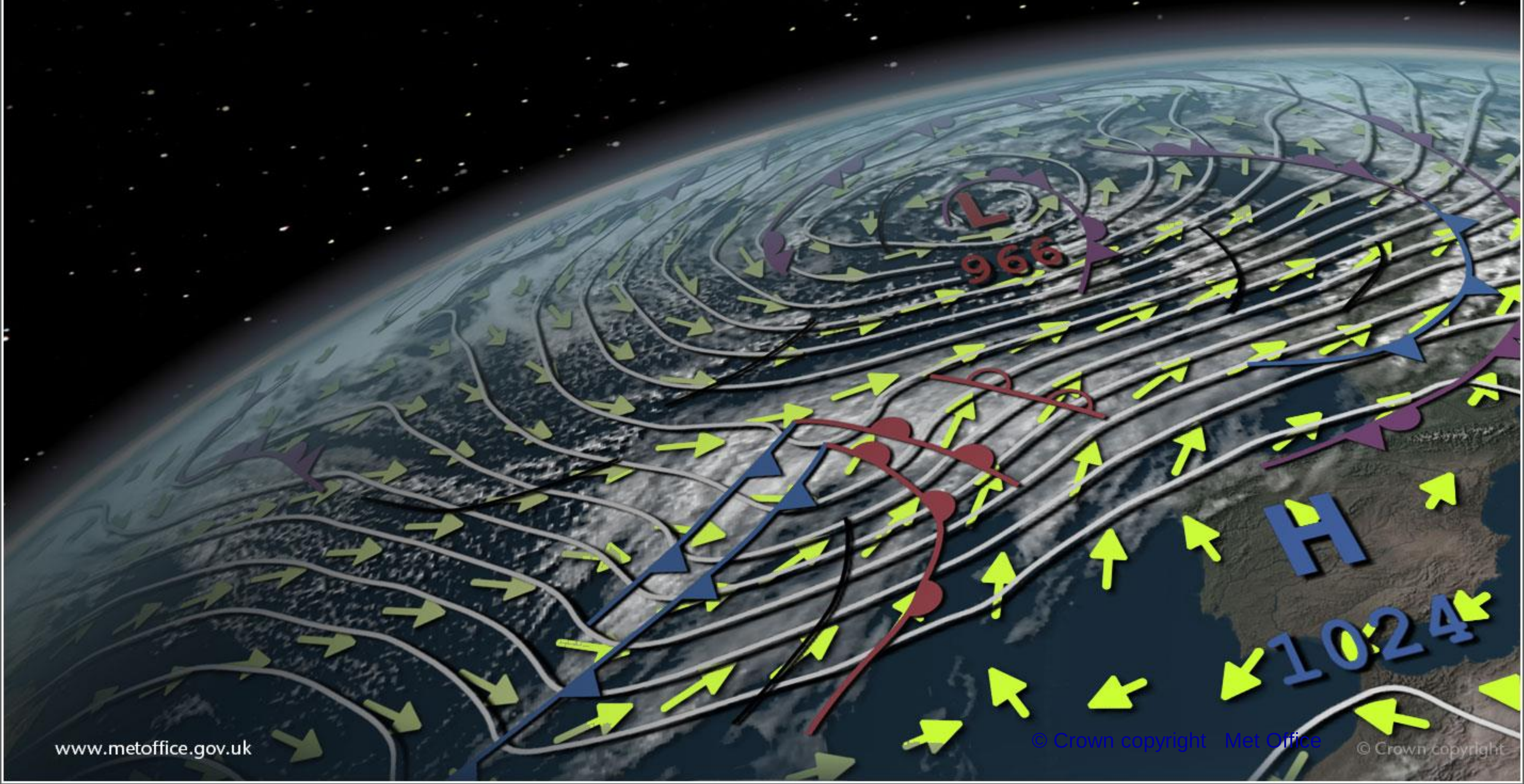
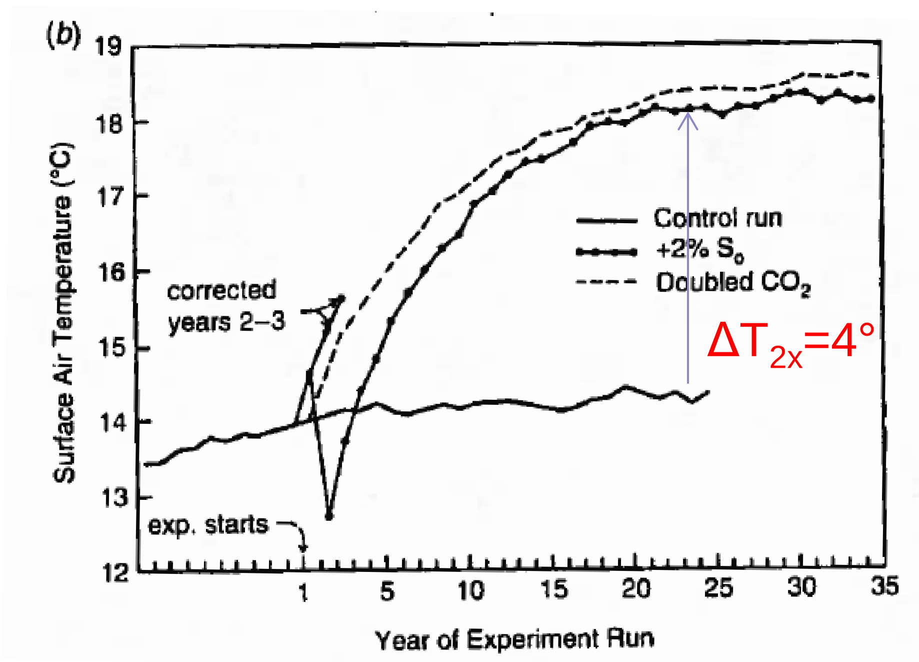
Transient v Equilibrium Climate Sensitivity

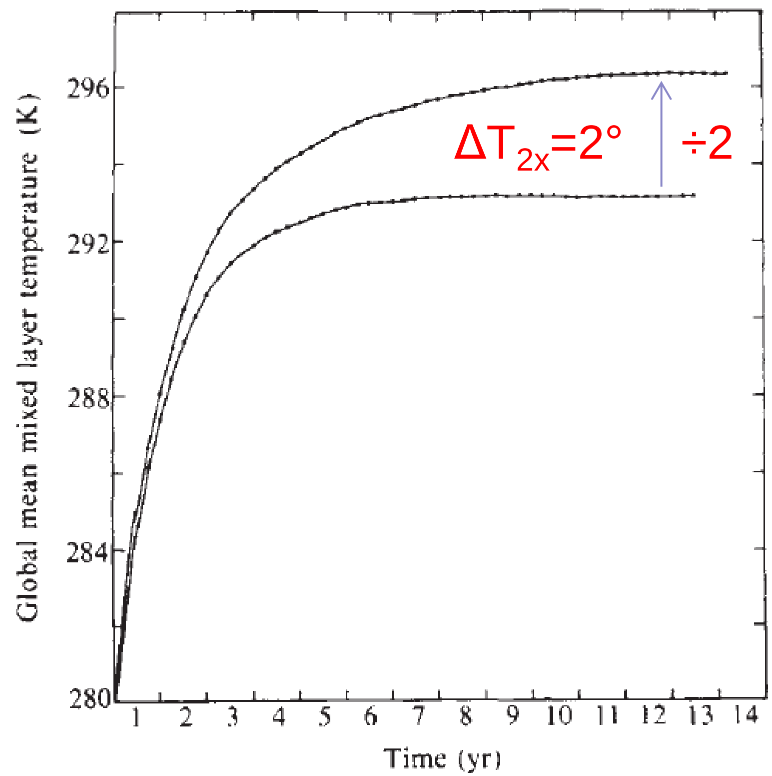
Catherine Senior, Met Office Hadley Centre, U.K.

The Ronald J. Stouffer Symposium, GFDL, June 6th 2016



Climate Sensitivity estimated from slab models: Basis of Charney report (1979)



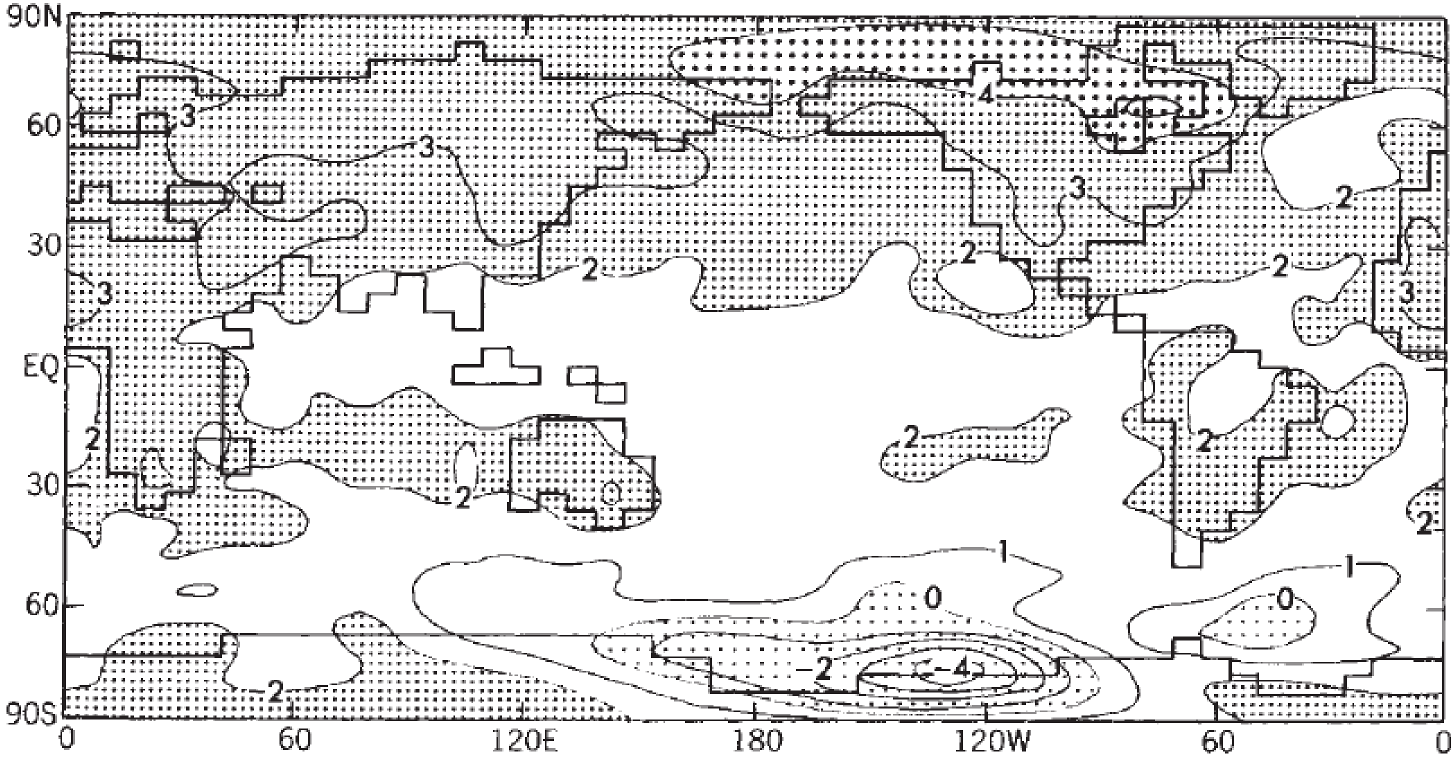


Hansen et al, 1984: Climate sensitivity: Analysis of feedback mechanisms. AGU Geophysical Monograph 29

Manabe and Stouffer , 1979: A CO_2-climate sensitivity study with a mathematical model of the global climate. Nature 282, 491-493

First estimates from 3D-Coupled Models

*'The model response exhibits a marked **and unexpected** inter-hemispheric asymmetry. In the circumpolar ocean of the Southern Hemisphere, a region of deep vertical mixing, the increase of surface air temperature is very slow. In the Northern Hemisphere of the model, the warming of surface air is faster and increases with latitude, with the exception of the northern North Atlantic where it is relatively slow because of the weakening of the thermohaline circulation'*



Stouffer et al, 1989: Interhemispheric asymmetry in climate response to a gradual increase in atmospheric CO_2. Nature 342, 660-662

Measures of Climate Response

Equilibrium Climate Sensitivity (ECS) – steady state global average surface temperature change for a doubling of CO_2
Climate Sensitivity Parameter (s) – ECS/F_{2x}

Transient Climate Response (TCR) - average surface temperature response over a twenty-year period centred at CO_2 doubling in a transient simulation with CO_2 increasing at 1% per year
Transient Climate Sensitivity (TCS) – TCR/F_{2x}

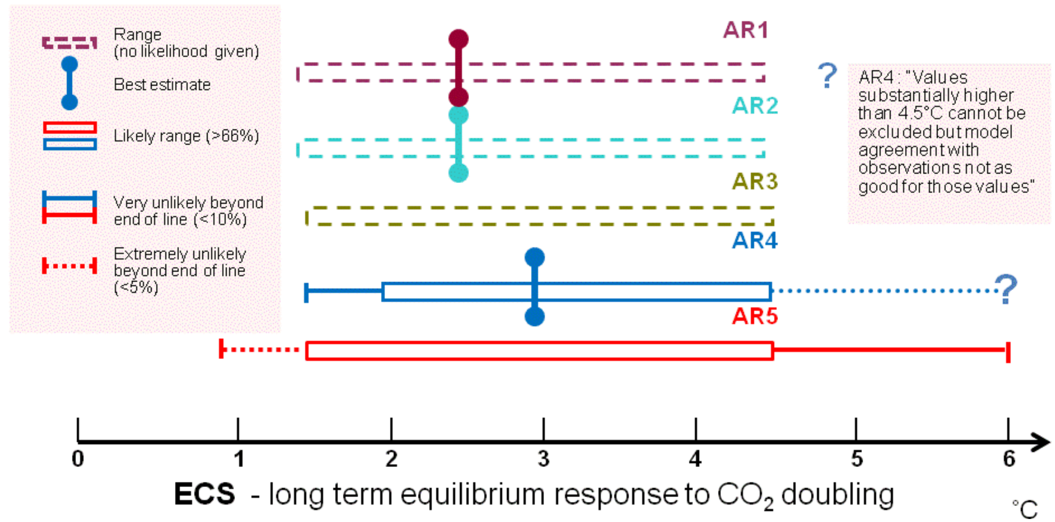
- Range and uncertainty due to feedbacks on T
- Used to calibrate simple models
- Determines allowable emissions for given long term temperature target
- ‘Effective’ CS can be estimated from transient simulations

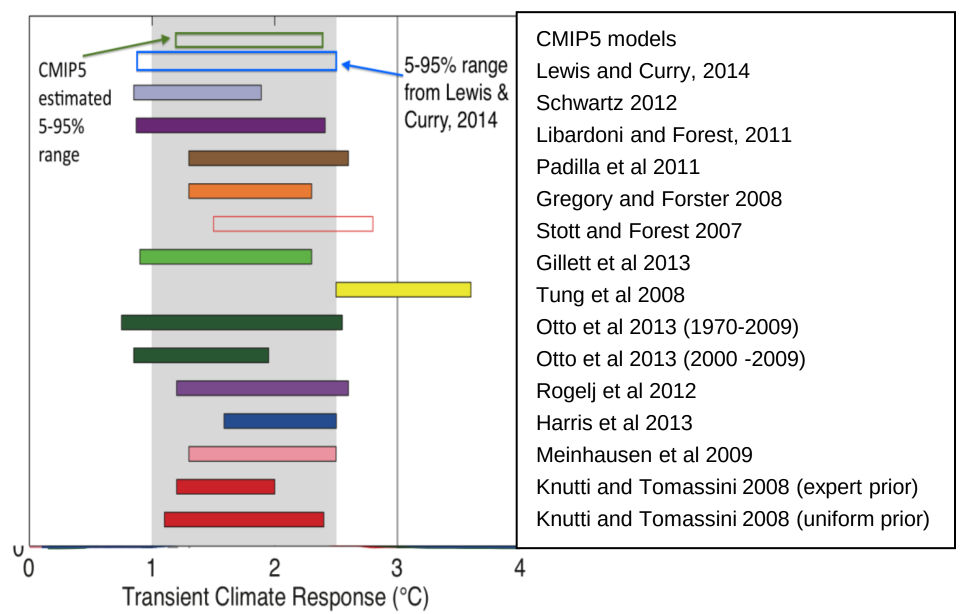
- TCR is lower than ECS due to ocean heat uptake
- More relevant to decadal timescales of warming as forcing continues to rise

What do we know about ECS and TCR?

- Range of ECS has changed little since Charney report (1979)

- Ability to constrain both measures from modelling and observations has suffered from discrepancies in estimates from different approaches

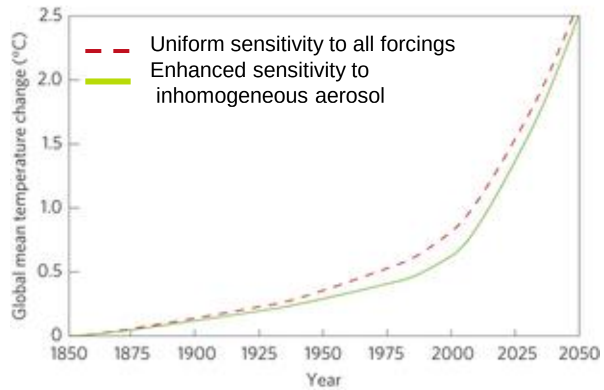




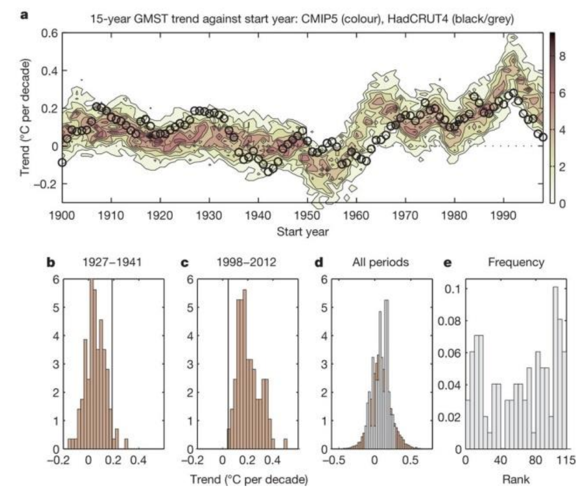
Observationally based studies

Factors influencing the applicability of observationally based studies for quantifying climate sensitivity include…

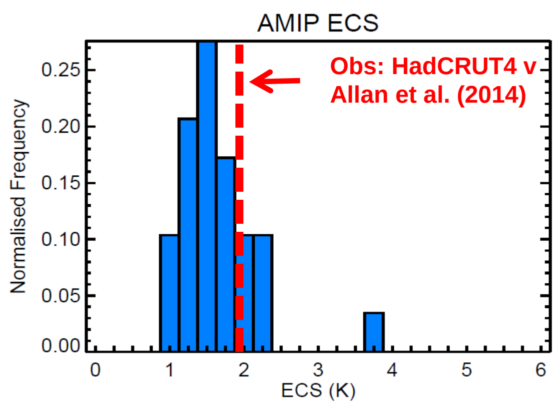
- Efficacy of different forcing factors
- Limited length of observational data records and role of natural variability
- Process and statistical choices in EBMs
- Potential for feedbacks to strengthen in time

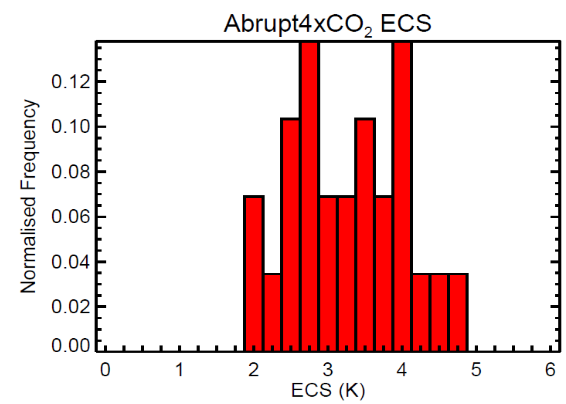


Shindell et al, 2014



Marotzke and Forster 2015

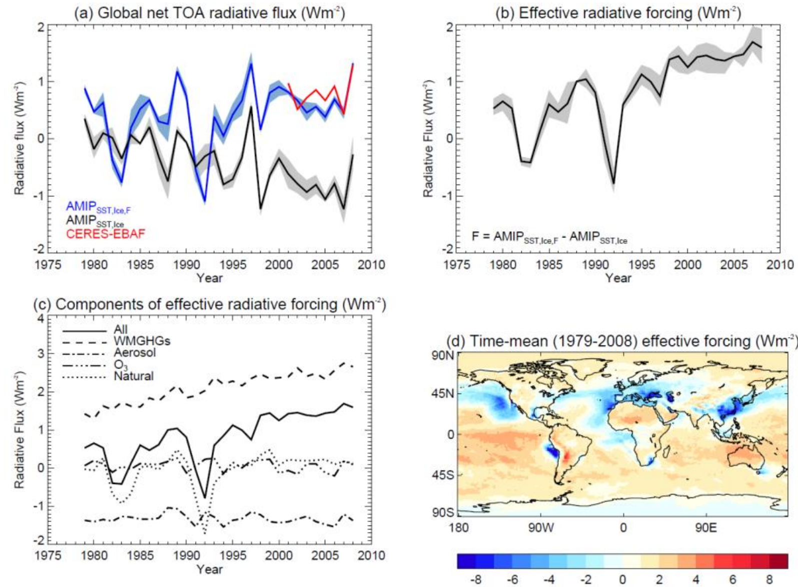




Andrews, Gregory and Webb 2015

Modelling based studies

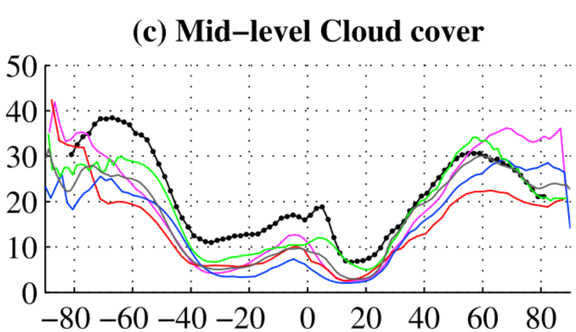
Factors influencing the applicability of model based studies for quantifying climate sensitivity include…



Andrews 2014

- Separation of forcing and response

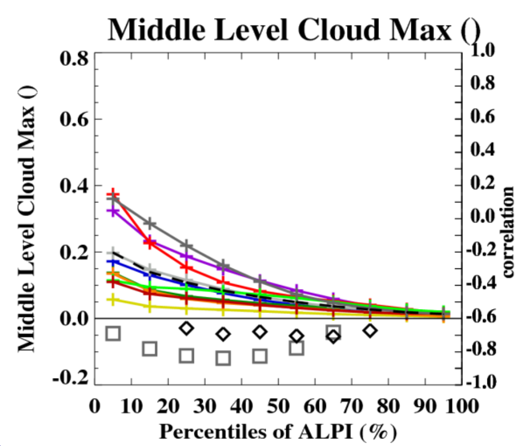
- Missing or poorly represented processes?



Cesana and Chepfer, 2012

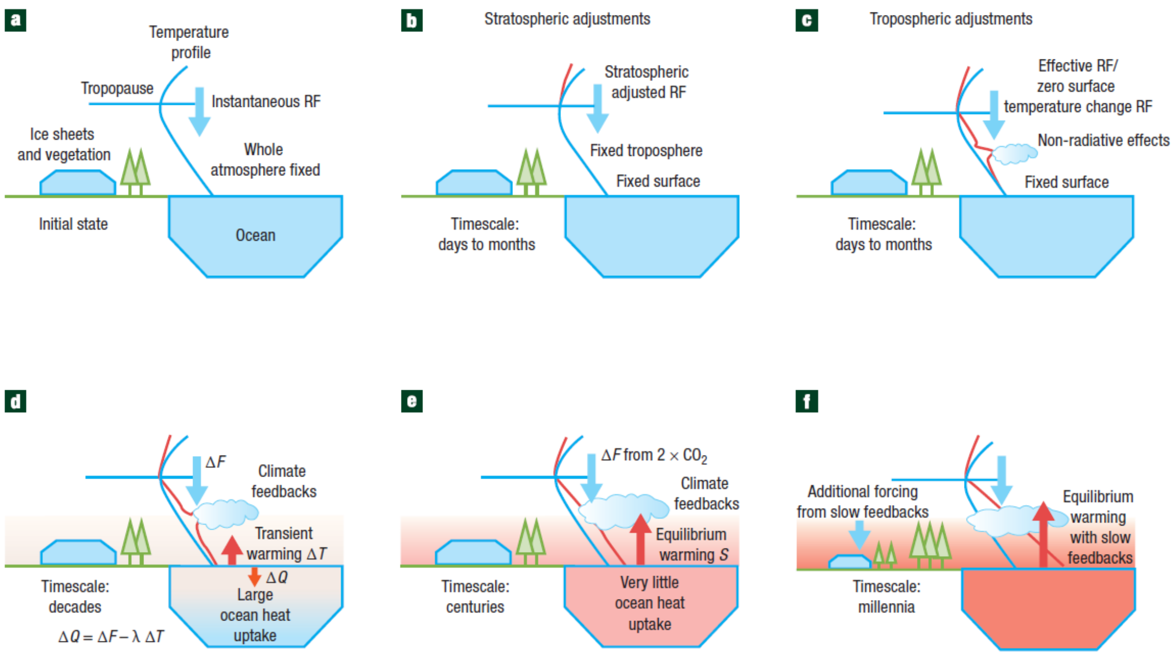
Models underestimate tropical mid level clouds….

… and those with fewer mid level tropical clouds have more positive cloud feedbacks



Webb et al., 2015

Forcing , Feedback and Climate Sensitivity



Knutti and Hegerl, 2008:The equilibrium sensitivity of the Earth's temperature to radiation changes. Nature Geoscience, 1, 735-743

Forcing-response framework is underpinned by a simple linear relationship

$$N=F+\alpha\Delta T$$

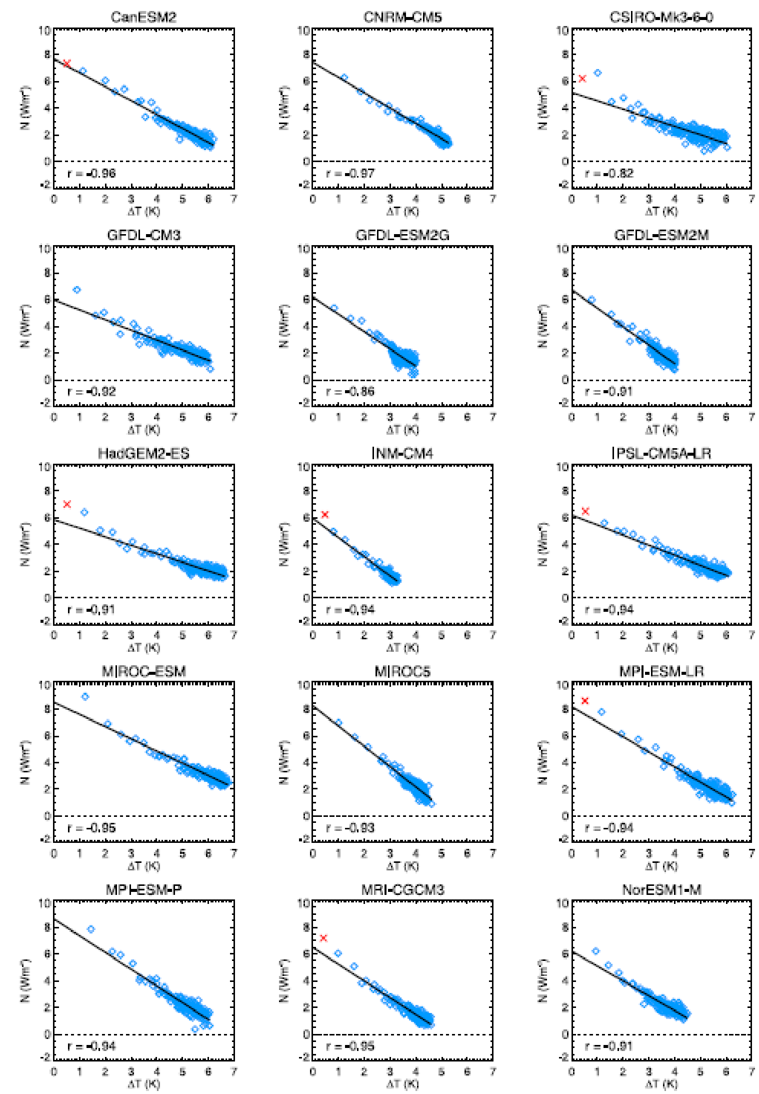
Assumes constant α – which has been shown to be a good approximation in idealised studies

Met Office
Hadley Centre

Non-constancy of climate feedbacks in real world scenarios

- Feedbacks in Slab models can be different from coupled models and more recent focus on transient simulations have required new methods to estimate climate sensitivity e.g. Gregory et al 2004

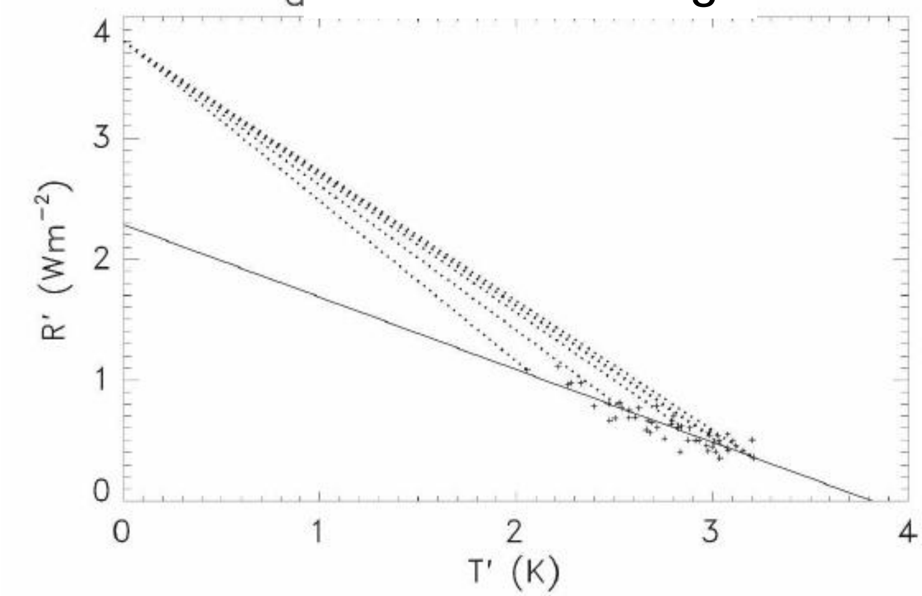
- Application of Gregory et a 2004 to CMIP5 models shows that linearity is a reasonable assumption but that many models show significant non-linearities



Andrews et al, 2012. GRL 39, doi:10.1029/2012GL051607

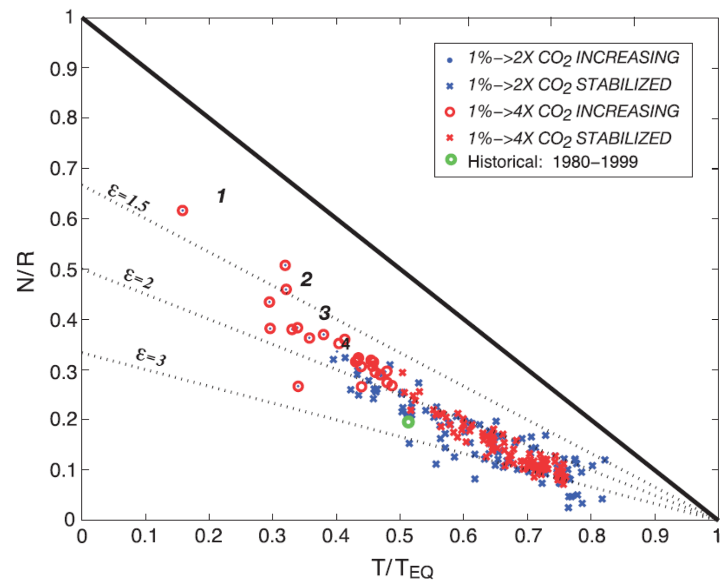
Non-constancy of climate feedbacks in real world scenarios

Effective Forcing



Williams et al, 2008. J. Clim. 21, 5076-5090.

OHU efficacy



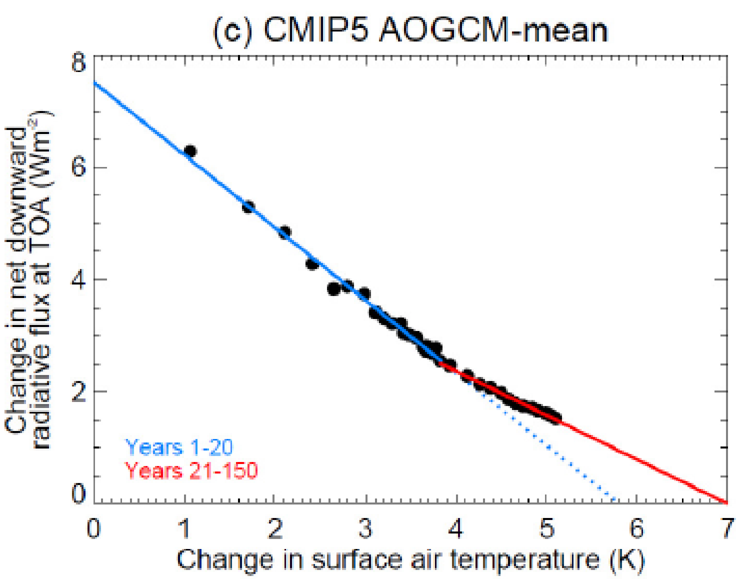
Winton et al, 2010. J. Clim. 23, 2333-2344.

New ideas such as ‘effective forcing’ and ‘ocean heat uptake efficacy’ have been evoked to develop conceptual frameworks to fit the time evolution of climate feedbacks

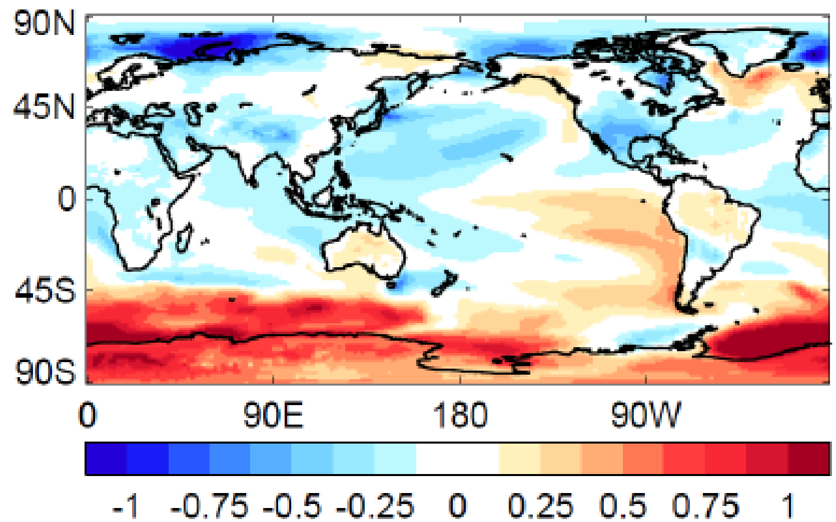
Dependence of climate forcing and feedback on evolving surface temperature patterns

• 23 out of 27 CMIP5 models under abrupt $4CO_2$ forcing show cloud feedback parameter becomes significantly less negative as warming develops

• Driven by emerging patterns of SST response notably in tropical pacific and southern Ocean

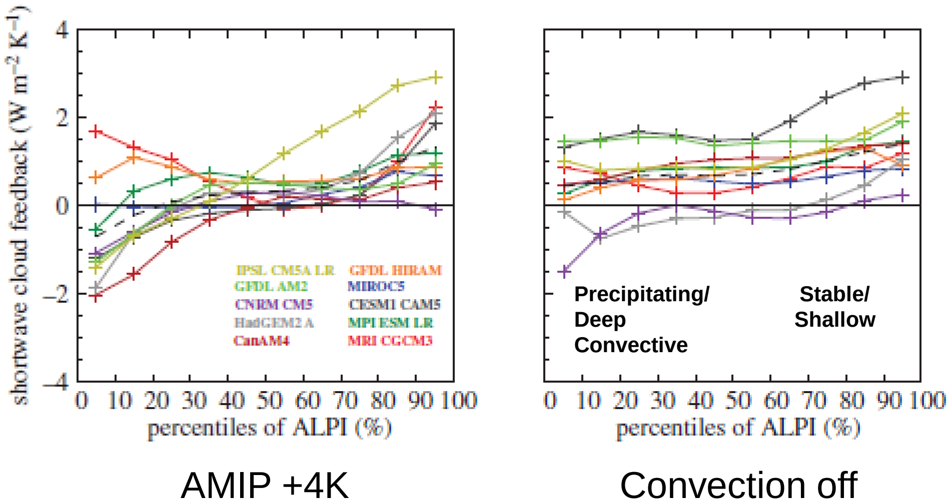


Change in warming pattern Yrs (21-150) – (1-20)



Andrews et al, 2014. J. Clim. 28, 1630-1648.

Use of simplified models to understand model uncertainty

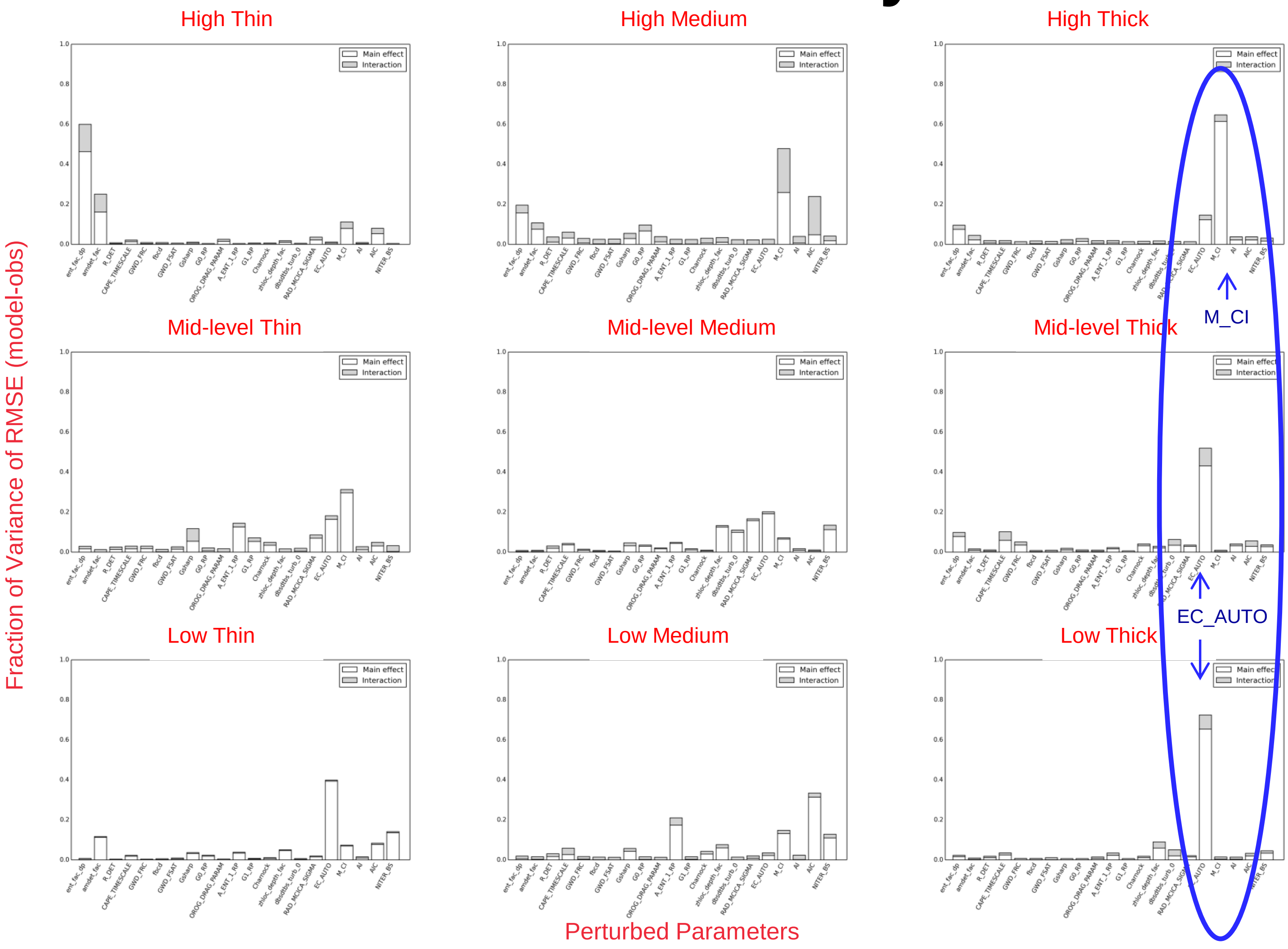


- Selected Processes On/Off Klimate Experiment (SPOOKIE) CFMIP initiative
- Switched off parameterized convection in ten models. Strong convergence in LW cloud feedback associated with precipitating deep convection. SW cloud remain positive in shallow regimes
- Processes other than parametrized convection are responsible for positive subtropical cloud feedback.
- Future experiments will examine contribution from changes in turbulent mixing in the PBL

Webb et al, 2015

PPE and feedback uncertainty

- ISCCP cloud types v satellite data
- HadGEM3-GA4 PPE-AMIP, 10-year simulations, 73 ensemble members, 21 perturbed parameters
- emulator used to increase ensemble size
- **Allows us to identify which parameterizations are driving the spread across the ensemble**



- Use PPE to examine feedbacks & forcing in our model
- New insight into the interpretation of uncertainty in our projections

Yoko Tsushima, David Sexton

Summary

- *Reducing uncertainty in both transient and equilibrium sensitivities remains important and relevant to mitigation options and regional adaptation choices*
- *Increased understanding of factors that influence the difference between equilibrium and transient climate sensitivities is leading to*
  - *Better understanding of how to constrain measures of climate response*
  - *Better calibration of simple model projections of future climate change*
- *Evidence for time-dependence of climate feedbacks in fully coupled AOGCMs highlights the need to study transient climate change*
- *Work to investigate this highlights shortwave cloud processes as the main contributor*
- *Progress can be made by focusing on process understanding – use of idealised models/PPE can help here*