Towards understanding and attributing the causes for changing probability of climate extremes

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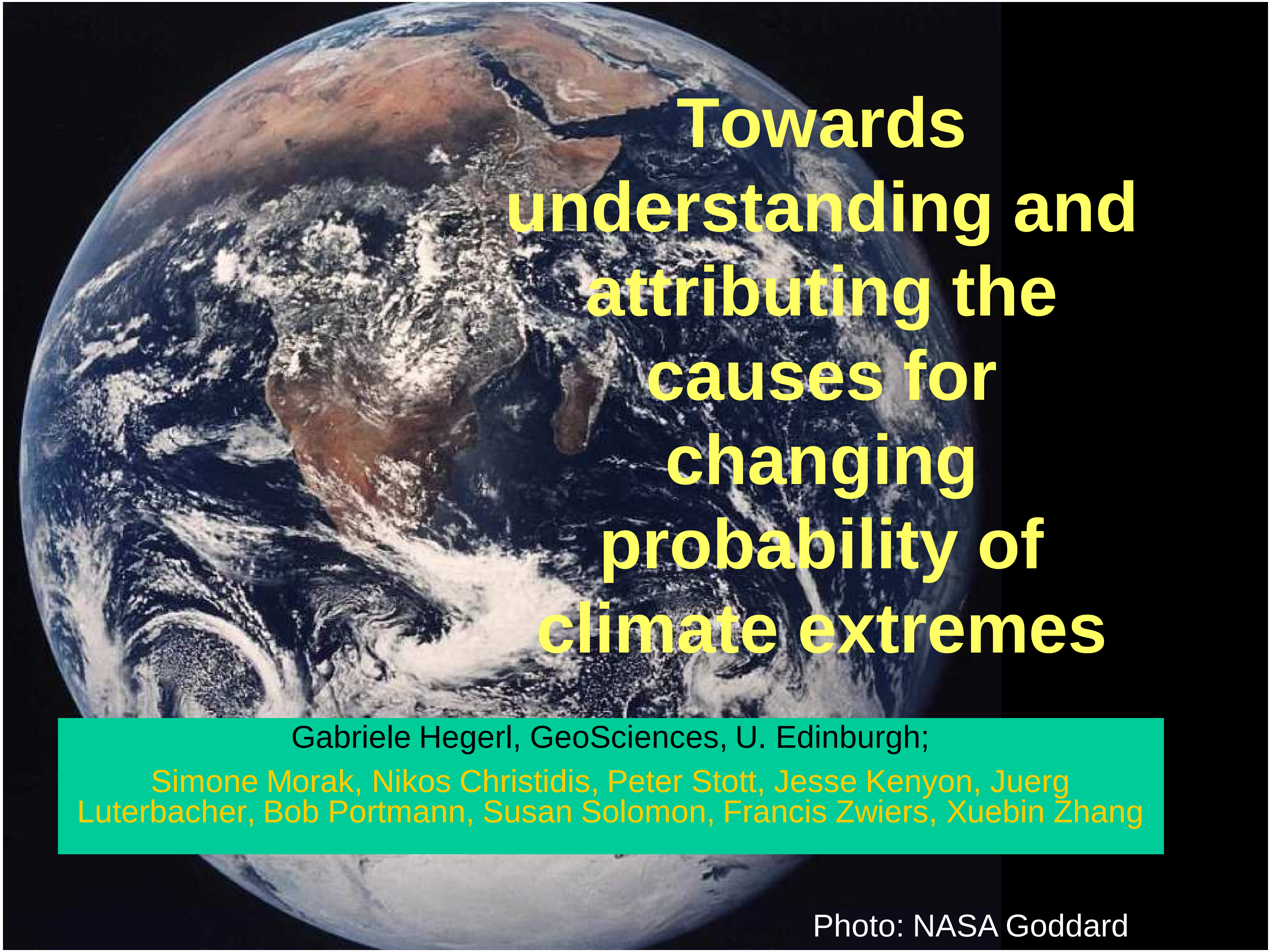


Photo: NASA Goddard

Definitions: IPCC guidance paper

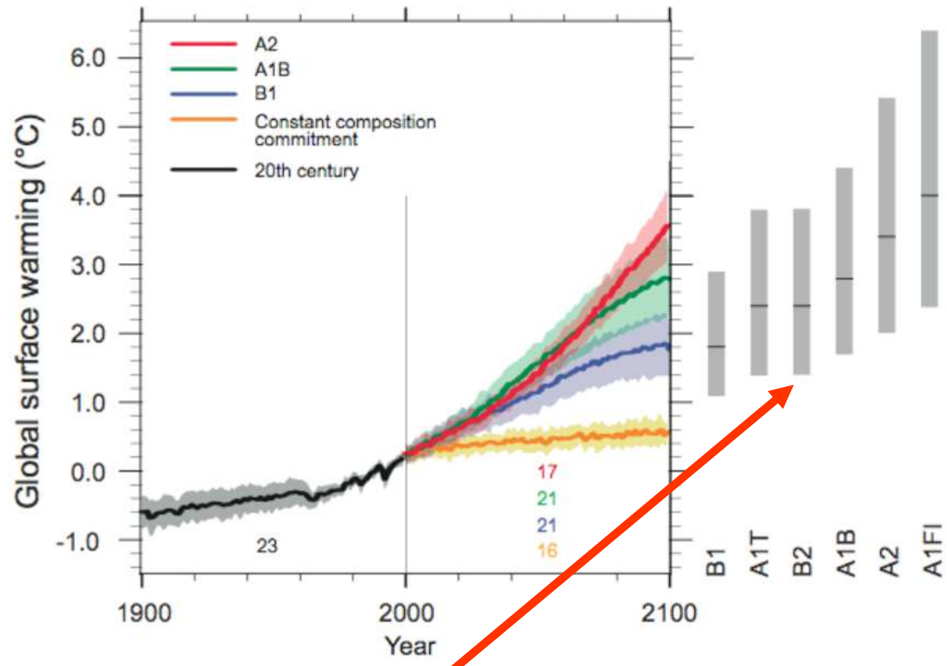
- ***"External forcing"*** refers to a forcing factor outside the climate system that causes a change in the climate system – typically by affecting the radiative balance
- ***"Internal variability"*** Variability generated within the climate system
- ***"Detection"*** of climate change: demonstrating that climate (or a system affected by climate) has changed in some statistical sense without providing a reason for that change (i.e., if its likelihood of occurrence by chance due to internal variability alone is small, for example, <10%) (not just a stat. significant trend!)
- ***"Attribution":*** process of evaluating the relative contributions of multiple causal factors to a change or event with an assignment of statistical confidence. The process of attribution requires the detection of a change in the observed variable or closely associated variables

Why detection and attribution of changes in extremes?

Quantifies how much change has been caused by greenhouse gases and other external forcings

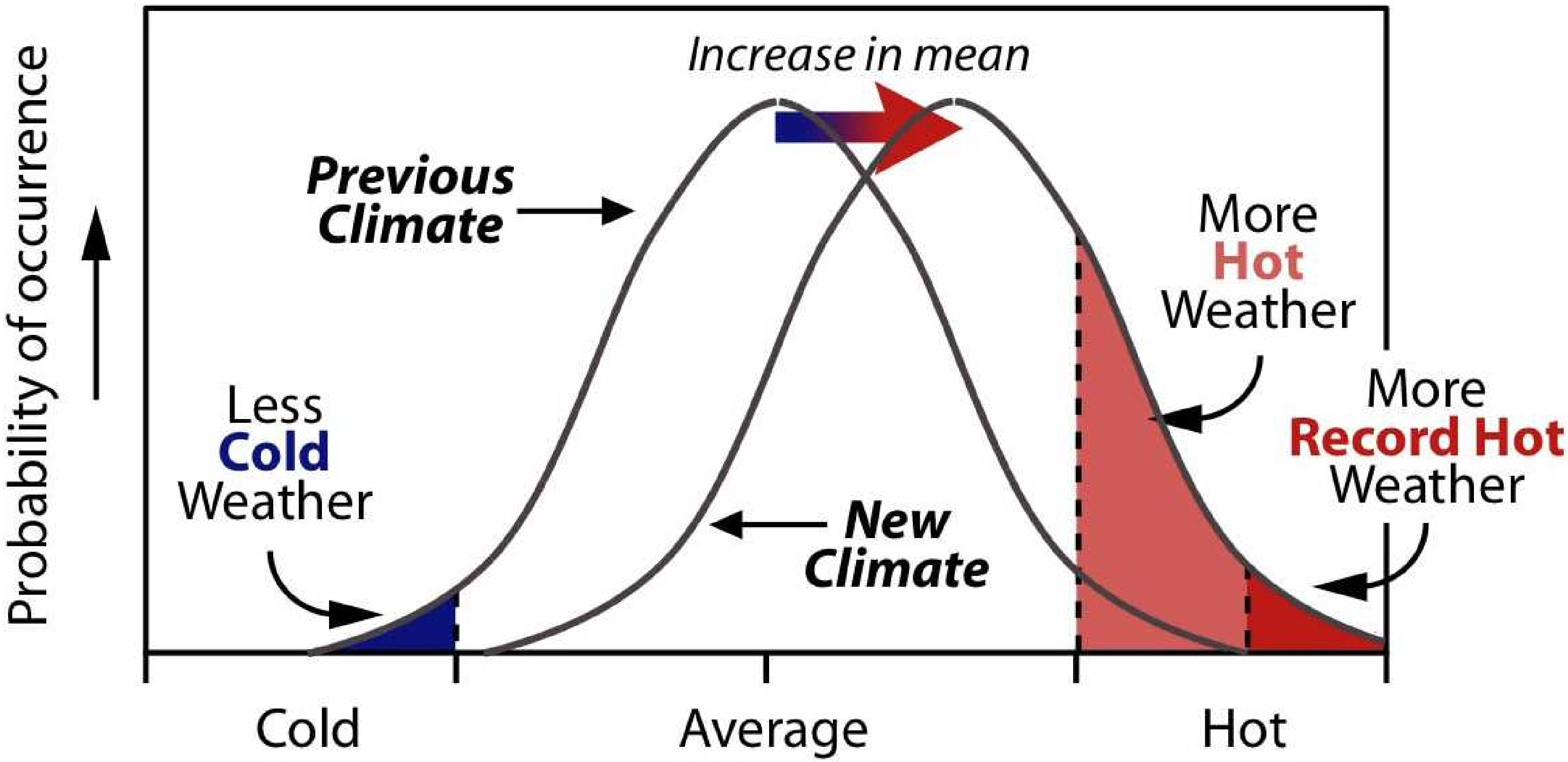
Evaluating ability to predict change (including physical processes)

Adjusting predictions and quantifying their uncertainty



For European Heat Waves and Drought: EQUIP (see Helen Hanlon poster)

Or could we just detect and predict from the mean?



From IPCC AR4, TS

Not for precipitation extremes!

- changes in precipitation disproportionally affect the tail (from Hegerl et al., 2004)
- More available moisture (Clausius Clapeyron)
- Change in total precipitation < Clausius Clapeyron, in extremes approaches CC (eg Allen and Ingram, 2001)

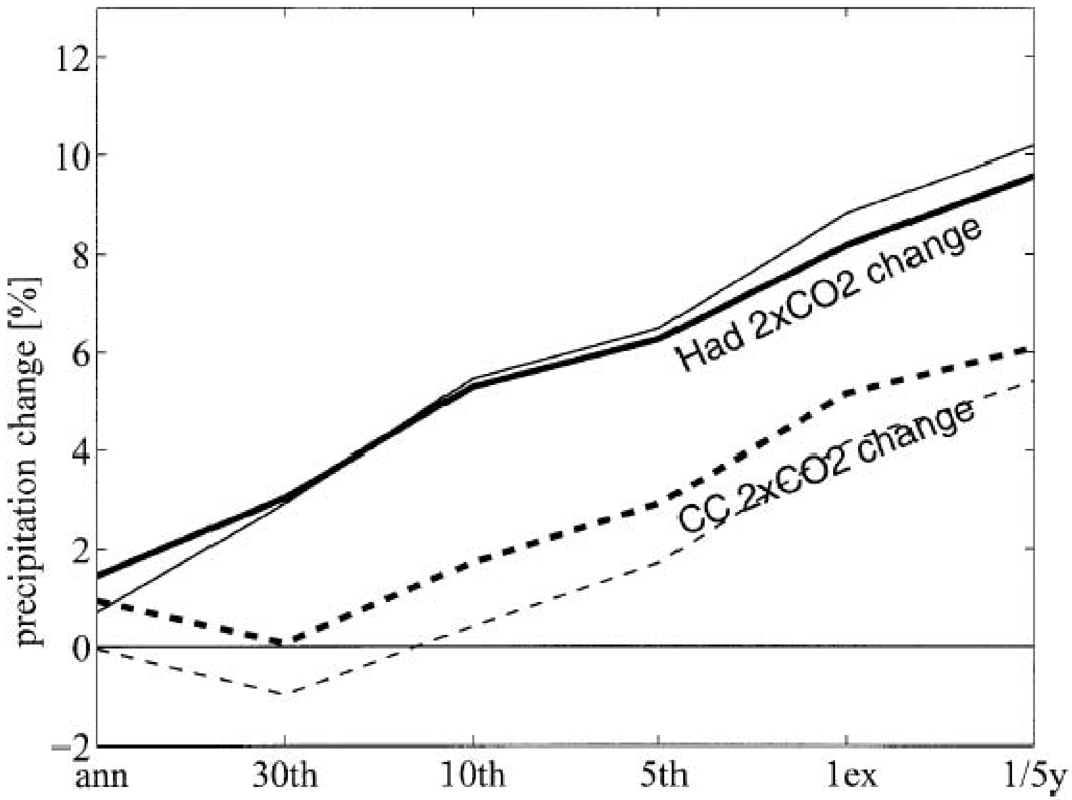
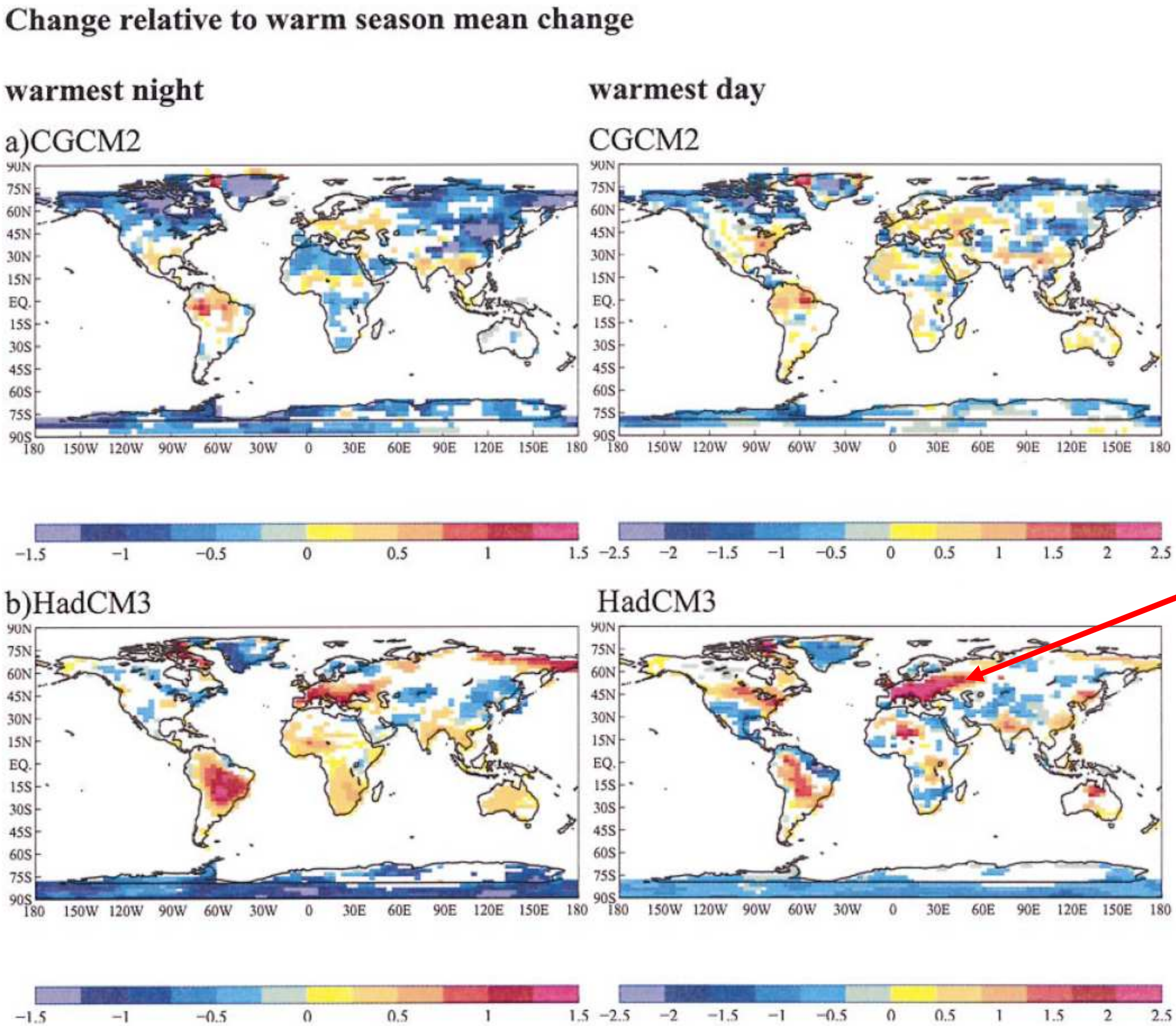


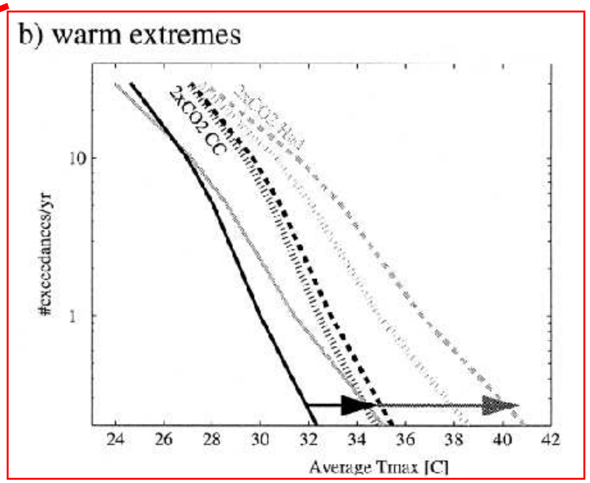
FIG. 8. Global mean precipitation change for HadCM3 (solid) and CGCM2 (dashed) between the 1 × CO_2 and 2 × CO_2 segments for the annual mean (ann), and the 30th, 10th, 5th, and 1st wettest day of the year (1ex) and the wettest day in 5 yrs (1/5yr). Values for land only are shown as thin lines. The changes are expressed as the global (or land only) mean of the precipitation change divided by the climatological global (or land only) mean precipitation for each index. Units are %.

For temperature: mean is good predictor but incomplete



colours where change in hottest day /night (land) significantly different from change in seasonal mean at 2xCO_2 (from Hegerl et al., 2004)

Reason: moisture, cloud?



How can extremes in daily temperature and precipitation be described?

- Frequency of events: Number of exceedances of a threshold
- Intensity of events: absolute value of the extreme (=> can be treated by GEV) , or amount by which threshold is exceeded
- Timescale: 1-day to multiday events, varying length (heat wave duration index)
- Lots of choices….=> we need relationship between these choices to span range of changes with few studies

ETCCDI

Expert Team on Climate Change Detection and Indices has

- Developed and researched indices for climate extremes that can be applied regionally and globally
- Identified idiosyncrasies and found solutions
- Developed and disseminated software
- Provided capacity building workshops
  - Results published in the peer-reviewed literature
  - Indices produced generally available from ETCCDI web site
- Produced a WMO Guidelines document on extremes
  - http://www.wmo.int/pages/prog/wcp/wcdmp/wcdmp_series/documents/WCDMP_72_TD_1500_en_1.pdf

ECA produces complementary information for Europe (http://eca.knmi.nl), including preliminary long period return values

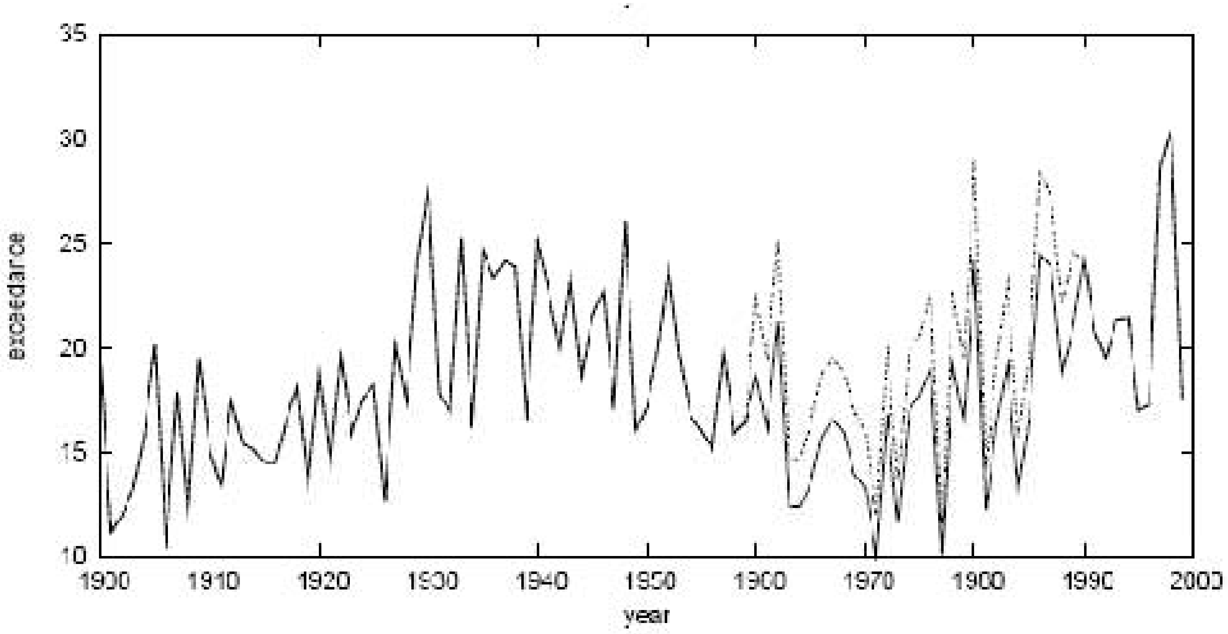
ETCCDI indices are basis of a number of detection studies, either published or underway; extensive contributions to IPCC AR4

Examples

- Warmest / coldest day/night in a year: absolute extreme. Depends on seasonal cycle. intensity
- Number of warm/cool days/nights: counted as threshold exceedances, usually 90th and 10th percentile based on climatology with seasonal cycle. Index of frequency of 'Moderate' extremes; usually recorded in %exceedances
- Wettest day / 5-day period in a year

- Ideosynchrasies?

Percentile exceedance counts using a 1961-1990 base period (common practice)



Zhang, Hegerl Kenyon, 2006

- Threshold: sampling 90th percentile of temperature distribution 5 days around target date from 30 yrs (ie max 150 points)
- Sampling error and choice of plotting point leads to inhomogenity

Graininess

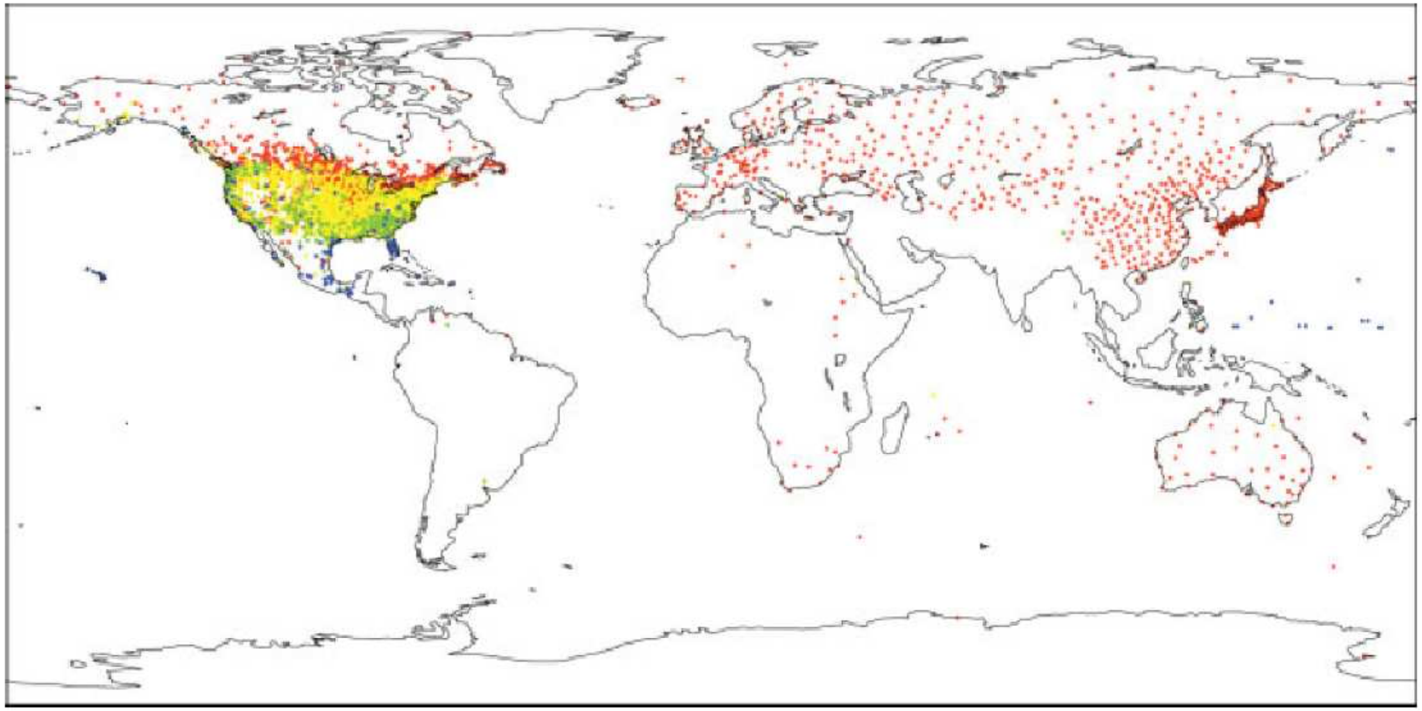


Figure 2. Percentage of time daily minimum temperatures are greater than their corresponding 90th percentiles averaged over the base period 1961–1990. Red, yellow, green, blue dots indicate stations with exceedance rate greater than 10%, between 10 and 9.5%, between 9.5 and 9%, and less than 9%, respectively.

Rate of exceedances in base period: >10%, 9.5-10%, 9-9.5%, <9%

Reason: temperatures recorded with limited accurracy => lots of identical values (Zhang Zwiers Hegerl 2008)

What changes the probability of climate extremes?

circulation

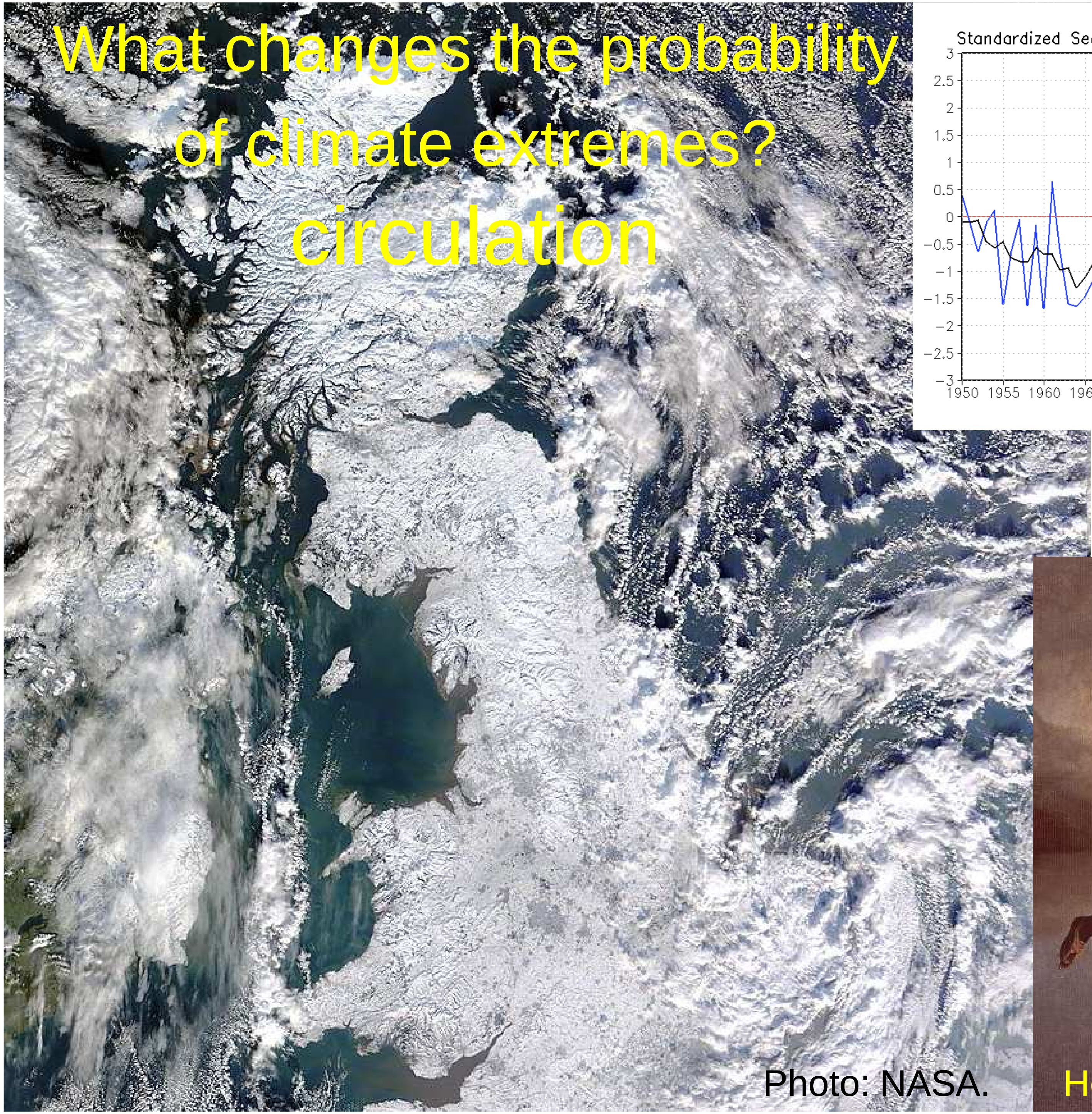
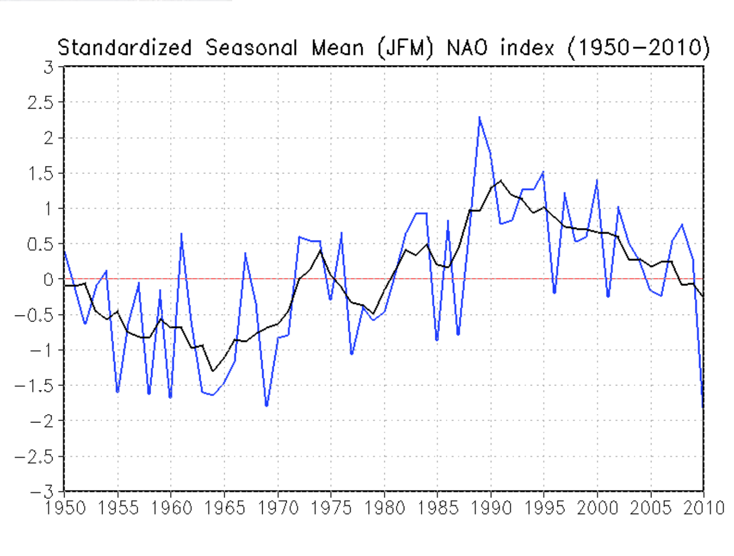
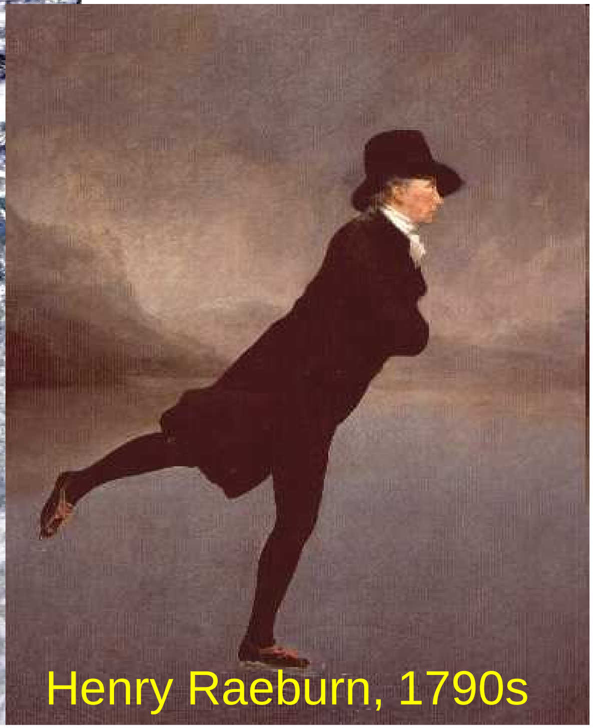


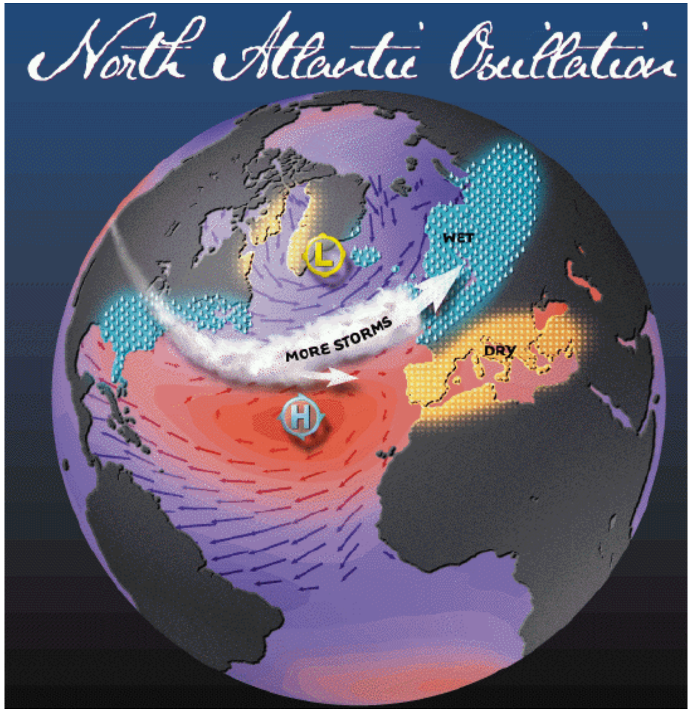
Photo: NASA.



NCEP/NCAR



Henry Raeburn, 1790s

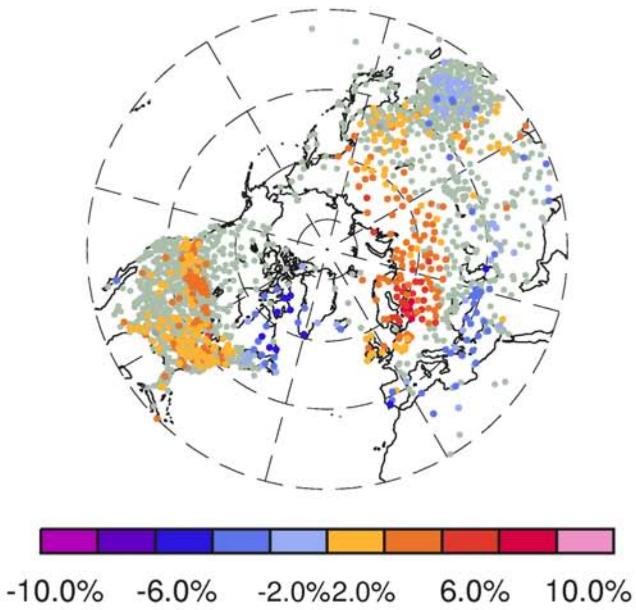


Thompson and Wallace, 2001:
17/1 snow days in Dallas for
NAM - /NAM+

Warm days **cold nights**

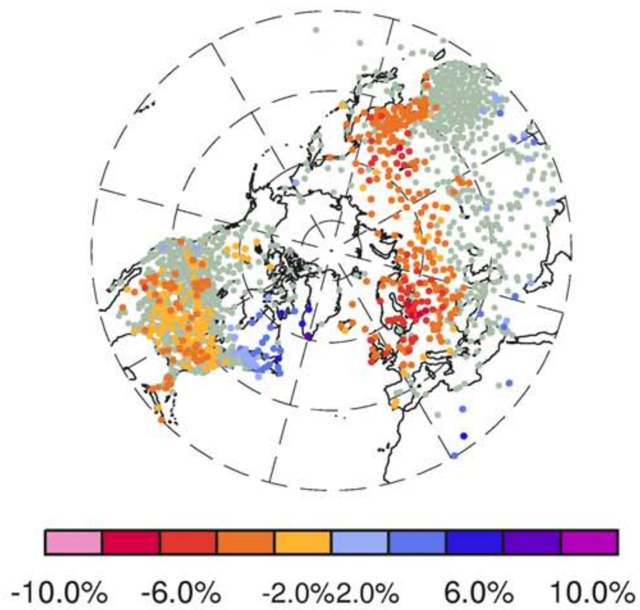
TN90

Difference pos NAO from climate



TX10

Difference pos NAO from climate

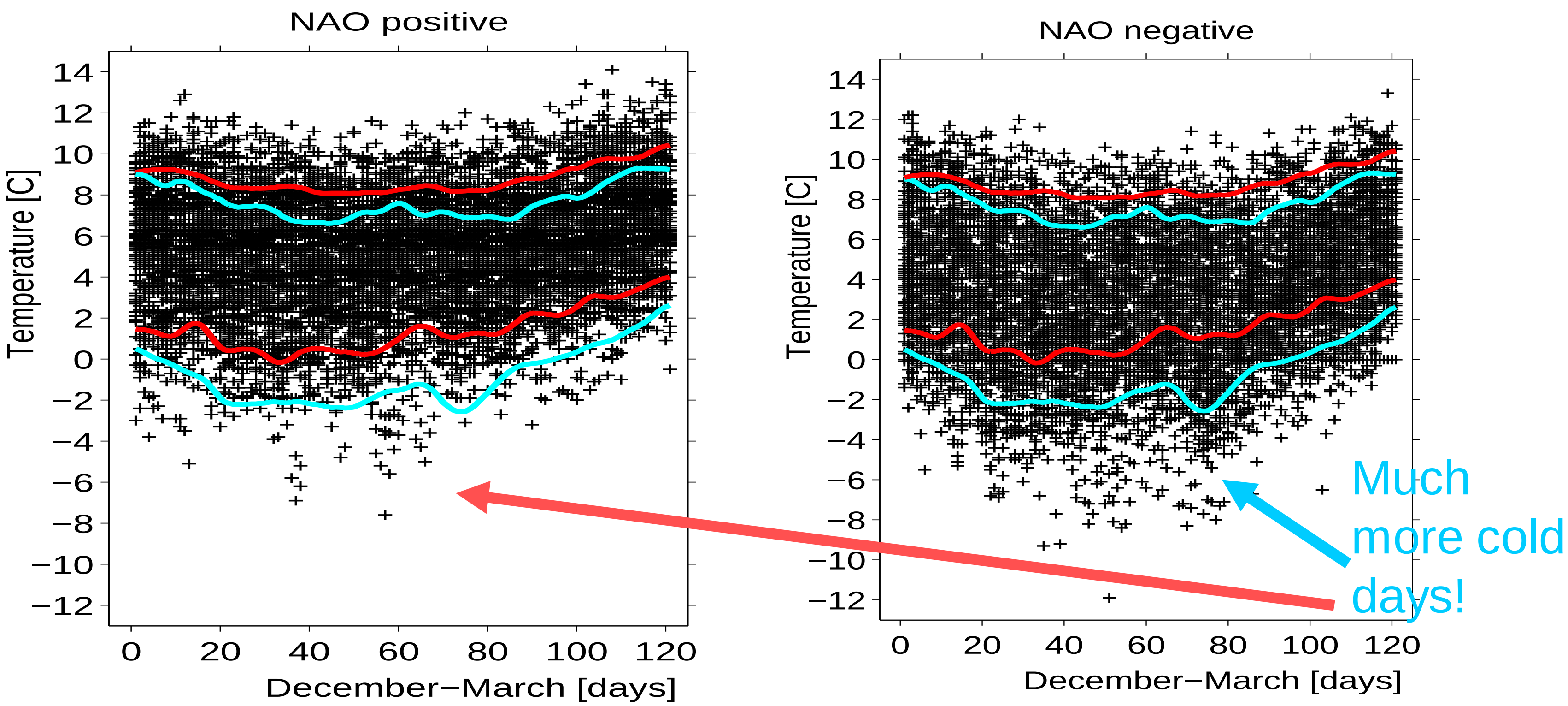


NAO Influence on cold season T extremes

(Kenyon and Hegerl, 2008)

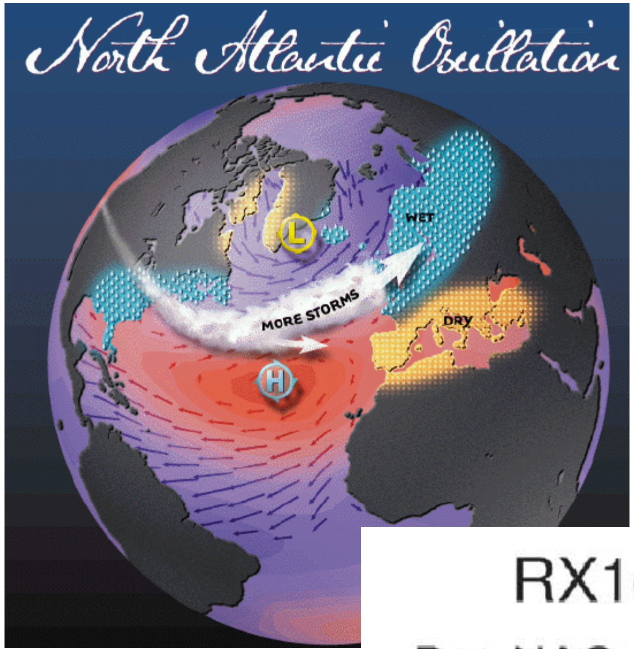
NAO response of daily Central England Temperature in winter

Not just a shift.

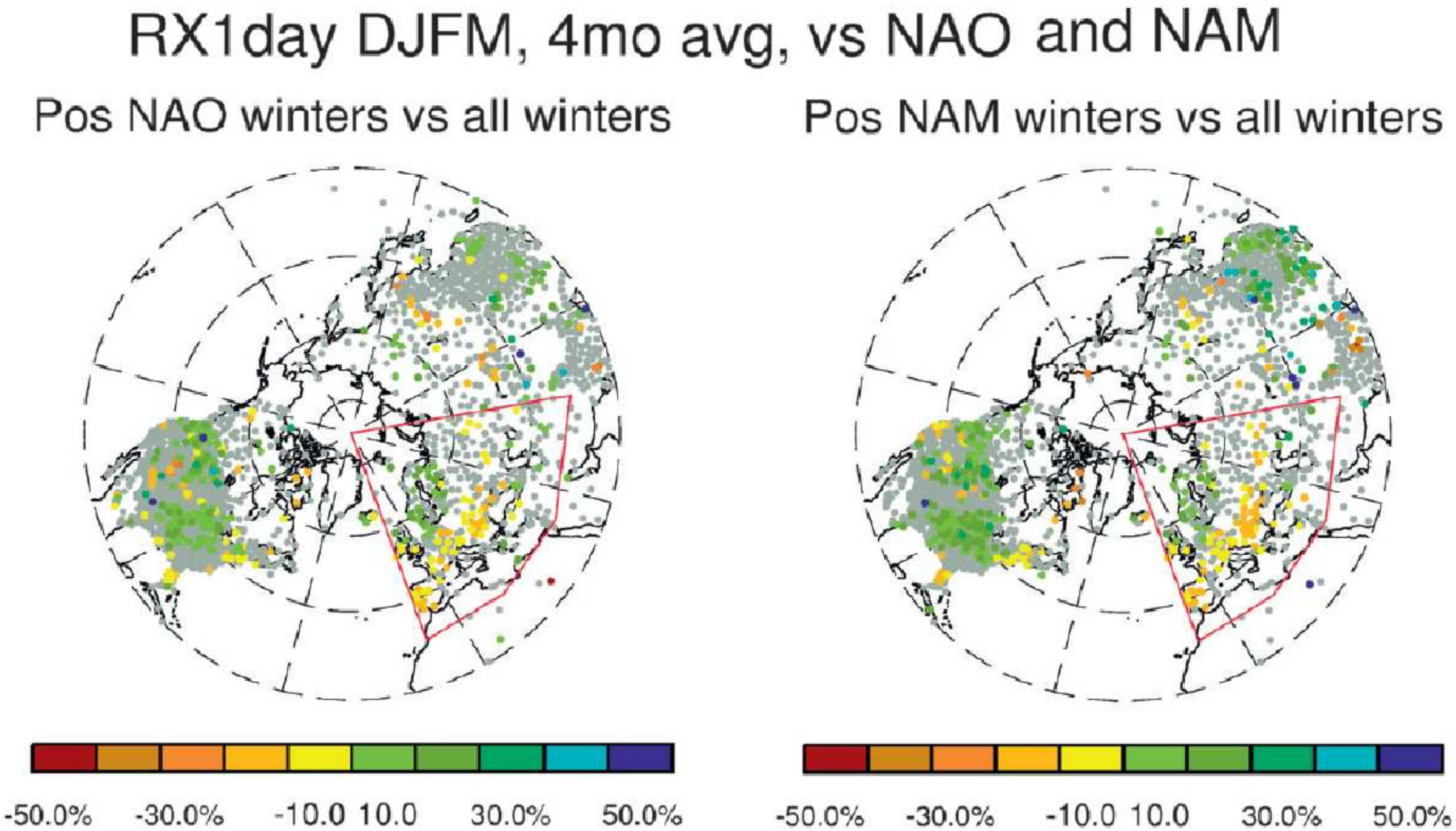


Days in NAO+ winters

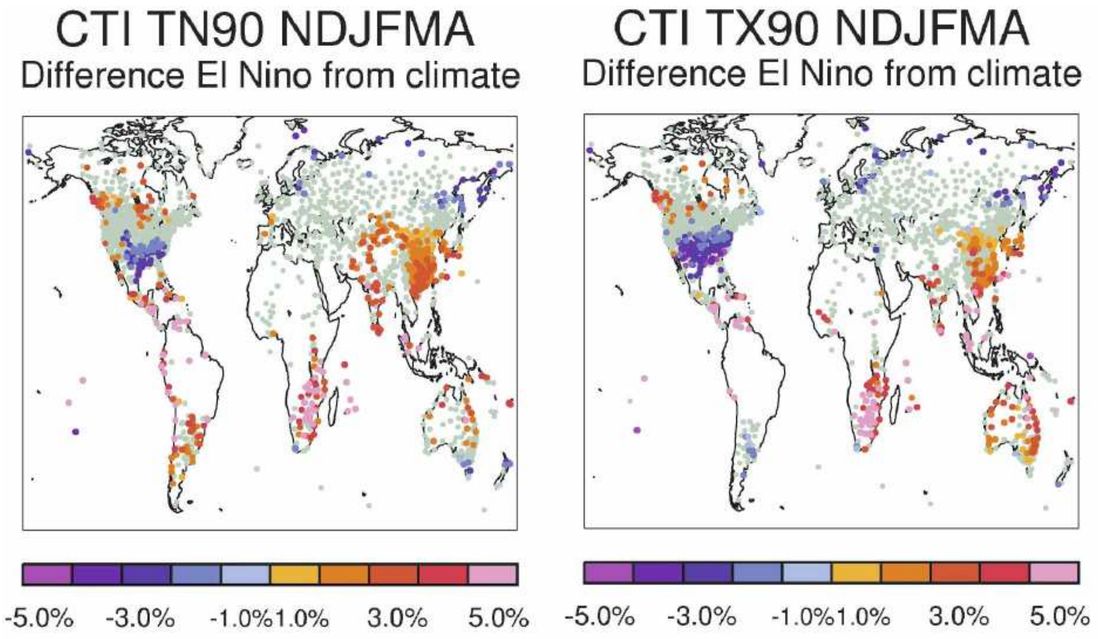
Days in NAO- winters



NAO Influence on cold season pcp extremes (Kenyon and Hegerl, 2010)

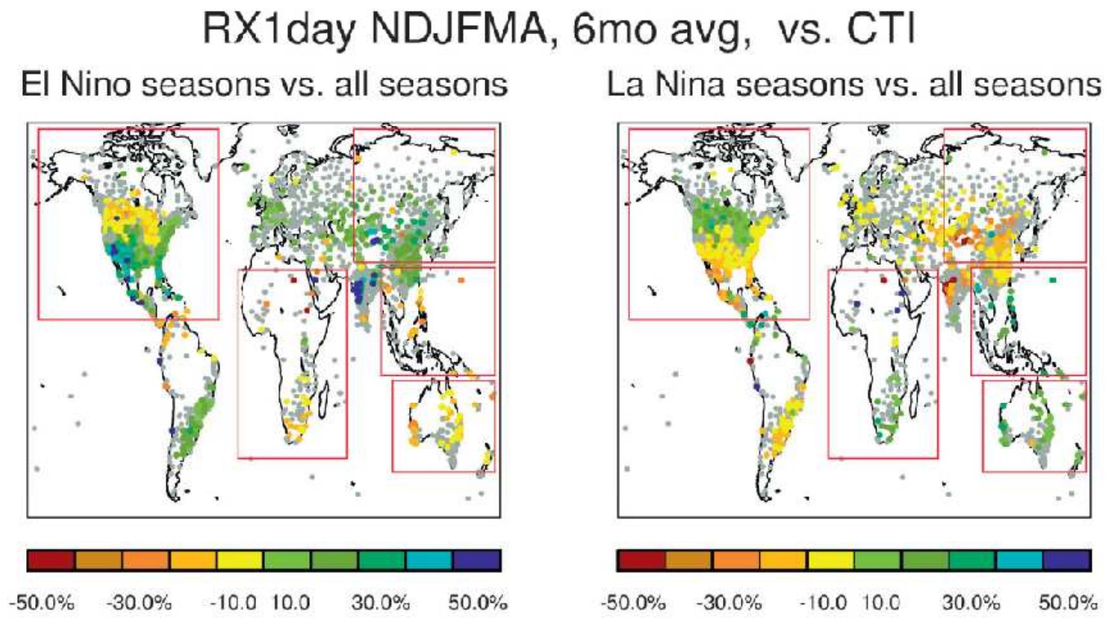


Other modes of climate variability influence extremes: El Nino; Decadal variability…

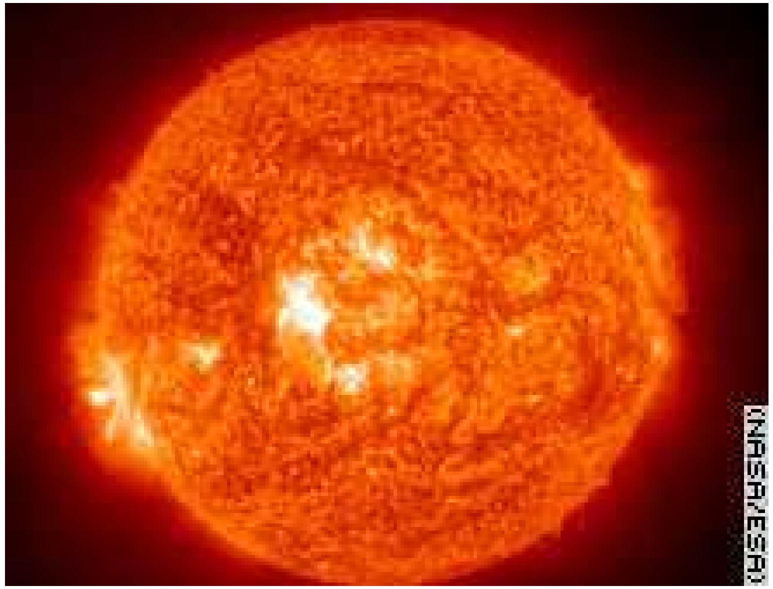


Number of warm nights number of hot days

Wettest event/month



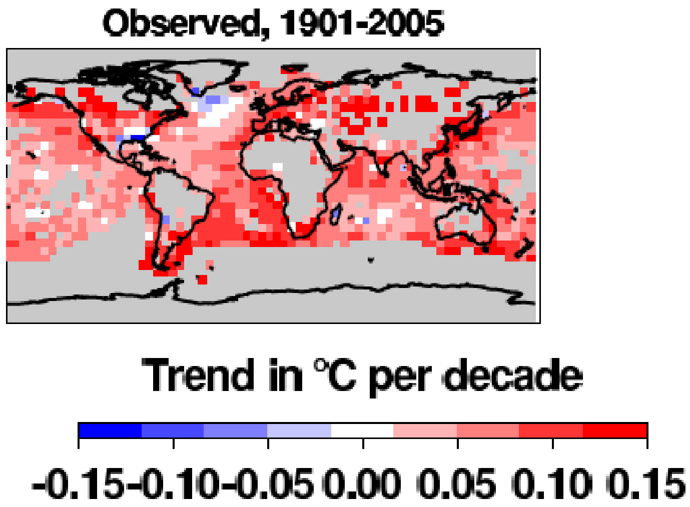
External effects on climate: Detection and attribution estimates its influence



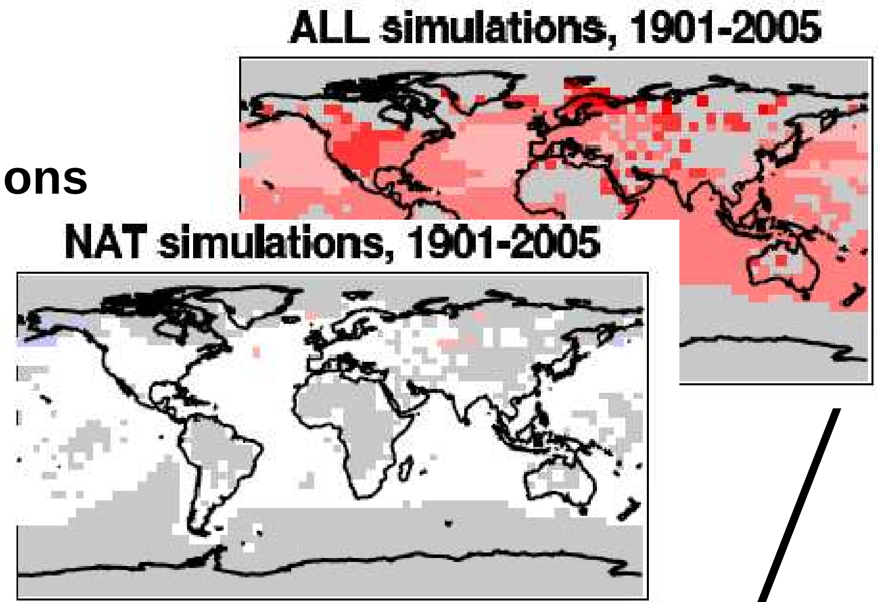
Fingerprint methods for estimating externally forced changes

Webschool.org.uk

- Use information about the shape of the expected change in time and space (eg from models)
- Can account for possibility that models misestimate the magnitude of response, (eg sensitivity, feedbacks incorrect)
- Determine the causes of **observed change** (statistically)



Climate model simulations



$$\mathbf{Y}$$

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

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

Total least squares regression in reduced dimension space

Best Linear Unbiased Estimator

Test $\beta=(\beta_{ant}, \beta_{nat})$
$\beta=0$ (detection)
$\beta=1$ (attribution)
or:~model

$\leftarrow \hat{\beta}$

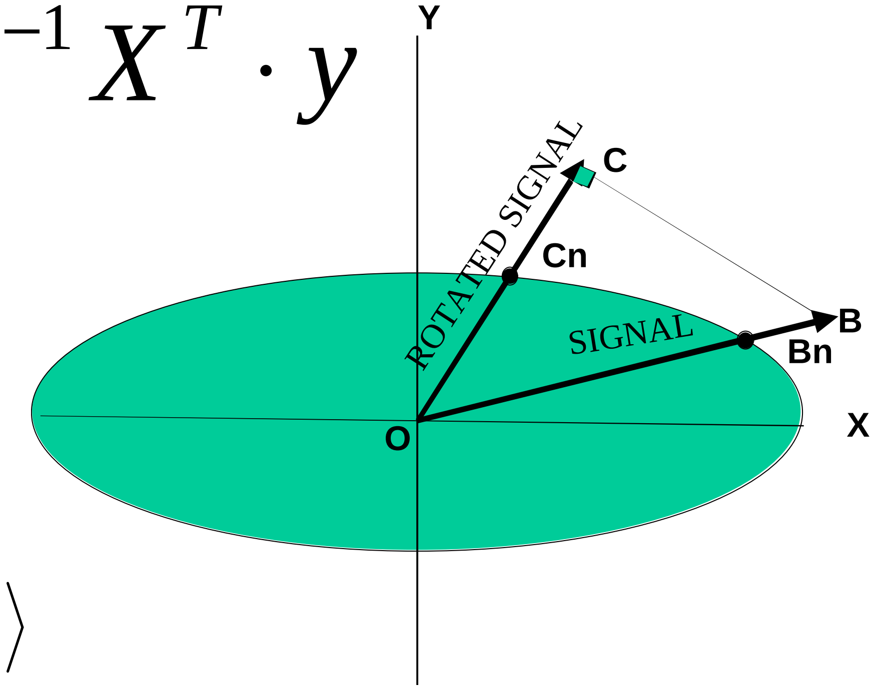
$\hat{\varepsilon} \rightarrow$

Evaluate goodness of fit

Observed amplitude estimate

Signal amplitude

$$(\beta_i)_{i=1,n} = (X^T \cdot X)^{-1} X^T \cdot y$$



scalar product

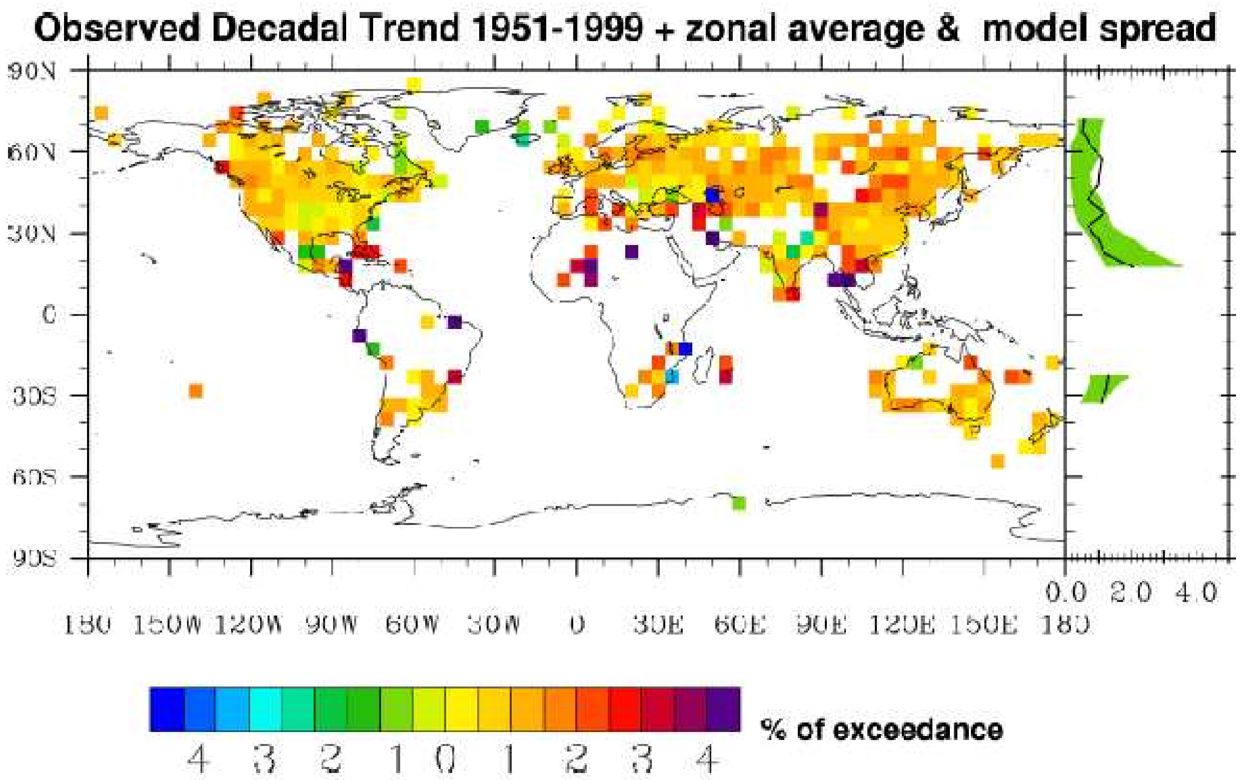
$$X \cdot y = XC^{-1}y$$

using inverse noise covariance $C = \langle \varepsilon \quad \varepsilon^T \rangle$

C estimated from samples of internal variability (models)

Test if residual v consistent with properties of model noise. Alerts to model problems in simulating internal variability and sampling problems in C^{-1}!

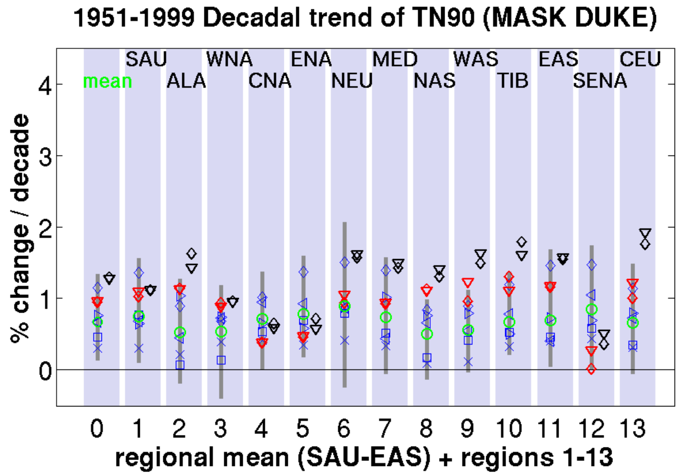
Large-scale increase in the number of warm nights

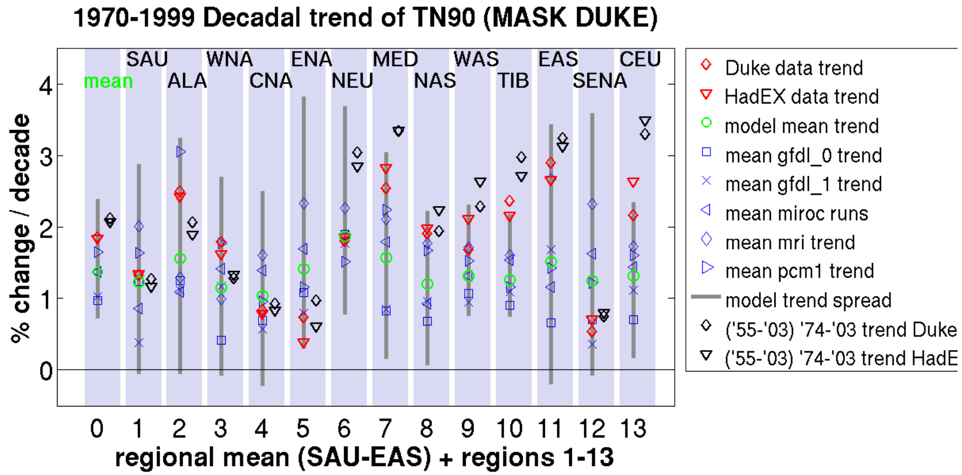


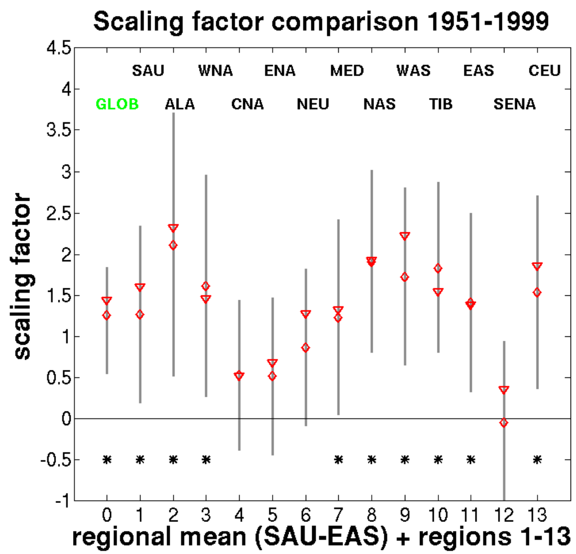
Assemble into Giorgi regions and compare model simulated with 2 observed datasets (hand-assembled into 5x5boxes, Hadex); Detection analysis: regression of observations on multi-model all forcing fingerprint

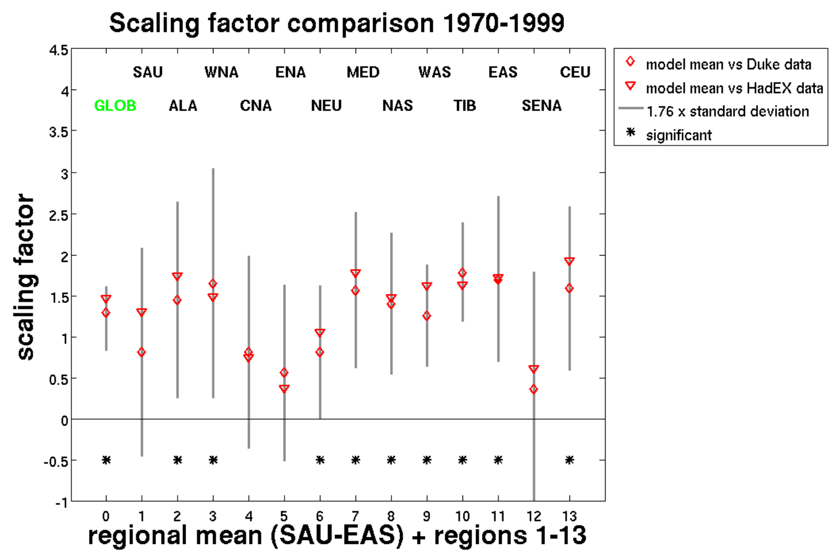
1951-99 results 1970-99 results

(black: extension to 2003)









*: 5% significant change in number of warm nights in region (non-optimized)

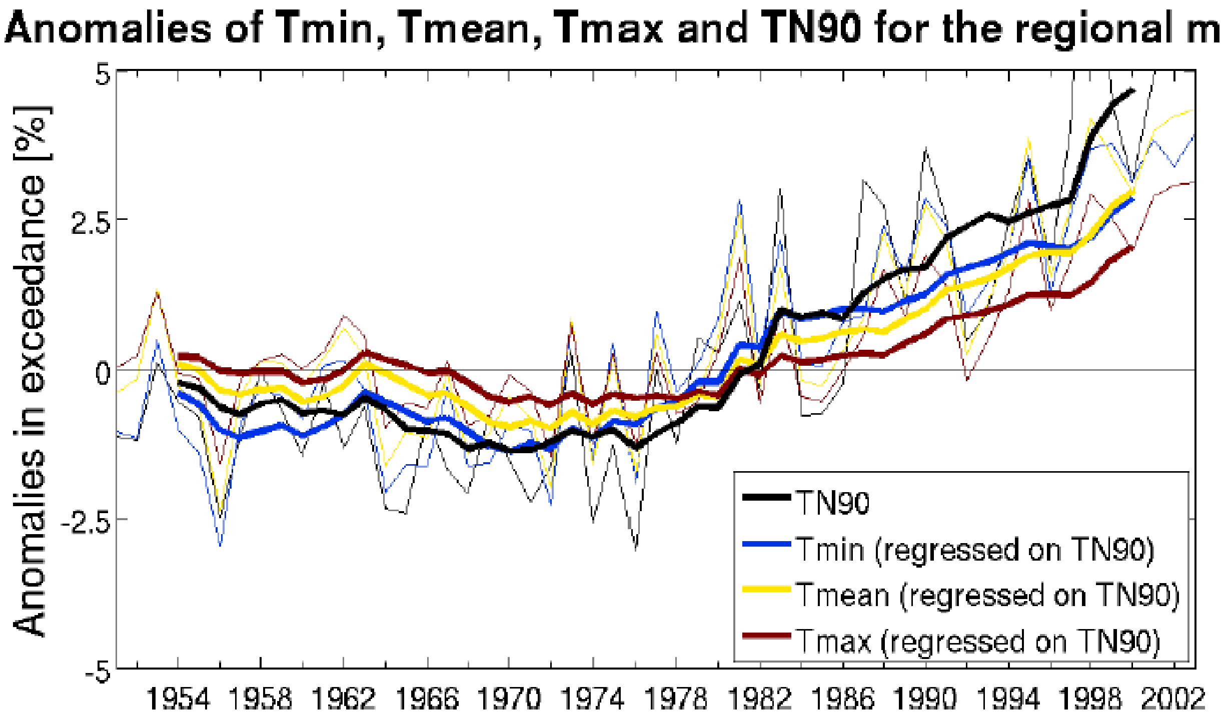
Morak and Hegerl, to be submitted

What caused this change?

From IPCC guidance document on attribution (GPGP)

II. Multi-step attribution to external forcings

- Assessments that attribute an observed change in a variable of interest to a change in climate and/or environmental conditions, plus separate assessments that attribute the change in climate and/or environmental conditions to external drivers and external forcings.
- (example: a change in the frequency of rare heatwaves may not be detectable, while a detectable change in mean temperatures would lead to an expectation of a change in that frequency).

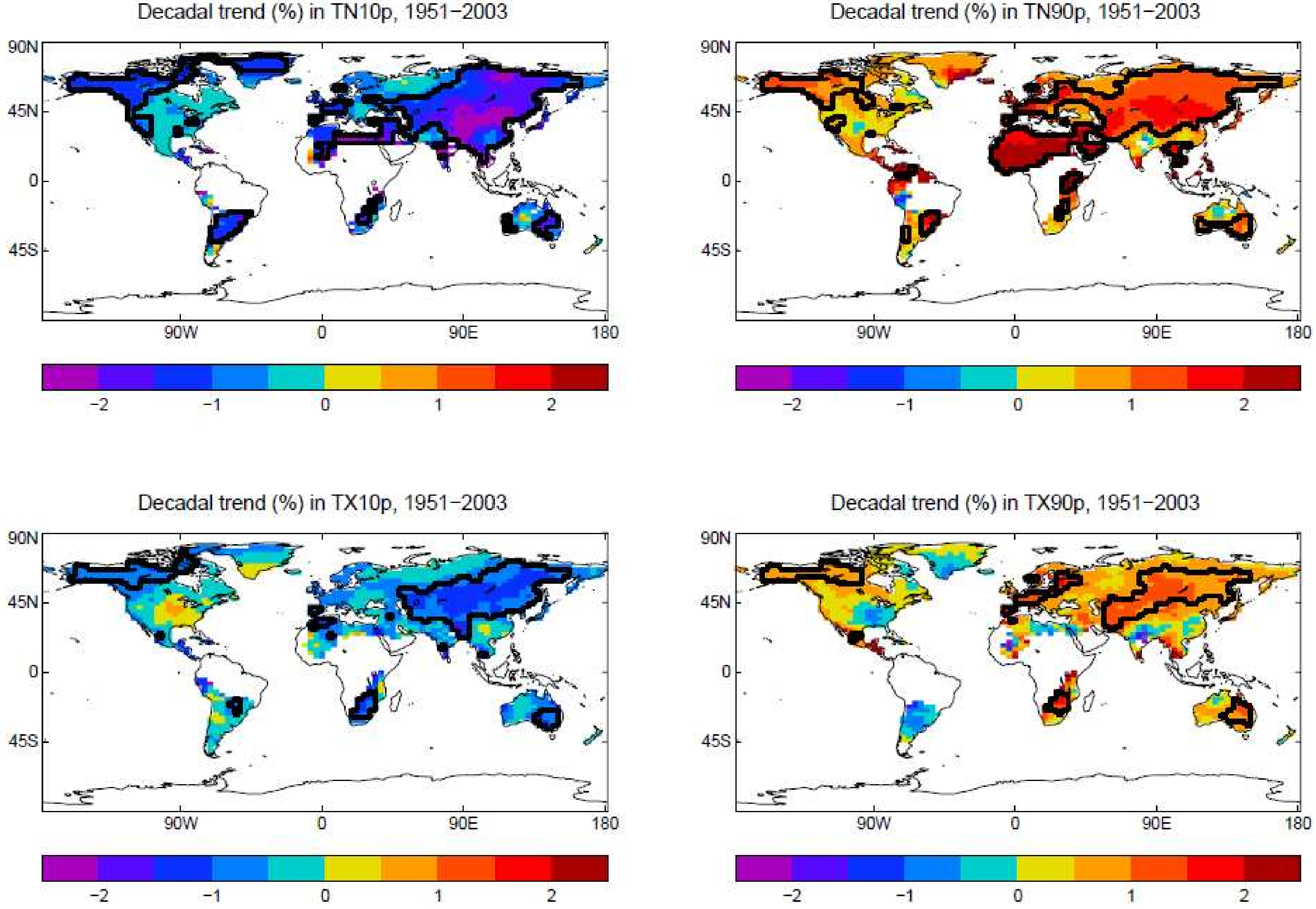


Multi-step attribution

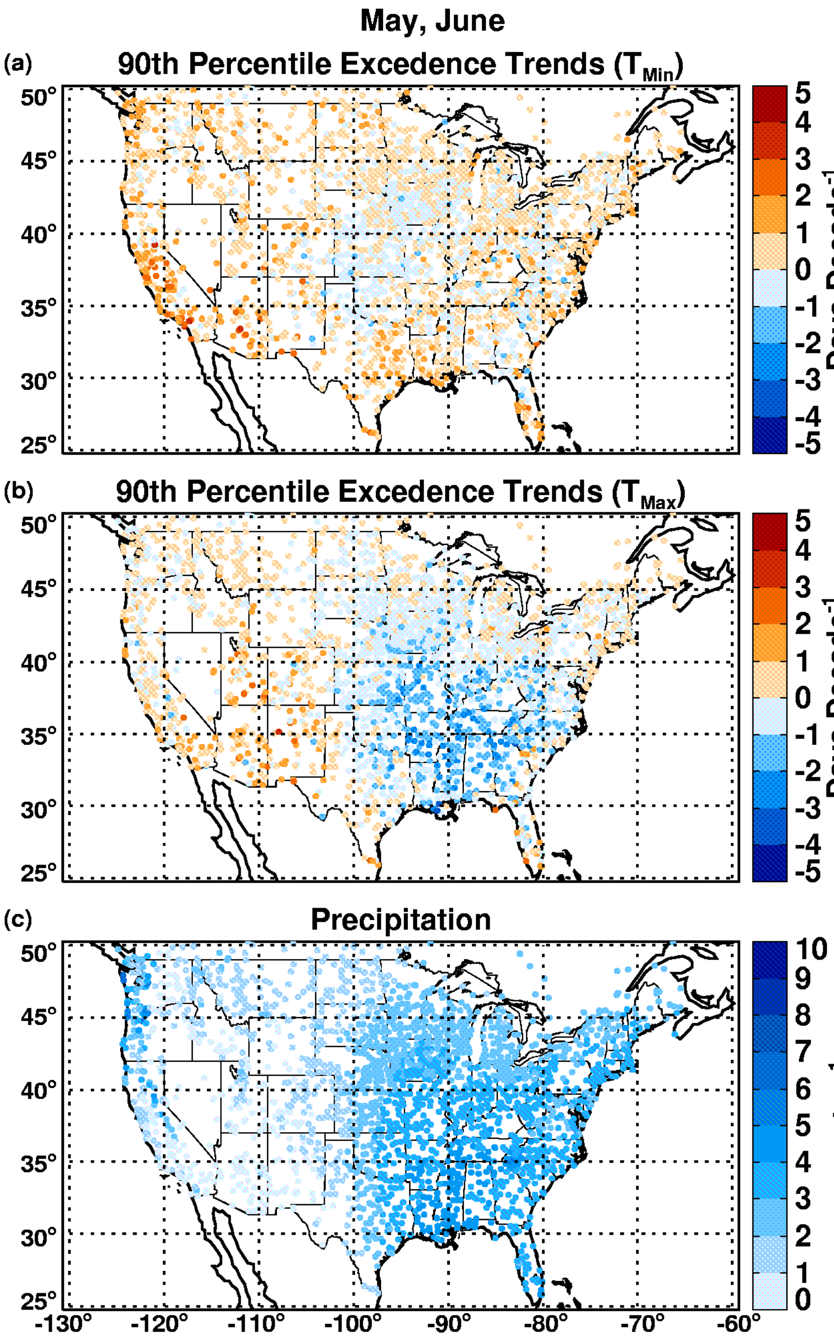
- We have detected a significant change that projects on the fingerprint of external forcings
- TN90 correlates strongly with SAT interannually (trend subtracted)
- most of the trend in TN90 is predicted based on interannual correlation with Tmean
- Much of change in Tmean over continents and most globally has been attributed to greenhouse gas increases

=> Observed increase in Tmean probably largely due to greenhouse gas increases (note we cant easily estimate the contribution)

TN90, TX90, TN10, TX10 don't change at the same rate



Alexander et al., 2006



May and June Trend pattern in number of hot days 1950-2006

Spatial and seasonal patterns in climate change, temperatures, and precipitation across the United States

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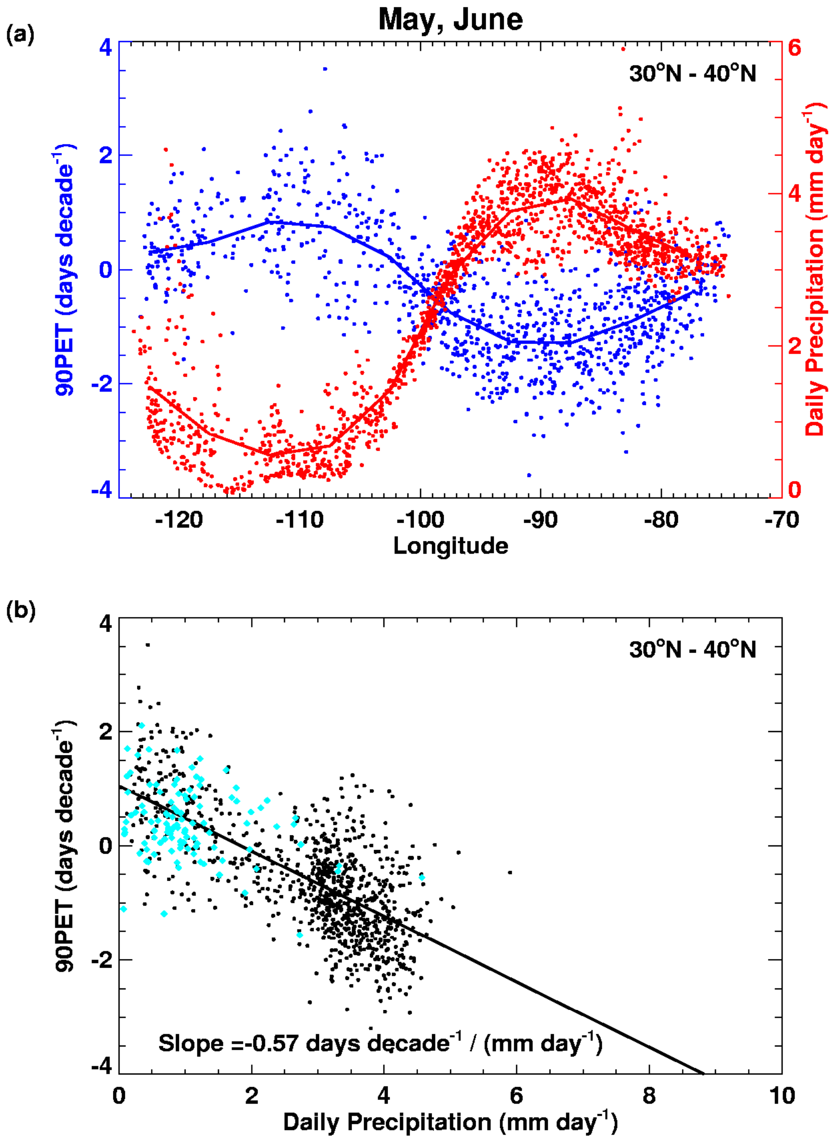
Edited by Isaac M. Held, National Oceanic and Atmospheric Administration, Princeton, NJ, and approved March 17, 2009 (received for review August 28, 2008)

Strength of trend in number of hot days anticorrelates with precipitation



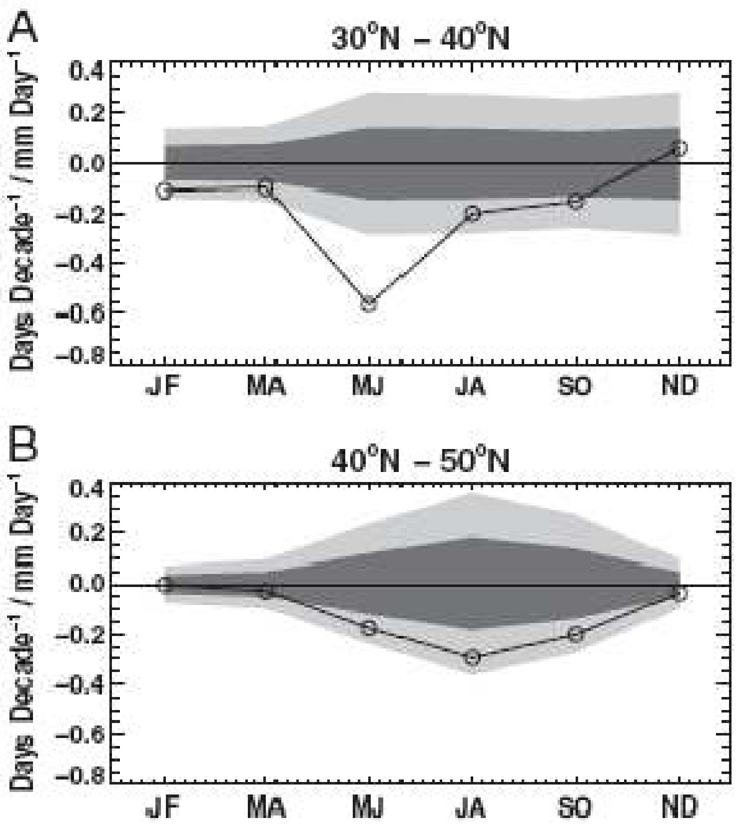


Fig. 7. Slope of the relationship between the daily maximum temperature 90th percentile exceedance trends (90PET) and the daily mean precipitation for 30–40°N (*A*) and 40–50°N (*B*) versus time (2-month intervals labeled by leading initials of the months). One- and 2-sigma confidence intervals based on the approach outlined in the text are indicated by the dark and light shading, respectively.

strong seasonal cycle in correlation of daily Tmax extremes and climatological precipitation: peak in early summer

sign. changed that prevents daily maxs to increase, particularly in wet regions in early summer

Biogenic Aerosols?

Christidis Stott Hegerl in preparation: Land use change?

Conclusions

- Changes in extremes don’t always follow the mean, not even for temperature
- Where they follow the mean, inferences can be drawn from attributable changes in the mean in multi-step attribution; but direct assessment preferable
- Anthropogenic changes in frequency (and intensity) of warm nights are detectable
- Warm daytime extremes are more difficult and have not changed everywhere
- Estimation of human contribution to extremes provides challenges for years to come

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