U.S. DEPARTMENT OF ENERGY | Office of Science

CALIBRATED AND SYSTEMATIC CHARACTERIZATION, ATTRIBUTION, AND DETECTION OF EXTREMES

With shifting earth system patterns, extreme weather events pose great hazards to both society and the environment. Extreme weather focuses public attention on the dramatic consequences of these events.

In 2011, for example, unusually high precipitation, combined with high snowpack, caused extensive flooding throughout the central United States. Heat waves across the same region in 2012 and 2015 produced the country's two hottest years in recorded history. And most recently, 2017 brought record precipitation to California and devastating hurricane impacts to the U.S. Gulf Coast and the Caribbean.

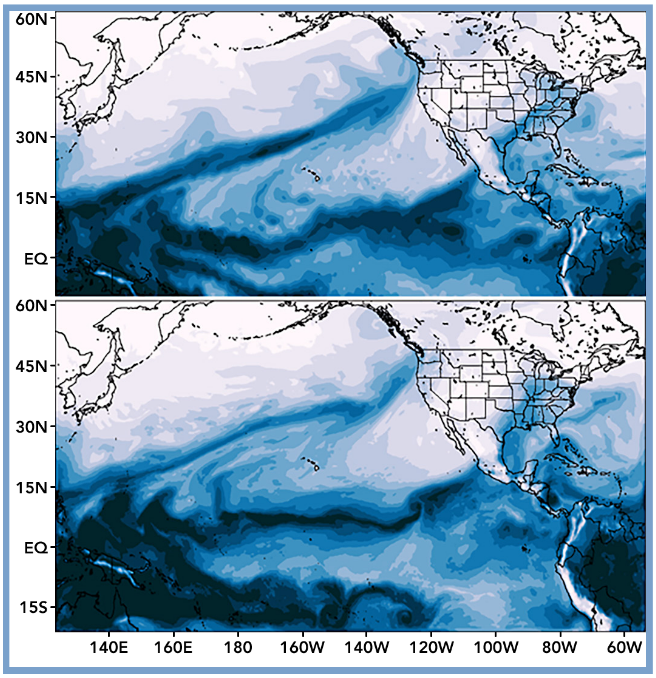
Current research points to an increase in the severity of extreme weather events, and this will constitute one of the most stressful challenges to the nation's environment, economy, and society. For scientists, it is critical to predict with greater reliability how these extreme events might change in the future and, to advance that objective, determine with as much certainty as possible whether and why the nature of extreme events has already changed.

CASCADE: TAKING A SCIENTIFIC FOCUS

The intersection of climatic extremes with critical water and energy resources is a key focus area for the U.S. Department of Energy (DOE). This priority is reflected in the DOE Climate and Environmental Sciences Division Strategic Plan, the 2012 DOE Workshop on Community Modeling and Long-Term Predictions of the Integrated Water Cycle, and a 2013 DOE report on U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather.

Sponsored by DOE's Earth and Environmental System Modeling program, the Calibrated and Systematic Characterization, Attribution, and Detection of Extremes (CASCADE) project addresses the critical knowledge gaps on earth system extremes needed to advance DOE's mission. CASCADE is developing capabilities to accelerate DOE's research portfolio in extremes and to advance scientific capabilities in earth system analysis:

- Understand the drivers of observed changes in extremes.
- Characterize the dominant sources of uncertainty in extremes.
- Understand and simulate the physical behavior of extreme events.
- Develop high-performance software for exascale analysis of extreme events.



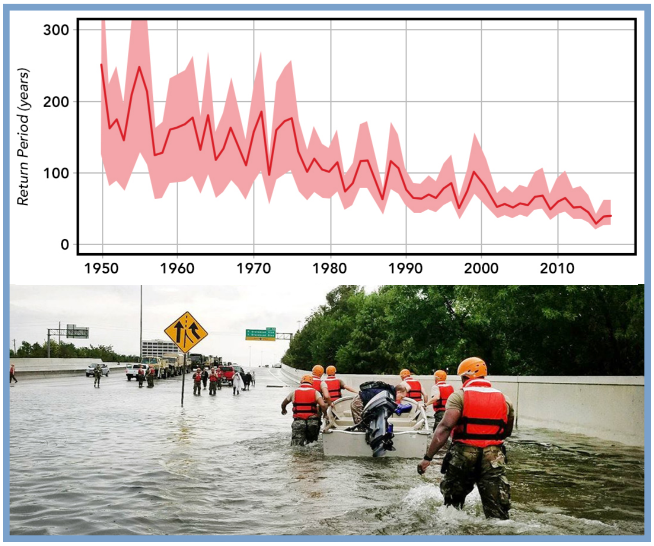
CASCADE investigates what causes some years to have many wintertime 'atmospheric rivers'—while other years have few—and how this relates to drought in the western United States. CASCADE researchers run simulations of atmospheric rivers (bottom) and compare them with observed atmospheric rivers (top) to build confidence that earth system models can be used in experiments that inform how atmospheric rivers work in the real world.

These capabilities will be used to answer several key science questions:

- How has the nature of extreme events changed in recent history (for example, frequency, duration, intensity, and spatial extent)?
- What has contributed to this change?
- How can the nature of extreme events change in the future?

CASCADE PROGRAM OBJECTIVES

Understanding drivers of observed changes in extremes: CASCADE investigates the causes of specific extreme events and their driving mechanisms, quantifies changes



Extreme weather events, such as flooding caused by Hurricane Harvey in 2017 (bottom), are used as case-studies for understanding how impactful hurricanes are changing. Analysis of observations (red line) and consideration of uncertainty (red shading) indicate that storms like Hurricane Harvey are becoming much more common.

in both the magnitude and frequency of extreme events, develops state-of-the-art statistical tools for characterizing coincident extremes, and expands the scope of uncertainty quantification for detection and attribution. In terms of project goals, the investigation has several outcomes:

- Development of robust hindcast methodologies (model validation to test the ability to reproduce the observed past) to quantify why rare weather events have changed over the past century.
- Systematically describe global changes in classes of extreme events.
- Provide localized information on both the changes in extremes and their causes.

Characterization of dominant sources of uncertainty in extremes: CASCADE is taking a systematic approach to considering dominant sources of uncertainty in research on extremes. These drivers include the chaotic behavior of the earth system (i.e., the butterfly effect), choices that model developers make about the structure of earth system models, and uncertainty in underlying observations. CASCADE uses advanced statistical and experimental techniques to characterize the impact of these sources of uncertainty. This approach is designed to:

- Produce defensible scientific conclusions about how and why there are observed changes in extreme events.
- Advance fundamental understanding of extremes by reducing ambiguities that are caused by uncertainties.
- Produce data sets that the broader science community can use for similar research.

Understanding and simulating the physical behavior of extreme events: CASCADE advances understanding of the physical mechanisms that drive variability and change in the spatiotemporal characteristics of extreme events. This research enhances resiliency to extremes by:

- Quantifying how the probability distributions of multivariate extremes respond to trends and patterns of atmosphere-ocean variability.
- Identifying the thermodynamic and dynamic processes that drive extremes and their multi-scale interactions in the earth system.
- Evaluating the ability of earth system models to represent extremes.

High-performance software for exascale analysis of extreme events: CASCADE creates high-performance, open-source computational and statistical tools that can be shared, reused, and further developed for research beyond the project's central research challenges. The effort is designed to produce significant new capabilities for climate science:

- Create high-fidelity statistical tools for quantifying extremes.
- Develop a high-throughput tool to identify and track weather features in terabytes to exabytes of climate data.
- Extend uncertainty quantification frameworks to treat a wide of variety of extreme phenomena.

COLLABORATIONS

The CASCADE project is a collaborative work at Lawrence Berkeley National Laboratory (LBNL), University of California, Berkeley, and University of California, Davis. CASCADE scientists collaborate with related projects at LBNL and across BER's earth system modeling efforts. These projects include earth system modeling efforts; land, ocean, and atmosphere diagnostics projects; and stakeholder-driven science projects. The resulting connections and related projects ensure tight integration of observations, experiments, and modeling of extreme events.

CONTACTS

Renu Joseph, Ph.D.
DOE Program Manager
Earth and Environmental System Modeling
renu.joseph@science.doe.gov

William Collins, Ph.D.
Principal Investigator
Lawrence Berkeley National Laboratory
wdcollins@lbl.gov

Travis A. O'Brien, Ph.D.
Technical Co-Manager
Lawrence Berkeley National Laboratory
taobrien@lbl.gov