Why is “event attribution” hard?

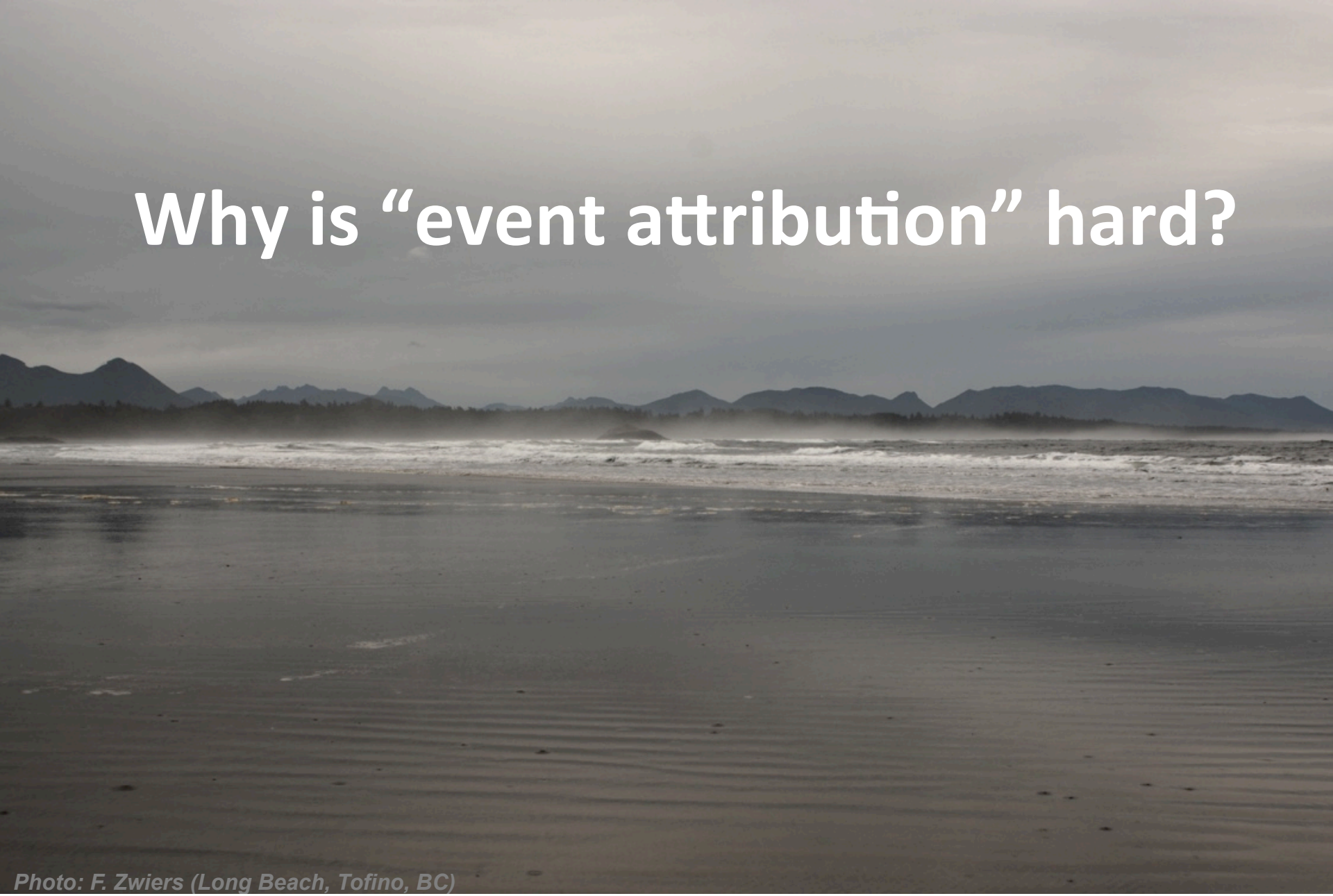


Photo: F. Zwiers (Long Beach, Tofino, BC)

Sun Yat-Sen University
6 April 2016

中山大學
SUN YAT-SEN UNIVERSITY

Francis Zwiers, Pacific Climate Impacts Consortium
University of Victoria, Victoria, Canada

The context for this talk

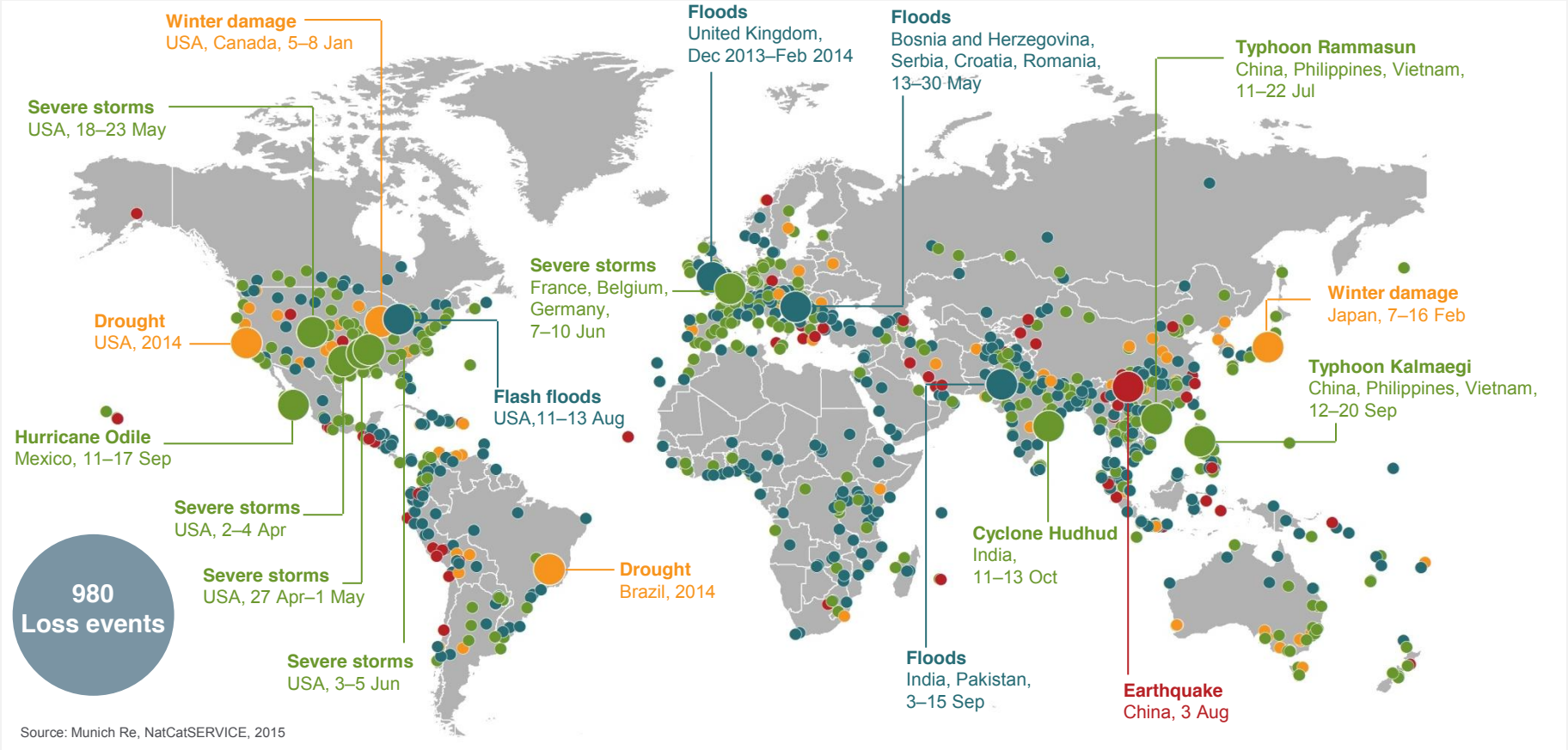
- Extensive reporting in the media on extreme events
  - Google News searches of Canadian new publications for the past year find
    - 55,300 items that refer to “extreme weather”
    - 17,500 items that refer to “drought”
    - 31,400 items that refer to “floods”
  - Similar searches for 2006 yield very small numbers
- Public perception is that frequency and intensity is increasing
- Growing economic impact of extreme events, which we are experiencing via increases in insurance premiums
- Growing concern that is expressed by the insurance industry, for example, via annual reporting by Munich Re

NatCatSERVICE

Loss events worldwide 2014

Geographical overview

Munich RE



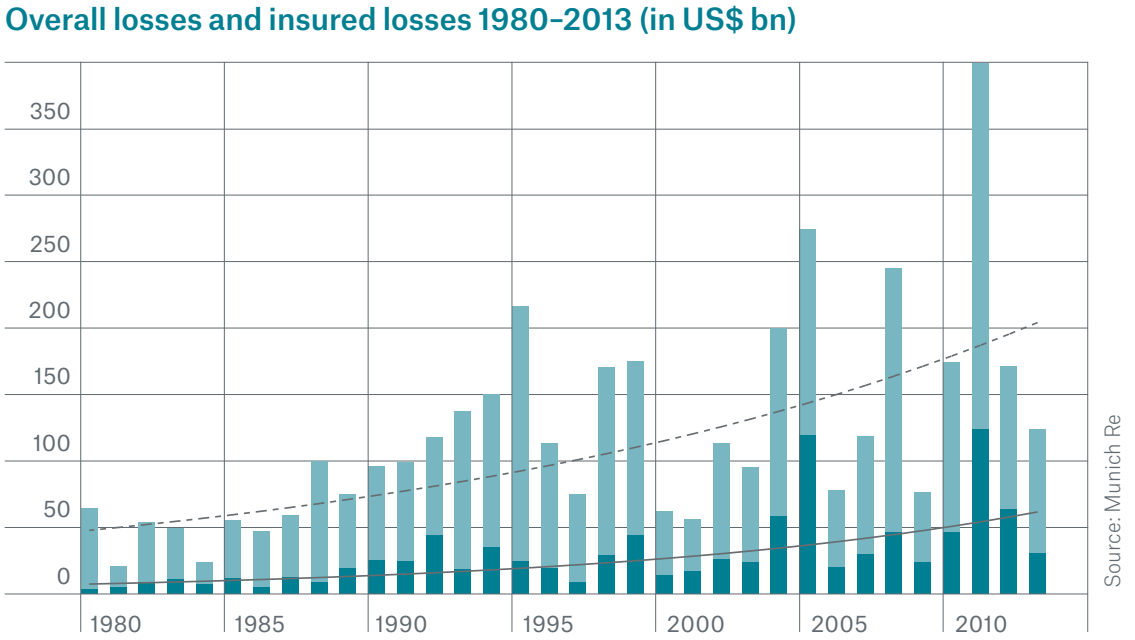
890 loss events in 2013

The 5 largest losses in 2013 were Calgary ($5.7B), hurricanes Manuel and Ingrid in Mexico ($5.8B), earthquakes in China ($6.8B), typhoon Haiyan ($10B), floods in western and eastern Europe ($15.2B)

Financial Losses

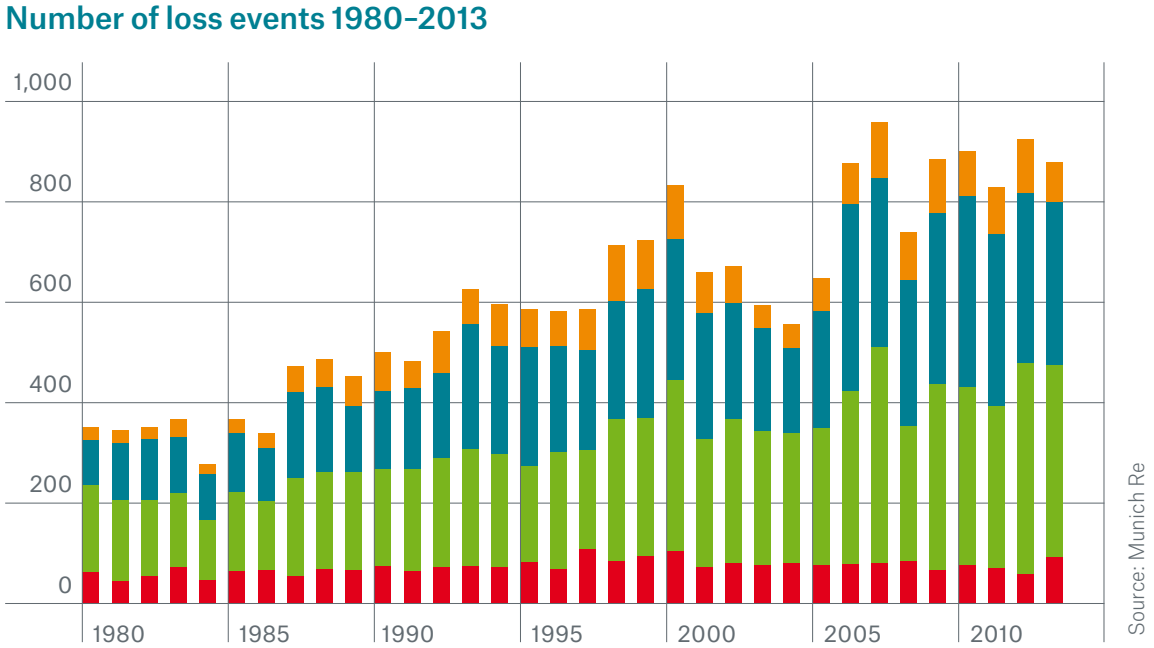
Billions of US$
Inflation adjusted

- Overall
- Insured



Number of events

- Geophysical
- Meteorological (storms)
- Hydrologic (flooding, mass movements)
- Climatological (temperature extremes, drought, wildfire)

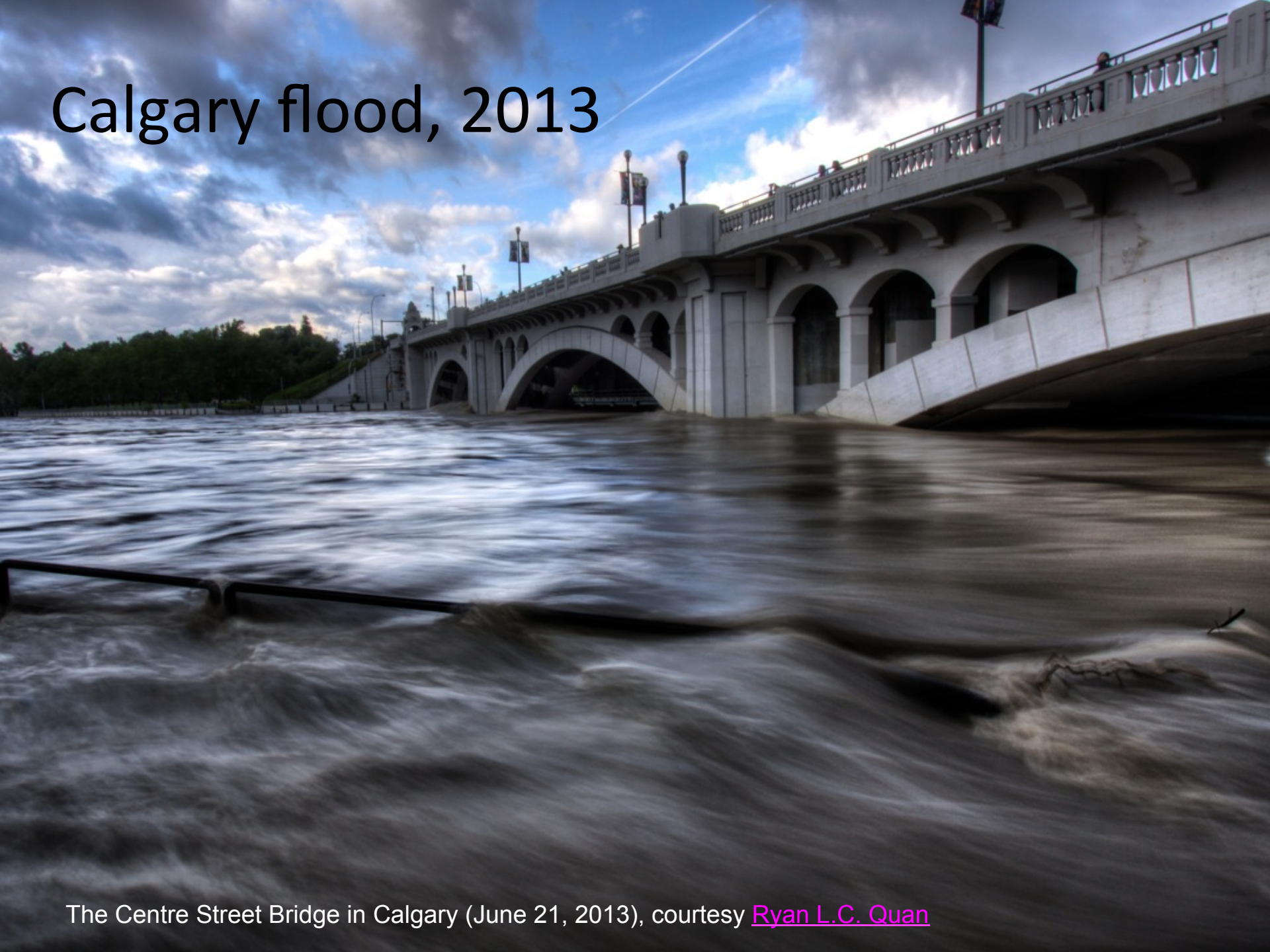


More context: the Calgary flood, 2013

- 100,000 displaced, 5 deaths
- Costliest disaster event in Canadian history
- Estimated $5.7B USD loss ($1.65B USD insured)

Flood waters rush by the Okotoks 32nd Street bridge, June 20, 2013, courtesy Stephanie N. Jones

Calgary flood, 2013



The Centre Street Bridge in Calgary (June 21, 2013), courtesy Ryan L.C. Quan

Calgary flood, 2013

Calgary East Village (June 25, 2013), courtesy Ryan L.C. Quan

The Calgary Flood in the Media

- Public discourse often quickly makes the link to climate change (e.g., Maclean's, *Alberta flooding sets records, prompts calls for action on climate change*, 24 June 2013)
- The majority of Canadians believe that climate change is to blame (Toronto Star, 24 July 2013)
- Even if we can't attribute cause, we as scientists point to the similarity between recent events and projected change (eg, CBC News, *Calgary floods spotlight cities' costly failure to plan for climate change*, 28 July 2013)

Outline

- Introduction and context
- What is event attribution?
- How is it done?
- Framing affects the answer
- US National Academies of Science Report
- Conclusions

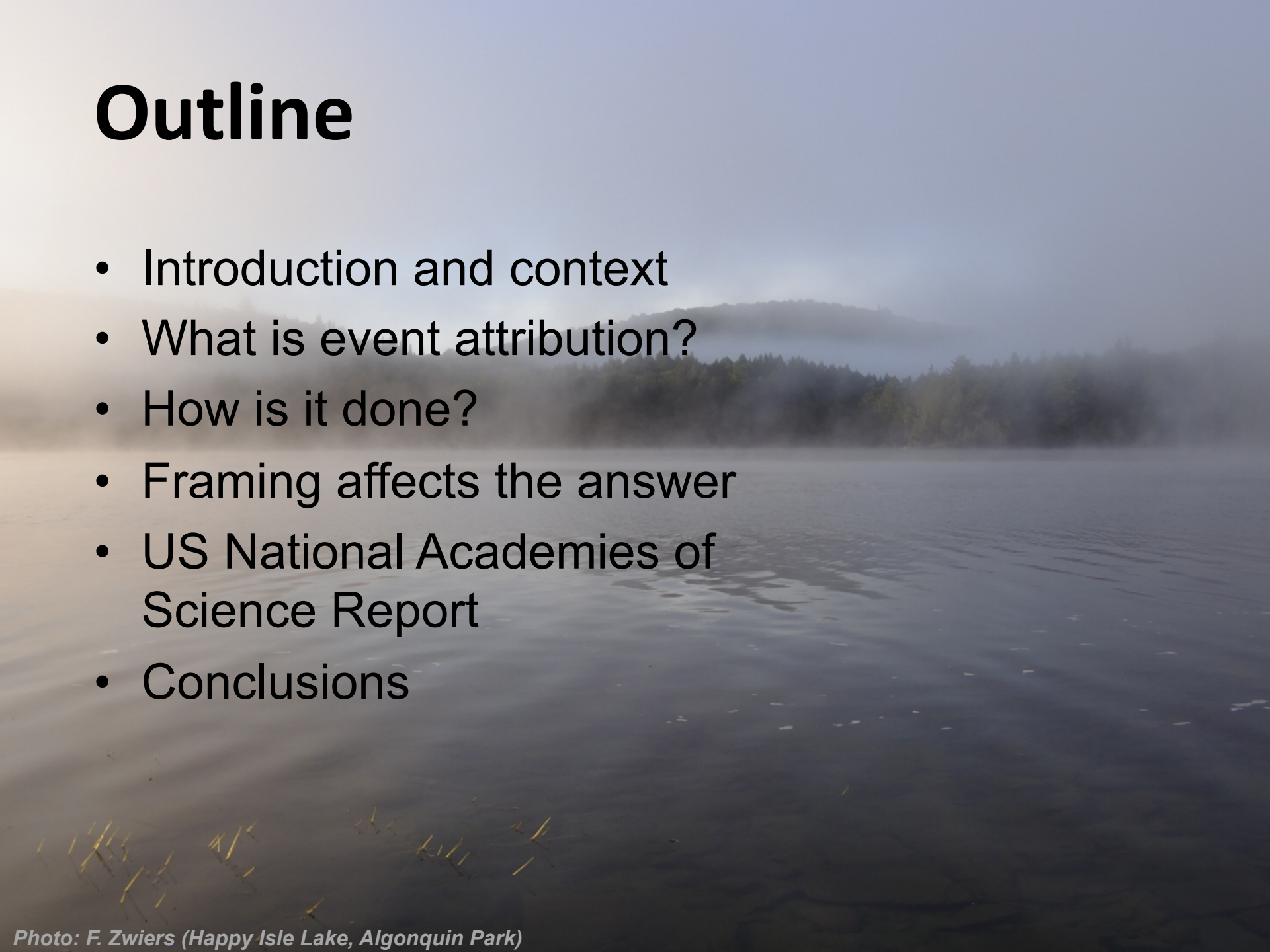


Photo: F. Zwiers (Happy Isle Lake, Algonquin Park)

What is “event attribution”?

Photo: F. Zwiers (Happy Isle Lake, Algonquin Park)

Event Attribution …

- Is what reporters, officials and the public ask us to do immediately after (or during) an event
- The usual question (did climate change cause this event) is not well posed
- Might ask
  - Did climate change increase the intensity?
  - Was the event more likely to happen because the climate had changed?
- We can aim to respond on three time scales
  - Immediately
  - Within the media cycle (maximum 1-2 weeks)
  - Research time scale

Event attribution

- How we respond is important because (we might suspect that) adaptation decisions are still most often taken in the wake of damaging events
- A key new paper is Hannart et al (2016a) – *Causal counterfactual theory for the attribution of weather and climate-related events*
  - Distinguishes between "necessary" and "sufficient"
  - Could be a high likelihood that anthropogenic climate change was *necessary* for the event to occur, but a small likelihood that it was *sufficient* to cause the event
- Adaptation needs to account for all possible causes (sufficiency), but event attribution focuses on who/what is to blame (necessity)

Two key numbers

- Many event attribution studies focus on the "Fraction of Attributable Risk" (Allen, 2003)

$$\mathrm{FAR} = \frac{p_1 - p_0}{p_1} = 1 - \frac{p_0}{p_1}$$

p_1 = Prob of event in factual world

p_0 = Prob of event in "counterfactual" world

- Under suitable conditions

$$\mathrm{PN} = \Pr\{\text{necessary causation}\} = \mathrm{FAR}$$

- Hannart et al (2016) also show that

$$\mathrm{PS} = \Pr\{\text{sufficient causation}\} = 1 - \frac{1 - p_1}{1 - p_0}$$

Note that $\mathrm{PS} \approx p_1$ when $p_0 \approx 0$ and $p_1 \gg p_0$

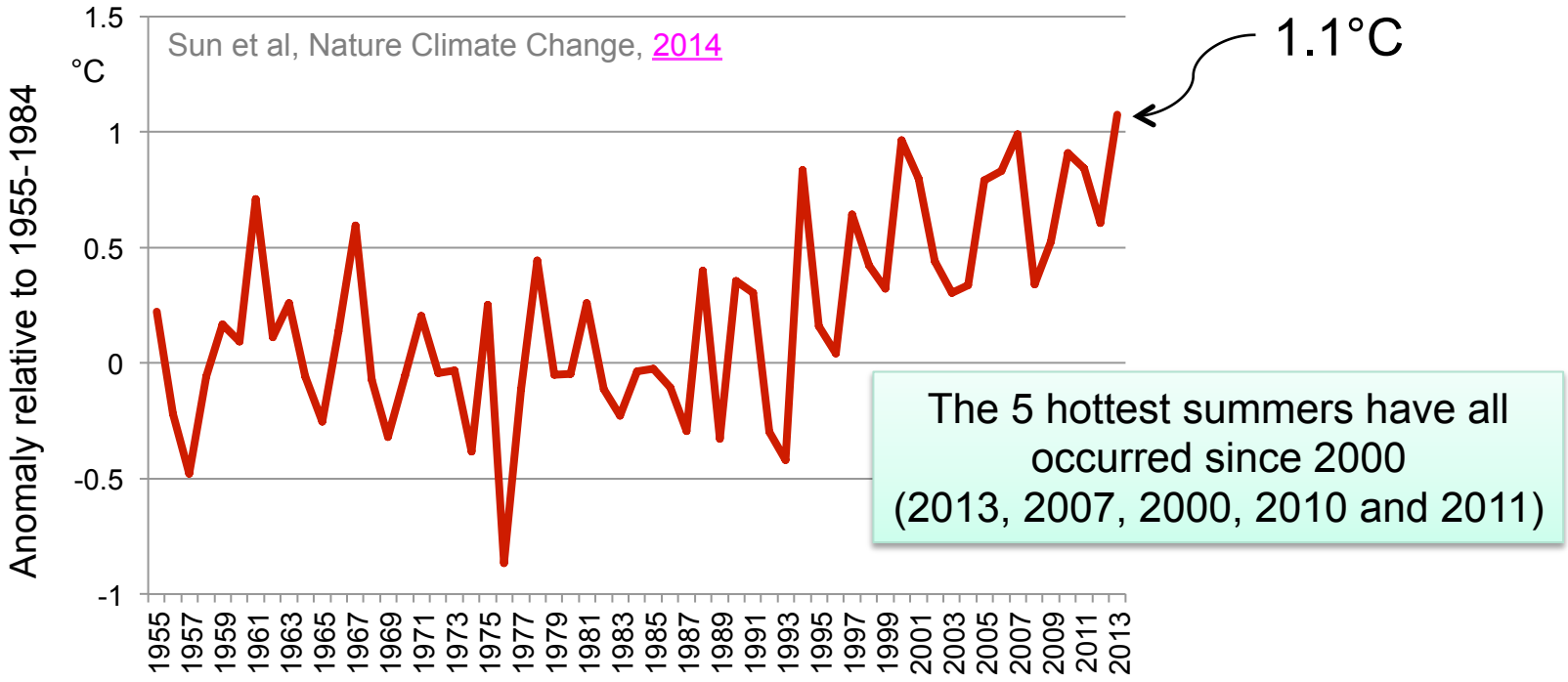
How is “event attribution” done?

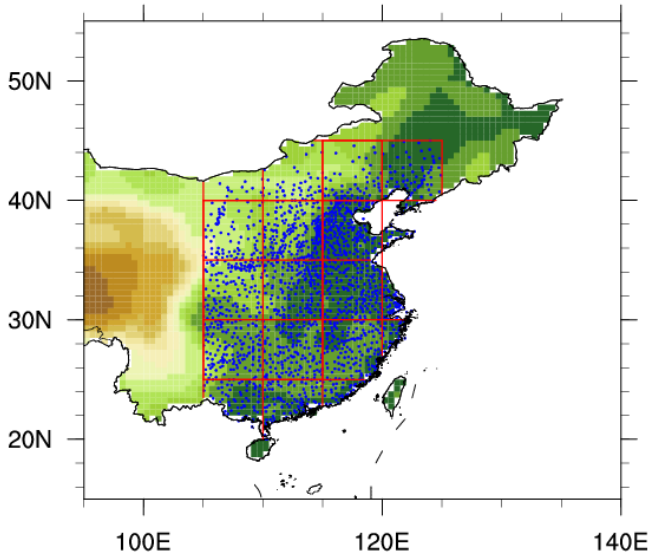
Photo: F. Zwiers (Wood Duck, King’s Pond, Victoria, BC)

China’s Summer of 2013

Photo: F. Zwiers (Lijiang – Black Dragon Pool)

JJA mean temperature in Eastern China

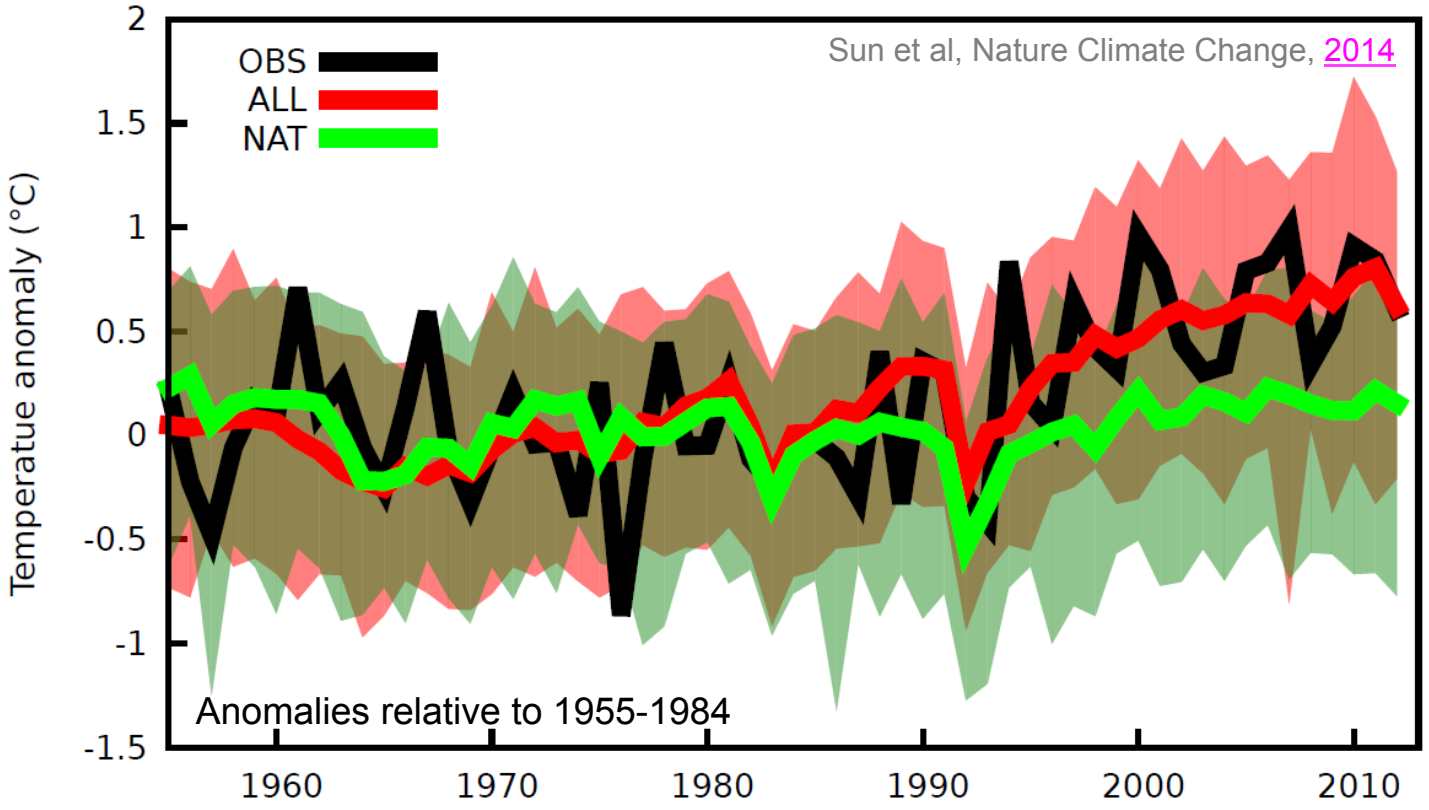




Eastern China is densely observed

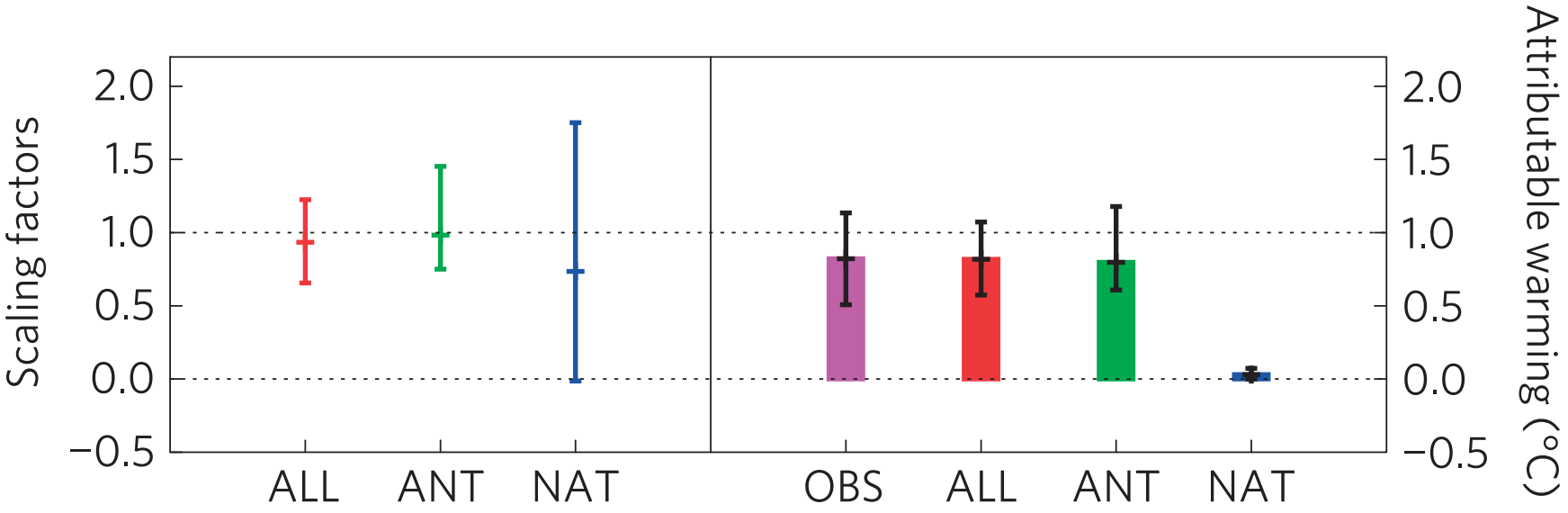
- 1749 stations (1955 onwards)
- JJA mean temperature increased 0.82°C over 1955-2013
- records were broken at more than 45% of stations in JJA 2013

Observed and simulated JJA mean temperature in Eastern China (1955-2012)



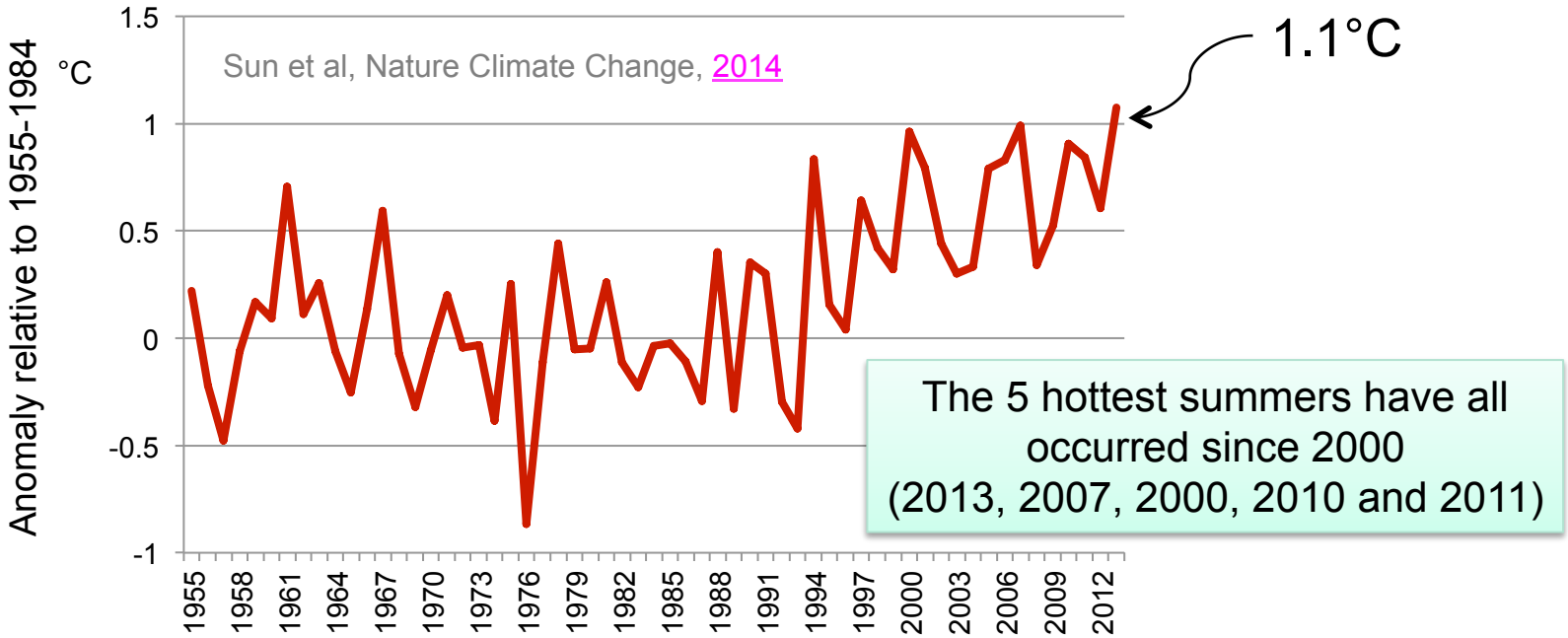
The multi-model ensemble mean (ALL forcing) well simulates the observed temperature record.

Detection and attribution results for change JJA climate over 1955-2012



- ALL forcing → 0.82°C (0.57°C, 1.07°C)
- NAT forcing → 0.03°C (-0.00°C, 0.07°C)
- Urban warming may be responsible for part of the "ALL" attributed warming - possibly 0.21°C (0.16°C, 0.26°C)

How rare was JJA of 2013?



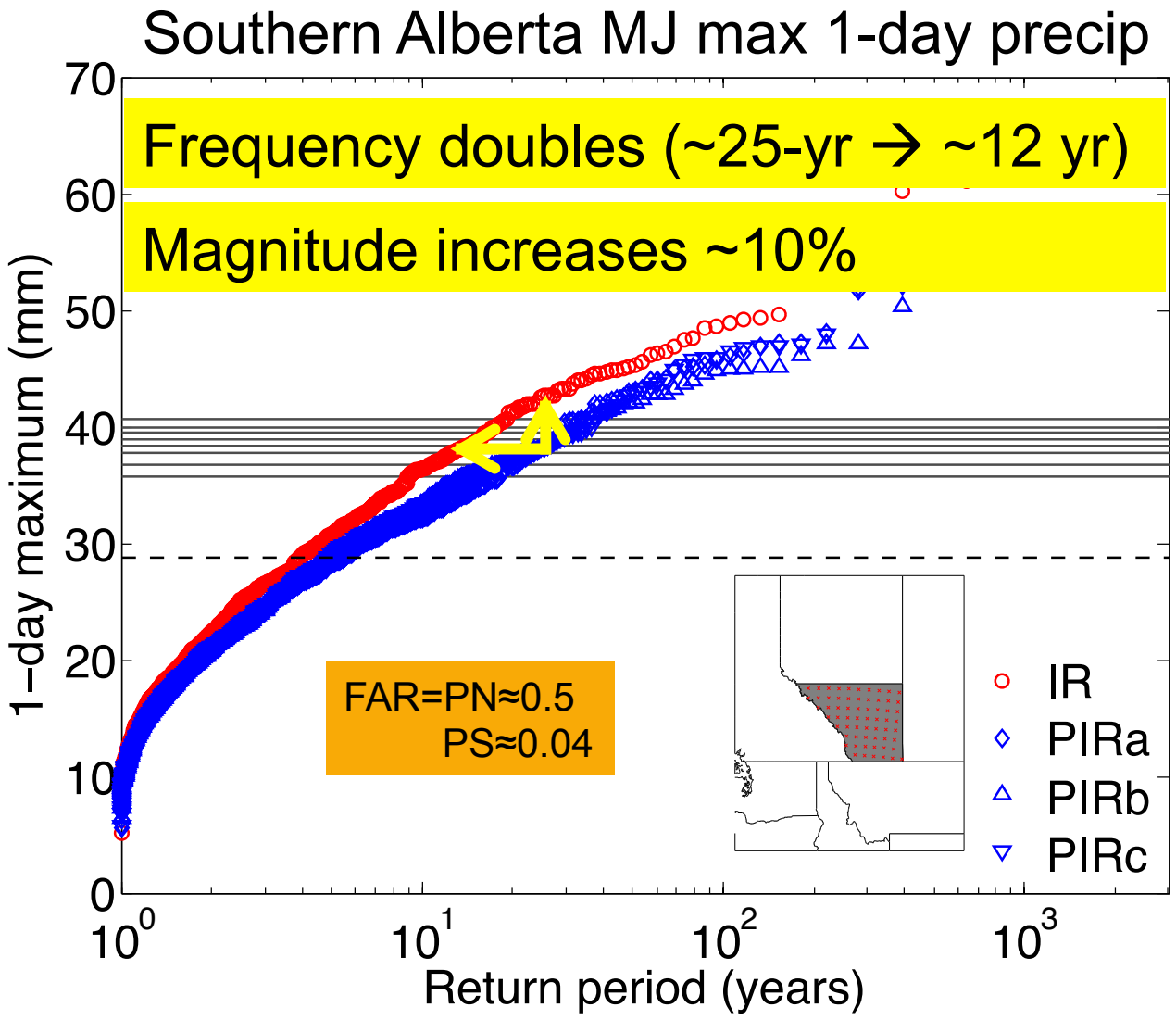
- 1.1°C ≈ 3.5 SD above the 1955-1984 mean
  - ANT forcing contributed ~2.6 SD
- Estimated event frequency
  - once in 270-years in control simulations
  - once in 29-years in "reconstructed" observations
  - once in 4.3 years relative to the climate of 2013
- PN=FAR≈0.984, PS≈0.23

Calgary flood, 2013

Looking towards downtown Calgary from Riverfront Avenue (June 21, 2013), courtesy Ryan L.C. Quan

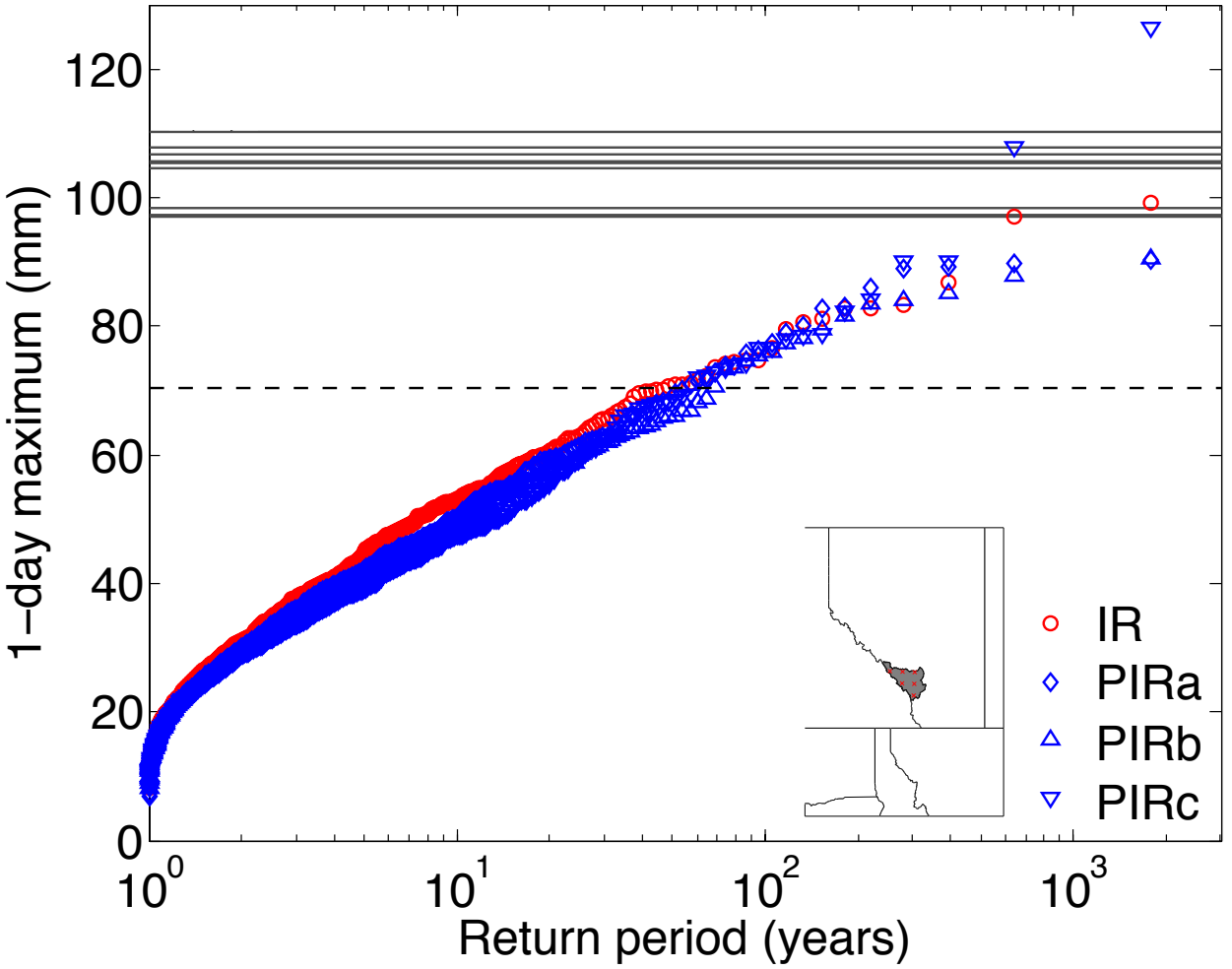
Calgary floods (Teufel et al, submitted)

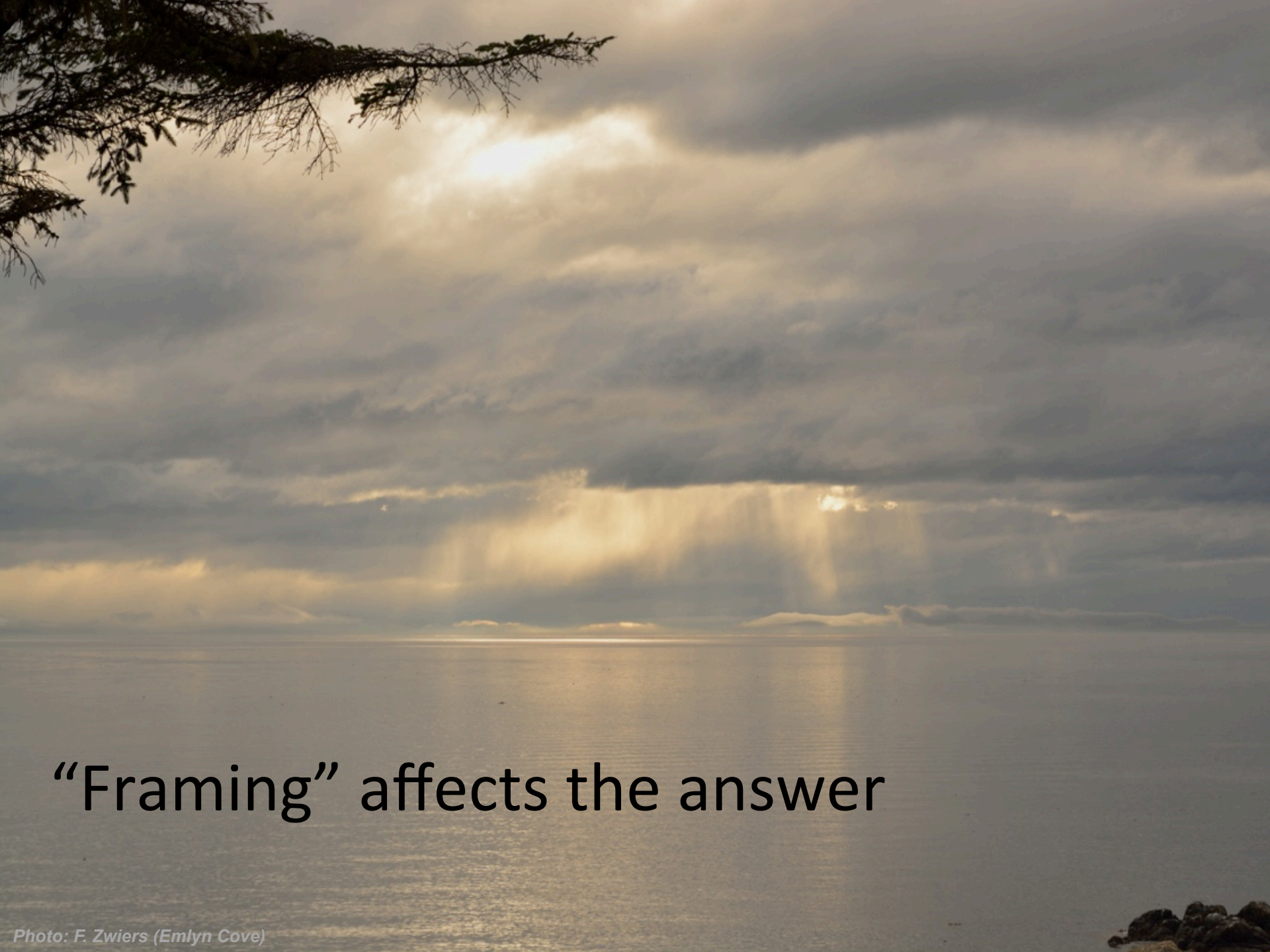
Distribution of annual May-June maximum 1-day southern-Alberta precipitation in CRCM5 under factual and counter-factual conditions (conditional on prevailing global pattern of SST anomalies)



Calgary floods (Teufel et al, submitted)

Distribution of annual May-June maximum 1-day Bow River Basin precipitation in CRCM5 under factual and counter-factual conditions (conditional on prevailing global pattern of SST anomalies)

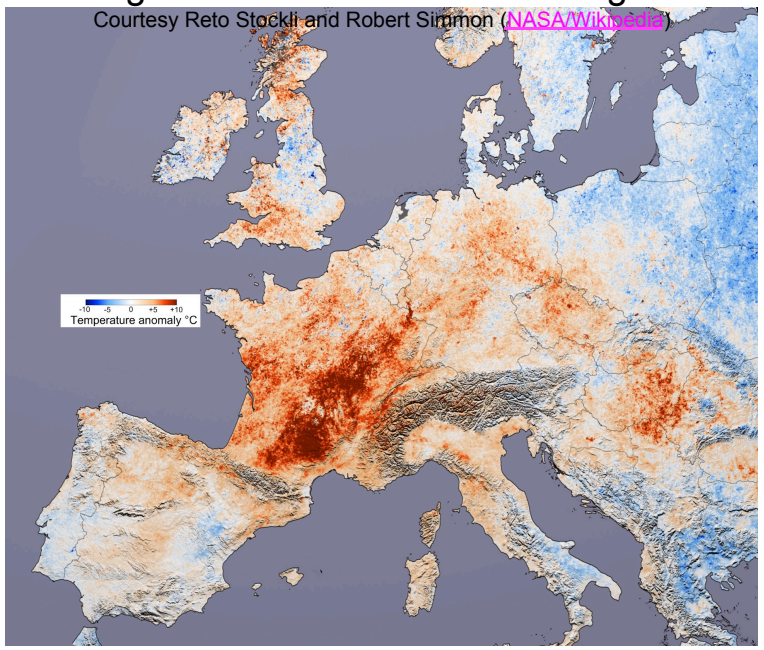



“Framing” affects the answer
Photo: F. Zwiers (Emlyn Cove)

What is framing?

- How the question is posed
  - For example, how detailed is the question?
  - The first “event attribution” study (Stott et al., 2004) was motivated by the 2003 European heat wave
  - The exact definition of the evident (duration and spatial extent) is unclear, and thus the study was focused on mean summer conditions across a large region encompassing the Mediterranean and southern Europe

20 July – 20 Aug 2003 vs the same period averaged over 2000-2004 excluding 2003



JJA temperature anomalies relative to 1961-1990

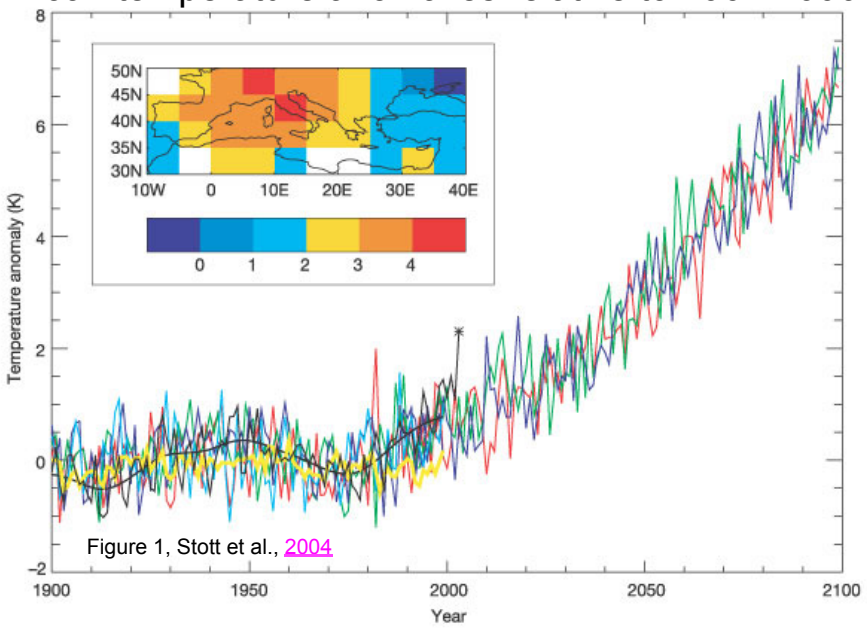
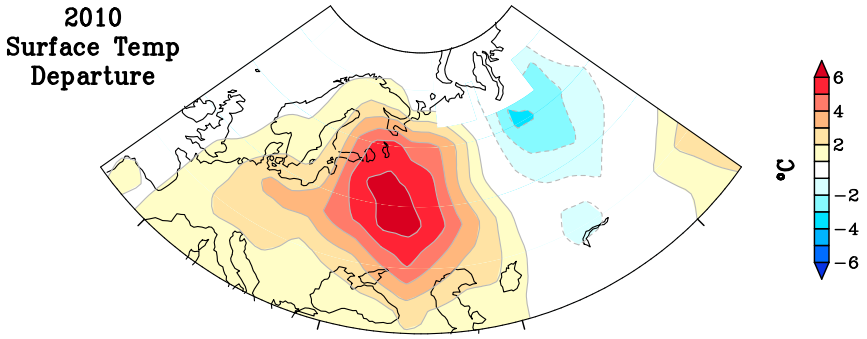


Figure 1, Stott et al., 2004

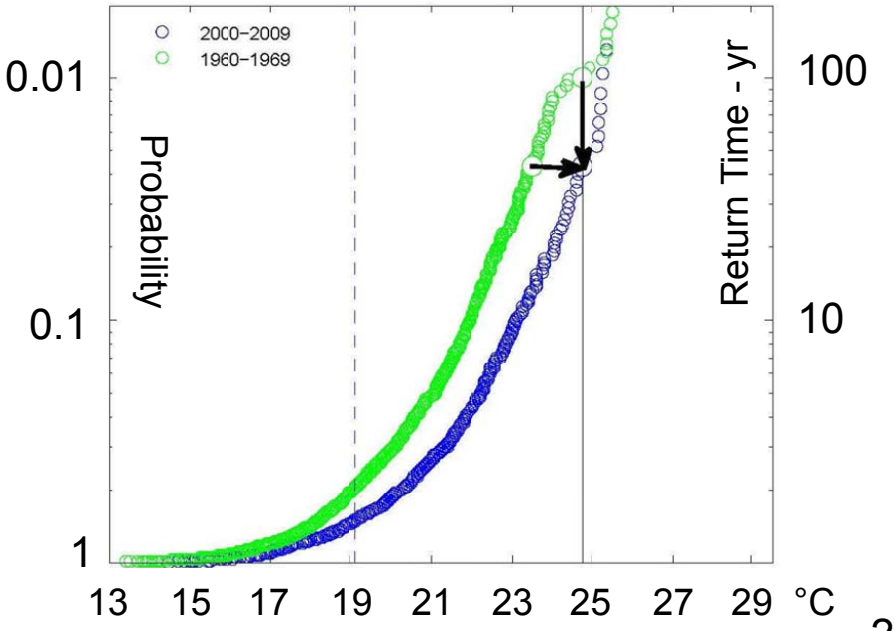
What is framing?

- Which question is posed (frequency vs intensity)
  - Two studies of the Russian 2010 heat wave (mid-June to mid-August) came to conflicting conclusions
  - One focused on intensity (found little human influence)
  - The other focused on frequency (found a large human influence)
  - Answering both questions avoids confusion, and answers questions posed by different users

July 2010 mean surface temperature anomaly relative to 1880-2009



"Factual" and "Counterfactual" Russian (50-60°N, 35-55°E) July surface temperature distributions



What is framing?

- What factors are controlled in the analysis
  - Statisticians call this “conditioning”
  - Two distributions of event magnitude could be calculated taking the presence or absence of anthropogenic forcing into account

“Factual” “Counterfactual”

$$f(T_t \mid ANT_t + NAT_t) \quad \text{vs} \quad f(T_t \mid NAT_t)$$

  - Or the calculations could take additional factors into consideration as well, such as the prevailing pattern of SST anomalies

“Factual” “Counterfactual”

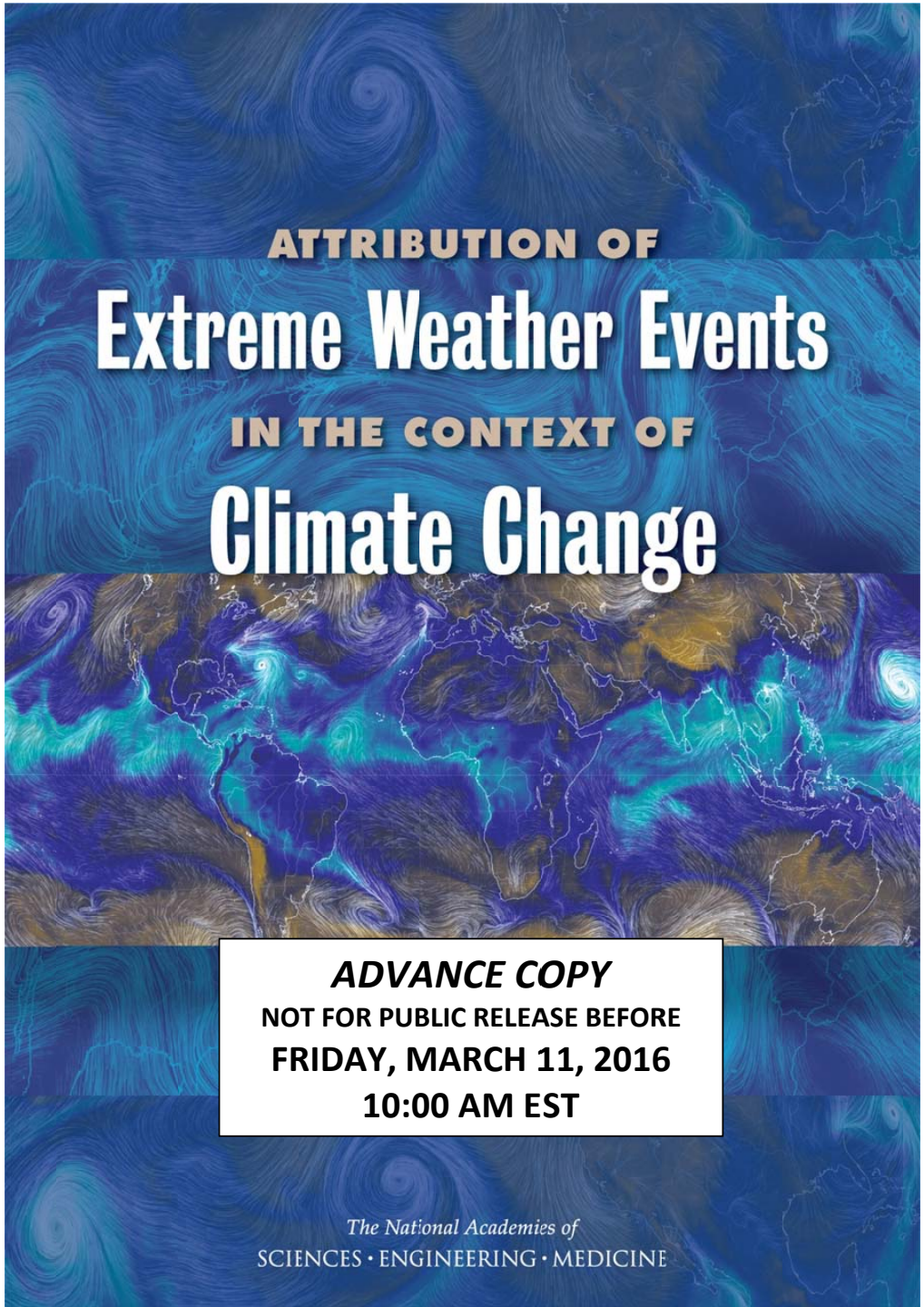
$$f(T_t \mid ANT_t + NAT_t, SSTA_t) \quad \text{vs} \quad f(T_t \mid NAT_t, SSTA_t)$$

What is framing?

- Many studies condition on SST anomalies
  - Restricting a source of variability may improve signal-to-noise ratios
  - Specifying the state of the sea surface allows the use of atmospheric, rather than coupled models
    - Cheaper
    - Can sometimes use 1000's or 10000's of simulations
    - One approach is to use personal computers volunteered by the public via the weather@home/climateprediction.net system
- Conditioning may add uncertainties
  - Need to estimate the counterfactual SST base state
  - Likelihood of the SSTA pattern may change

US National Academies of Science Report on Extreme Event Attribution

Photo: F. Zwiers (Marsh Wren)



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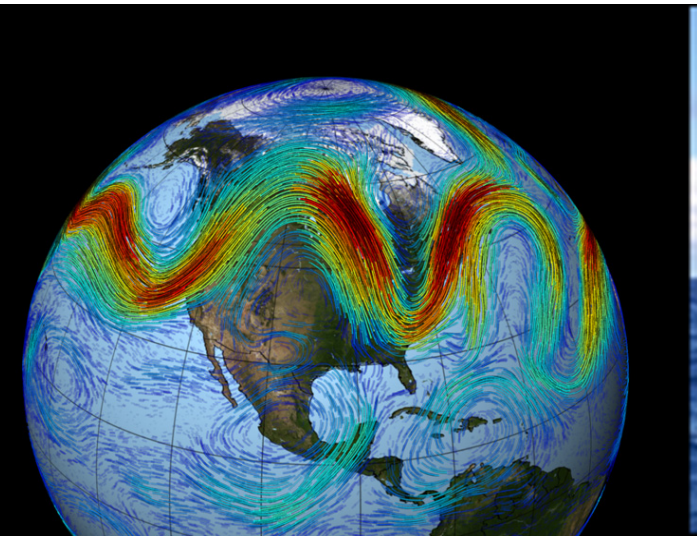
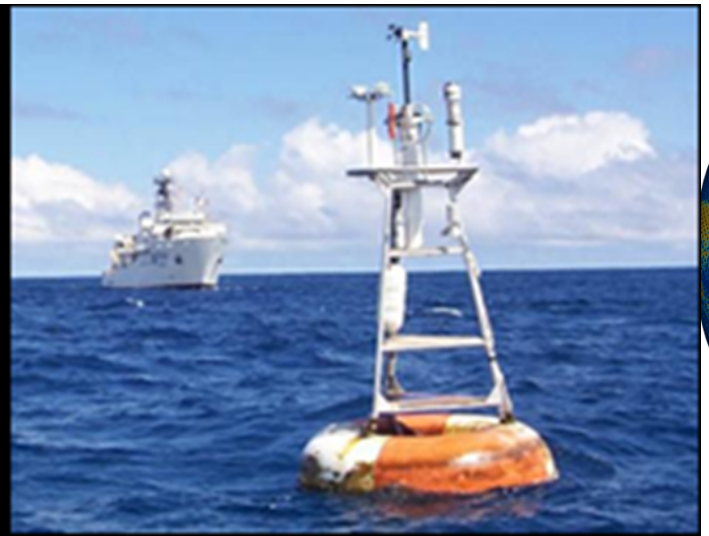
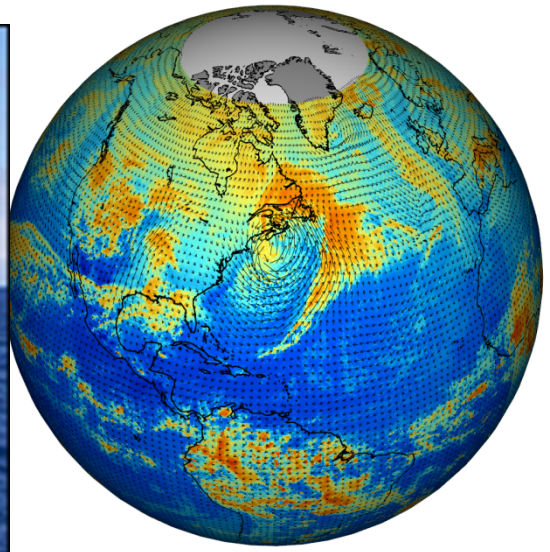
THEODORE G. SHEPHERD, University of Reading
ADAM H. SOBEL, Columbia University
JOHN WALSH, University of Alaska, Fairbanks
FRANCIS W. ZWIERS, University of Victoria

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

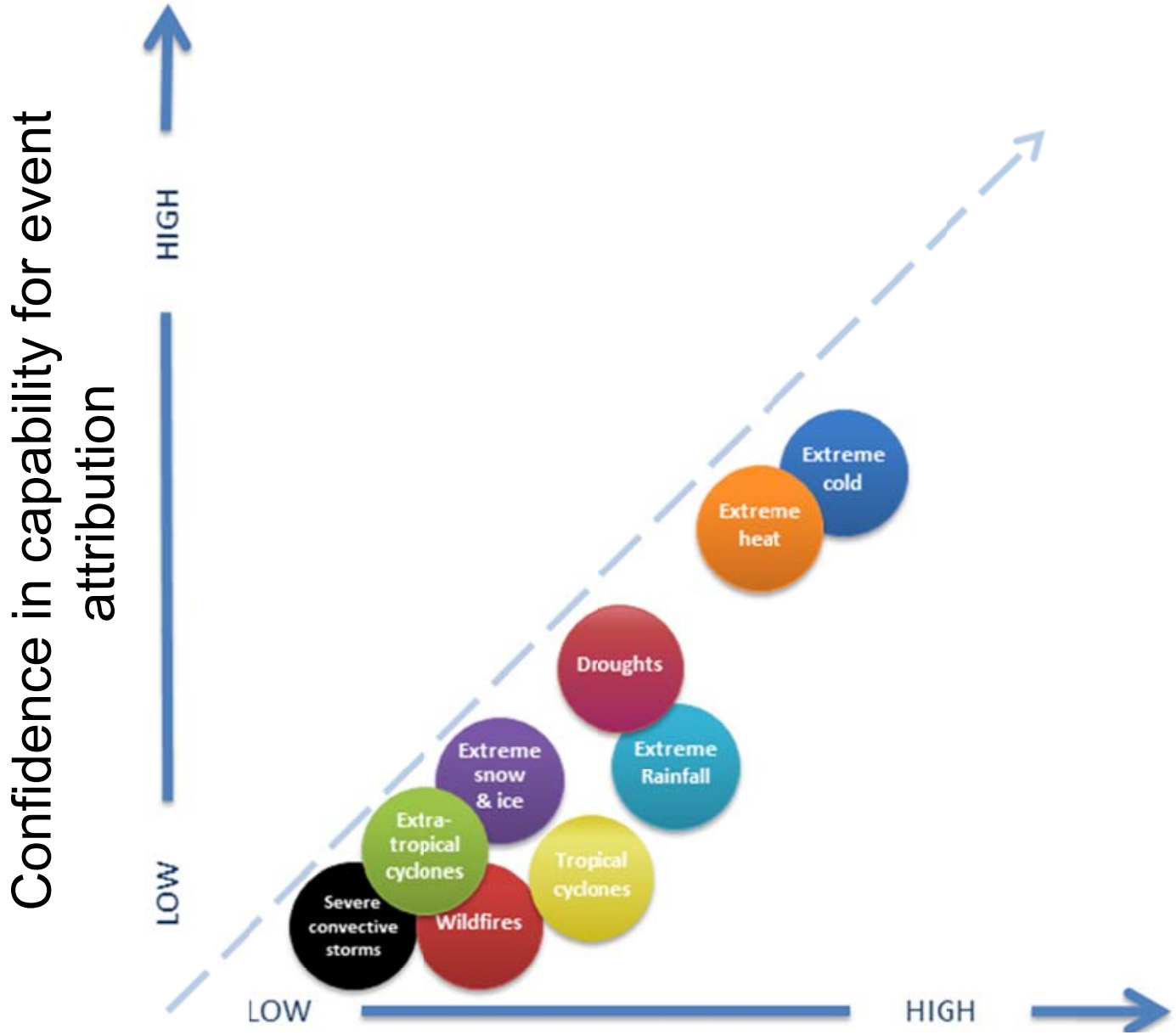






Some Events are More Attributable than Others

- 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**


Confidence in capability for event attribution
HIGH
LOW
Extreme cold
Extreme heat
Droughts
Extreme Rainfall
Extreme snow & ice
Extra-tropical cyclones
Tropical cyclones
Severe convective storms
Wildfires
LOW
HIGH
Understanding of effect of climate change on event type

● = high

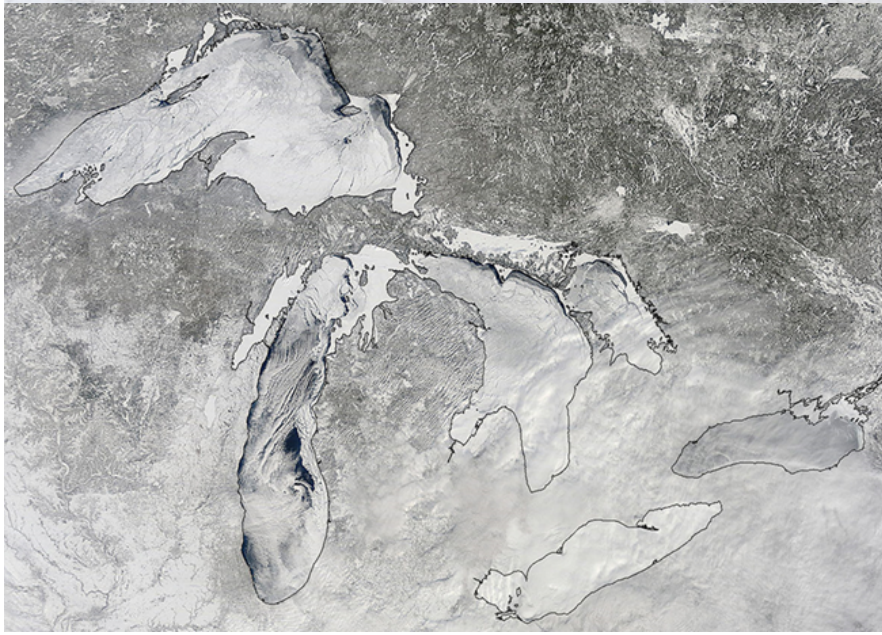
◎ = medium

○ = 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 / ice storms	◎	○	◎
Tropical cyclones	○	○	◎
Extratropical cyclones	◎	○	○
Wildfires	○	◎	○
Severe convective storms	○	○	○

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

Conclusions

Photo: F. Zwiers (Big Trout Lake, Algonquin Park)

Conclusions

- Ability to attribute causes to events remains limited
  - Relatively high confidence for extreme temperature
  - Some confidence in precipitation extremes and perhaps some kinds of drought
  - Can say relatively little about frozen and freezing precipitation, storms, floods, wildfire
- Confidence is often limited by
  - Data quality and length of historical record
  - Process understanding, and ability of models to simulate events
  - Lack of supporting research on detection and attribution of long-term change related to the event type

Conclusions

- Findings are sensitive to framing choices
  - event definition
  - what question is asked
  - whether conditioning factors are taken into account
- Methods are still evolving, and are at least partially determined by the framing
- Need to develop objective event selection criteria
- Don’t yet have a good way to ask highly specific questions (most studies consider classes of events)
  - But note that Hannart et al (2016b) suggest an approach using a data assimilation technique

Questions?

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Photo: F. Zwiers (Fern uncurling, Botanical Beach)