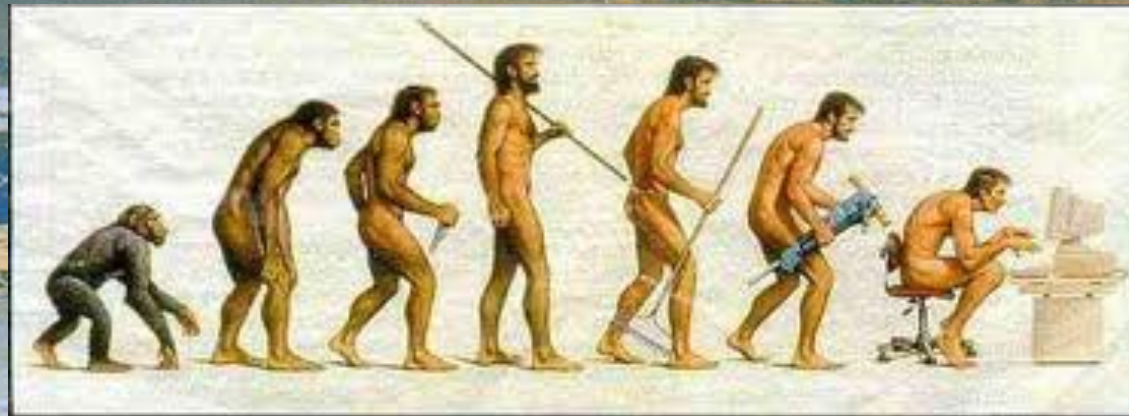


Climate Sensitivity and Cloud Feedbacks in the Evolution of a GCM



A. Gettelman (NCAR, ETH-Zürich),
J. E. Kay, J. T. Fasullo (NCAR), K. M. Shell (OSU)



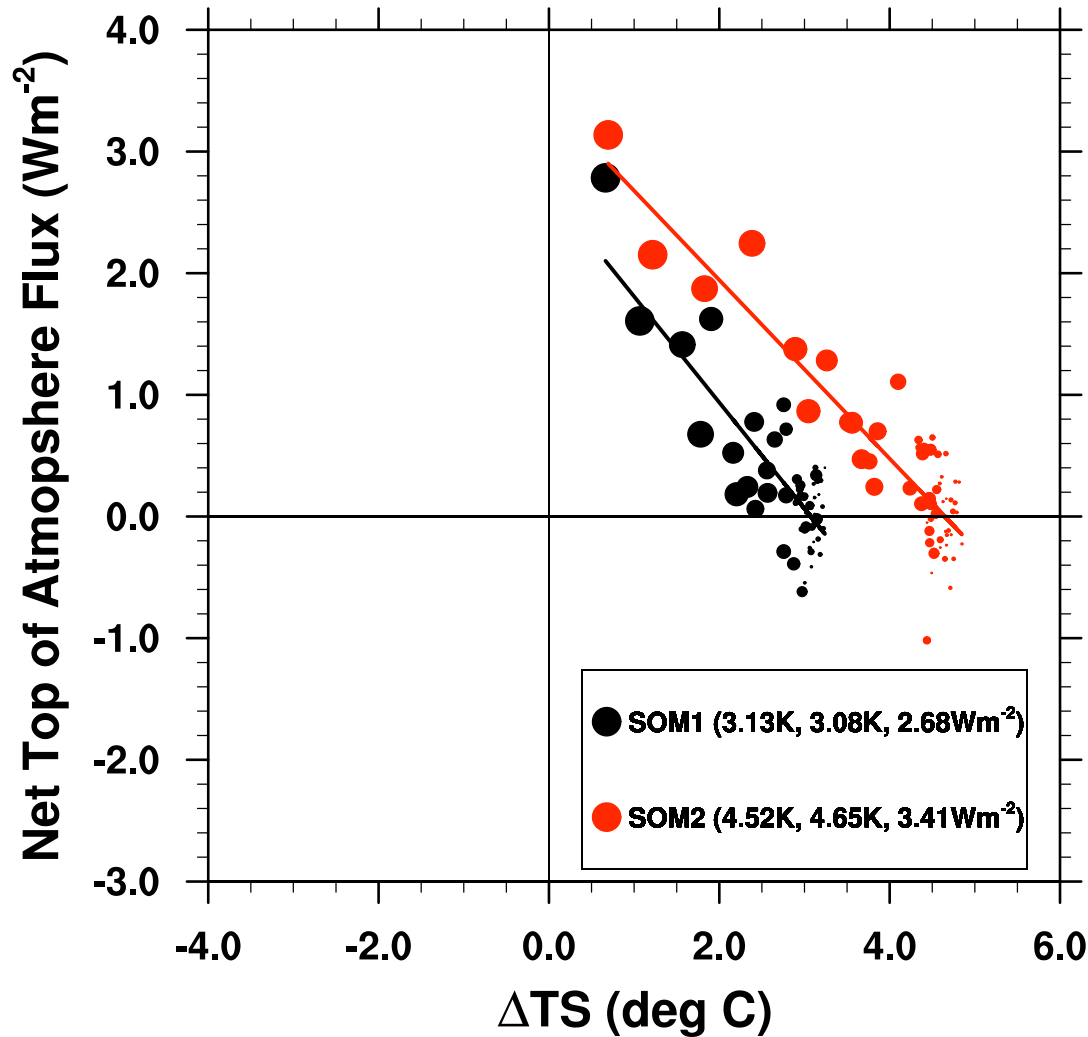
IAC **ETH**

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich



CESM Evolution

2xCO₂ SOM Climate Sensitivity



CCSM4/CESM1 (CAM4): 3.1K
CESM1 (CAM5): 4.5K

What is the difference?
40% Forcing
60% Feedbacks

Note: forcing confirmed by
off line radiation calculations

'Evolution' of Feedbacks in CESM

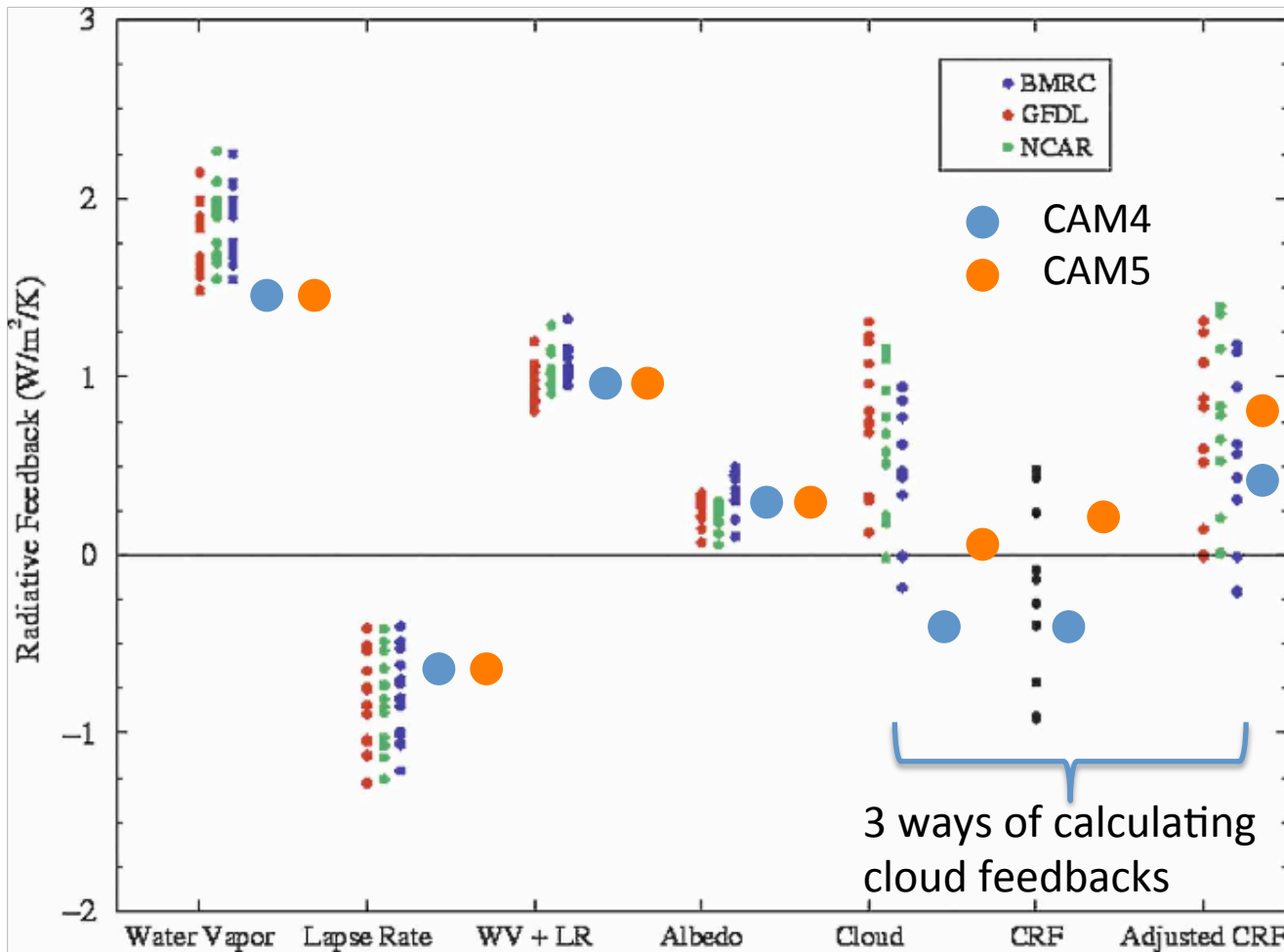
CCSM4 = CAM4 CESM1-CAM5 = CAM5

Radiative Kernel Estimated Feedbacks

Climate Sensitivity:

CCSM4: 3.2K

CESM1: 4.1K

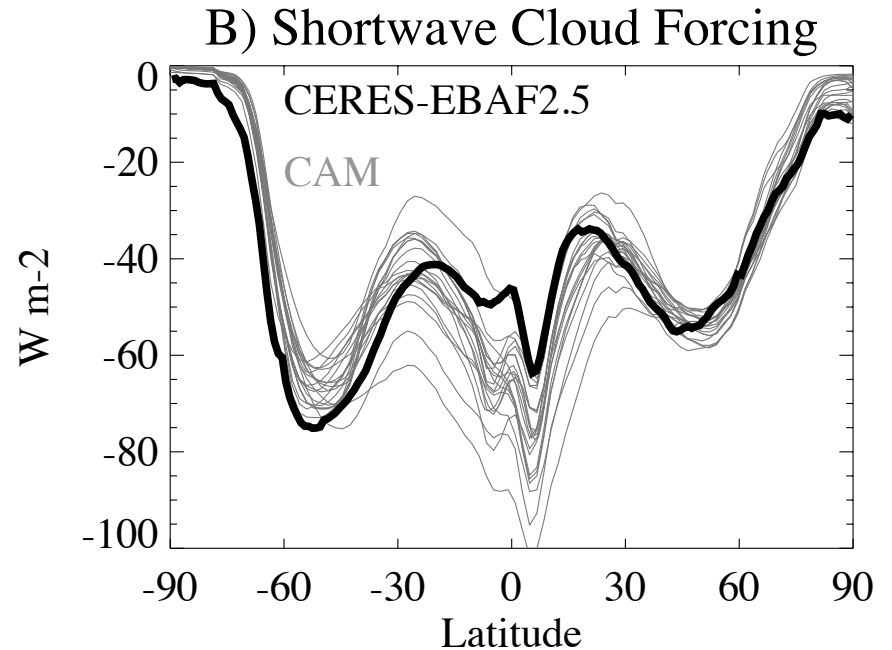
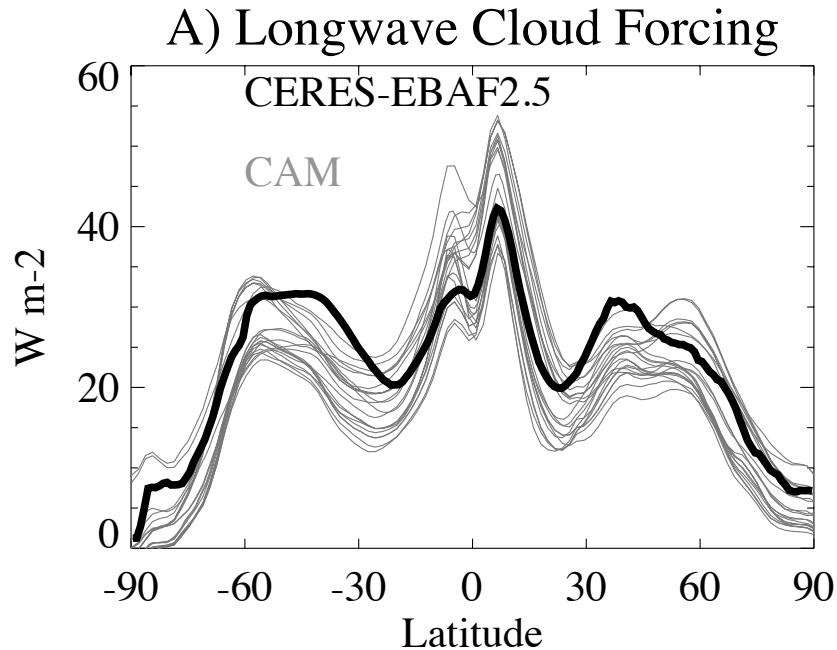


Soden, 2008 (also Colman, Bony)

Methodology

- CESM Development ensemble (21 experiment pairs)
- Estimate feedbacks with radiative kernels
 - $\lambda = \Delta F / \Delta T_s$ ($\lambda=1/\gamma$)
 - $\lambda_x = \Delta F / \Delta X \Delta X / \Delta T_s$
 - ‘kernel’ $K = \Delta F / \Delta X (x,y,z,t)$
 - Cloud feedbacks: Kernel adjusted Cloud Radiative Forcing
- Correlate feedbacks (especially clouds) with sensitivity (γ)
- Also correlate with mean state of ‘critical’ parameters (show one example)

CESM Ensemble looks like 'Earth'



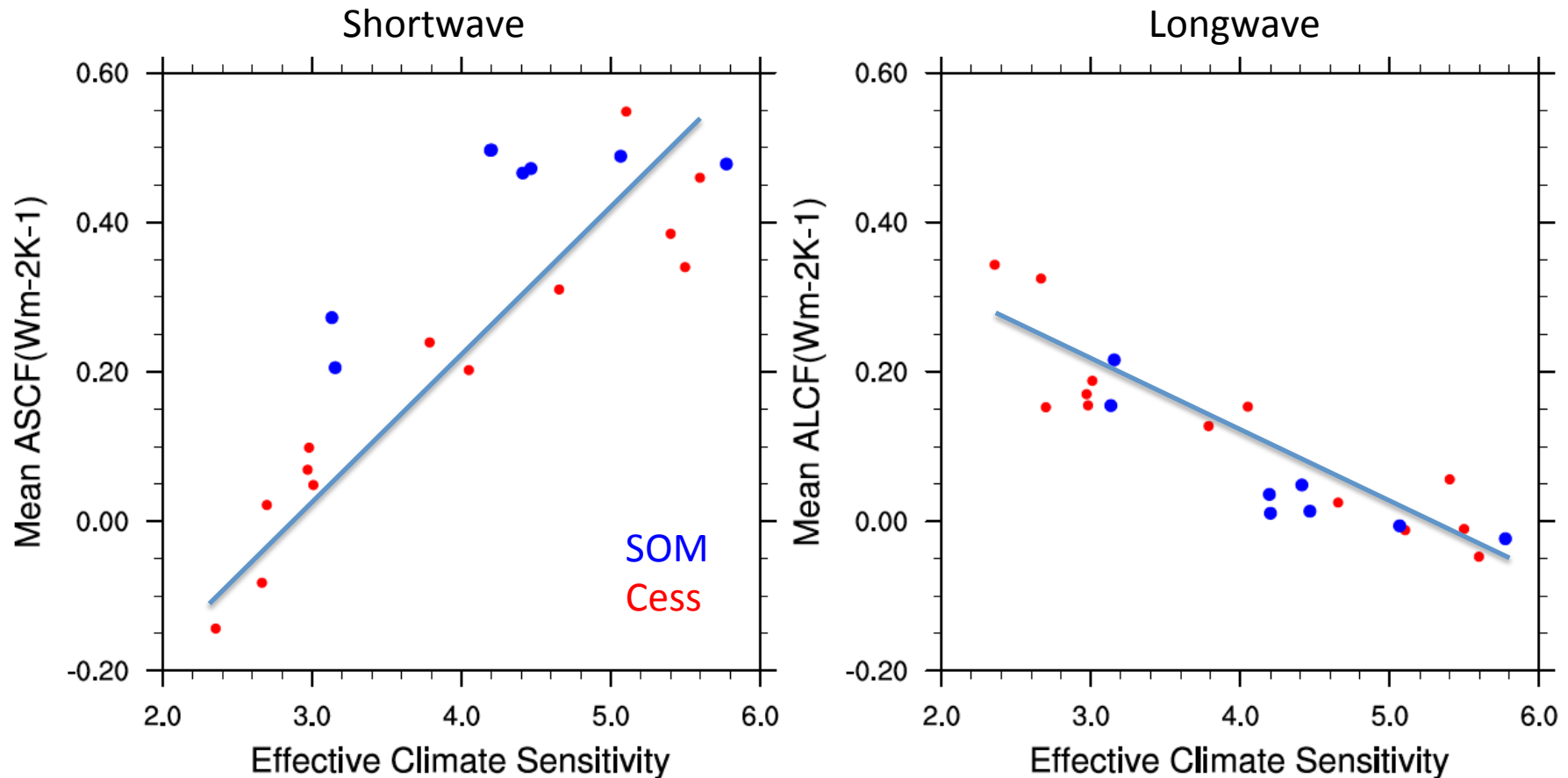
21 CESM Experiments: CAM4 → CAM5

7 Slab Ocean (SOM), 14 Fixed SST (Cess): 1x & 2x CO₂

Model climates are 'earth like'

Model feedbacks look like other CMIP3 models

Sensitivity (γ) and Cloud Feedback



- Look at individual Experiment pairs (SW is dominant)
- Slope, correlation and goodness of fit provide statistics
- Do also for a range of feedbacks/properties, and at different points

Which Feedbacks?

Global Feedback Correlations with Climate Sensitivity

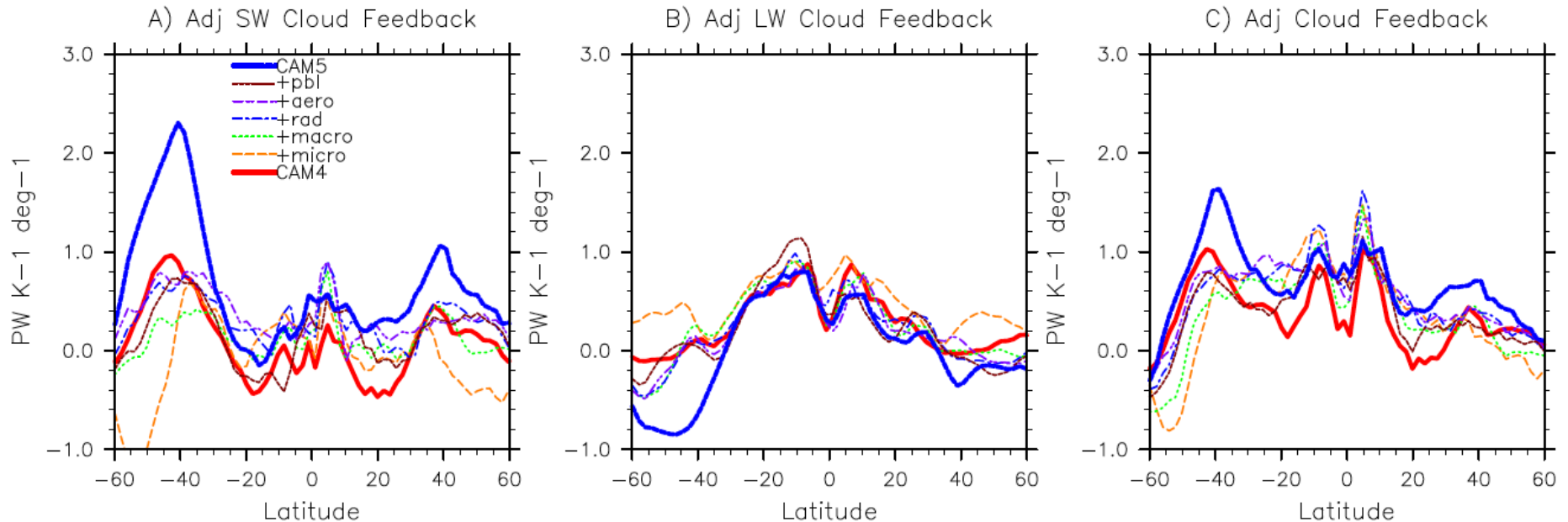
Slope: $\text{Wm}^{-2} \text{K}^{-2}$

Clouds and Albedo
are significantly
correlated with
climate sensitivity
Albedo has a small
slope

	Mean		
Feedback	Corr	r^2	Slope
Net Cloud	0.67*	0.44	0.07
LW Cloud	-0.90*	0.80	-0.09
SW Cloud	0.84*	0.71	0.16
Albedo	-0.56*	0.32	-0.01
H2O + LR	0.21	0.04	-0.006
Temp+ LR	-0.11	0.01	-0.01
TS	-0.45	0.20	-0.006

Which Parameterization Changes?

Zonal Mean Kernel Adjusted Cloud Feedback



Biggest changes:

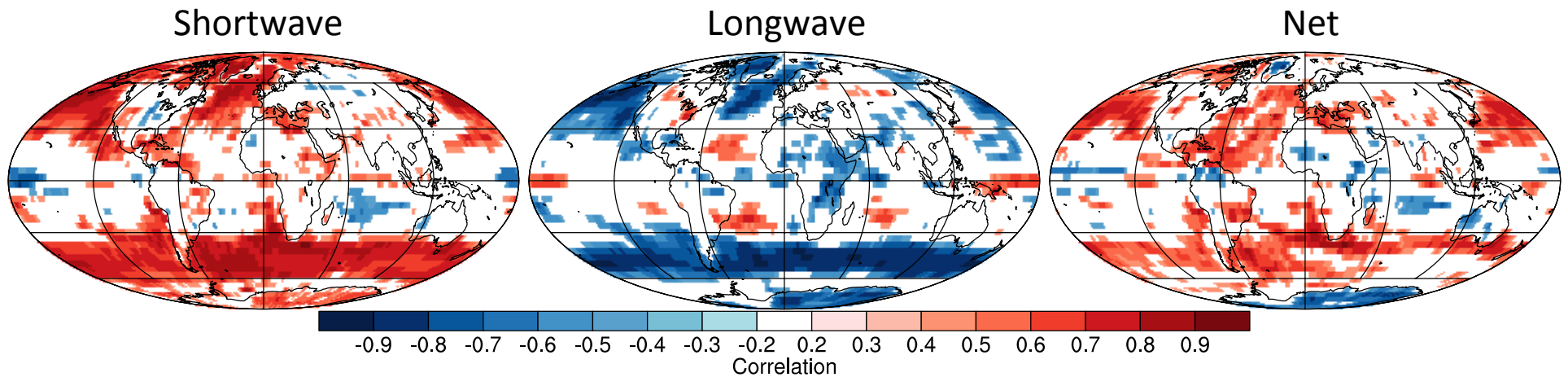
- (1) Microphysics (**CAM4** → **+Micro**)
- (2) Radiation (**+F_{CO2}**) (**+Macro** → **+Rad**)
- (3) PBL makes it more negative (**+Aero** → **+PBL**)
- (4) Shallow Convection (last step) has largest impact (**+PBL** → **CAM5**) **LARGEST**

Regions: Subtropics, Storm tracks, Deep convection over land

Note: can also see this in divergence metrics of present state

Which Regimes?

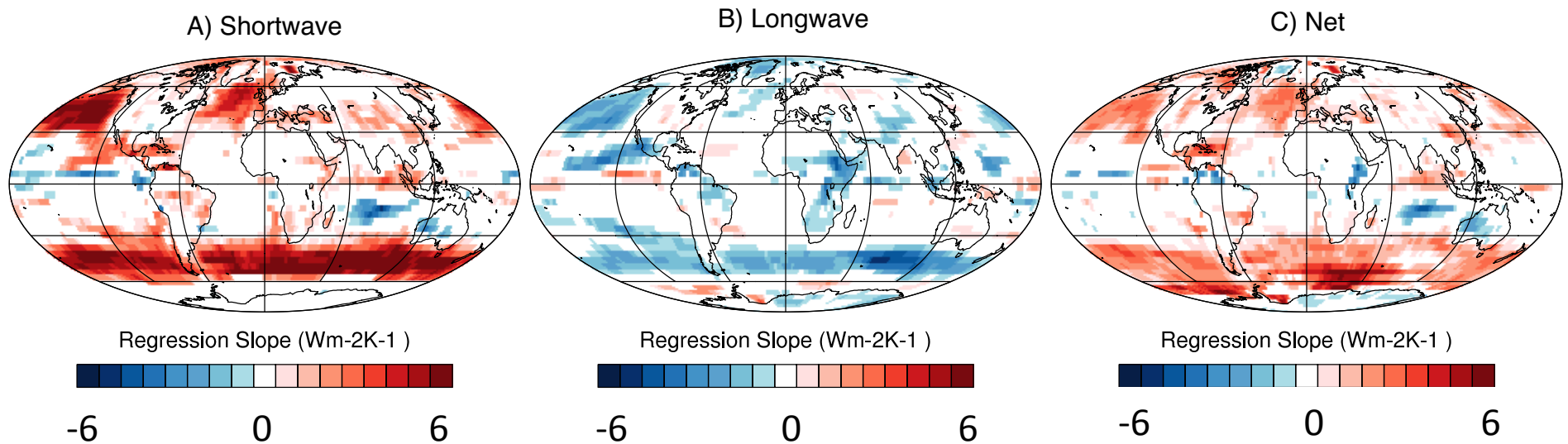
Pattern Correlation between cloud feedback (each point) and global γ (sensitivity)
= Slope of the line on scatter plots (but λ_{clid} at each point)



Where are highest correlations with sensitivity?
In the storm tracks (especially subtropical edge)

Regressions

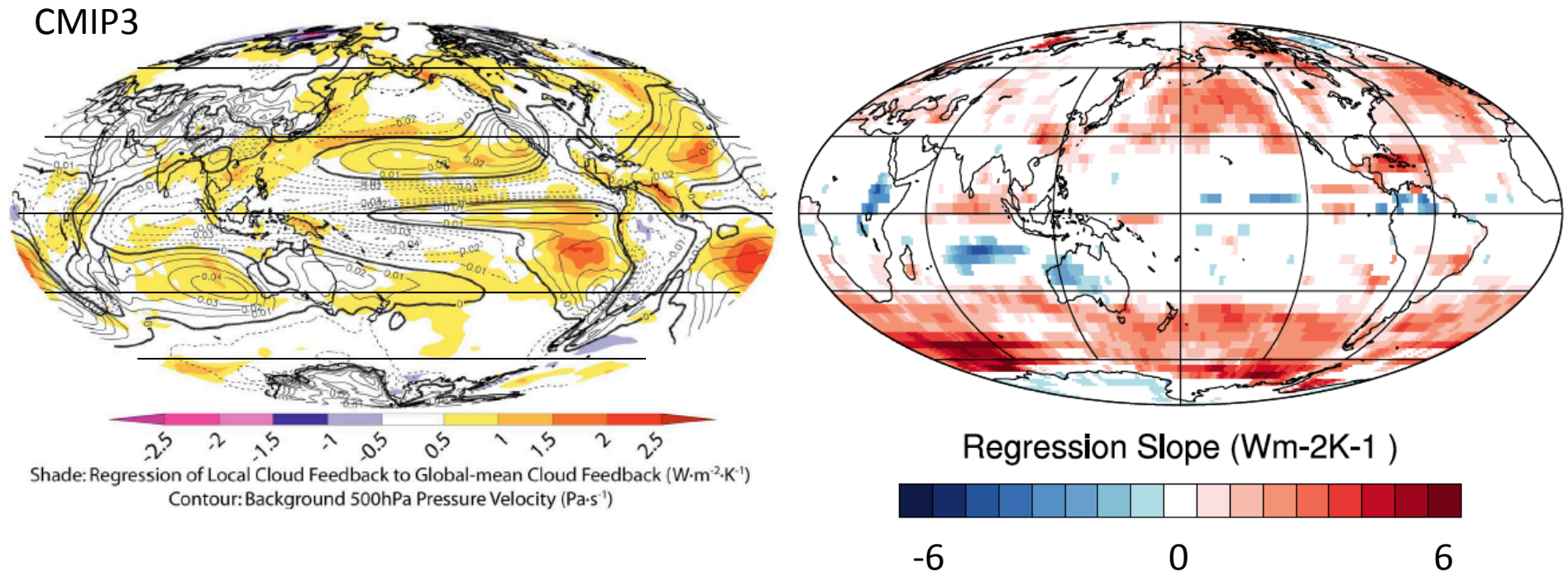
Regression of local cloud feedback on global cloud feedback in CESM ensemble



Regression on global sensitivity (γ) looks similar

Regressions: Compared to CMIP3

SODEN AND VECCHI: VERTICAL DISTRIBUTION OF CLOUD FEEDBACK



- CESM different than CMIP3 even with feedback sign change in Strato-cu regions...
- CMIP3: tied to sub-tropical descent regions (no correlation where forcing is large)
- CESM: looked at ω_{500} : not strong correlations or regression
- CESM: more storm track focused (where forcing is large)

Sample regression of parameters on γ

Regression of mean 1xCO2 LWP and IWP on global climate sensitivity

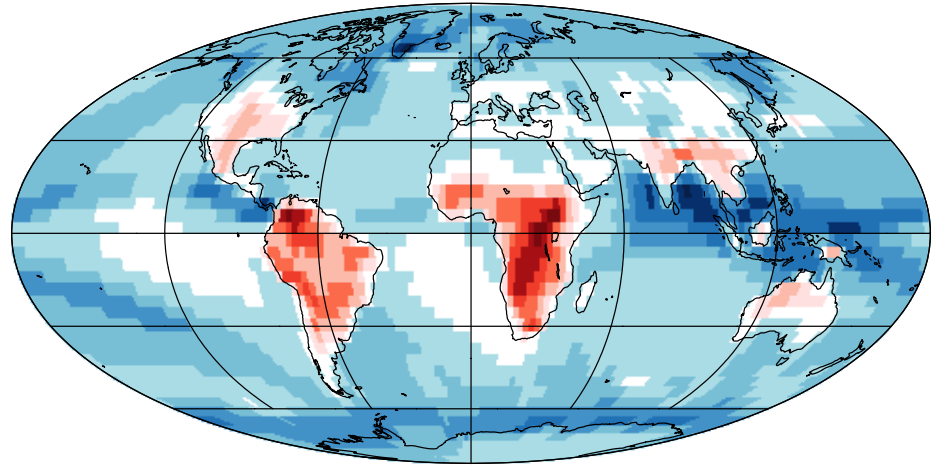
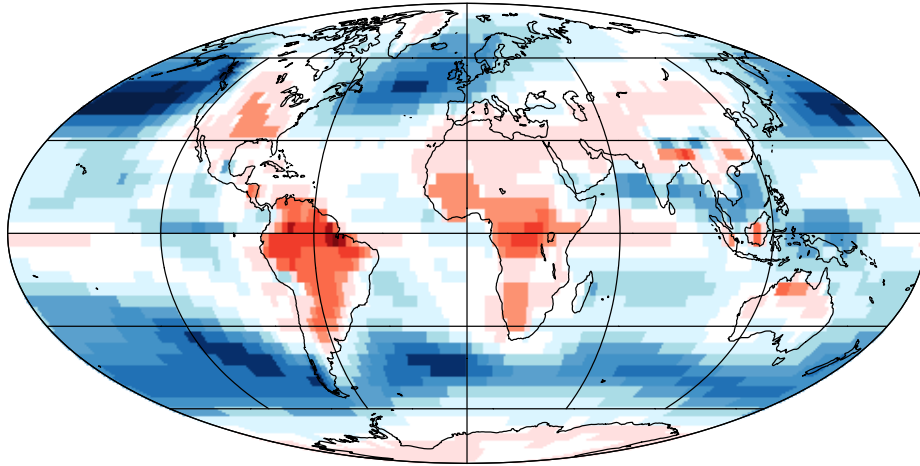
Liquid Water Path

Ice Water Path

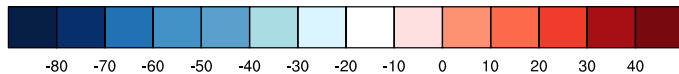
Correlation

95% sig Correlation

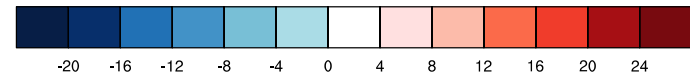
95% sig



Regression Slope (gram/m2 K-1)



Regression Slope (gram/m2 K-1)



Colored = significance

- Large slope (correlation) with Liquid Water Path
 - Higher sensitivity associated with lower mean condensate
- Ice moderately correlated: patterns are a ‘feature’
 - Different treatment of convective water: land & ocean

What is happening in CESM?

- Change to shallow convection = largest jump in sensitivity
- Due to shortwave cloud feedbacks around storm tracks
- Different than CMIP3 ensemble (SV2011)
- Cloud fraction changes on Equator-ward branch storm tracks
- LWP & microphysics (optical depth) change poleward
- Why?
 - Change in convective detrainment in storm tracks
 - motion of storm tracks
 - liquid and ice partitioning
- Parameterization dependent in CESM (CAM4→CAM5)
- Process by which it occurs has a physical basis

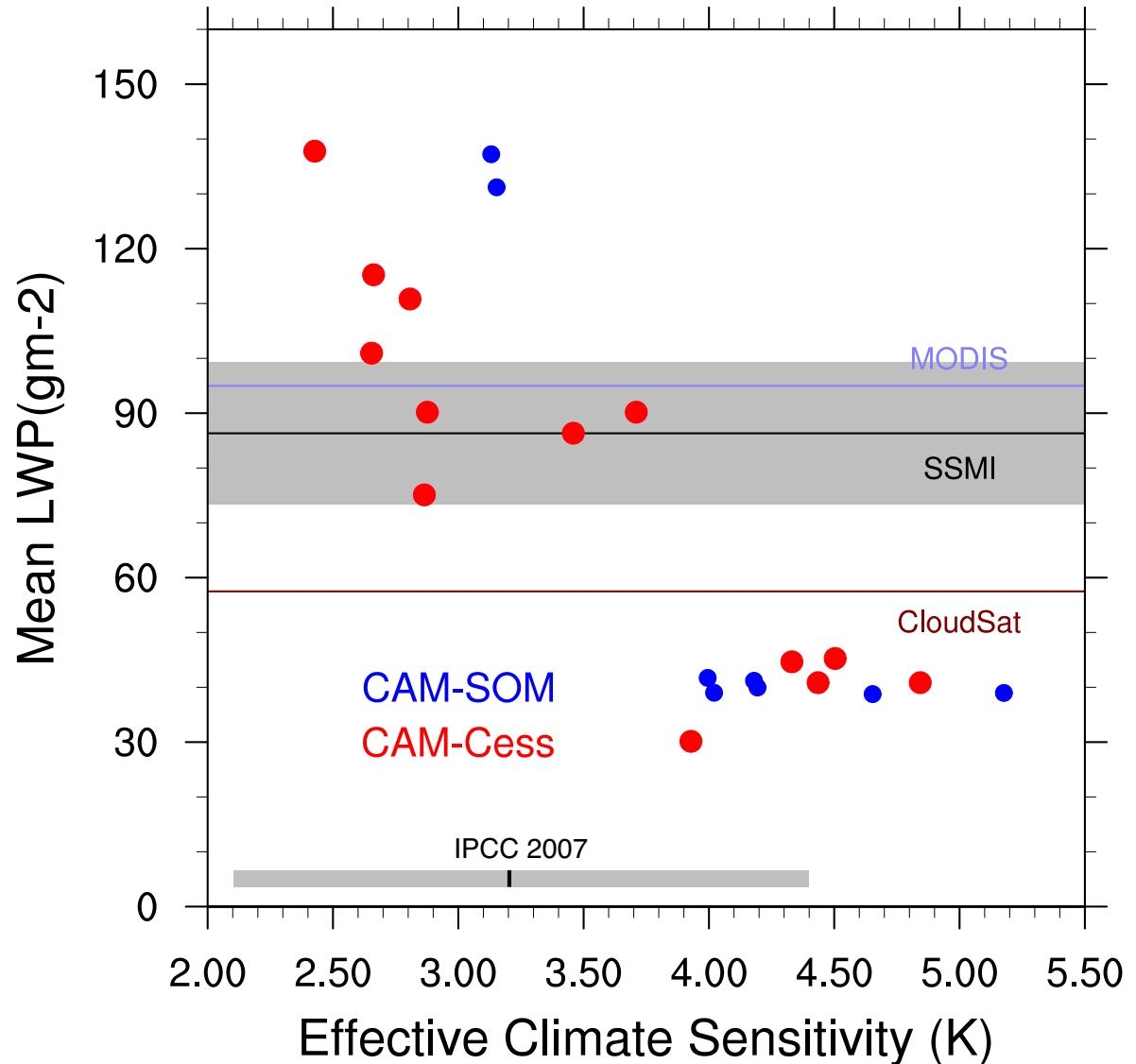
Sensitivity v. 60S-60N LWP

γ correlated with mean state properties in **CESM** and **SOM** experiments.

Have looked at CMIP3:
less conclusive

Others (e. g. Pincus et al 2008) have looked for different parameters or correlations: generally not seen them.

Why? Models have same forcing. Different balance to get there.



Why does LWP matter?

Cloud forcing (R_{CLD}) is observed and 'well known'

$$R_{\text{CLD}} = f(a, \tau) \quad (a = \text{fraction}, \tau = \text{optical depth})$$

Both a, τ are 'known' outside of Arctic (not well known)

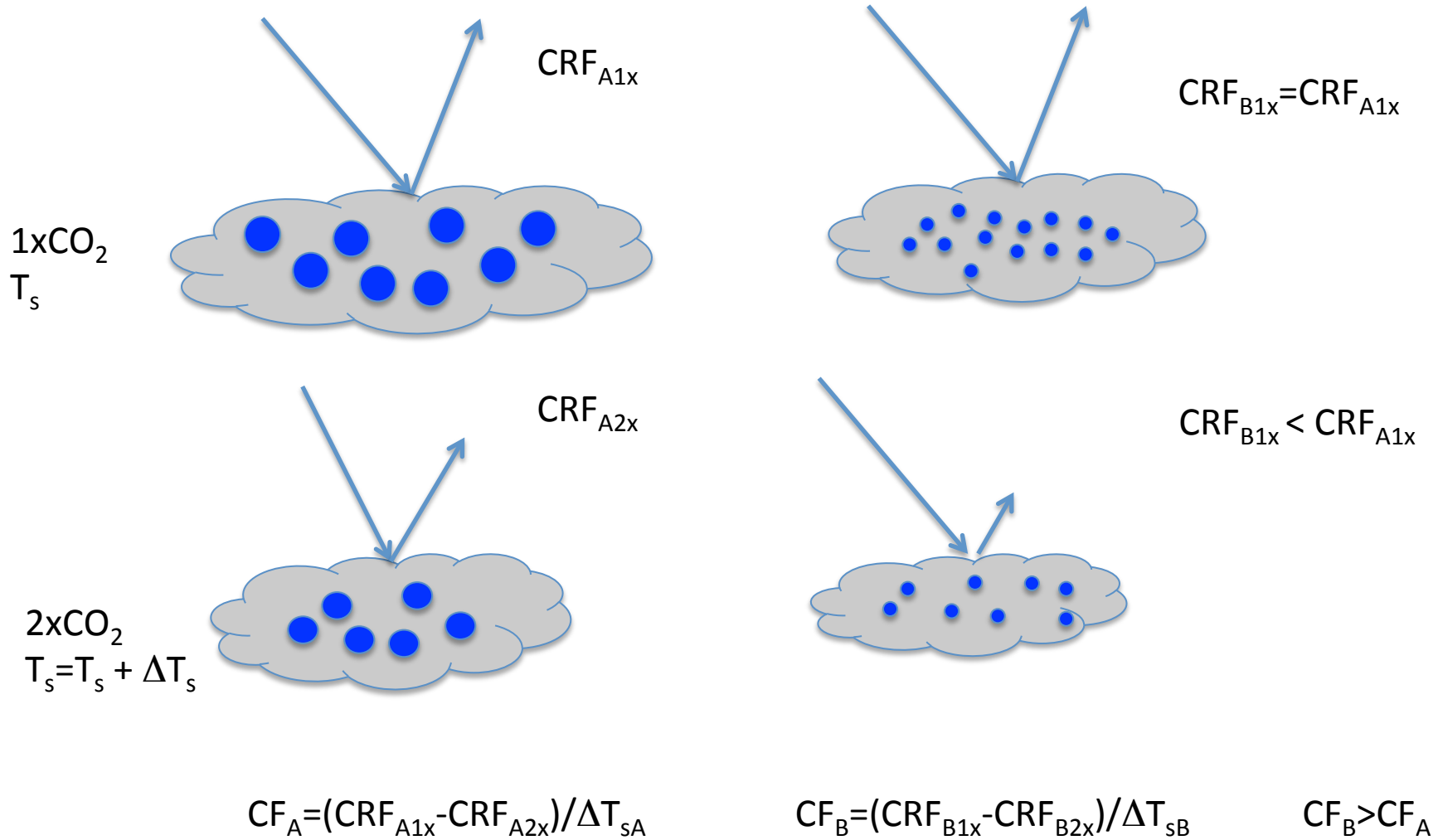
$$\tau = f(N_c, \text{LWP}) \quad [\text{mass}, \#]$$

Satellites only measure τ , make assumptions about N_c to get LWP, and have different a (viewing geometry).

Still 20-40% uncertainties in LWP (see plot again): may be able to use them to 'rule out' some ranges of climate sensitivity?

Bad news: CAM5 ($\gamma = 4\text{K}$) has much better clouds and low LWP

Cloud Feedback (CF) and Mean State

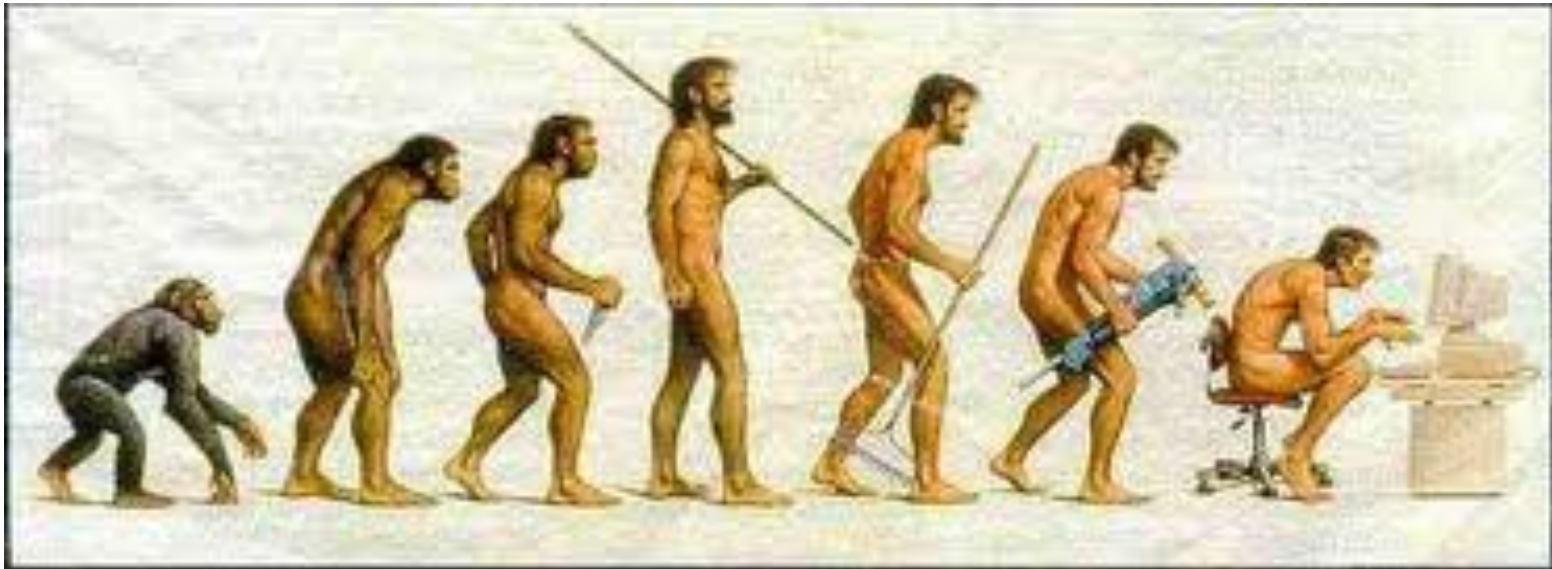


References:

Conclusions

- Cloud feedbacks dominate climate sensitivity spread
- Note: effects of 'tuning' parameters and aerosols on climate sensitivity are small
- SW cloud feedbacks on equator-ward part of the storm track: when shallow convection is introduced
- Less spread due to stratocumulus regions than CMIP3 results (even though these feedbacks change in CESM).
- Base state microphysical balance of clouds is different between CESM models: base state of cloud microphysics says something about climate sensitivity in CESM
- (Micro) Physical reasons why clouds matter: optical depth of clouds non unique (some relation of LWP and r_e)

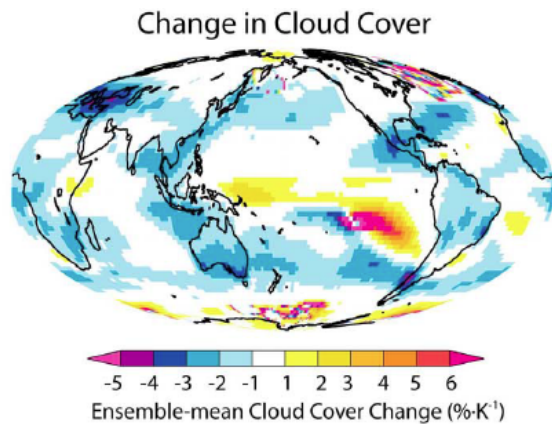
Questions, Comments or *'Feedback'*?



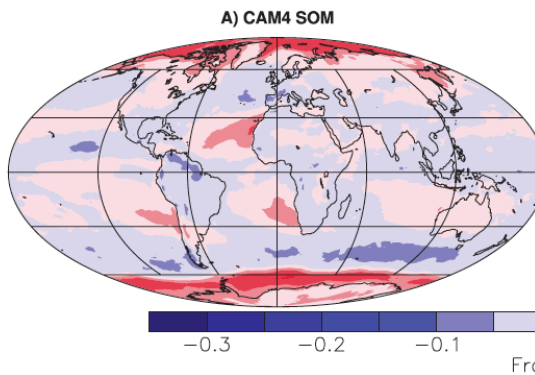
- A. Gettelman, J. E. Kay, K. M. Shell, The Evolution of Climate Sensitivity and Climate Feedbacks in the Community Atmosphere Model, J. Climate, 2012
- A. Gettelman, J. T. Fasullo, J. E. Kay, Spatial Decomposition of Climate Feedbacks in the Community Earth System Model, Submitte to J. Climate, 2012

Change in Cloud Fraction

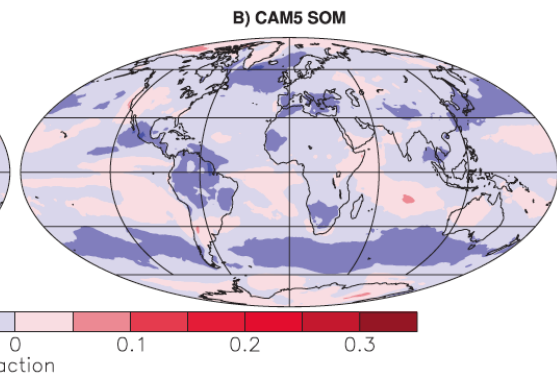
CMIP3 (Soden & Vecchi 2011)



CAM4 (CCSM4)



CESM1-CAM5



Change of sign in cloud fraction changes: larger reductions in CESM1-CAM5
CAM5 more similar to CMIP3 models.

High, Med, Low Cloud Feedback

CMIP3 (Soden & Vecchi 2011)

CAM4 (CCSM4)

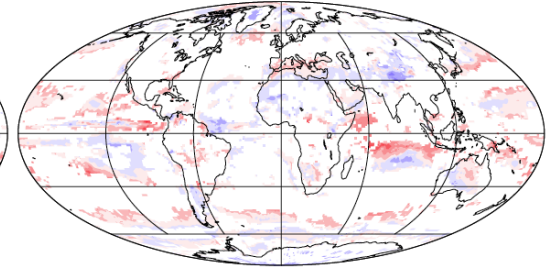
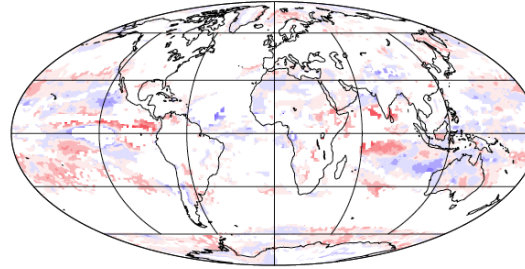
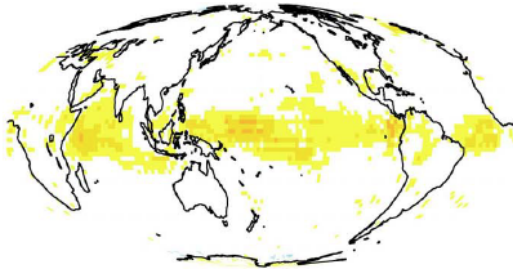
CESM1-CAM5

High Cloud Feedback

A) CAM4 SOM

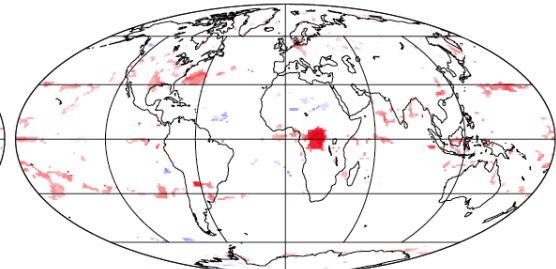
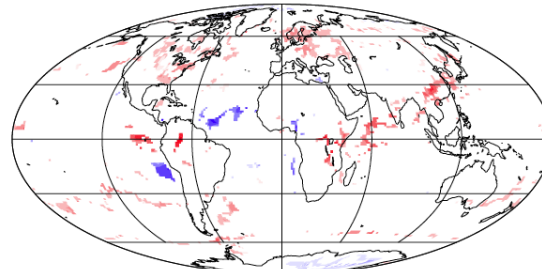
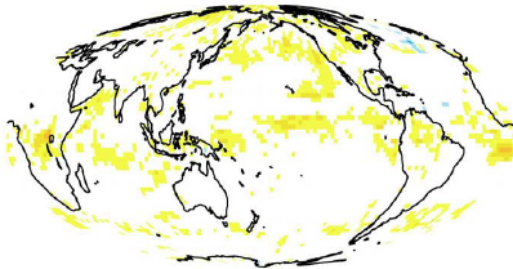
B) CAM5 SOM

High



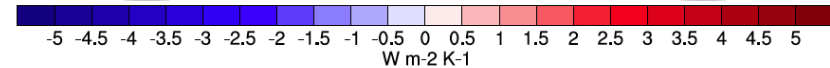
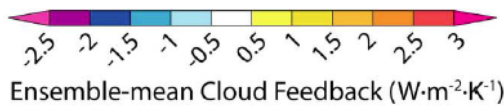
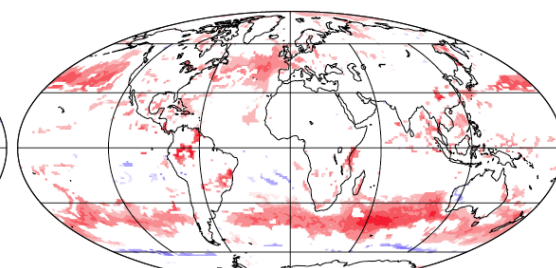
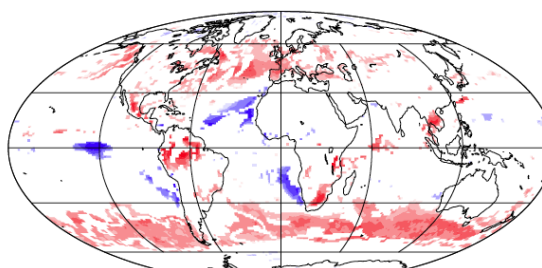
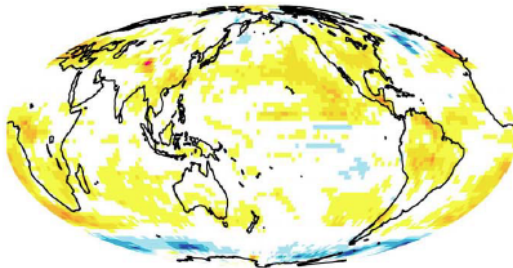
Mixed Cloud Feedback

Medium



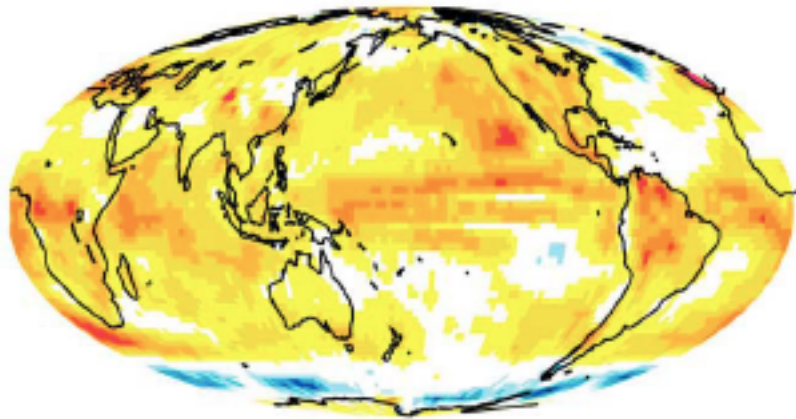
Low Cloud Feedback

Low

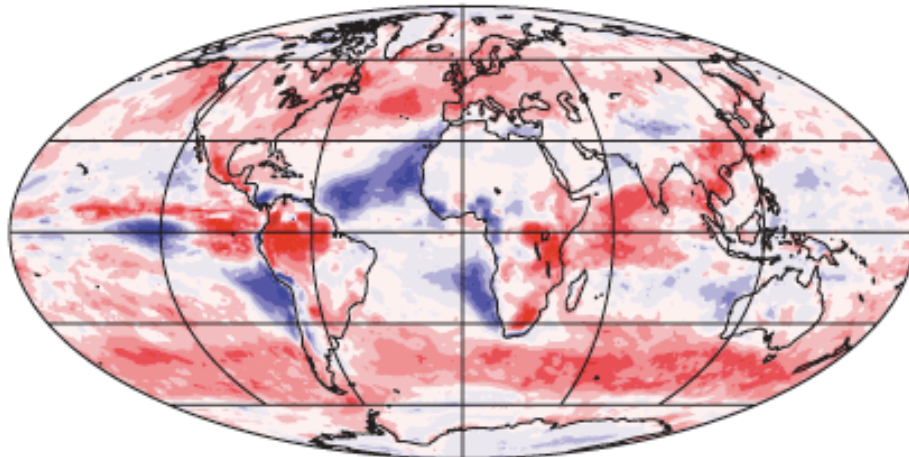


CESM Net Cloud Feedback

Net Cloud Feedback



E) CAM4 SOM



F) CAM5 SOM

