Changing Extremes
Is it real, or just imagined?

Modifications des conditions climatiques extrêmes; sont-elles réelles, ou tout simplement imaginées?

CMOS Tour Speaker, 2016
conférencier itinerant SCMO - 2016

Francis Zwiers
PCIC, University of Victoria
Fredericton, 15 April 2016

Photo: F. Zwiers (Long Beach, Tofino)

University of Victoria | PACIFIC CLIMATE IMPACTS CONSORTIUM | CMOS-SCMO Canadian Meteorological and Oceanographic Society Société canadienne de météorologie et d'océanographie | Environment and Climate Change Canada

The context for this talk

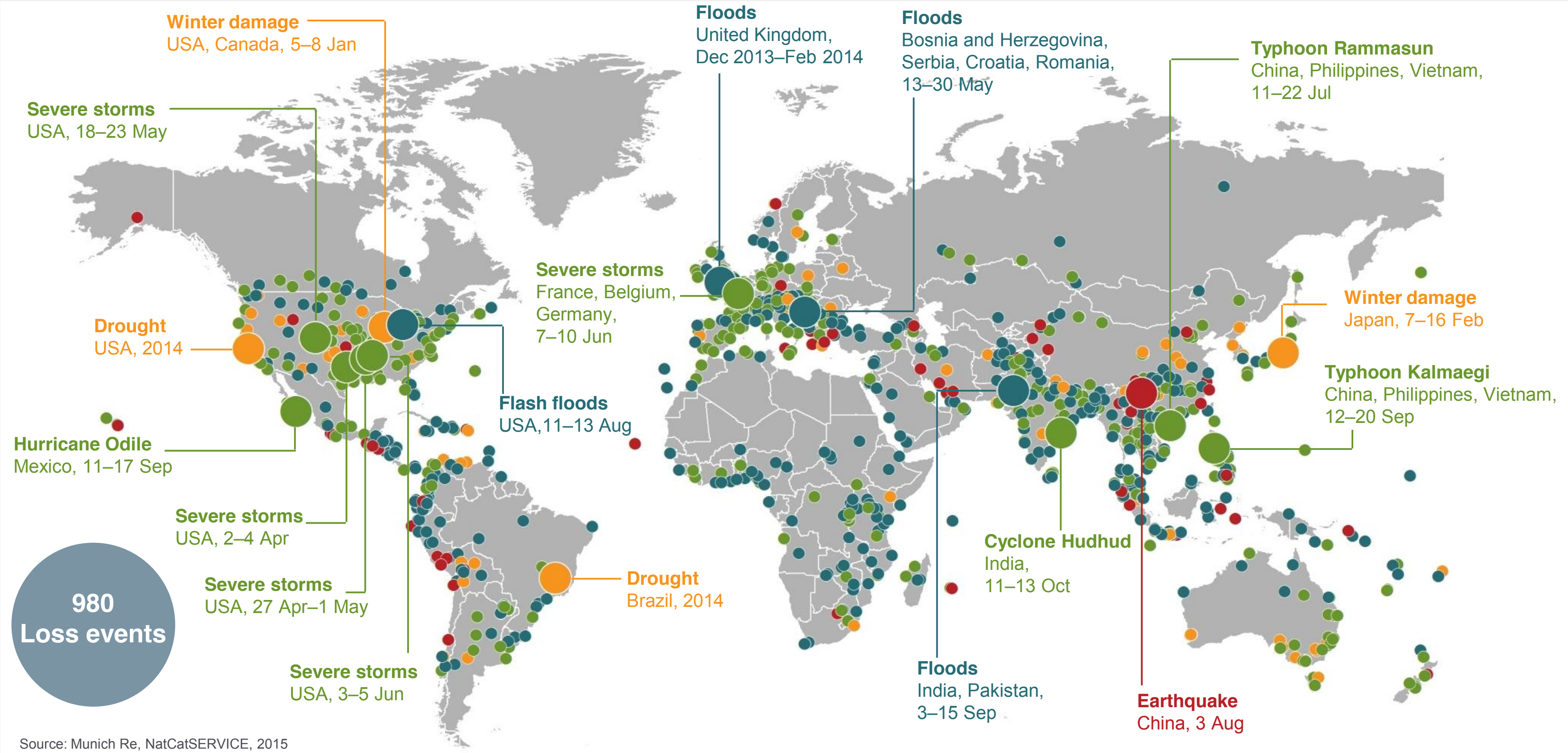
- Extensive reporting in the media on extreme events
  - Google News searches of Canadian new publications for the past year find
    - 55,300 items that refer to “extreme weather”
    - 17,500 items that refer to “drought”
    - 31,400 items that refer to “floods”
  - Similar searches for 2006 yield 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



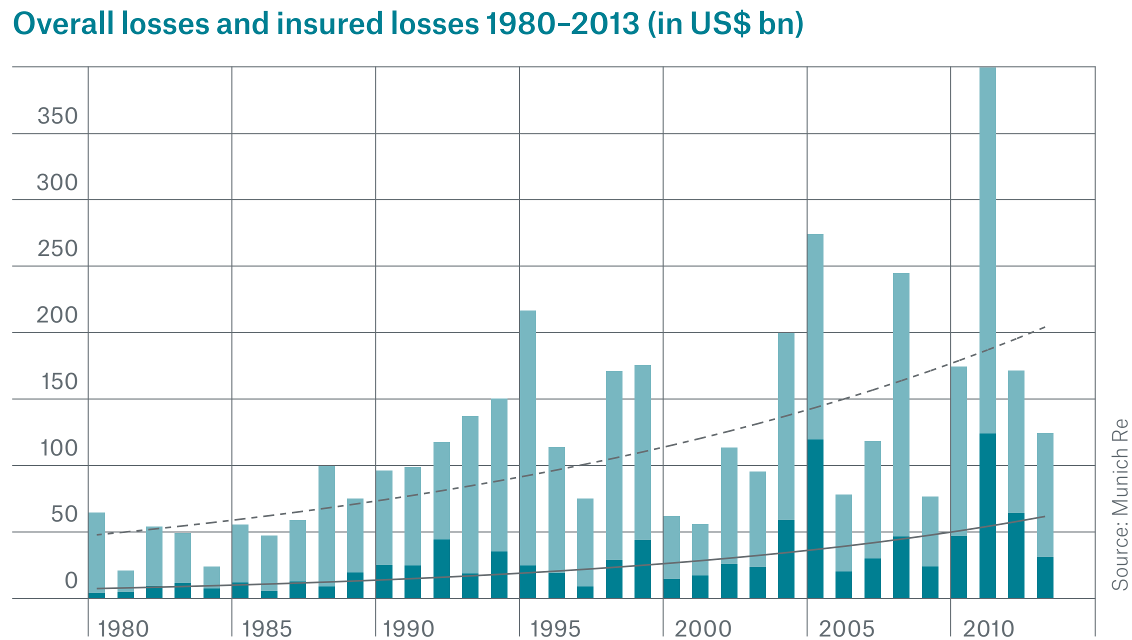
890 loss events in 2013

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

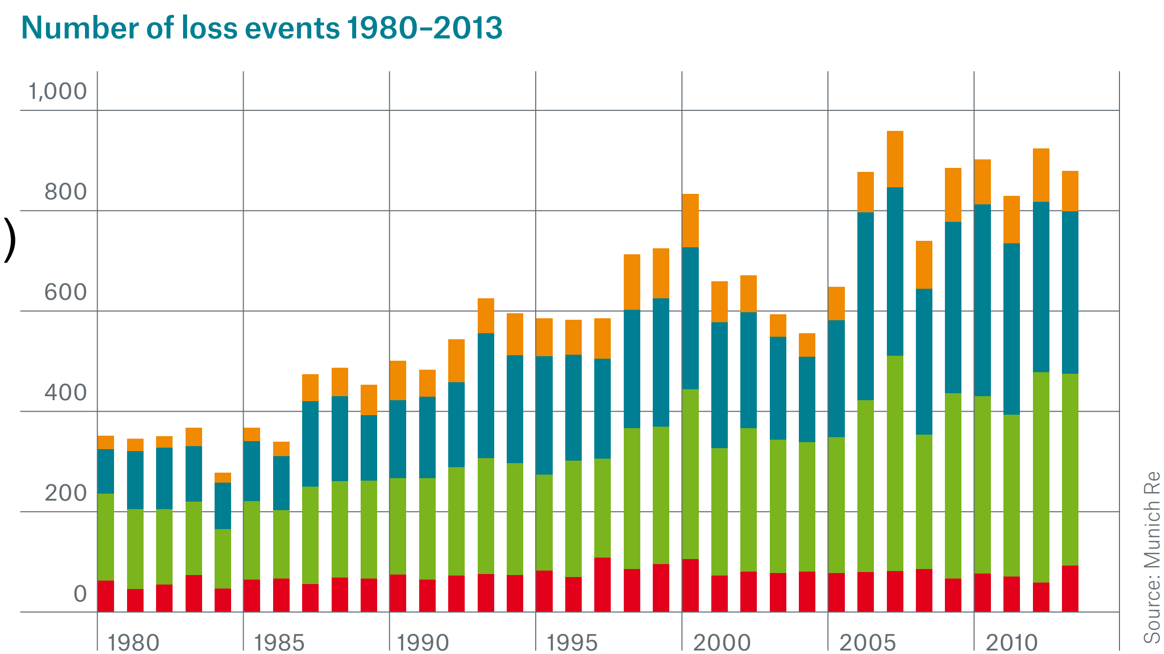
Billions of US$
Inflation adjusted

Overall
Insured



Number of events

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

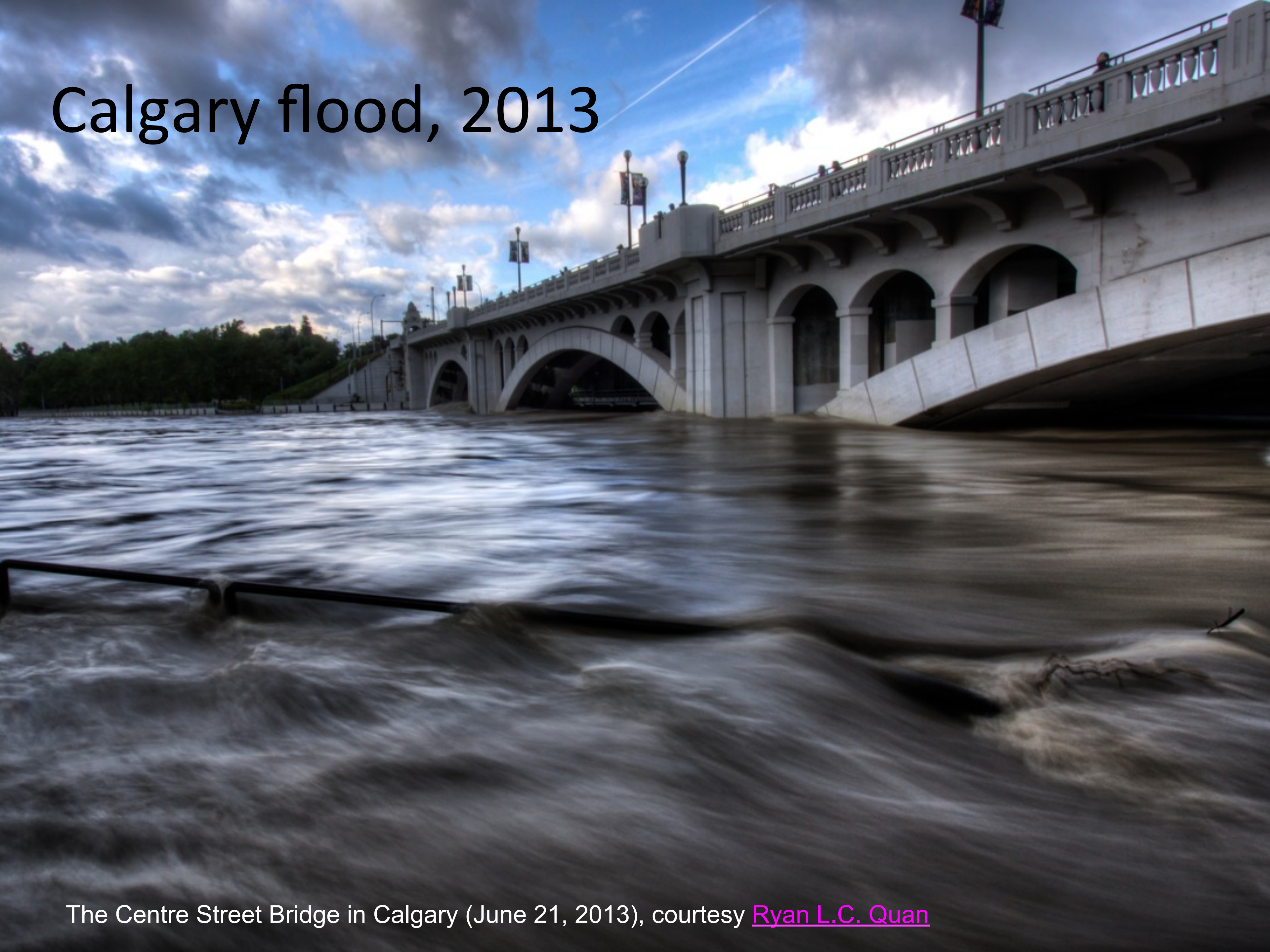


More context: the Calgary flood, 2013

- 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)

Hence the questions

… and partial answers

1. Are extreme events more frequent and intense than in the past and is human activity the driving force?
2. Did human influence on the climate cause the devastating event that has just occurred?

1. Review of research on long-term changes in extremes and whether human influence is a factor
2. Brief introduction to "event attribution"

Photo: F. Zwiers (Cordova Bay Sunrise)

Detection and attribution of Long Term Change in Extremes

Photo: F. Zwiers (Ring-Necked Duck, Victoria)

Some definitions

- *Detection* of change is the process of demonstrating that the climate or a system affected by the climate has changed in some defined statistical sense

- *Attribution* is the process of evaluating the relative contributions of multiple causal factors to a change or event with an assignment of statistical confidence

- Casual factors refer to *external influences*
  - Climate: *anthropogenic* and/or *natural*
  - Systems affect by climate: *climate change*

IPCC Good Practice Guidance Paper on Detection and Attribution, 2010

Methods

- Involve simple statistical models
- Complex implementation due to data volumes (which are both small and large)

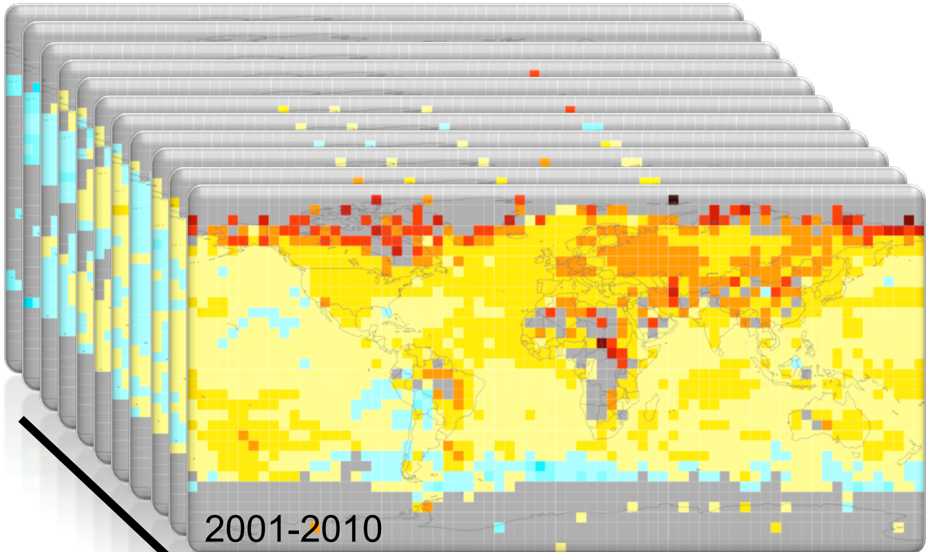
Usual assumptions

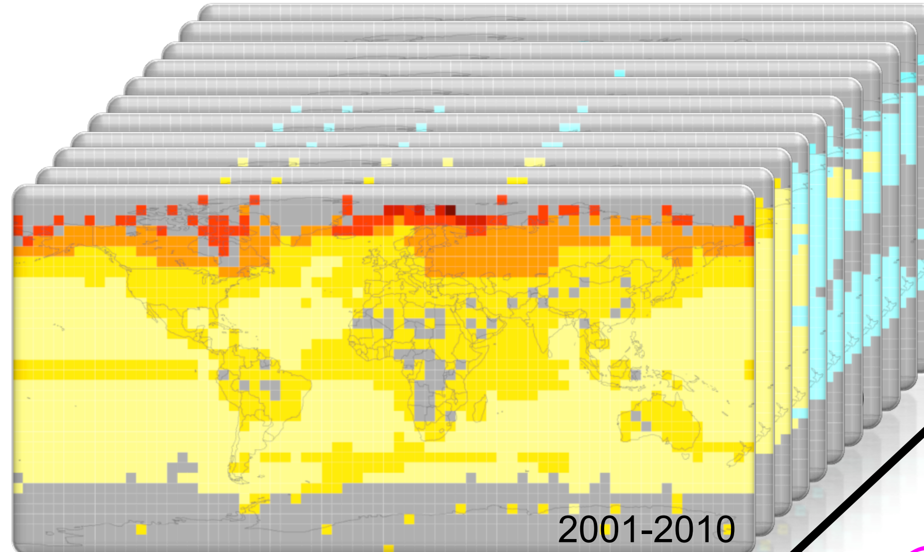
- Key forcings have been identified
- Signals and noise are additive
- Model simulation of large-scale forcing response patterns ok, but signal amplitude is uncertain

→ leads to a regression formulation

Observations (HadCRUT4)

Multi-model mean (ALL forcings)





11 decades (1901-1911 to 2001-2011)

$\mathbf{Y}$

$\mathbf{X}$

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

Evaluate scaling factors ← $\hat{\boldsymbol{\beta}}$

$\hat{\boldsymbol{\varepsilon}}$ → Evaluate residuals

After Weaver and Zwiers (2000)

That formulation has been evolving

$$\mathbf{Y} = \sum_{i=1}^{s} \boxed{\beta_i} \mathbf{X}_i + \boldsymbol{\varepsilon}$$

$$\mathbf{Y} = \mathbf{Y}^* + \boldsymbol{\varepsilon}_{\boldsymbol{y}}$$

$$\mathbf{X}_{\boldsymbol{i}} = \mathbf{X}_{\boldsymbol{i}}^* + \boldsymbol{\varepsilon}_{\boldsymbol{x}_{\boldsymbol{i}}}$$

$$\mathbf{Y}^* = \sum_{i=1}^{s} \boxed{\beta_i} \mathbf{X}_i^*$$

$$\mathbf{Y} = \mathbf{Y}^* + \boldsymbol{\varepsilon}_{\boldsymbol{y}}$$

$$\mathbf{X}_{\boldsymbol{i}} = \boxed{\mathbf{X}_{\boldsymbol{i}}^*} + \boldsymbol{\varepsilon}_{\boldsymbol{x}_{\boldsymbol{i}}}$$

$$\mathbf{Y}^* = \sum_{i=1}^{s} \mathbf{X}_i^*$$

- Hasselmann (1979, 1993)
- Hegerl et al (1996, 1997)
- Tett et al (1999)
- Allan and Stott (2003)
- Huntingford et al (2006)
- Hegerl and Zwiers (2011)
- Ribes et al (2013a, 2013b)
- Hannart et al (2014)
- Hannart (2015, accepted)

- Ribes et al (in review)

Adaptation to extremes

- Not completely straightforward
- Relatively easy for indices of moderate extremes (such as frequency indices)
- Best to use extreme value theory for rarer extremes (e.g., study of change in the annual maximum or long period return levels)
- Methods for extremes are actively evolving (taking dependence into account is a key issue)
- For temperature extremes
  - Large body of literature, high confidence
- For precipitation extremes
  - Emerging evidence, medium or lower confidence

Temperature extremes

Photo: F. Zwiers (Lanzhou)

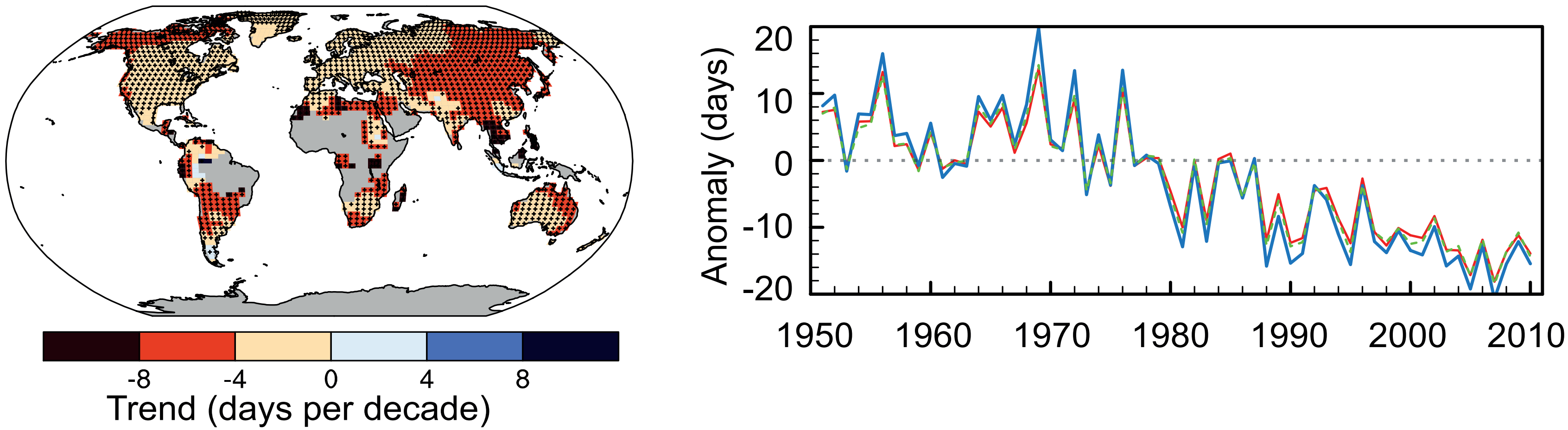
See WCRP summer school on extremes, ICTP, July, 2014

Temperature extremes

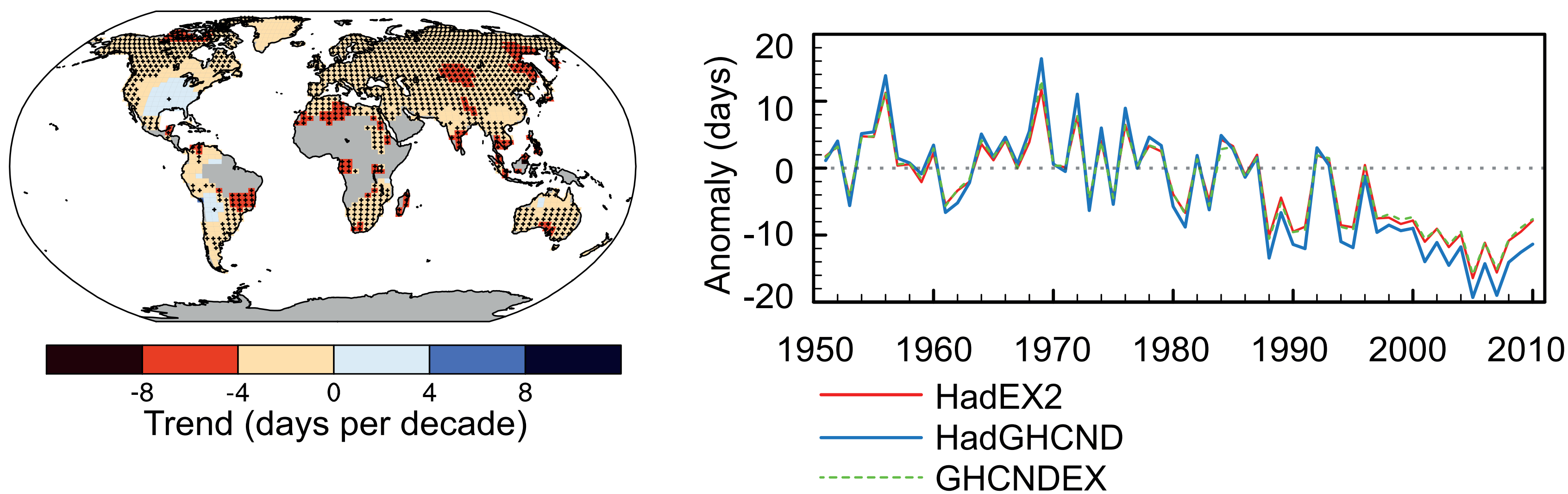
- Extremes warmed during the "global warming hiatus"
  - Seneviratne et al, 2014; Sillmann et al, 2014
- D&A studies looking at either frequency of events or event intensity consistently find that human influence has
  - Increased the frequency of warm extremes,
  - Intensified warm extremes,
  - Reduced the frequency of cold extremes, and
  - Weakened cold extremes
- Supported by high confidence in attribution of change in mean temperature

Change in Frequency of "Extremes"

(a) Cold Nights (TN10p)



(b) Cold Days (TX10p)

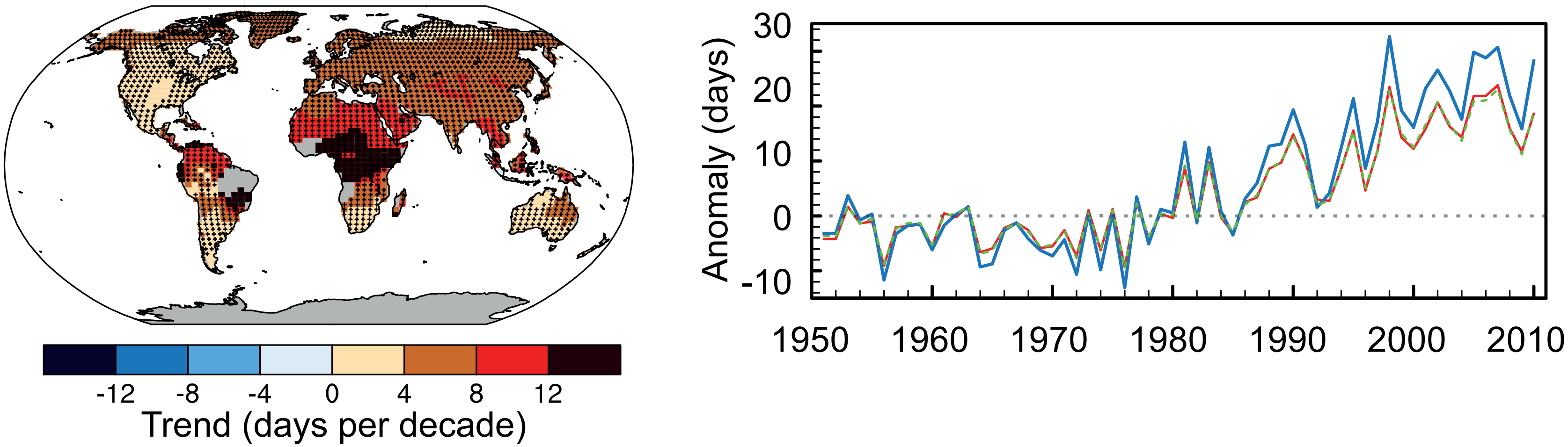


+ indicates the trend is statistically significant (at the 10% level)

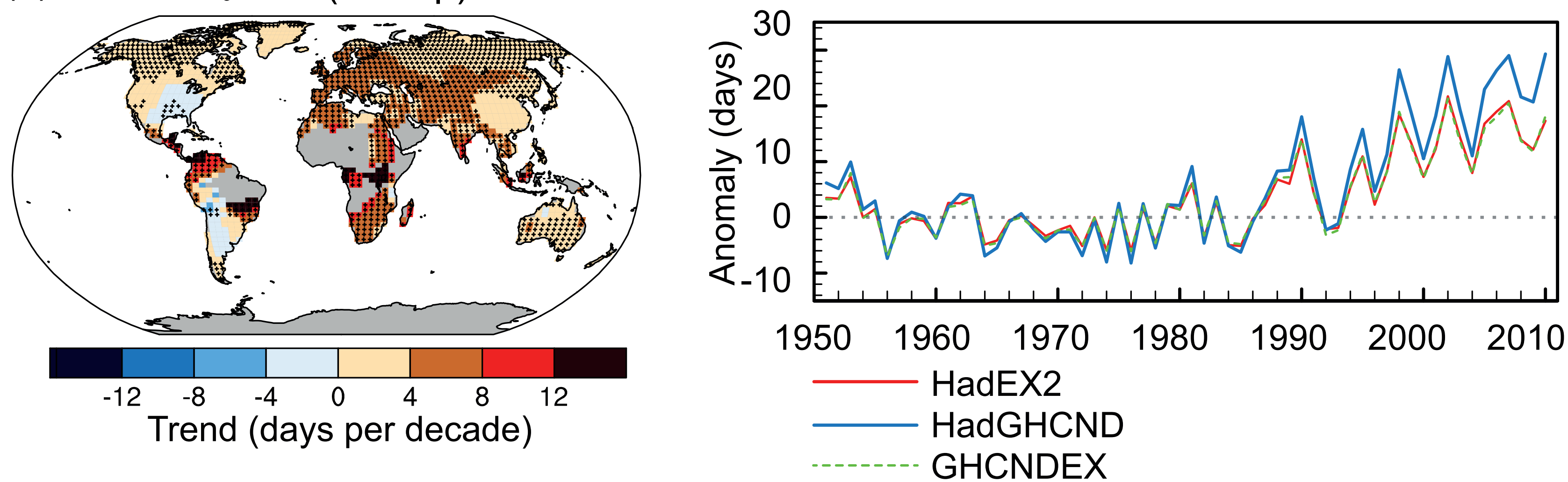
Fig. 2.32, IPCC AR5 WG1, Chapter 2 (See also Donat et al, 2013)

Change in Frequency of “Extremes”

(c) Warm Nights (TN90p)



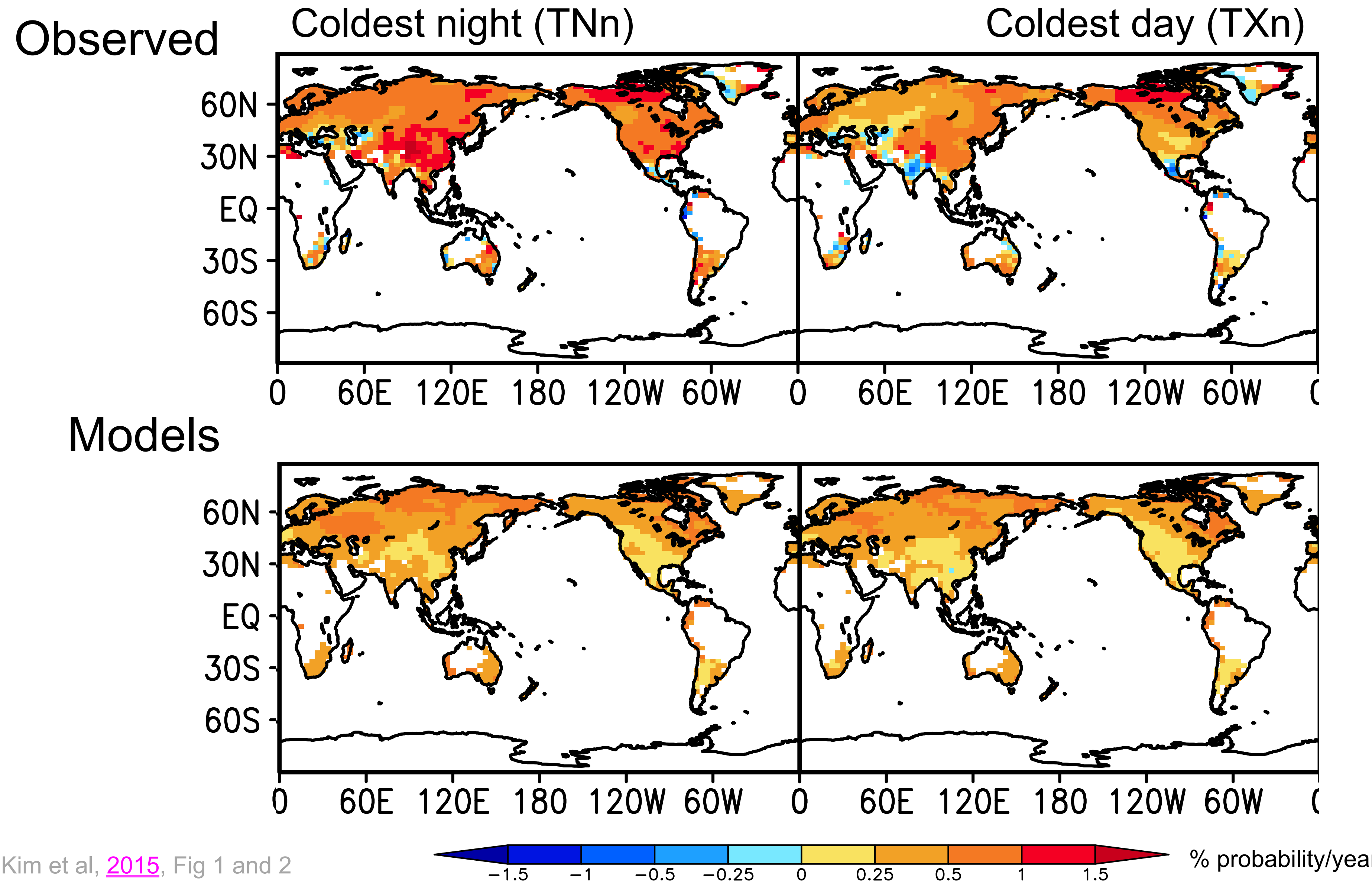
(d) Warm Days (TX90p)



+ indicates the trend is statistically significant (at the 10% level)

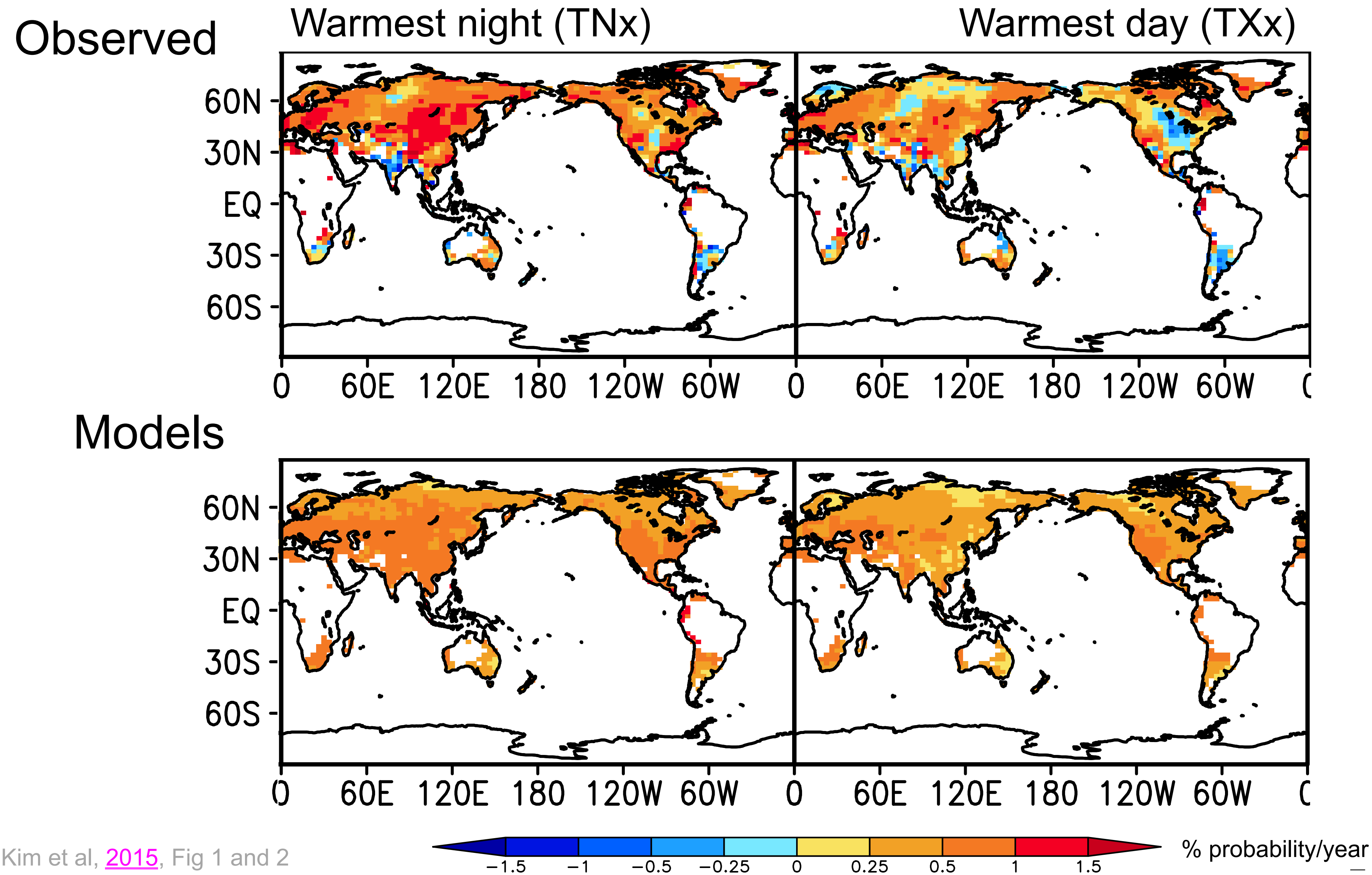
Fig. 2.32, IPCC AR5 WG1, Chapter 2 (See also Donat et al, 2013)

Change in magnitude of annual extremes



Kim et al, [2015](), Fig 1 and 2

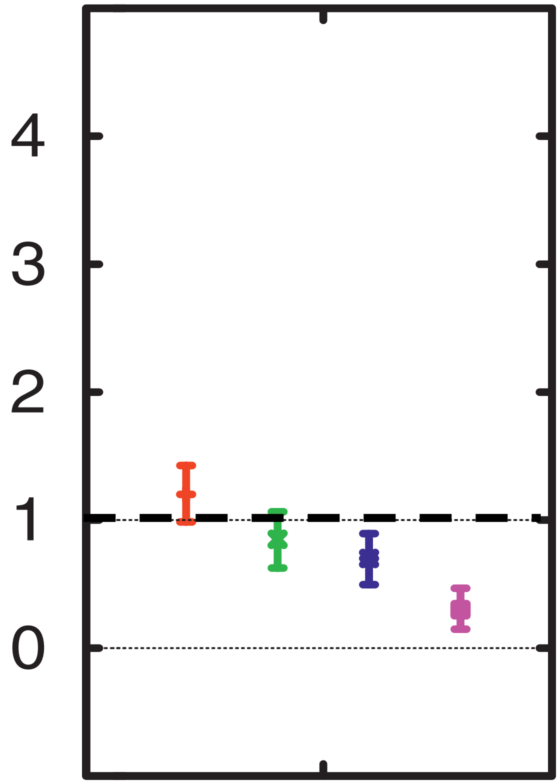
Change in magnitude of annual extremes



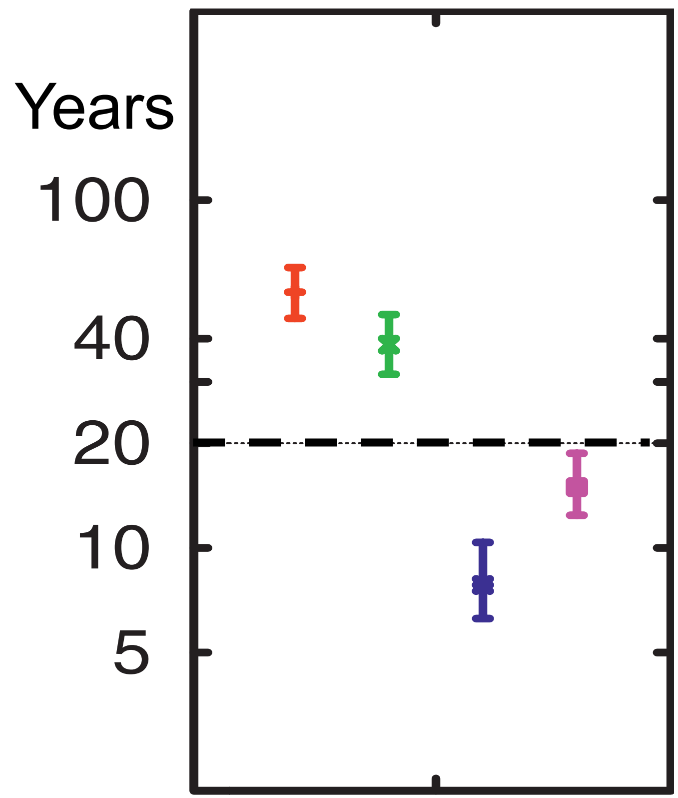
Kim et al, 2015, Fig 1 and 2

Detection and attribution results

Scaling factors and uncertainty ranges



Change in waiting times for 20-year events (1990's vs 1960's)



TNn - Coldest night annually

TXn - Coldest day annually

TNx - Warmest night annually

TXx - Warmest day annually

Zwiers, et al., 2011, *J Climate*

Limitations

- Observational data
  - Need long homogeneous records of daily data
  - Geographical coverage
  - Traceability, updatability of indices
  - Order of operations
- Process understanding and representation in models, such as
  - Coupled land-atmosphere feedback processes
  - Representation of blocking in models

Precipitation extremes

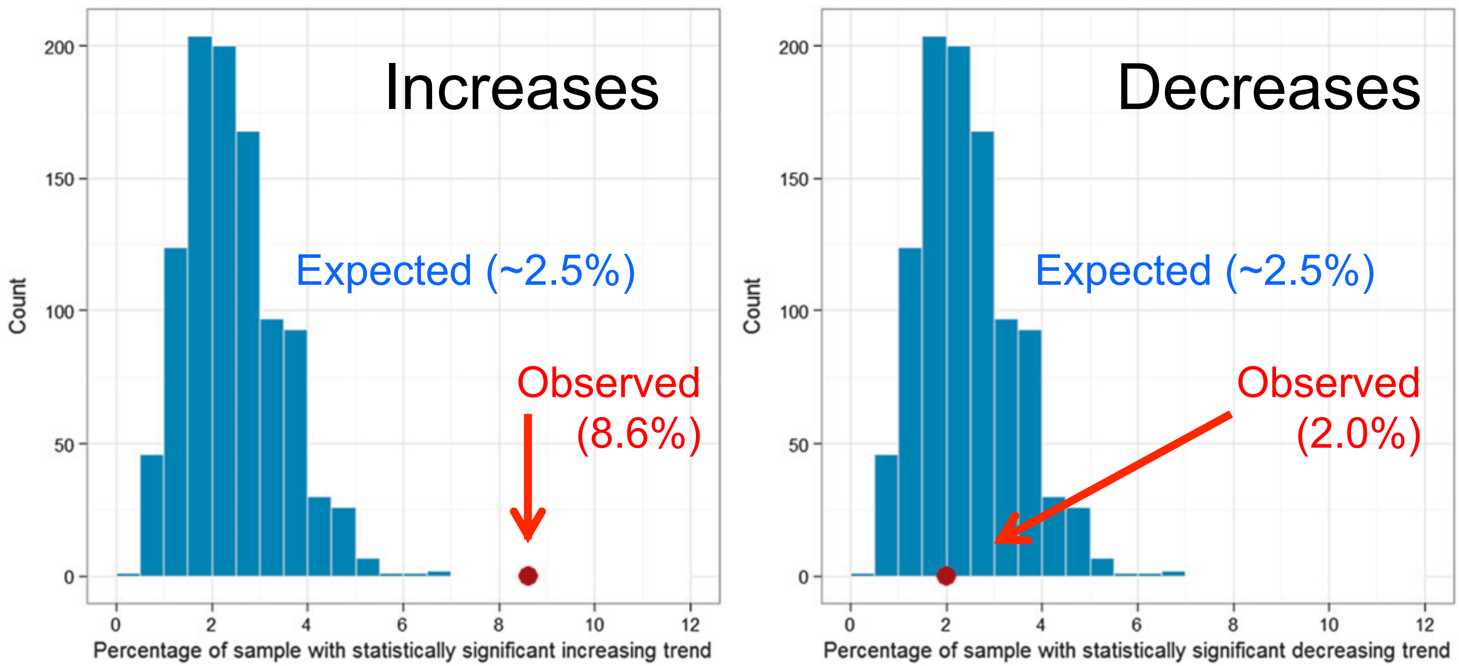
Photo: F. Zwiers (Longji)

Precipitation extremes

- Observational studies suggest intensification is occurring, although local detection is very hard (eg., Westra et al, 2013)
- Expectation of intensification is supported by
  - attribution of warming (eg, Bindoff et al, 2013),
  - attribution of observed increase in atmospheric water vapour content (eg, Santer et al, 2007), and
  - D&A studies of change in mean precipitation (eg., Zhang et al., 2007; Noake et al., 2012; Polson et al, 2013; Marvel and Bonfils, 2013; Wu et al, 2013) and surface salinity (eg., Pierce et al., 2012).
- But very few D&A studies yet on extreme precipitation (eg, Min et al 2011, Zhang et al, 2013)

Stations with significant trends in annual maximum 1-day precipitation (1900-2009)

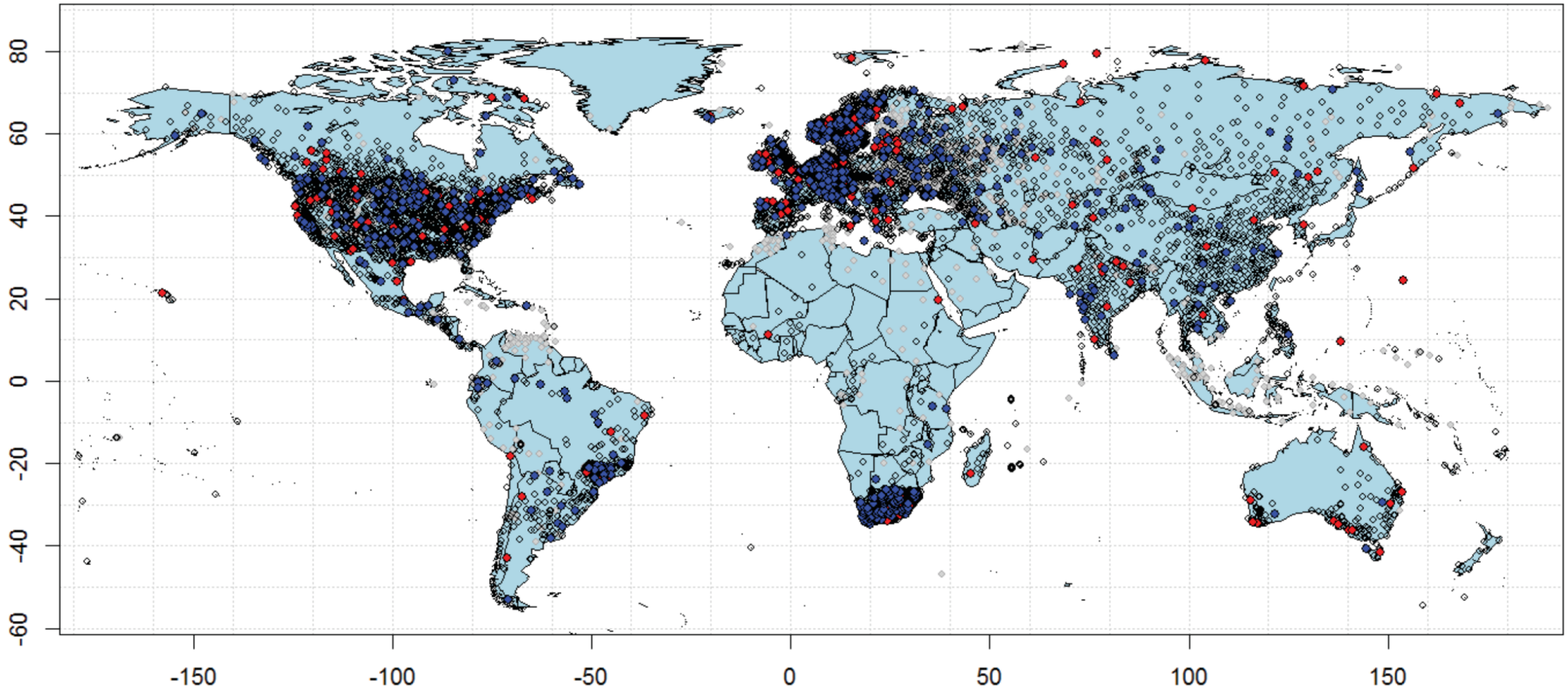
Based on 8376 stations with 30-years or more data



Westra et al 2013, Fig. 3

- Tests conducted at the 5% level (two sided)
- There are more statistically significant increasing trends than expected by random chance (blue bootstrap distributions for rejection rate).

Is there an association between annual maximum 1-day precipitation and global mean temperature?



- 8376 stations with > 30 yrs data, median length 53 yrs
- Significant positive (10.0% of stations, expect 2.5%)
- Significant negative (2.2% of stations, expect 2.5%)
- Estimate of mean sensitivity over land is ~7%/K

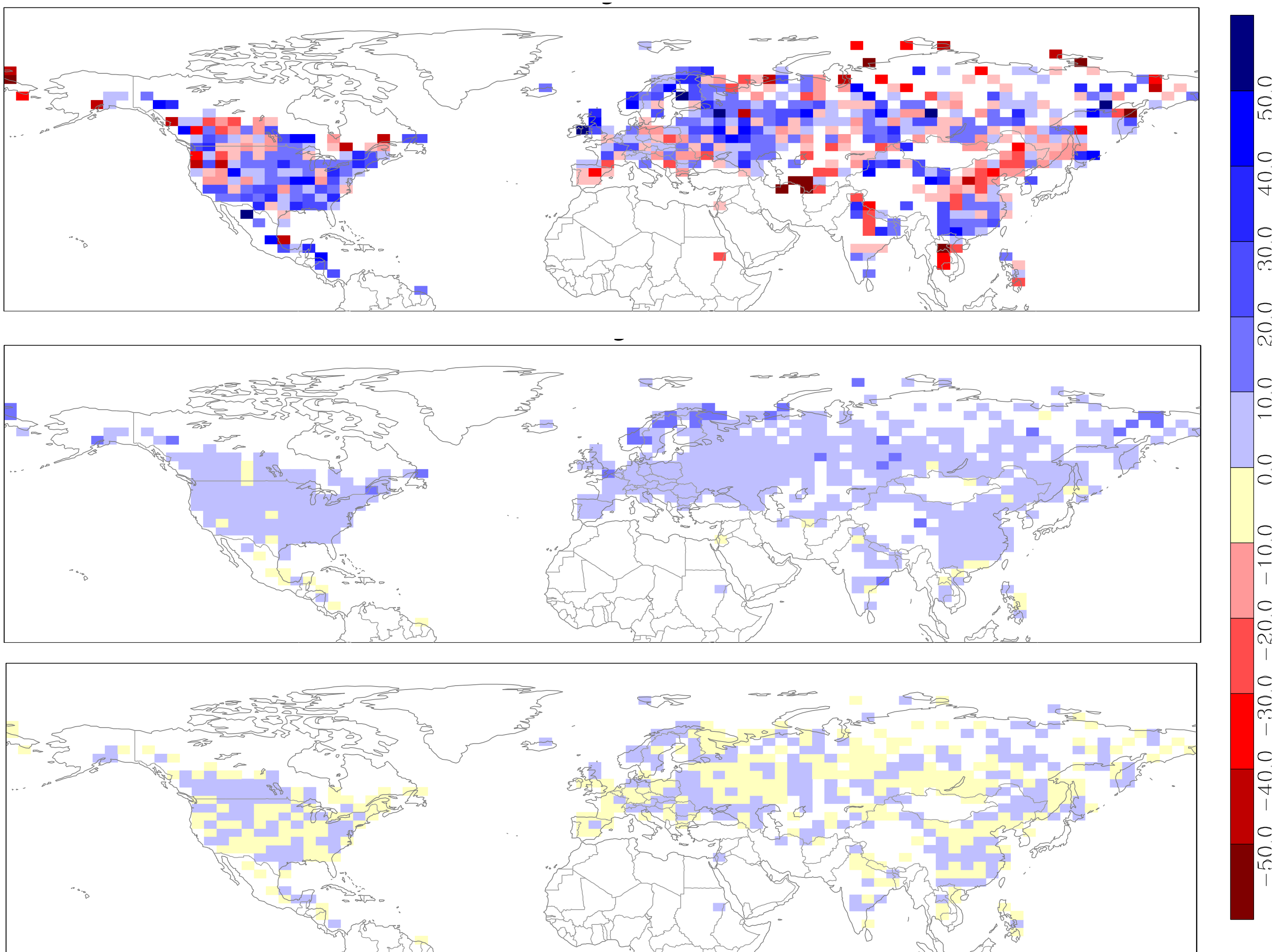
Westra et al (2013, Fig. 5)

Trends in Annual maximum 1-day Precipitation Extremes (1951-2005)

Observed

Models
(ALL forcings)

Models
(NAT forcings)



Zhang et al., [2013](#) (see also Min et al [2011](#))

Detection and attribution results

We can detect the human influence on precipitation extremes using formal detection and attribution methods:

- Climate models that include anthropogenic external forcing intensify precipitation similarly to observed
- Climate models with only natural external forcing fail to intensify precipitation

Attributed intensification:

- 3.3% increase over 55 years due to human effects
  - uncertainty range [1.1 – 5.8]%
- 5.2% increase per degree of warming
  - uncertainty range [1.3 – 9.3]%

Estimated waiting time for 1950's 20-year event:
~15-yr in the early 2000's

Zhang et al., 2013 (see also Min et al 2011)

Limitations

- Data (availability, spatial coverage, record length, quality, observational uncertainty between dataset)
- Confidence in models (e.g., circulation impacts, topography, parameterization of sub-grid scale processes)
- Low signal-to-noise ratio with possible offsetting influences from GHGs and aerosols (different for means than for extremes)
- Spatial and temporal scaling
- Characterization of spatial dependence

Terrestrial hydrological cycle

Photo: F. Zwiers (Canmore, AB)

Hydrologic extremes

- Very limited literature on D&A of mean change in hydrologic quantities
  - Barnett et al, 2008 (Western US)
  - Najafi et al, 2016 (part of BC; see AGU poster H43E-1551)
  - Both detect thermodynamic impact on snowpack and streamflow
- Strong need for study of extremes given impacts
- Limitations include
  - Data (very often inhomogenious due to river regulation)
  - Complex spatial variation in hydrologic sensitivity (Grieve et al, 2014; Kumar et al, 2015) which complicates robust detection of responses (Kumar et al, AGU poster GC53B-1199)
  - Complexity and uncertainty in the modelling chain that ultimately allows an assessment of change in stream flow, etc
  - Confounding effects

Storms

Storms

- Some evidence of attributable long-term change in surface pressure distribution (indicative of long-term circulation change)
- Few, if any, D&A studies of long-term change in position of extratropical storm tracks, storm frequency or intensity
- Limitations include
  - Data (length of record, homogeneity)
  - Models (eg, broad range of frequency biases in the occurrence of explosive cyclones in CMIP5 class models – Seiler and Zwiers, 2015a, 2015b) – and concern about whether resolution in climate models is sufficient to model storm details relevant to impacts correctly

Answers to question 1

Are extreme events more frequent and intense than in the past and is human activity the driving force?

- IPCC Assessment Reports a good source
- *Very likely* in the case of temperature extremes
- Lower confidence for virtually everything else

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

Answers to question 1

Phenomenon	Assessment of observed change	Human contribution?
Warmer/fewer cold days, nights	*Very likely* {2.6} >90, >90, >90	***Very likely*** {10.6} >99, >66, >66
Warmer/more hot days, nights	*Very likely* {2.6} >90, >90, >90	***Very likely*** {10.6} >99, >66, >66
More frequent/ longer hot spells and heat waves	***Medium confidence*** on a global scale *Likely* in large parts of Europe, Asia and Australia {2.6} MC, MC, >66	***Likely***[a] {10.6} >66, NA, >50
More frequent/ intense heavy precipitation	*Likely* more land areas with increases than decreases[c] {2.6} >66, >66, >66	***Medium confidence*** {7.6, 10.6} MC, MC, >50
More intense/ longer droughts	***Low confidence*** on a global scale *Likely* changes in some regions[d] {2.6} LC, MC, >66	***Low confidence*** {10.6} LC, MC, >50
Increased intense tropical cyclone activity	***Low confidence*** in long term (centennial) changes *Virtually certain* in North Atlantic since 1970 {2.6} LC, LC, >66	***Low confidence***[i] {10.6} LC, LC, >50
More frequent/higher extreme sea levels	*Likely* (since 1970) {3.7} >66, >66, >66	***Likely***[k] {3.7} >66, >66, >50

Event attribution

Photo: F. Zwiers **(Jordan River kite day)**

Event Attribution …

- Is what reporters and the public ask us to do immediately after (or during) an event
- The usual question (did climate change cause this) 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

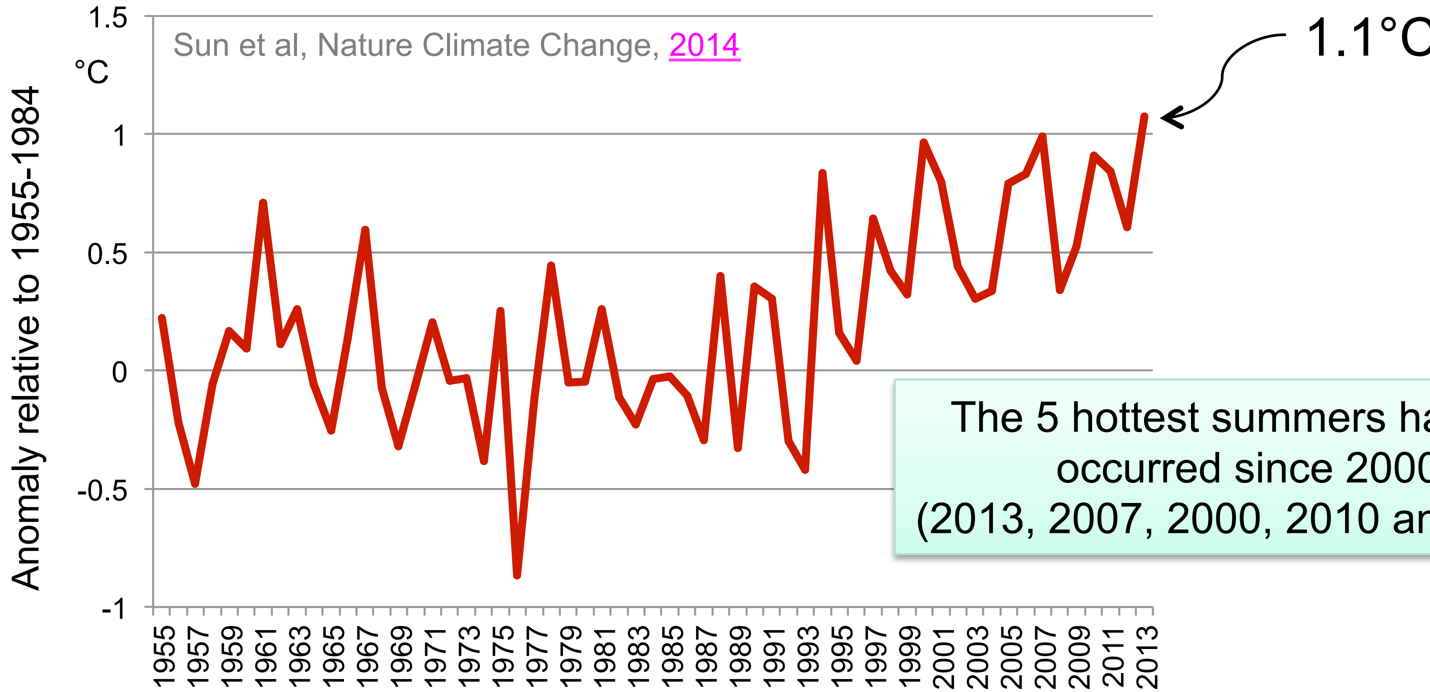
Event attribution

- 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 (2016) – *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)

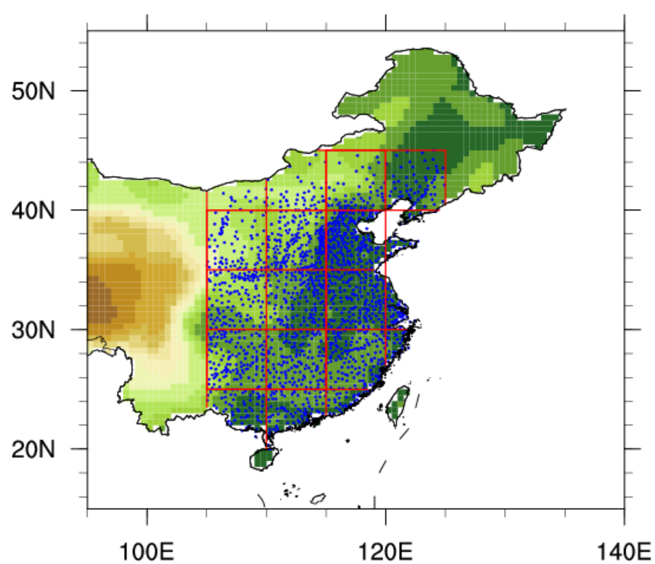
China’s Summer of 2013

Photo: F. Zwiers (Yangtze River)

JJA mean temperature in Eastern China



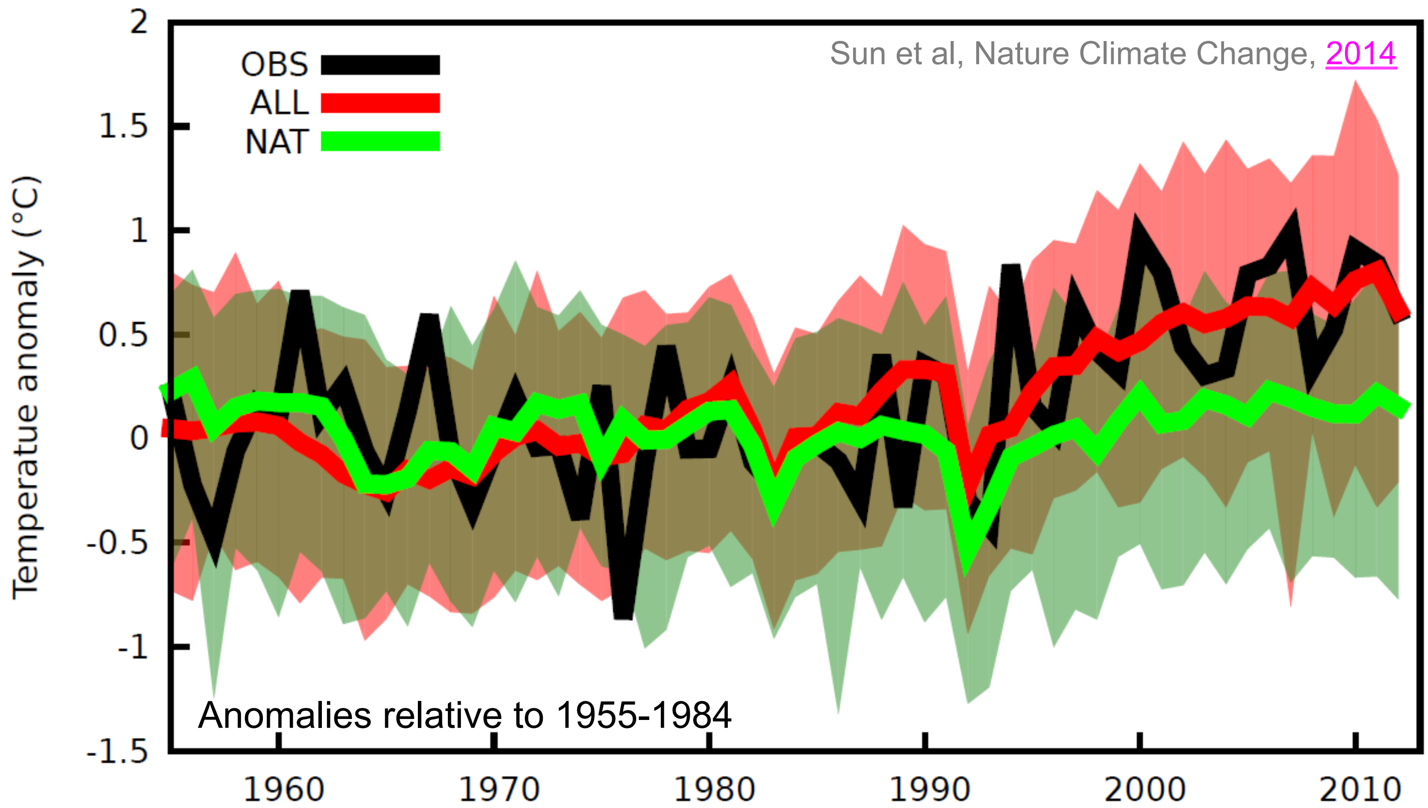
The 5 hottest summers have all occurred since 2000 (2013, 2007, 2000, 2010 and 2011)



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)

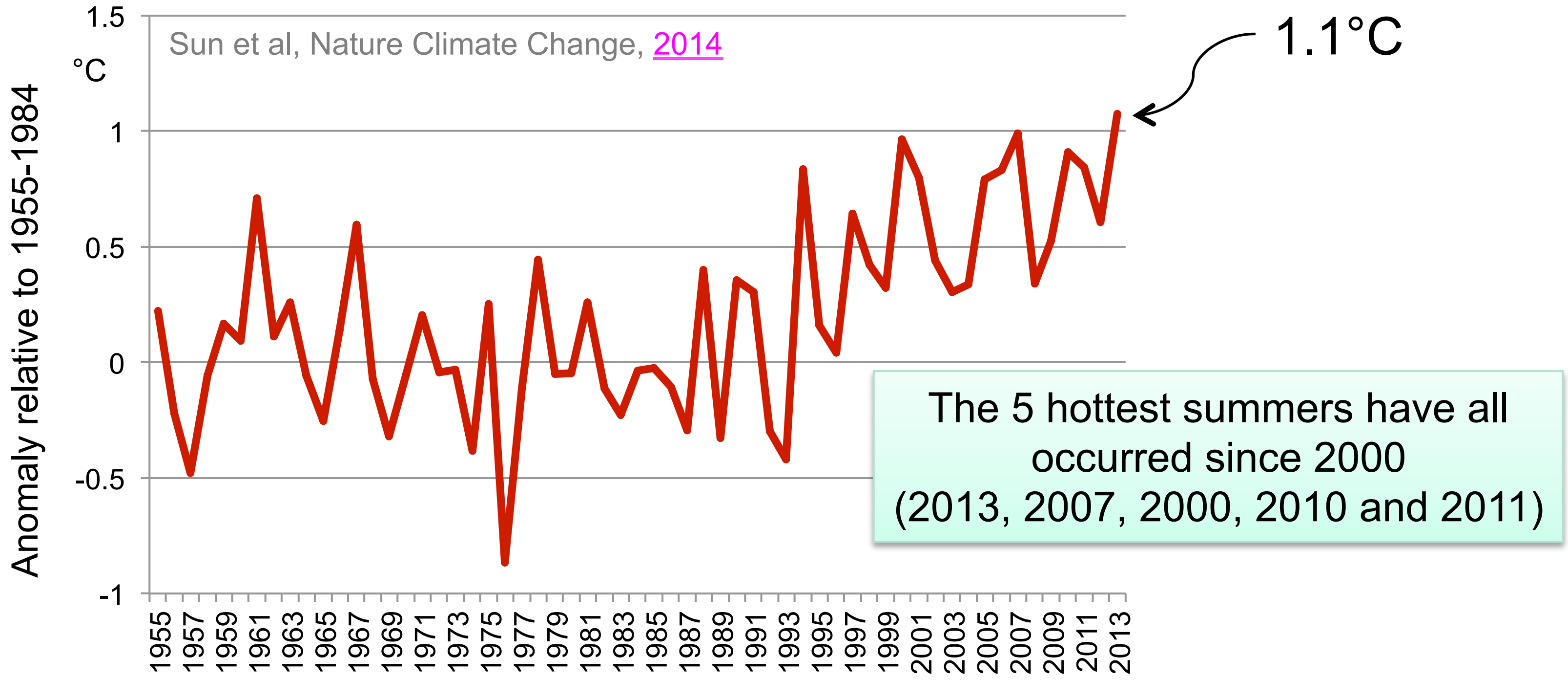


125 (26)

49 (12)

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

JJA mean temperature in Eastern China



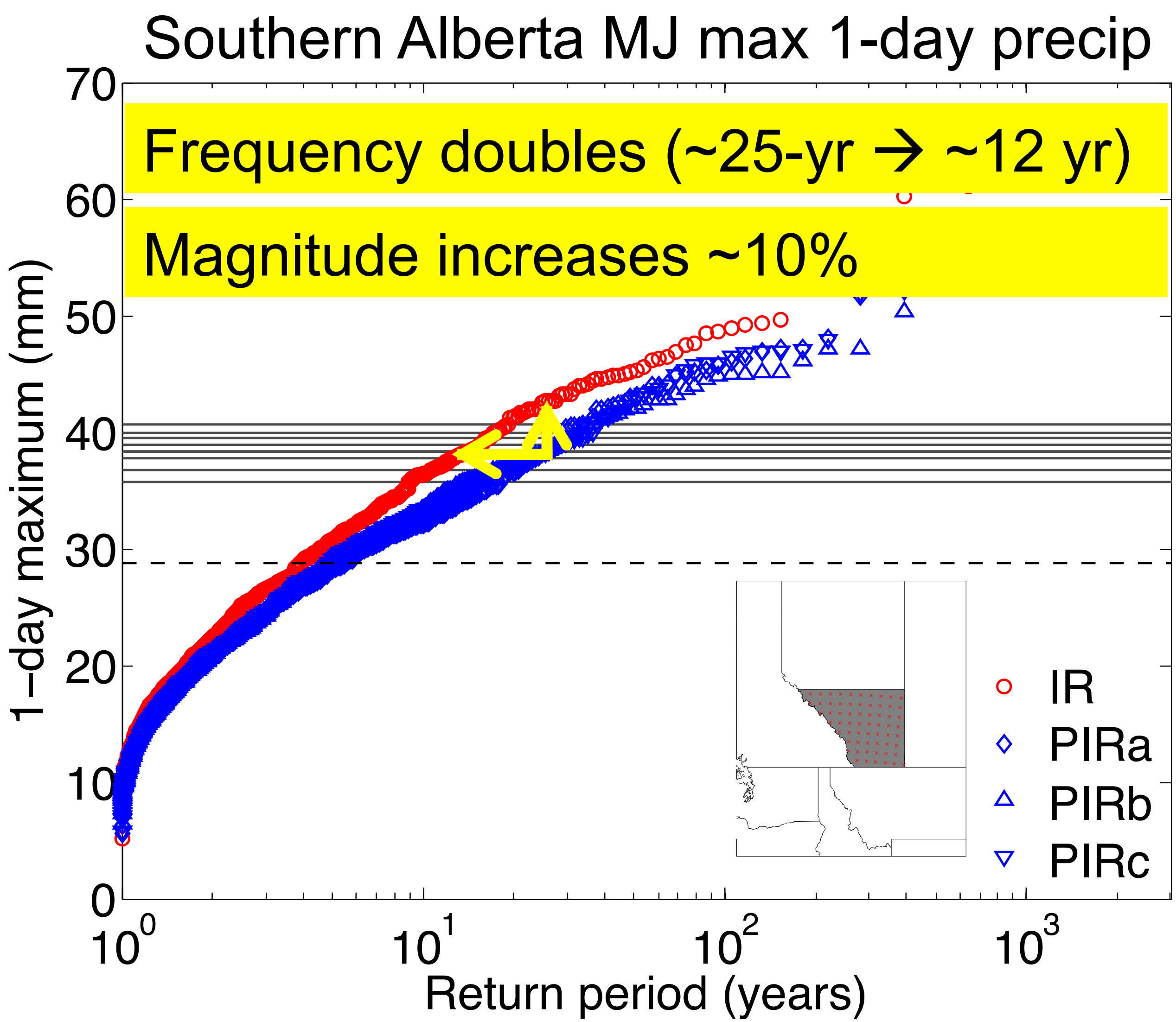
- How rare was this event?
  - once in 270-years in control simulations
  - once in 29-years in “reconstructed” observations
  - once in 4.3 years relative to the climate of 2013
- Fraction of Attributable Risk in 2013: $(p_1 – p_0)/p_1 \approx 0.984$

Calgary flood, 2013

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

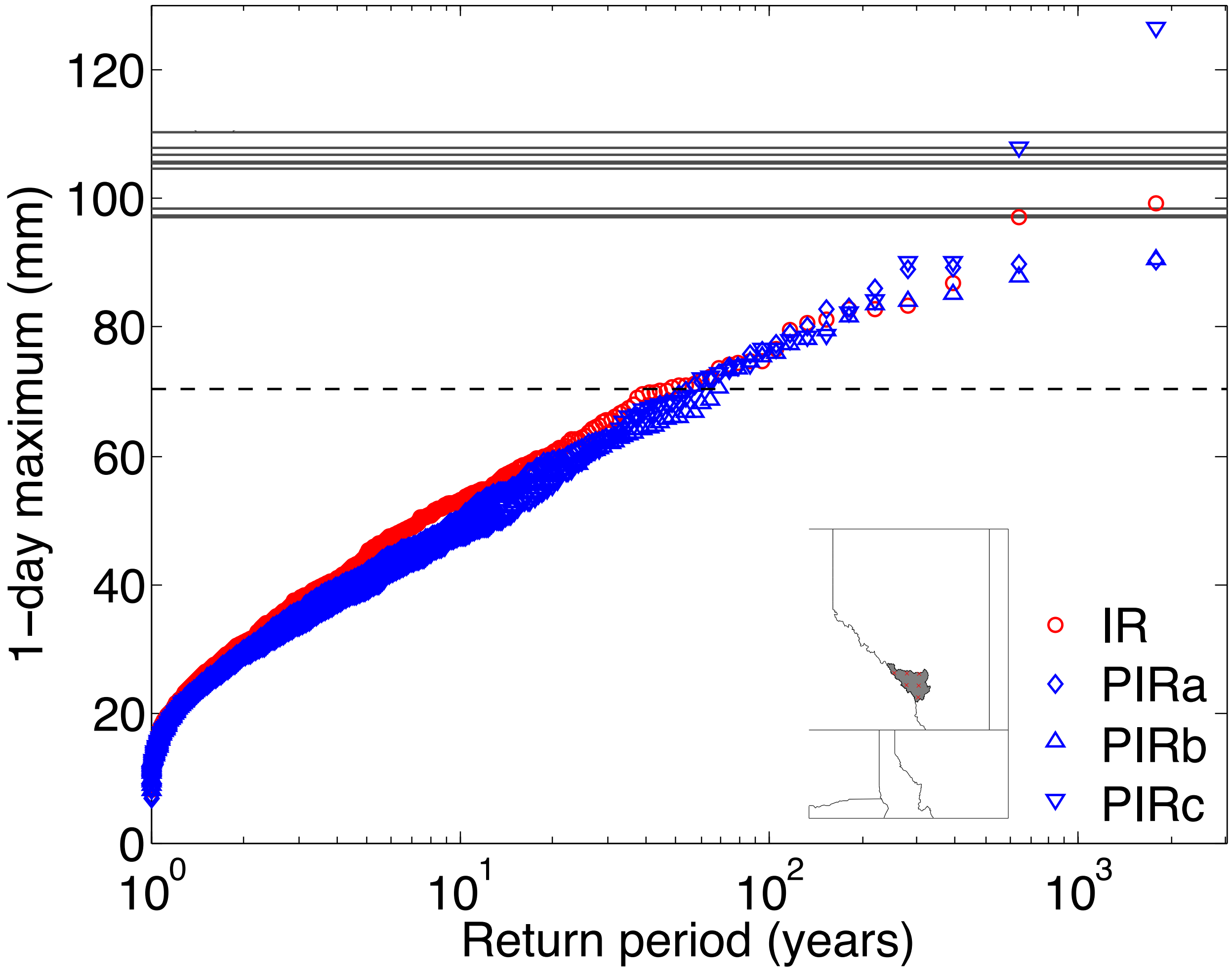
Calgary floods (Teufel et al, submitted)

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)



Fraction of Attributable Risk

Photo: F. Zwiers (Emlyn Cove)

Fraction of Attributable Risk

- Many event attribution studies focus on the "Fraction of Attributable Risk"

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

$p_1 =$ Prob of event in factual world

$p_0 =$ Prob of event in "counterfactual" world

- Use observations to define the event
- Use models to estimate the probabilities
- Many studies "condition" on climate state
- For the Chinese hot summer event, FAR ≈ 0.98
- For southern Alberta precip, FAR ≈ 0.50

Answers to question 2

Did human influence on the climate cause the devastating event that has just occurred?

- Not quite the right question
- Can sometimes say something about frequency or intensity
- Still a developing science

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

Conclusions

Photo: F. Zwiers (Ucluelet)

Conclusions

- Understanding of the impact of anthropogenic forcing on extremes remains limited
  - Relatively high confidence for temperature extremes
  - Some confidence in precipitation extremes
  - Can say relatively little about storms, droughts, floods
- Often very limited by data (models and methods can be improved; historical data is much harder)
- Need further methodological development and improved process understanding
- Event attribution is increasingly undertaken
  - Still much work to do to develop methods and capabilities, understand implications of framing choices, and develop objective evaluation techniques

Questions?

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Photo: F. Zwiers (Emlun Cove sunrise)