Collaborative Research: Reducing tropical precipitation biases in CESM — Tests of unified parameterizations with ARM observations

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1. Introduction

In state-of-the-art climate models, each cloud type is treated using its own separate cloud parameterization and its own separate microphysics parameterization. This use of separate schemes for separate cloud regimes is undesirable because it is theoretically unfounded, it hampers interpretation of results, and it leads to the temptation to overtune parameters.

In this grant, we are creating a climate model that contains a unified cloud parameterization and a unified microphysics parameterization. This model will be used to address the problems of excessive frequency of drizzle in climate models and excessively early onset of deep convection in the Tropics over land. The resulting model will be compared with ARM observations.

2. Major Project Objectives

1. Quantify and understand biases in the diurnal cycle of precipitation over land and in the frequency of occurrence of light precipitation. To do so, we will use observations from TWP-ICE, ARM-TWP, TRMM, and simulations by a cloud-resolving model (WRF).

2. Develop a version of CESM that contains a unified cloud parameterization, a unified microphysics scheme, and the capability to refine the resolution in regional areas.

3. Compare this version of CESM to observations of clouds and precipitation obtained during the TWP-ICE field experiment and at the ARM-TWP sites in the tropical Pacific warm pool. Comparison will be aided by a “sounding simulator” that we have developed.

4. Make this version of CESM available to the community for future analysis and simulation of regional climate, and improvement of the representation of tropical precipitation.

3. Tasks to be performed

Over the 3-year grant period, we hope to complete the following tasks. The primary institution responsible for a task is listed after the task in parentheses.

a. Analyze radar, precipitation, and radiosonde observations from TWP-ICE. (UColorado)

b. Implement and test code to diagnose correlations between hydrometeors in SILHS. (UWM)

c. Test MG2 and CLUBB in a version of CESM that contains the MPAS and SE dycores. (NCAR)

d. Simulate TWP-ICE observations using WRF. (ESRL)

e. Simulate TWP-ICE observations using SCAM-MG2-CLUBB. (UWM)

f. Simulate TWP-ICE observations using CESM-MG2-CLUBB. (UWM)

g. Compare global CESM-MG2-CLUBB simulations at uniform horizontal resolution to ARM-TWP observations. (UWM)

h. Compare CESM-MG2-CLUBB to TRMM precipitation distribution over all tropics. (NCAR)

i. Troubleshoot CESM biases in the timing and frequency of precipitation using WRF simulations. (ESRL)

j. Analyze CESM-MG2-CLUBB with refined horizontal resolution over the maritime continent. (NCAR)

4. Highlights of accomplishments to date

We are pleased with our progress to date:

- CLUBB has been implemented in CESM as a unified parameterization and tested in global simulations. Encouragingly, both the frequency of precipitation and the diurnal cycle of convection are improved as compared to the standard version of CESM.

- In a separate version of CESM, a microphysics parameterization with prognostic precipitation (MG2) was implemented. It too shows encouraging results, with the aerosol indirect effect reduced to a more reasonable value.

- In addition, our project's research has shown that a key assumption in CLUBB (that the standard deviation of rain spatial variability is proportional to the mean) is approximately true in radar observations of TWP-ICE.

- Finally, our project has driven WRF-CLUBB simulations using forcings from a GCM grid column in order to better understand model errors in CLUBB.

- We also have a version of CAM-CLUBB with more unified cloud physics without a deep scheme.

Our project holds an all-hands web conference every month in order to discuss progress. Dr. Joseph attended one of these web conferences.

5. NCAR Specific Progress

We have been actively working both on the parameterization front and the diagnostic front at NCAR. Accomplishments include: (a) development of a comprehensive diagnostic package of tropical variability to assist diagnosis of the global model, (b) simulations of CAM-CLUBB as a unified convective scheme, and (c) development and implementation of an advanced microphysics parameterization with prognostic precipitation.

We have had extensive collaborations with UWM on CLUBB. We have also had discussions and input from CU and NOAA. We expect closer collaboration in the next year as we start to simulate more detailed cases with CAM-CLUBB and new microphysics. We hope to more closely parallel small scale simulations and reproduce observations and diagnostics they have been developing.

5.1 Variability Diagnostics

We have developed a comprehensive diagnostic package for CESM and the atmospheric component (CAM) that focuses on variability below the monthly scale. This package looks at space-time variability of high frequency modes such as the diurnal cycle, and the tropical intra-seasonal mode also called the Madden-Julian Oscillation (MJO). The package brings data and model output together for detailed comparisons. It is open source, and an early version has now been released to members of the CESM community for testing while we continue development. The package works on 3 hourly, 6 hourly and daily fields, as well as monthly data. It also features a standard switch in CAM to turn on all the appropriate output for the diagnostics. The package will be distributed to the community in the next year or so, and we are working on expanding the package.

Figure 1 shows an example of the diurnal cycle of June, July and August precipitation from the standard version of CAM5 compared to TRMM satellite rain radar data. The color indicates the local time of precipitation maximum, and the intensity (hue) indicates the amplitude of the diurnal cycle. This highlights some of the tropical biases, particularly over land, where the peak in precipitation is just after local noon, while in observations it is typically several hours later.

Problems are mostly over land. Timing of the precipitation maximum over the ocean is in the early morning hours in both model and observations. A major goal of the project is to improve some of the biases over land, and this package now enables easy and repeatable diagnosis.

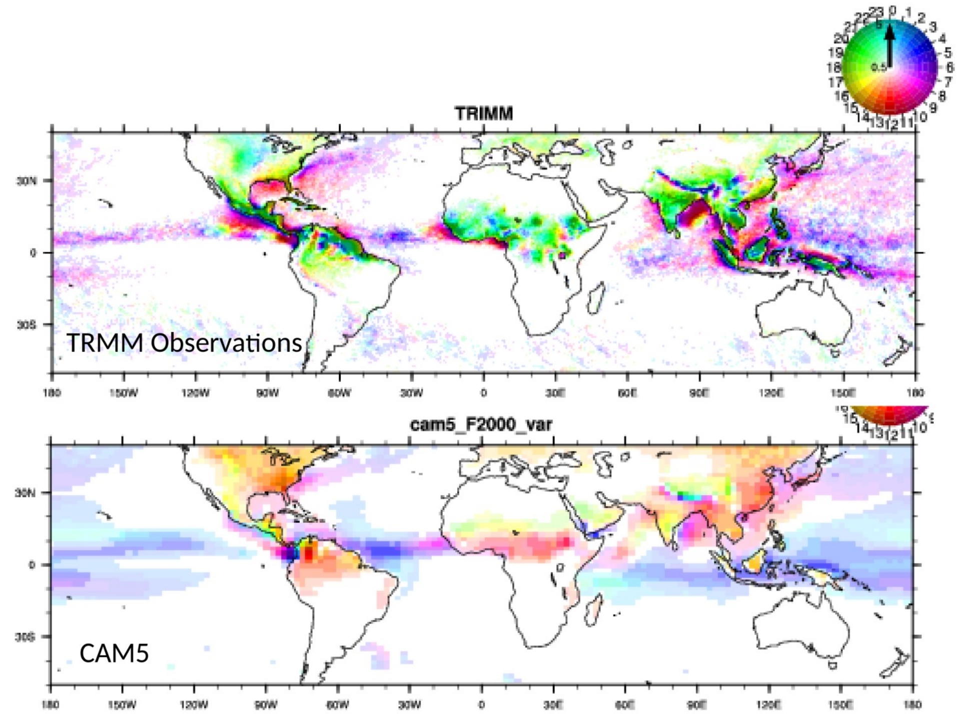

Figure 1: Diurnal cycle of June-August precipitation from TRMM satellite (top) and CAM5 base code output (bottom), produced by the new variability diagnostic package. Color indicates local time of the peak of the first harmonic of precipitation, and the intensity of the color indicates the amplitude of the diurnal cycle.

The package also can produce power spectra of tropical wave modes, shown in Figure 2. Figure 2 illustrates the power spectrum of the symmetric or background filtered Outgoing Longwave Radiation from CAM5. The different tropical wave modes are indicated. The figure shows a good representation of eastward moving equatorial Kelvin waves. However, there is no power at long timescales (~30 days) and low wavenumbers (1-3) where the MJO should be seen.

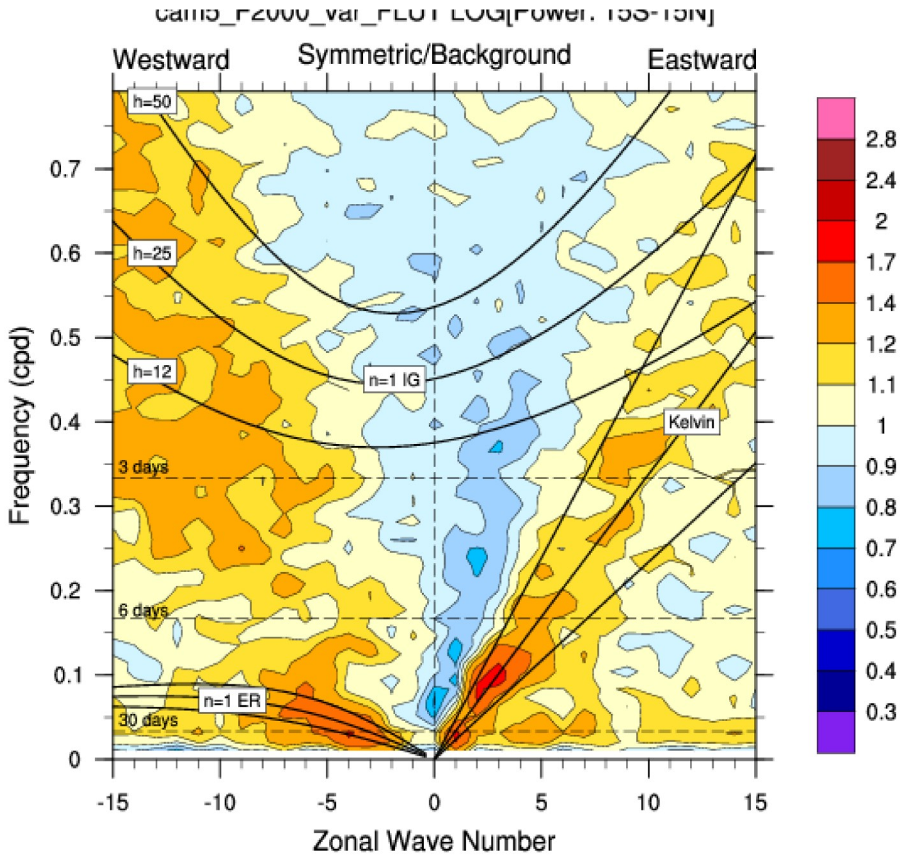

Figure 2: Power spectrum of the symmetric or background filtered Outgoing Longwave Radiation from CAM5 based on 6 hourly output.

5.2 CAM-CLUBB With Unified Convection

We modified CAM-CLUBB and extend it so that CLUBB can work as a unified turbulence scheme from deep convection to the boundary layer. This has involved close collaboration among members of the team, especially between NCAR and UWM. The work has included analysis of the model and changes to the CLUBB code to better represent deep convection, such as modifying vertical correlations, and also adding further processes, such as a rain evaporation feedback. Preliminary results from a development version of CAM-CLUBB are shown in Figure 3 for June-August precipitation diurnal cycles, similar to Figure 1, except for CAM-CLUBB run without a separate deep convection scheme.

CAM-CLUBB without a deep scheme shows a very good global representation of the diurnal cycle of precipitation over land in the tropics. Rain peaks in the evening hours local time over land. The representation of monsoonal diurnal cycles in South Asia and of sea breeze contrasts between land and ocean over the maritime continent or Florida.

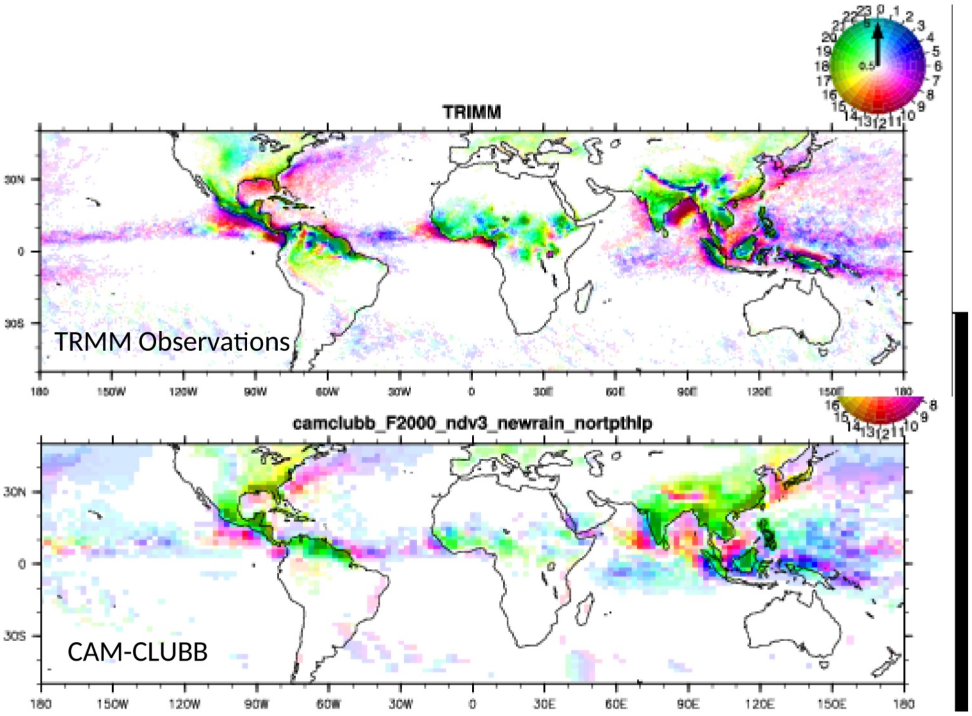

Figure 3: Diurnal cycle of June-August precipitation maximum from TRMM (top) and CAM-CLUBB (bottom). Color indicates local time of the peak of the first harmonic of precipitation, and the intensity of the color indicates the amplitude of the diurnal cycle.

5.3 Development of Next Generation Microphysics

We implemented prognostic precipitation into the Morrison and Gettelman, 2008 microphysics package in CESM. This scheme, now called MG version 2 (MG2), has been entirely refactored to be more flexible and extensible. It can now easily be ported into other models, and we are using it in a community off-line microphysics driver (the Kinematic Driver, KiD: Shipway et al 2012). The microphysics is also being developed for the NASA GEOS Model (Barahona et al 2013, submitted) and GISS (A. Ackerman, personal communication) as well as already being in the GFDL model (Saltzmann et al 2010). The microphysics is documented in Gettelman and Morrison (2015) and Gettelman et al (2015). It was utilized for some new understanding of aerosol-cloud interactions in Gettelman (2015).

MG2 adds prognostic precipitation (precipitation which persists across time steps). Prognostic precipitation is thought to modify aerosol-cloud interactions, as suggested by Posselt and Lohmann, 2008 and Gettelman et al 2013. The new scheme performs well against other schemes (Figure 4), as documented in Gettelman and Morrison (2015). The Morrison and Thompson schemes were developed for mesoscale models. The scheme was tested over a range of scales (this 1-D simulation is 25m vertical and 1s timesteps) and looking at numerical stability. We have also explored the coupling of the microphysics to the rest of the General Circulation Model (GCM) cloud physics (Gettelman et al 2015), which may also matter for the representation of clouds and microphysical processes, and which will improve the integration of the microphysics with CAM-CLUBB.

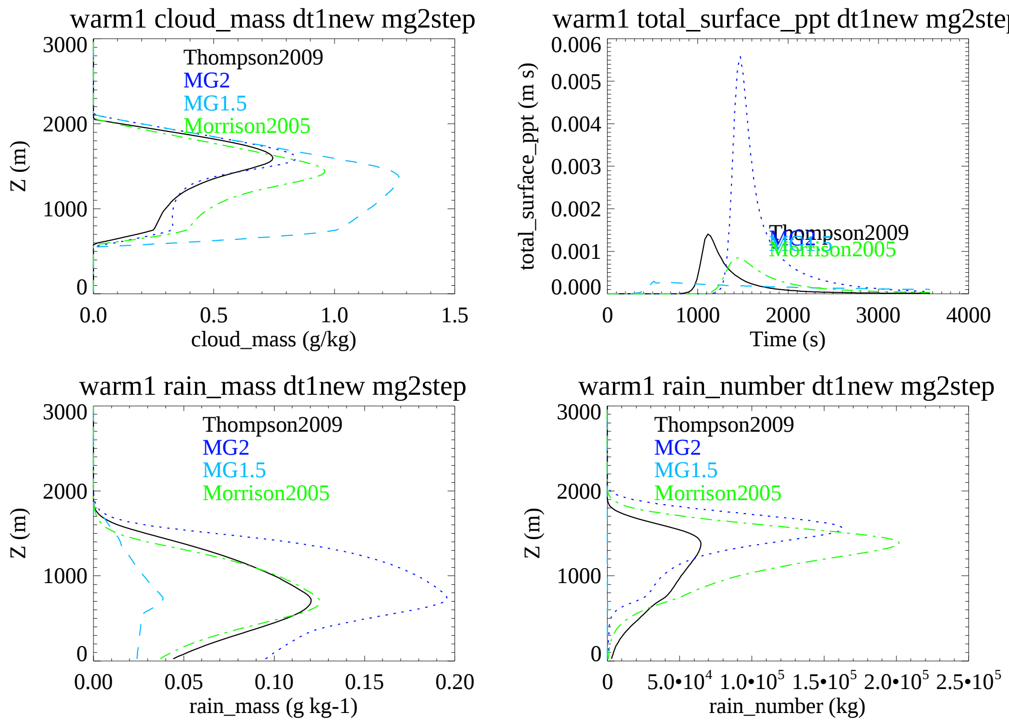

Figure 4: MG2 simulations from the offline driver, KiD. Warm rain case, 2m/s updraft. Clockwise from upper left: Cloud mass, surface rain, rain mass and rain number. Shown are 4 microphysics schemes. The new scheme, MG2, is dark blue dotted. The old scheme (MG1.5) is cyan dashed.

6. Summary

The project was very successful from the NCAR perspective. We successfully developed the new physical parameterizations of CLUBB and MG2. We now have stable simulations of CLUBB as a unified convection scheme and are moving on to work with these schemes at high-resolution in CESM2. We will be making this version of CESM available to the community in CESM2, and are writing publications on CLUBB as a unified convection scheme, and have already published the cloud microphysics, MG2 (Gettelman and Morrison, 2015; Gettelman et al 2015)

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