Calibration and signal-to-noise of near term projections

Work in progress!

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Met Office Hadley Centre

Outline

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- Calibration of near-term projections

- Projections of signal-to-noise

~~model uncertainty~~

response uncertainty

Sources of uncertainty in decadal climate predictions

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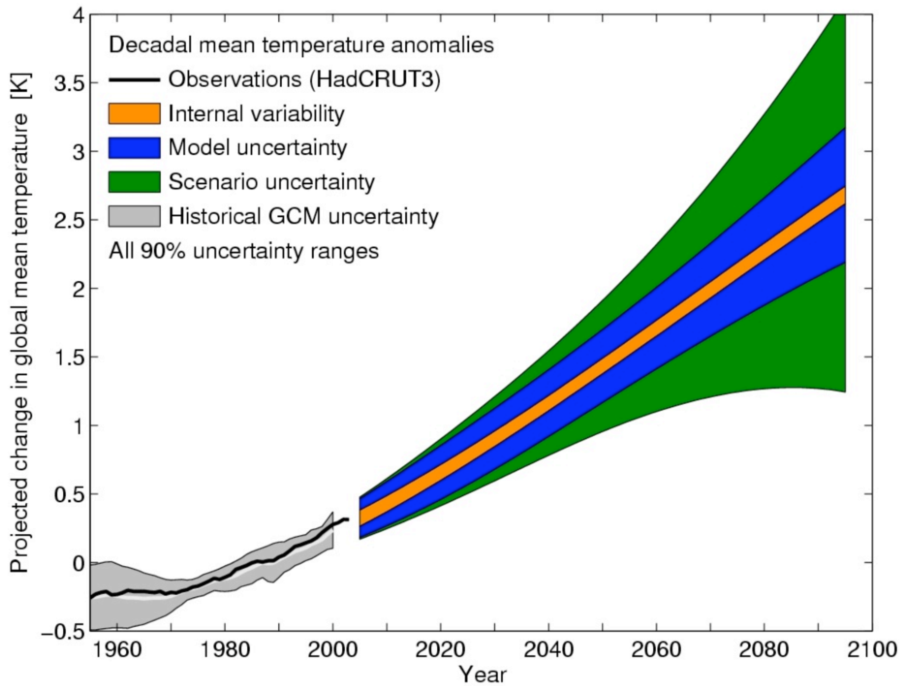
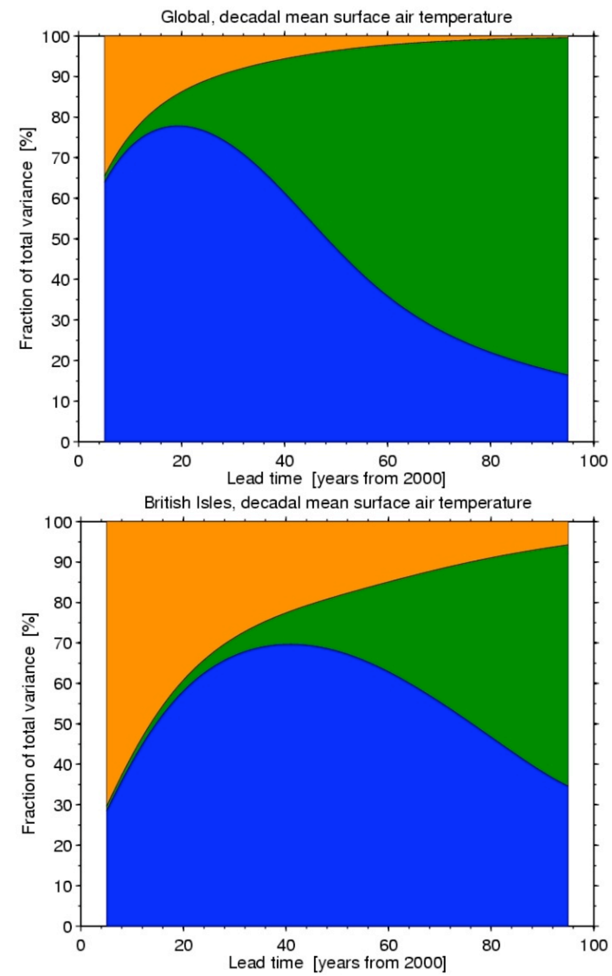
Contributions estimated from the CMIP3 ensembles

Decadal mean surface air temperature





Hawkins & Sutton, 2009, 2010

Sources of uncertainty in decadal climate predictions

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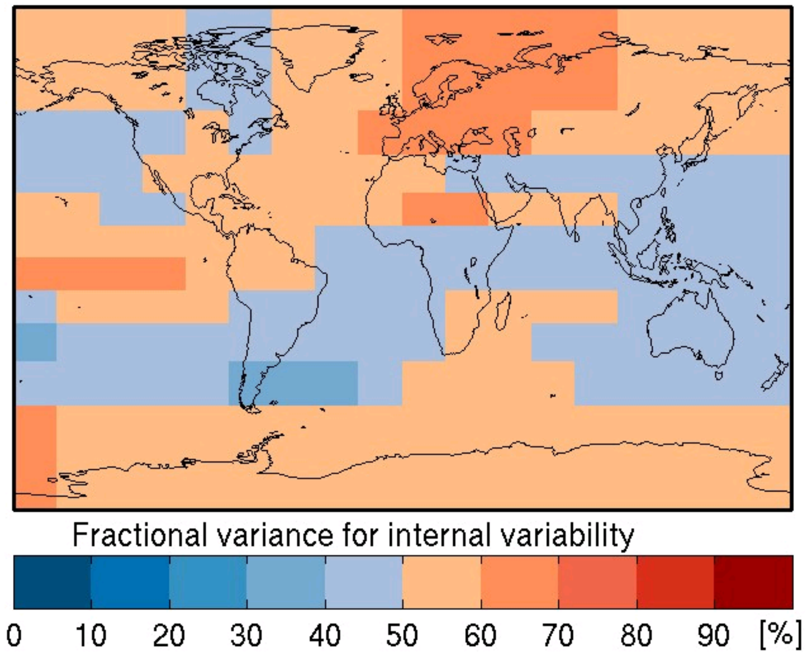
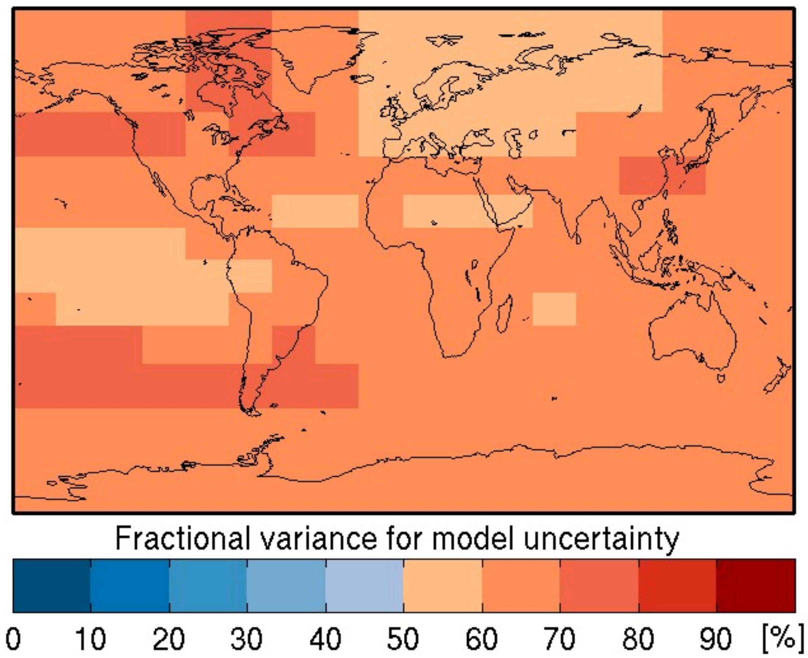
Fraction of total variance explained by **internal variability** for predictions of the **first decade ahead**



Fraction of total variance explained by **response uncertainty** for predictions of the **second decade ahead**



Decadal mean surface air temperature

Hawkins & Sutton, BAMS, 2009

Sources of uncertainty in decadal climate predictions

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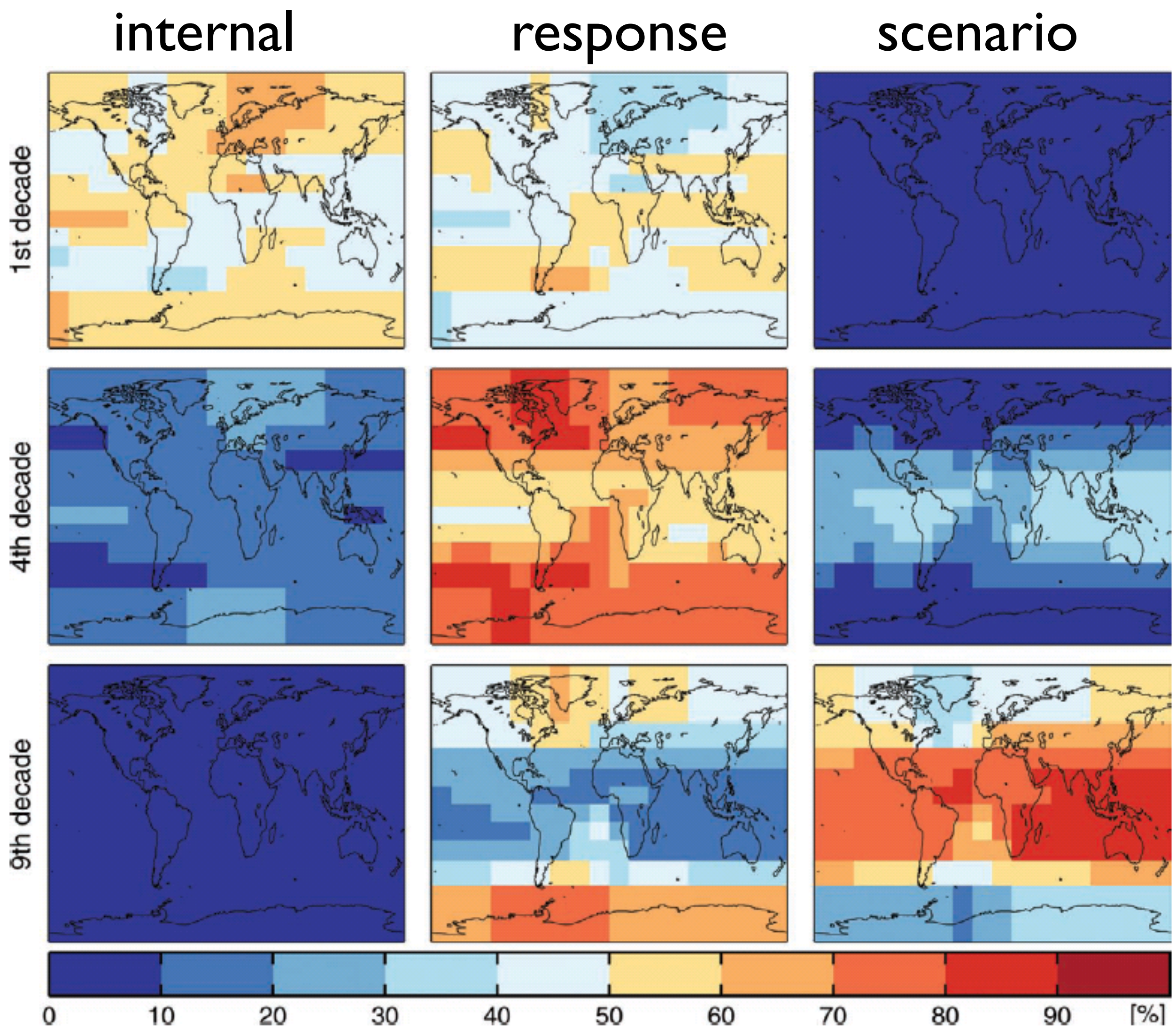
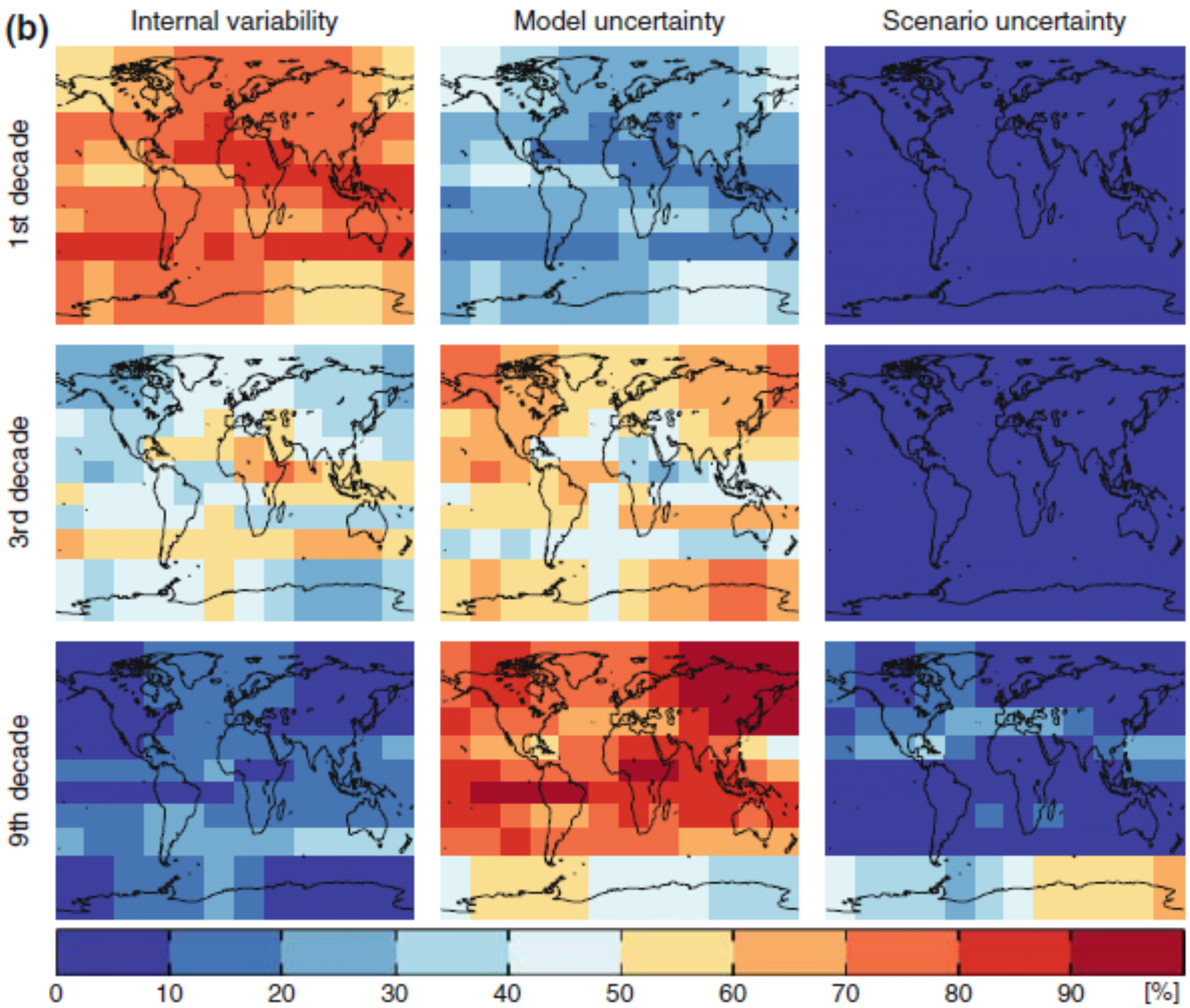
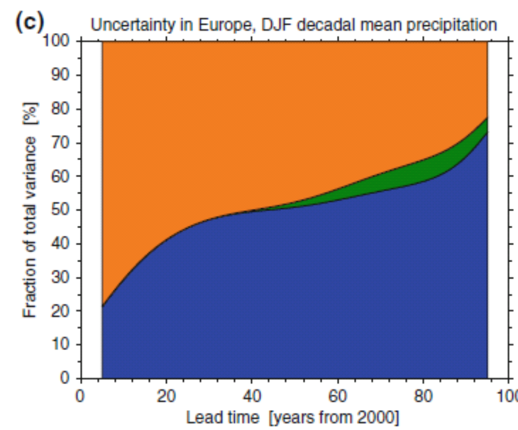


Decadal mean surface air temperature

Hawkins & Sutton, 2009, 2010

Decadal mean DJF precipitation





Hawkins & Sutton, 2009, 2010

The potential to narrow uncertainty in decadal climate predictions

- Uncertainty in decadal predictions is dominated by internal variability and **response uncertainty**

- Both contributions are potentially reducible through progress in climate science, but in the case of internal variability there are fundamental predictability limits

- **Quantifying and reducing *response uncertainty* is the most important challenge**

The need for calibration

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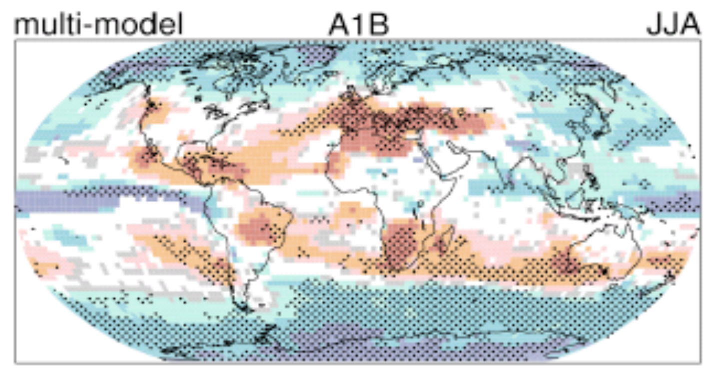
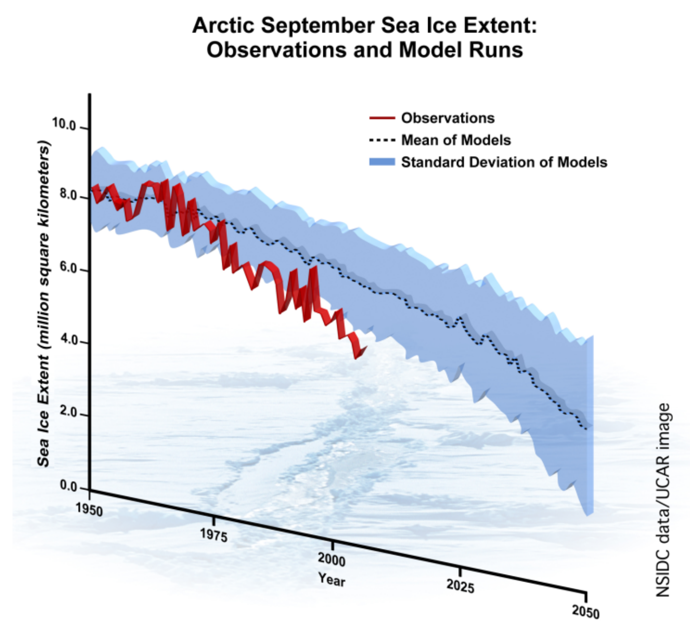
- CMIP-style ensembles of opportunity do not provide a reliable measure of response uncertainty
- Model consensus is not a reliable basis for trust
- How can we quantify response uncertainty without relying on model spread?
- Projections should be conditioned on an understanding of *model adequacy:*
  - is the model capable of simulating the relevant aspects of climate (i.e. the response to forcing on the scales of interest)?
- Close links to attribution





Using D&A approaches to make decadal predictions – Peter Stott

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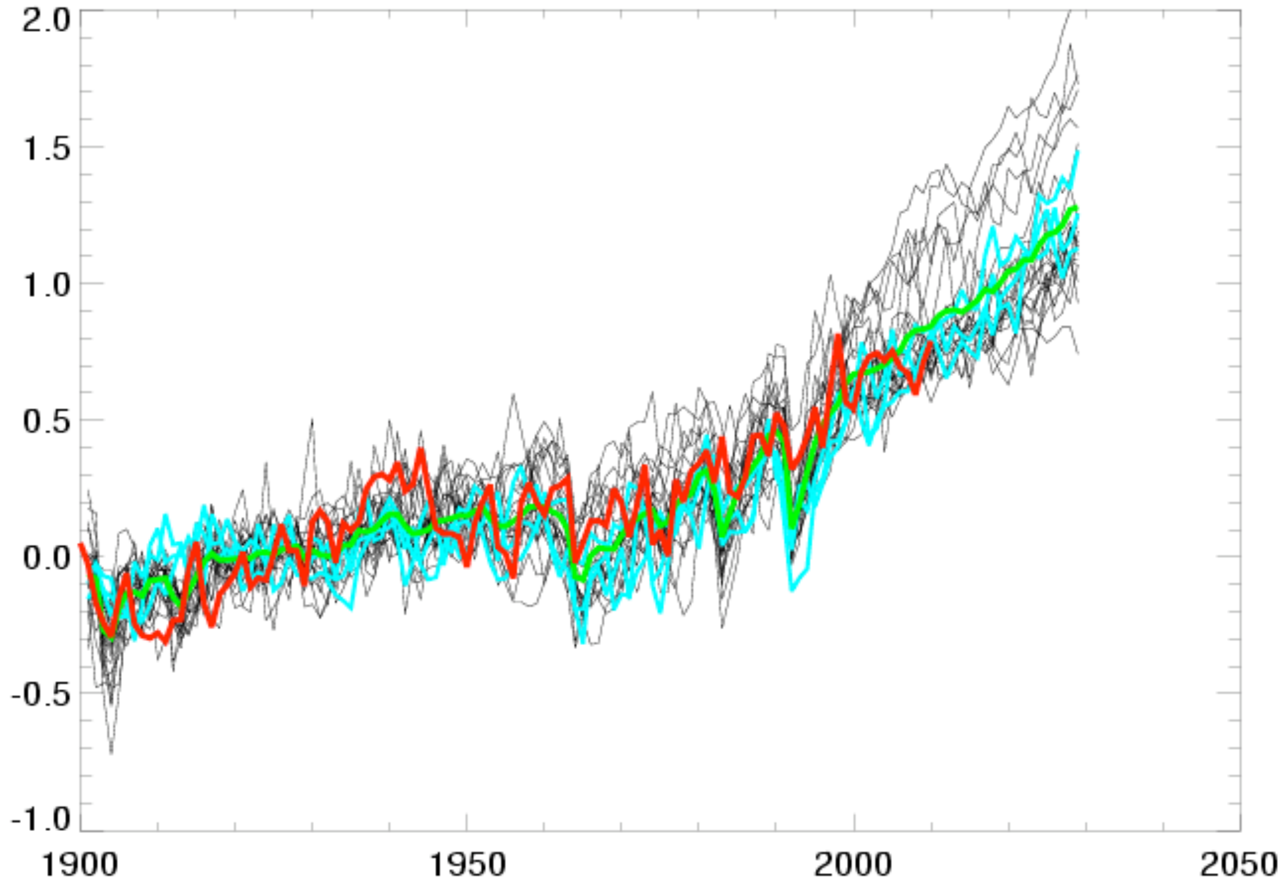
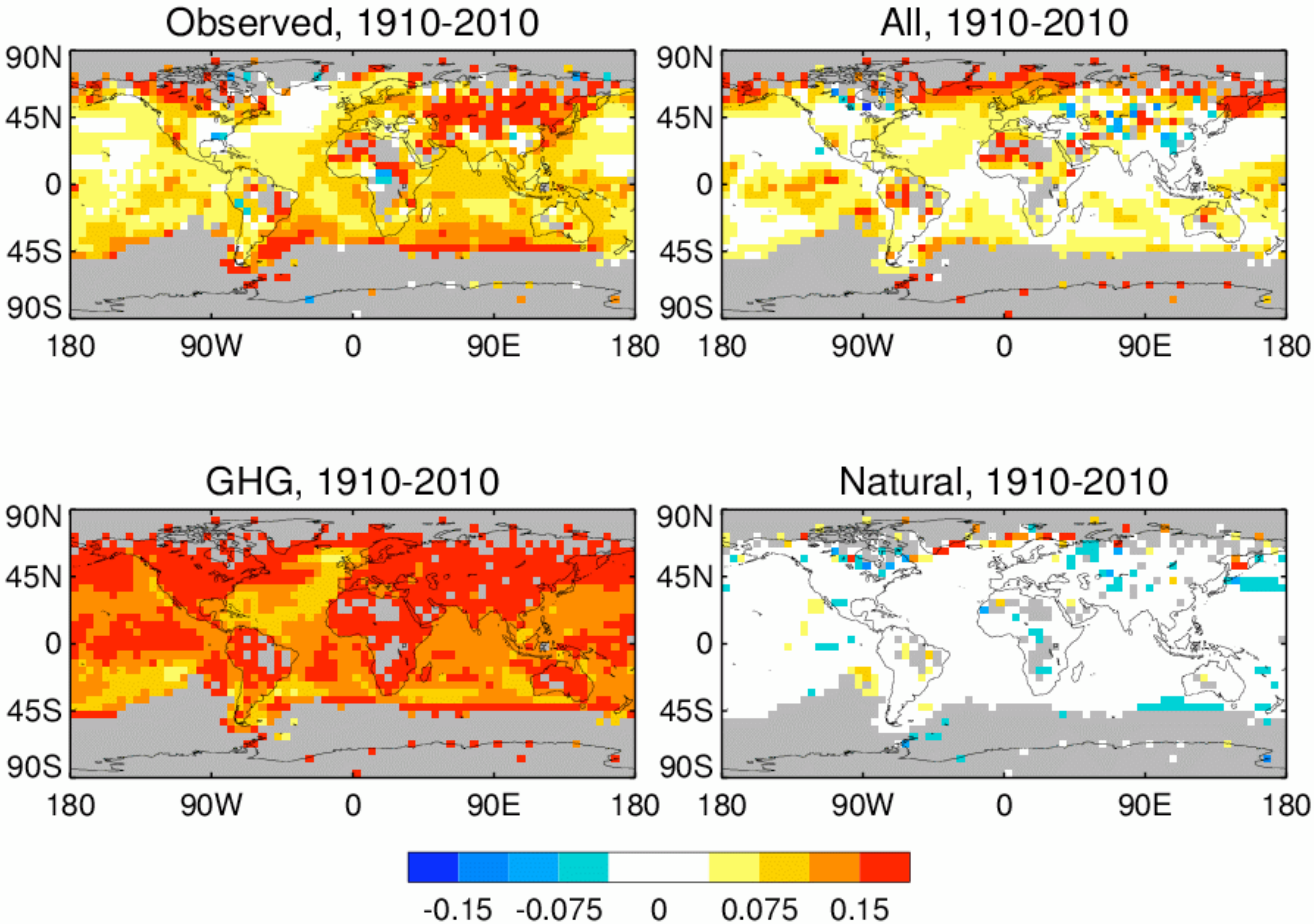
- "ASK", based on optimal detection

- Allen, Stott et al, Nature, 2000
- Stott and Kettleborough, Nature, 2002
- Stott, Kettleborough, Allen, GRL, 2006
- Stott et al, J. Climate, 2006
- Stott and Forest, Phil Trans Roy Soc, 2007
- Stott et al, Tellus, 2008



Peter Stott, UK Met Office



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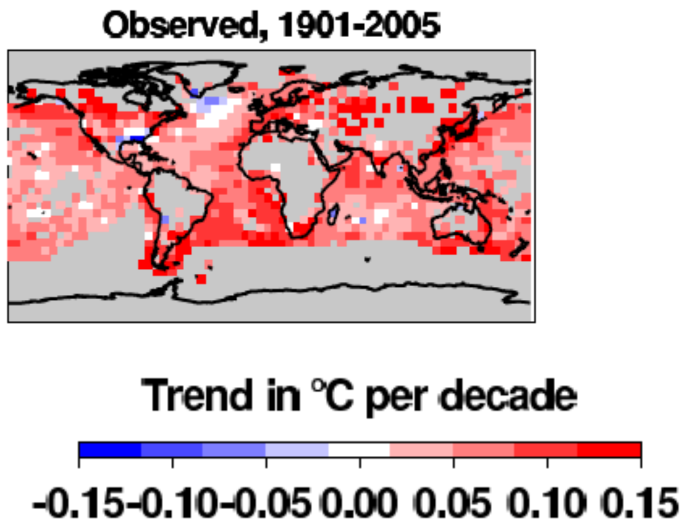
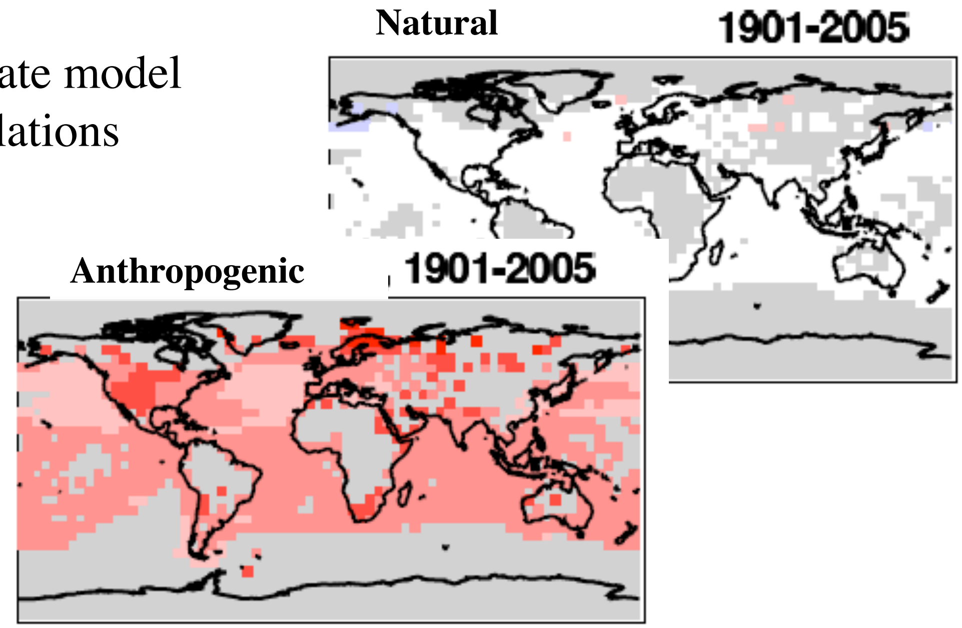


Climate model simulations



$$\mathbf{Y}$$

$$\mathbf{X} = (\dot{x}_{ghg}, \dot{x}_{sul}, \dot{x}_{nat})$$

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

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

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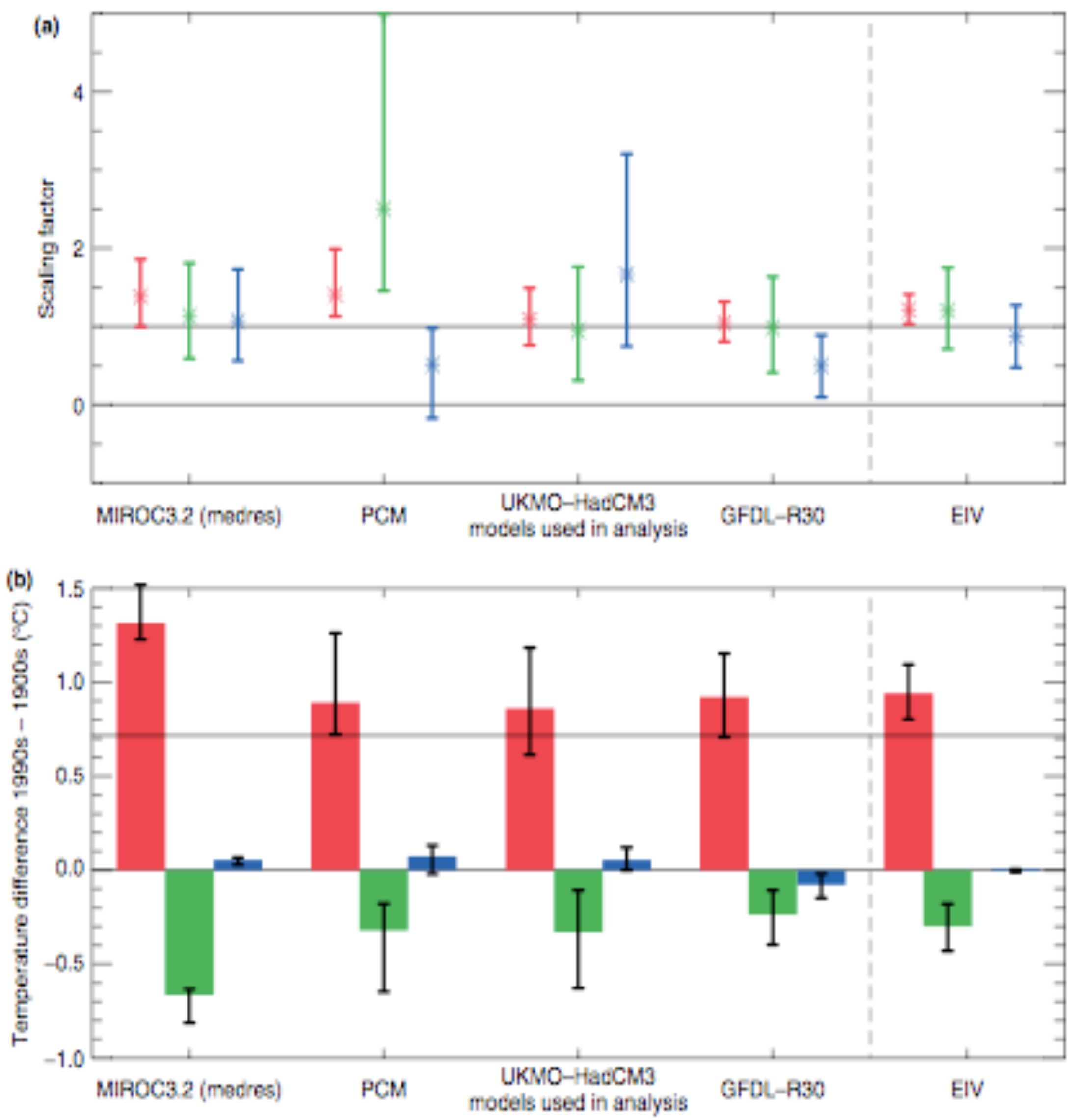

By exploiting separate forcing runs ASK is able to discriminate between errors in sensitivity and forcing

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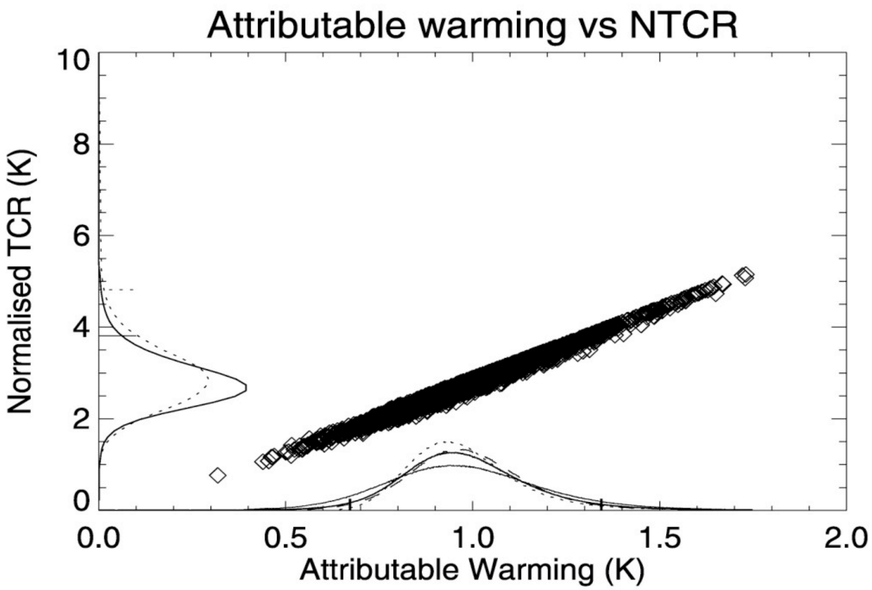
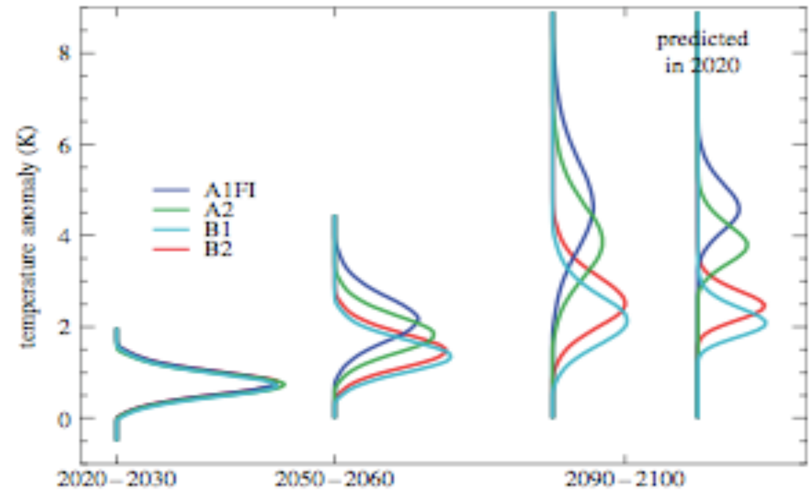
Robust quantification of contributors to past temperature change enables quantification of likely future rates of warming (ASK)





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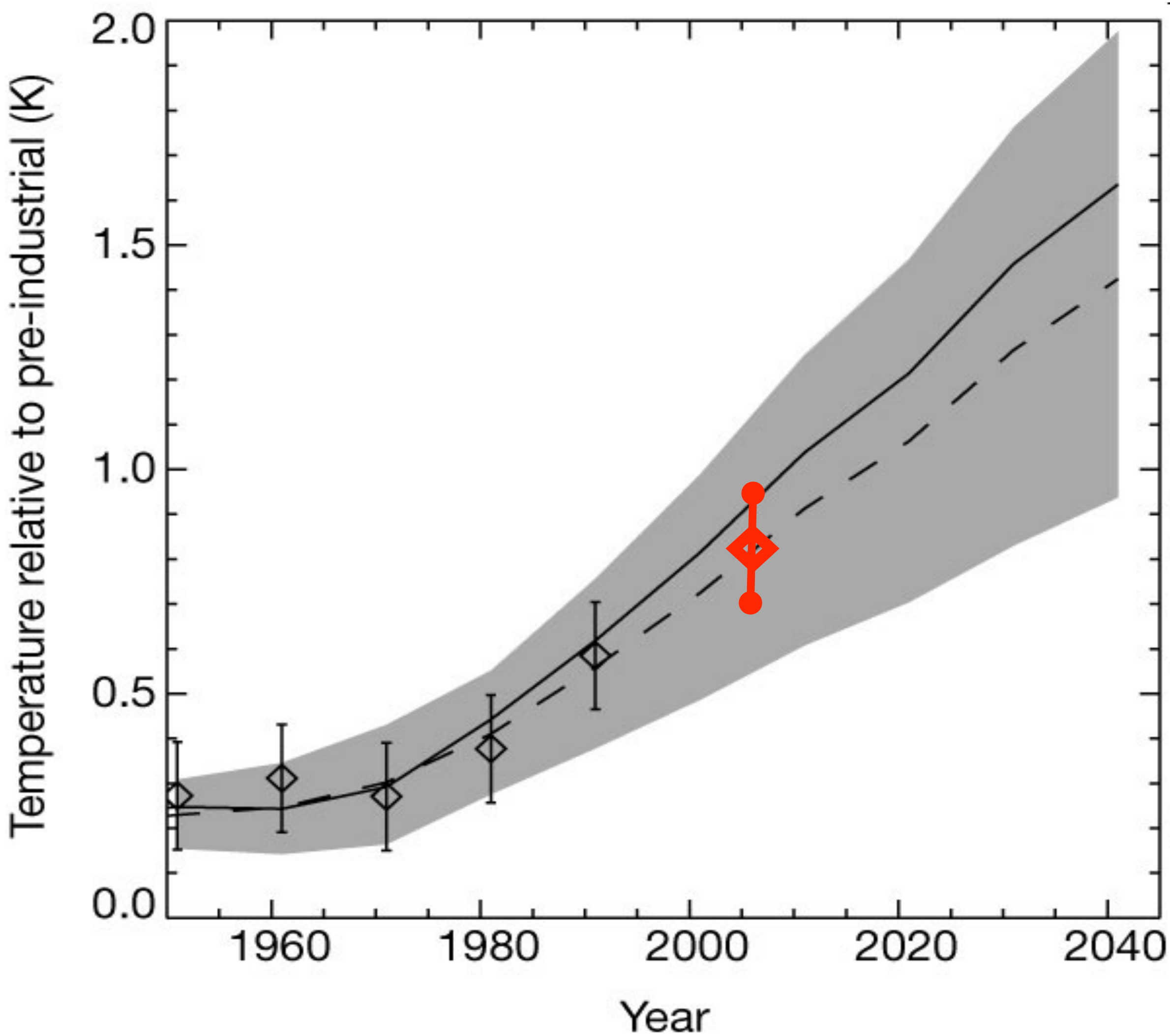
The two extremes proposed by Andreae et al (2005) as consistent with strong and weak present day aerosol cooling are very unlikely

Year

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

Peter Stott, UK Met Office

Global temperatures are evolving as predicted



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

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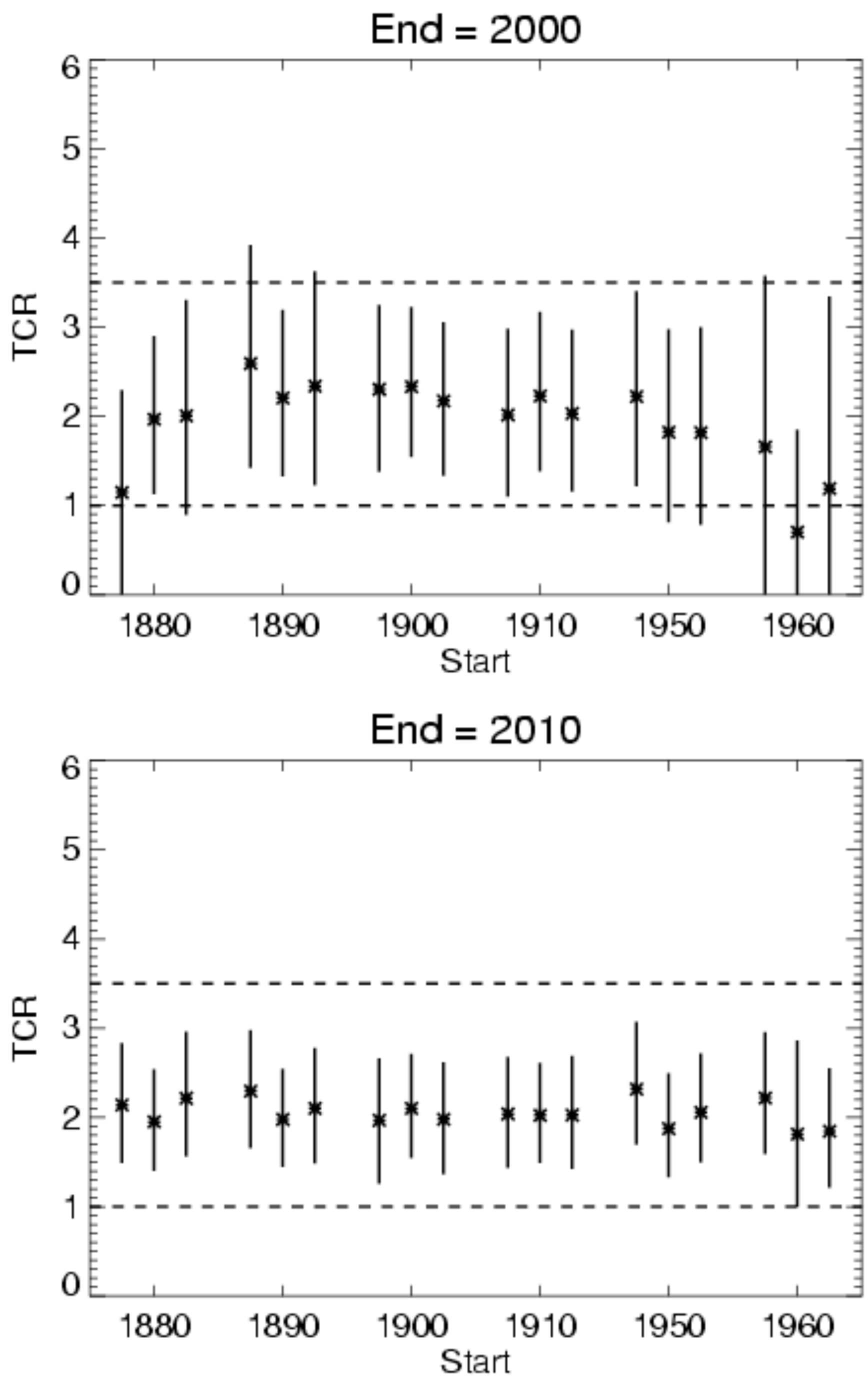
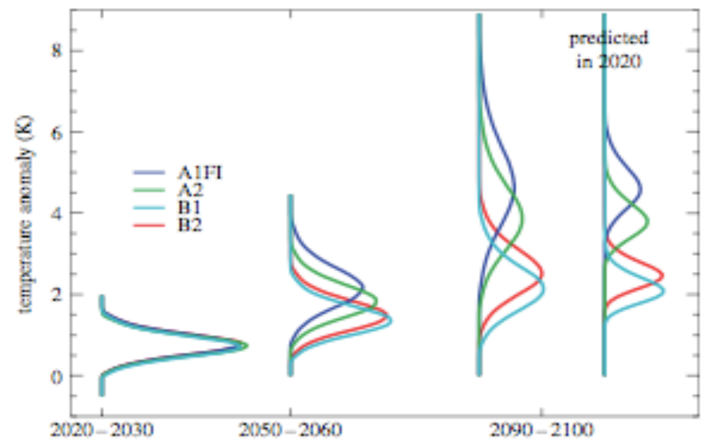


A longer observational record reduces the uncertainty in projections



Perfect model post 2000
Perfect data
Perfect world post 2000

See also Ed's talk 2

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Comparing ASK with CMIP3
Preliminary results…

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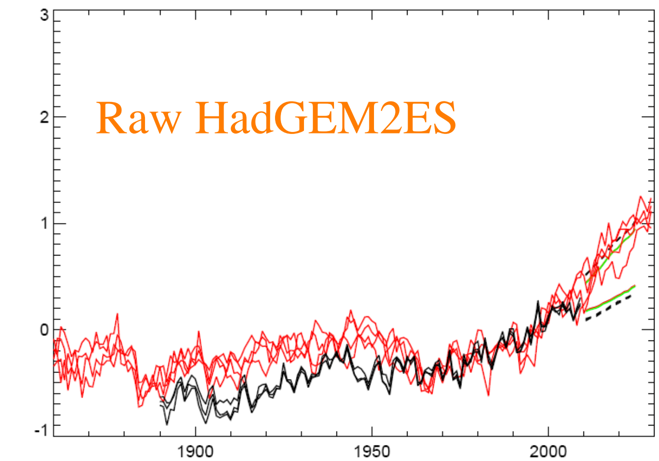
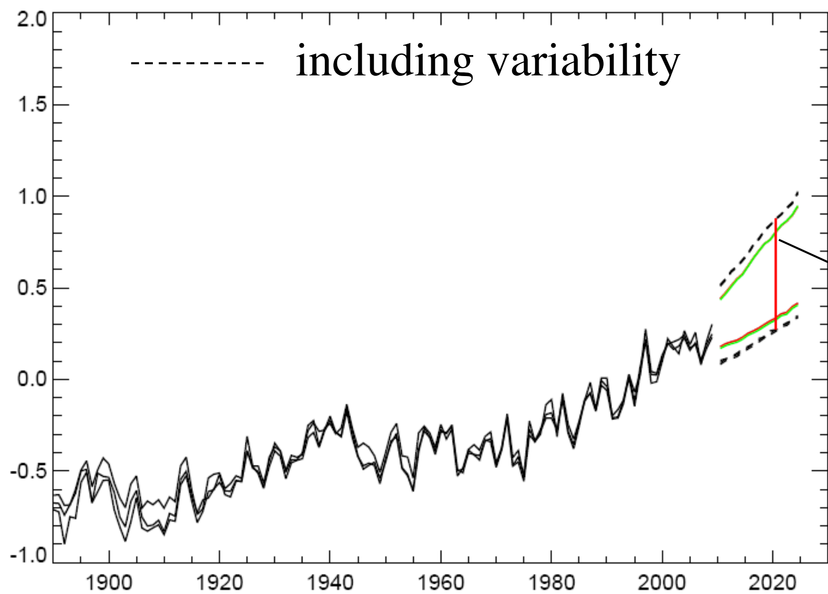


Relative to 1986-2005

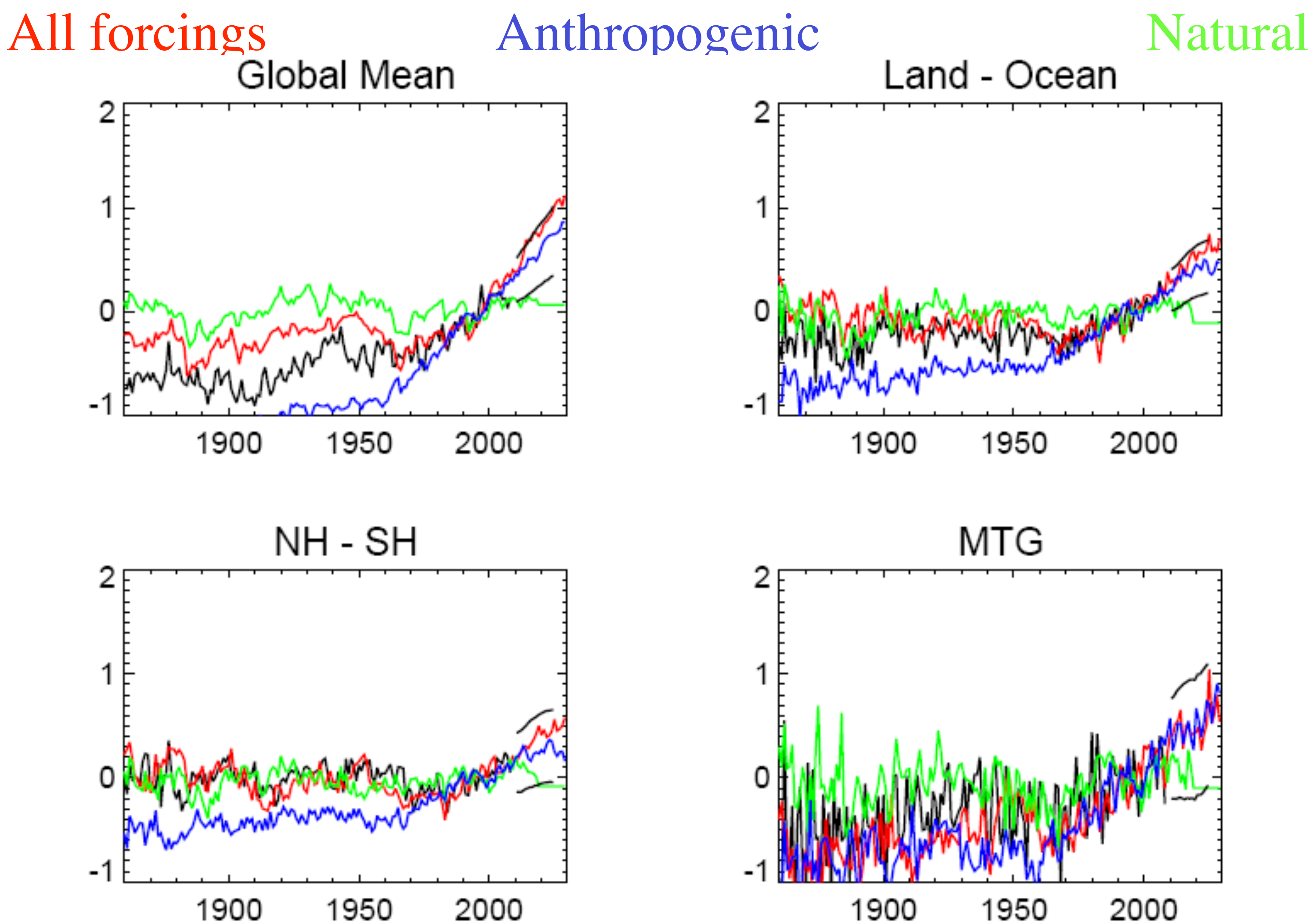


Projections of global mean SAT 2016-2025 relative to 1986-2005

Method	Range (5-95%)
Raw CMIP3 exc variability	0.34 - 0.75
ASK exc variability	0.34 - 0.81
Raw CMIP3 inc variability	0.31 - 0.77
ASK inc variability	0.27 - 0.88

Note the uncertainty range is larger due to the choice of a twenty year reference period

Patterns of temperature change



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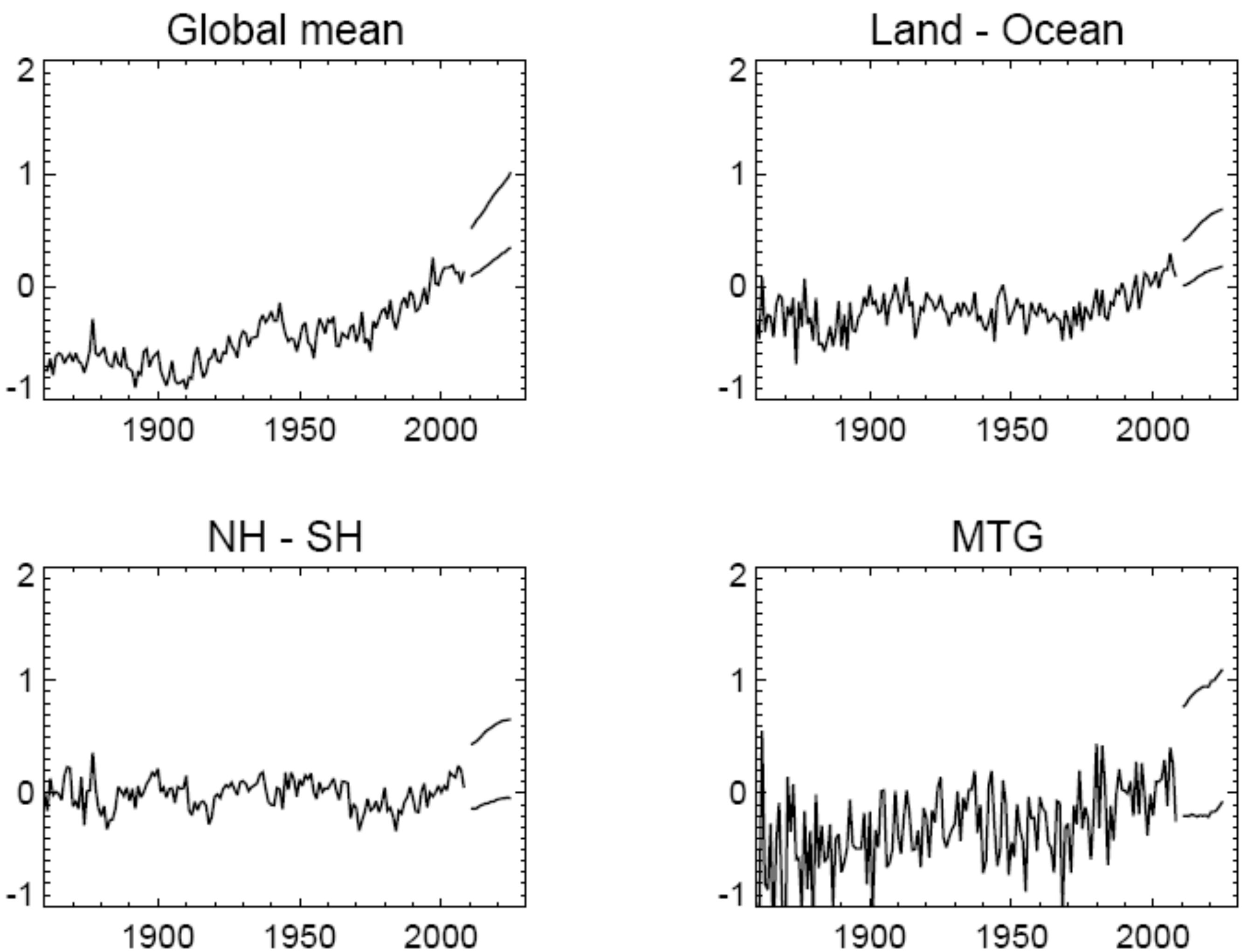
Patterns of temperature change



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Further work

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- Apply to CMIP5 models (Need future GHG-only runs)
- Extend to regional scales
- Extend to non temperature variables
- Test ASK in “imperfect model” setting. Does ASK correctly predict other models, probabilistically ?

Projections of signal-to-noise

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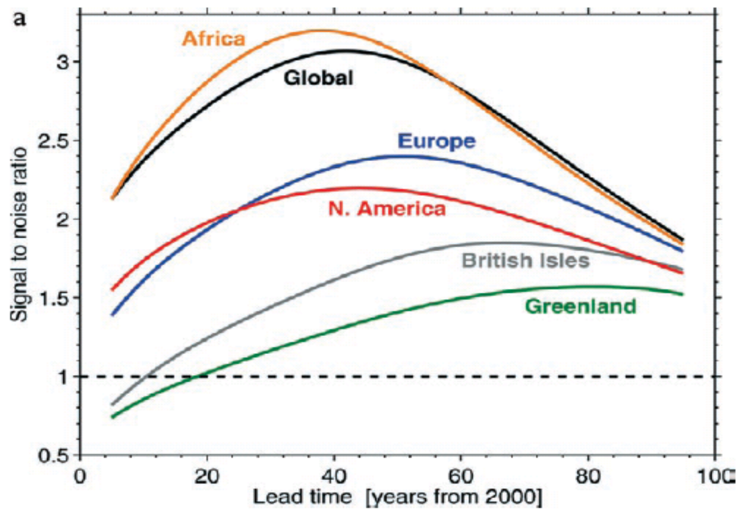
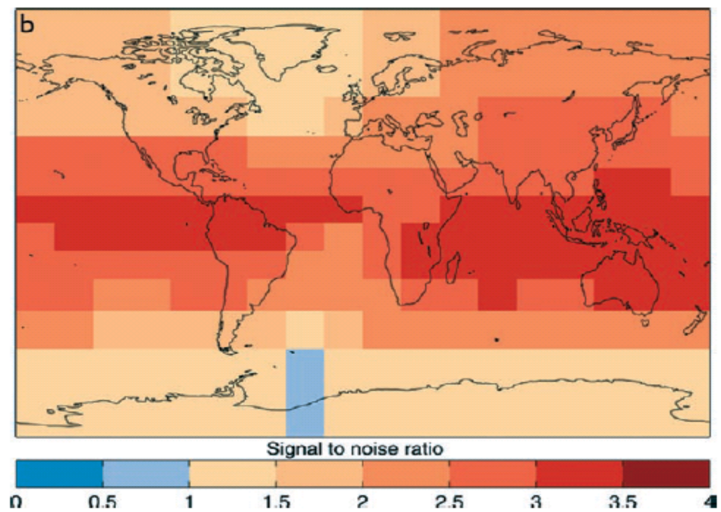
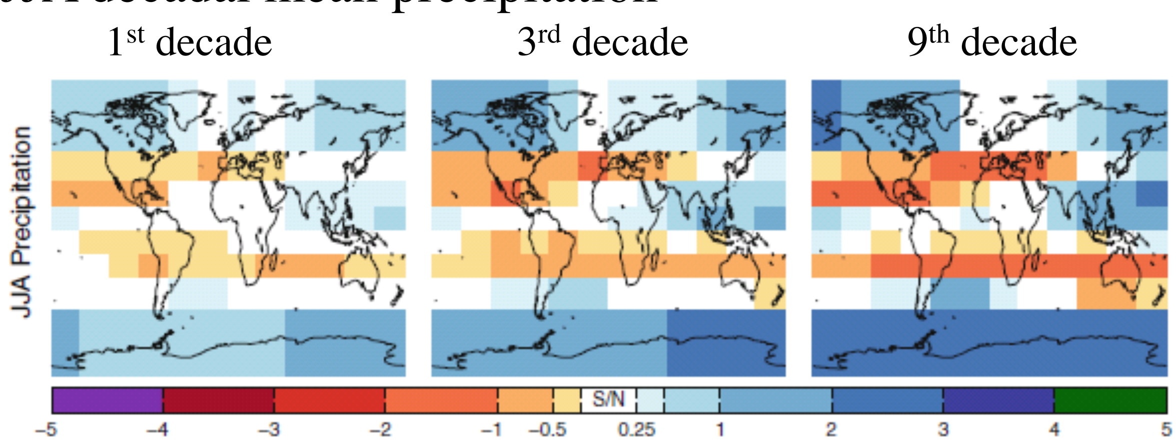
- Key importance for impacts (& hence policy)

Decadal mean Surface air temperature





JJA decadal mean precipitation



Hawkins & Sutton, 2009, 2010.
See also Mahlstein et al, 2011

Projections of signal-to-noise

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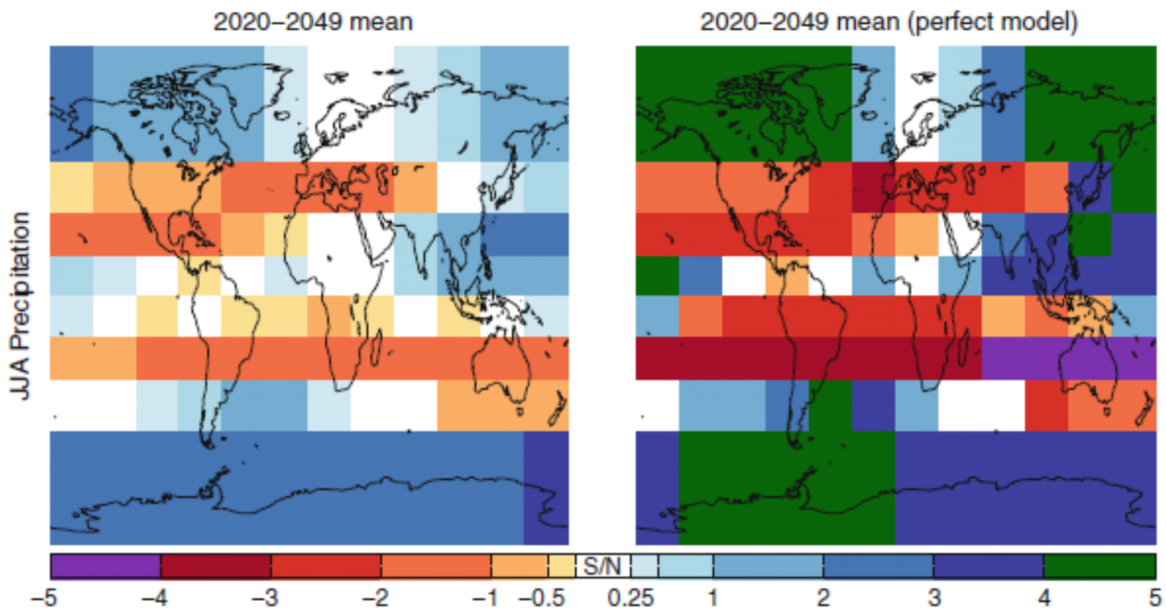
- How we calculate it matters…
- Hawkins and Sutton (2009) chose:
  - Signal = multi-model mean change relative to a reference period
  - Noise = multi-model estimate of internal variability + estimate response uncertainty + estimate of scenario uncertainty
- But:
  - Helpful to separate different contributions to the noise
  - Individual models vary greatly, not only in climate sensitivity/TCR but also in natural variability

Removing response and scenario uncertainty

Fig. 7 Signal-to-noise ratio for projections of JJA precipitation changes for a 30-year mean period (2020–2049) with (*left*) and without (*right*) model uncertainty



Hawkins and Sutton, 2010

Variability varies…

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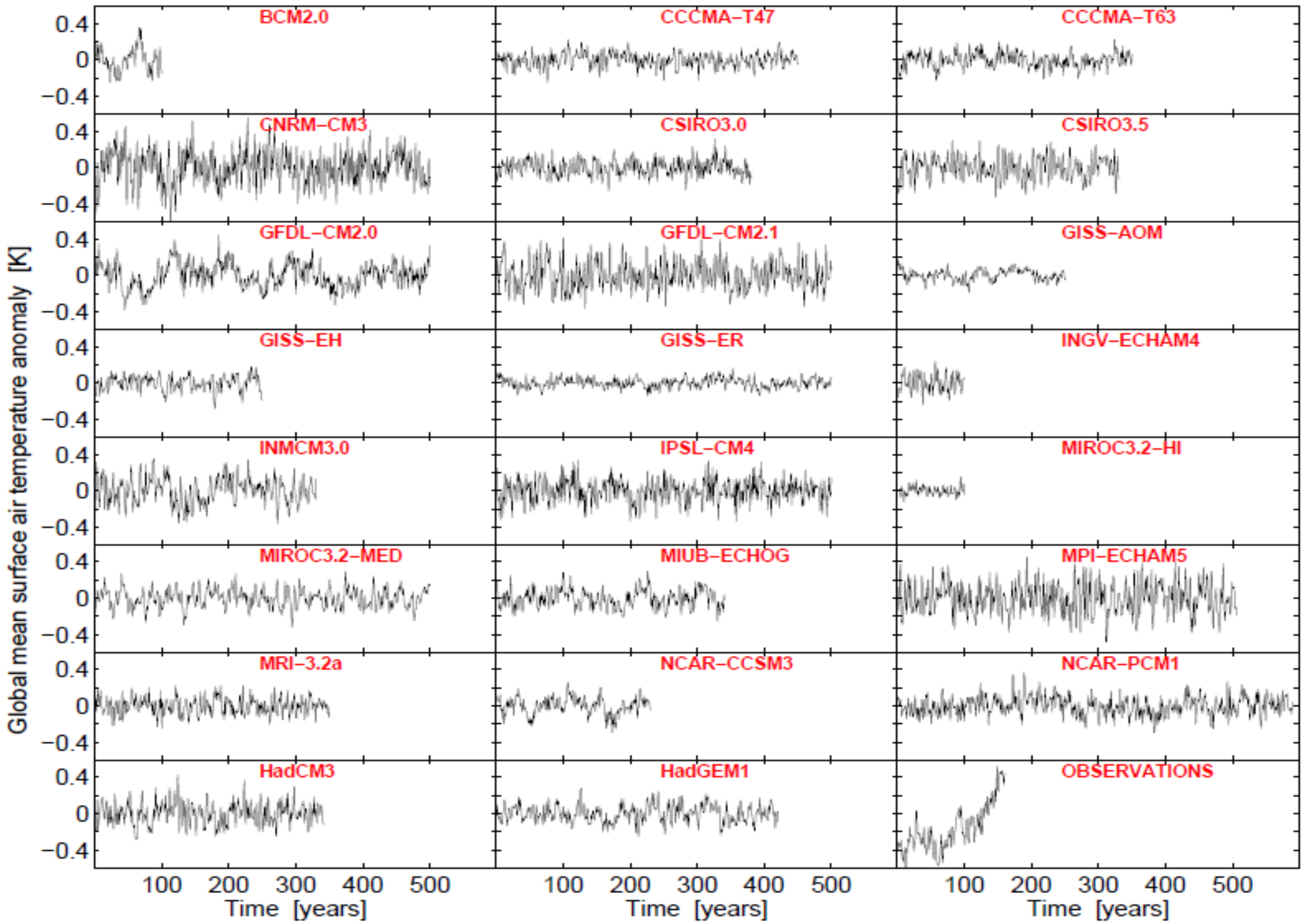

Variability varies…

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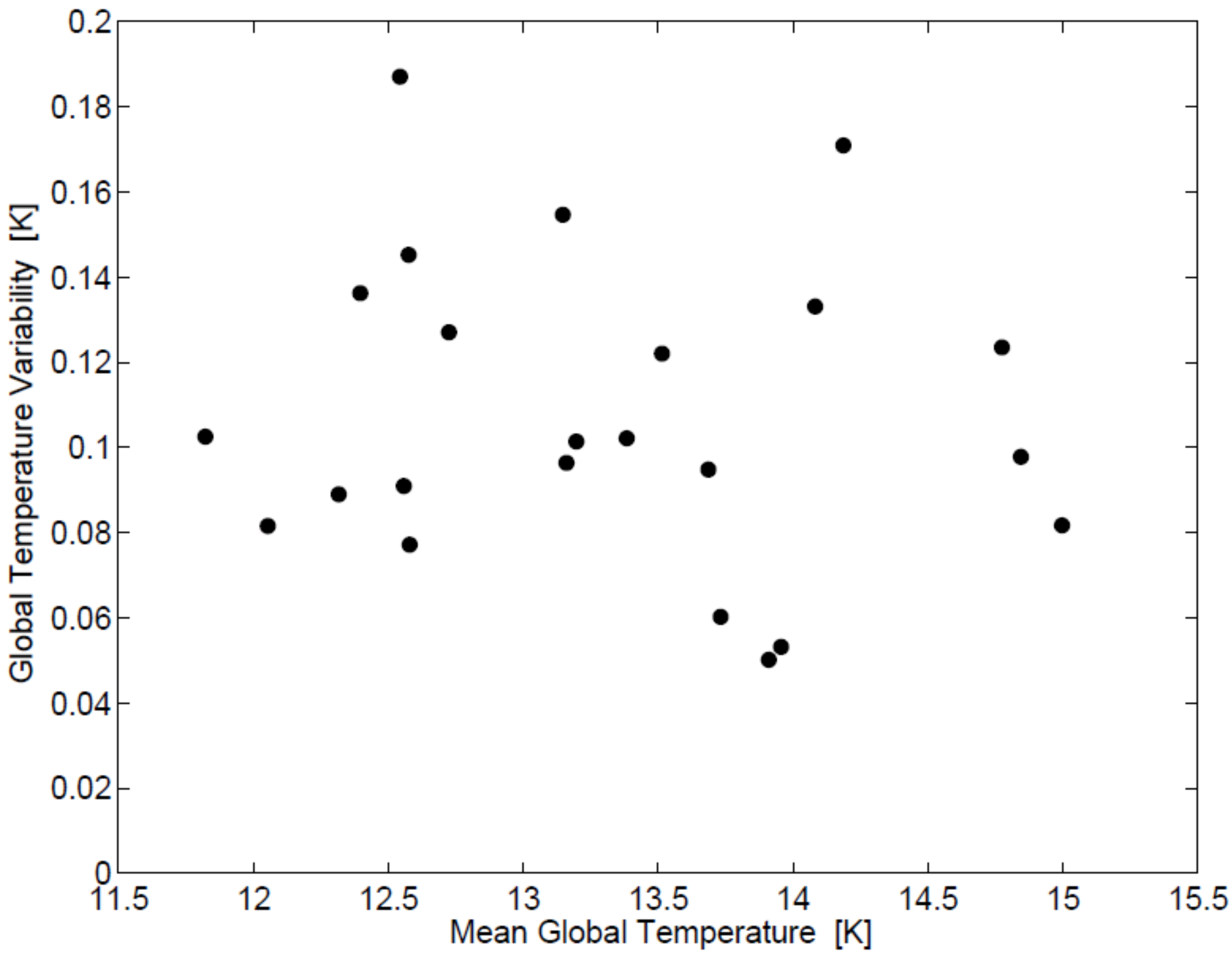

Alternative projections of signal-to-noise

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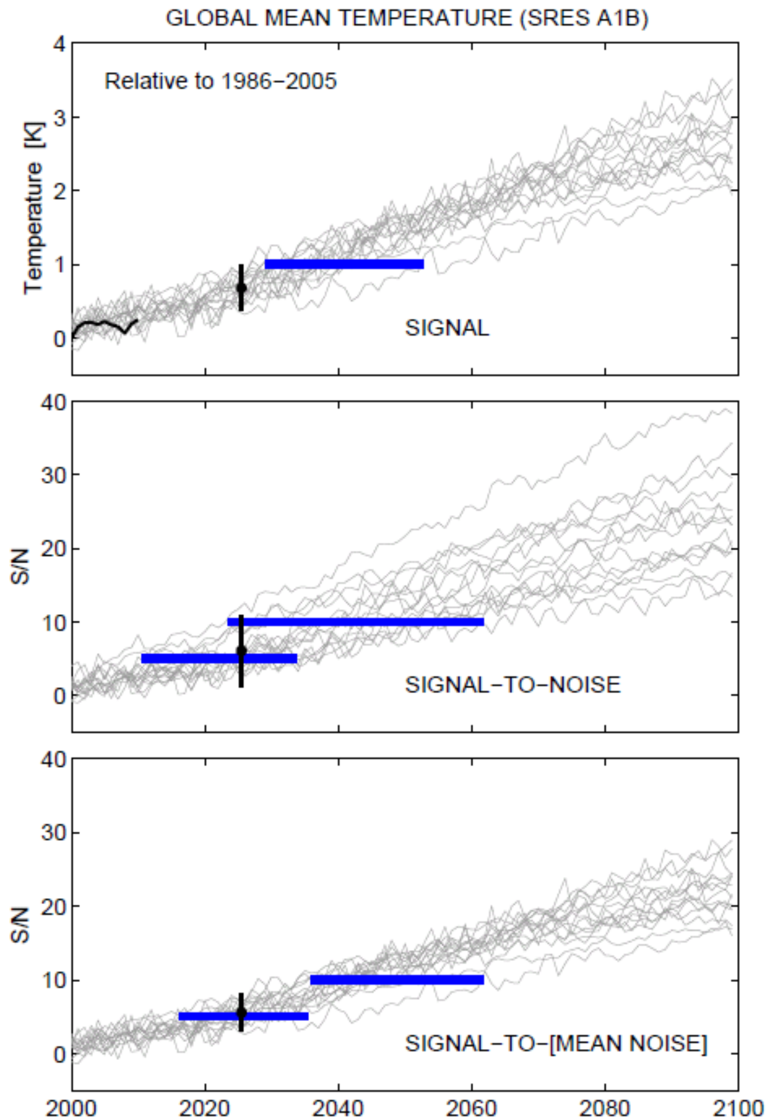

- ➢Projections for SRES A1B scenario
- ➢Black bars show 5-95% ranges for temperature and s/n in 2016-2035
- ➢ Blue bars show 5-95% ranges in the projected time for crossing temperature or s/n thresholds

The role of Detection and Attribution in decadal climate prediction

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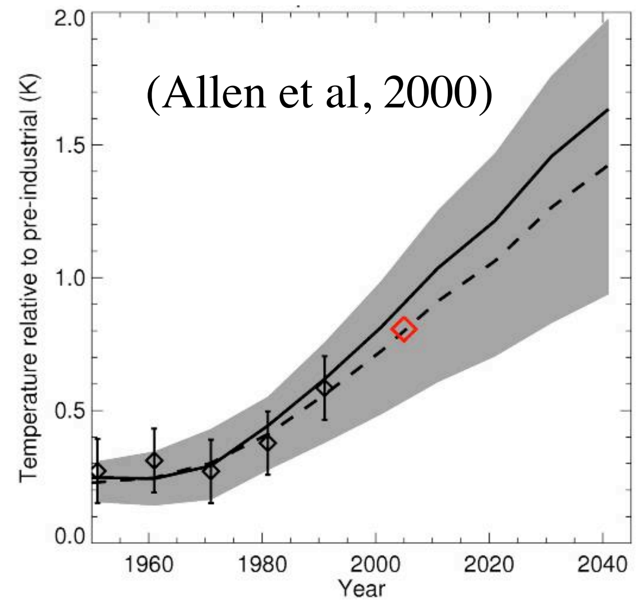
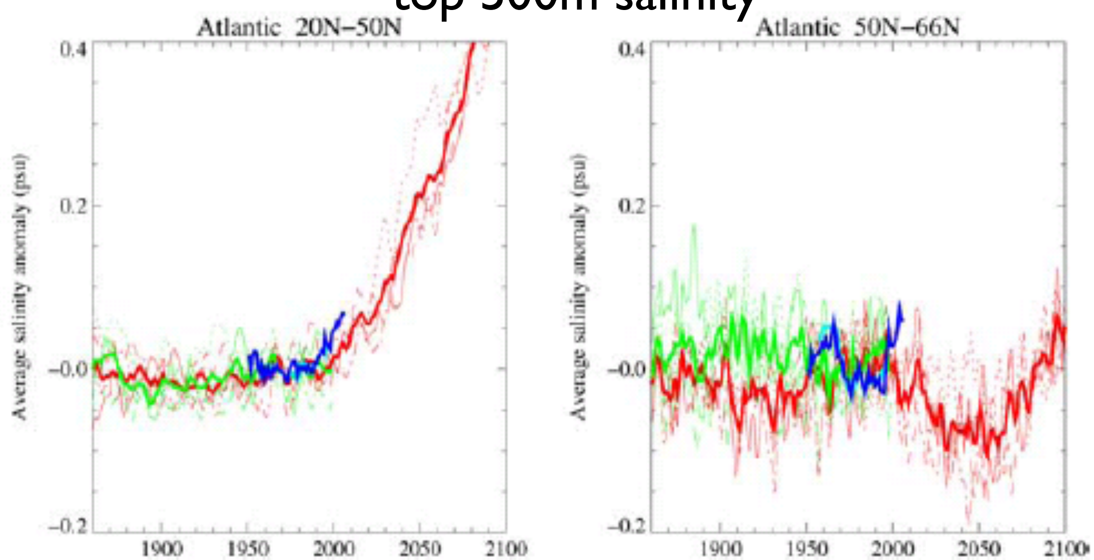
- D&A is a key approach for testing consistency of models and observations (wrt response to radiative forcings)
- Can be used to provide observationally constrained decadal predictions
- Scope for wider application to oceans, especially using a more process-based approach



Detection & Attribution of Atlantic salinity changes, P. Stott, R. Sutton, D. Smith, GRL, 2008

top 500m salinity



Increasing the *trustworthiness* of climate models and predictions

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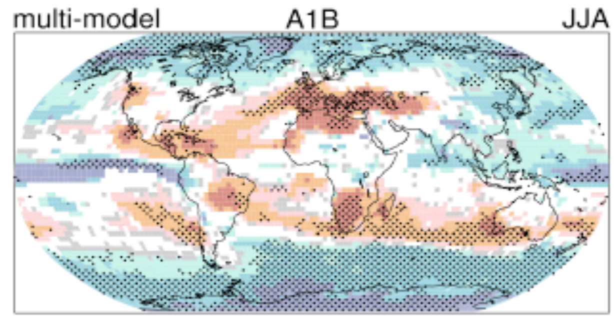
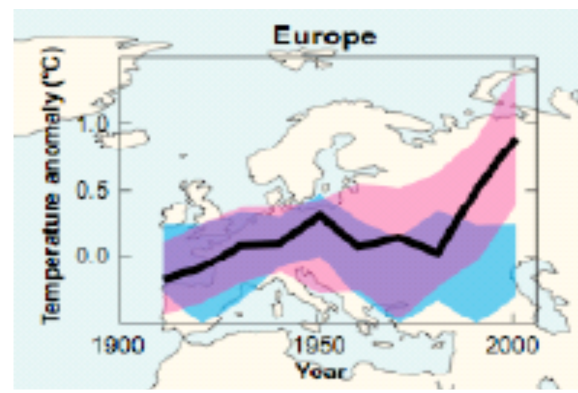
Increased role of observations &
Increasing trustworthiness of predictions

A hierarchy of evidence:

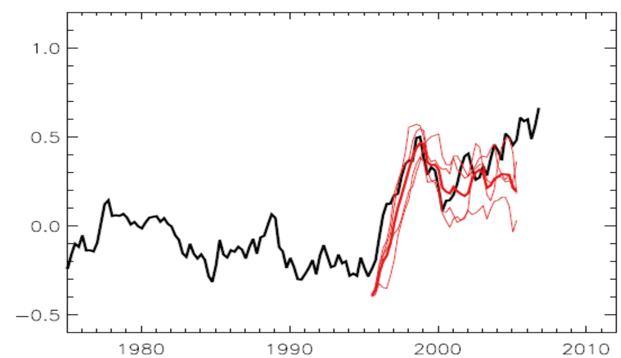
1. Model consensus
   - Weak role for observations



2. Detection and attribution
   - Tests response to specific forcings; model errors may lead to false attribution

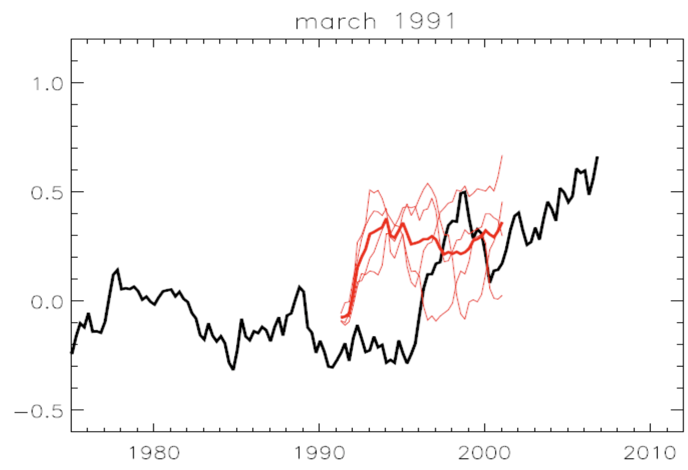


3. Initialised decadal hindcasts
   - Test full evolution of the system *on timescale of the predictions we want to use*



The role of initialisation in decadal climate prediction

- Initialisation usually motivated by the need/opportunity to predict aspects of internal variability (e.g. AMO).
- Arguably it will prove *more important* as a tool to address model uncertainty by identifying errors
- Analysis of error growth provides a powerful new way to test models and prediction systems *at a process level,* and thereby improve them.
- Long used in NWP; arguably *the* big opportunity in climate prediction



Predictability of natural internal climate variability

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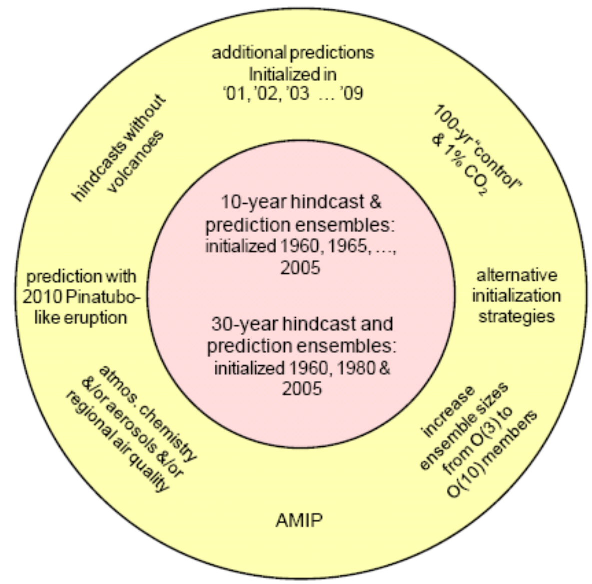
Low resolution "perfect model" studies suggest predictability:

- up to a decade for large scale climate variables (heat content, salinity, AMOC)
- is state dependent (forecasts of opportunity)
- very rarely exceeds 2 years at most for surface climate variables (regional scales)



- *So why are 30 year initialised hindcasts included in CMIP5?*

- Need more work to understand mechanisms responsible for predictability, including state dependence + robustness e.g. at higher resolution

Model uncertainty also "infects" internal variability…

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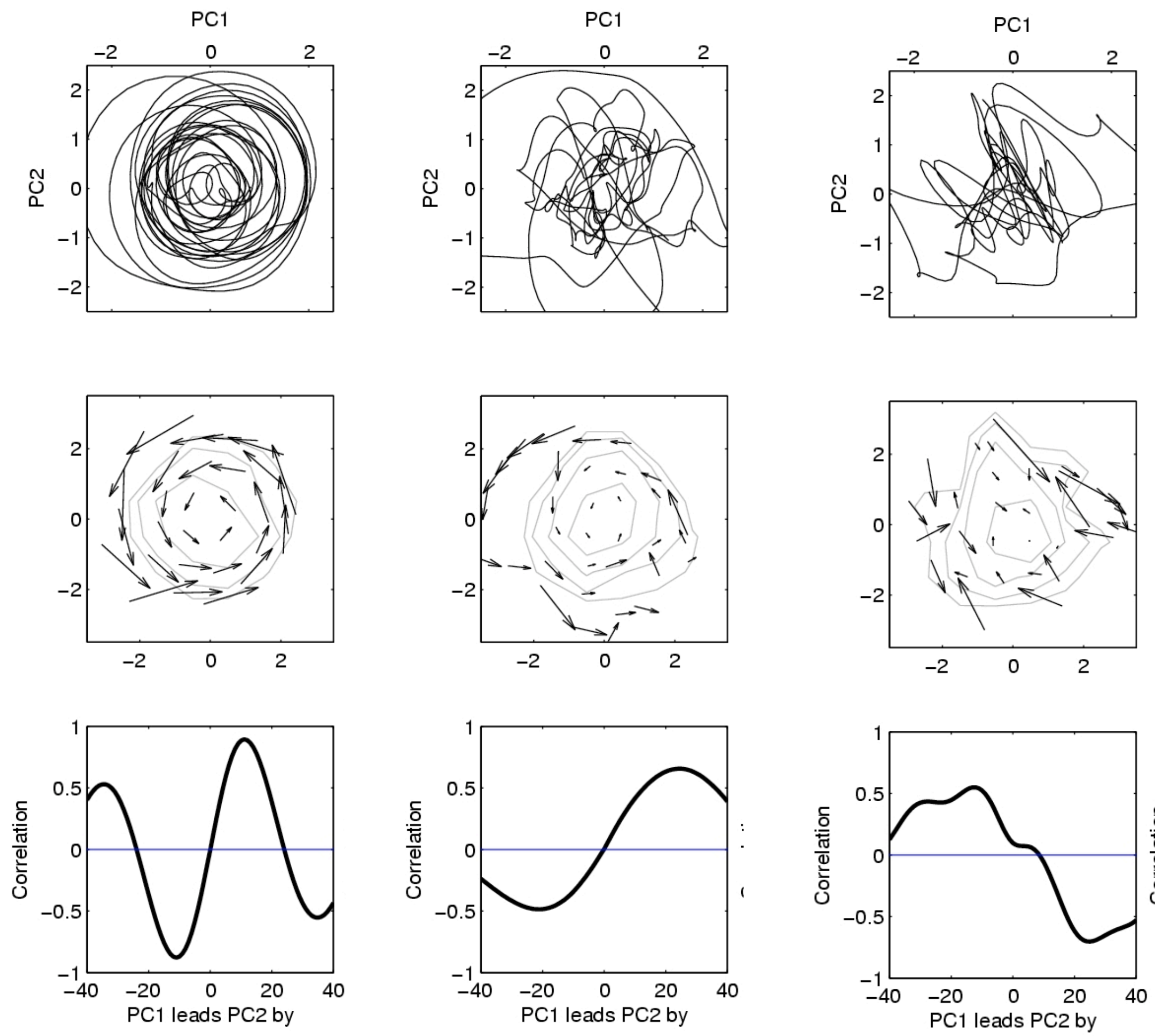
North Atlantic decadal variability in coupled GCMs

Evolution in the subspace of the leading 3D EOFS of T and S (after Hawkins & Sutton, 2007)



MPI | HadCM3 | GFDL CM2.1

Model uncertainty: sensitivity to resolution

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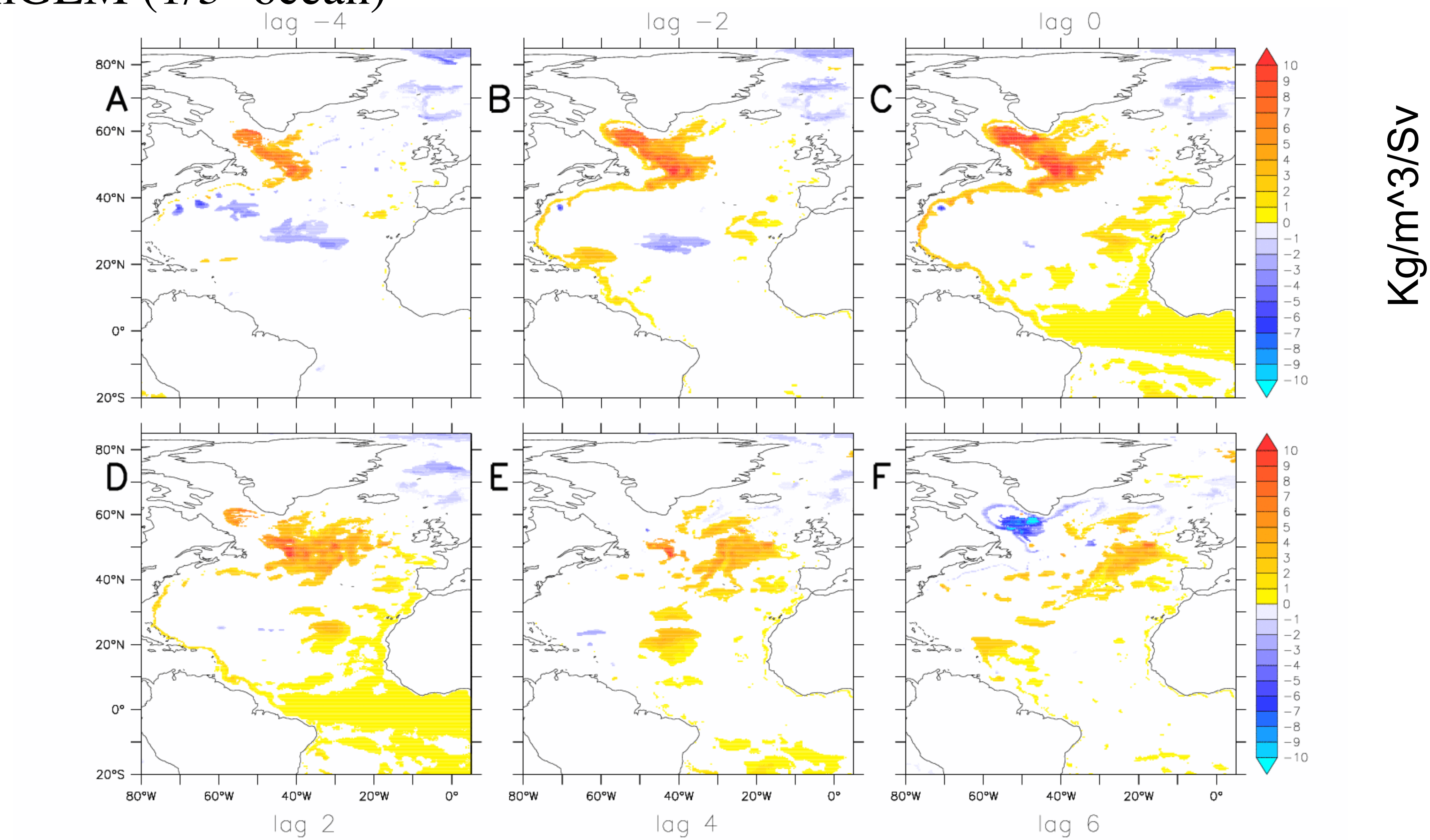
HiGEM (1/3^{o} ocean)



1500-3000m density regressed on MOC @ 40N

Model uncertainty: sensitivity to resolution

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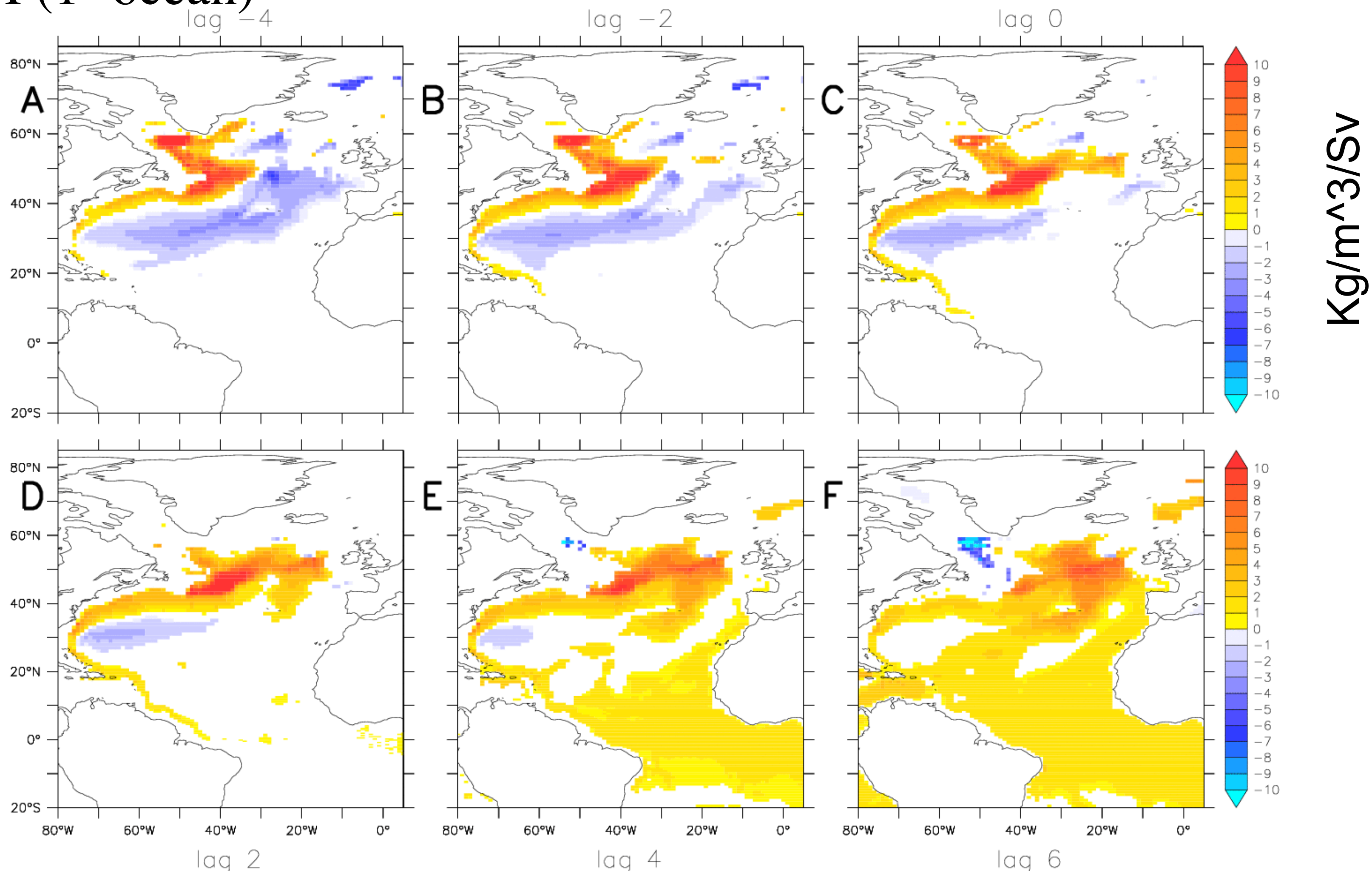
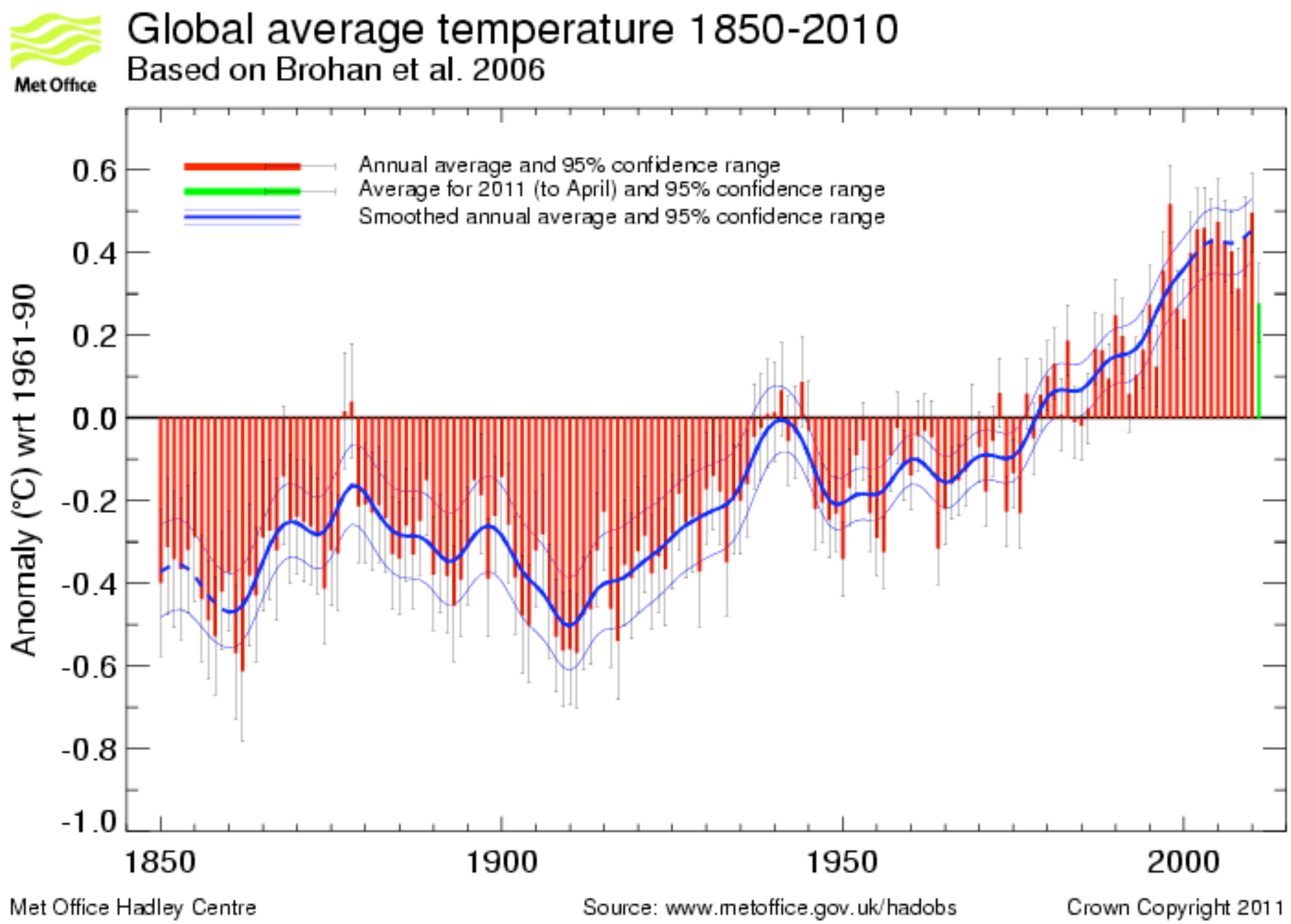
HadGEM (1° ocean)

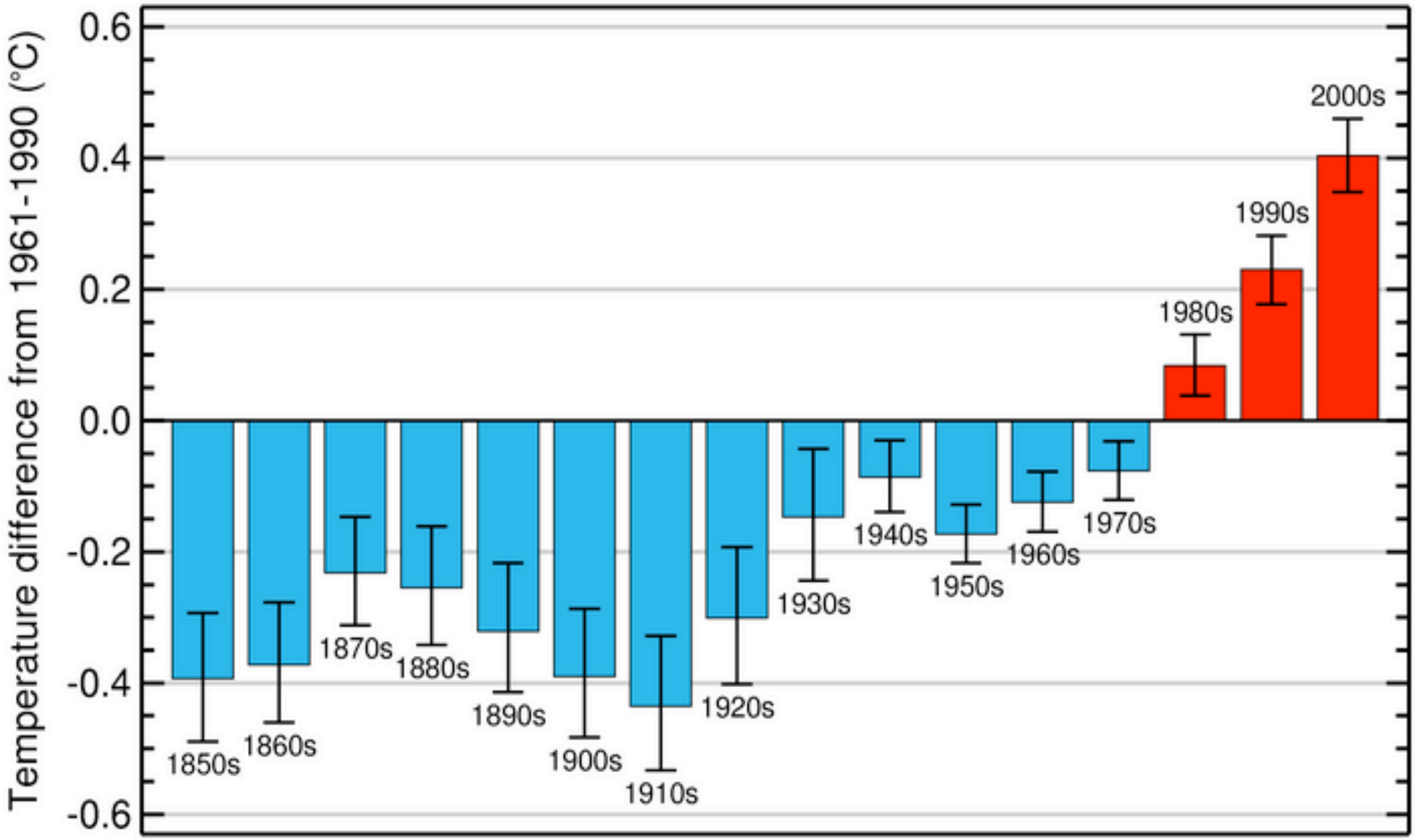


1500-3000m density regressed on MOC @ 40N

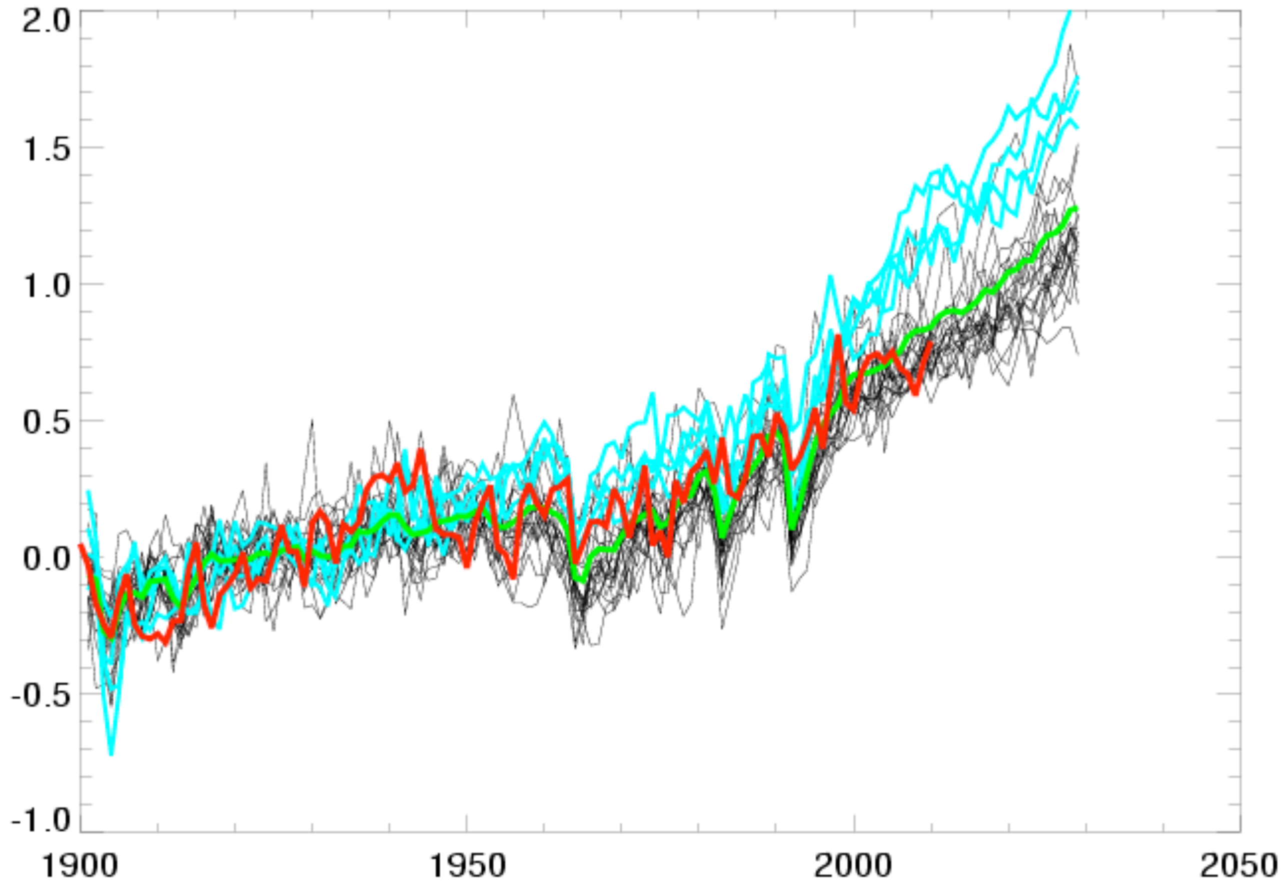
HadCRUT3 Global Temperature Record



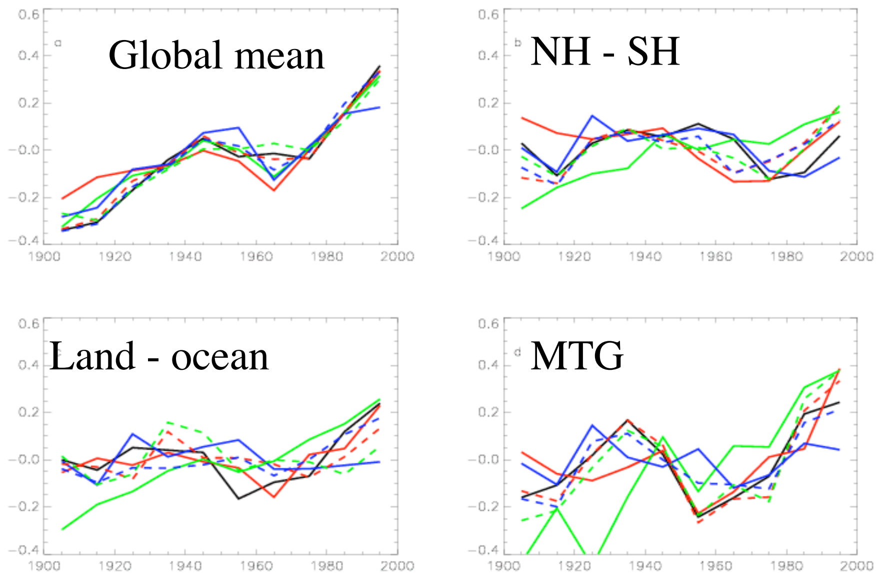
Global average temperature 1850-2009
2000s warmest decade

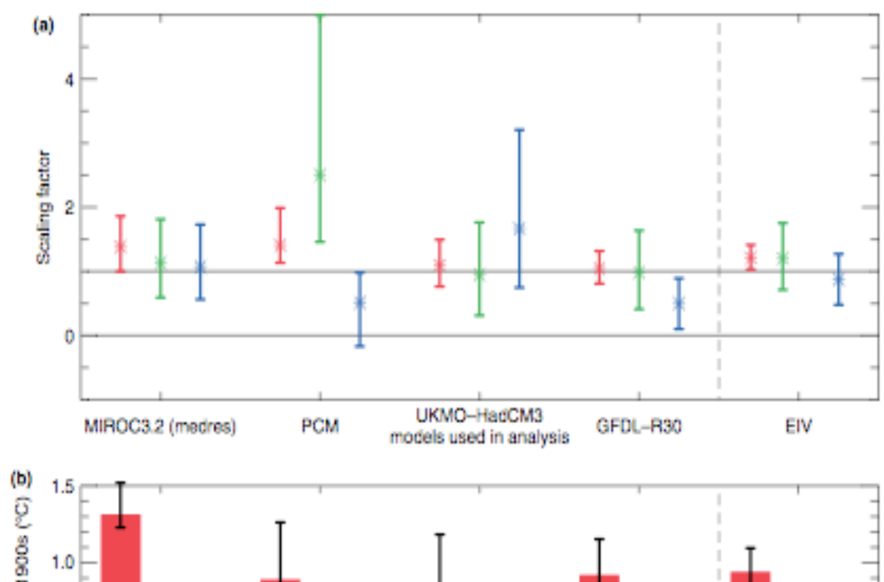


CMIP models



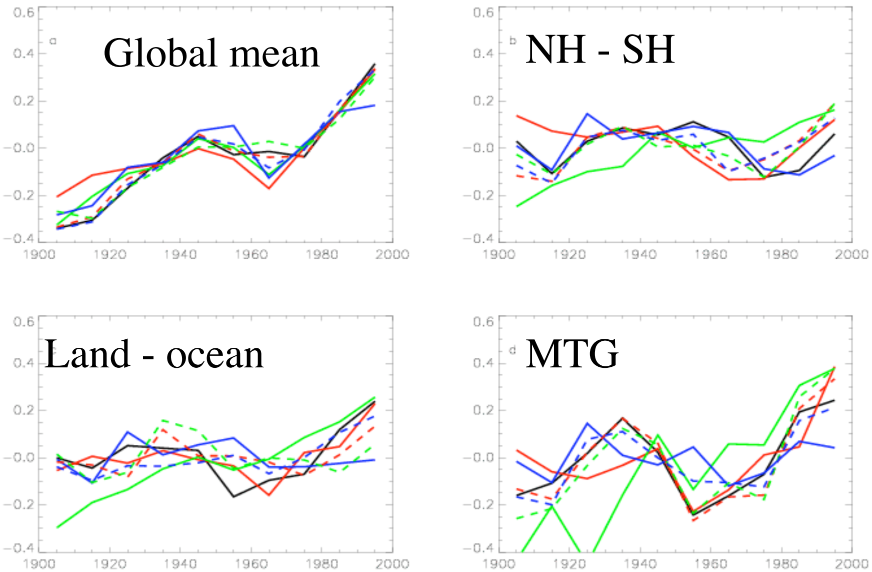
Robust quantification of contributors to past temperature change enables quantification of likely future rates of warming (ASK)

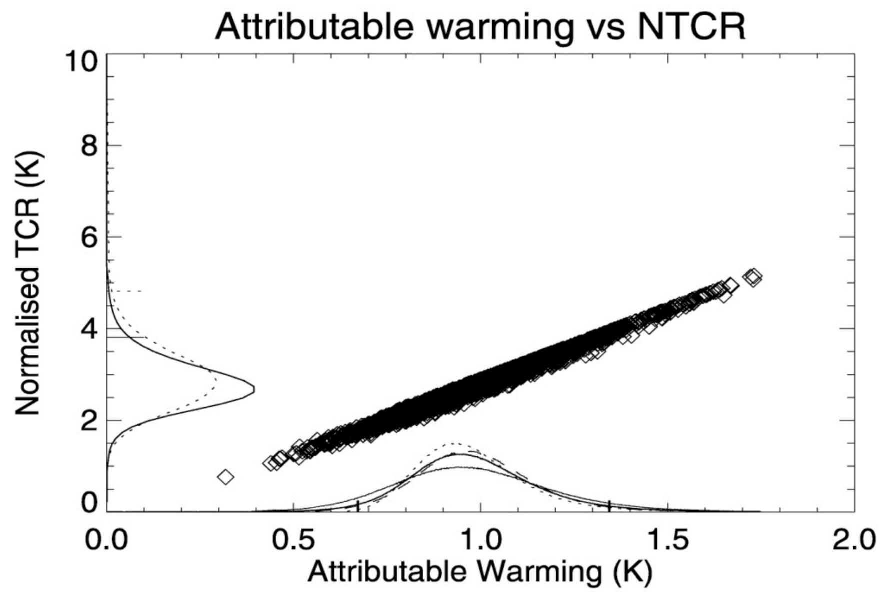




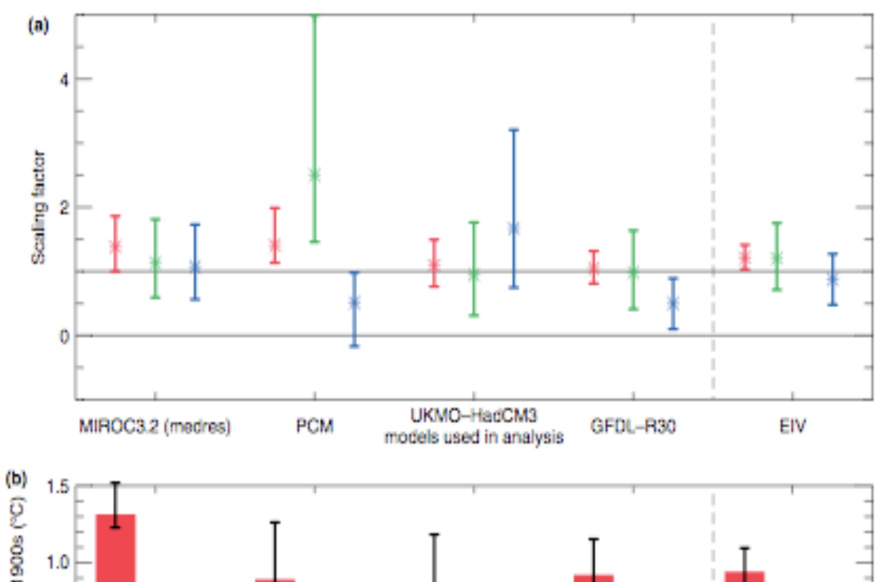
Stott et al, 2006

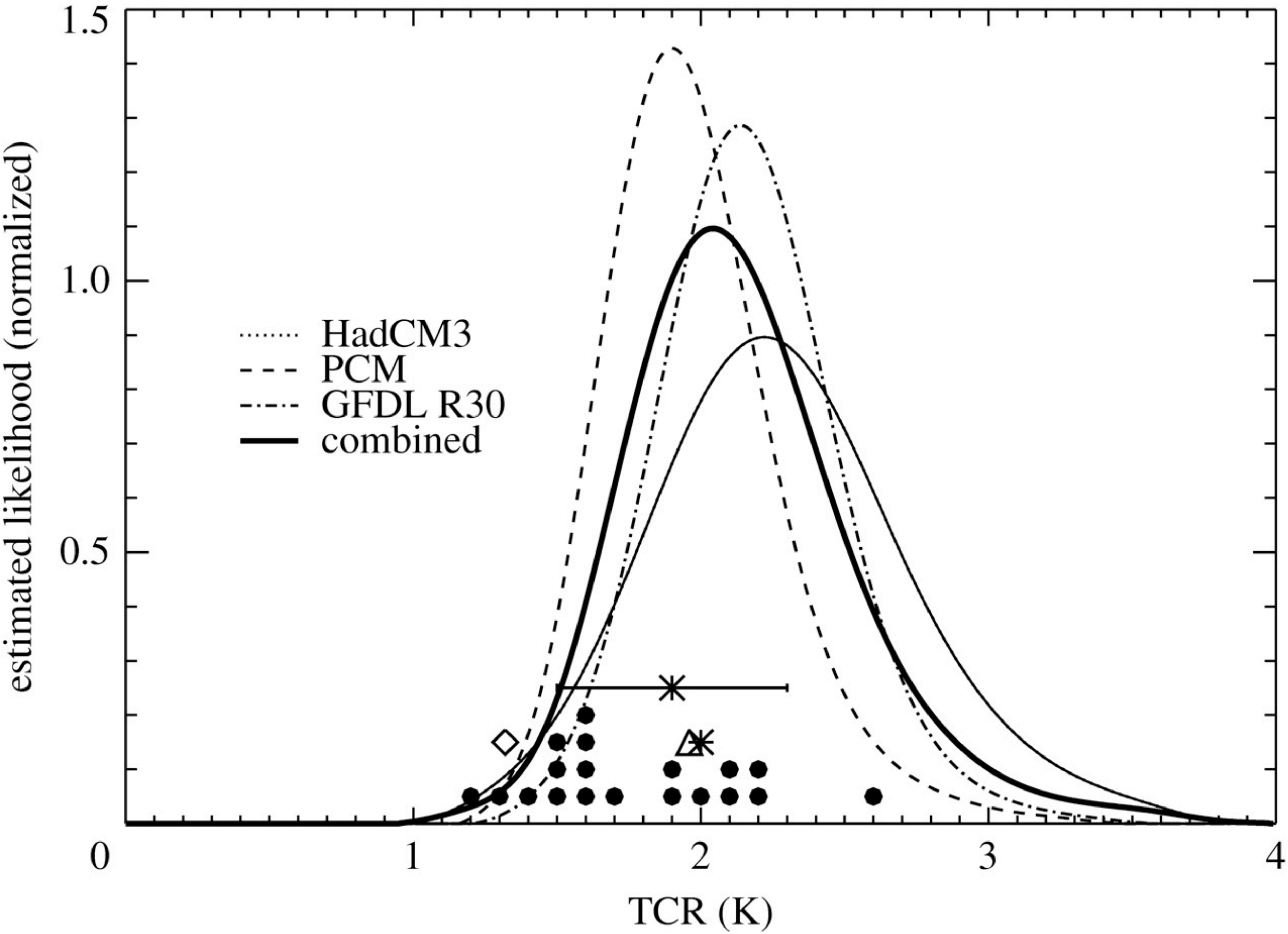
Robust quantification of contributors to past temperature change enables quantification of likely future rates of warming (ASK)

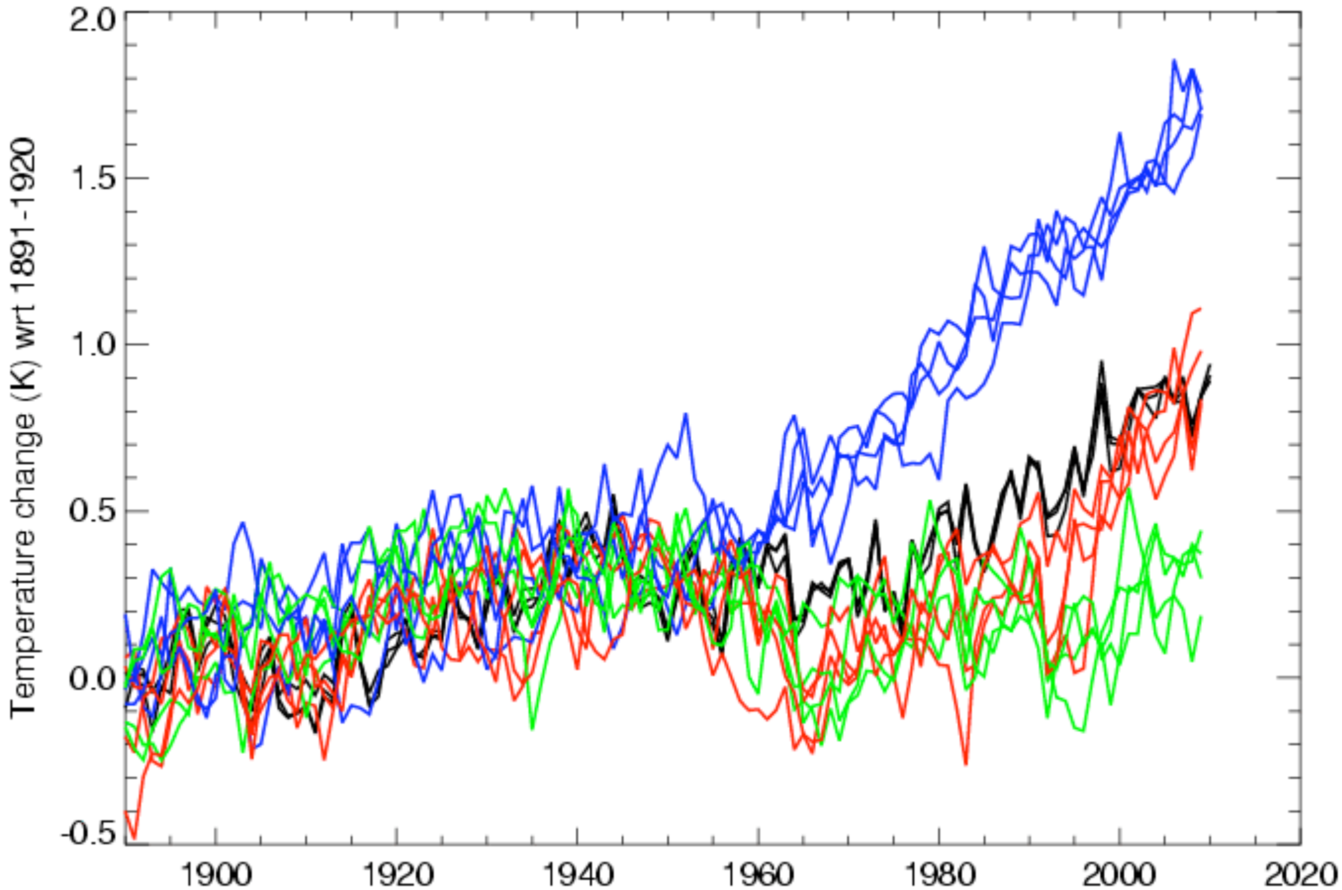




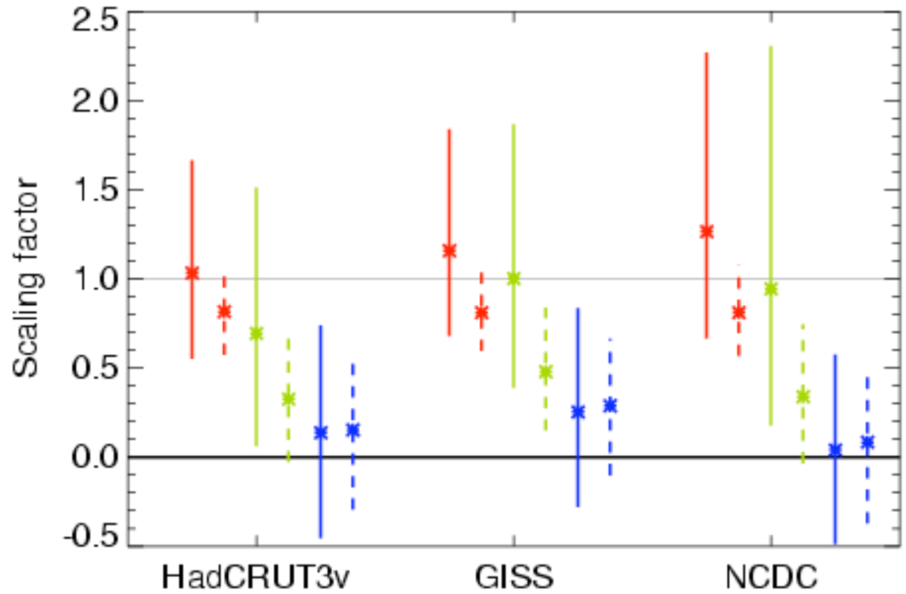
Frame et al, 2006

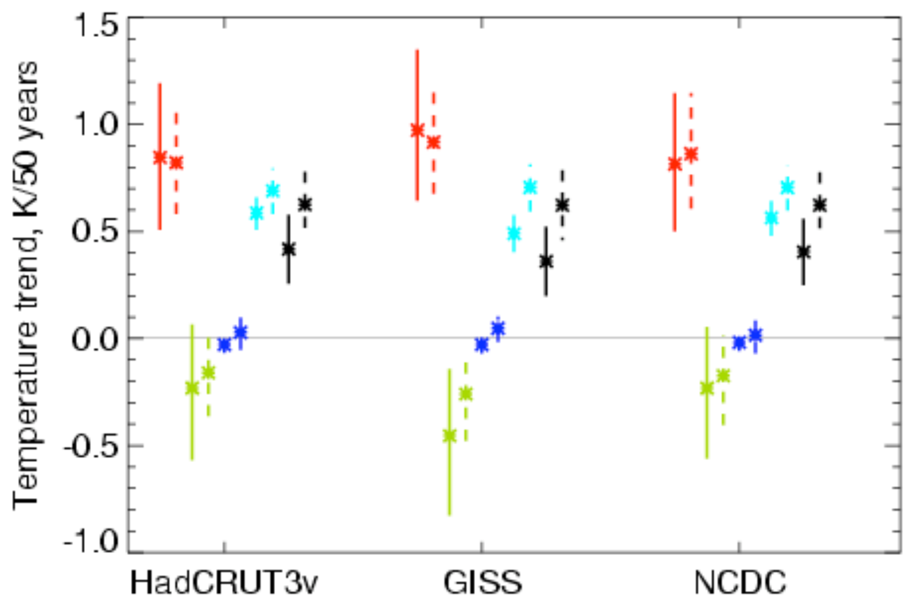



1.5
1.0
0.5
0
1
2
3
4
estimated likelihood (normalized)
TCR (K)
HadCM3
PCM
GFDL R30
combined

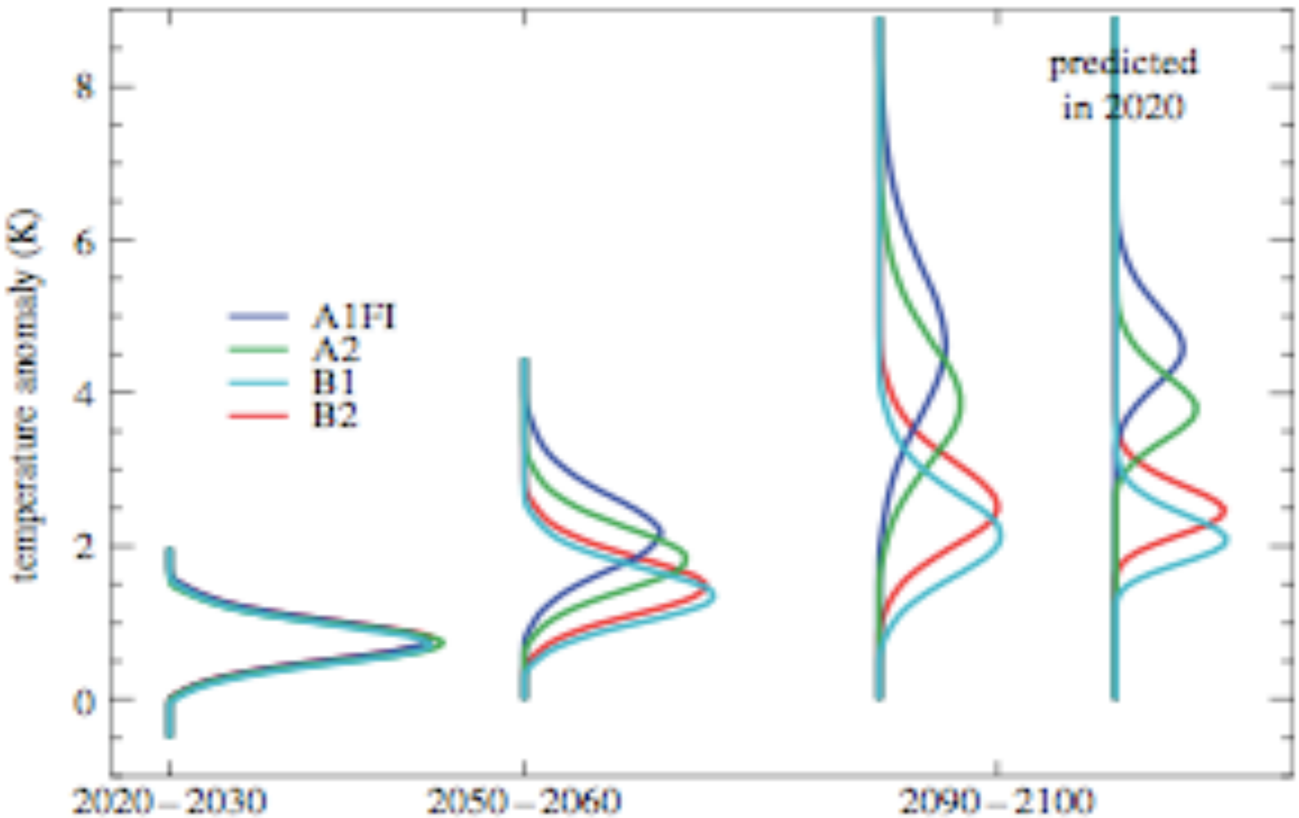


Temperature change (K) wrt 1891-1920
2.0
1.5
1.0
0.5
0.0
-0.5
1900
1920
1940
1960
1980
2000
2020

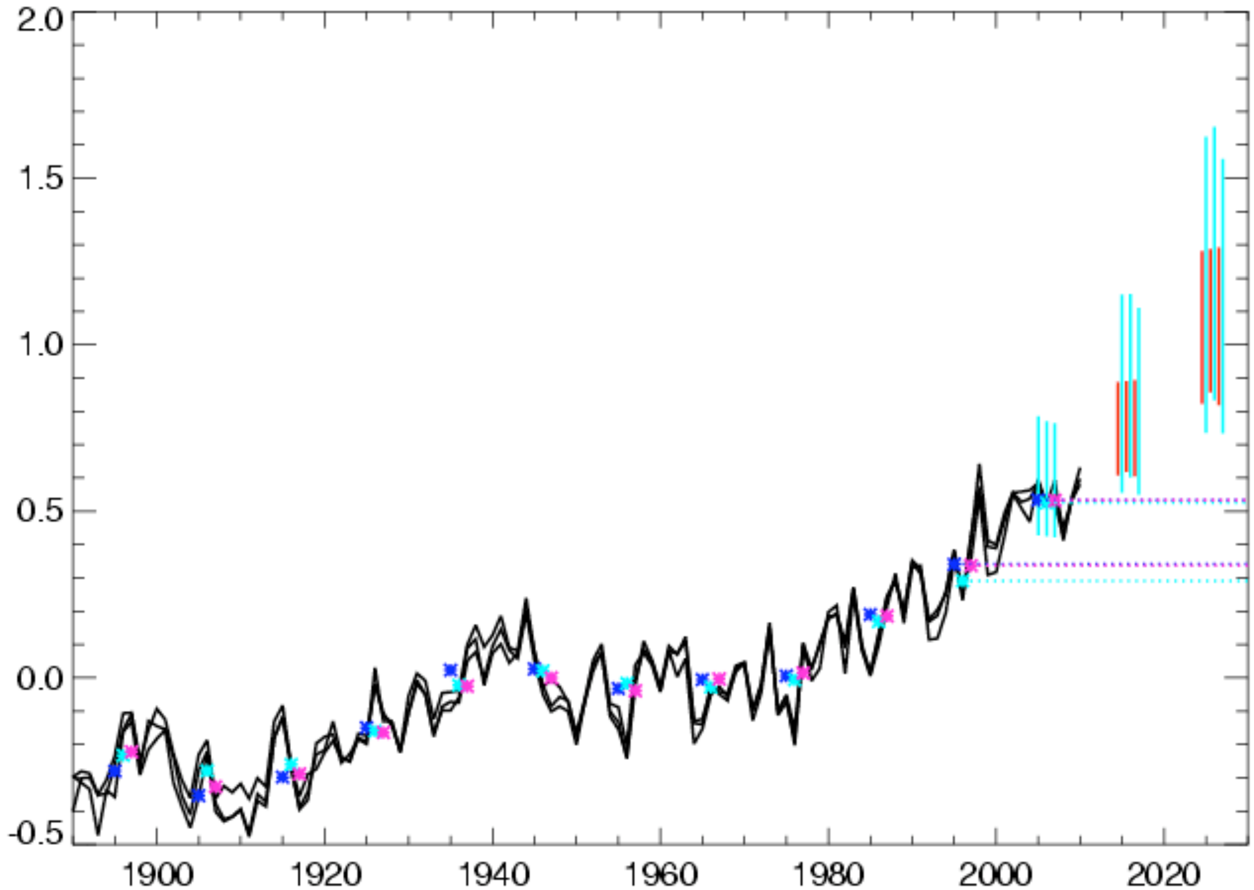

2.5
2.0
1.5
1.0
0.5
0.0
-0.5
Scaling factor
HadCRUT3v
GISS
NCDC


1.5
1.0
0.5
0.0
-0.5
-1.0
Temperature trend, K/50 years
HadCRUT3v
GISS
NCDC

Perfect model post 2000
Perfect data
Perfect world post 2000



Stott and Kettleborough, 2002



2.0
1.5
1.0
0.5
0.0
-0.5
1900
1920
1940
1960
1980
2000
2020

ASK

- By separating out forcing vs response by including separate forcing runs ASK is able to discriminate between errors in sensitivity and forcing
- Another 10 years of data do seem to have reduced uncertainties as SK02 predicted they should