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Forcing, Feedbacks & Climate Sensitivity in CMIP5

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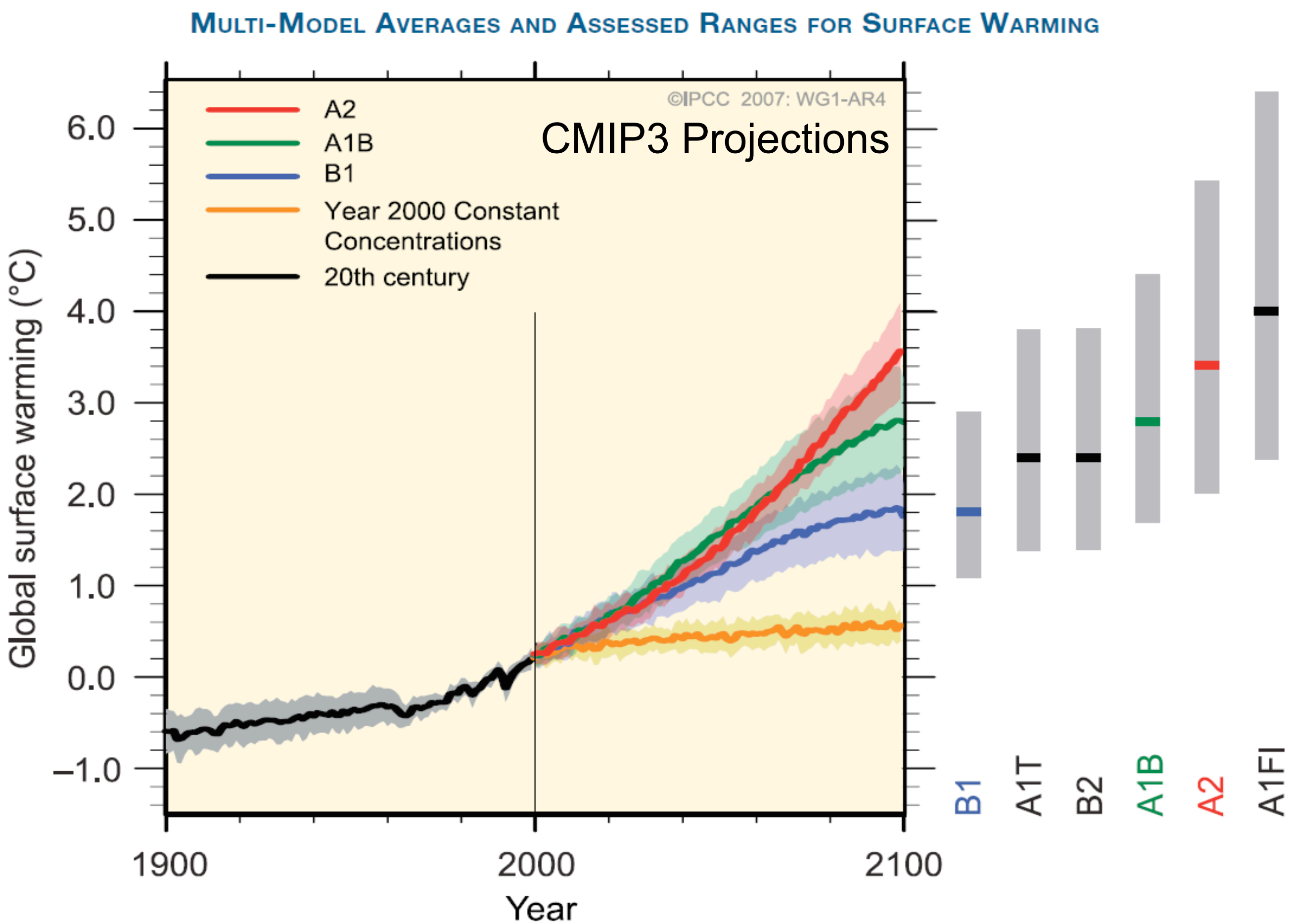
OSC Conference – Oct 2011, Email: timothy.andrews@metoffice.gov.uk

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

- Review Gregory's method for diagnosing "forcing" and global "climate sensitivity" and apply it to CMIP5 models

- To what extent do differences in "radiative forcing" and the strength of various feedbacks explain the spread in model responses?

- Resolve feedbacks into components: LW vs. SW; clear-sky vs. cloud effects

- Do feedbacks evolve in transient climate change experiments?

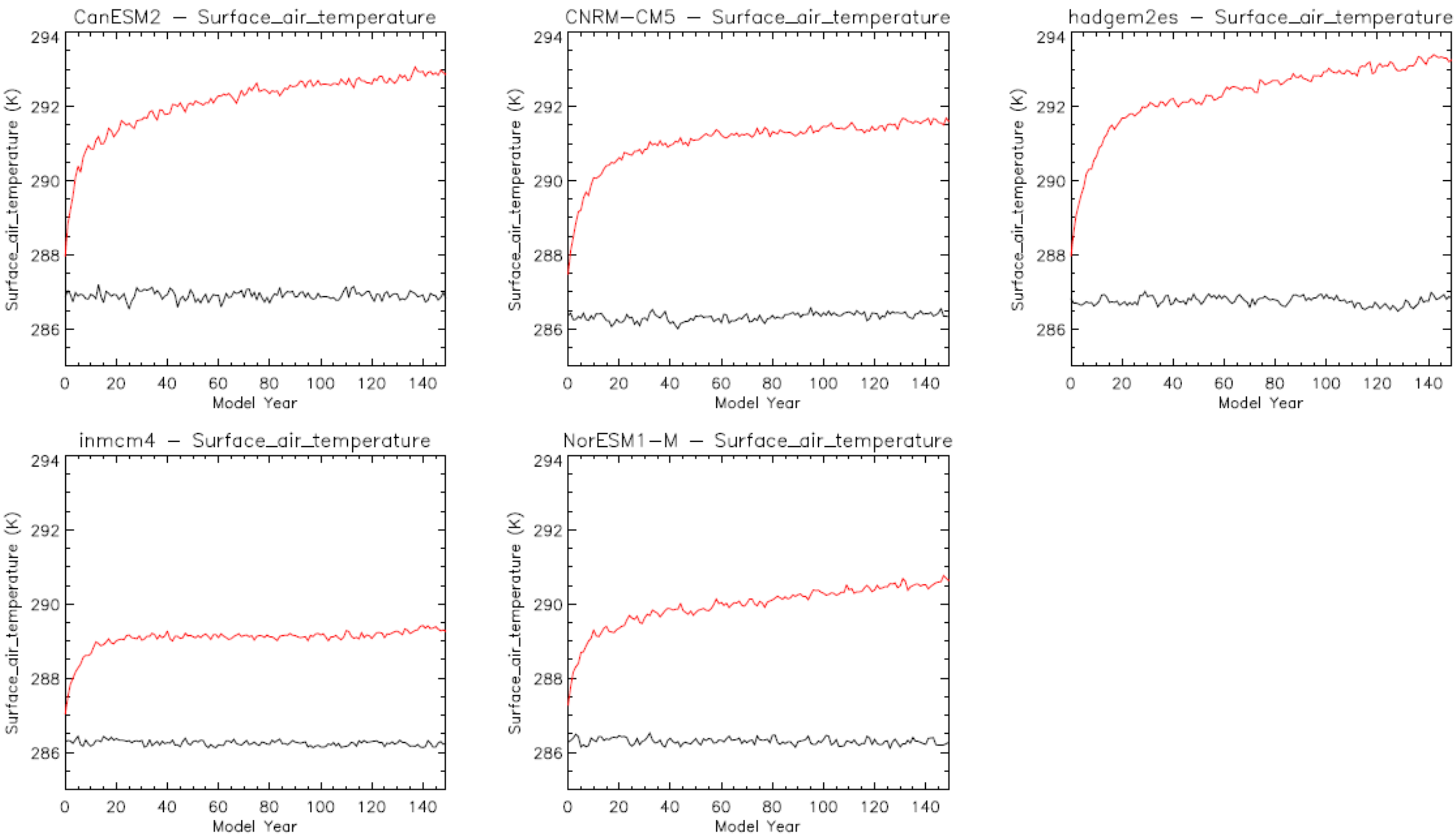
Current CMIP5 data (6th Oct)

	Abrupt4xCO2	piControl	CMIP3 generation ΔT_{2x}
CanESM2	150yr	100s yr	3.4 K
CNRM-CM5	150yr	100s yr	n/a
CSIRO-Mk3-6-0	150yr	100s yr	3.1 K
HadGEM2-ES	270yr (in house)	100s yr	4.4 K
INM-CM4	150yr	100s yr	2.1 K
IPSL-CM5A-LR	150yr	100s yr	4.4 K
MIROC5	150yr	100s yr	4.0 K
MRI-CGCM3	150yr	100s yr	3.2 K
NorESM1-M	150yr	100s yr	n/a
…	…	…	…

Spanned CMIP3 climate sensitivity range

- Data is now coming online regularly…

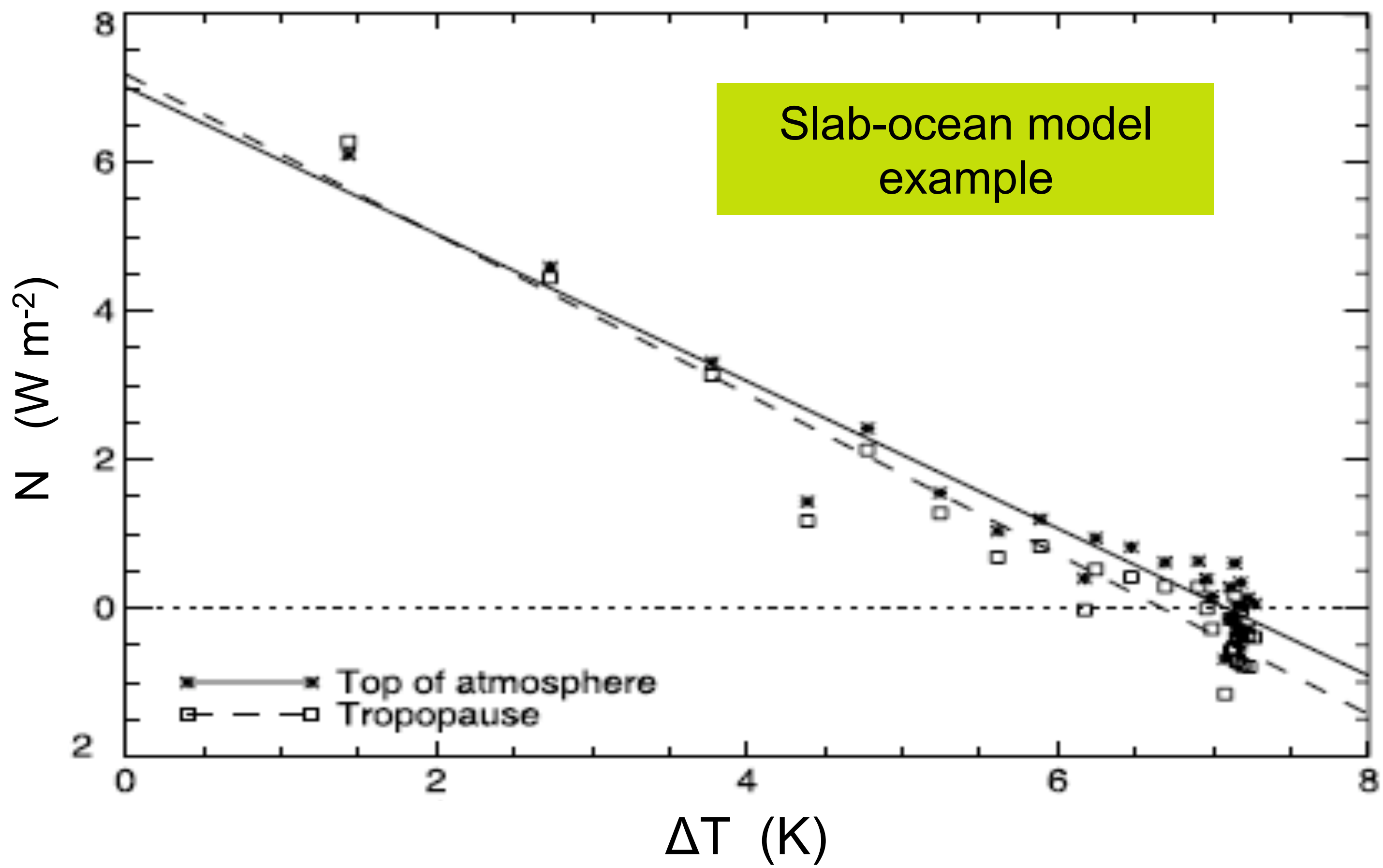
CMIP5 piControl & abrupt4xCO2



How do we quantify model response?

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

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



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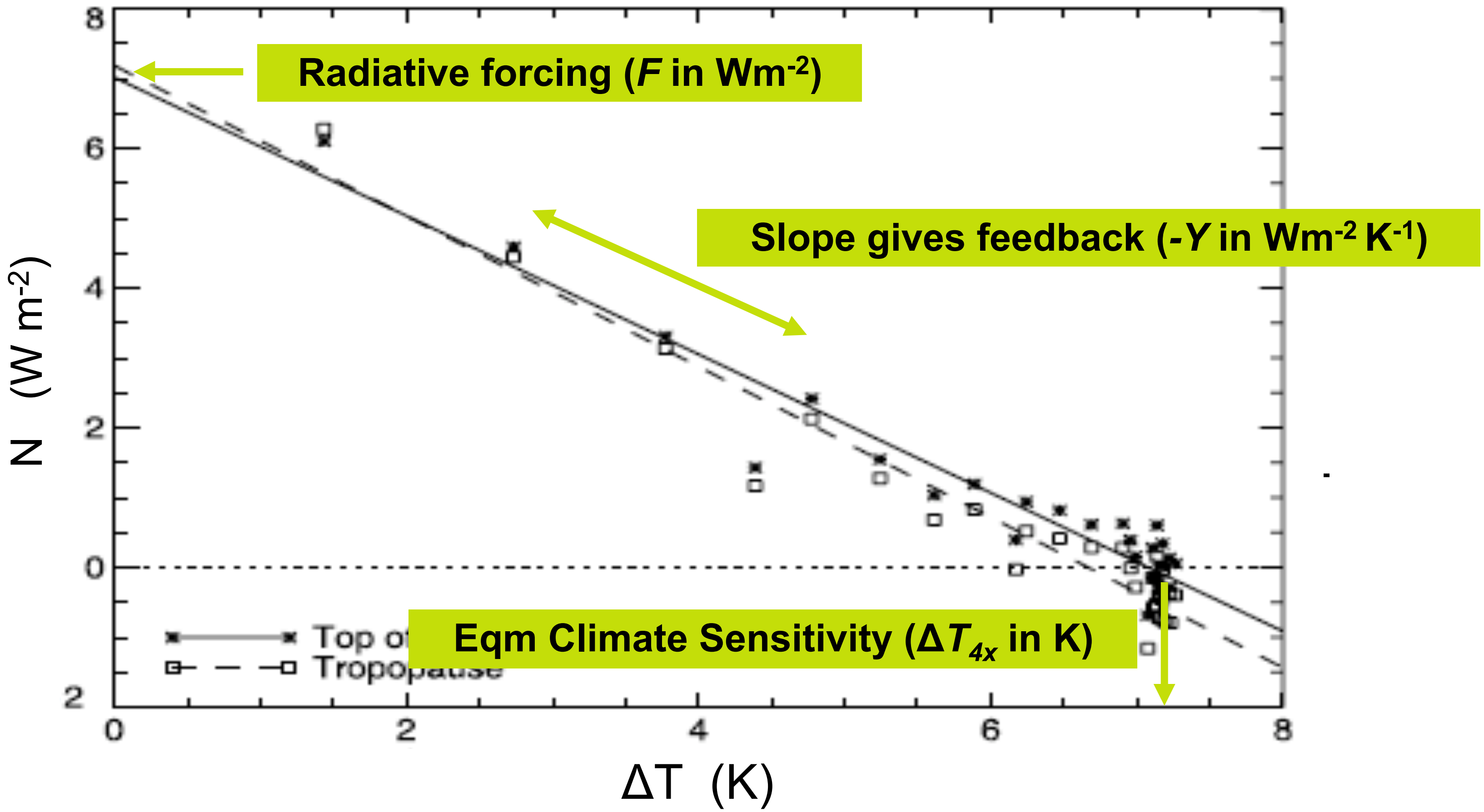
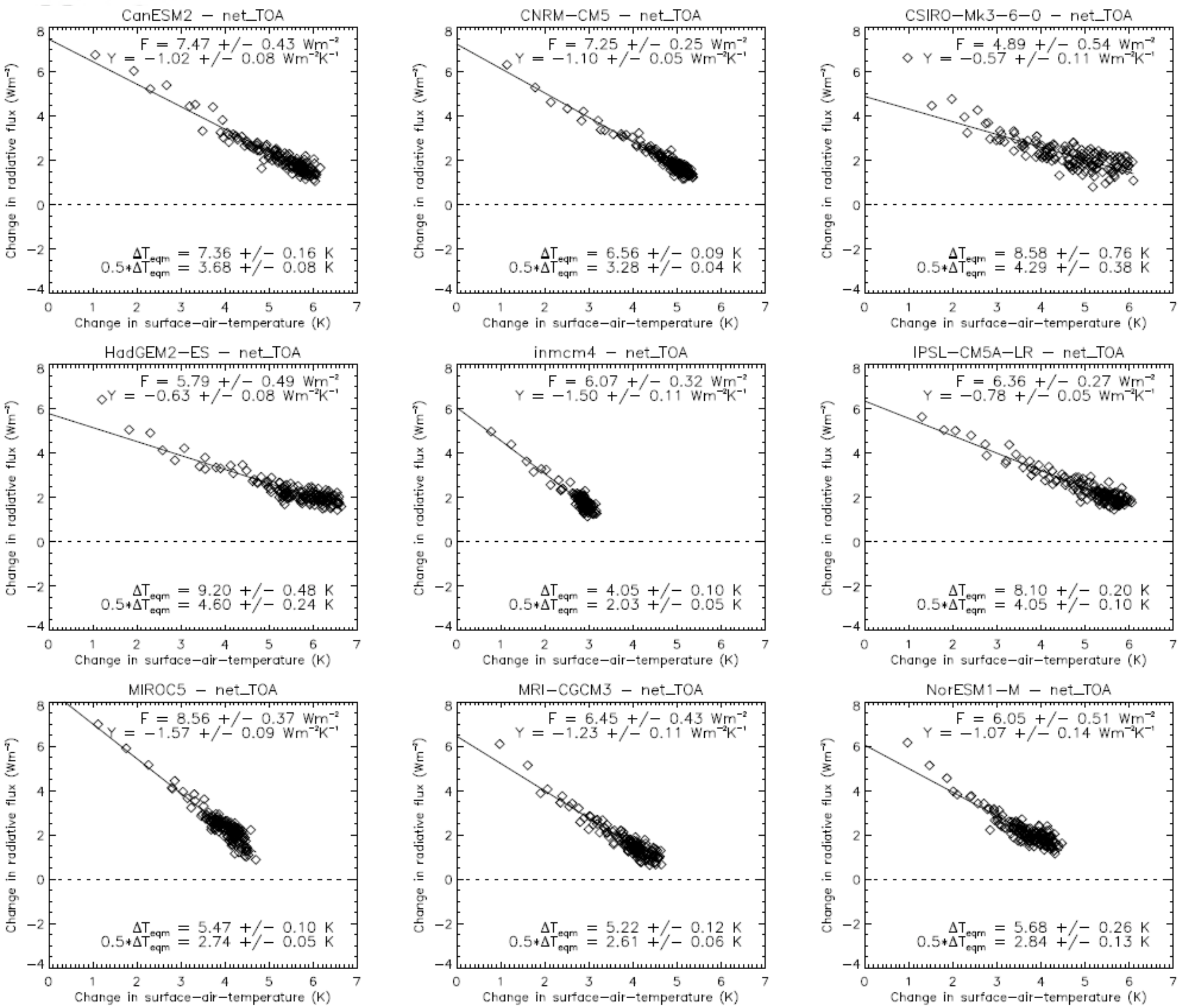


In CMIP5, we will only be part way along this curve…

CMIP5 Models



Ranges

Climate fdbk (-Y) =

0.6 – 1.6 W m^{-2} / K

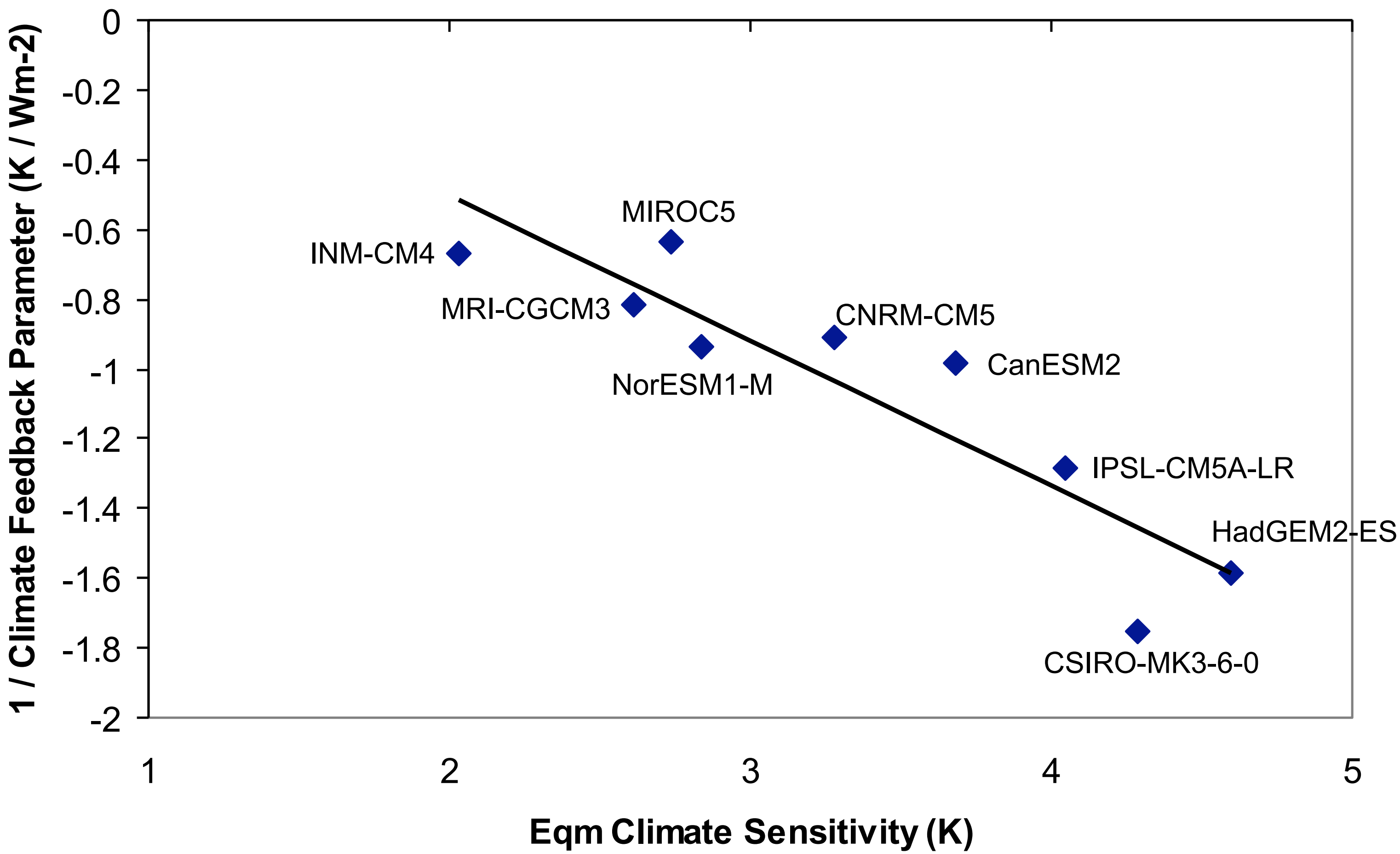
Forcing =

4.9 – 8.6 W m^{-2}

$2xCO_2$ equilibrium climate sensitivity =

2.0 – 4.6 K

Equil. Climate sensitivity vs. the inverse of the feedback parameter



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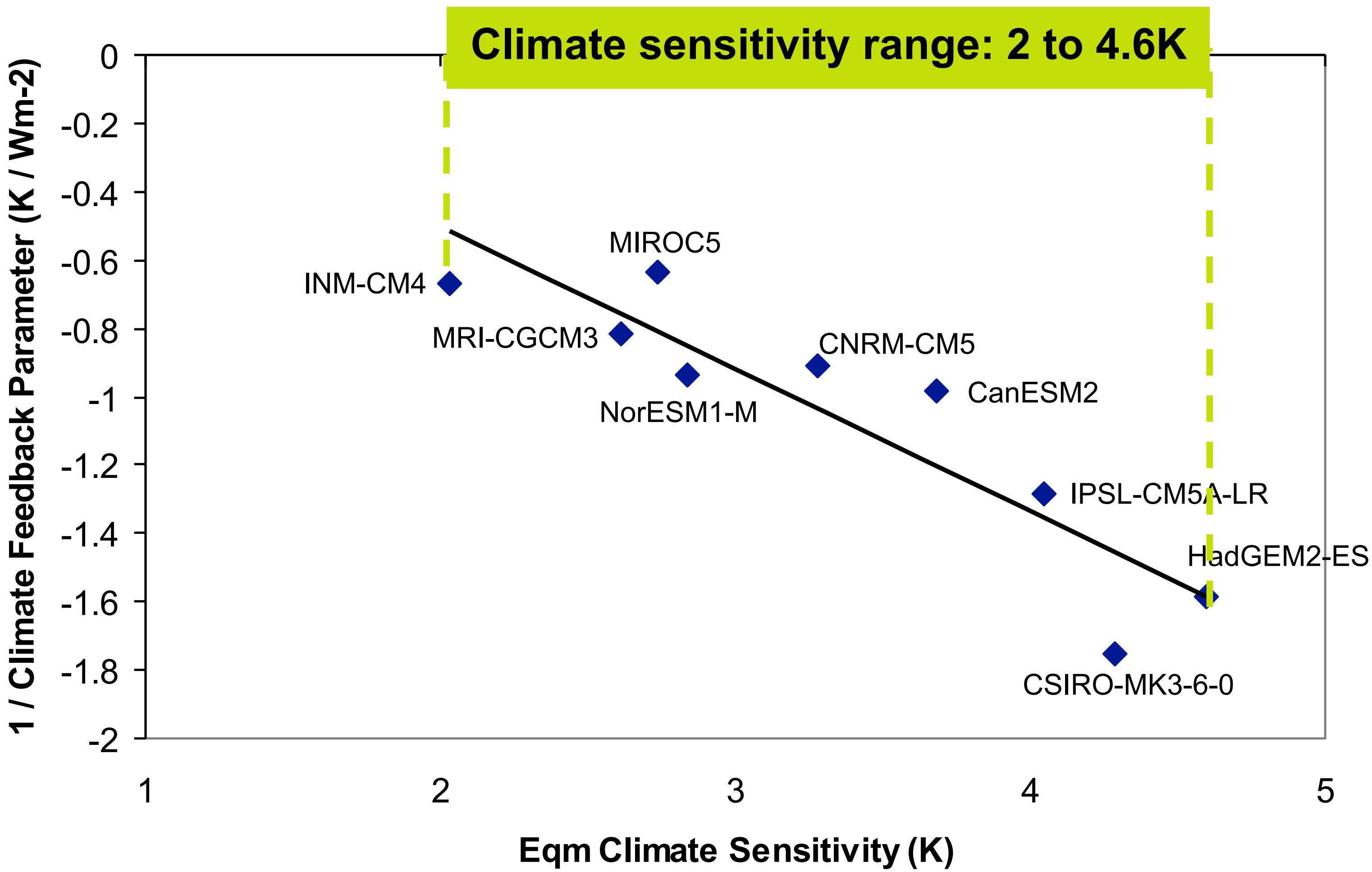

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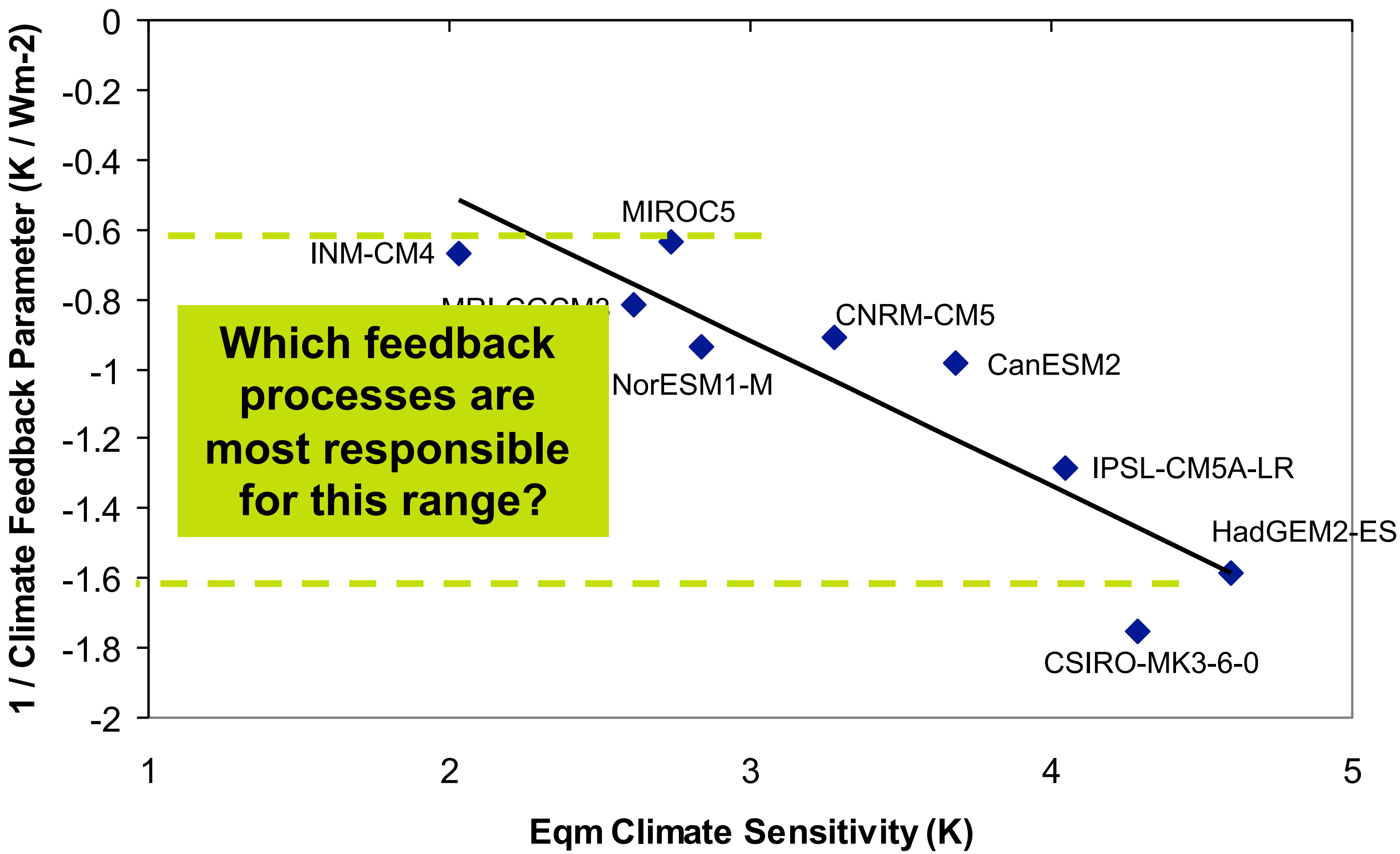
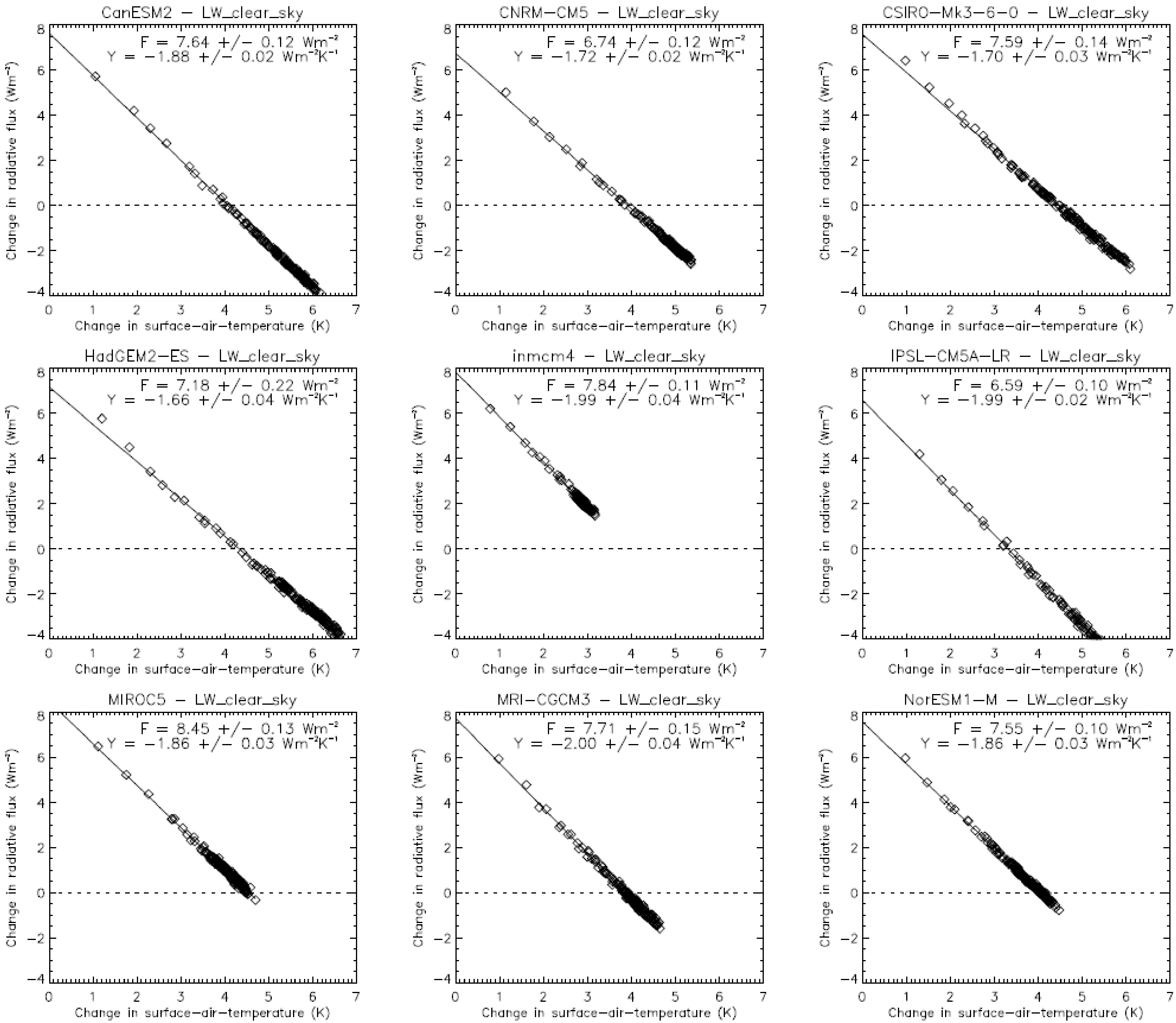
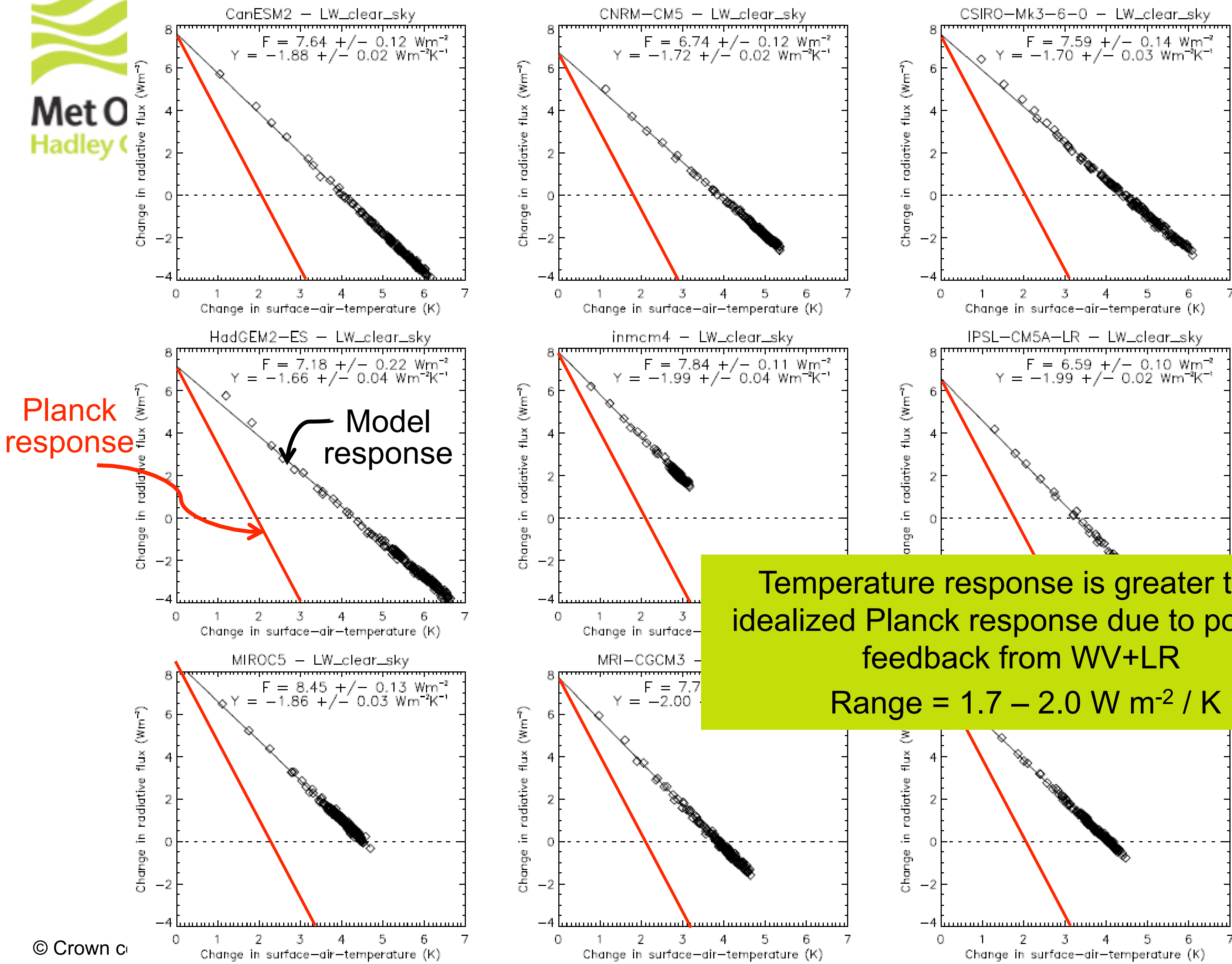


LW Clear-sky



CanESM2 – LW_clear_sky
F = 7.64 +/– 0.12 Wm^{-2}
Y = –1.88 +/– 0.02 Wm^{-2}K^{-1}
CNRM-CM5 – LW_clear_sky
F = 6.74 +/– 0.12 Wm^{-2}
Y = –1.72 +/– 0.02 Wm^{-2}K^{-1}
CSIRO–Mk3–6–0 – LW_clear_sky
F = 7.59 +/– 0.14 Wm^{-2}
Y = –1.70 +/– 0.03 Wm^{-2}K^{-1}
HadGEM2–ES – LW_clear_sky
F = 7.18 +/– 0.22 Wm^{-2}
Y = –1.66 +/– 0.04 Wm^{-2}K^{-1}
inmcm4 – LW_clear_sky
F = 7.84 +/– 0.11 Wm^{-2}
Y = –1.99 +/– 0.04 Wm^{-2}K^{-1}
IPSL–CM5A–LR – LW_clear_sky
F = 6.59 +/– 0.10 Wm^{-2}
Y = –1.99 +/– 0.02 Wm^{-2}K^{-1}
MIROC5 – LW_clear_sky
F = 8.45 +/– 0.13 Wm^{-2}
Y = –1.86 +/– 0.03 Wm^{-2}K^{-1}
MRI–CGCM3 – LW_clear_sky
F = 7.71 +/– 0.15 Wm^{-2}
Y = –2.00 +/– 0.04 Wm^{-2}K^{-1}
NorESM1–M – LW_clear_sky
F = 7.55 +/– 0.10 Wm^{-2}
Y = –1.86 +/– 0.03 Wm^{-2}K^{-1}
Change in radiative flux (Wm^{-2})
Change in surface–air–temperature (K)

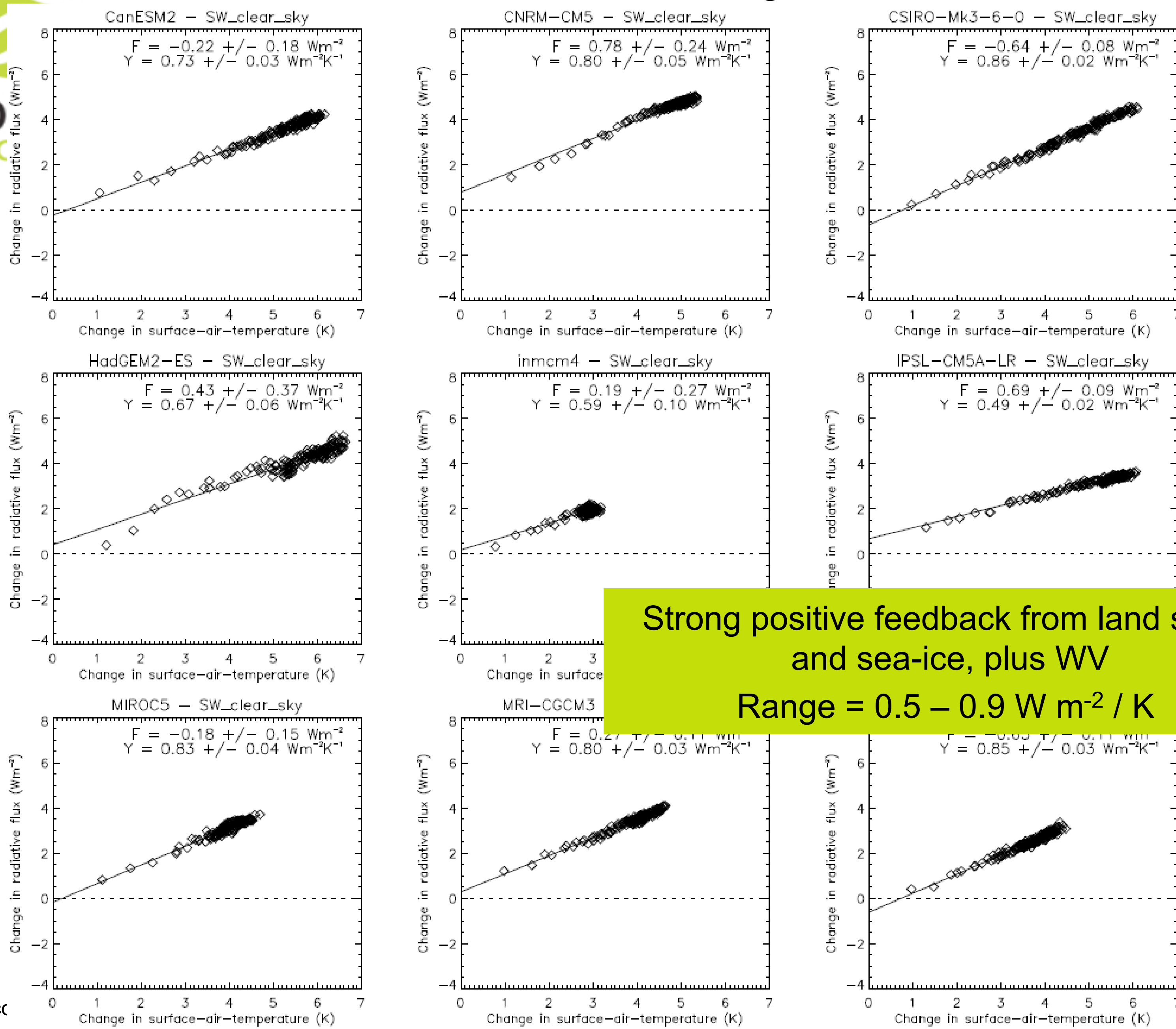
LW Clear-sky



Temperature response is greater than idealized Planck response due to positive feedback from WV+LR

Range = 1.7 – 2.0 W m^{-2} / K

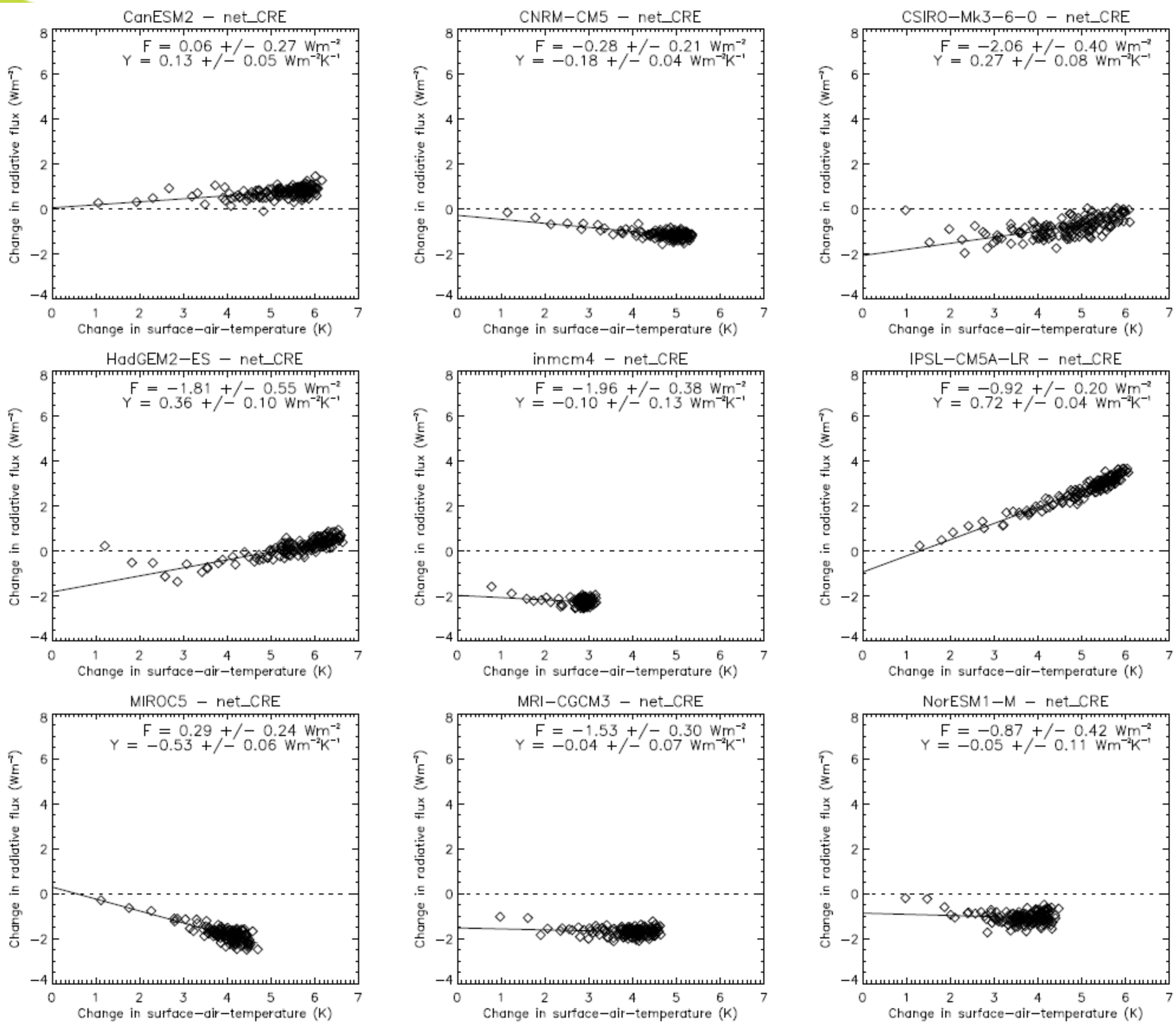
SW Clear-sky



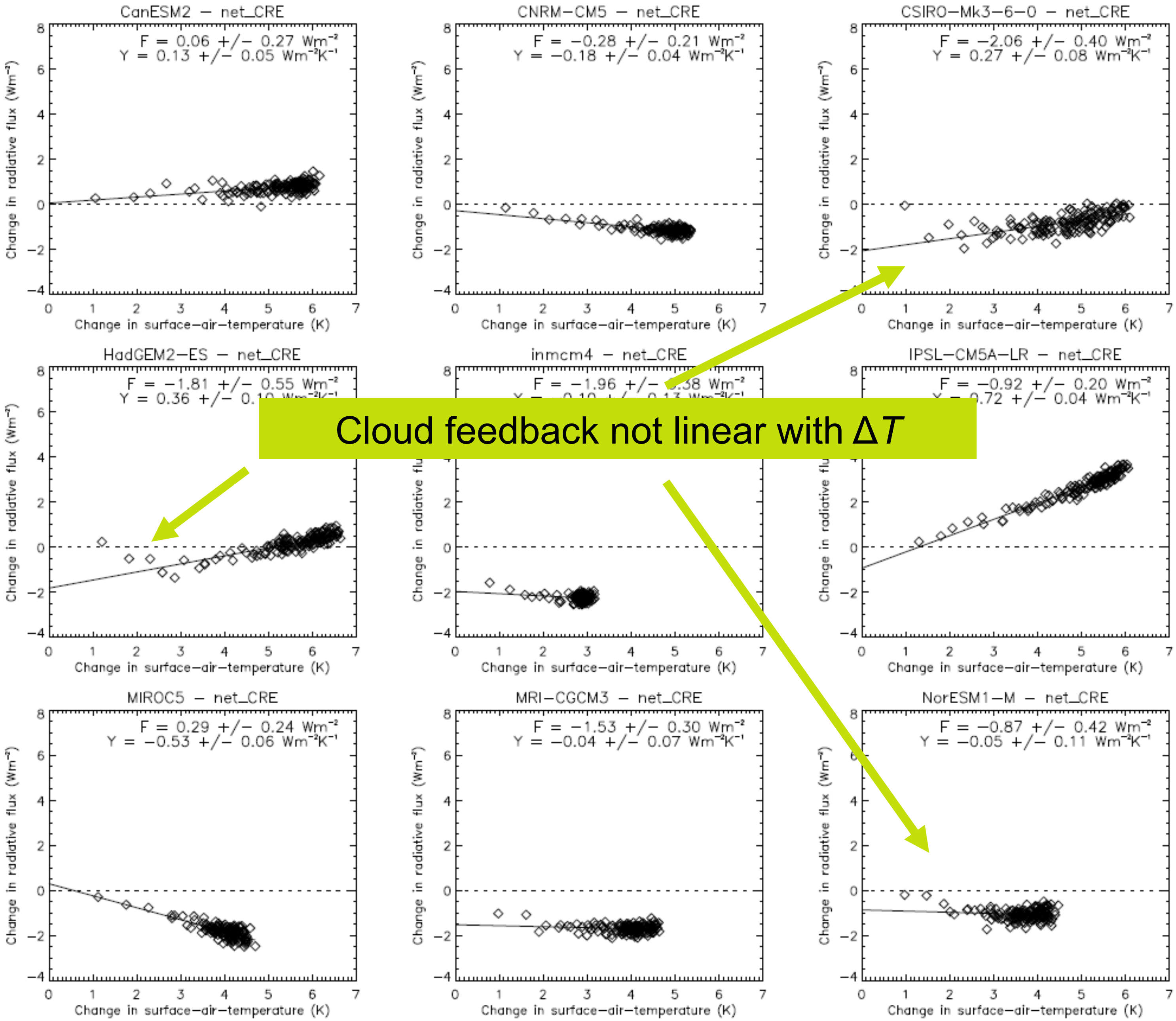
Strong positive feedback from land snow and sea-ice, plus WV

Range = 0.5 – 0.9 W m^{-2} / K

Cloud Radiative Effect

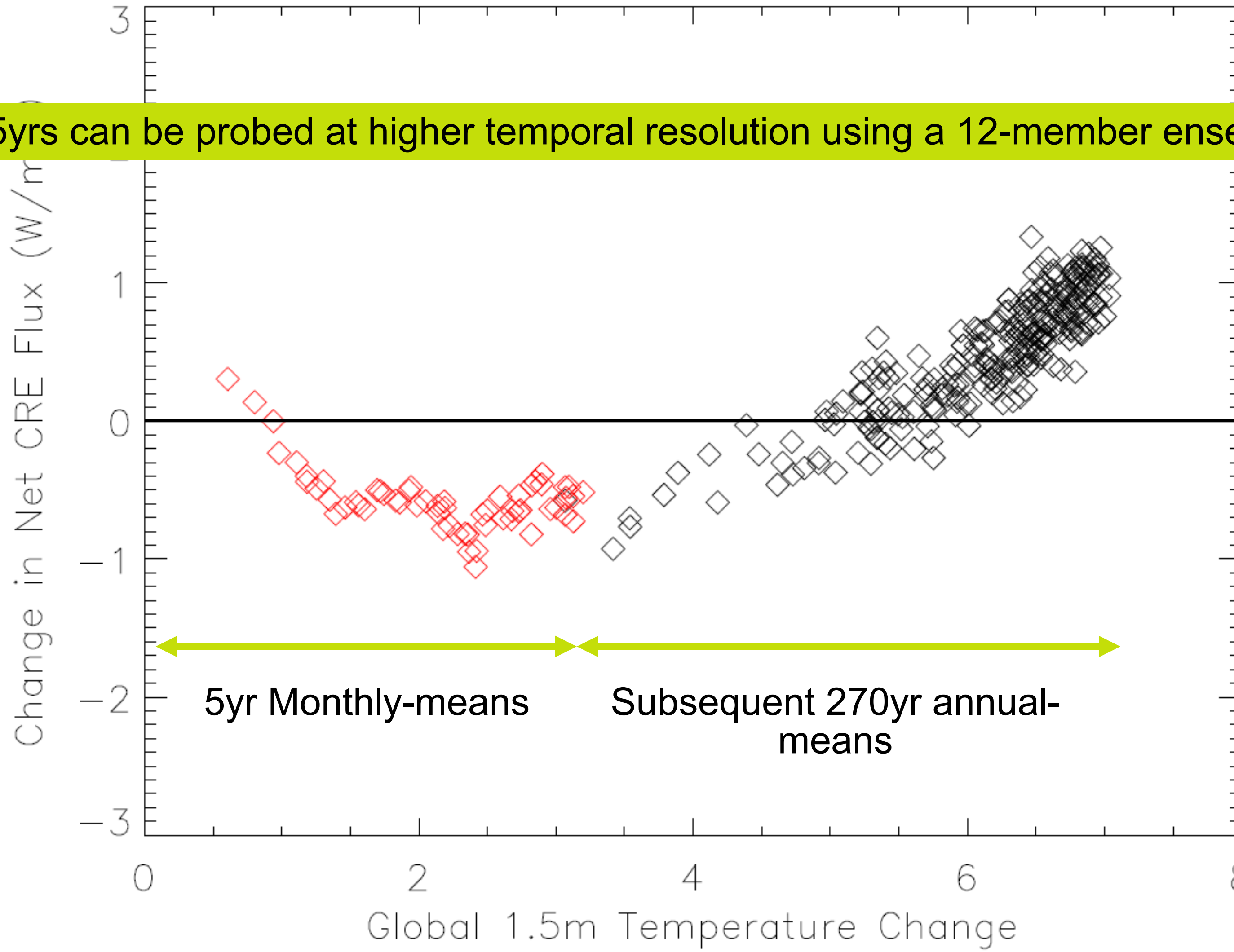


Cloud Radiative Effect



Cloud response in a 270yr 4xCO_2 HadGEM2-ES simulation

The initial 5yrs can be probed at higher temporal resolution using a 12-member ensemble



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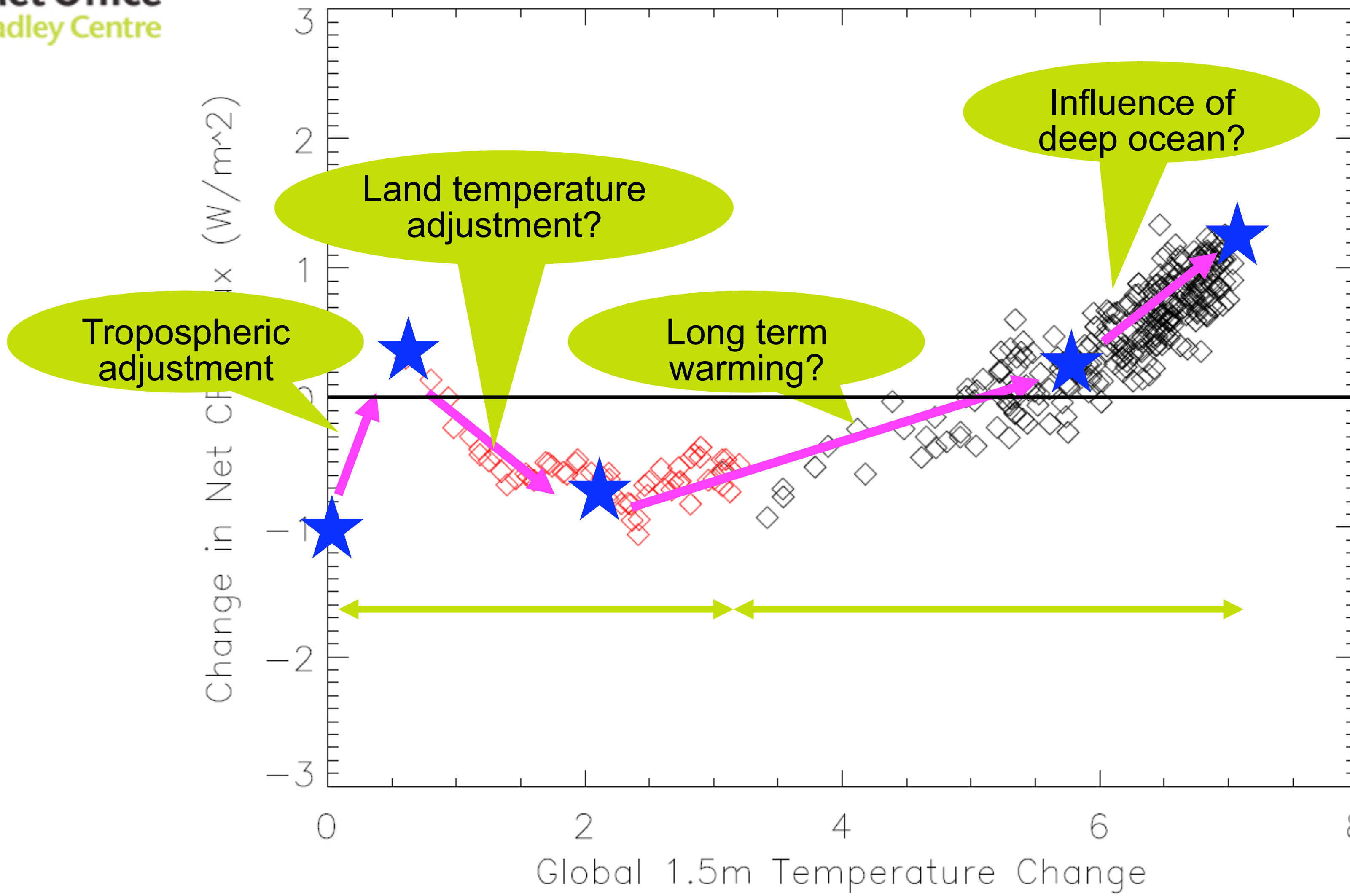
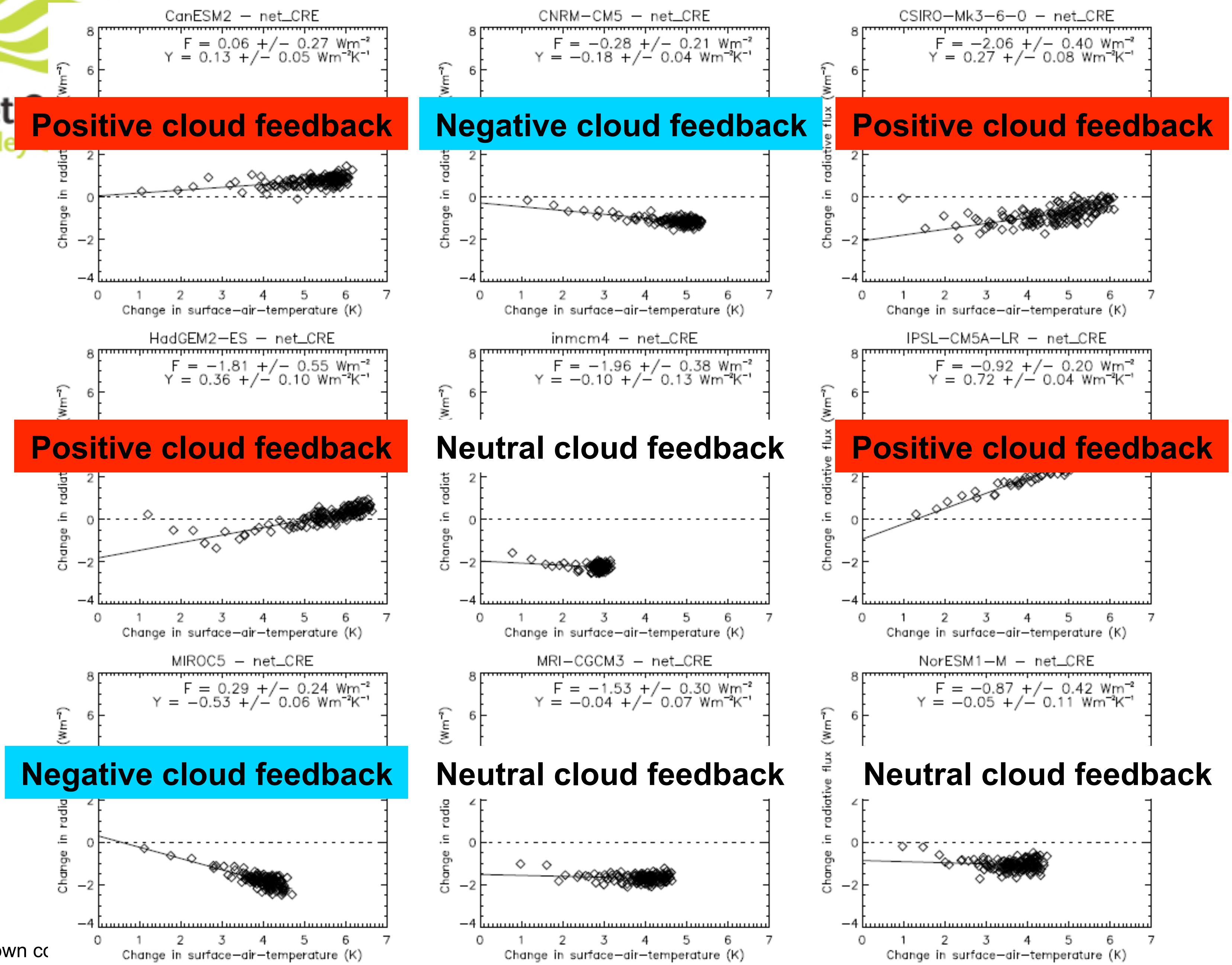
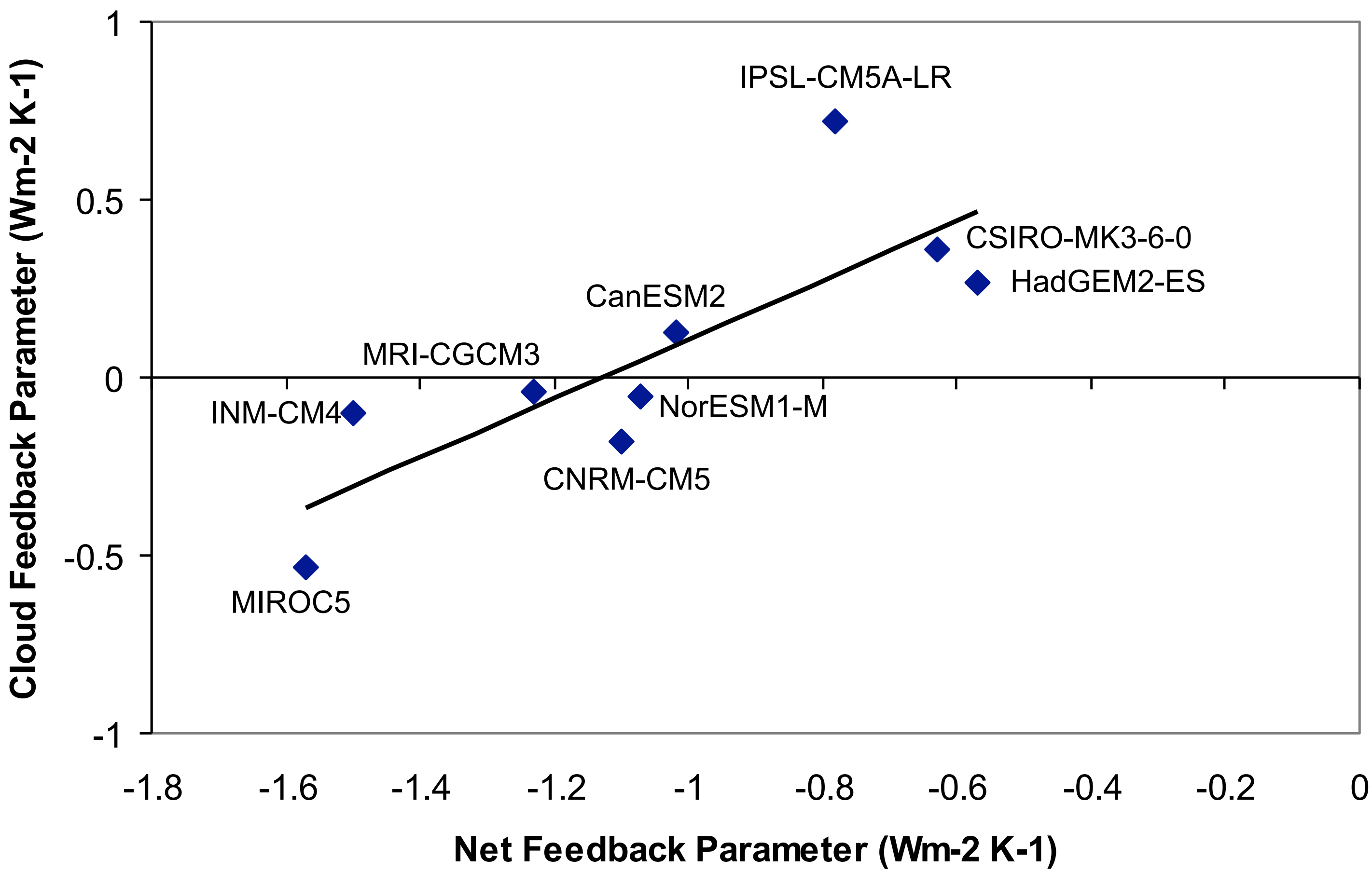


‘Long term’ Cloud Feedback



Cloud effect feedback vs. total feedback



Differences in cloud feedback continue to be the largest (but not the only) source of uncertainty in feedbacks (range from –0.5 $Wm^{-2} K^{-1}$ to +0.7 $Wm^{-2} K^{-1}$)

Summary

- For the first time, Gregory method applied to a multi-model ensemble of coupled atmosphere-ocean models
- Preliminary results show that the range of equilibrium climate sensitivity has not decreased and that differences in cloud feedback, once again, appear to be a large source of this uncertainty.
- There are limitations on the methods used when applied to models with full oceans. Estimating both forcing and equilibrium climate change become more difficult.
- These systems are perhaps better characterized by a time-evolving feedback parameter.
- Future work:
  - More models
  - Analysis of 12-member 5-year ensembles
  - Comparison of forcing estimates with those derived using the fixed-SST method
  - More complete analysis of feedbacks

Discussion: How important will Earth system feedbacks be in CMIP5 models?

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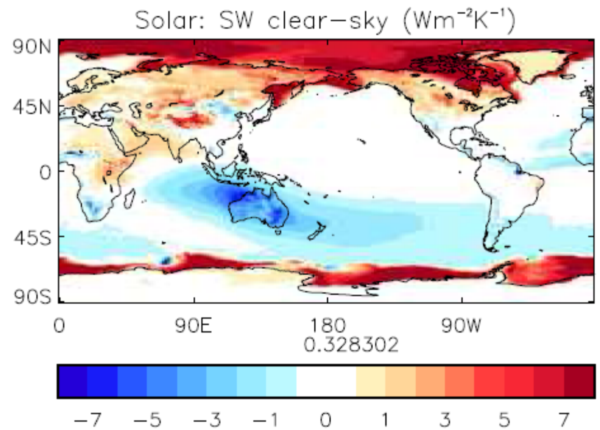
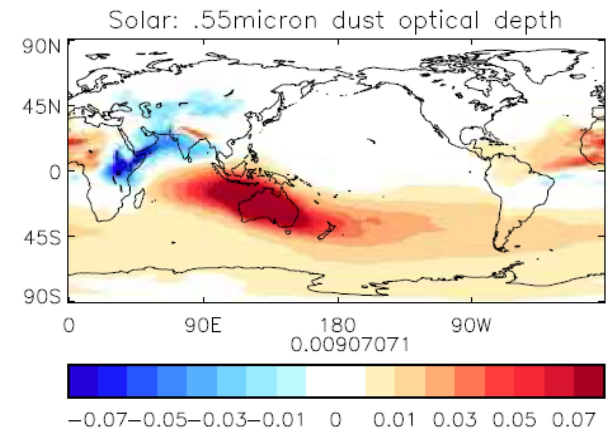
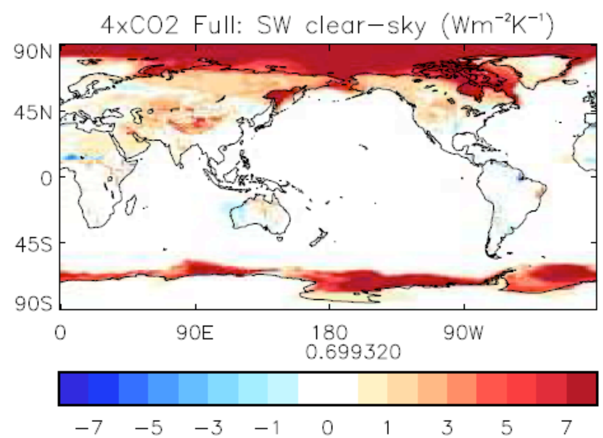
HadGEM2-ES Solar:

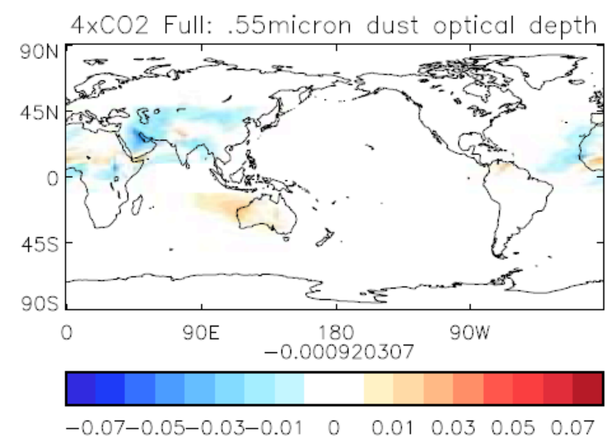




Strong negative SW clear-sky feedback under solar forcing from desertification of Australia kicking up dust

HadGEM2-ES $4xCO_2$:





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