Attribution of Extreme Weather Events in the Context of Climate Change

Board on Atmospheric Sciences and Climate
David Titley (chair), Marshall Shepherd, Theodore Shepherd, John Walsh
March 11, 2016

Thank you to DOE, the Heising Simons Foundation, the Litterman Family Foundation, The David and Lucile Packard Foundation, NASA, NOAA, and the Arthur L. Day Fund of the National Academy of Sciences for supporting this study.
Climate is Changing

• The signs of changing climate are all around us:
  – Greenhouse gases are increasing
  – Sea level is rising
  – Ice sheets and glaciers are melting
  – Global temperatures are increasing

• Climate change impacts people, ecosystems, and the economy
Climate Change and Extreme Events

- Observed frequency, intensity, and duration of some extreme weather events have been changing as the climate system has warmed.

- Strong interest from public and media in the connection between climate change and extreme events.

We plan for climate; we live in weather.
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.
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

**Bottom Line Up Front**

Asking the right questions: The way attribution questions are posed influences how they are answered.
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.
What is Attribution?

• Attribution
  – process of evaluating the relative contributions of multiple causal factors to a change or event

• Extreme event attribution
  – studies that calculate how much human-induced climate change (or another factor) has affected an individual event’s magnitude or probability of occurrence
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

Cattiaux et al., 2010
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
Multiple Approaches are Ideal

- Helps distinguish results that are robust from those that are more sensitive to framing and approach.
- Ideally, analyses would include:
  - **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**
  - Clear communication of remaining **uncertainties**, **assumptions made**, or **conditions imposed**

*Stott et al., 2011*
Some Events are More Attributable than Others

• Event attribution is more reliable when based on:
  – sound physical principles
  – consistent evidence from 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

Confidence in capabilities for attribution of specific events
### Capabilities of Climate Models to Simulate Event Class

<table>
<thead>
<tr>
<th>Event Class</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme cold events</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extreme heat events</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Droughts</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Extreme rainfall</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Extreme snow and ice storms</td>
<td>○</td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Tropical cyclones</td>
<td>○</td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Extratropical cyclones</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Wildfires</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Severe convective storms</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

### Quality/Length of the Observational Record

<table>
<thead>
<tr>
<th>Event Class</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme cold events</td>
<td>●</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Extreme heat events</td>
<td>●</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Droughts</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Extreme rainfall</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Extreme snow and ice storms</td>
<td>○</td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Tropical cyclones</td>
<td>○</td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Extratropical cyclones</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Wildfires</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Severe convective storms</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

### Understanding of Physical Mechanisms that Lead to Changes in Extremes as a Result of Climate Change

<table>
<thead>
<tr>
<th>Event Class</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme cold events</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Extreme heat events</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Droughts</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Extreme rainfall</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Extreme snow and ice storms</td>
<td>○</td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Tropical cyclones</td>
<td>○</td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Extratropical cyclones</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Wildfires</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Severe convective storms</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
Asking the Right Questions

• 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
- There is no single best method or set of assumptions for event attribution
Framing Example: Magnitude vs. Frequency

Russian Heatwaves Summer 2010

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

Otto et al., 2012
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
Selection Bias

- Events that have been selected for attribution studies are **not a representative sample**
- Attribution studies of individual events should not be used to draw general conclusions about the impact of climate change on extreme events as a whole
Improving Extreme Event Attribution Capabilities

- Transparent, community standards for attributing classes of extreme events
- Systematic criteria for selecting the events to be studied
  - minimize selection bias
  - permit systematic evaluation of attribution performance
Research to Improve Event Attribution Capabilities

- Model characteristics required to reproduce extreme events of different types and scales
- Changes in natural variability and the interplay with climate change
- Sources of uncertainty from using models in event attribution
- Influence of conditioning on study results
- Long homogeneous observation records
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

More information:
Katie Thomas
kcthomas@nas.edu
202-334-3860

Join the conversation: #ExtremeWeather
Questions?

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

Understanding of effect of climate change on event type