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

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Name of Recipient: University of Wisconsin System

Lead P.I.: Vincent Larson
University of Wisconsin — Milwaukee (UWM)

Co-PI: Andrew Gettelman, Co-Is: Hugh Morrison, Julio Bacmeister
NCAR, University Corporation for Atmospheric Research

Co-PIs: Graham Feingold, Seoung-soo Lee
ESRL, National Oceanographic and Atmospheric Administration

Co-PI: Christopher Williams
University of Colorado

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DOE/Office of Science Program Office Contact: Dr. Renu Joseph / Dr. Ashley Williamson

1. Executive Summary

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 have created a climate model that contains a unified cloud parameterization ("CLUBB") and a unified microphysics parameterization ("MG2"). In this model, all cloud types --- including marine stratocumulus, shallow cumulus, and deep cumulus --- are represented with a single equation set. This model improves the representation of convection in the Tropics. The model has been compared with ARM observations.

The chief benefit of the project is to provide a climate model that is based on a more theoretically rigorous formulation.

2. Comparison of Accomplishments with Goals

Goal 1: *Quantify and understand biases in precipitation over Tropical land masses. To do so, we will use ARM observations and simulations by a cloud-resolving model (WRF).*

Davies et al. (2013) intercompared a variety of single-column parameterized models with ARM observations and cloud-resolving models, and found that the single-column models have errors in their representation of surface evaporation and cloud ice.

Lebo et al. (2015) studied CLUBB's assumption about the variance of subgrid rain mixing ratio and found that CLUBB's assumption is largely correct, although there is some variation within horizontal grid box size that ought to be taken into account.

Goal 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.*

CLUBB and SILHS have been implemented in CESM (a.k.a. CAM). The resulting model, CAM-CLUBB-SILHS, uses one and the same microphysical scheme to represent all precipitation processes. This fully unified model was demonstrated to produce accurate simulations of climate in Thayer-Calder et al. (2015). That paper is a significant achievement.

Goal 3: *Compare this version of CESM to observations of clouds and precipitation obtained during the TWP-ICE field experiment and at sites in the tropical Pacific warm pool.*

CLUBB-SILHS was compared in standalone mode to TWP-ICE observations in Davies et al.

(2013). Comparisons were also made using Tropical data in Lebo et al. (2015).

Goal 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.*

The version of Thayer-Calder et al. (2015) is stored within the CAM svn repository, and is available to anyone upon request. CLUBB-SILHS is stored in its own repository, and any version of that code is available publicly at any time through a website, clubb.larson-group.com.

3. Summary of Project Activities

The main project activities involved constructing the CAM-CLUBB-SILHS model, comparing it to observations or large-eddy simulations, and troubleshooting problems in the model. This latter part was by far the most time consuming. Tracking down bugs and the source of poor model formulations is difficult. More funding should be allocated to it.

4. Products Developed Under the Award

2015: “A unified parameterization of clouds and turbulence using CLUBB and subcolumns in the Community Atmosphere Model." K. Thayer-Calder, A. Gettelman, C. Craig, S. Goldhaber, P. A. Bogenschutz, C.-C. Chen, H. Morrison, J. Höft, E. Raut, B. M. Griffin, J. K. Weber, V. E. Larson, M. C. Wyant, M. Wang, Z. Guo, and S. J. Ghan, Geosci. Model Dev., 8, 3801-3821.

2015: “Parameterization of rain rate variability for large-scale models." Z. J. Lebo, C. R. Williams, G. Feingold, and V. E. Larson, J. Appl. Meteor. Climatol., 54, 2027–2046.

2015: “Parameterizing deep convection using the assumed probability density function method." R. L. Storer, B. M. Griffin, J. Höft, J. K. Weber, E. Raut, V. E. Larson, M. Wang, and P. J. Rasch, Geosci. Model Dev., 8, 1–19.

2013: “A single column model ensemble approach applied to the TWP-ICE experiment." L. Davies et al. (including V. E. Larson), J. Geophys. Res., 118, 6544–6563

5. Information about computer models.

a. Model description. CLUBB is a single-column model of clouds, turbulence, and subgrid-scale variability. CLUBB predicts the multivariate PDF of thermodynamic, turbulent, and microphysical quantities. SILHS is a Monte Carlo sampler that samples CLUBB’s PDF and feeds the samples into a microphysics scheme. CAM is a climate model that contains CLUBB and SILHS as options. The version used in Thayer-Calder et al. (2015) is stored in tag subcol16_SILHS_cam5_3_38 of the svn repository at NCAR. The intended use of CAM-CLUBB-SILHS is climate modeling.

b. Performance criteria for the model related to the intended use.

The main criteria is better representation of clouds and precipitation in climate simulations.

c. Test results to demonstrate the model performance criteria were met (e.g., code verification/validation, sensitivity analyses, history matching with lab or field data, as appropriate).

CLUBB's diagnostic formula governing the subgrid variance of rain mixing ratio was evaluated in Lebo et al. (2015). The single-column version of CLUBB-SILHS was tested against ARM observations in Davies et al. (2013) and against large-eddy simulations in Storer et al. (2015). Global simulations by CAM-CLUBB-SILHS were compared to satellite observations in Thayer-Calder et al. (2015). In all cases, the model cases compared satisfactorily with observations or large-eddy simulations.

d. Theory behind the model, expressed in non-mathematical terms.

There are two key novel benefits of the formulation of CLUBB. First, it describes all cloud types with a single equation set, in contrast to the separate schemes for separate regimes approach. Second, CLUBB's mathematical framework adheres closely to the governing equations of fluid flow. Assumptions are made only once that framework is in place.

e. Mathematics to be used, including formulas and calculation methods.

The mathematical approach to closing CLUBB's equations is the Assumed PDF method. The shape of the subgrid probability density function is assumed, and integrals are performed over it in order to close certain terms in the equations.

f. Whether or not the theory and mathematical algorithms were peer reviewed, and, if so, include a summary of theoretical strengths and weaknesses.

The mathematical algorithm was peer reviewed in Storer et al. (2015) and several earlier publications supported by other funds. The main strength of the method is its theoretical rigor: CLUBB does not embed assumptions into its foundation, as does a mass-flux scheme. The main weakness of CLUBB is its computational expense.

g. Hardware requirements

The global simulations were run on the Yellowstone supercomputer administered by NCAR.

The single-column simulations can be run on a desktop workstation.

h. Documentation (e.g., user guide, model code).

The user guide for CAM is located at

http://www.cesm.ucar.edu/models/cesm1.2/cesm/doc/usersguide/x382.html

The user guide for CLUBB-SILHS is contained within a README file in the top directory of a checkout of the CLUBB-SILHS software.