Cloud Feedback and Aerosol Radiative Forcing in the IPCC AR4 Models

Brian Soden
Rosenstiel School for Marine and Atmospheric Science
University of Miami

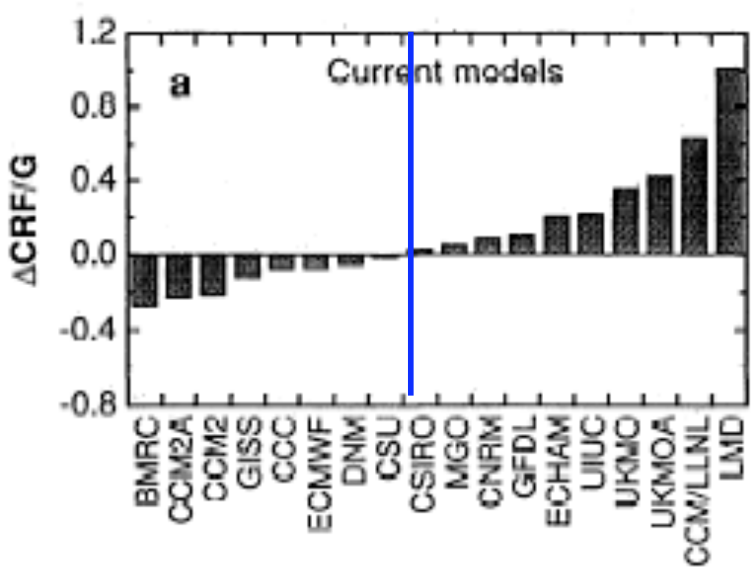
Isaac Held, Gabriel Vecchi
Geophysical Fluid Dynamics Laboratory/NOAA

Outline

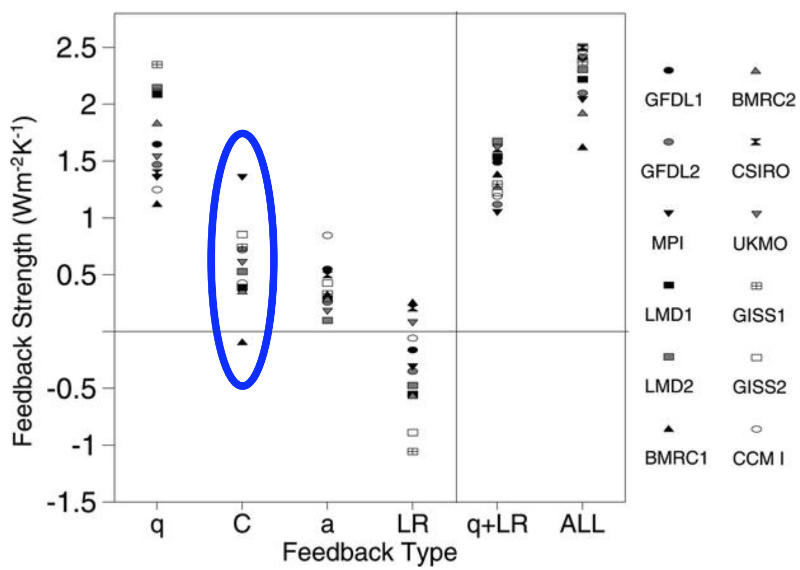
- Introduce "Radiative Kernels" to describe the differential response of radiation to changes in state variables.
- Use Kernels to:
  - Analyze cloud feedbacks for IPCC AR4 GCMs.
  - Analyze radiative forcings for IPCC AR4 scenarios.
  - Details: Soden et al., 2008, *J. Climate*, in press.

What is the Range of Cloud Feedback?

Cess et al. (1996)
ΔCRF Method



Colman (2003)
Radiative Perturbation Method



- 8 of 18 models have negative cloud feedback
- 1 of 10 models has negative cloud feedback

Climate Feedbacks using Radiative Kernels

$$\Delta T_s = \frac{G}{\lambda}$$

G = radiative forcing
λ = climate sensitivity
R = net radiation at TOA

$$\lambda = \frac{\delta R}{\delta T}\frac{dT}{dT_s} + \frac{\delta R}{\delta W}\frac{dW}{dT_s} + \frac{\delta R}{\delta C}\frac{dC}{dT_s} + \frac{\delta R}{\delta \alpha}\frac{d\alpha}{dT_s}$$

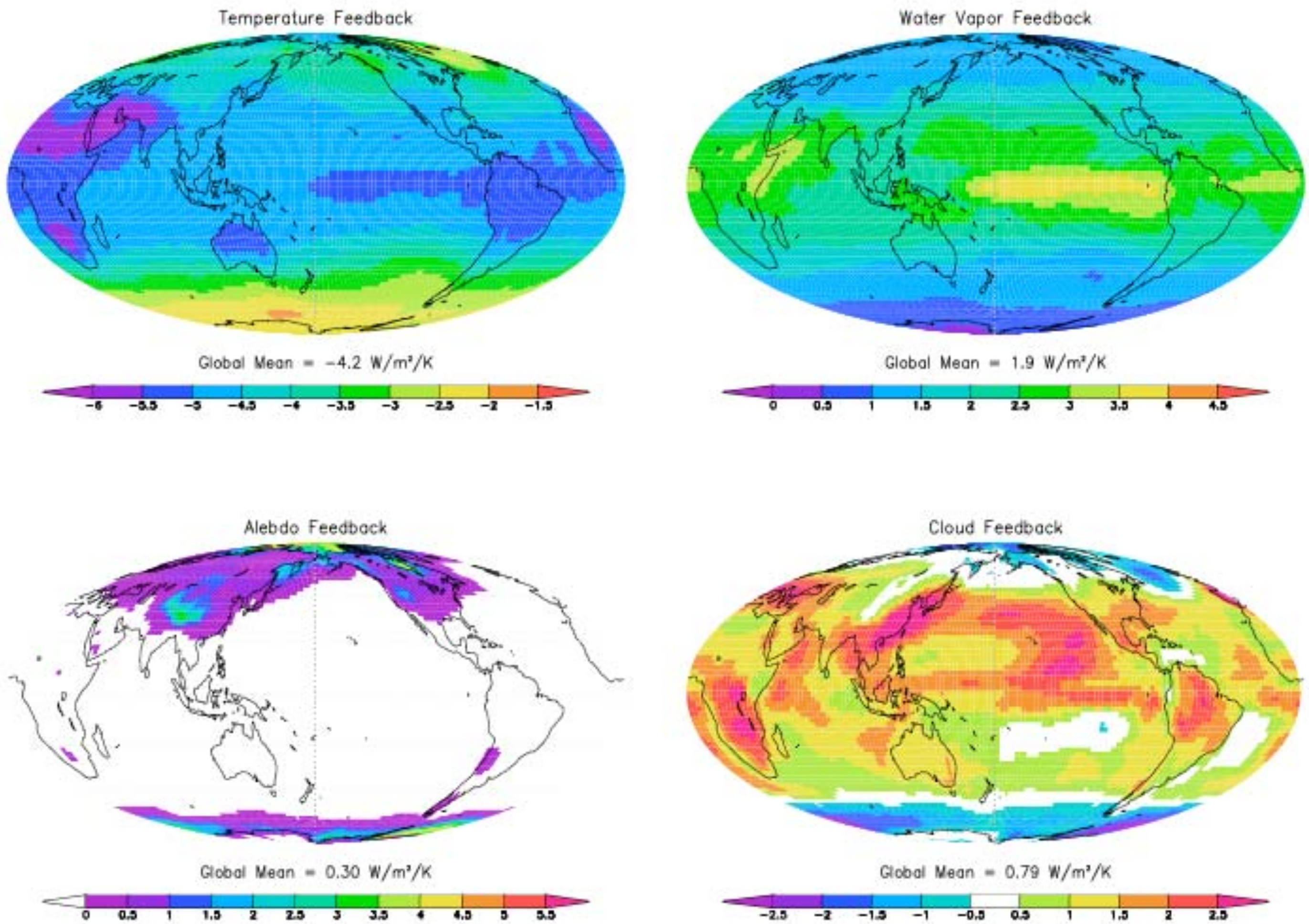
Temperature Feedback | Water Vapor Feedback | Cloud Feedback | Sfc Albedo FeedbacK

Climate Feedback = $\delta R/\delta X$ x dX/dT_s

Radiative Transfer (Kernel)

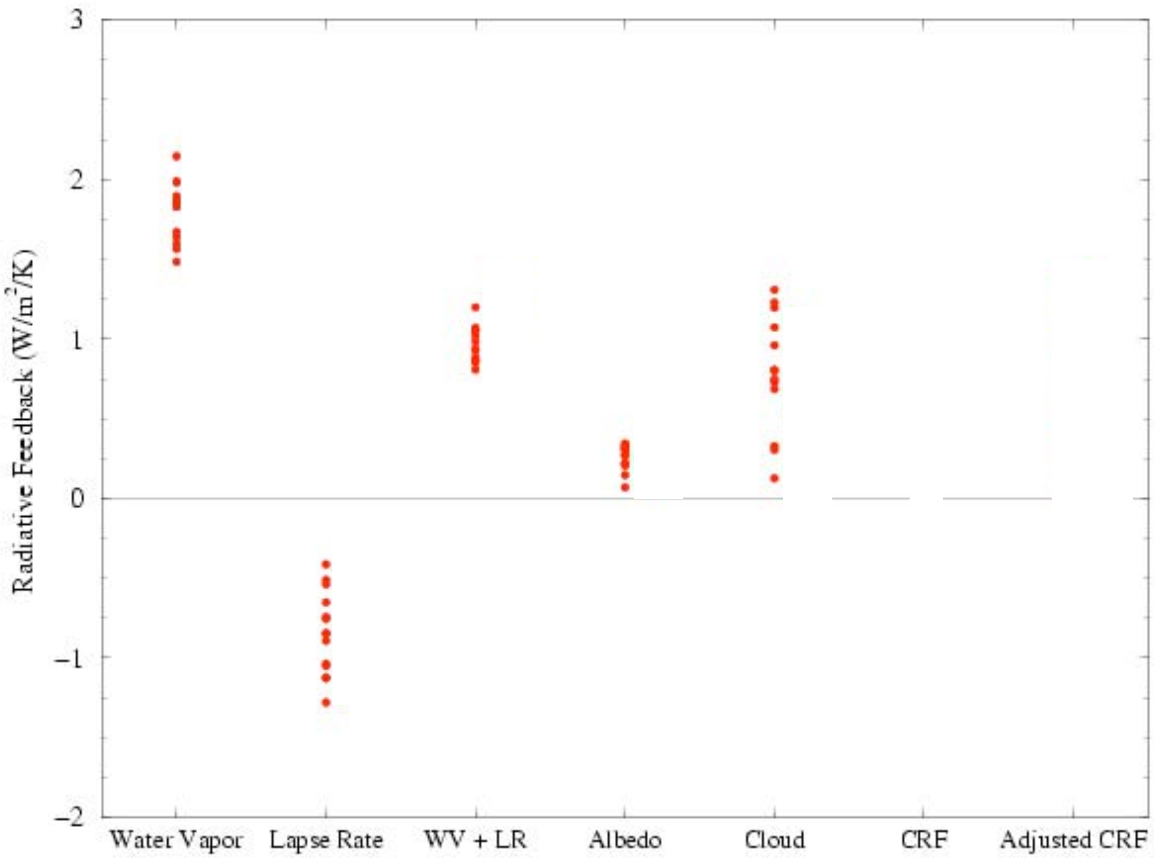
Climate Response

Multi-Model Ensemble Mean Feedbacks: IPCC AR4 GCMs



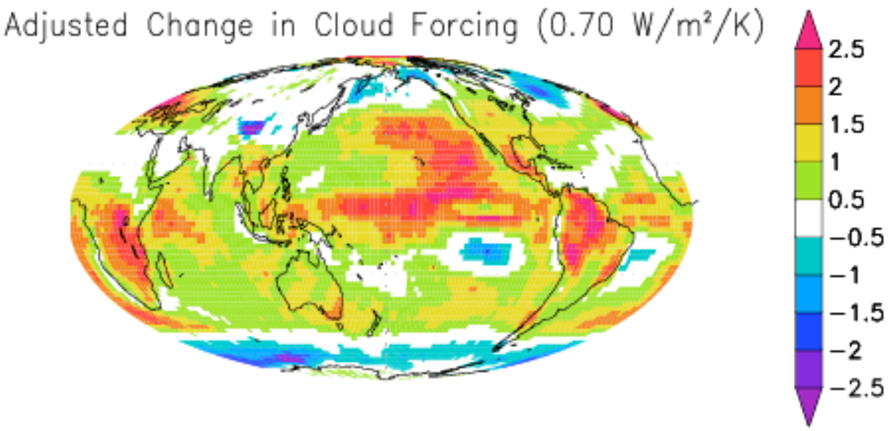
RSMAS

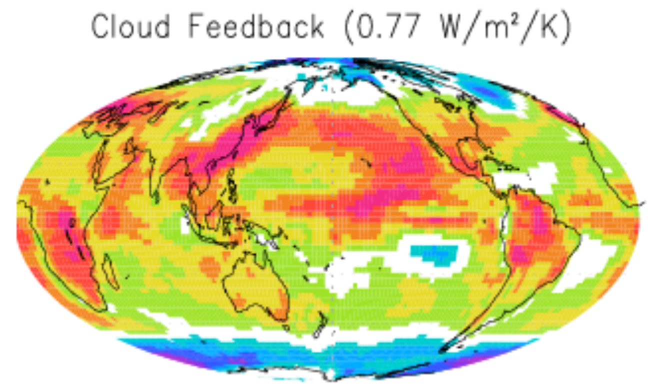
Global Mean Feedbacks: IPCC AR4 GCMs

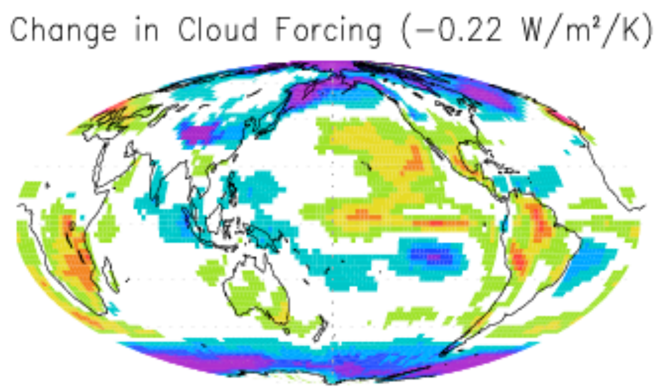


- Range cloud feedback is ~4 times larger than other feedbacks.
- Cloud feedback is neutral to positive in all models, even though ΔCRF is not.

Cloud Feedback vs Δ Cloud Forcing

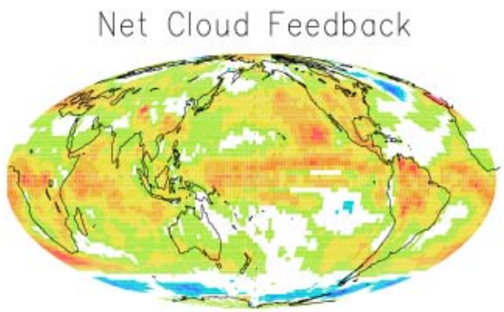




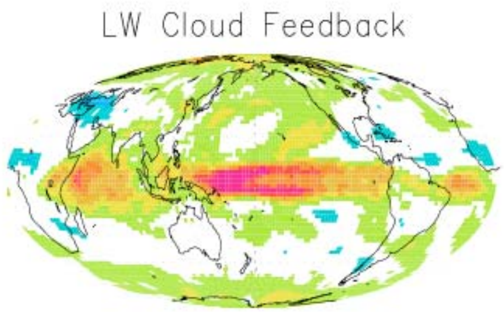


Changes in cloud radiative forcing include effects from changes in other variables (e.g., CO2).

Ensemble Mean Cloud Feedback: SW vs LW



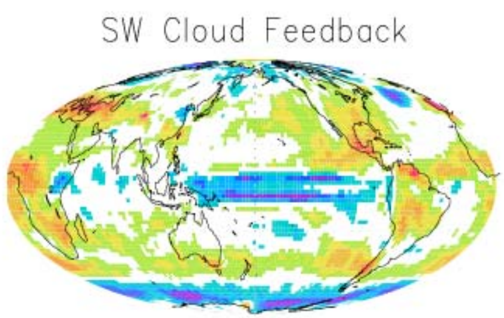
Ens. Mean: 0.66 W/m²/K   Intermodel Range: 0.2 to 1.3

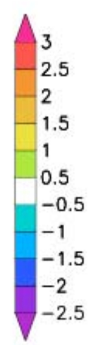


Ens. Mean: 0.40 W/m²/K   Intermodel Range: 0.1 to 0.5

LW cloud feedback is consistently positive in all models

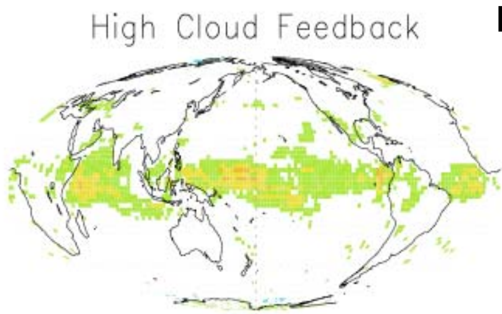
Ens. Mean: 0.26 W/m²/K   Intermodel Range: -0.5 to 1.3



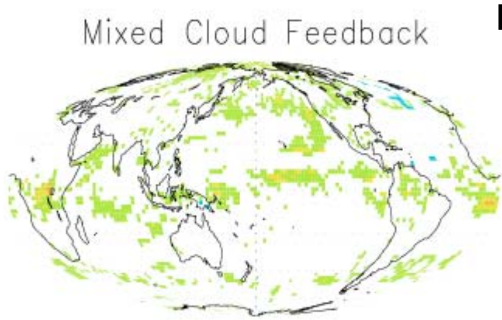


SW cloud feedback ranges from modest negative to strong positive.

Ensemble Mean Cloud Feedback: High vs Low

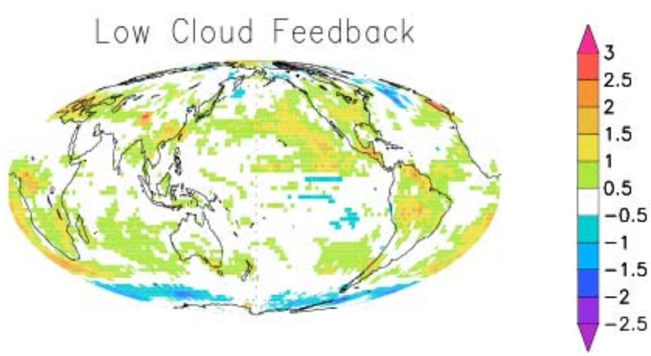


Ens. Mean: 0.18 W/m²/K Intermodel Range: 0.1 to 0.3



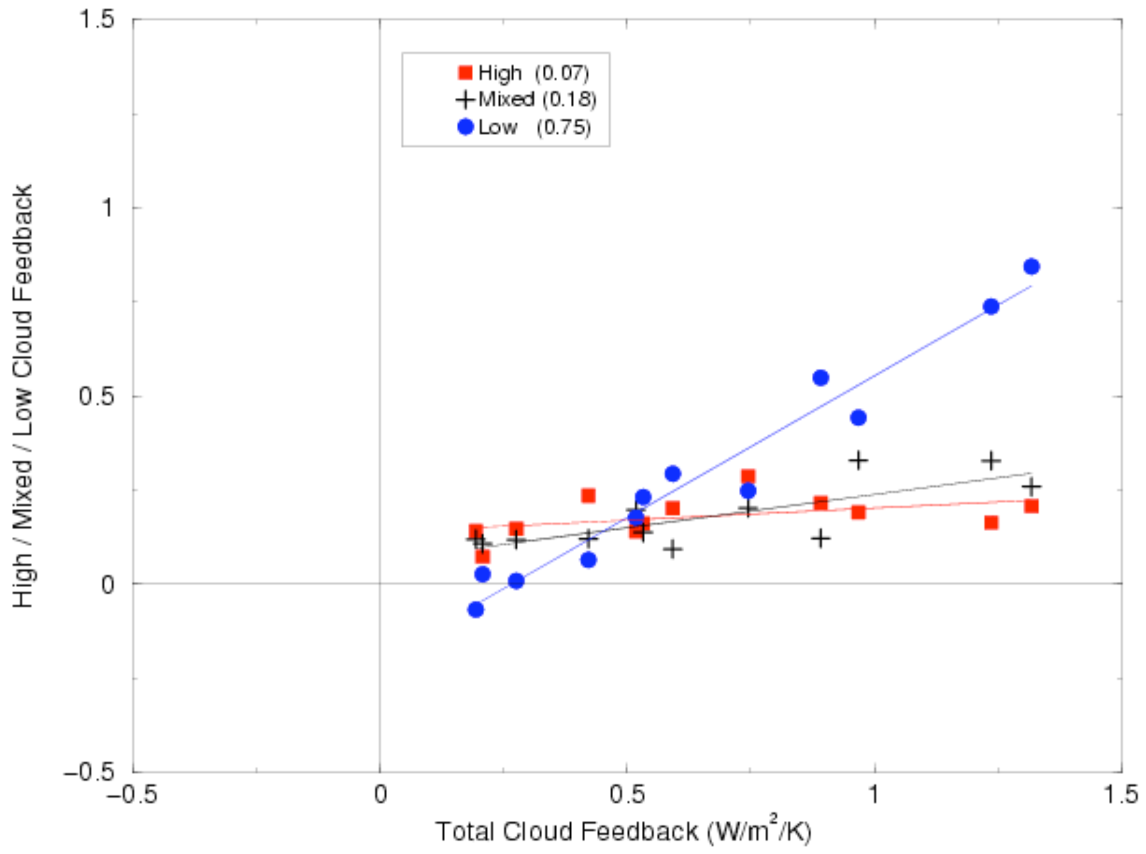
Ens. Mean: 0.18 W/m²/K Intermodel Range: 0.1 to 0.3

Ens. Mean: 0.30 W/m²/K Intermodel Range: -0.1 to 0.9



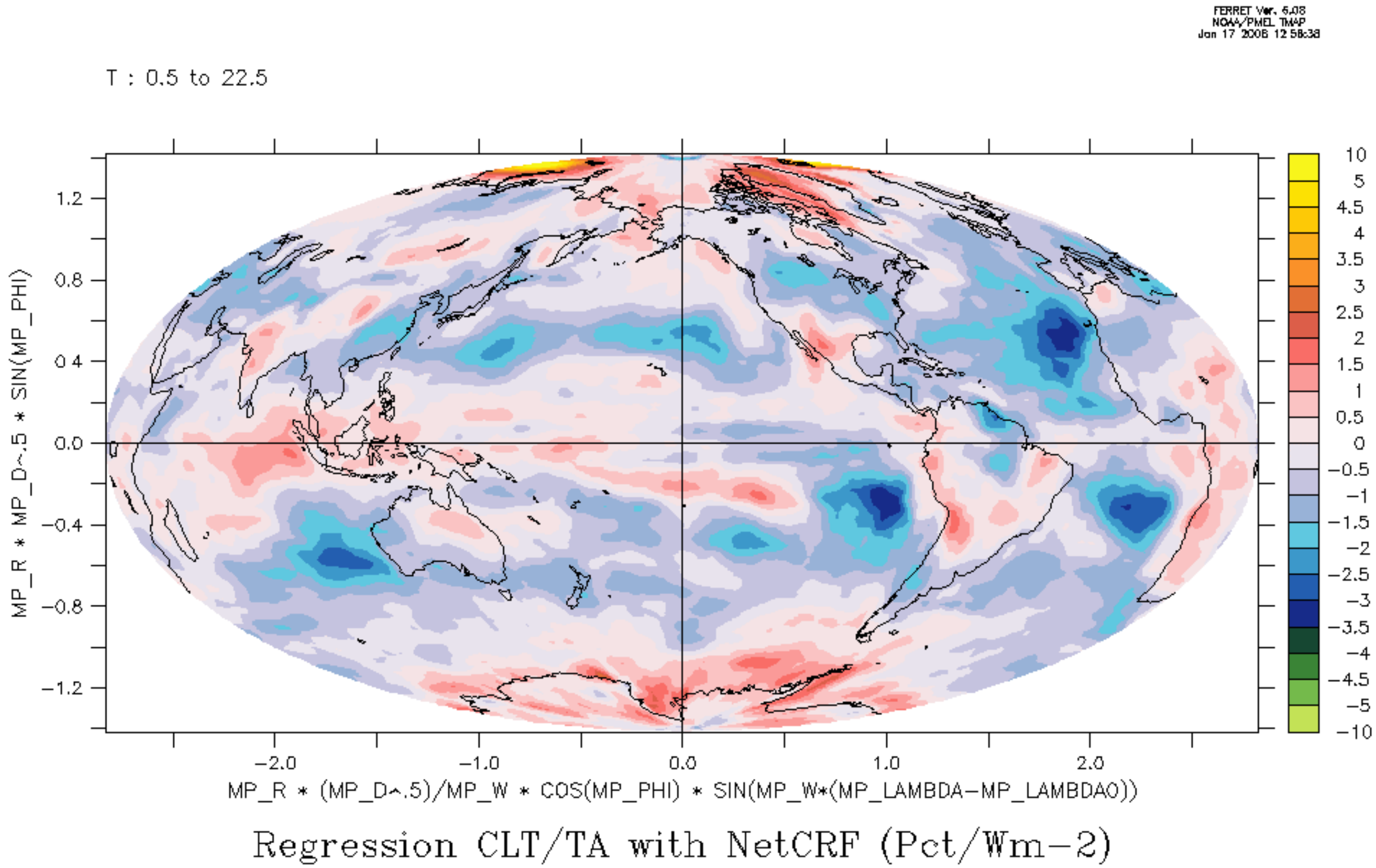
Roughly 50% of net feedback is from low clouds

Which Clouds Contribute to the Intermodel Spread in Global Mean Cloud Feedback?



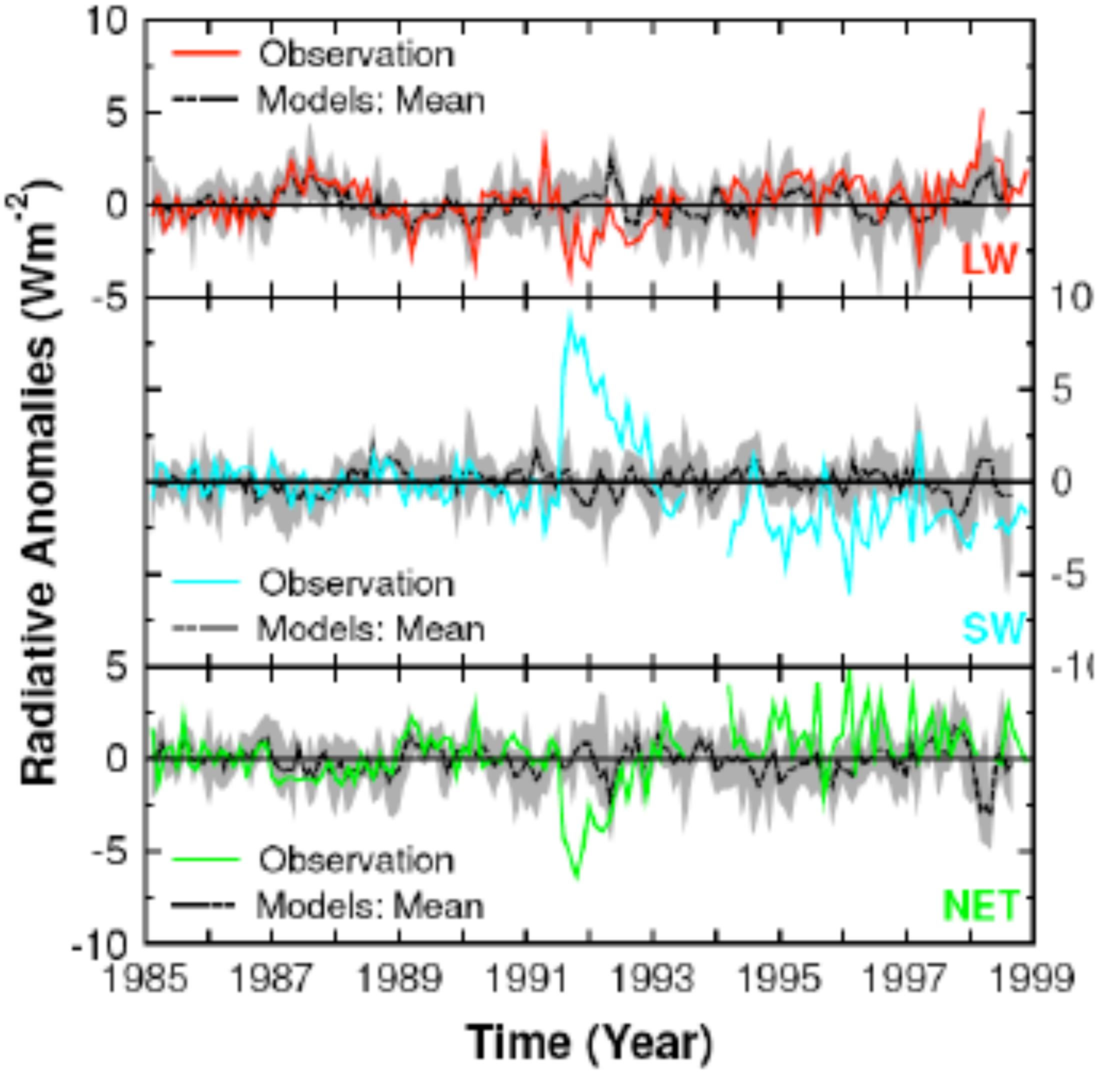
Intermodel spread in net cloud feedback is dominated by SW feedback from low clouds.

Which Regions Contribute to Intermodel Spread?



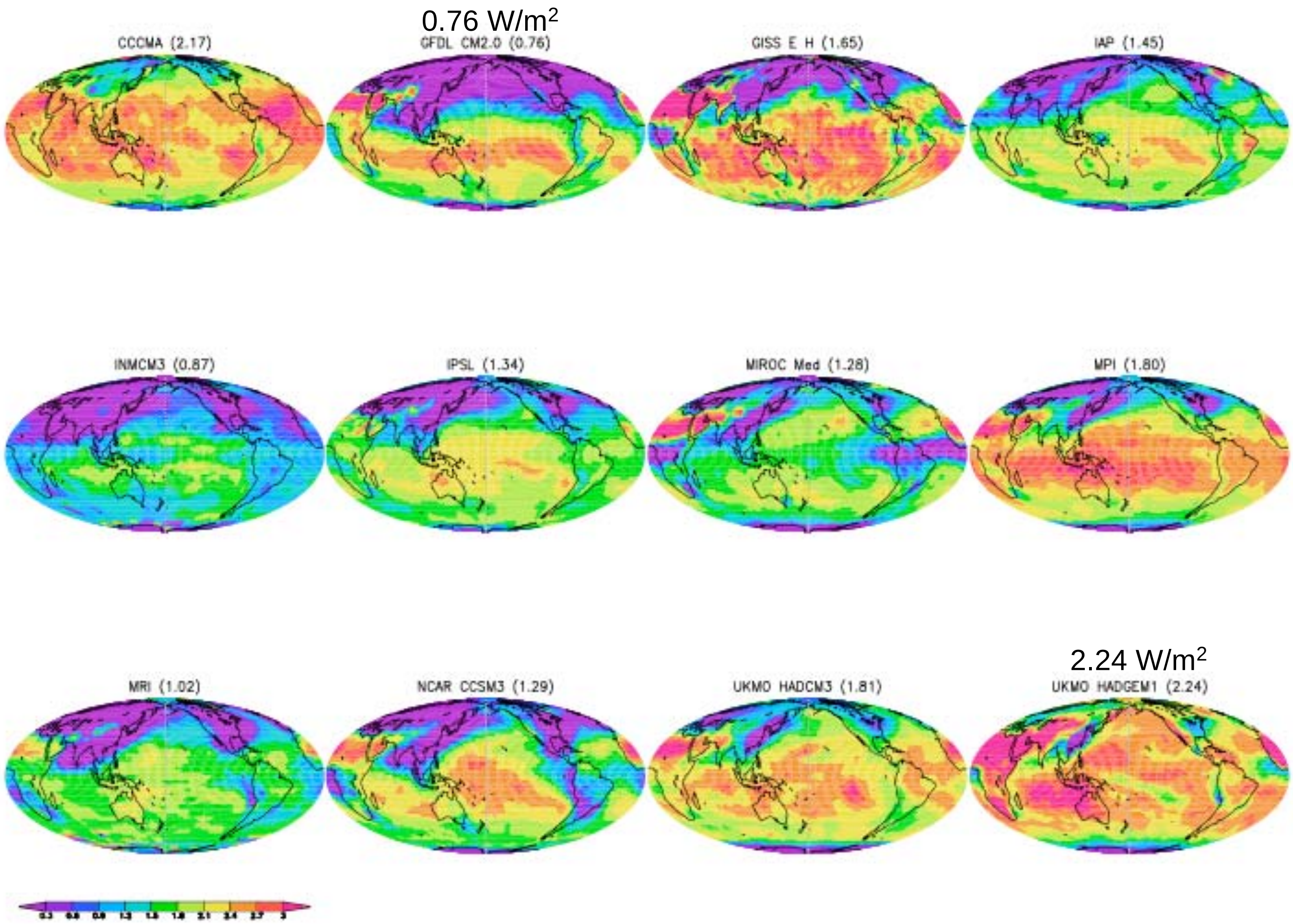
Regional contribution to intermodel spread in global mean cloud feedback is dominated by stratocumulus.

Are these changes detectable in observations?

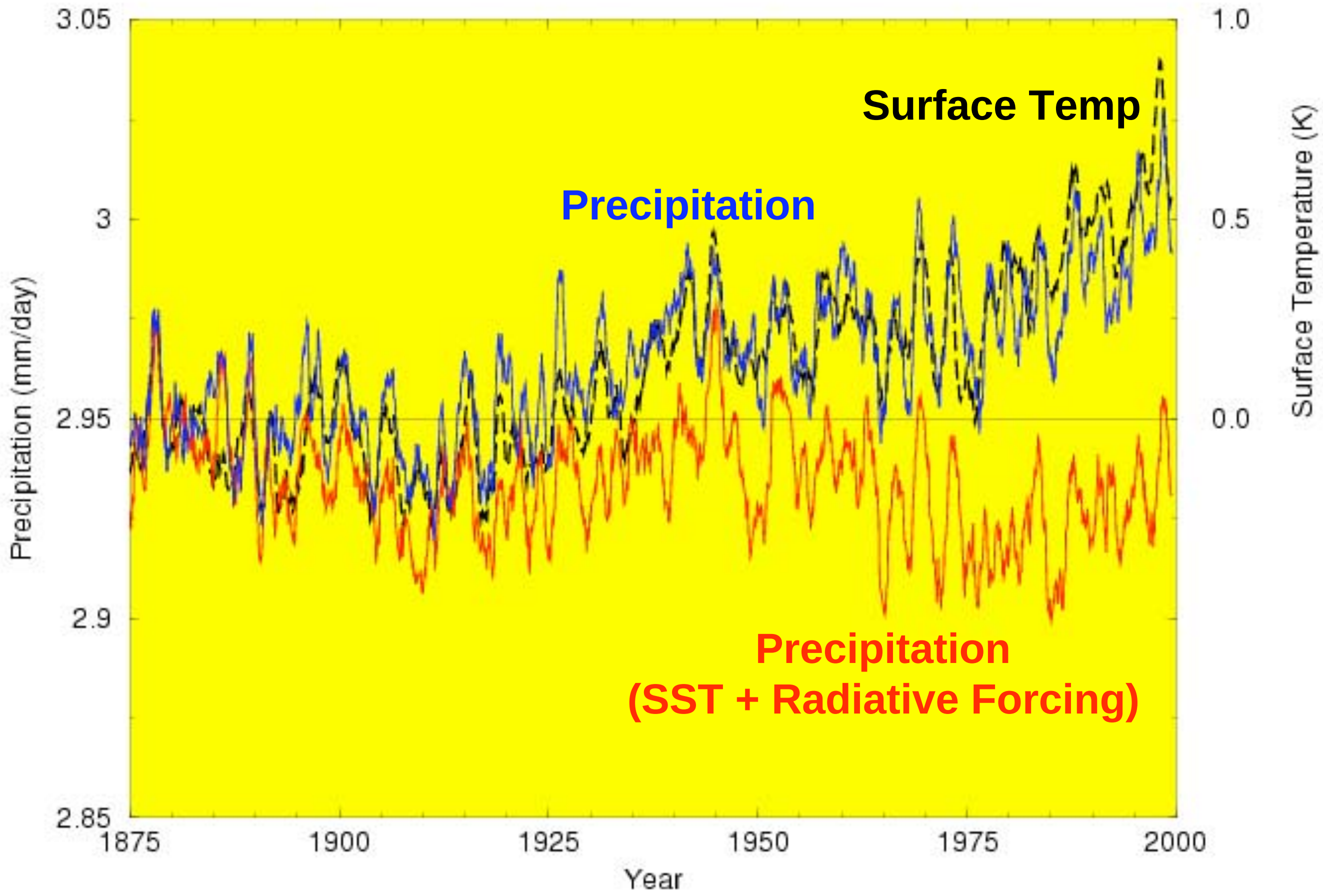


Wong et al. 2006

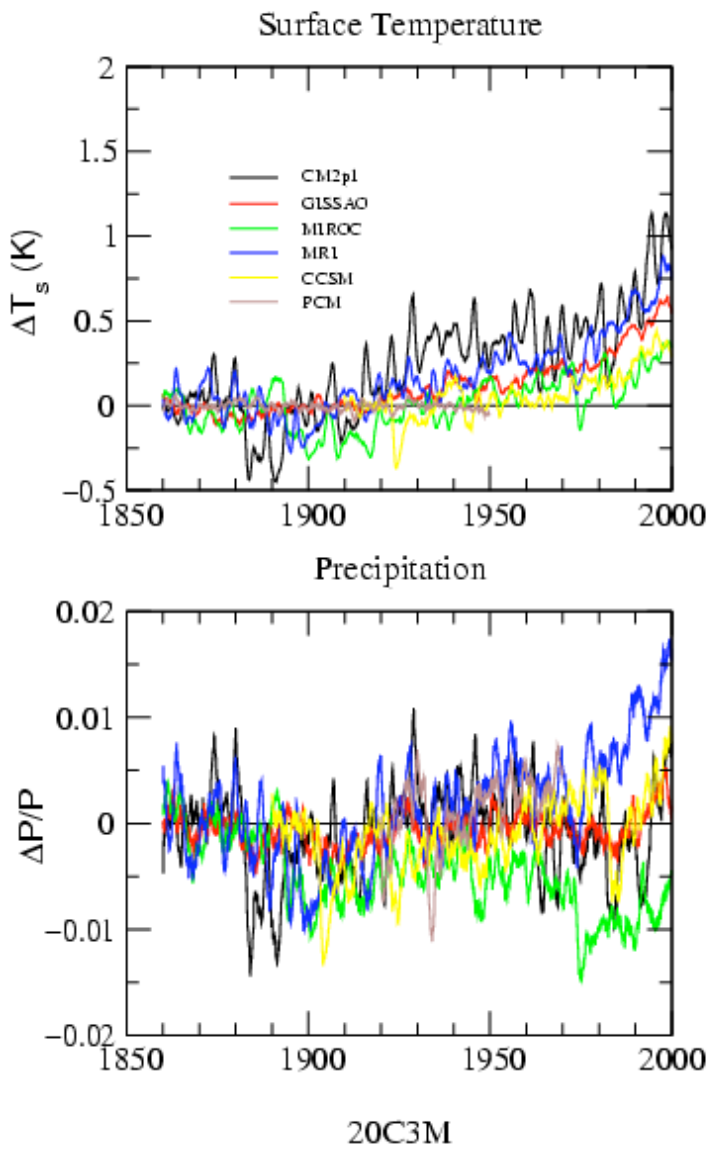
Intermodel Differences in Radiative Forcing: 20th Century (20C3M)



GFDL AM2 Simulations with Prescribed SST: 1850-2000



IPCC AR4 20th Century Model Projections (20C3M)



Surface temperature increases in all models.

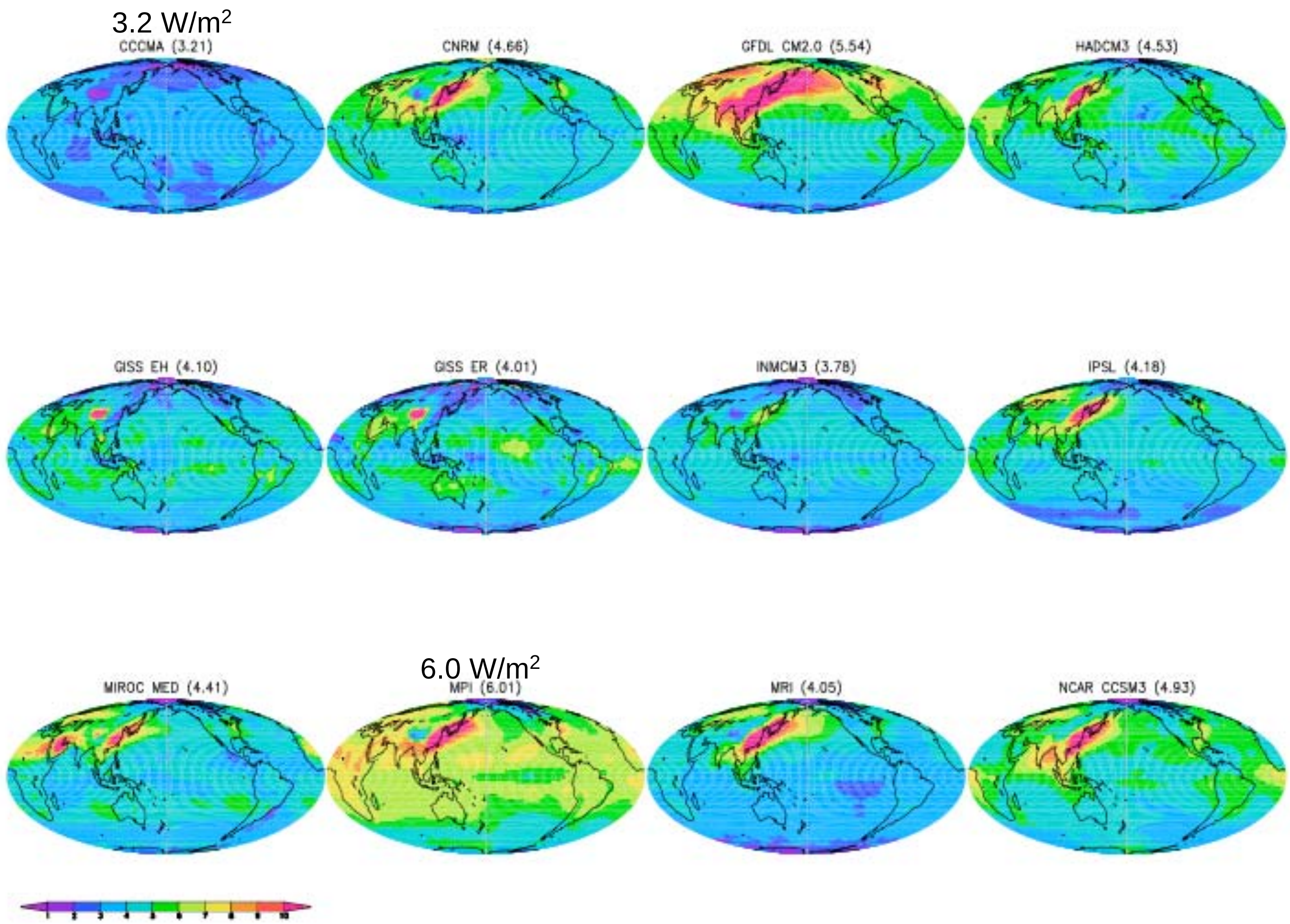
Precipitation may increase, decrease or remain unchanged.

Summary

- Cloud feedback is neutral to positive in all models. Why?
- SW feedback from stratocumulus clouds is the primary cause of intermodel differences in cloud feedback … and thus climate sensitivity.
- Long-term, stable ERB measurements will be needed to reduce uncertainty in cloud feedback.
- Intermodel differences in aerosol radiative forcing are a significant source of uncertainty in both 20th and 21st Century climate projections.

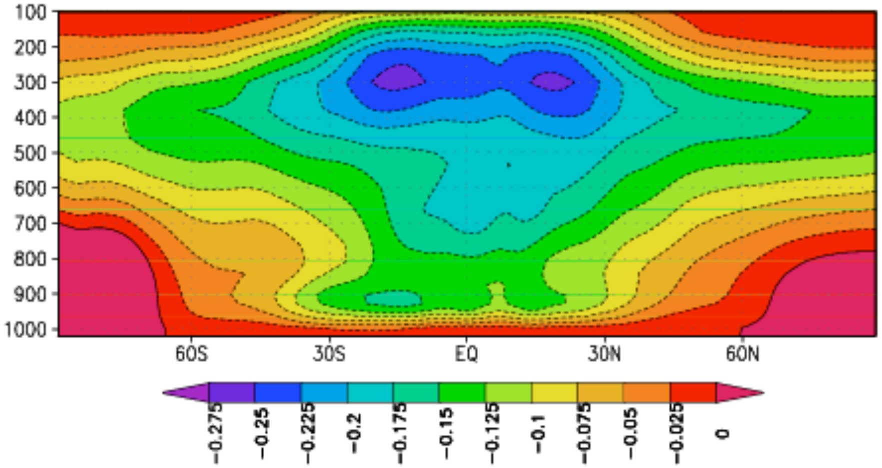
Extra Slides

Intermodel Differences in Radiative Forcing: 21st Century (A1b)



Water Vapor Feedback using Kernels

Water Vapor Kernel
($\delta R/\delta W$ from RT code)



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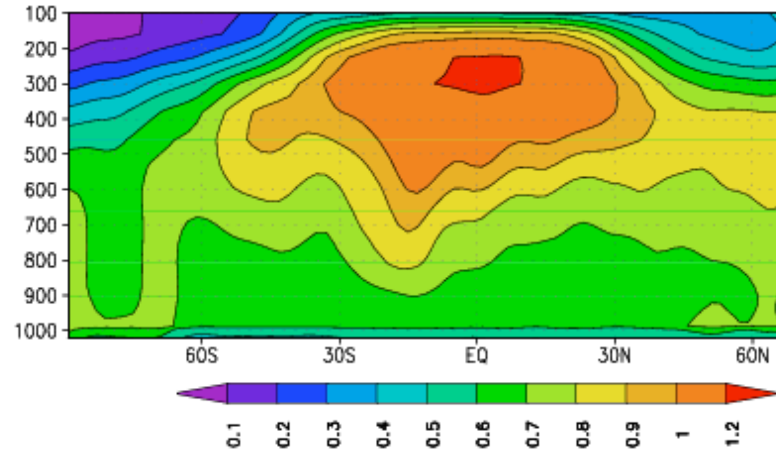
Water Vapor Response to 2xCO2
(dW/dT_s from GCM)



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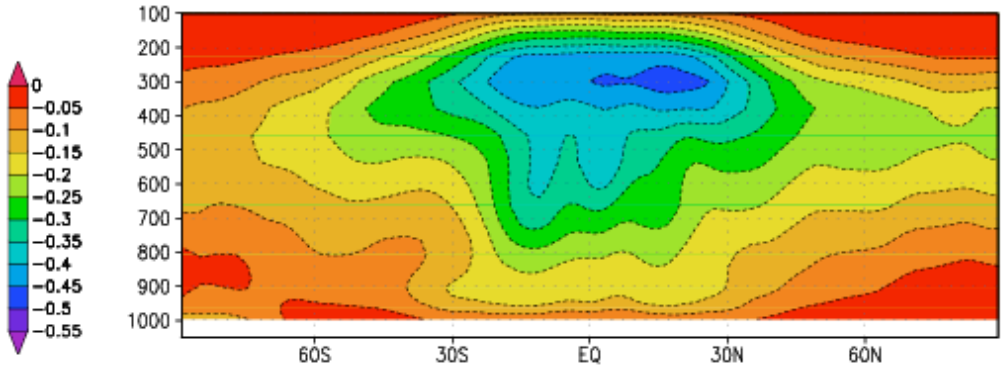
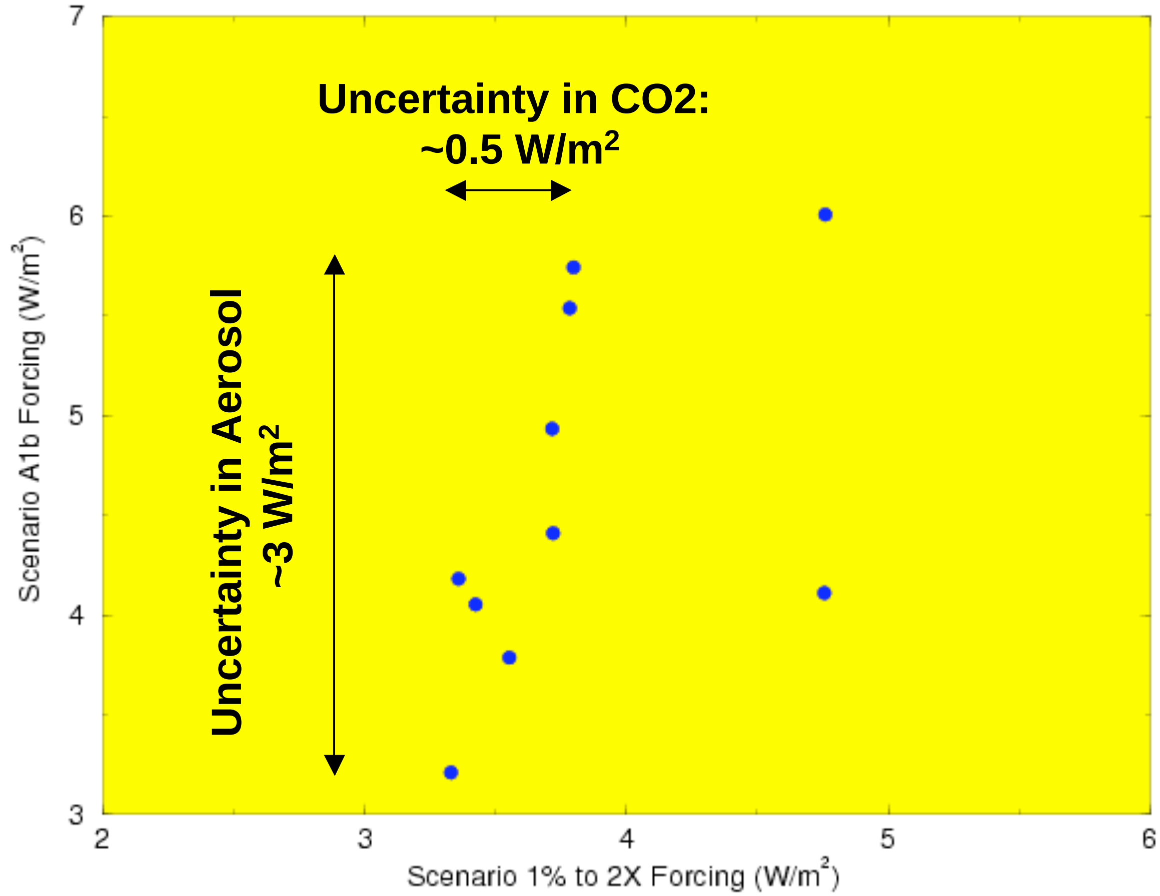
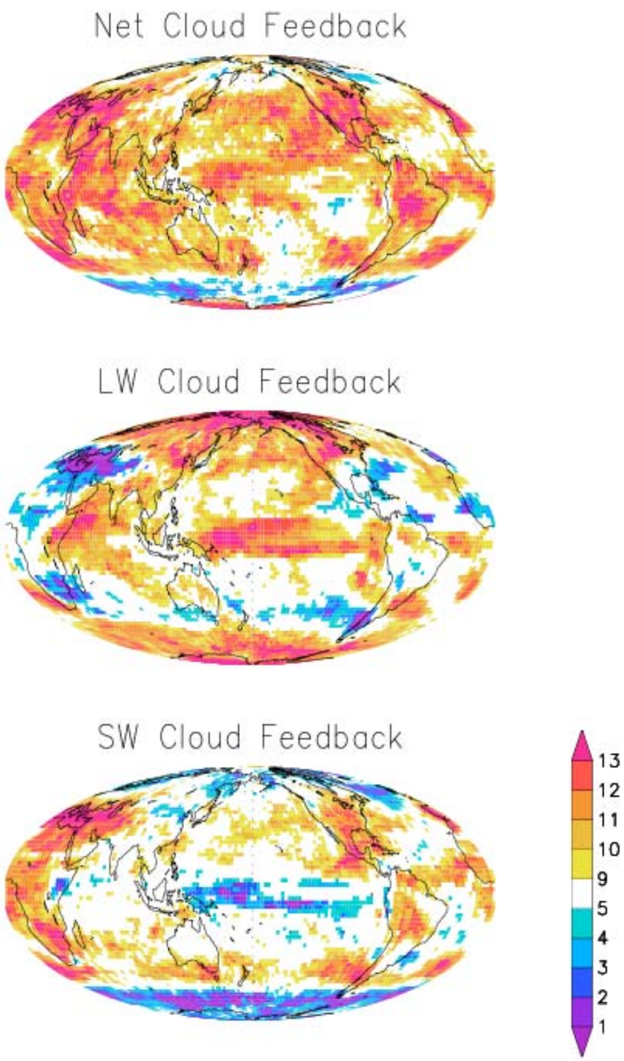
Water Vapor Feedback = Kernel x Response



Intermodel Differences in Radiative Forcing: A1b vs 1% to 2XCO2

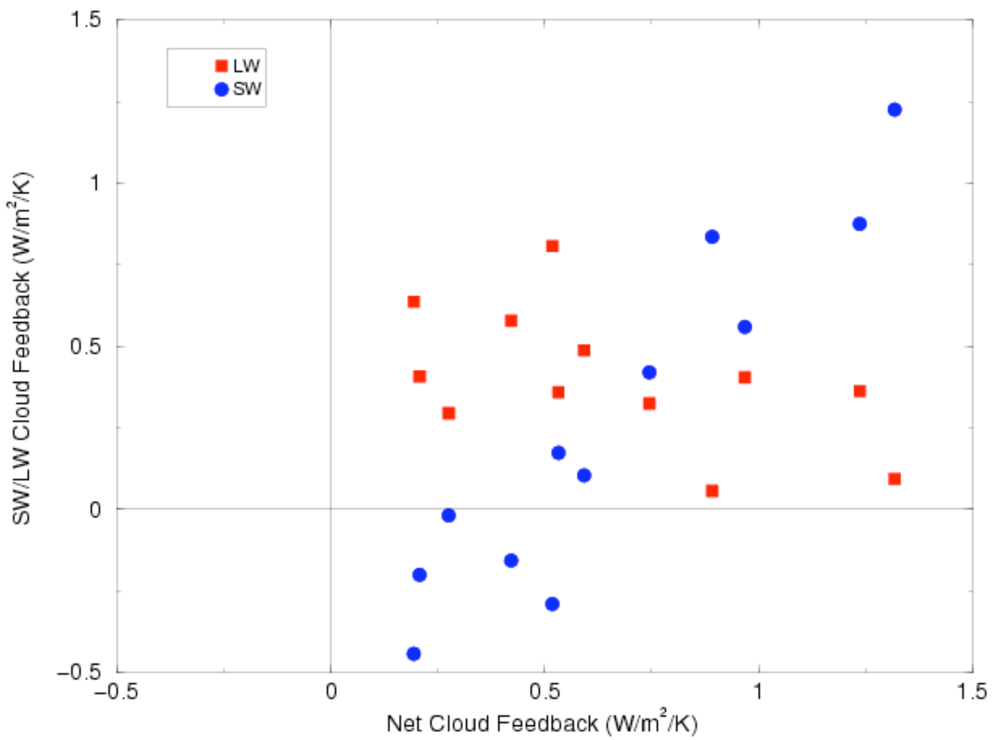


Ensemble Mean Cloud Feedback: Robustness



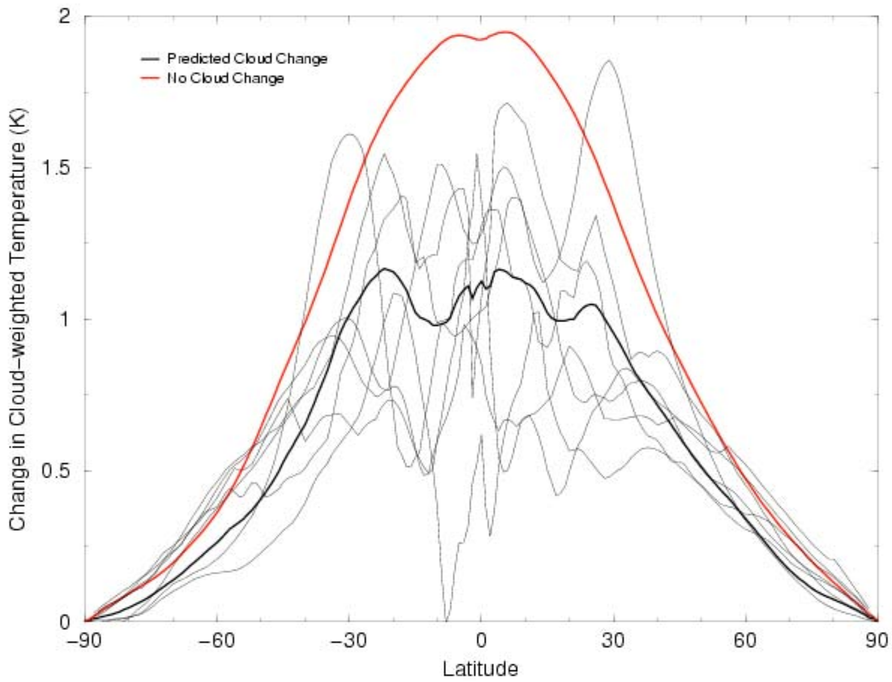
Number of models with a positive cloud feedback in each grid box (out of a total of 12).

Intermodel Spread in Global Mean Cloud Feedback



Intermodel spread in net cloud feedback is dominated by SW feedback.

How FAT is Cloud Feedback in AR4 GCMs?



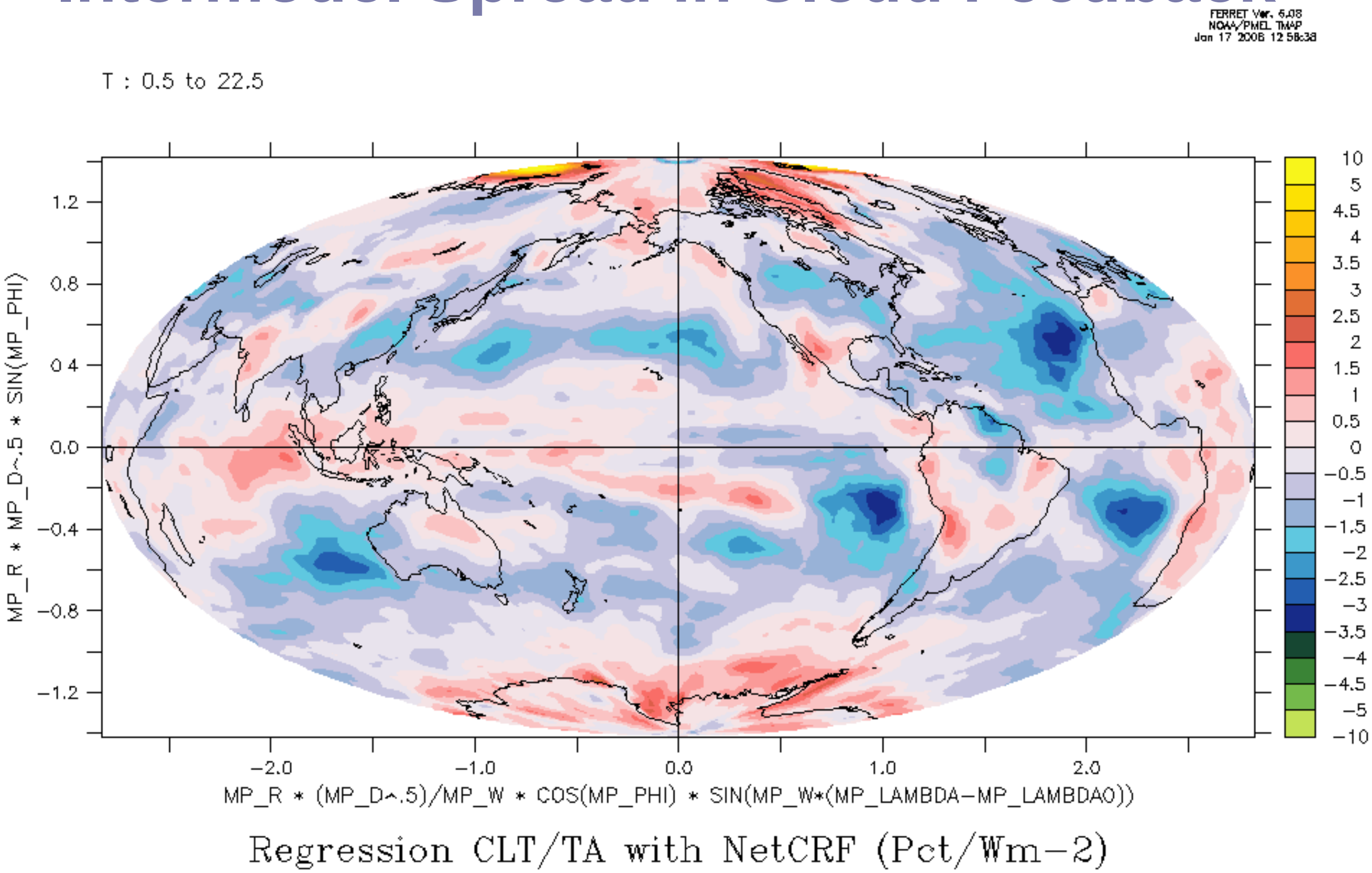
High clouds do warm in response increased CO2, but do so more slowly than a fixed cloud response.

Comparison Feedback Calculations: PRP vs. Kernel Method

Feedback	Kernel	Forward PRP	Reverse PRP	Average PRP
Temperature	-4.06	-4.42	-3.64	-4.03
Water Vapor	2.01	2.12	1.78	1.95
Surface Albedo	0.15	0.17	0.13	0.15
Clouds	0.37	0.28	0.39	0.34

Feedback calculations agree to within ~10% of conventional PRP.

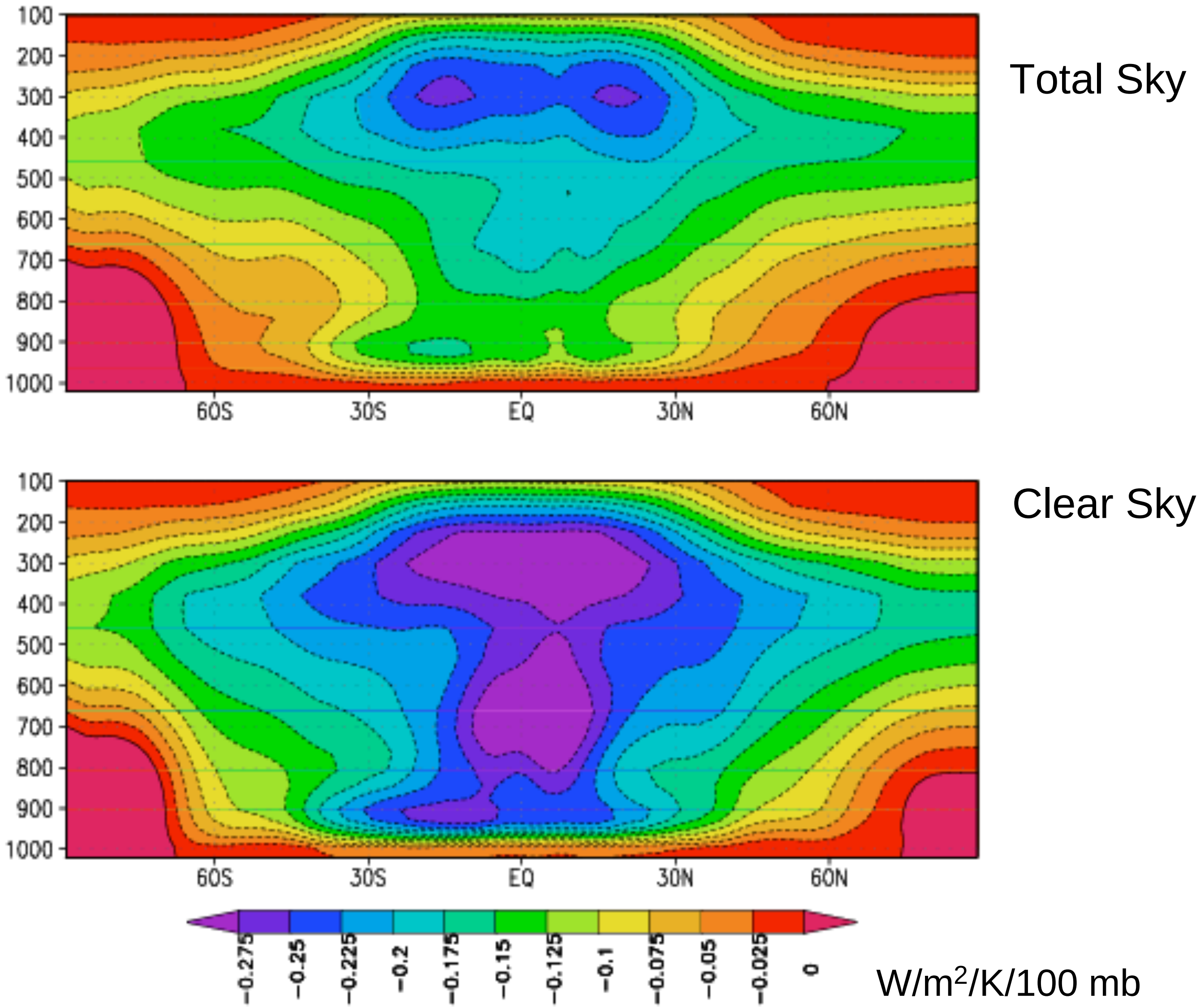
Intermodel Spread in Cloud Feedback



Regional contribution to intermodel spread in global mean cloud feedback is dominated by stratocumulus.

Water Vapor Kernel: δR/δW (zonal, annual mean)

Change in OLR due to constant RH increase in WV



W/m^2/K/100 mb