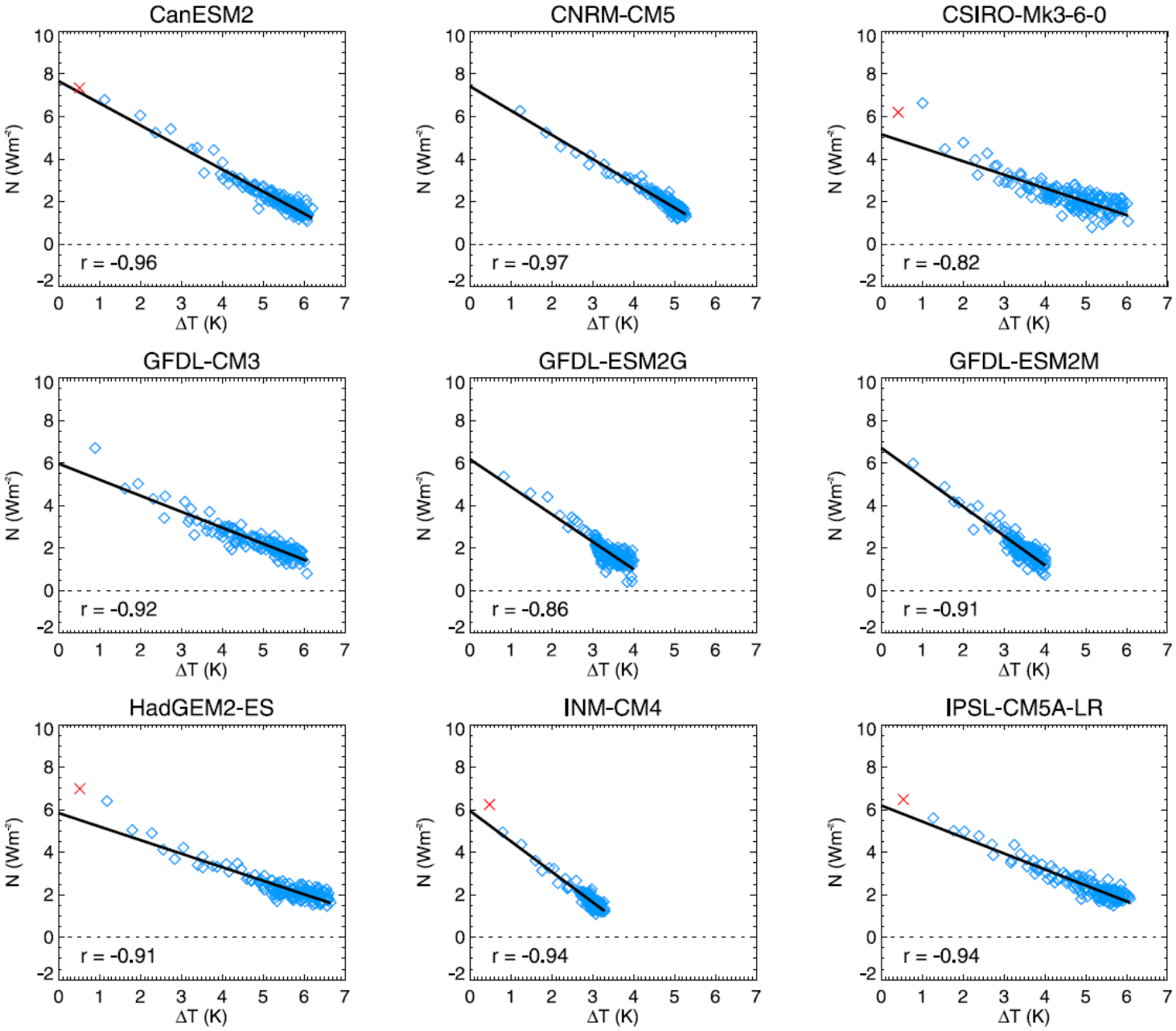
The non-linear dependence of radiative feedbacks on global temperature change

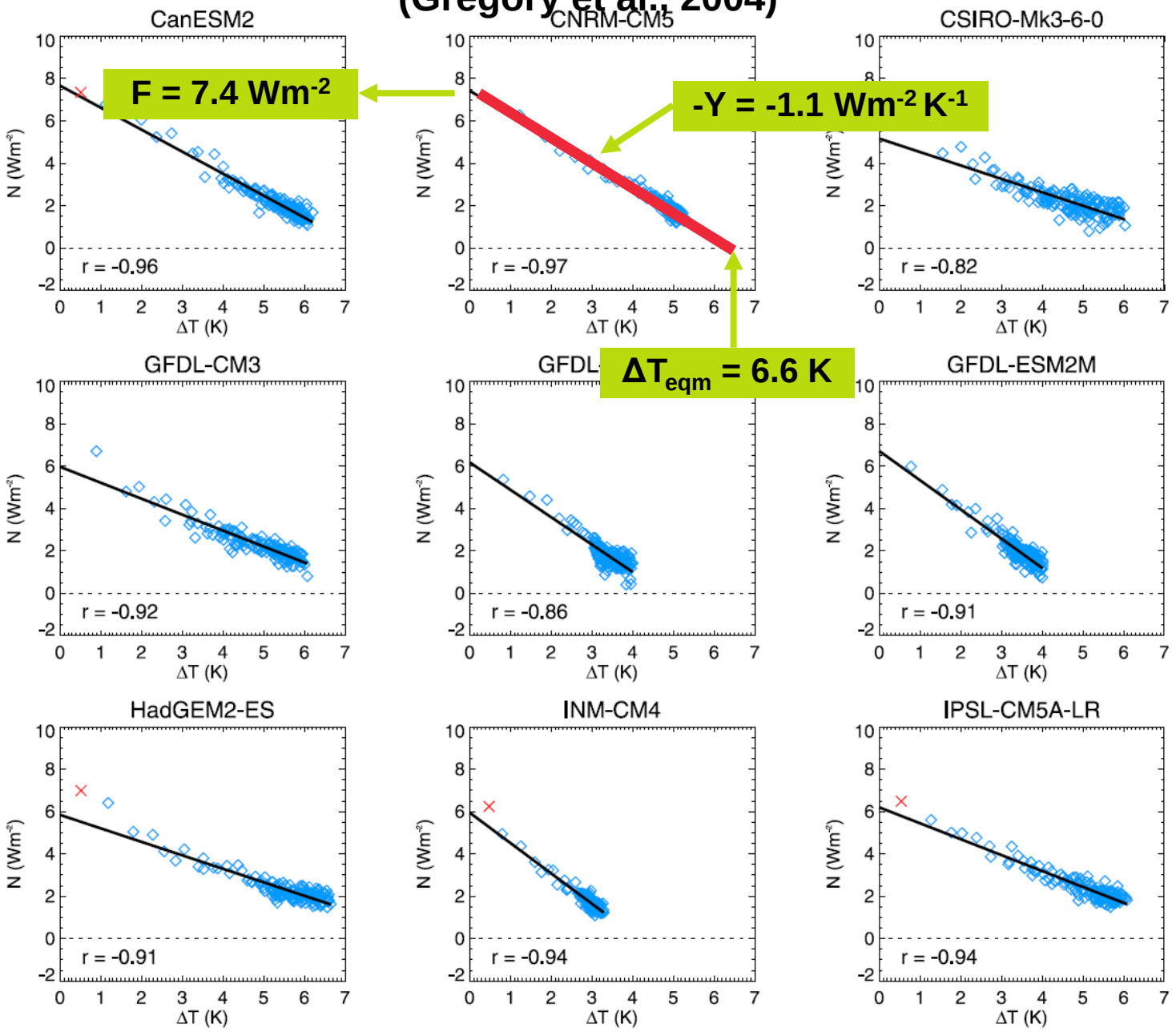
Timothy Andrews, Jonathan Gregory and Mark Webb

CFMIP – July 2014

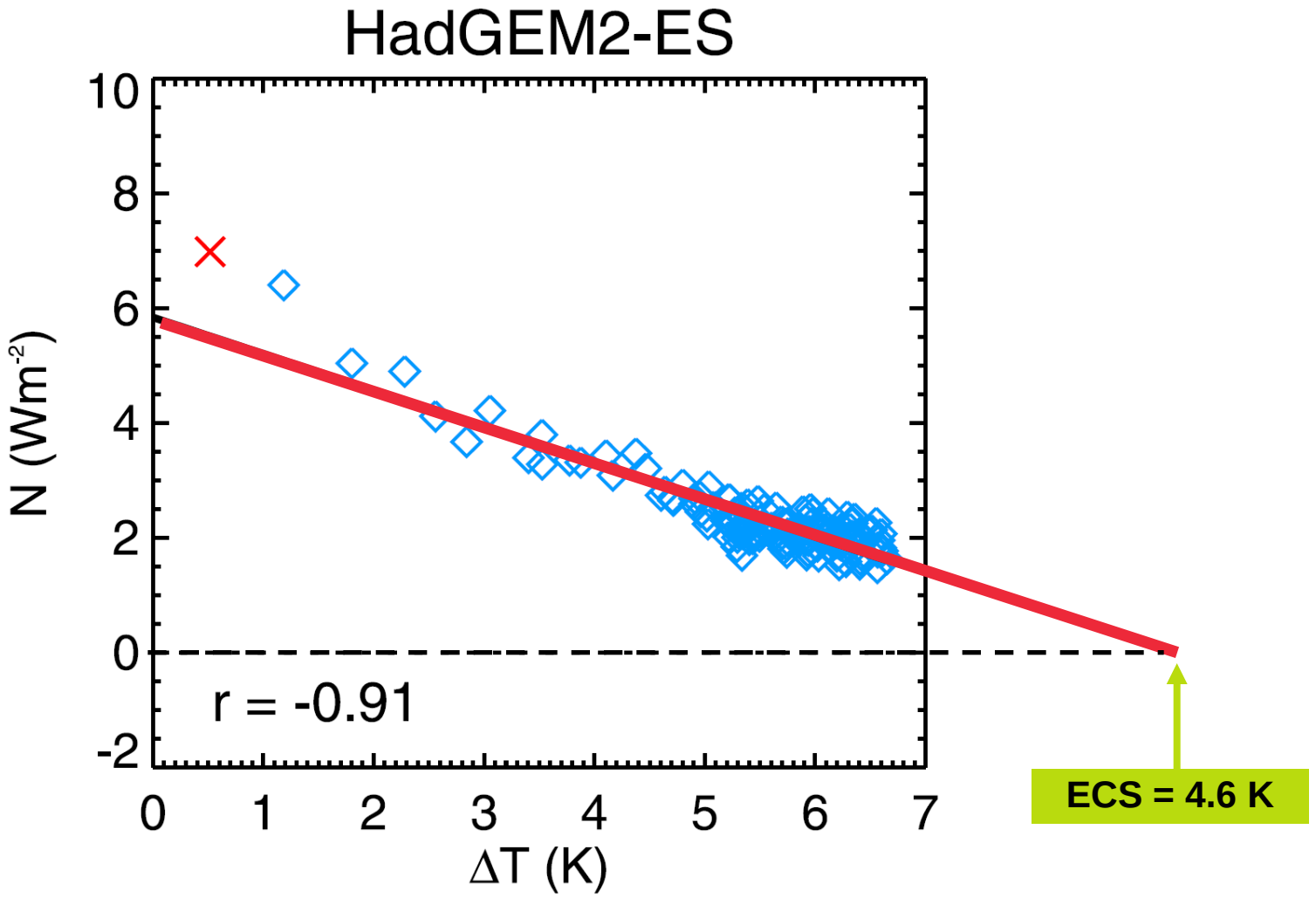
CMIP5 Gregory plots to estimate F, Y and ECS



Feedback strengths assumed constant in linear forcing-feedback paradigm (Gregory et al., 2004)



But feedback strengths appear to evolve…



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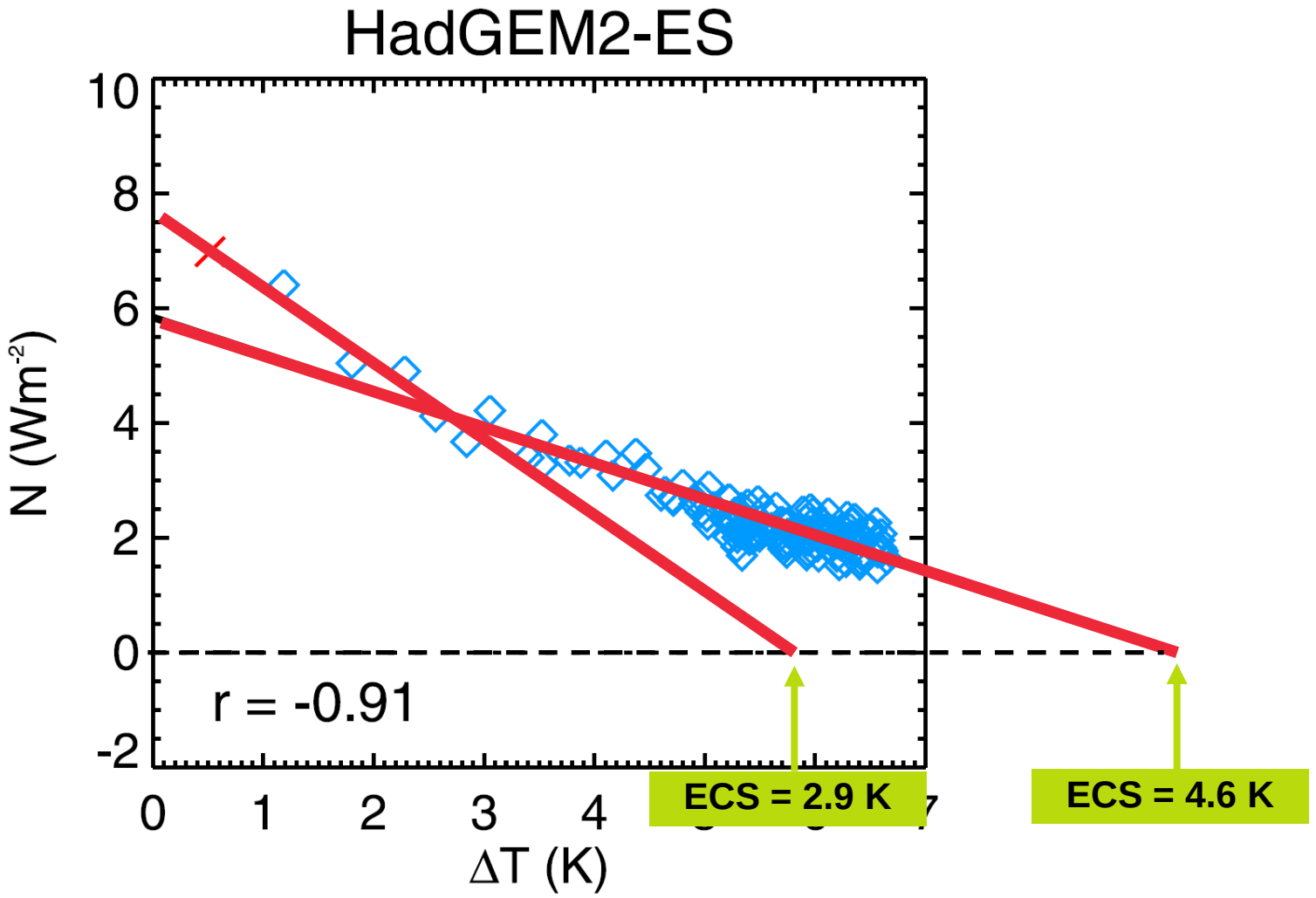

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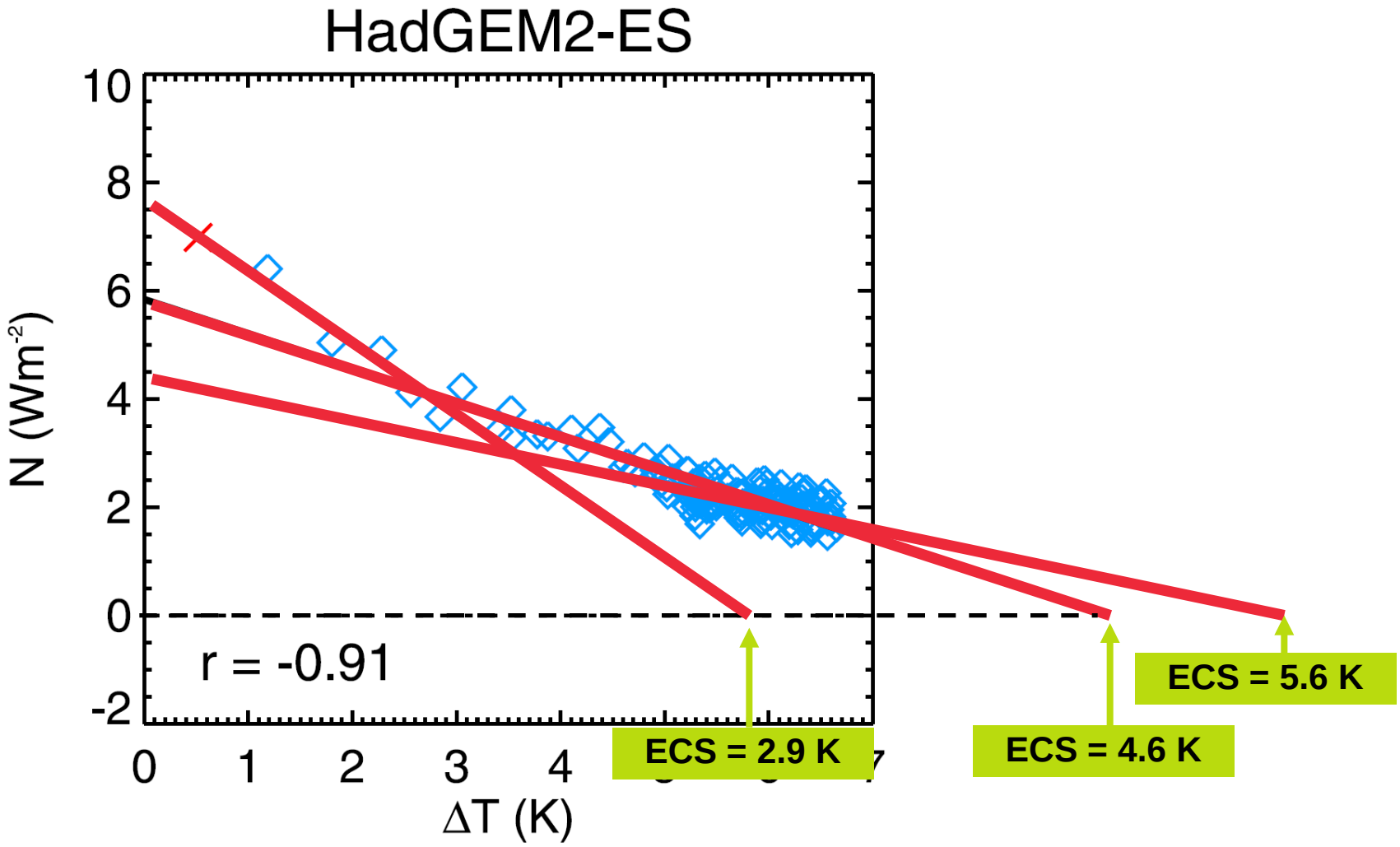
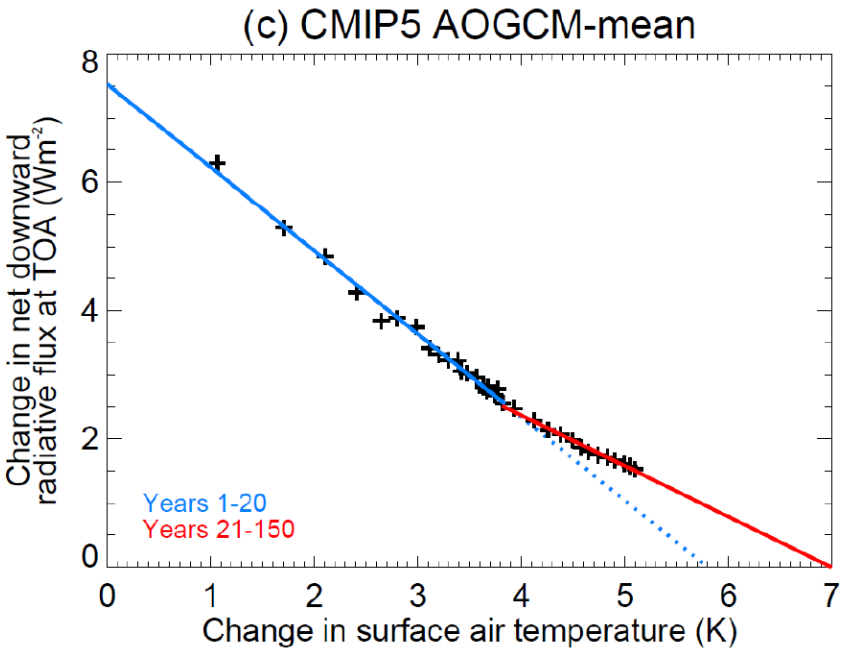
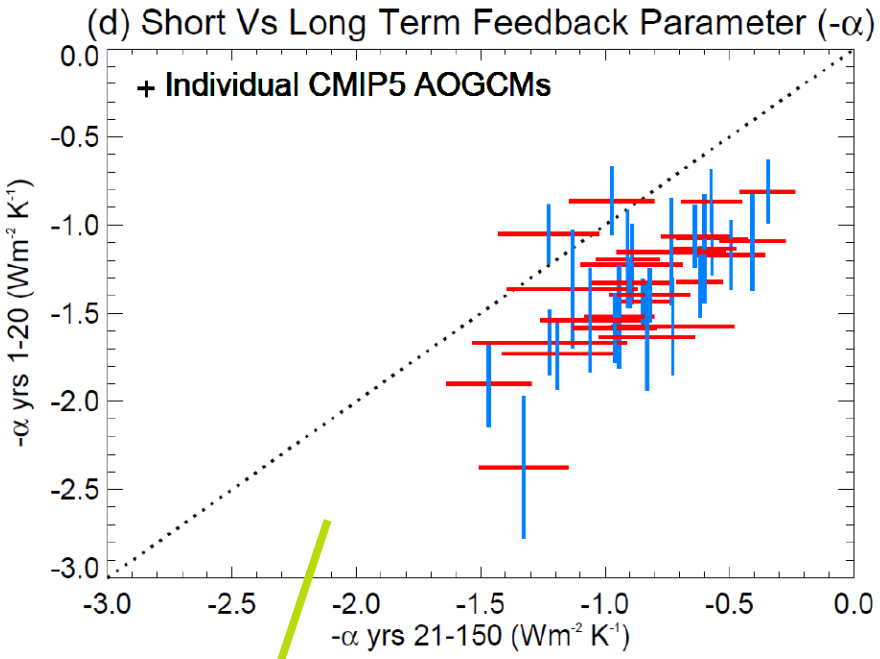


Strengthening positive feedbacks in abrupt4xCO2 is a largely robust result across CMIP5 AOGCMs

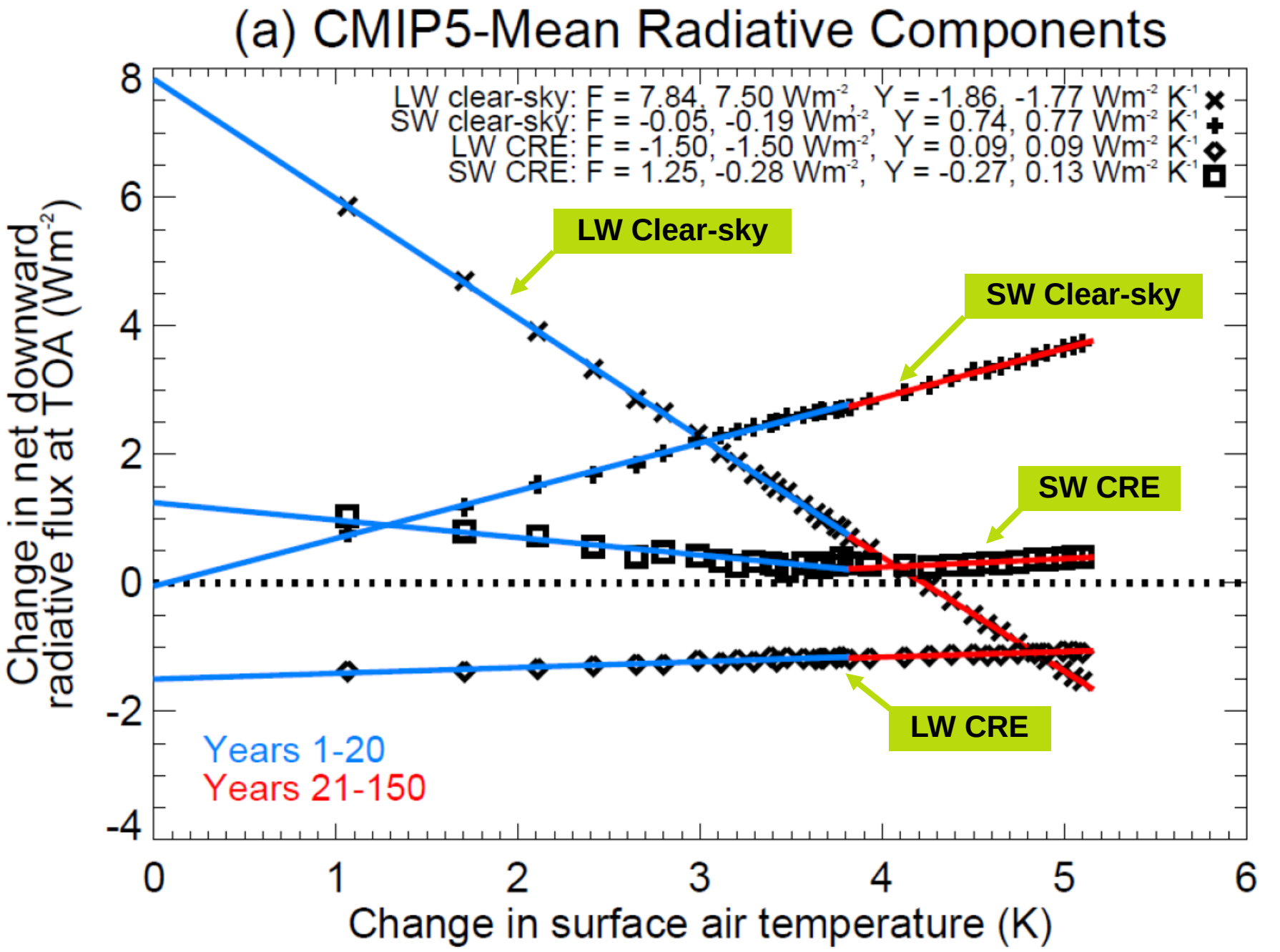


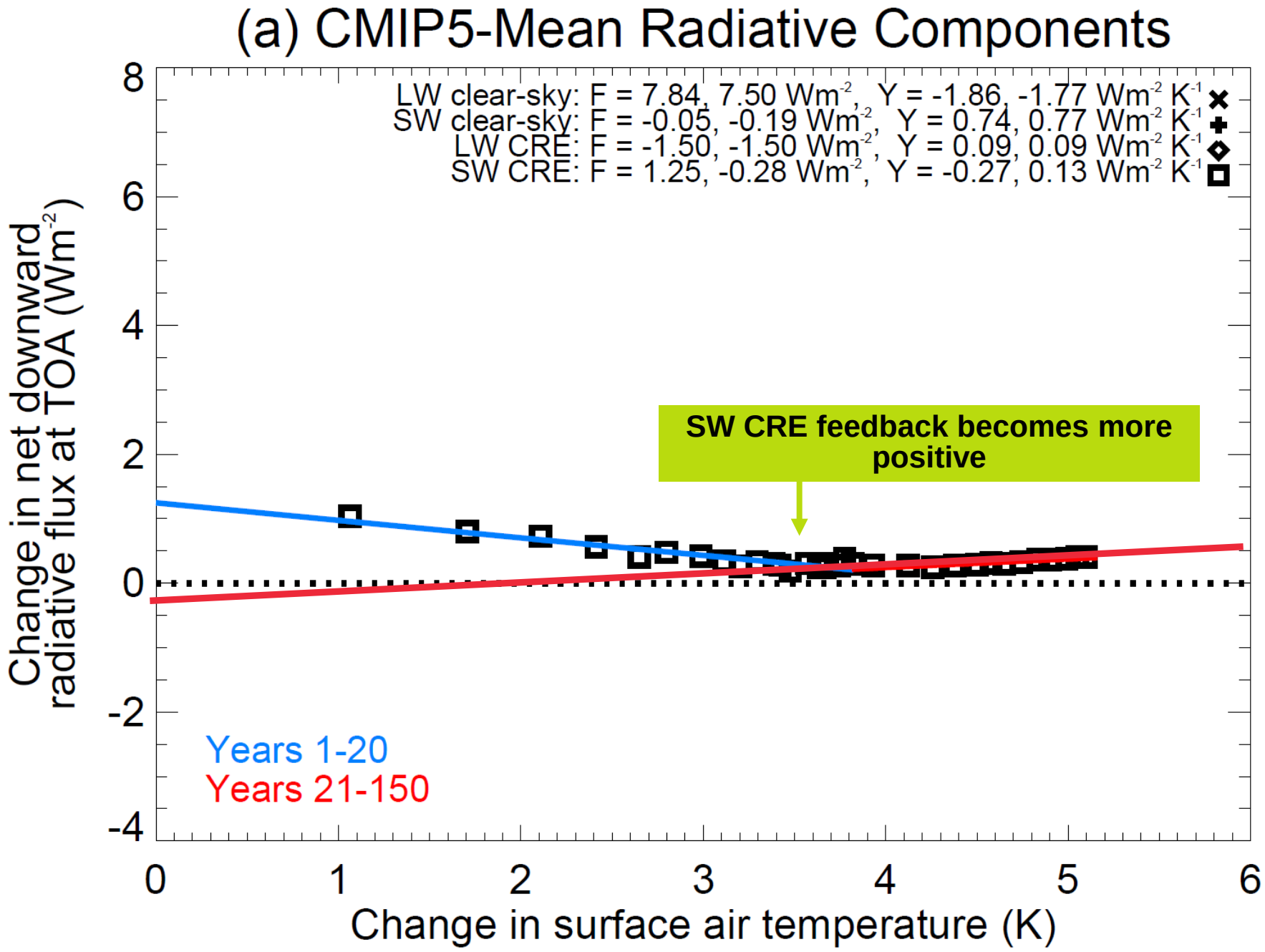


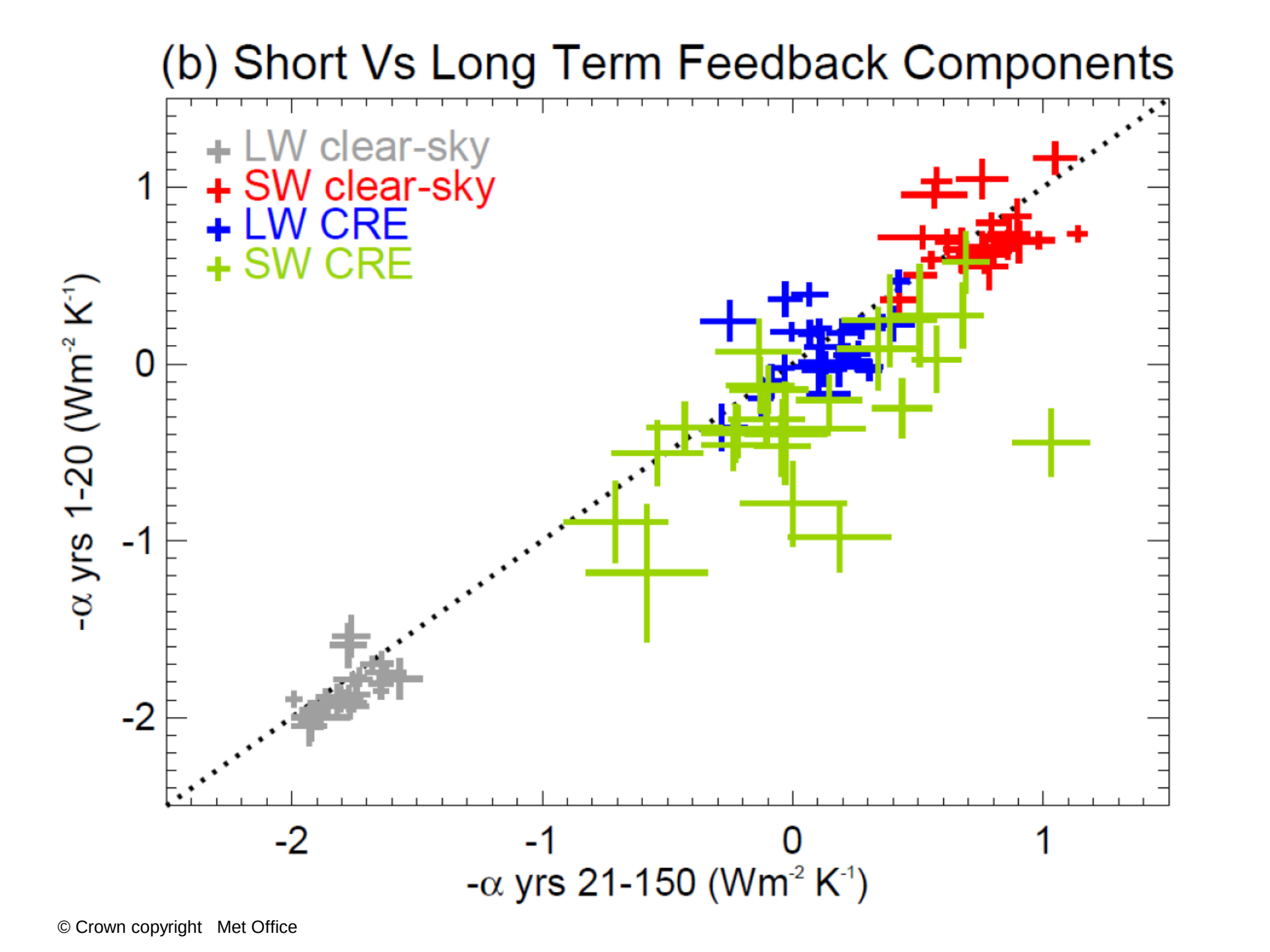
23 out of 27 AOGCMs simulate a significant (95% CI) change in feedback parameter: feedbacks and ECS becomes more positive as time passes

What could cause non-linear feedbacks with dT?

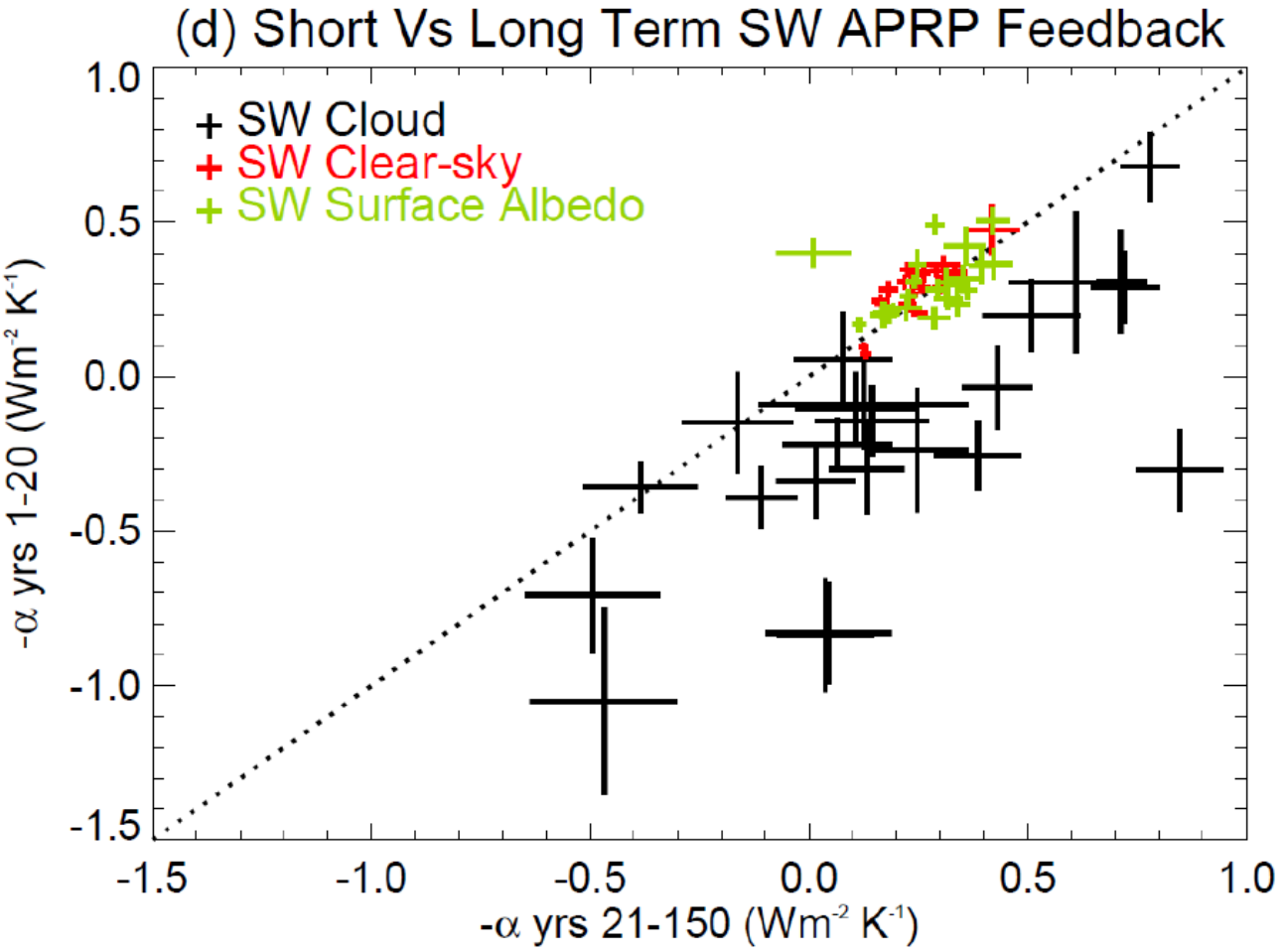
- Some climate feedbacks could be *state dependent* (characterised by global T)
  - Sea-ice/snow-cover feedbacks diminish are climate warms
  - WV feedback strengths with T (Meraner et al., 2013)
- Some feedbacks will have *timescales not closely tied to dT*
  - Vegetation changes
  - Ice sheets
- Some feedbacks, particularly cloud feedback, maybe sensitive to an *evolving pattern of surface warming* in AOGCMs (Senior and Mitchell, 2000)
- **Rest of this talk**:
  - We are not trying to quantify non-linearity, nor fit a curve or develop new conceptual frameworks (e.g. Winton et al., 2010; Geoffroy et al., 2013; Armour et al., 2013).
  - We will try to understand it, develop a hypothesis and test it.

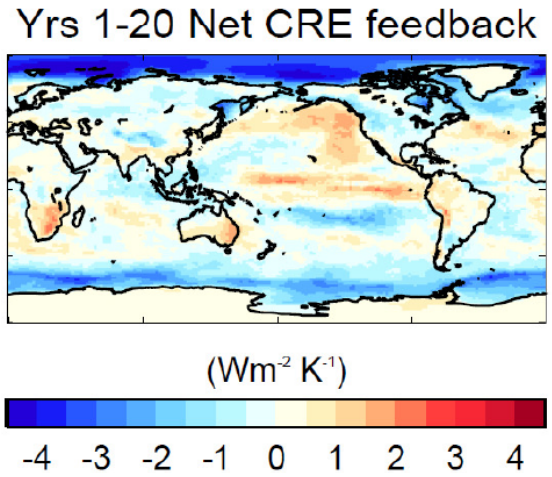


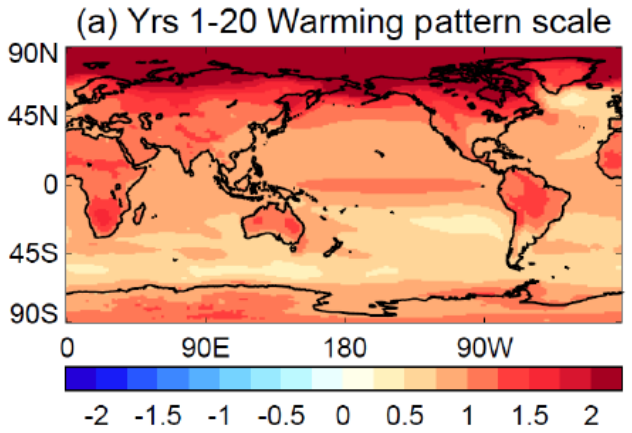




SW APRP (Taylor et al., 2007) analysis confirms that changes in cloud properties are responsible for strengthening of cloud feedback, not masking effects







- So cloud cause it, but why?

- Hypothesis: cloud feedback is sensitive to an evolving pattern of surface warming in AOGCMs

Met Office
Hadley Centre

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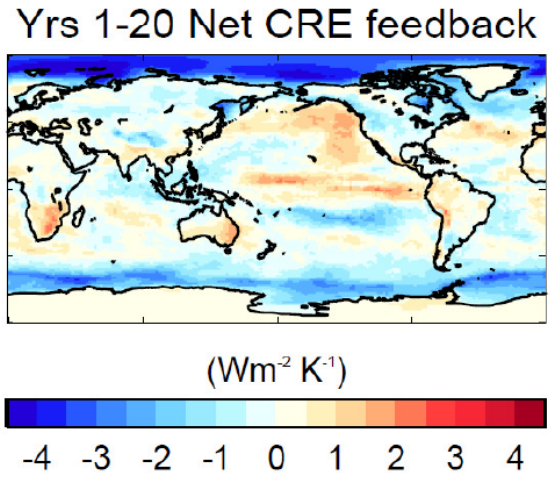

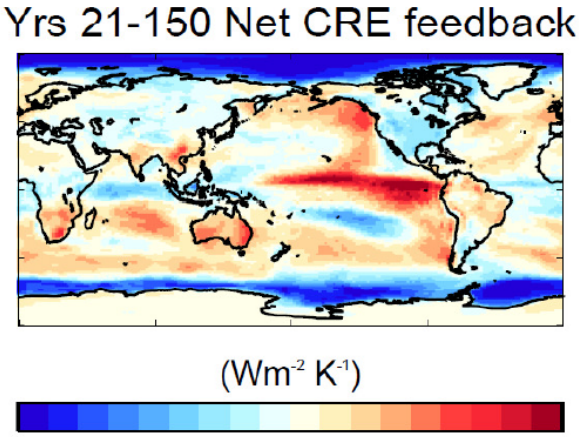

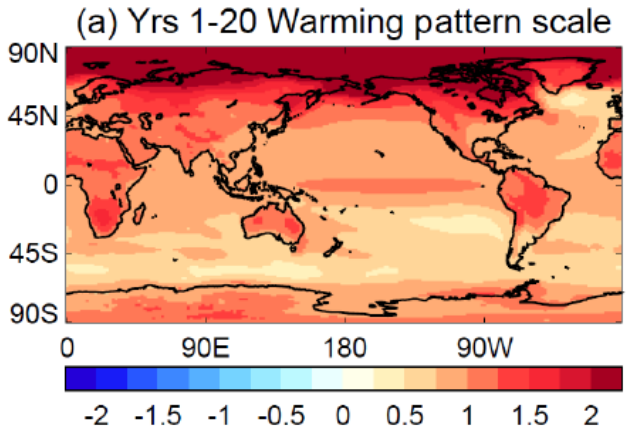

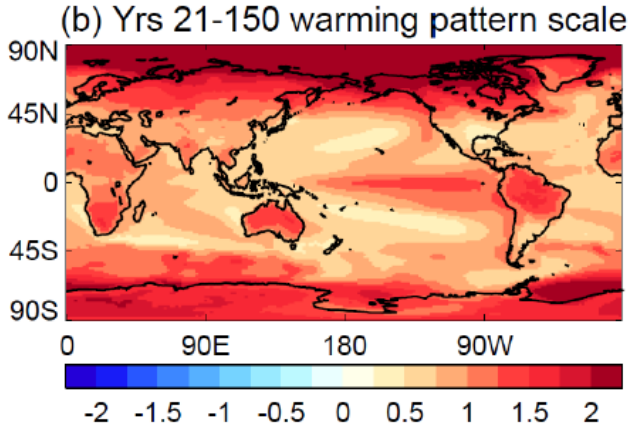

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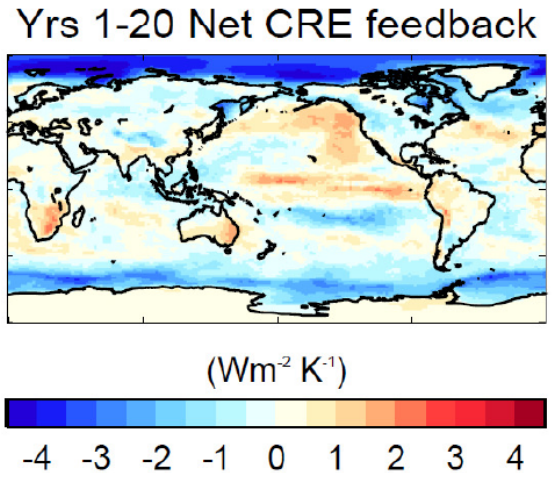
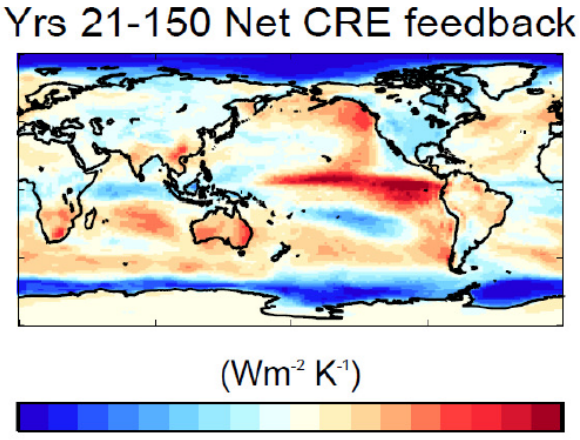
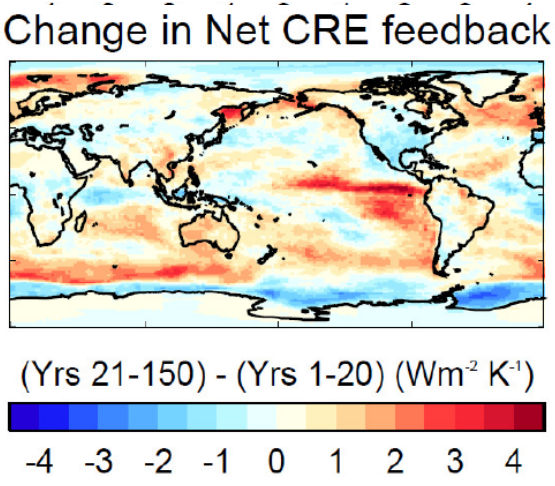
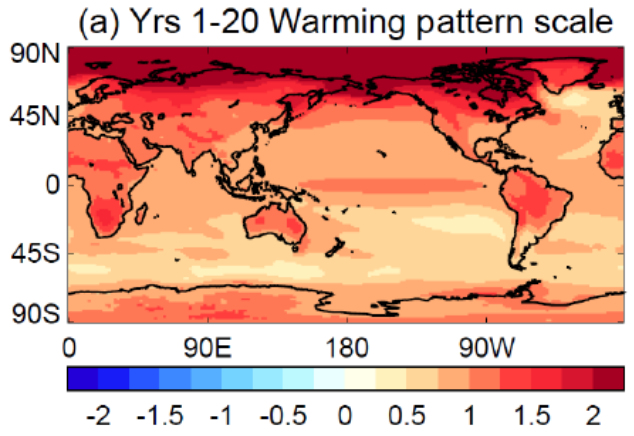
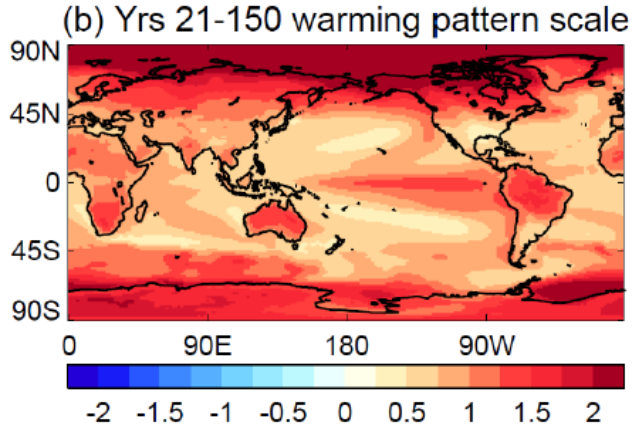
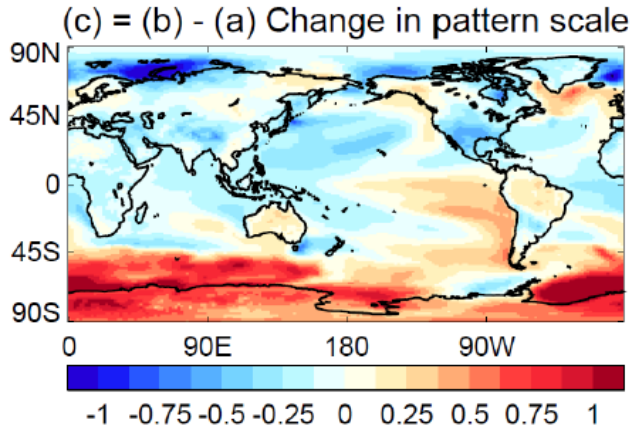




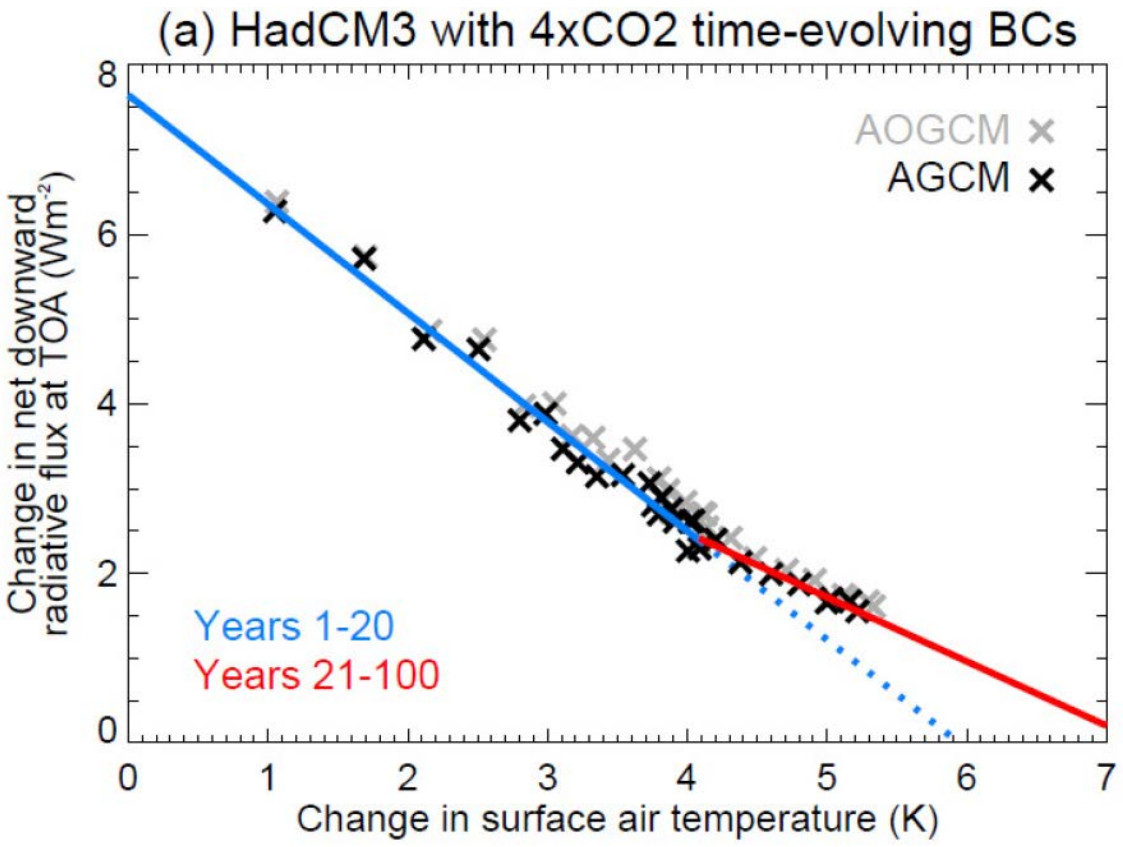








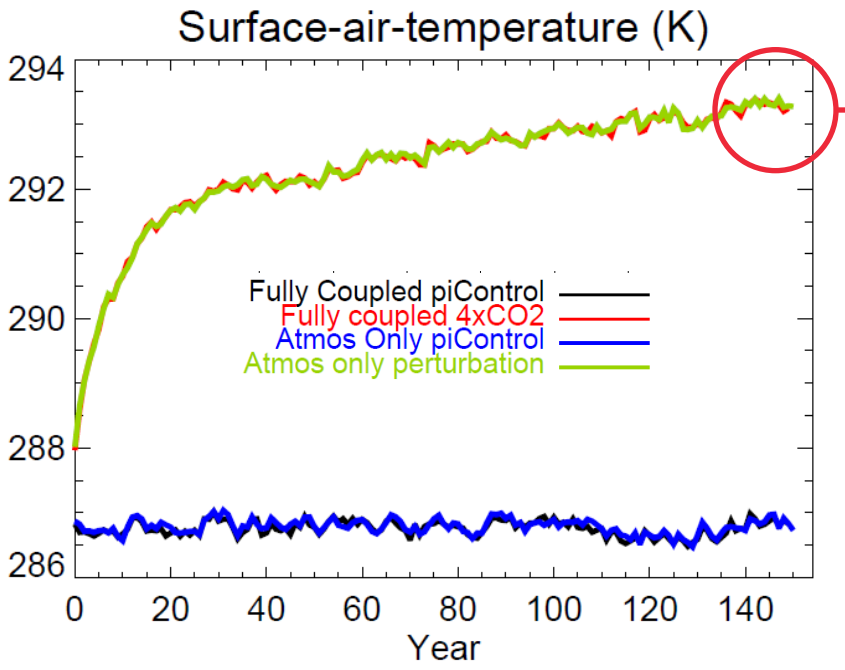
Test the hypothesis by fixing the pattern of warming

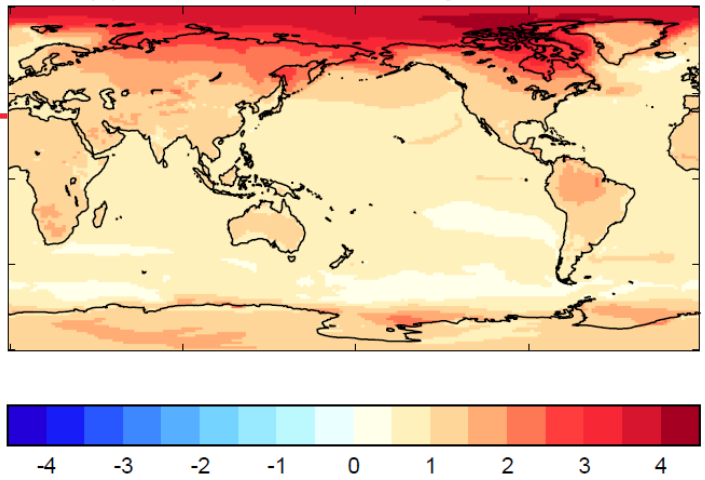


(i) First replicate the AOGCM by forcing AGCM with CO2 and monthly SST and sea-ice boundary conditions from the AOGCM output

Reproduces the curvature within an AGCM framework, allows us to test hypothesis…

Test the hypothesis by fixing the pattern of warming

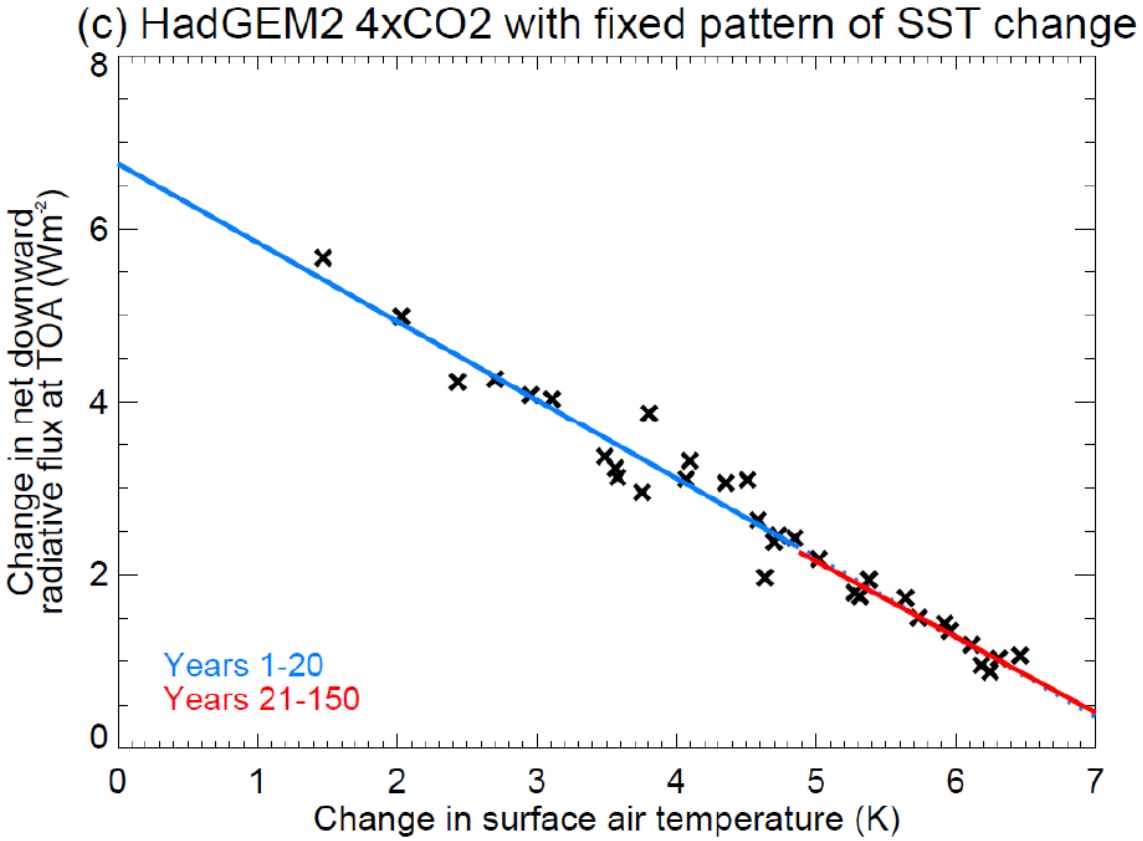




(ii) Now take a monthly pattern of warming, scale by monthly dT and add it to control

forces model to take same global dT path as AOGCM but with fixed pattern of warming

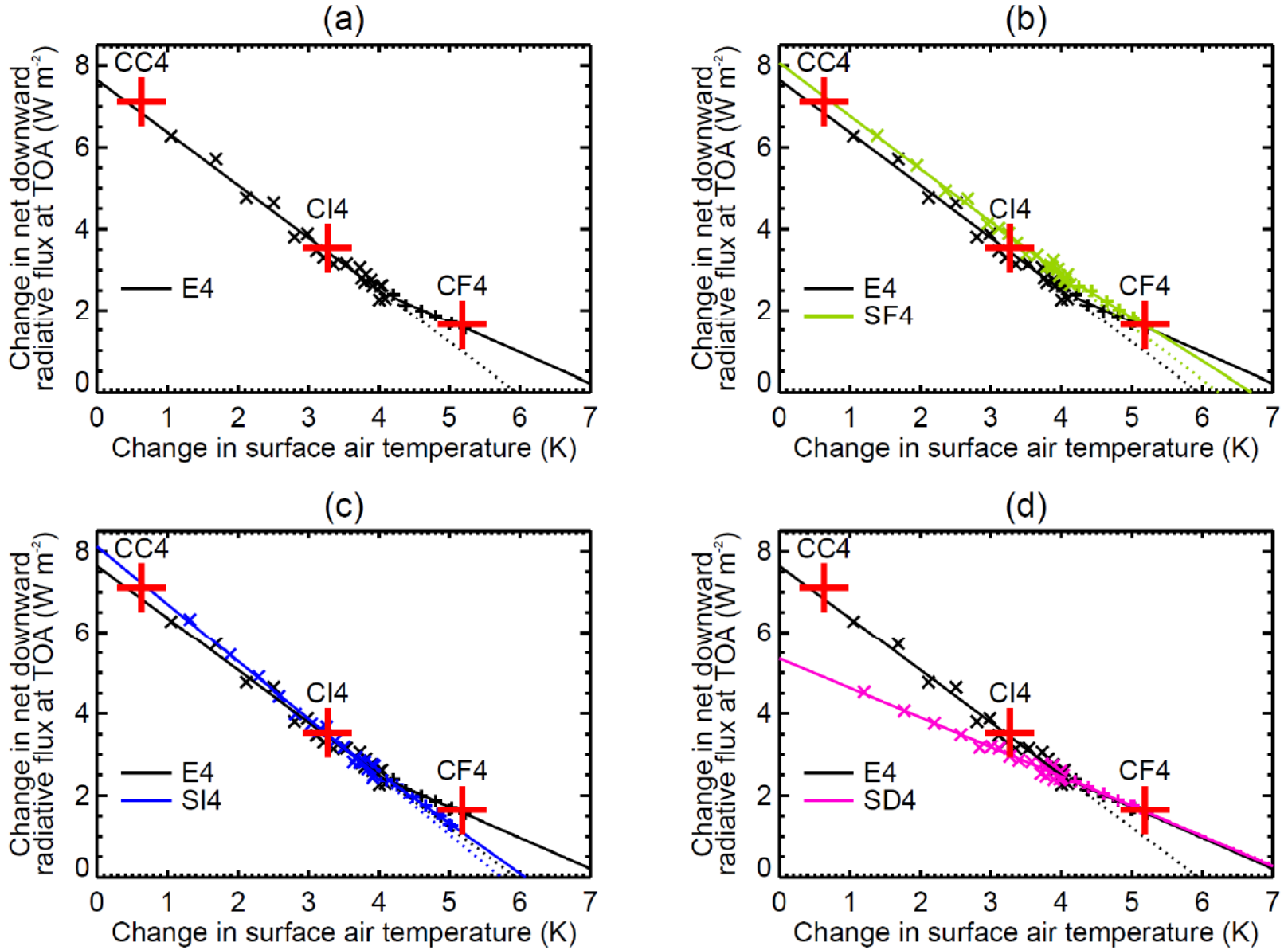
Test the hypothesis by fixing the pattern of warming



Radiative feedbacks are now linear with dT if the SST patterns are prevented from evolving

Points an evolving pattern of surface warming in AOGCMs as the dominant cause of time-varying cloud feedbacks

AGCM design is very powerful. We can replicate, and hence explain, any part of (N,dT) space by the different patterns of SST change that prevail as the evolution proceeds

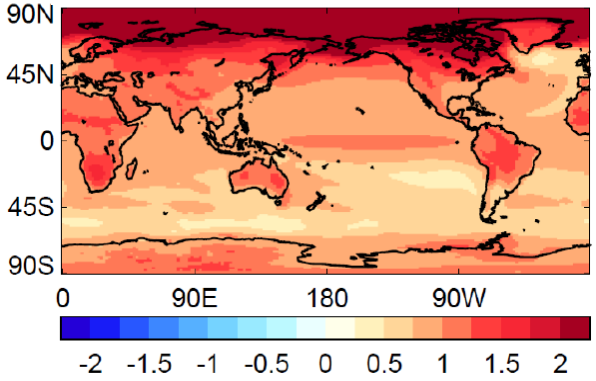


Science Gap: Process understanding of the dependence of cloud feedback on the pattern of SST change seen in AOGCMs

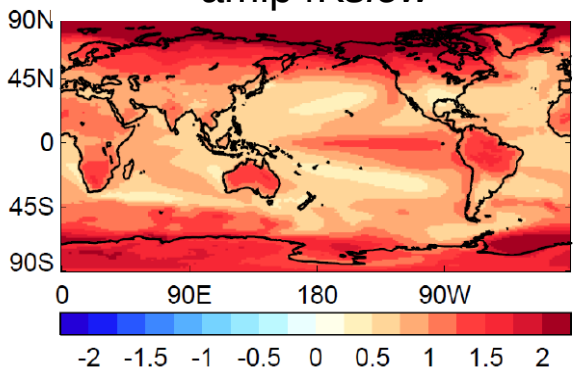
- The CFMIP2 design is unable to investigate why cloud feedback is so sensitive to evolving SST patterns in AOGCMs since the amip4K experiments (uniformed and patterned) are not sufficiently different.

➢ **CFMIP proposal:** targeted experiments to investigate the sensitivity of atmospheric feedbacks to the *'fast'* and *'slow'* SST response patterns:

amip4K*fast*



amip4K*slow*



➢ Using the AGCM design to reproduce the time-varying feedbacks then gives us a basis to better understand the physical processes (better signal-to-noise, process diagnostics etc.)

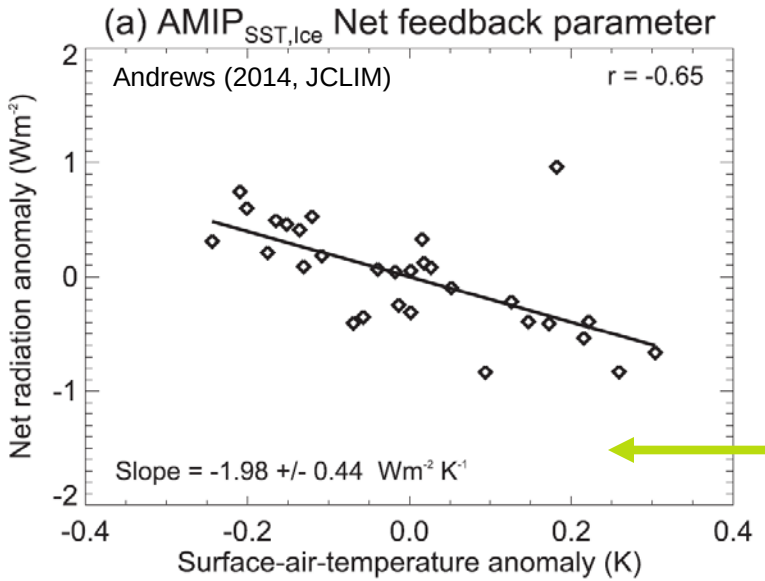
➢ Can then be used as a platform for further sensitivity experiments (e.g. to test which regions are the most important) which are hard to do with AOGCMs

Science Gap: Are climate feedbacks during the 20th century different to those acting on long term climate change and climate sensitivity?

- Could observed estimates of climate sensitivity be in error if the evolution of SSTs & feedbacks over the past century are different from those to be realised in the future? Potential to bridge the gap between observed and model estimates of climate sensitivity?

- The CFMIP2 design is unable to diagnose time varying forcing & feedbacks relevant to observed climate change & historical AOGCM simulations.

CFMIP proposal: amip with pre-industrial forcings amip*NoForcing (*Andrews, 2014)



➢ amip – amip*NoForcing* allows diagnosis of time-varying effective radiative forcing and adjustments (including aerosol components)

➢ Can then derive atmospheric feedbacks to observed SST changes

HadGEM2 feedbacks in response to observed (1979-2008) SST and sea-ice changes imply a climate sensitivity ~ 2K, much lower than the actual ~4.6K. Are observed estimates of ECS biased low due to time varying feedbacks?