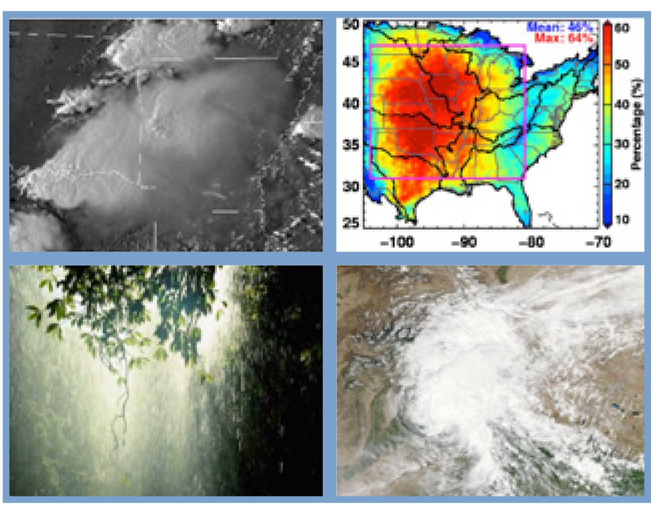
U.S. DEPARTMENT OF ENERGY | Office of Science

WATER CYCLE AND CLIMATE EXTREMES MODELING

Since the dawn of the industrial era, human activities have significantly perturbed the climate system and water cycle, with serious consequences for human society and ecosystems. Achieving robust prediction of water cycle changes in the future has been challenging because large-scale circulations have dominant control on regional precipitation, but the dynamical and thermodynamical processes that govern large-scale circulation changes are not well understood. For example, while progress has been made in documenting and understanding the robust changes in the zonally symmetric component of the general circulation, the global warming signal associated with the zonally asymmetric circulation, such as the monsoon, is still unclear. Latent heat release associated with convection is a key driver of large-scale circulation. However, representing convection has been one of the foremost challenges in climate modeling. Limitations in modeling convection have implications not only for depicting large-scale circulation features through multiscale convection-circulation interactions, but mesoscale-organized convection is a ubiquitous mechanism responsible for heavy rainfall and flooding worldwide. By improving understanding and modeling of water cycle processes, this project addresses the strategic goal of the U.S. Department of Energy's Climate and Environmental Sciences Division to "advance a robust predictive understanding of Earth's climate and environmental systems and to inform the development of sustainable solutions to the Nation's energy and environmental challenges."



As mesoscale convective systems account for up to 64% of warm-season precipitation in the U.S. Great Plains (top panels) and frequent many regions including the Amazon basin and Indian sub-continent (bottom panels), they play an important role in the hydrological cycle worldwide. With most climate models failing to capture these organized convective storms, the consequential biases in the latent heating in the atmosphere, surface energy, and water balances have important implications to simulating large-scale circulation, land-atmosphere interactions, and regional precipitation response to global warming.

SCIENCE OBJECTIVES

The 10-year vision of the Water Cycle and Climate Extremes Modeling (WACCEM) project is to tackle the above challenges to advance robust predictive understanding of water cycle processes and associated

KEY QUESTIONS FOR FY 2016-18:

- What are the governing mechanisms of monsoon systems and their impact on the zonally asymmetric circulation, and how will they change in response to climate warming?
- What are the dynamical linkages between the jet stream and wave breaking with atmospheric rivers and their moisture transport, and what are the implications of changes in these circulation features for extreme precipitation in the extratropics?
- What are the relative impacts of atmosphere and land-surface conditions on convection in the central U.S. and Amazon?
- How may the structure of mesoscale convective systems change in a warmer climate and impact extreme precipitation?
- What are the roles of diabatic processes, particularly associated with convection and aerosols, in the Asian monsoon system and their responses to future warming?
- What are the climatological relationships between the South Asian monsoon and North Indian Ocean tropical cyclones, and how may these relationships change in a warmer climate and affect precipitation?

extremes and their changes in a warming climate. It will address three overarching science questions:

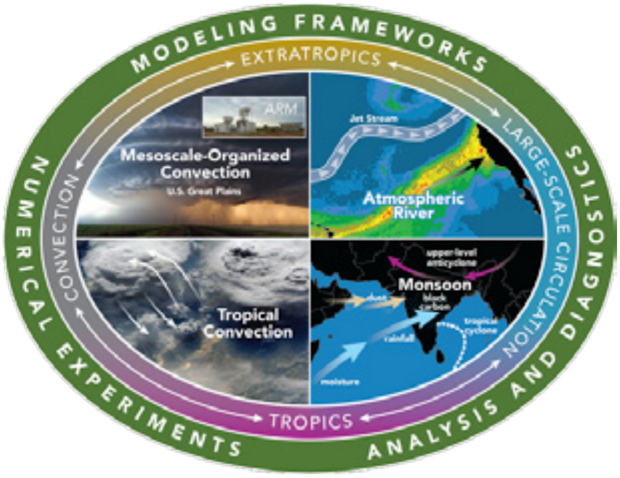
1. How do large-scale circulation features, such as the extratropical storm tracks and monsoon systems, modulate regional mean and extreme precipitation, and how will they change in the future?
2. What processes control mesoscale-organized convection and associated warm-season regional mean and extreme precipitation, and how will they change in a warmer climate?
3. What are the robust multiscale connections between atmospheric circulation features and water cycle processes, and how do they influence regional precipitation?

RESEARCH FOCUS

WACCEM is organized into four major elements for fiscal years (FY) 2016-18. Research Element 1 advances modeling frameworks, performs a hierarchy of numerical experiments, and develops diagnostic/analysis methods. Research Elements 2 through 4 probe the mechanisms and processes underlying each science question.

Research Element 1: Modeling Frameworks, Analysis and Diagnostics, and Numerical Experiments

The main objective is to advance a global multi-resolution modeling framework based on the non-hydrostatic Model for Prediction Across Scales (MPAS) coupled with the Community Atmosphere Model physics for simulations down to convection-permitting resolution. A suite of diagnostics and analysis methods will be developed to address the science questions targeted by Research Elements 2 through 4.



The objectives of WACCEM will be advanced through research in four elements: (1) Modeling frameworks, analysis and diagnostics, and numerical experiments; (2) Large-scale circulation (monsoon and atmospheric river); (3) Convection (U.S. Great Plains and Amazon); and (4) Multiscale monsoon-convection interactions (Asia).

Research Element 2: Large-scale Circulation

This element targets two important large-scale circulation features—monsoon systems and atmospheric rivers—with important implications for regional precipitation and extremes. Building an idealized modeling hierarchy, a first-order picture and governing principles of the monsoon will be developed. By linking atmospheric rivers to the jet stream and wave breaking, and using observations from the CalWater 2 and ACAPEX (ARM Cloud Aerosol Precipitation Experiment) field campaign, the moisture sources and transport pathways of atmospheric rivers will be quantified.

Research Element 3: Convection

This element evaluates the relative impacts of atmospheric and land-surface conditions on convection and investigates potential changes of the structure of mesoscale convective systems in a warmer climate and the implications to extreme precipitation. Model simulations will be evaluated using observations from the Atmospheric Radiation Measurement (ARM) Climate Research Facility at the Southern Great Plains and the GoAmazon 2014/2015 field campaign.

Research Element 4: Multiscale Monsoon-Convection Interactions

This element investigates the roles of diabatic processes in the Asian monsoon and their responses to global warming. Moisture budget analysis will be used to attribute specific diabatic heating fields associated with the Asian monsoon divergent circulation and moisture transport. Numerical experiments will investigate changes in monsoon precipitation and tropical cyclone activity in response to greenhouse gases and absorbing aerosols.

CONTACTS

Renu Joseph, Ph.D.
DOE Program Manager
Regional and Global Climate Modeling
renu.joseph@science.doe.gov

L. Ruby Leung, Ph.D.
Principal Investigator
Pacific Northwest National Laboratory
ruby.leung@pnnl.gov

Project Website
http://climatemodeling.science.energy.gov/projects/water-cycle-and-climate-extremes-modeling