3 | Global Water Cycle

Strategic Research Questions

5.1 What are the mechanisms and processes responsible for the maintenance and variability of the water cycle; are the characteristics of the cycle changing and, if so, to what extent are human activities responsible for those changes?

5.2 How do feedback processes control the interactions between the global water cycle and other parts of the climate system (e.g., carbon cycle, energy), and how are these feedbacks changing over time?

5.3 What are the key uncertainties in seasonal to interannual predictions and long-term projections of water cycle variables, and what improvements are needed in global and regional models to reduce these uncertainties?

5.4 What are the consequences over a range of space and time scales of water cycle variability and change for human societies and ecosystems, and how do they interact with the Earth system to affect sediment transport and nutrient and biogeochemical cycles?

5.5 How can global water cycle information be used to inform decision processes in the context of changing water resource conditions and policies?

See Chapter 5 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

The global water (and energy) cycle plays a critical role in the functioning of the Earth system. Through complex interactions, the global water cycle integrates the physical, chemical, and biological processes that sustain ecosystems and influence climate and related global change. Inadequate understanding of the water/energy cycle is one of the key sources of uncertainty in climate prediction and climate change projections. Clouds, precipitation, and water vapor play important roles in feedbacks that are not well represented in many climate models. These processes alter surface and atmospheric heating and cooling rates, leading to adjustments in atmospheric circulation and precipitation patterns. Improved understanding of these processes will be essential to developing options for responding to the consequences of water cycle variability and change. For assessing the impacts of global and regional climate change on human societies, industrial and economic systems, and natural and managed ecosystems, water is considered a more rigid or critical constraint or limiting factor than temperature. To address these issues the CCSP Global Water Cycle element expends considerable effort to improve observations, data assimilation, and modeling/prediction systems that in turn deliver the information necessary for decision-support tools and assessments that provide a basis for "best practices" in the management of water resources.

The ultimate goal of water cycle research is to provide a solid foundation for decisions and investments by policymakers, managers, and individuals, be it at the Federal, State, or local level. Achieving this goal requires a program of activities that significantly improves understanding of water/energy cycle processes, incorporates this understanding in an integrated modeling/prediction framework, and tests predictions and data products in real decisionmaking contexts. In order to demonstrate techniques and effectiveness to potential users, the Global Water Cycle program also aims to expedite the transfer of science results from the research/experimental realm to operational applications.

Significant progress is being made in the understanding of cloud properties, the direct and indirect effect of aerosols on cloud and precipitation processes, and the interaction of cloud systems with land surface hydrological conditions. To this end, the Global Water Cycle program's first integrated priority activity was completed in June 2007 through multi-agency participation in DOE's Cloud and Land Surface Interaction Campaign (CLASIC). Comprehensive satellite monitoring of water cycle parameters—such as global precipitation and cloud structure in storm systems and hurricanes [with the Tropical Rainfall Measuring Mission (TRMM) and Cloudsat], soil moisture [with the Special Sensor Microwave/Imager (SSM/I) and the Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E)], and water bodies [with the Gravity Recovery and Climate Experiment (GRACE)], as well as more accurate atmospheric

profiles of temperature, humidity, and land/ocean surface parameters (with the multi-sensor Terra and Aqua satellites)—have resulted in integrated data sets and improved models of the Earth system. Ensemble Kalman filtering techniques have demonstrated the potential use of satellite-derived surface soil moisture estimates to improve the characterization of soil moisture at depth in land information systems. The incorporation of research results in models has led to better simulation/prediction capabilities for hydroclimatic variables. Multi-model and ensemble modeling techniques developed by CCSP have led to improved seasonal predictions of both the atmospheric and terrestrial hydrological cycle. Techniques have also been developed by USDA's Agricultural Research Service, DOI/USGS, and the DOI Bureau of Reclamation, in collaboration with NOAA, NASA, EPA, and DOE, among others, for the downscaling of intra-seasonal and seasonal precipitation forecasts to temporal scales consistent with the input requirements for agricultural and water resources management as well as conservation planning and decision-support tools. Experimental seasonal hydrological prediction systems have been developed that use multi-model climate forecast products and empirical tools to "force" land/hydrological prediction models.

Highlights of Recent Research

The following are selected highlights of recent research supported by the CCSP-participating agencies. These research results address the strategic research questions on the global water cycle identified in the CCSP Strategic Plan.

Interagency Cloud and Land Surface Interaction Field Experiment. Improved understanding of the water/energy cycle is a key factor in reducing uncertainty in climate prediction. Parameters such as regional scale soil moisture and key processes involving the interactions between cloud formation and the moisture availability of land surfaces are characteristic of needed improvements. The development of continental cumulus convection is strongly modulated by land surface conditions, while influencing the land surface through rain-induced changes in soil moisture and photosynthesis. To improve understanding of cloud properties, the direct and indirect effect of aerosols on cloud formation processes, and interactions between clouds and the land surface, the first of a series of interagency CLASIC field studies was conducted in June 2007 (see <science.arm.gov/clasic>. The region surrounding DOE's Southern Great Plains

(SGP) site in Oklahoma was chosen for the field experiment due to its extensive surface-based instrumented facilities. In addition, three "supersites" were also heavily instrumented to obtain ground-based measurements to link observed carbon and moisture fluxes to atmospheric structure. Several instrumented research aircraft were provided by the CCSP agencies involved. Collaborations were established between CLASIC and the North American Carbon Program's Mid-Continent Intensive (MCI) study, recognizing the strong synergy between measurements in SGP and the northern MCI locations, particularly because of air masses flowing from south to north and the influence of the land surface on atmospheric concentrations of aerosols, gases, and other constituents (see Figure 8).

Cloud Boundaries and Reflectivity

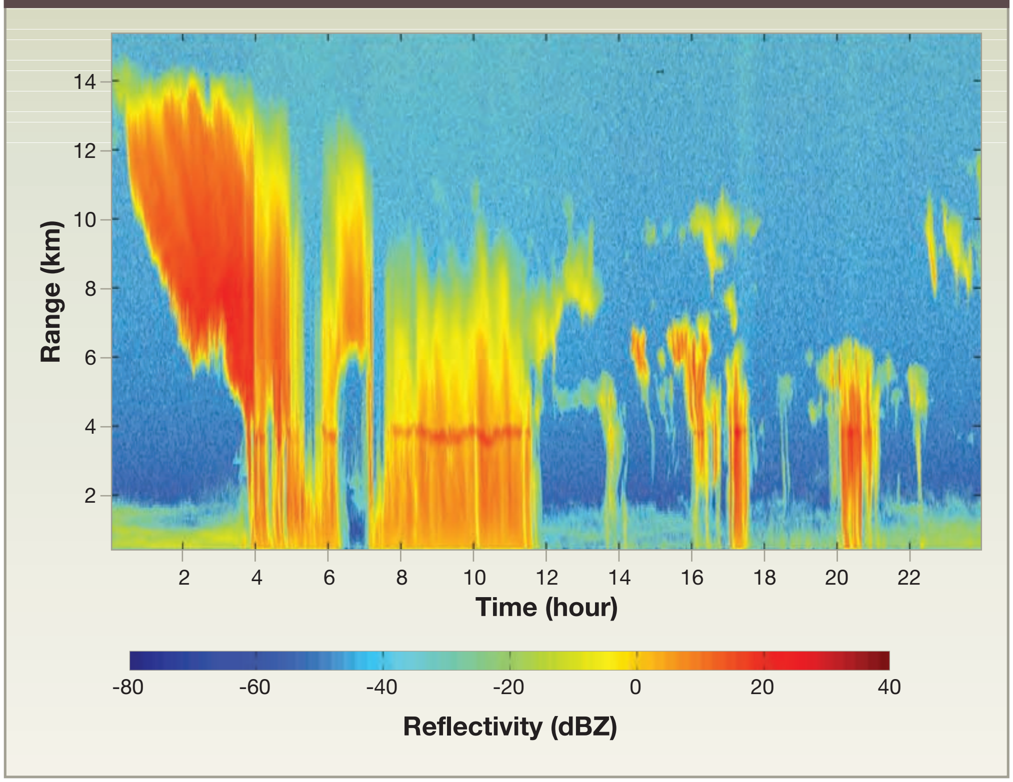
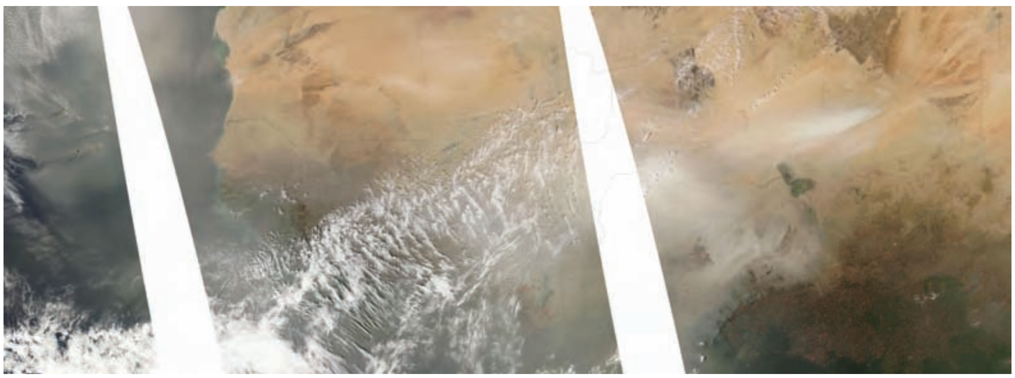


Figure 8: Cloud Boundaries and Reflectivity. As part of the Cloud and Land Surface Interaction Campaign (CLASIC), three supersites were instrumented to obtain ground-based measurements to link observed carbon fluxes to atmospheric structure. Nine aircraft—including a helicopter—participated. The SGP site's Central Facility served as the primary source of information for cloud distribution and carbon feedbacks. The other two supersites were located in pastured lands near the Little Washita Watershed and oak forests near Okmulgee State Park. This image is from a millimeter wavelength cloud radar, which probes the extent and composition of clouds to provide information about cloud boundaries and reflectivity. On the morning of June 14, the radar detected a thunderstorm as it descended on the SGP site, followed by about 5 hours of heavy rain and then brief showers throughout the rest of the day. These data represent a rather complicated case from a modeling perspective, and therefore the need to better understand interactions and feedbacks at the land surface. *Credit: W. Ferrell, DOE*.

Improved Methodology to Validate Remotely Sensed Soil Moisture Products.[1] A novel methodology has been developed to validate the added value of remotely sensed soil moisture products [e.g., from AMSR-E, TRMM microwave imager (TMI)] using a Kalman filter-based strategy that does not require the availability of ground-based soil moisture measurements, and one that can be applied anywhere relatively high-quality rain gauge observations are available (e.g., the contiguous United States). The validation of global remote sensing products is typically based on the use of test bed sites in data-rich areas to characterize retrieval accuracy and value in higher order applications. However, the ability to validate space-borne soil moisture products against ground-based observations is currently limited by difficulties in maintaining soil moisture instrument networks and upscaling sparse point-scale observations of highly variable soil moisture fields to space-borne footprint scales (10-30 km). The new approach provides a quantitative measure of soil moisture with an accuracy linked to that of currently available global rainfall products by means of a simple water balance model. Results indicate that even retrievals from non-optimal X-band frequency sensors over heavily vegetated areas significantly enhanced the quality of soil moisture predictions derived from a simple water balance model and the space-borne precipitation data set. Overall, this study represents an important benchmark that remotely sensed soil moisture products must improve upon in order to contribute value to global land surface modeling applications. The presence of detectable skill at X-band frequencies bodes well for future space-borne missions based on lower frequency L-band measurements better suited for soil moisture measurements and penetration through dense vegetation canopies.

Influence of Land Cover and Soil Moisture on Heat Fluxes.[2] Analysis of aircraft, surface-flux tower, and radar wind profiler data on six fair weather days with southerly winds and near-clear skies from the Cooperative Atmosphere-Surface Exchange Study (CASES-97) and the International H_2O Project (IHOP-2002) shows that land-use patterns have a strong influence on the horizontal distribution of sensible and latent heat fluxes (H and LE) over southeastern Kansas. Combined with Land Surface Model (LSM) runs, the

data suggest that soil moisture influences the relative magnitude of H and LE horizontal variation. In both field programs, H maxima occurred over dormant/sparse vegetation, with a minimum over green vegetation. To a lesser degree, LE maxima occurred over green vegetation, with a minimum over dormant/sparse vegetation. Small day-to-day differences in flux distribution occurred due to the effect of wind direction and speed and surface buoyancy fluxes at the scale of the surface heterogeneity as well as statistical uncertainty. The soil moisture and length of time after rainfall affect the amplitude and coherence of the LE and H horizontal patterns. Terrain could also modulate the horizontal variability in fluxes in this region.



Impact of Desert Dust Radiative Forcing on Sahel Precipitation.[3] A recent investigation considered the role of radiative forcing by dust particles in the Sahelian drought, which occurred over the last 3 decades of the 20th century. The study compared atmospheric general circulation model simulations with meteorological and hydrological measurements. In comparison to previous studies, dust particles that are less absorptive of solar radiation and more emissive at long wavelengths were used in the present study. Cooling of the atmosphere due to dust radiative forcing was found to play an important role in reducing the precipitation over North Africa. The newly modeled circulation responses to this cooling over North Africa provide better agreement with the observations made in dry years in the Sahel region. The results are important because they show that the direct radiative forcing by dust has played a role in the observed droughts in the Sahel comparable to the roles played by sea surface temperatures and vegetation, which have been extensively studied. These results also provide a mechanism whereby drought in the Sahel region can cause increased dust, which then feeds back to cause a further precipitation reduction.

Climate Variability and Fluctuations in Daily Precipitation over the United States.[4] Fluctuations in the frequency and intensity of daily precipitation over the United States during the period 1948 to 2004 were identified and linked to leading sources of interannual and interdecadal climate variability. The El Niño-Southern Oscillation (ENSO) phenomenon

was implicated in interannual fluctuations while the Pacific Decadal Oscillation (PDO) and the Arctic Oscillation (AO) were linked to recent interdecadal fluctuations. For the conterminous United States as a whole, there have been increases in the annual frequency of occurrence of wet days and heavy precipitation days and in the mean daily and annual total precipitation over the past several decades, though these changes have not been uniform. The study explored the possibility of significant natural forcing of these interdecadal variations in precipitation, and found that the PDO is associated with these fluctuations over the western and southern United States, while the AO is also associated with them but to a much lesser extent over the southeastern United States. Because the interdecadal fluctuations are linked to changes in the global-scale circulation and sea surface temperatures associated with the PDO, the results imply that a significant portion of the skill of climate models in anticipating fluctuations in daily precipitation statistics over the United States will arise from an ability to forecast the temporal and spatial variability of the interdecadal shifts in tropical precipitation and in the associated teleconnection patterns into the mid-latitudes.

Consensus U.S. Drought Monitor. The National Drought Mitigation Center (NDMC) has developed an "integrated" Drought Monitor—a synthesis of multiple indices, outlooks, and new accounts that represents a consensus of Federal and academic scientists (see <drought.unl.edu/dm/monitor.html>). The experimental drought monitor product shown in Figure 9, to be refined over time, has improved techniques that are found to better reflect the needs of decisionmakers and others who use the information. The Drought Monitor integrates information from a range of data on rainfall, snowpack, streamflow, and other water supply indicators into a comprehensible picture. Drought measures used include Percent of Normal; Standardized Precipitation Index; Palmer Drought Severity Index; Crop Moisture Index; Surface Water Supply Index; Reclamation Drought Index; and Deciles, among others. With an emphasis on preparation and risk management, rather than crisis management, NDMC helps people and institutions develop and implement measures to reduce vulnerabilities to drought. The NDMC works in partnership with several of the CCSP agencies. These activities also contribute to the National Integrated Drought Information System (NIDIS).

Regional Climate Model for North and South America.[5,6] Proper evaluation of climate change at regional scales is crucial for society planning to mitigate the impact of global climate change. A study using the National Centers for Environmental Prediction Eta regional climate model indicates that under proper choices of model domain size, imposed lateral boundary conditions, and horizontal resolution, the regional model is capable of producing better regional features, such as precipitation and the low-level jet than the general circulation model that provides the lateral boundary conditions to the regional model.

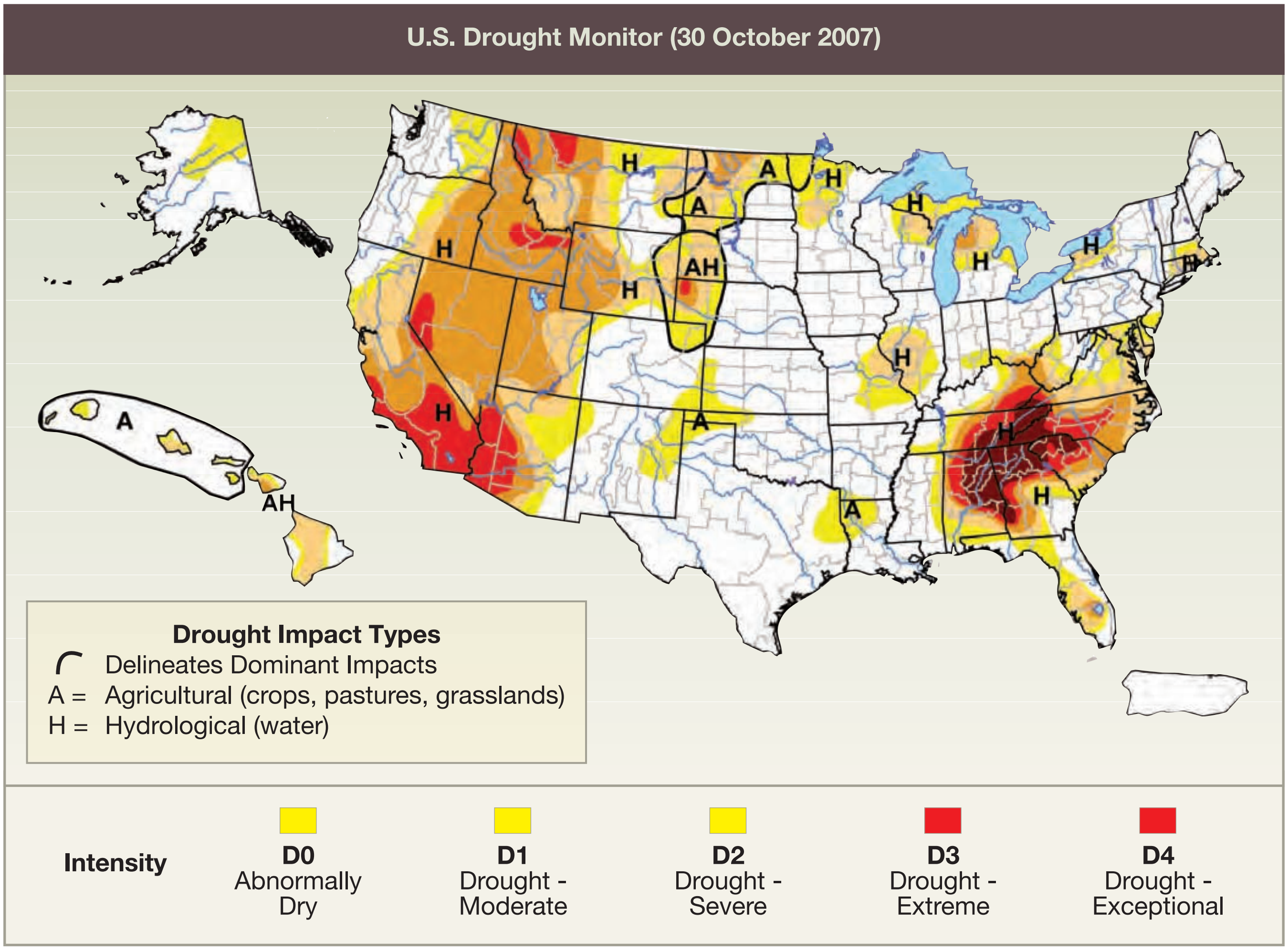
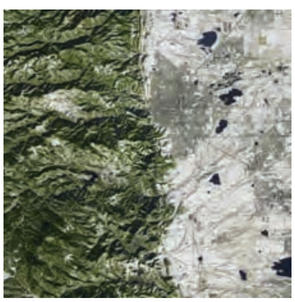


Figure 9: U.S. Drought Monitor (30 October 2007). The U.S. Drought Monitor blends quantitative measures of drought and experts' best judgment into a single map every week. The Drought Monitor grew out of a Western Governors' Association initiative to provide timely and understandable scientific information on water supply and drought for policymakers. The U.S. Drought Monitor—a Federal, State, and academic partnership—has been operational since 1999, and is produced by a rotating group of authors from USDA, NOAA, and NDMC. It incorporates review from a group of more than 250 climatologists, hydrologists, meteorologists, extension agents, and others across the nation. Each week an author revises the previous map based on rain, snow and other events, observers' reports of how drought is affecting crops and wildlife, and other indicators. Authors balance conflicting data and reports to come up with a new map every Wednesday afternoon, with release the following Thursday morning. *Credit: USDA, NOAA, and NDMC (University of Nebraska-Lincoln).*

Impact of Vegetation and Soil Moisture Feedback on Precipitation.[7,8] Accurate seasonal climate predictions of precipitation are critical for agriculture, water management and planning, and for the mitigation of natural hazards. Both large-scale oceanic forcing and local land surface conditions are important factors in determining precipitation over the United States. Past seasonal predictions have primarily relied on sea surface temperature due to its slow variation. Research over the past decade has produced abundant evidence that positive feedback between soil moisture and precipitation over most of the United States promotes the persistence of seasonal hydrological conditions. The time scale of

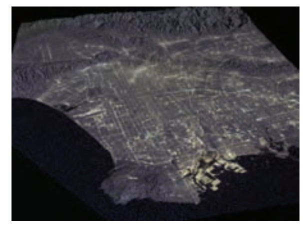
this persistence, or the memory length of the land-atmosphere system, can be as long as 3 months in late spring and summer, suggesting that the slowly varying soil moisture can potentially serve as a good predictor for seasonal climate. To use soil moisture as a "predictor," numerical model-based seasonal prediction requires accurate soil moisture initialization and the realistic simulation of important processes involved in soil moisture-precipitation coupling. One of these processes is the seasonal vegetation feedback. At the seasonal time scale, vegetation responds to concurrent and cumulative hydro-meteorological conditions and feeds back to further influence the hydro-meteorological processes. This feedback has largely been neglected in the past as most models prescribe, instead of predict, the seasonal course of vegetation. In a recent study, a predictive phenology scheme (which predicts the seasonal variation of vegetation) was incorporated into a coupled land-atmosphere model, and the impact of soil moisture anomalies on subsequent precipitation examined. Vegetation feedback was found to enhance the impact of wet soil moisture anomalies on subsequent precipitation over most of the Mississippi River Basin. The contribution from soil moisture-induced vegetation feedback was found to be as important as the contribution from the initial soil moisture anomalies. This finding shows the importance of including predictive phenology schemes in seasonal prediction models.



A High-Resolution Meteorological Distribution Model for Atmospheric, Hydrologic, and Ecologic Applications.[9] A snow evolution modeling system (SnowModel) was used to simulate seasonal snow evolution across three 30-km by 30-km domains enveloping the Cold Land Processes Field Experiment (CLPX) meso-cell study areas in Colorado. Simulations were performed using a 30-m grid increment and spanned the snow accumulation season for this region (1 October 2002 through 1 April 2003). Meteorological forcing was provided by 27 meteorological stations and 75 atmospheric analysis grid points distributed across the model simulation domains using a micrometeorological distribution model (MicroMet). The simulations included a data assimilation sub-model (SnowAssim) that adjusted snow water equivalent (SWE) toward a collection of ground-based and airborne SWE observations. Simulated SWE distributions displayed considerably more spatial heterogeneity compared with observations alone, and the simulated distribution patterns closely fit understanding of snow evolution processes and observed snow depths.

Land Surface-Atmosphere Interactions studied by Comparing Simulated vs. Observed Fluxes and Feedbacks.[10] Land atmosphere interactions in the Weather Research and Forecasting (WRF) model and the Noah Land Surface Model (Noah LSM) were analyzed by comparing simulated fluxes and feedbacks to *in situ* and remotely sensed observations. Vegetation cover, vegetation water content, and land surface temperature data acquired from remotely sensed platforms are strongly correlated in semiarid regions, such as the

North American Monsoon Region, compared to more humid regions. The assimilation of these data, including their covariance, into the Noah LSM improved the simulation of soil moisture and other land surface fields. However, the latent heat flux to the atmosphere, and therefore likelihood of precipitation, were found to be overestimated due to the parameterization of vegetation physiology.



New Water Stress Index to Assess the Impacts of Environmental Change on Water Availability and Use in the United States.[11] Watershed water stress is caused by both water availability (i.e., lack of supply) and use (i.e., demand), both of which are influenced by ecosystem conditions and humans. This study developed a water stress index that integrates both natural and anthropogenic effects on water availability and use. Future availability and use scenarios were modeled via changes in climate, land management, land use/land cover, and population. Results suggest that population growth will greatly increase water use in metropolitan areas, but overall, changes in population will have little impact on total water demand over the next 40 years. In contrast, changes in air temperature and precipitation will likely affect regional water availability significantly in coming decades.

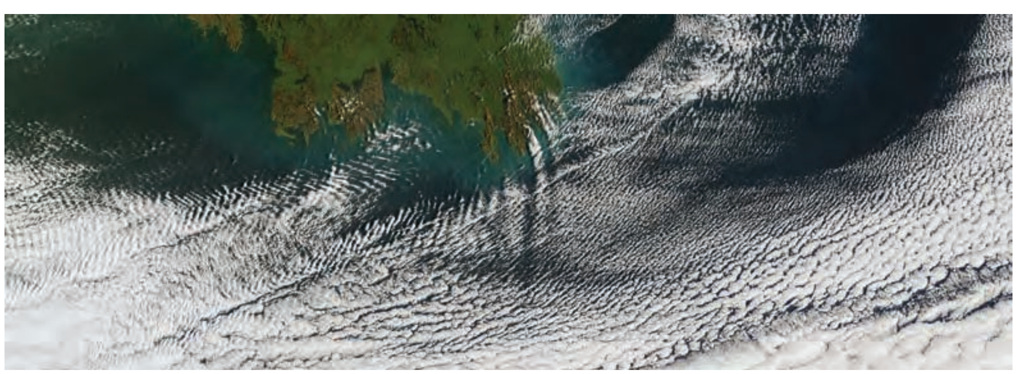
Will Thunderstorms be Stronger in a Warmer Climate?[12] How thunderstorm intensity will change with global climate change is an interesting and particularly important question. While there is some evidence that the intensity of hurricanes will increase, predictions for the nature of thunderstorms that are not part of hurricanes is lacking. Using a global climate model with a new parameterization of vertical velocities (or updrafts) in thunderstorms, Atmospheric Radiation Measurement (ARM) researchers examined how

the intensity of thunderstorms varies from region to region over ocean and land and how the vertical velocity will increase in a warmer climate. Their results indicate that a simple estimate of the upward velocity of thunderstorm updrafts in a global climate model reproduces observed land-ocean differences in thunderstorm intensity. Under a climate change scenario, updrafts strengthen by about 1 $m\ s^{-1}$ in the lightning-producing regions of continental thunderstorms, primarily due to an upward shift in the freezing level. For the western United States, drying in the warmer climate reduces the frequency of thunderstorms that initiate forest fires, but the strongest storms occur 26% more often. For the central-eastern United States, stronger updrafts combined with weaker change of winds with height (or wind shear) suggest little change in severe storm occurrence with global climate change, but the most severe storms occur more often.

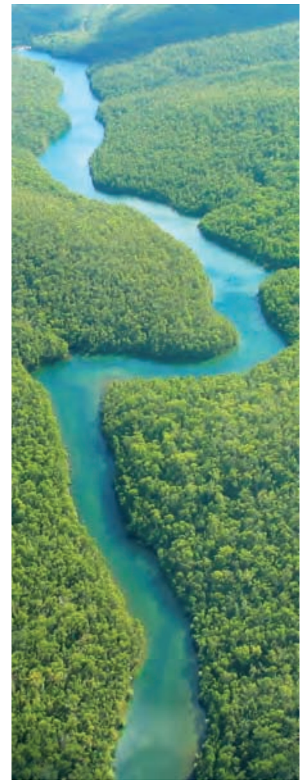
Rock Glaciers as Hydrologic Refugia in a Warming World.[13] Rock glaciers are widespread but little studied landforms in semi-arid mountain ranges of the world. Rock mantling insulates ice from solar heating, creating a lag in response to climate relative to typical glaciers and winter snowpacks. A classification system has been developed and used to survey over 400 features in canyons of the Sierra Nevada, California. It was found that these features are undocumented sources of mountain water, and provide wetland refugia for mountain biodiversity. As snowpacks diminish in the future, they will likely gain in local importance.

Highlights of Plans for FY 2009

The Global Water Cycle research element continues to pursue important long-term priorities. For example, insights into the formation and behavior of clouds and precipitation, including better characterizations of the phase changes of water in clouds and the phases and onset of precipitation, are emerging from field campaigns and model studies and will be promoted in continuing activities. Water vapor and cloud-radiation feedback are considered a critical part of global water cycle studies that need



to be addressed to reduce uncertainties associated with climate change projections. The predictability of regional precipitation is another topic of vital interest: It will be assessed and better understood by ongoing diagnostic and modeling studies that identify the connections between regional- and global-scale phenomena, land surface conditions such as soil moisture and water table fluctuations, and the interface fluxes of energy and heat between the atmosphere and the land surface-vegetation-hydrology combination. Preliminary analyses from recent studies show promise of leading to earlier (and more accurate) predictions, improved ability to assess hazards and risks of extremes such as floods and droughts, and more efficient water resource management.



In FY 2009, continuing U.S. and global observations, field campaigns and experiments, improvements to data integration and analysis systems, diagnostic and predictive model development, and applications to decision-support systems will be priorities under the CCSP Global Water Cycle program. A fundamental objective is to ensure that observational capability is enhanced and improved, and that the data assimilation and modeling/prediction systems are more reliable and accurate at the point of application. Several promising results from the past years of research will be further explored with an aim to transfer this research knowledge to operational applications that provide societal benefit. To this end, the program has developed a series of priority activities for the FY 2009 (and beyond) time frame. Concurrently, a cohesive research strategy will be implemented to improve current deficiencies in understanding all aspects of the regional and global water cycle. Several science questions remain to be answered related to warnings of natural hazards and to the impact of global climate change, be it from natural or anthropogenic causes. A considerable research focus will be placed in FY 2009 and beyond on "downscaling" from the recently released IPCC Fourth Assessment Report climate projection model assessments. That is, downscaling, using a combination of high-resolution dynamical/statistical models, to the regional scales of critical import to decisionmaking as regards water resource management and associated infrastructures.

The program outlined for FY 2009 will lead to improvements in fundamental research, as well as in the planning and decisionmaking for, and management of, natural and human-made resources—a major aim of the program in addition to its fundamental research goals. A strong effort will continue to focus on major unresolved research issues that will require longer term commitments. To address both research and multi-sectoral applications needs, several initiatives will be launched in FY 2009 and beyond.

New Land Cover Visualization Tool for the Analysis of Land Cover Change with Time. Land-cover data has been a largely untapped information resource. Both natural processes and human influences shape land cover—the pattern of natural vegetation, agriculture, and

urban areas. Information about land cover is needed by managers of public and private lands, urban planners, agricultural experts, and scientists for studying such issues as climate change or invasive species. With increasing population and the challenging prospect of climate change, comprehensive information about the condition of land, and how it is changing, becomes more and more vital. Recently, USGS announced the launch of the new USGS Land Cover Visualization and Analysis Tool, which allows users to analyze, in specific detail, how land cover has changed over time. Designed for both novice and expert users, the web-based system provides an intuitive interface able to selectively view and analyze land-cover data from any web browser. USGS is soliciting users to evaluate the preview release of the application (see <lcat.usgs.gov>).

This activity will address CCSP Goals 1, 2, 3, 4, and 5 and Questions 5.1, 5.2, and 5.3 of the CCSP Strategic Plan.

Planning for an L-Band Soil Moisture Active-Passive (SMAP) Space-Based/Satellite Instrument Platform. Accurately measuring global terrestrial moisture is considered a high priority for a vast range of terrestrial hydrological science and applications that are of primary relevance to societal benefits. Following the prioritized recommendations of the National Research Council's Decadal Survey, CCSP-supported actions have been taken to begin development of the space-based instrument sensors required to measure terrestrial soil moisture with substantially improved accuracy compared to that currently provided by various passive microwave satellite instruments such as the SSM/I series and the microwave imager onboard the TRMM satellite (TRMM-TMI). NASA initiated planning with a dedicated SMAP design workshop in July 2007. Several CCSP agencies are involved in this process, as well as a diverse group of university researchers including representatives from the Massachusetts Institute of Technology who were involved with the Hydrosphere State Mission (Hydros) platform a few years ago. In a sense, Hydros provides the legacy for SMAP planning. Hydros was designated as an alternate to Aquarius but not finally selected (at that time) due to budgetary constraints. SMAP will contain an instrument suite broader in scope than Hydros. In FY 2009 and subsequent years, the SMAP mission will be designed, built, and launched contingent on budgetary considerations and national policy directives.

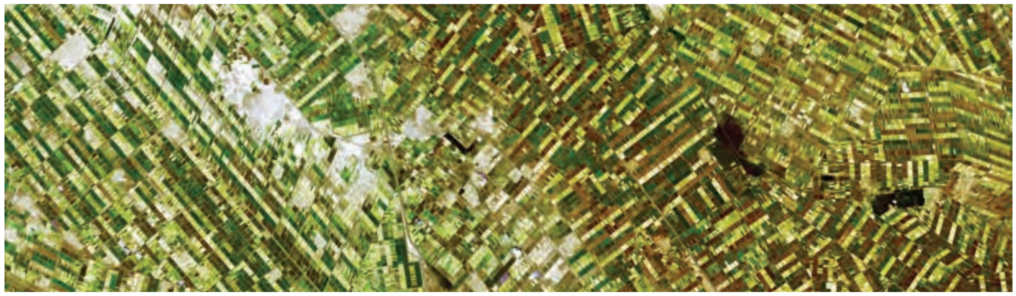
This activity will address CCSP Goals 1, 2, 3, 4, and 5
and Questions 5.1, 5.2, and 5.3 of the CCSP Strategic Plan.

Planning for a National Groundwater Recharge Monitoring Network. In the United States and around the world, groundwater is being withdrawn at unprecedented rates. Increasing pressures are being placed on hydrological systems to support urban expansion and rising demand from the agricultural industry, including the rapidly increasing demand arising from the bio-fuel industry as reported in many journals. Global and regional climate change imposes various scenarios and constraints regarding the sustainability of current water management infrastructures. To understand this situation better, planning has been initiated, led by USGS but with multi-agency collaboration, to develop a groundwater recharge monitoring network. The observation/measurement problem is complex and requires several research and monitoring aspects that currently do not exist. The Global Water Cycle interagency working group intends to integrate this key parameter (groundwater recharge) into the construct of an integrated, interagency project to address the "closure" of the water budget on the scales of a river basin and/or catchment area. Results from this research/observations exercise will contribute to development of improved models, which then can be applied to better assess water availability issues under a climate change scenario.

This activity will address CCSP Goals 1, 2, 3, 4, and 5
and Questions 5.1, 5.2, and 5.3 of the CCSP Strategic Plan.

International Hydrologic Ensemble Prediction Experiment. CCSP's Climate Prediction Program for the Americas (CPPA) will continue to support the Hydrologic Ensemble Prediction Experiment (HEPEX), an international project to demonstrate how to produce reliable hydrological predictions that can be used with confidence for decisionmaking. An initial experimental operational prototype system, using weather and climate forecasts to produce input forcing for hydrologic forecast models, will be tested at several National Weather Service (NWS) River Forecast Centers. This includes a strategy for seamless integration of weather and climate forecasts for all lead times from 1 hour to more than 1 year. Future CPPA plans include:

- Development of "supporting data sets" for hydrologic ensemble prediction research within the HEPEX test-beds and improved pre-processing methodologies
- Collaborative activities among the international science community, CPPA researchers, NWS , and Hydrologic Development and River Forecast Centers to improve seasonal hydrologic forecasting techniques
- Evaluation of improved models and techniques for making probabilistic hydrologic forecasts that integrate with CPPA research in land memory processes, orographic



processes, remote sensing, and climate predictions for possible operational application in NWS hydrologic forecast systems

- Demonstration of improvements in end-to-end hydroclimatic forecasting technologies at intra-seasonal and seasonal time scales.

This activity will address CCSP Goals 2, 3, and 5 and Questions 5.1, 5.2, and 5.3 of the CCSP Strategic Plan.

New "Holistic" Earth Surface Observations to Focus on the Science of Watershed Evolution. NSF has selected sites for three critical zone observatories (CZO) as an initial impetus to a long-term program. In FY 2009 and beyond, these observatories are designed to provide scientists with an understanding of what is called a "critical zone"—the region between the top of the forest canopy and the base of unweathered rock (the living environment)—and its response to climate and land-use changes. CZOs represent the first set of systems-based observatories dedicated to Earth surface processes. Scientists at each CZO will investigate the integration and coupling of Earth surface processes and how they are affected by the presence and flux of freshwater. CZOs will use field and analytical research methods, space-based remote sensing, and theoretical techniques. These projects will add to the environmental sensor networks already in place and those planned by NSF, including EarthScope, the National Ecological Observatory Network, and the Ocean Observatories Network. The CCSP Global Water Cycle interagency process will explore means by which sites such as CZOs and others can be complemented with additional multi-agency observational capabilities to meet the broader science objectives of the research element and, in particular, the planned Global Water Cycle priority activities/projects.

This activity will address CCSP Goals 1, 2, 3, and 4 and Questions 5.1, 5.2, and 5.3 of the CCSP Strategic Plan.

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