Impact of Southern Ocean radiation biases on climate change and variability in the Community Earth System Model

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Excessive absorbed shortwave radiation (ASR) over the Southern Ocean: a large long-standing climate model bias

Trenberth and Fasullo 2010
Cloud phase biases in CAM5
(using simulator-enabled comparisons with CALIPSO)

Over the Southern Ocean: Too much ice, Not enough liquid

Kay et al. 2016a
PROGRESS:
We “fixed” both Southern Ocean and Tropical shortwave radiation biases in CESM1!

Figure 5 - Kay et al. 2016b
PART I

What is the impact of increased Southern Ocean albedo on the mean climate?
Sea Surface Temperature Response: Cooling in the Southern Ocean, Warming Elsewhere

Years 1-30

Years 150-200

SST Response (K)
Stronger meridional temperature gradients and stronger jet (SH, especially in DJF)

Atmospheric circulation response (years 150-200) Kay et al. 2016b
Fixed Ocean Circulation Response (slab ocean)

Dynamic Ocean Circulation Response (fully coupled)

Kay et al. 2016b
Summary:
Impacts of “fixing” large cloud phase and shortwave radiation biases on the mean state

1. Mean state response to “fix”: cooler Southern Ocean, warmer Tropics, stronger SH jet, more poleward heat transport, more southward cross-equatorial ocean heat transport, and small tropical rainfall changes.
2. Brightening Southern Ocean clouds does not shift the ITCZ as hypothesized in Hwang and Frierson (2013)!
3. Dynamic ocean heat transport is crucial when assessing the influence of inter-hemispheric temperature gradients on climate.

Key References:
Kay et al. 2016a – JGR-Atmospheres
Kay et al. 2016b – J. Climate
Hawcroft et al. 2016 – Climate Dynamics
PART II:

What is the impact of reduced shortwave radiation and cloud phase biases on climate change?
**Hypothesis:** Models overestimate the magnitude of the negative cloud phase feedback because they overestimate the amount of cloud ice in the mean state.

**Implication:** Models underestimate warming in response to increased greenhouse gas forcing!
Hypothesis Verified!
Reducing cloud ice increases equilibrium climate sensitivity (ECS)

Tan et al. 2016
Bill Frey Research Questions

1. Which feedbacks cause increased climate sensitivity?
2. How does Southern Ocean heat uptake and transport impact the pace and pattern of warming?

Bill Frey
ATOC Ph.D.
Talk tomorrow in the PCWG
Result #1: Increased equilibrium climate sensitivity of 1.5 K, consistent with Tan et al. 2016

Frey and Kay (under review)
Result #2: Two shortwave cloud feedbacks explain the increased climate sensitivity

1) weaker negative cloud phase feedback (expected)
2) stronger positive cloud amount-SST feedback (unexpected, important!)

Frey and Kay (under review)
Result #3: dynamic ocean slows warming and reduces warming differences

Slab Ocean Response to 2xCO₂

Dynamic Ocean Response to 2xCO₂

Frey and Kay (under review)
Summary:
Impacts of “fixing” large cloud phase and shortwave radiation biases on climate change

1. Decreasing the absorbed shortwave radiation biases in CESM increases equilibrium climate sensitivity (consistent with Tan et al. 2016).
2. Initial warming is driven by a smaller negative cloud phase feedback and amplified by a positive SST – cloud amount feedback in the mid latitudes.
3. Deep ocean heat uptake delays surface warming over the Southern Ocean which delays the positive SST – cloud amount feedback.
4. **Dynamic ocean heat transport can be crucial when assessing the influence of cloud feedbacks on climate change.**

Key References:
Frey and Kay (under review)
Tan et al. (2016)
PART III:
Can we see the impacts in individual storms (relevant for observational field campaigns such as NSF-funded SOCRATES and NASA-proposed Southern Cross)?
Opportunistic Case Study Comparisons

Plots above show daily mean total precipitation (colors) and sea level pressure (black lines).
Plots above show daily mean opaque cloud fraction observed by CALIPSO (colors) and sea level pressure (black lines)
Plots above show daily mean opaque cloud fraction observed by CALIPSO (colors) and sea level pressure (black lines).
References:

Frey, W. and J. E. Kay (under review), The influence of extratropical cloud phase and amount feedbacks on climate sensitivity, *Climate Dynamics*

Hwang, Y.-T. and D. M. W Frierson (2013), Link between the double-Intertropical Convergence Zone problem and cloud biases over the Southern Ocean, *PNAS*


EXTRA SLIDES
Motivated by CAPRICORN
March-April 2016 cruise
Plots above show daily mean sea salt burden (colors) and sea level pressure (black lines). Sea salt proxy for wind speed.
Precipitation shows the front location and structure. April 1 looks occluded. April 3 still has cold front and warm front. Frontal zones are NE-SW vs. NW-SE.
cloud occurrence is higher in the April 3 case with SCminus20 maybe?? Circled this.
Opportunistic Case Study Comparisons

Plots above show daily mean sea salt burden (colors) and sea level pressure (black lines). Sea salt proxy for wind speed.
TOTAL PRECIPITATION

Julian Day: 80

Julian Day: 94

CONTOUR FROM 955 TO 1030 BY 5

CONTOUR FROM 958 TO 1028 BY 4
CALIPSO OPAQUE CLOUD

Julian Day: 80

Lidar Total Optically Opaque Cloud Fraction

CONTOUR FROM 968 TO 1028 BY 4

Julian Day: 94

Lidar Total Optically Opaque Cloud Fraction

CONTOUR FROM 955 TO 1030 BY 5
PART III:

What is the impact of reduced shortwave radiation and cloud phase biases on climate variability?

credit: Climate Variability Diagnostics Package
Southern Annular Mode
Atlantic Meridional Overturning Circulation

AMOC Means (annual)