Detection and attribution of climate change at regional scales

Peter Stott, 18 August, 2010

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Met Office
Hadley Centre

Overview

Detection and attribution of climate change: a regional perspective

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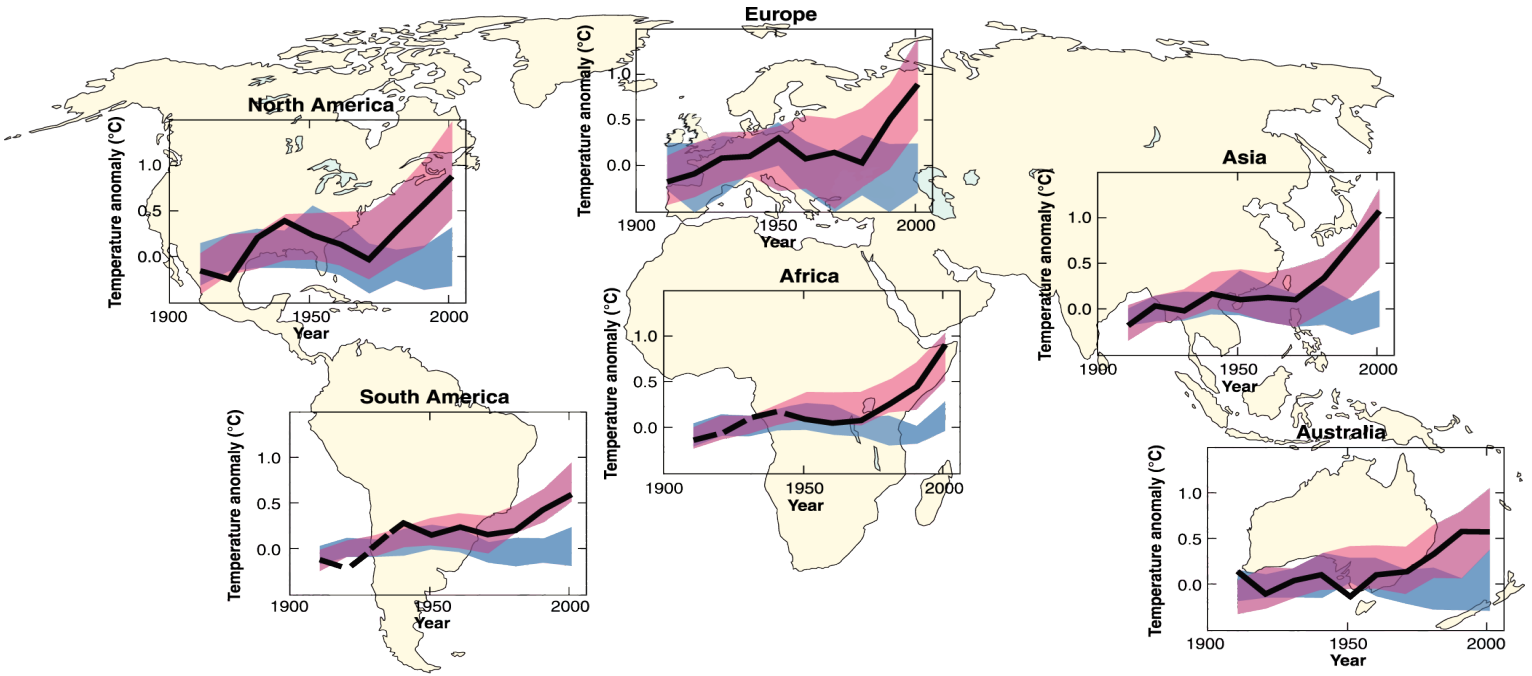
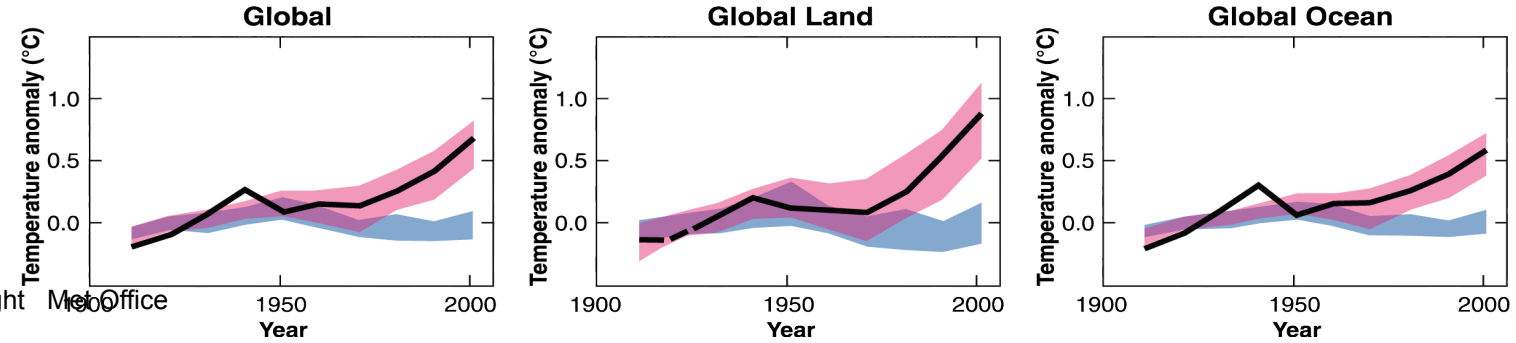
David J. Karoly,[4] Dáithí A. Stone,[5] Xuebin Zhang[6] and Francis Zwiers[6]

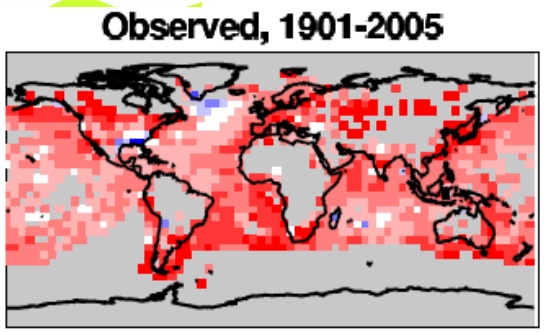
The Intergovernmental Panel on Climate Change fourth assessment report, published in 2007 came to a more confident assessment of the causes of global temperature change than previous reports and concluded that 'it is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica'. Since then, warming over Antarctica has also been attributed to human influence, and further evidence has accumulated attributing a much wider range of climate changes to human activities. Such changes are broadly consistent with theoretical understanding, and climate model simulations, of how the planet is expected to respond. This paper reviews this evidence from a regional perspective to reflect a growing interest in understanding the regional effects of climate change, which can differ markedly across the globe. We set out the methodological basis for detection and attribution and discuss the spatial scales on which it is possible to make robust attribution statements. We review the evidence showing significant human-induced changes in regional temperatures, and for the effects of external forcings on changes in the hydrological cycle, the cryosphere, circulation changes, oceanic changes, and changes in extremes. We then discuss future challenges for the science of attribution. To better assess the pace of change, and to understand more about the regional changes to which societies need to adapt, we will need to refine our understanding of the effects of external forcing and internal variability. *WIREs Clim Change*

- Identification of anthropogenic fingerprint in an increasing number of aspects of the climate system
- Identification of spatio-temporal fingerprints
- Difficulties of attribution on regional scales
  - Illustration with an example for New Zealand
- IPCC guidance note on detection and attribution
- Prospects for attribution for climate services

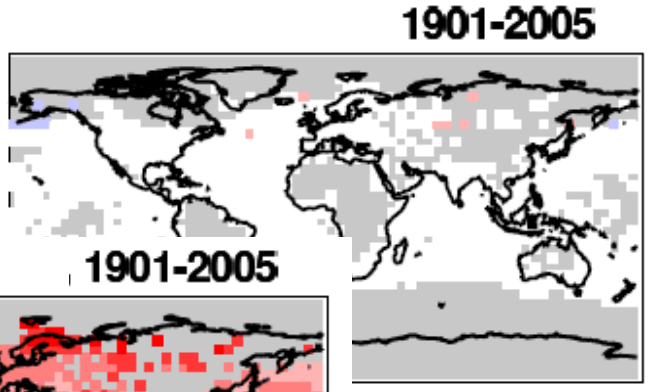
Human-induced warming has been detected on every continent (except Antarctica) AR4

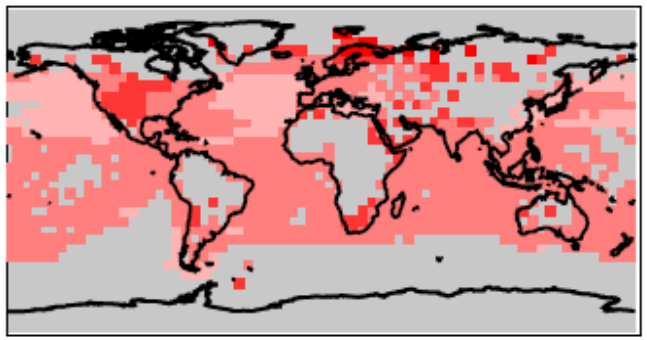






Climate model simulations





Trend in °C per decade

-0.15 -0.10 -0.05 0.00 0.05 0.10 0.15

□ → **Y**

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

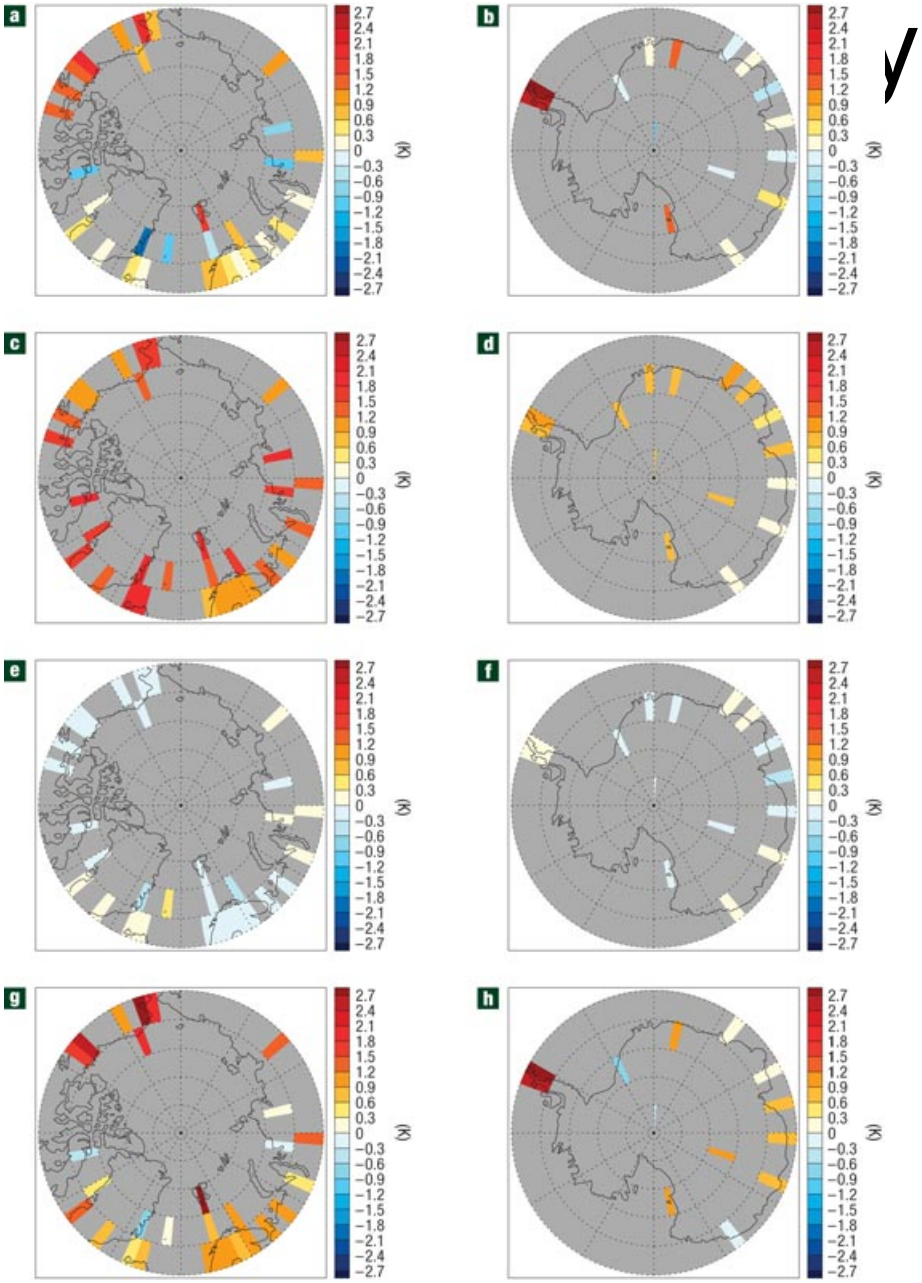
$$\mathbf{Y} = \beta\mathbf{X} + \varepsilon$$

Total least squares regression in reduced dimension space

Best Linear Unbiased Estimator

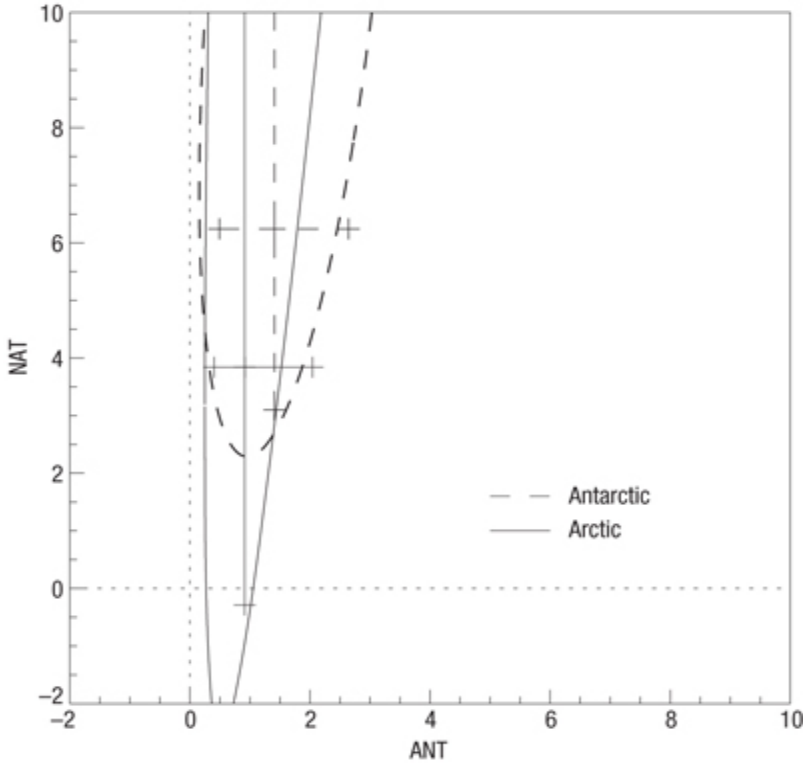
$\hat{\beta}$ → **Test $\beta=(\beta_{ant}, \beta_{nat})$ $\beta\neq 0$ (detection) $\beta=1$ (consistent)**

$\hat{\varepsilon}$ → **Evaluate goodness of fit**



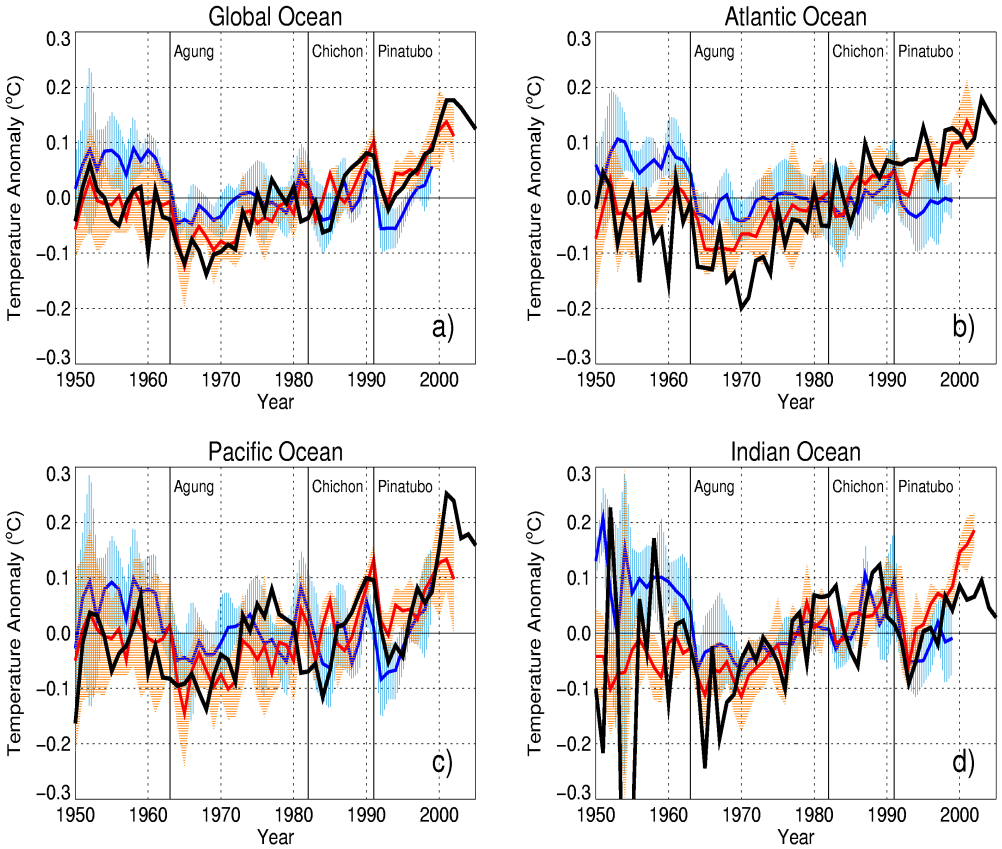
Gillett et al, 2008 detected human-induced warming in the Antarctic as well.

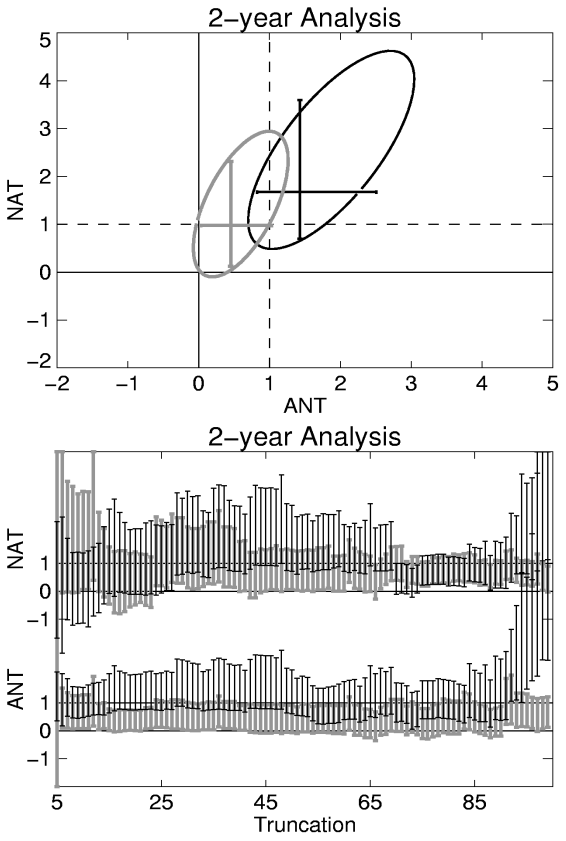
(Gillett et al, Nature Geoscience, 2008, 1, 750-754)



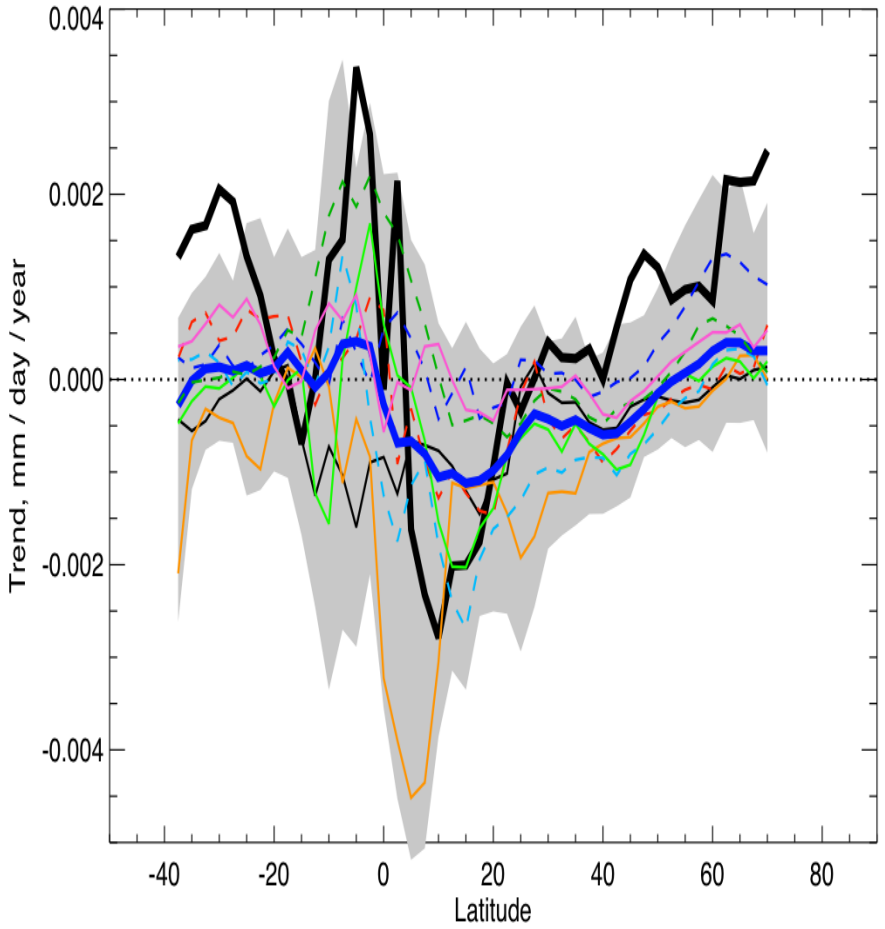
Human and volcanic influences on ocean temperatures have been detected.

GPalmer et al, 2009

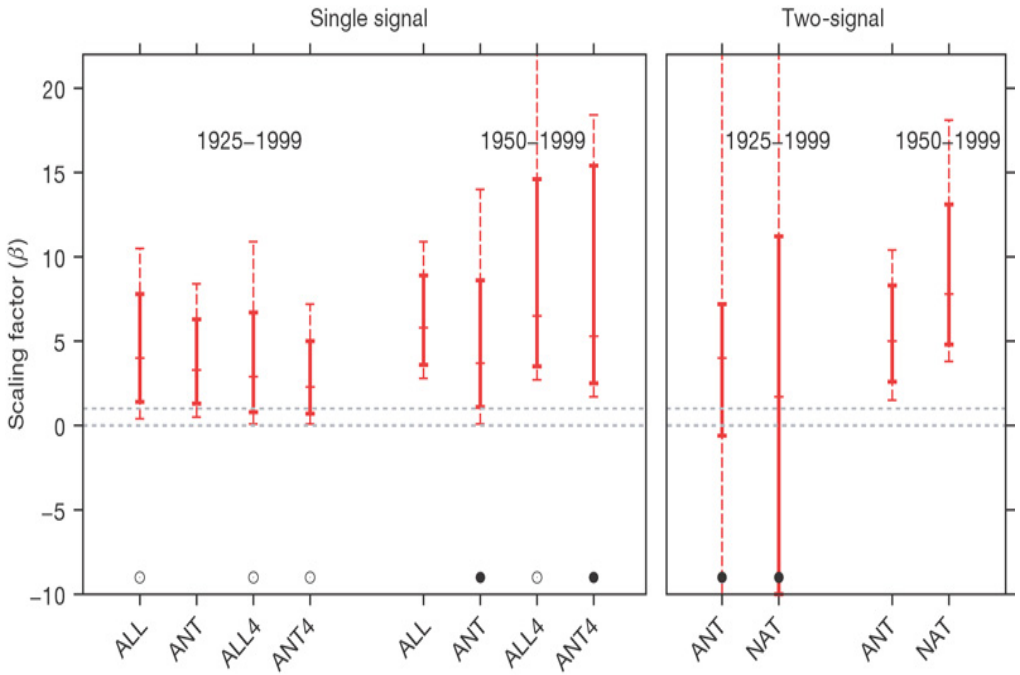




The fingerprint of human influence on the spatial patterns of zonal mean trends of precipitation over land has been detected in the observed record

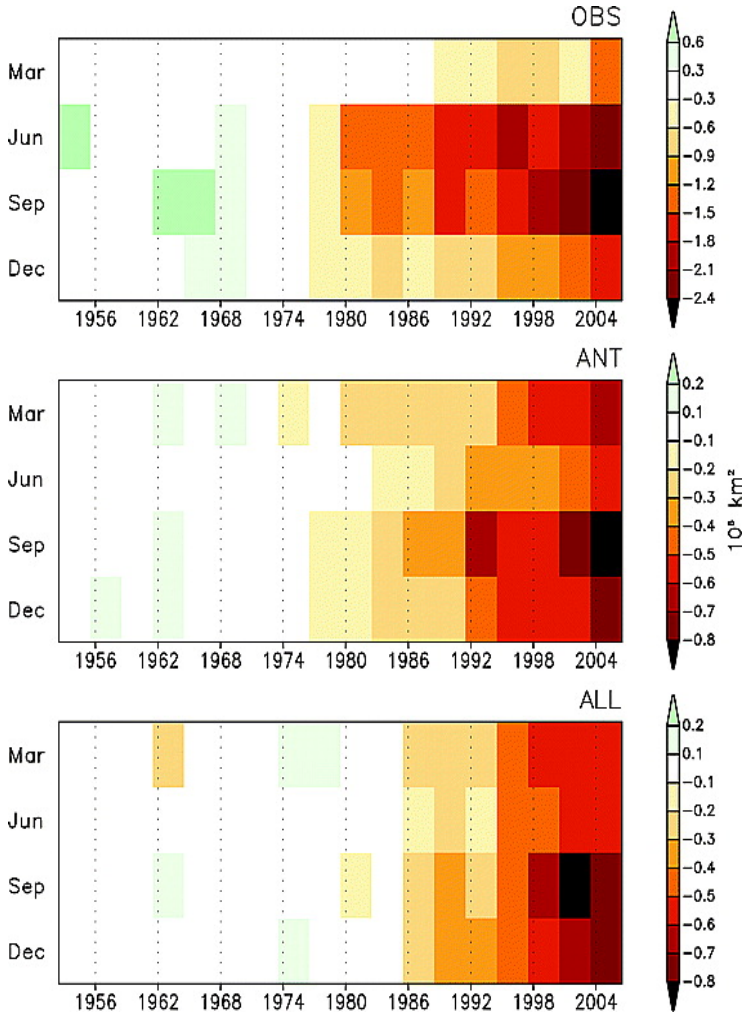


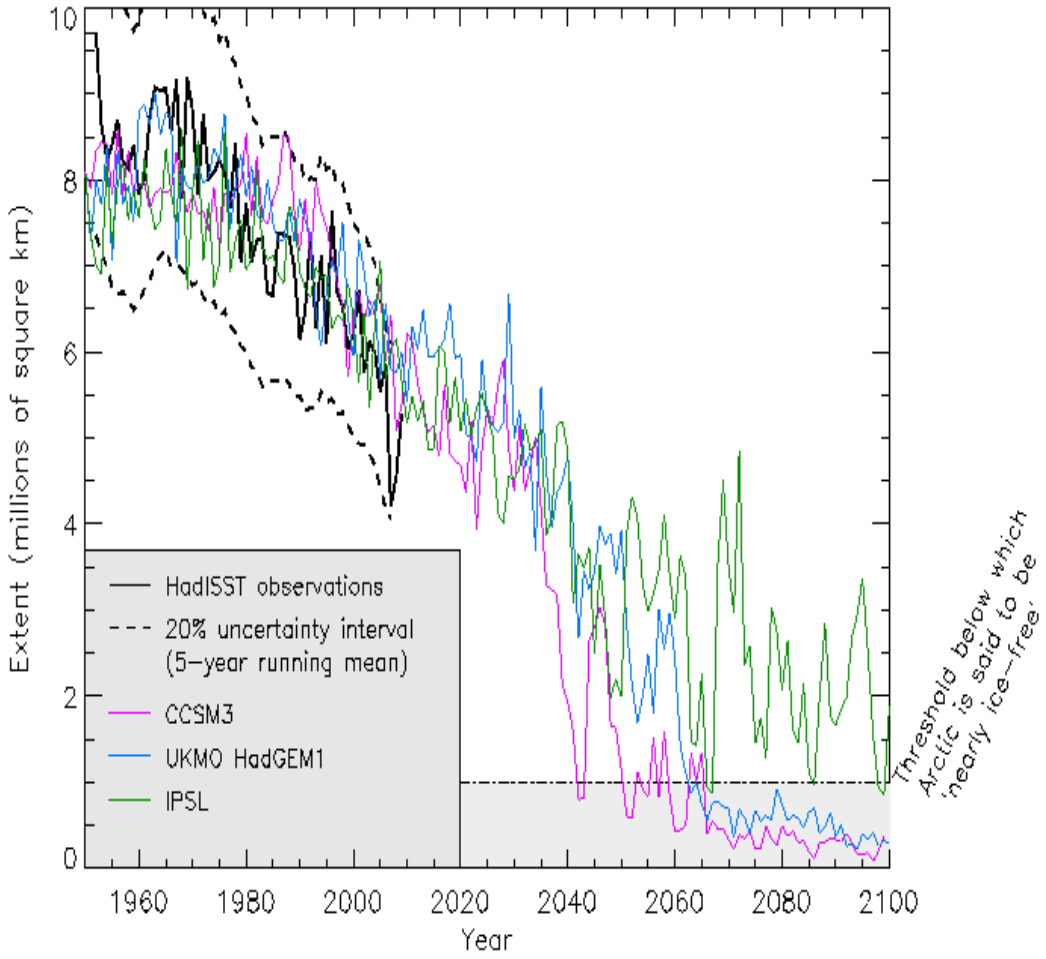
1901-1998



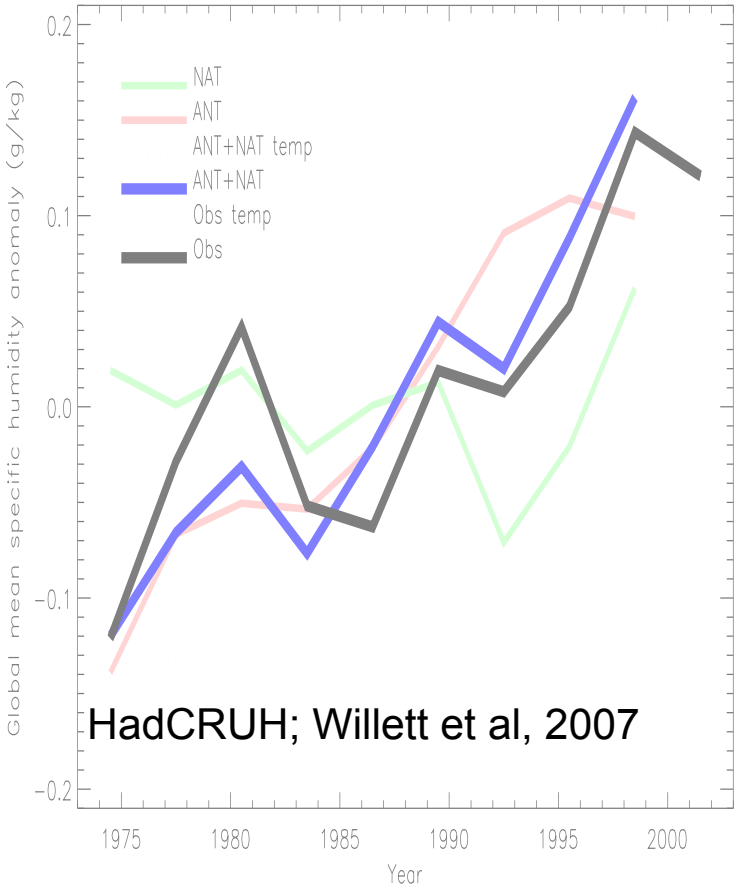
Zhang et al, Nature, 2007

Detection of human influence on Arctic sea-ice decline
Min et al, 2008, GRL.

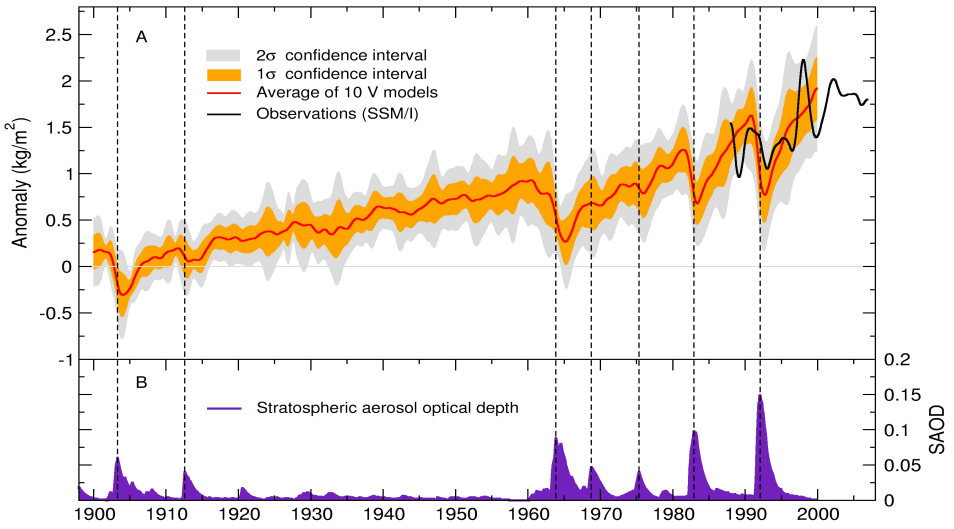




Human influence detected on increases in surface specific humidity and from atmospheric moisture content measured from satellite.



HadCRUH; Willett et al, 2007

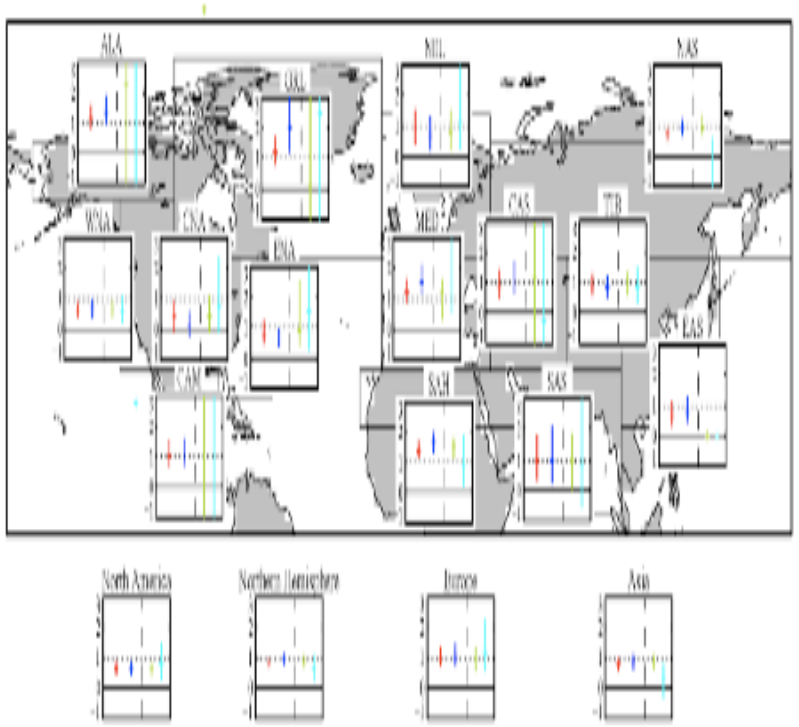


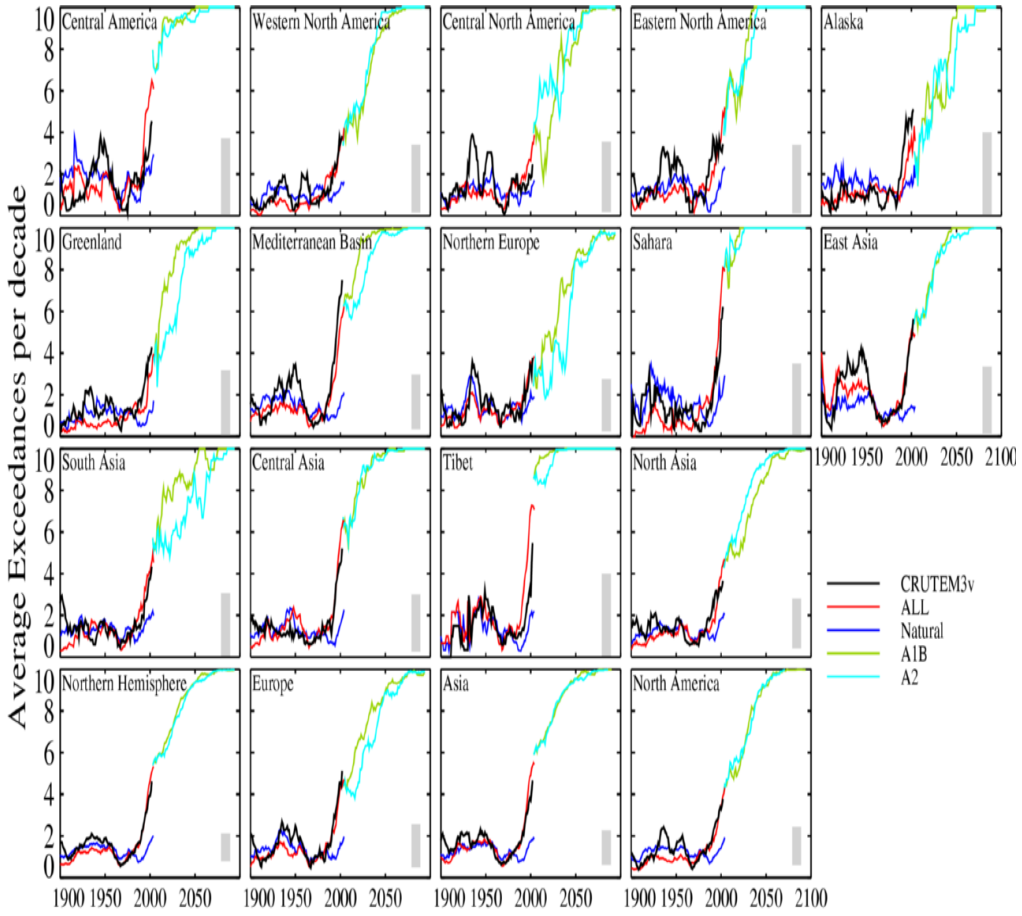
Santer et al, PNAS, 15248-15323, 2007
And robust to different choices of models Santer et al, 2009

The fingerprint of human influence has been detected in many different aspects of observed climate changes

- Air temperatures warming
- Ocean temperatures warming
- Increases in atmospheric humidity
- Salinity changes in the oceans
- Reducing Arctic sea-ice
- Changing rainfall patterns

Detection of human influence on temperatures at sub-continental scales





Hot summers that during the 1961-1990 period were experienced 1 year in 10 are now being experienced at least 3 years in 10. Jones et al, 2008

Attribution of European seasonal temperatures (Christidis et al, 2010, submitted)

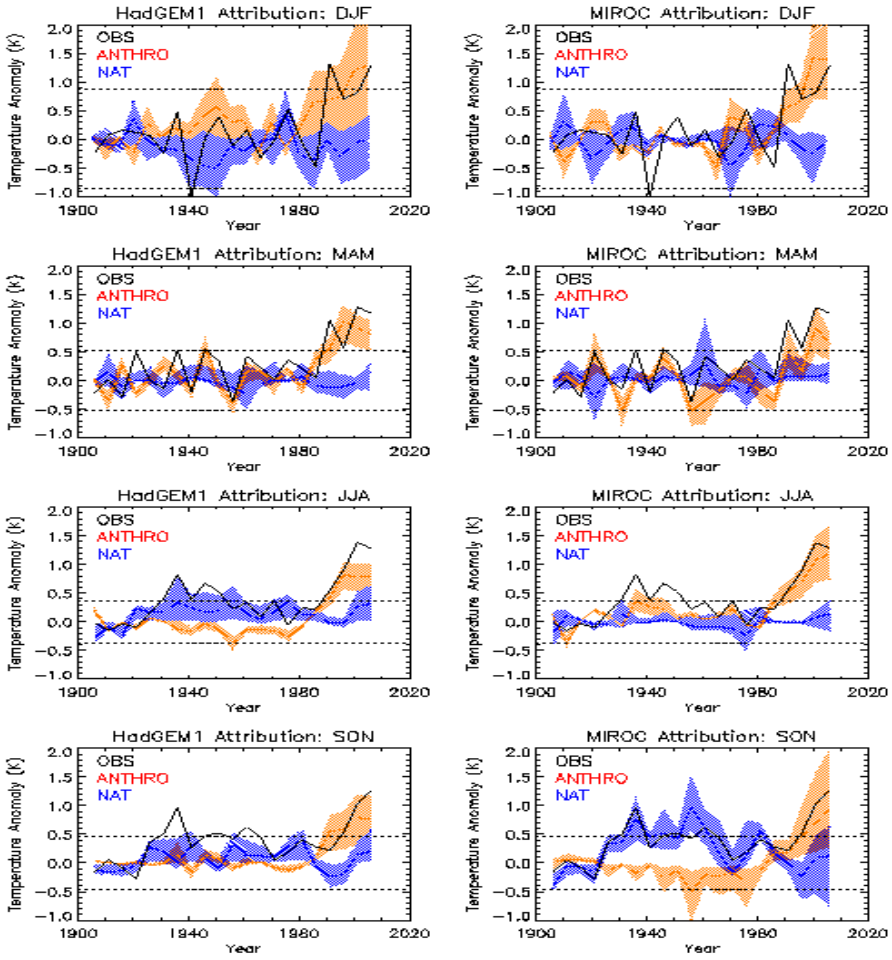
ANTHRO

and

NAT

components of the seasonal mean temperatures.

The uncertainty comes from the uncertainty in the scaling factors.



Attribution: 1999-2008 PDFs

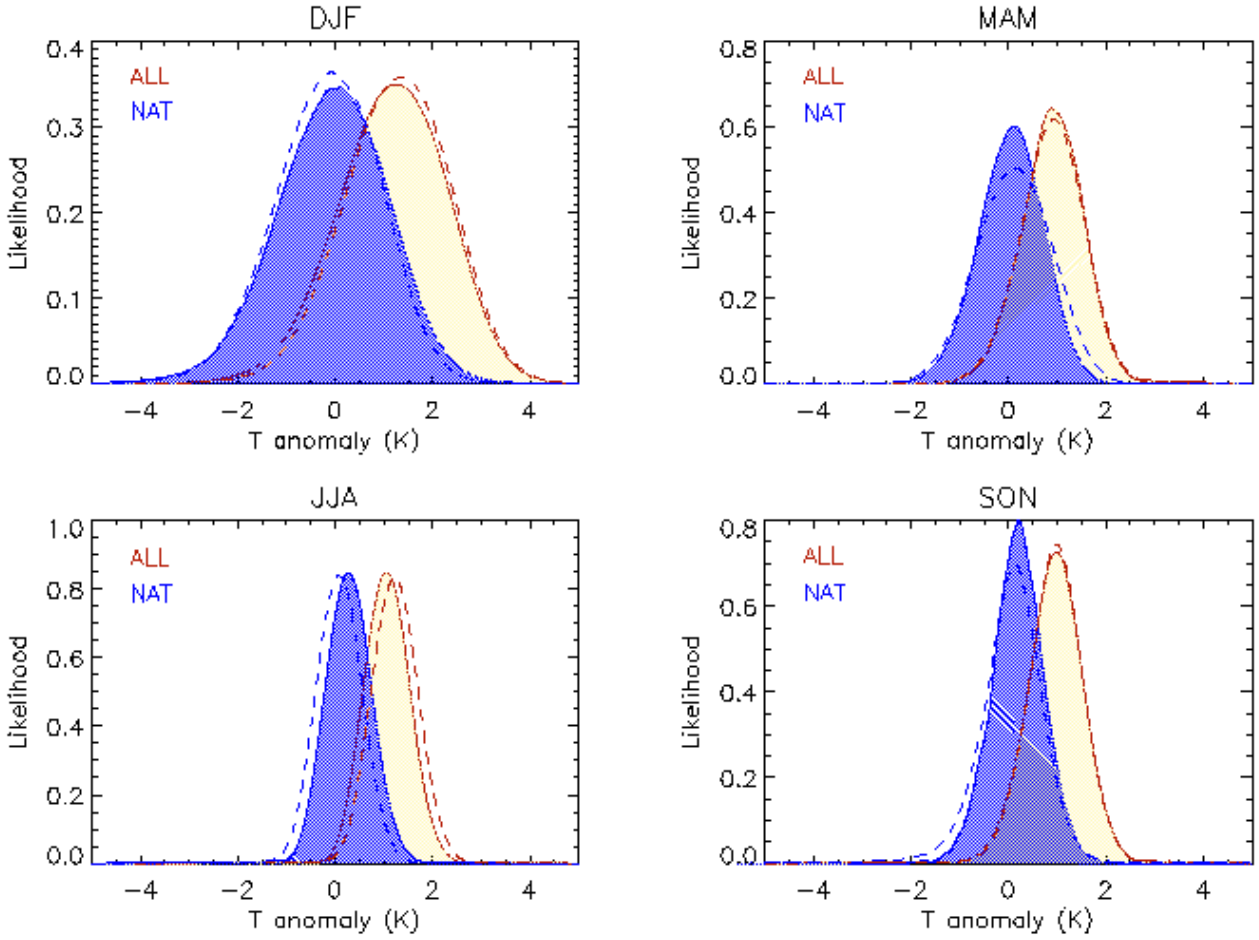
ALL and NAT components

+

internal variability (CONTROL)

Solid Lines: HadGEM1

Dashed Lines: MIROC



Fraction of Attributable Risk (FAR)

$$FAR = 1 - (P_0 / P_1)$$

P_0: Probability of exceeding a temperature threshold in a "natural world" (no anthropogenic forcings).

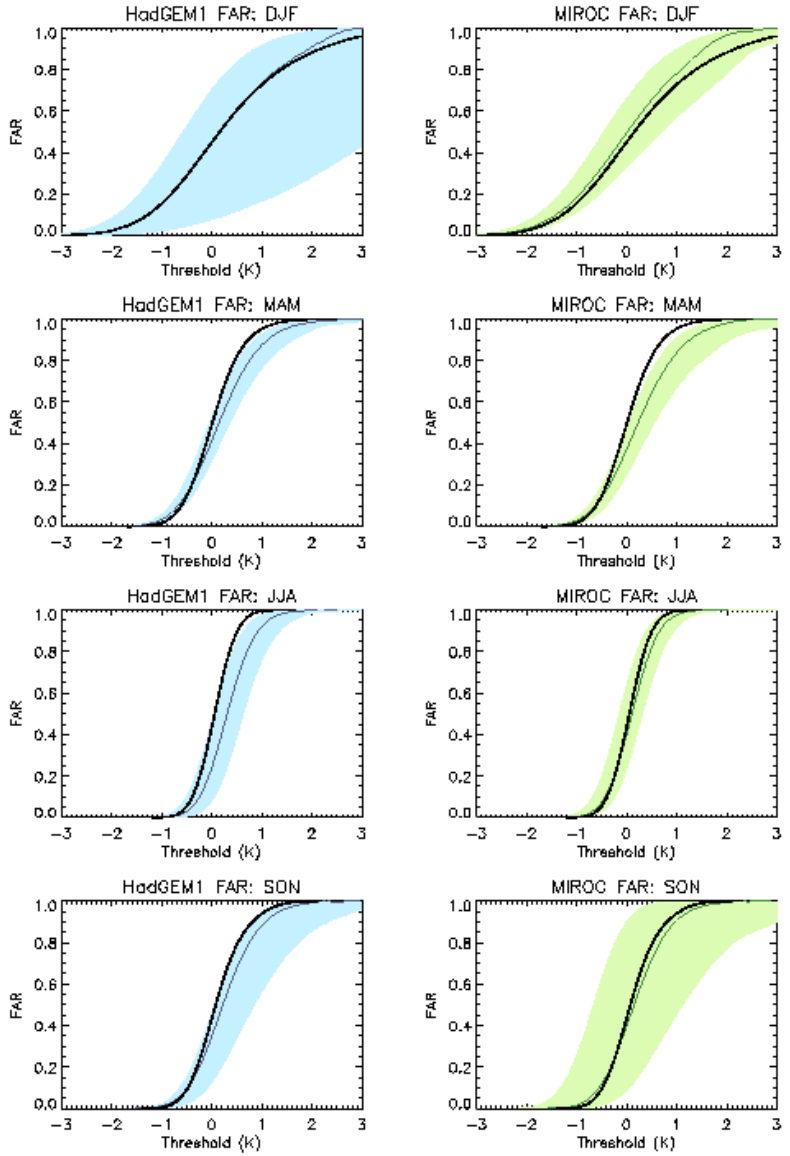
P_1: Probablity of exceeding a temperature threshold in the real world.

FAR over a range of thresholds for the 1999-2008 climate

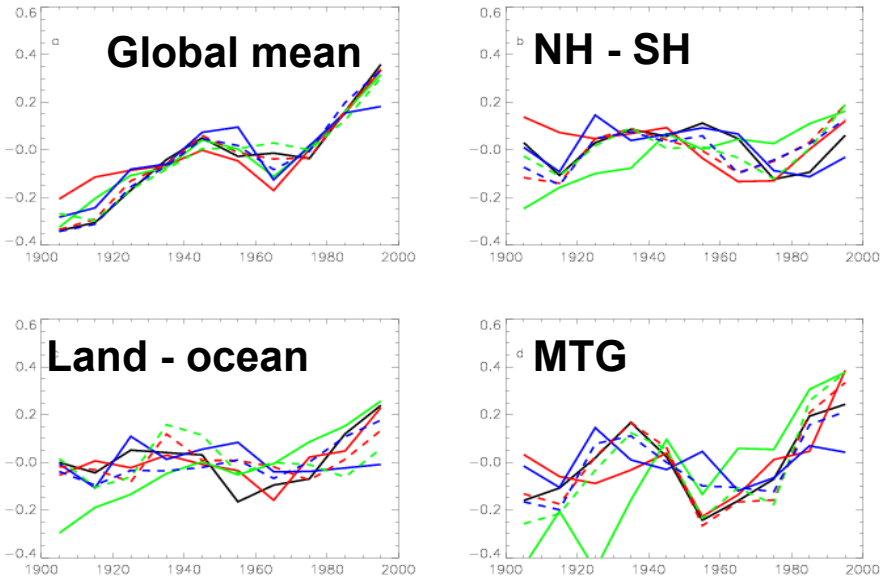
The black lines provide an independent estimate based on the *Luterbacher et al.* (2004) temperatures reconstructions.

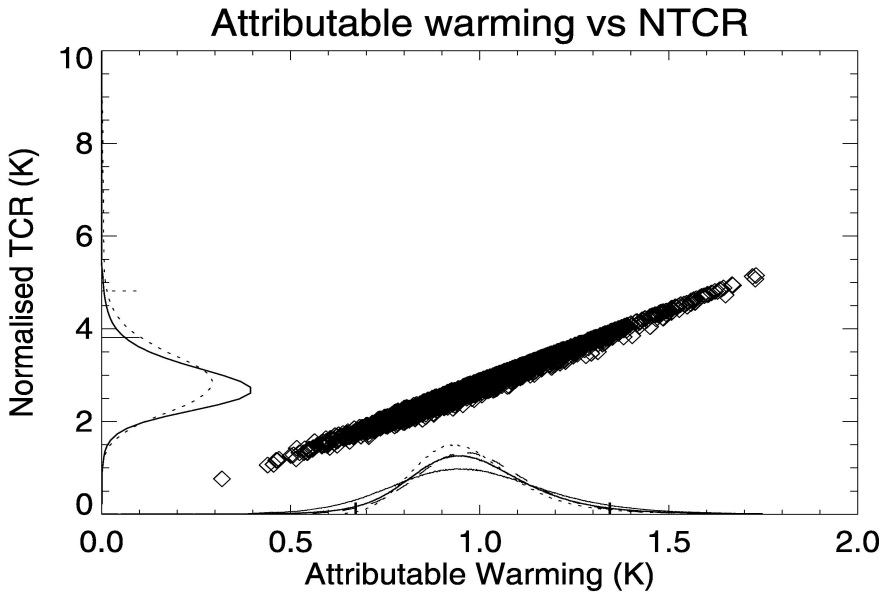
P_o was computed by fitting a normal distribution to the 1500-1800 seasonal mean temperatures.

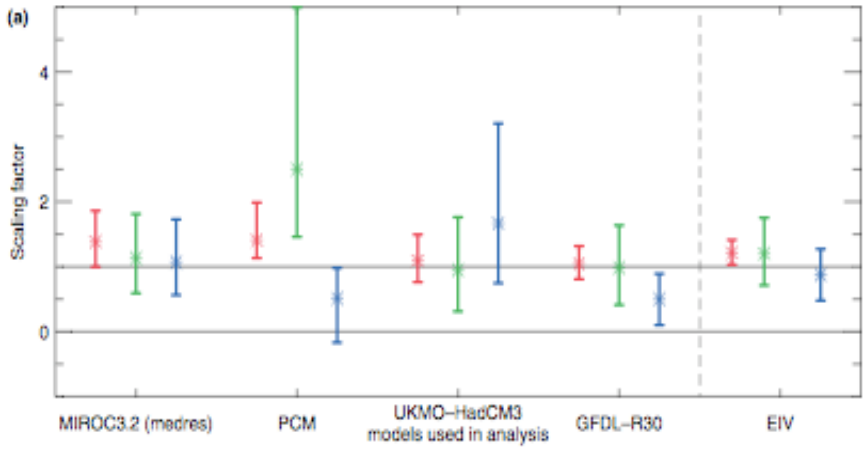
P_1 was computed using the seasonal temperatures of the most recent decade and *t*-statistics.

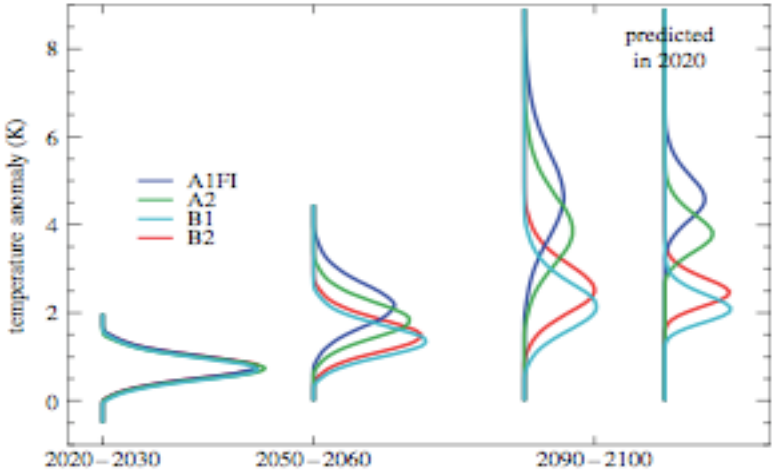


Robust quantification of contributors to past temperature change enables quantification of likely future rates of warming (ASK)

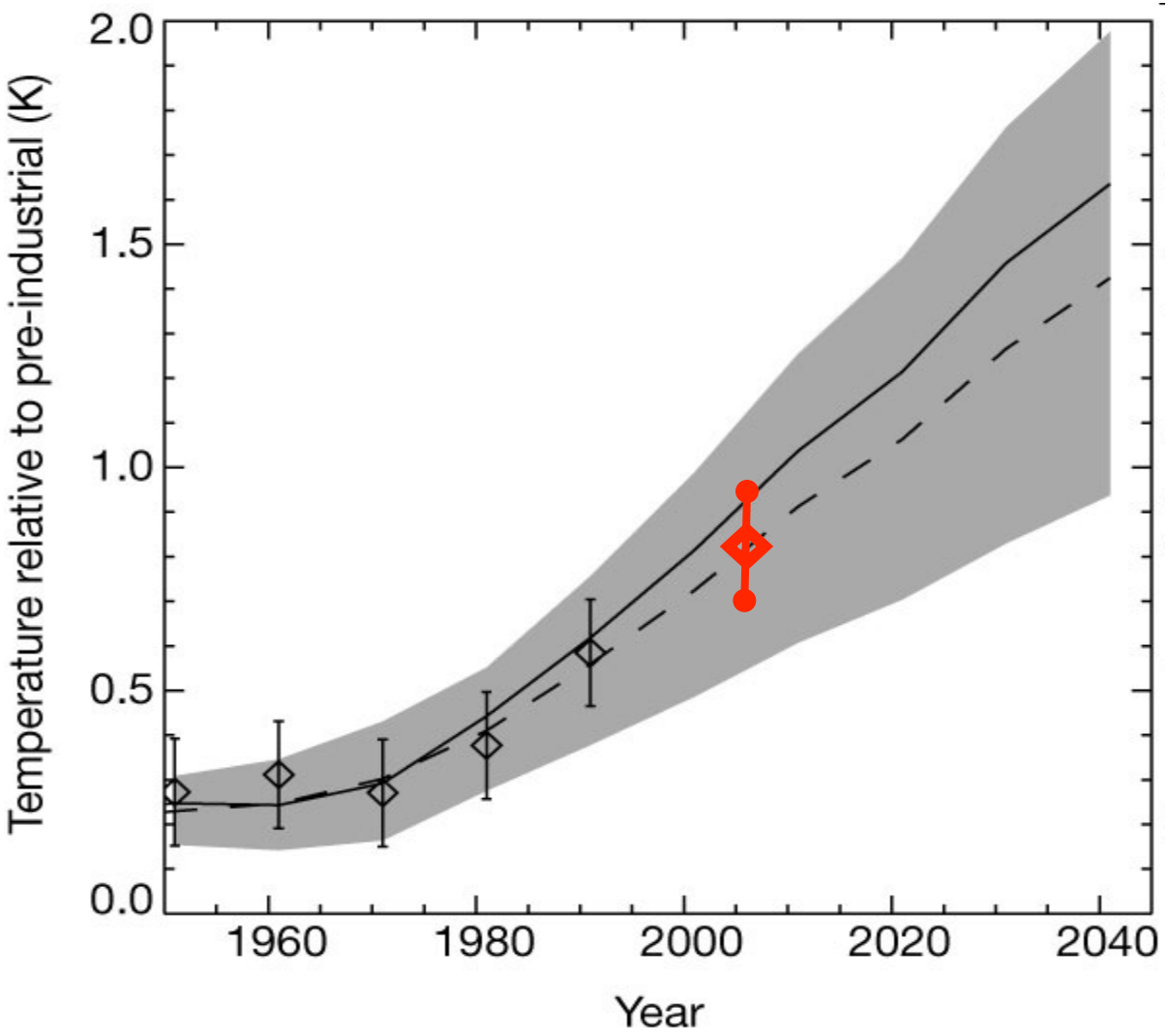








Global temperatures are evolving as predicted in response to human influence



Global temperature response to greenhouse gases and aerosols
Solid: climate model simulation (HadCM2)
Dashed: recalibrated prediction using data to August 1996
(Allen, Stott, Mitchell, Schnur, Delworth, 2000)

Observed decadal mean temperature September 1999 to August 2009 inclusive

Detection and attribution : from global to regional

- Wealth of evidence now available shows there is an increasingly remote possibility that climate change is dominated by natural rather than anthropogenic factors (Stott et al, WIRE, 2010)
- Human influence on Antarctic warming has been detected
- Increasing evidence that human influence on temperature is becoming significant below continental scales
- Major challenges still remain in obtaining robust attribution results at scales needed for evaluation of impacts
- Climate models often lack processes needed to realistically simulate regional details
- Observed changes in non-climate quantities could be the result of additional influences besides climate thus complicating attribution studies
- Extremes pose a particular challenge since they are rarely observed and models don't necessarily represent droughts, floods and hurricanes
- At regional scales, many challenges remain
  - Lower signal to noise ratios
  - Difficulties of separately attributing effects of different forcings relevant at the region
  - Limitations of models in capturing some aspects of regional climate variability

The effect of local circulation variability on the detection and attribution of New Zealand temperature trends

Sam Dean, Peter Stott

Dean and Stott, J. Climate, 22, 6217-6229, 2009.

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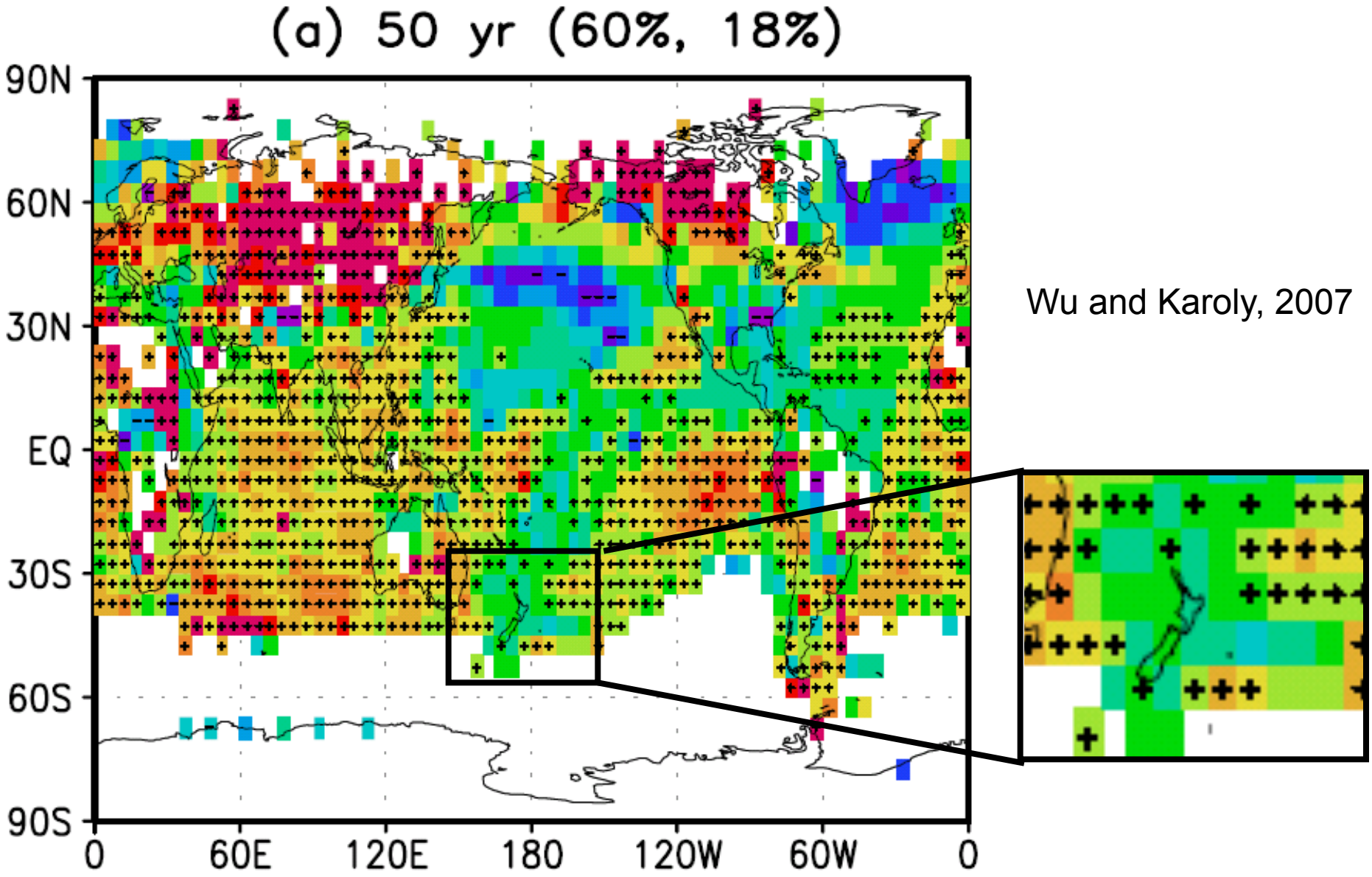
Taihoro Nukurangi



Wu and Karoly, 2007

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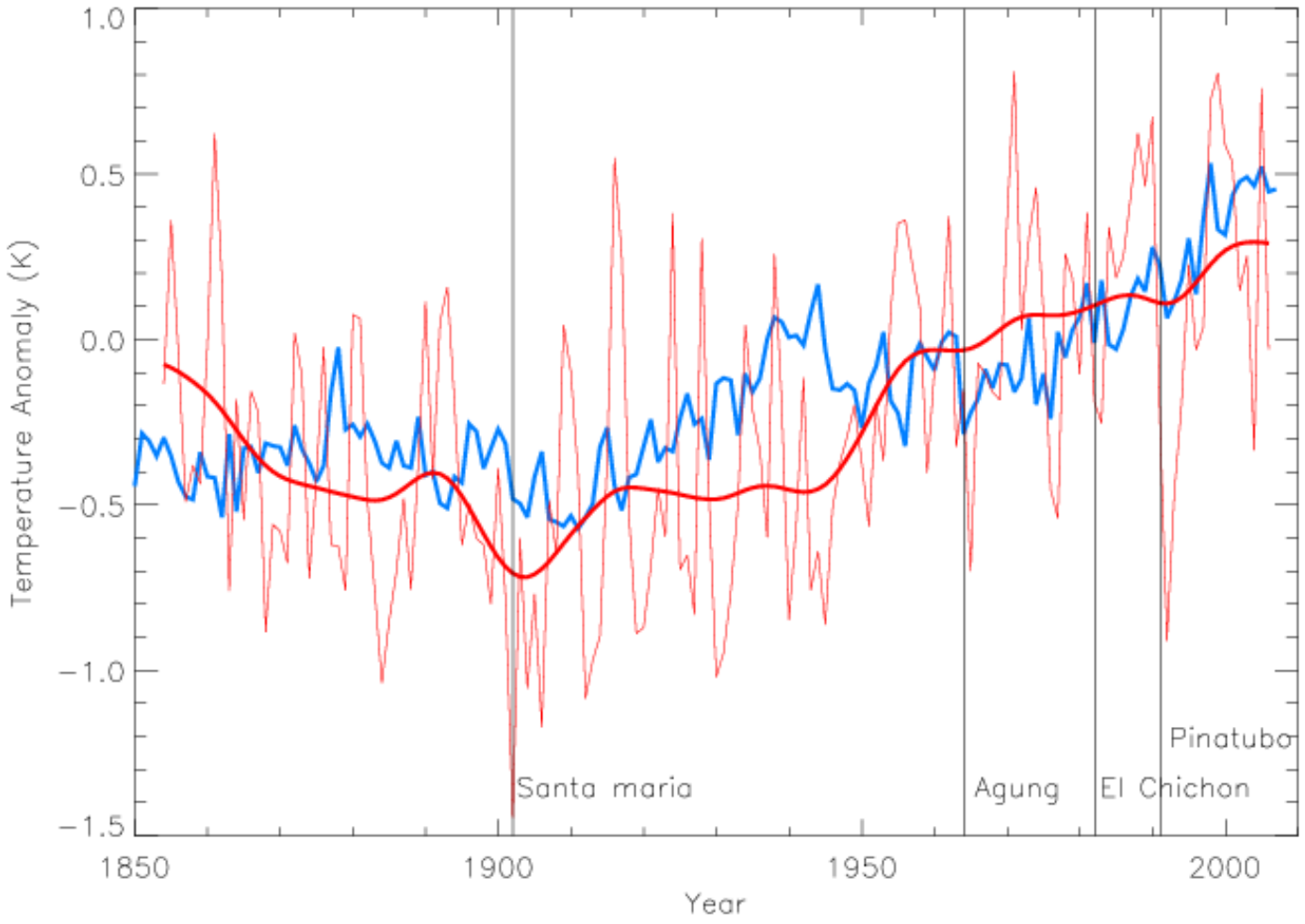
Historical temperature



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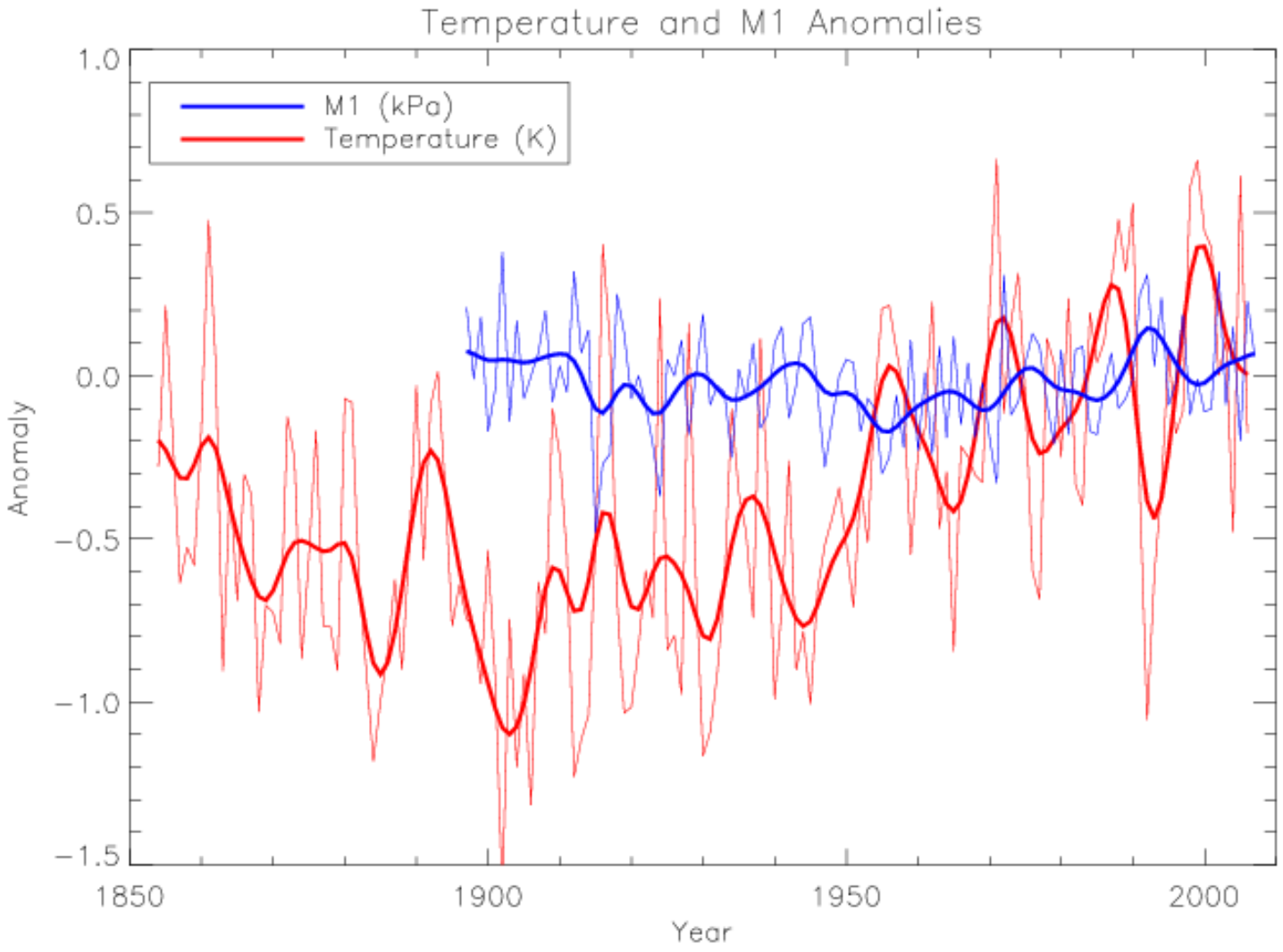
Historical temperature & the M1



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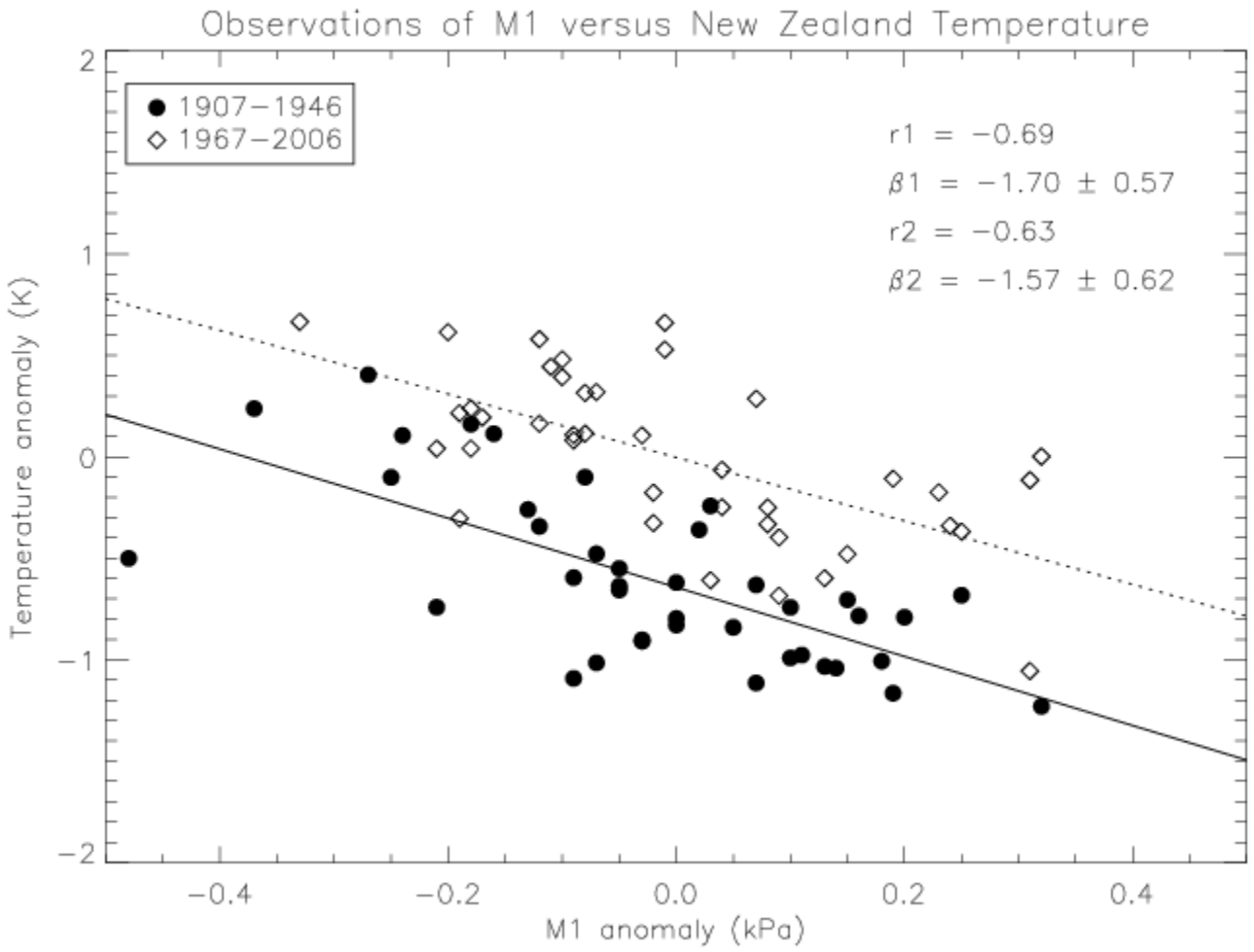
Removal of the M1



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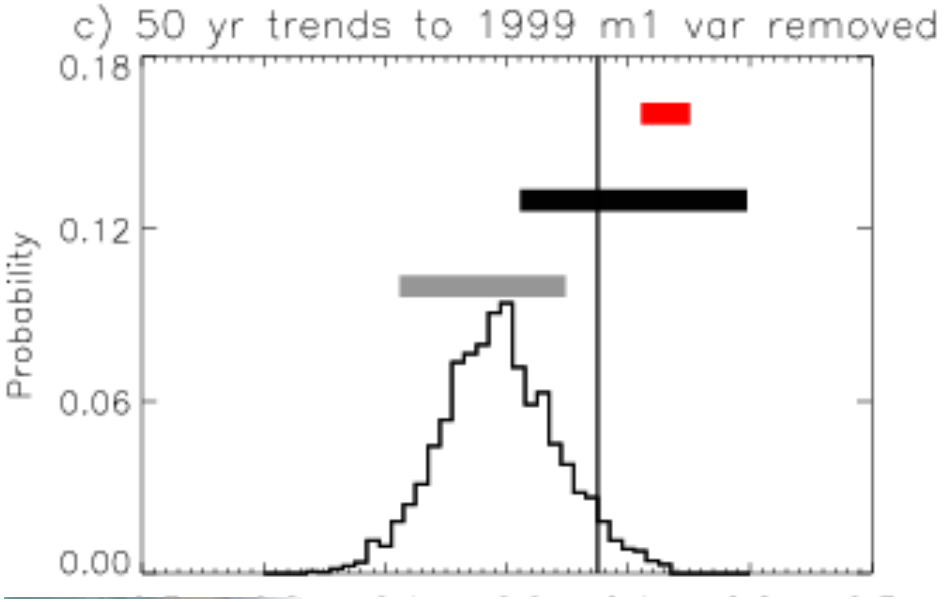

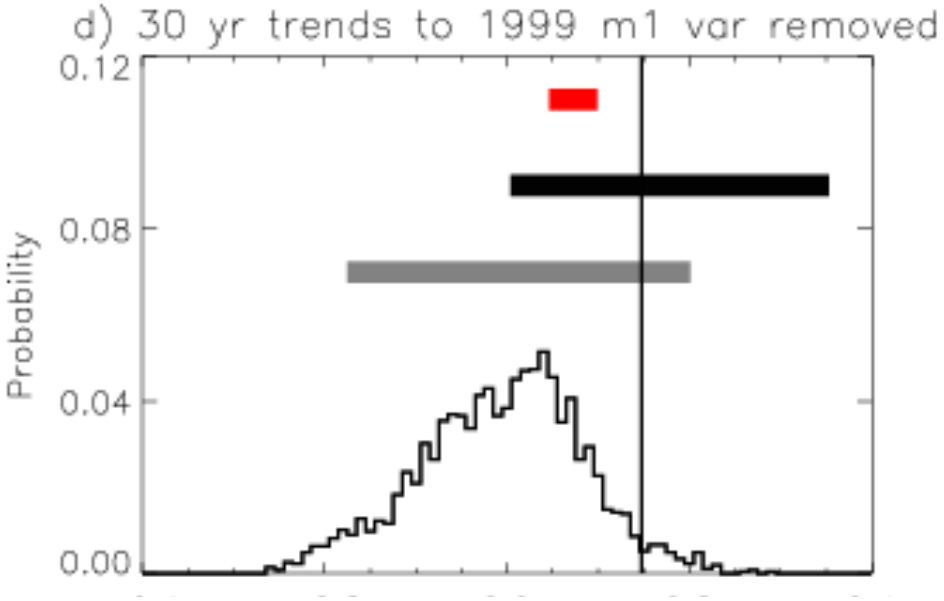

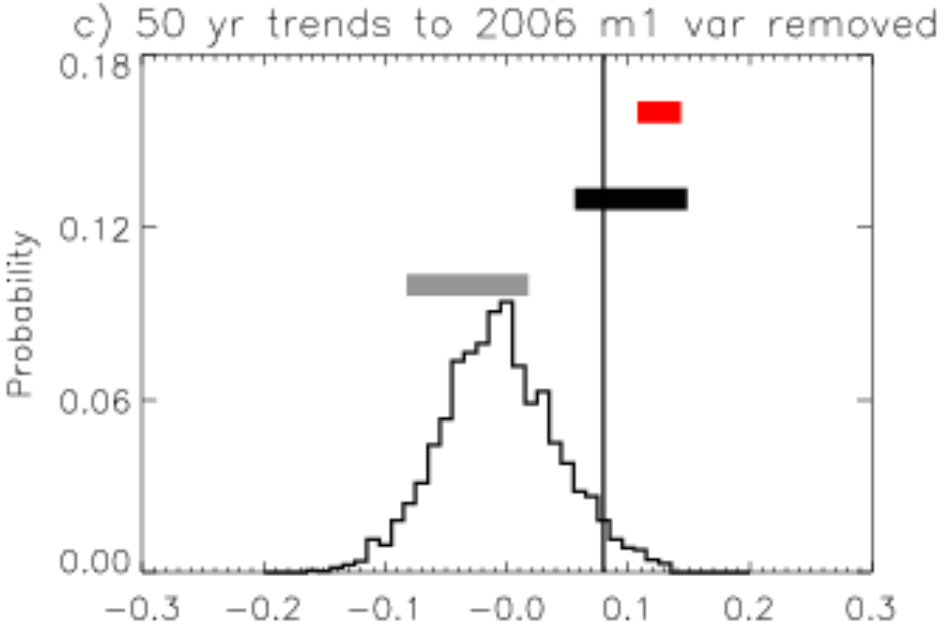

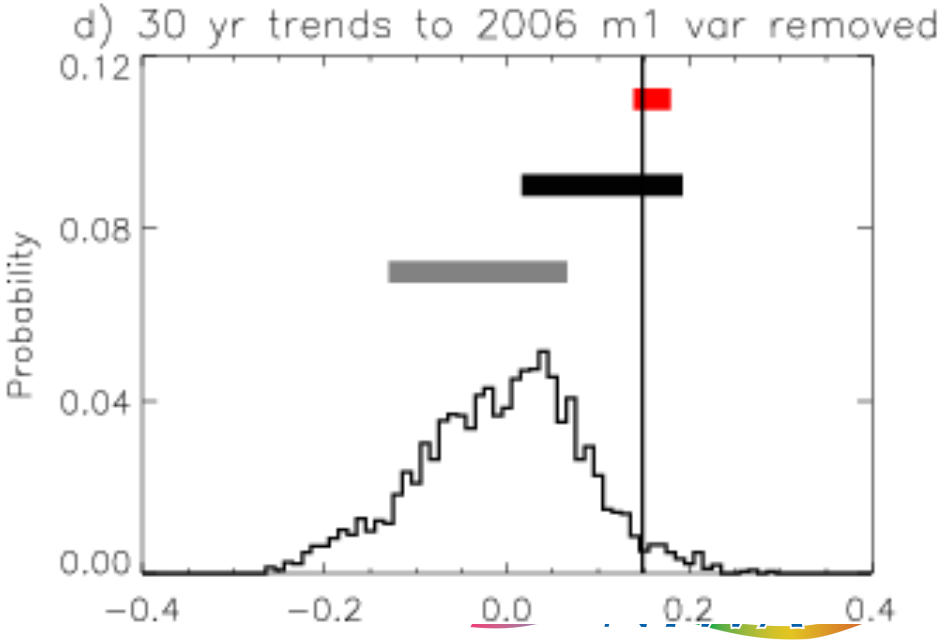

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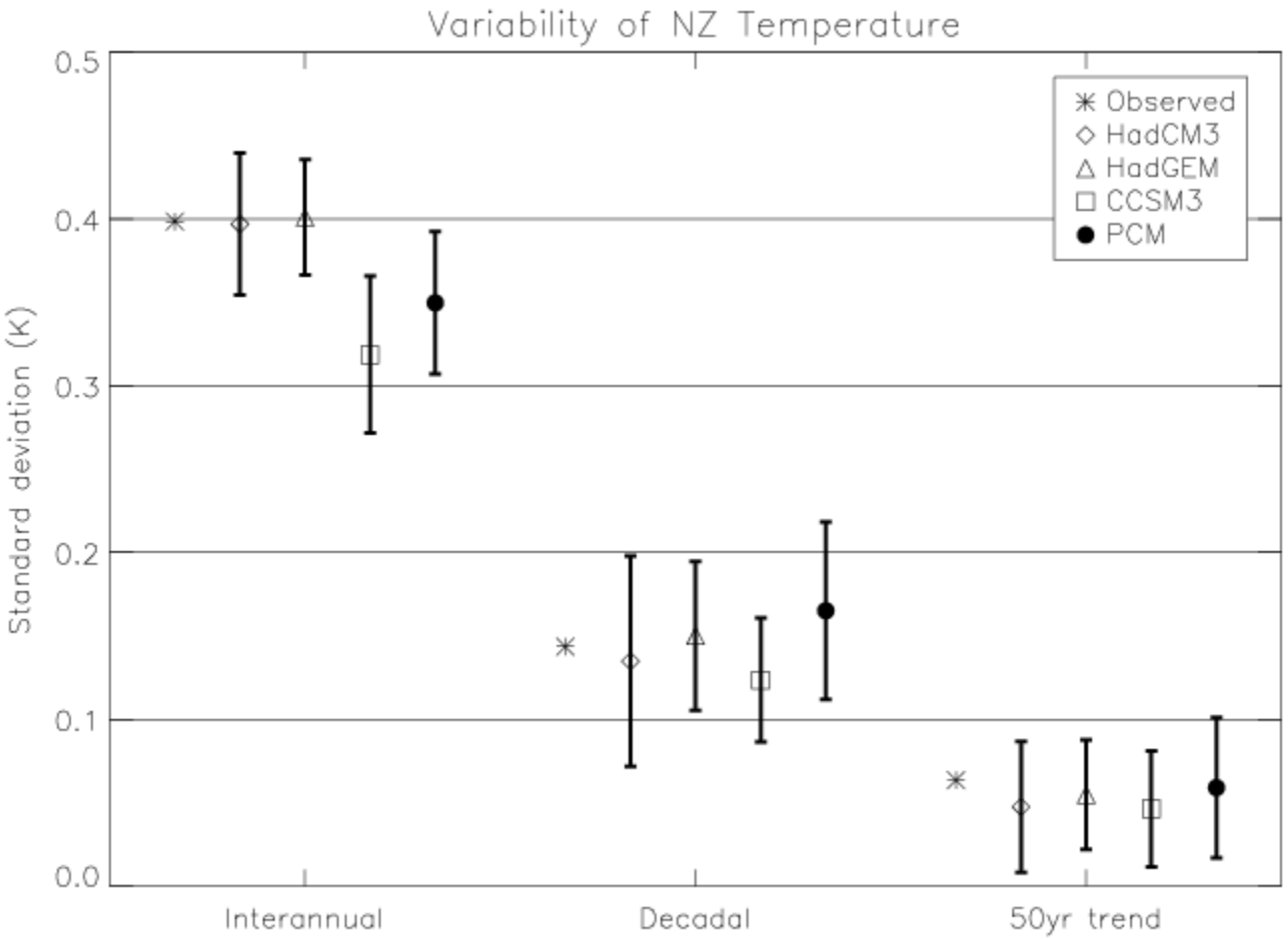
Simulated variability



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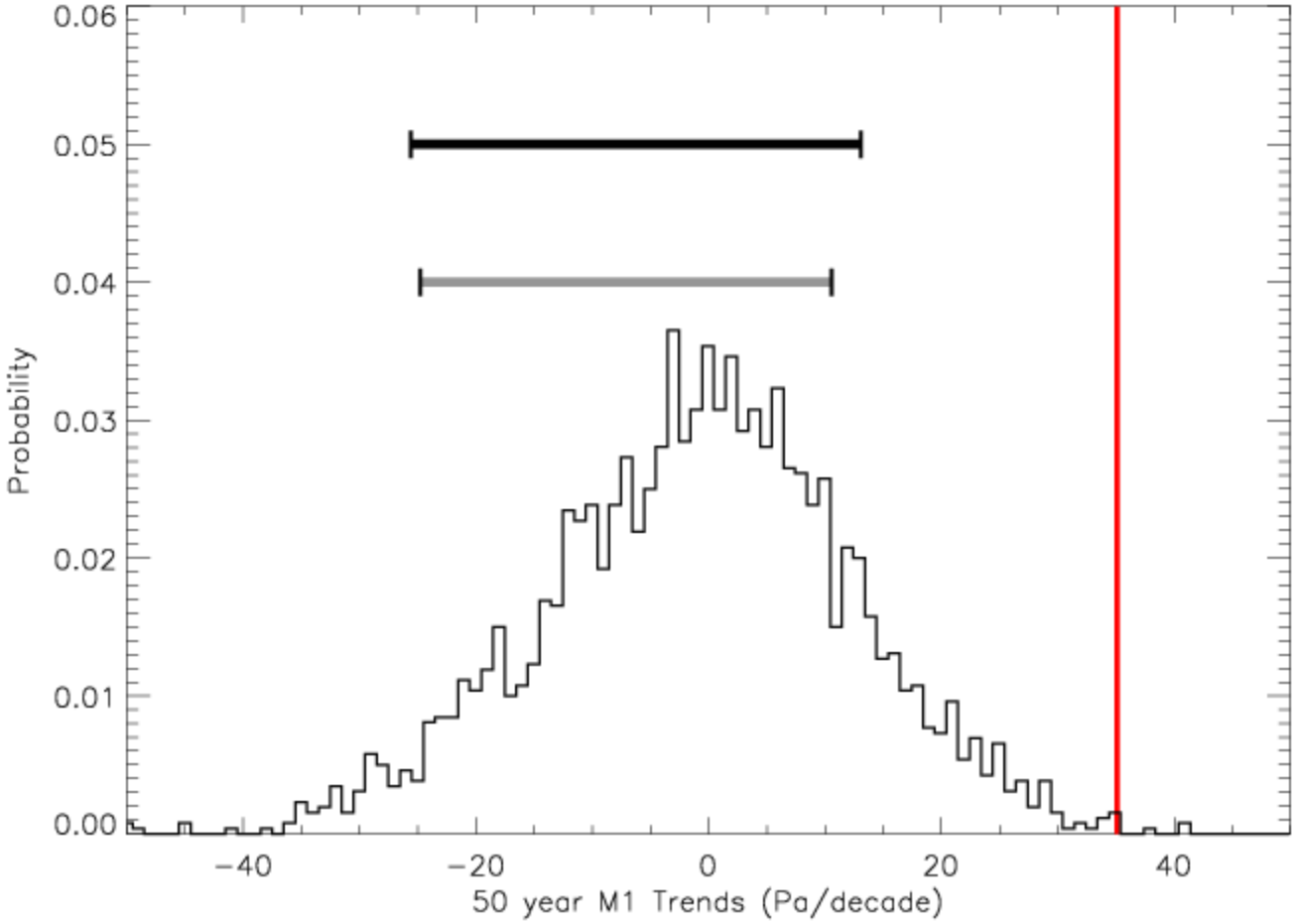
Trend in the M1



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Summary

- After removal of the M1 trend 50 year temperature trends are consistent with simulations with greenhouse gases but not consistent with natural variability or simulations which included only natural forcings.
- Models underestimate the M1 variability and do not simulate a trend.
- A better understanding is required of the processes leading to M1 variability for a robust attribution of New Zealand temperature trends to anthropogenic and natural factors

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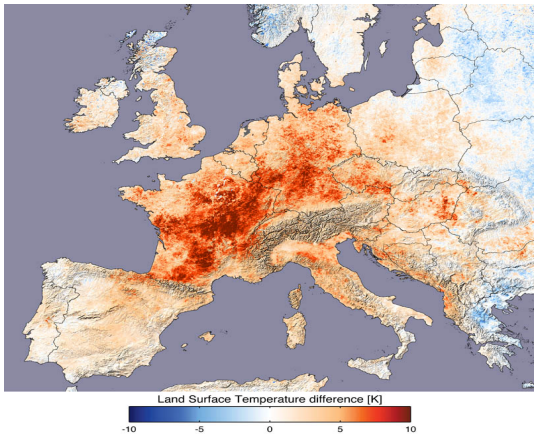
IPCC Good Practice Guidance Paper on Detection and Attribution Related to Anthropogenic Climate Change

- Single-step attribution to external forcings
  - Based on explicitly modelling the response of the variable to external forcing
- Multi-step attribution to external forcings
  - An assessment that attributes 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
  - It is recommended that the component assessments be made explicitly and that an overall assessment of the combined result be made
- Associative pattern attribution
  - Synthesis of large number of results
- Attribution to a change in climatic conditions
- Confidence in assessments influenced by
  - Extent to which attribution of change to causal factor robustly quantified
  - Understanding of processes involved in proposed causal link
  - Study considers other possible drivers, confounding factors, observational limitations

What is the link between recent extreme weather events and climate change ?
What does this mean for the future ?
Do we need to adapt to a greater frequency of such events in future – or not ?

Tewkesbury flooding, July 2007



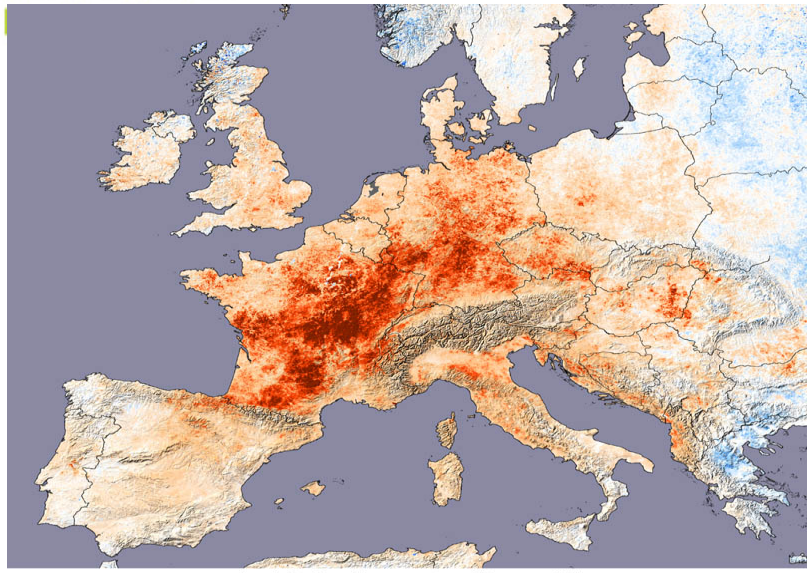
European heatwave, 2003

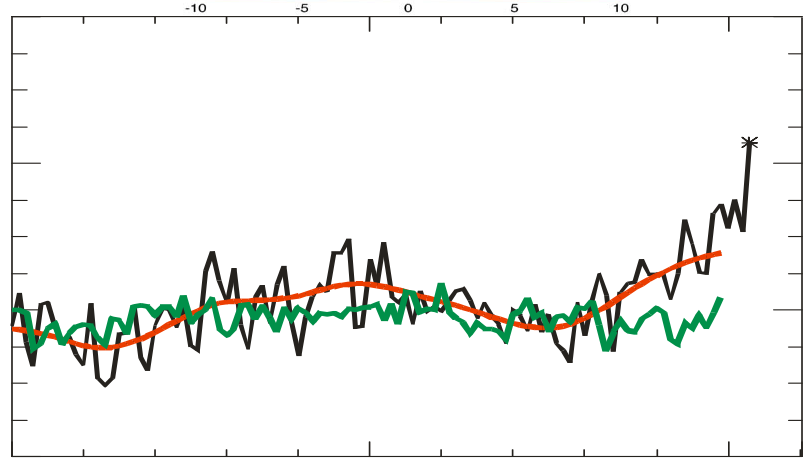
Australian fires, Feb 2009

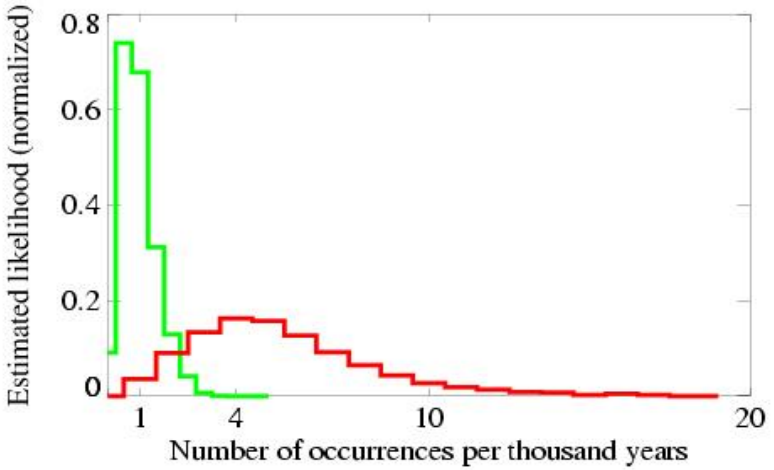
Cold UK, January 2009

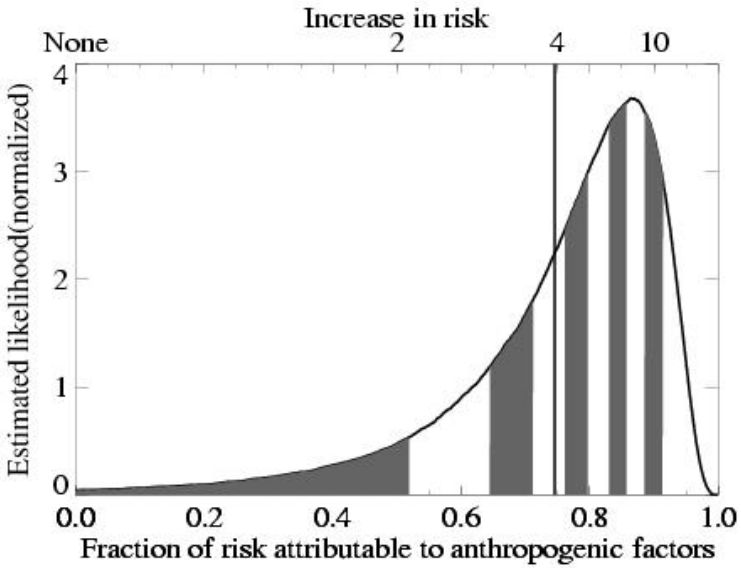
- It is possible to make attribution statements about individual events
- By calculating the odds of such events and the change in odds attributable to particular factors
- Allen, 2003

Human influence has very likely at least doubled the risk of European summer temperatures as hot as 2003









Stott, Stone, Allen, 2004

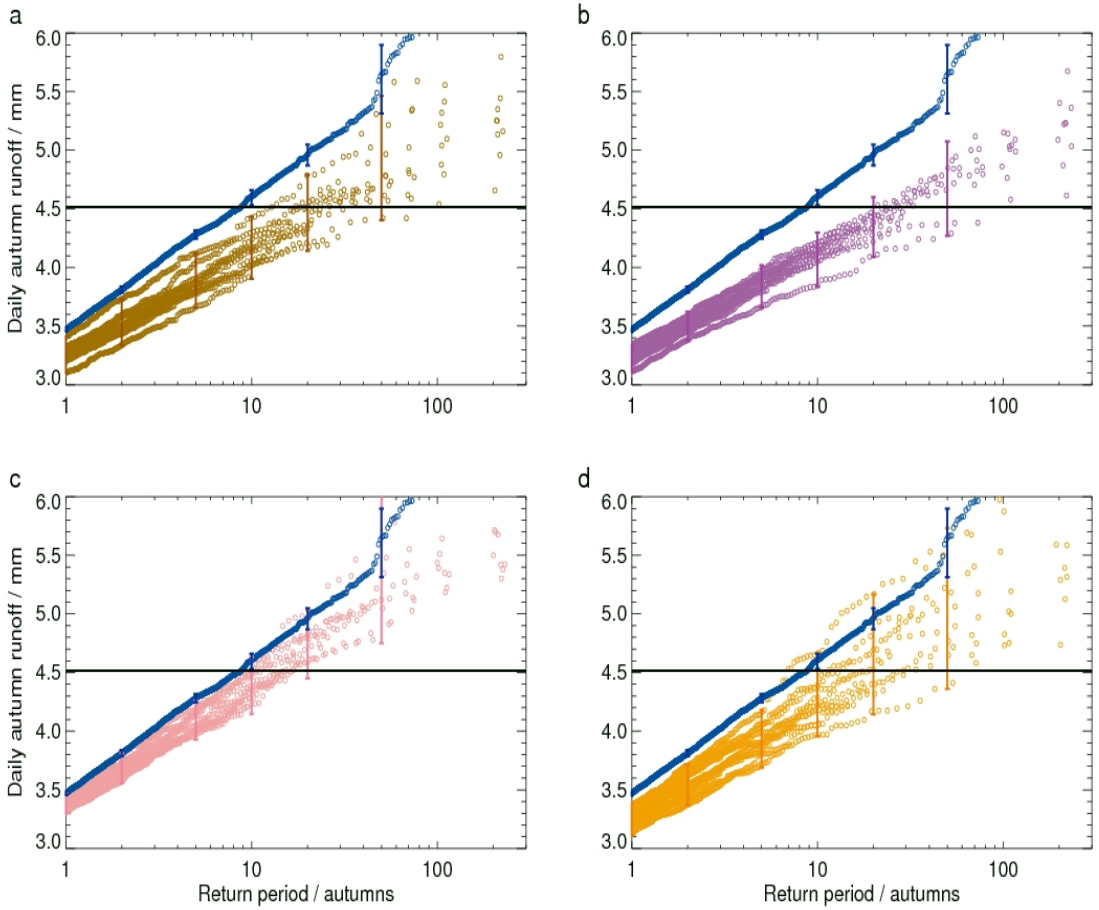
Anthropogenic greenhouse gas contribution to UK autumn flood risk. Pall et al, 2010, submitted.

HadCM3 N144 1.25°x0.83° 30L

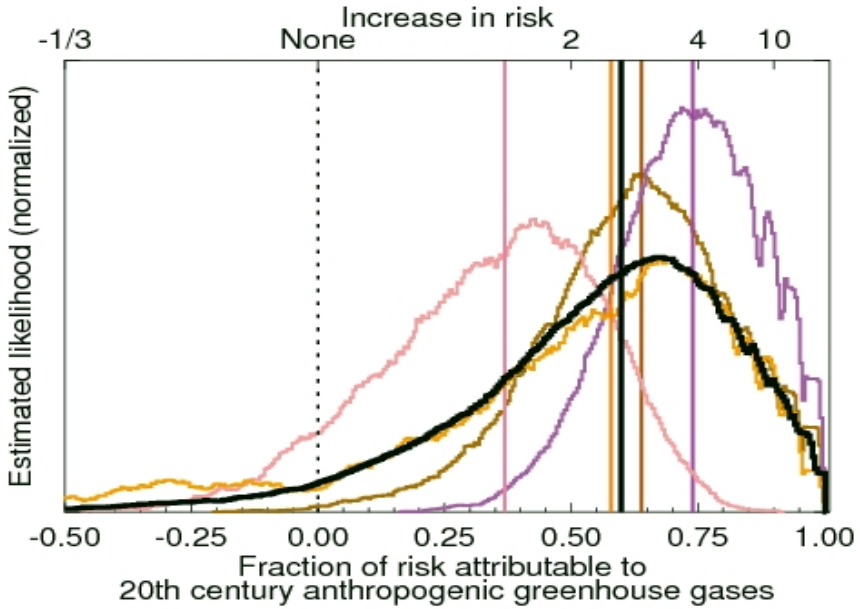
A2000 : Observed SSTs for Autumn 2000

A2000N : SSTs due to GHG increases subtracted off observed SSTs

Several thousand perturbed initial condition simulations



"Our model results indicate 20th century anthropogenic greenhouse gas emissions significantly (at 10% level) increased England and Wales flood risk in Autumn 2000 and most probably about trebled it" Pall et al, 2010, Submitted.



Change in risk of severe daily river runoff for England & Wales Autumn 2000. Histograms (smoothed) of the fraction of risk of severe synthetic runoff in the A2000 climate that is attributable to 20th century anthropogenic greenhouse gas emissions. Each coloured histogram shows this Fraction of Attributable Risk (FAR) in the A2000 climate, relative to one of the four A2000N sub-climates in Fig. 3 (with corresponding colours).

Prospects

- Successful adaptation would benefit from improved information about societal vulnerabilities in a changing climate. Adaptation financing : changed likelihood of weather events attributable to anthropogenic change
- Near-real time monitoring and attribution systems have potential to relate recent events to climate variability and change
- By finding robust relationships between observed quantities and predictor variables, can find observationally constrained estimates of uncertainties in future changes. [IPCC Expert Meeting on Assessing and Combining Multi Model Climate Projections]
- By identifying model data differences that are outside the range expected from internal variability can highlight inadequacies in model formulation or problems with observational datasets.
- Attribution of climate changes and impacts at regional scales remains a big scientific challenge [IPCC Good Practice Guidance Paper on Detection and Attribution]

Additional slides

Summary

- Wealth of evidence now available shows there is an increasingly remote possibility that climate change is dominated by natural rather than anthropogenic factors (Stott et al, WIRE, 2010)
- Antarctic warming has been attributed to human influence
- Increasing evidence that human influence on temperature is becoming significant below continental scales
- Major challenges still remain in obtaining robust attribution results at scales needed for evaluation of impacts
- Climate models often lack processes needed to realistically simulate regional details
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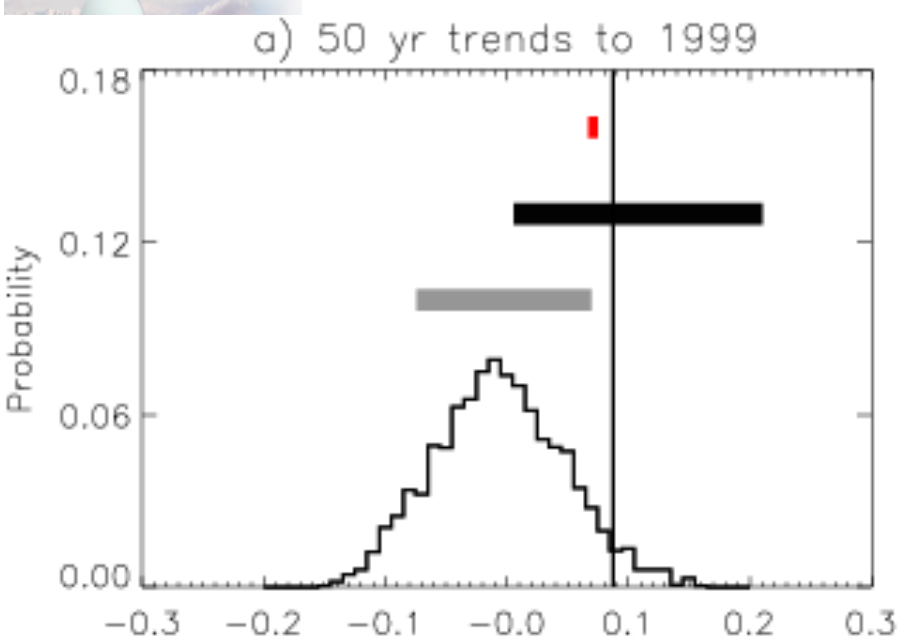
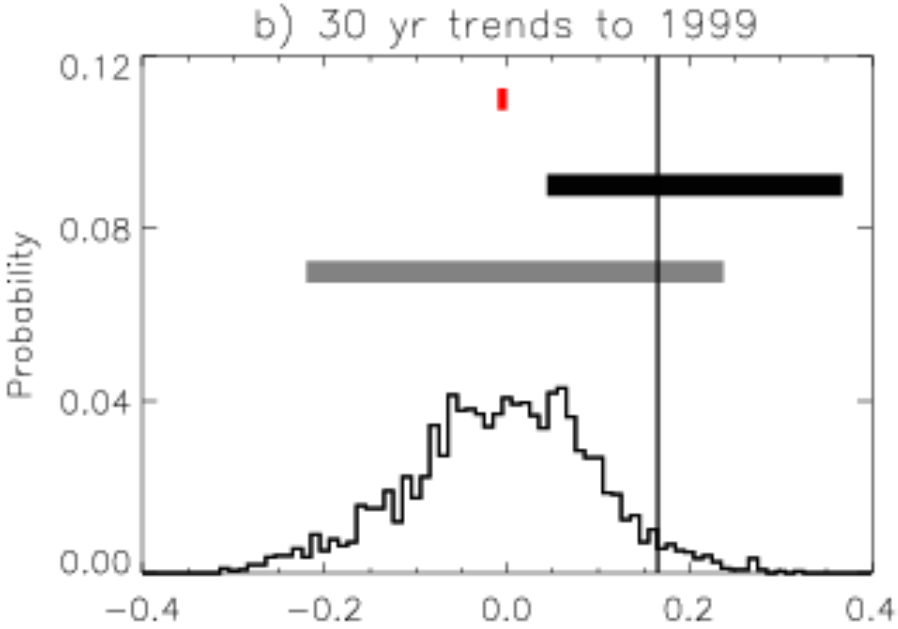
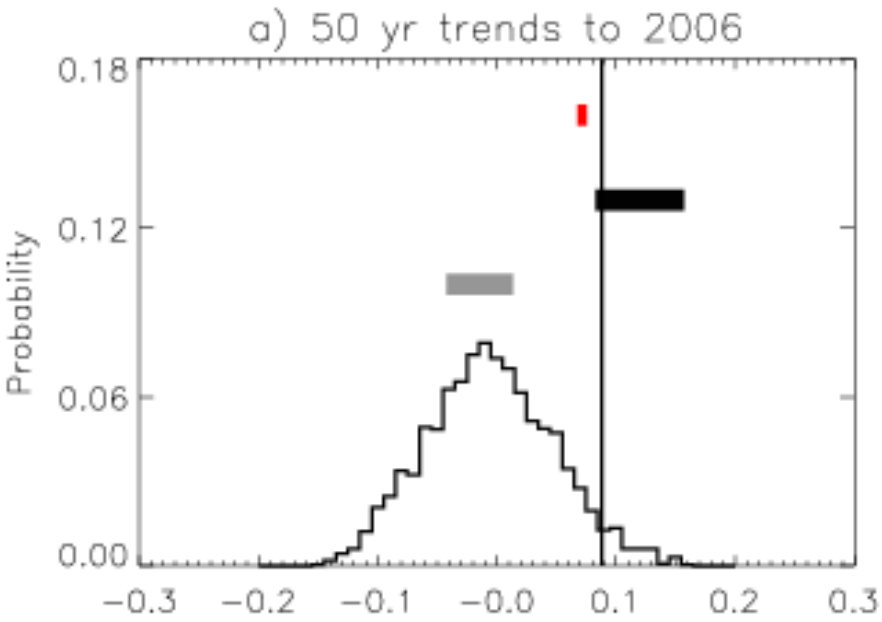
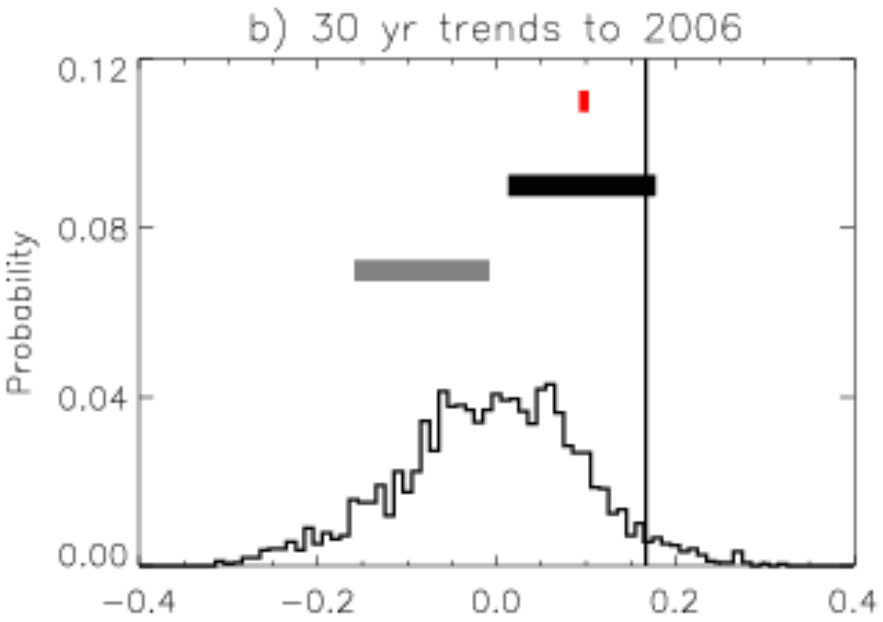
- Extremes pose a particular challenge since they are rarely observed and models don't necessarily represent droughts, floods and hurricanes
- At regional scales, many challenges remain
  - Lower signal to noise ratios
  - Difficulties of separately attributing effects of different forcings relevant at the region
  - Limitations of models in capturing some aspects of regional climate variability


a) 50 yr trends to 1999
Probability
0.18
0.12
0.06
0.00
−0.3
−0.2
−0.1
−0.0
0.1
0.2
0.3


b) 30 yr trends to 1999
Probability
0.12
0.08
0.04
0.00
−0.4
−0.2
0.0
0.2
0.4


a) 50 yr trends to 2006
Probability
0.18
0.12
0.06
0.00
−0.3
−0.2
−0.1
−0.0
0.1
0.2
0.3


b) 30 yr trends to 2006
Probability
0.12
0.08
0.04
0.00
−0.4
−0.2
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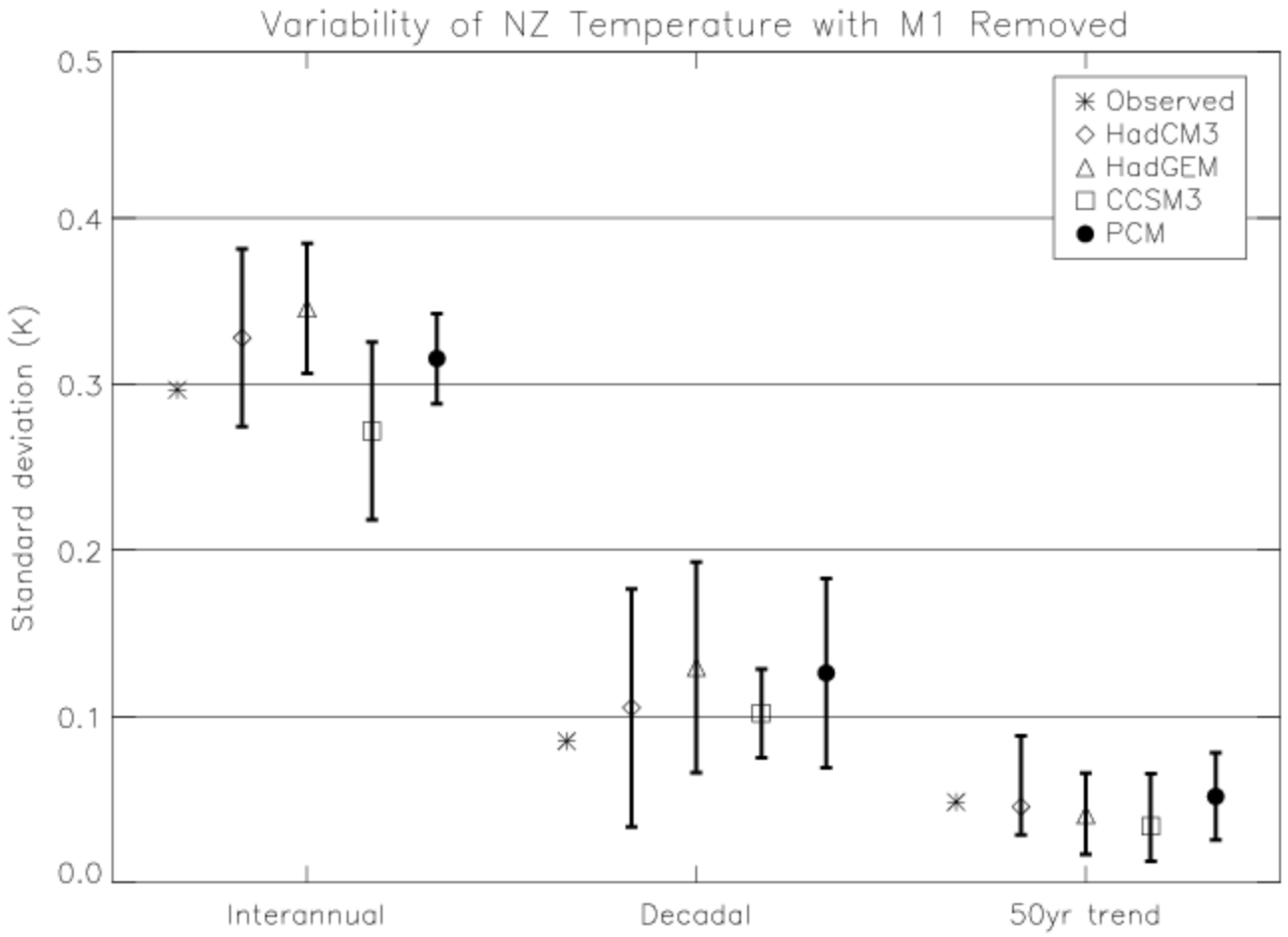

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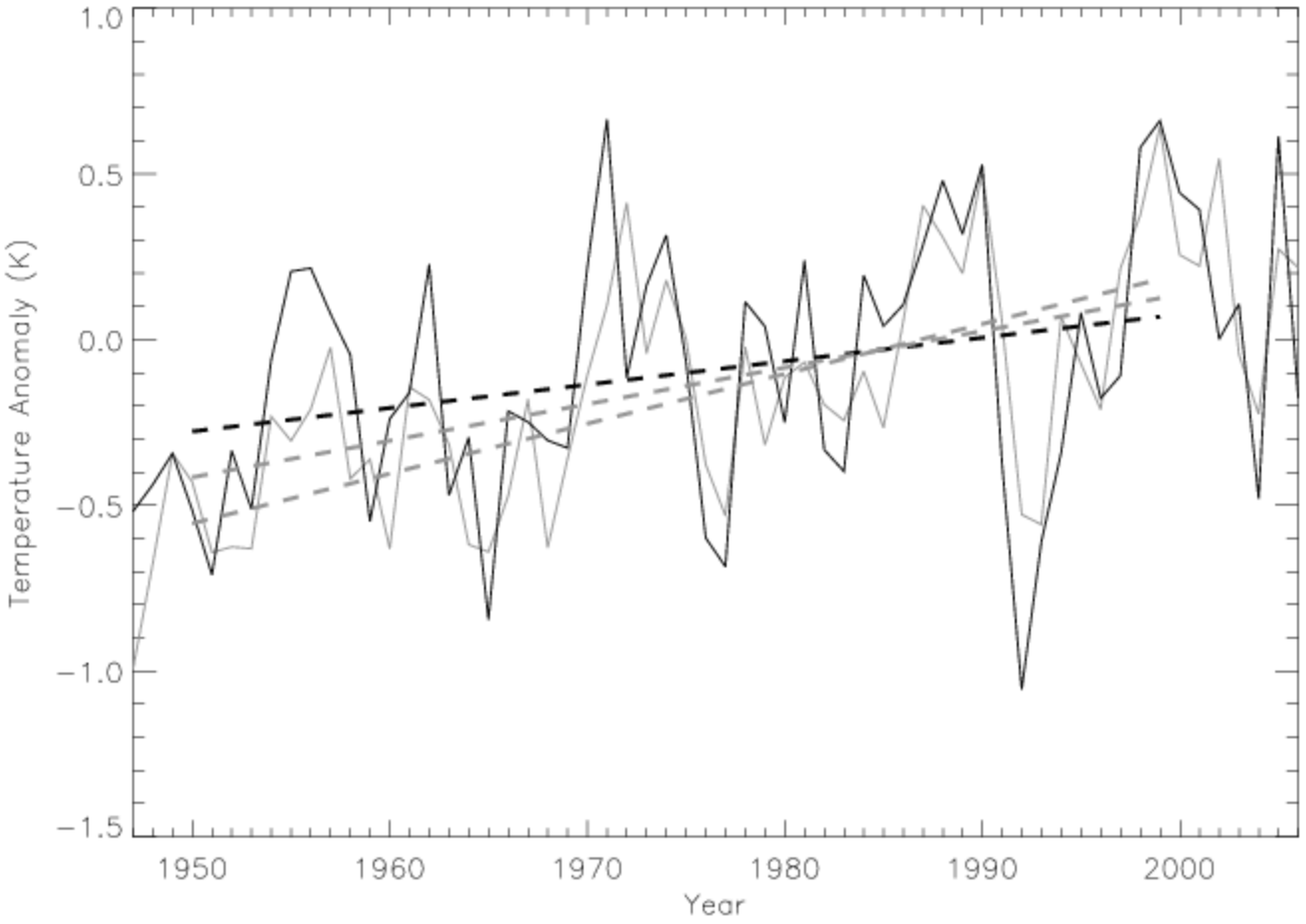

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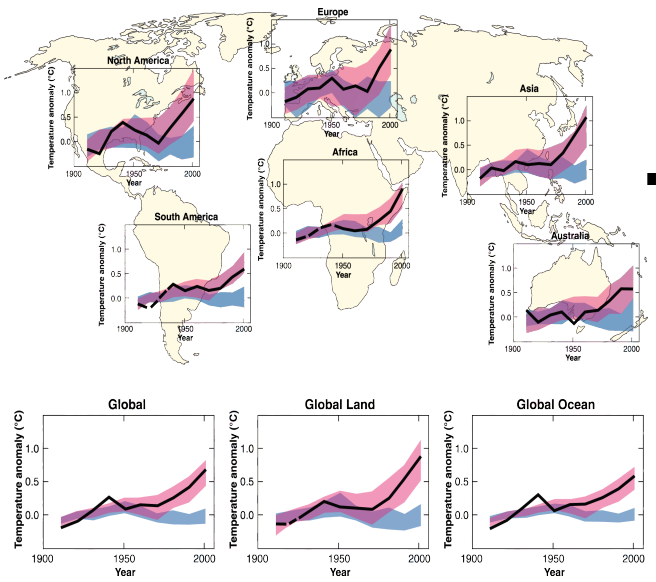
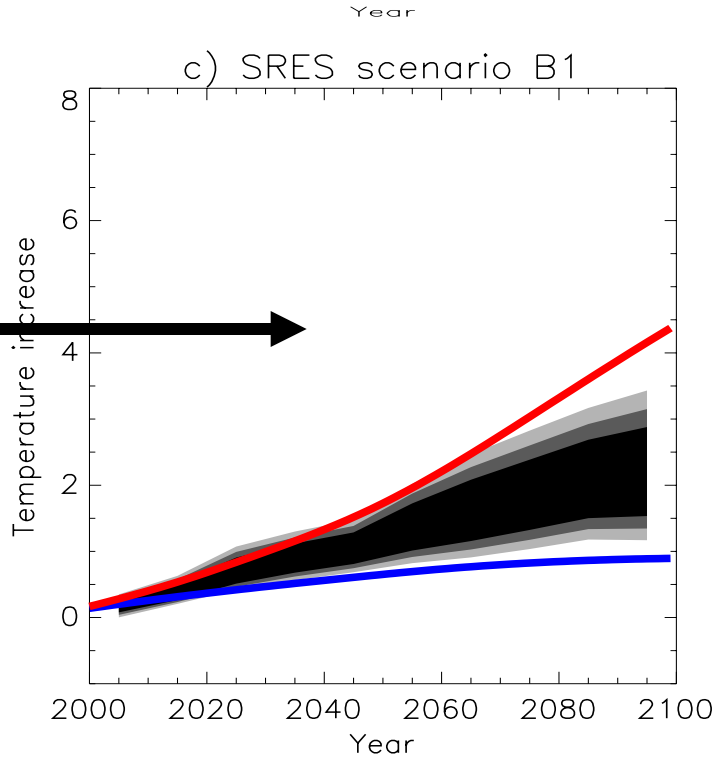
Taihoro Nukurangi

Stott et al, 2010 WIRES review

- Increasingly remote possibility that climate change is dominated by natural rather than anthropogenic factors
- By funding robust relationships between observed quantities and predictor variables, attribution studies can be used to obtain estimates of uncertainties in predictions
- Attribution studies can highlight differences between models and observations that require further investigation
- Successful adaptation would benefit from improved information about societal vulnerability in a changing climate – near-real time attribution
- Attribution at regional scales remains a challenge

Understanding of past climate change enables quantification of likely future rates of warming

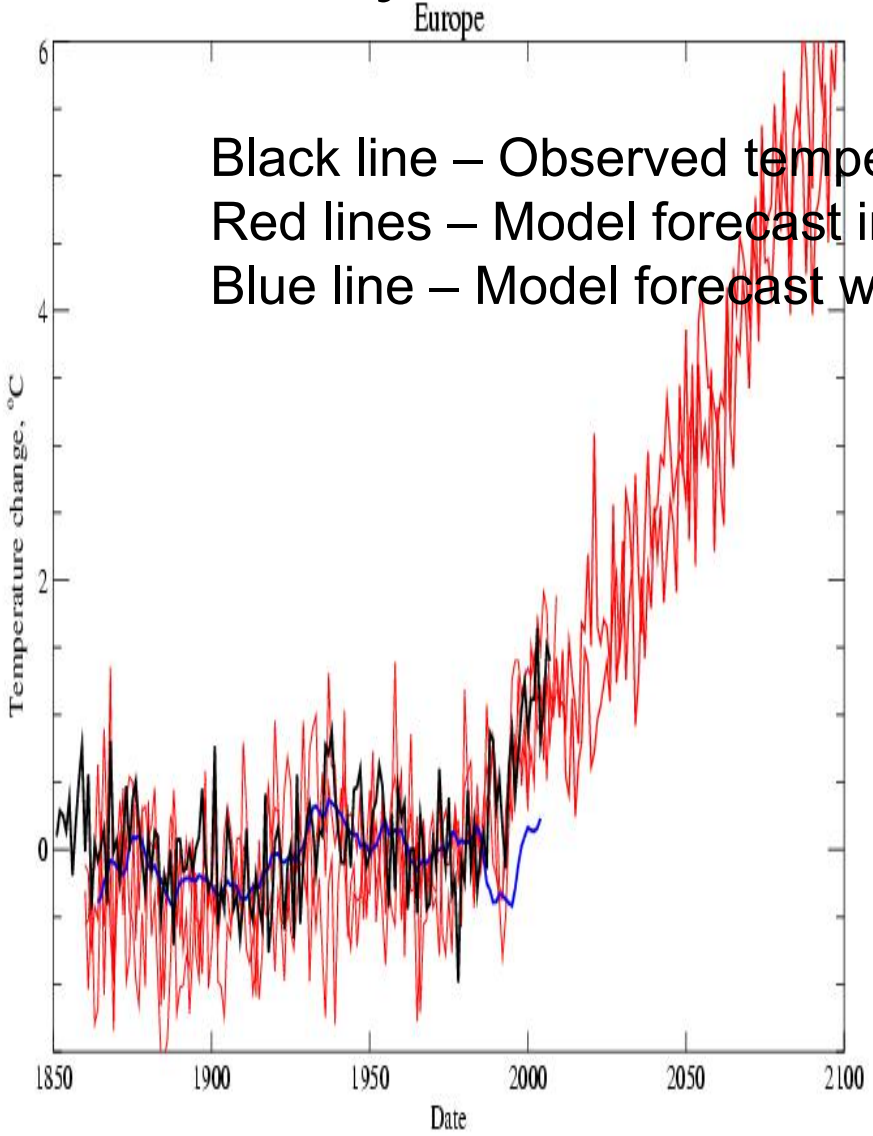


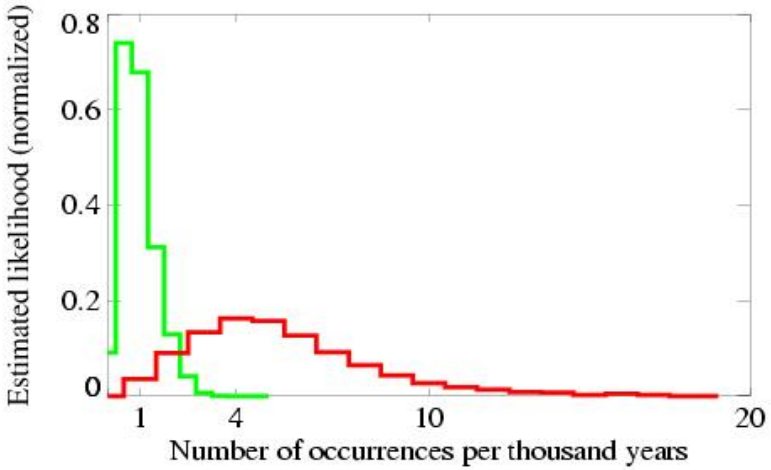


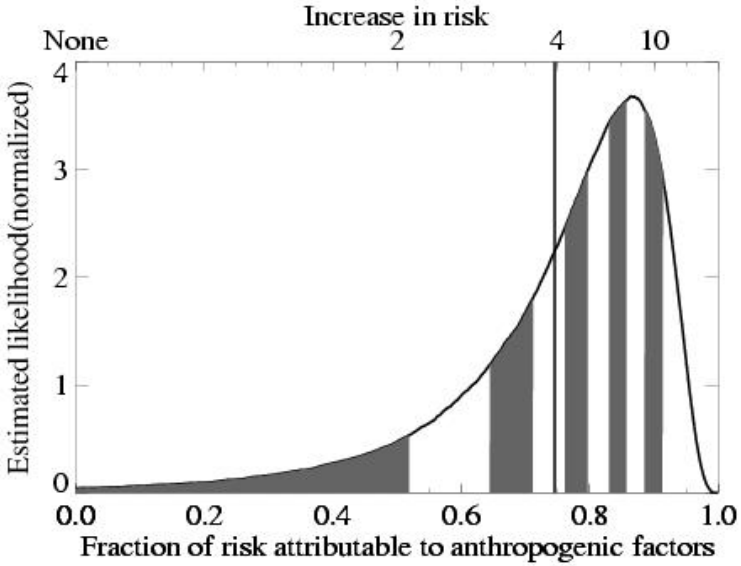
- Andreae et al, Nature, 2005.
- Stott and Forest, 2007 Phil. Trans. Roy. Soc.; Stott et al, Tellus, 2007.

Present day aerosol cooling implies a greater future warming as aerosol pollution is reduced. Strong present-day aerosol cooling implies a higher climate sensitivity and more future warming as aerosol forcing decreases (red curve) whereas no aerosol cooling at present implies a lower climate sensitivity and less warming in future (blue curve). Estimates based on attribution analyses imply a likely future somewhere between the two extremes (grey plume).

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







Met Office
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