been highlighted because of their superior skill over those using a single model or configuration (Krishnamurti et al., 2000; Fritsch et al., 2000; Gillett et al., 2002; Peng et al., 2002; Rajagopalan et al., 2002; Palmer et al., 2004; Murphy et al., 2004; Liang et al., 2007).

Therefore, we propose to apply an optimal ensemble mesoscale prediction system (Figure 3) to downscale and improve the NASA GMAO and NCEP CFS prediction of U.S. seasonal-interannual climate variations at regional-local scales needed for impacts study, focusing here on precipitation and hydrology, which are crucial for effective drought forecast and mitigation. The ensemble system consists of 24 realizations based on different model configurations: driving lateral boundary conditions (LBCs) from the NCAR CAM (Community Atmosphere Model) forced by GMAO- and CFS-predicted SST anomalies; and the CWRF (Climate extension of the Weather and Research Forecasting model) downscaling with best combinations of key alternative physics representations and realistic land surface initializations through assimilation of NASA remote sensing data. The GMAO and CFS driving CAM predicts the evolving LBCs and SSTs and the initial land surface conditions that carry, respectively, the planetary circulation forcing and North American surface memory. The CWRF integrating these signals more realistically resolve regional characteristics and physical processes, including orographic effects, coastal oceans, terrestrial storages, water recycling, moisture transport, convection and cloud microphysics, and, as a whole system, better predict the likely distribution of plausible regional climate anomalies representing various model uncertainties. The interfaces between CFS, CAM, and CWRF are being developed under the support of the ISWS (Illinois State Water Survey) pilot study on seasonal-interannual climate prediction. Similar interfaces for GMAO are planned to be developed in collaboration with Dr. Siegfried Schubert at NASA GSFC. They will be ready and freely available for this proposed research.

Procedures

Climate System Design and Prediction

Figure 3 illustrates the ensemble regional prediction system components and domain design. The mother domain, centered at (37.5°N, 95.5°W), covers the whole continental United States with a 30-km grid spacing, and represents U.S. climate variations that result from interactions between the planetary circulation (as forced by LBCs) and North American surface processes, including orography, soil, vegetation, and coastal oceans. The buffer zones are located across 14 grids along 4 domain edges, where LBCs are specified throughout the forecast period using a dynamic relaxation technique (Liang et al., 2001). This configuration has produced skillful simulation of U.S. precipitation, surface temperature, and soil moisture (Liang, 2004a,b, 2005d, 2006b; Zhu and Liang, 2005, 2007). To enhance the representation of local surface temperature and soil moisture (Liang, 2004a,b, 2005d, 2006b; Zhu and Liang, 2005, 2007). To enhance the representation of local terrestrial hydrologic processes, a subdomain at 10-km grid spacing is

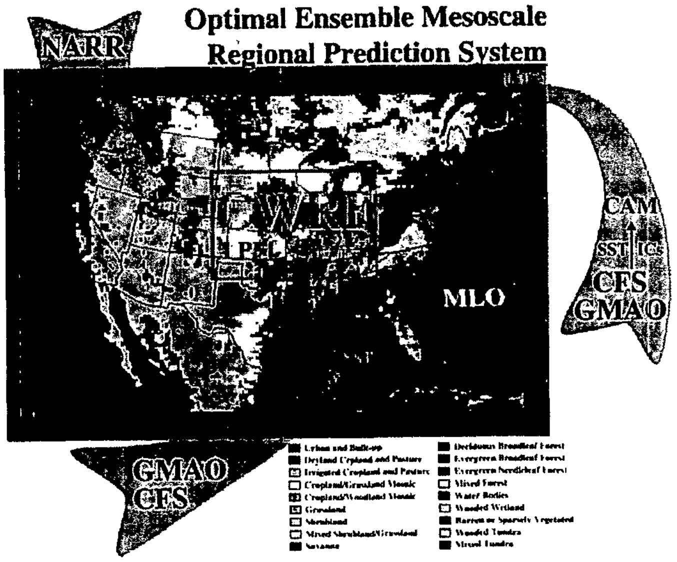

Figure 3: The optimal ensemble mesoscale regional prediction system components and domain design. The outer mother domain and inner nested subdomain use, respectively, 30- and 10-km grid spacing. The background is the USGS land cover types. The shaded edge areas are the buffer zones, where LBCs are specified. The arrows represent the interfaces to couple with the NASA and NCEP products (GMAO, CFS, NARR) for U.S. seasonal climate predictions.

nested to provide finer resolution of climate conditions for a more effective application of the DM-DSS over the Midwest.

Currently, GMAO and CFS predict, at a 10-month lead, global SST variations. These daily SST data will be used to drive CAM (Collins et al., 2006) to simulate the 6-hourly planetary circulation responses, which provide the LBCs for subsequent CWRF downscaling. The initial conditions (ICs) of atmospheric and land surface states for CAM will be taken from the global GMAO Reanalysis (Rienecker, 2006), and for CWRF, they will be taken from the high-resolution North American Regional Reanalysis (NARR) and its near-real time counterpart, the Regional Climate Data Assimilation System (R-CDAS), all maintained by NCEP (Mesinger et al., 2004). The CWRF will then integrate the planetary forcing via the LBCs and the surface memory by the land ICs (e.g., soil moisture and temperature, snow cover) and ocean anomalies (daily SSTs) to produce the mesoscale ensemble prediction of U.S., and finer-resolution Midwest, seasonal-interannual climate variations. This downscaling prediction procedure is determined by several physical and practical reasons:

First, CWRF requires 6-hourly LBCs during the entire forecast period, with primary variables equivalent to 180 (265) horizontal fields, having more than 840 (350) Gb data for the ensemble of 20 (15) realizations in a 10-month GMAO (CFS) prediction per calendar month and 12 times that number for a year. This is impossible for NASA and NCEP to archive and prohibitive for online access. Our solution is to run a state-of-the-art atmospheric GCM as forced by the GMAO- and CFS-predicted daily SST variations. We choose CAM for this purpose. Our preliminary study showed that CAM driven by CFS-predicted SSTs simulates U.S. precipitation variations more realistically than CFS itself. This single choice of the atmospheric GCM is mainly determined by the funding limitation and the existing effort. Because the current GMAO and CFS predictive skill is very limited beyond 3 months in the extratropics, we will focus on the initial season for CWRF to make the regional climate forecast over the United States. As such, we will acquire from NASA and NCEP only GMAO and CFS daily SST data during the first 3-month forecast period. These data, less than 1 Gb in total for a seasonal ensemble prediction per each calendar month, are readily accessible online.

Second, the global atmospheric and land ICs prepared from GMAO for the coarse CAM branch runs are likely insufficient for the fine-resolution CWRF downscaling predictions. They can be improved by using NARR, which is a long-term, consistent, high-resolution climate dataset for North America (Mesinger et al., 2004). The NARR adopts a 32-km grid, close to that of the CWRF mother domain, and provides 3-hourly atmospheric and land data over an extensive area that completely includes the latter. The outcome represents a major improvement on the earlier global reanalysis datasets in both resolution and accuracy. In addition, NARR provides soil temperature and moisture in 4 layers (instead of 2 levels in GMAO) at 0-10, 10-40, 40-100, and 100-200 cm below the surface. Because the atmosphere has a dynamic memory of only 1-2 weeks, the land variables carry the most information that the ICs may contribute to the CWRF seasonal climate predictive skill.

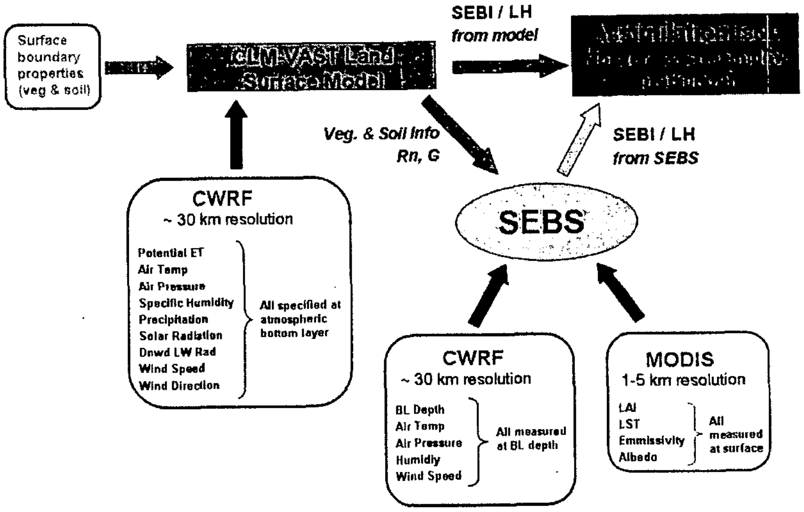

Figure 4: Schematic showing the assimilation of MODIS land surface variables in the CLM-VAST formulation using the SEBS framework. SEBI (surface energy balance index) relates the actual and potential evapotranspiration.

Third, CWRF differs in physical and dynamic formulations from the data assimilation model used in NARR and require additional fields that must be carefully initialized to achieve complete balance with the available analyses. Since land-atmosphere interactions can cause surface hydrologic persistence and modify precipitation recycling through soil water retention and subsequent evaporation, carrying important climate memory for seasonal prediction (Dirmeyer, 2000; Koster and Suarez, 2001, 2003; Koster et al., 2004), the initialization must incorporate observed atmospheric variations during a sufficiently long spin-up period so that complete consistency between the atmosphere and surface states is established. This can be achieved by nudging CWRF atmospheric variables toward NARR for a sufficient period. The best result is anticipated if the nudging is done over the entire CWRF domain. Past experiences have demonstrated that CMM5 driven by LBCs from global reanalyses with a robust buffer zone treatment (Liang et al., 2001) can reproduce observed precipitation, surface temperature, and soil moisture well (Liang et al., 2004a,b, 2005d, 2006b; Zhu and Liang, 2005, 2007). We will adhere to this relaxed approach, where CWRF will be driven by 3-hourly LBCs from NARR and daily SSTs from the NCEP blended real-time global (RTG) analysis (Thiébaux et al., 2003) for at least 2 years before the actual seasonal climate prediction takes place. The main purpose of so doing is to obtain the optimal land ICs for the CWRF that incorporate the observed memory coherently into the coupled surface-atmosphere modeling system while minimizing the inconsistency due to model mismatch from NARR. In the continuous operational mode, this initialization procedure is efficient since the CWRF integration needs to be extended by only one month for the next forecast realization.

Satellite Data Assimilation

To improve the prediction of soil-moisture states, a critical element for the improved hydroclimate forecast using the CWRF, we will assimilate remote-sensing MODIS data directly into the coupled CLM-VAST and CWRF model. An effective scheme to accomplish this using the SEBS (Surface Energy Balance System, Su et al., 2002) framework has been developed by Chintalapati and Kumar (2007) (see Fig. 4). It uses the land surface state variables (land surface temperature, vegetation properties, albedo, and emmissivity) from MODIS and atmospheric boundary layer properties predicted by the climate model. The energy fluxes are then assimilated into a land surface model to update the soil moisture profile and associated fluxes. The SEBS framework is used in conjunction with the land surface model, so as to take advantage of the empirical parameterization of SEBS based on satellite remote sensing data and the underlying physics representation in the land surface model. Implementation of this assimilation scheme will enable significantly better estimates and prediction of soil-moisture and evapotranspiration flux as well as streamflow.

Ensemble Prediction and Verification

For each prediction case, there will be 6 CAM branch forecasts (forced by the ensemble mean and ± one standard deviation from the 20 and 15 realizations of SST anomalies predicted by GMAO and CFS, respectively) times 4 CWRF downscaling runs (each with a different PBL scheme). All temporal samples from the 24 forecast members will be used to provide the statistics, including the ensemble mean and probability distribution, for the derivation of the probability density function (PDF) of the key drought indicators used by the DM-DSS.

The verification of the ensemble prediction system skill will be evaluated by the actual hindcasts or forecasts during 2007-2010, with the tentative forecast period of 3 months. This practice will follow the full procedure for CAM branch forecasts and CWRF downscaling initialization. The verification observations include precipitation and surface temperature, relative humidity and wind analyses based on station measurements (Kunkel et al., 2003, 2004), soil moisture and soil temperature (Hollinger and Isard, 1994), NOAA snow cover analyses from a blend of visible imagery, passive microwave information and *in situ* observations (Robinson et al., 1993, 1999), and USGS streamflow measurements, as well as radar and satellite retrievals.

CWRF Brief Description

The CWRF is the state-of-the-art RCM under continuous development and intensive validation (Liang et al., 2005a-d, 2006b; Choi et al., 2007). For the past 5 years, we have developed CWRF from WRF (Skamarock et al., 2005) with numerous crucial modifications to improve surface-atmosphere and convection-cloud-radiation interactions, and system consistency throughout all process modules. In particular, CWRF incorporates: [1] realistic surface characteristics that are the most comprehensive among current climate models using numerous NASA satellite products (Liang et al., 2005a,b); [2] an advanced land surface albedo parameterization based on MODIS retrievals that represents the predictable albedo dependences on solar zenith angle, surface soil moisture, fractional vegetation cover, leaf plus stem area index and greenness, along with a statistical correction for static effects specific to local surface characteristics (Liang et al., 2005c); [3] a state-of-the-art Common Land Model (CLM, Dai et al., 2003, 2004), with many important updates and new modules, to predict temperature, moisture, snow, and surface fluxes of soil and vegetation; [4] an improved CAM version of Holtslag and Boville (1993) to represent the planetary boundary layer (PBL) process including the nonlocal effect of transport by large eddies; [5] an improved treatment of the grid-scale topography using an analytic terrain-following reference model standard atmosphere (Liang et al., 2005d), and effective parameterizations of subgrid orographic effects on momentum by small-scale and mesoscale terrain variability as well as on radiation (Liang et al., 2006b); [6] an advanced terrestrial hydrology module that integrates a 1-D dynamic surface routing model (for unsteady flow overland and through the channel network) and a 3-D volume averaged soil moisture transport model with a scalable parameterization of subgrid topographic effects to better predict runoff and streamflow geographic distributions (VAST, Choi et al., 2007); [7] an interactive mixed-layer ocean (MLO) that resolves instant air-sea exchange of heat, mass and momentum, penetration of solar radiation and momentum through the mixed layer, variation of the mixed-layer depth, vertical mixing, convective adjustment, and entrainment from subsurface water or thermocline (Liang et al., in preparation); [8] a cloud microphysics (CMP) bulk parameterization (Thompson et al., 2004) that explicitly predicts variations of vapor, liquid, ice, rain, snow, graupel, and ice number concentrations as well as grid-scale precipitation; [9] the ensemble cumulus parameterization (ECP) of Grell and Dvénéyi (2002) to predict cloud formation and unresolvable subgrid precipitation; [10] a parameterization for cloud covers and optical properties based on the CMP and ECP cloud hydrometers (Xu and Randall, 1996; Liang et al., 2004b); and [11] a comprehensive radiation transfer based on the latest NASA/GSFC solar (Chou and Suarez, 1999) and thermal infrared (Chou et al., 2001) schemes. These default CWRF physics options* can be combined with other existing WRF schemes. We will consider three alternative PBL schemes: YSU (Hong et al., 2003), MYJ (Mellor and Yamada, 1982; Janjić, 2002) and UW (Grenier and Bretherton, 2001), since they produce substantially different (also from CAM) PBL heights and vertical mixings of critical importance to surface-atmosphere interactions and thus seasonal-interannual climate predictions.

Task 2: Probability-based drought prediction

This task will undertake two procedures using the ensemble hydroclimate forecasts and predictions: 1) Deriving the probability of the key drought indicators used by the DM-DSS; 2) deriving the joint probability of drought levels.

In the DM-DSS, drought intensity categories (D0-D4, abnormally dry to exceptional drought, Figure 1) are based on five key indicators: Palmer Drought Index (PDI), Standardized Precipitation Index (SPI), CPC Soil Moisture and USGS Weekly Streamflow, and Short- and Long- Term Drought Indicator Blends. Additional indicators are used in the West, where winter snowfalls have a strong bearing on water supplies. In this project, the ensemble hydro-climatic predictions will be translated into the prediction of those drought indicators. This procedure will be undertaken through a typical Box-Cox power transformation (Box and Cox, 1964), which transforms the sample forecast values into normally or log-normally distributed random variables, while preserving the rank order and the one-to-one correspondence between the original and transformed distribution.

Once the probability distributions of the key drought indicators are determined, the drought intensity probability distribution will be derived by a standard Monte Carlo simulation method. This is justified by the availability of 1) a quantified relationship between the drought intensity and the key drought indicators, and 2) the probability distribution of each of the key indicators (as stated above). Because the ranges of the various indicators often do not coincide, the final drought category tends to be based on what the majority of the indicators show or a weighted average of all indicators. The current DM-DSS weighs the indicators according to how well they perform in various parts of the country during different times of the year. Because of the existence of correlation between the various indicators (e.g., precipitation vs. soil moisture or streamflow, soil moisture vs. streamflow, etc.), it almost impossible to find an analytical solution of the drought intensity probability;, and Monte Carlo simulation will be a more realistic and usually effective approach.

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* All these modules [1-11] were built with only the CWRF, except for the CMP [8] and ECP [9] currently available in the WRF V2.1 release. Here we use a new ECP version that facilitates the varying weights on individual closures.

Spatial downscaling might be needed when the hydroclimatic predictions that result from a spatial resolution of 30km for the whole country are used for drought prediction at the county level or the watershed level, although it may not be necessary for the predictions in the Midwest, which will be provided as a demonstration with a finer resolution (10km). Spatial bias needs to be corrected when coarse gridded climate forecasts are applied to local climatology, including correcting the regional biases and the spatial and temporal discrepancy between the forecast model and the historical data (e.g., Clark and Hay, 2004; Miller, 2003). This project spatial bias correction, if needed, will be performed at individual weather stations, each defining its own climatologic values (precipitation and temperature) for monthly distributions. Finally, a forecast skill test will be carried out to display the relative accuracy of a set of forecasts corresponding to an observed value, with respect to a set of reference forecasts (forecast in random space—e.g., randomly selected values from a normal density function in a given month). Forecast skill is usually measured using a prescribed skill score method such as the Heidke skill score or the Kuipers skill score (Wilks, 1995).

Task 3: Develop Decision Analysis Models and Conduct Case Studies

Two-stage stochastic optimization model

The two-stage stochastic decision-making problem can be formulated as a scenario-based two-stage stochastic programming model. The fundamental idea of the model is the concept of *recourse,* which is the ability to take corrective action after a random event has taken place. For the problem here, the first stage (now) is to determine "what to do now"; the second stage (then) is to determine the best measures to employ under a particular drought scenario. The measures in the second stage can, to some degree, correct the first-stage decisions, which may become incorrect by random drought events. The two stages are coded into an endogenous model with the recourse mechanism

$$\text{Min} \quad d_1(\mathbf{x}_1|\xi_1) + \mathrm{E}\left[d_2(\mathbf{x}_1,\mathbf{x}_2)|\xi_2\right] \quad or \quad d_1(\mathbf{x}_1|\xi_1) + \mu[P \le \eta(\mathbf{x}_1,\mathbf{x}_2)|\xi_2]$$

$$\text{s.t.} \quad d_1(\mathbf{x}_1) \in d_1^*, \qquad d_2(\mathbf{x}_1,\mathbf{x}_2) \in d_2^*$$

in which $\mathbf{x}_1$ and $\mathbf{x}_2$ are the vectors of first and second stage decision variables, respectively; d_1 and d_2 are the drought damage function representing the damage in the first and second stage, respectively; ξ_1 is the current drought level (climatic and hydrologic conditions), which is deterministic; ξ_2 is the prediction of the future drought level, which is represented by a probability distribution. d^* represents a feasible space derived from the hydrologic-infrastructural model and the economic damage evaluation model, including constraints and institutional regulations on water allocation, environmental flow reservation, etc. μ is the drought damage corresponding to a prescribed conditional exceedance probability η, e.g., damage with exceedance probability of 75%.

Notice that the two-stage decision procedure described above will be rolled over from one stage to the next with the updated current drought level (ξ_1) and future drought prediction (ξ_2). Therefore, the value of the first stage variable ($\mathbf{x}_1$) represents the actual information for decision making. That is to say, with continuously updated prediction (i.e., real-time prediction), the decision component always informs users "what to do now". This procedure will be applied to two specific, typical decision-making cases, irrigation scheduling and reservoir operation, which are further described below.

Irrigation scheduling model and agricultural case study

Farmers usually irrigate crops to prevent damage caused by drought. Irrigation scheduling determines when and how much water to apply during the crop growth season, which should be based on soil moisture condition as well as weather forecasts and seasonal prediction. However, in the real world, farmers' empirical knowledge and judgment often dominate decision making in irrigation scheduling. Optimization is often used to find an optimal schedule for certain designed management objectives such as maximizing crop production for profit with constrained risk-aversion under water stress, minimizing operation cost, etc. (e.g., Cai and Rosegrant, 2004 ; Prasad et al., 2006; Wang and Cai, 2007). This project will develop an irrigation scheduling optimization model, as an extension of the DM-DSS decision support capabilities. A hydrologic-agronomic simulation is to be coupled with an optimization algorithm to search for the optimal irrigation schedule under probability-based drought forecasts.

The simulation model is to simulate water, heat, and solute transport in saturated and unsaturated zones, including modules for simulating crop growth and irrigation practices. This study will adopt the Soil and Water Assessment Tool (SWAT), one of the most popular DM-DSS tools for agricultural water management in the United States and many other countries around the world. The SWAT model provides two methods for irrigation input: "auto-irrigation" pursuant to predefined criteria coded in the model, and externally prepared irrigation with fixed times and depths. The latter will be used in this project, which is to determine the irrigation input through an external optimization algorithm. Wang and Cai (2007a) applied the genetic algorithm (GA) with a hydrologic-agronomic simulation model (SWAP, Van Dam et al., 1997) that is similar to the SWAT at the crop field scale. GA is a random search optimization algorithm particularly suitable for large-scale integrated simulation-optimization models (Goldberg, 1989). GA generates alternative irrigation schedules, which are taken as input to the simulation model; the crop yield resulting from each of the irrigation schedules, as well as irrigation costs, is used to evaluate the "fitness" of the schedule, which will guide the GA to generate better irrigation schedule alternatives. Wang and Cai (2007a) assumed deterministic climatic and hydrologic inputs to the simulation model. In the proposed study, the model inputs will be stochastic and represented by a probability function and will extend the deterministic simulation-optimization model developed by Wang and Cai (2007) into a stochastic model, following the two-stage stochastic optimization procedure described above.

An important feature for the hydrologic-agronomic simulation at the crop field scale is to assimilate remotely sensed data to estimate actual crop evapotranspiration (ETA). Wang and Cai (2007b) implemented the surface energy balance algorithm for land (SEBAL) (Bastiaanssen et al., 1998) for estimating ETA from corn fields in central Illinois using the Moderate Resolution Imaging Spectroradiometer (MODIS) data at the Terra platform. This result confirmed the survey conducted by Bastiaanssen et al. (2005), which found that for a range of soil wetness and plant conditions, the typical accuracy of daily ETA at the field scale is 85%, increasing to 95% on a seasonal basis.

The irrigation scheduling decision model will be applied to irrigated land in the Republican River Basin, Nebraska, and Mason County in the Fox River basin, Illinois (which has the largest irrigation system in Illinois because of the sandy soil). However, it should be pointed out that the model (SWAT) is appropriate for any agricultural watersheds in the United States, the methodology (GA, SEBAL) is general, and data (MODIS, climatic and hydrologic prediction to be generated in this project) are available for the entire United States Therefore, this decision analysis component will be applicable to any agricultural lands in the United States.

Reservoir operation model and an urban case study

To test how the ensemble forecast/prediction of drought will help with reservoir operation, this study will use streamflow predicted by the hydroclimate models as an input to a reservoir operation model particularly applied for drought management. The model was developed by Co-PI J. Ryu and one of his colleagues at the University of Washington (Ryu and Palmer, 2007). The current model is deterministic, although it needs to be improved to test the impact of the quality of streamflow forecasts on water use profit. In this study, a similar procedure applied to the irrigation scheduling model will be undertaken to extend the reservoir model to a two-stage stochastic optimization model using ensemble streamflow forecasts. The outputs of the extended model will be the reservoir release at the current period (deterministic) and the future releases under a specific probability. Since the model will be rolled over from one period to next with updated streamflow forecasts, the decision information for reservoir managers is "how much to release in the current period." The extended model will be applied to an urban case study area, the Fox River Basin in Illinois, to modify the regular reservoir operation rules under drought conditions. Recent extreme hydrologic events such as droughts create large economic impacts, significant environmental and societal effects, and severe conflicts between consumptive and non-consumptive water use (e.g., conflicts between water supply and navigation in year 2005) in the basin.

Task 4: Benchmark development

This task is to demonstrate that the information from the DM-DSS that has been enhanced with NASA earth science research results is improved from the baseline status. Both quantitative and qualitative performance measures and management metrics will be used for the benchmark development. This section describes the procedures and activities for benchmark development, while the performance measures and management metrics are described in details later on in this proposal. The improvement of the DM-DSS will be benchmarked from both scientific testing and verification and drought management practices.

Scientific testing for the DSS benchmark

Retrospective verification: We will use a historical drought occurrence in the Midwest region as a *reference* to examine the outcomes from several scenarios designed with different levels of remote sensing data use, including 1) full use as proposed, 2) limited use, and 3) no use. It is expected that these scenarios will result in drought predictions with different levels of uncertainties and bias from the actual occurrence (the *reference*), which will influence decision making and drought impacts. It is hypothesized that the full use of the remote sensing data as proposed will result in the least prediction uncertainty and distance to the actual occurrence and also the lowest drought damage. The drought prediction uncertainty will be evaluated from the PDF of drought intensity resulting from the various scenarios. Drought impacts will be evaluated using the output of the decision analysis model (e.g., the irrigation scheduling model and the reservoir operation model).

Forecast verification: During the latter stage of the project (at least the last year), an enhanced DM-DSS will be available for real-time drought prediction in the entire United States and an even more improved prediction for the Midwest region with a finer spatial resolution. The prediction to the various time horizons (week, month, or season) will be traced and then verified with the "wait-a-see" actual occurrence. The accuracy of the predictions will be synthesized, which will be an important evidence of DM-DSS improvement. Scenarios regarding the use of the earth science results as defined in the retrospective verification will also be tested to show the value of the earth science results.

Justification of data, models and procedures: This procedure will provide the details of 1) the reliability of the data, including the remotely sensed data and other categories of data used in drought prediction; 2) robustness and accuracy of the models; and 3) the effectiveness of the procedures. Besides the justification from the research team, external sources will include the literature and peer reviews on the publications based on or related to this project.

Management evaluation for the DM-DSS benchmark

The benchmark through drought management practices will be based on the comparison of the results from the two users' surveys. The degree of acceptance of the DM-DSS changes through the project and potential behavior change of the users will be used as indicators of DM-DSS improvement.

The nationwide surveys will be conducted periodically throughout the development of the project and will focus on users' 1) perceptions of the DM-DSS, 2) additions or deletions of information provided by the DM-DSS, and 3) expected uses of the DM-DSS in drought monitoring and decision making. The periodic evaluation will guide improvements throughout the development process and will demonstrate if the improvements made to the DM-DSS are meeting the needs of users.

The survey administered to stakeholders in the Republican River Basin, Nebraska, and the Fox River Basin, Illinois, will be conducted at the midpoint of the project development. Conducting the survey at the mid-point of the project, when a functional enhanced DM-DSS is available that has incorporated feedback obtained from the nationwide survey, will allow stakeholders in the river basins to better evaluate the usefulness of the tool in making management decisions and allow scenarios to be presented to them.

The combination of the two survey methodologies will provide stakeholders the opportunity to be actively involved in the development of the project. They will also provide indications of the likelihood of stakeholders to utilize the DM-DSS in their decision making. Moreover, for the two typical case studies on decision-making analysis, the collaborators (users) will evaluate the additional benefit under the benchmark scenarios. Such involvement will be an important part of benchmarking the use of the DM-DSS.

Finally, a benchmark report will be prepared, which will include the adoption of NASA inputs within the DM-DSS and the resulting impacts and outcomes. The final milestone of the benchmark is a ready-to-use product, i.e., the DM-DSS with new prediction and decision analysis capability.

Transition Approach/Activities

The "exit strategy" of this project will focus on how to establish an effective online version of the enhanced DM-DSS and enable it to serve numerous existing and new users across the country. Because DM-DSS is different from other decision support systems, the users do not need to run it themselves; rather, they extract the information represented in maps and statistical tables "automatically" provided and continuously updated by the DM-DSS.

The first transition issue is with the three institutes involved in the project, which are developing different components for the enhanced DM-DSS. The concern here is how to connect those products into an integrated system and ensure that the integration will work as expected after the project period. We plan to have an online connection using the hydroclimate prediction models to be developed at the Illinois State Water Survey and the University of Illinois, which will be linked to the original DM-DSS and become a part of the improved DM-DSS. After the project, the updated version of the prediction models will be available for use by the DM-DSS (Water Survey letter). Based on the research outcomes from this project, NDMC, the host of the DM-DSS, will enhance the online display and the illustration of seasonal drought prediction results so that end-users can easily access and understand the information.

One concern is how to make end-users accept and then adopt the DM-DSS enhancements, particularly in the beginning. We will develop some on-line demonstrations following the benchmark development activities, by which users can visualize the verification of the enhanced DM-DSS with some historical drought events. We will also synthesize and publish the prediction accuracy routinely by comparing the predictions with occurrences during the past periods.

On the users' side, the decision analysis component (irrigation scheduling and reservoir operation) will be transferred to local collaborators through a technical tutorial including:

1) An explanation of the decision model formulation with relevance to specific management objectives (e.g., mitigating crop production loss, maintaining water supply reliability)
2) An online interface that connects the DM-DSS and the decision analysis component, by which the decision models can extract drought predictions from the online DM-DSS
3) A pre-processor of earth science products and an interface between the products (e.g., MODIS) and the decision analysis component.

Immediate extensions of the product after the project are expected to include the update of the prediction capability with a finer spatial resolution (10km) for the entire United States (30km will be used in this project), provided that the refined prediction capability in the Midwest (the demonstration area in this project) results in significantly reduced prediction uncertainty and improved decision support. The data requirements and technical procedures needed to extend the product at 10km spatial resolution to other regions in the United States will be presented so that the extension can be implemented when necessary resources are available.

Another extension is to add the two-stage stochastic decision model for other watersheds or areas in the country. The interface between the DM-DSS and the decision model at the local scale will adopt an open structure, which will allow the local model to extract online data from the DM-DSS and obtain relevant assistance in decision analysis. Users who are interested in the extension will find guidelines from this project to develop their own decision support component using the general two-stage stochastic optimization decision framework. A general guideline to connect a decision analysis component to other decision issues in other regions will be prepared so that users can conduct their own extensions.

Performance Measures

Performance measures are defined to assess and articulate the outputs, impacts, and benefits of the project. The measures will be assessed within a three-dimension (3-D) framework, i.e. *people* (who to measure), *themes* (what to measure—baseline, benchmarks, or both) and *sources* (how to measure), as outlined below.

1. Drought prediction accuracy

This measure will be synthesized from the retrospective and forecast verification procedures as described before. The accuracy might be defined as an inverse of the distance between the predicted and occurred drought levels. Following the forecast verification procedure, the accuracy will be updated from one period to the next and will continue after the project period as a quality indicator of the DM-DSS.

2. Drought prediction uncertainty

Based on the probability distribution of predicted drought, which is to be derived from the ensemble hydroclimate prediction, the drought prediction uncertainty can be represented by variance. As stated before, the uncertainty level depends on the quality (spatial resolution) and choice of earth science result usage (full, limited, or no use), as well as the quality of other input data and model structure. This measure will also be used as a long-term quality indicator of the DM-DSS, with potential improvements of those dependent factors (including earth science data and models) to be made in the future.

Performance measures 1 and 2 above will be assessed by the research team during the project and can be continued by the NDMC, who will host the DM-DSS after the project. The two measures will be updated over time and published as DM-DSS quality indicators. In particular, the measures will compare the refined predictions in the Midwest to the rest of the country, which uses different spatial resolutions of input data to the climatic prediction model.

3. Drought damage reduction

For the two local areas, which are used as case studies for extended decision support, the likelihood of drought damage reduction will be estimated by the decision models and the results from the survey. For other areas around the country, this measure will be estimated according to the responses from the DM-DSS users who participate in the periodic nationwide surveys.

4. Change in drought response time

Given the prediction, users will be asked if they would be willing to adjust their response time to drought or their decision making related to drought mitigation (for example, if irrigators would be likely to use the DM-DSS in their irrigation scheduling or if reservoir managers would be likely to use the DM-DSS in developing reservoir operation schedules under different drought scenarios).

5. Satisfaction with the DM-DSS

During the user survey, participants will be invited to evaluate the DM-DSS initially and periodically throughout the development of the DM-DSS to report their level of satisfaction with the DM-DSS.

Performance measures 3, 4, and 5 will be quantified according to user survey responses, as well as the modeling output (only for the local areas selected by this project). These measures will be assessed for both the baseline and the benchmarks, which will then be used as indicators for the potential DM-DSS improvements based on earth science research results.

Anticipated Results

The results from this project will include

- Hydroclimate prediction models that can be used to predict seasonal droughts crossing a range of spatial scales from local to the whole country, with refined regional prediction with finer spatial resolution (Midwest).
- Decision support extension for irrigation scheduling and reservoir operation at the local scale, which will fill the gap between the current DM-DSS capability and the needs of end users for risk-based decision making.
- An enhanced drought prediction and monitoring decision support system, available to the public like the current Drought Monitor, which may contribute to reducing drought losses and stabilizing farmers' income considerably.

The expected improvements over the "baseline" performance of the DM-DSS are presented as below:

Baseline performance of DM-DSS	Performance of the enhanced DM-DSS
• Up-to-date summary of current hydrological and agricultural drought at multiple scales (national, state, county) • Common starting point of decision making • Supporting tactical decisions for crisis management	• Baseline + • Short-term forecast and seasonal prediction of drought: Probability-based drought levels for the whole country with refined regional (Midwest) demonstration • Moving forward from the starting point and providing more relevant decision support for irrigation scheduling and reservoir operation based on drought damage and water supply profit (local) • Supporting strategic decisions for risk management and providing real-time decision, i.e., "what to do now"

This project will first contribute to water management by extending earth science results to enhance short-term drought forecasts and seasonal prediction capability for a drought management DSS. The outcomes of this project will directly contribute to the USGEO activity on drought by developing prototype tools for drought management under the framework of the National Integrated Drought Information System (NIDIS). Following the NIDIS goals, this project will create a drought early warning system based on earth science results and provide user communities the ability to easily access required information for drought decision making. Additionally, it will integrate drought-related management problems and objectives with the information obtained from the enhanced DSS. The early warning system will be beneficial for the USDA Drought Insurance Program. Currently, the USDA Risk Management Agency (RMA), which operates and manages the Federal Crop Insurance program, depends on the Natural Resources Conservation Service (NRCS) to monitor and predict drought and water availability throughout the growing season. Actions are taken for rain-fed and irrigated acres, including prevented planting provisions in insurance policies that provide valuable coverage to producers when drought prevents expected plantings. The short-term drought forecast and seasonal prediction to be developed in this project will improve the NRCS's work and the corresponding decisions of the RMA.

Secondly, this project will also contribute to "disaster management" and "agricultural efficiency." The enhanced DM-DSS will extend earth science results to mitigating drought (a common disaster), using an improved approach similar to NOAA's National Weather Service Advanced Weather Interactive Processing System (AWIPS) for disaster management applications. Since droughts most frequently affect agricultural enterprises, this project has placed a priority on agricultural users by combining drought prediction and irrigation scheduling optimization with an existing simulation model on crop stage development and crop productivity and yield predictions, with additional use of NASA remotely sensed data such as GRACE and MODIS that are also used in hydroclimate predictions. This extension will provide quantified decision support information for irrigators, such as enhanced irrigation scheduling and the estimation of drought losses based on crop production loss.

Budget Justification

The proposed budget consists of the following categories of expenditures, listed with specific justification for each category.

A. Personnel

Partial months of salaries are included for the Principal Investigator (PI) and Co-Principal Investigators (Co-PIs). The PI, Dr. Jae Ryu will spend 2 months (equivalent to 16.7%) of his effort in the proposed project. The Co-PIs, Dr. Mark Svoboda, Dr. Cody Knutson, and Meghan Sittler, will spend 1.5 month (equivalent to 12.5%) effort in the this project, respectively. Dr. Donald Wilhite will commit necessary effort to work with one of Graduate Research Assistants (GRA). Salary for 12 months per year (equivalent to 100% effort) of one GRA, who will be performing studies related to developing hydrologic models, characterization of modeling parameters, and performing analyses of the system, is requested. It is anticipated that involvement of the graduate student is integral for timely completion of the proposed studies. A 4% increase in salaries and stipend per year is included.

Fringe benefits at the University of Nebraska-Lincoln are calculated at a rate of 28% for faculty and staff.

B. Participant/Trainee Support Costs

1. The University of Nebraska-Lincoln requires that tuition remission at the rate of 32% of the stipend is requested for graduate student supported by grant funds. In addition, GRA health insurance benefits are calculated as follows: $1,000 for year one, $1,100 - year two, and $1,200 - year three.

C. Travel

Expenses are included for travel and lodging to University of Illinois at Urbana-Champaign as well as national conferences (with destinations to be determined) and the cost of attending the regional workshop/meeting (including regional symposium related to drought monitoring and management, if any) to gather input on the management alternatives. Per Diem rates are $40 per day. Travel cost to participating professional meeting, such as the American Society of Agricultural Engineer and the American Society of Civil Engineer are also requested. This is necessary to present our research findings in these meetings and discuss with other researchers in professional communities.

D. Other Direct Costs

1. Material & Supplies. Reasonable costs for supplies and materials to carry out the proposed studies are requested. The National Drought Mitigation Center will serve as the project collaborative leader and will be producing a wide variety of maps and printed materials for review by project collaborators. These include consumable costs of materials for research such as computer peripherals, server (if any), software upgrade and licensing, and communications. In addition, page charges and other dissemination costs are included in this budget line.

2. Publication Costs: Expenses to cover page charges for publication of research data in the second and third year of the project. Note that color page charges is normally expensive than black and white.

E. Facilities and Administrative Costs

The University of Nebraska-Lincoln negotiated Facilities and Administrative Costs is 44.9% on modified direct costs.

University of Nebraska: $345,000

Budget Narrative Worksheet

University of Nebraska-Lincoln (UNL)
Title: Developing a Predictive Capability Decision Support System for Drought Mitigation
NASA-ROSES (A.20 Decision Support through Earth Science Research Results)
Principal Investigators at UNL: Jae Ryu, Mark Svoboda, Cody Knutson, Meghan Sittler, Donald Wilhite
Sponsor: NASA-ROSES
Project Period: 10/1/2007 through 9/30/2010

		Year 1	Year 2	Year 3	Total
A. NDMC Salaries					
Personnel					
1. Jae Ryu	2 months/year	$8.584	$8,842	$9.107	$26.532
2. Mark Svoboda	1.5 months/year	$7,864	$8.100	$8.343	$24.306
3. Cody Knutson	1.5 months/year	$7,725	$7,957	$8,195	$23,877
4. Meghan Sittler	1.5 months/year	$4,875	$5,021	$5,172	$15,068
5. Donald Wilhite	0 months/year	$0	$0	$0	$0
Subtotal (Salary Only)		$29,048	$29,919	$30.817	$89,784
Fringe Benefits (28%)		$8.133	$8,377	$8,629	$25.140
Total Salaries (Investigators) and Benefits		$37.181	$38,297	$39.446	$114,924
6. Research Assistant	12 months	$18,504	$19,059	$19.631	$57,194
Tuition Remission	1 # of GSA	$5,921	$6,099	$6.282	$18.302
GSA Health Insurance		$1,000	$1,100	$1,200	$3.300
Subtotal		$24,425	$25.158	$25.913	$75,496
Total Salaries Only		**$47,552**	**$48,978**	**$50,448**	**$146,978**
Total Salaries and Benefits		**$62,607**	**$64,555**	**$66,558**	**$193.720**
B. Travel (Urbana-Champaign, UIUC for meetings)					
1. NDMC travel (Transportation)		$3,000	$3.000	$3,000	$9,000
2. Hotels (4 people x 3 nights x $60)		$722	$722	$722	$2,167
3. Per diem (4 people x 6 days x $40)		$960	$960	$960	$2.880
4. Conference and professional meetings			$4,000	$5.000	$9,000
Total Travel		**$4,682**	**$8,682**	**$9,682**	**$23,047**
C. Other Direct Costs					
Supplies and Materials					
1. Printing supplies		$3,000	$3,000	$3,000	$9,000
2. Computers (Server and peripherals)		$2,000	$2,000	$2,000	$6,000
3. Communications		$2,000	$2,000	$2,000	$6,000
Subtotal		$7,000	$7,000	$7,000	$21,000
4. Publication costs			$3,000	$3,000	$6,000
Total Dicrect Costs		$7,000	**$10,000**	**$10,000**	**$27,000**
Total Direct Cost		**$74,289**	**$83,237**	**$86,241**	**$243,766**
Total Modified Direct Costs		**$68,368**	**$77,138**	**$79,959**	**$225,464**
UNL F&A (44.9%)	0.45 NASA-ROSES	**$30,697**	**$34,635**	**$35,901**	**$101,234**
Total Project Costs		**$104,986**	**$117,872**	**$122,142**	**$345,000**