Event attribution:
the emerging science of attributing causes to extreme events

Francis Zwiers
PCIC, University of Victoria
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CNRCWP

NSERC
CRSNG

Introduction

- Enormous interest in event attribution
  - Event and media driven (eg, Calgary floods, Fort McMurray fires)
  - Questions are mostly retrospective
- Requires “rapid response” science
  - Recently assessed by US National Academies of Science
- Topics for this talk
  - Detection and attribution of long-term change
  - Event attribution
  - Discussion

Detection and Attribution of long term change

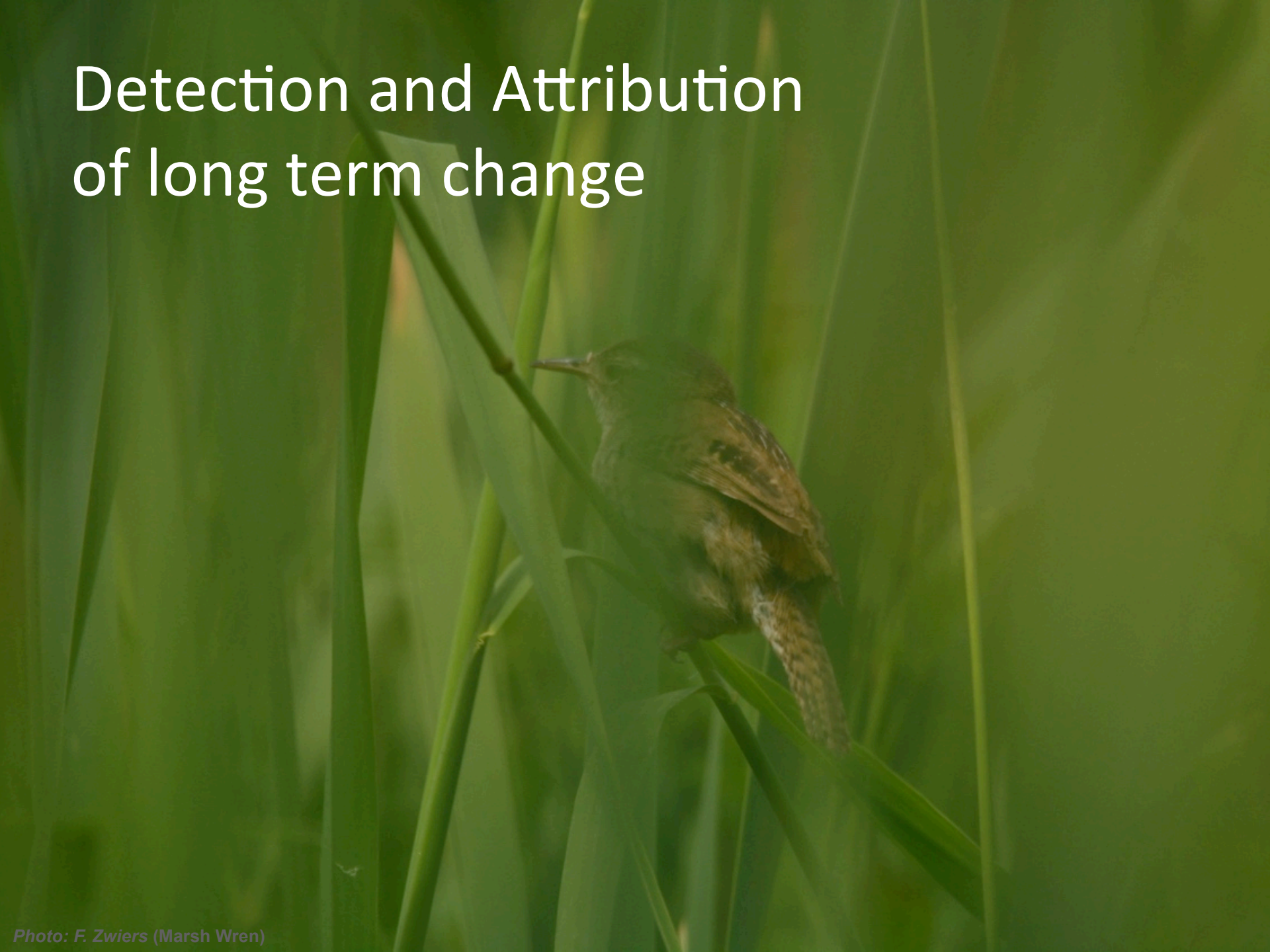


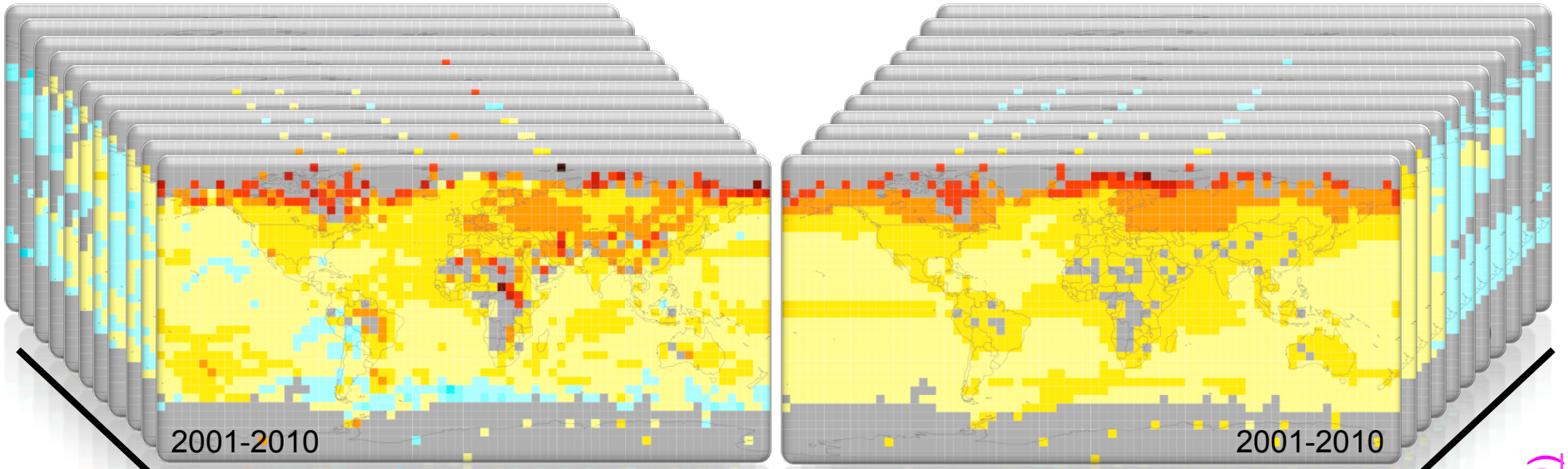
Photo: F. Zwiers (Marsh Wren)

D&A of long-term change

- Definitions
  - *Detection* – identifying that a change has occurred
  - *Attribution* – evaluating contributions from causal factors
- Methods
  - Involve simple statistical models
  - Complex implementation due to data volumes (which are both small and large)
- Usual assumptions
  - Key forcings have been identified
  - Signals and noise are additive
  - Climate models simulate large-scale patterns of response correctly
- Leads to a regression formulation

Observations (HadCRUT4)

Multi-model mean (ALL forcings)



11 decades (1901-1911 to 2001-2011)

$\mathbf{Y}$

$\mathbf{X}$

$$\mathbf{Y} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon}$$

$\hat{\boldsymbol{\beta}}$

Evaluate scaling factors

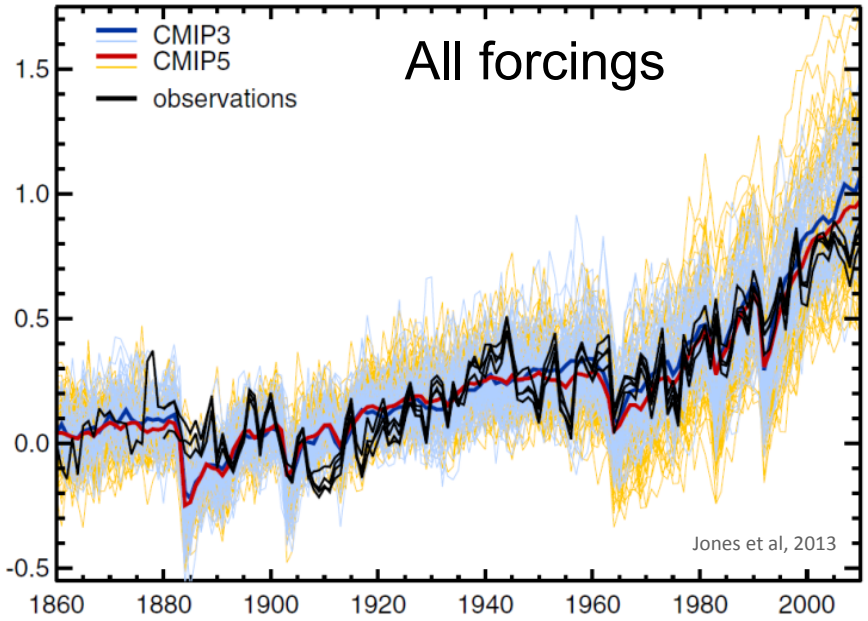
$\hat{\boldsymbol{\varepsilon}}$

Evaluate residuals

After Weaver and Zwiers (2000)

Global warming attribution

Global mean temperature relative to 1880-1919



See also Figure 10.1, IPCC WG1 AR5

Trend in global surface temperature (1951-2010)

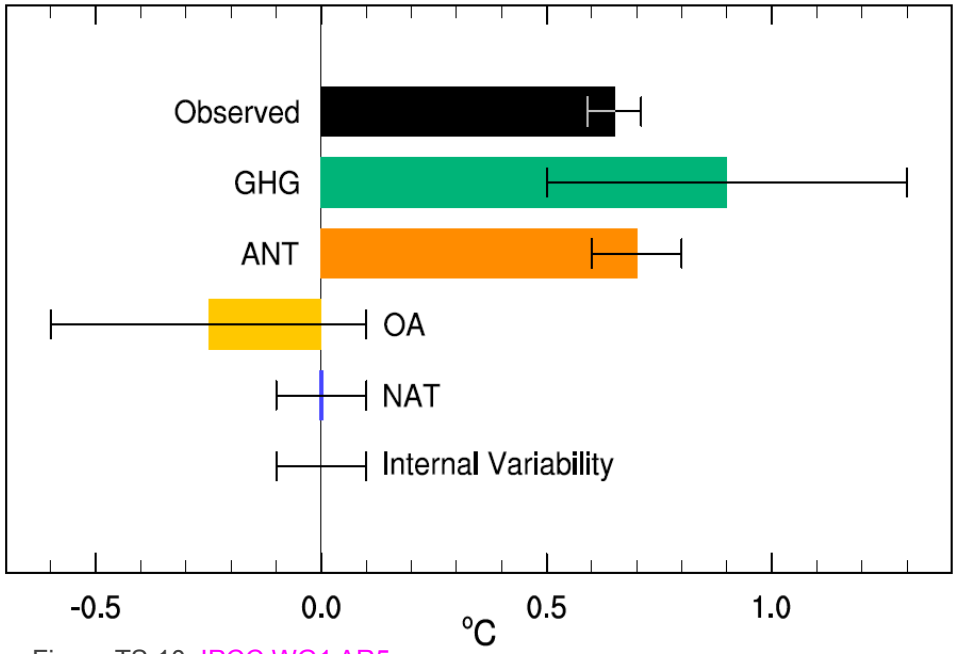


Figure TS.10, IPCC WG1 AR5

It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century.

Detection and Attribution Summary

- Concerned with long term change
- Quantifies how the mean state (or some other statistic) has changed over time due to forcing

- Examples
  - Global and regional mean temperature
    - Large body of literature, very high confidence
  - Temperature extremes
    - Growing literature, high confidence
  - Precipitation extremes
    - Emerging evidence, medium or lower confidence

Temperature Extremes

Estimated return period for a 1960's 20-year temperature extreme in the 1990's

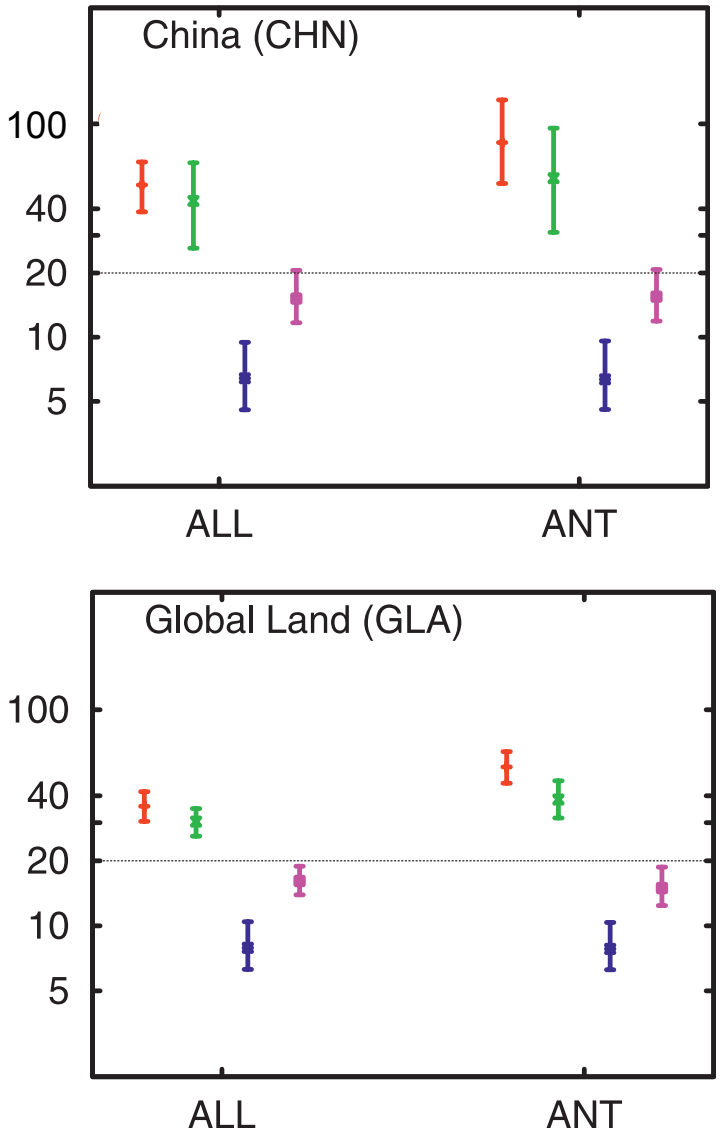
Coldest night annually

Coldest day annually

Warmest night annually

Warmest day annually

Zwiers et al., 2011



Event attribution

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

Event attribution

- The public asks: Did human influence on the climate system …
  - Cause the event?
- Most studies ask: Did it …
  - Affect its odds?
  - Alter its magnitude?
- Some think we should reframe the question …
  - Rather than "Did human influence …" (which requires comparison with a counterfactual world)
  - Ask "How much (eg, of a given storm's precipitation) is due to the attributed warming (eg, in the storm's moisture source area)" (after Trenberth et al, 2015)

Most studies

- Compare factual and “counterfactual” climates
  - Counterfactual → the world that might have been if we had not emitted the ~600GtC that have been emitted since preindustrial
- These studies almost always
  - Define a class of events rather than a single event
  - Use a probabilistic approach
- Shepherd (2016) defines this as “risk based”
  - Contrasts it with a “storyline” based approach
  - i.e., analysis of the specific event that occurred

"Framing" event attribution studies

- Event type
  - Class vs individual
- Analysis approach and approach
  - "risk based" or "storyline"
- Event definition
  - What spatial scale, duration, etc
- Which risk-based question
  - Did climate change alter the odds, or the magnitude?
- What factors should be taken into account
  - "Conditioning"
  - e.g., coincident SST anomaly pattern

The NAS Report (2016) struggled with these distinctions

“Conditioning” examples

- Did human influence alter its likelihood

$$Prob(E|forcing)\ \ vs\ \ Prob(E|\neg forcing)$$

$$Prob(E|forcing, SST)\ \ vs\ \ Prob(E|\neg forcing, \widetilde{SST})$$

- Did human influence alter its magnitude

$$f(M|E, forcing)\ \ vs\ \ f(M|E, \neg forcing)$$

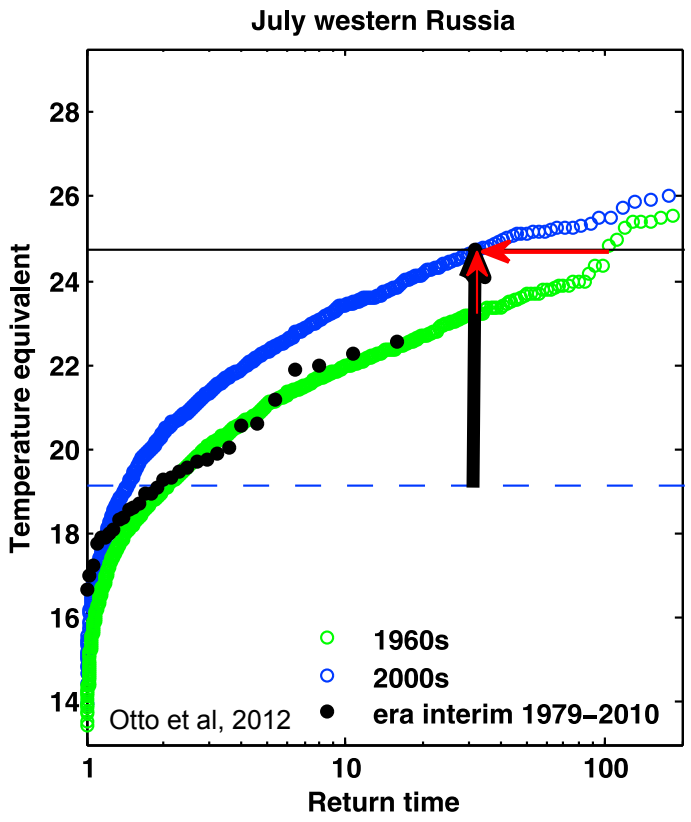
$$f(M|E, forcing, SST)\ \ vs\ \ f(M|E, \neg forcing, \widetilde{SST})$$

Different questions can lead to seemingly contradictory conclusions

- Russian July 2010 heatwave
  - Dole et al (2011)
    - human influence did not substantially affect magnitude
  - Rahmstorf and Coumou (2011)

$$Prob(E|warming) \approx 5 * Prob(E|\neg warming)$$

  - Otto et al (2012)
    - not necessarily inconsistent
    - a small increment in magnitude can lead to a large change in likelihood



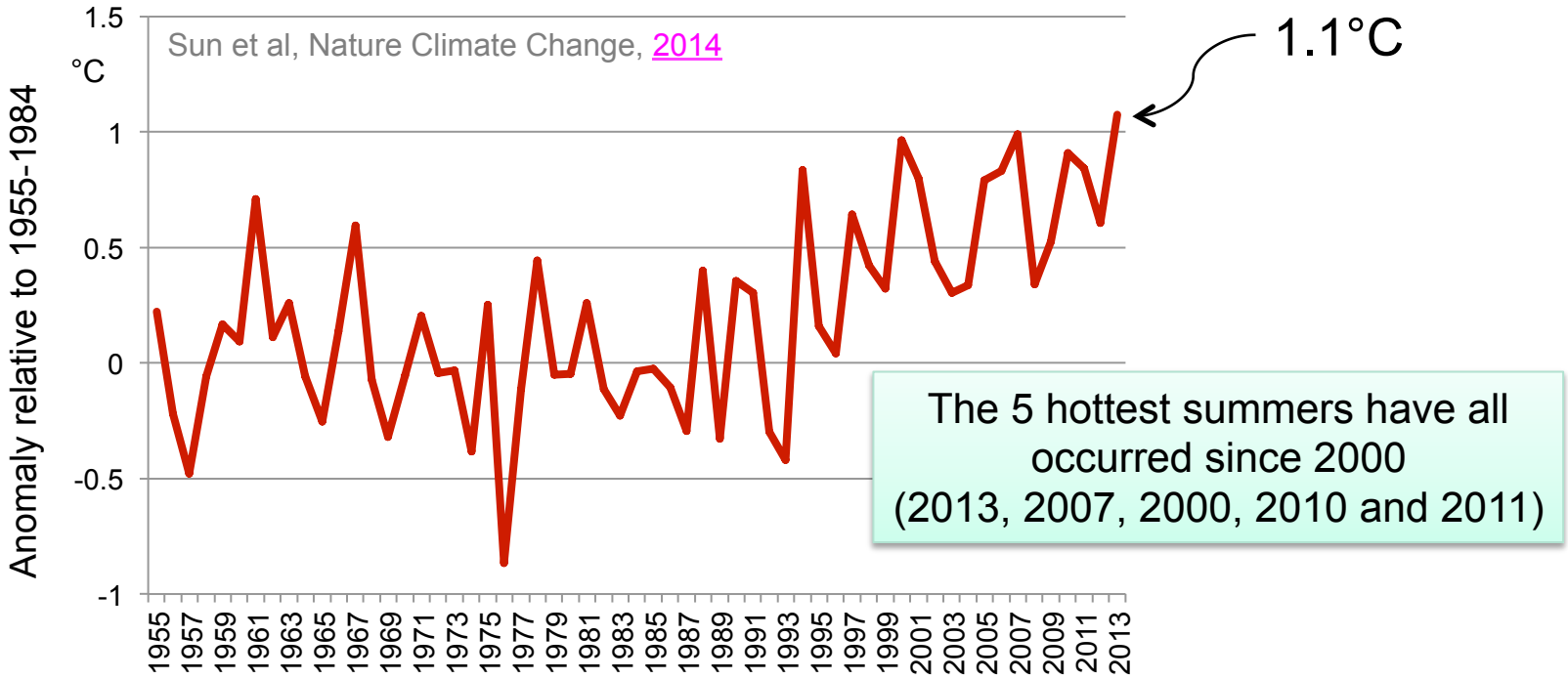
Recent examples

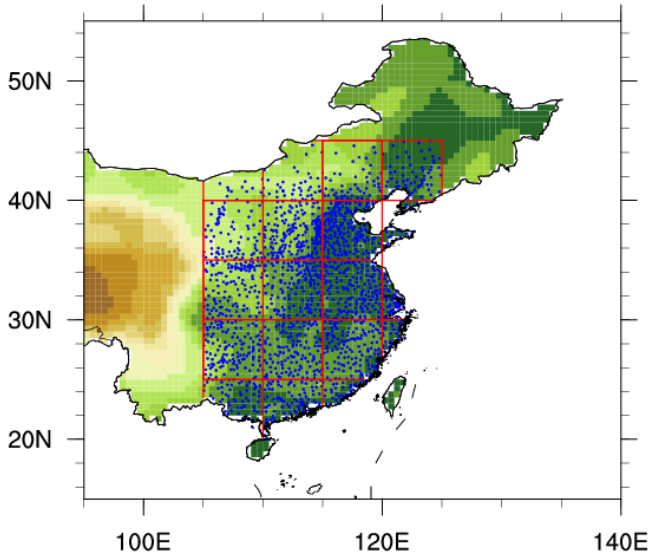
- China's very hot summer of 2013
  - Sun et al. (2014)
  - Condition only on anthropogenic forcing
- Calgary floods
  - Teufel et al (submitted)
  - Condition on anthropogenic forcing and SSTs
  - Uses both risk based and storyline approachs
- Arctic low sea-ice extent events
  - Kirchmeier-Young et al (submitted)
  - Extreme low summer minimum of Sept, 2012
  - Extreme low winter maximum of March, 2015

China’s Summer of 2013

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

JJA mean temperature in Eastern China

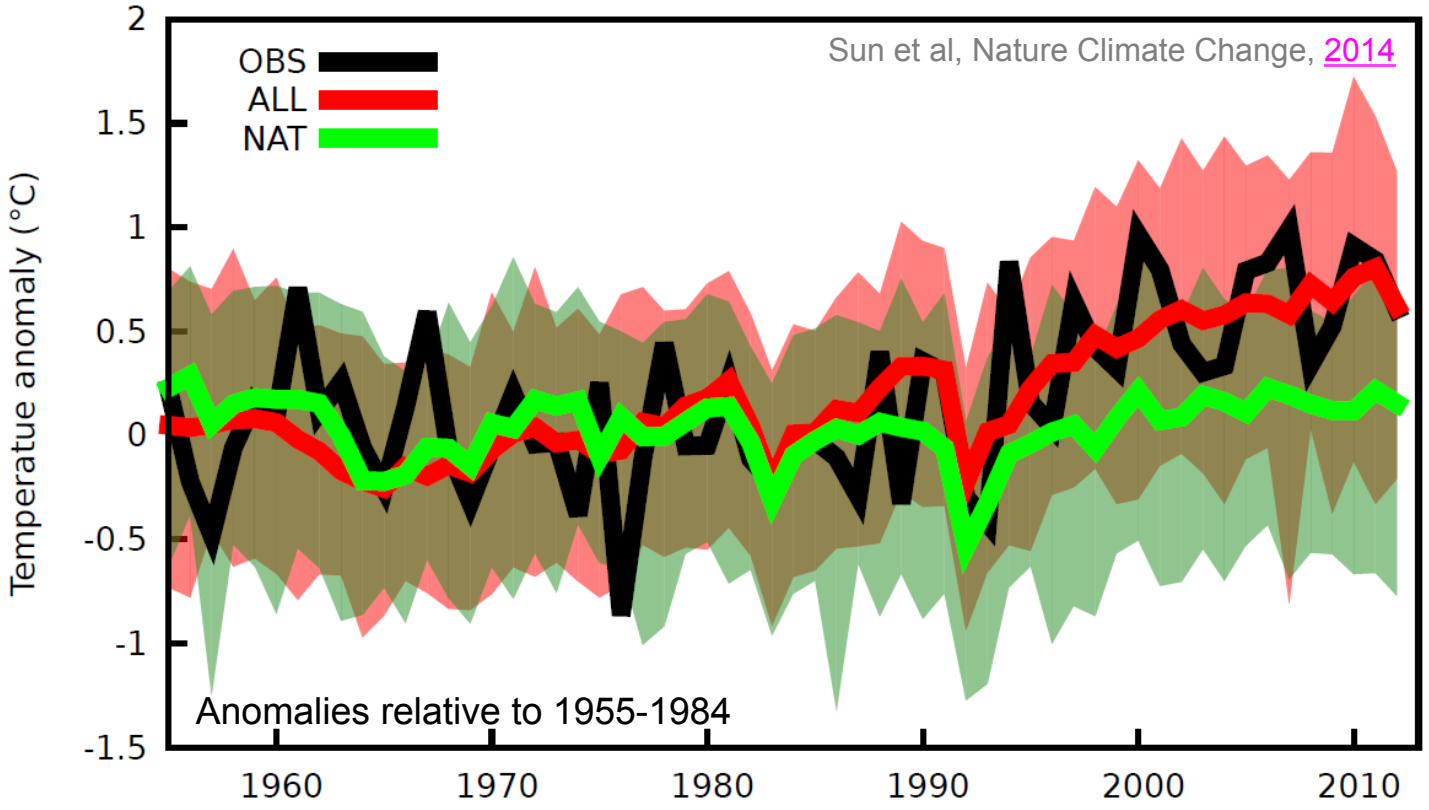




Eastern China is densely observed

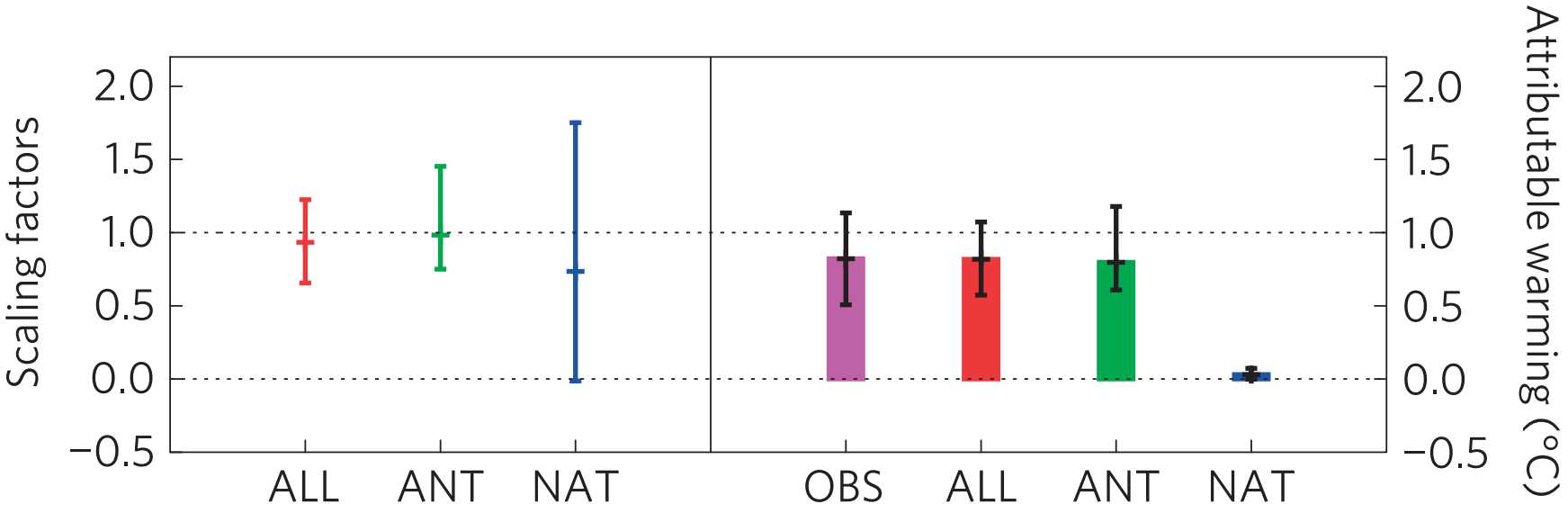
- 1749 stations (1955 onwards)
- JJA mean temperature increased 0.82°C over 1955-2013
- records were broken at more than 45% of stations in JJA 2013

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



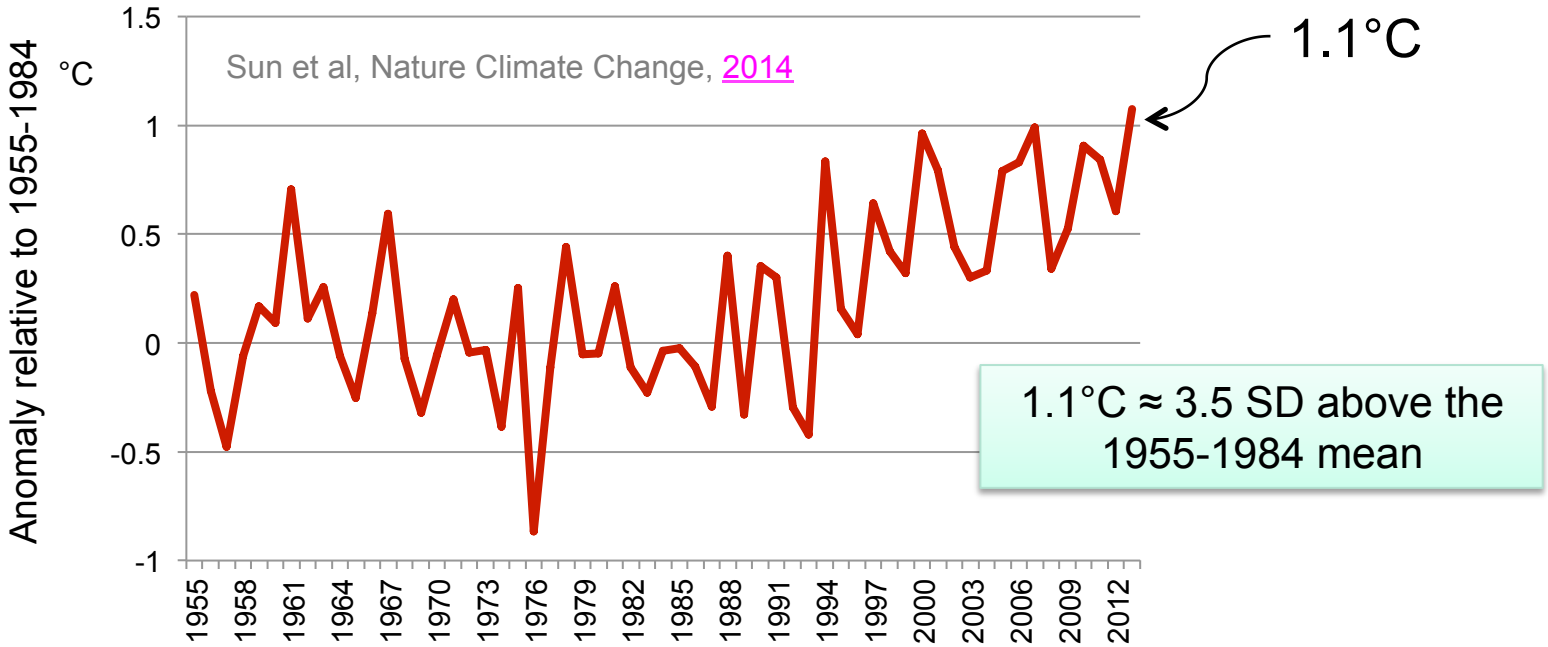
The multi-model ensemble mean (ALL forcing) well simulates the observed temperature record.

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?



- 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
- Fraction of Attributable Risk in 2013: $(p_1 - p_0)/p_1 \approx 0.984$
- Prob of "sufficient causation": $PS=1-((1-p_1)/(1-p_0)) \approx 0.23$

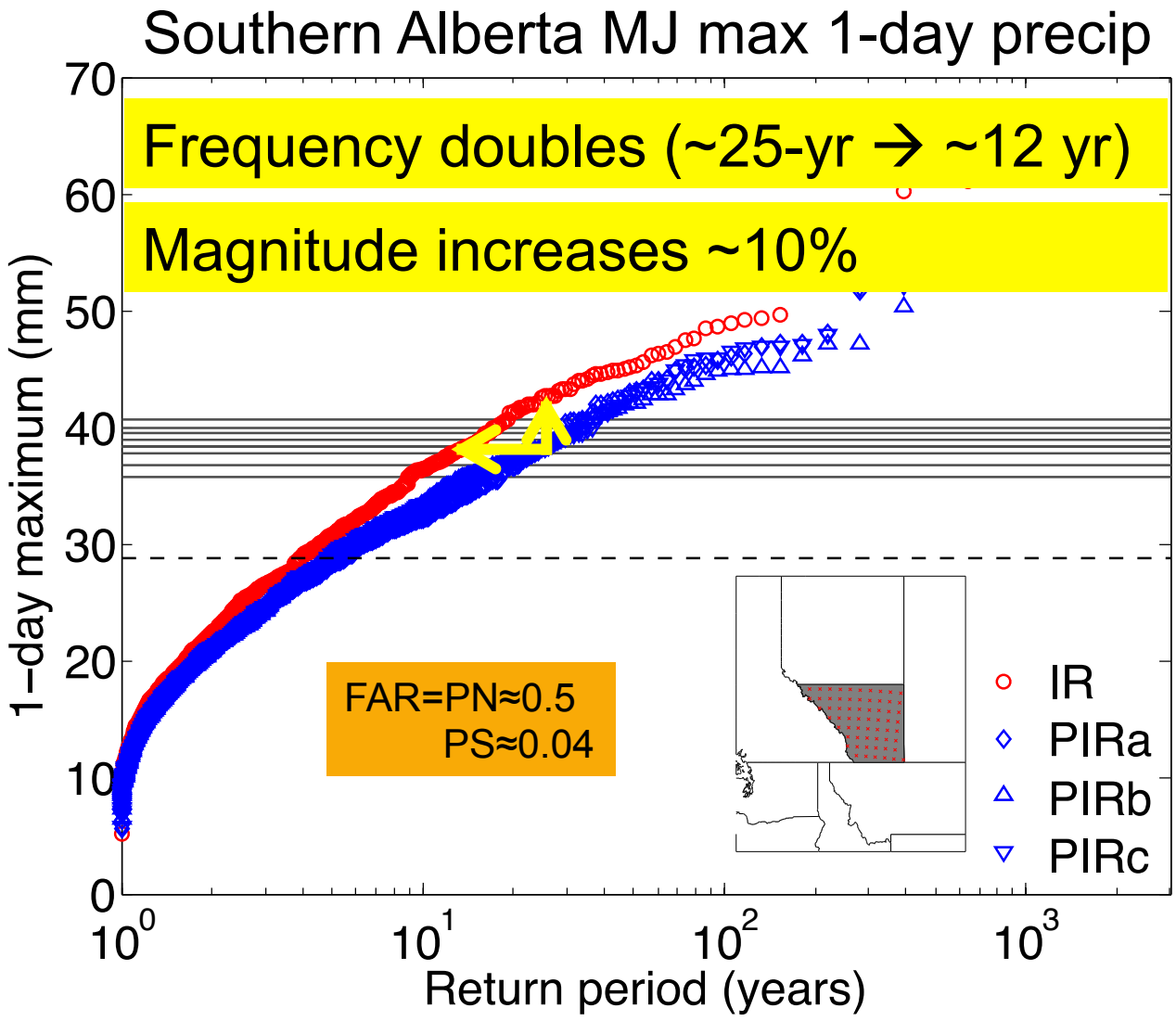
Calgary flood, 2013

★ This morning, 11:00 am

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

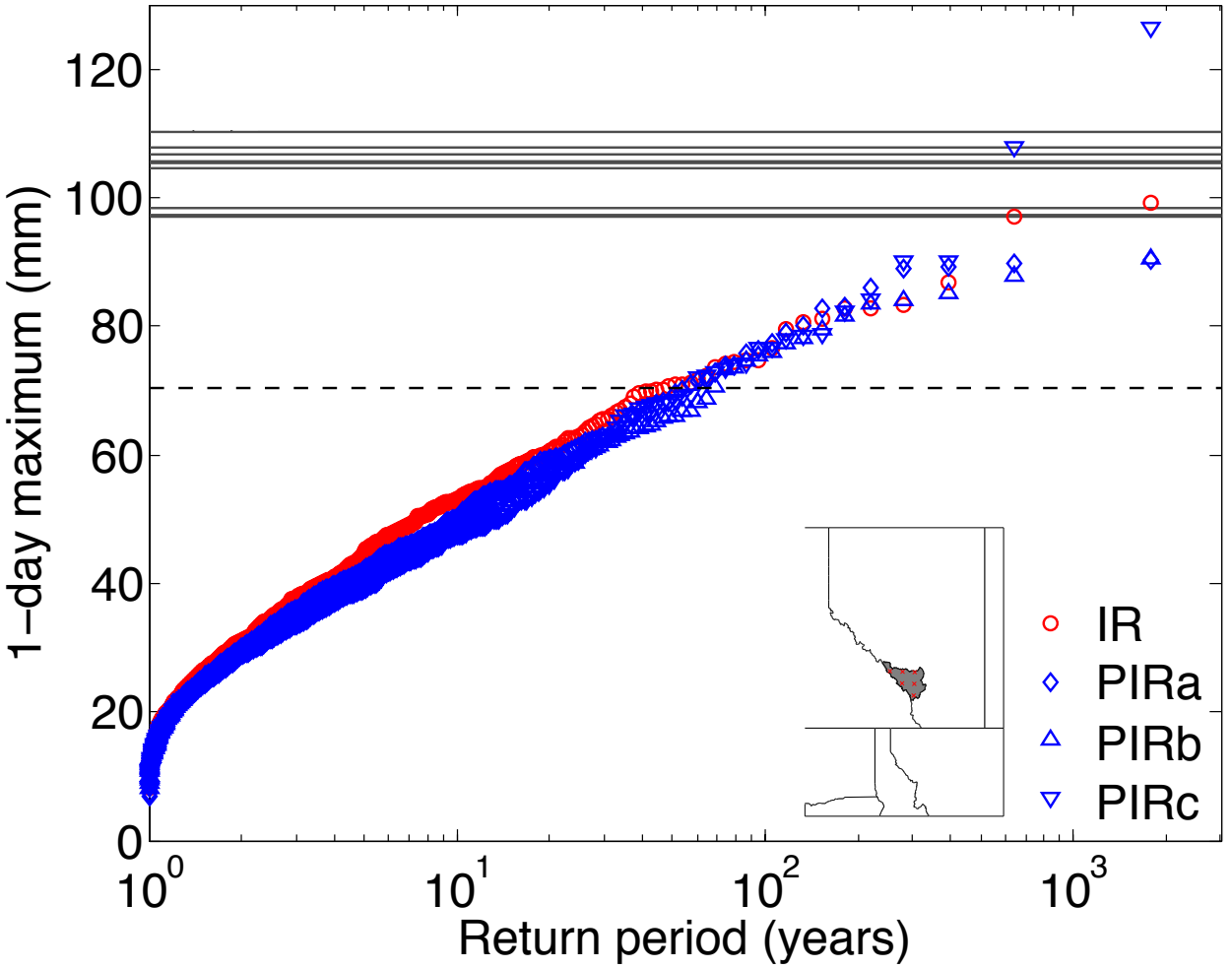
Calgary floods (Teufel et al, submitted)

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)



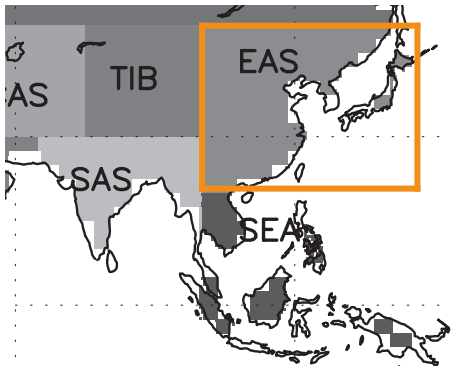

Arctic sea-ice extent extremes
★ This session, 2:45 pm
Photo: F. Zwiers (approach to Alert, Aug., 2009)

Some unresolved issues

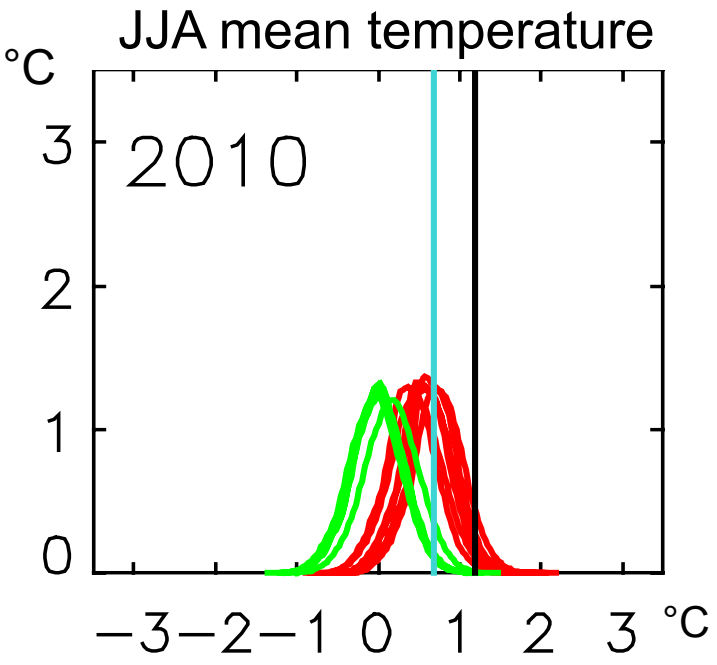
Photo: F. Zwiers (Lijiang, Snow Mountain)

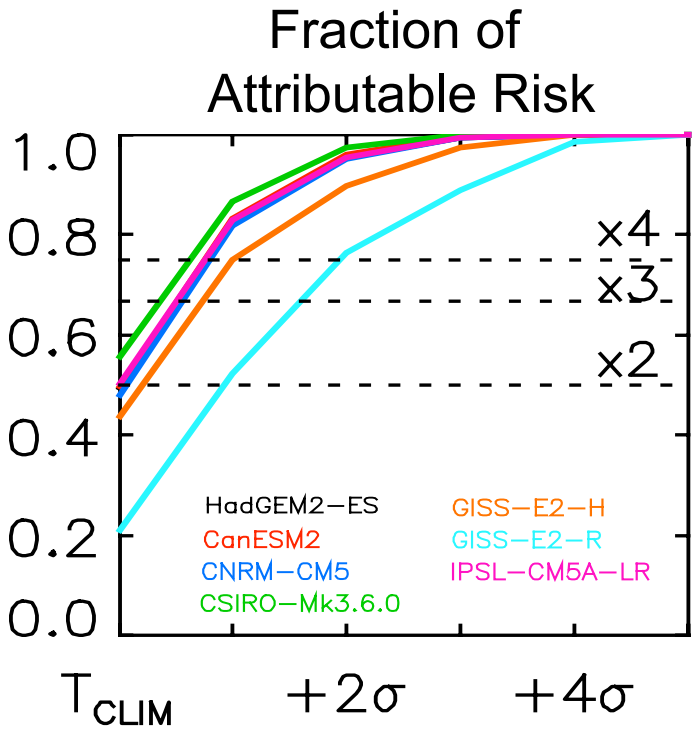
Retrospective vs prospective

- Most studies are prompted by specific events
- Alternatively, could study pre-defined events



Distribution of annualJJA temperature in the 2000's relative to 1961-90 in East Asia with and without ANT forcing





Christidis et al, 2014

Some unresolved issues

- Event characterization
  - Class vs individual, risk-based vs storyline
  - Individual is not synonymous with storyline
  - Data assimilation approach of Hannart et al (2016)
- Event definition
- Dependence on models
- Counterfactual state specification uncertainty when conditional approach is used
- Selection bias
  - Need objective event selection criteria
- Communications
  - At each stage media and response/recovery cycle


Questions?
Photo: F. Zwiers