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

Francis Zwiers
PCIC, University of Victoria
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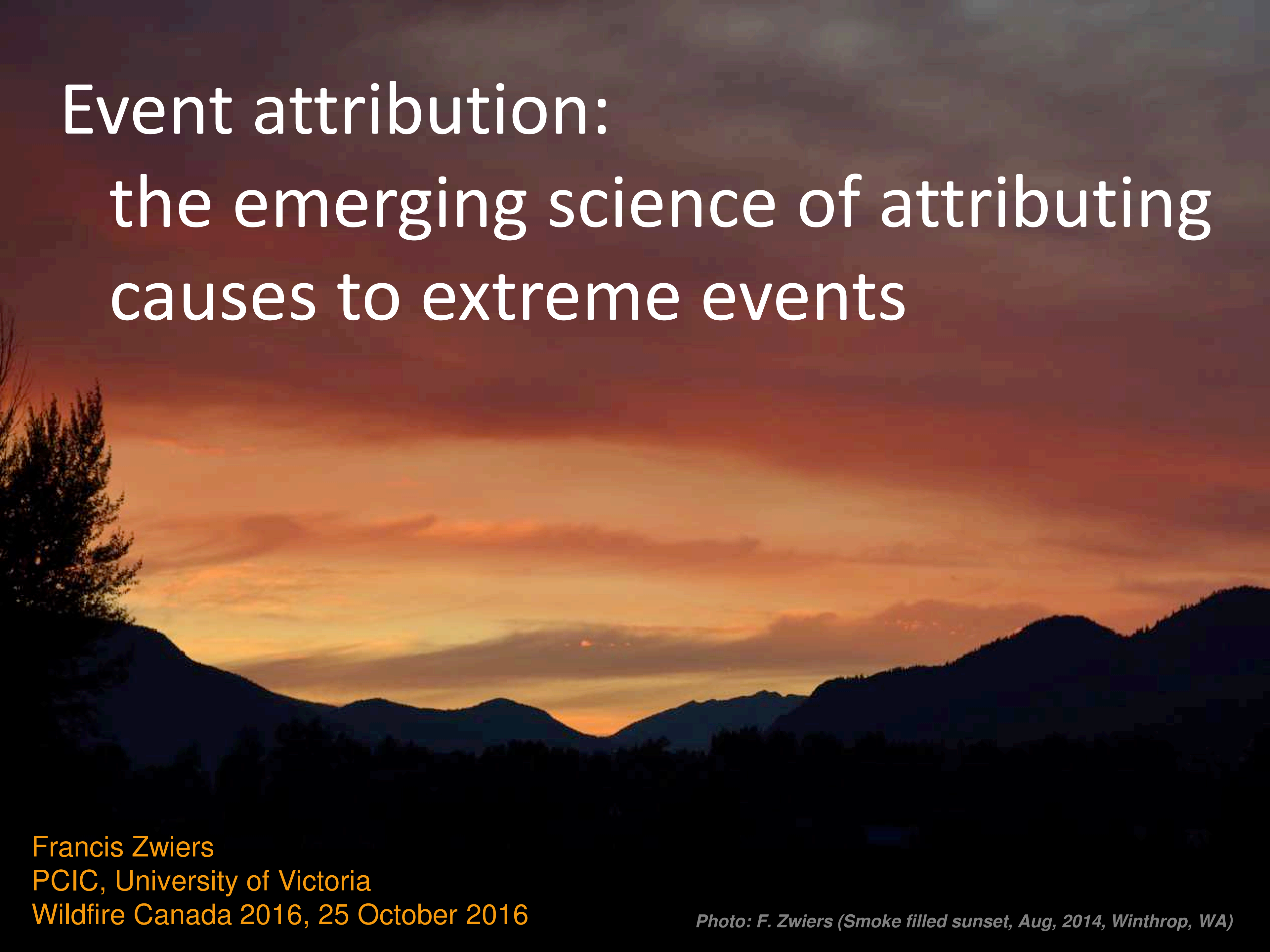


Photo: F. Zwiers (Smoke filled sunset, Aug, 2014, Winthrop, WA)

Outline

- Introduction
- Extreme event attribution overview
- Examples
  - Horse River Fire (2016)
  - Calgary Floods (2013)
  - China’s hot summer of 2013
  - Record low Arctic sea ice cover (2012)
- Discussion

Acknowledgements: Megan Kirchmeier-Young, Bernado Teufel
Ying Sun, Nathan Gillett, Xuebin Zhang and many others

Photo credit

Fort McMurray evacuation

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
- Growing insurance industry concern (e.g., Munich Re)

The context …

- Media discourse tends to quickly evoke possible links to climate change
- As a default, we scientists tend to 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
- Places high demands on process understanding, data, models, and statistical methods
- Recently assessed by US National Academies of Science

Event attribution

Photo: F. Zwiers (Jordan River, gathering storm)

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
  - “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., prevailing SST anomaly pattern, circulation, etc

The NAS Report (2016) struggled with these distinctions

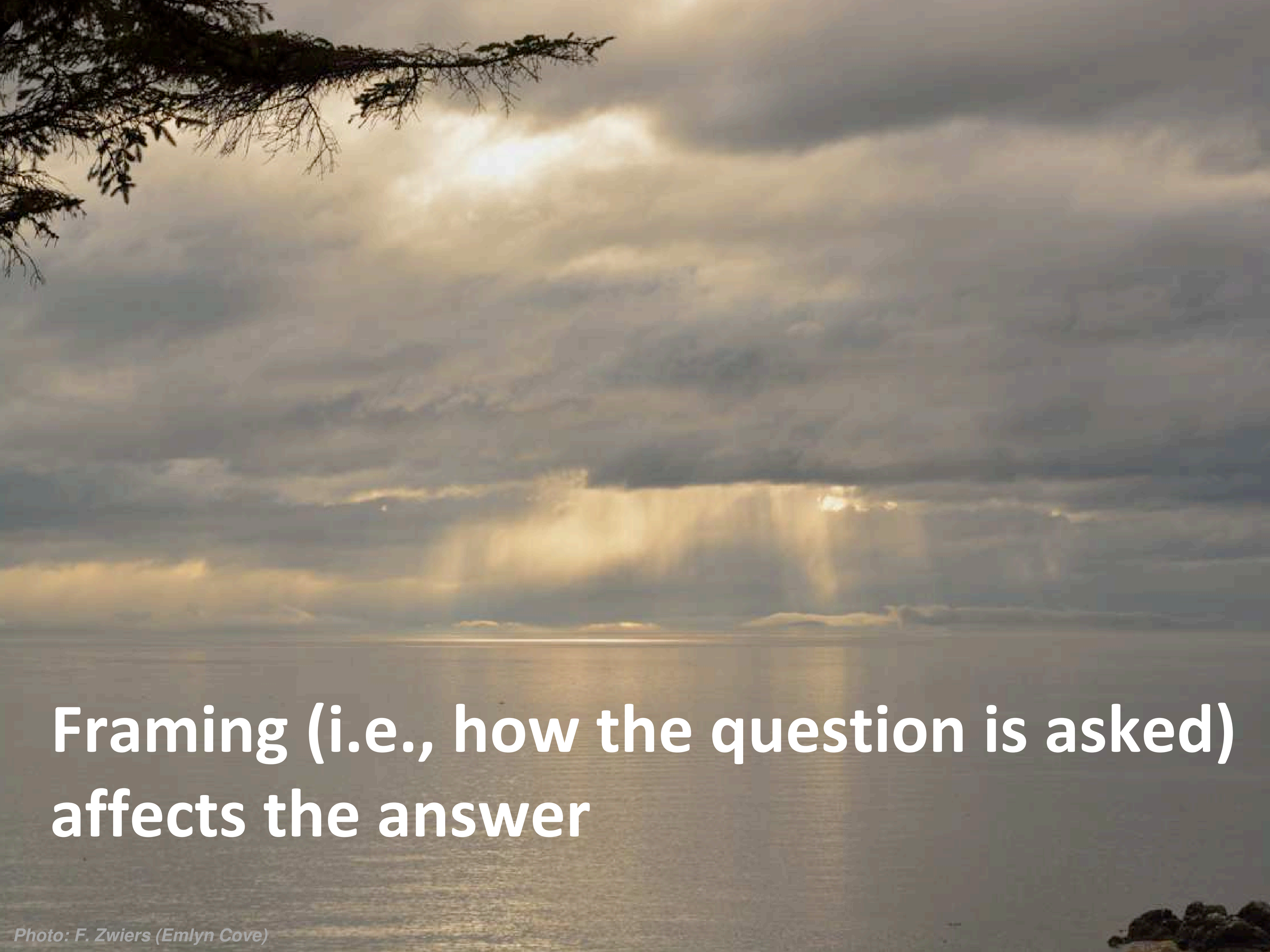


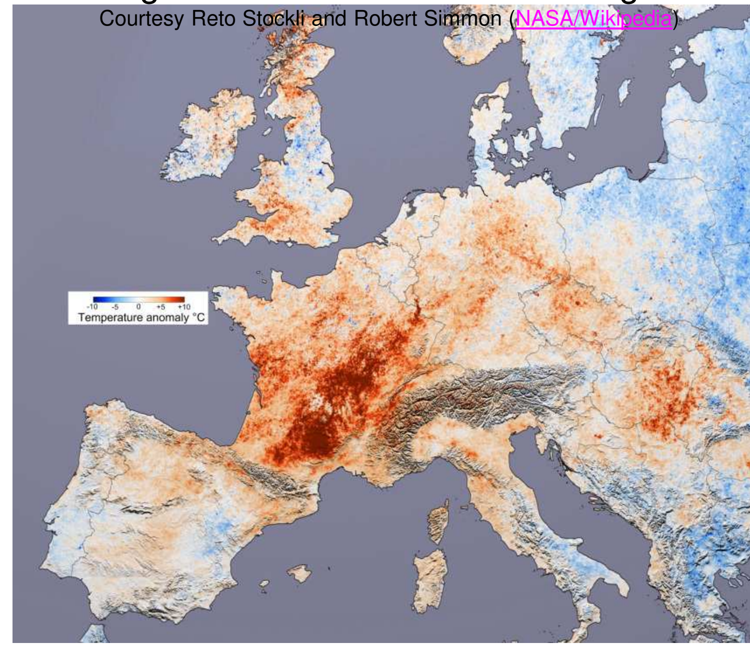
Photo: F. Zwiers (Emlyn Cove)

Framing …

How the event is defined

- For example, how detailed is the definition?
- The first "event attribution" study (Stott et al., 2004) dealt with the 2003 European heat wave
- The exact definition of the evident (duration and spatial extent) is unclear, …
- Therefore the study focused on mean summer conditions across southern Europe

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



Courtesy Reto Stockli and Robert Simmon (NASA/Wikipedia)

JJA temperature anomalies relative to 1961-1990

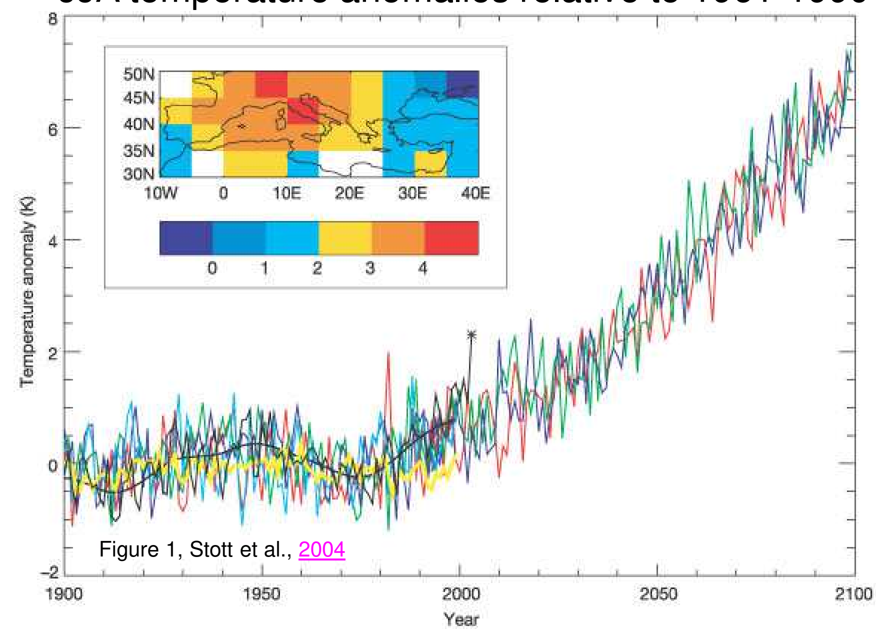


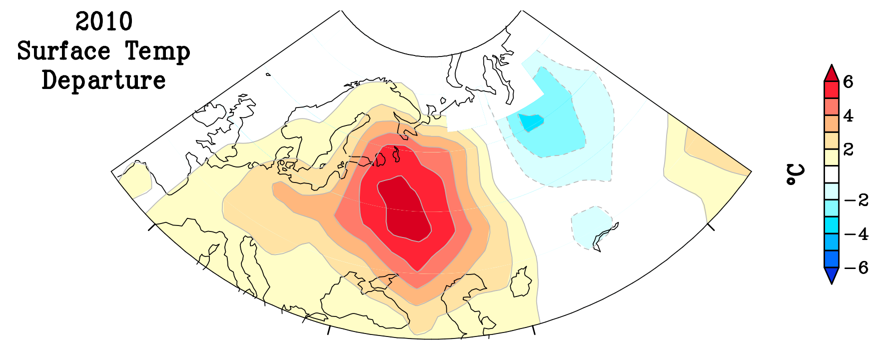
Figure 1, Stott et al., 2004

Framing …

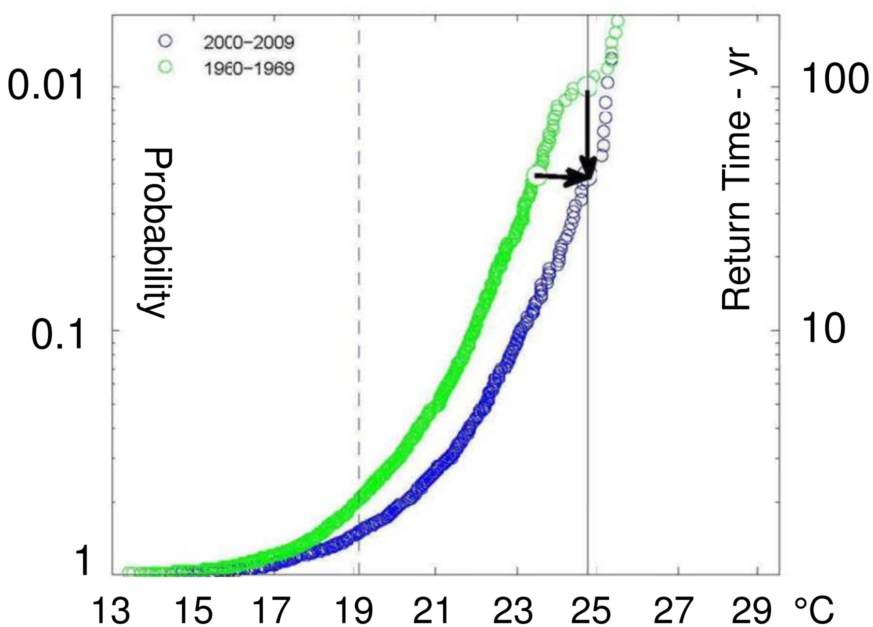
Choice of risk based question

- Two studies of the Russian 2010 heat wave 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 mean surface temperature distributions



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”

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

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 cheapers models
    - Cheaper
    - Can sometimes use 1000's or 10000's of simulations
    - One approach is to use personal computers volunteered by the public via weather@home/climateprediction.net
- Conditioning may add uncertainties
  - Need to estimate the counterfactual SST base state
  - Likelihood of the SSTA pattern may change

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

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

Horse River Fire – May through July 2016

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

Mandatory evacuation. Photo, Jason Franson/CP

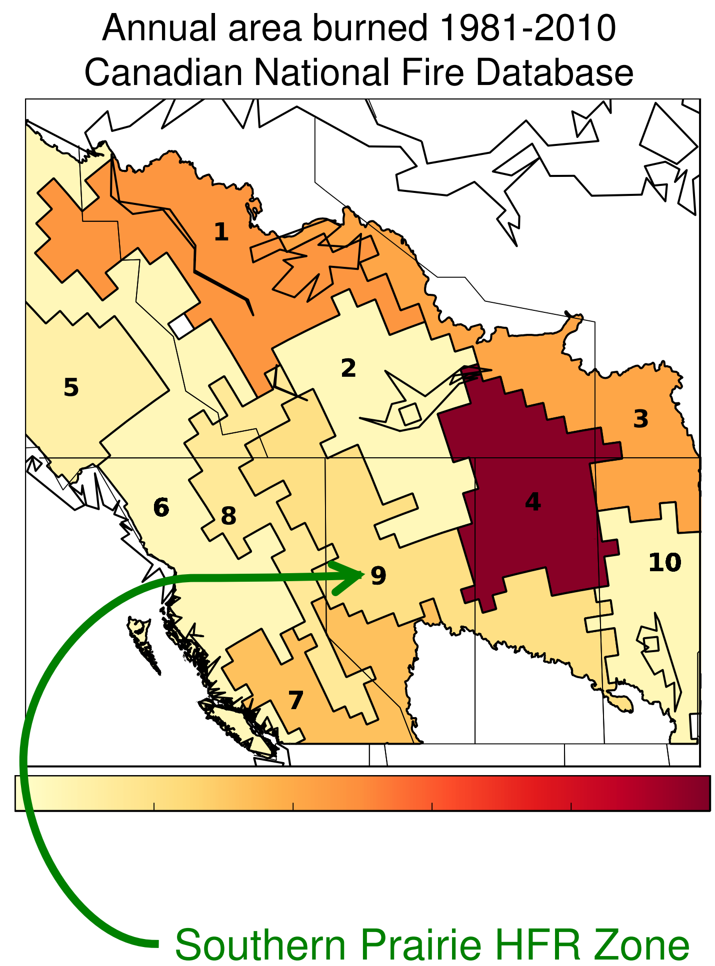
Avian escape. Photo, Mark Blinch/Reuters

Edmonton Expo Centre at Northlands. Photo, Chris Bolin

Timberlea. Photo, Chris Bolin

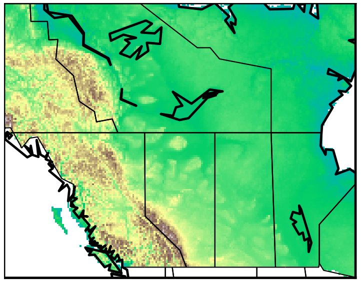
Fire risk (Kirchmeier-Young et al, in prep)

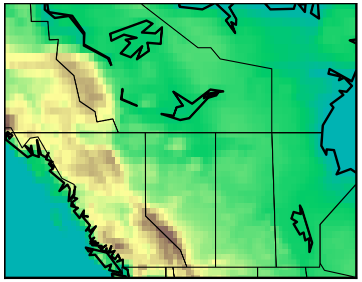
- We ask whether human induced climate change has affected extreme fire indices
- We consider
  - 90th percentile of fire index values for each fire season (MJJAS)
  - the "Southern Prairie" Homogeneous Fire Regime zone
  - fire indices that reflect variations in fire risk on different time scales
    - Fire Weather Index
    - Fine Fuels Moisture Code
    - Duff Moisture Code
    - Drought Code
  - the indices depend on temperature, relative humidity, wind speed, and precipitation



Models, data processing

- We use the CanESM2 large ensemble simulations
  - 50 run ensembles with historical anthropogenic and natural forcing combined (ALL) and historical natural forcing (NAT) only
- We downscale the model to a finer resolution
  - using an advanced statistical downscaling scheme

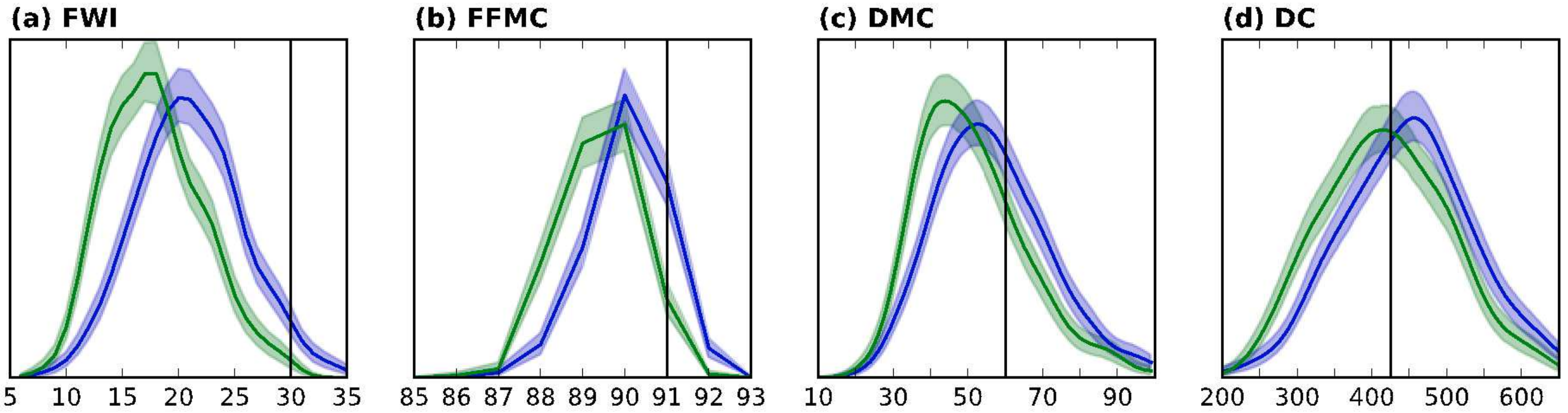




  - surface air temperature, relative humidity, wind speed and precipitation are downscaled using the Global Fire Weather Database (MERRA reanalysis based) and a new, high resolution blended precipitation dataset as the “downscaling targets”
  - fire indices are derived using the downscaled data

Results for HFR zone 9

Estimated distributions of the 90th percentiles of the fire indices for 2011-2020 under **ALL** and **NAT** forcing



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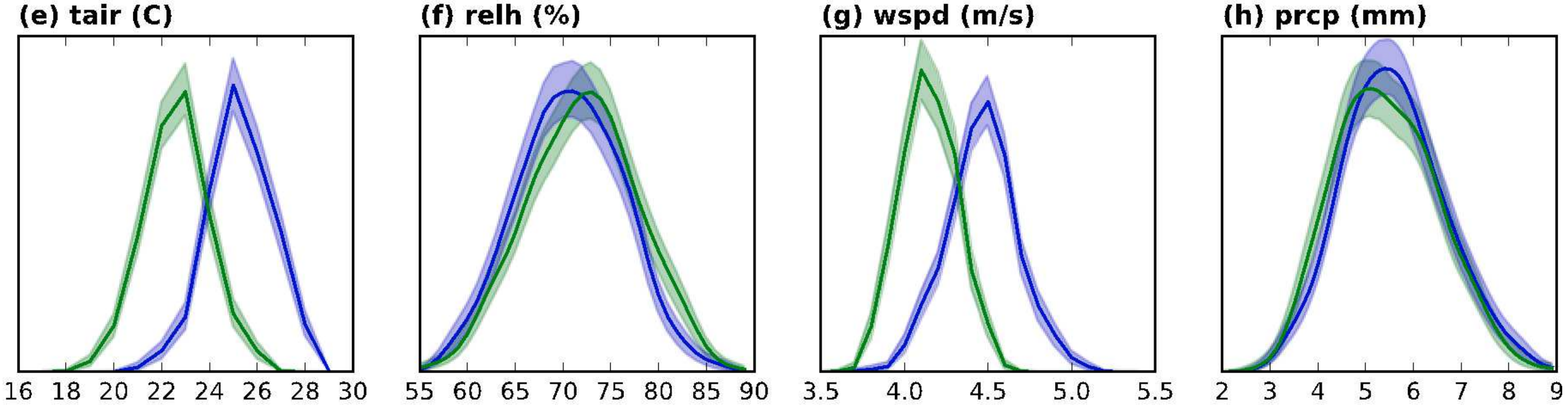

The shift towards higher values is driven primarily by changes in temperature and wind speed as seen from the distributions of the 90th percentiles of the underlying meteorological variables

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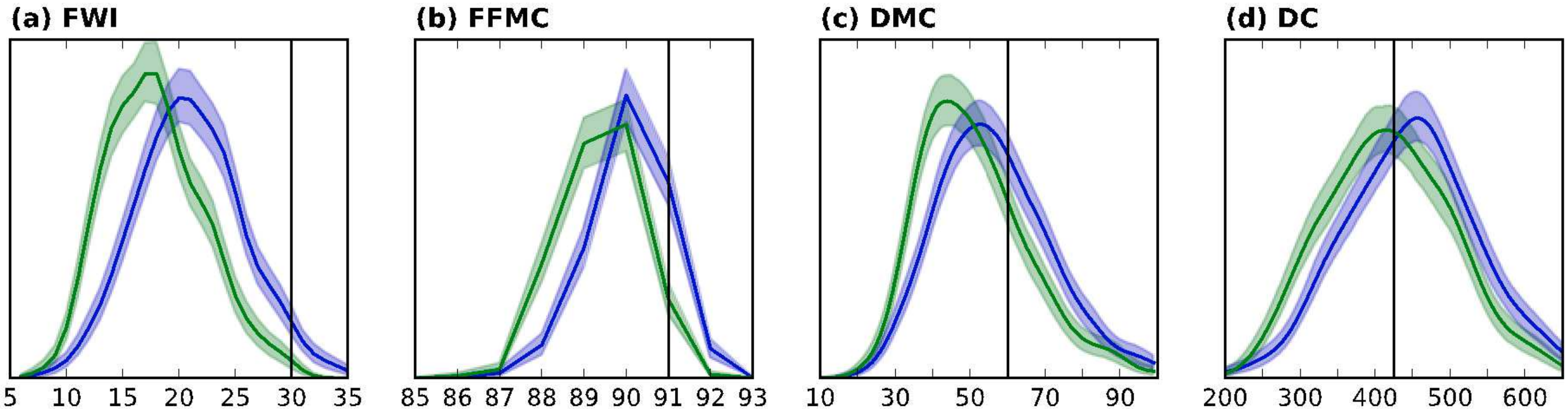
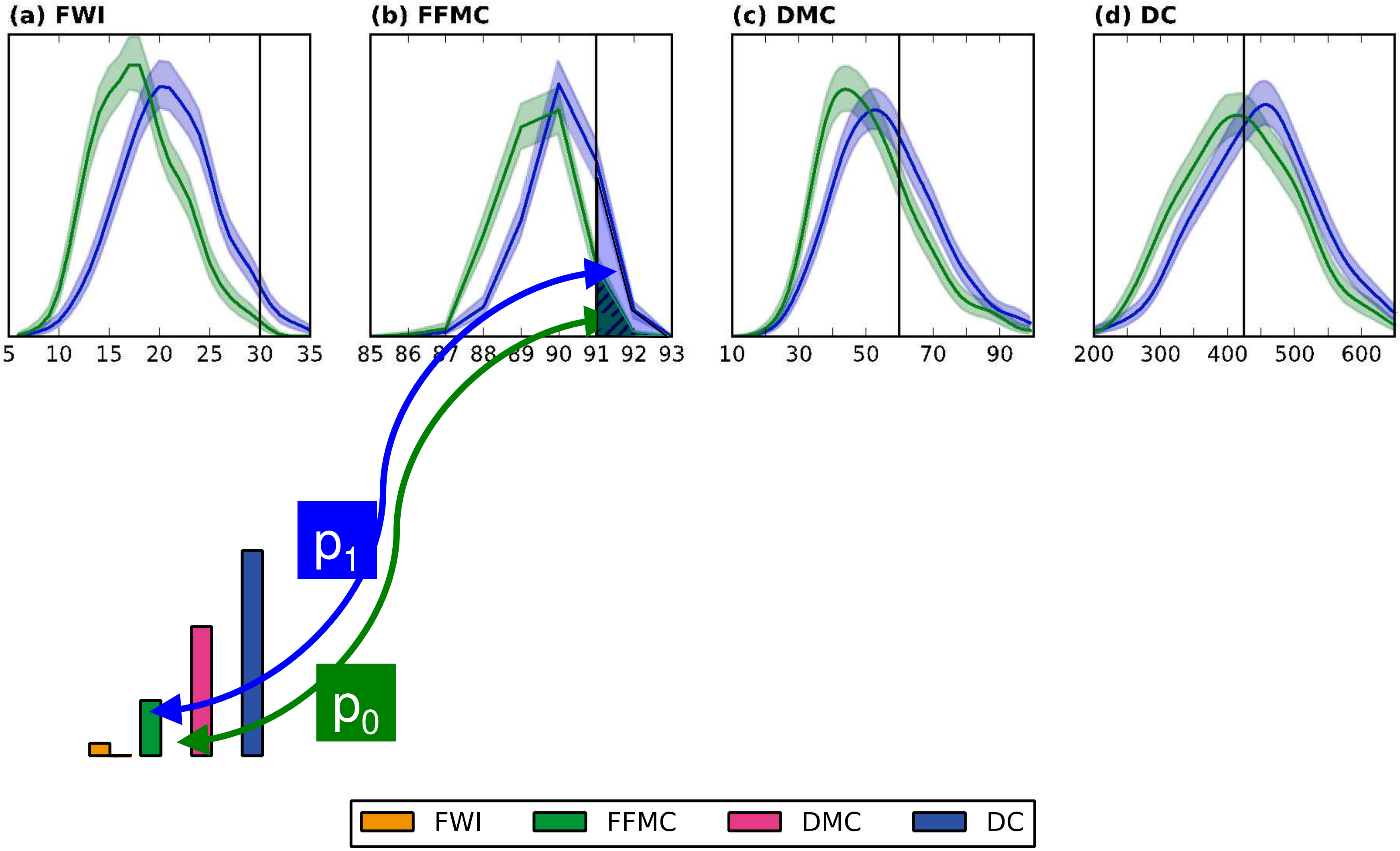


The shift towards higher values is driven primarily by changes in temperature and wind speed as seen from the distributions of the 90th percentiles of the underlying meteorological variables

Vertical lines represent *Canadian Wildland Fire Information System* (CWFIS) "extreme" levels

Has human induced climate change increased fire risk in HFR zone 9?



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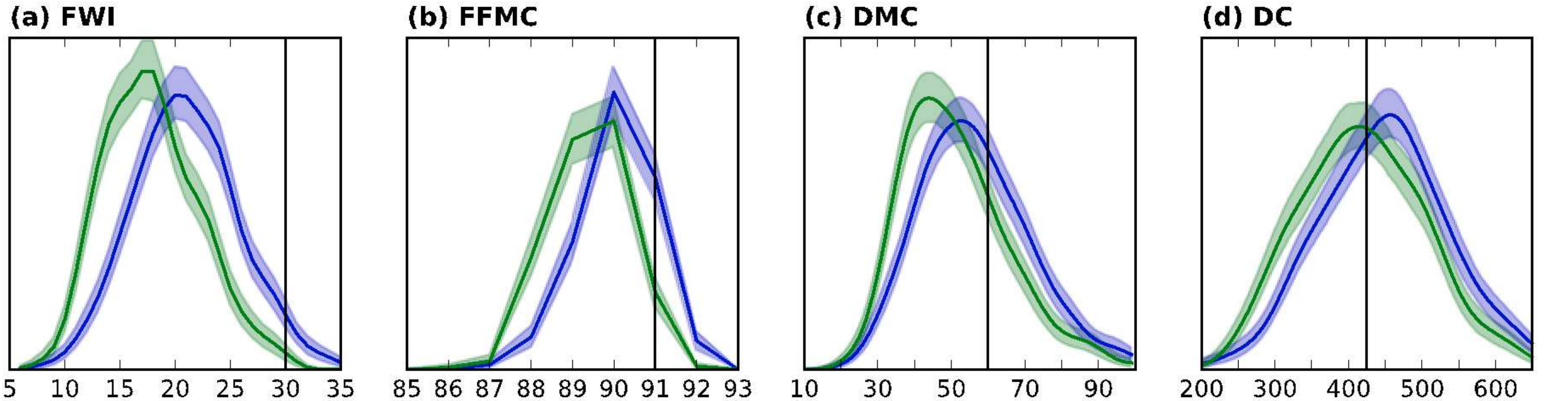


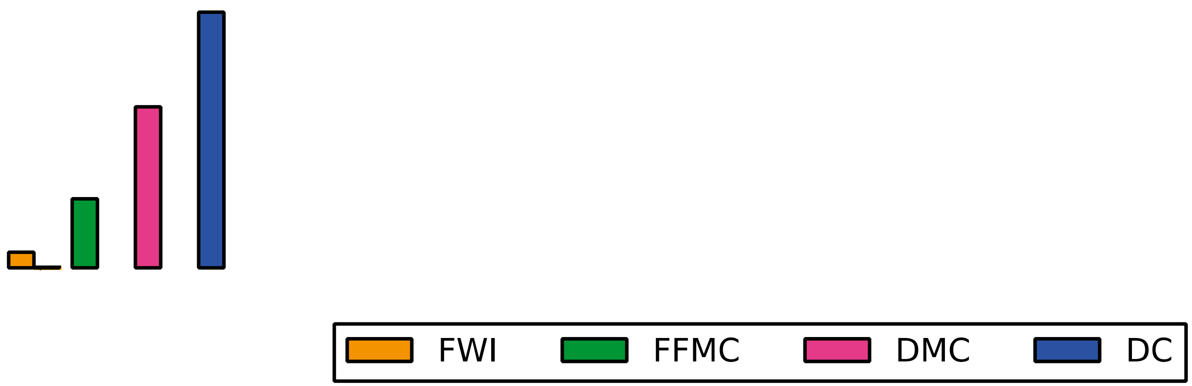
=FAR

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

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

d) RR

$$\mathrm{RR} = \frac{p_1}{p_0}$$



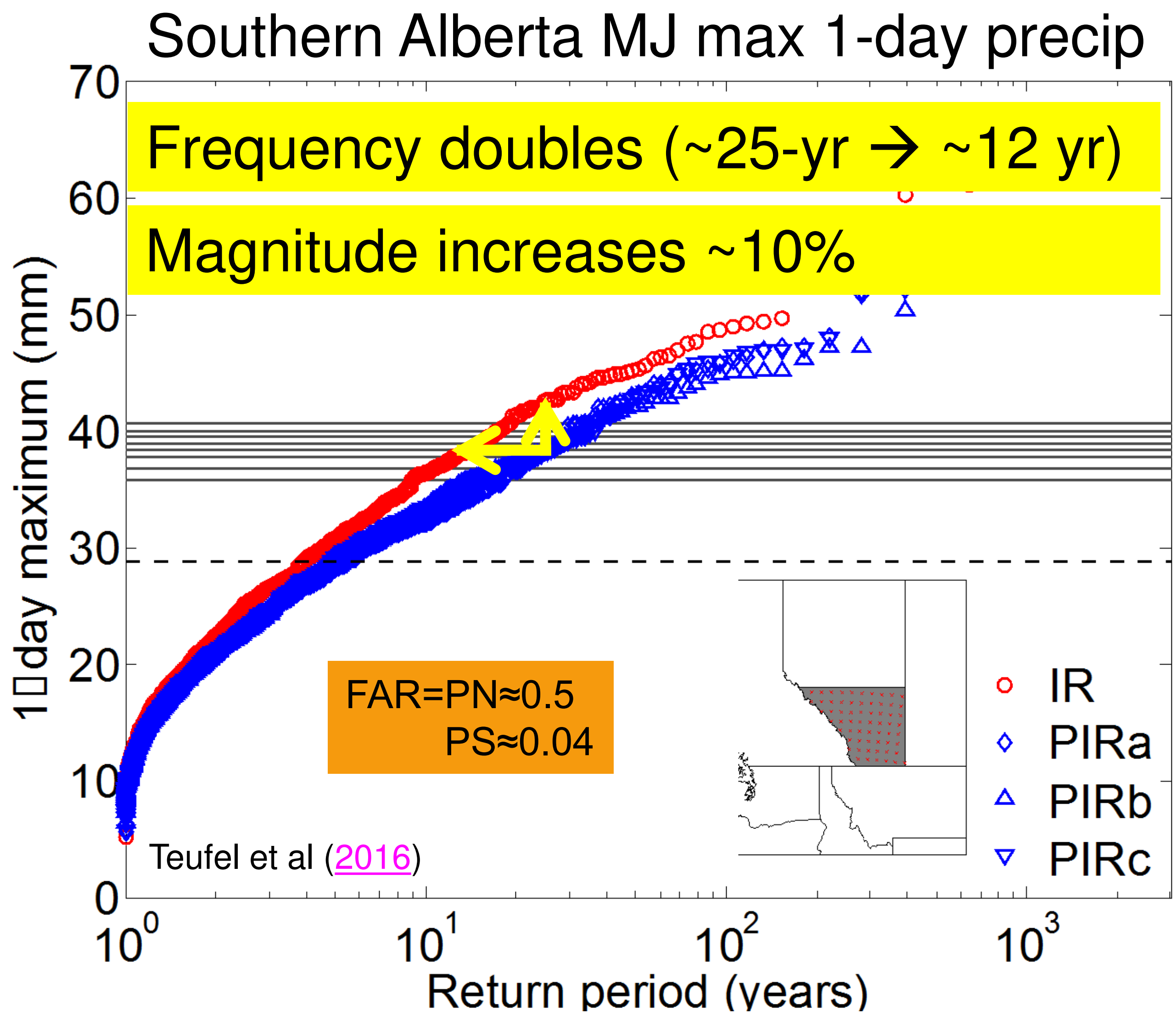
Calgary flood, 2013

- 100,000 displaced, 5 deaths
- 2nd 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)

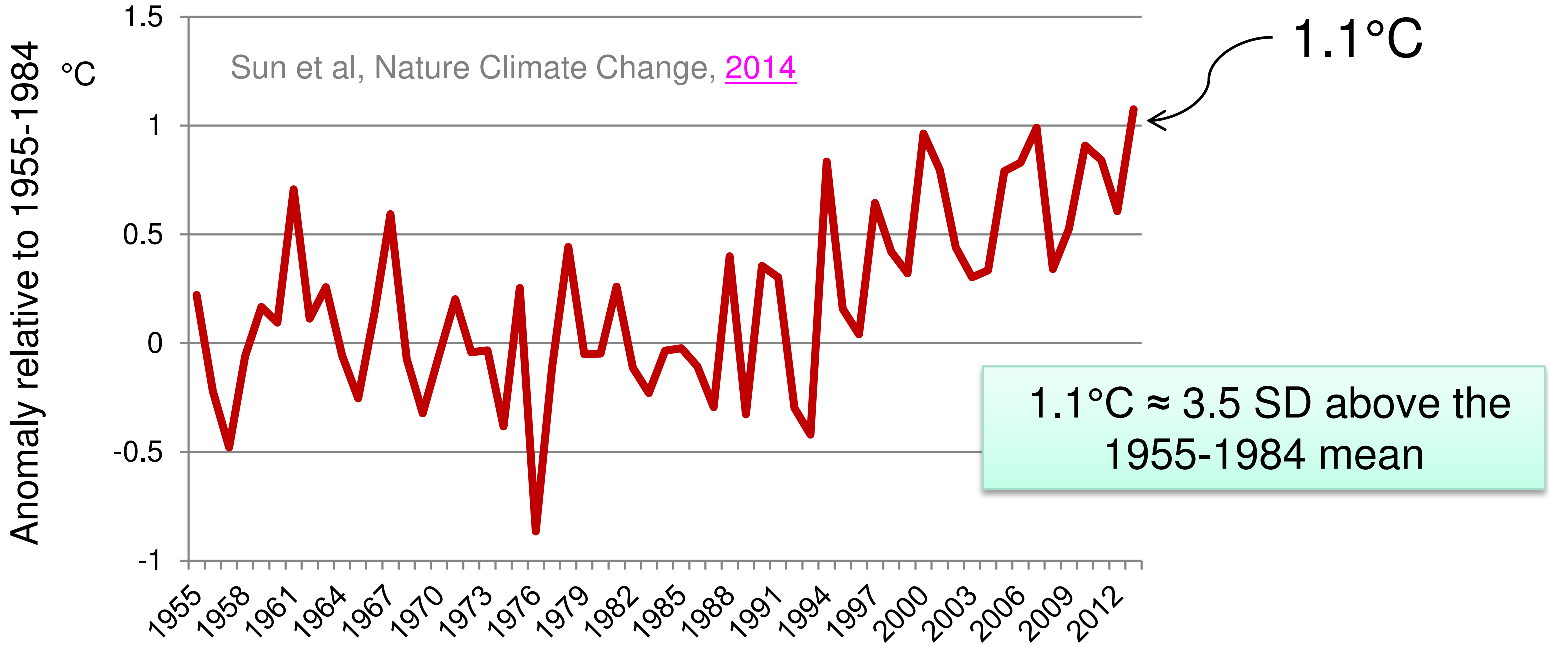


China’s Hot Summer of 2013

- 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

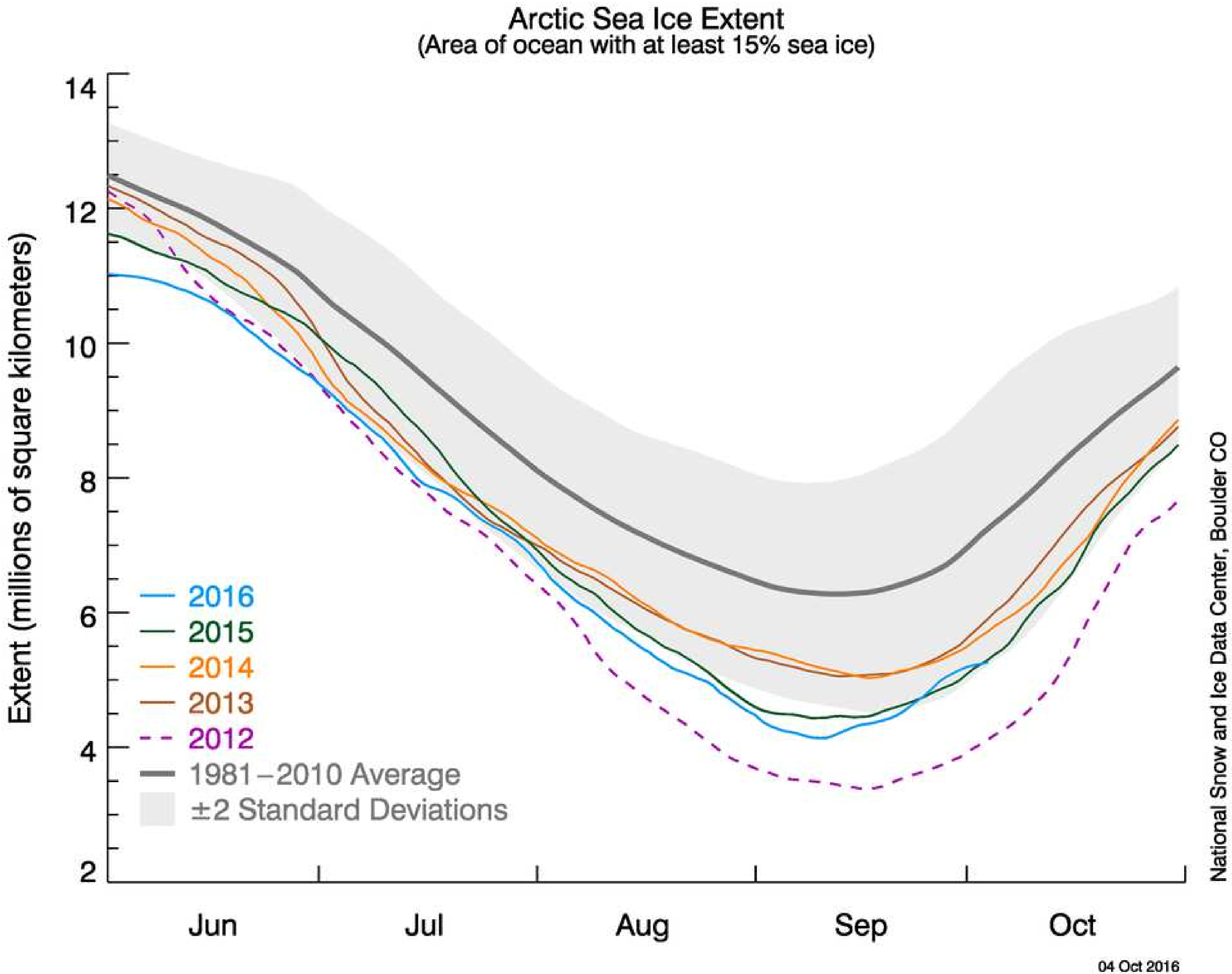
RCP4.5
RCP8.5

Frequency
Mean temp

23%, 4.3-yr →

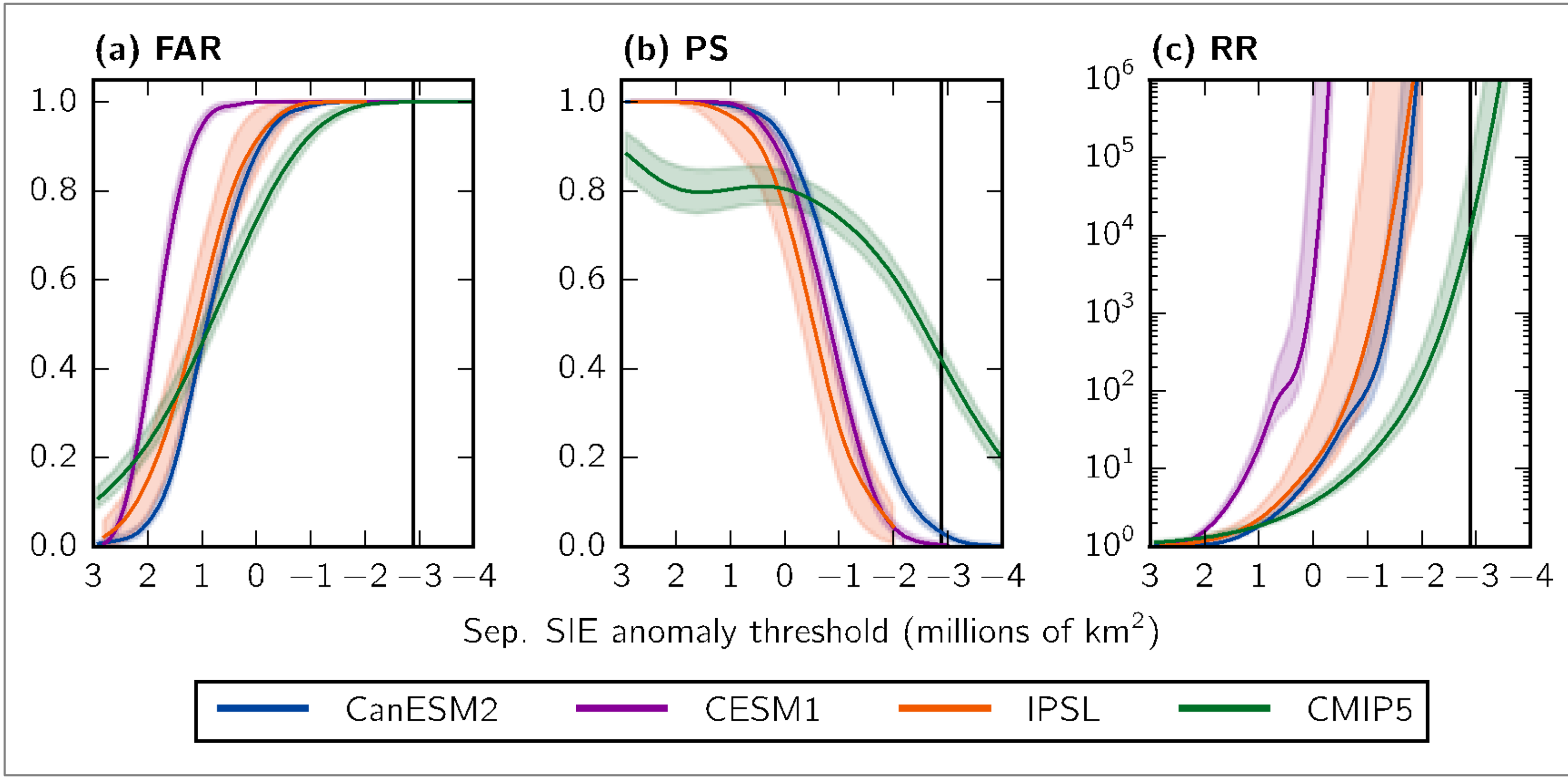
Record low Arctic sea ice cover - 2012

Photo: F. Zwiers **(approach to Alert, Aug., 2009)**



Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)
Extent (millions of square kilometers)
14
12
10
8
6
4
2
Jun
Jul
Aug
Sep
Oct
2016
2015
2014
2013
2012
1981−2010 Average
±2 Standard Deviations
National Snow and Ice Data Center, Boulder CO
04 Oct 2016

Arctic sea-ice extent event attribution



Kirchmeier-Young et al (2016; in press)

All models indicate an event of a magnitude equal to or more extreme than the 2012 record minimum would be *exceptionally unlikely* to occur under natural forcing alone.
ALL forcing is a necessary, but not sufficient cause.

Some unresolved issues

Photo: F. Zwiers (Marsh Wren)

Some unresolved issues

- Event characterization
  - Class vs individual, risk-based vs storyline
  - *Individual* is not completely 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 of the media and disaster response/recovery cycle


Questions?
https://www.pacificclimate.org/
Photo: F. Zwiers