Clouds and Sensitivities Across a Hierarchy of GFDL CMIP6 Models

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Abstract

The newest atmospheric climate model at GFDL, AM4, succeeded at significantly reducing the toa radiative flux biases as compared to CERES observations. Despite a relatively low top-of-atmosphere sensitivity to uniform warming of SSTs (Cess warming experiments), the corresponding coupled climate model, CM4, has high transient and equilibrium climate sensitivities. We will present a systematic picture of the modeled clouds across a hierarchy of model configurations which utilize this atmospheric model. This hierarchy includes the CFMIP Aquaplanet and AMIP experiments, fully coupled model experiments (using GFDL's CM4 model) as well as additional AMIP-like experiments with particular SST patterns. This demonstrates the large range of sensitivities that are possible from a single atmospheric climate model. Looking at the global mean radiative feedbacks across the different model configurations as well as in the context of CMIP5 and CMIP6 models will allow us to assess to what extent the cloud feedbacks in the idealized experiments relate to the fully coupled experiments and to observed clouds.

AM4.0 clouds compared to satellites

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Comparison with Satellite Observed Clouds

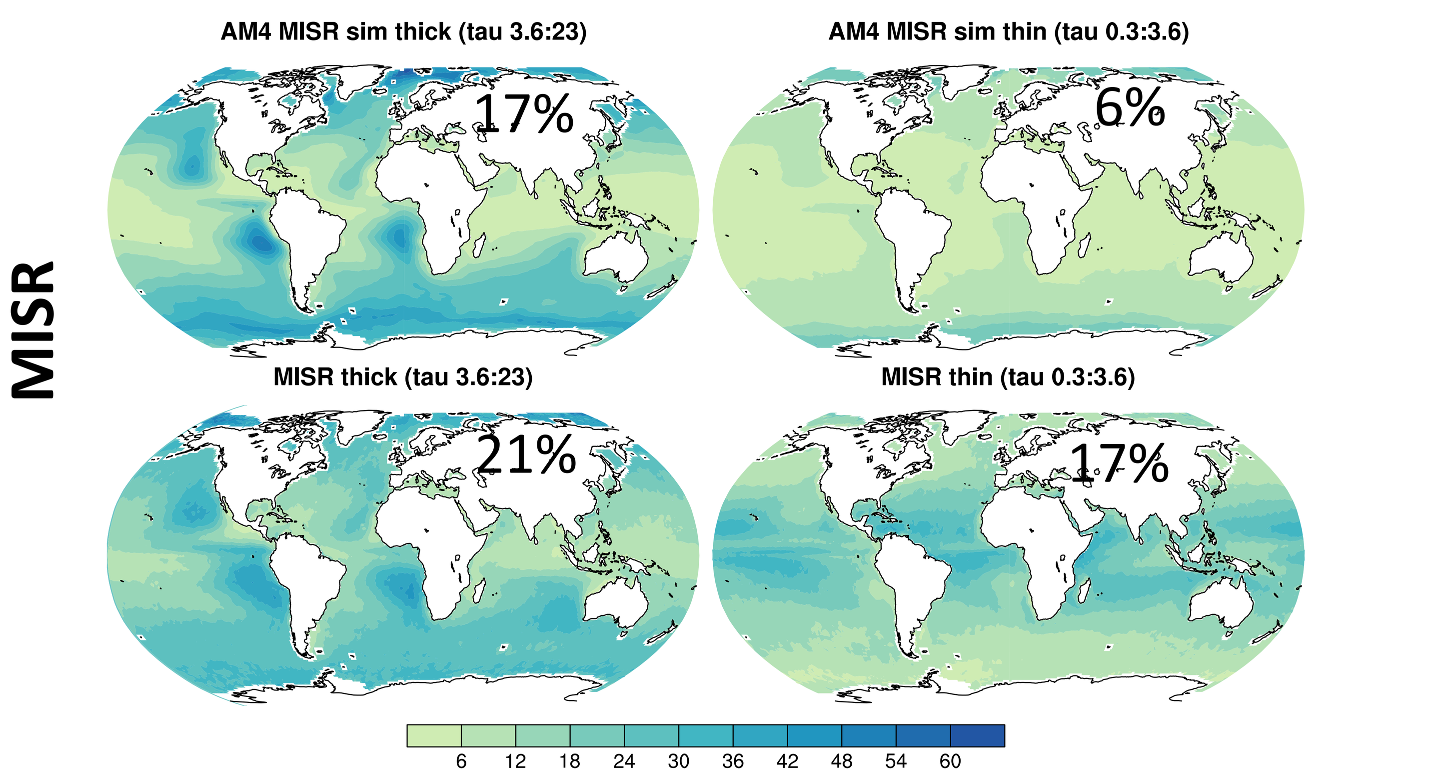


Figure: Clouds below 3 km: AM4.0 has a smaller thick (left) cloud bias (4%), than thin (right) cloud bias (11%)

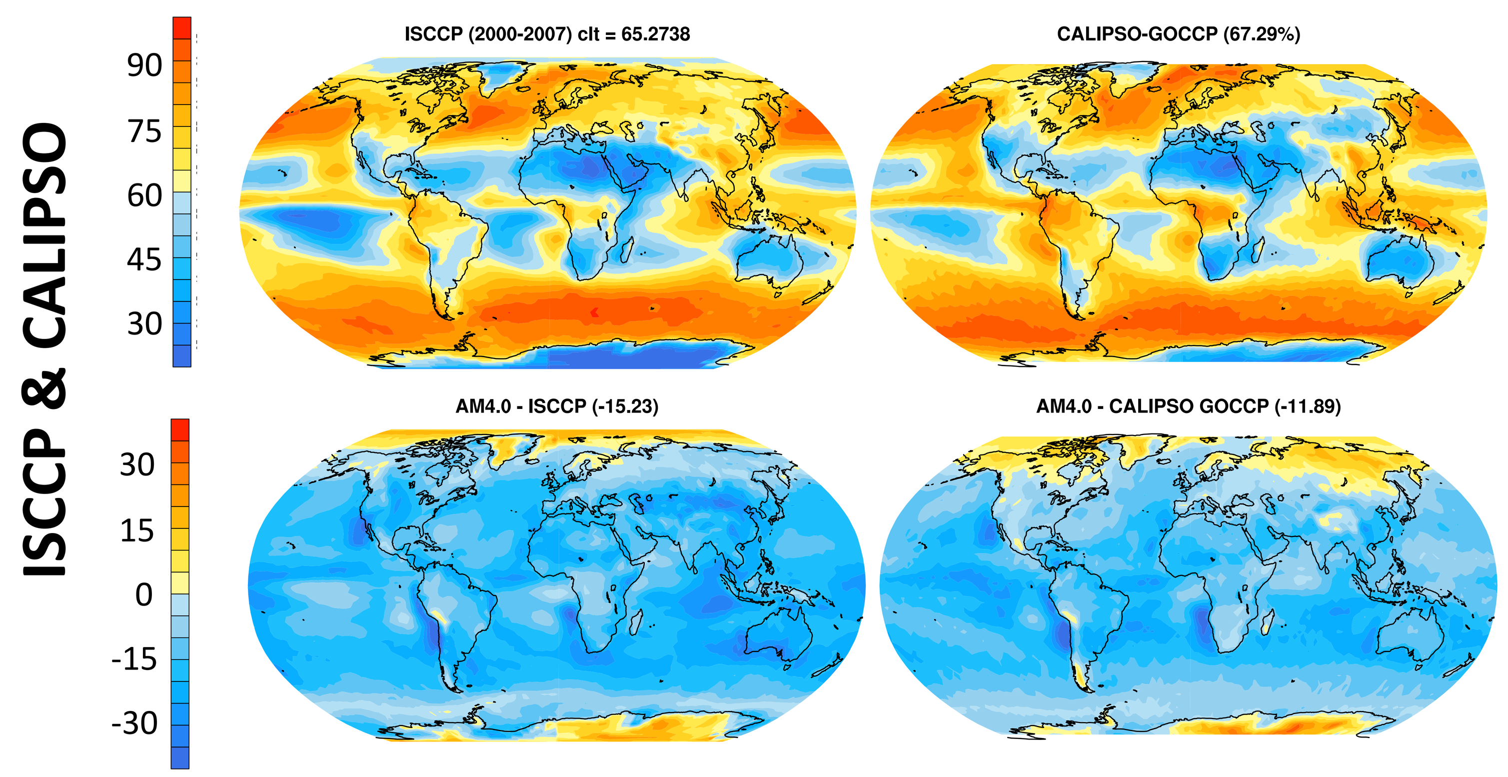


Figure: Total cloud fraction observations from ISCCP (top left) and CALIPSO (top right). The AM4.0 bias is shown in the bottom panels.

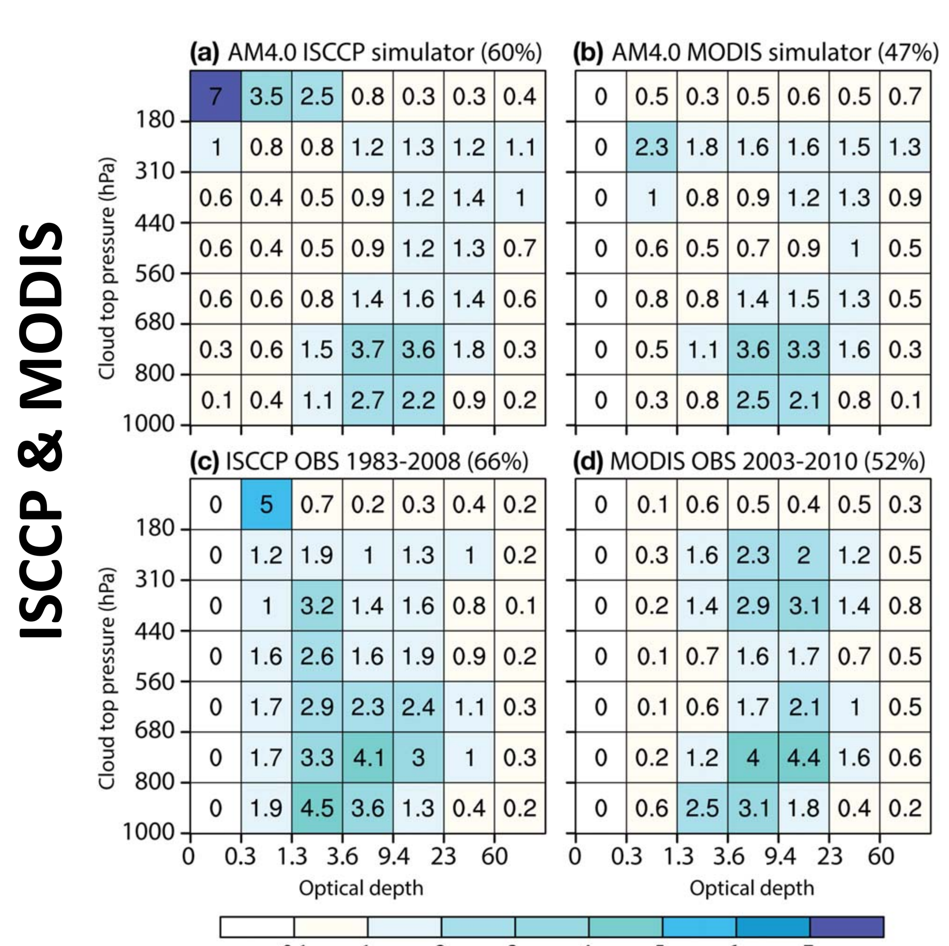


Figure: AM4.0 cloud fraction (top) compared to observations from ISCCP (left), and MODIS (right). From Zhao et al., 2018.

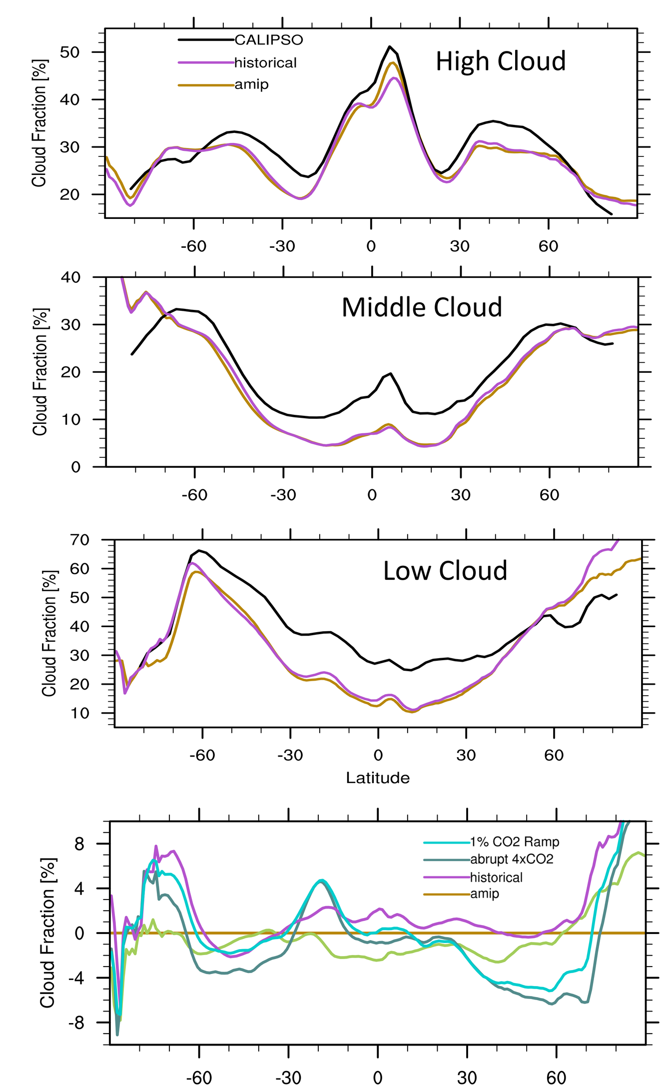
Conclusions

1. Patterns of observed clouds and the TOA energy budget are captured well by AM4.0/CM4.0.
2. The quantity of clouds in AM4.0/CM4.0 is underestimated, especially low-level clouds over the 50% of Earth centered on the equator.
3. Climate Sensitivity depends strongly on surface temperature patterns and the response of clouds.

CLIMATE SENSITIVITY

The climate sensitivity of simulations using the AM4.0 atmospheric model ranges from 1.7K to 5K. These warming simulations include an aquaplanet, amip-type experiments, and fully coupled abrupt and ramp increased CO_2 experiments.

CALIPSO



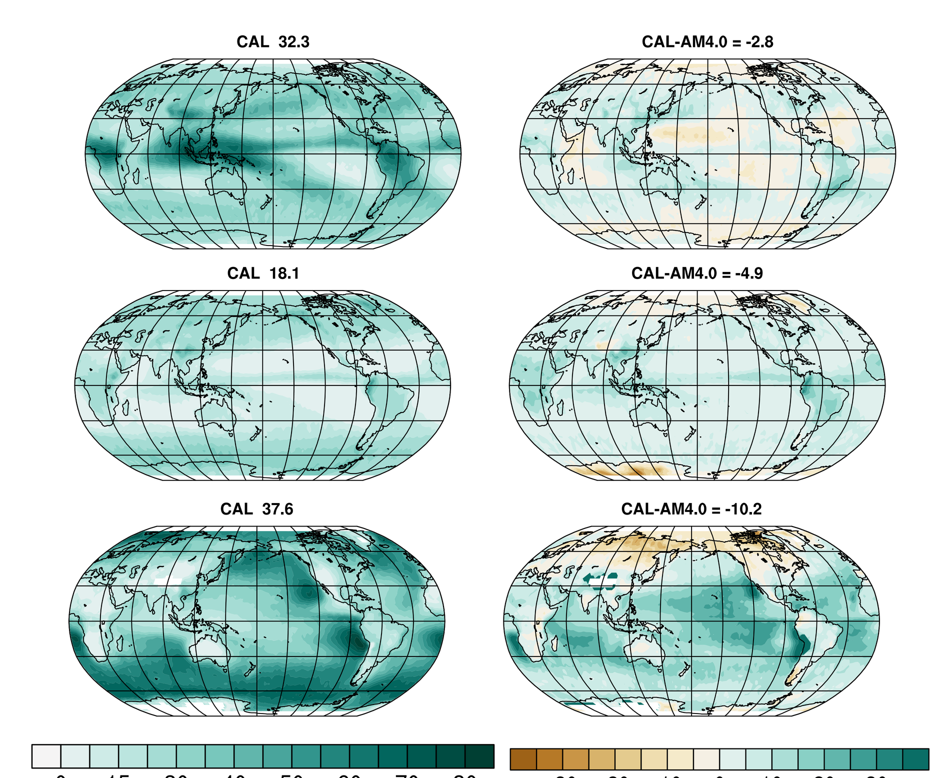
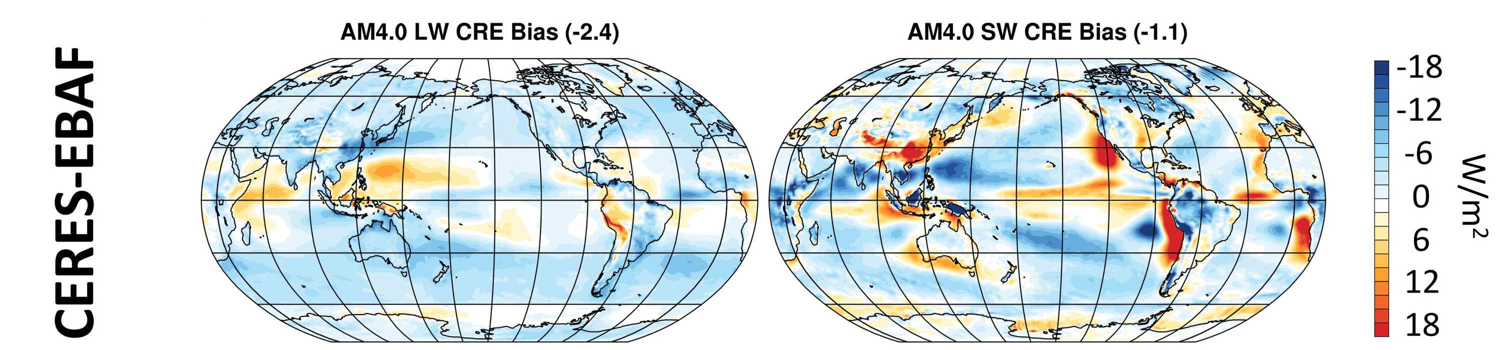


Figure: Comparison AM4/CM4 clouds with observations from CALIPSO. Global maps show biases in the amip experiment. Meridional profiles include comparisons of clouds from the coupled historical, ramp CO_2, and abrupt CO_2 experiments.

Papers Documenting AM4,.0 and CM4.0:

- Zhao, M., et al., 2018a: The GFDL Global Atmosphere and Land Model AM4.0/LM4.0: 1. Simulation Characteristics With Prescribed SSTs, *J. Adv. Model. Earth Syst*
- Zhao, M., et al., 2018b: The GFDL Global Atmosphere and Land Model AM4.0/LM4.0: 2. Model Description, Sensitivity Studies, and Tuning Strategies, *J. Adv. Model. Earth Syst.*
- Held, I. M., et al., 2019: Structure and performance of GFDL's CM4.0 climate model, *J. Adv. Model. Earth Syst.*
- Winton, M., et al., 2019: Climate Sensitivity of GFDL's CM4.0., *in revision, , J. Adv. Model. Earth Syst.*

Top of the Atmosphere Fluxes and the Cloud Radiative Effect



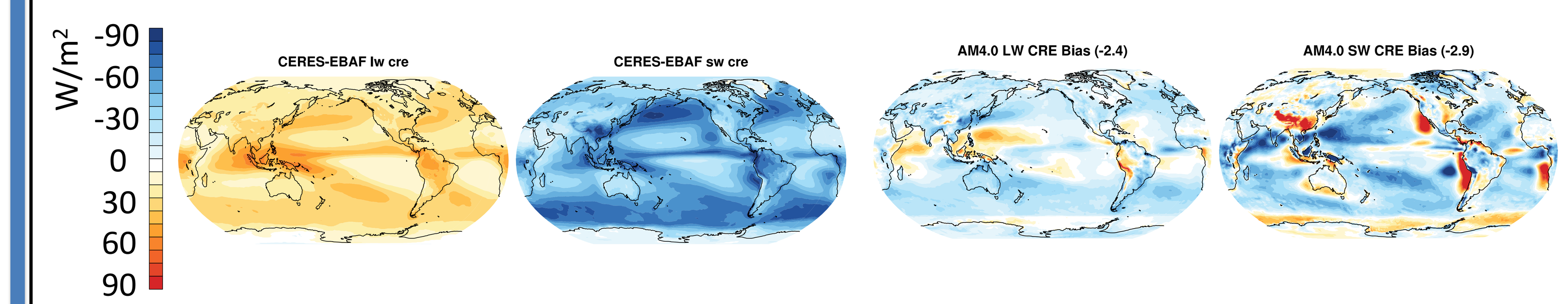


Figure: Top: AM4 CRE bias relative to CERES-EBAF version2.8. Bottom Left: Observed Cloud Radiative Effect for longwave (left) and shortwave (right) radiation as measured by CERES, Bottom Right: AM4 CRE bias relative to CERES-EBAF version 4.1.

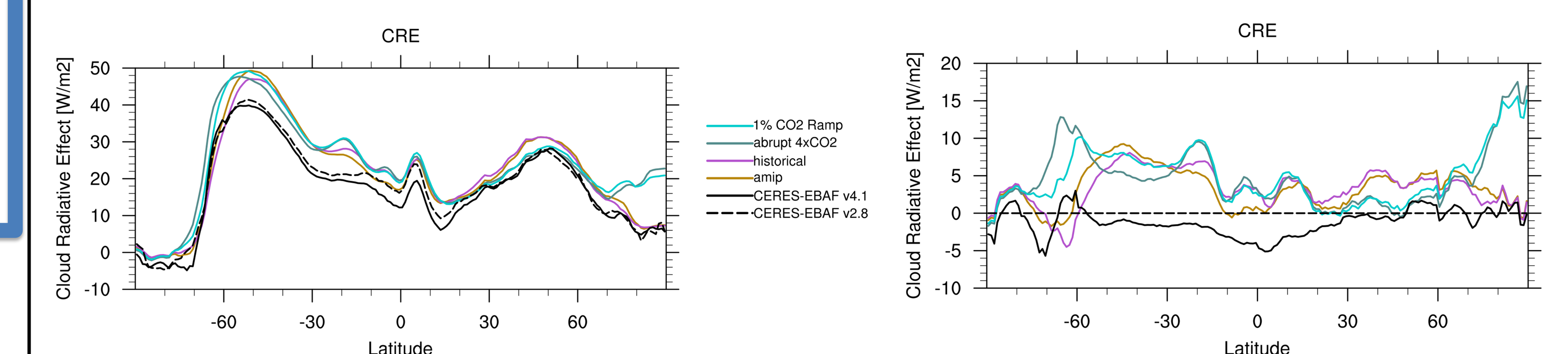


Figure: Comparison of experiments with CERES-EBAF Cloud Radiative Effect (CRE) observations. The left panel shows the total CRE while the right panel shows the bias relative to CERES-EBAF v2.8.

Methodology

We use GFDL's CMIP6 AMIP contribution to test the simulations of clouds over the last few decades. Satellite observing products are used along with the satellite simulators that are part of the COSP project.

- Test AM4.0's clouds against satellite data
- Use Satellite Simulators from COSP
- Compute Climate Feedbacks and Sensitivity across a range of GFDL CFMIP experiments
- Compare the cloud fields across a hierarchy of experiments using AM4.0/CM4.0

Background

It has been known for decades that the spread of cloud feedbacks among models contributes to a large portion of the spread in climate sensitivity among those same models (Cess et al., 1989; Bony and Dufresne, 2005). It also now clear that the climate sensitivity estimated from constant temperature perturbation experiments is not a good indicator of the climate sensitivity that is estimated from regression techniques of abrupt 4xCO2 warming experiments (e.g. Andrews et al., 2012), and that both of these measures of sensitivity underestimate the equilibrium sensitivity that is attained when a coupled climate model reaches equilibrium after multiple millennia (Paynter et al., 2018).