Observed and Projected Changes in Extremes: Detection, Attribution and Uncertainty Characterization

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IMAGe TOY2012
Uncertainty in Climate Change Research: An Integrated Approach

- Detection and Attribution
  - Definitions
  - Quick look at the methodology (to highlight challenges and sources of uncertainty)

- Event Attribution
  - Methodologies
  - Examples

D&A

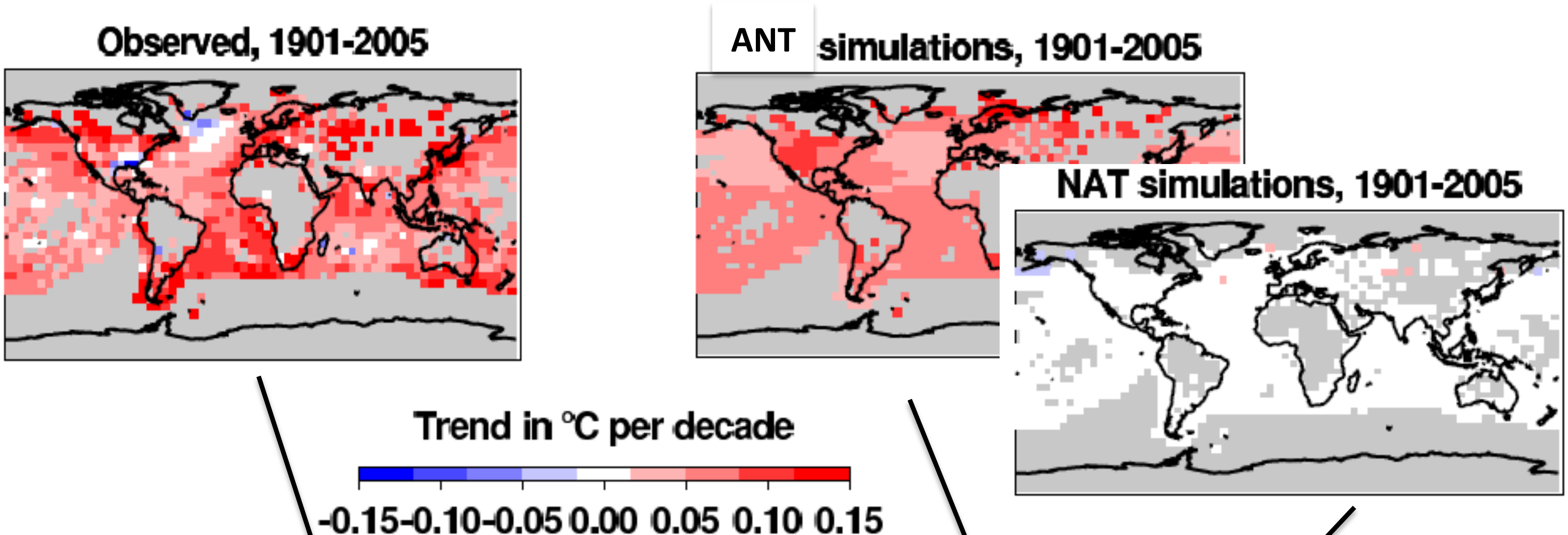
- Detection: the process of demonstrating that changes in a system's behavior are *statistically significant beyond what can be explained by internal (natural) variability* alone.

- Attribution: the process of determining the *relative contribution of multiple factors* that may be responsible for those changes, and *assigning a level of confidence* to this comparative evaluation.

Formal D&A

Formal D&A identifies a pattern in observations, the *fingerprint* (spatial field or temporal trend or both, representing *long-term/large scale change* in a variable), and utilizes *model output* to

- characterize the internal variability of that pattern,
- extract the corresponding fingerprints from model experiments run with different external forcings.



$$\mathbf{Y} \qquad \mathbf{X} = (\vec{x}_{ant}, \vec{x}_{nat})$$

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

Slide from Gabi Hegerl's presentation at Geneva IPCC WG1/WG2 Meeting on D&A, September 2009

Formal D&A (continued)

A *regression analysis* relates observed and modeled fingerprints and a *formal hypothesis testing* on the coefficients of the individual modeled fingerprints takes place to determine

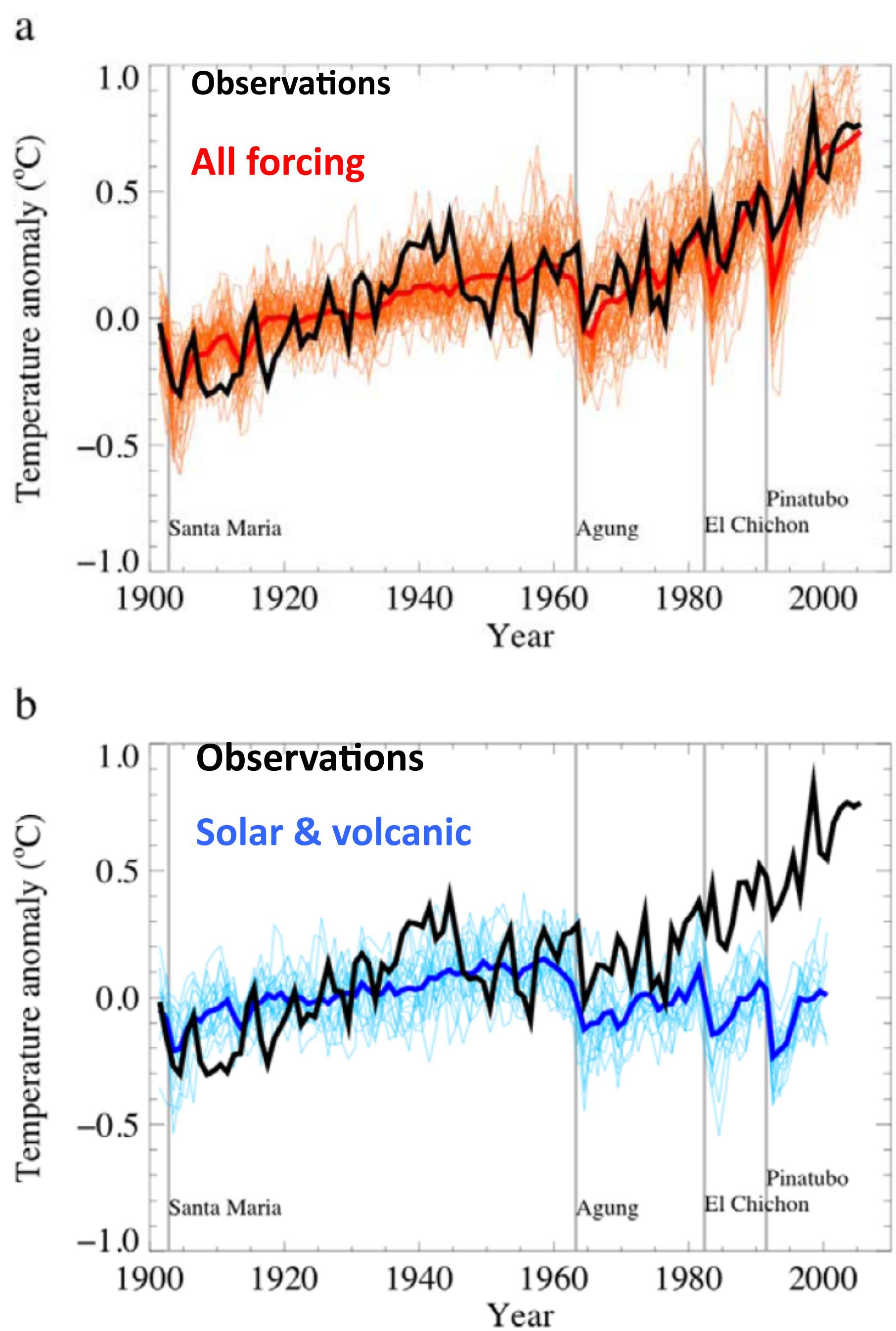
A) that the coefficients are significantly different from zero (it is not all noise) and
B) the relative magnitude of the coefficients of the anthropogenically forced/naturally forced fingerprints.

Formal D&A (continued)

A critical component in the regression analysis is the *error term*, which needs to characterize the behavior of **Y** when left alone (its internal variability). In all cases, the error term is not assumed to be the realization of a white noise process, and control simulations are used to characterize its covariance structure.

Less formal D&A

For some variables D&A has taken place more qualitatively, by *evaluating the consistency/coherence of the observed changes with the changes modeled* in the presence of anthropogenic/ all forcings, as opposed to the changes (or their absence) modeled in the presence of natural-only forcings.


a
Observations
All forcing
Temperature anomaly (°C)
1.0
0.5
0.0
−0.5
−1.0
Santa Maria
Agung
El Chichon
Pinatubo
1900
1920
1940
1960
1980
2000
Year
b
Observations
Solar & volcanic
Temperature anomaly (°C)
1.0
0.5
0.0
−0.5
−1.0
Santa Maria
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Pinatubo
1900
1920
1940
1960
1980
2000
Year

Less formal D&A (continued)

- For some variables D&A has taken place by focusing the formal work on a *closely related parameter* (e.g., attribution of **extreme temperatures** in Europe in 2003 through D&A of changes in **mean summer temperatures**. Stott et al. 2004).

D&A of Extremes (from the SREX)

- Warming of extreme daily minimum and maximum temperatures at the global scale *Likely*

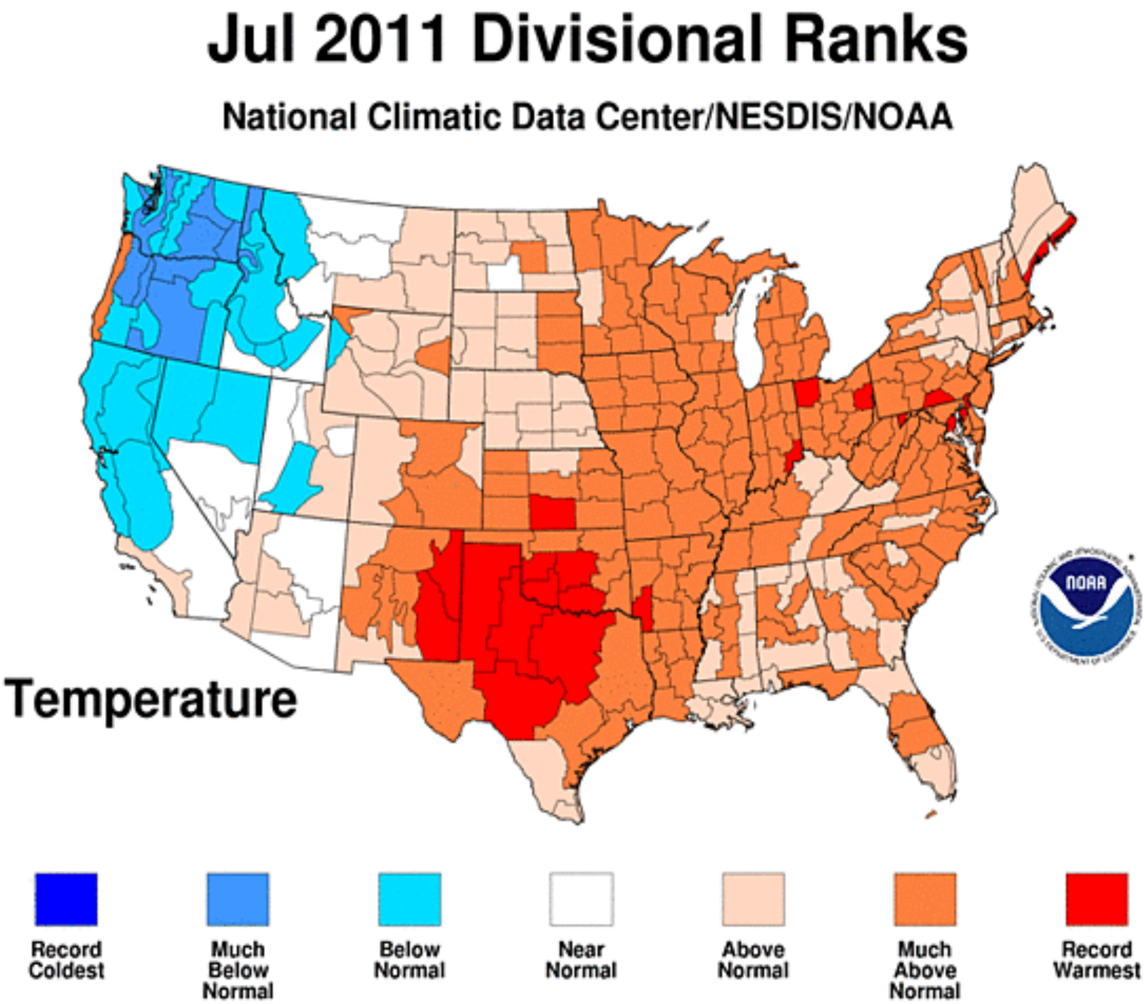
- Large-scale increase in heavy precipitation cannot be explained by natural variability alone

  Medium confidence

Attribution of individual (extreme) weather events

The link between **individual extreme weather events** and anthropogenic climate change is investigated by process-based studies or probabilistic approaches.

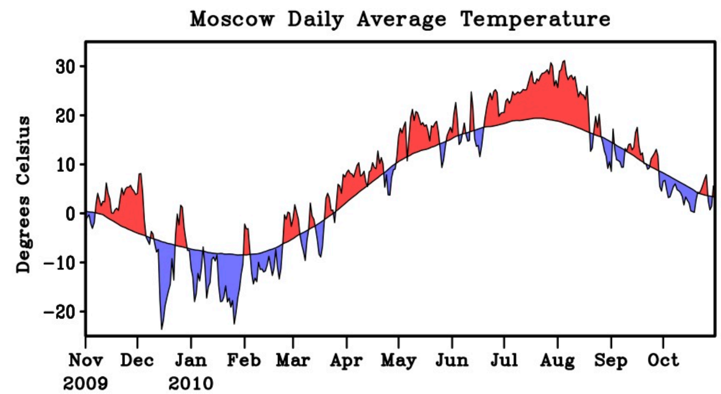
- Fraction Attributable Risk
  - 2003 European heatwave
  - 2000 UK floods
- Analysis of large circulation patterns/observed record statistics/ad-hoc modeling studies
  - 2010 Moscow heatwave
  - 2011 Texas drought & heat

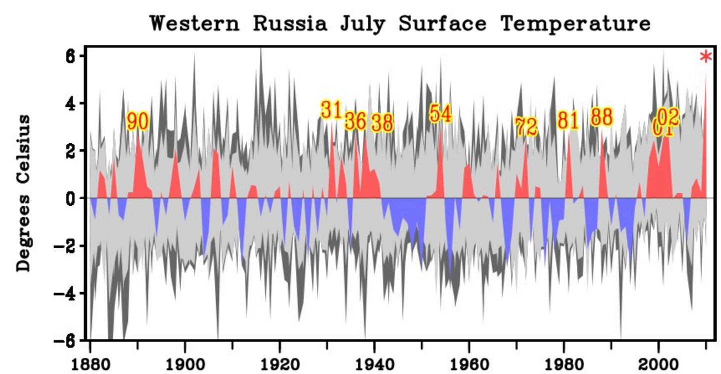


- Oklahoma and Texas had their warmest months ever on record, with average temperatures of 88.9 degrees F and 87.1 degrees F, respectively.
- Dallas exceeded 100 degrees F on 30 of the 31 days in July.
- The July heat wave was characterized by unusually warm minimum temperatures, during nights and early mornings. This is typical of U.S. heat waves in the last decade, and consistent with increasing warm summer nighttime extremes observed across much of the country since the late 20th century.

Central Russia heatwave, 2010

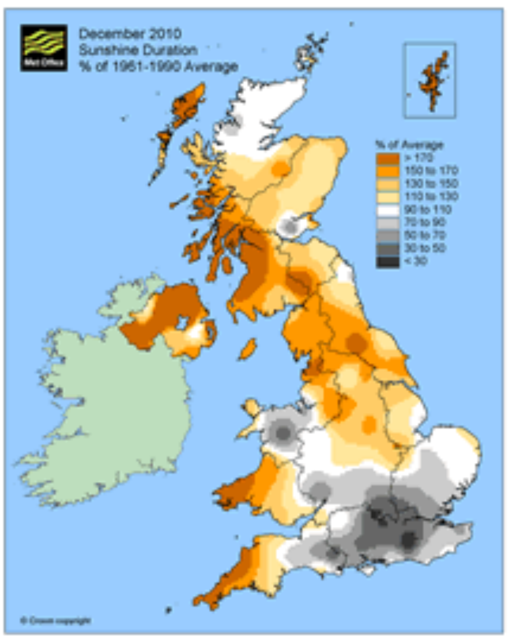
- Moscow beat previous record for July temperatures by 2.5°C

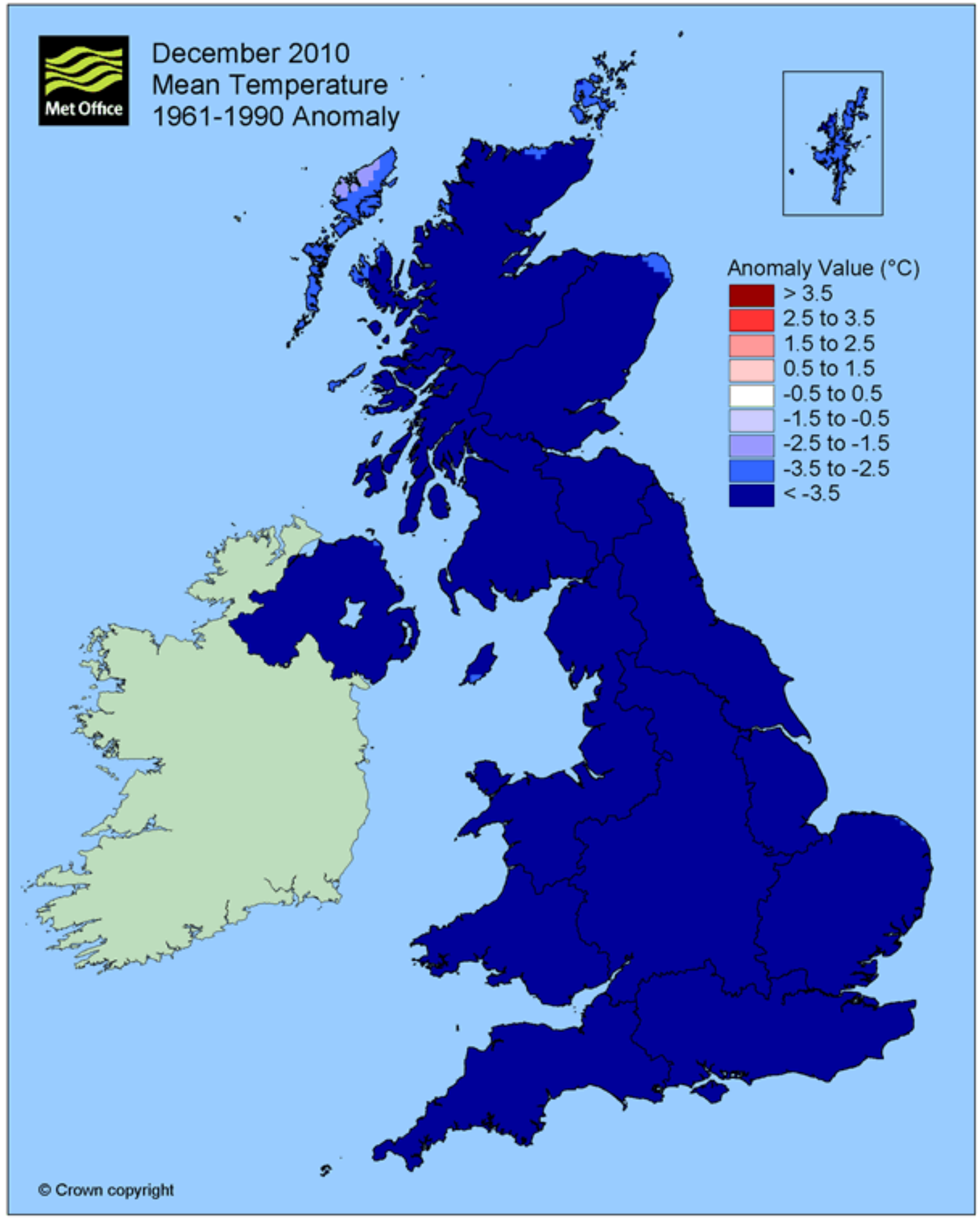




December 2010 in the UK

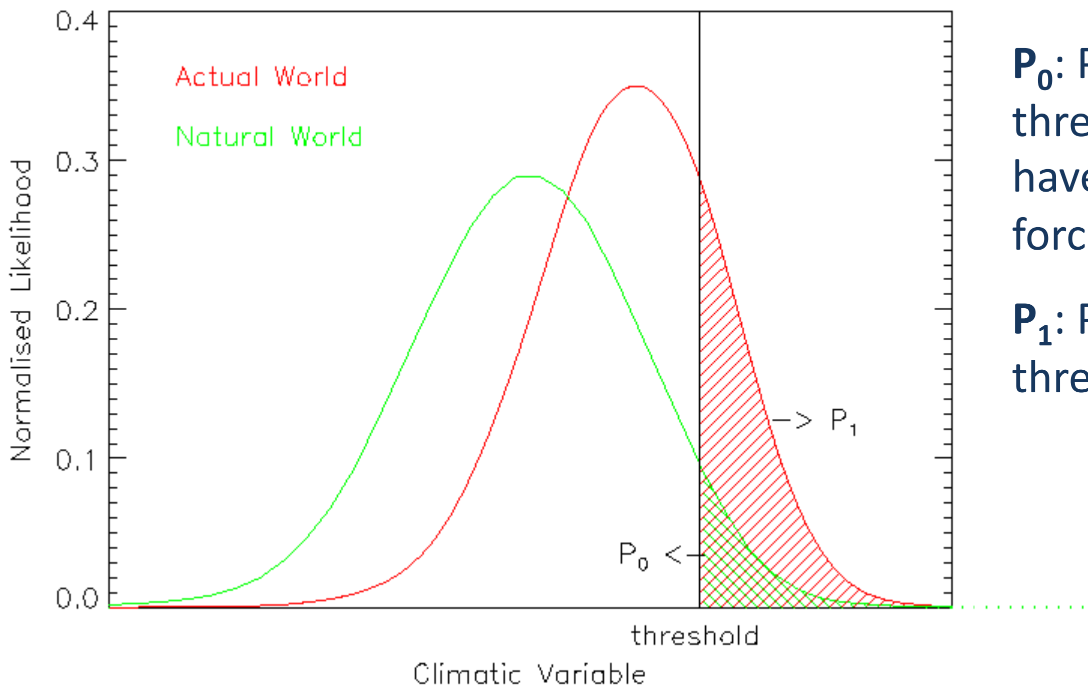
- The coldest December across the UK since the national series began in 1910.





It is possible to make attribution statements about individual events by calculating the odds of such events and the change in odds attributable to particular factors, e.g., anthropogenic GHG emissions.

Fraction of Attributable Risk

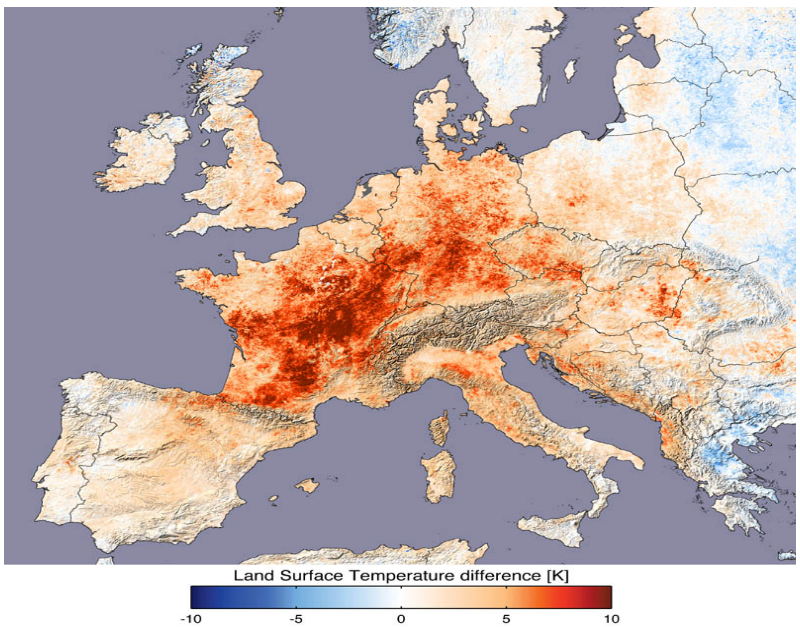


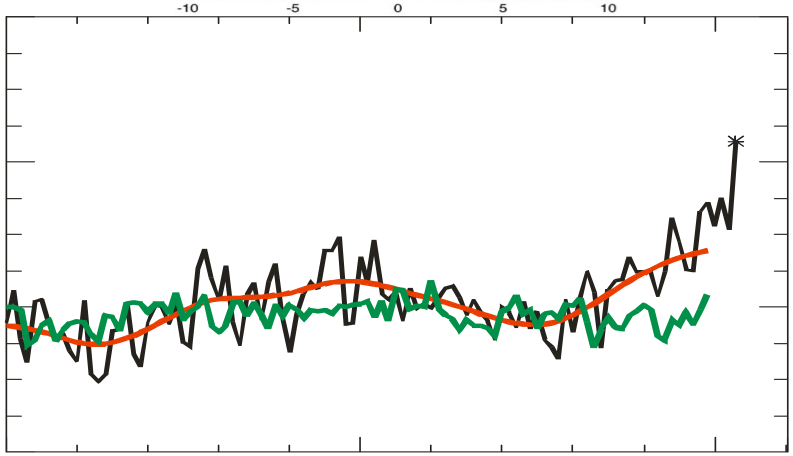
P_0: Probability of exceeding a threshold in the “world that might have been” (no anthropogenic forcings).

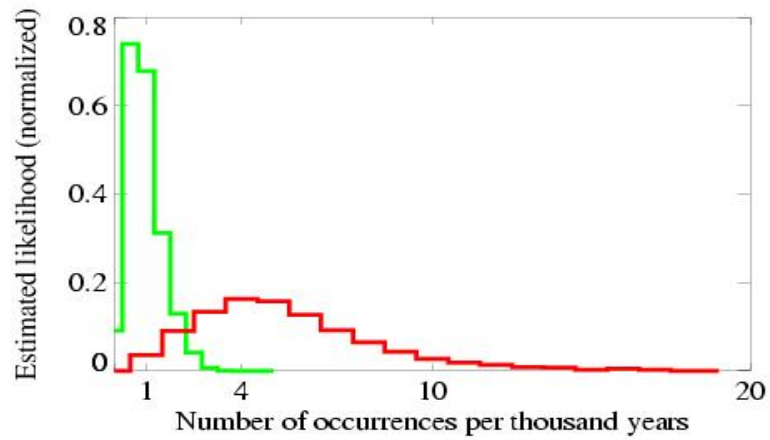
P_1: Probability of exceeding a threshold in the actual world.

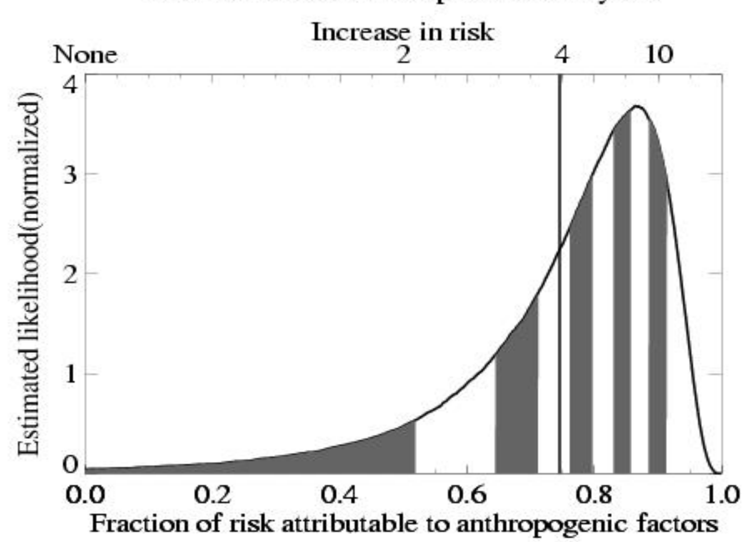
FAR = 1 – (P_0 / P_1)

Human influence has very likely at least doubled the probability of European summer temperatures as hot as 2003 (Stott et al., 2004)

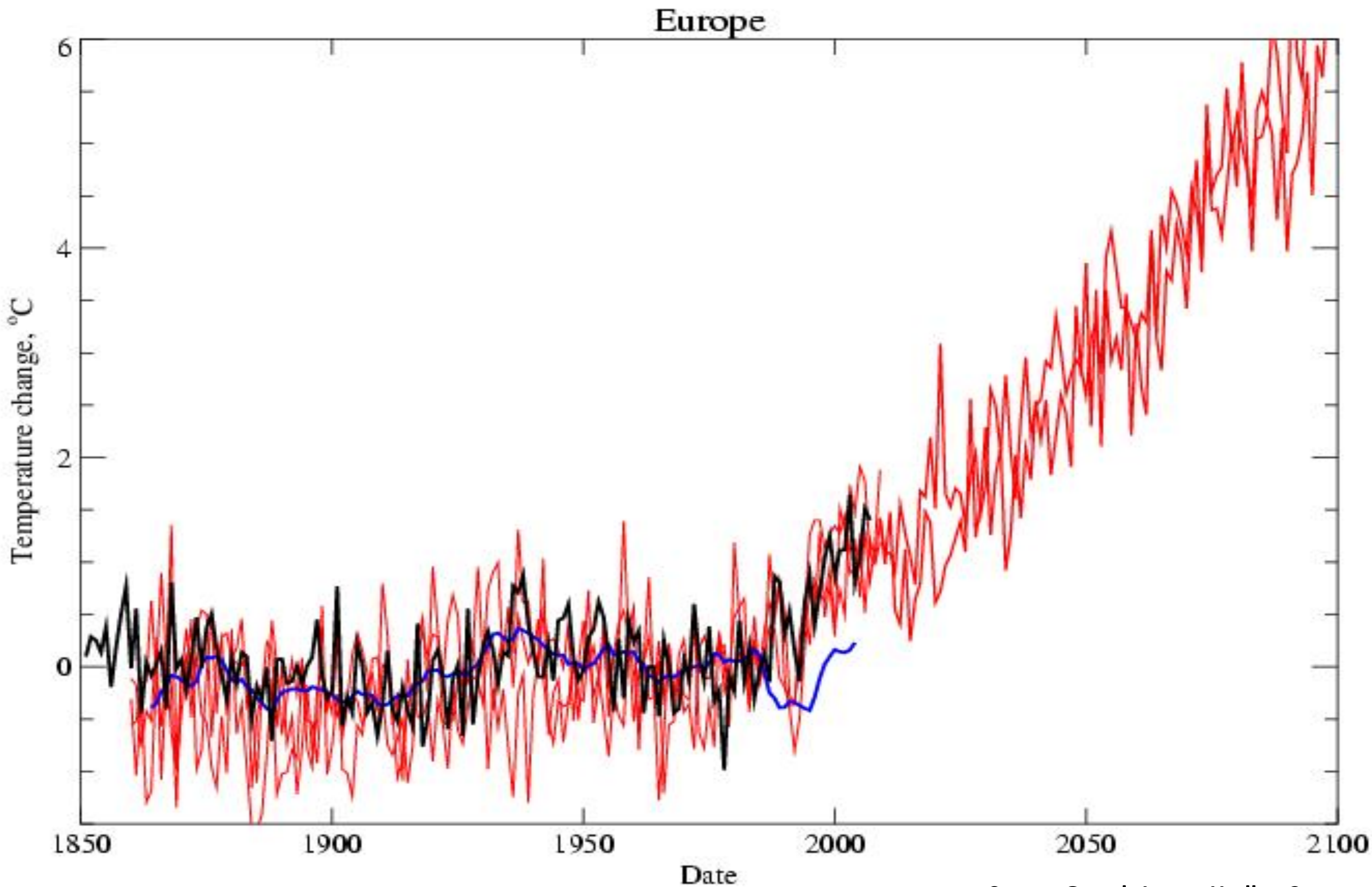








The European summers of 2003 and 2006 could be normal by 2040 and cool by 2060



Source Gareth Jones, Hadley Centre

Ad-hoc modeling studies, process-based analysis

Use A-GCMs driven by observed and idealized SSTs to simulate:

i) Current world with observed SSTs -> $\mathbf{P_1}$
ii) The World that Might Have Been
(SSTs altered to remove human-induced component) -> $\mathbf{P_0}$

England and Wales flood risk

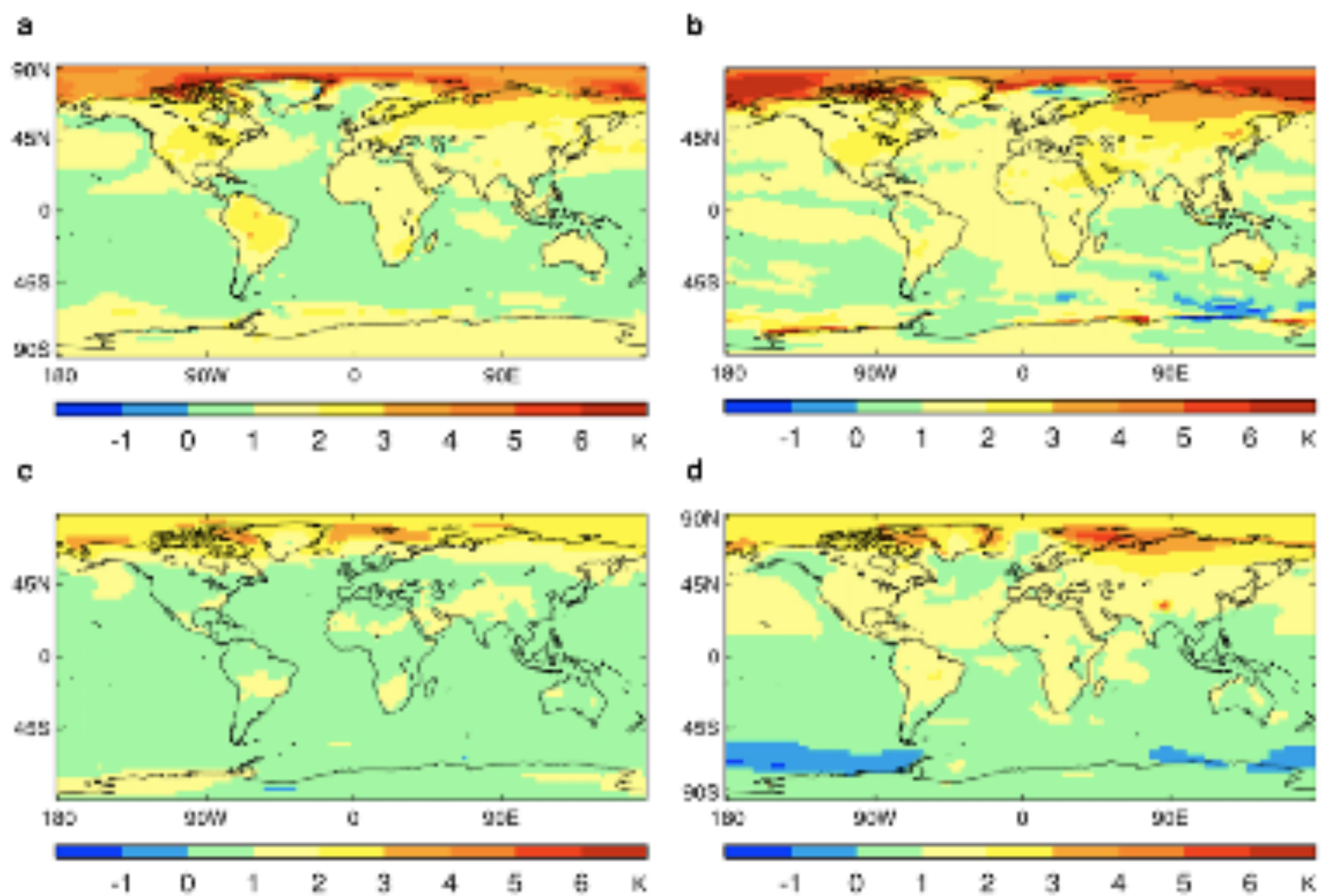
Pall et al., 2011

- UK flooding in October and November 2000 occurred during the wettest autumn in England & Wales since records began in 1766

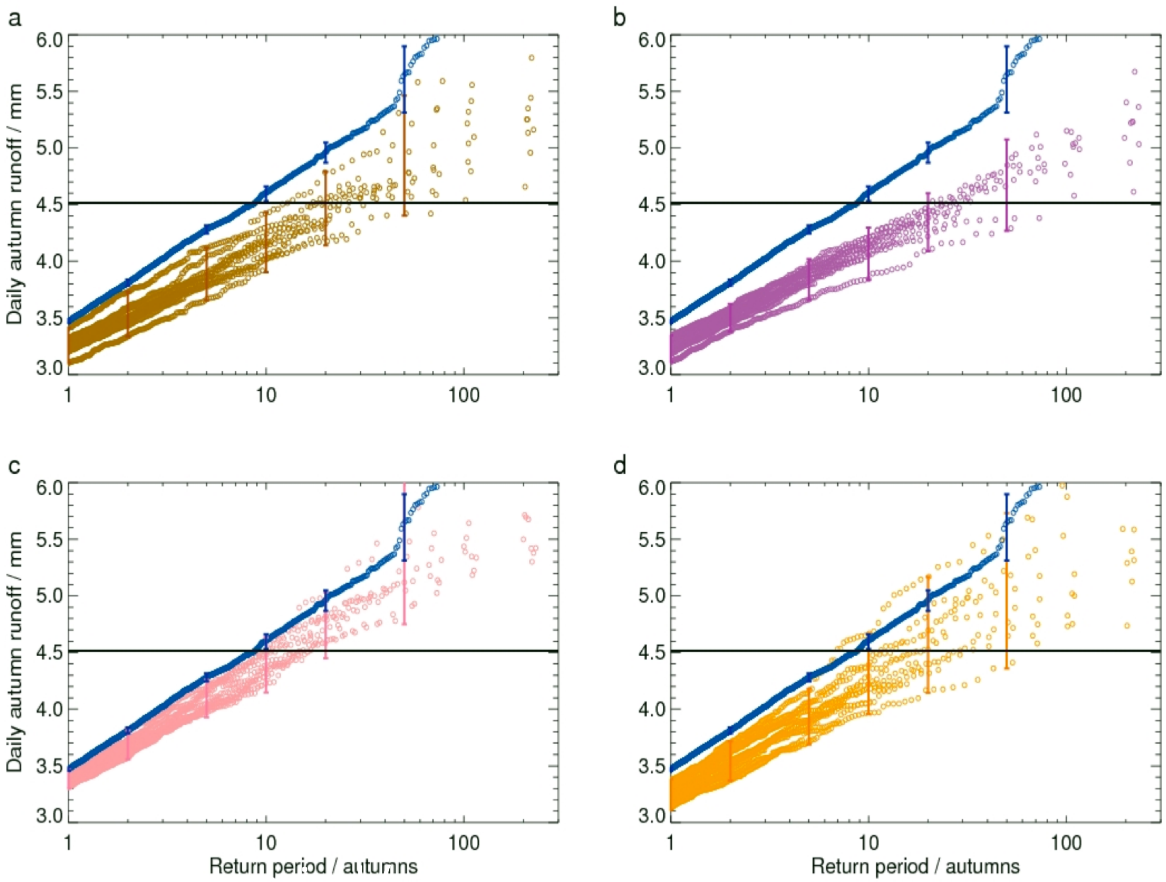
- Autumn 2000 weather was characterized by a general eastwards displacement of the North Atlantic jet stream from its climatological position, bringing intense systems further into western Europe

- Associated with a commonplace but anomalously strong 'Scandinavia' atmospheric circulation pattern

Patterns of SSTs representing estimates of SST changes due to human-induced GHG emissions are subtracted from the observed SSTs

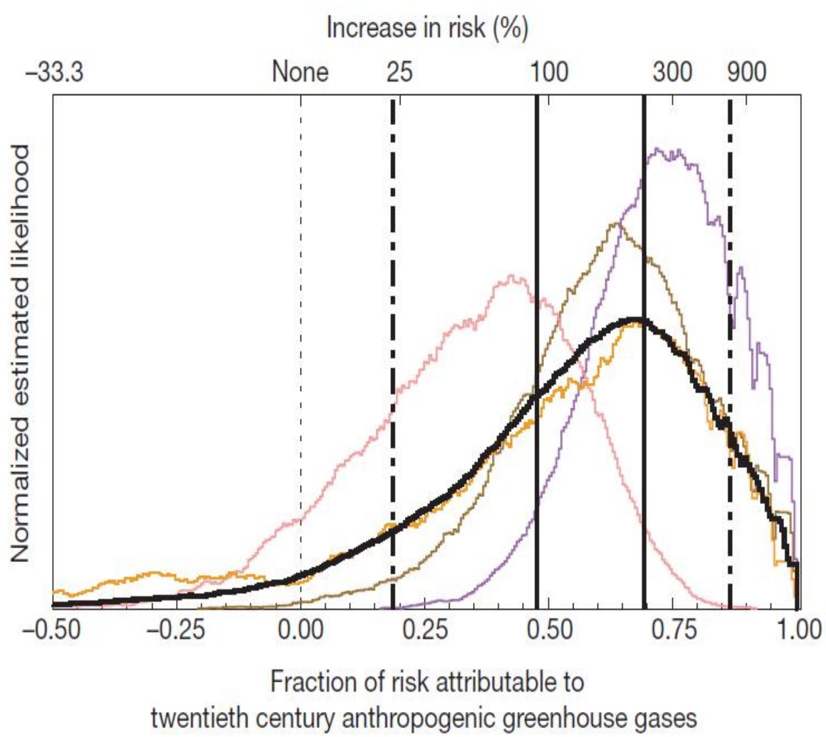


Change in return periods of daily river runoff



Publicly volunteered distributed computing used to generate several thousand seasonal-forecast-resolution climate model simulations of Autumn 2000 weather, for scenarios both with and without anthropogenic emissions, and feed them into a precipitation-runoff model to produce daily river runoff measures for England & Wales.

Change in risk of severe daily river runoff

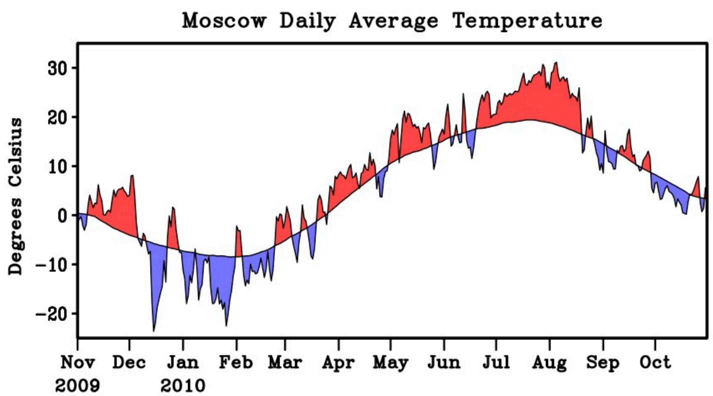


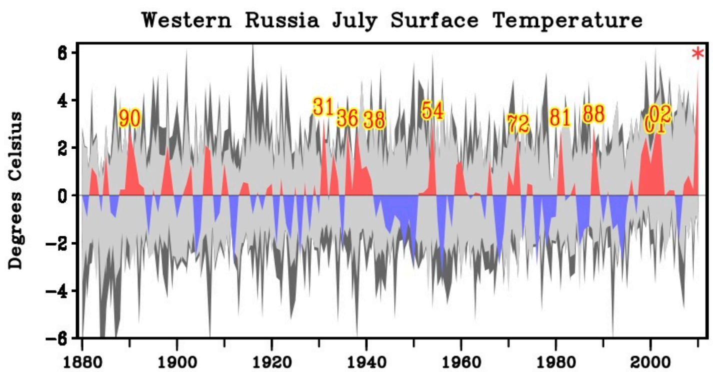
•Threshold representative of UK flooding in October and November 2000, occurring during the wettest autumn in England & Wales since records began in 1766

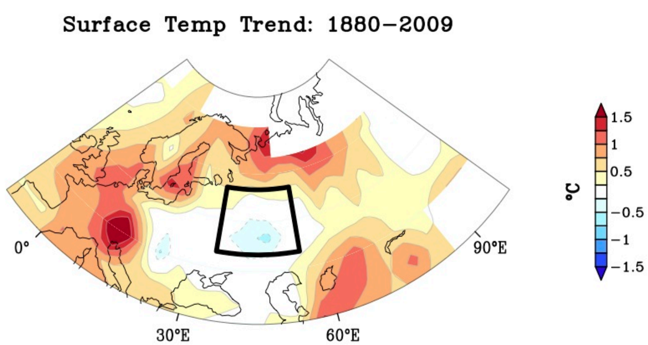
•In 9-out-of-10 cases model results indicate 20th century anthropogenic greenhouse gas emissions increased England & Wales flood risk in Autumn 2000 by more than 20%, and in 2-out-of-3 cases by more than 90%.

Pall et al., 2011

- Concludes that human-induced greenhouse gases increased the risk of flooding in 2000.
- Demonstrates the application of a methodology using climate models constrained by observed patterns of SSTs.
- Uses a single model with sensitivity tests carried out to test robustness but still only limited validation of the approach.
- Further work is needed to extend this approach to a wider variety of extreme weather events.
- There is a need to carry out rigorous assessments of model reliability/ model sensitivity.





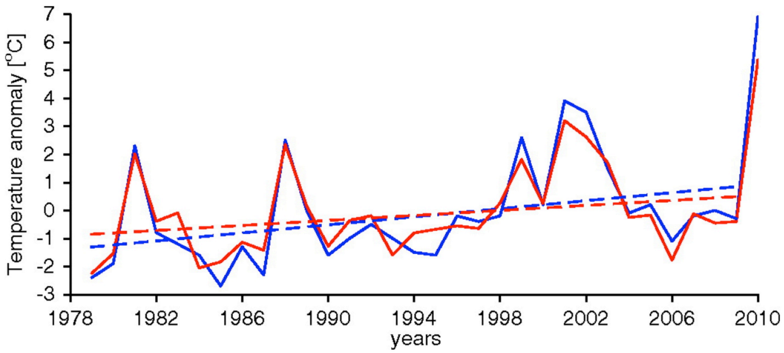


Dole et al., 2011

- Dole et al 2011 conclude that the heatwave was **primarily caused by internal atmospheric dynamical processes** and that it is very unlikely that warming attributable to increasing greenhouse gas concentrations contributed substantially to the magnitude of this heatwave.
- Unlike in central and Southern Europe**, there has been no long term warming trend** in Western Russia.
- From modeling experiments, they conclude that the persistent atmospheric blocking observed in July 2010 over Western Russia and responsible for the extreme heatwave, is **not attributable to external drivers**.
- While Dole et al (2011) demonstrate the large role played by natural factors they do not rule out the possibility that although the Moscow heatwave was a very rare event associated with a very unusual pattern of atmospheric blocking, **such an extreme heatwave could have been even less likely without human-induced climate change.**

Rahmstorf and Coumou, 2011

Comparison of temperature anomalies from remote sensing systems surface data (red; ref. 15) over the Moscow region (35ºE–40ºE, 54ºN–58ºN) versus Moscow station data (blue; ref. 21).



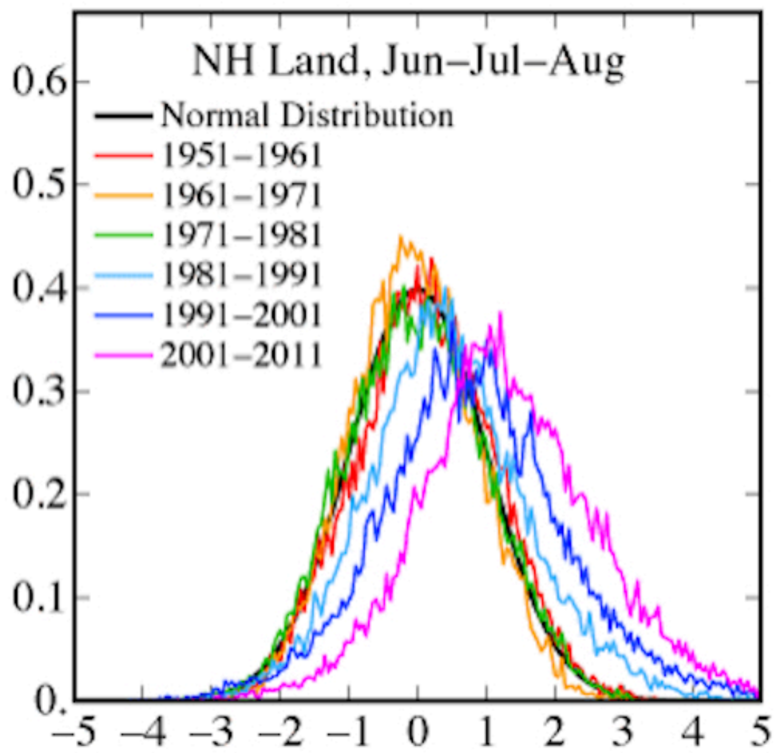
Rahmstorf S , Coumou D PNAS 2011;108:17905-17909

PNAS

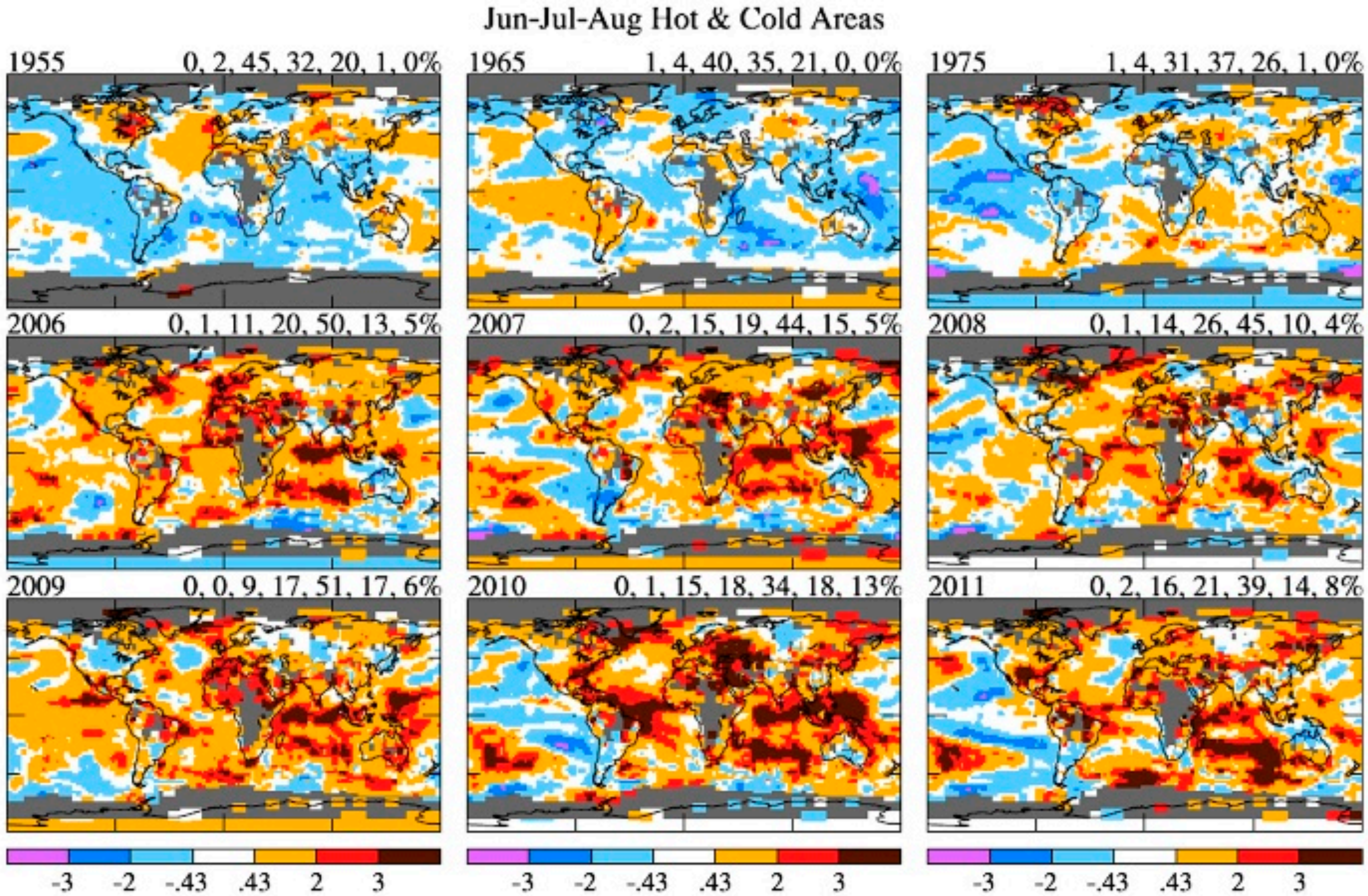
- Quantify the effect of long-term trends on the expected number of extremes.
- Estimate that **climatic warming has increased the number of new global-mean temperature records expected in the last decade from 0.1 to 2.8.**
- For July temperature in Moscow, estimate that **the local warming trend has increased the number of records expected in the past decade fivefold, which implies an approximate 80% probability that the 2010 July heat record would not have occurred without climate warming**.

Hansen et al., 2012

- Anomalies in exceedance of 3σ are becoming more and more common.
- Almost certainly Paris 2003, Moscow 2010 and Texas 2011 would not have happened.



Hansen et al., 2012



Projections of changes in extremes

How do we define extremes?

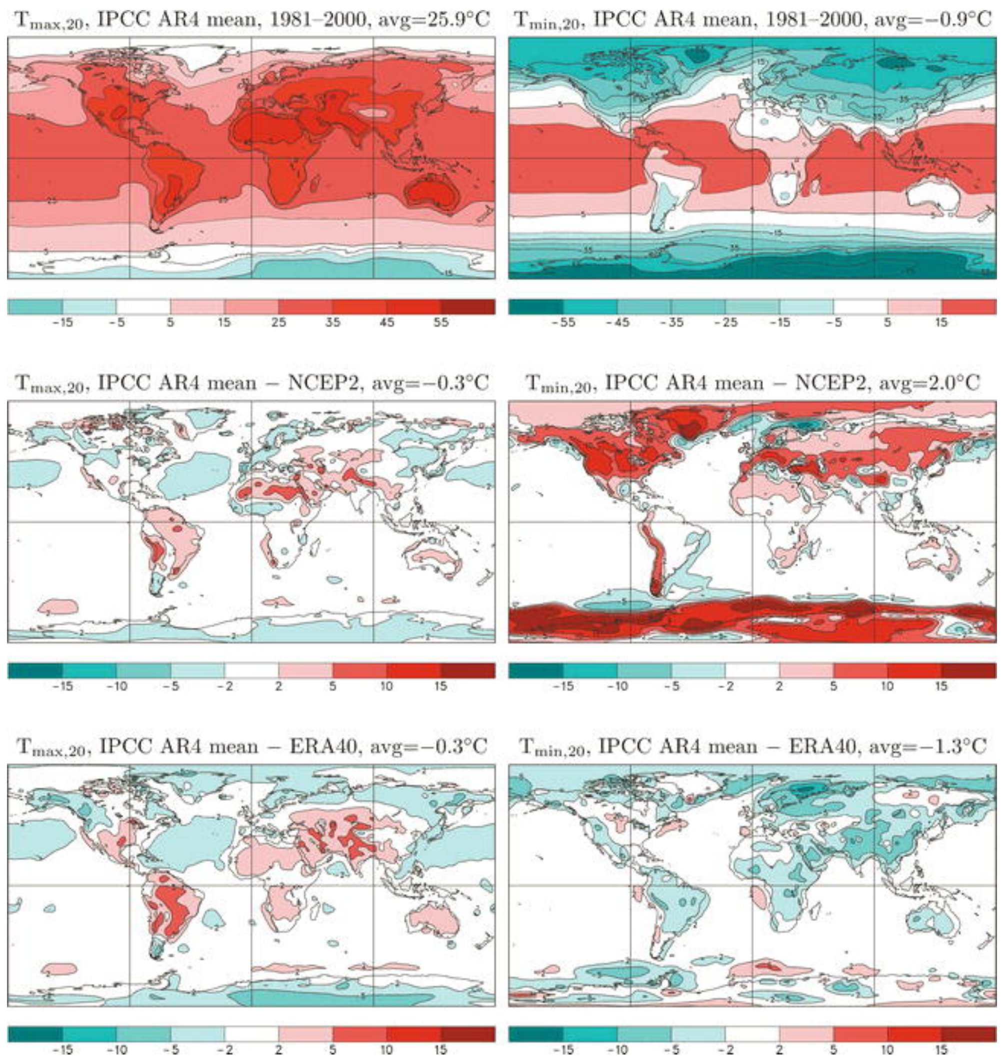
- Indices (Number of days in the year w/temperature above 90th percentile of climatology; Maximum 5-day precipitation; Frost days; Number of consecutive dry days…)

- Extreme value statistics (Return levels/return periods)

An example of multi-model analysis using the latter approach

Kharin et al., 2007

20-yr return levels for warm extremes (left) and cold extremes (right)



Multi-model means

Red areas: warm biases

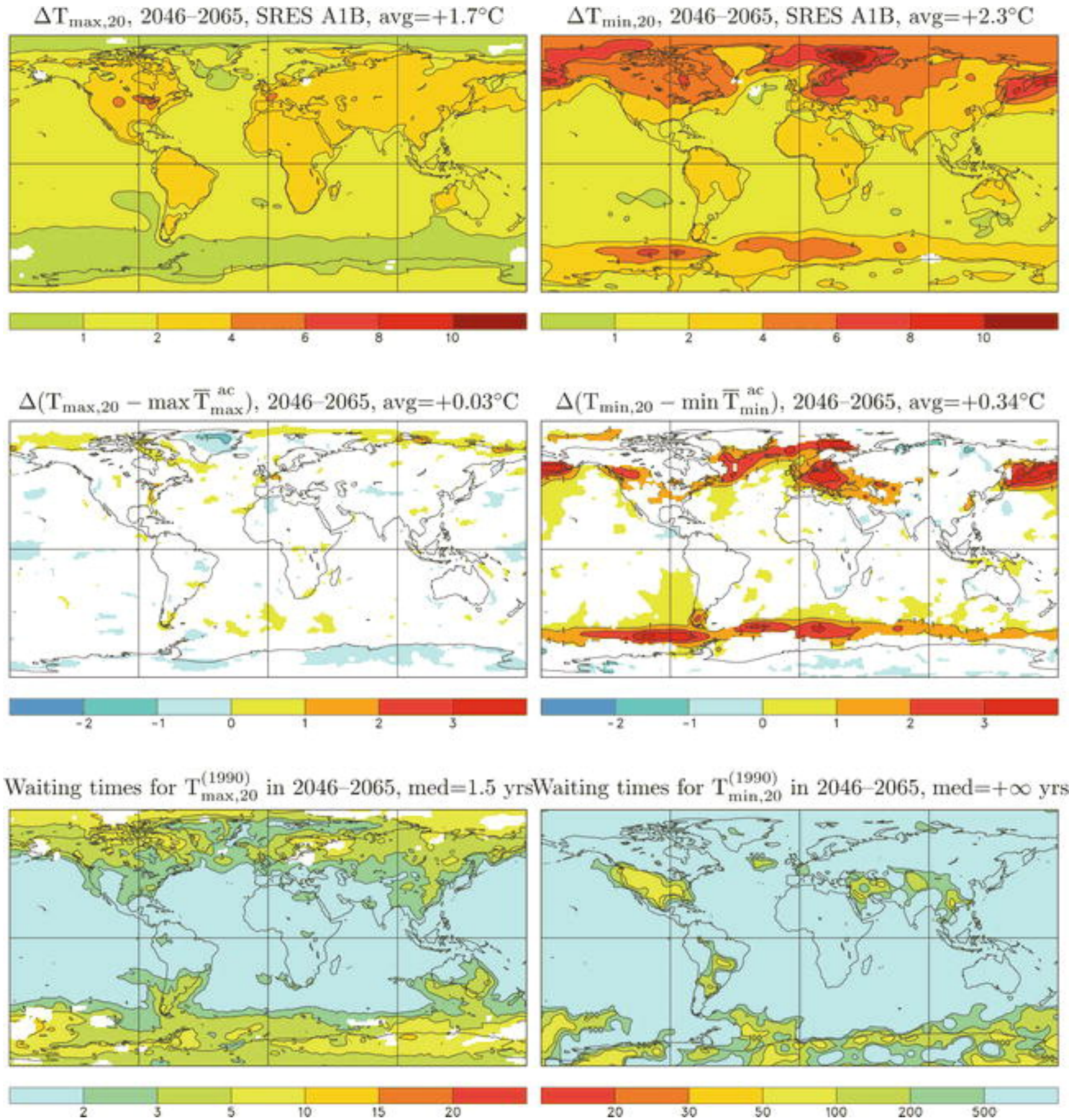
Blue areas: cold biases

Differences with obs

Changes in return values by mid-century

Comparison with changes in warmest (coldest) month of average maxT (minT)

Changes in return period



The analysis of future changes only uses ensemble means, standard deviations, ranges.

Many characteristics of the multi-model ensemble make those statistics of limited value:

- are these models exploring the relevant range of uncertainties?
- are they providing independent pieces of information?
- are they all equally valid?

These issues plague any attempt at fully and rigorously characterizing uncertainty in future projections through statistical/probabilistic models.

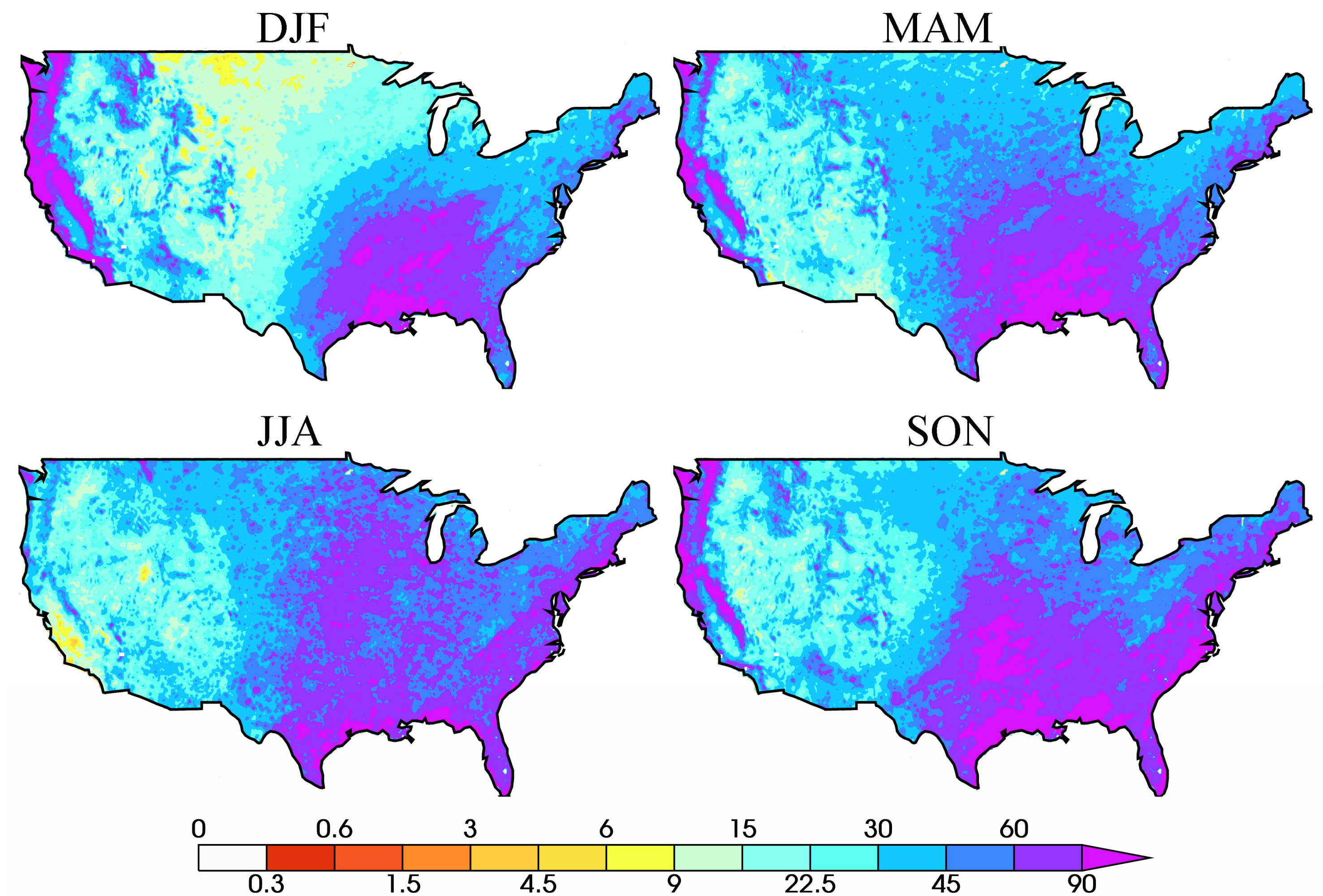
And we are not even considering the issue of model performance…

Remember Ben's & David's talks yesterday!

Validation of CMIP models on extreme precipitation over the US

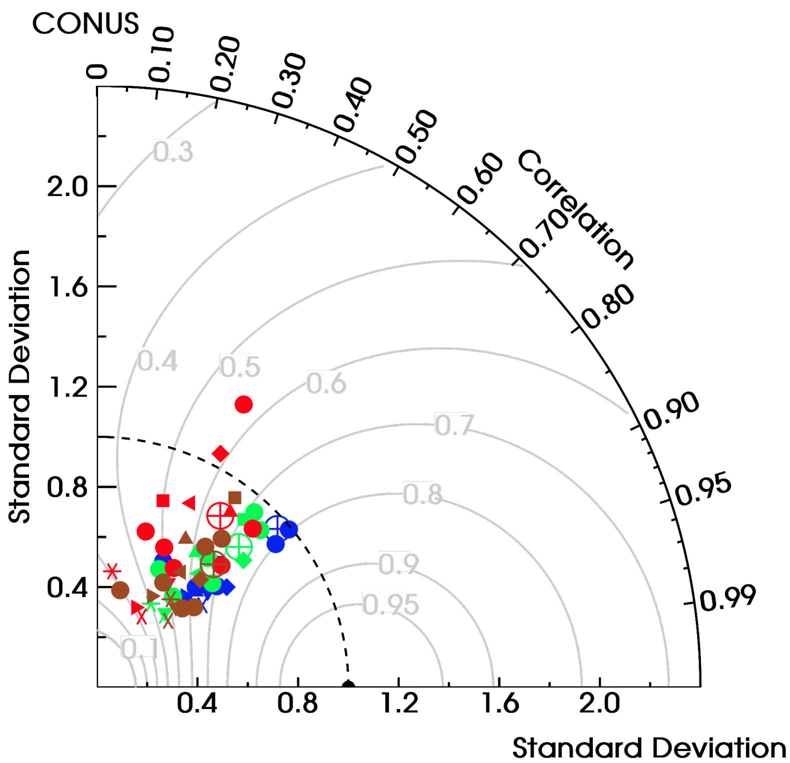
- A comparison of 20 year seasonal return values over the continental US
- CMIP3 models exhibit systematically low values as compared to observations due to grid resolution constraints
  - Individual storms do not become intense enough.
  - Projections are lacking in credibility.
- Do the somewhat higher resolutions of CMIP5 or other developments improve this bias?
- How do the CMIP3/5 models compare to high resolution regional or global atmospheric models?

20-year Return Values
from a high quality 1/8º gridded observations

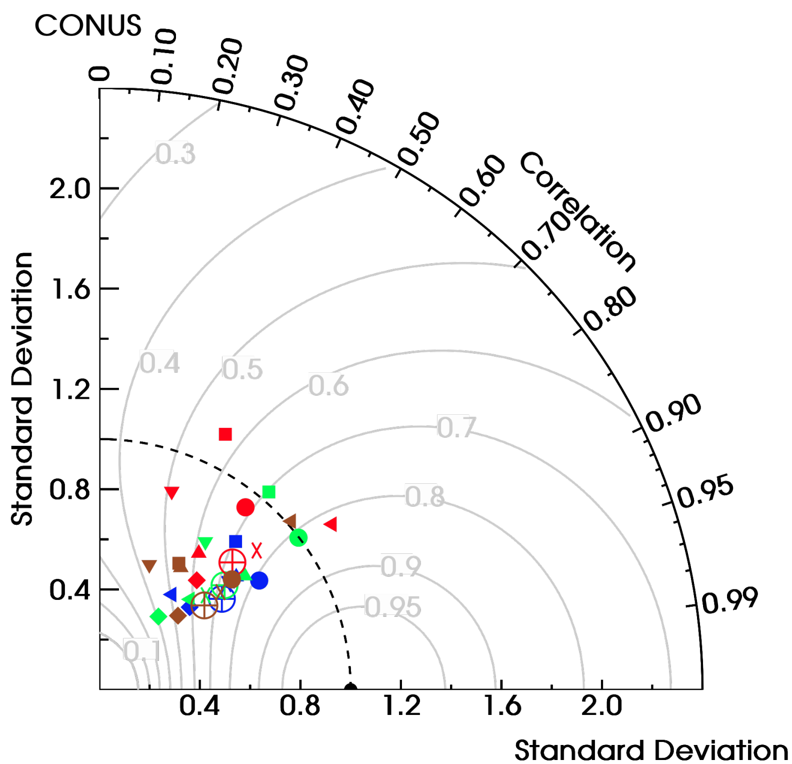


Slide courtesy of M. Wehner

CMIP Taylor Diagrams



CMIP3

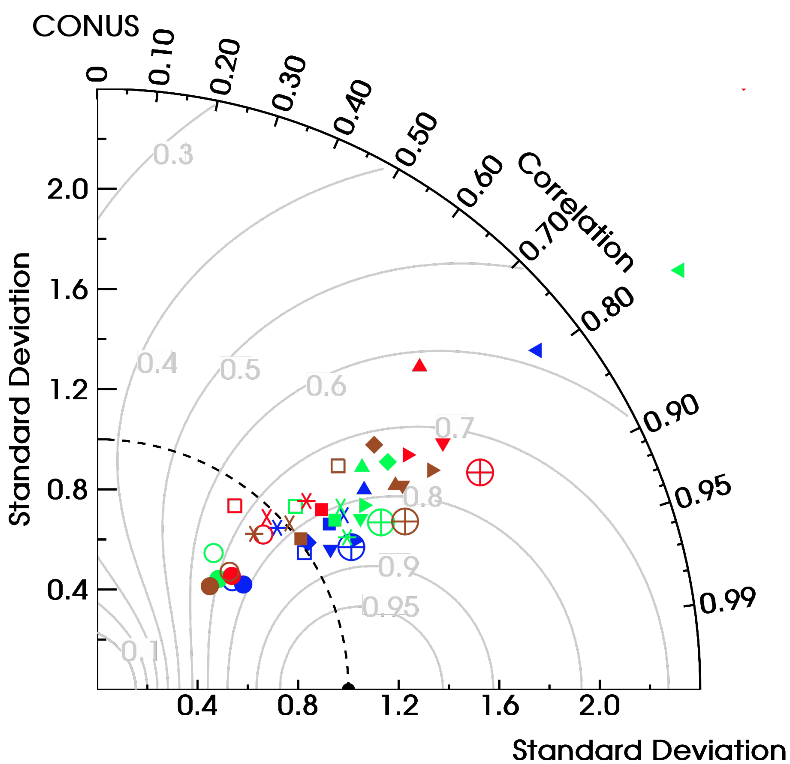


CMIP5

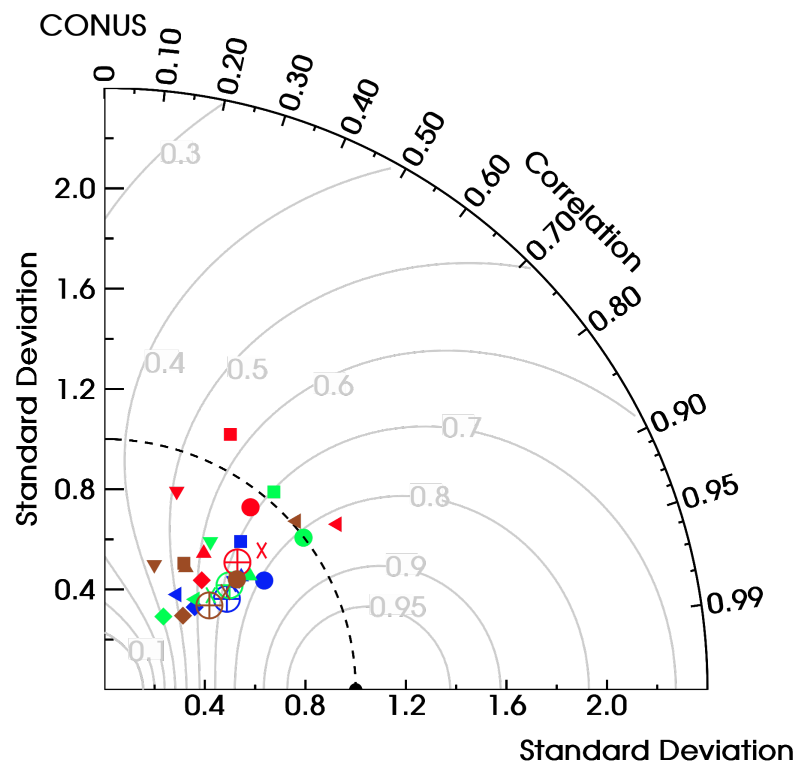
No significant improvements in skill

Strong CMIP5 storms do not become as intense as observed

Slide courtesy of M. Wehner



NARCCAP
Regional models

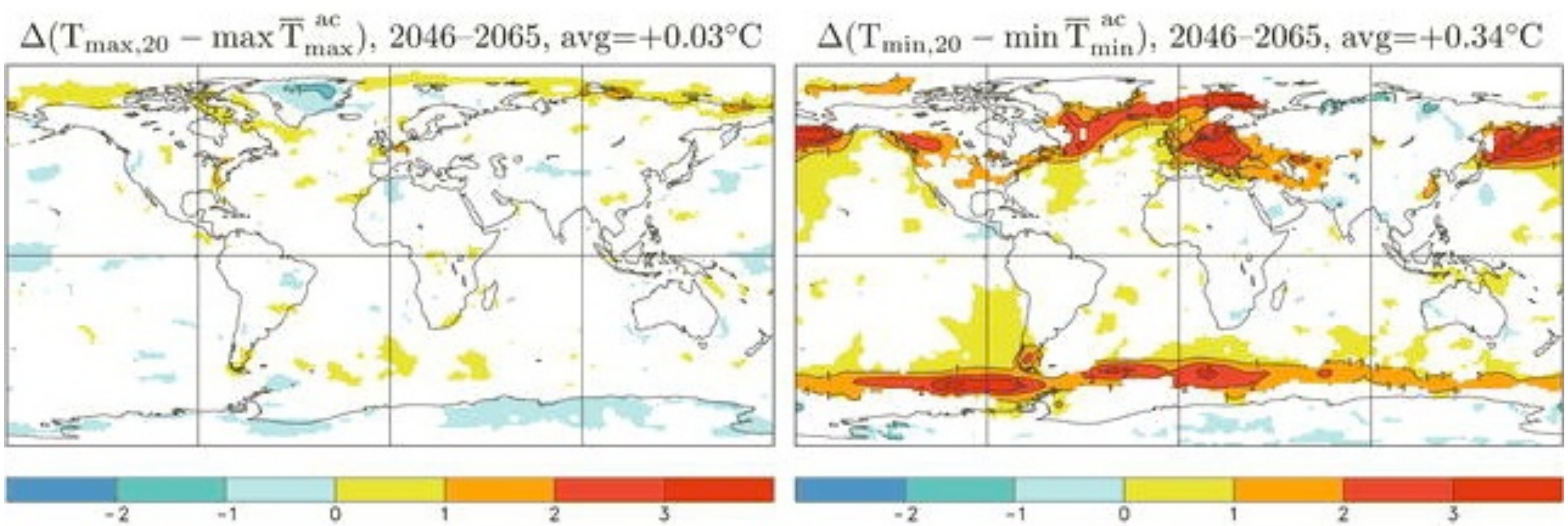


CMIP5

NARCCAP models (~50km) exhibit somewhat higher skill
Some NARCCAP storms are too intense!

Slide courtesy of M. Wehner

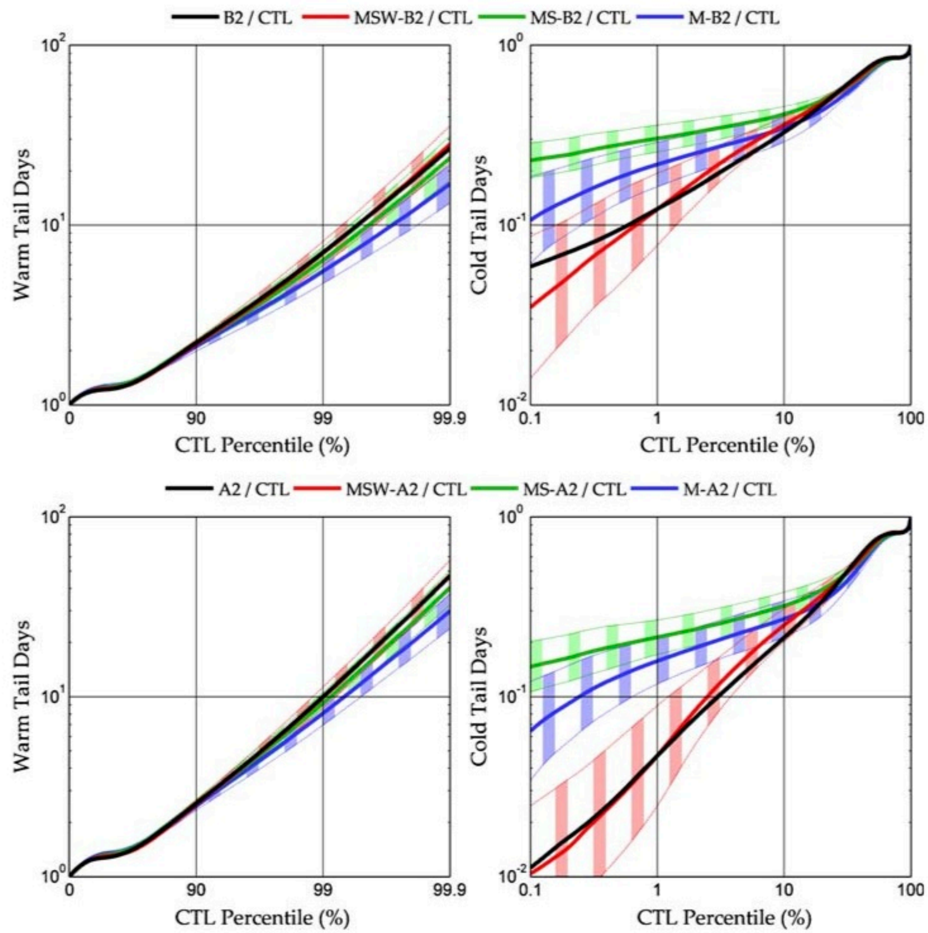
Characterizing uncertainty in extremes through the uncertainty in the mean



It may work or it may not….

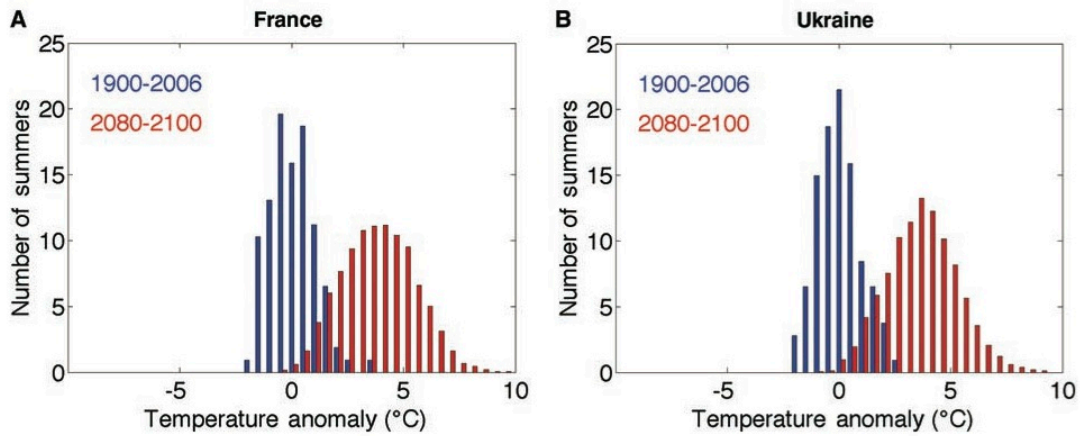
Changes in frequency of exceedances as a function of the threshold (percentile)

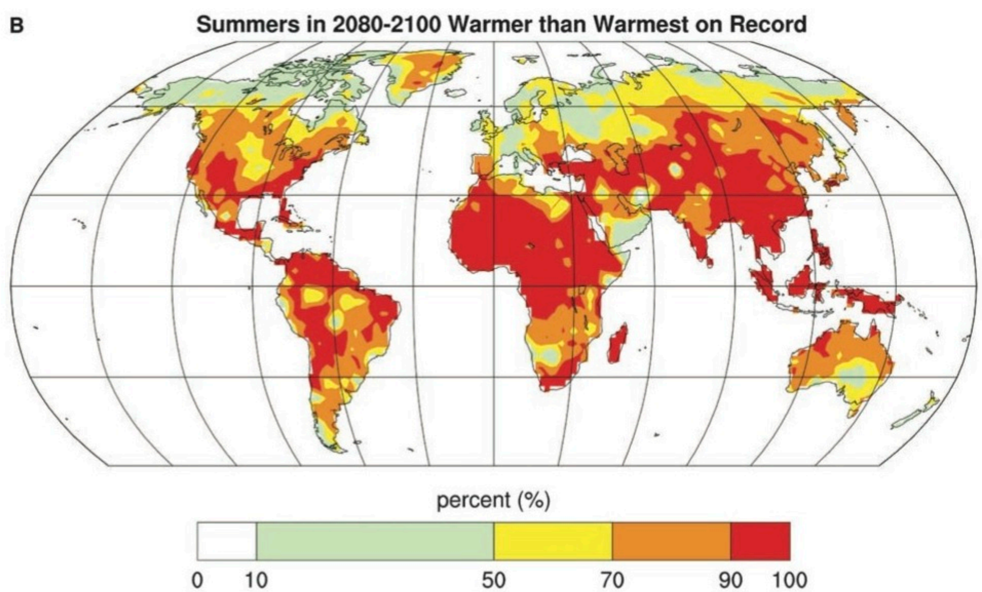
Ballester et al., 2010



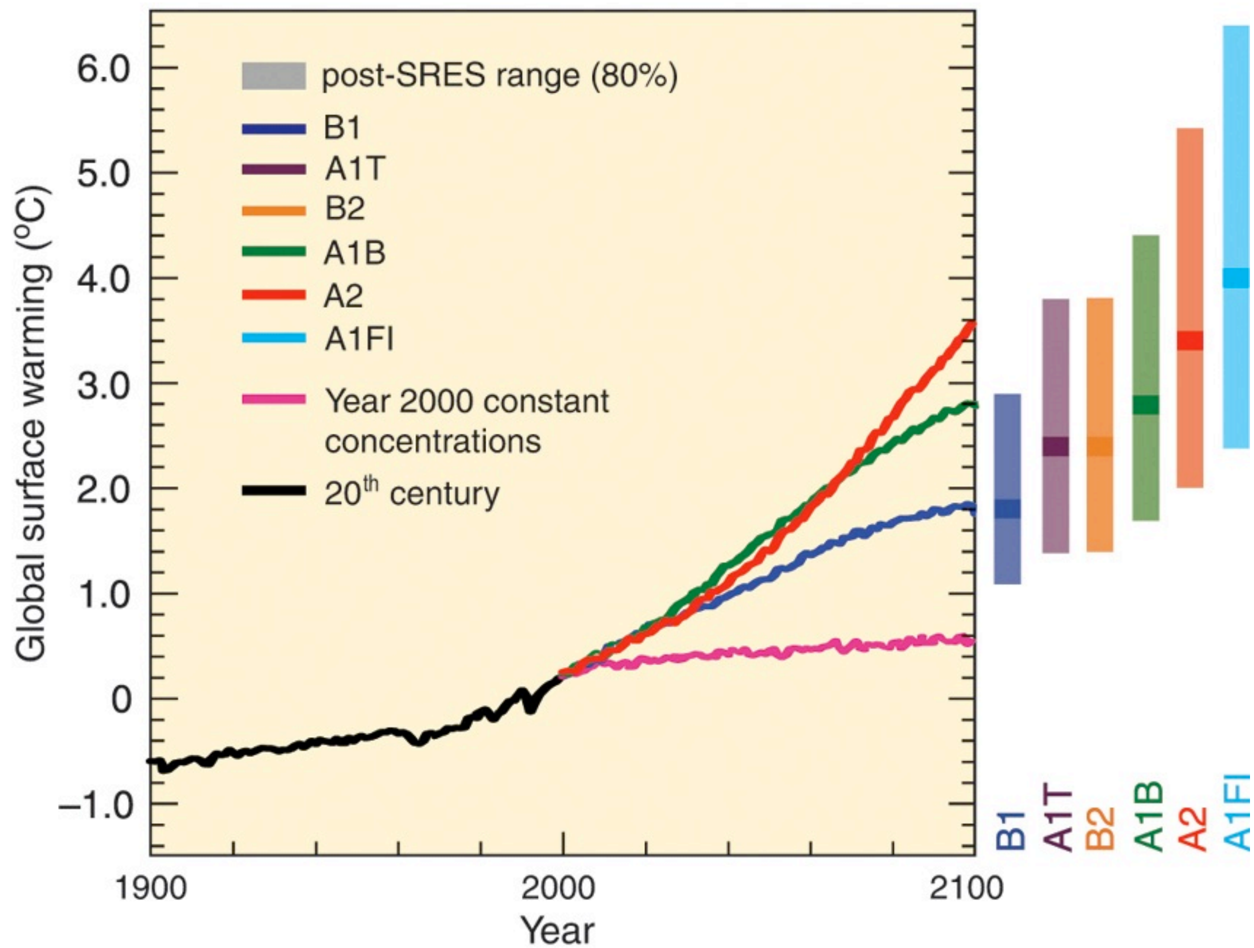
If you go for it…

Battisti and Naylor, 2009





Still, it's only CMIP3 (CMIP5 now). If you don't believe those ensembles encompass the range of uncertainty, the only way out is the use of simplified models, and the exploration of uncertainty in large scale quantities like global average temperature.

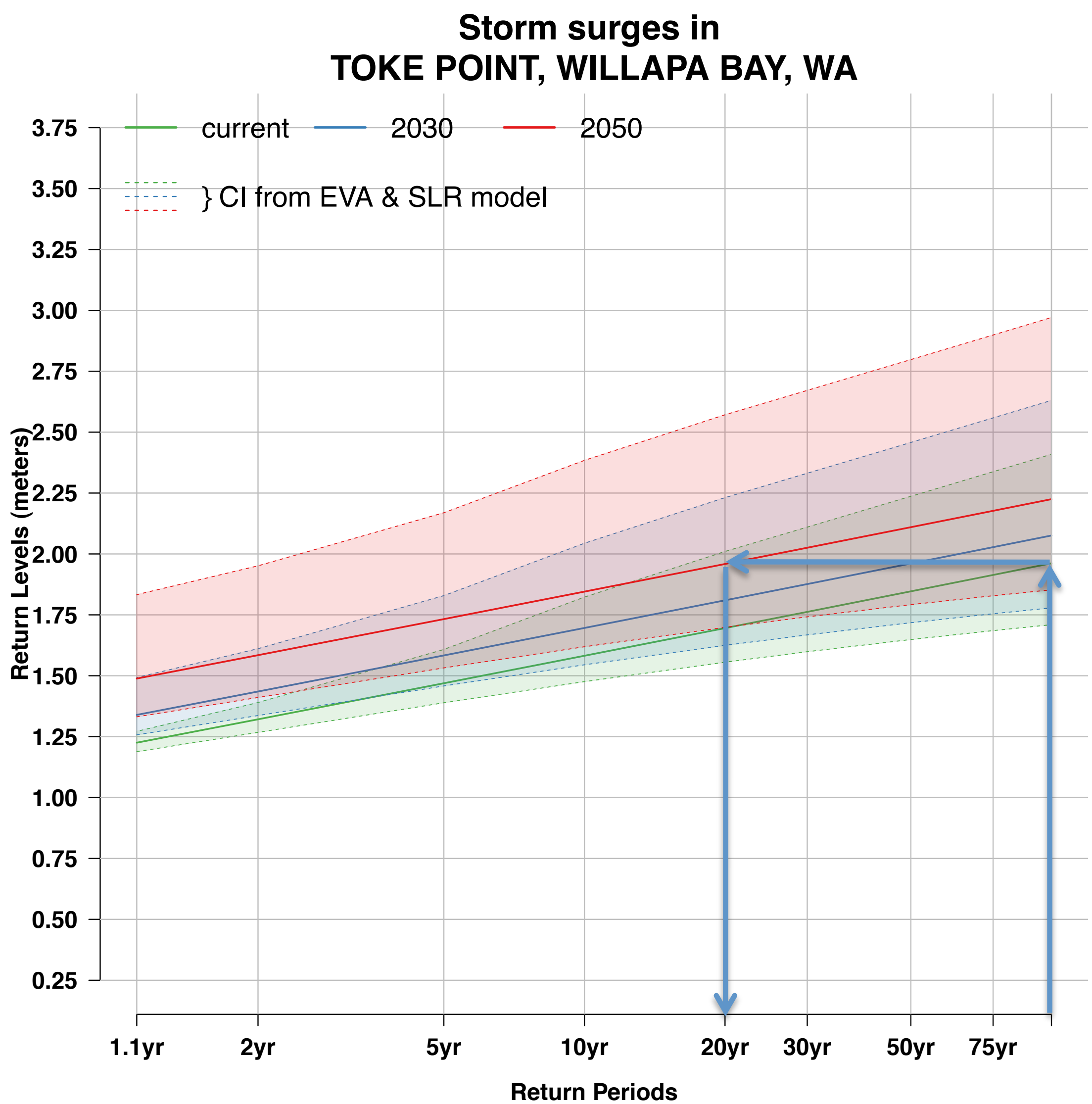


So then the recipe may be:

Estimate a transfer function between global average temperature and regional/ seasonal mean temperature (pattern scaling?) or other quantity of interest (sea level rise?)

Relate behavior of extremes to the behavior of the latter quantities.

An example: effects of sea level rise on storm surges (Tebaldi et al., 2012)



Today's **100-yr event** becomes the **20-yr event** by 2050