Met Office
Hadley Centre

Feedbacks: their inconstancy & dependence on SST patterns

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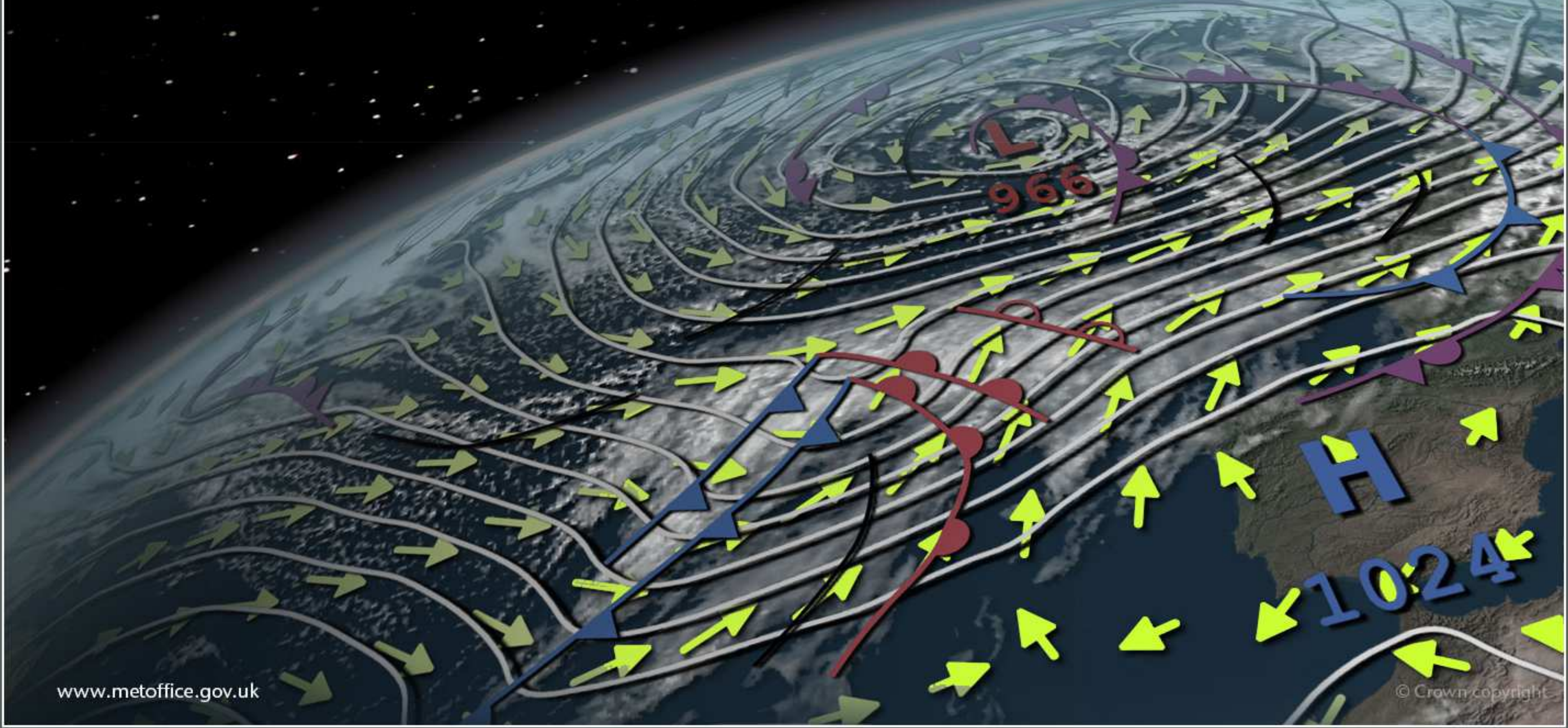
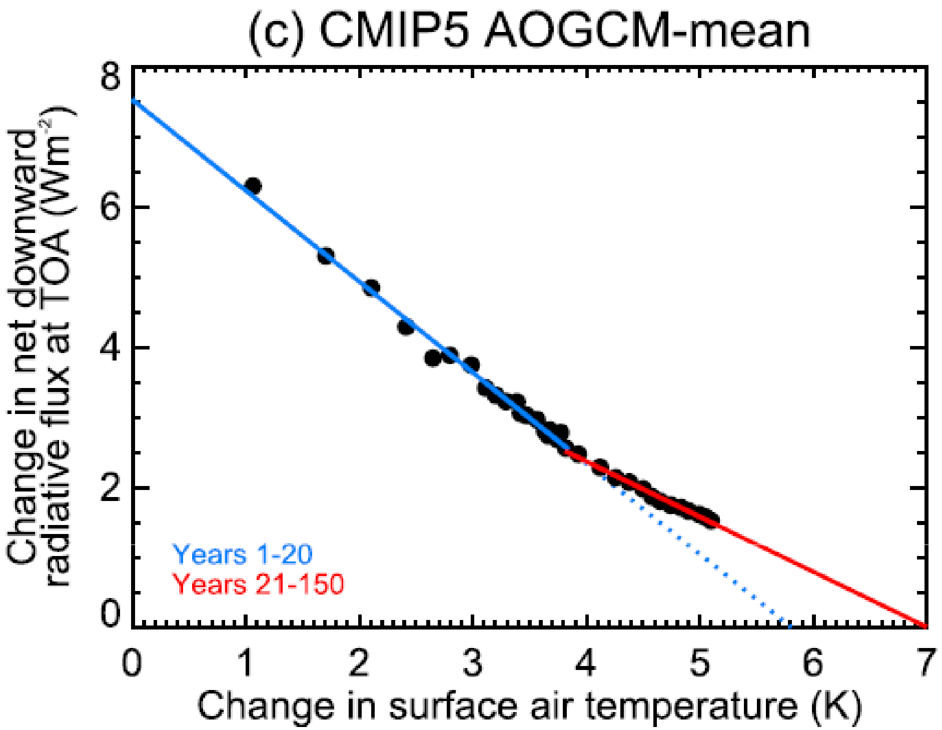
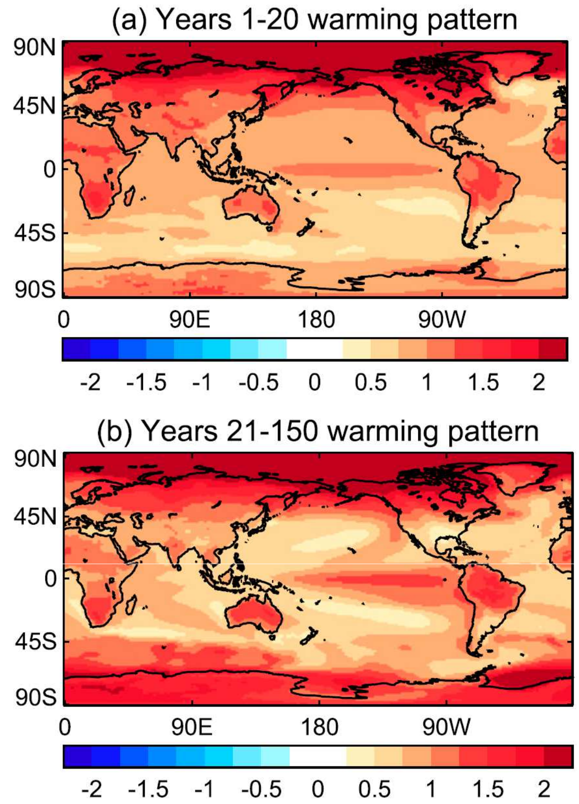
Presented by Mark Webb

CFMIP meeting June 2015; timothy.andrews@metoffice.gov.uk



Thinking fast & slow: SST patterns & feedbacks





- The surface warming pattern is not constant, e.g. delayed east tropical Pacific and Southern Ocean warming.
- Atmospheric feedbacks change with the pattern of warming, giving more positive feedbacks (shallower slope) after ~20yrs – involves local and nonlocal processes.
- Largely robust across CMIP5 AOGCMs. All feedbacks show some change, though the largest increase is in cloud feedback.

Andrews, T., J.M. Gregory and M.J. Webb, 2015: The dependence of radiative forcing and feedback on evolving patterns of surface temperature change in climate models. J. Climate, 28, 1630-1648, doi:10.1175/JCLI-D-14-00545.1.

Science gaps

Time-varying feedbacks appears to be an issue in AOGCMs

Process understanding:

- Why do feedbacks become more positive rather than more negative?
- Why do some models show larger curvature than others?
- How does variability affect SST patterns and feedbacks?

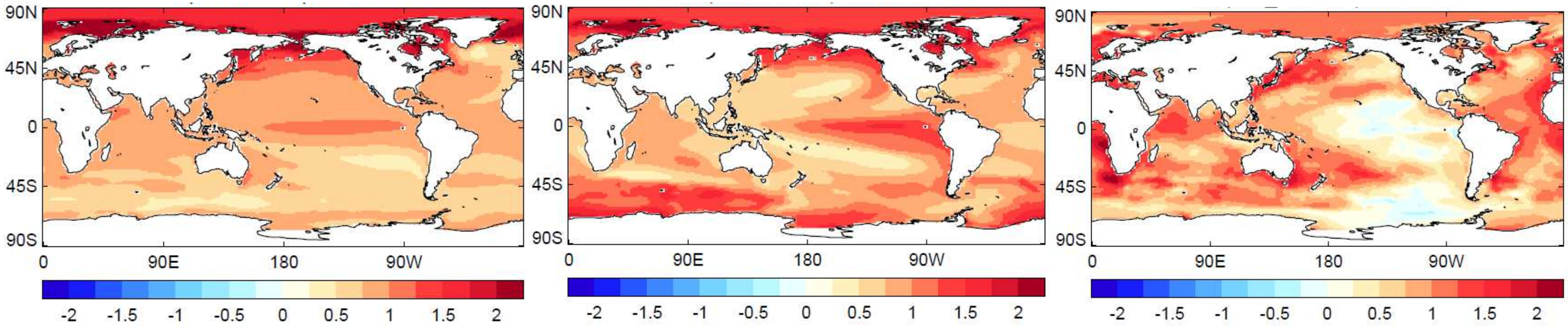
Implications:

- What does this imply for observed estimates of climate sensitivity?
- Are they biased low?

<u>Two new experimental designs have been included in CFMIP3/CMIP6 to address these questions</u>

1. Process understanding of the dependence & spread of climate feedbacks on the pattern of SST change

$4xCO_2$ fast SST pattern | $4xCO_2$ slow SST pattern | 1900-2012 obs SST pattern



<u>**CFMIP proposal:** amip4K*fast*, amip4K*slow*, and now amip4K*20C*?</u>

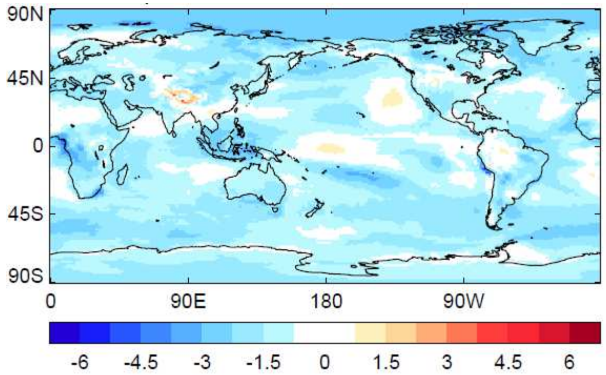
- Equivalent to the CFMIP amip4K uniformed & patterned experiments, but with patterns of SST change derived from the transient behaviour of AOGCMs and observations

- Allows us to readily determine the atmospheric feedbacks to any given SST pattern and gives us a clear regional signal with process diagnostics to help understand the mechanisms involved across models

- Allows us to test whether observed 20^{th} century warming generates feedbacks of relevance to long term climate change and ECS

HadGEM2-A feedbacks from amip4K experiments with observed & simulated SST patterns

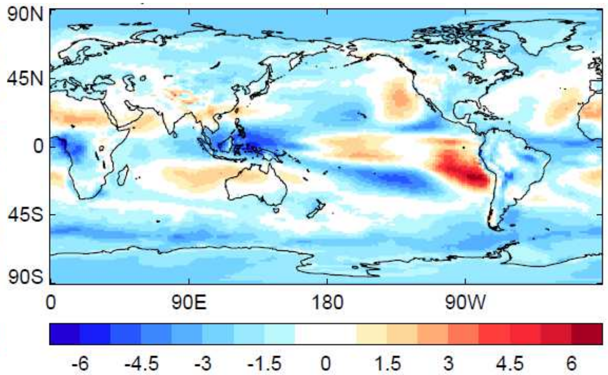
4xCO_2 fast SST pattern



$dN/dT = -0.9\ Wm^{-2}K^{-1}$

ECS ~ 3.3K

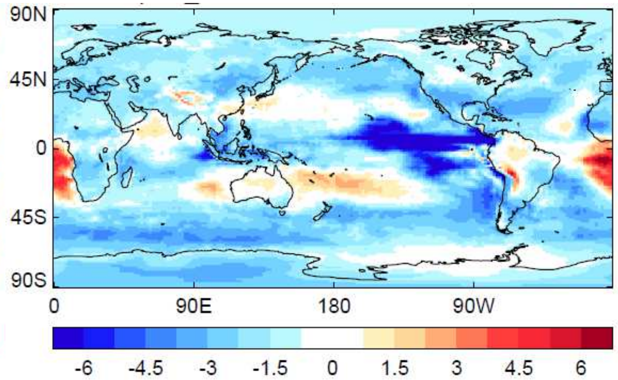
4xCO_2 slow SST pattern



$dN/dT = -0.6\ Wm^{-2}K^{-1}$

ECS ~ 5K

1900-2012 obs SST pattern



$dN/dT = -1.3\ Wm^{-2}K^{-1}$

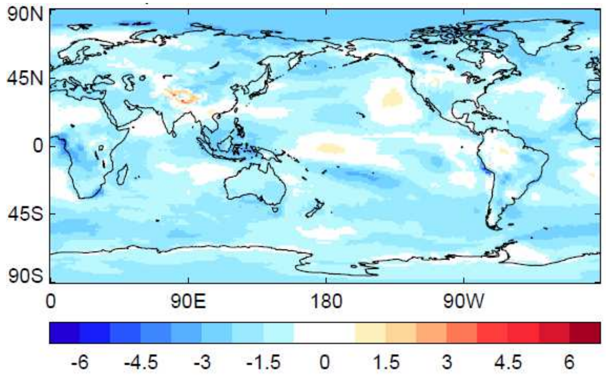
ECS ~ 2.3K

- Reproduces the curvature in the Gregory plot, i.e. amip4K*slow* has more positive feedbacks (larger ECS) than amip4K*fast*

- 20th century warming pattern gives very small ECS (~½ of 'known' ECS for this model). Why is this? Does it implies observed estimates of climate sensitivity will be biased low?

HadGEM2-A feedbacks from amip4K experiments with observed & simulated SST patterns

$4xCO_2$ fast SST pattern



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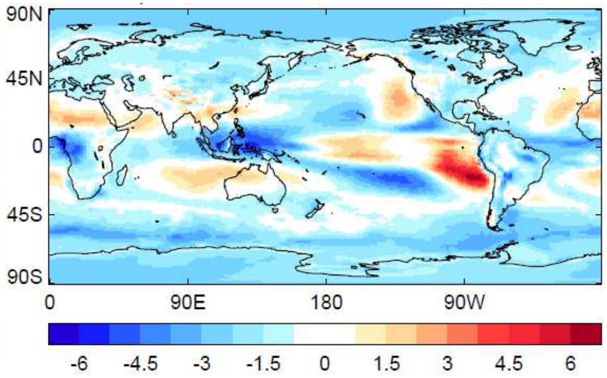

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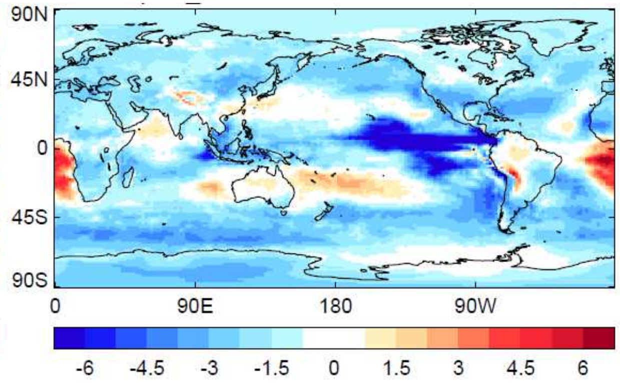
1900-2012 obs SST pattern

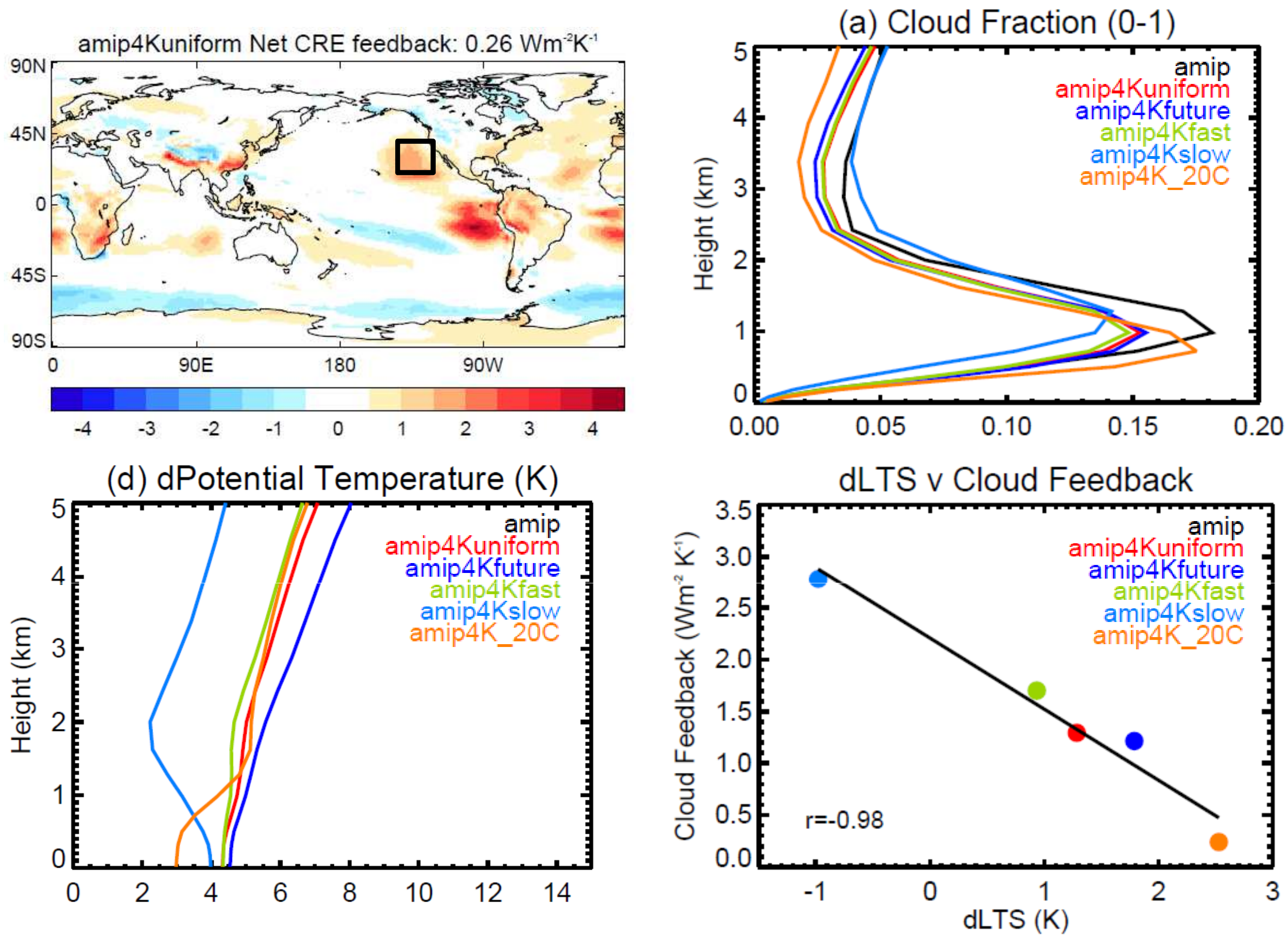


$dN/dT = -1.3\ Wm^{-2}K^{-1}$

ECS ~ 2.3K

Climate sensitivity halved just by changing warming pattern, note no change in model physics!

Process understanding: an example from marine low clouds off the coast of California

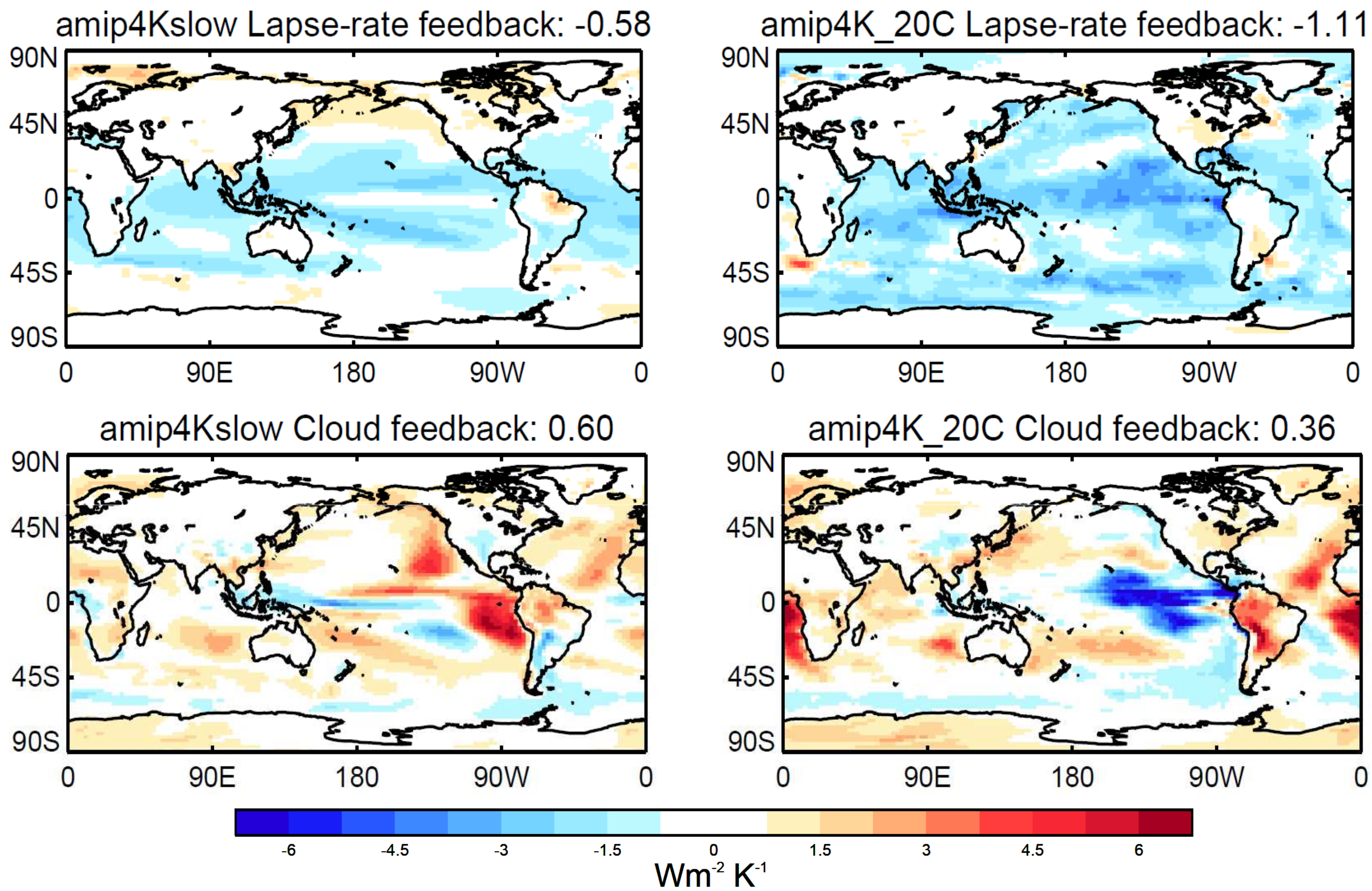


- Spread in dT is larger aloft than at the surface

- Spread in lower tropospheric stability (LTS) strongly correlates with spread in cloud feedback. 20th century SSTs produce such a large LTS increase it throttles the thermodynamic cloud feedback.

- Warming profile therefore appears key in determining dLTS and modifying cloud changes

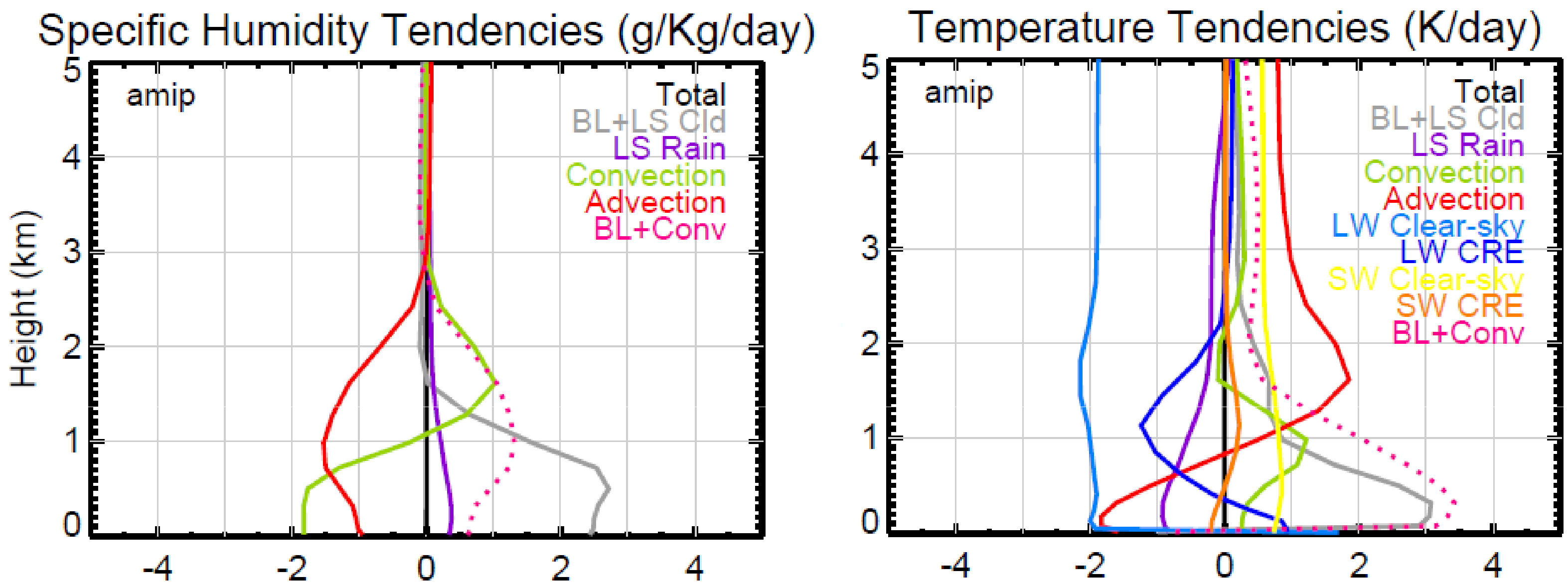
Are stability arguments key to understanding time-varying feedbacks?



- Kernel feedback analysis reveals lapse-rate and cloud feedbacks to be the most sensitive to SST patterns. Both intimately related to changes in atmospheric stability.

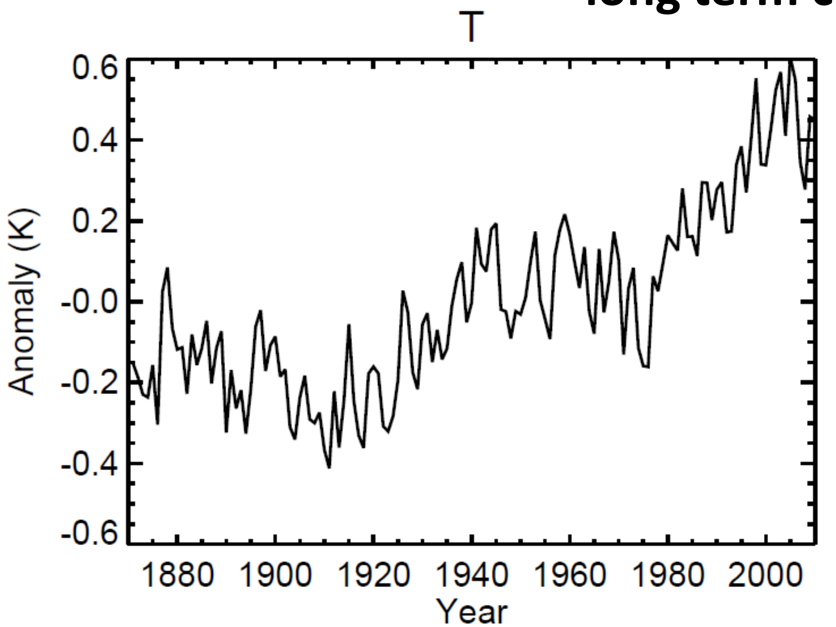
- For example, warming aloft in the east tropical pacific while the SSTs are pegged back in the 20thC pattern generates a large increase in stability & enhances lapse-rate feedback

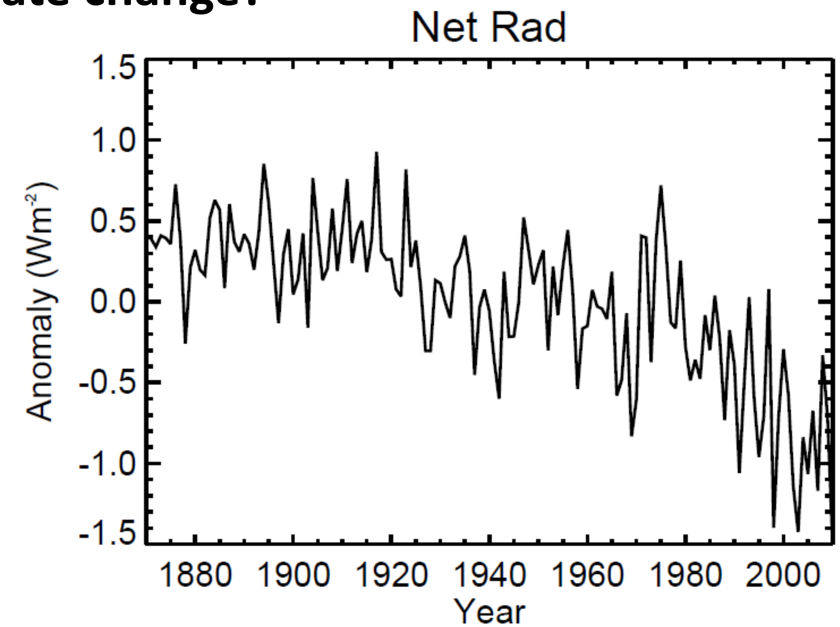
Exploring tendency terms will give more physical insight into the underlying processes/mechanisms

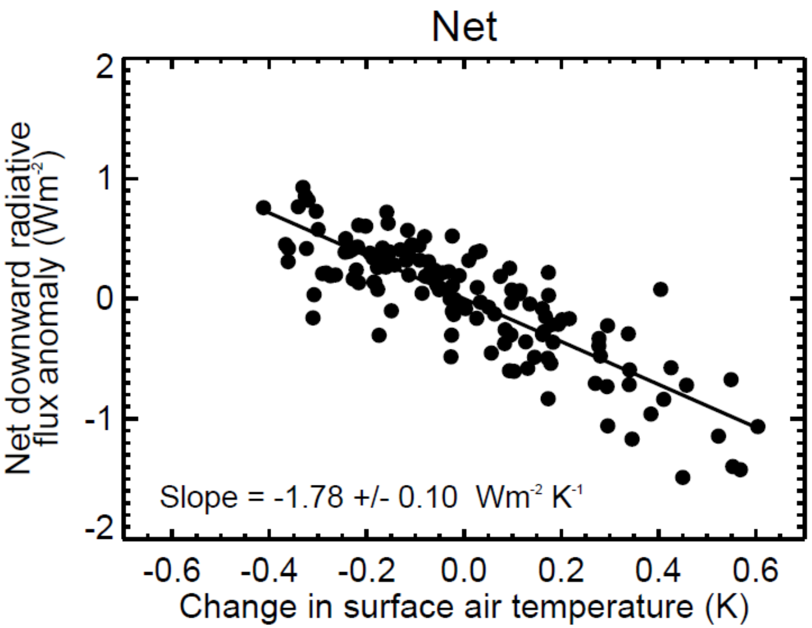


- Humidity and temperature tendency terms allow us to probe the processes further and test various hypothesis regarding mechanisms of cloud changes (e.g. Webb and Lock, 2013)

2. Are climate feedbacks during the 20[th] century different to those acting on long term climate change?





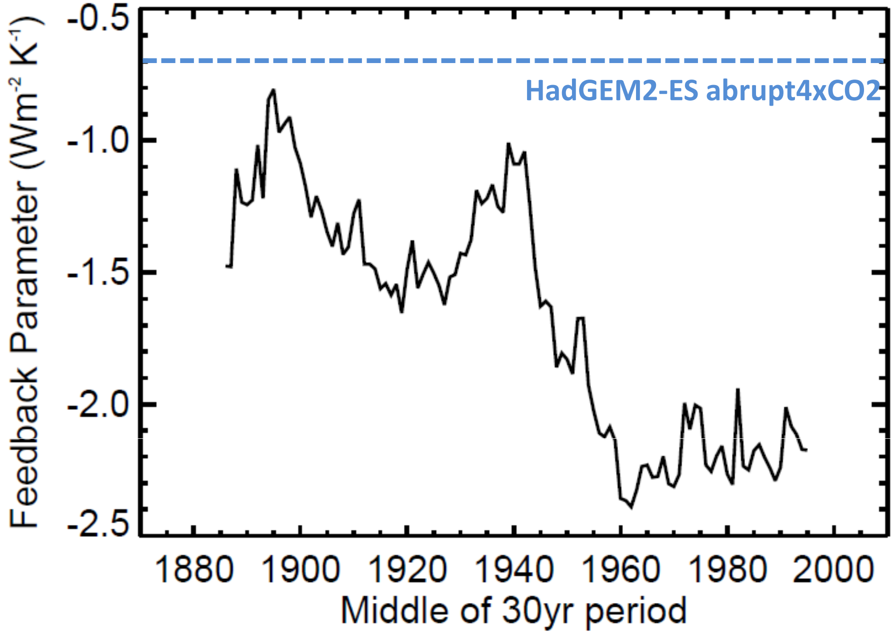


CFMIP/CMIP6 proposal: amip 1870-2013 with piControl forcings (amip*PIforcing)*

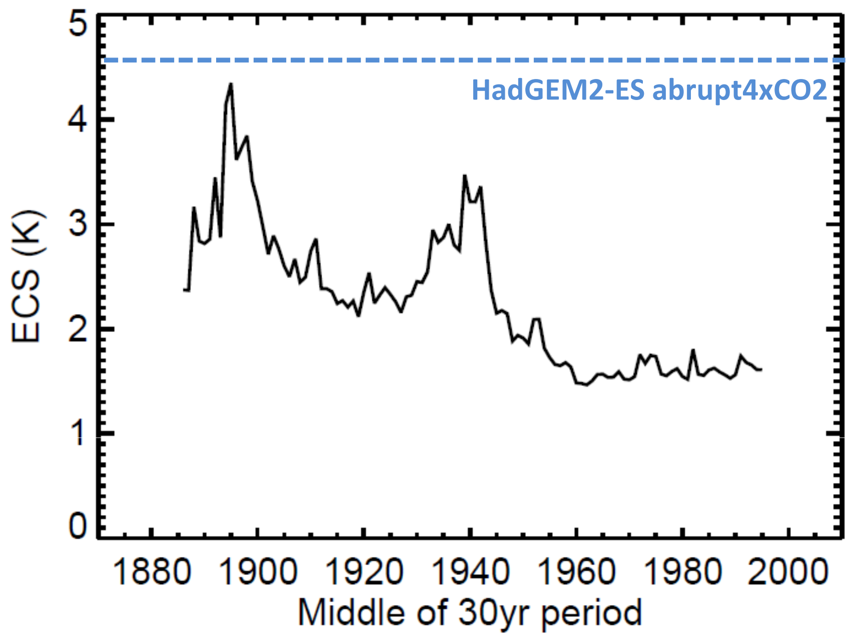
- Same as amip (i.e. observed SST & ice boundary condition) but with piControl forcings & extended back to 1870.
- HG2 forced with observed sea-ice & SST gives a feedback parameter of ~-1.8 $Wm^{-2}K^{-1}$.
- This implies a climate sensitivity of ~1.7K, way below 'known' ECS of 4.5K.

Can also diagnose time-variation of feedbacks over 20th century

Feedback parameter from historical SST in HG2



Implied ECS from historical SST in HG2



- HadGEM2-A forced with observed SST and sea-ice tends to give lower effective climate sensitivity than the same model forced with ‘long term’ dSST patterns

- Time variation likely related to modes of variability and timescales of forced change

- If real world behaves like this then it undermines constant feedback assumption and estimates of climate sensitivity from the observed record may be biased low.

Summary & discussion

- Targeted AGCM experiments with various SST patterns – traceable to AOGCM transient behaviour and observations – are a valuable tool in understanding the mechanisms and processes related to time varying feedbacks

- Feedbacks are very sensitive to warming patterns: we can get ECS values from 1.3 to 5K just by changing the warming pattern in HadGEM2!

- HadGEM2-A results give some insight into why lapse-rate and cloud feedbacks varies with SST patterns, relates to atmospheric stability (e.g. LTS change for low clouds).

- AGCM experiments forced with observed SST variations give low feedback and ECS estimates and show significant time-variation.

- Much more to understand and do. Detailed results mostly from a single model.

Project	Experiment	Description	# years
CMIP6	**amipPI*forcing***	As amip but with pre-industrial forcings and extended back to 1870	143
CFMIP3	**amip4K*fast***	As amip4K but using pattern of SST from fast response of AOGCMs	30
CFMIP3	**amip4K*slow***	As amip4K but using pattern of SST from slow response of AOGCMs	30
CFMIP3	**amip4K_*20C***	As amip4K but using pattern of SST from observations	30

<u>Please do these runs, they are cheap and an early multi-model pilot study welcome!</u>