Evolution of Climate Sensitivity & Climate Feedbacks in CESM1

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Equilibrium Climate Sensitivity (γ)
CAM4= 3.1K CAM5.1 = 4.1K

Outline

- Why is γ different? What drives it?
- Method: Explore climate feedback processes
- Describe runs, results
- Focus on regions, regimes and processes

Conclusions:

- Climate sensitivity can be tested in short runs
- Governed by 'fast physics' (clouds).
- It may not be exactly what we think.
- Interesting relationships to the mean state

Radiative Kernel Method

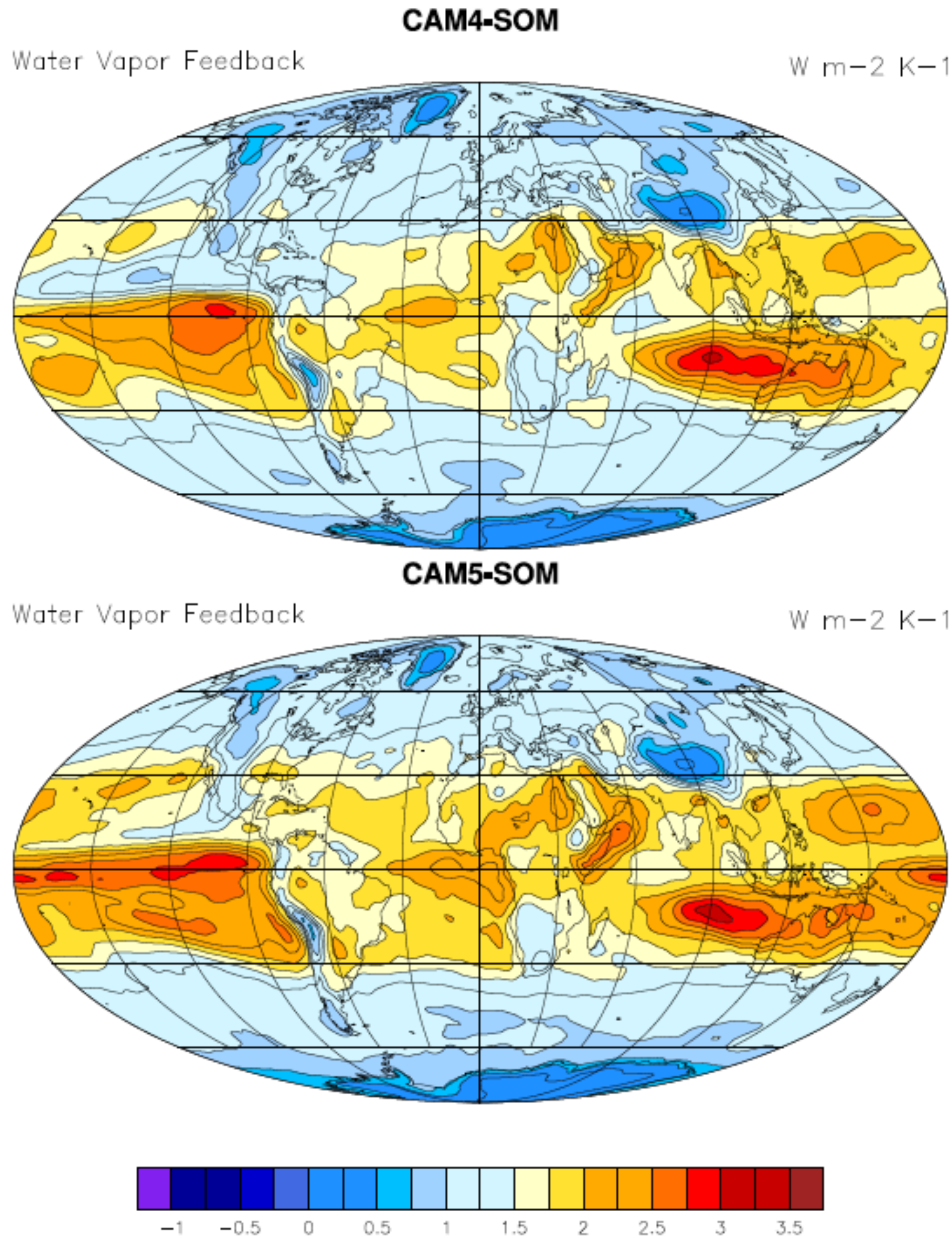
- Key feedbacks ($\lambda = \Sigma\lambda_x$):
- T (& lapse rate Γ), H_2O, Albedo, Clouds
- Decompose with a 'Kernel'
  - $\Delta F = \lambda\ \Delta Ts$ or $\lambda = \Delta F / \Delta Ts$ ($\lambda=1/\gamma$)
  - $\lambda_x = \Delta F/\Delta X\ \Delta X/\Delta Ts$
  - 'kernel' $K = \Delta F/\Delta X$ (x,y,z,t)
  - Radiative Response=$\Delta X/\Delta Ts$
- Clouds are a residual
- Here: use kernels to adjust cloud forcing

Model Simulations

- Final & Development versions of:
  - CAM4 & CAM5.1 in CESM1
- Radiative kernels from CAM3
- Two types of runs:
  - SOM runs, last 20 years of 40 or 60 year runs.
  - 'Modified Cess' experiments (prescribe ΔTs)
  - Cess (±2K uniform) does not seem to reproduce feedbacks, but 'Modified' ($Ts + \Delta Ts(x,y,t)$ does

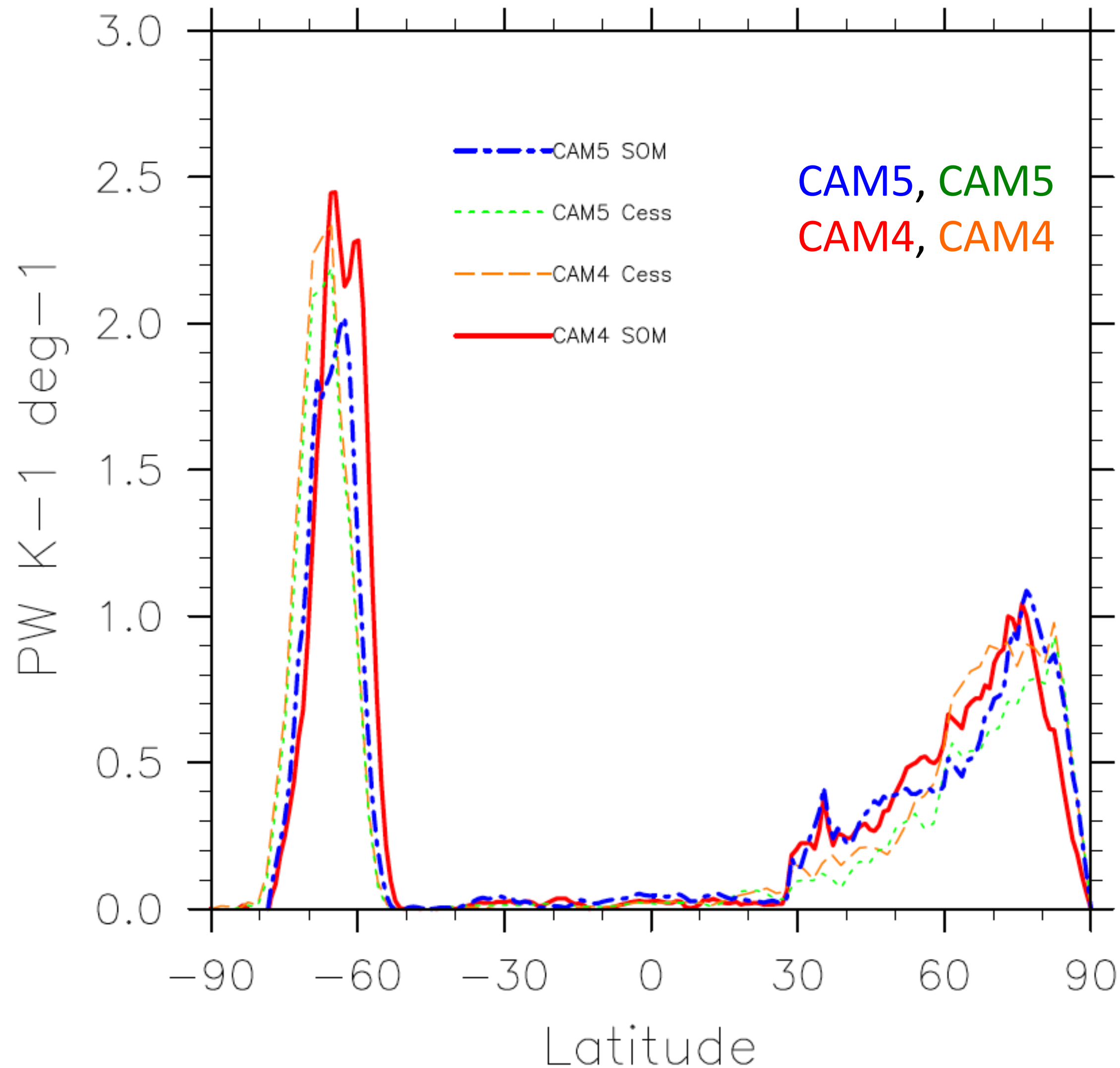
H_2O Feedback

- Water Vapor and Temperature feedbacks very similar between CAM4 & CAM5
- Some pattern differences, global mean similar

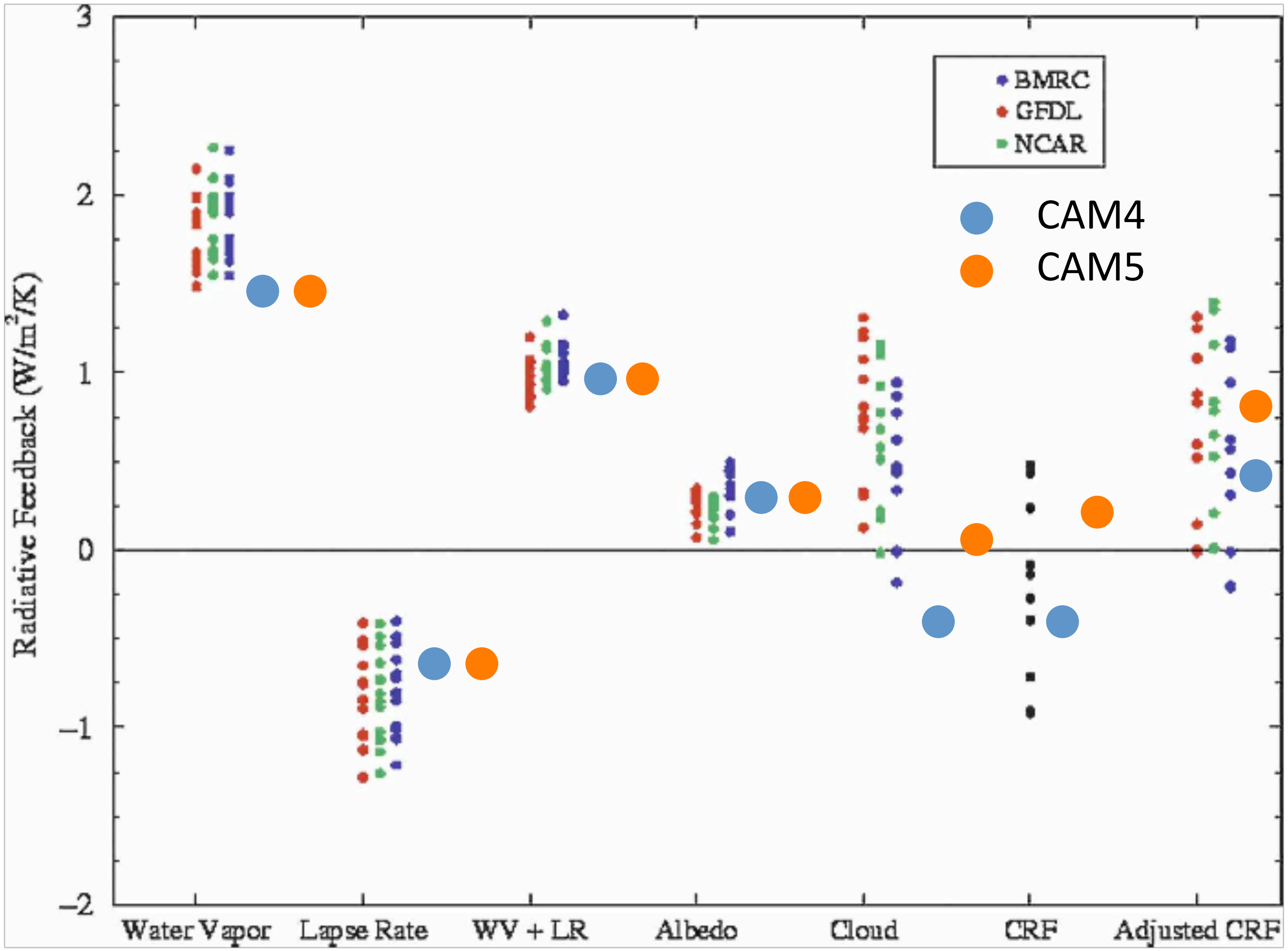


Surface Albedo Feedback

- Surface Albedo feedbacks also similar.
- Slight poleward shift in CAM5
- Modified Cess & SOM results are similar
- Cess experiments use CAM5 ΔSST



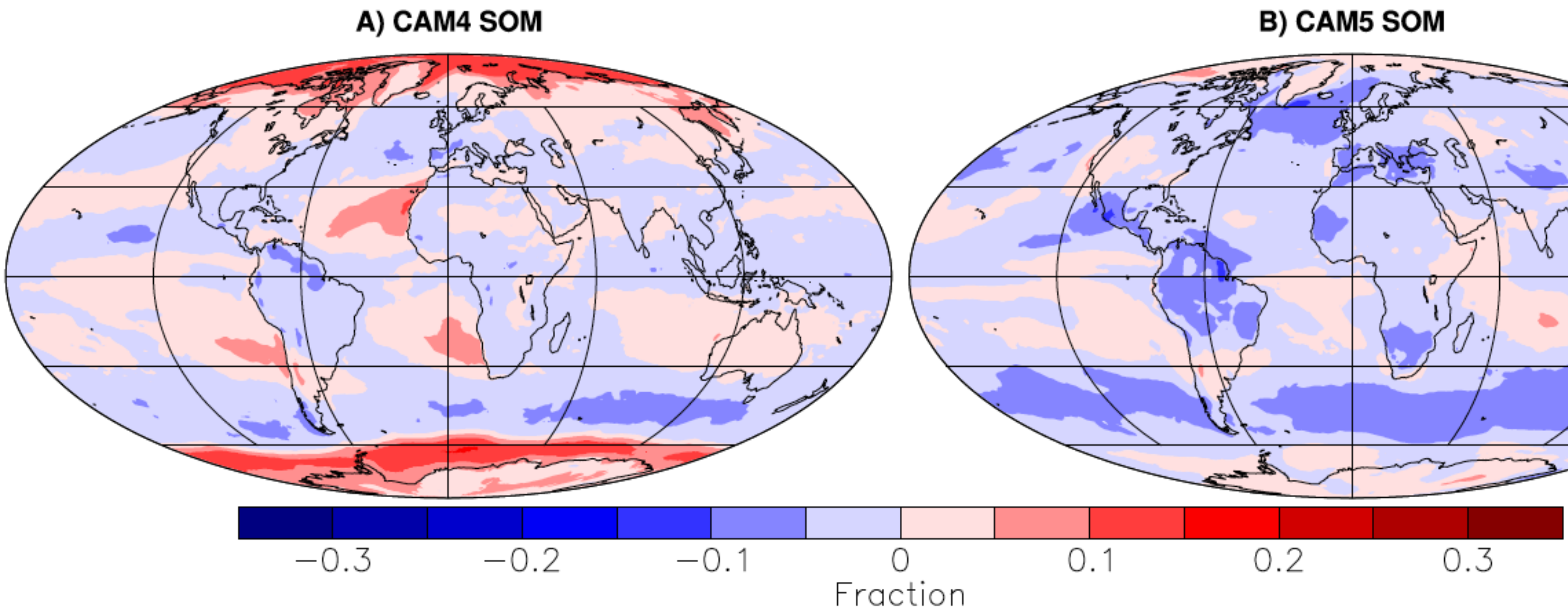
Feedback Comparison



Soden, 2008 (also Colman, Bony)

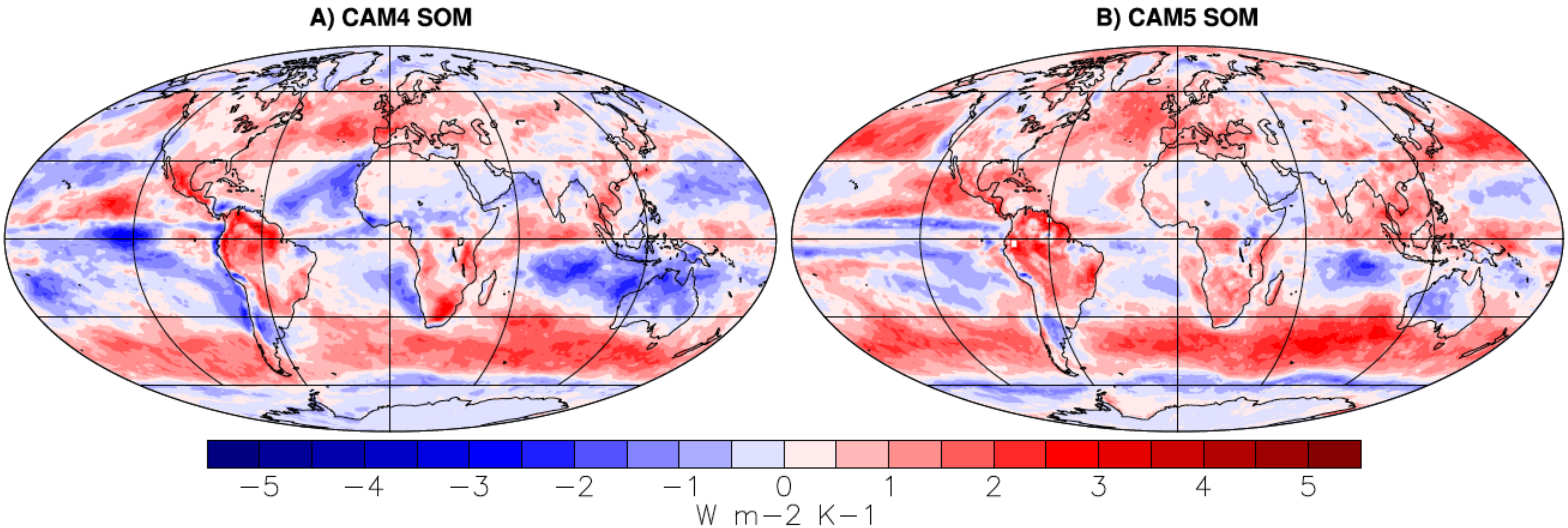
Note: results not sensitive to kernel used

Cloud Fraction Change



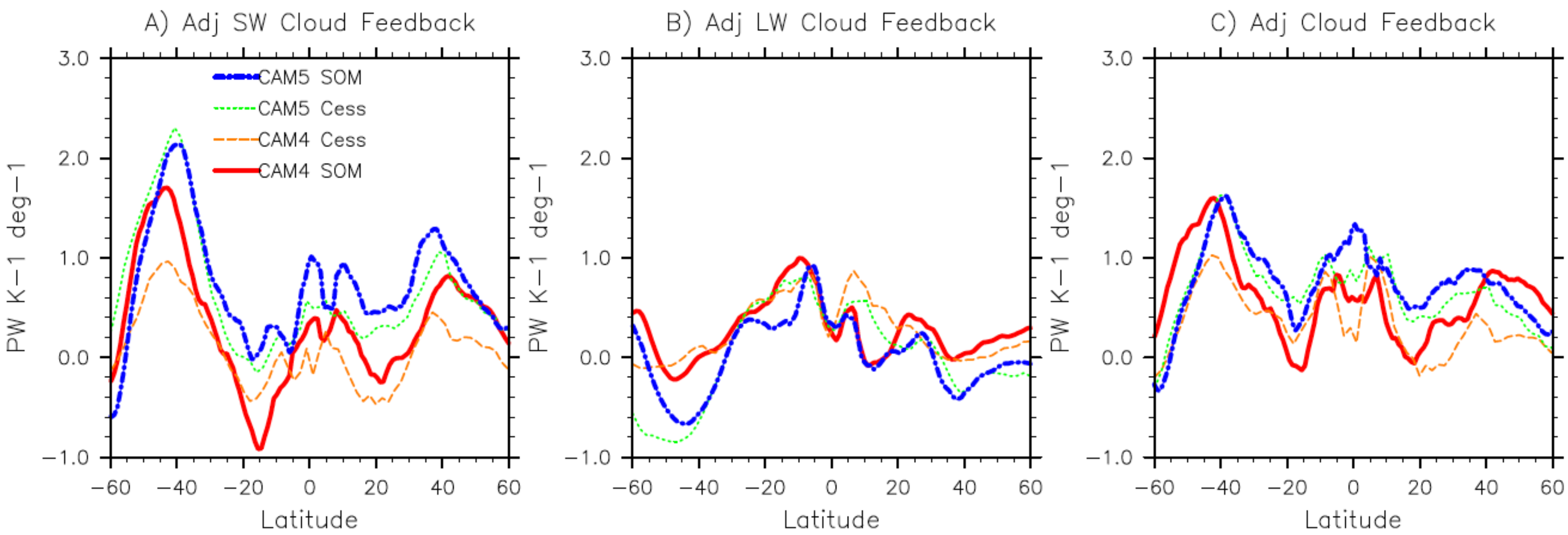
Differences evident in CF ($2xCO_2$ – $1xCO_2$)

Adjusted SW Cloud Feedback



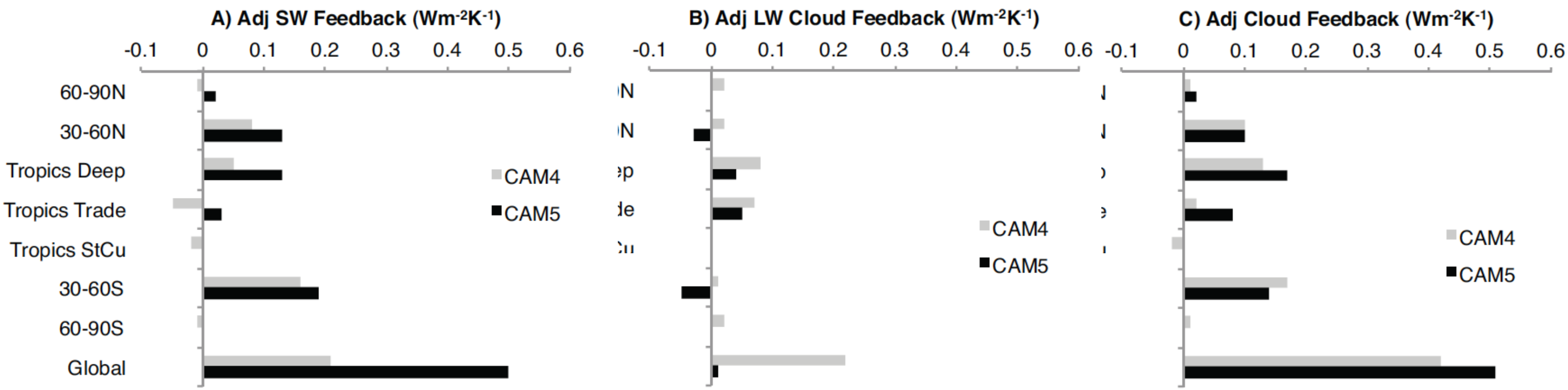
- Warming, Cooling
- Sub-Tropics, Storm Tracks and Stratocumulus Transition Regions are key differences

Adjusted Cloud Feedback



- Feedback differences due to sub-tropics & equator-ward side of storm tracks.
- This holds globally for CMIP3 models.

Where is ΔCloud Feedback Largest?



Tropics (30S-30N):

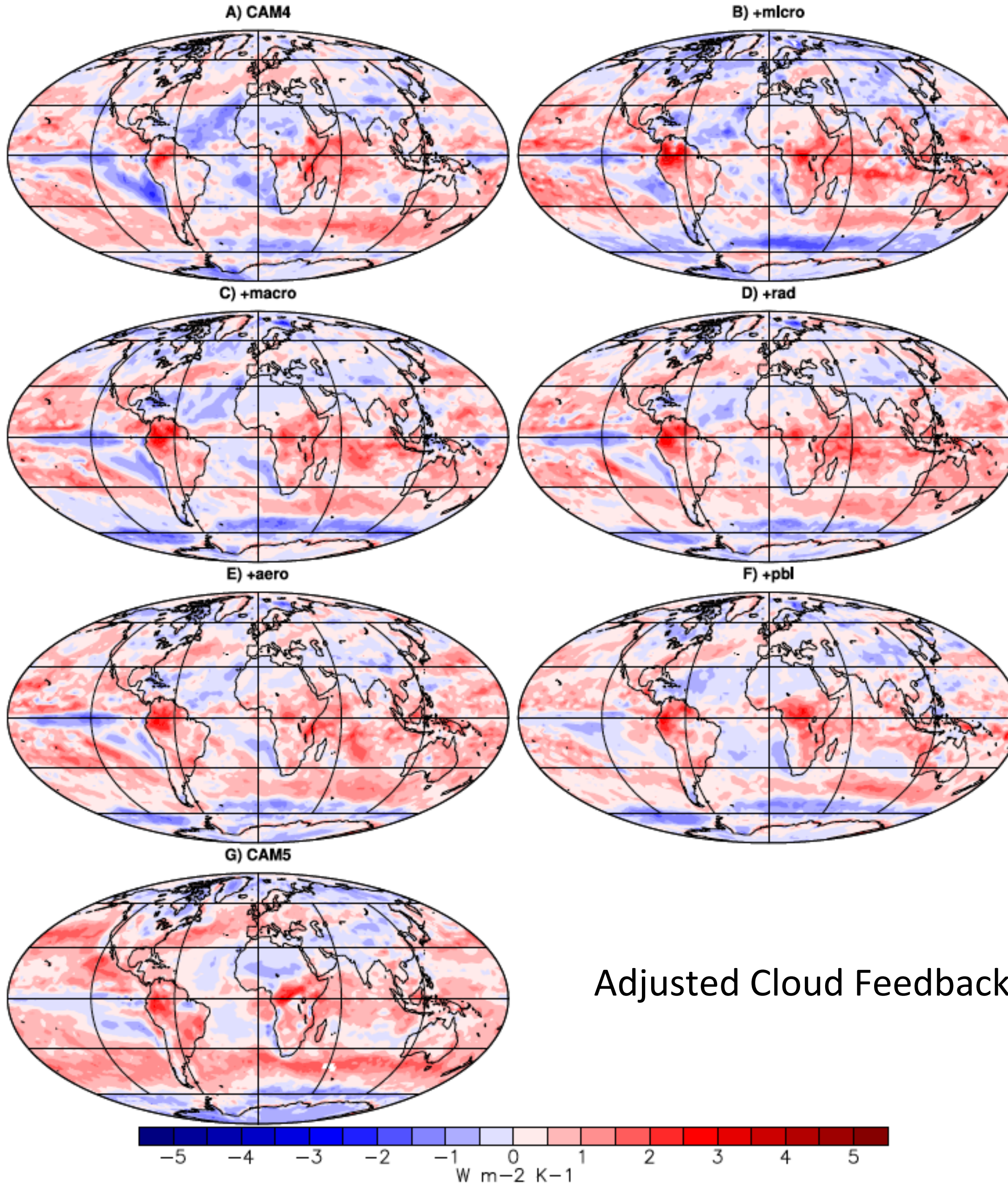
- Deep= land and $\omega_{500} < 0$
  StCu = $\omega_{500} < 0$ & LTS > 17K
  Trade Cu= $\omega_{500} < 0$ & LTS < 17K

Stratocumulus regions do not dominate: deep convection has offsetting LW & SW. Trade cumulus is most important region.

Not really dependent on the definition of stratocumulus.

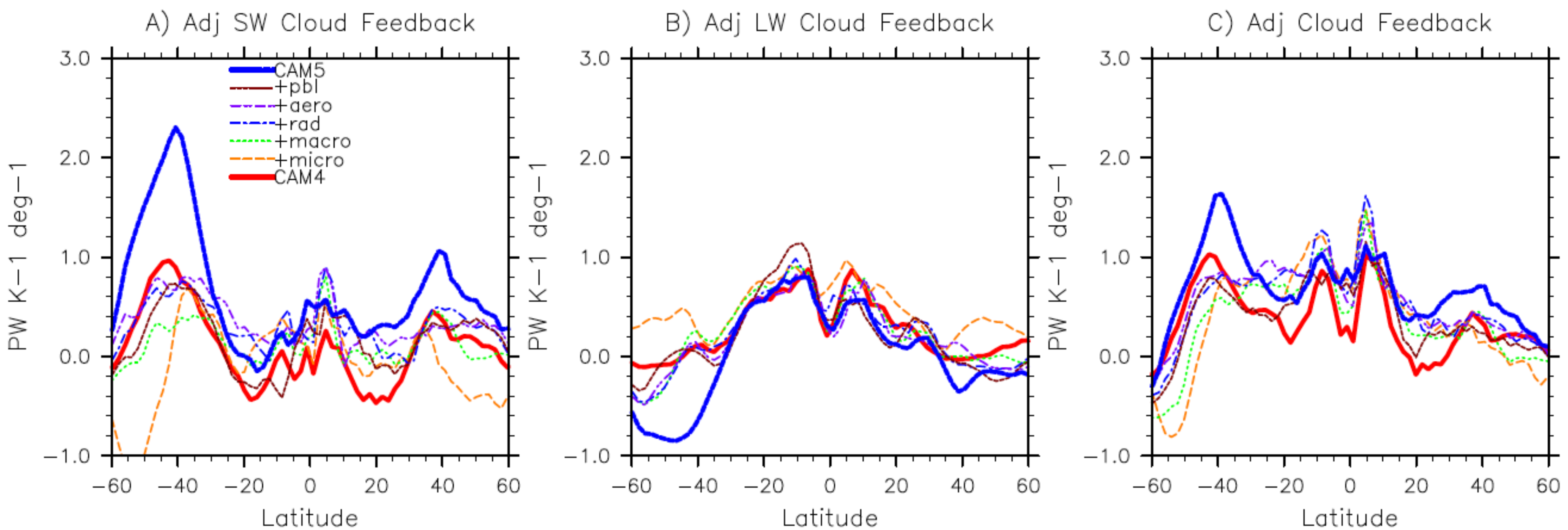
Which Processes?

- Step through parameterization changes with Modified Cess experiments CAM4→CAM5
- Biggest changes:
  - Radiation (+F_{CO2})
  - PBL makes it more negative
  - Shallow Convection (last step) has largest impact
- Regions:
  - Subtropics, transition
  - Storm tracks
  - Deep convection over land



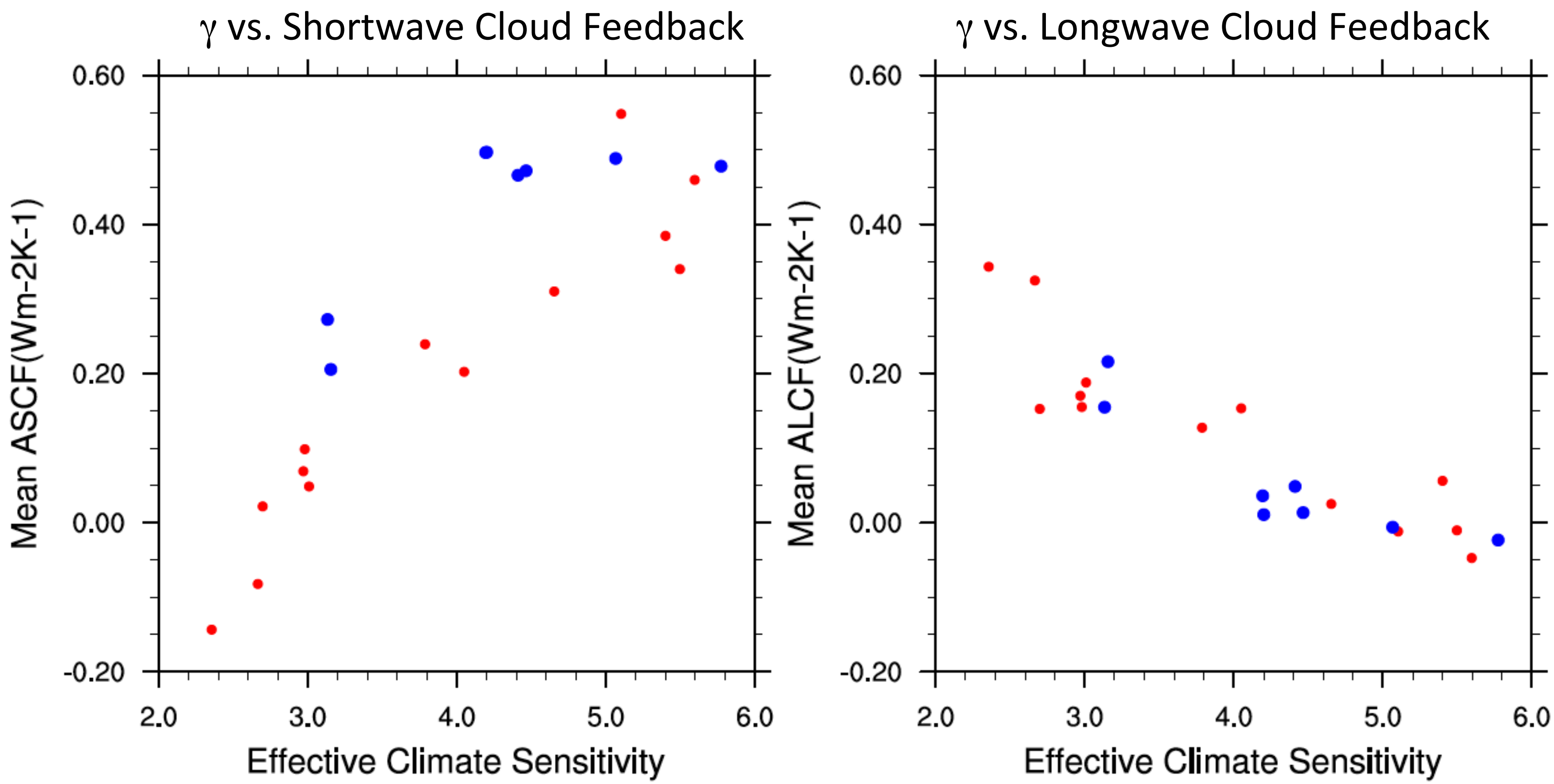
Adjusted Cloud Feedback

Zonal Mean Cloud Feedback

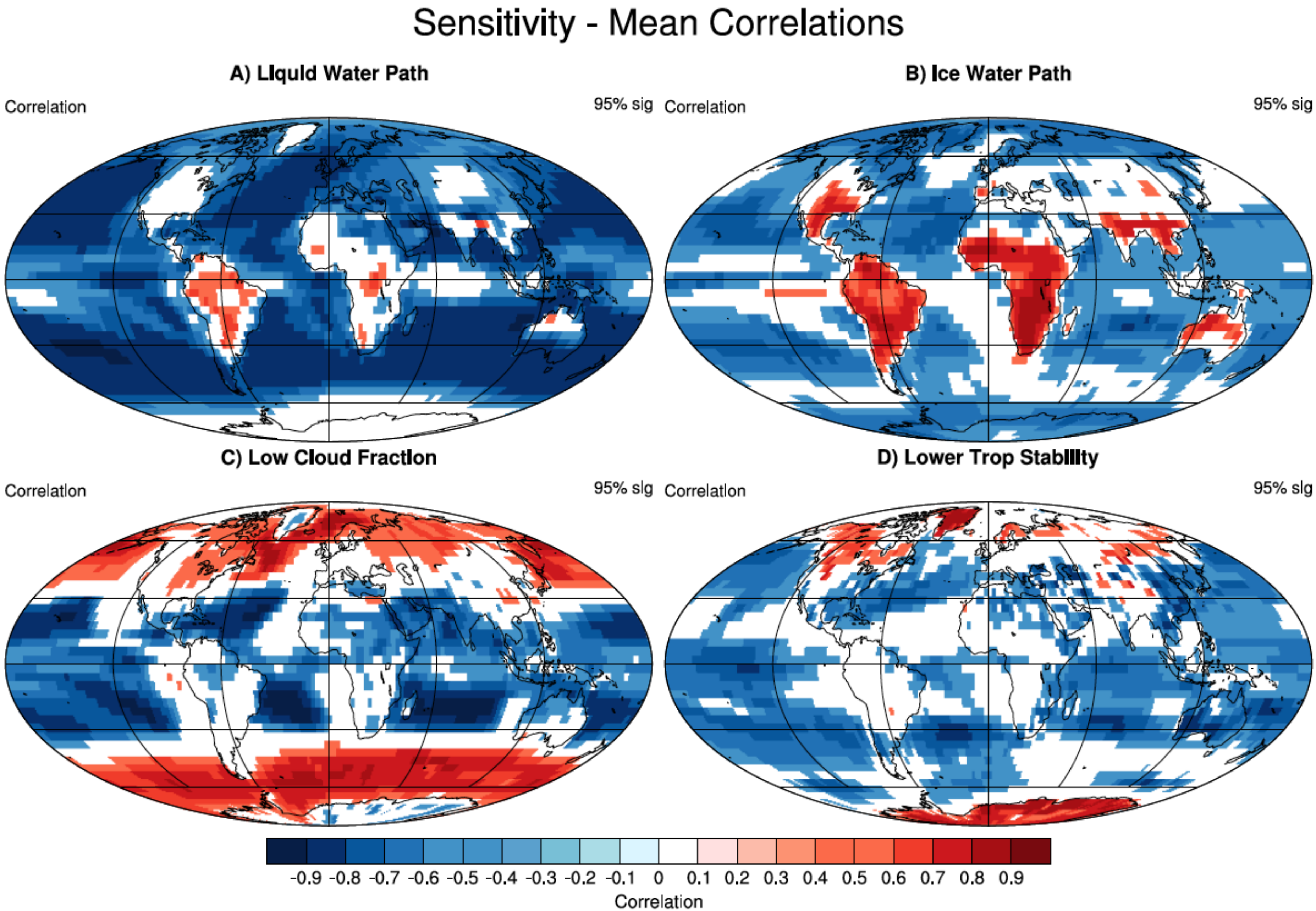


Shallow convection is the biggest change. Large impact in storm tracks.

Sensitivity and Cloud Feedback



- Look at individual Experiment pairs (shows SW is dominant)
- Consistent w/ Trenberth & Fasullo (2010): SH SW is important (& badly simulated)
- Slope, correlation and goodness of fit provide statistics.
- Now do this for a range of properties, and at different points.


Sensitivity - Mean Correlations
A) Liquid Water Path
Correlation
95% sig
B) Ice Water Path
Correlation
95% sig
C) Low Cloud Fraction
Correlation
95% sig
D) Lower Trop Stability
Correlation
95% sig
-0.9 -0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
Correlation

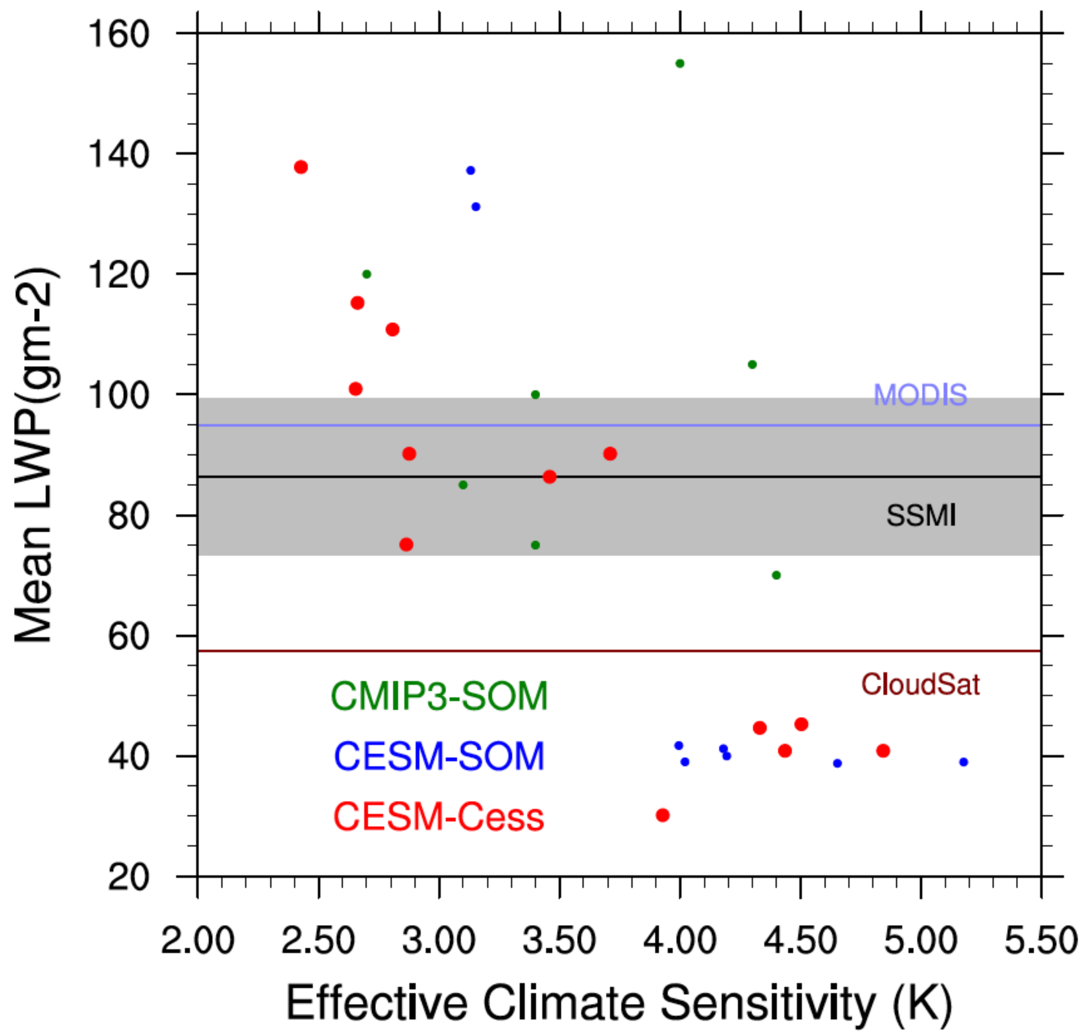
Sensitivity (γ) v. 60S-60N LWP

Climate sensitivity is correlated with mean state properties. CAM4, CAM5, CMIP3.

$R_{CLD} = f(a,\tau)$ [a=cloud fraction]
$\tau = f(N_c, LWP)$ [mass,#]

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

Still 20-40% uncertainties (SSM/I has best error analysis): use obs to 'rule out' some ranges of climate sensitivity?



Conclusions

- CAM5 has higher sensitivity than CAM4
- 'Modified Cess' experiments reproduce feedbacks
- Why? Cloud Feedbacks: driven by Trade-Cumulus in the sub-tropics and storm tracks
- Also: lower mean LWP in clouds and a different microphysical balance.
- CAM4, CAM5 and CMIP3 SOM runs have strong correlations between mean LWP and climate sensitivity
- Microphysical balance of clouds is important
- Observational uncertainties are large
- Further note: Climate sensitivity is a function of state!

Results documented in submitted CESM special paper & GRL submission:
Google "Gettelman Papers"