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, \( \lambda \) = feedback parameter
  \( H \) = Ocean Heat content, \( T_s \) = surface temperature
Climate Feedbacks

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

Water Vapor
+T & RH=C \( \rightarrow \) +H2O (+)

Lapse Rate (-)

Albedo (snow, ice)
+T \( \rightarrow \) less snow, ice (+)
-T \( \rightarrow \) more snow, ice (+)

Clouds: Complicated (+)

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

Adjusted Forcing in 2003 vs. Equilibrium Climate Sensitivity (K)

CMIP5: $R^2 = 0.1941$
CMIP5 selection: $R^2 = 0.7369$
CMIP3 (Knutti): $R^2 = 0.2414$
Kiehl: $R^2 = 0.5027$

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

Bottom Line for Equilibrium Climate Sensitivity (ECS)

CESM1 = 4.0K       CESM1.5 ≈ 3.8K       CESM2 ≈ 4.2K

From SOM Simulations

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

From SOM simulations
Cloud Feedback (Zonal Mean)

A) Adj SW Cloud Feedback

B) Adj LW Cloud Feedback

C) Adj Cloud Feedback

CESM2 (125)
CESM1.5 (28)
CESM1 (LENS)
Adjusted Short Wave Cloud Feedback

A) CESM1-SOM

B) CESM1.5 (28)-SOM

C) CESM2 (125-SOM)
Adjusted Long Wave Cloud Feedback

A) CESM1-SOM

B) CESM1.5 (28)-SOM

C) CESM2 (125-SOM)
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

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

• 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 (~0.2 Wm\(^{-2}\))
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?)

New Autoconversion reduces effects in Sub-Tropics
20th Century Global $T_s$ Anomalies

Temperature anomalies from 1850-1899 average

![Graph showing 20th Century Global $T_s$ Anomalies](image)

- CESM1(LENS01)
- CESM2 (125)
- HadCRU (Obs)
20th Century Global $T_s$ Anomalies

Temperature anomalies from 1850-1899 average

- CESM1(LENS01)
- CESM2 (125)
- HadCRU (Obs)
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)

A) Adj SW Cloud Feedback

B) Adj LW Cloud Feedback

C) Adj Cloud Feedback

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