Forcing and Feedbacks in CESM2

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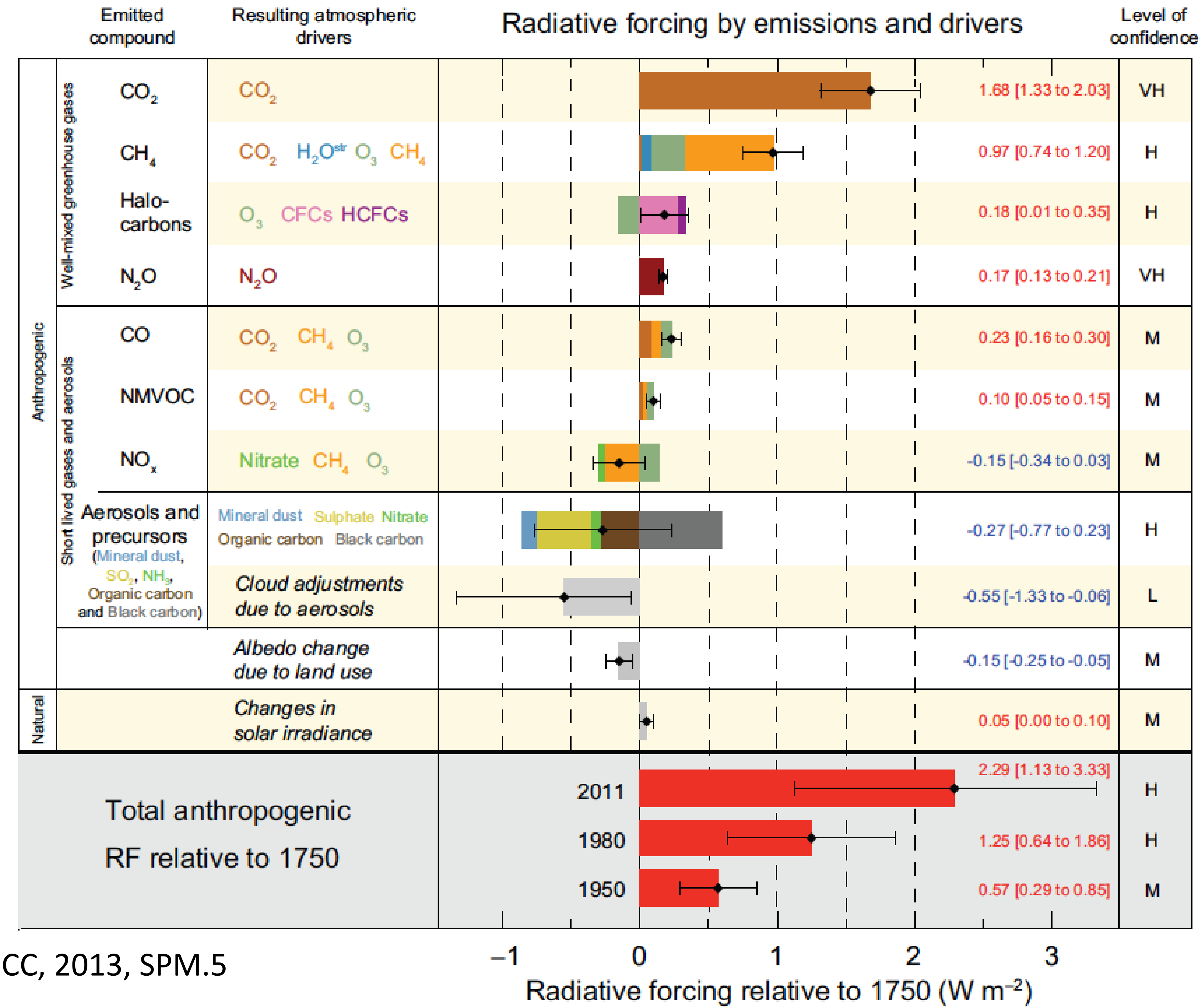
Outline/Motivation

- Understand forcing and feedbacks in CESM2
  - Update from last year with CESM1.5
- Forcing is a balance between aerosol forcing and GHG forcing $F = F_{GHG} + F_{aero}$
- Feedbacks: response of the system
- Formally:

$$R = F - \lambda dT_s + dH$$

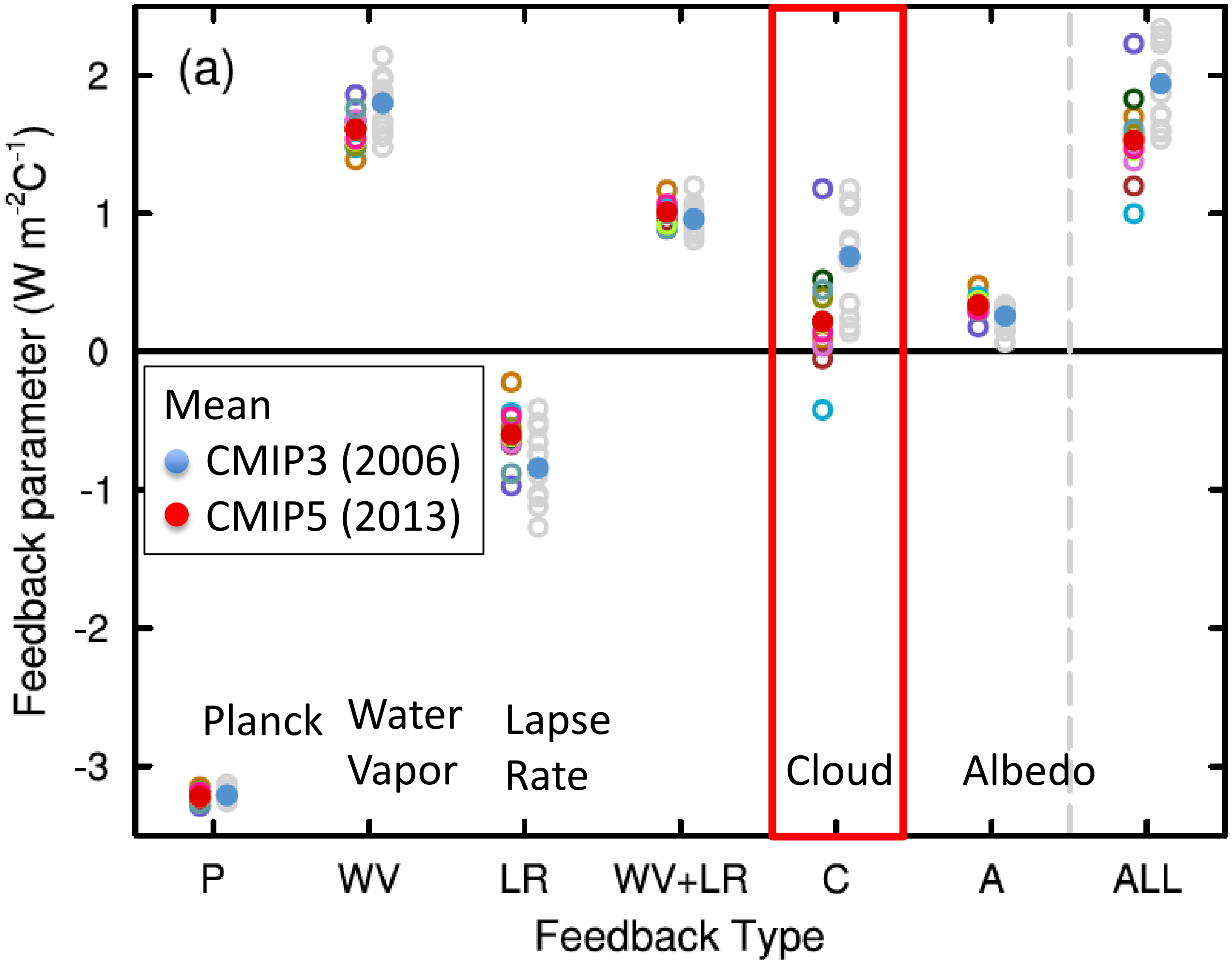
R= TOA imbalance, F=Forcing, λ= feedback parameter

H= Ocean Heat content, T_s = surface temperature



IPCC, 2013, SPM.5

Climate Feedbacks



Planck $\varepsilon = \sigma T^4$ (-)

Water Vapor
+T & RH=C → +H2O (+)

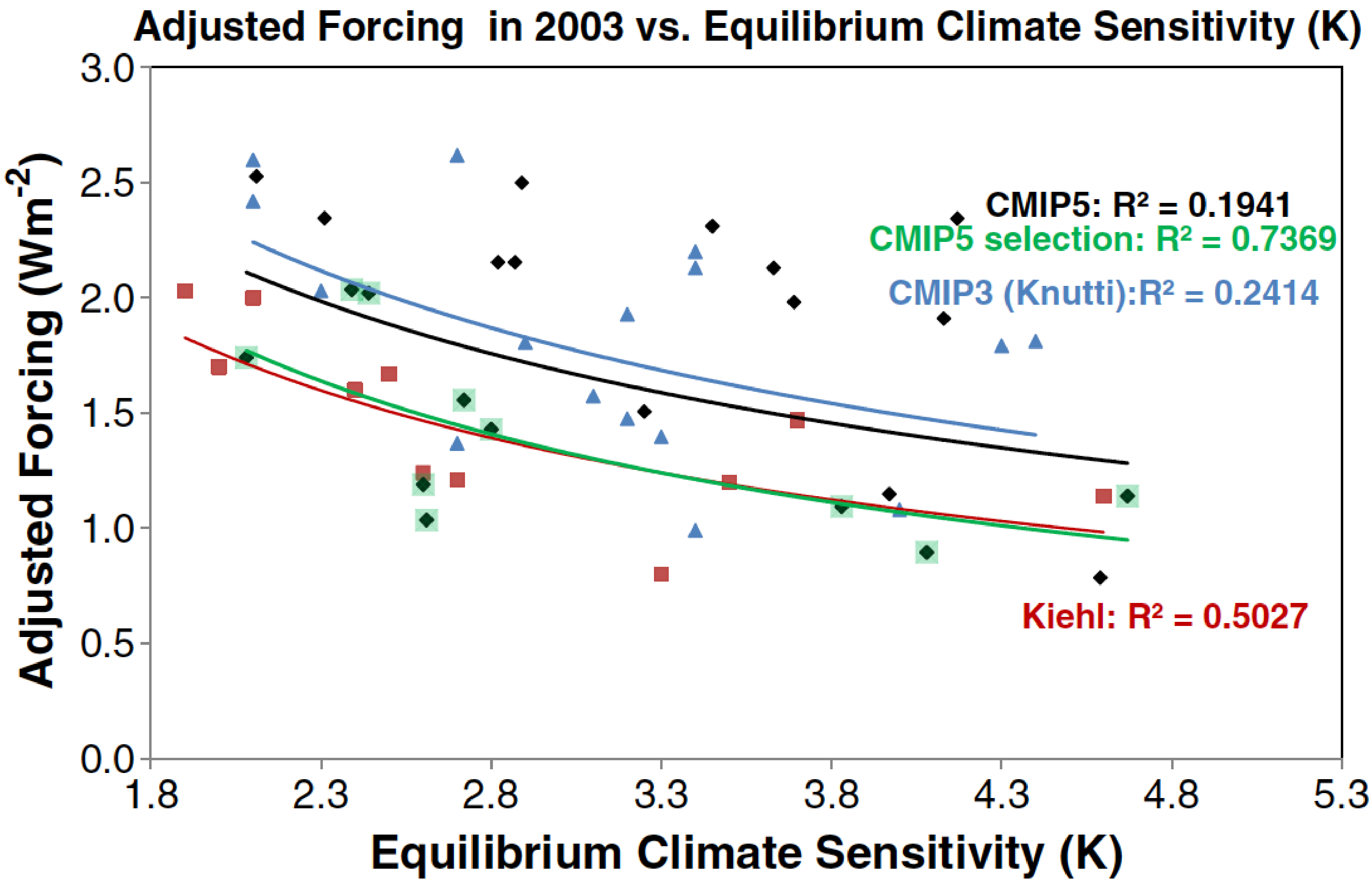
Lapse Rate (-)

Albedo (snow, ice)
+T → less snow, ice
-T → more snow, ice (+)

Clouds: Complicated (+)

IPCC, 2013 (Ch 9, Hartmann et al 2013) Fig 9.43. Updated from Coleman 2003

Forcing Uncertainty



Models that reproduce 20th Century

Forster et al 2013, Figure 7
Updated from Kiehl et al 2007

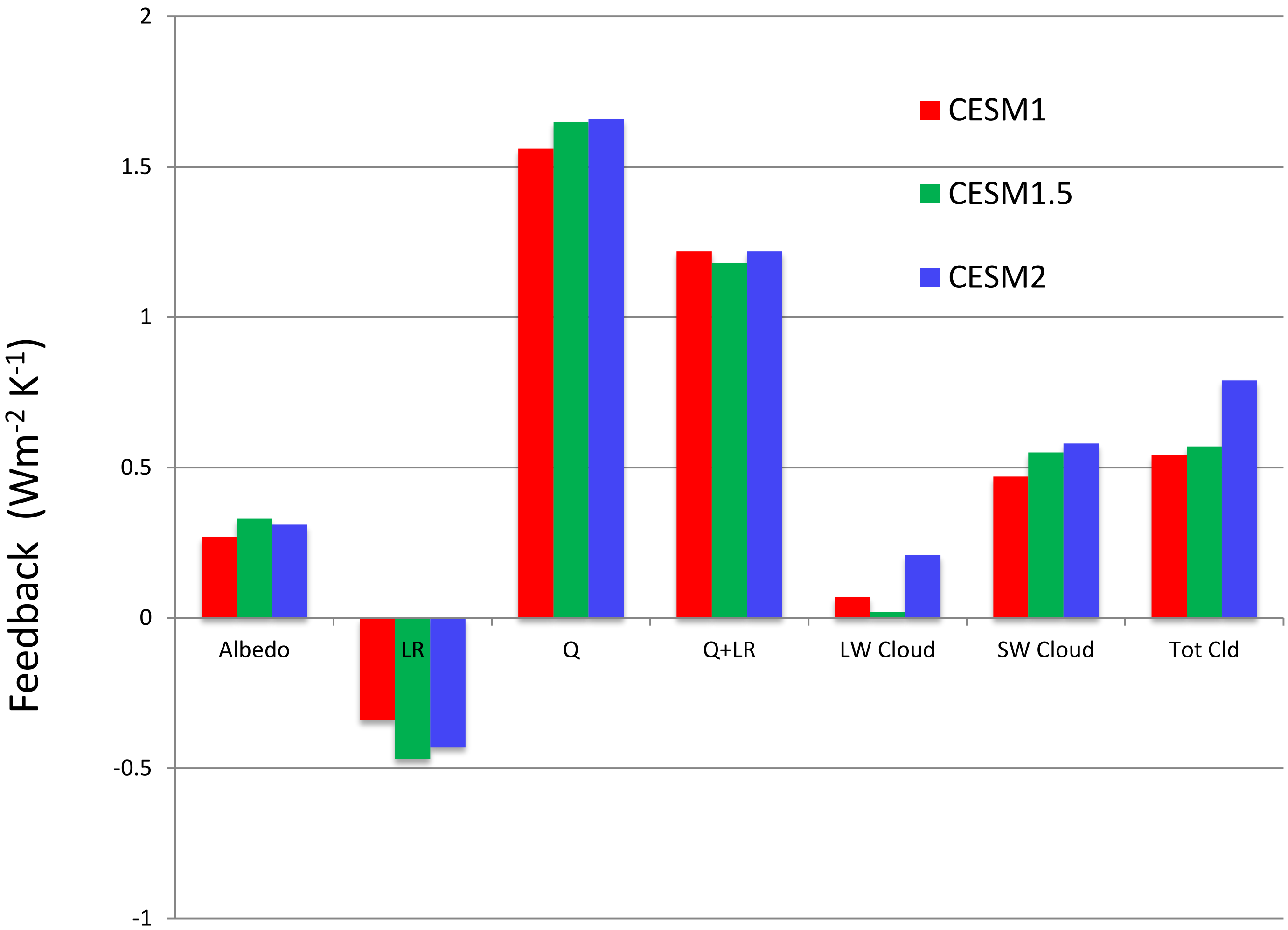
Methods

- Feedbacks: Radiative Kernels
  - Apply to Slab Ocean Model (SOM) experiments
  - CESM1-CAM5.3
  - CAM5.5 (‘28’) ≈ CESM1.5
  - CESM2 = ‘125’ Configuration (SOM not quite long enough)
  - Also: SST +4K sensitivity tests
- Forcing: Aerosol Forcing (total and indirect)
  - Indirect = Aerosol Cloud Interactions (ACI)
  - Use off line calculations
  - ‘Clean Sky’ aerosol forcing (Ghan et al 2013). Slightly higher than ΔCRE

Feedback Summary

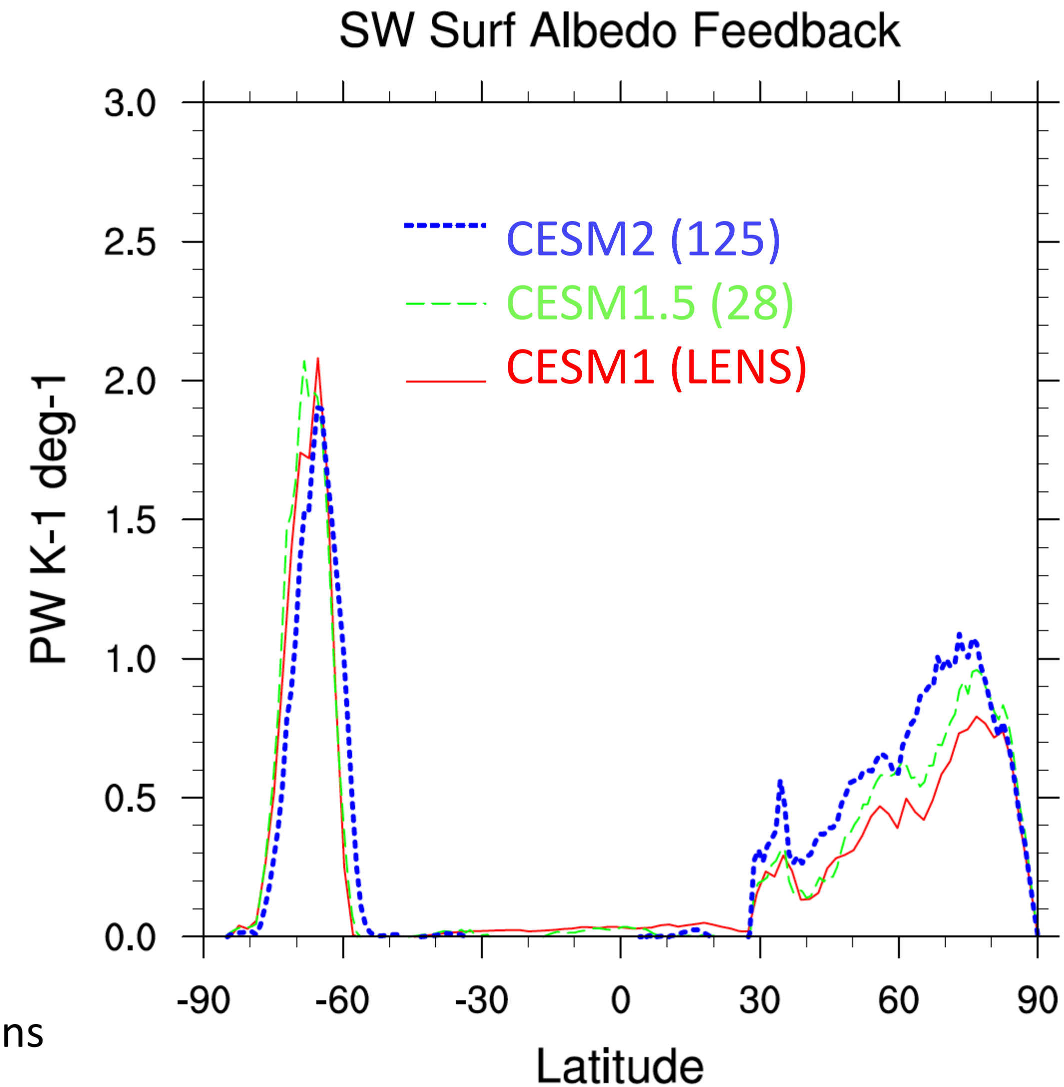
From SOM Simulations

Note: not long enough
(years 30-48 analyzed)



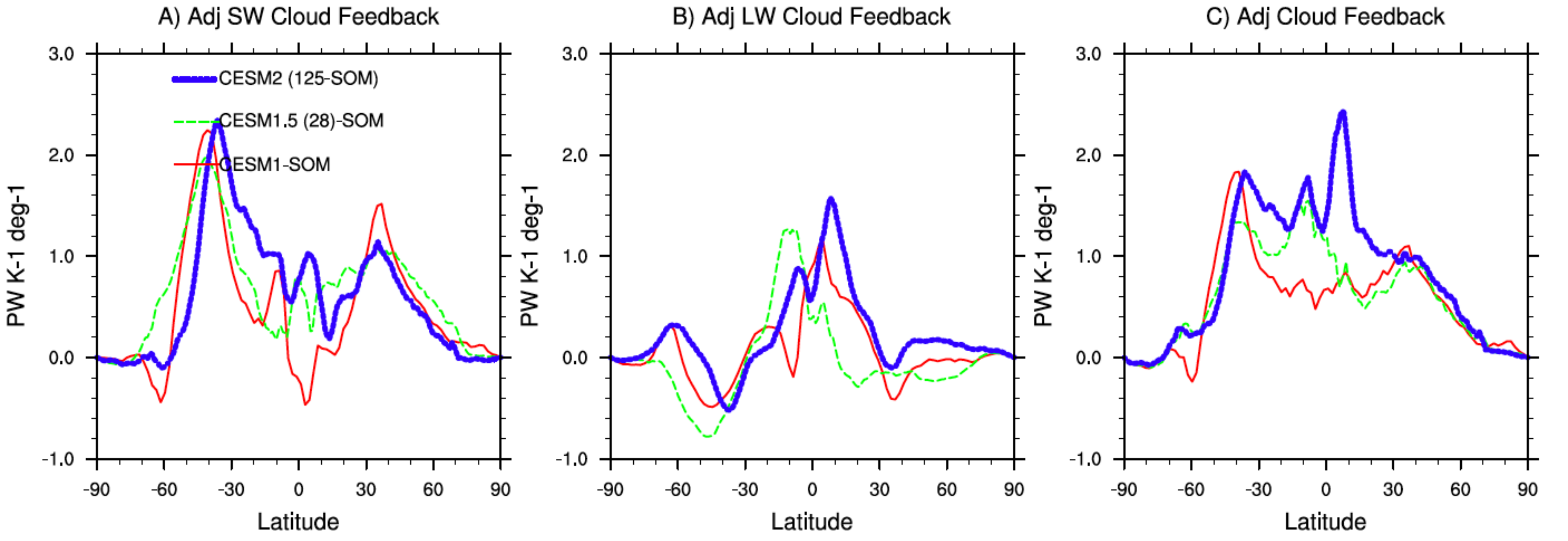
Bottom Line for Equilibrium Climate Sensitvity (ECS)
CESM1 = 4.0K CESM1.5 ≈ 3.8K CESM2 ≈ 4.2K

Surface Albedo Feedback



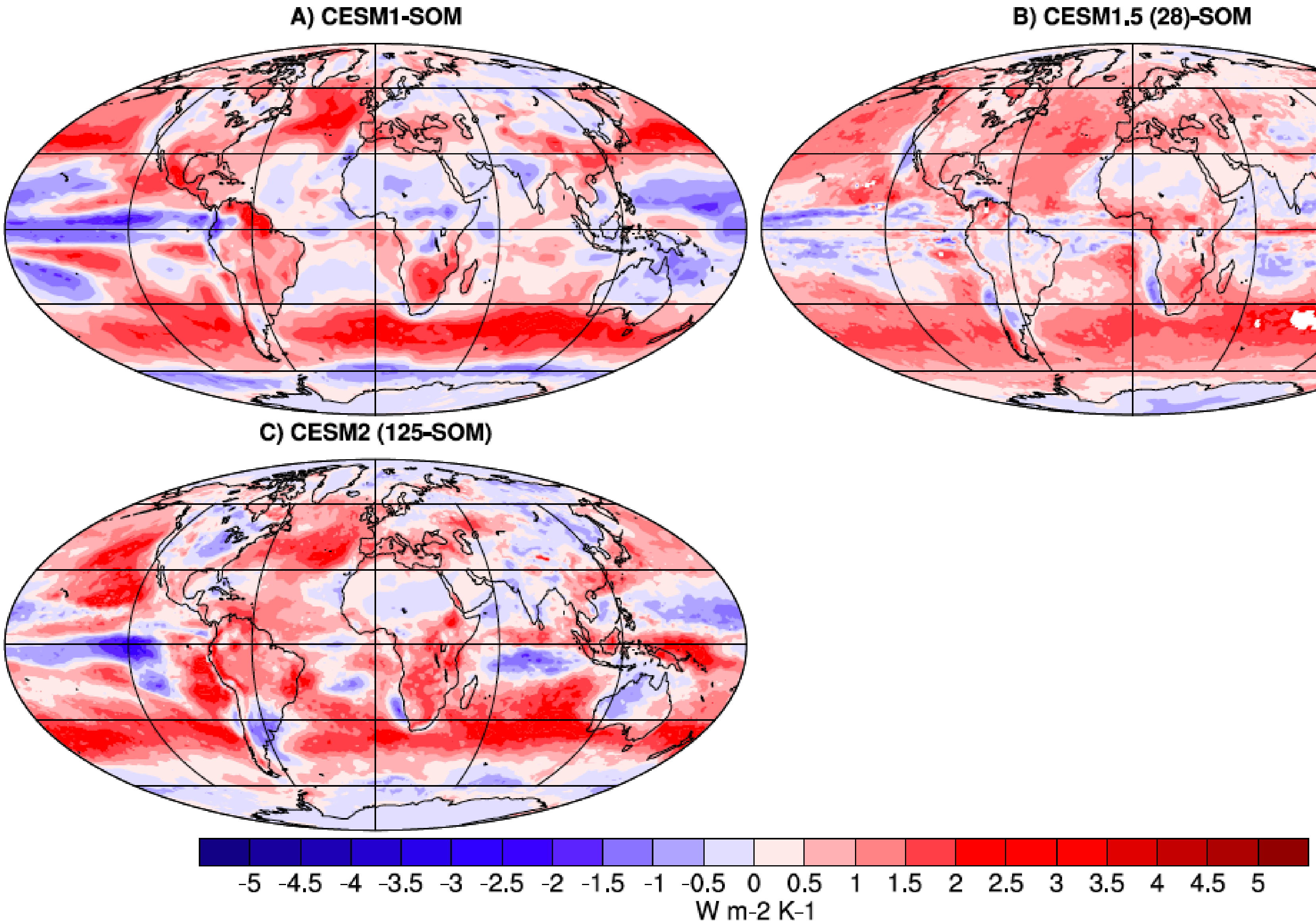
From SOM simulations

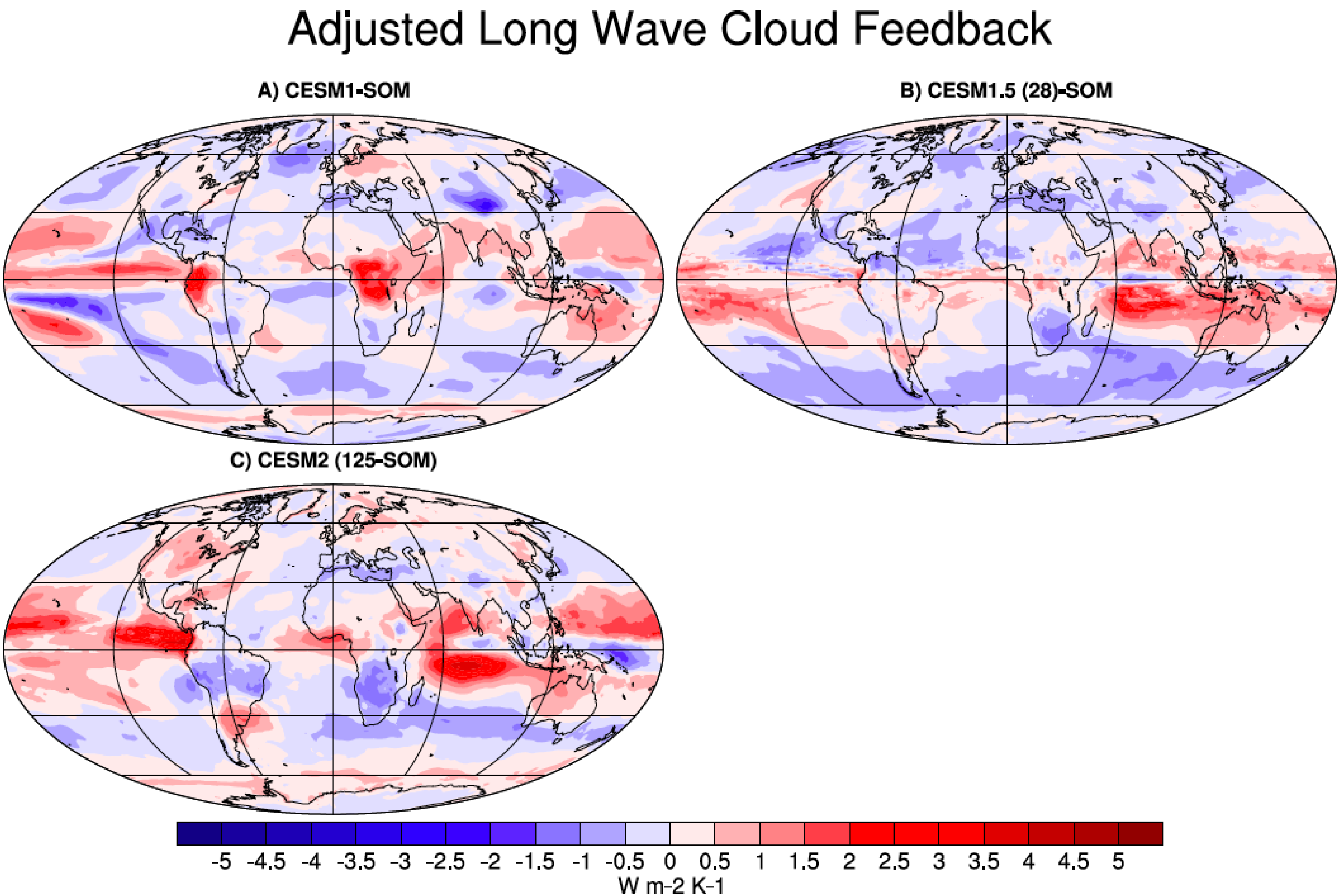
Cloud Feedback (Zonal Mean)



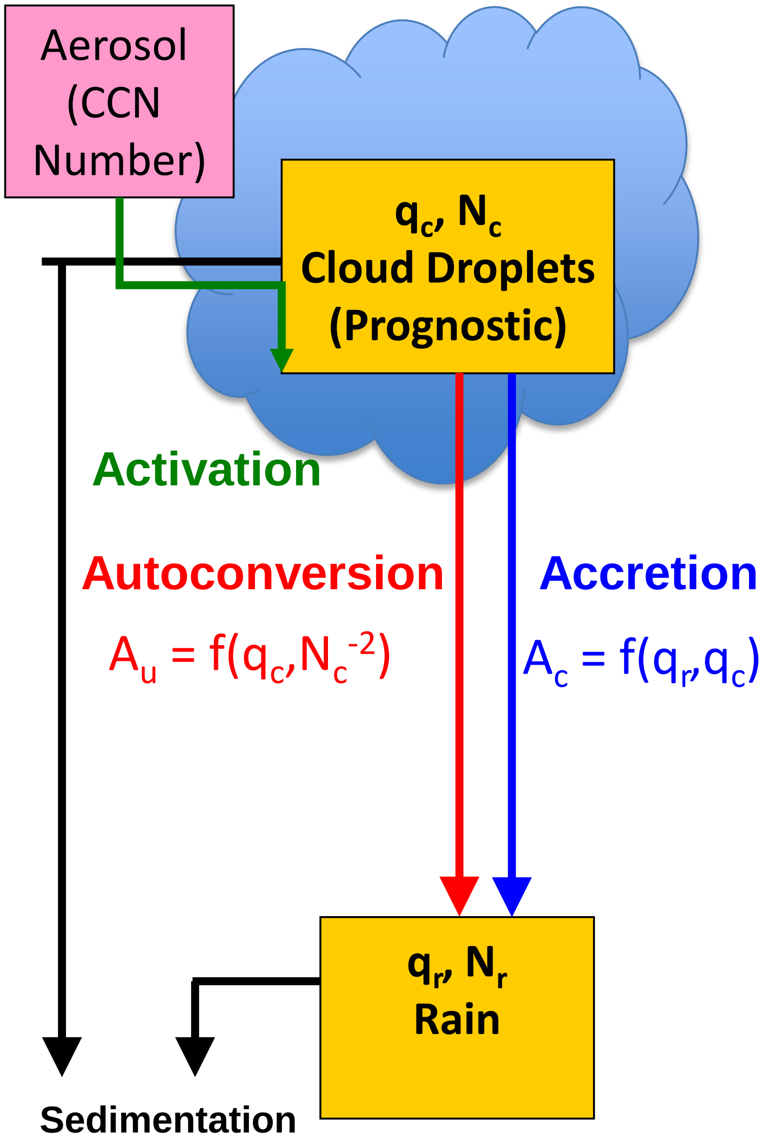
CESM2 (125)
CESM1.5 (28)
CESM1 (LENS)

Adjusted Short Wave Cloud Feedback




Adjusted Long Wave Cloud Feedback
A) CESM1-SOM
B) CESM1.5 (28)-SOM
C) CESM2 (125-SOM)
-5 -4.5 -4 -3.5 -3 -2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5
W m-2 K-1

Aerosol Cloud Interactions in CESM2

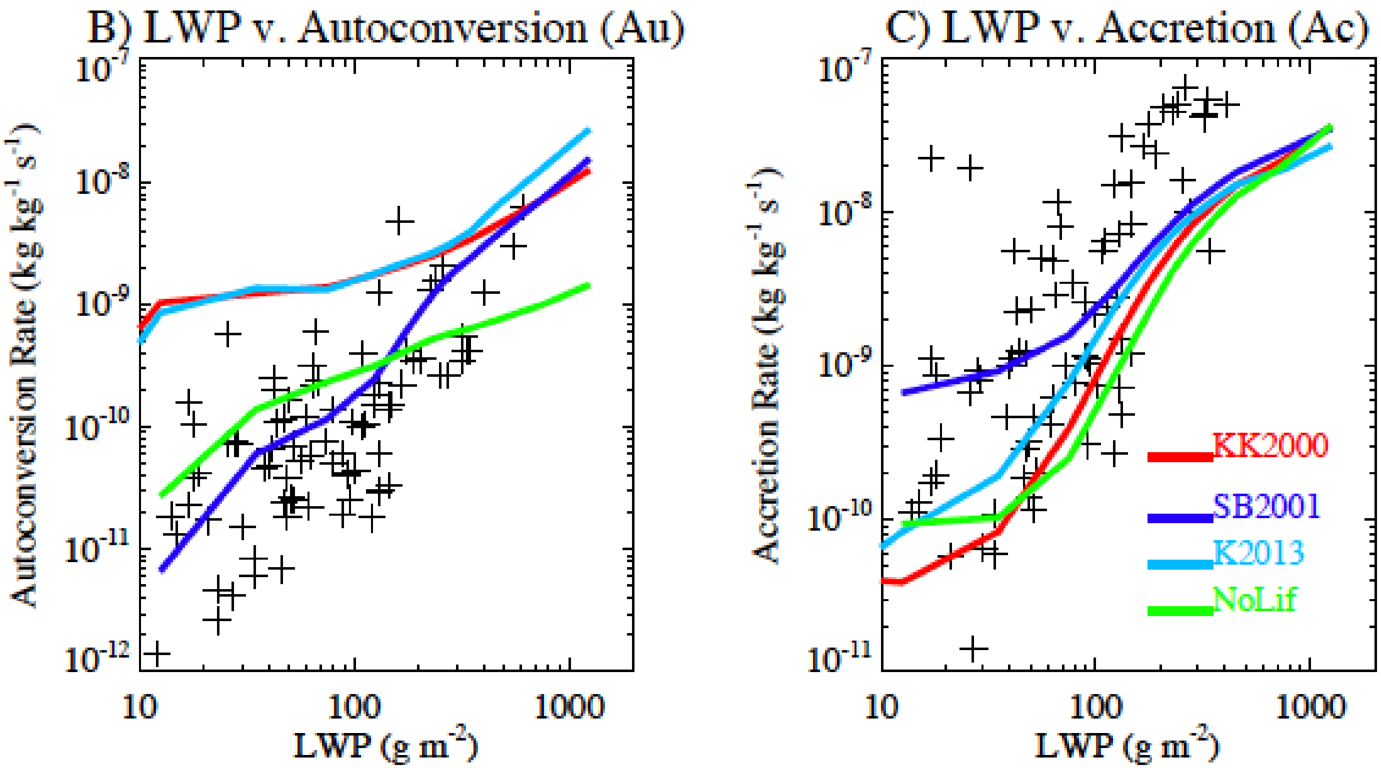


1. Activation (CCN) = f(RH,w)
   W at cloud scale is critical
2. Autoconversion (loss process) is a function of N_c^{-2} (=ACI)
3. Accretion depends on q_r

- New microphysics increase A_c/ A_u =Reduced ACI
- CLUBB = ACI in new regimes. = Increased ACI
- Altered Cloud Microphysics to reduce it

Process Rates: Autoconversion Effects

Gettelman 2015, ACP



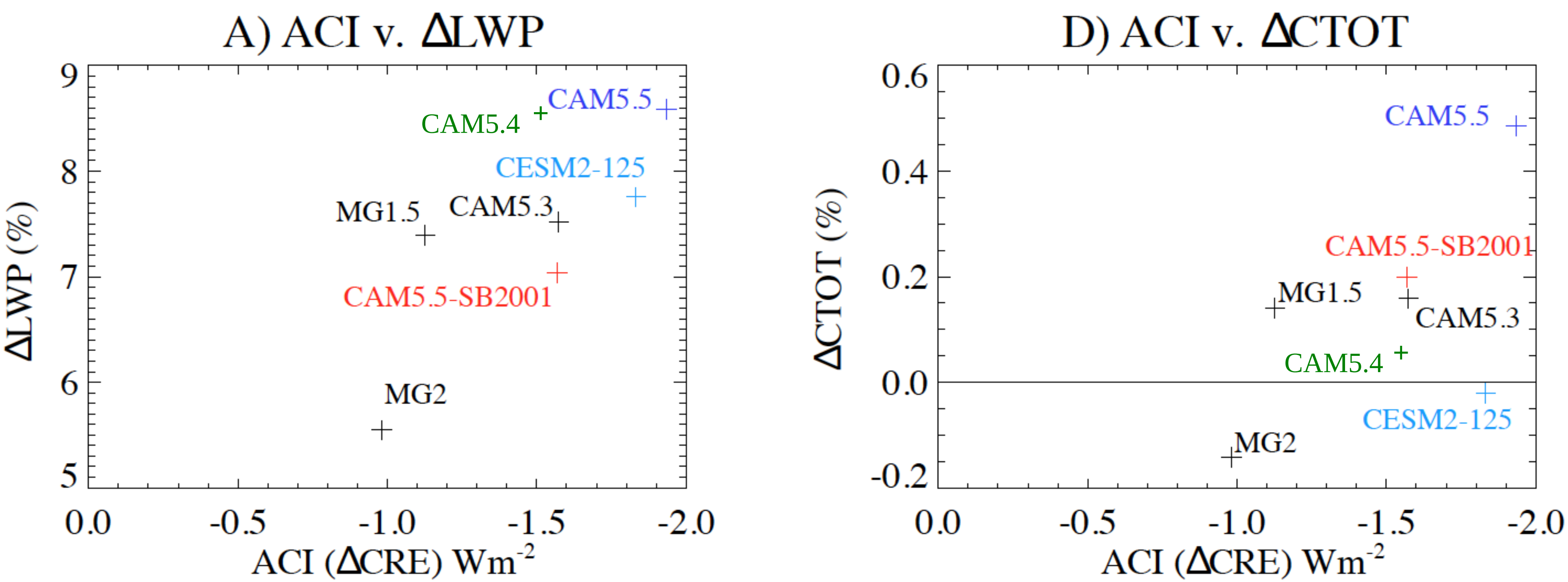
Observations = Calculations with detailed model and observed size distributions from S. E. Pacific (Terai and Wood)

MG2 Autoconversion, Alternative Schemes, No Lifetime Effects

Also remove 'relative variance' enhancement on Ac and Au (too high in CAM5.5)

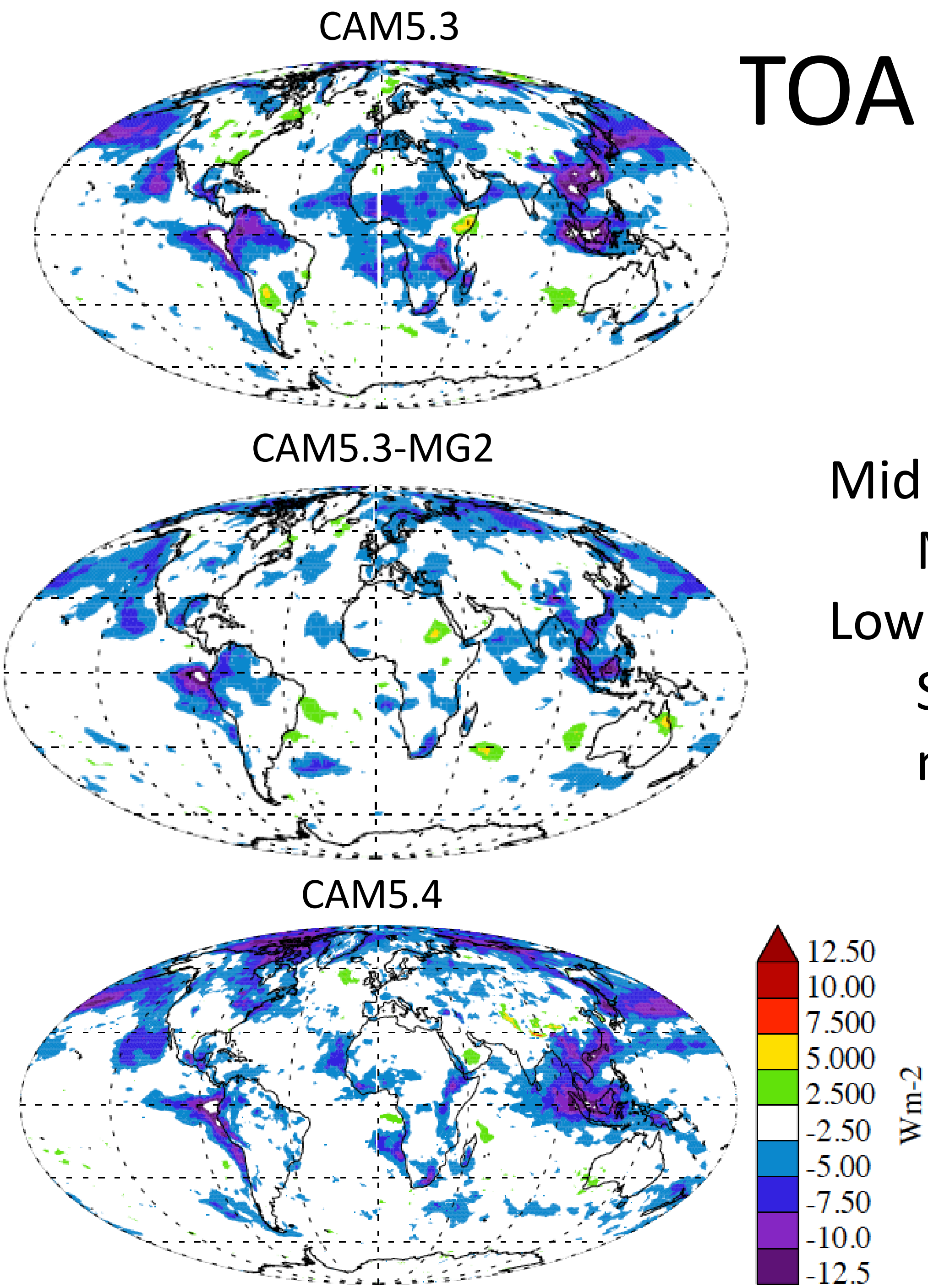
ACI Evolution

ACI Definition following Ghan 2013



- Started (CAM5.3) with ACI about -1.5 Wm^{-2}
- Decrease with MG1.5 and MG2
- Increase with CAM5.4 (mixed phase ice nucleation+ MAM4)
- Increase with CAM5.5 (shallow convective regime)
- Decreases with new Autoconversion (SB2001)
- Increase with final configuration CESM2 (cloud tuning)
- May drop a little bit with CMIP6 emissions (~$0.2Wm^{-2}$)

TOA Flux Anomalies



Mid & High Latitudes:

Mixed Phase ice Nucleation

Low Latitudes: Aerosols

SO_2 lifetime change with new mode widths (higher SO_4)

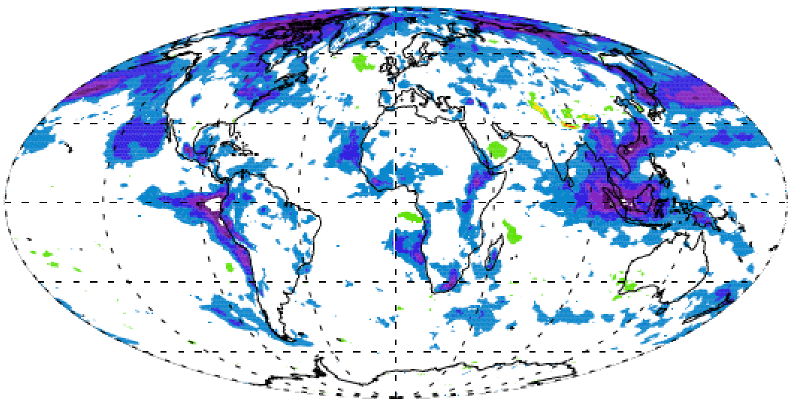
TOA Flux Anomalies (2)

Subtropics and Middle Latitudes:

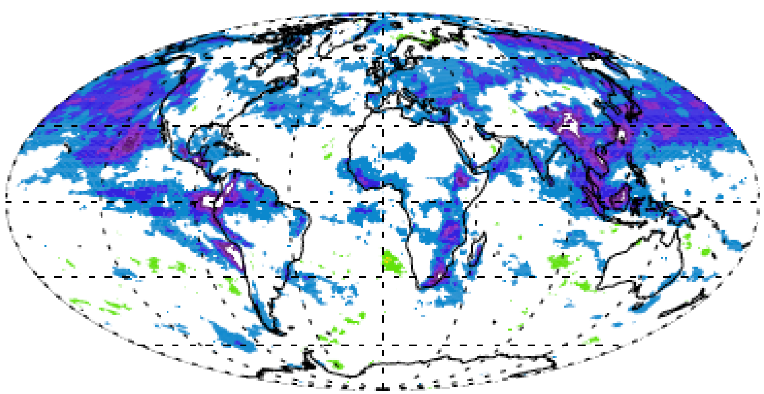
Shallow convection Regime

Arctic effects decrease (Robust?)

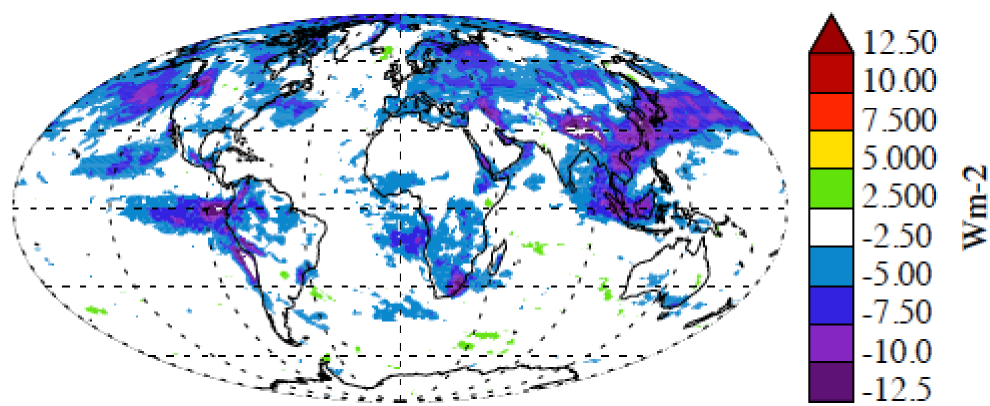
CAM5.4



CAM5.5

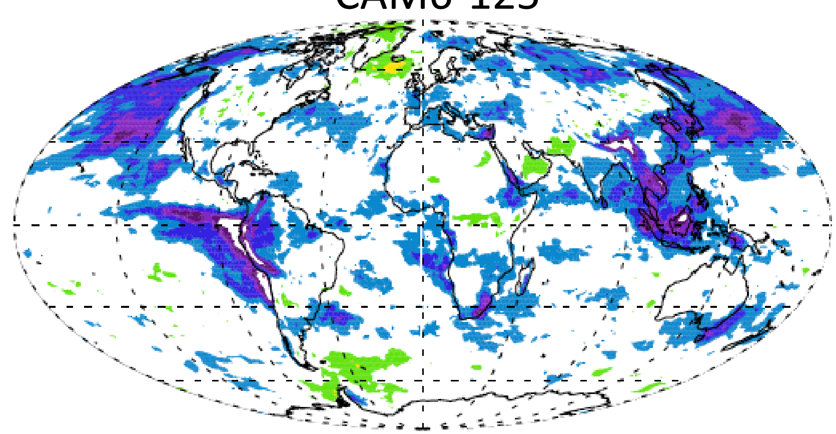


CAM5.5-SB2001



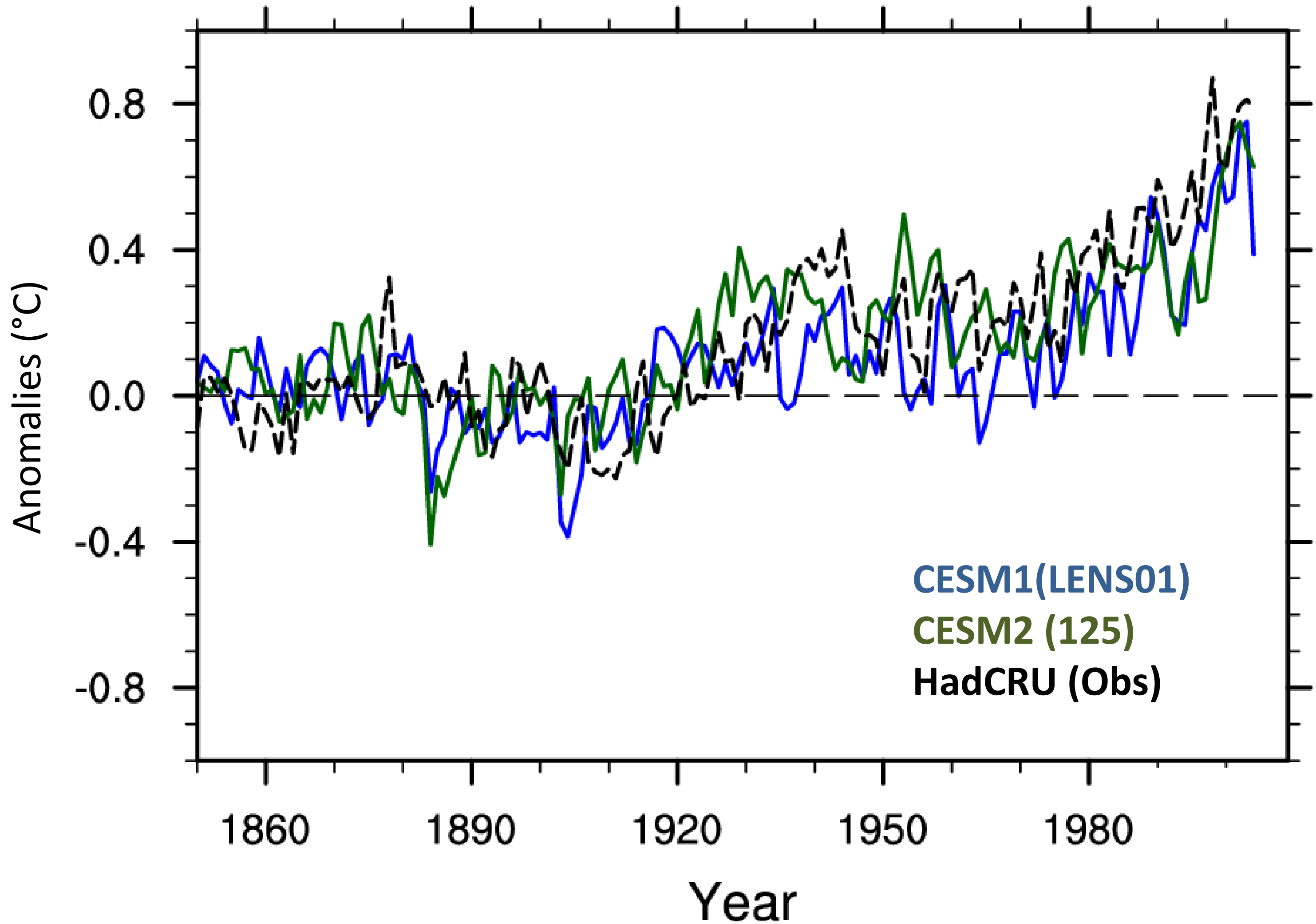
New Autoconversion reduces effects in Sub-Tropics

CAM6-125



20th Century Global T_s Anomalies

Temperature anomalies from 1850-1899 average



20^{th} Century Global T_s Anomalies

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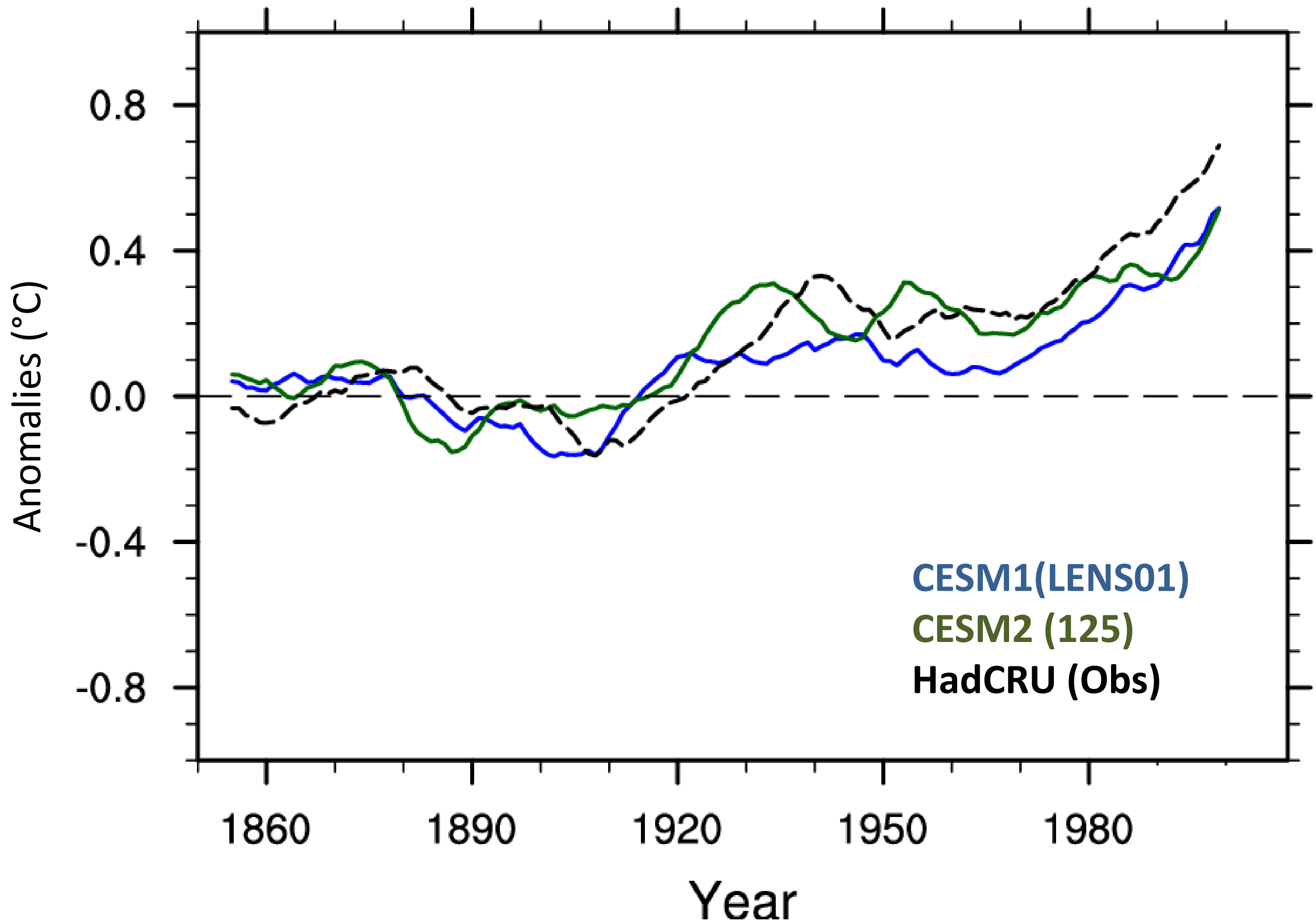
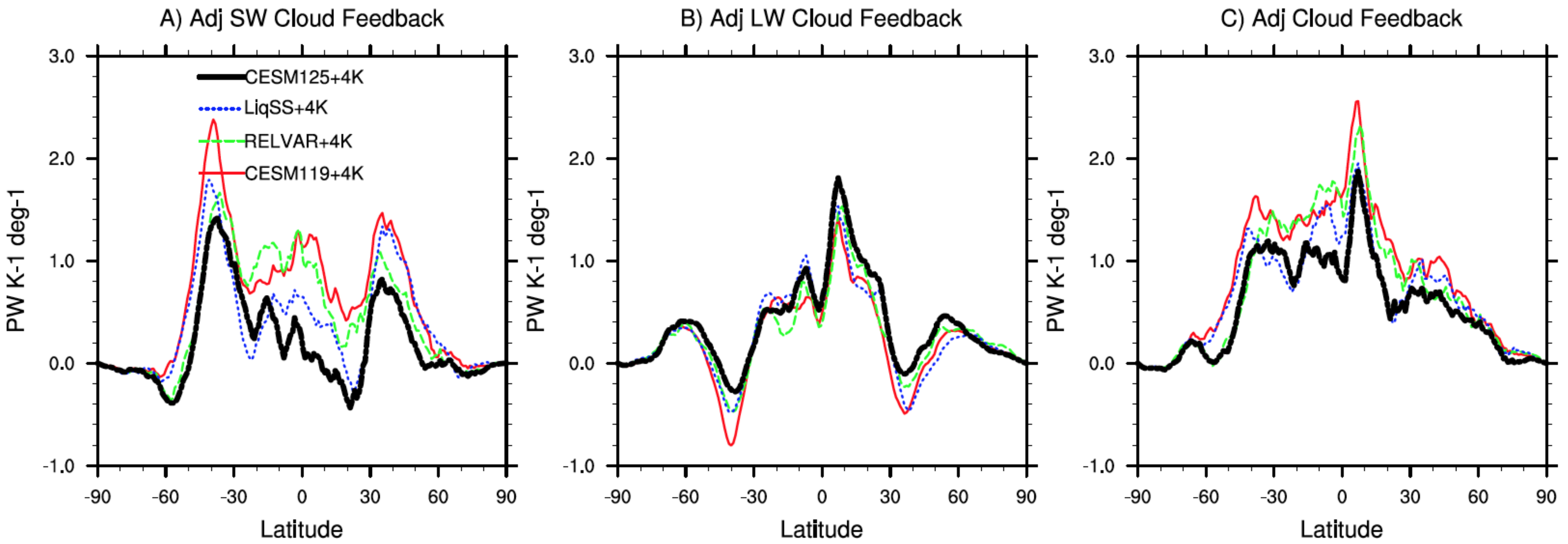


The road not taken

- Removing liquid supersaturation from CLUBB was done with an ‘alternative’ cloud scheme
  - This resulted in higher sensitivity
- Also, relative variance was left in with SB2001
  - This configuration was not appropriate for SB2001
- Produced a reasonable 1850 climate, but…

Evolution of Cloud Feedback

SST+4K Experiments (Fixed SSTs)



Current CESM2 (125)

CESM1.5 (119): 'High' Sensitivity

Remove Liquid Supersaturation (LiqSS) subtropical decrease

Remove Relative Variance (RELVAR) extra tropical decrease

Summary

- Climate Feedbacks in CESM2 similar to CESM1
  - Water vapor, albedo, clouds
  - Interesting: changed shallow convection scheme
  - Equilibrium climate sensitivity (ECS) CESM2 ≈ 3.9K (CESM1≈4K)
  - Still a few oddities from SOM run: cloud feedback is high
- Aerosol Forcing: Increased, then reduced
  - Added new regimes (shallow convection)
  - Adjusted cloud microphysics
- High sensitivity configuration is an interesting detour
  - Will analyze and investigate further
- Note: the 20th century was potentially a constraint
  - We might have changed the model if it was not acceptable
- Heat budget analysis (Trenberth) indicates lower ‘H’ (Ocean Heat Uptake) than observed. Also lower R (TOA imbalance)
  - May indicate forcing is too weak