OFFICE OF BIOLOGICAL AND ENVIRONMENTAL RESEARCH
Earth and Environmental System Modeling

U.S. Department of Energy | Office of Science

WATER CYCLE AND CLIMATE EXTREMES MODELING

WACCEM
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EXTREMES MODELING

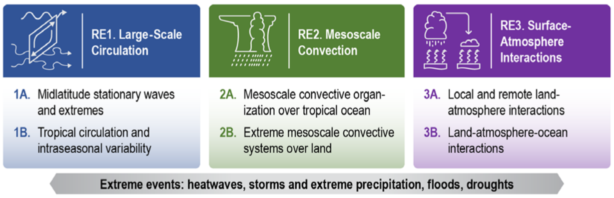
Variability and changes in the Earth's water cycle profoundly influence water availability and hydrologic extremes. The Water Cycle and Climate Extremes Modeling (WACCEM) Scientific Focus Area began in fiscal year (FY) 2016 with a 10-year vision to advance a robust predictive understanding of water cycle processes, especially hydrologic extremes, and their variabilities and multi-decadal changes.

Achieving this long-term goal will strengthen the ability to inform mitigation and adaptation planning to address water and energy security challenges facing the nation and the world.

As the water cycle is strongly influenced by large-scale circulation, convection, and multiscale interactions, WACCEM's research is organized around three overarching science questions:

- 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?
- What processes control mesoscale convection and associated warm-season regional mean and extreme precipitation, and how will they change in the future?
- What are the multiscale interactions between atmospheric circulation features and water cycle processes, and how do they influence regional precipitation?

Building on the WACCEM research in Phases 1 and 2 (FY 2016–2023), the Phase 3 research has a stronger focus on (a) extreme events, which have increasingly threatened lives, properties, and water and energy security; (b) organized convection with significant implications for tropical energy balance, hydrological cycle, and global climate; and (c) surface-atmosphere interactions and their contributions to the predictability of extreme events at subseasonal-to-interannual timescales.



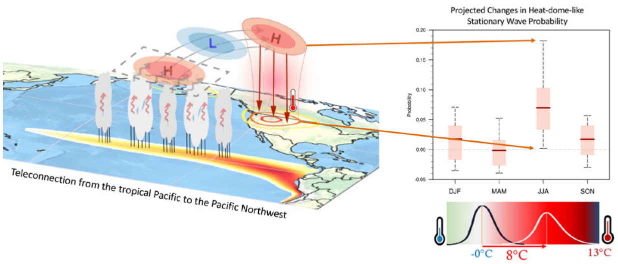
Overview of WACCEM research elements (RE 1–3) and thrust areas (A, B) under each RE for Phase 3 (FY 2024–2026).

WACCEM is organized by three research elements (REs), each with two thrust areas. With a focus on the water cycle and extreme events, WACCEM contributes substantially to DOE BER's mission to advance fundamental research in climate sciences to support DOE's energy, environment, and national security goals.

1. LARGE-SCALE CIRCULATION

Midlatitude stationary waves and extremes: Concurrent and compound extreme events have become more frequent and organized since the satellite era. How the atmospheric circulation may respond to climate change and dynamically impact regional extremes is still being debated. Aided by a new Energy Exascale Earth System Model (E3SM) model hierarchy developed by WACCEM and interpretable machine learning approaches, we strive to unravel the dynamic constraints behind the midlatitude summer circulation and the robust changes in the leading modes of variability.

Tropical circulation and intraseasonal variability: In the tropics, the boreal summer intraseasonal oscillation (BSISO) is a dominant subseasonal mode of variability in the tropical Indian and Western Pacific regions. Possible changes in the BSISO under warming can lead to life-threatening heat and deluges. Guided by the moisture mode theory and its associated conceptual framework and leveraging the feedback denial experiments in the E3SM model hierarchy,



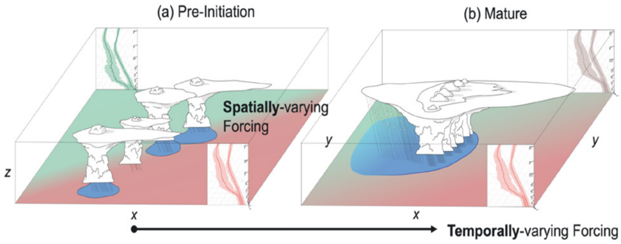
Under global warming, stronger convection associated with the larger sea surface warming over the tropical Eastern Pacific induces a stationary wave that increases the frequency and intensity of heat extremes in Northwestern North America.

we aim to understand the role of climate feedback on the BSISO and the mechanisms underlying future changes in the BSISO and their impacts on extreme events.

2. MESOSCALE CONVECTION

Mesoscale convective organization over tropical ocean: Tropical deep convections that organize and grow upscale into mesoscale convective systems (MCSs) substantially impact the hydrological cycle. Major gaps in understanding convective self-aggregation and mesoscale convective organization over the tropical oceans and the response to warming are being addressed using observations, global MCS tracking data, machine learning models, a kilometer-scale MCS reanalysis, and large eddy simulations..

Extreme mesoscale convective systems over land: In the central United States, MCSs that cluster in space and time are more effective in producing floods than individual MCSs. However, the role of clustered MCSs in producing extreme rainfall in regions other than the United States is largely unknown. Extending the WACCEM MCS datasets, tracking tools, and water tracer modeling, researchers are investigating the characteristics of extreme MCS precipitation over global land areas, their environments and predictability, and the role of land-atmosphere interactions.

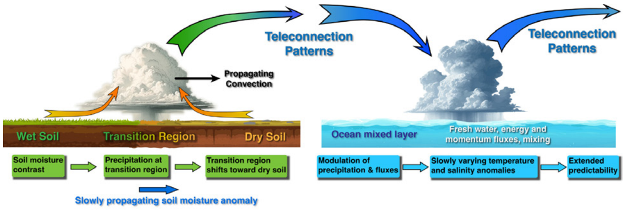


Large eddy simulations are being performed under spatially and temporally varying forcing to understand how individual deep convective cells aggregate to form mesoscale convective systems.

3. SURFACE–ATMOSPHERE INTERACTIONS

Local and remote land-atmosphere interactions: The societal benefits of subseasonal-to-seasonal (S2S) forecasts of extreme events have been well recognized. While progress has been made in exploiting the predictability associated with the Madden-Julian Oscillation (MJO), the role of soil moisture has not received as much attention. To understand the predictability of extreme events at the S2S timescale, we are investigating the predictability associated with the two-way interactions between intraseasonal signals (e.g., MJO, BSISO) and land-atmosphere interactions by using a new WACCEM-developed land-coupled data assimilation system in E3SM and other tools.

Land–atmosphere-ocean interactions: Land-surface anomalies associated with intraseasonal signals can affect sea surface temperature (SST) through teleconnections. Such land–ocean teleconnections through Rossby wave propagation in the atmosphere may introduce predictability for extremes at subseasonal-to-interannual timescales, as ocean has longer memory. Such predictability is being studied using a moist linear baroclinic model and E3SM land-coupled data assimilation.



Convection induced by soil moisture gradients over land (left) may excite Rossby waves that influence precipitation and surface fluxes over the ocean in remote regions and provide predictability of extreme events through teleconnection.

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