“Did Climate Change Cause That _ _ _ _ _ _ ?”:
Finding One’s Way to the Right Answer

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State of the Science: Attribution
Science involving Climate Change
and Extreme Weather

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Information

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Outline

• What is an ‘extreme event’?
• What is extreme event attribution, and why does it matter?
• Five examples of event attribution, and what we can learn from them.
• Future attribution research directions and applications
• Interpretation and Communication
Extreme Weather

• Short definition: Weather that’s newsworthy
• Long definition: two kinds
  – Weather that’s extremely unlikely
  – Weather that’s unhealthy or damaging
  – (The same event often fits both definitions)
The Good Old Days

• Q: “What caused that cold weather?”
The Good Old Days

• Q: “What caused that cold weather?”
• A: “Some unusually strong lithification developed over Manitoba and led to diagenesis.”
The ways the odds can change
Shifted Mean

a)

<table>
<thead>
<tr>
<th>Probability of Occurrence</th>
</tr>
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<tbody>
<tr>
<td>less cold weather</td>
</tr>
<tr>
<td>less record cold weather</td>
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<tr>
<th>Future Climate</th>
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<td>more hot weather</td>
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<tr>
<th>Previous Climate</th>
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<tbody>
<tr>
<td>more record hot weather</td>
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</tbody>
</table>

IPCC SREX
Shifted Mean

- Previous Climate
- Future Climate

- Less cold weather
- More record hot weather
- More hot weather
- Less record cold weather
Increased Variability

Probability of Occurrence

more cold weather

more record cold weather

more hot weather

more record hot weather

IPCC SREX

National Centers for Environmental Information
The diagram illustrates the shift in mean probability of occurrence for weather conditions between previous and future climates. The solid line represents the previous climate, with less cold weather and less record cold weather, while the dashed line represents the future climate, showing a shift towards more hot weather and more record hot weather. This suggests an increase in the frequency of extreme weather events in the future.
Old Probability

New Probability

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Old Probability

New Probability

National Centers for Environmental Information
Climate change turned a 96°F day into a 100°F day.
Climate change turned a 96°F day into a 100°F day

Climate change turned a 4°F above normal day into an 8°F above normal day
Climate change turned a 96°F day into a 100°F day.
Climate change turned a 4°F above normal day into an 8°F above normal day.
Climate change increased the odds of at least 100°F from 1:50 to 1:7.
Event Attribution Science
What is attribution research

“The relatively young science of event attribution seeks to tease out the influence of human-caused climate change on extreme weather events.”

- NAS 2016 report on attribution science

• Goal is to understand the drivers of an extreme event.
• Climate change does not cause extreme events
• Climate change can change the odds an event will or will not occur.
• Approach is an “NTSB-style” investigation of the causes.
  – An initial report can be available quickly, but extensive investigation may be needed to fully understand what happened.
Why do attribution research

- Improve understanding of the drivers of extremes and how they are changing.
- To link our knowledge about the changing climate with societal impacts to inform decision making.

Agriculture  Energy  Health  Transportation
The challenge:
Consider a driving analogy

• Adding just a little bit of speed to your highway commute each month can substantially raise the odds that you’ll get hurt someday [anthropogenic climate change]

• But if an accident does occur, the primary cause may not be your speed itself
  – It could be a wet road or a texting driver [natural variability]

The challenge is to determine the precise sensitivity of driving speed on risks of accidents in particular conditions such as with wet roads or texting drivers.
Attribution Confidence by Event Type

Confidence in capabilities for attribution of specific events to anthropogenic climate change

Understanding of effect of climate change on event type

High

Low

National Academy of Sciences, 2016
How do you do attribution of extreme events?

- Lots of different ways
- What is the ‘best’ approach? The science is very unsettled in this regard, in part because it can vary from event to event.
- Indeed, one of the reasons the annual BAMS Explaining Extremes report was started was to foster the growth of this science
- The following are some examples of approaches used
  - Not a comprehensive list
Two general approaches to Event Attribution that can be applied, and usually they are used together:

1. Use observations to determine the change in probability or magnitude of events over the historical record; and

2. Use model simulations to compare the manifestation of an event in a world with human-caused climate change to that in a hypothetical world without climate change.
Method 1: Observations - Compare to other years with similar circulation

- Extremes are partly caused by atmospheric circulation patterns.
- How do you separate the effect of circulation patterns from long-term climate change effects?
- Compare the current year extremes with past years that had very similar circulation patterns.
- In this case, the spring 2012 warmth in the eastern US was mainly explained by atmospheric circulation.
- From Julien Cattiaux and Pascal Yiou, 2012
Method 2: Compare models w/ and w/o Climate Change

Seasonal and annual mean precipitation extremes occurring during 2013 in north-central and eastern U.S. regions:

- Used models to show events were partly attributable to anthropogenic forcings. Natural variability played the dominant role.
- Knutson, Zeng & Wittenberg 2013
Method 3: Model many causal factors to determine which was key

In this case, the lack of adequate ice growth for an 11-city ice skating race on the canals in The Netherlands was caused by snowfall rather than not cold enough temperatures.

From Hylke de Vries, Rudolf van Westrhenen and Geert Jan van Oldenborgh (2012)
Event Attribution Examples
Observed 2011 JJA Temperature

Reference: Hoerling et al., 2013, Journal of Climate

Degrees Celsius (°C)

Texas Summer (JJA) Temperature Departures

Year

Degrees Celsius (°C)

Probability Density Function

Degrees Celsius (°C)

JJA 2011 OBS
TX03 Seasonal Temperature Anomalies
Tmax plus, Tmin minus
Tmax smoothed solid, Tmin smoothed dotted

Difference from 20th Century Average (°F)
Historical relationship: Summer Precipitation and Temperature
Observed Atmosphere-only model, observed sea surface temperatures

Atmosphere-Ocean model, observed climate forcings
**Summer Tmp vs. Summer Pcpn**

### 1981–2010

- **R** = -0.74
- **b** = -0.021

### 2011

- **R** = -0.83
- **b** = -0.023

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The Three Pillars of Sound Attribution
The Three Pillars of Sound Attribution

A clear historical trend
The Three Pillars of Sound Attribution

- A clear historical trend
- Consistent model projections

National Centers for Environmental Information
The Three Pillars of Sound Attribution

A clear historical trend

Consistent model projections

A sound physical basis
The Three Pillars of Sound Attribution

Quality of Observation

Ability of models to simulate

Mechanism of changes known

National Academy of Sciences report

High

Medium

Low

Extreme cold events
Extreme heat events
Droughts
Extreme rainfall
Extreme snow and ice storms
Tropical cyclones
Extratropical cyclones
Wildfires
Severe convective storms
The Three Pillars of Sound Attribution

Quality of Observation

Ability of models to simulate

Mechanism of changes known

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Extreme cold events
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Extreme rainfall
Extreme snow and ice storms
Tropical cyclones
Extratropical cyclones
Wildfires
Severe convective storms
Coastal flooding

National Centers for Environmental Information
Example #2: Heavy Rain
The Faucet

- Climate change’s thermodynamic impact: the size of the pipe
  + 7% per °C
- Climate change’s dynamic impact: turning the handle
The Faucet

• The size of the pipe matters most when the faucet is wide open
Texas April-July Precipitation (9-yr smoothing)

Percent of Long Term Average Precipitation


Series1  Series2  Series3  Series4  Series5  Series6  Series7  Series8  Series9  Series10
8" Observations Per Year

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8" Events Per Year

National Centers for Environmental Information
Odds of 8" Event at Any Given Station per Year
Number of One-Year Two-Day Events Per Year

- Harris
- Galveston
- Brazoria
- Fort Bend
- Waller
- Montgomery
- Liberty
- Chambers
- Average
99.98th %ile (14-yr return period)
Change in Frequency

- 0.0x to 0.11x
- 0.11x to 0.25x
- 0.25x to 0.43x
- 0.43x to 0.67x
- 0.67x to 1.0x
- 1.0x to 1.5x
- 1.5x to 2.3x
- 2.3x to 4x
- 4x to 9x
Example 3: California Drought

U.S. Drought Monitor
DroughtMonitor.unl.edu

NIDIS
www.drought.gov
Many Factors Cause Extremes

Extreme events are born from a set of ingredients.

A combination of factors lead to a drought

- Lack of precipitation, temperature, evaporation rates, soil moisture, etc.
- Human activity such as land and water usage
Example 3: California Drought

Weather conditions were key to explaining the CA drought:

- A high pressure ridge off the West Coast diverted the track of storms during all three winters, typical of historical droughts.
- West Coast high pressure was rendered more likely during 2011-14 by effects of sea surface temperature patterns over the world oceans.
- The drought's first year (2011/2012) was likely the most predictable, when La Nina effects largely explained high pressure off the West Coast, though simulations indicate that high pressure continued to be favored due to ocean effects in 2012-14.
Example 3: California Drought

Over the years, multiple reports on the California drought have looked at many variables. A clear picture of how long-term climate change impacted the California drought is still emerging. Examples of selected results:

– **Influence on geopotential heights found (Swain et al).** The influence on actual changes in precipitation or temperature remain uncertain

– **No influence found on SSTs (Funk et al).** Long-term sea surface temperature warming did not contribute to the California drought risk

– **Conflicting influences found with no NET impact (Wang and Schubert).** Found increases in anomalies that divert storms away from California (increased drought risk), but also found increases in humidity (decreased drought risk)

– **No influence on decreased precipitation, but likely increased temperatures (NOAA’s CA Drought Assessment).** CA precipitation shows no appreciable trend since 1895, but temperature increases that exacerbated the drought were linked to climate change.
When a Signal is Not Found

• A human influence on an event is not always found in these studies.
• Natural variability is always part of any weather and climate extreme.
• How should this be interpreted? Any of the following could explain the absence of a climate change signal:
  – There was no human influence on the event
  – The particular factors investigated were not influenced by human-caused climate change
  – The human influence could not be identified with the scientific tools available today
• In all cases, as models, data, and analysis methods improve, future studies could yield new information.
The Value of Multiple Studies

• Extreme events are often complex and influenced by multiple factors
  – Some variables are more difficult to discern whether there was a human influence than others (e.g., hurricanes vs. temperature)
• Any single factor that influences an event is accompanied by other variables that have supporting/opposing influences and need to be considered
• Multiple studies that use different methods and examine different factors can give us a more robust understanding of the role of climate change
Example 4: Coastal Flooding

- The rising global average sea level is one of the hallmarks of a warming planet.
- Rates of sea level rise are not uniform along U.S. coasts, and can be exacerbated locally by land subsidence or reduced by uplift.
  - On the West Coast of the United States, sea level has fallen slightly since the early 1990s, possibly because the Pacific Decadal Oscillation has counteracted most or all of the global sea level signal there.
  - Along the Gulf Coast local geological factors including extraction of oil, natural gas, and water from underground reservoirs are causing the land to sink, which could increase the effect of global sea level rise.
- When looking at specific events an understanding of local drivers of sea level is important to assess the role of sea level rise caused by climate change.
Sea Level Rise Along the U.S. Coast

http://tidesandcurrents.noaa.gov/sltrends/sltrends.html

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Past High-Water Events

The ten top high-water events at lower Manhattan (NYC/Battery Park, 1900–2012)

Note no events in top 10 prior to 1950.

Sea-level rise is a small but increasing part of the total storm surge.

Figure from Richard W. Reynolds (2013).
Example 4: Coastal Flooding
Change in return intervals

Hurricane Sandy flooding was a very extreme, very rare event. Observations tell us:

- Once every 295 years at Sandy Hook
- Once every 1570 years at the Battery

The huge surge was primarily from Sandy with sea-level rise contributing only a small portion. But a portion with strong implications
Example 4: Coastal Flooding

- Relative to 1950, SLR due to climate change contributed to decreased return intervals for Sandy impact levels by (Sweet et al. 2013):
  - One-thirds at Sandy Hook and Battery Park
  - Two-thirds at Atlantic City and southward in the mid-Atlantic
- With future sea-level rise, by 2100 it can become
  - Once every 20 and 50 years event

Example #5: Hurricanes
Problems with Smaller-Scale Extreme Weather Phenomena

- Lack of stability in data record
- Low signal-to-noise ratio
- No direct information from climate models
Problems with Smaller-Scale Extreme Weather Phenomena

• Low signal-to-noise ratio
  – Natural (and random) variability drives individual events and clusters
  – Small trends have large monetary impact
  – Once clear trend is detectable, it’s too late
Hurricanes: The Balance of Evidence

- Increase in peak intensity (1.5 pillars)
- Decrease in frequency (1 pillar)
  - ...but spatially variable (1.5 pillars)

Vecchi and Soden: Atlantic Wind Shear and Global Warming
Global Projections of Intense Tropical Cyclone Activity for the Late Twenty-First Century from Dynamical Downscaling of CMIP5/RCP4.5 Scenarios

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Change in hurricane frequency

c) Late 21st century minus present-day
Effect of Upper-Ocean Evolution on Projected Trends in Tropical Cyclone Activity

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(Manuscript received 7 June 2015, in final form 3 August 2015)

ABSTRACT

Recent work has highlighted the possible importance of changing upper-ocean thermal and density stratification on observed and projected changes in tropical cyclone activity. Here seven CMIP phase 5 (CMIP5)-generation climate model simulations are downscaled under IPCC representative concentration pathway 8.5 using a coupled atmosphere–ocean tropical cyclone model, generating 100 events per year in the western North Pacific from 2006 to 2100. A control downscaling in which the upper-ocean thermal structure is fixed at its monthly values in the year 2006 is compared to one in which the upper ocean is allowed to evolve, as derived from the CMIP5 models. As found in earlier work, the thermal stratification generally increases as the climate warms, leading to increased ocean mixing–induced negative feedback on tropical cyclone intensity. While trends in the frequency of storms are unaffected, the increasing stratification of the upper ocean leads to a 13% reduction in the increase of tropical cyclone power dissipation over the twenty-first century, averaged across the seven climate models. Much of this reduction is associated with a moderation of the increase in the frequency of category-5 storms.
What’s Next?
Advancing the Science

• Moving to the upper-right
• Communicating the numbers.
  – Going beyond ‘yes’ and ‘no’, to ‘by how much and with what confidence’.
*These are not a random sampling of extreme events from around the world

Includes 2011-2014 Reports
Connecting Extreme Events to Impacts

Climate Change and Human Health

Access this report and the National Climate Assessment at: http://www.globalchange.gov/
Climate Change and Human Health

- The research connecting these boxes is growing.
- Qualitative understanding is increasing.
- Quantitative understanding of impacts still challenging.
- Quantitative information needed to inform preparedness decisions.
Examples of Connecting to Impacts

- Weather related crashes (*in progress*)
  - Data from National Highway Traffic Safety Administration, NOAA, CDC.

- U.S. Heat related mortality and morbidity (*in progress*)
  - Data from NOAA, CDC, Medicare/Medicaid, Society of Actuaries
Communication Challenges

- Who?
- What?
- When?
- Where?
- Why?
Communication Challenges

• Who?
  – News or weather
  – Experts or self

• What?

• When?

• Where?

• Why?
Communication Challenges

• Who?
• What?
  – Change in odds or change in magnitude
  – Nature of evidence
• When?
• Where?
• Why?
Communication Challenges

• Who?
• What?
• When?
  – Right after event, or before or after event season, or when new study released
• Where?
• Why?
Communication Challenges

• Who?
• What?
• When?
• Where?
  – Global or regional or local
• Why?
Communication Challenges

• Who?
• What?
• When?
• Where?
• Why?
  – Multiple factors or multiple opinions
  – Uncertainties or luck
Presenting Attribution Studies (1) (from NAS report)

• Did climate change cause it? Wrong question.

• Questions with better answers:
  – Are events of this severity becoming more or less likely because of climate change?
  – To what extent was the event intensified or weakened because of climate change?

• Learn from politicians: Answer the question you wish you’d been asked
Presenting Attribution Studies (2)

• Framing and context matter
  – Example: did climate change make Sandy worse?

• Don’t generalize from individual events
  – Selection bias
  – Curiosity bias
Resources

• IPCC.ch
  – Special report on extremes (SREX)
  – Fifth assessment report, working group 1 (AR5 WG1)

• National climate assessment

• News items
  – AP + USA TODAY + NYTIMES – Network news

• National Academies report: Attribution of Extreme Weather… (DOI: 10.17226/21852)
Houston Minimum Wintertime Temperatures

Degrees F

2016