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Attribution of Extreme Weather Events in the Context of Climate Change

Board on Atmospheric Sciences and Climate

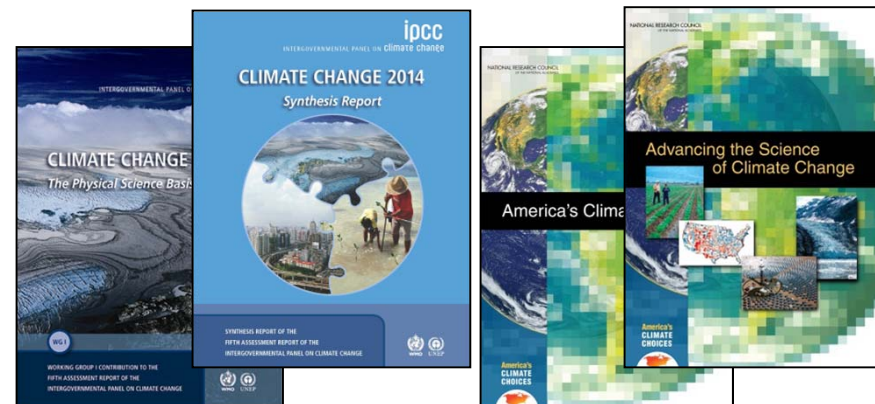
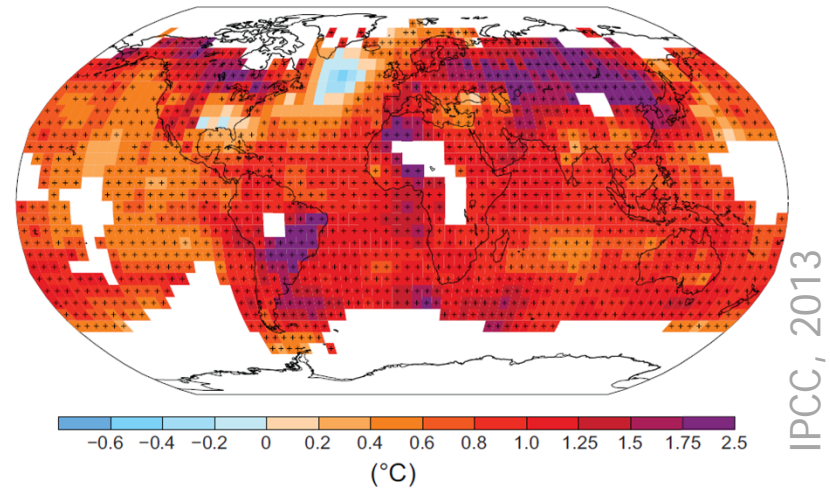
Adam Sobel, Columbia University

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Climate is Changing

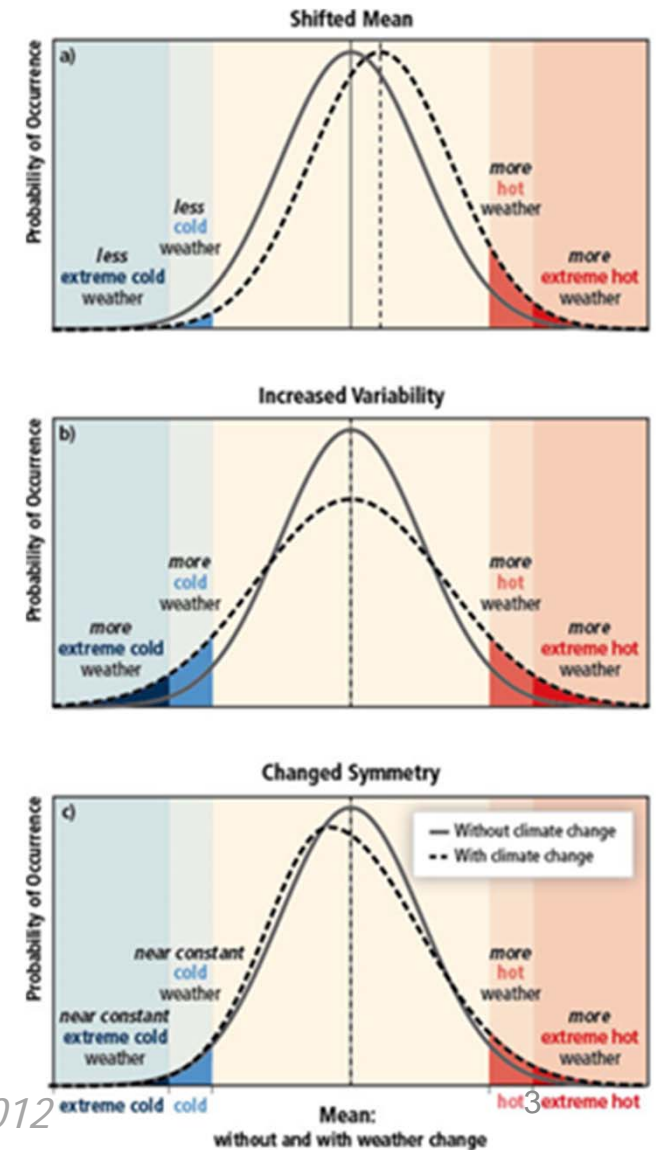
- Humans have contributed to the warming of the climate system globally
 - Predominantly though increases in greenhouse gases
- Finding is supported through multiple lines of evidence

Observed Change in Surface Temperature



Climate Change and Broad Trends in Extreme Events

- Climate change has led to changes in the observed frequency, intensity, and duration of some types of extreme events
- Some of the reasons for these changes are well-understood
 - Warming increases the likelihood of extremely hot days and nights, leading to more evaporation that may exacerbate droughts



What is Attribution?

Draws the explicit connection between climate science as a whole and a specific event, making the science concrete in a way that statements about broader trends and future projections do not

- **Attribution:** process of evaluating the relative contributions of multiple causal factors to a change or event
- **Extreme event attribution:** calculate how much human-induced climate change (or another factor) has affected an individual event's magnitude or probability of occurrence

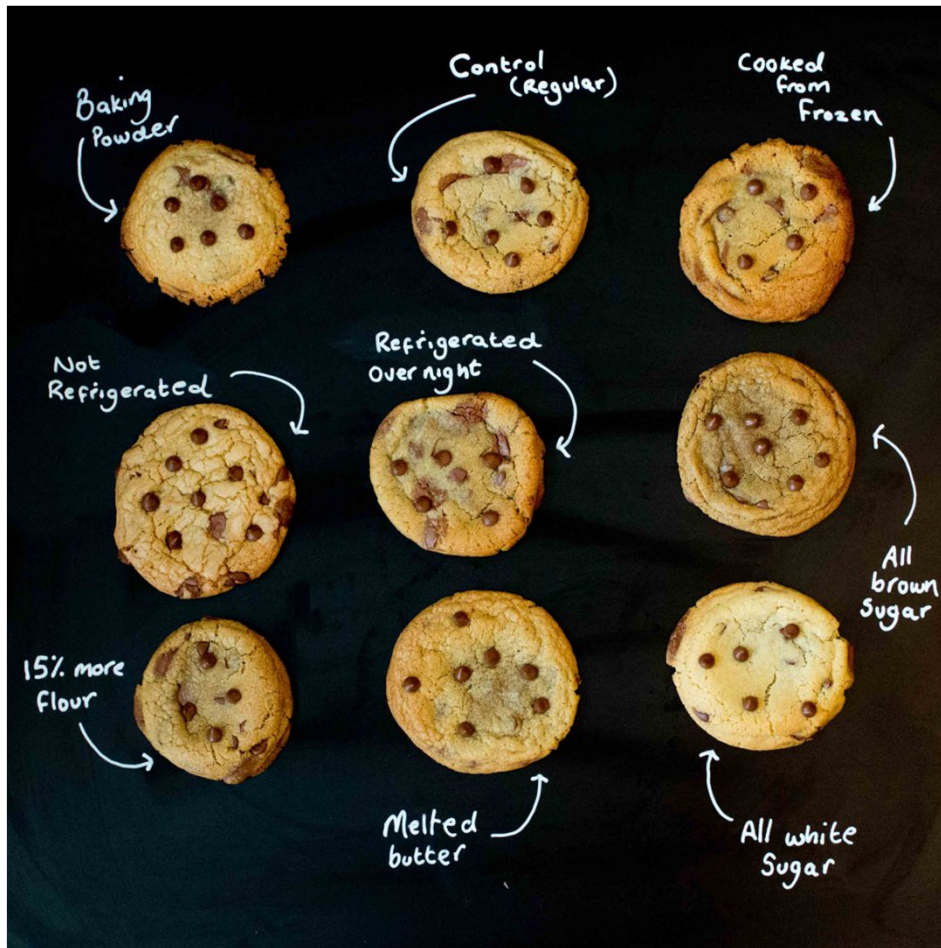


What Factors Influence an Extreme Event?



- Many conditions must align to set up a particular event
- Each extreme event has a host of possible causes
 - Natural → large-scale circulation, internal modes of climate variability, specific weather pattern
 - Human-caused → climate change, but also land use, etc.

A Baking Analogy



- Cookie = an event
- Ingredients = factors that align to cause an event
- Baking surface and oven temperature = conditions in which the event occurred
- Tinker with an ingredient, baking surface, or oven temperature, you still end up with a cookie, but it might result in a slightly different texture, color, taste.

The Science of Event Attribution

- Advanced rapidly in recent years:
 - generalized statements about expecting events to increase in frequency or intensity
 - documented increases in frequency or intensity
 - probability-based attribution of individual events
- Drawn interest from public and media because of frequently devastating impacts of events that are studied
- Methods are relatively novel and there are a range of views on how to conduct and interpret the analyses



Our Task

Examine the science of attribution of specific extreme weather events to human-caused climate change and natural variability.

- **Assess current scientific understanding** and capabilities for attribution.
- **Provide guidance about the robustness** of extreme event attribution science.
- **Identify research priorities** for further development of the approaches.

Committee Membership

DAVID W. TITLEY (*Chair*), Pennsylvania State University

GABRIELE HEGERL, University of Edinburgh

KATHARINE L. JACOBS, University of Arizona

PHILIP W. MOTE, Oregon State University

CHRISTOPHER J. PACIOREK, University of California, Berkeley

J. MARSHALL SHEPHERD, University of Georgia

THEODORE G. SHEPHERD, University of Reading

ADAM H. SOBEL, Columbia University

JOHN WALSH, University of Alaska, Fairbanks

FRANCIS W. ZWIERS, University of Victoria

- The Committee held 2 in-person meetings including a large community workshop in October 2015 as well as numerous webinars and conference calls.
- The report was reviewed by 12 outside experts.

Why Investigate the Causes of Extreme Events?

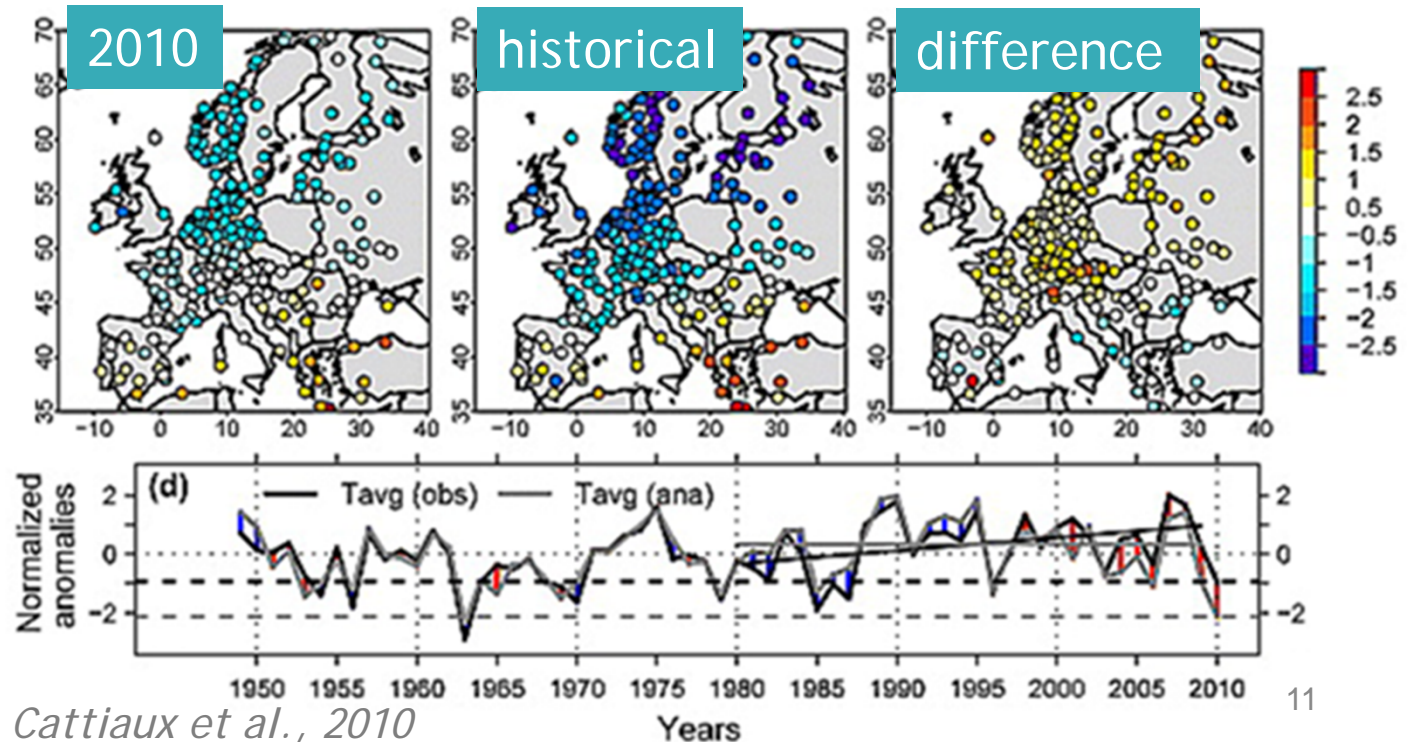
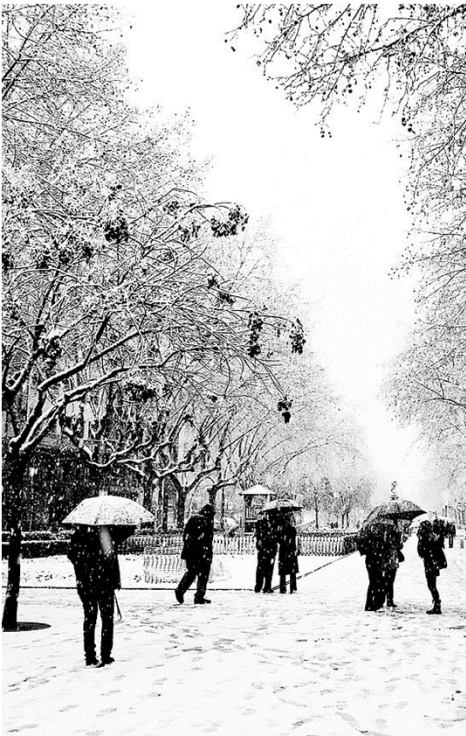
- **Increase understanding** of how and why extremes have changed over time
- **Inform choices** about assessing and managing risks and adaptation strategies



Approaches: Observational Record

Use **observational record** to determine the change in probability or magnitude of events

- Statistical analysis of observed change in events
- Observed circulation analogues to determine how meteorologically similar events have changed

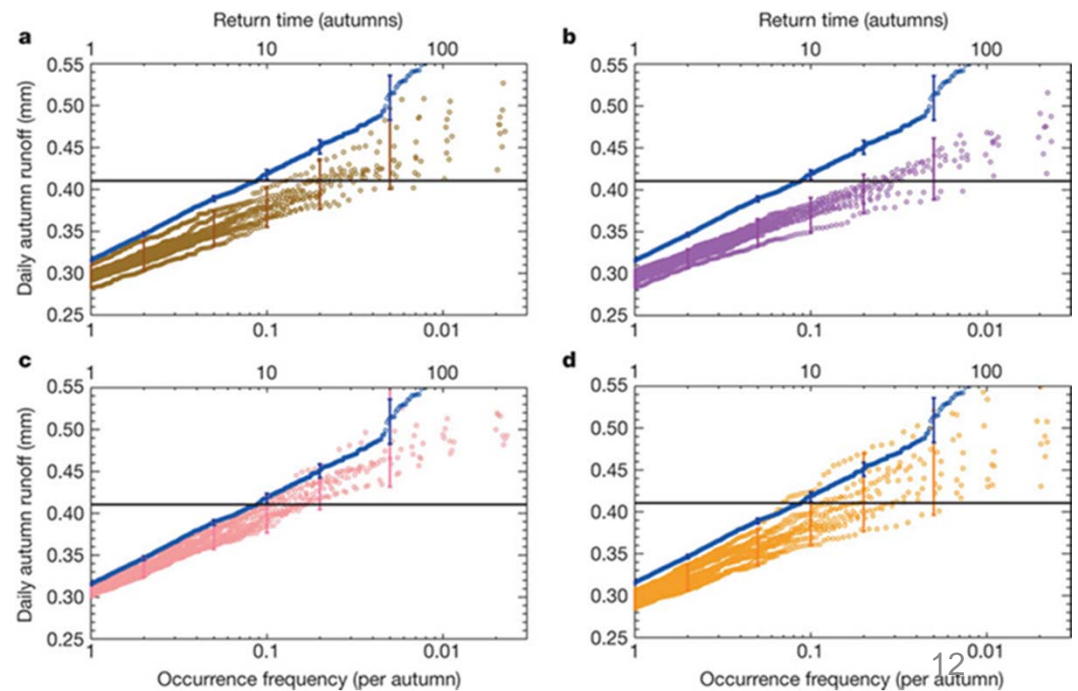


Approaches: Model Simulations

Use **model simulations** to compare event in a world with human-caused climate change to that in a world without.



- Coupled Climate Models
- Atmosphere-Only Models using Observed SSTs
- Studies Conditioning on Seasonal Forecasts
- Downscaling
- Highly Conditioned Simulations



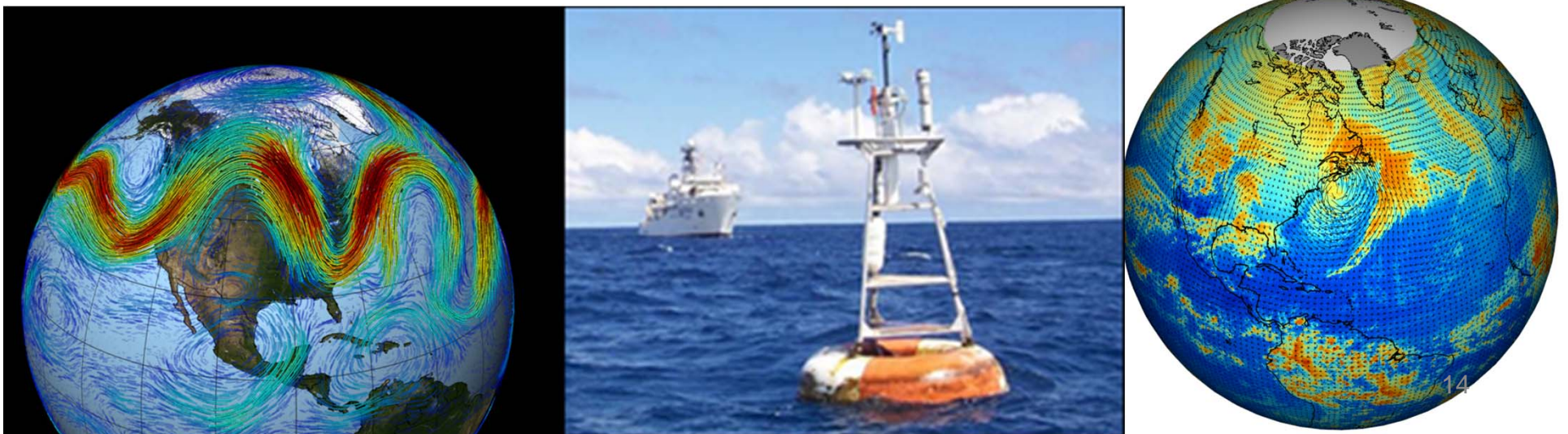
Pall et al., 2011

The science of event attribution has advanced to the point where it is now possible to estimate the influence of climate change on some types of specific extreme events, in particular:

- Heat waves
- Cold events
- Droughts
- Heavy Precipitation

Some Events are More Attributable than Others

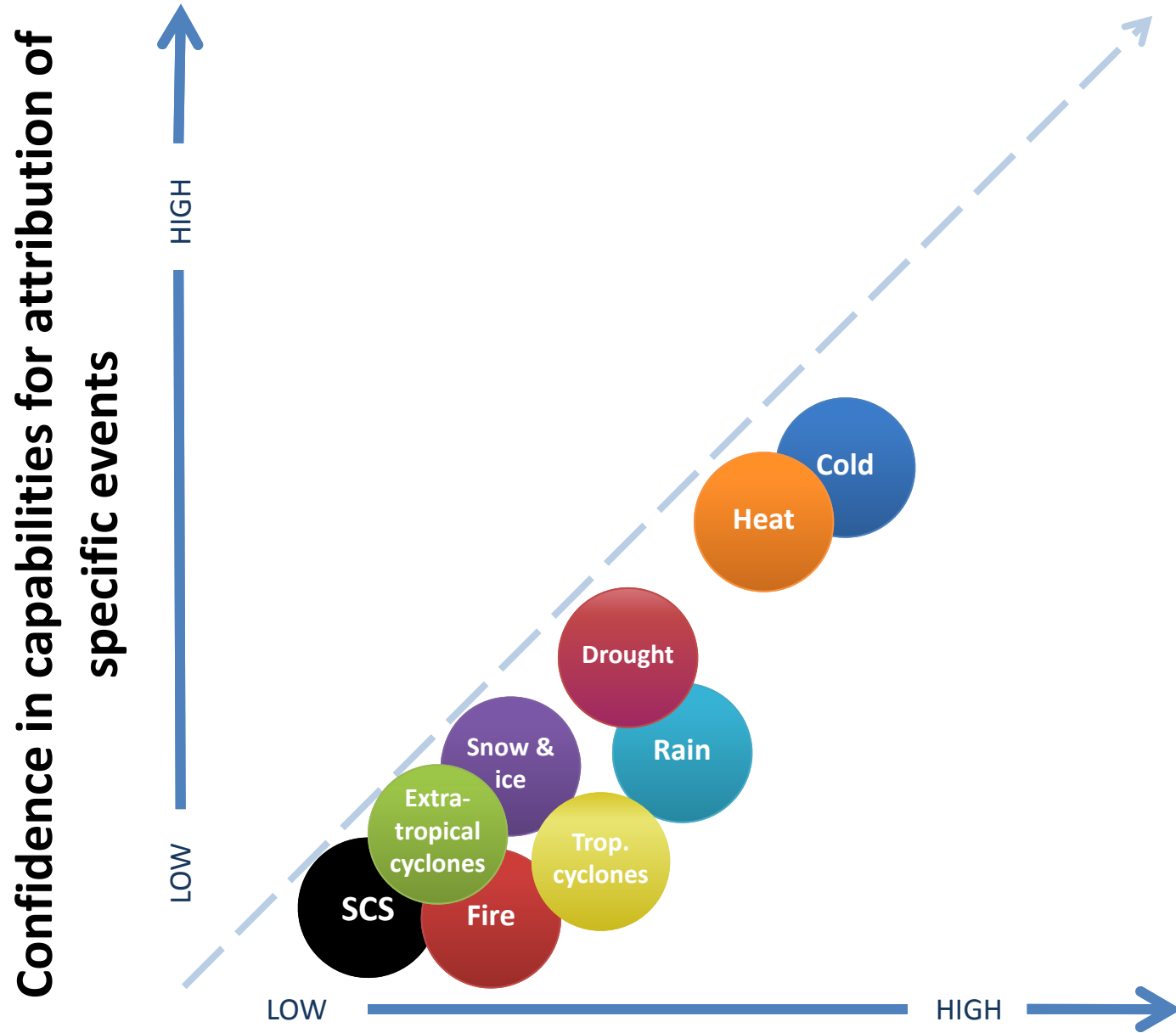
- Event attribution is more reliable when based on:
 - sound physical principles
 - consistent evidence from long-term observations
 - numerical models that can replicate the event



Some Events are More Attributable than Others

- Confidence is greatest for those extreme events that are related to an aspect of temperature
 - Highest for extreme heat and cold events
 - Followed by hydrological drought and heavy precipitation
 - Little or no confidence in the attribution of severe convective storms and extratropical cyclones





Understanding of effect of climate change on event type

- = high
- ◐ = medium
- = low

	Capabilities of Climate Models to Simulate Event Class	Quality/Length of the Observational Record	Understanding of Physical Mechanisms that Lead to Changes in Extremes as a Result of Climate Change
Extreme cold events	●	●	●
Extreme heat events	●	●	●
Droughts	◐	◐	◐
Extreme rainfall	◐	◐	◐
Extreme snow and ice storms	◐	○	◐
Tropical cyclones	○	○	◐
Extratropical cyclones	◐	○	○
Wildfires	○	◐	○
Severe convective storms	○	○	○

Asking Questions that the Science Can Answer

- A definitive answer to the commonly asked question of whether climate change “caused” a particular event to occur cannot usually be provided
- Natural variability almost always plays a role (cookie analogy)

Not-so-great question:

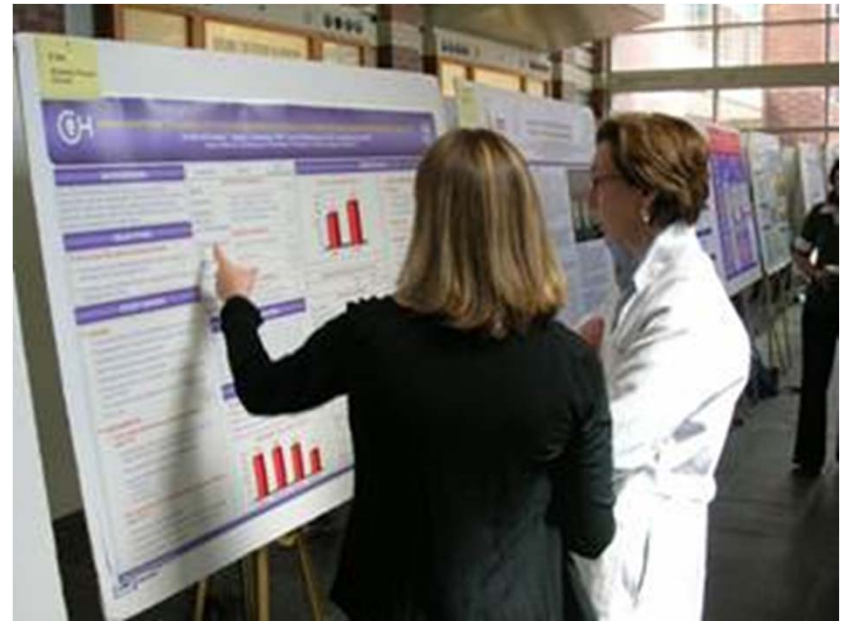
- Was this event caused by climate change?

Better questions:

- Are events of this severity becoming more or less likely because of climate change?
- To what extent was the storm more or less intense because of climate change?

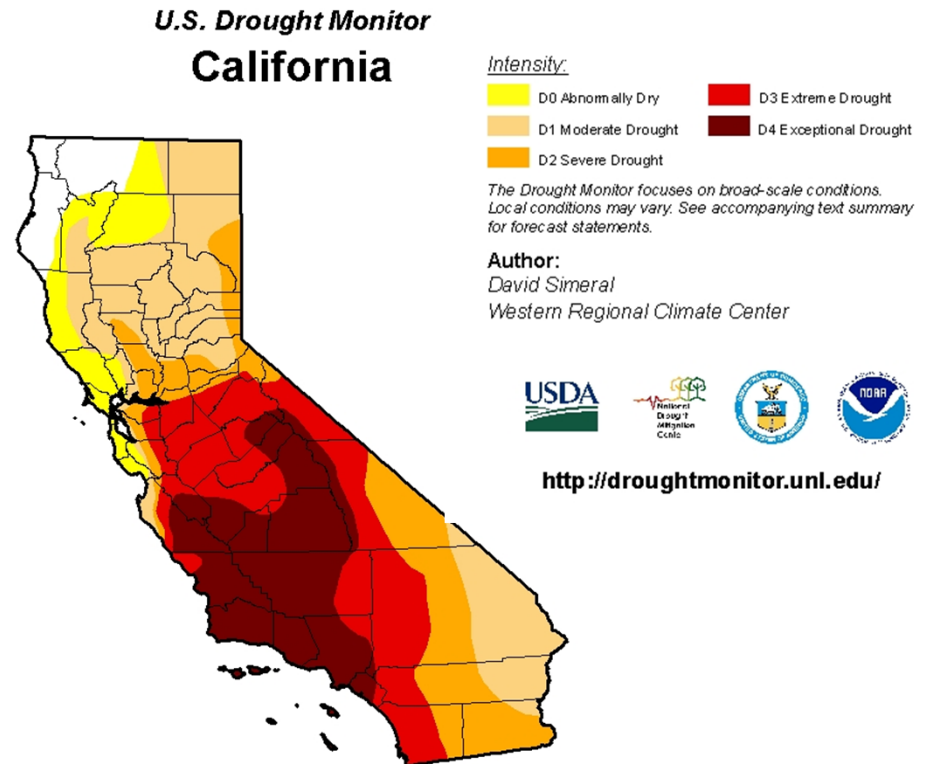
Interpreting Event Attribution Studies

- Statements are sensitive to the way the questions are posed and the context within which they are posed
- Method choice and assumptions made depend heavily on the framing of the question and the amount of time available to answer it



Examples of Choices Made in Conducting Event Attribution Studies

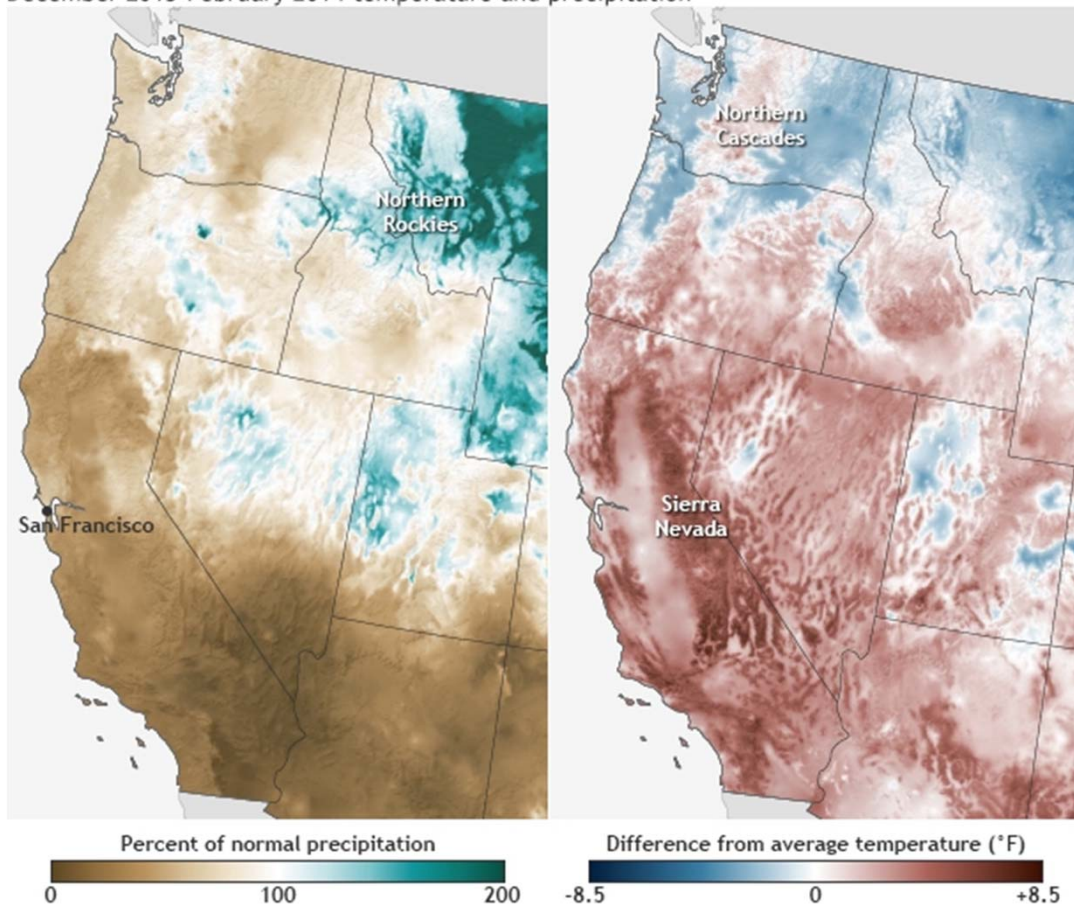
- How to define and interpret the event
 - When did the event start?
 - What was the geographic scope?
 - What physical variable will be considered?
 - What approach will be taken?
- The type of conditioning to use
 - SST patterns or features of an event
- Whether to assess frequency or magnitude



Framing Example: Event Definition

California Drought: Choice of physical variables to consider can impact the result

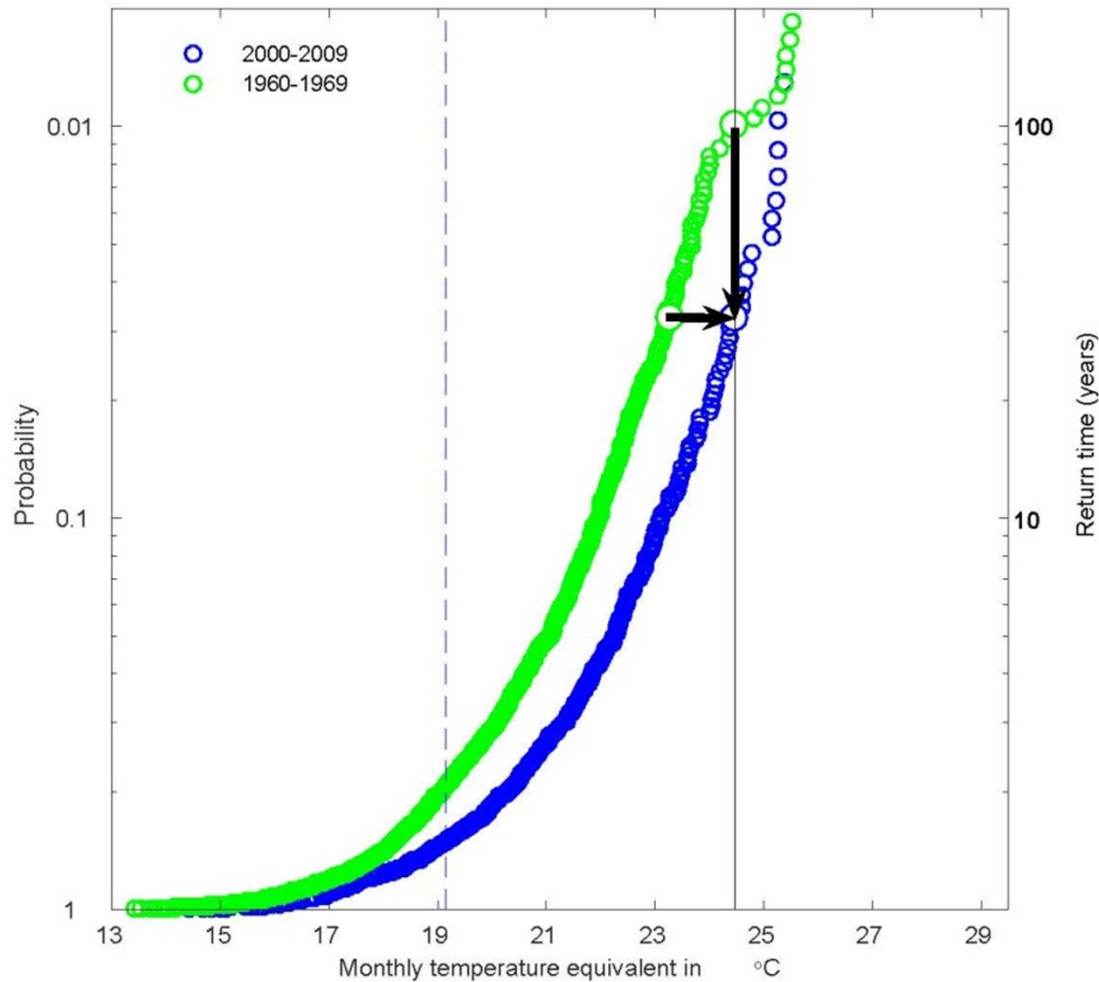
December 2013-February 2014 temperature and precipitation



- Analyses that focus on precipitation deficit have tended to find no discernable human influence
- Analyses that focus on precipitation deficit and high temperature tend to find a human influence

Framing Example: Magnitude vs. Frequency

Russian Heatwaves Summer 2010



A small change in magnitude can correspond to a large change in frequency



Increasing the Robustness of Attribution Analyses

- No single best method or set of assumptions for event attribution
- Multiple approaches help distinguish results that are robust from those that are more sensitive to framing and approach
- Ideally, analyses would include:
 - Clear communication of **uncertainties, assumptions and choices made, or conditions imposed**
 - **Models** that adequately reproduce the event
 - **Reliable observations** to show whether the class of events has changed over time
 - Extent to which results are consistent with **physical understanding**

Rapid Attribution

- Time constraints may affect framing and methodological choices by limiting analyses to approaches that can be undertaken quickly.
- Examples of possible limitations:
 - Reliance on station data that has not been quality controlled or single models with specified SSTs
 - Insufficient time to investigate causal mechanisms or evaluate the model for the particular extreme events
- Should follow up on any rapid attribution with studies that are not subject to such limitations to evaluate and improve the reliability.



Selection Bias

- Events that have been selected for attribution studies are **not a representative sample**
- Counts of attribution studies with either positive, negative, or neutral results are not expected to give a reliable indication of the overall importance of human influence on extreme events



Improving Extreme Event Attribution Capabilities

- Transparent, community standards for attributing classes of extreme events
- Systematic criteria for selecting and defining the events to be studied
- Research on
 - Model characteristics required to reproduce extreme events of different types and scales
 - Changes in natural variability and the interplay with climate change
 - Influence of conditioning on study results



Development of a Predictive Extreme Event Capability

- Some future event attribution activities could benefit from being linked to an integrated weather-to-climate forecasting effort on a range of timescales
- Goal → provide **predictive (probabilistic) forecasts of future extreme events** at lead times of days to seasons, or longer

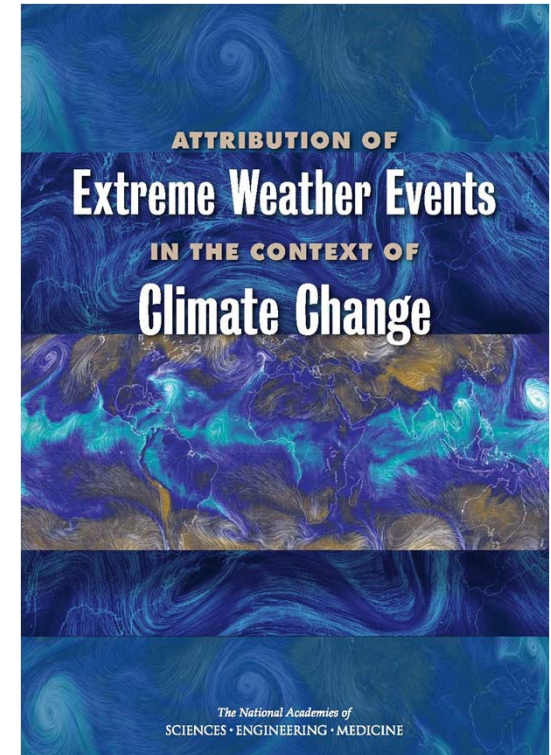


Acknowledgements

- Thank you to sponsors, committee members, reviewers, NAS staff, and numerous colleagues consulted during this study

Please visit americasclimatechoices.org to find:

- Complete report available for free PDF download
- Report in Brief (4-page summary)
- Press release
- Information about upcoming events
- Briefing slides and archived public release webcast

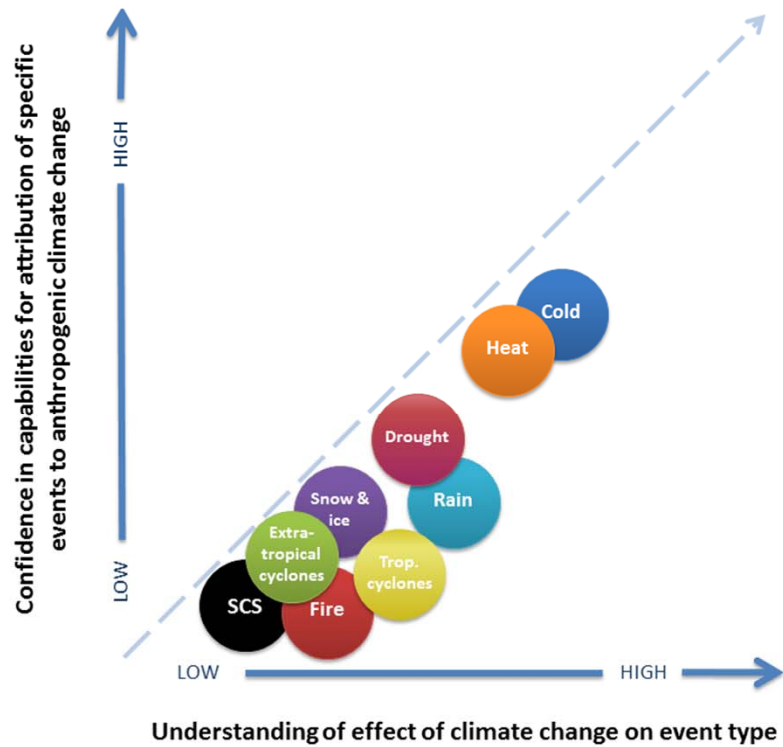


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Join the conversation: #ExtremeWeather

Questions?

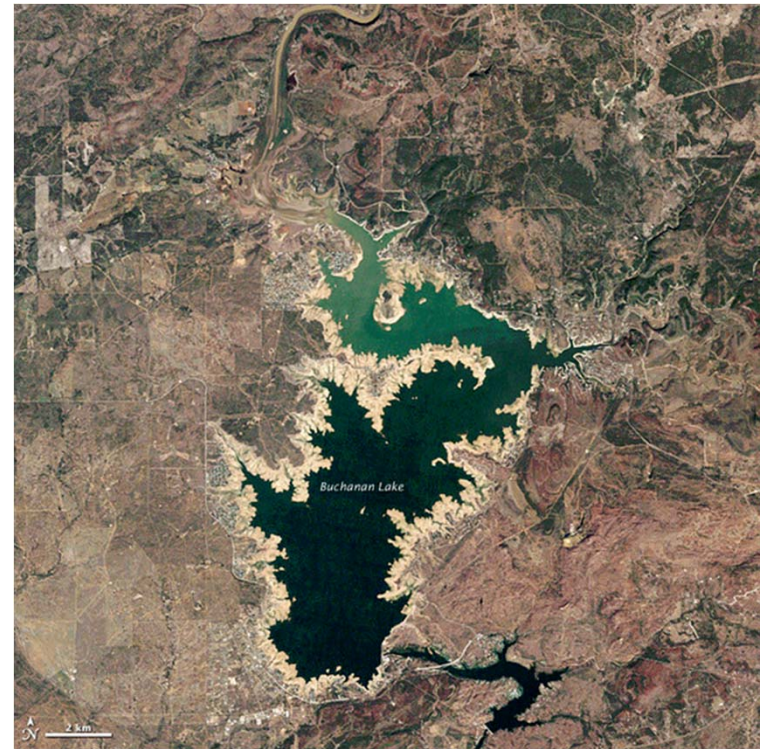


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Severe convective storms	○	○	○

Extra Slides

Conditioning

- The process of limiting an attribution analysis to particular types of weather or climate situations.
 - Conditioning on SST patterns
 - Conditioning on Features of an Event
- Weather-type forecasts over time periods of days:
 - Hurricane Sandy (Lackmann 2015)
- Seasonal forecasts over a period of a few months:
 - 2011 Texas drought (Hoerling et al. 2013)

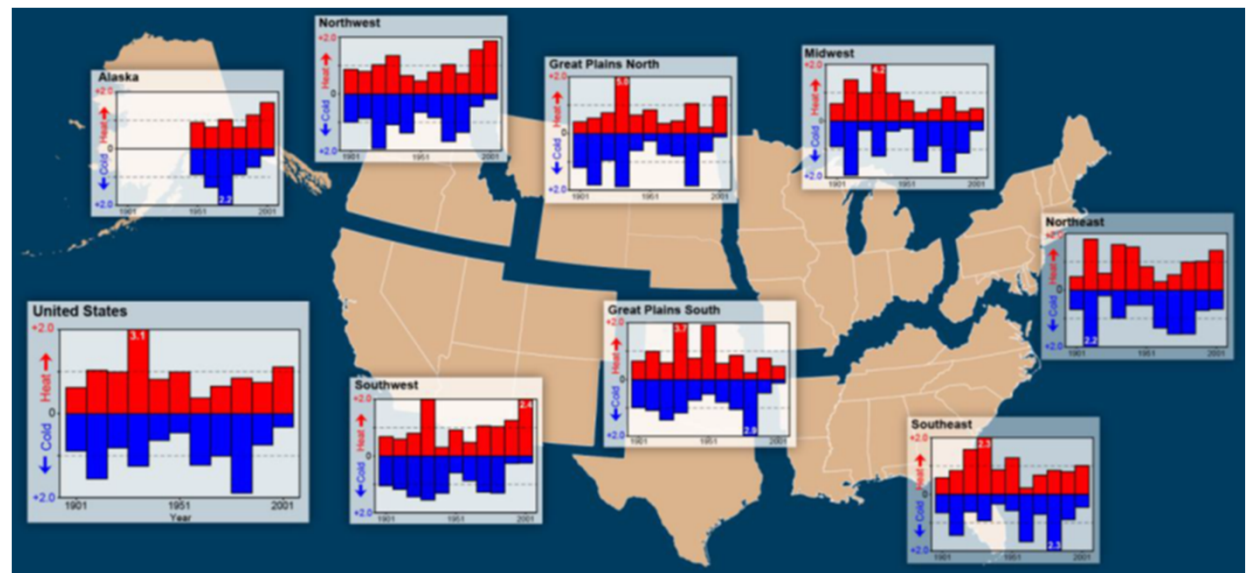


Attributes of a Successful Operational Event Attribution System

- Objective event-selection criteria
- Provision of stakeholder information about causal factors within days of an event, followed by periodic updates
- Clear communication of key messages to stakeholders about the methods and framing choices as well as the associated uncertainties and probabilities
- Reliable assessments of performance of the event attribution system

Unforced Natural Variability

- Attribution of events to anthropogenic climate change may be complicated by low frequency natural variability, which influences the frequencies of extreme events on decadal to multidecadal timescales



Presenting Event Attribution Results

- Event attribution study is less likely to be misinterpreted when the assumptions and choices that were made in conducting the study are clearly stated, and uncertainties are carefully estimated
 - State of the climate system
 - Magnitude, frequency, uncertainty
 - Risk ratio or return periods
 - Impact of assumptions
 - Statements of confidence