U.S. DEPARTMENT OF ENERGY | Office of Science

CHALLENGES OF COMMUNITY MODELING AND LONG-TERM PREDICTIONS OF THE INTEGRATED WATER CYCLE

Water is essential for a wide range of life-sustaining human activities and is a major component underlying a suite of important processes and feedbacks that affect climate. The hydrological cycle is projected to intensify in a warmer climate, and the impacts on human and natural systems will be profound. Today's scientific uncertainties in predicting long-term changes in global and regional hydrologic cycles, and implications for water supplies and energy production and use, fundamentally limit the Nation's ability to develop sustainable energy solutions.

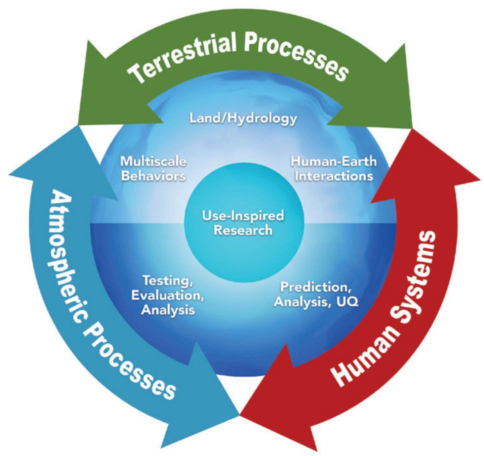
The water cycle is influenced by human activities related to energy, water, and land use. Understanding, modeling, and predicting the water cycle requires knowledge of the *integrated water cycle*, which consists of storage and transport of water in various phases and forms controlled by natural processes in the Earth system, as well as storage and transport of real and virtual water controlled by infrastructures and management of the human systems.

INTEGRATED WATER CYCLE WORKSHOP

Modeling the integrated water cycle is a significant scientific challenge that is well aligned with the Department of Energy climate program's mission to advance a robust predictive understanding of Earth's climate and environmental systems and to inform the development of sustainable solution to the Nation's energy and environmental challenges. To identify the challenges of next-generation earth system models, a workshop on Community Modeling and Long-Term Predictions of the Integrated Water Cycle was organized by DOE in September 2012 in Washington DC. This workshop, with interagency participation, discussed critical gaps in three overarching science grand challenges.

SCIENCE GRAND CHALLENGES

Modeling the multi-scale processes in the atmospheric and terrestrial systems and their interactions that are integral to predicting water cycle variability and change
Understanding and predicting the evolution of the human-arth system and interactions with water supply and use
Providing the science basis from modeling to support decision-making and mission oriented objectives



The workshop focused discussions on a limited set of key processes/systems and topics relevant to modeling of the integrated water cycle in the above schematic.

1. Predicting the integrated water cycle is challenging because water cycle processes span a wide range of spatial and temporal scales. Modeling these multi-scale processes requires:

- advanced scaling theories
- quantification of errors and advanced methods for modeling multi-scale processes
- testbed and multi-scale observational data for model evaluation and diagnostics.

2. To understand and model the dynamics of human-Earth system interactions, more research is needed to:

- understand and represent the wide range of interactions between human system and atmospheric and terrestrial processes across scales
- test and evaluate human-earth system models
- untangle the role of human versus physical perturbations in past water cycle changes.

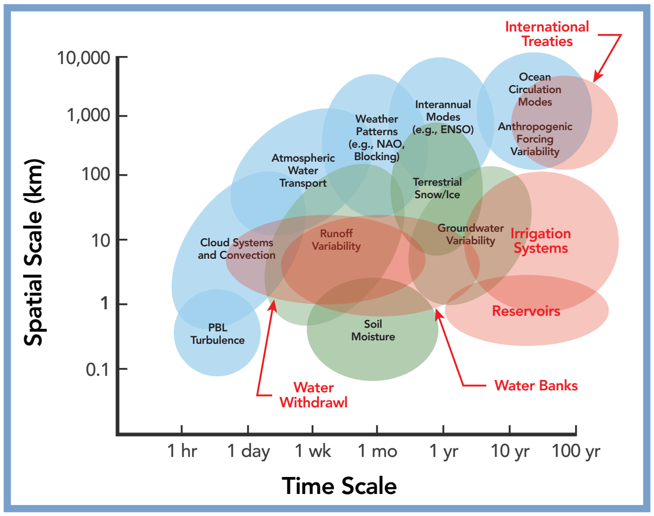
3. Water cycle predictions have important societal implications. To provide robust, relevant science for decision-making, more research is needed to:

- understand and quantify the sources of human-Earth system predictability
- improve predictions using a hierarchy of models
- develop user-relevant metrics and risk quantifications
- advance use-inspired research through interdisciplinary team approaches.

In addition to addressing the science grand challenges, workshop participants identified advanced modeling capabilities that address crosscutting research. Three examples of integrative modeling challenges that build and connect different elements of crosscutting research are given below.

1. ***Climate change and socio-economic response to climate may alter land use and irrigation practices. Increased frequency/amplitude of droughts can lead to increased irrigation investments. Conversely, irrigation and land use change can impact precipitation variability and extremes. Because of the significant interactions among climate, land use, and water availability and use, predicting future energy, water, and food supply requires integrating and analyzing feedbacks of irrigation and land use on climate and water and energy systems in an integrated Earth system modeling framework.***

2. ***There is a need for crosscutting research to address a wide range of user needs for integrated water cycle predictions. Targeting key phenomena such as heavy precipitation and high frequency river flow can help focus research to improve prediction targets to better address risk-based decisions. Depending on the user end point, the extent to which human influence should be an integrated component of the modeling system is variable, so developing a hierarchy of models with flexibly formulated and interchangeable components is important for both advancing understanding and predictions.***



A schematic of the space-time characteristics of atmospheric, terrestrial, and human system processes.

INTEGRATIVE MODELING CHALLENGES

Implications of water management and land cover and land use changes for energy and water resources and climate
Modeling frameworks/hierarchy driven by actionable requirements to predict the water cycle for different user needs
Sustainability of the water and energy supply over the contrasting landscapes and water use of western and eastern North America under projected changes in climate and human activity

3. ***North America is marked by diverse landscapes and resources. Predicting the vulnerability and adaptability of the contrasting regimes of mountain and snow-fed water cycle of western North America in comparison to the lower elevations, less-seasonal precipitation regimes of eastern North America—each with their own profiles of human influence—is an important challenge to critically test the ability to model the integrated water cycle in a way meaningful to the Nation's regional decision makers.***

To address these challenges, the following are needed:

- a set of interconnected models describing multiple systems involving different scales, in order to determine the changes in the water cycle and energy supply/demand; land use; and their interactions
- strategic development of model frameworks and hierarchy to exploit different sources of system predictability and available data to meet different user needs
- advances to meet computational challenges in model coupling, computing resources, and software infrastructure for effective develop ensemble modeling frameworks and to address uncertainty
- engagement within the stakeholder community with key decision makers integrated from the beginning to develop buy-in and key user guidance.

The challenges identified at the workshop represent remarkable opportunities for interagency collaborations to improve predictions of the integrated water cycle for significant scientific and user impacts.

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