Heatwaves
Past, present and future

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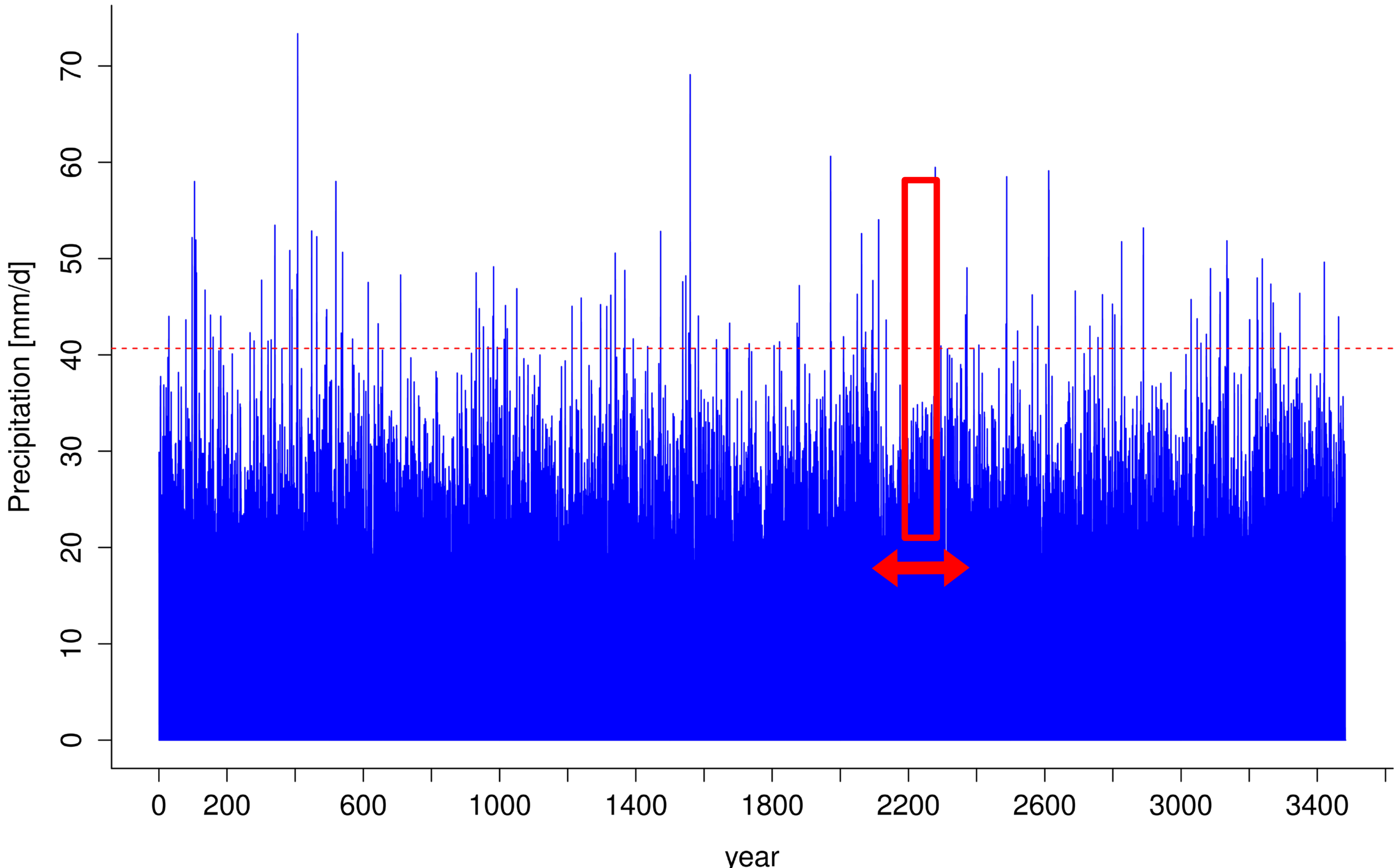
Outline

- Detection – the challenge due to internal variability
- The challenge of model evaluation
- Irreducible uncertainties in near-term projections
- Long-term projections

The challenge of detecting trends

Locally internal variability is very large

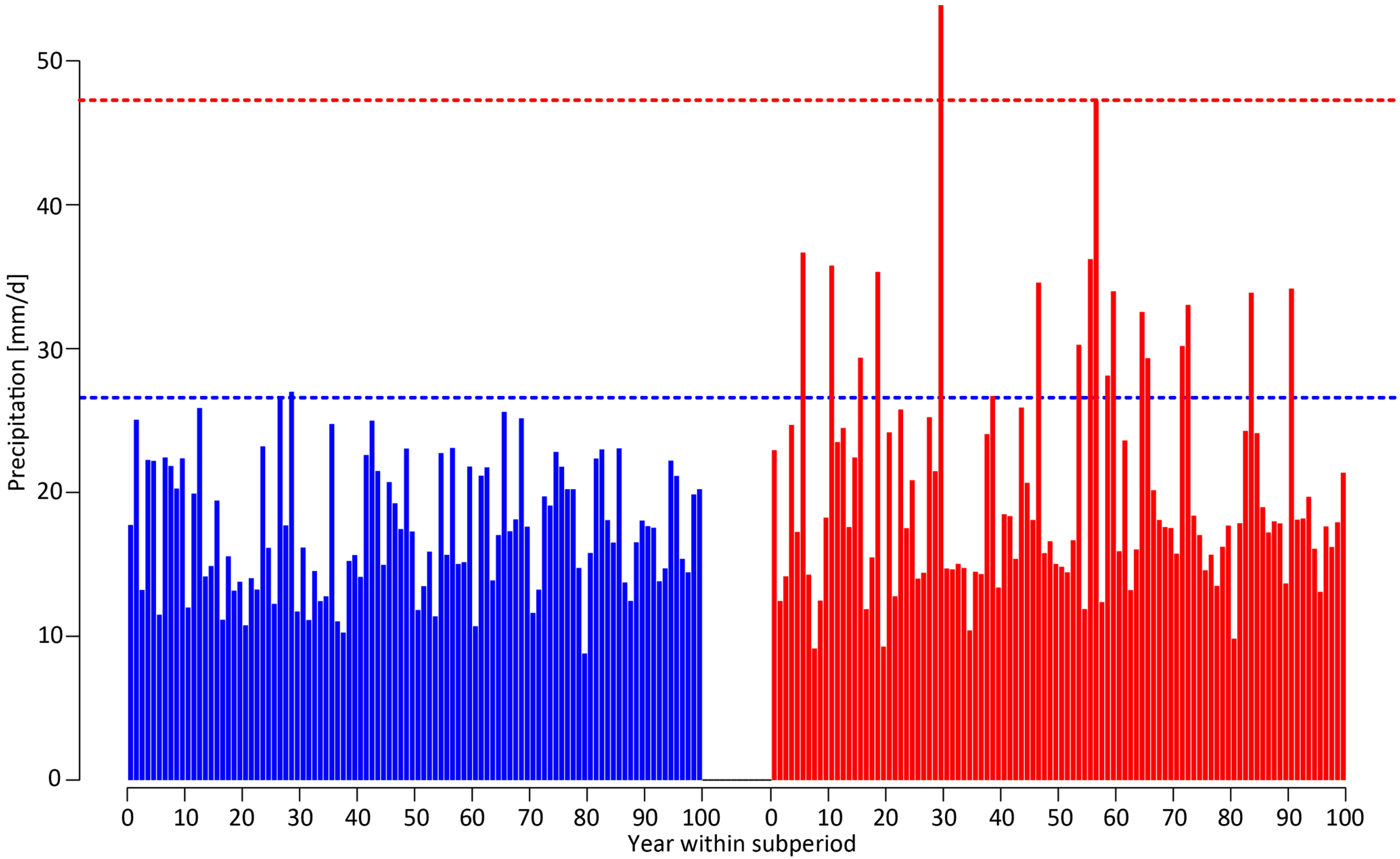
Daily precipitation in pre-industrial control run



Disaster gaps consistent with Pfister et al. 2009

Variability can bring lots of suprises

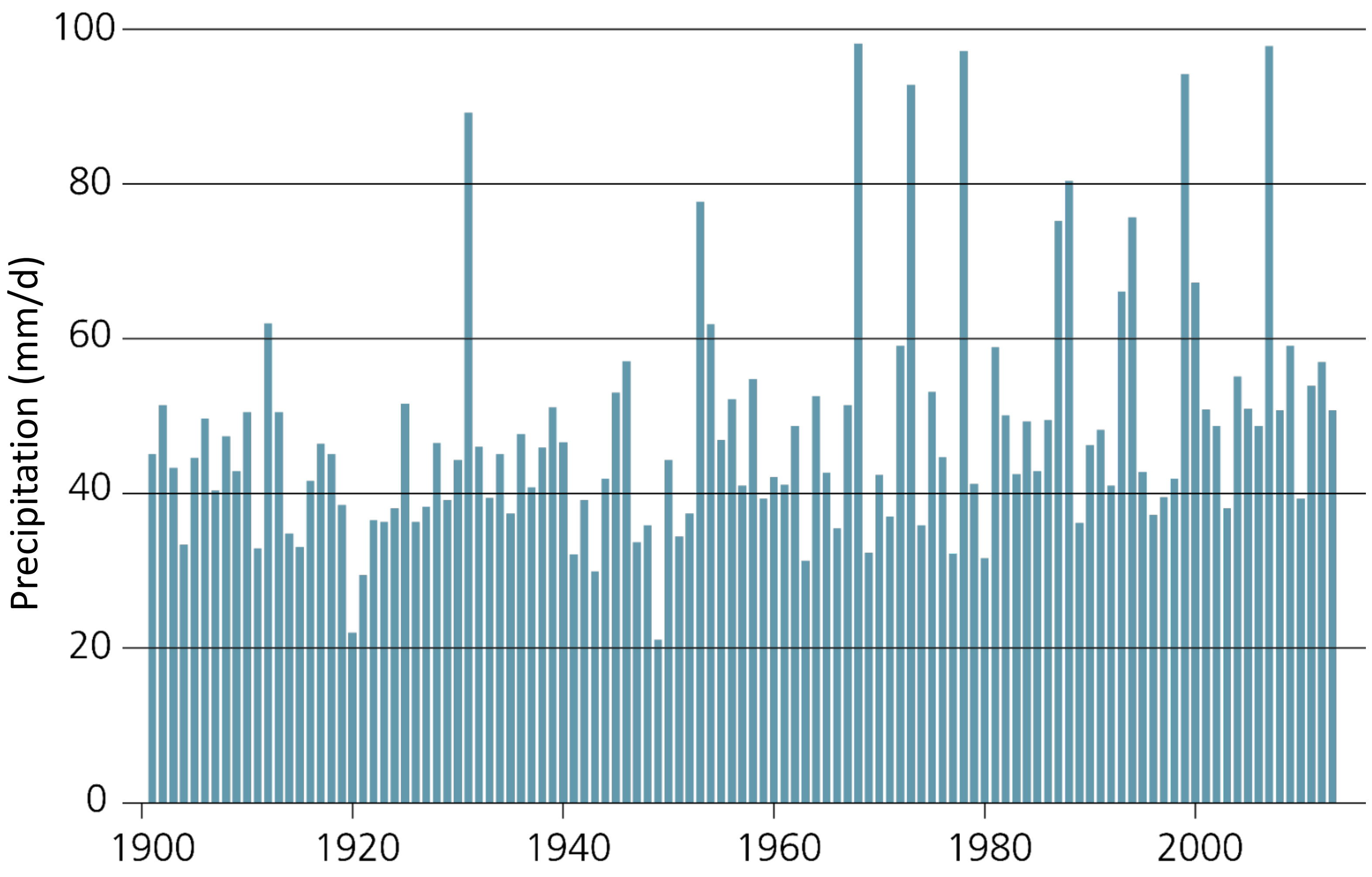
Quiescent and clustering century in control simulation



Variability is huge: observational record is often much too short to inform **reliable risk** assessments

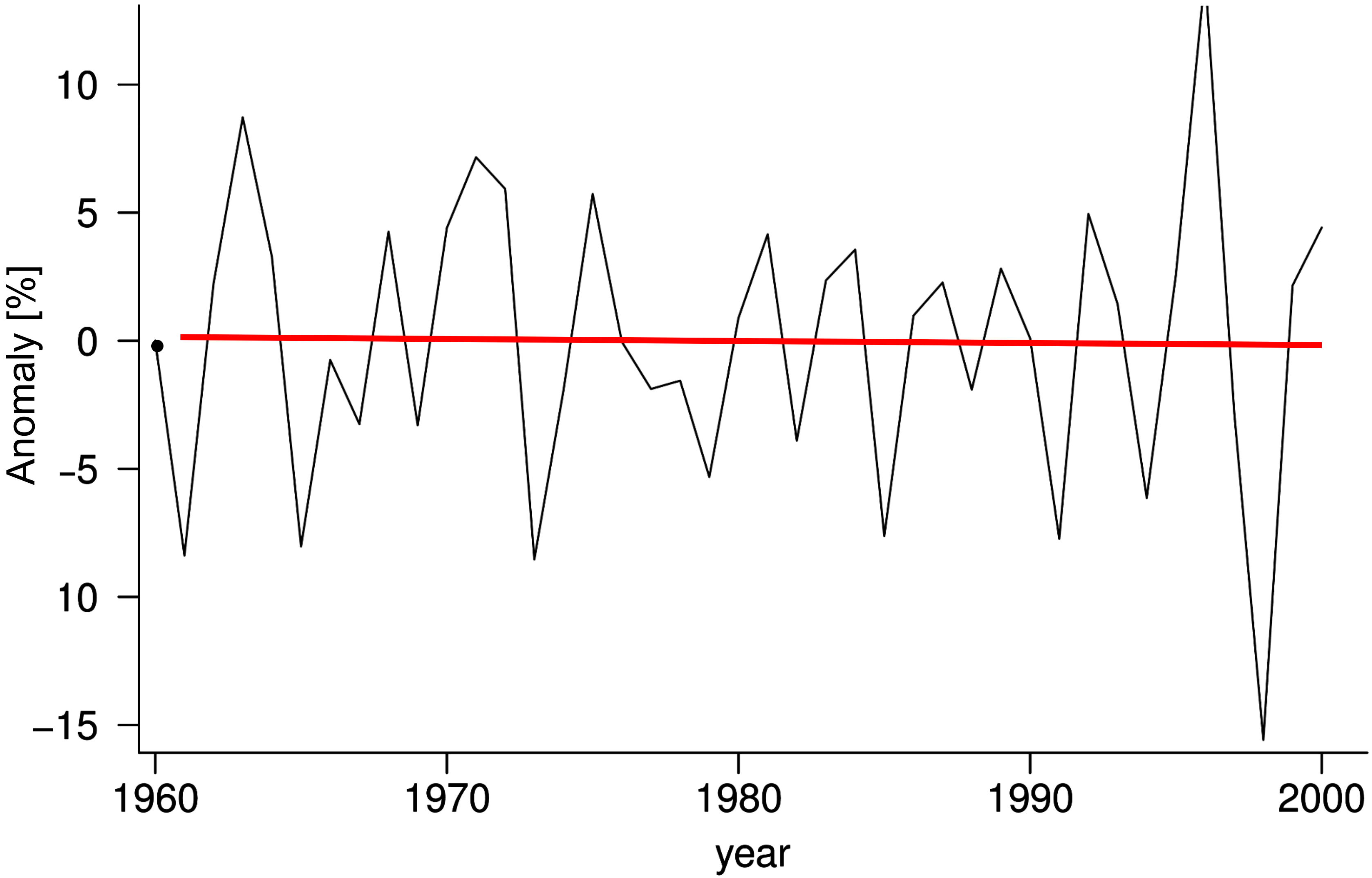
Precipitation example: change or no change?

1-day precipitation maxima 1901-2017 (Zurich)



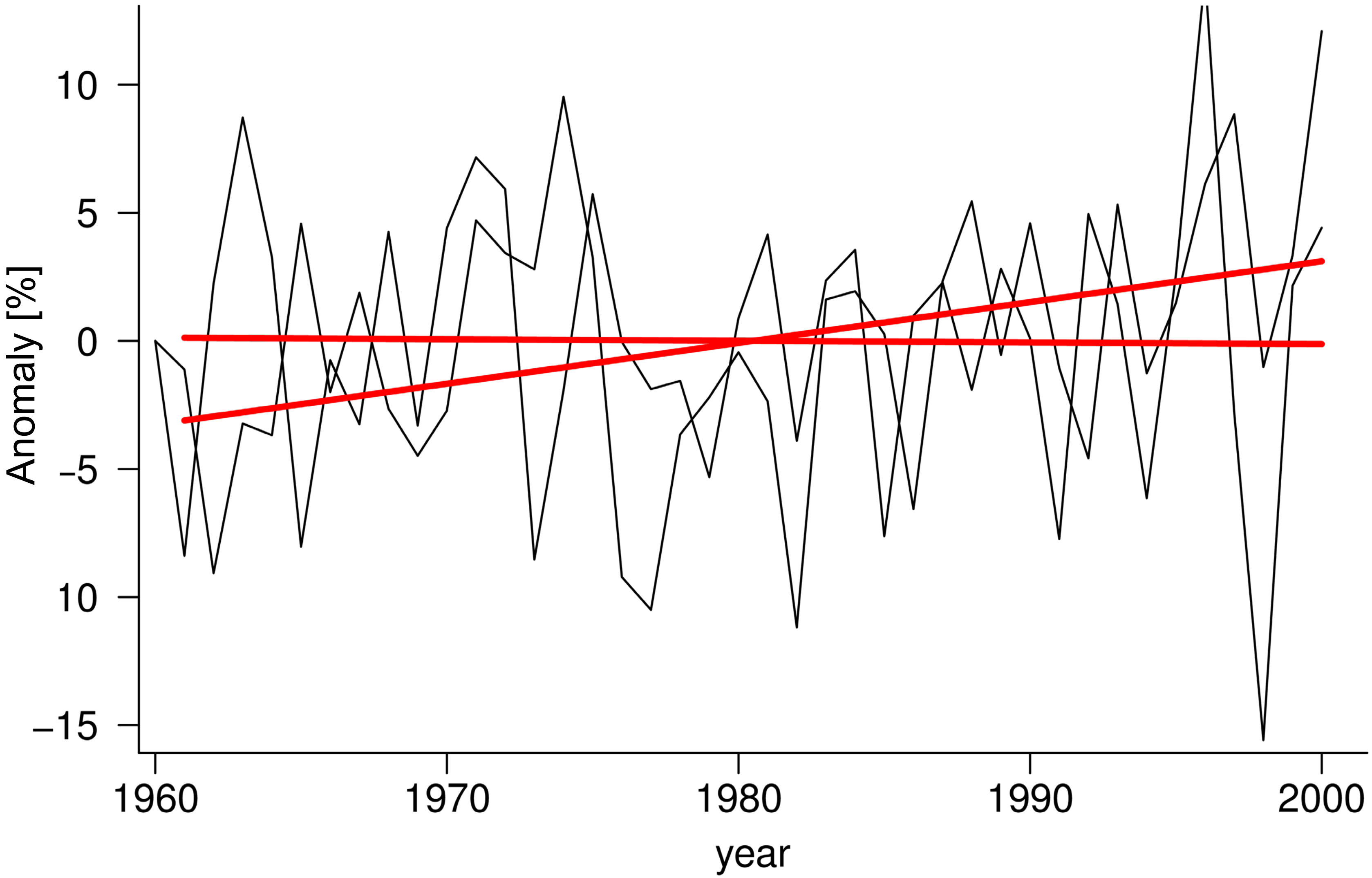
The butterfly effect

Annual 1-day rainfall maxima (rx1day) N Europe



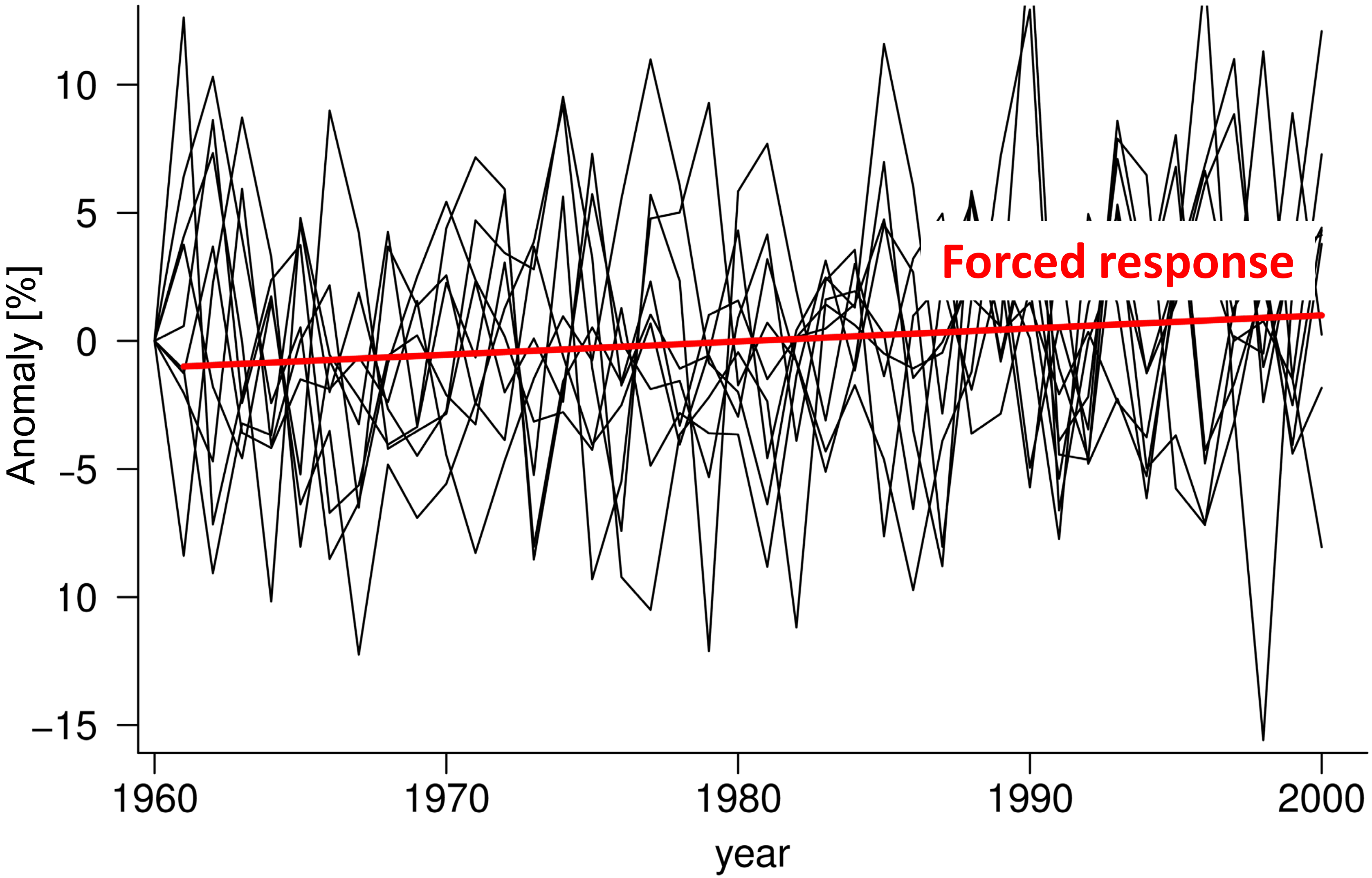
The butterfly effect

Two realizations of exact same model

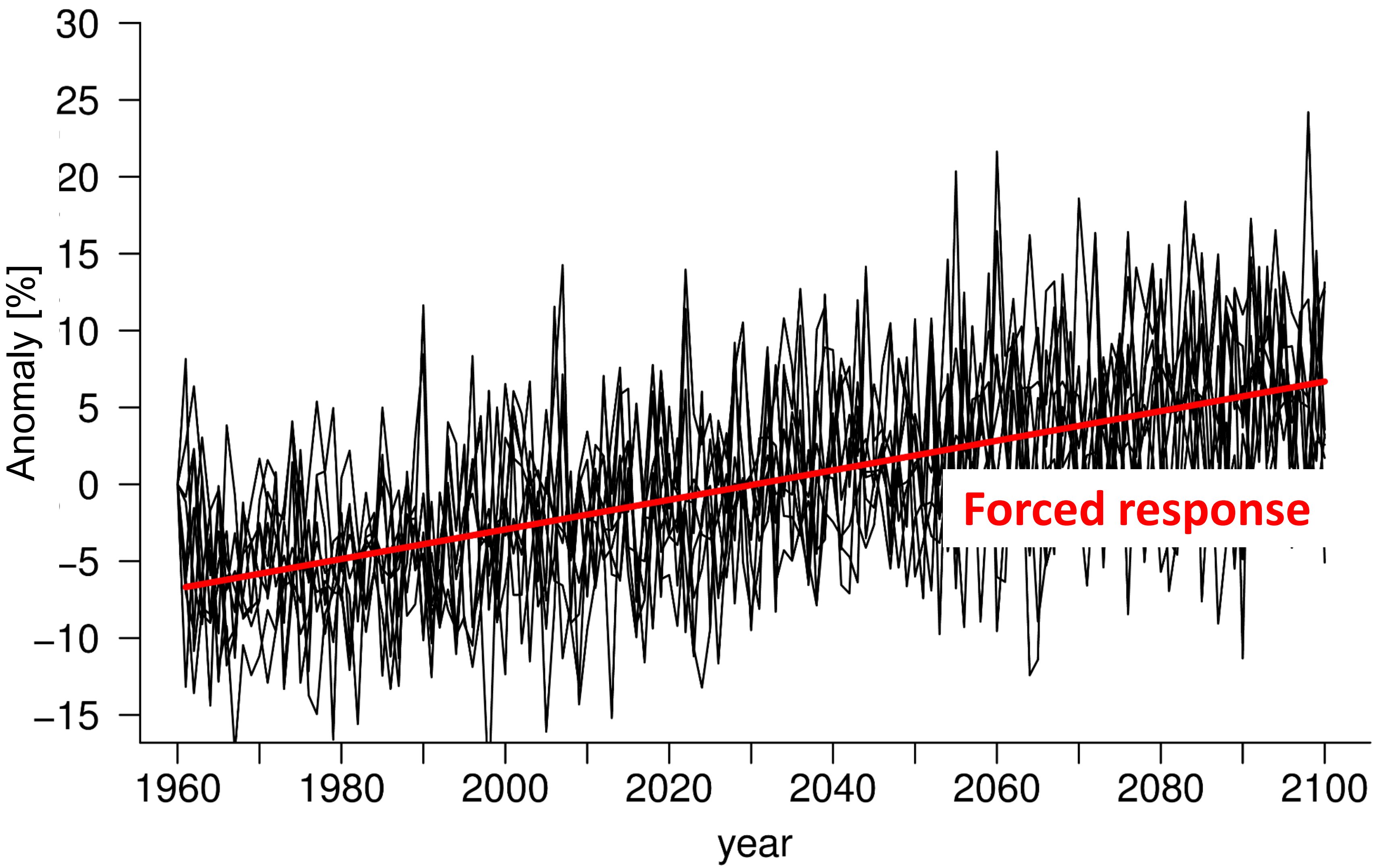


Forced response

The underlying signal that determines return period

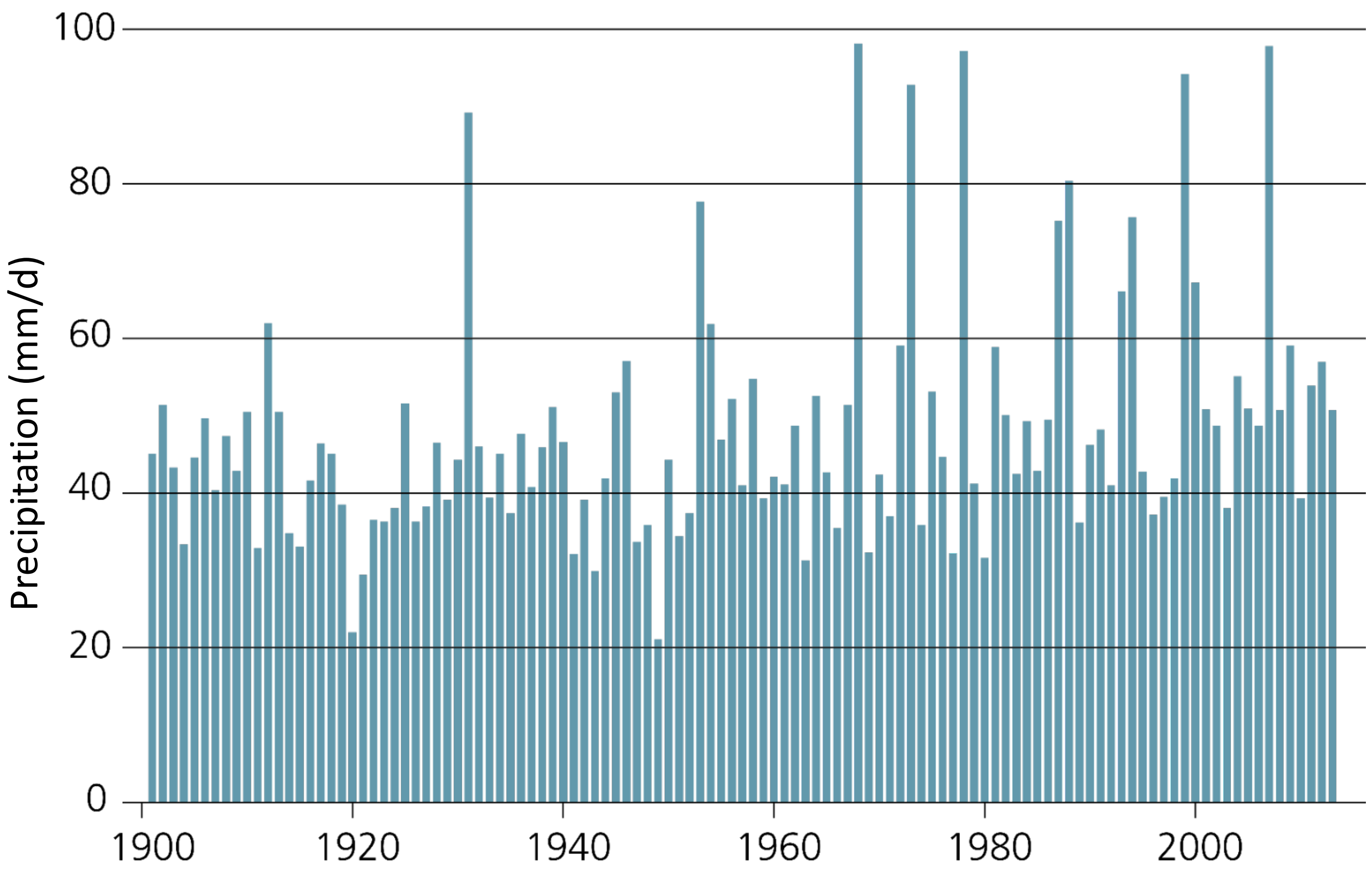


Forced response determines long-term change



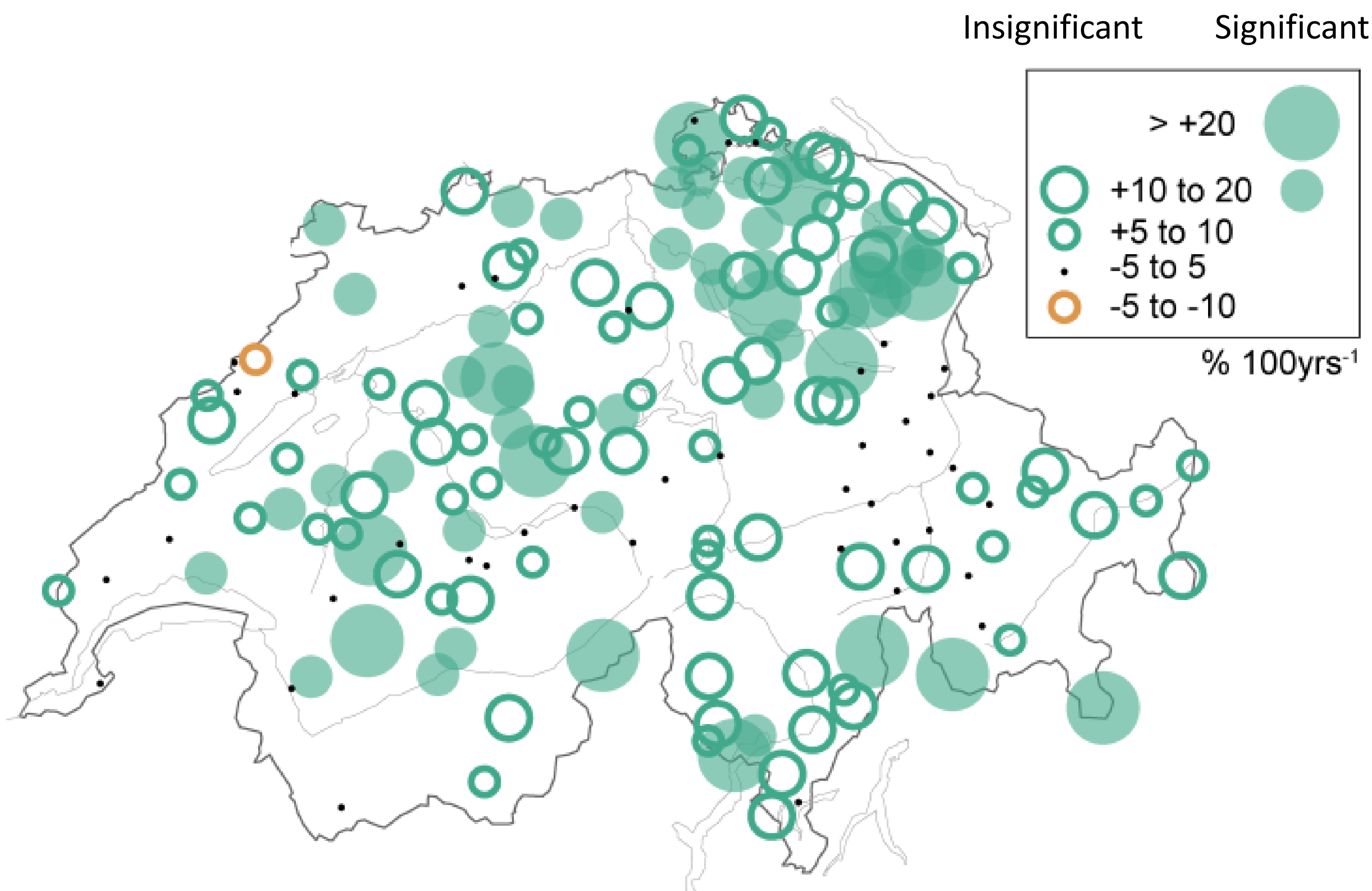
Erring on the side of least drama?

1-day precipitation maxima 1901-2017 (Zurich)



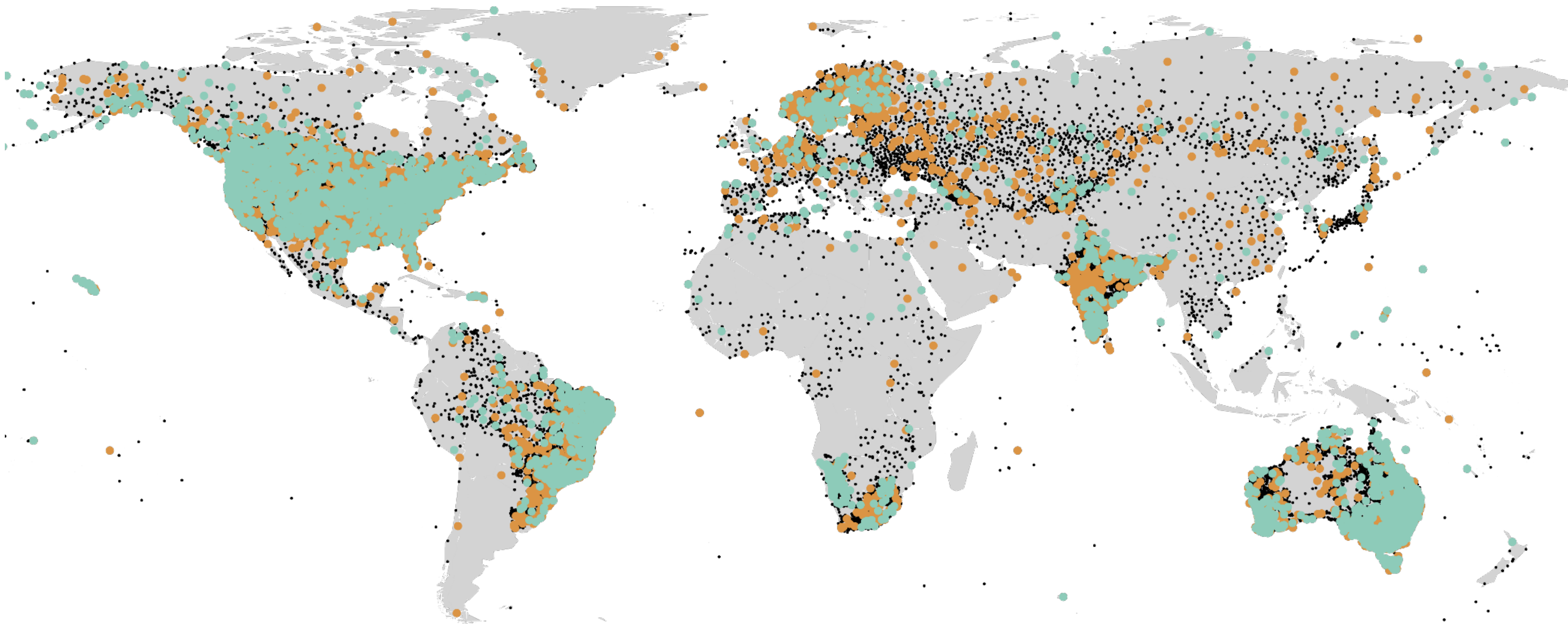
The score 31:0

Trends in 1-day precipitation maxima 1901-2014



Scherrer et al. (2016), *J Geophys Res.*

More increase than decrease in heavy precip



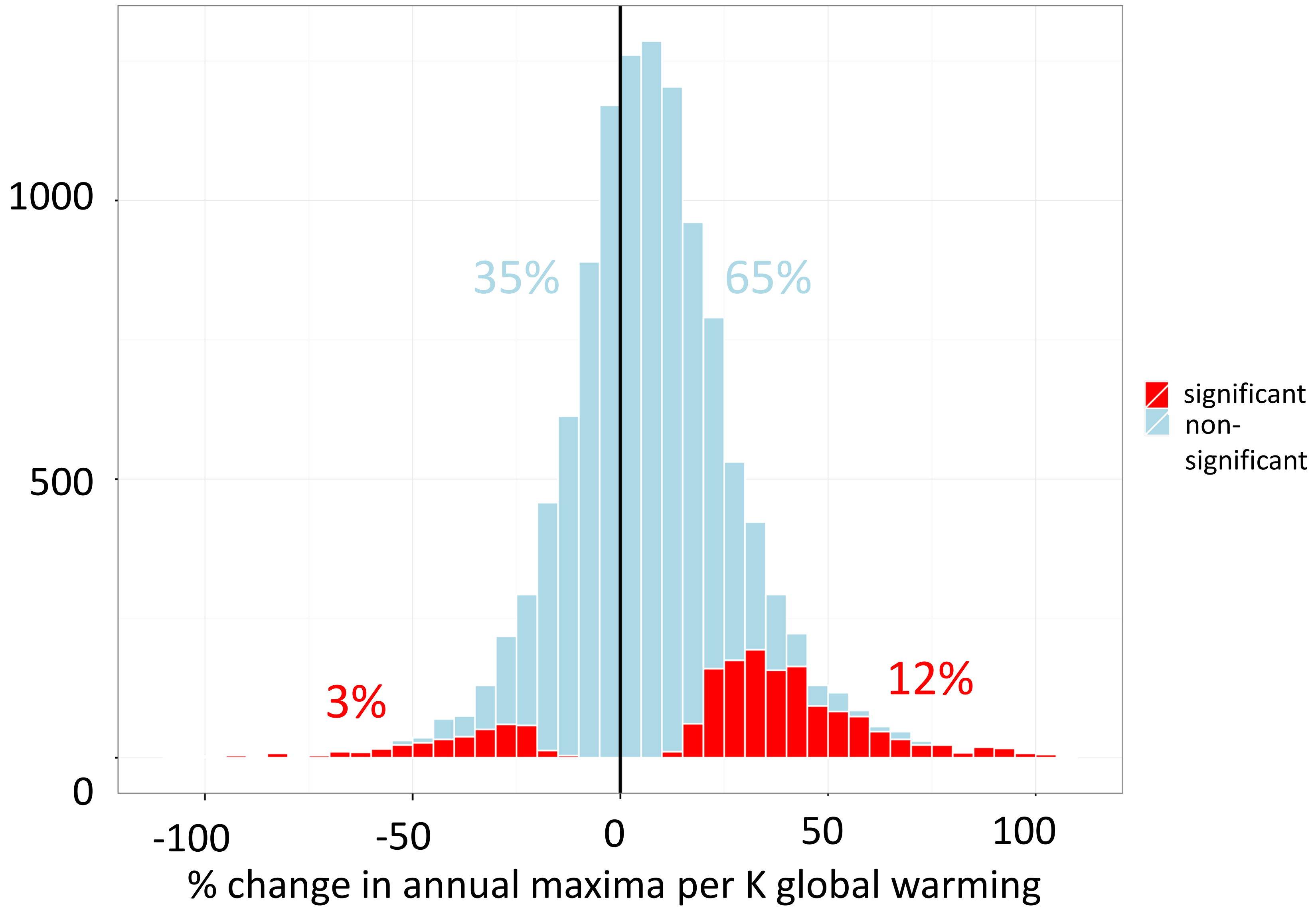
significantly negative relationship with global mean temperature

significantly positive relationship with global mean temperature

non-significant relationship with global mean temperature

Update of Westra et al. 2013

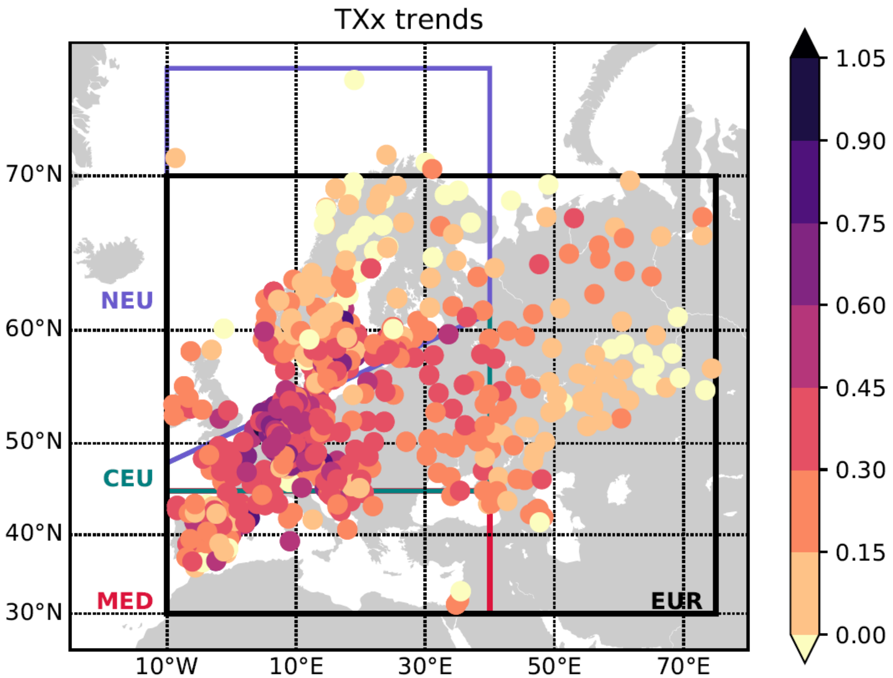
More than expected by chance



Local noise to large-scale confidence:
Changes detectable
at aggregated scales

Europe: Fischer and Knutti (2016), *Nature CC*, Zeder and Fischer, *in prep.*
Global: Westra et al. (2013) *J Climate;* Fischer and Knutti (2014) *GRL*

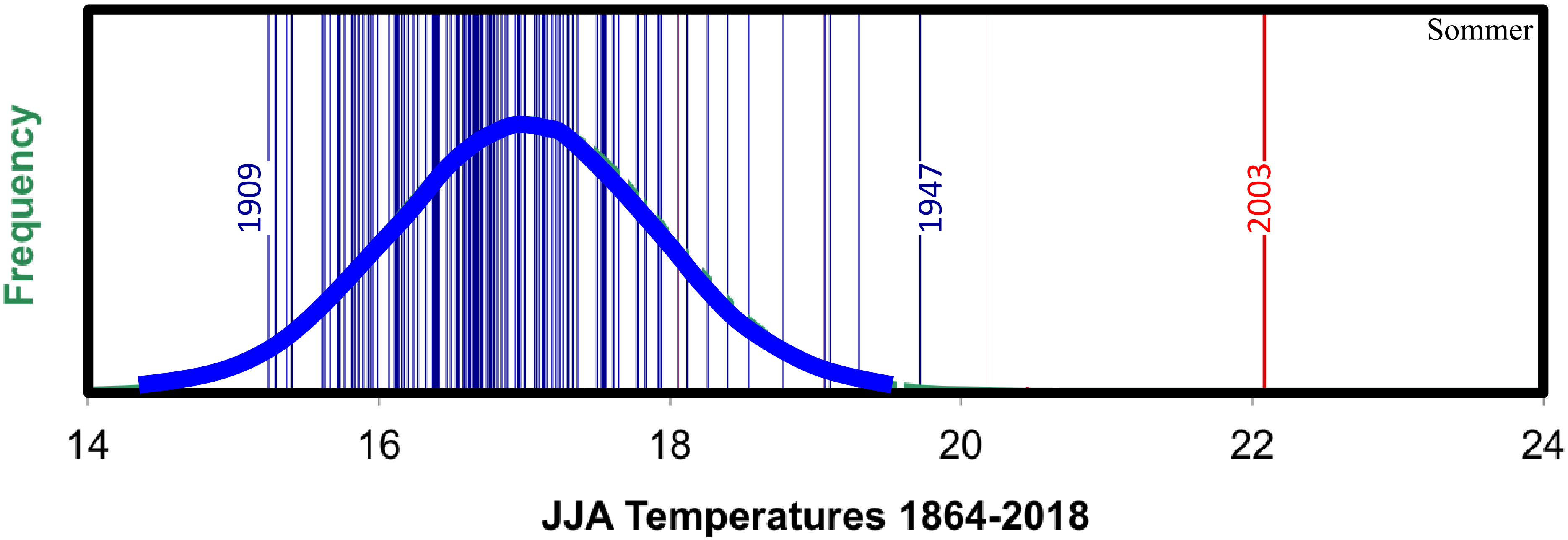
Observed trend in hot extremes



Lorenz, Stahlhandske and Fischer, 2019, *GRL*

The prime example of an extreme

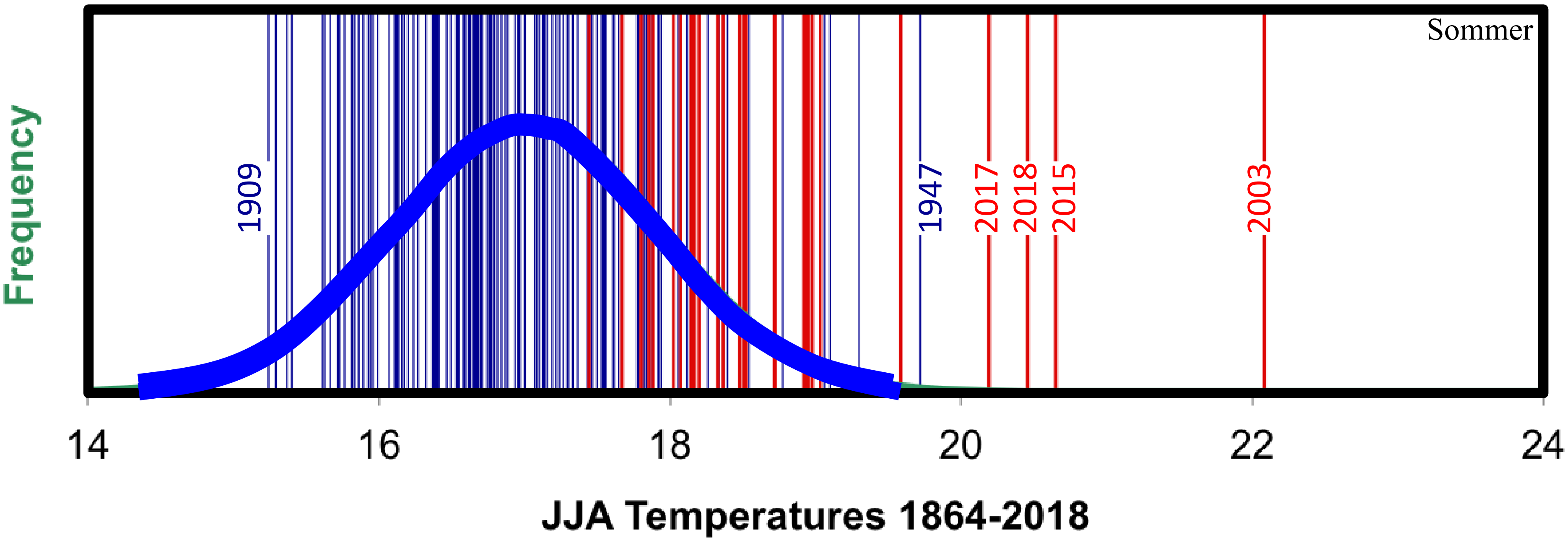
Average summer temperature at 4 Swiss stations



Schär et al. 2004, *Nature*

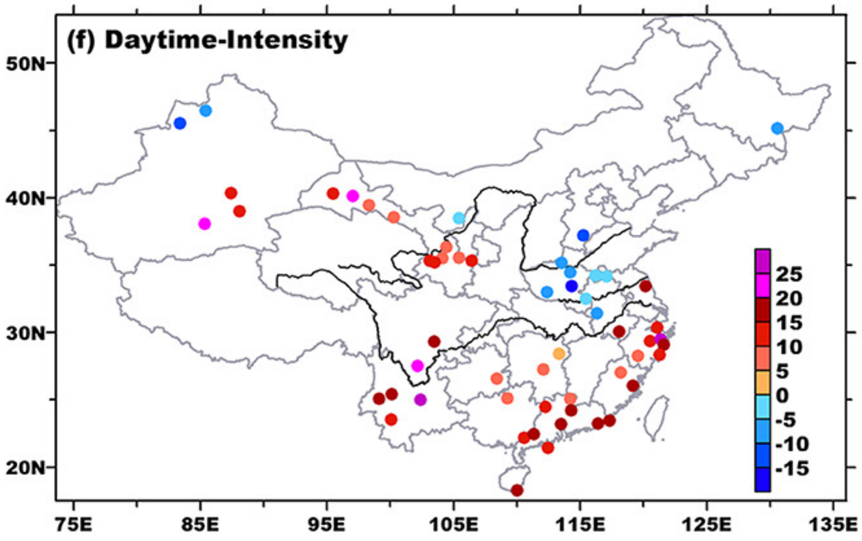
Detection of changes in hot extremes

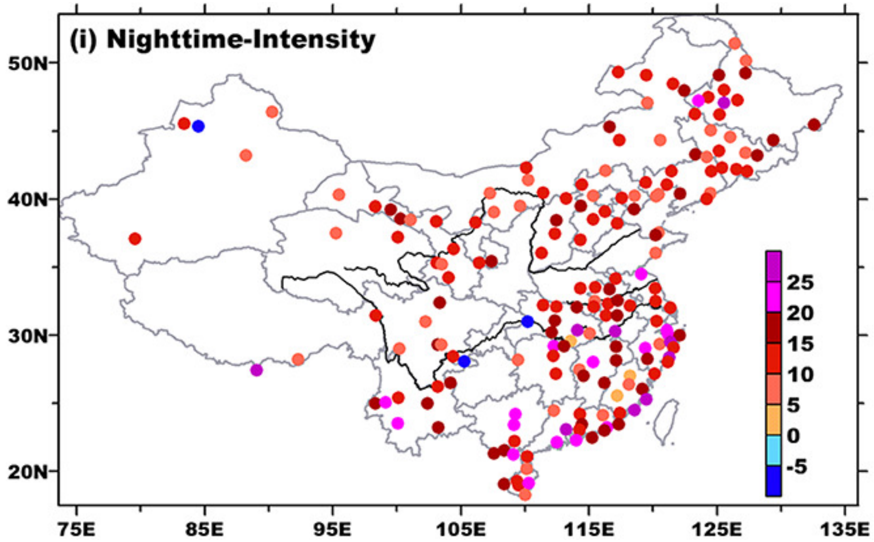
1864-1989 vs. 1990-2018



Schär et al. 2004, *Nature*

Daytime vs. nighttime





Chen and Zhai (2018) *GRL*

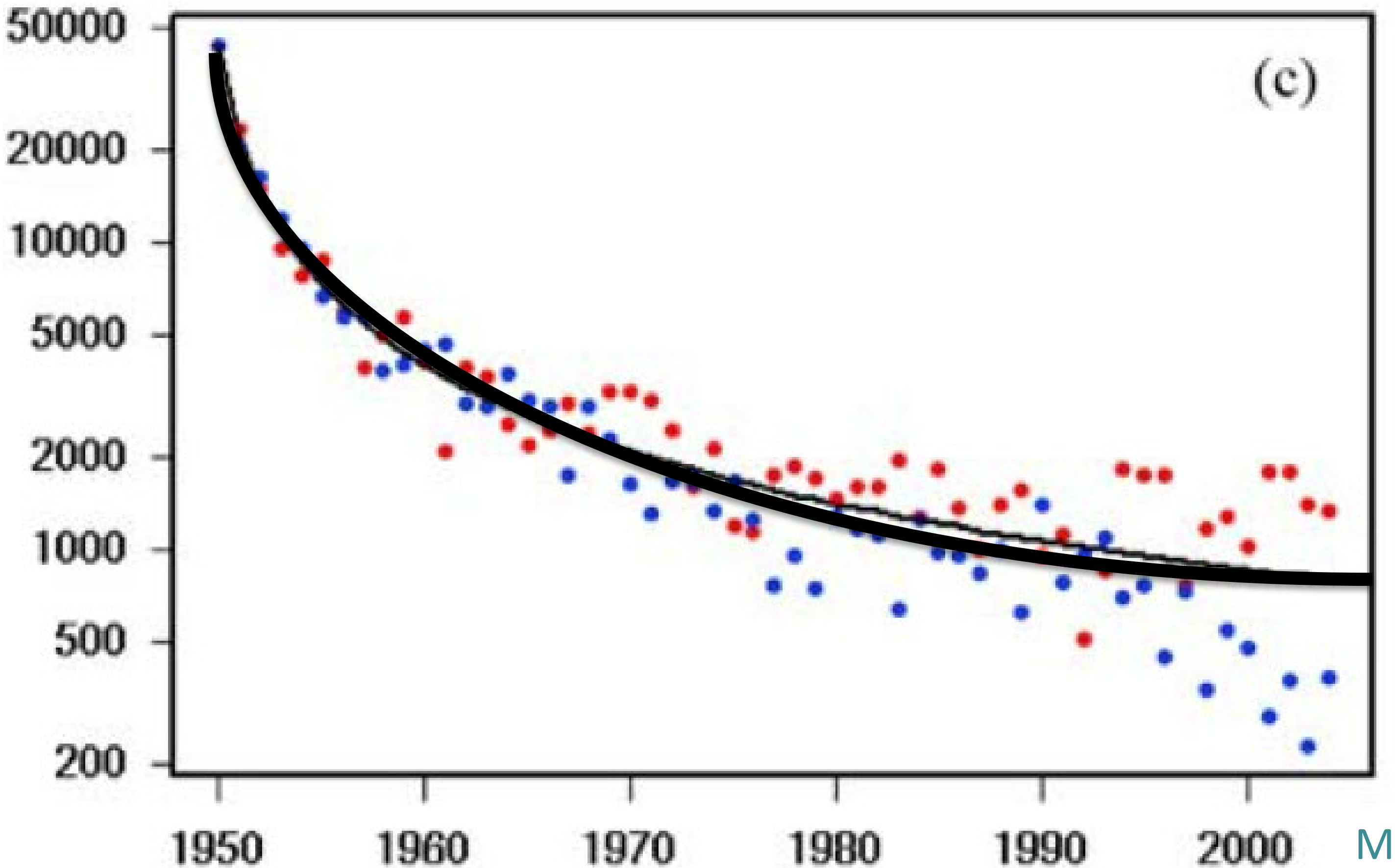
Record-breaking extremes


SEIKO
9.58

Record-breaking events

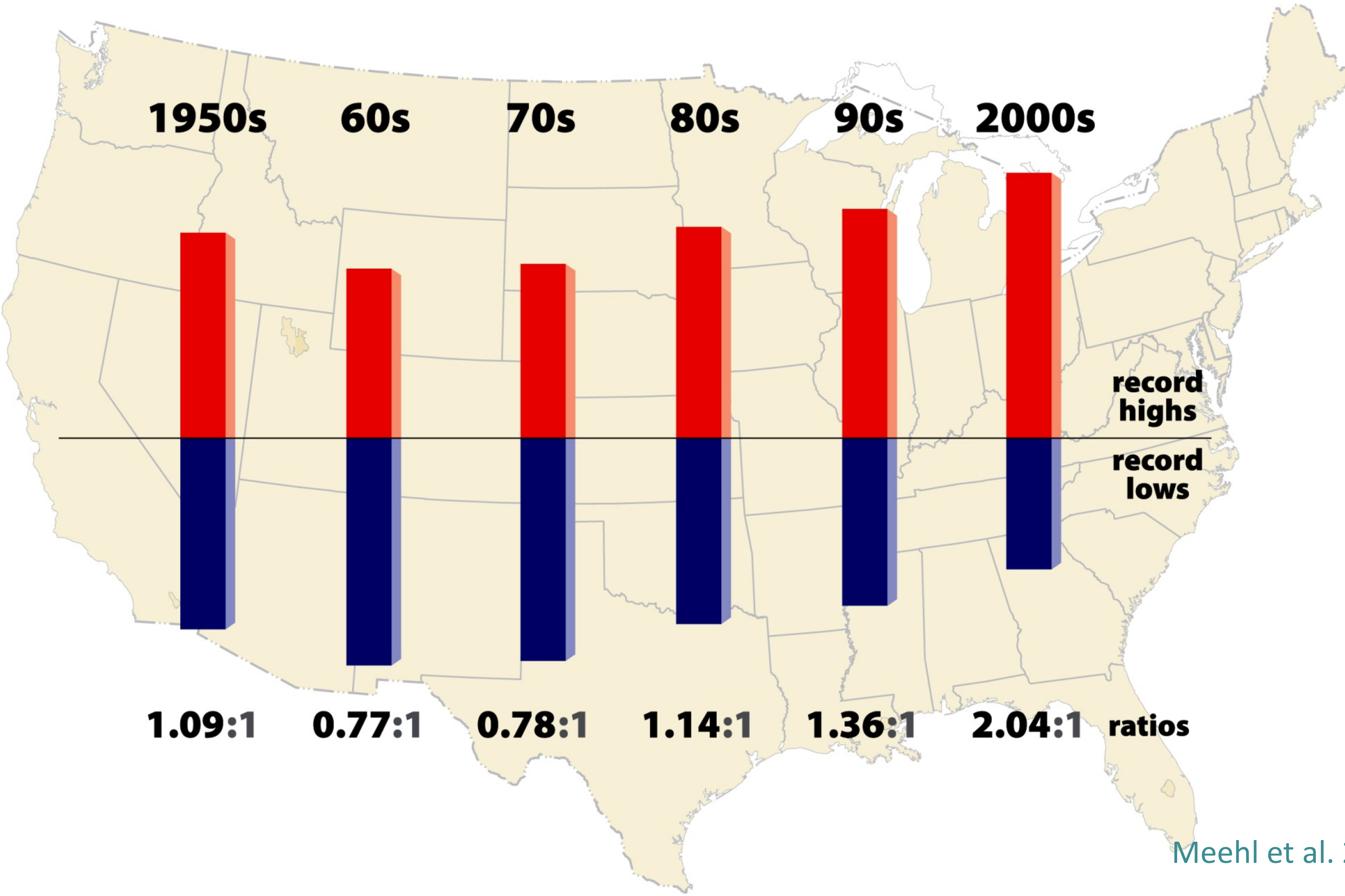
We would expect them to become rarer…

… but some don't



Meehl et al. 2009

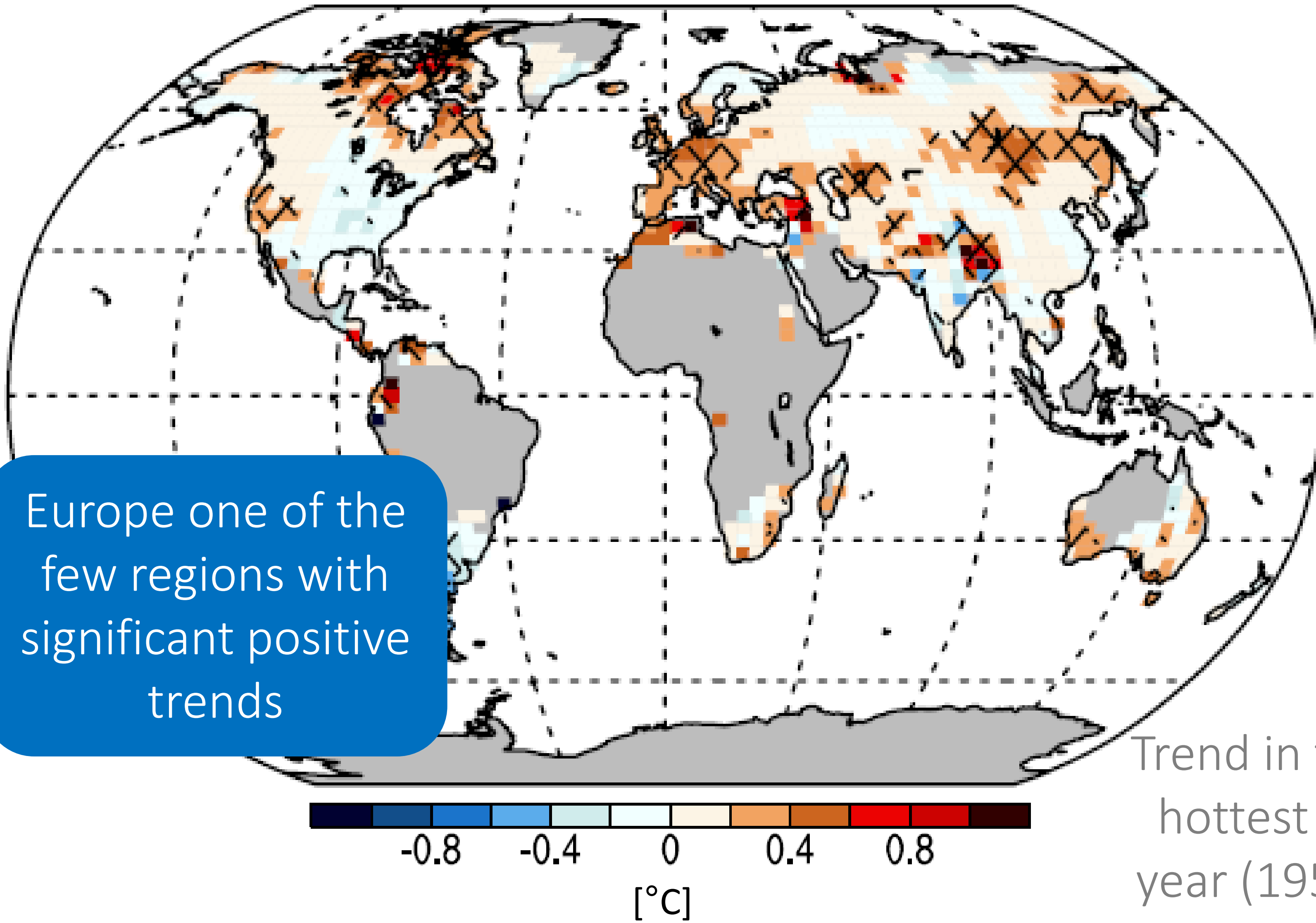
More hot – less cold extremes



Meehl et al. 2009

The challenge of model evaluation

Observed trends in hot extremes



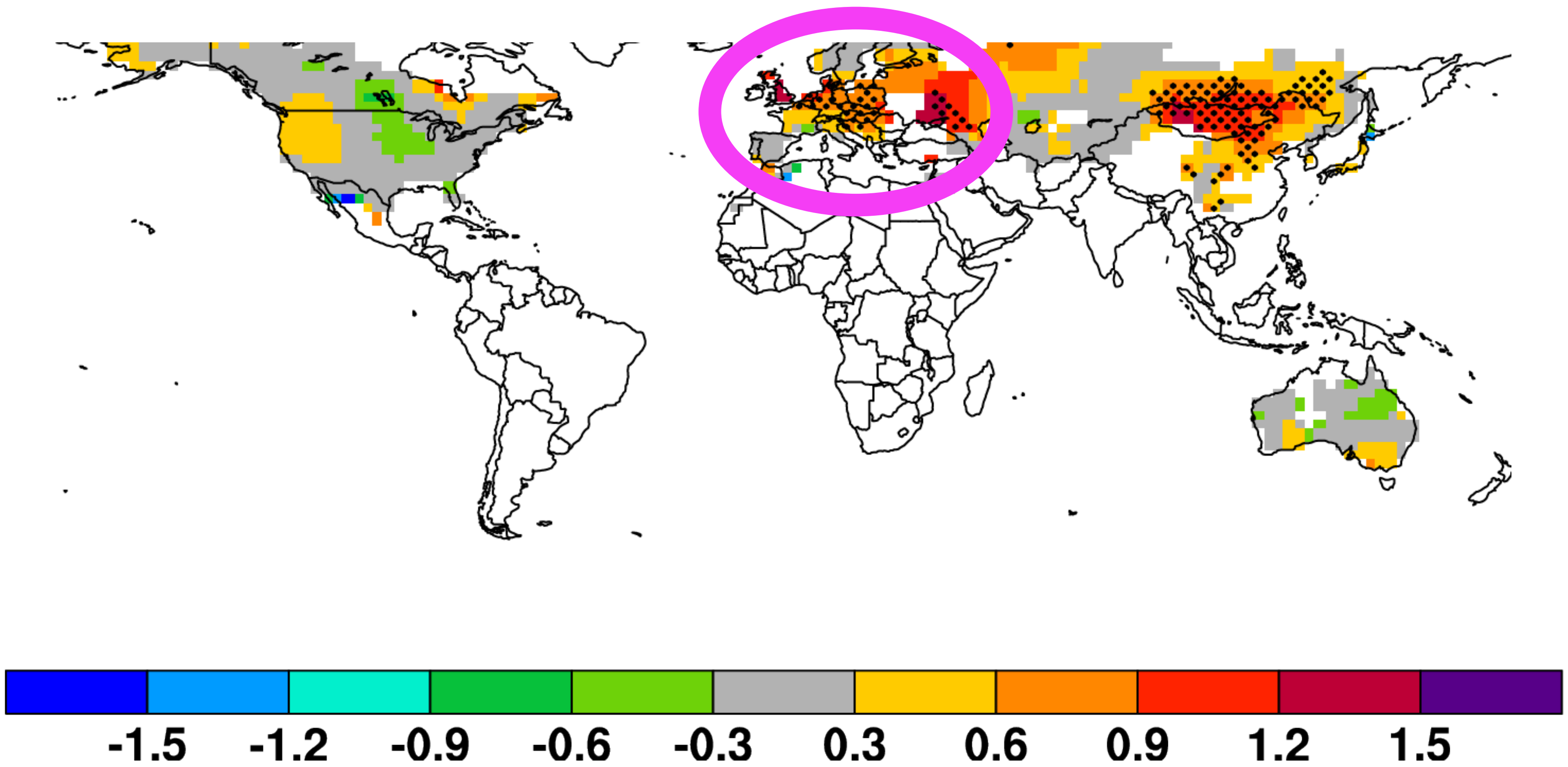
Europe one of the few regions with significant positive trends

Trend in temp. on hottest day per year (1951-2010)

Donat et al. 2013, *JGR*

Observed trends in hot extremes

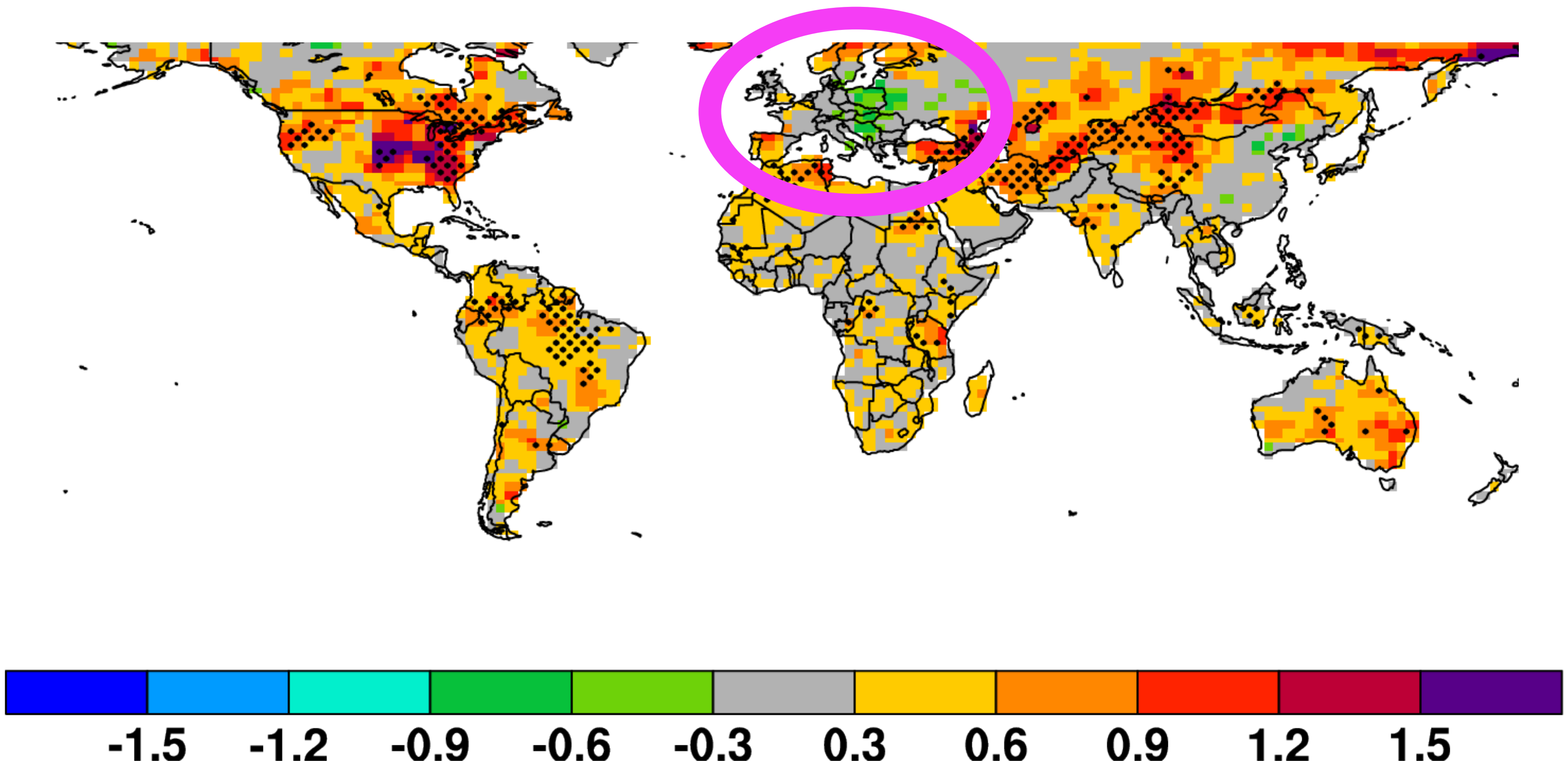
Trends in TXx 1979-2010 (GHCNDEX)



Fischer and Knutti (2014), *Geophys. Res. Letters*

Poor agreement

Trends in TXx 1979-2010 (CESM)



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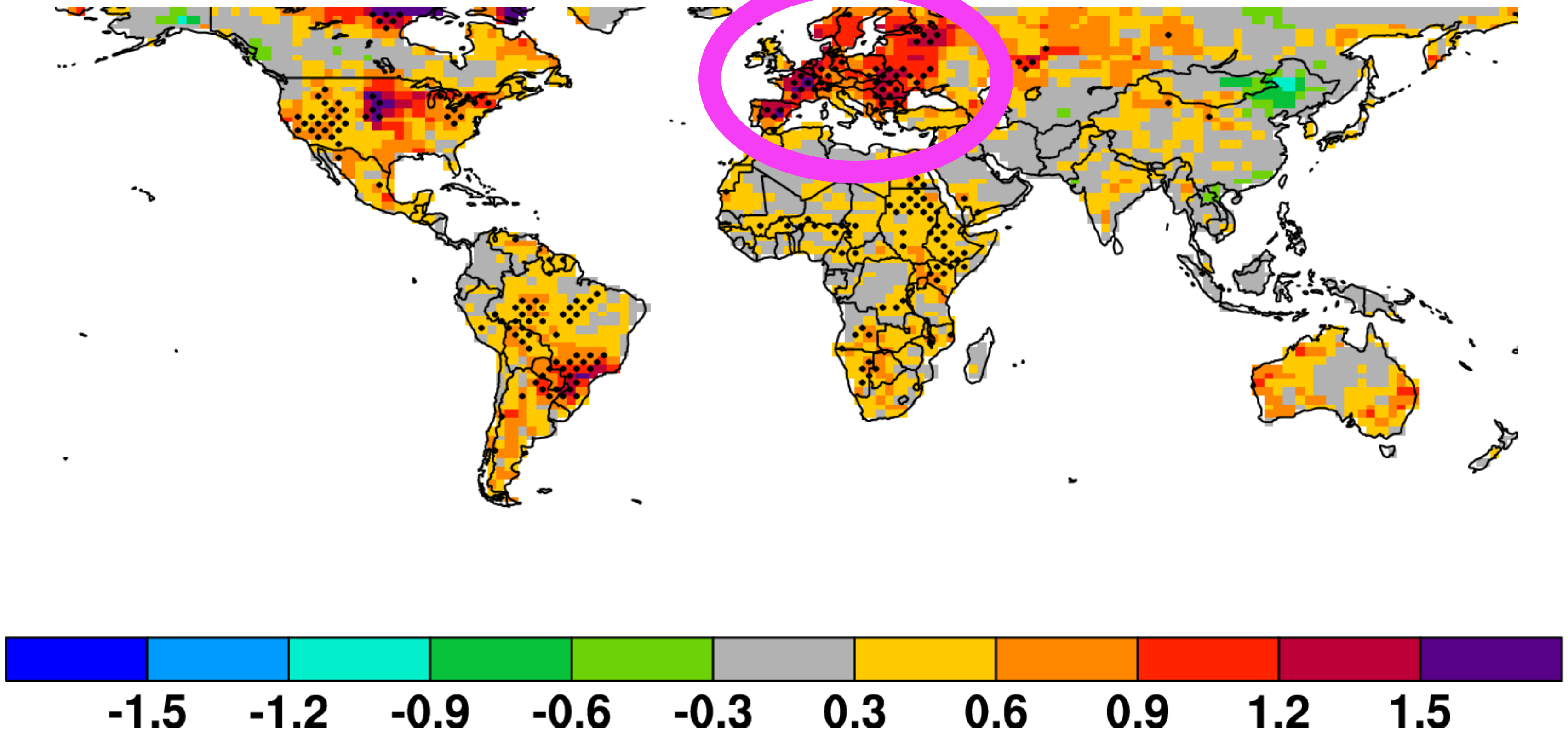
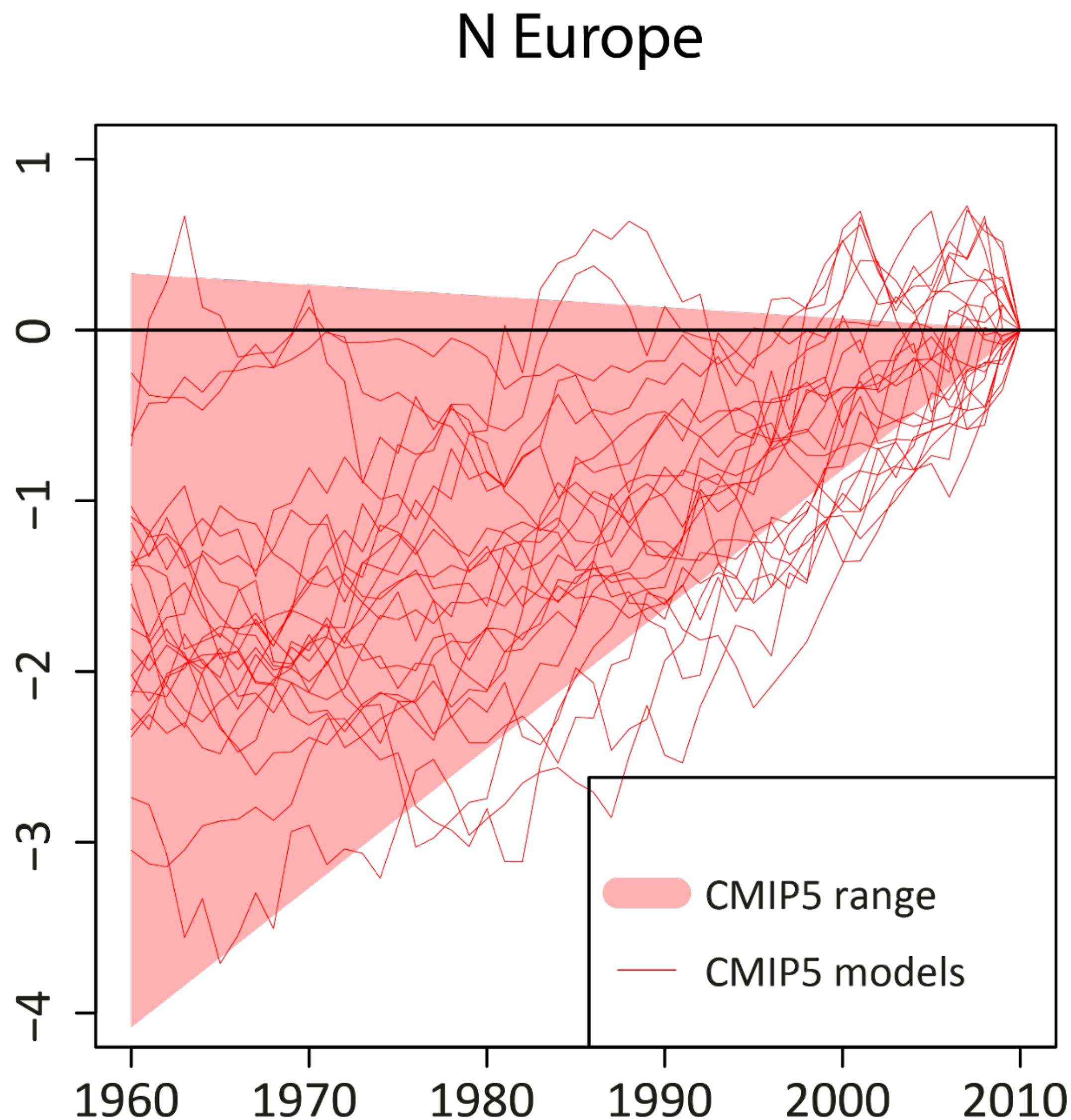


Fischer and Knutti (2014), *Geophys. Res. Letters*

Observed changes in hot extremes

Trends in TXx 1979-2010 (CESM)



Observed changes in hot extremes

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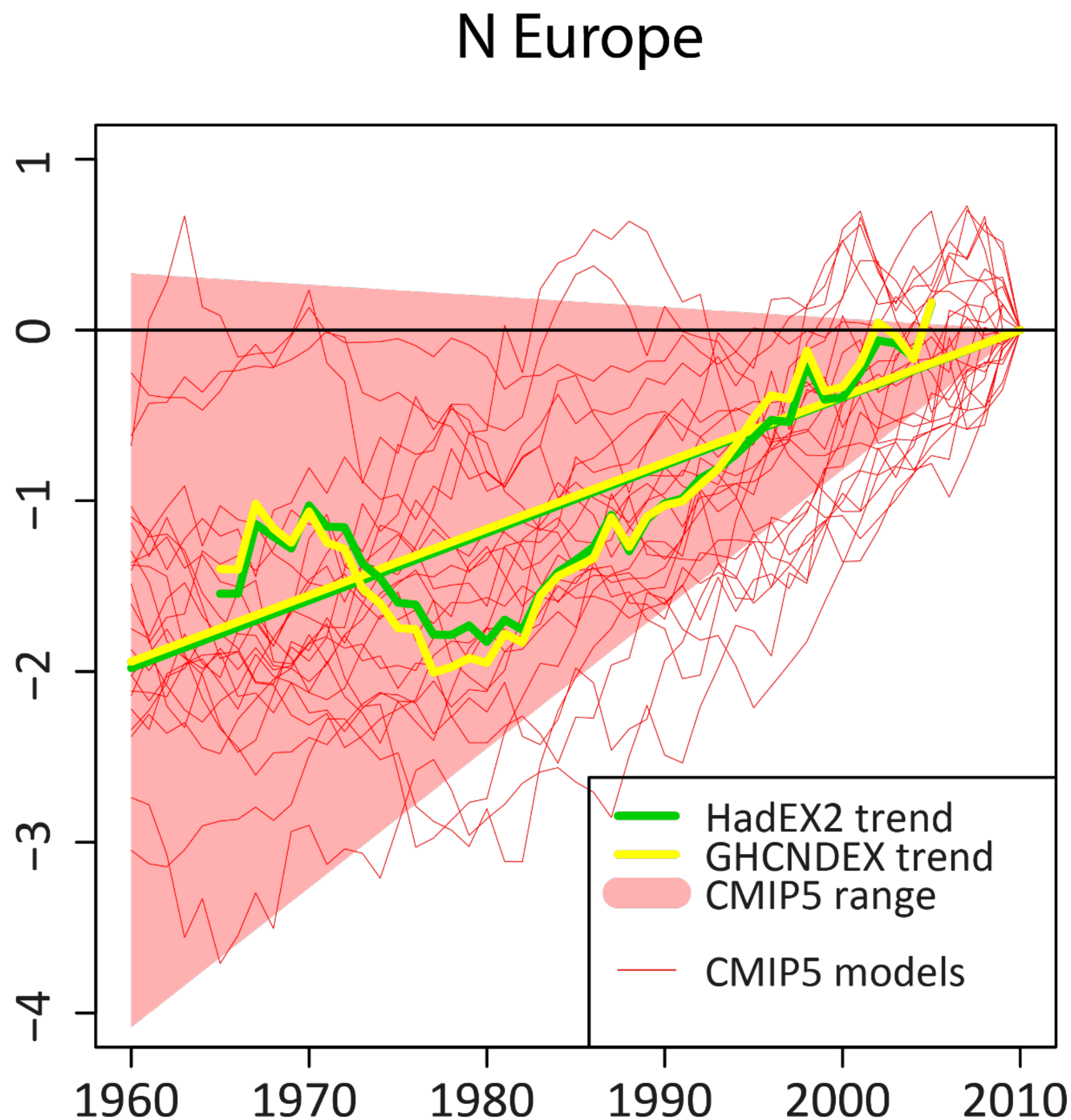

Observed changes in hot extremes

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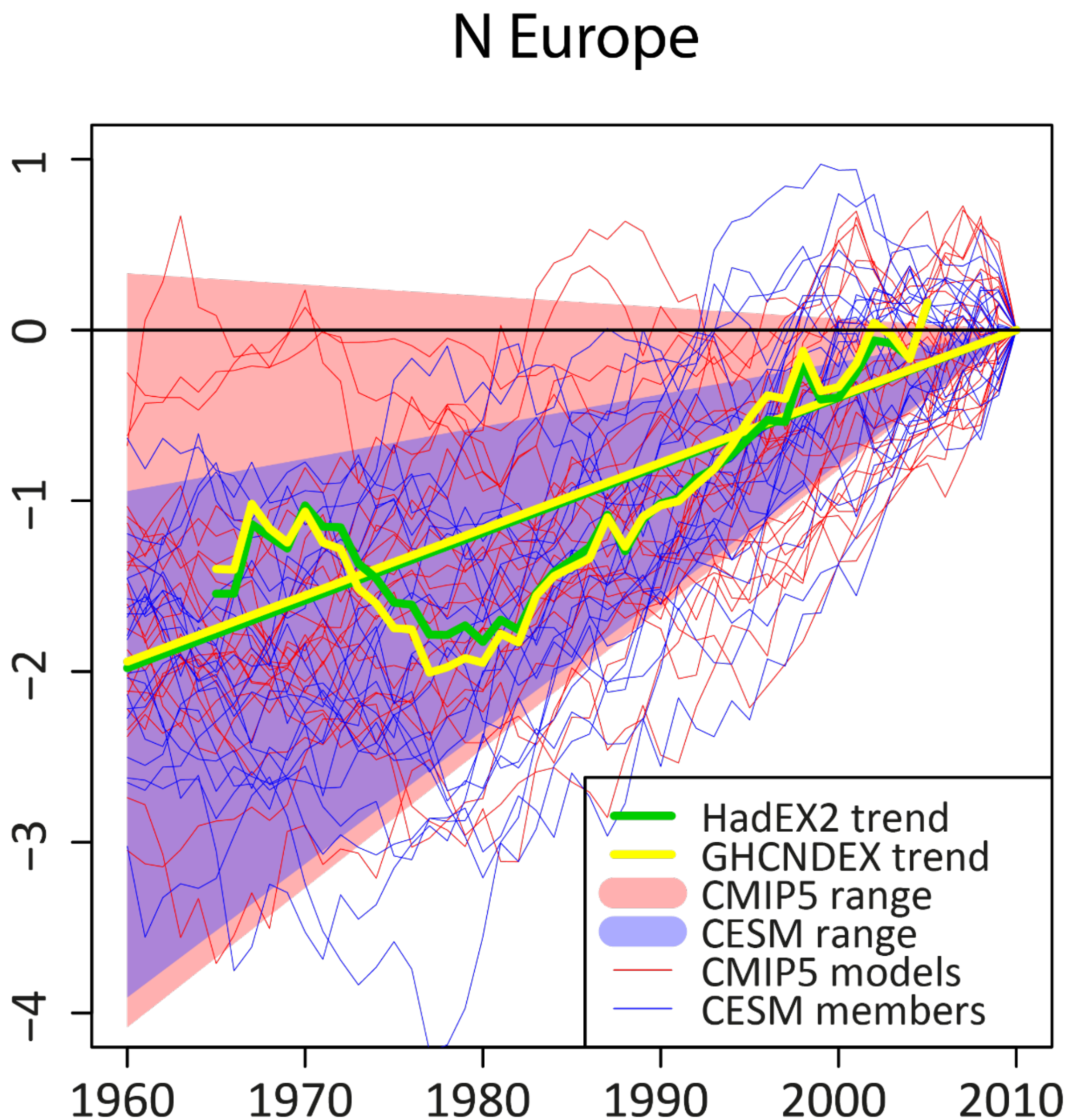
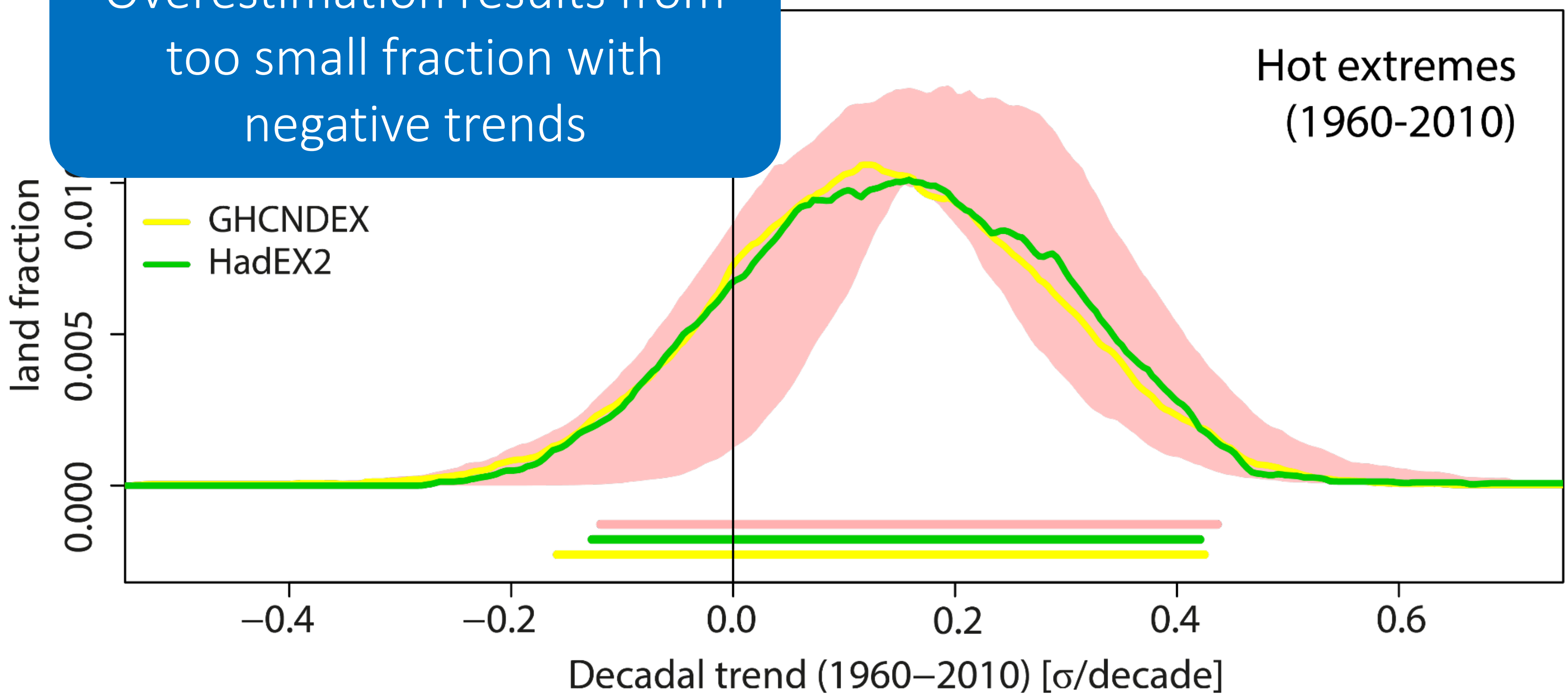


Model overestimate trends in hot extremes

Overestimation results from too small fraction with negative trends



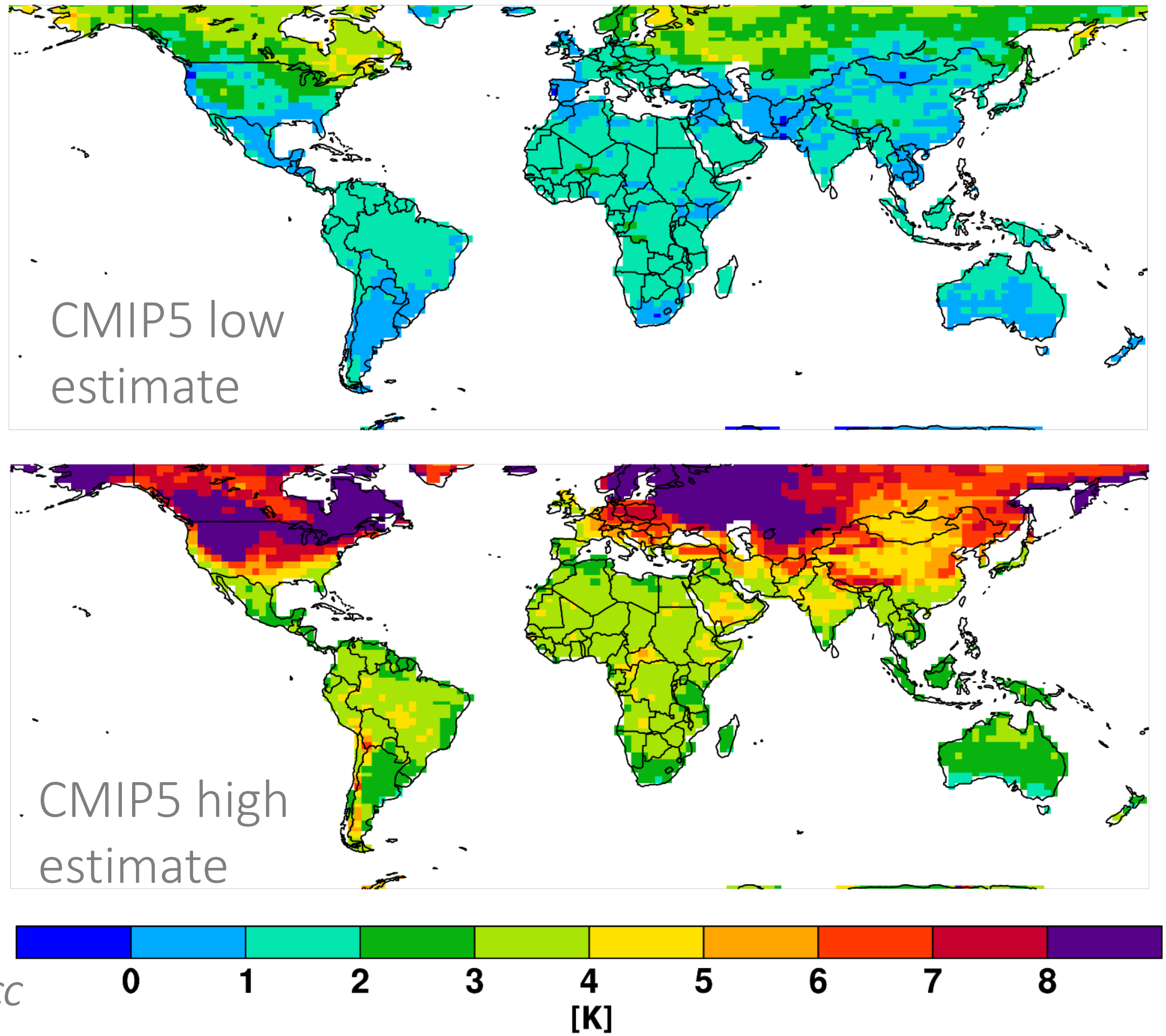
Fischer and Knutti (2014), *Geophys. Res. Letters*

Model evaluation is challenging
due to **internal variability**

An uncertain future

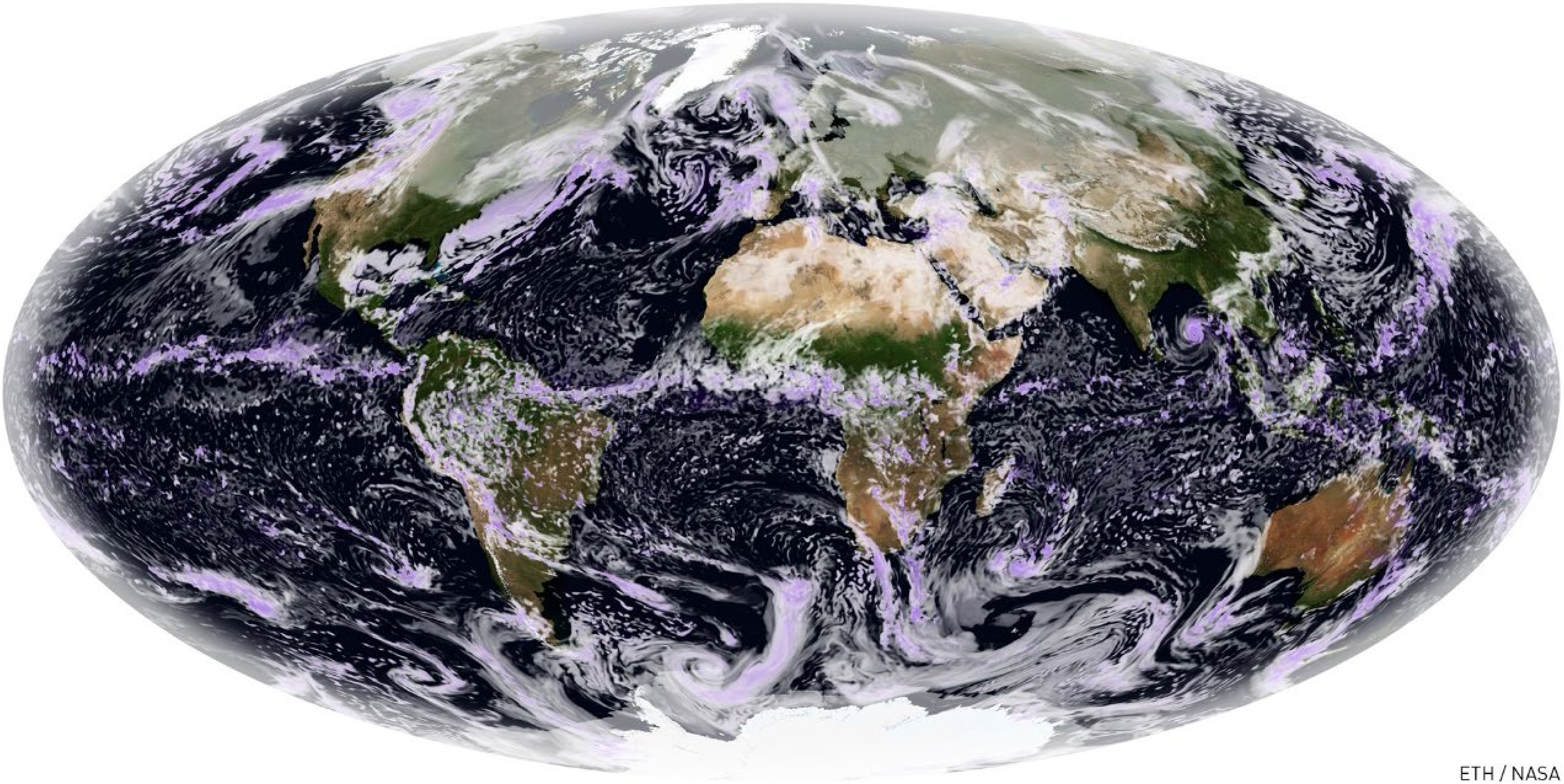
Uncertainties in cold extremes are very large

Model uncertainties too large to make statement about changes in temperature extremes?



Fischer et al., 2013, *Nature CC*

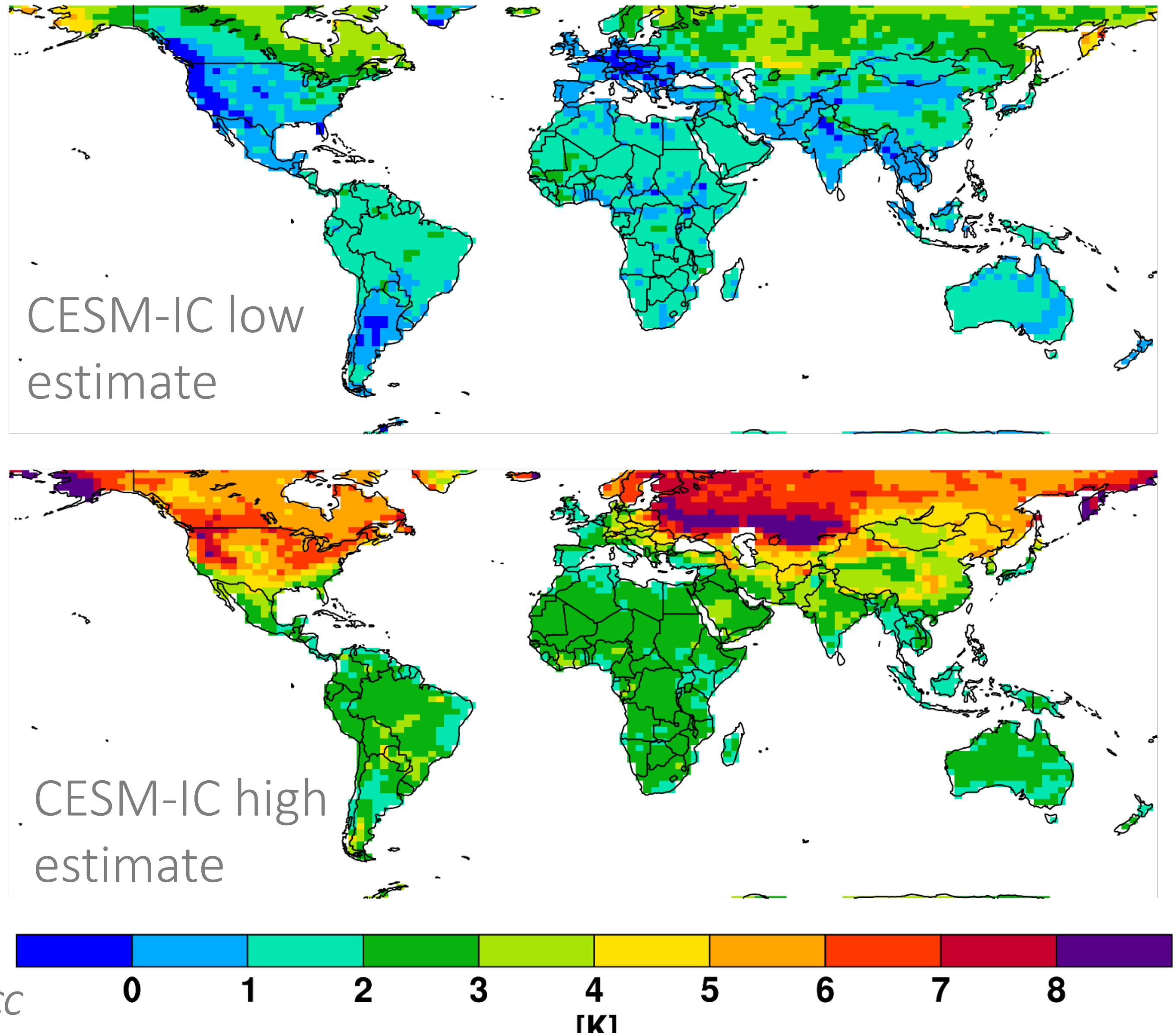
What if we had the perfect model?



ETH / NASA

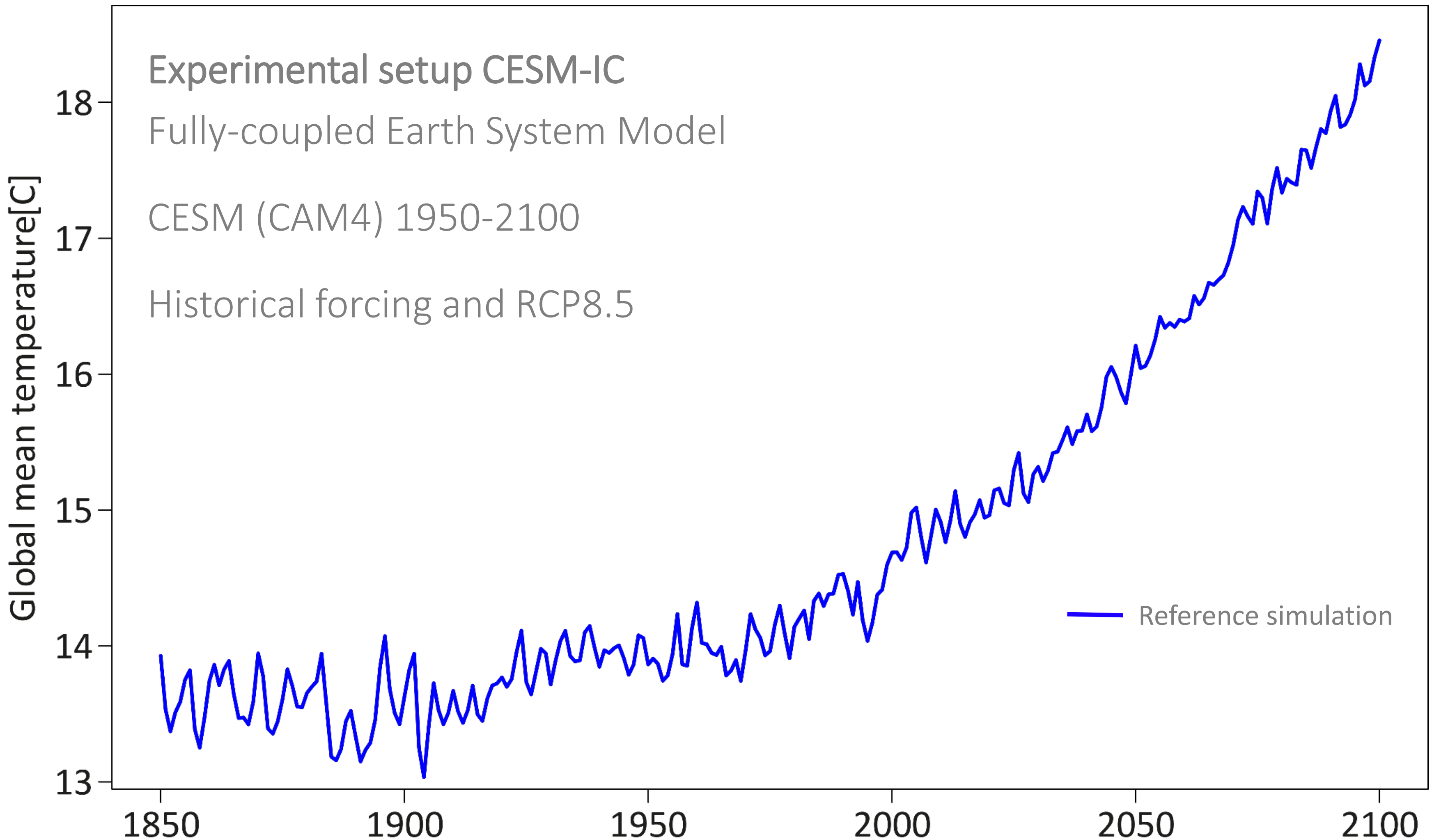
Largely due to internal variability

Cold extremes (TNn) 2041-60 wrt 1986-2005 (RCP8.5)



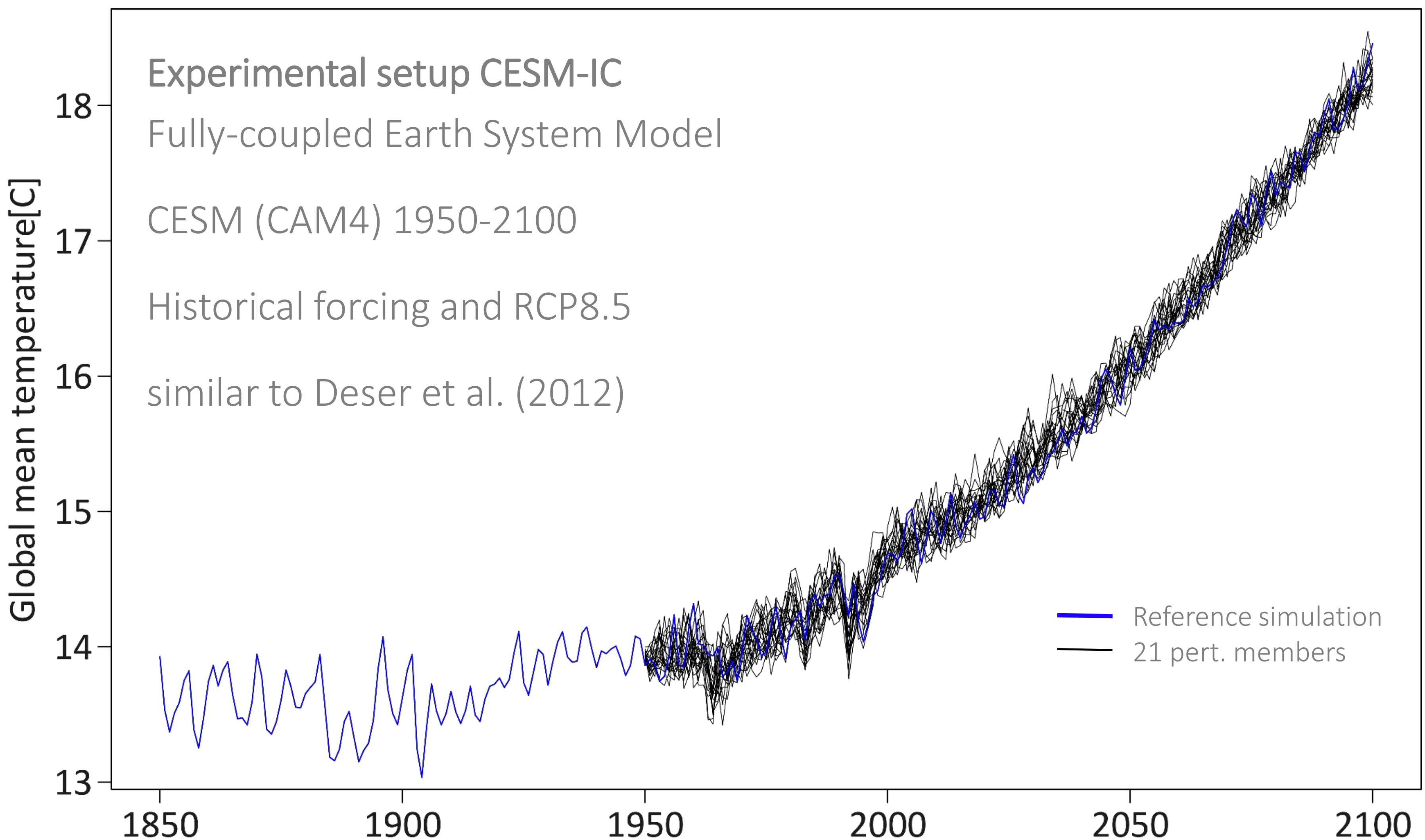
Fischer et al., 2013, *Nature CC*

Initial condition ensemble setup



Fischer et al., 2013, *Nature CC*

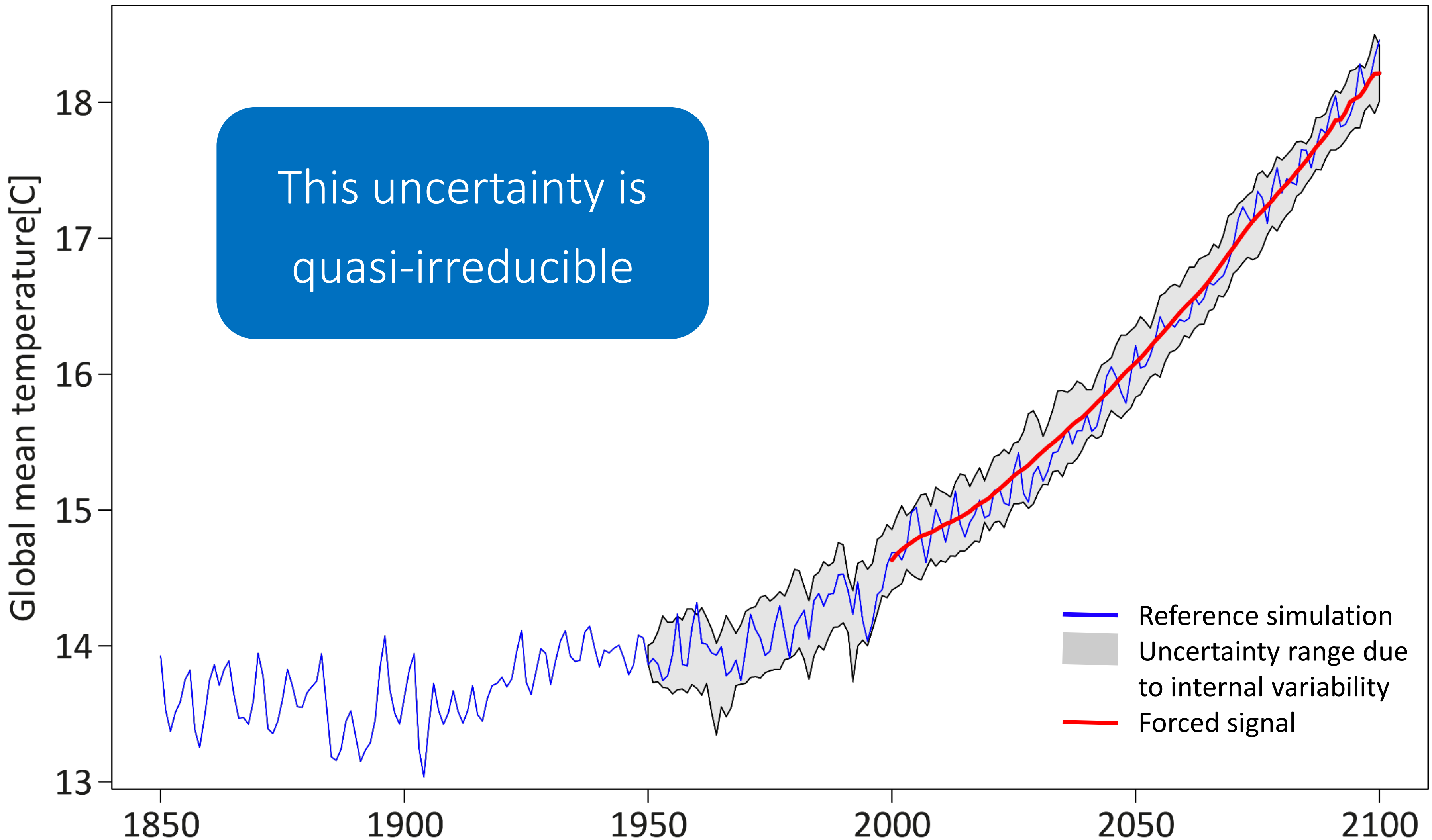
Atmospheric perturbation



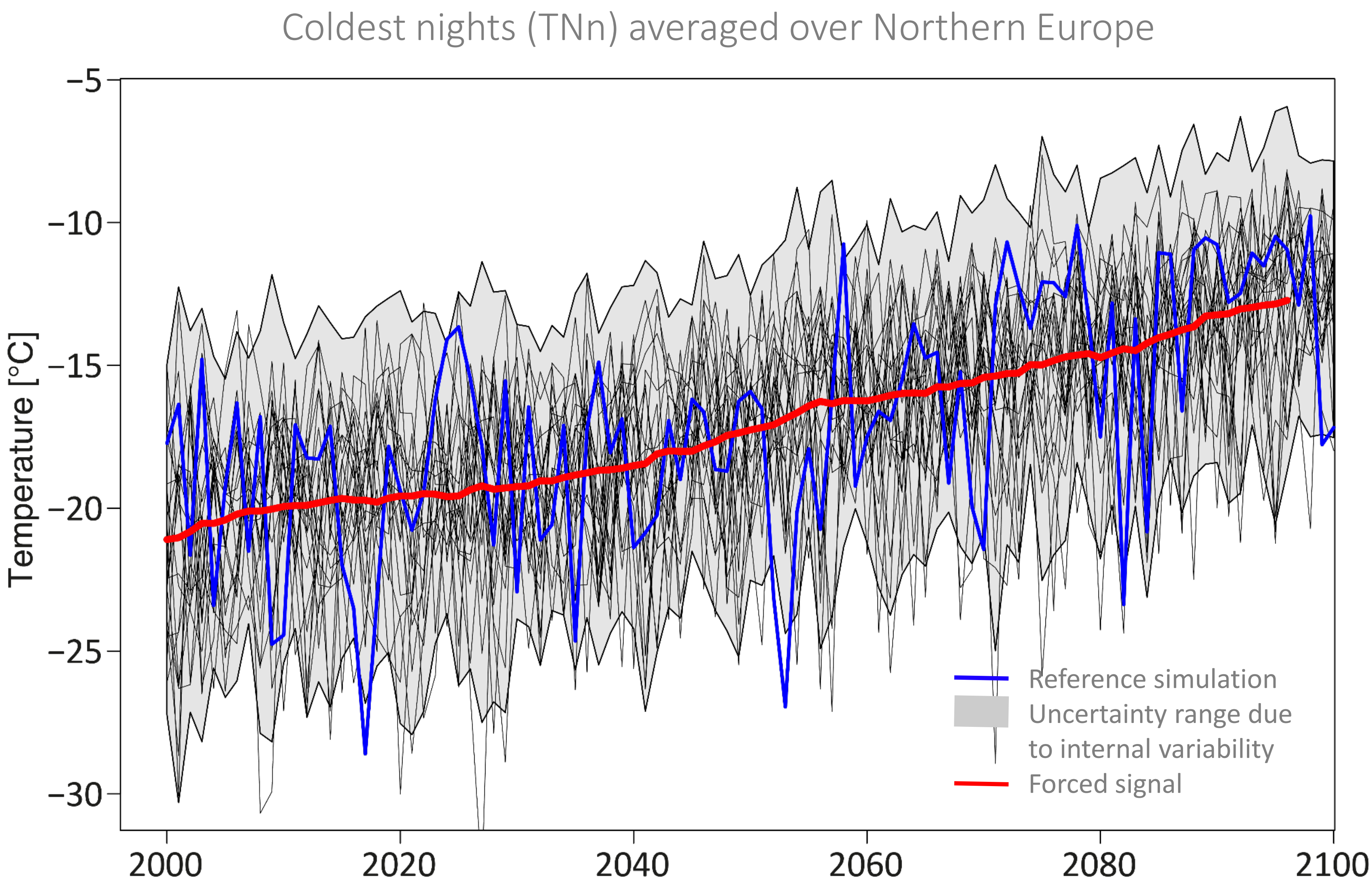
Fischer et al., 2013, *Nature CC*

Some terminology

This uncertainty is quasi-irreducible



Large internal variability at regional scale



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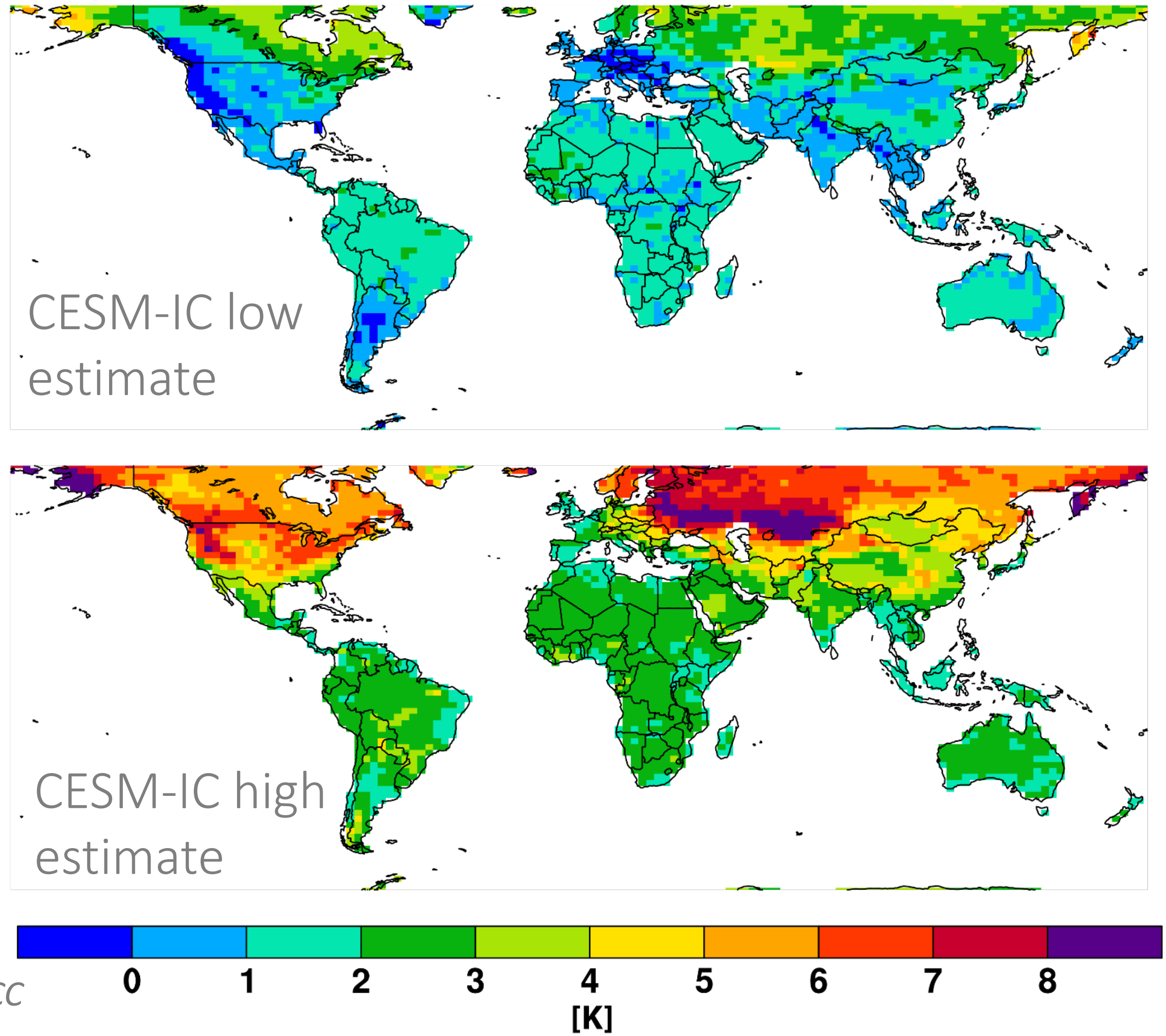
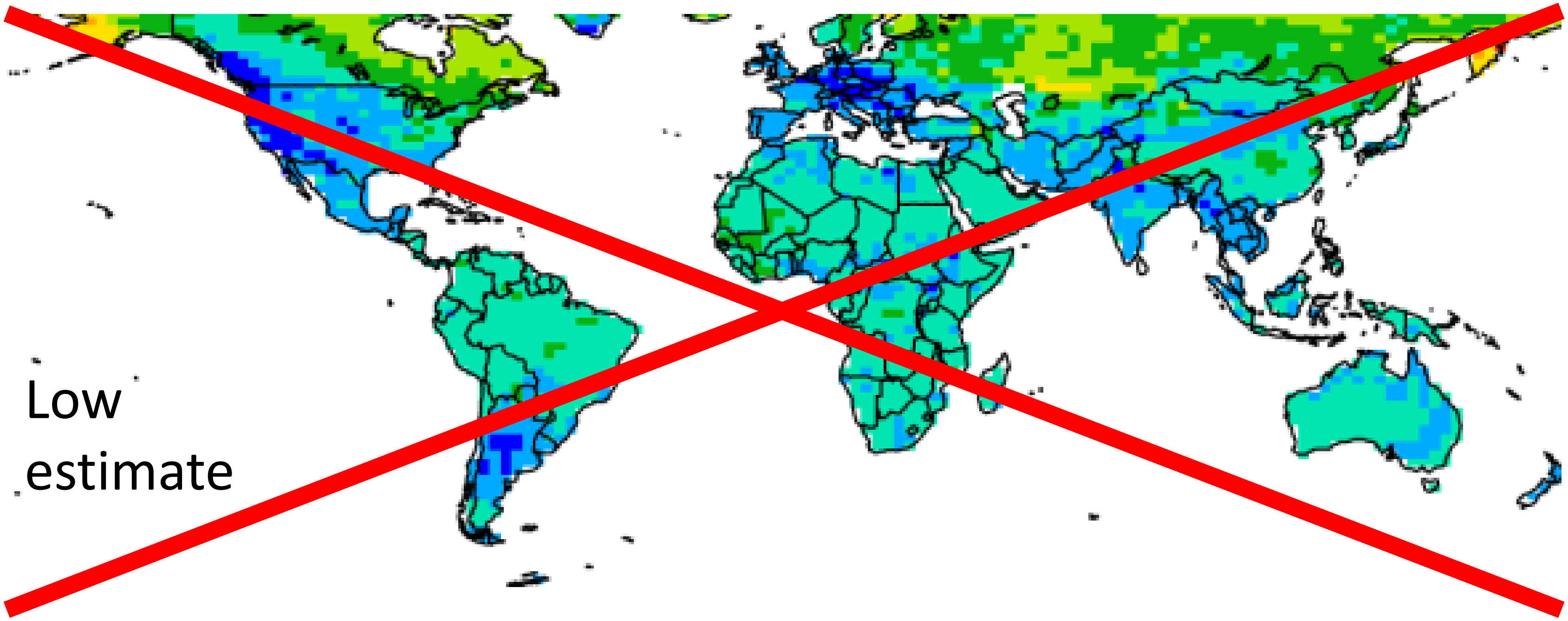


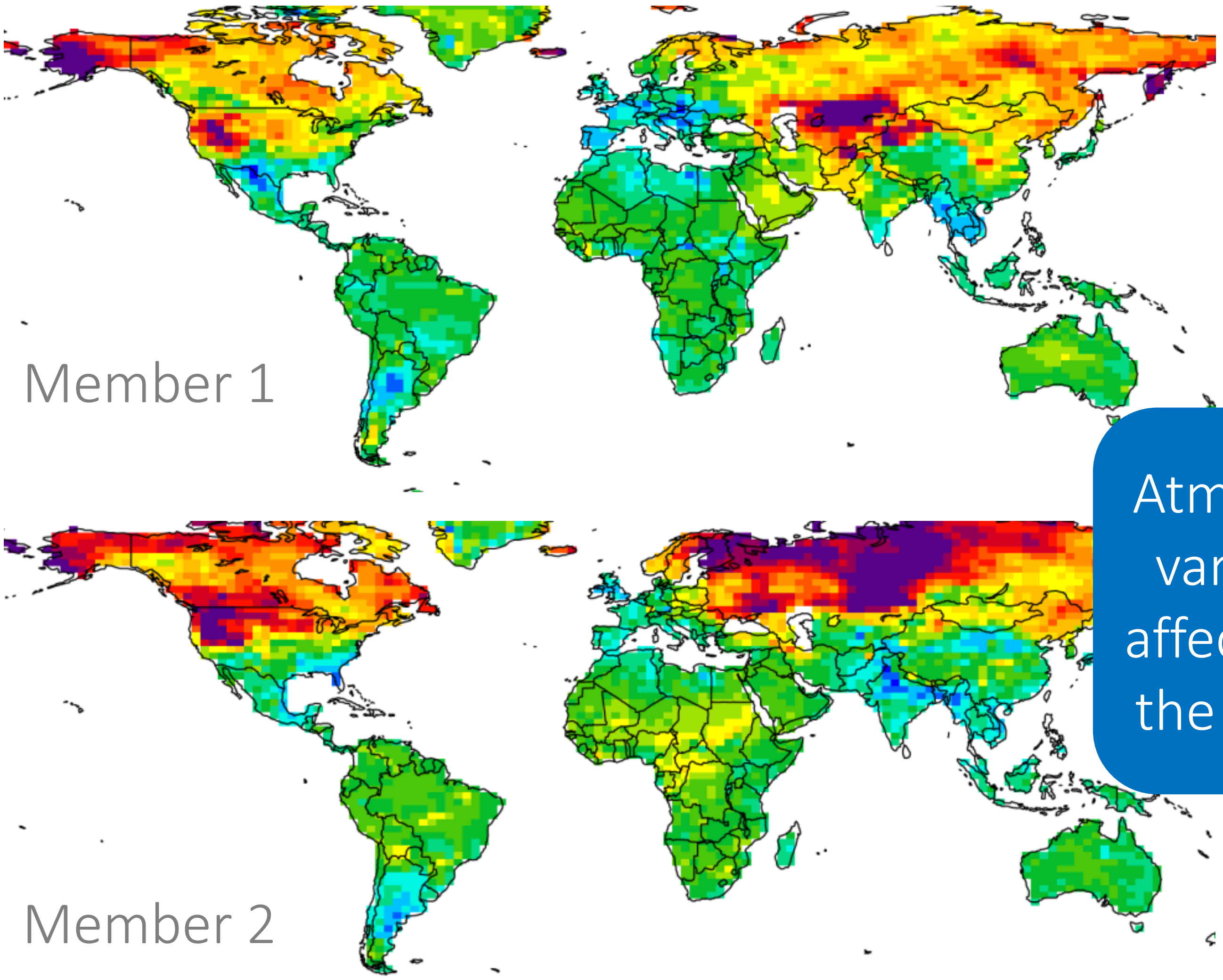
Fischer et al., 2013, *Nature CC*

Major uncertainties in multi-decadal regional projections are **quasi-irreducible**

No clue where we are going?

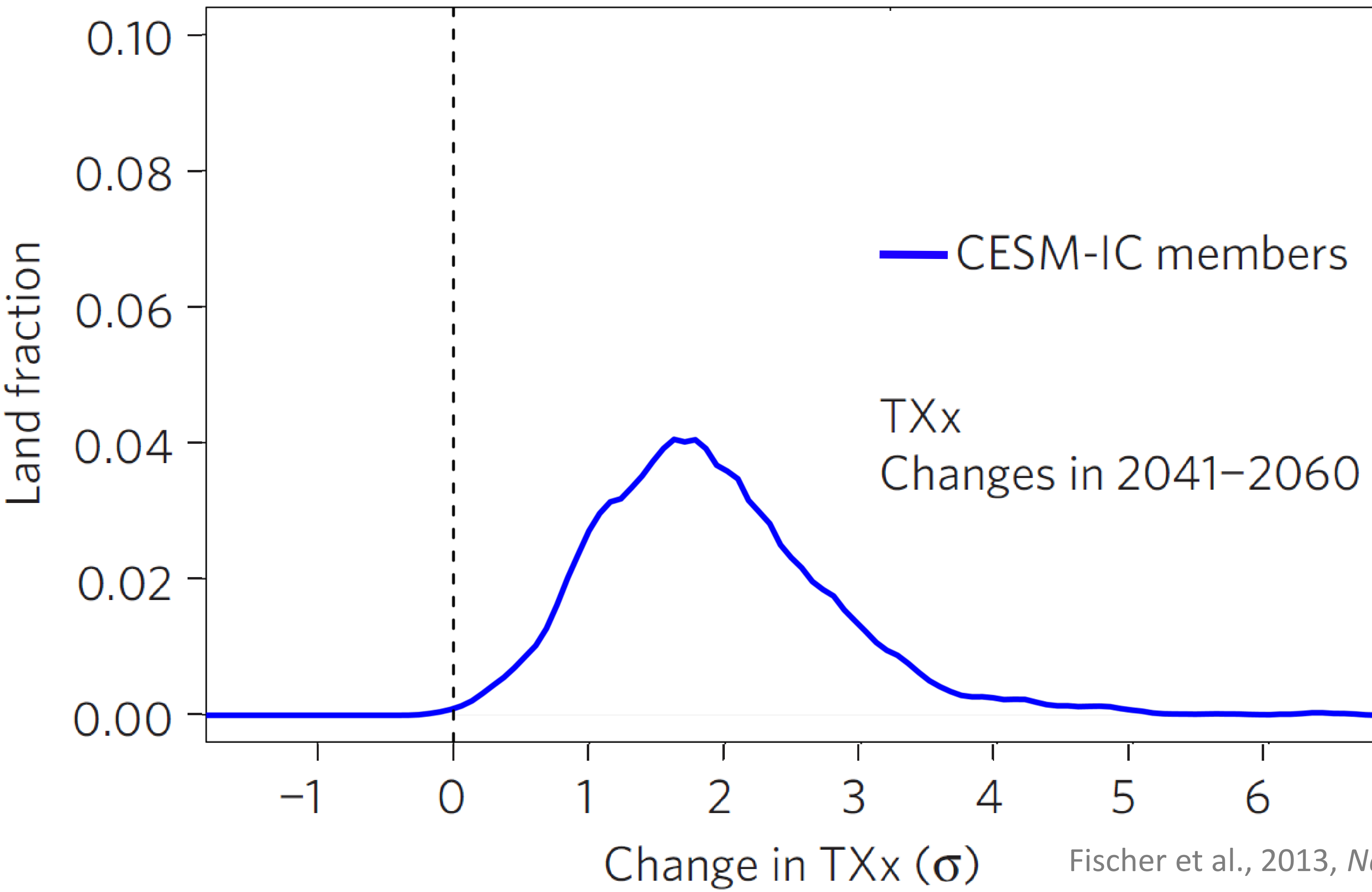


Internal variability affects location of changes



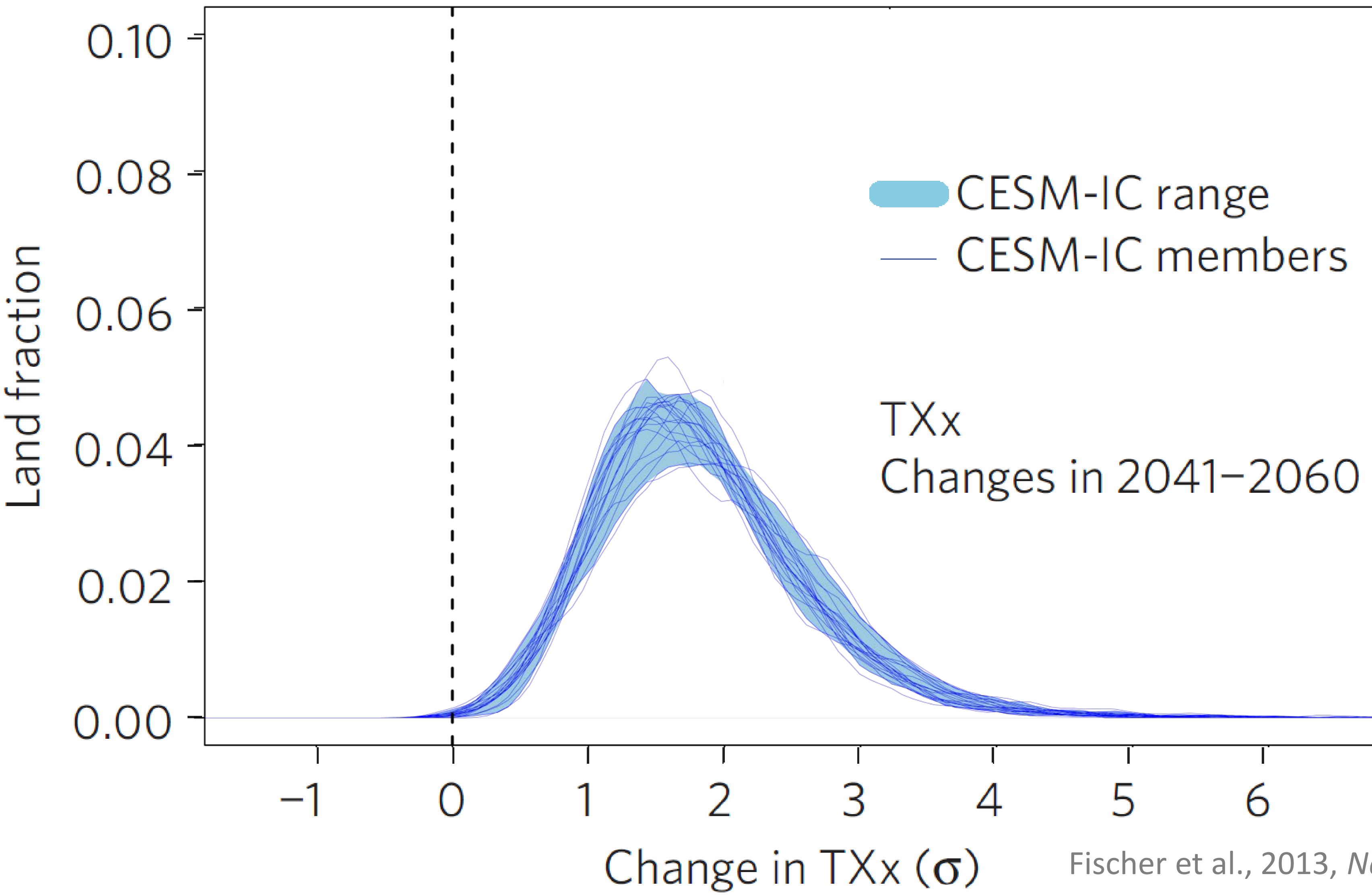
Atmospheric internal variability primarily affects the location of the greatest changes

A simple spatial perspective



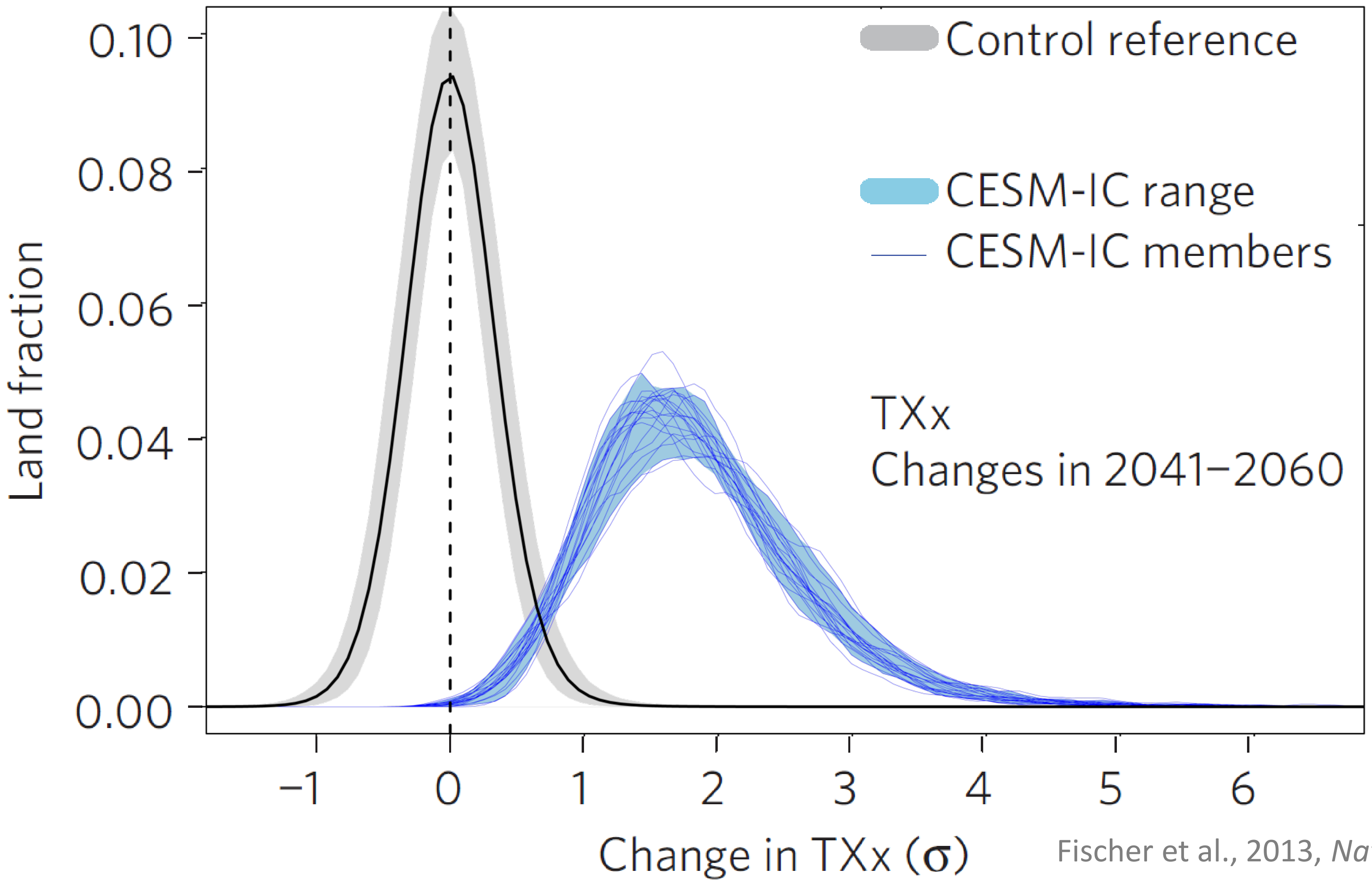
Fischer et al., 2013, *Nature CC*

Members agree on spatial PDF



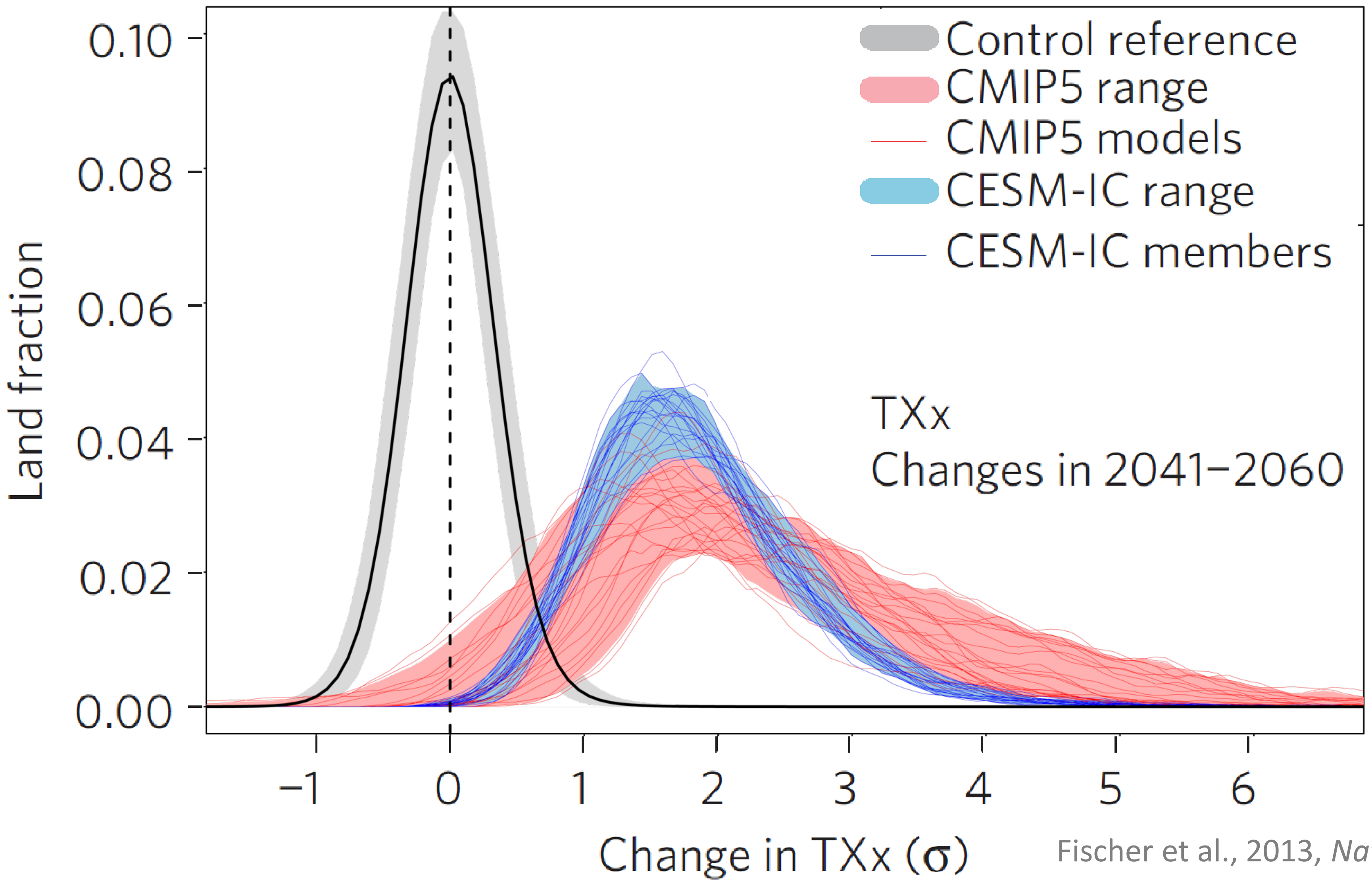
Fischer et al., 2013, *Nature CC*

Hot extremes emerge within decades



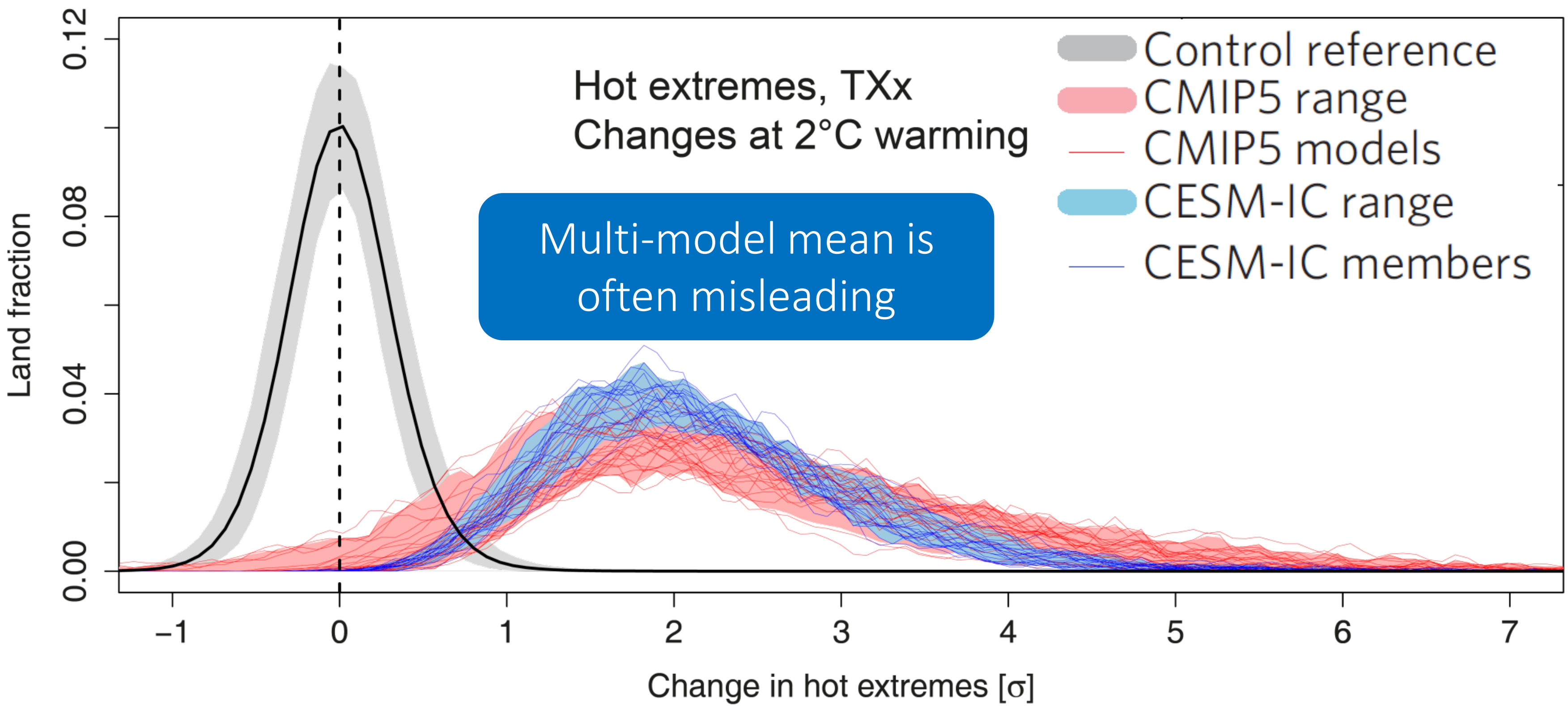
Fischer et al., 2013, *Nature CC*

Major changes in hot extremes in all models



Fischer et al., 2013, *Nature CC*

Good agreement on changes at 2°C warming

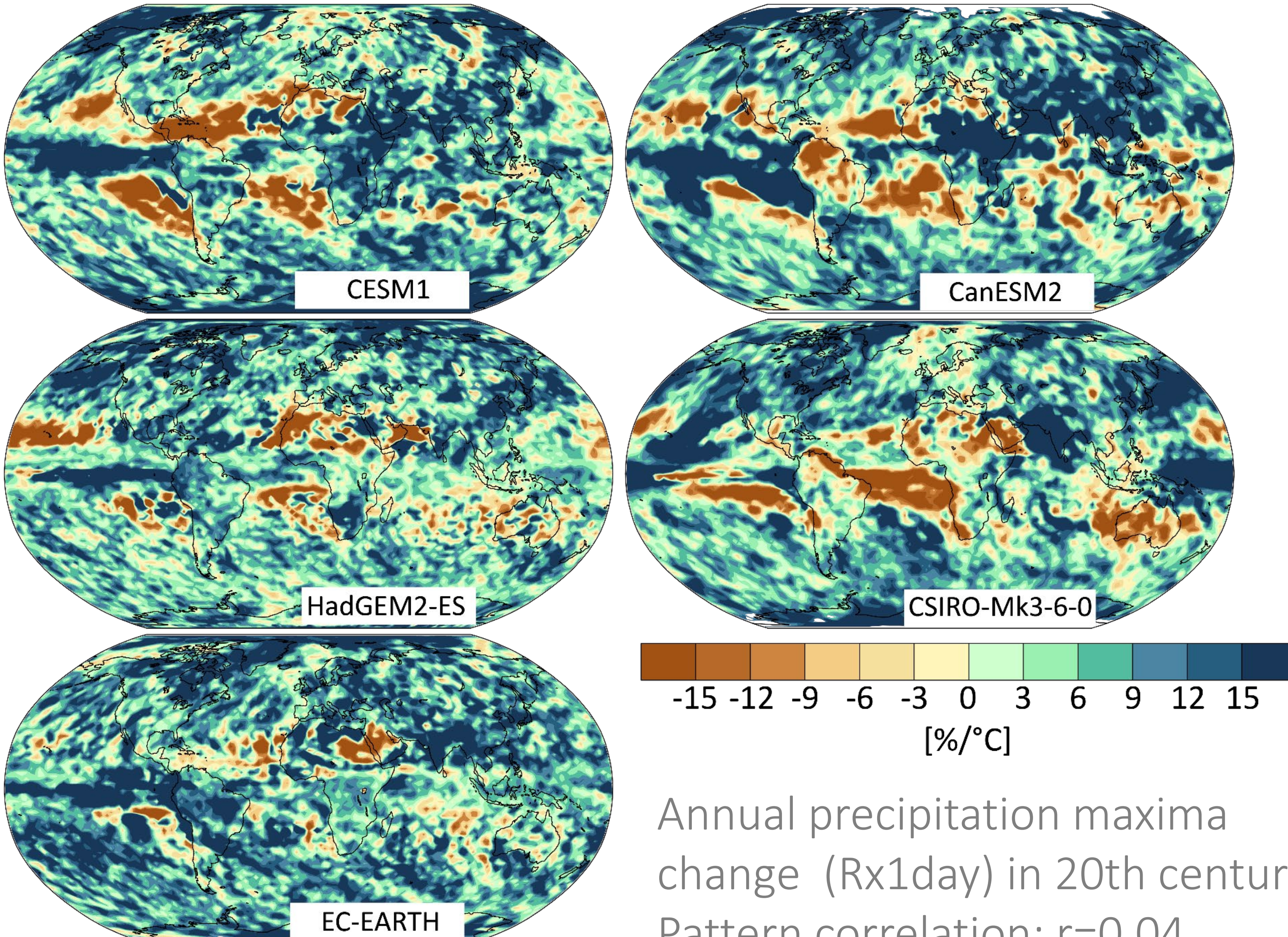


Fischer et al., 2013, *Nature CC*

Models agree that temperature extremes change already **within next decades**

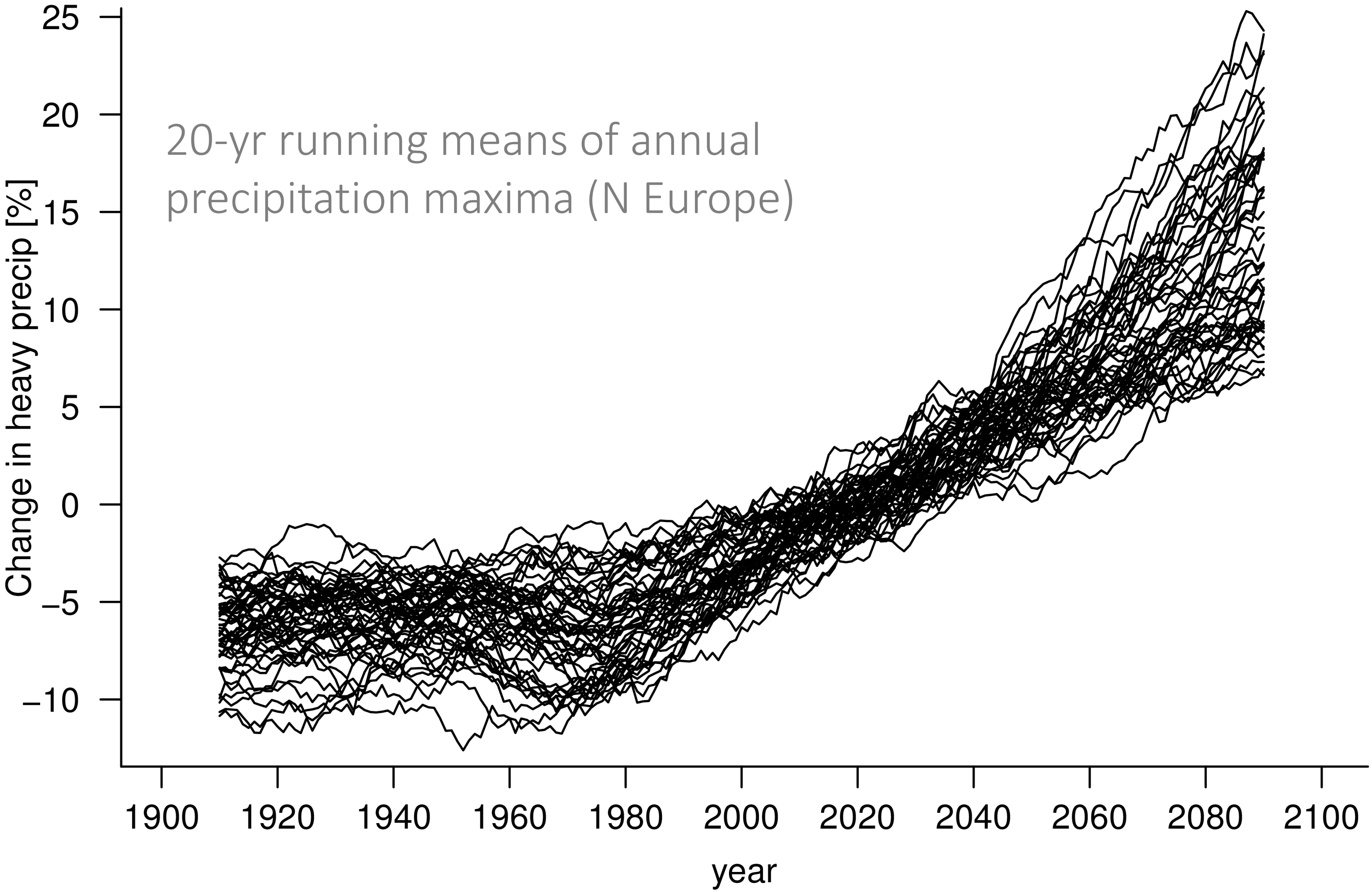
Robust forced response

Poor agreement on heavy precip signal

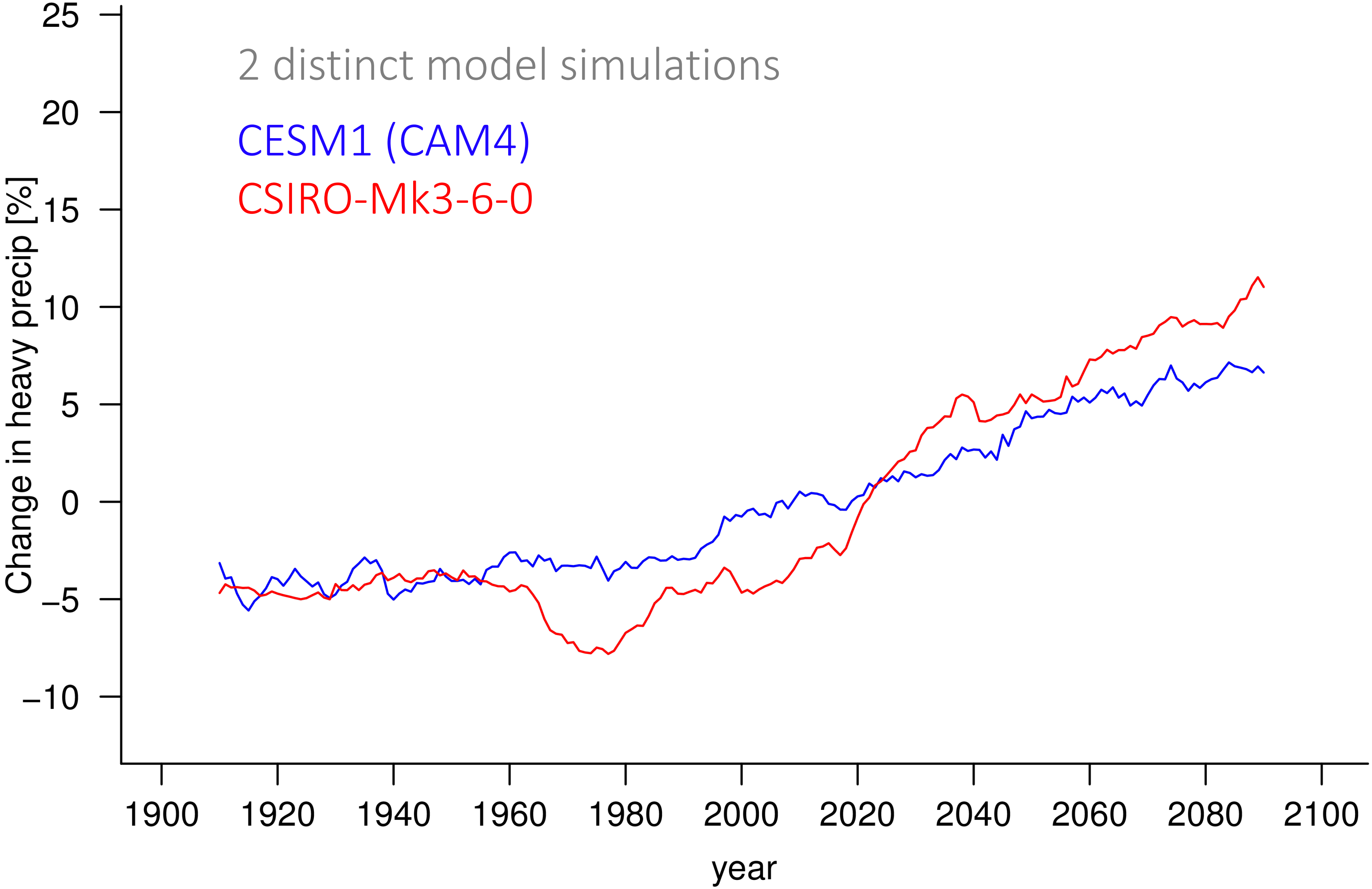


Annual precipitation maxima change (Rx1day) in 20th century
Pattern correlation: r=0.04

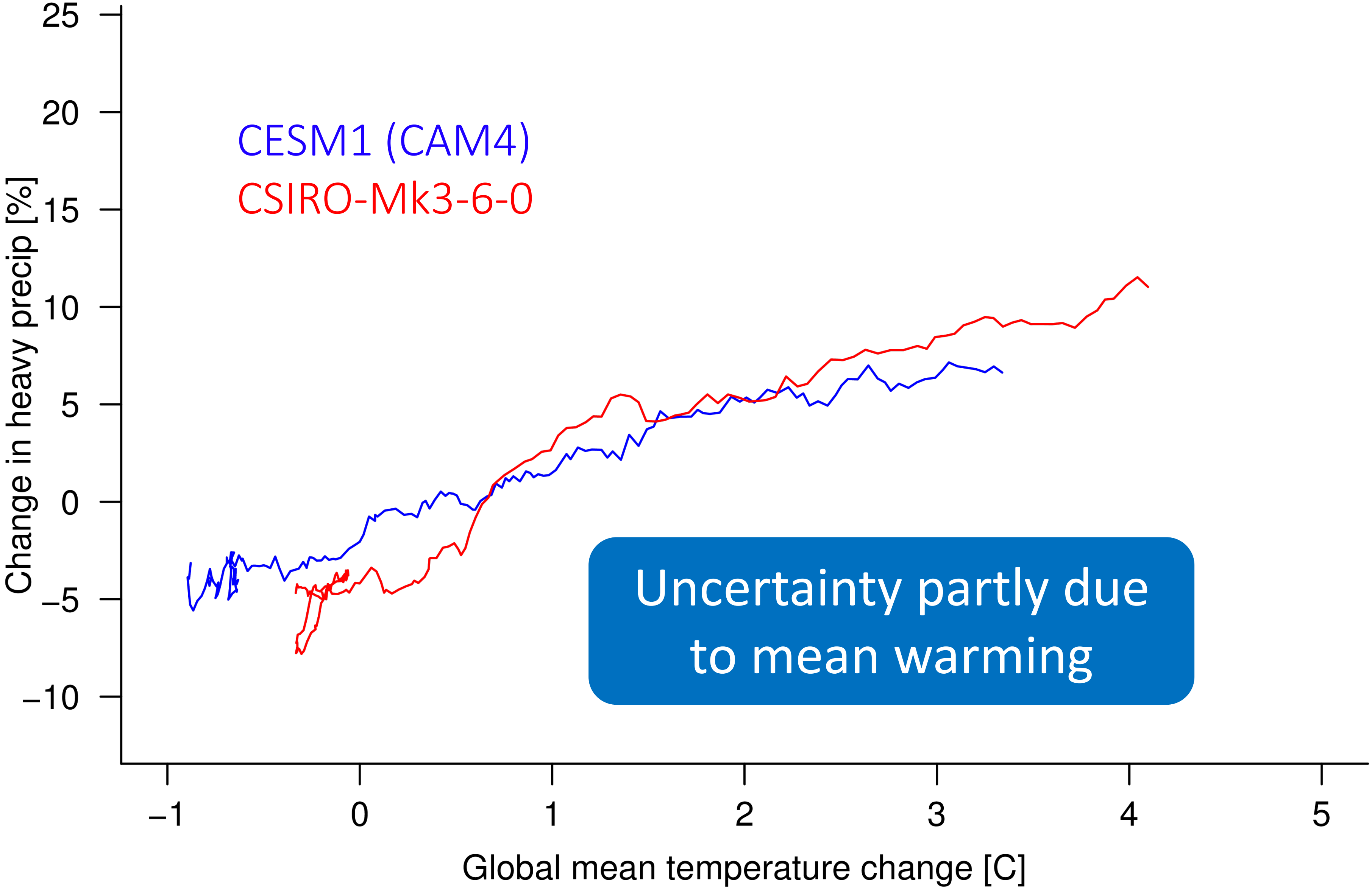
Large differences even in running means



Two example model runs

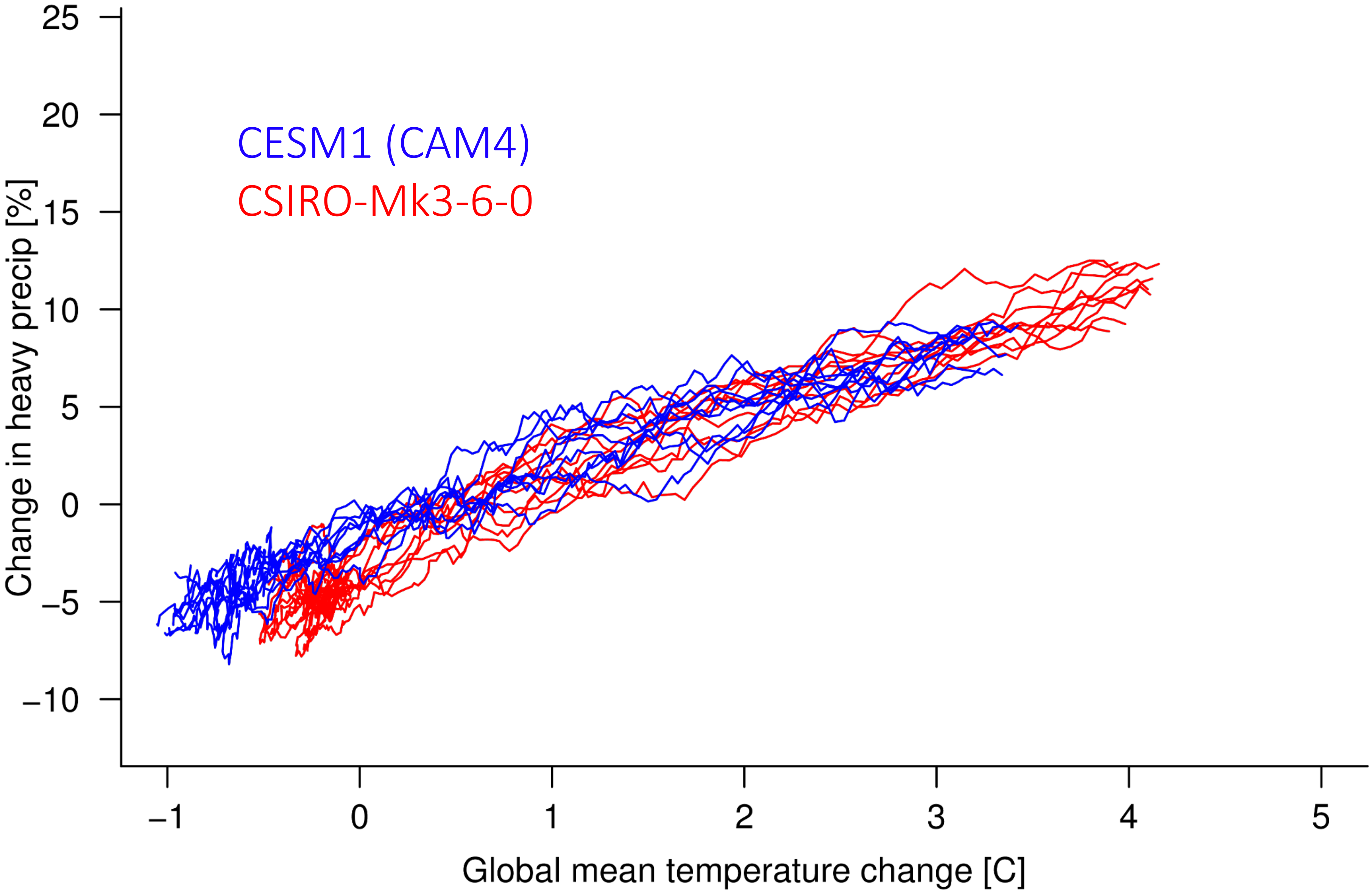


Scaling with global mean temperature

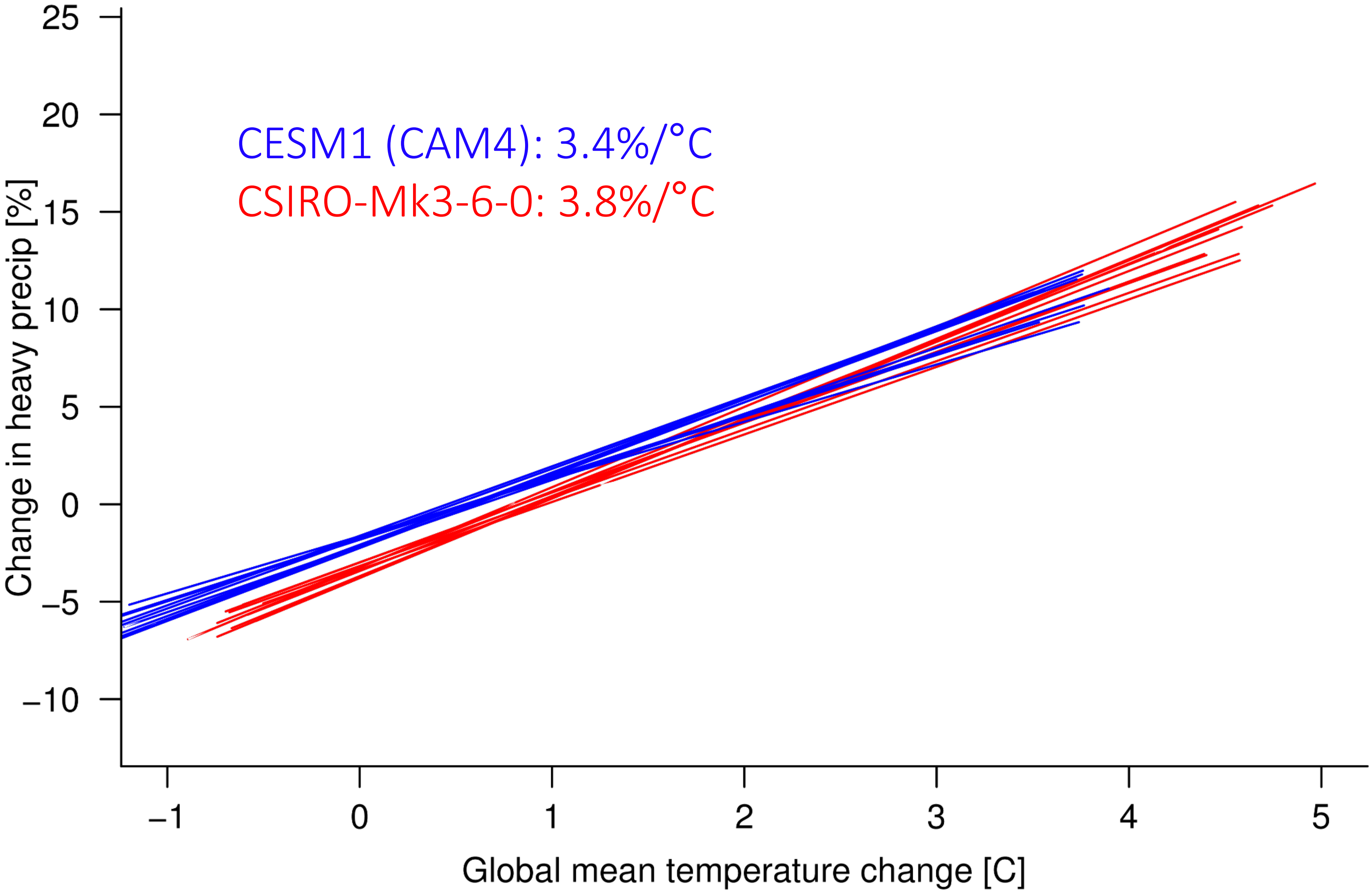


Uncertainty partly due to mean warming

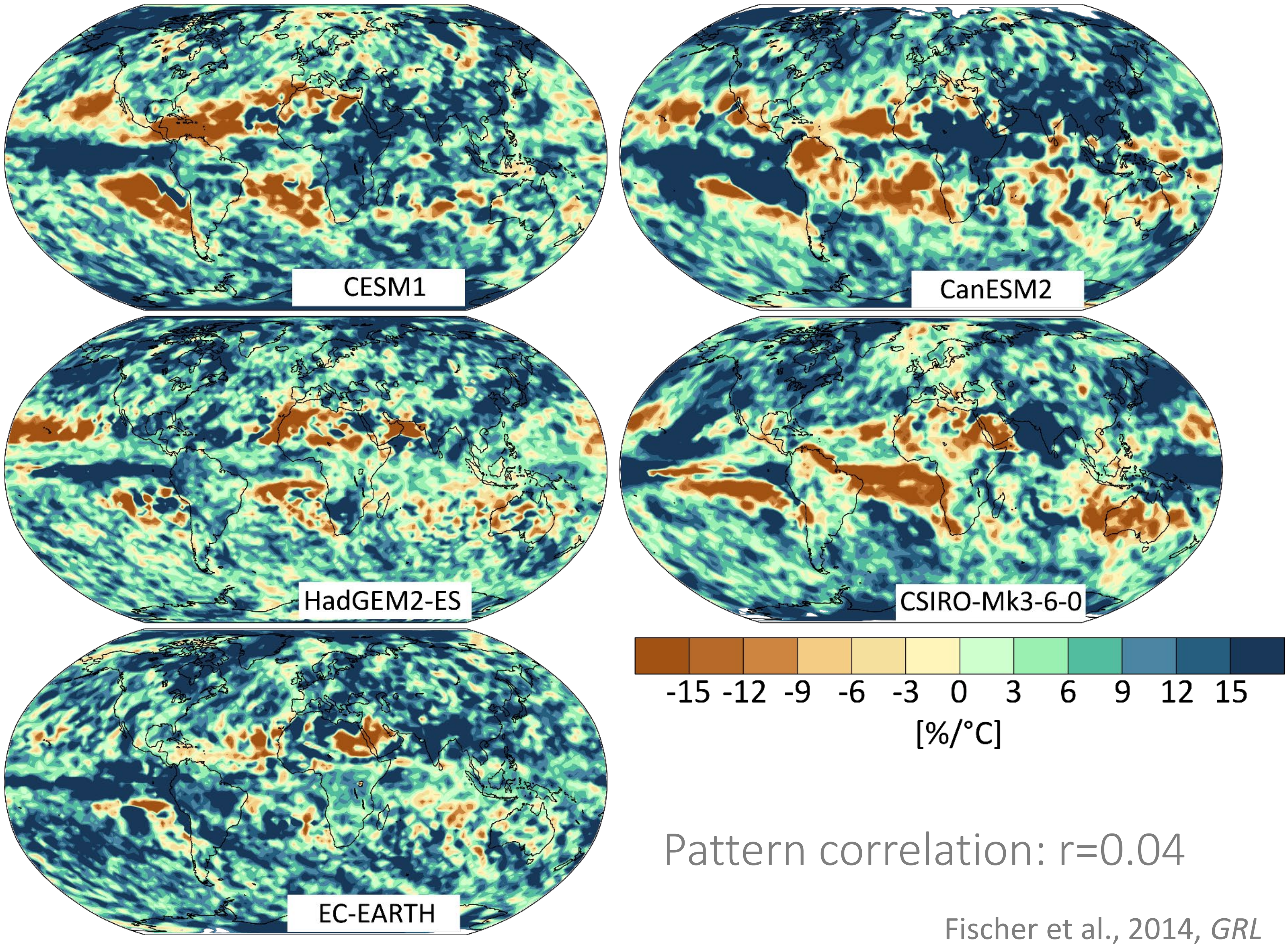
Scaling with global mean temperature



High agreement in forced signal



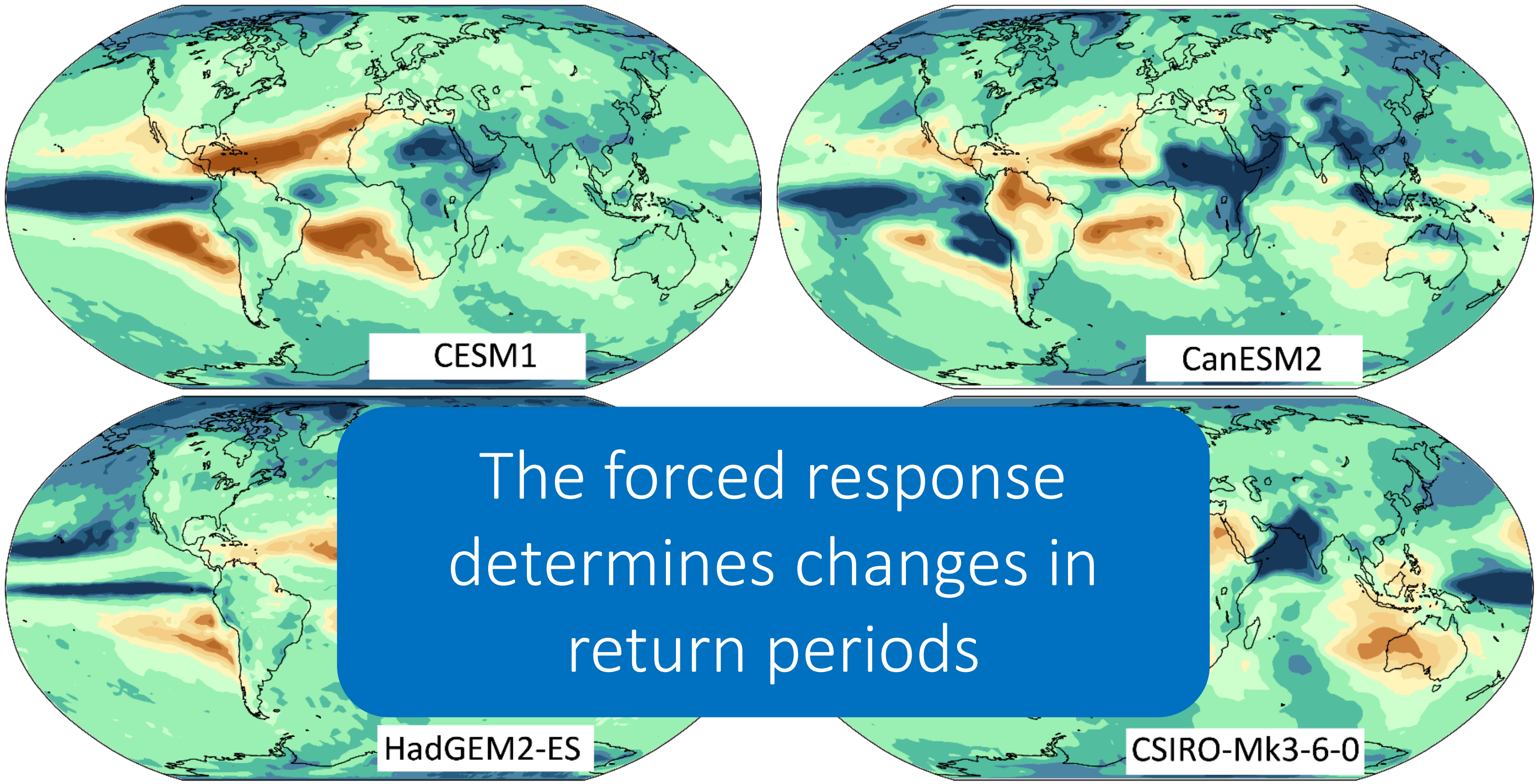
Poor agreement in observational period



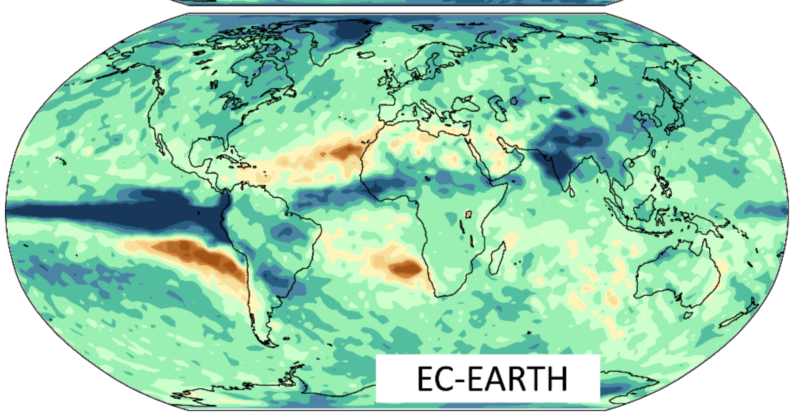
Pattern correlation: r=0.04

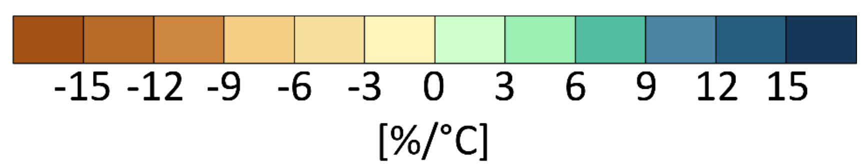
Fischer et al., 2014, *GRL*

High agreement in forced signal



The forced response determines changes in return periods





Pattern correlation: r=0.59

Across CMIP5 models: r=0.51

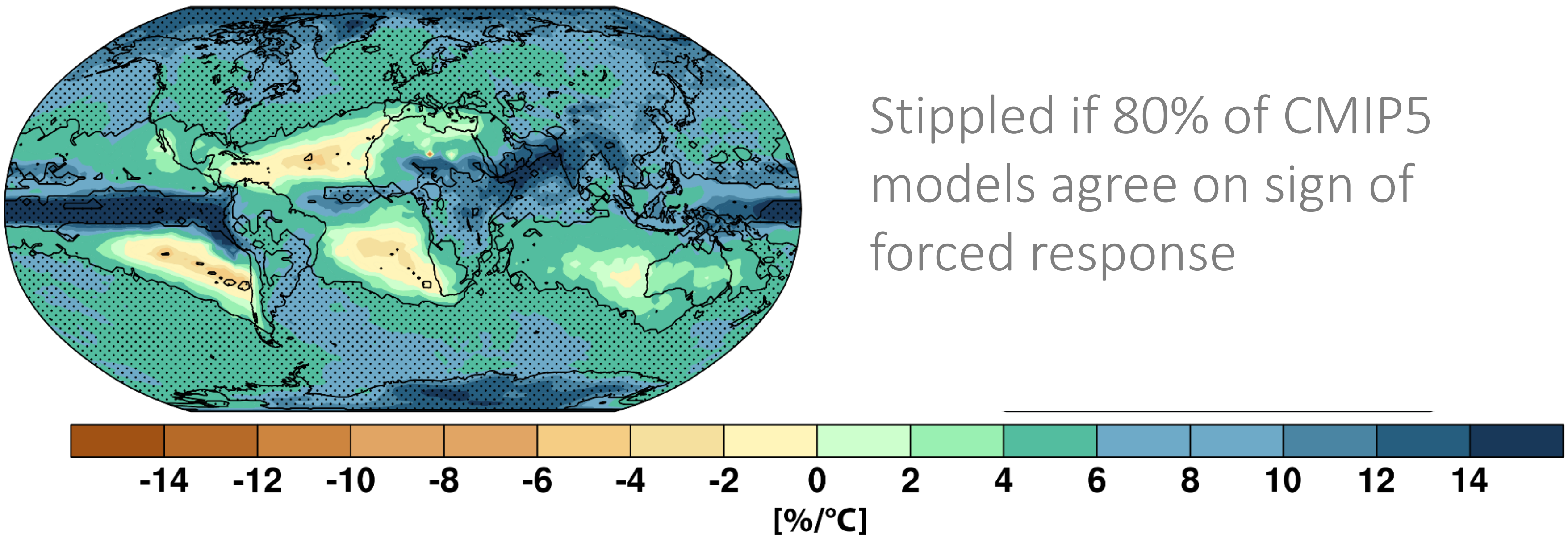
Fischer et al., 2014, *GRL*

see also Zhang et al. 2013, *GRL*

Heavy precip more robust than mean precip

Change in heavy precipitation

Change in annual mean precipitation



Stippled if 80% of CMIP5 models agree on sign of forced response

Stippled area fraction: 73%

Stippled area fraction: 27%

Fischer et al., 2014, *GRL*
see also Zhang et al. 2013, *GRL*

Forced response is often **more robust**
than widely recognized

Conclusions

- Changes in extremes are detectable at regional, to continental and global scale
- Internal variability is large – local uncertainties are often irreducible