An introduction to event attribution

Changing weather extremes
Who or what is to blame?

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WCRP Institute of Advanced Studies in Climate Extremes and Risk Management, NUIST, 29 October 2019

Outline

- Long term trends in extremes
- Event attribution
- Examples
  - Calgary flood, 2013
  - Fort McMurray wildfire, 2016
  - China’s hot summer of 2013
  - Heat stress risk in eastern and western China
- Discussion and Conclusions

Photo: F. Zwiers (Smoke filled sunset, Aug, 2014, Winthrop, WA)

Long term trends in extremes

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

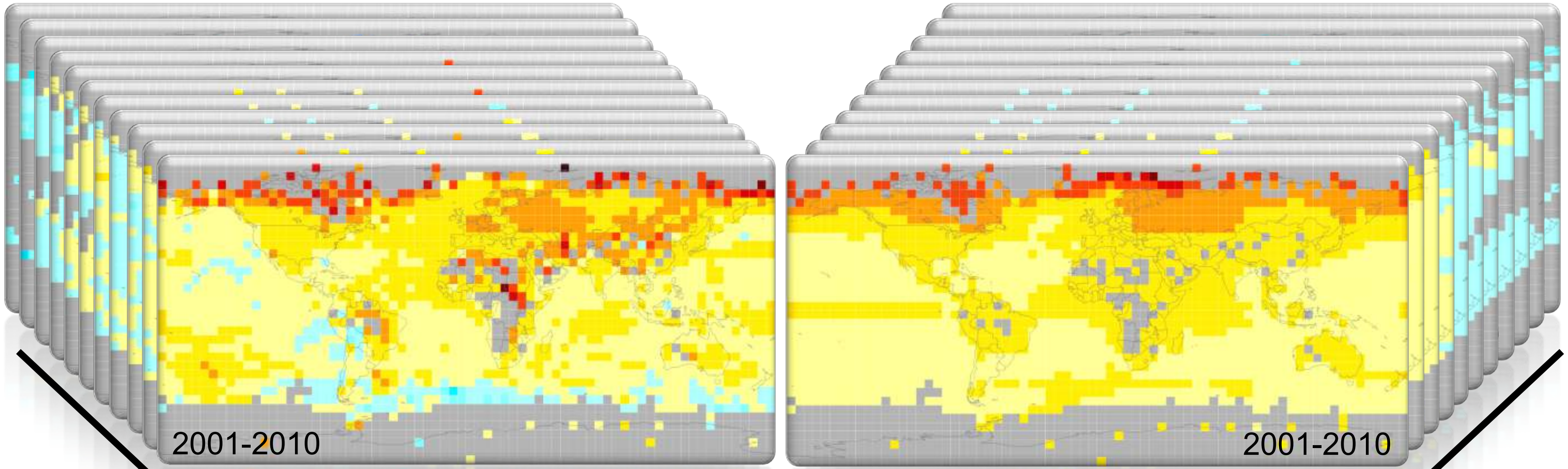
General idea

- Postulate a set of change “signals” that might be present in observations
- Look for those signals using a detection and attribution formalism (basically a regression)
- Eliminate other causes

Usual assumptions

- Key external drivers of climate change are known
- Signals and noise are additive
- Model simulated signal patterns ok, magnitude less certain

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 $\leftarrow \widehat{\boldsymbol{\beta}}$

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

After Weaver and Zwiers (2000)

Temperature extremes

Photo: F. Zwiers (Lanzhou)

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

Temperature extremes

- Studies looking at long term changes find
  - More frequent and more intense warm extremes
  - Less frequent and less intense cold extremes
- Changes are found to be largely due to human influence (i.e., greenhouse gas increases)
- Supported by very high confidence in our understanding of the change in mean temperatures
- Extremes warmed during the “global warming hiatus”
  - Seneviratne et al, 2014; Sillmann et al, 2014, Johnson et al, 2015

Limitations

- Observational data
  - Need long homogeneous records of daily data
  - Incomplete geographical coverage
  - Traceability, updatability of indices
  - Order of operations
- Process understanding and representation in models, such as
  - Coupled land-atmosphere feedback processes
  - Blocking
- Analysis methodology

Precipitation extremes

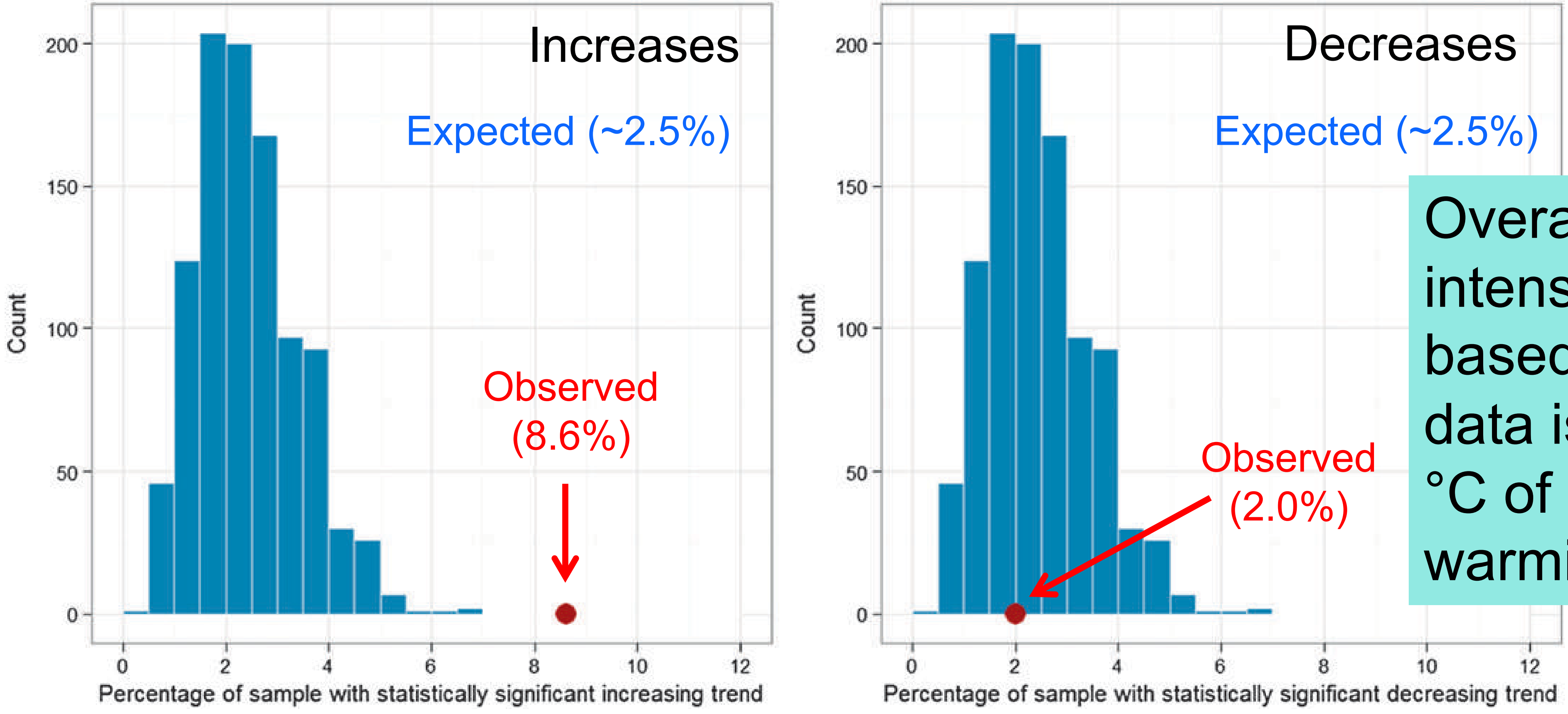
Photo: F. Zwiers (Longji)

Precipitation extremes

- Observational studies suggest intensification is occurring
- Expectation of intensification is supported by attribution of
  - global warming
  - atmospheric water vapour content increase
  - large scale changes in mean precipitation
  - ocean surface salinity changes
- Only a few D&A studies to date on extreme precipitation
  - detect human influence at the ”global” scale
- Considerable challenges remain in understanding regional precipitation change (e.g., Sarojini et al., 2016)
- Local detection of change is very hard

Percentage of stations globally with statistically significant trends in annual maximum 1-day precipitation

Based on 8376 stations with 30-years or more data in period 1900-2009



Overall intensification based on station data is ~7% per °C of global warming

Westra et al 2013, Fig. 3

Limitations

- Data (availability, spatial coverage, record length, quality, observational uncertainty between datasets)
- Confidence in models (e.g., circulation impacts, topography, parameterization of sub-grid scale processes)
- Low signal-to-noise ratio with possibly offsetting influences from GHGs and aerosols (may be different for means than for extremes)
- Understanding of spatial and temporal scaling (e.g., Zhang et al., 2017)
- Characterization of spatial dependence

Terrestrial hydrological cycle

Photo: F. Zwiers (Canmore, AB)

Hydrologic extremes

- Few studies linking change in mean hydrologic conditions to GHGs
  - Barnett et al, 2008, Fyfe et al., 2017 (Western US)
  - Najafi et al, 2016, 2017 (part of British Columbia)
  - Detect the effect of warming on snowpack and/or streamflow characteristics
  - Also detect the effect of warming on snow cover extent
- Some attempts to study changes in flood frequency
- Challenges 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, 2016)
  - Complexity and uncertainty in the modelling chain
  - Confounding effects

Storms

Photo: F. Zwiers

Photo: F. Zwiers (Ucluelet)

Storms

- Some evidence of attributable 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
- Challenges include
  - Data (type, source, 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)
  - Dynamical downscaling with a regional climate model helps reduce bias somewhat (Seiler et al, 2017)

Event attribution

Photo: F Zwiers

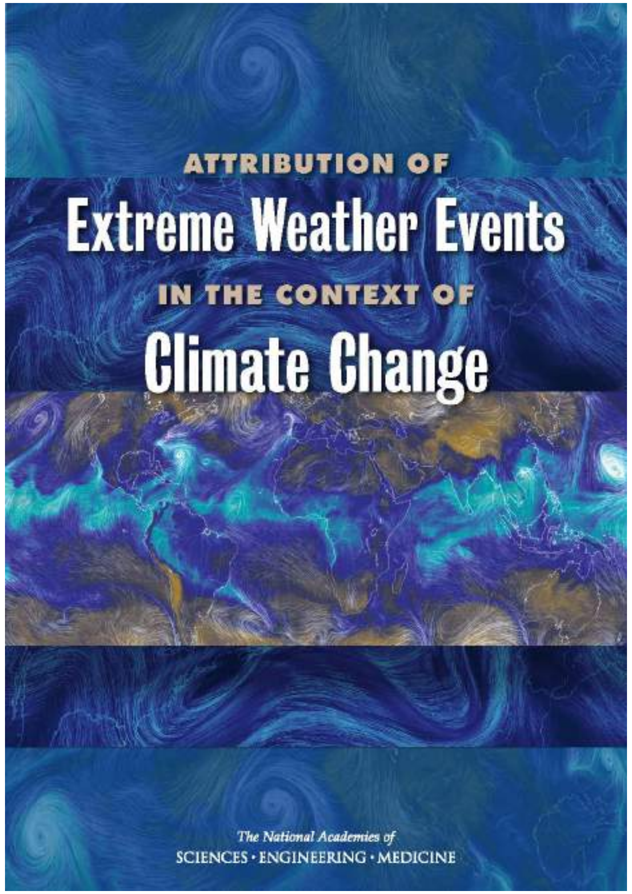
The context …

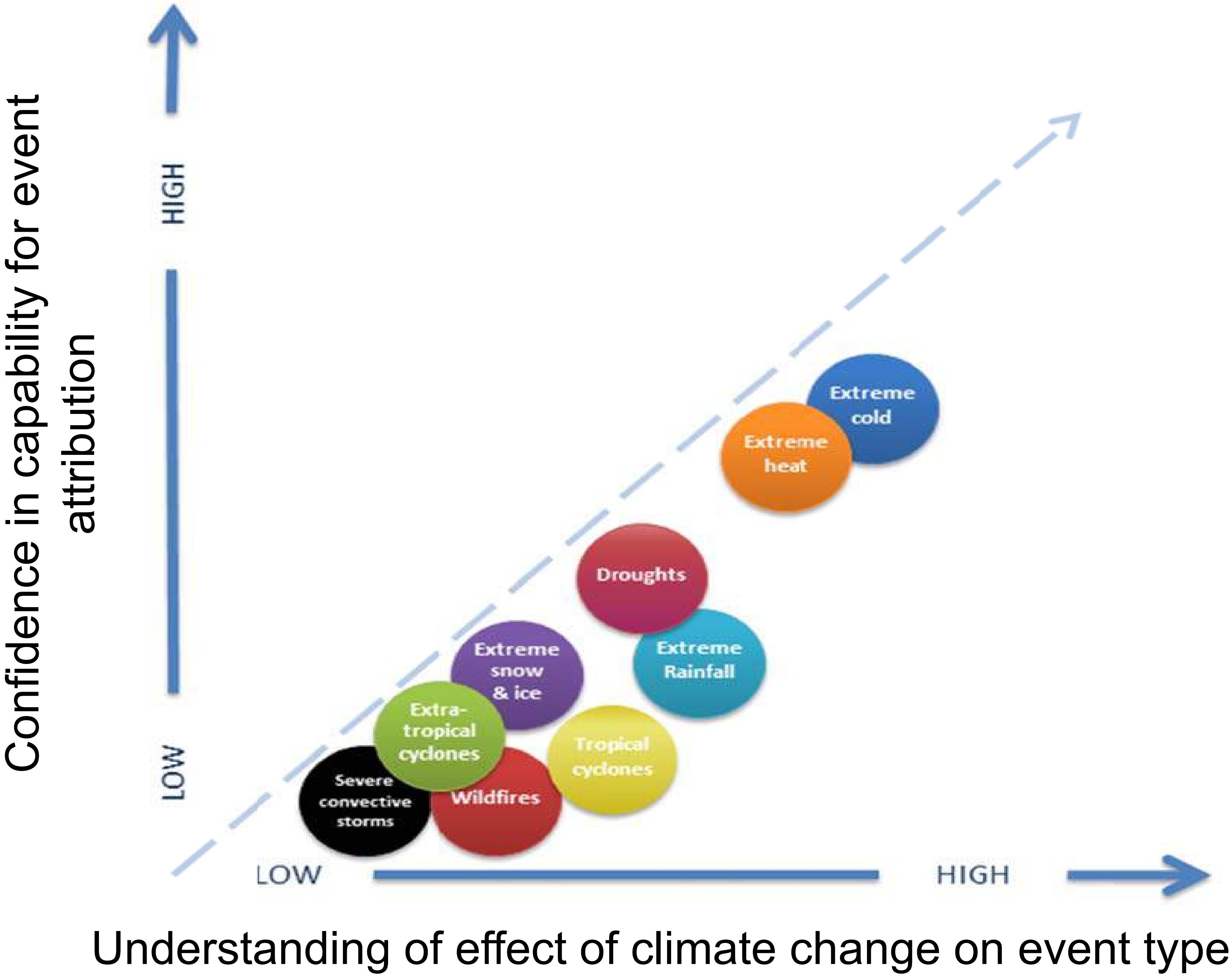
- Policy makers and officials demand to know if climate change was a factor in events that have just occurred
- Media discourse tends to evoke links to climate change
- As a default, scientists point to the similarity between recent events and projected change
- Event attribution science has been trying to find a way for science to do better than this
- Requires "rapid response" science
  - e.g., see annual BAMS report on extreme events
- Places high demands on process understanding, data, models, and statistical methods

Extreme event attribution

- The public, policy makers and officials asks:
  - Did human influence on the climate system … Cause the event?
- Most studies ask:
  - Did it … Affect its odds?
  - Alter its magnitude?
- Usual approach is compare factual and “counterfactual” climates using climate models
  - Counterfactual → the world that might have been if we had not emitted the ~2200GtCO_2 (and counting) that have been emitted since preindustrial
- Shepherd (2016) defines this as “risk based”
  - Contrasts it with a “storyline” based approach

Recently assessed by US NAS





“Framing” affects the answer

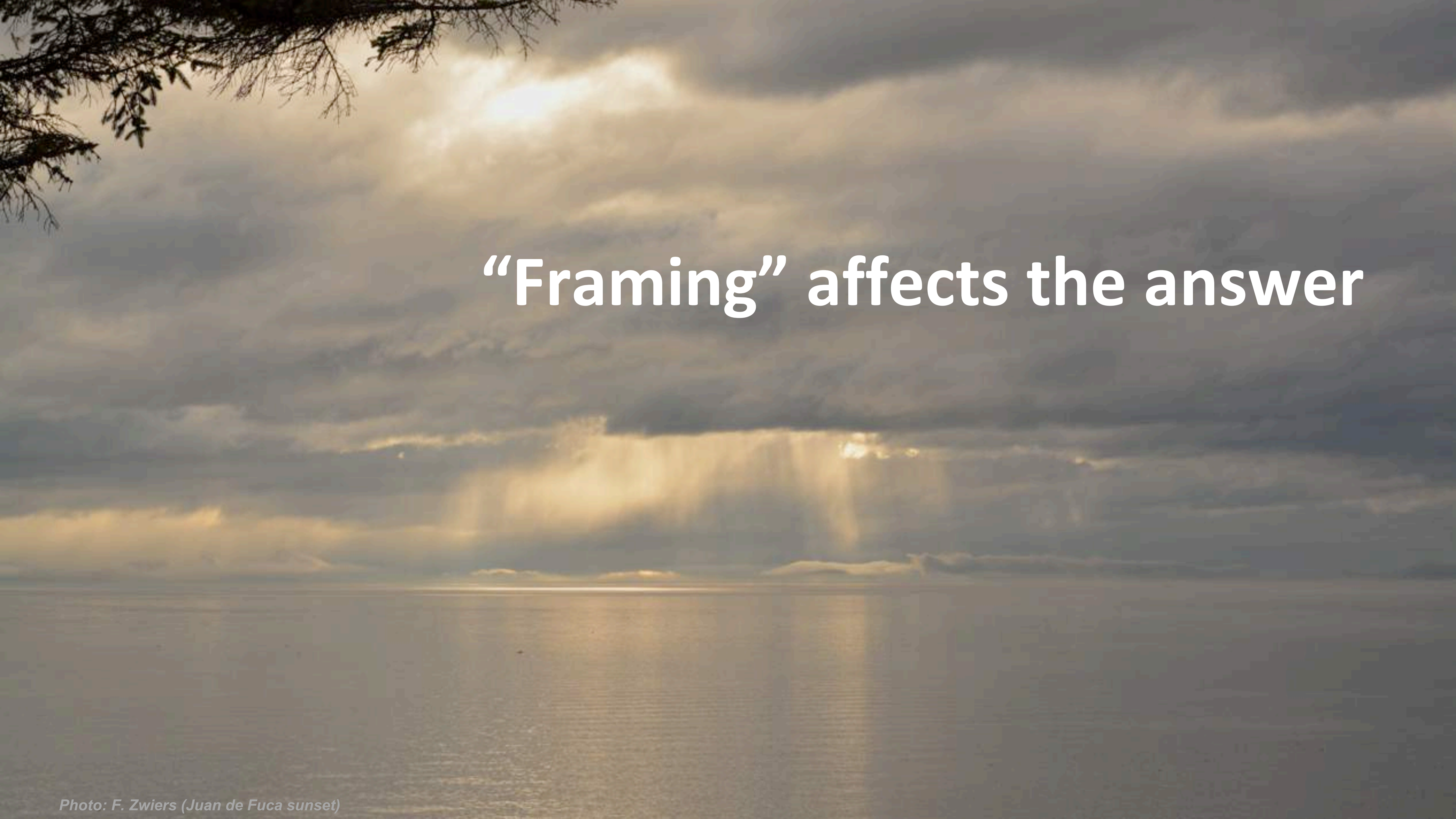


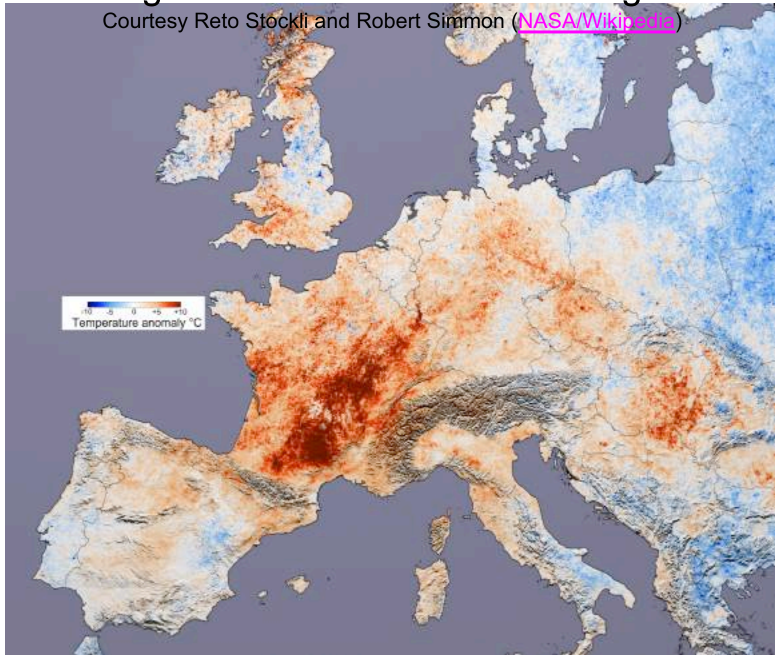
Photo: F. Zwiers (Juan de Fuca sunset)

Framing → How the question is posed

- How is the ”event” defined?
- What sources of unforced variability are controlled?
  - No sources control?
  - Sea-surface temperature pattern?
  - Circulation pattern?
- What question is asked about the defined event?
  - Likelihood?
  - Intensity?

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

Courtesy Reto Stöckli and Robert Simmon (NASA/Wikipedia)



JJA temperature anomalies relative to 1961-1990

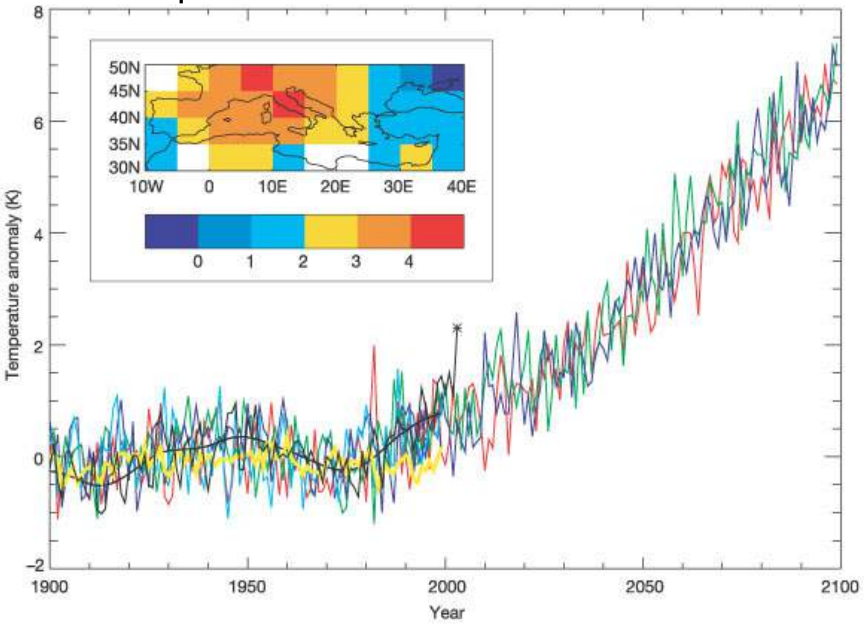


Figure 1, Stott et al., 2004

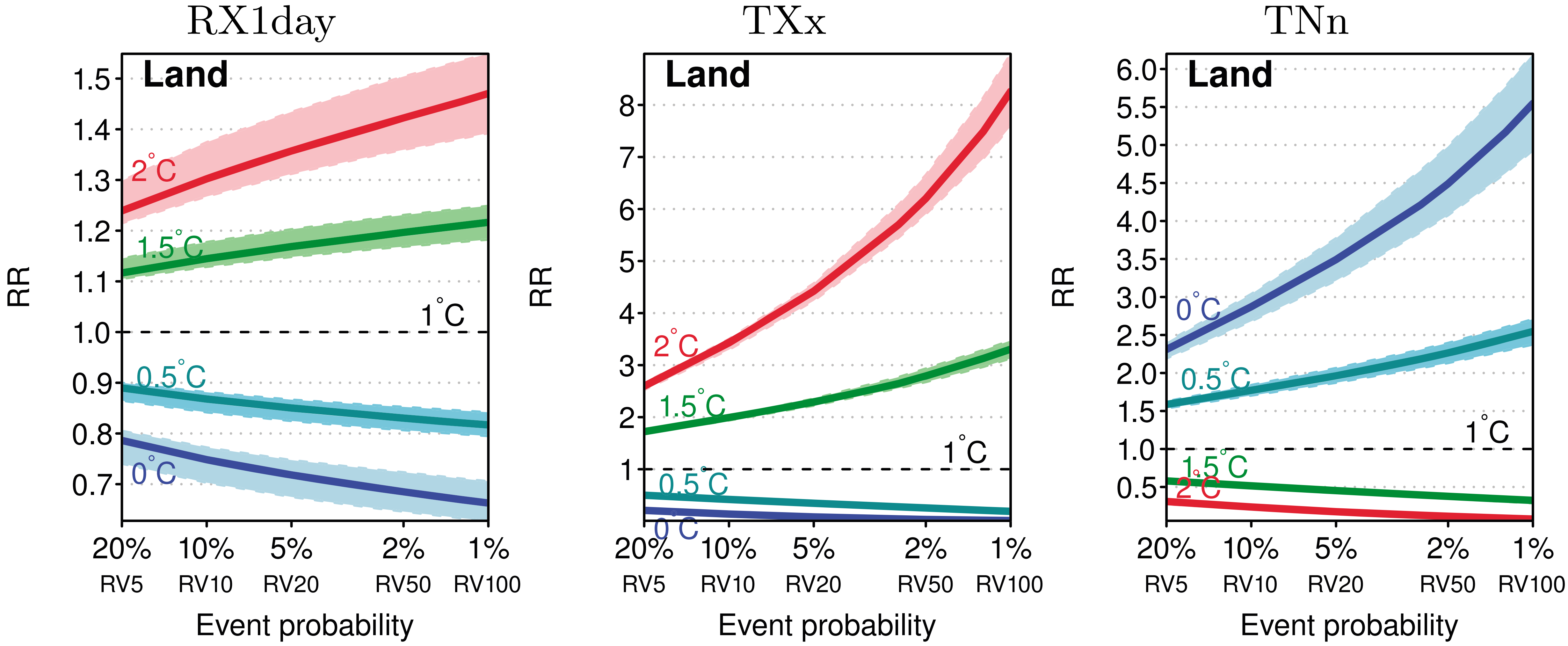
Rarity affects the answer

- A frequently used diagnostic is the probability (or risk) ratio

$$PR = \frac{p_1}{p_0}$$

- The probability ratio can be understood as a risk ratio if losses incurred by the event are the same in the counterfactual and factual climates
- PR can be used to compare historical with present climates or present climates with either past or future climates
- The deviation of PR from 1 is larger when p_0 is smaller

PR vs p_0 for different warming levels relative to today's climate (note different vertical scales)



Kharin et al, 2018, Fig 4b

Rarity affects the answer

- Another metric used in event attribution is the Fraction of Attributable Risk (or fraction of attributable probability)

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

- Both metrics are sensitive to the choice of reference event (i.e., framing)
- Much potential to affect (and perhaps abuse) the sense of urgency that is conveyed to "users"
- A solution might be to provide PR curves (PR as a function of rarity), on which observed events can be situated

Conditioning may also affect the answer

- Conditioning refers to sources of variability that are controlled by the analyst
- Conditioning examples include
  - SST anomaly pattern at the time of the event
    - Allows use atmospheric models rather than coupled models
  - Synoptic state at the time of the event controlling, for example, moisture advection and convergence
    - Allows use of forecast models (e.g., recent Hurricane Florence)
- Discussion about risk based versus storyline approaches reflects a spectrum of conditioning choices (stronger conditioning → more "storyline" like)

Conditioning may affect the answer

- Stronger conditioning usually implies results are less generalizable
- If $\mathbf{C}$ represents the conditions that are held constant, we need to understand that the probability ratio we calculate is

$$PR|_{\mathbf{C}} = \frac{p_1(\mathrm{E}|\mathbf{C})}{p_0(\mathrm{E}|\mathbf{C})} \neq PR$$

- This is because

$$PR = \int_{\mathbf{C}} PR|_{\mathbf{C}} dP_{\mathbf{C}}$$

Event Attribution Examples

Photo: F. Zwiers

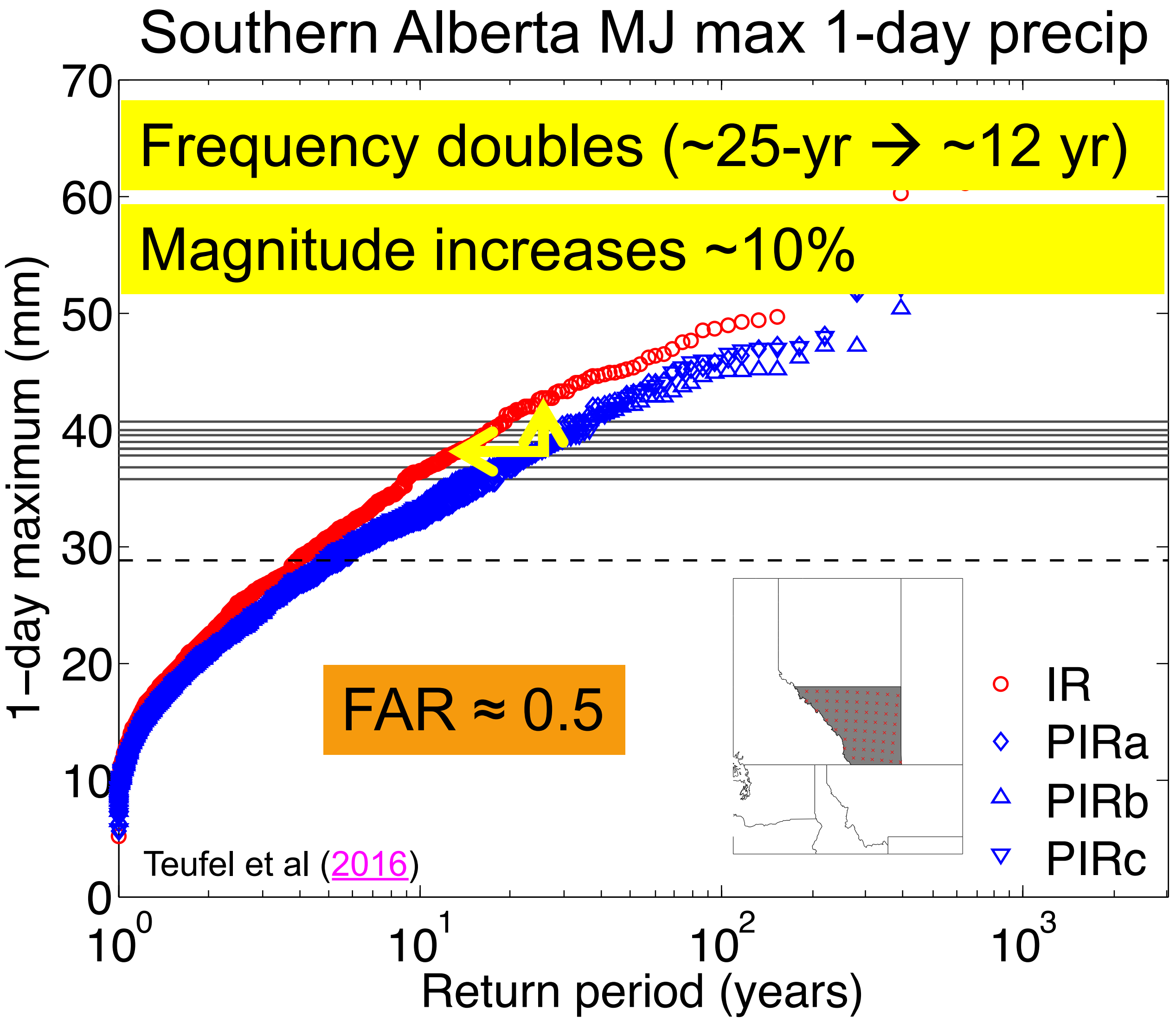
Calgary flood, June, 2013

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

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

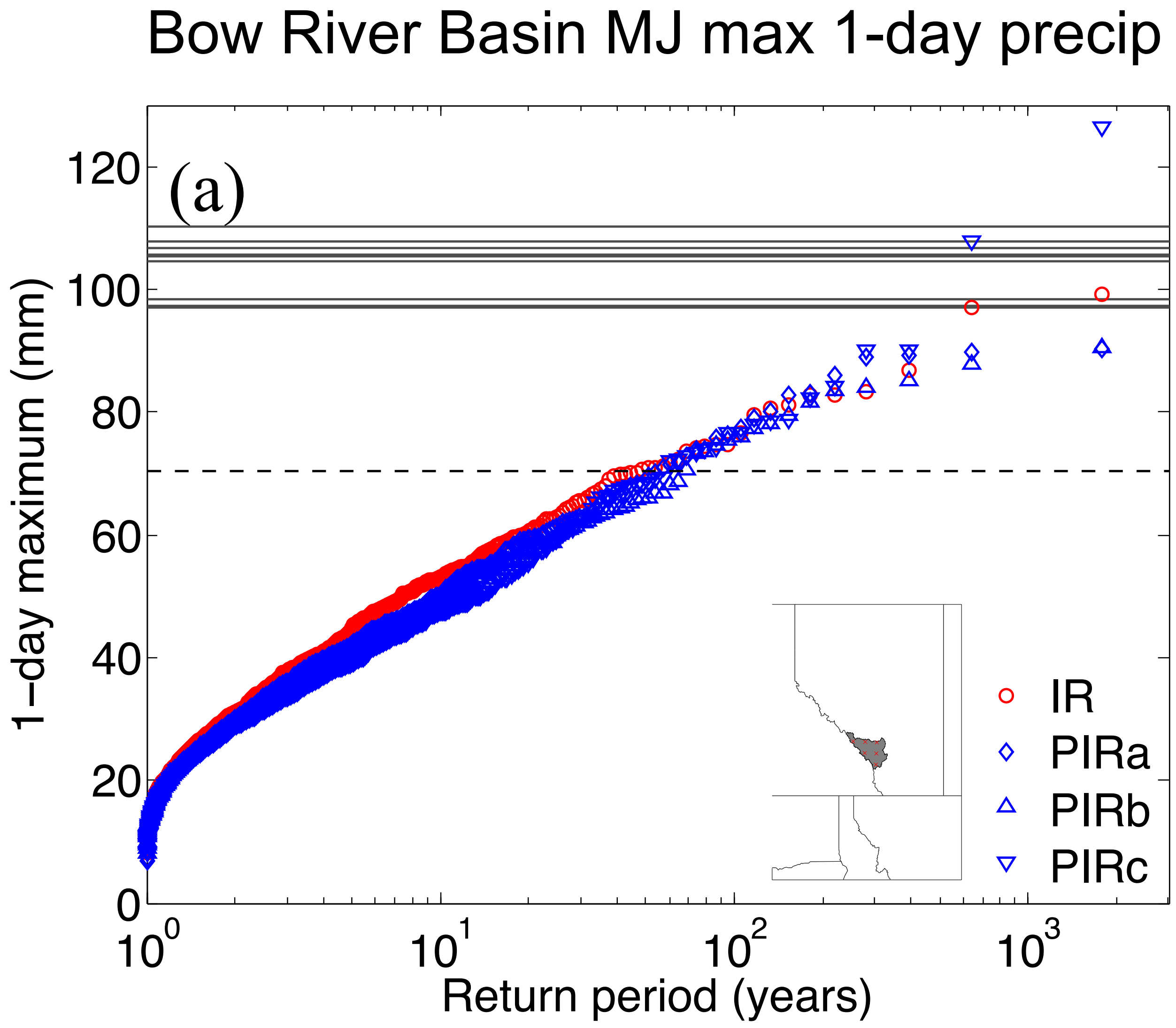
Calgary floods

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



Calgary floods

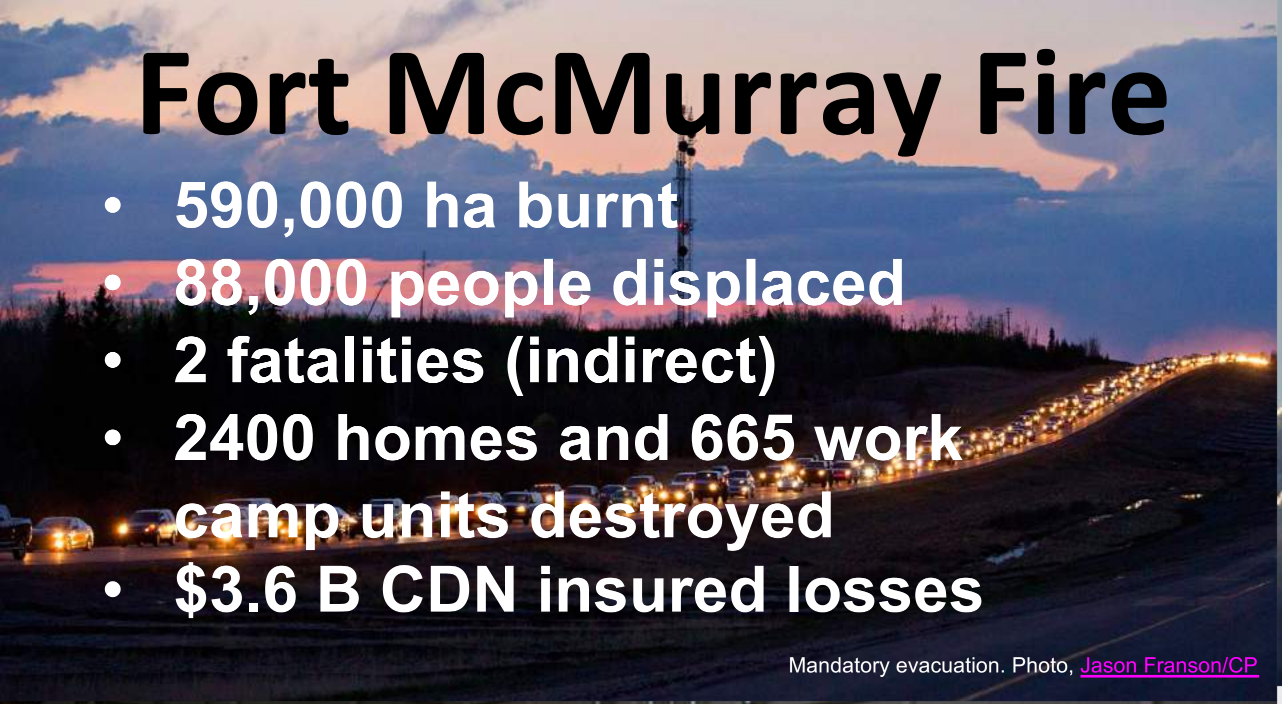
Distribution of annual May-June maximum 1-day Bow River Basin precipitation in CRCM5 under factual and counter-factual conditions (conditional on the prevailing global pattern of SST anomalies)



Teufel et al (2016)

Fort McMurray Fire

- 590,000 ha burnt
- 88,000 people displaced
- 2 fatalities (indirect)
- 2400 homes and 665 work camp units destroyed
- $3.6 B CDN insured losses



Mandatory evacuation. Photo, Jason Franson/CP

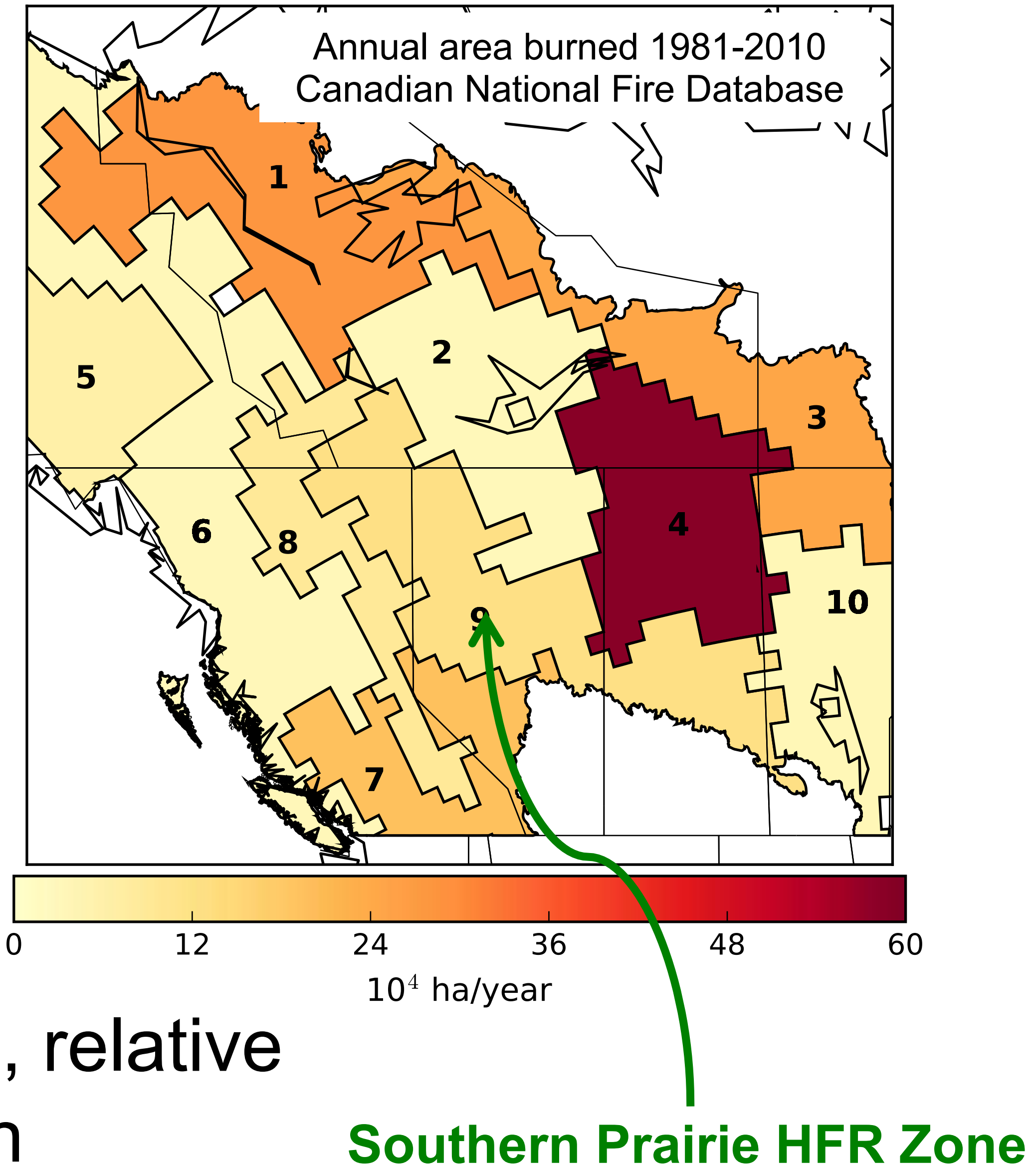
Avian escape. Photo, Mark Blinch/Reuters

Edmonton Expo Centre at Northlands. Photo, Chris Bolin

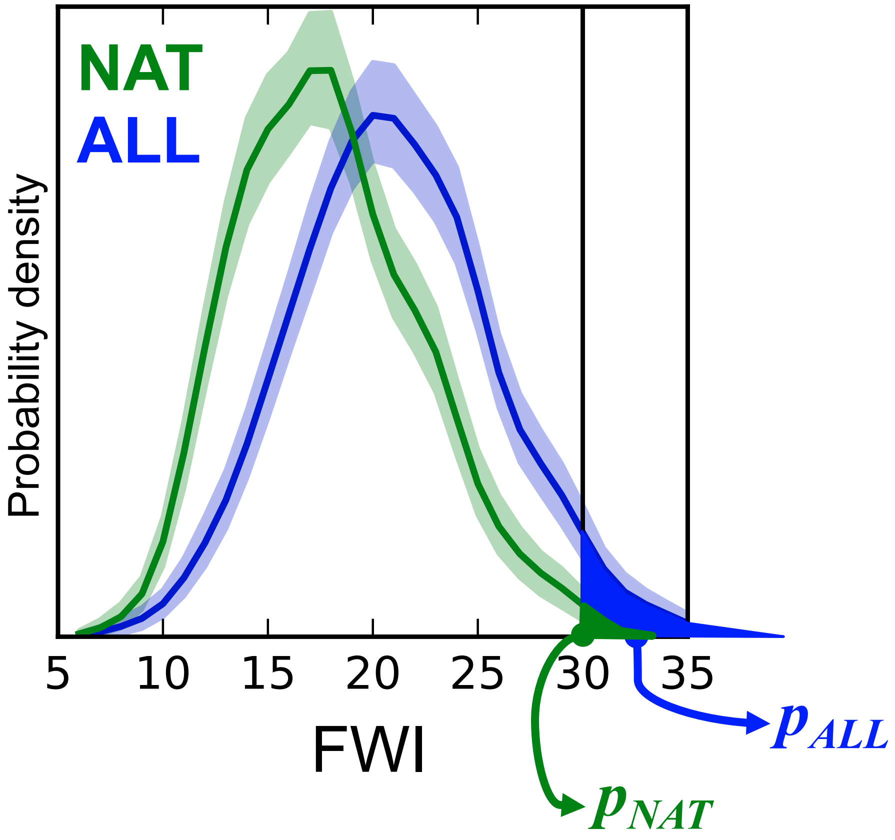
Timberlea. Photo, Chris Bolin

Fire risk (Kirchmeier-Young et al, 2017)

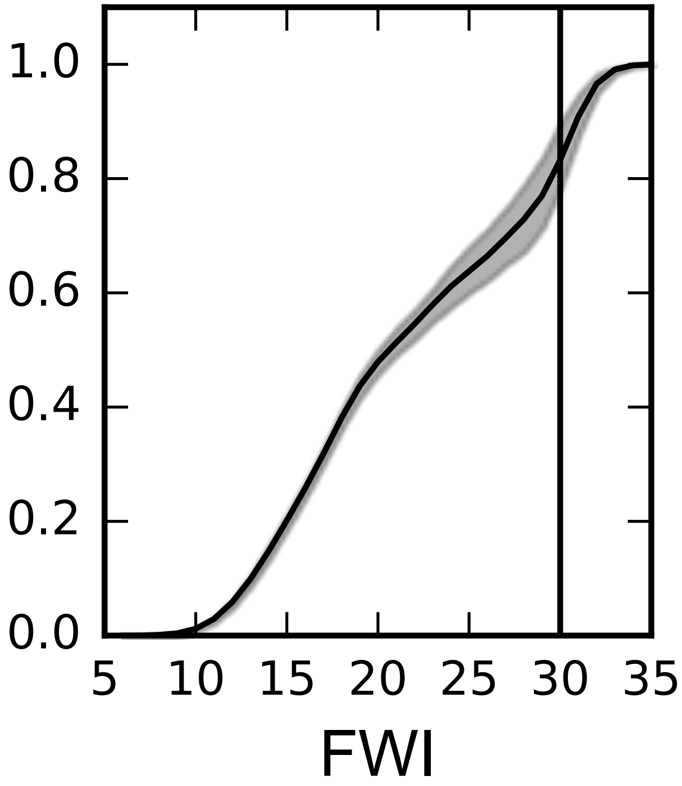
- We ask whether human induced climate change has affected fire risk in the"Southern Prairie" Homogeneous Fire Regime zone
- Measure fire risk using "CWFIS" system indicators
  - Fire Weather Index
  - Fine Fuels Moisture Code
  - Duff Moisture Code
  - Drought Code
- These indices depend on temperature, relative humidity, wind speed, and precipitation



Fire Weather Index for Southern Prairies HFR for the current decade (2011-2020)



$$FAR = \frac{p_{ALL} - p_{NAT}}{p_{ALL}}$$



CWFIS “Extreme” FWI level = 30

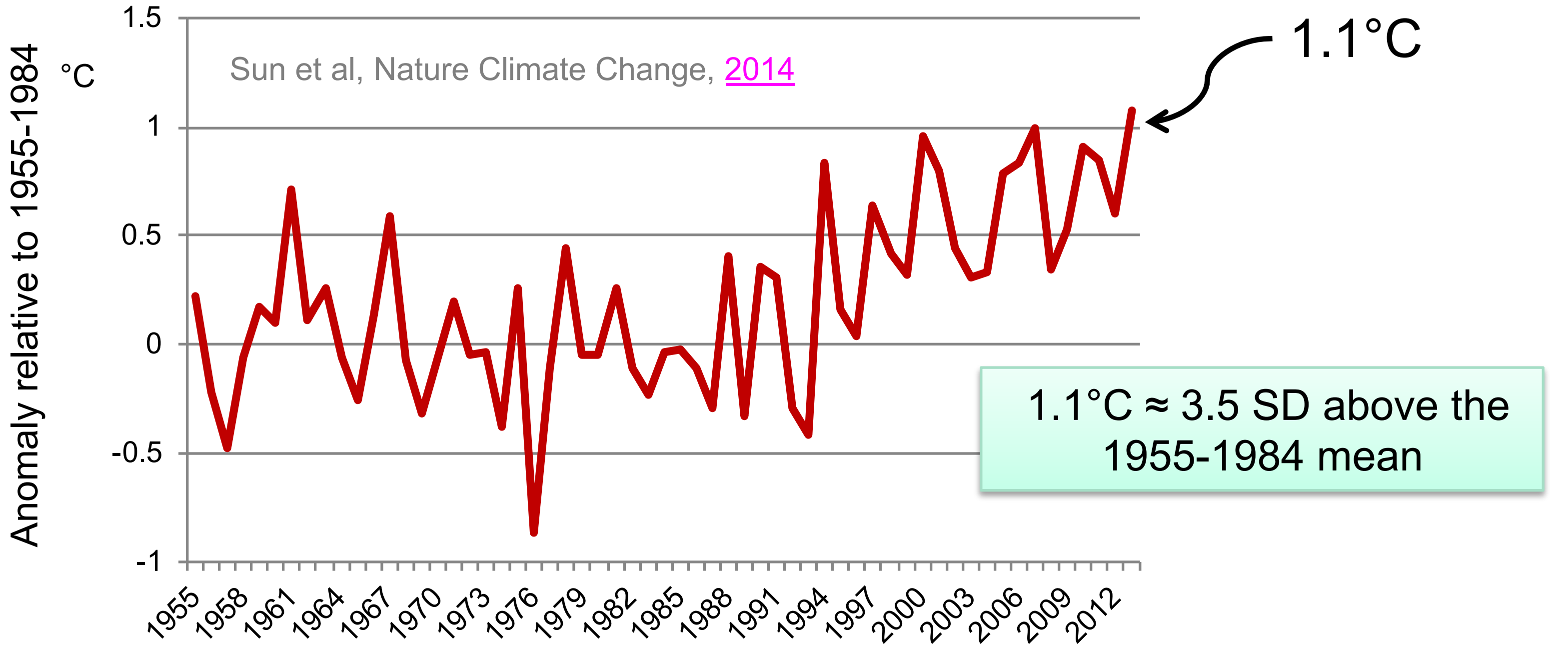
Observed FWI level in Fort Mac area ≈ 40

China’s Hot Summer of 2013

- Impacts included estimated $10B USD agricultural yield loss

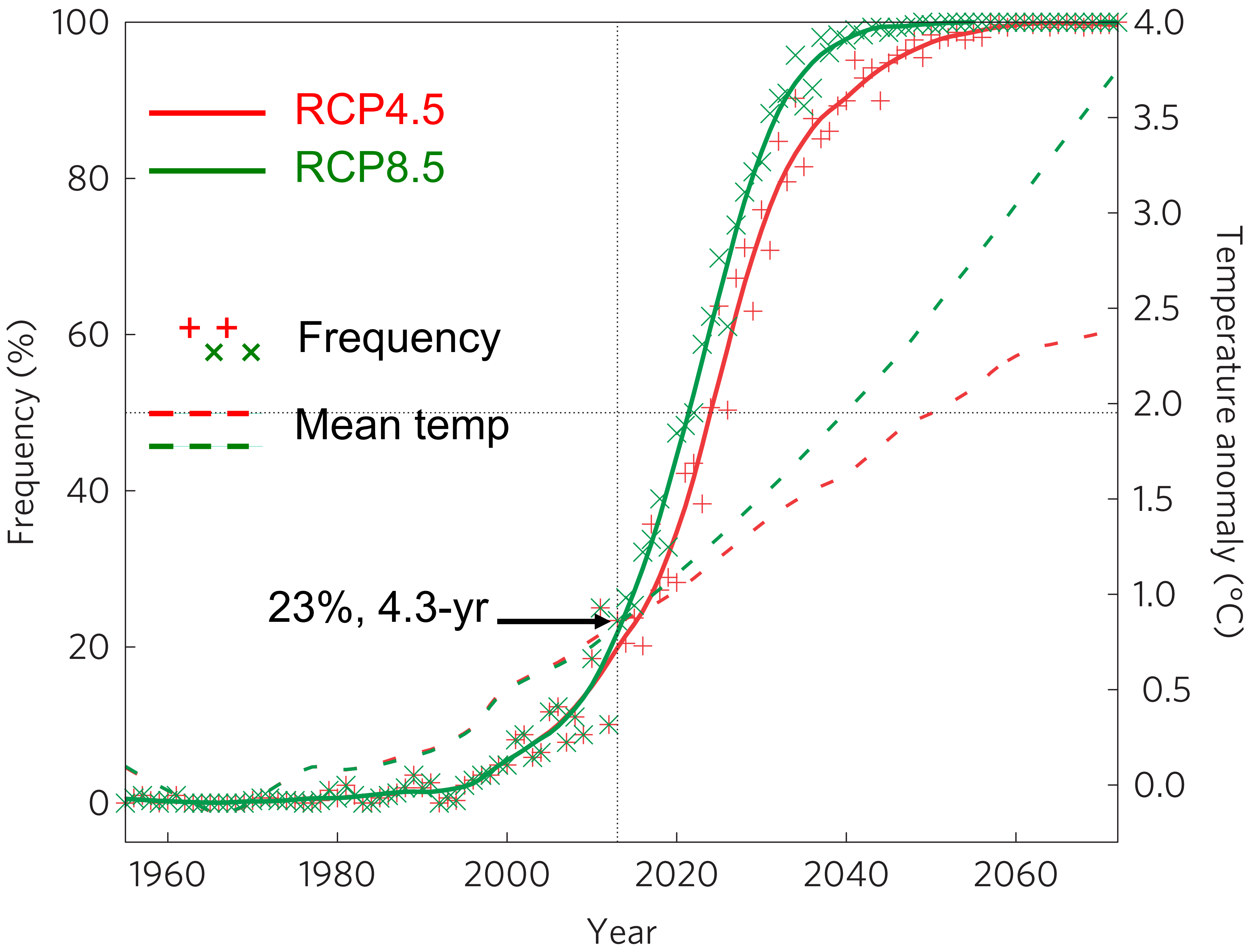
Photo: F. Zwiers (Yangtze River)

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”: $PS=1-((1-p_1)/(1-p_0)) \approx 0.23$

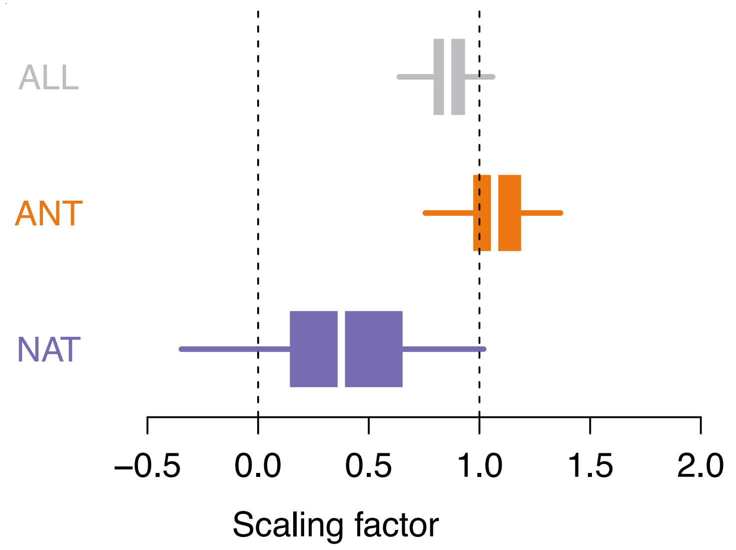
Projected event frequency



Increasing heat stress risk in China

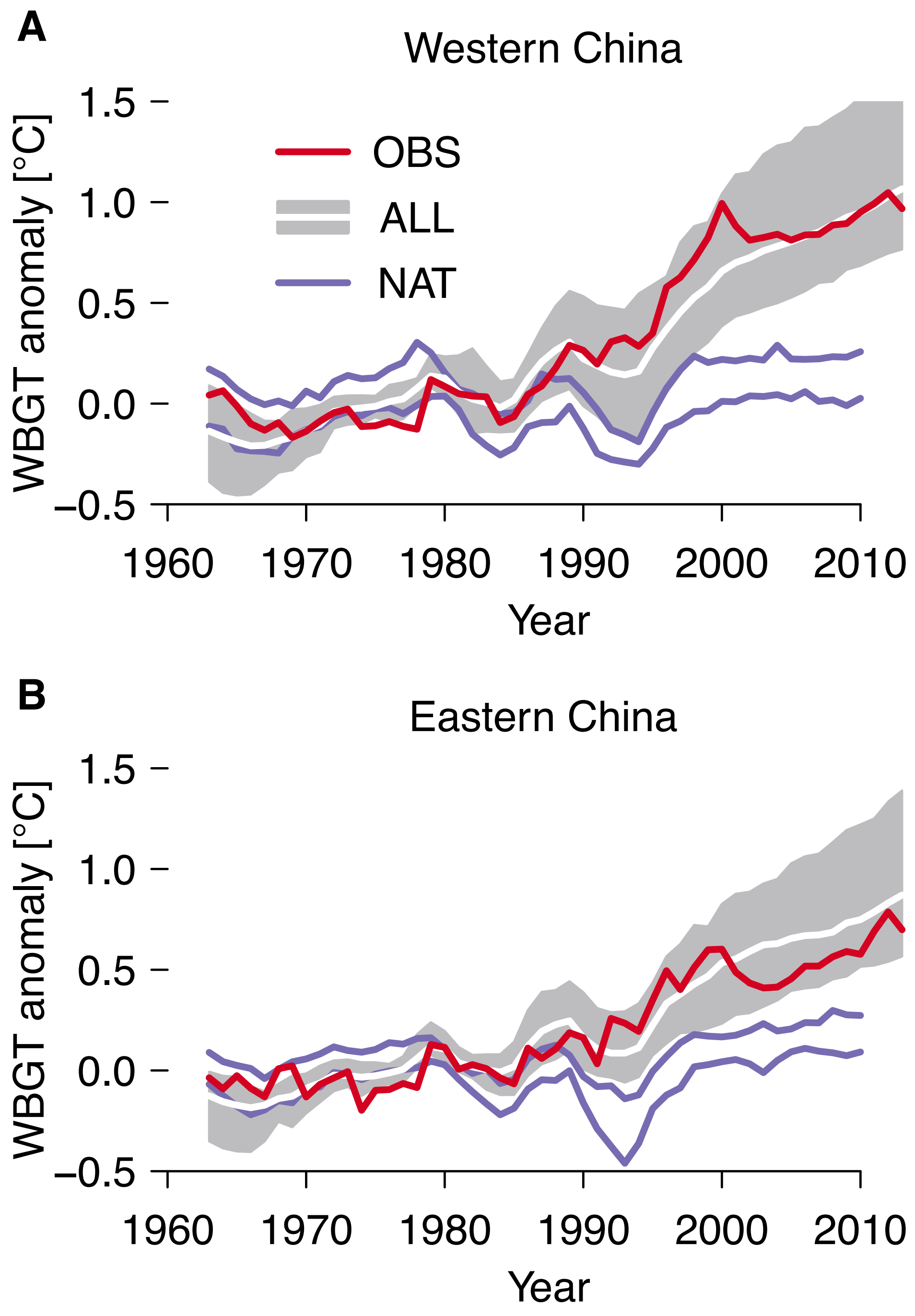
Photo: F. Zwiers (Huangguoshu Falls)

Evolution of JJA mean WBGT from observations and CMIP5 simulations



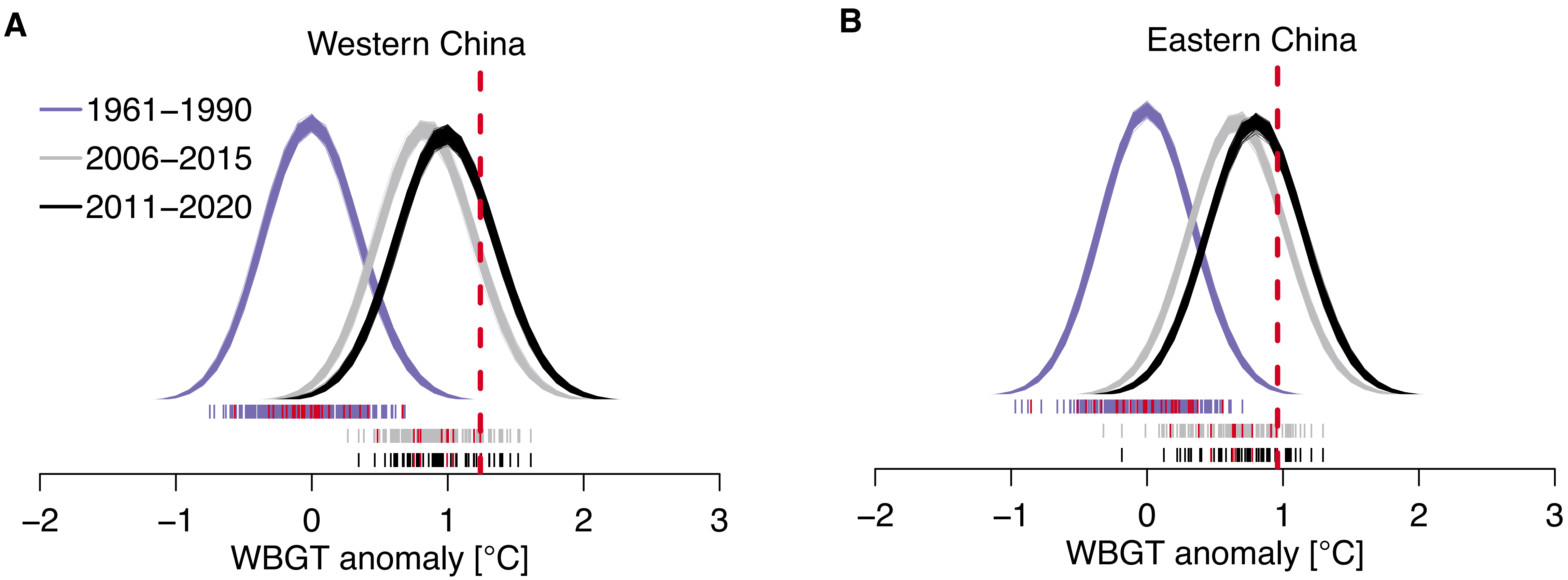
1- and 2-signal D&A results

(1961-2015, non-overlapping 5-year means, 2 spatial dimensions)



Li et al, submitted (2019)

Reconstructed observationally constrained distributions of JJA mean WBGT

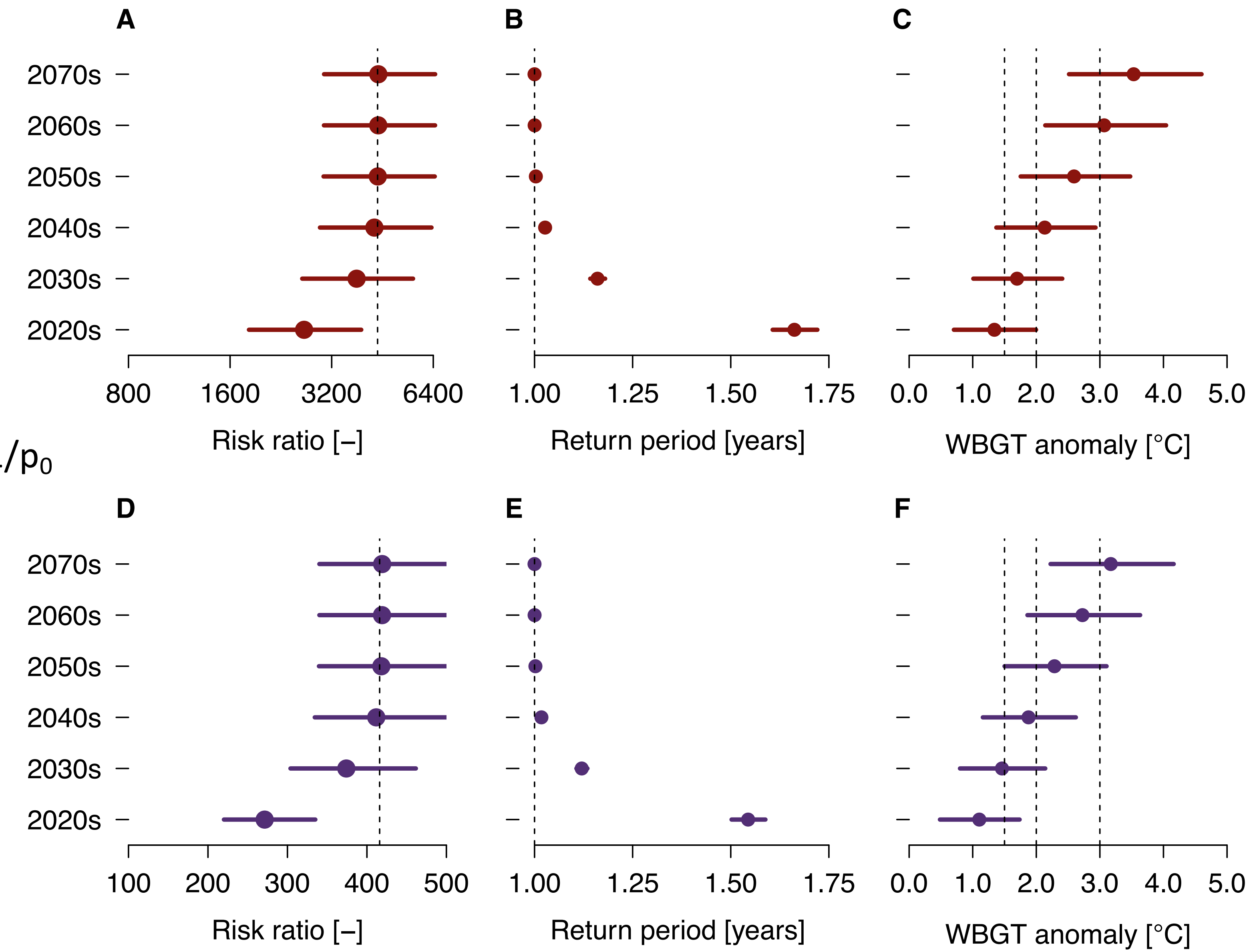


- - - 1961-2015 maximum (1.24°C; 2012)
PR ≈ 1100 (2011-2020 vs 1961-1990)

- - - 1961-2015 maximum (0.96°C; 2013)
PR ≈ 140 (2011-2020 vs 1961-1990)

Projected changes in distribution of JJA mean WBGT

Western China



Note that PR saturates at $1/p_0$

Eastern China

Conclusions

Definition of extremes

- The notion of extremes is relative
- While there is not a precise definition, we think of something as being extreme when it lies beyond its “normal” range of variation
- An instantaneous value, a large spatial extent, a high indicator of risk, an unusual seasonal mean can all be extreme
- The notion is often linked to impacts – we notice when a high temperature, wind, precipitation amount, snow melt rate, etc., produce a disruptive impact

Changes in extremes

- Increasing evidence that at least some types of extremes are being affected by human influence on the climate system
  - Temperatures
  - Precipitation and perhaps flash flooding
  - Storms?
- Event attribution studies are augmenting the evidence
  - Deal with specific events rather than long-term tendencies
  - Do not directly set events in historical or future contexts
- There is greater confidence in event attribution if it is supported by evidence of long-term change in a related quantity

Event attribution

- Questions tend to focus on frequency (the probability of the event) rather than intensity – but both are of interest, and they are, in fact, linked
- If we fix on a frequency, we can ask about differences in “return levels”, whereas if we fix on a “return level” (or observed threshold), we can ask about changes in frequency, or “return period”.
- This choice, and other aspects of “framing”, affect the answer

Event attribution

- Rarity affects event attribution results
  - Probability ratios and fractions of attributable risk are higher for rarer events
  - Longer time scales and larger spatial scales increase the signal-to-noise ratio, leading to events that are rarer within their distributions
  - This effect is more pronounced for precipitation (since s/n ratios for temperature are already high). See Kirchmeier-Young et al., 2019, *Earth's Future*
  - Puts great responsibility on practitioners to define events appropriately and to clearly explain the effect of the event definition on their results

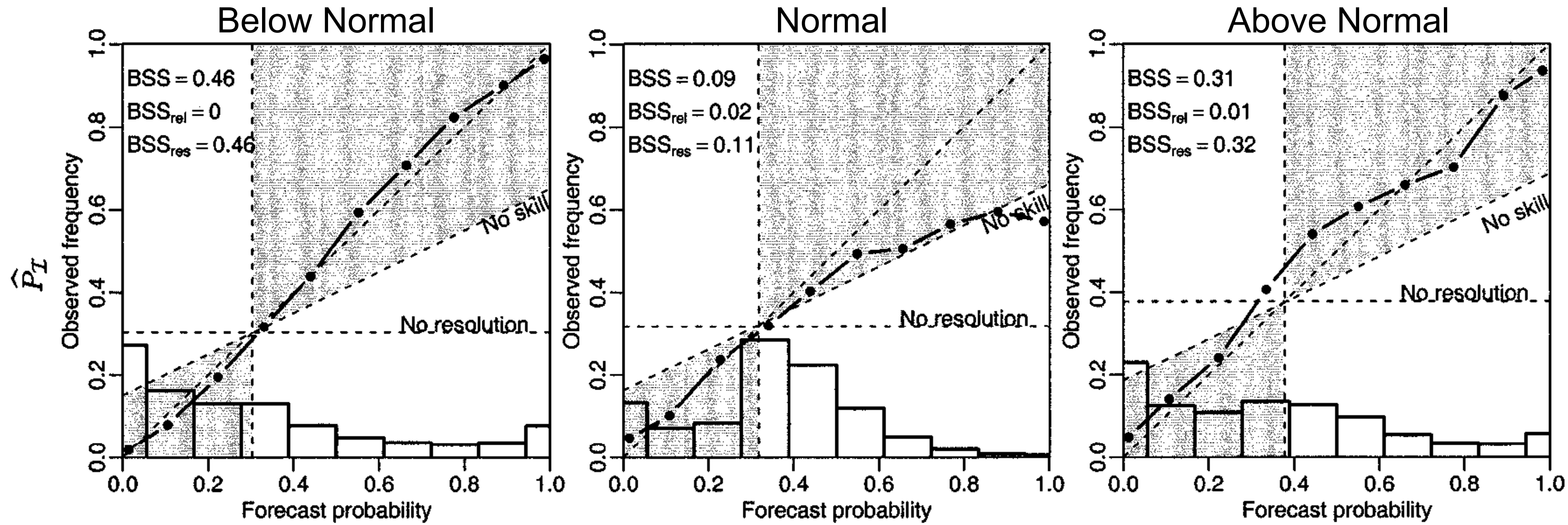
Event attribution

- Conditioning may affect the results
  - The more strongly we condition, the less we can generalize (and therefore use the information for future planning)
  - Again, practitioners have a responsibility to clearly explain limitations
  - There is a parallel with medicine (e.g., epidemiology vs pathology)

Event attribution

- The “reliability” of event attribution remains unknown
- We know how to assess reliabilty for probability forecasts, but are only starting to think about this for event attribution

“Attributes diagram” for a three-category DJF Z_{500} forecasting system



Kharin and Zwiers, 2003

Event attribution

- Communicating the results of event attribution science is a challenge
- The public discourse is very often far ahead of the science (in western society, every event is currently attributed to human influence on the climate)
- Event attribution studies tend to find that humans have altered the likelihood or intensity of the events we study, but that does not mean that we should conclude that world would have been free of the risk of similar events in the absence of human influence on the climate system

Questions?

https://www.pacificclimate.org/

Photo: F. Zwiers