Scientific highlights of the Cloud CPT

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Introduction

The Climate Process Team on Low-Latitude Cloud Feedbacks on Climate Sensitivity (cloud CPT) includes three climate modeling centers, NCAR, GFDL, and NASA's Global Modeling and Assimilation Office (GMAO), together with 8 funded external core PIs led by Chris Bretherton of the University of Washington (UW). Its goal has been to reduce uncertainties about the feedback of low-latitude clouds on climate change as simulated in atmospheric general circulation models (GCMs). To coordinate this multi-institution effort, we have hired liaison scientists at NCAR and GFDL, had regular teleconferences and annual meetings, and developed special model output datasets for group analysis. The cloud CPT web site http://www.atmos.washington.edu/~breth/CPT-clouds.html provides links to all its publications and activities. The cloud CPT has had many interesting subplots; here we focus on two of interesting recent results and its future plans. The results showcase a key CPT strategy - gaining insight from the use of several complementary modeling perspectives on the cloud feedbacks problem.

Two recent findings of the cloud CPT

(1) *The world's first superparameterization climate sensitivity results show strong negative cloud feedbacks driven by enhancement of boundary layer clouds in a warmer climate*.

Superparameterization is a recently developed form of global modeling in which the parameterized moist physics in each grid column of an AGCM is replaced by a small cloud-resolving model (CRM). It holds the promise of much more realistic simulations of cloud fields associated with moist convection and turbulence. Superparameterization is computationally expensive, but multiyear simulations are now feasible. The Colorado State University and UW cloud CPT groups collaborated on the first climate sensitivity analysis of a superparameterized AGCM (Wyant et al. 2006b). The Khairoutdinov-Randall (2001, 2005) superparameterized CAM3, hereafter CAM-SP, was used. Each CRM in CAM-SP has the same vertical levels as CAM3, 4 km horizontal resolution, and one horizontal dimension with 32 horizontal gridpoints.

Following Cess et al. (1989), climate sensitivity was assessed by examining the TOA radiative response to a uniform SST increase of 2K, based on the difference between control and +2K 3.5 year CAM-SP simulations. Fig. 2 compares the results to standard versions of the NCAR CAM3, GFDL AM2 and GMAO AGCMs. All these models have similar clear-sky responses, so we just plot the +2K changes in longwave (greenhouse) and shortwave (albedo) cloud radiative forcings (ΔLWCF and ΔSWCF). Since ΔSWCF tends to be larger than ΔLWCF. boundary-layer cloud changes (which have little greenhouse effect compared to their albedo enhancement) appear to be particularly important.

The CAM-SP shows strongly negative net cloud feedback in both the tropics and in the extratropics, resulting in a global climate sensitivity of only 0.41 K/(W m^{-2}), at the low end of traditional AGCMs (e.g. Cess et al. 1996), but in accord with an analysis of 30-day SST/SST+2K climatologies from a global aquaplanet CRM run on the Earth Simulator (Miura et al. 2005). The conventional AGCMs

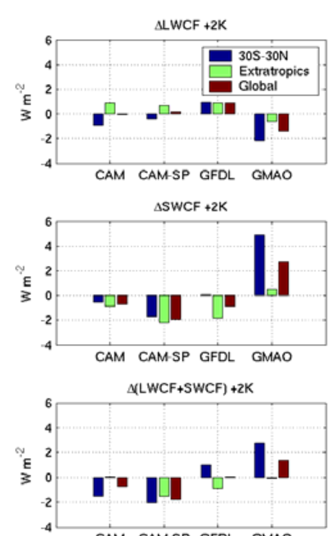

Fig. 2. Tropical and extratropical CRF components for CPT GCMs

differ greatly from each other but all have less negative net cloud forcings and correspondingly larger climate sensitivities than the superparameterization.

The coarse horizontal and vertical resolution of CAM3-SP means that it highly under-resolves the turbulent circulations that produce boundary layer clouds. Thus, one should interpret its predictions with caution. With this caveat, cloud feedbacks are arguably more naturally simulated by superparameterization than in conventional AGCMs, suggesting a compelling need to better understand the differences between the results from these two approaches.

(2) *The tropical cloud feedback differences between the NCAR and GFDL models are qualitatively captured in simplified settings, including single-column and aquaplanet models, and seem strongly tied to the models' cumulus parameterizations.*

Globally-important cloud feedbacks are much more easily understood if they can be reproduced in simpler contexts. The cloud CPT has been exploring two such contexts. One is an aquaplanet with zonally symmetric SST. Aquaplanet simulations provide a climate that is different yet similar to the real Earth and hence may be useful for testing the robustness of proposed cloud feedback mechanisms. Their zonal symmetry and simple lower boundary condition makes for comparatively easy interpretation of results.

UCLA CPT investigator Bjorn Stevens, his graduate student Brian Meideiros, and the cloud CPT modeling centers compared the response of fully realistic AGCM simulations to a near-global 2K SST increase with various aquaplanet configurations, following when possible the protocols of the Aqua-Planet Experiment intercomparison project (APE, http://www.met.rdg.ac.uk/~mike/APE/). Fig. 5 compares the 30S-30N average cloud feedback parameter of the NCAR CAM3 and the GFDL AM2 in response to the SST increase, starting from four mean states. These states are the model with fully realistic geography and SST ("Cess") and aquaplanet configurations with three different zonally symmetric SST patterns of varying degrees of flatness across the Tropics ("aqua," "qobs" and "flat"). For each climate perturbation, the cloud feedback parameter is defined as the ratio of the change in total cloud radiative forcing to the total change in radiative forcing. For each model, the cloud feedback parameter is very similar for all four mean initial states, with the GFDL AM2 exhibiting a large positive tropical cloud feedback and the NCAR CAM3 having a strong negative feedback. Thus, the aquaplanet configurations capture the gross cloud feedback of the full model in a simpler context.

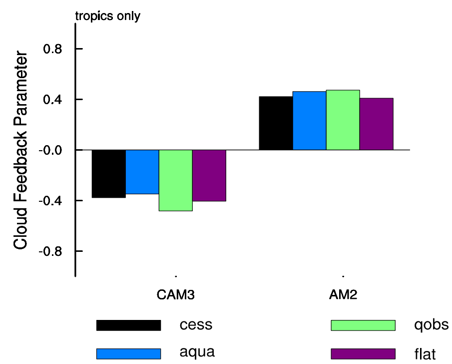

Fig. 2. Tropical-mean cloud feedback parameter for +2K SST changes from realistic ('Cess') and three aquaplanet mean states.

Another simplified analysis framework is single-column intercomparison. This allows a detailed diagnosis of how individual parameterizations in single-column versions of the three models contribute to the mean characteristics and climate sensitivity of their simulated clouds. The cloud CPT liaison scientists, Cecile Hannay of NCAR and Ming Zhao of GFDL, archived output profiles at selected grid columns from the CAM3 and AM2.12b for each time step of a simulated year. Fig. 3 compares sample

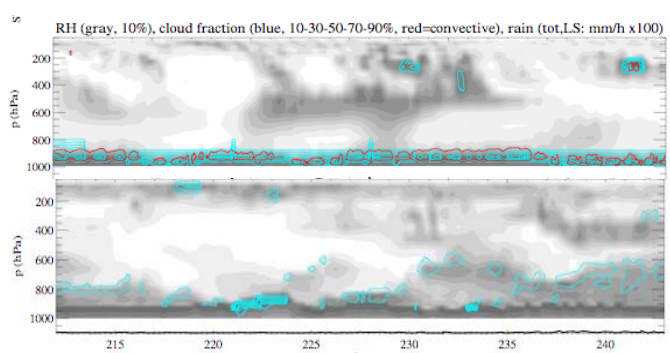

Fig. 3. October time-height sections of relative humidity (shading, darker grey = more humid) and cloud fraction (blue contours every 10%) at 85W, 20S in the SE Pacific stratocumulus regime from climatological CAM3 (top) and AM2 (bottom).

October time-height slices of relative humidity and cloud fraction from CAM3 and AM2 at a location in the heart of the SE Pacific stratocumulus regime. Although both models produce similar net cloud radiative forcings, their simulated cloud fields are quite different. with CAM3 having an overly shallow persistent stratocumulus layer, and AM2 having a deeper boundary layer, but spurious outbreaks of mid-level cumulus convection.

Clouds CPT investigator M. Zhang (Stony Brook) initiated a intercomparison of single-column versions of the three participating GCMs using steady forcings idealized from a subtropical trade wind regime with mean subsidence and 296 K SST, capped by a free troposphere with 15% relative humidity and a moist-adiabatic lapse rate tied to a warmer ITCZ SST of 300 K. Fig. 4 shows results for the CAM3, AM2 and GMAO SCMs run to equilibrium with these forcings. This took 50-100 days due to slow but persistent radiative feedbacks of the cool cloudy CTBL on the free-tropospheric temperature. The key point is that the SCMs exhibit similar cloud biases to their full AGCM counterparts, with the CAM3 SCM forming a shallow stratocumulus layer and the AM2 SCM producing unrealistically deep mid-level cumuli, and the GMAO model produced an even deeper and much thicker mid-level cloud layer. Different cloud responses led to different steady-state thermodynamic profiles, amplifying the model differences. An SCM climate sensitivity test in which local and ITCZ SSTs were raised by 2K also gave results qualitatively similar to the full AGCMs

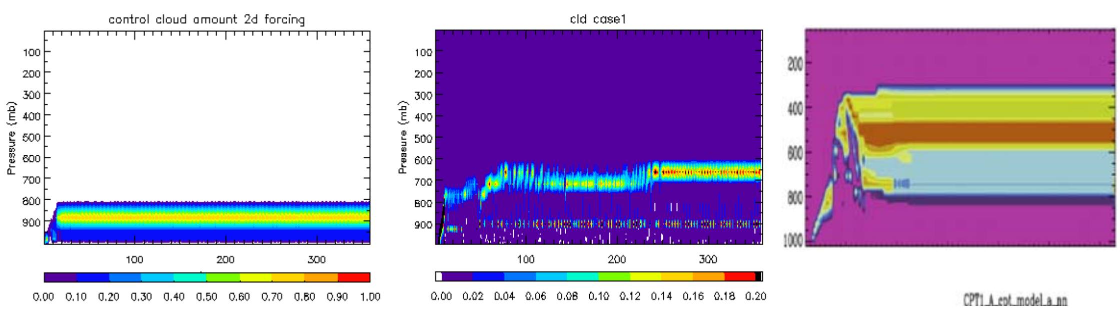

Fig. 4. Time-height sections of cloud fraction from single-column versions of the CAM3 (left), AM2 (middle, different color scale), and GMAO (right; purple =0 and brown > 0.9). Time is in days. GMAO simulation runs out to 300 days.

A diagnosis of the CAM3 SCM showed the cloud layer was maintained by a complex cycle with a few hour period in which different moist physics parameterizations take over at different times in ways unintended by their developers. A surprise was the unexpectedly large role of parameterized deep convection parameterization even though the cloud layer does not extend above 800 hPa. This emphasizes that an AGCM is a system whose mean behavior can reflect unanticipated and unphysical interactions between its component parameterizations.

Cloud CPT future plans

The focus of the cloud CPT will narrow to low-latitude boundary layer clouds, driven by recent findings by the CPT and other international groups (Wyant et al. 2006a, Webb et al. 2005; Bony and DuFresne 2005) that the net radiative feedbacks of these clouds on a climate perturbation are particularly large and uncertain. We are using our simplified frameworks to develop a process-level understanding of how changed parameterizations in current development versions of the three AGCMs and the superparameterized CAM affect their boundary layer cloud feedbacks. One interesting preliminary finding in this direction, from Ming Zhao and Isaac Held of GFDL, is that the climate sensitivity of AM2 is considerably lowered by changing only its parameterization of shallow cumulus convection to a UW scheme (Bretherton et al. 2004).. We are also pioneering the testing and improvement of cloud-related parameterizations through analysis of AGCM simulations in weather forecast mode, in close collaboration with the CCSP-ARM Parameterization Testbed (CAPT), a Department of Energy project housed at Lawrence Livermore National Laboratories (http://www-pcmdi.llnl.gov/projects/model_testbed.php; Phillips et al. 2004).

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