Extremes and Impacts

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Extreme events in the climate system take many forms and vary with location and time of year. These are often associated with severe weather, including extratropical and tropical cyclones (TCs), mesoscale-convective systems, atmospheric rivers (ARs), and snow storms. These phenomena and others drive precipitation extremes, wind extremes, drought, heat waves and cold air outbreaks, marine heat waves, and floods.

Impacts on human life and health, energy production, property and infrastructure, water, agriculture, ecosystems, and the environment can be driven by climatically extreme events; and they can also be driven by events that are more mundane by some measures, yet still correspond to, but represent a confluence of factors co-occurring in space and/or time.

Extreme events are, by definition, rare – they are sometimes defined as the statistical tail of climate system variability, which is influenced by interactions across timescales and by interactions among the atmosphere, land, ocean, ice, and human components of the Earth system. Impactful events are those that have repercussions for people, infrastructure, or the environment – and may or may not be associated with extreme events. Measuring and modeling drivers and responses to changes in extremes is central challenge of Earth system science, and of the RGMA program. In order to facilitate research on extremes and impacts, we propose framing it around the following grand challenge.

Grand Challenge Question: *What interactions across spatial and temporal scales drive extreme and impactful events, and how can we leverage understanding of such interactions to better understand, quantify, and predict extreme and impactful events?*

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Addressing this grand challenge question requires leveraging expertise across multiple disciplines and through research across multiple spatial and temporal scales. BER investments in Earth system models, and model hierarchies, will play a key role. Expertise across existing projects within RGMA offers a unique opportunity to advance our understanding of extremes and impacts by organizing research around the following science questions:

- What factors (including modes of variability) have contributed to extreme and impactful events in the historical record?
- How do interactions across time and space scales influence extreme and impactful events?
- To what degree and on what timescales are extreme events predictable?
- What is required to achieve such predictability of extreme events?
- How do interactions across different components of the Earth system (atmosphere, land surface, ocean, ice, and humans) influence extreme and impactful events?
- How well do existing model simulations capture and reproduce extreme and impactful events, and what is needed to improve simulations of these events?

Description of Current Challenges and Research in RGMA

Current work in RGMA addresses a number of interesting and important aspects of extreme and impactful events. Tropical cyclones represent a large focus in RGMA, given their role as one of the most destructive events driven by the climate system impacting the U.S. This includes understanding processes that influence TC characteristics, quantifying TC characteristics in climate models, through the use of high-resolution and variable-resolution capabilities, as well as attributing observed and projected changes in TCs. RGMA investments have resulted in new techniques for tracking and characterizing TCs in large climate datasets to allow for novel investigations of these events and improved understanding, such as the role of the ocean in storm intensification. ARs play an important role in western U.S. hydrology, and recent research within RGMA has started to explore the drivers, impacts, and uncertainties in these extremes. For example, RGMA support enabled the Atmospheric River Tracking Method Intercomparison Project (ARTMIP; Shields et al., 2018), which is designed to explicitly and systematically quantify uncertainties associated with different choices for defining atmospheric rivers. RGMA work has also investigated and quantified extremes in the integrated water cycle more generally, to evaluate their response to drivers of change in the Earth system.

Beyond TCs and ARs, research across RGMA has sought to understand how large-scale forcing and natural variability impacts the statistics and characteristics of a variety of extreme event types. These analyses include detailed studies into numerical model design, including resolution, on the characteristics of these extreme events (e.g., Leung et al., 2013, EOS). Such analyses have recently broadened beyond TCs and ARs, to tackle precipitation from mesoscale convective systems, hail events, and drought and aridity, with impacts from wildfire and human activities such as urbanization and irrigation.

Research Gaps and Future Directions

Improving fundamental understanding should remain the main driver for research within RGMA. That said, given the current research in RGMA and the overarching research goals described above, there are some specific research gaps that could be addressed through leveraging existing expertise and capabilities within RGMA. These research gaps fall within two main categories: gaps in our quantitative understanding of the drivers of extremes in the integrated water cycle, and gaps in our ability to effectively utilize Earth system models to simulate extremes and connect them to impacts. The following research directions will advance our ability to understand, quantify, and predict extremes and their impacts:

Short Term (3- 5 years) Research Goals

- Expand research to a broader portfolio of extremes, such as extreme wind events, drought and aridity, and heat waves (including marine heat waves).
- Synthesize extreme event tracking efforts across RGMA to enable a broader and more effective quantification and comparison of observations to models.
- Understand what spatiotemporal aspects of precipitation are important for translating into flood events, and develop diagnostic metrics that enable insightful evaluation of model fidelity.
- Continue efforts to define extreme and impactful events from a stakeholder-informed, use-inspired perspective, with an emphasis on efforts that are interdisciplinary, and that leverage expertise across EESD (e.g., Multi-Sector Dynamics) and other parts of DOE–and even other agencies.

Long Term (10 years) Research Goals

- Document observed extreme events (e.g., precipitation extremes) to enable meaningful evaluation of extremes in simulations, such as those in climate model intercomparisons.
- Continue to emphasize building basic physical understanding of extreme events and the environmental conditions they are associated with.
- Expand research on extremes in the coupled Earth system, especially their interactions with various components (e.g., ocean and land), with an emphasis on understanding the role of surface-atmosphere interactions in driving synoptic to interannual variations in weather extremes and our ability to simulate such variations.

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