Forcing, Feedbacks & Climate Sensitivity of the CMIP5 models

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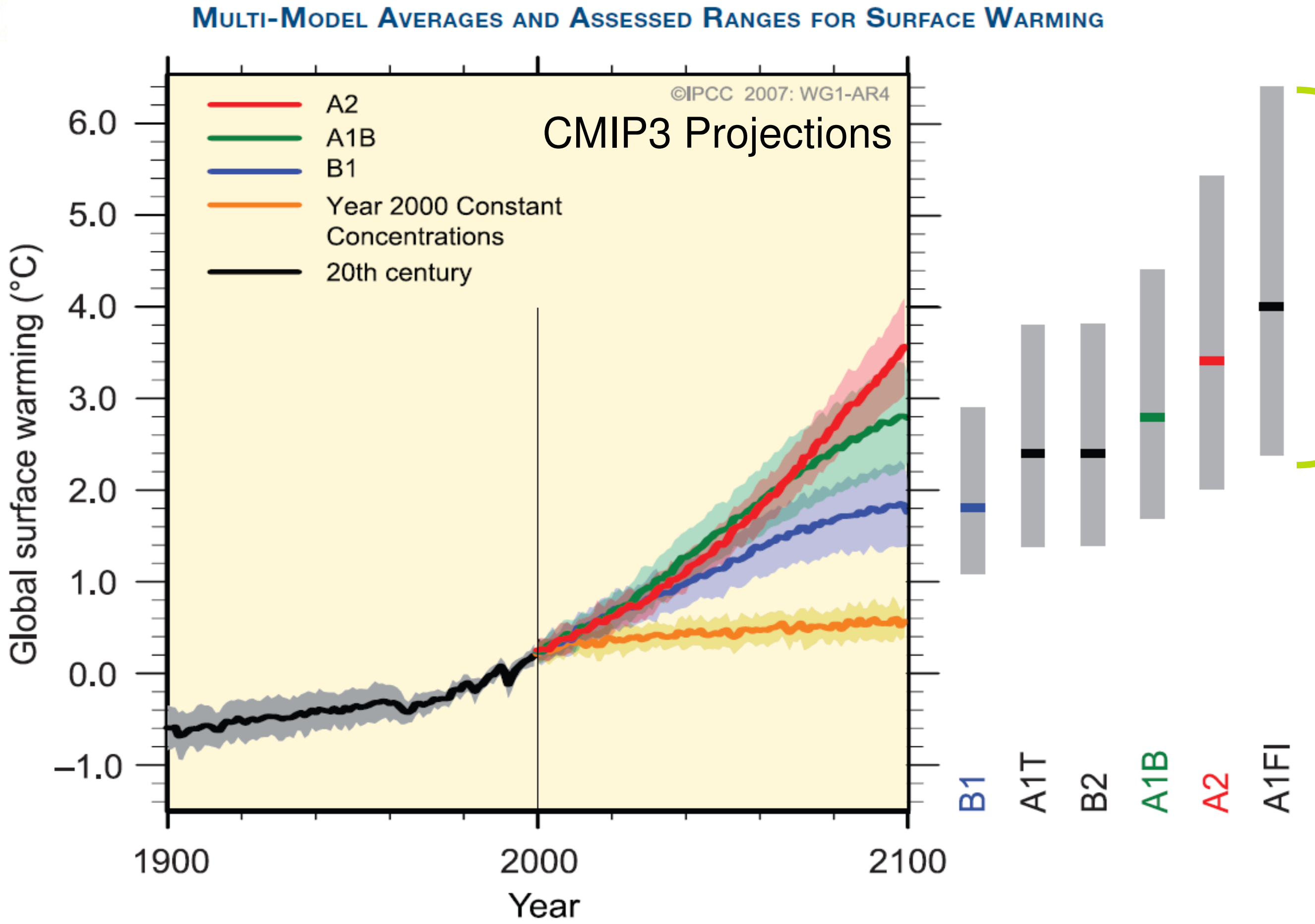
Motivation: Climate sensitivity and CMIP5



Climate sensitivity helps us understand the cause of this uncertainty

In CMIP5, we are also likely to have a range of projections, so we will need to explain why different models respond differently to the same external forcing

Outline

- Metrics for measuring a model's response to external forcing
- Methods that can be used to evaluate these metrics with the CMIP5 models
- Some early results from CMIP5 (3 models!)
- Limitations, discussion and summary

Climate change metrics in AOGCMS

- There are many metrics that can be used to quantify and compare a model's response to external forcing, how might they have changed since CMIP3?

- _Transient climate response_ (TCR): ΔT about yr 70 after 1% CO_2 increase. It is a more 'realistic' metric and can be readily computed, it can also provide some information about transient heat uptake & feedbacks (e.g. Gregory and Forster, 2008)

- _Eqm climate sensitivity_ (ΔT_{2x}): eqm ΔT after 2xCO_2. For CMIP5, this is too computationally expensive for AOGCMs, but large step forcing experiments are still a very useful 'science tool' for evaluating and comparing forcing and feedback processes

- This talk will focus on how we can use abrupt 4xCO_2 experiments in CMIP5 to diagnose and compare model forcing and feedback processes, as well as make a prediction of each models ΔT_{2x}

CMIP5 data

Coupled run that is not part of CFMIP2 experiments

	Abrupt4xCO2	sstClim4xCO2	CMIP3 ΔT_{2x}
INM-CM4	150yr	30yr	2.1 K
CNRM-CM5	150yr	n/a	n/a
HadGEM2-ES	270yr (in house)	30yr (in house)	4.4 K
…	…	…	…

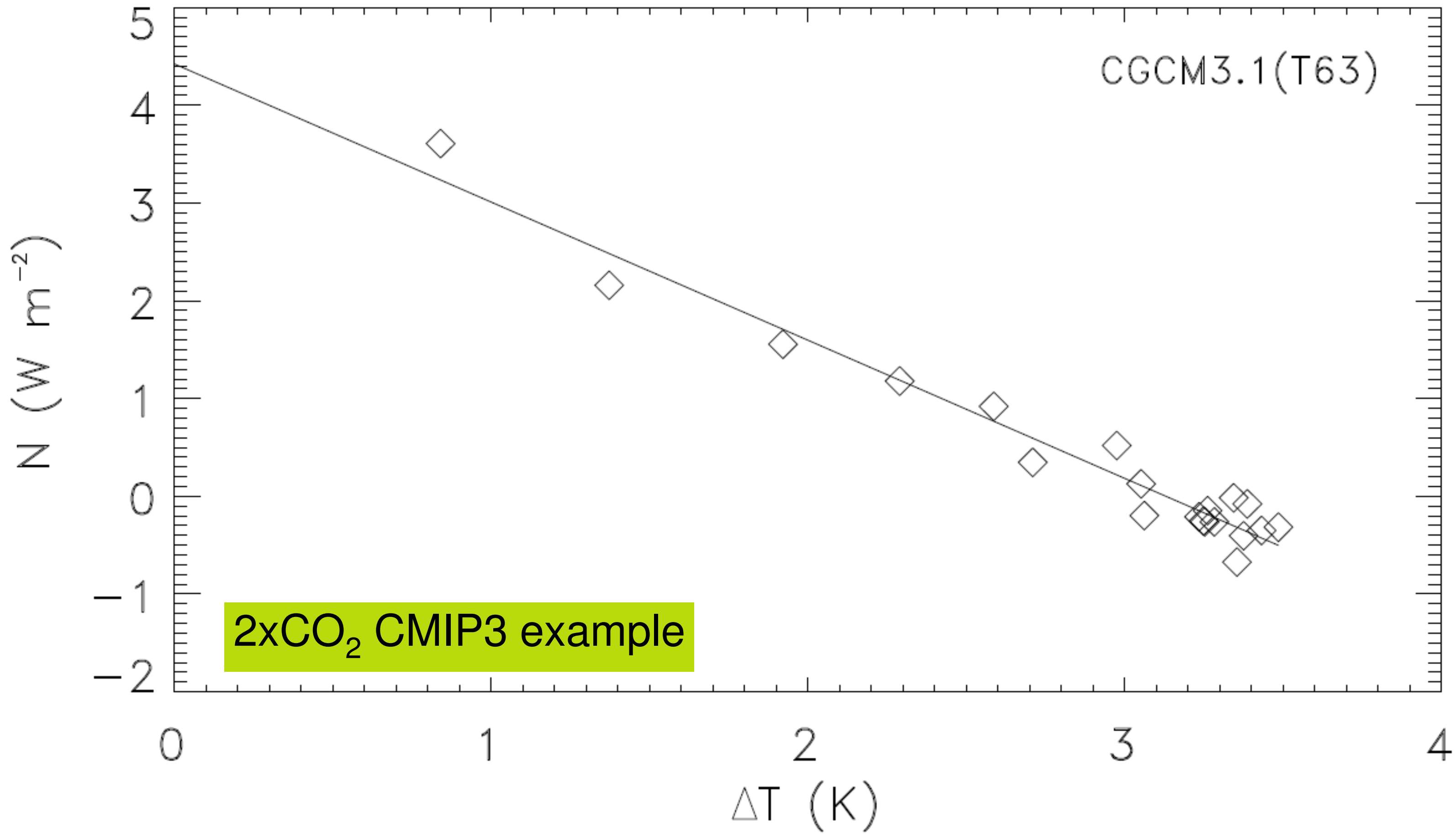
Spans CMIP3 climate sensitivity range

- Also includes corresponding pre-industrial fully coupled run and pre-industrial sst-climatology
- Not much of a multi-model intercomparison yet, but fortuitously these models represented the low and top end of the CMIP3 generation

How do we quantify model response?

Following, Gregory et al., (2004) and Gregory and Webb (2008), the energy balance of the climate system can be expressed by:

$$N = F - Y\Delta T$$



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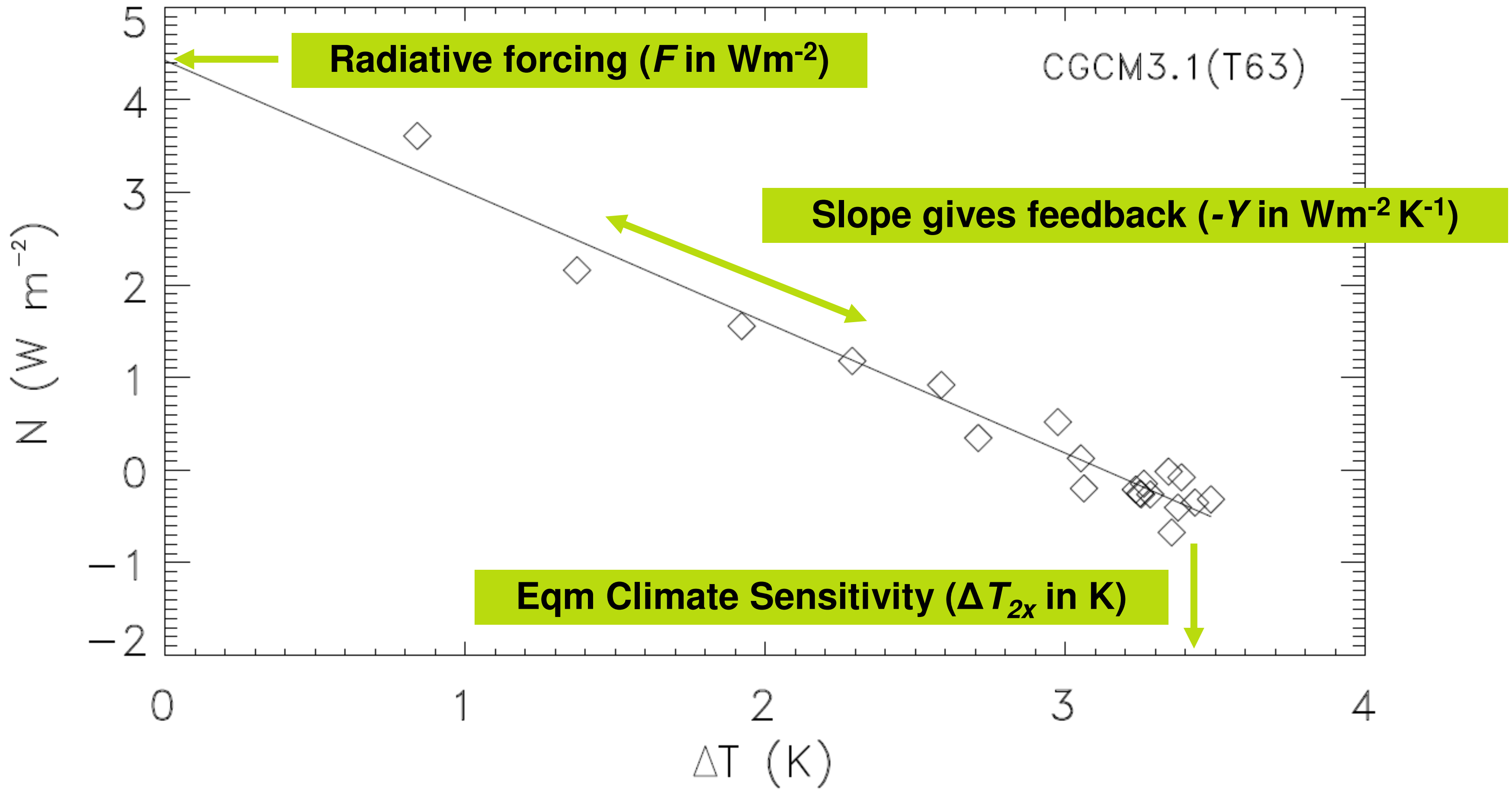
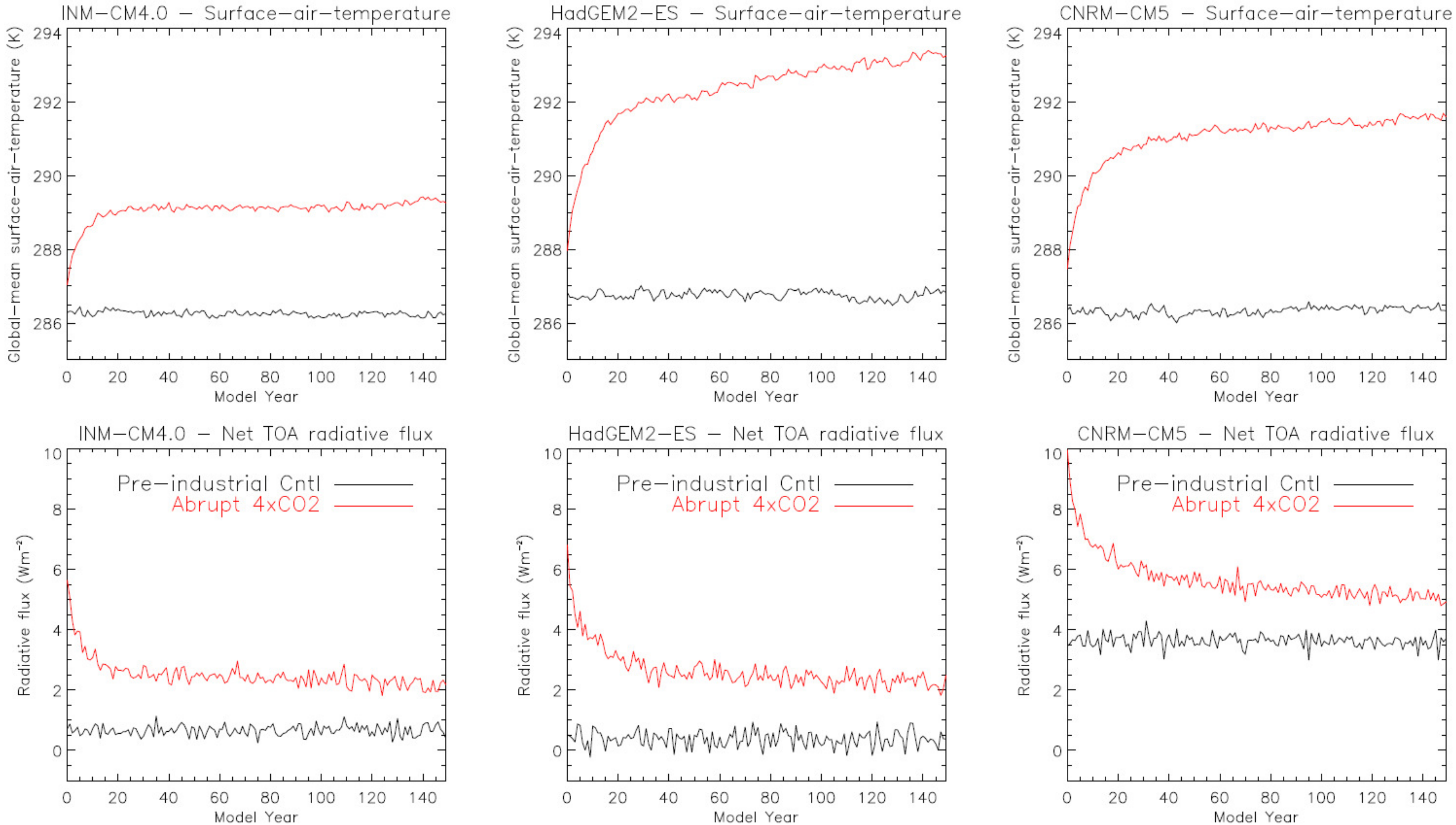
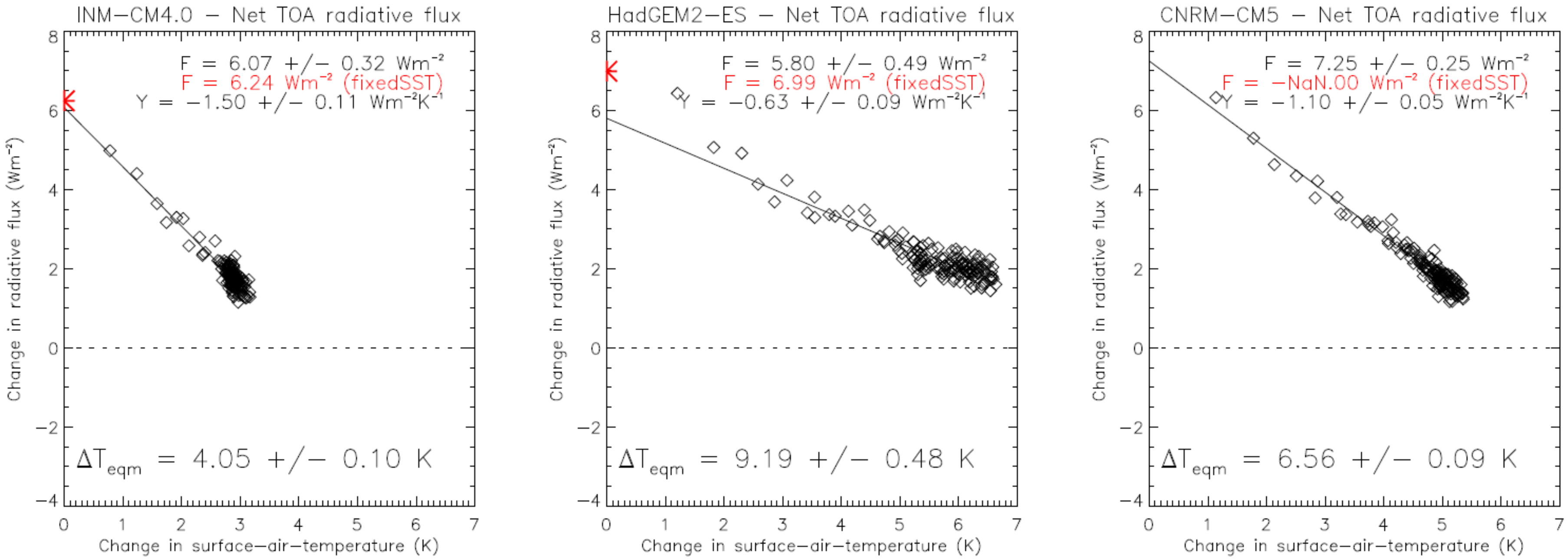


In CMIP5, we will only be part way along this curve…

CMIP5 piControl & abrupt4xCO2



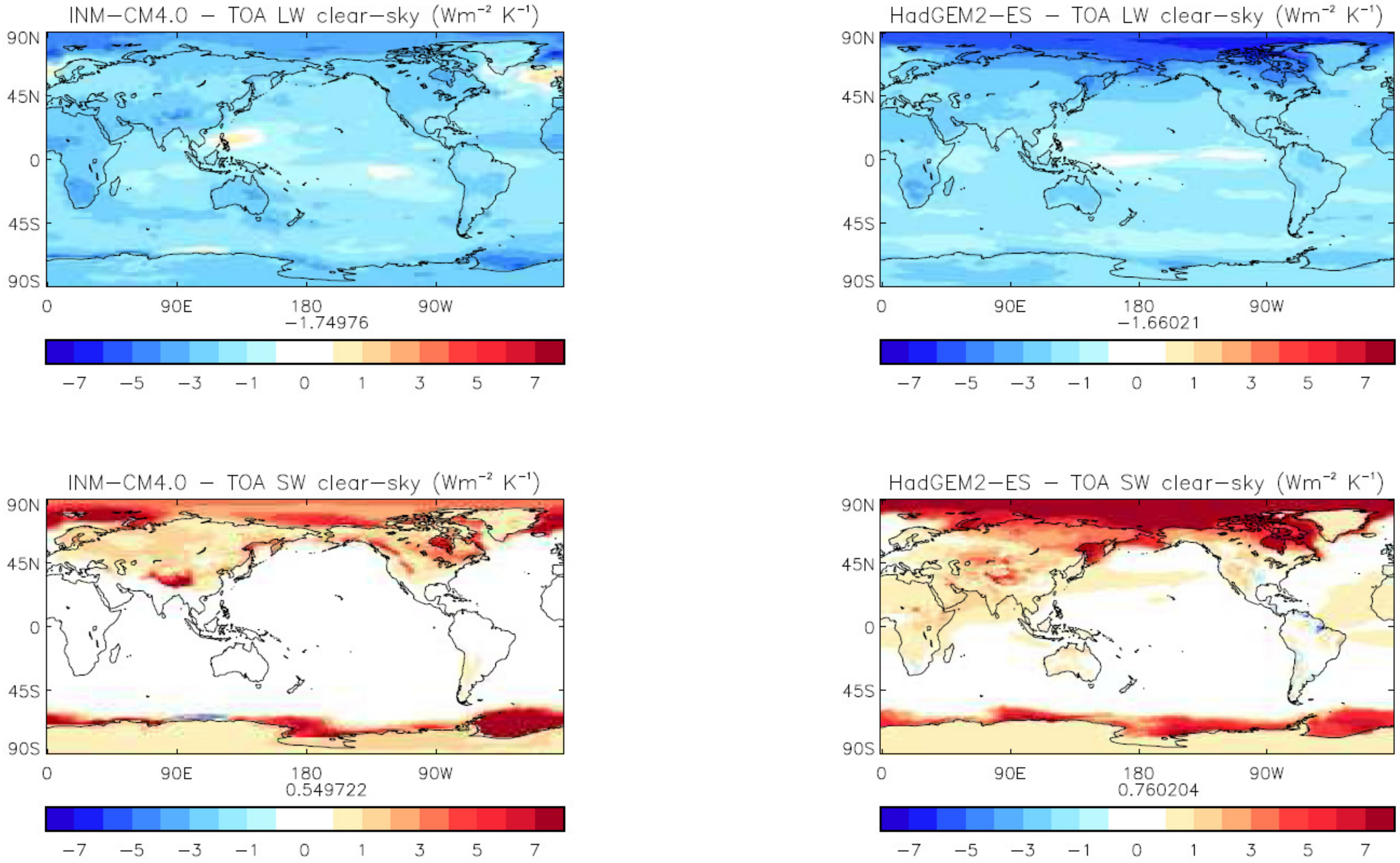
Climate feedback parameter & ΔT_{2x}



Prediction of ΔT_{2x} has a range ~ 2 to 4.6 K, very similar range to CMIP3

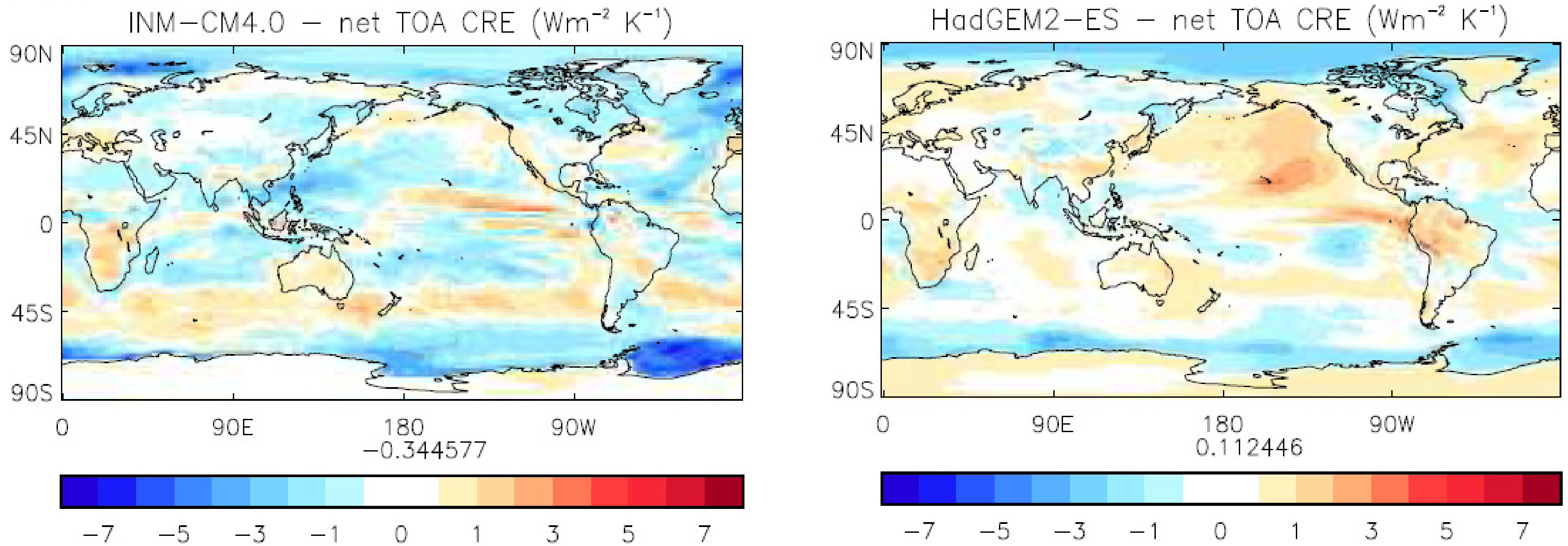
- Which feedback processes give rise to ~ -0.63 to -1.50 Wm^{-2} K^{-1} range?

Clear-sky feedback:- $Y = (F - N) / \Delta T_g$



Differences in clear-sky feedbacks not enough to explain sensitivity range

“Cloud Radiative Effect’ feedback



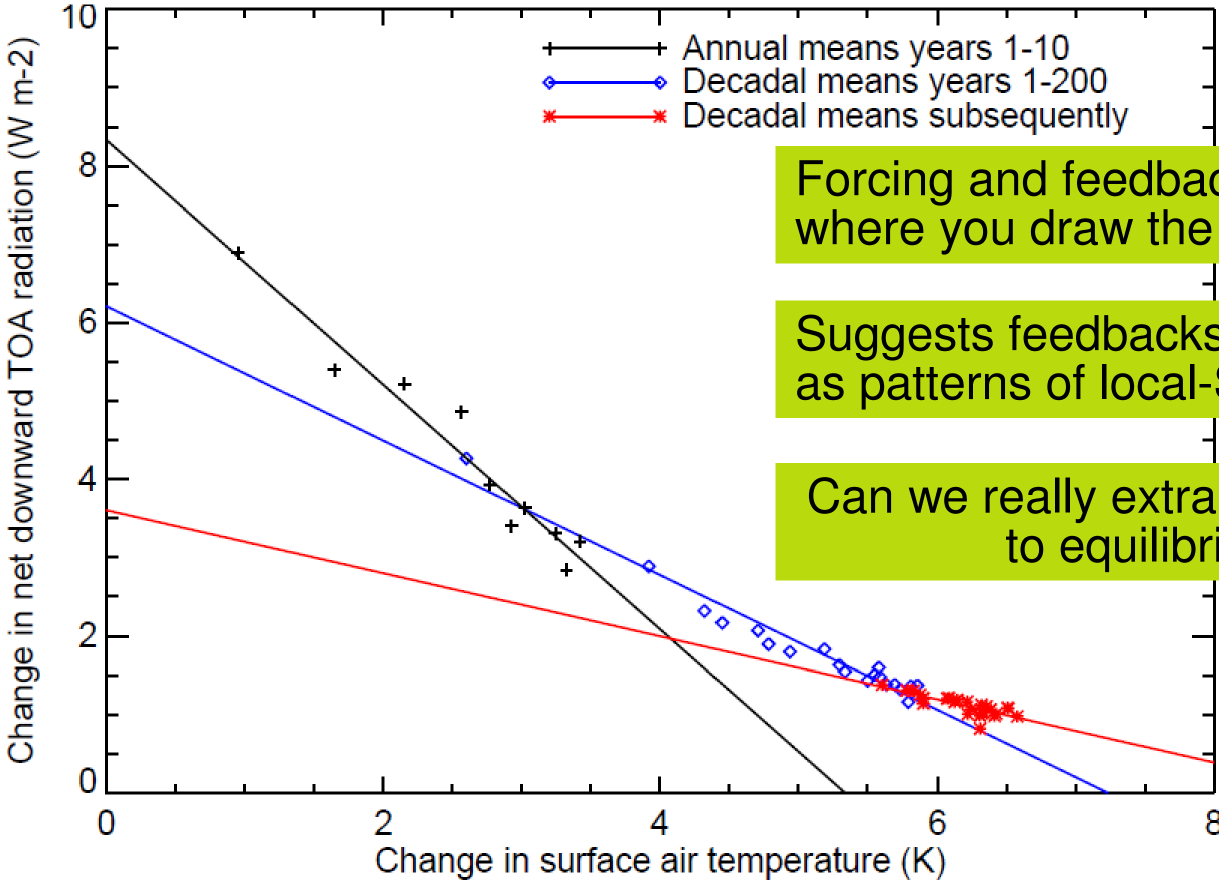
- As defined by CRE, cloud feedback is: ~ +0.1 $Wm^{-2}K^{-1}$ HadGEM2-ES
  ~ -0.35 $Wm^{-2}K^{-1}$ INM-CM4.0

- Largest differences occur in the Pacific basin, particularly in the NH

Differences in CRE feedback is the largest contributor to sensitivity range

Discussion: i) is it really linear?

- In AOGCMs, separating forcing and feedback can be complicated, as shown below for abrupt 4xCO_2 in HadCM3



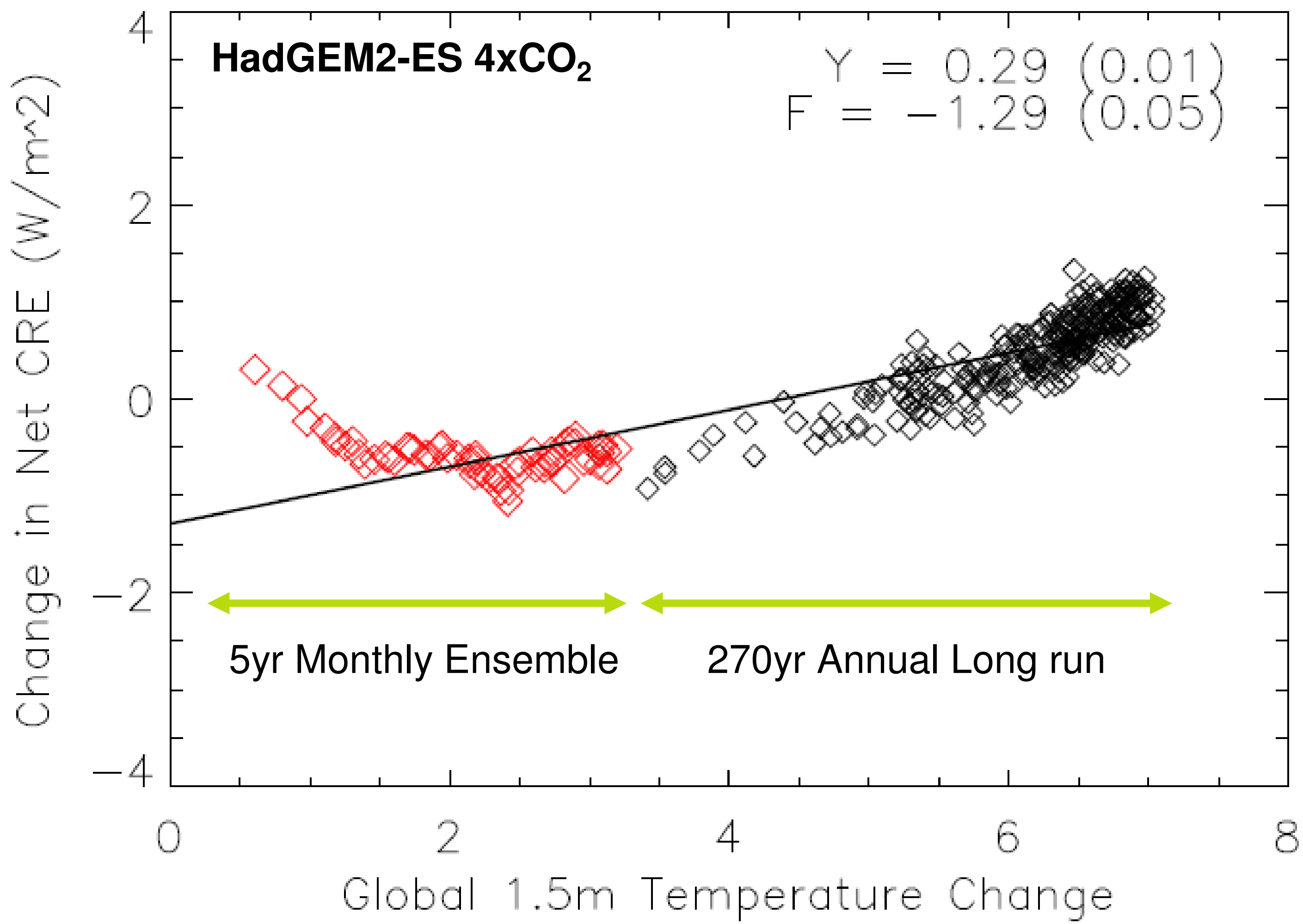
Forcing and feedback depends on where you draw the line!

Suggests feedbacks may change as patterns of local-SSTs change

Can we really extrapolate the line to equilibrium?

Courtesy of J.M. Gregory

Discussion: ii) how many different timescale responses are there?



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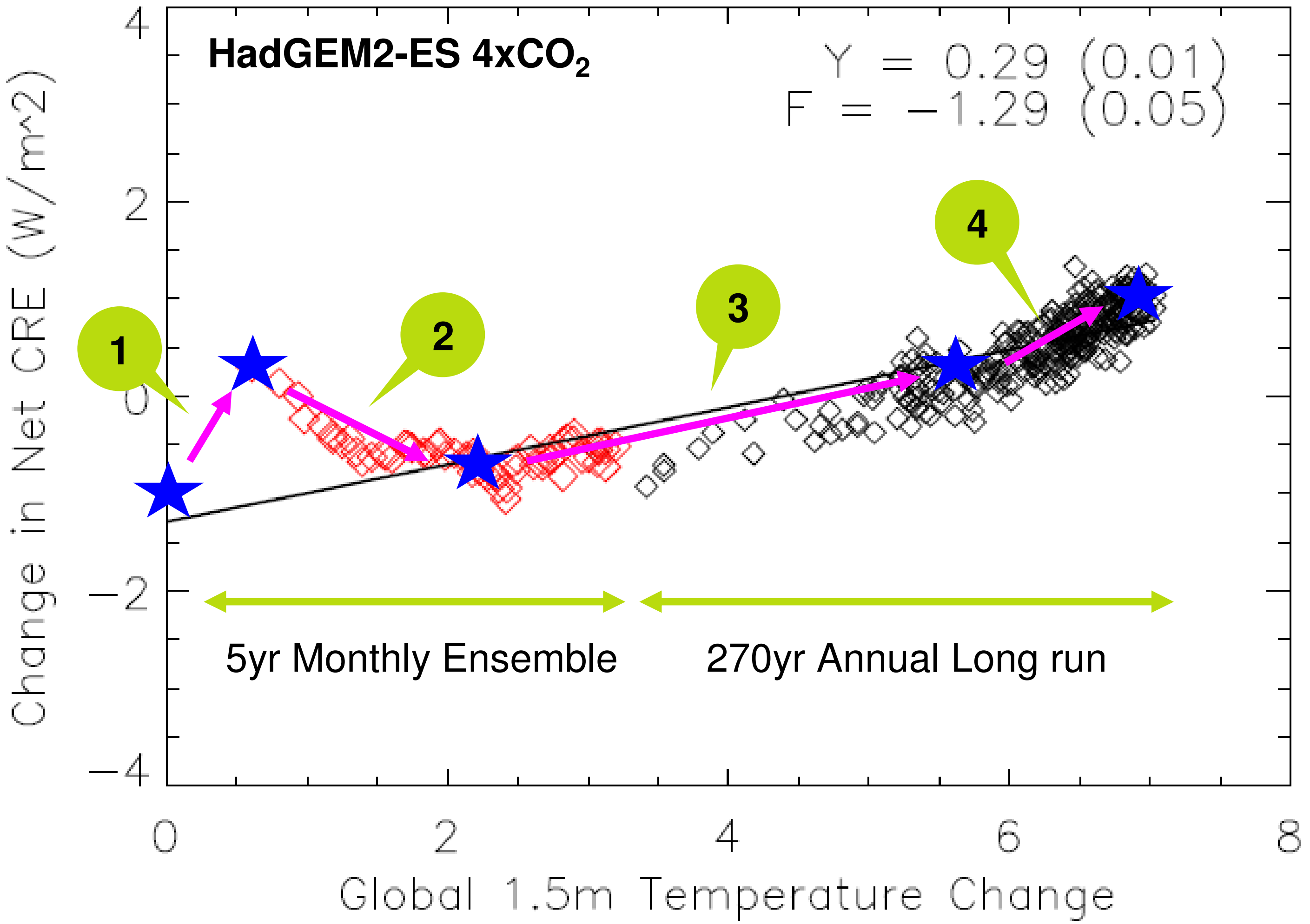
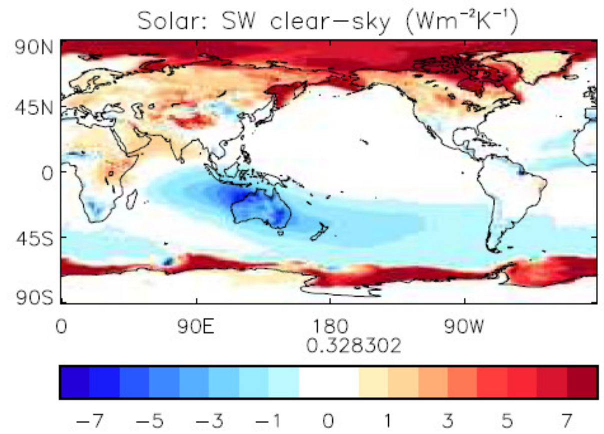
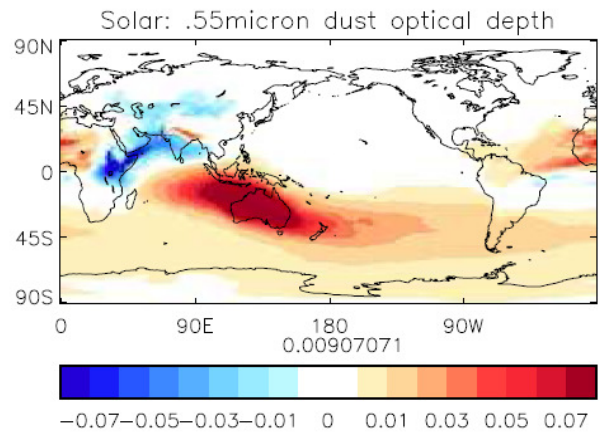


Discussion: iii) does sensitivity depend on the forcing agent, $4xCO_2$ v Solar?

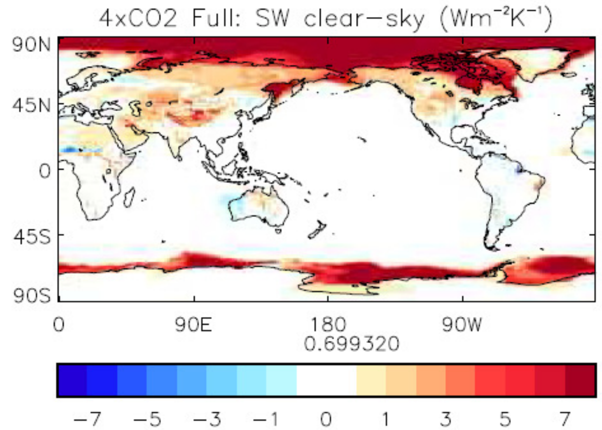
HadGEM2-ES Solar:

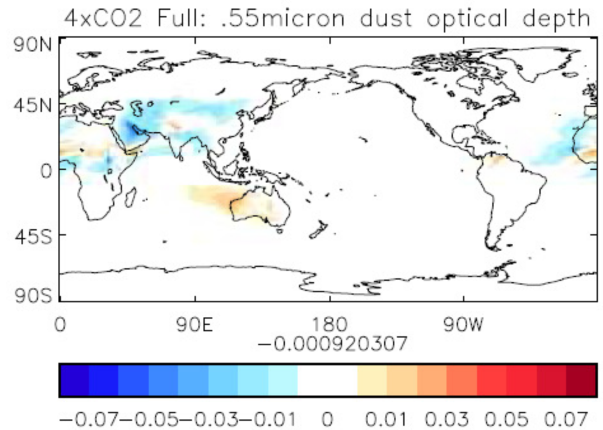




Strong negative SW clear-sky feedback under solar forcing from dust due to desertification of Australia

HadGEM2-ES $4xCO_2$:





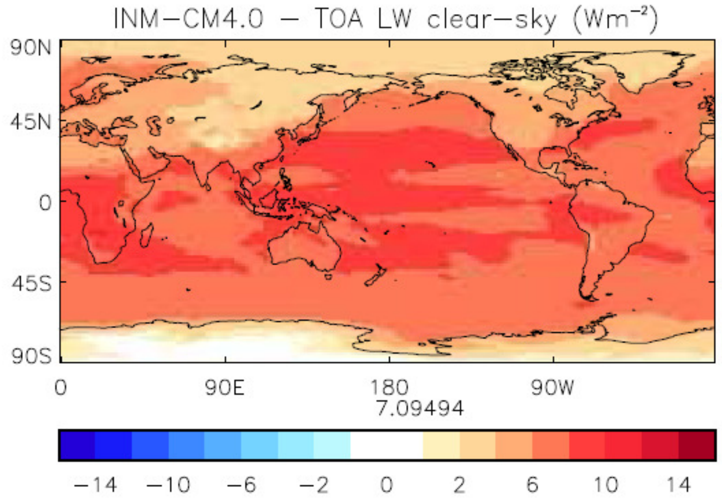
Not seen under CO_2 since physiological and fertilization effects prevent plants dying

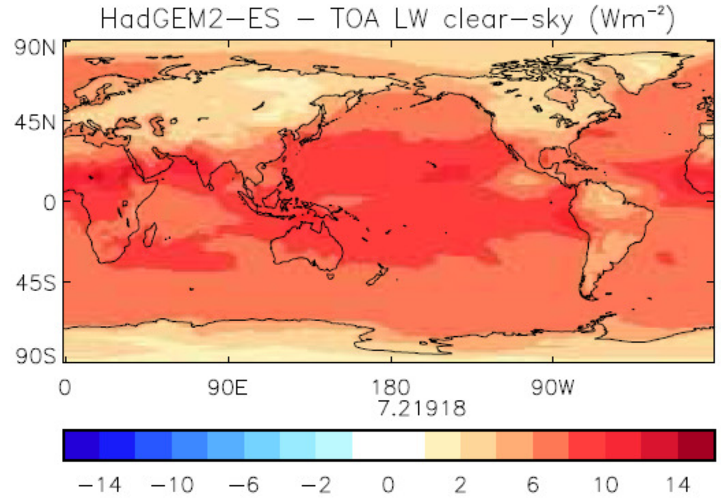
Summary

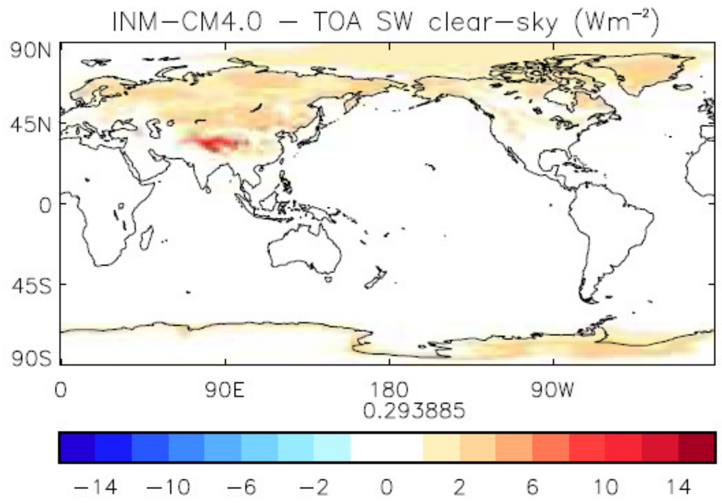
- Climate sensitivity helps us understand the causes of uncertainty in climate model projections.
- We can now look at this in some CMIP5 models as data becomes available.
- Preliminary results show that the range of eqm climate sensitivity has not reduced from the previous generation of models.
- Differences in cloud feedback, once again, appear to be the largest single cause of this uncertainty.
- There are limitations on the methods used, such as linearity. As more models become available this will indicate the extent of the problem.
- Finally, are we too CO_2 focused when performing sensitivity experiments?

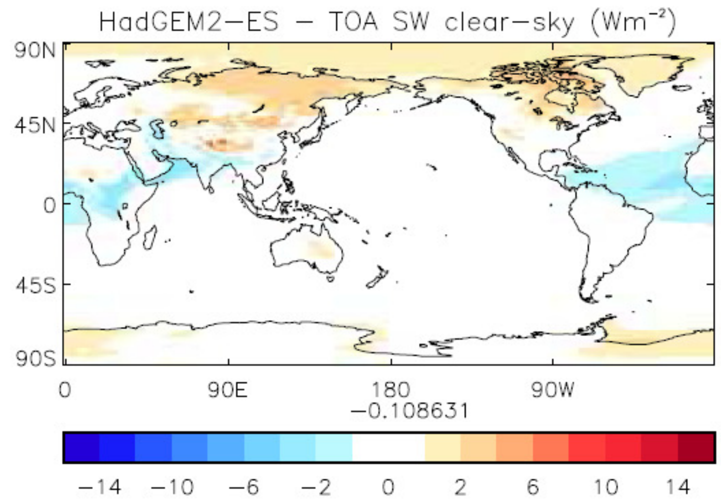
Additional slides

What about forcing?



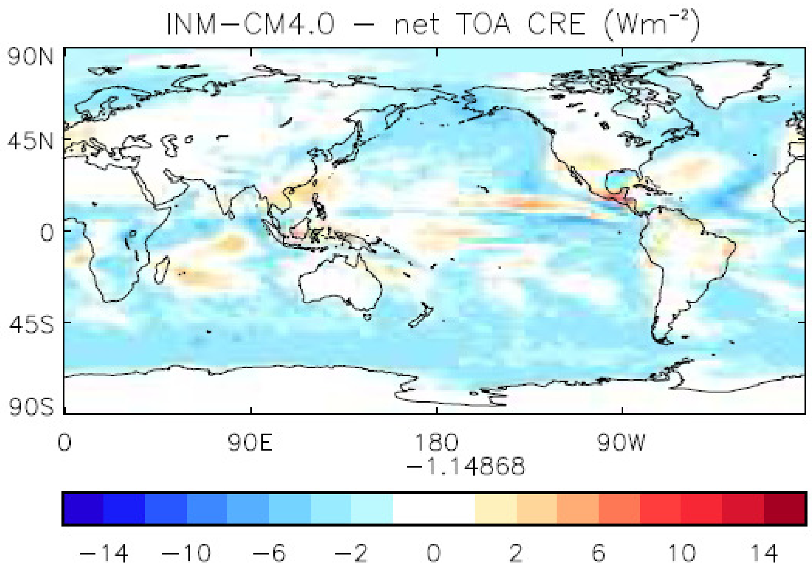


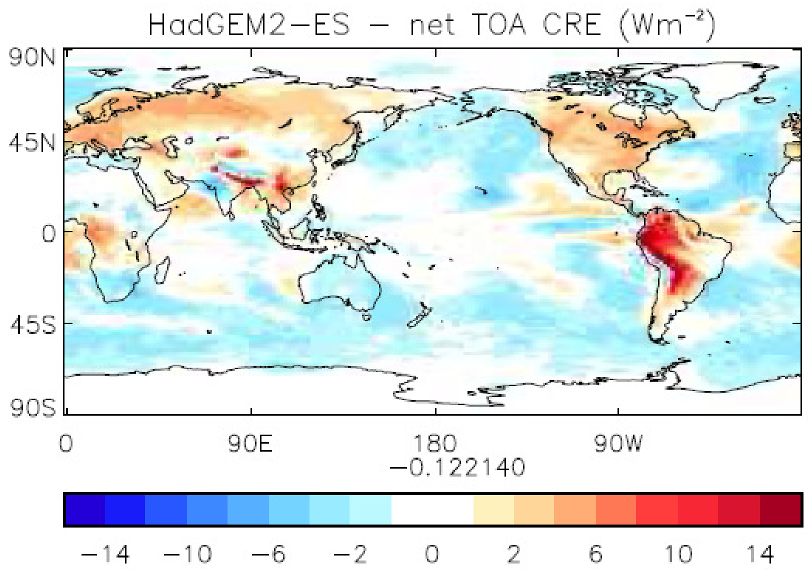




CRE forcing/adjustment

- Clouds shield the radiative effect of increasing CO_2, hence CO_2 forcing is larger in clear-skies than all-skies, giving rise to a cloud masking effect of ~ -1 Wm^{-2} for $4xCO_2$





- In HadGEM2-ES, there is also a “cloud adjustment” that comes about due to plant-CO_2 physiological effects, reducing transpiration and hence drying and warming the boundary layer (Doutriaux-Boucher et al., 2009)