U.S. DEPARTMENT OF ENERGY | Office of Science

CALIBRATED AND SYSTEMATIC CHARACTERIZATION, ATTRIBUTION, AND DETECTION OF EXTREMES

Risks of extreme weather events pose some of the greatest hazards to society and the environment as the climate system changes. Extreme weather has recently focused public attention on the dramatic consequences that follow from these events. In 2011, 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 first and second hottest years in recorded history. Most recently, the year 2017 brought intense record precipitation in California and enormous impacts to the US Gulf Coast and Caribbean Islands from Hurricanes Harvey, Irma, and Maria.

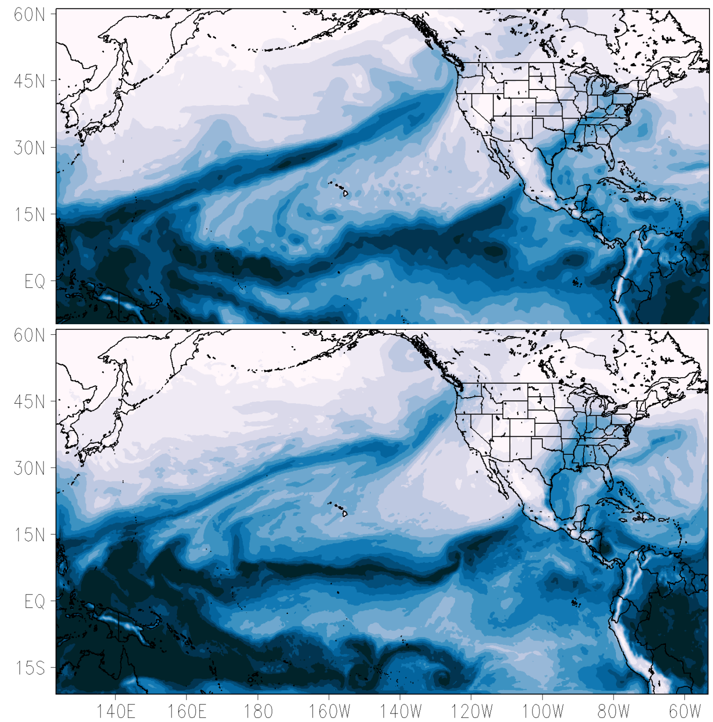
As the severity of extreme climate events continues to increase, this will constitute one of the most stressing forms of change for society and the environment. Therefore, it is crucial to predict with greater reliability how extreme events might change in the future and, in order to advance this objective, to determine with as much certainty as possible whether and why extreme events have already changed.

SCIENTIFIC FOCUS

The intersection of climatic extremes with critical water and energy resources for the United States is a key focal area for climate research in 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 the DOE's Regional and Global Climate Modeling program, the Calibrated and Systematic Characterization, Attribution, and Detection of Extremes (CASCADE) project addresses the critical knowledge gaps on climate extremes needed to advance DOE's mission.

CASCADE is developing the following capabilities to accelerate DOE's research portfolio in climate extremes and to advance scientific capabilities in climate analysis:

1. Understanding drivers of observed changes in extremes
2. Characterization of the dominant sources of uncertainty in extremes

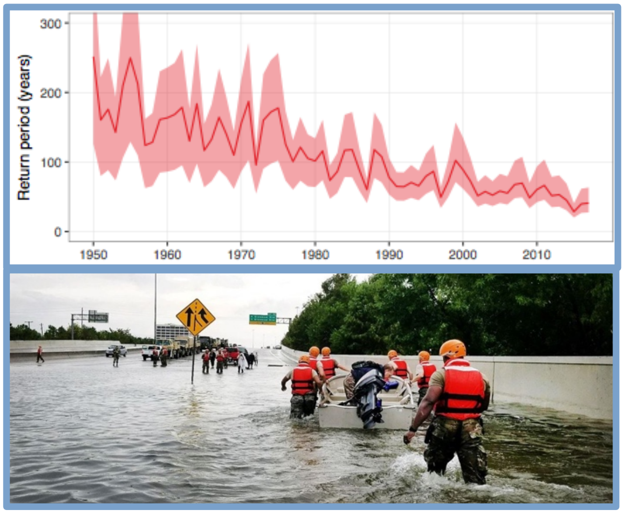


CASCADE is investigating what causes some years to have many wintertime 'atmospheric rivers'—while other years have few—and how this relates to drought in the Western U.S. CASCADE researchers run simulations of atmospheric rivers (bottom) and compare them with observed atmospheric rivers (top) to build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

3. Understanding and simulating the physical behavior of extreme events
4. High performance software toward exascale analysis of extreme events

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

1. How has the nature of extreme events changed in recent history (e.g., the frequency, duration, intensity, and spatial extent)?
2. What has contributed to this change?
3. How can the nature of extreme events change in the future?



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.

OBJECTIVES

Understanding drivers of observed changes in extremes

CASCADE investigates the causes of specific extreme events and their driving mechanisms, quantifies changes 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: (1) development of robust hindcast methodologies to quantify the human influence on exceptionally rare events; (2) systematically describe global changes in classes of extreme events; and (3) 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 climate system (i.e., the *butterfly effect*), choices that model developers make about the structure of climate models, and uncertainty in our underlying observations. CASCADE uses advanced statistical and experimental techniques to characterize the impact of these sources of uncertainty on our science. This approach is designed to: (1) produce defensible scientific conclusions about how and why we have observed extremes to change; (2) advance our fundamental understanding of extremes by reducing ambiguities that are caused by these uncertainties; and (3) produce datasets that the broader science community can use for similar research.

Understanding and simulating the physical behavior of extreme events

CASCADE advances our understanding of the physical mechanisms that drive variability and change in the spatio-temporal characteristics of extreme events. This research enhances resiliency to extremes by: (1) quantifying how the probability distributions of multivariate extremes respond to climate trends and patterns of atmosphere-ocean variability; (2) identifying the thermodynamic and dynamic processes that drive extremes and their multi-scale interactions in the Earth system; and (3) evaluating the ability of climate models to represent extremes.

High performance software toward 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: (1) creation of high-fidelity statistical tools for quantifying extremes; (2) development of a high-throughput tool for identifying and tracking weather features in terabytes to exabytes of climate data; and (3) extension of uncertainty quantification frameworks to treat a wide of variety of extreme phenomena.

COLLABORATIONS

The CASCADE project is a multidivisional, collaborative work at Lawrence Berkeley National Laboratory (LBNL), drawing upon expertise of scientists in the lab's Computational Research Division and Climate and Ecosystem Sciences Division as well as the University of California, Berkeley, and University of California, Davis campuses. CASCADE scientists collaborate with related projects at LBNL and across BER's climate 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 climate events. CASCADE is also active in national and international scientific activities, including CMIP, SAMSI, ARTMIP, etc.

CONTACTS

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

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