High-resolution global modeling of the effects of subgrid-scale clouds and turbulence on precipitating cloud systems

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1. Executive Summary

The Multiscale Modeling Framework (MMF) embeds a cloud-resolving model in each grid column of a General Circulation Model (GCM). A MMF model does not need to use a deep convective parameterization, and thereby dispenses with the uncertainties in such parameterizations. However, MMF models grossly under-resolve shallow boundary-layer clouds, and hence those clouds may still benefit from parameterization.

In this grant, we successfully created a climate model that embeds a cloud parameterization ("CLUBB") within a MMF model. This involved interfacing CLUBB's clouds with microphysics and reducing computational cost. We have evaluated the resulting simulated clouds and precipitation with satellite observations.

The chief benefit of the project is to provide a MMF model that has an improved representation of clouds and that provides improved simulations of precipitation.

2. Comparison of Accomplishments with Goals

Goal 1: *Create a Multiscale Modeling Framework (MMF) model that uses CLUBB to parameterize subgrid-scale clouds.*

This goal was successfully completed. The new model, MMF-CLUBB, is described in Wang et al. (2015). MMF-CLUBB includes 1) CAM as a global host model; 2) SAM as a cloud-resolving model, a copy of which is embedded within each grid column of CAM; and 3) CLUBB as a cloud and turbulence parameterization within each grid column of SAM. Building such a complex model is sizable project. Challenges included coupling CLUBB's representation of subgrid cloud variability to microphysics, representing cloud overlap, and reducing computational expense. The methods by which these challenges were overcome is described in Wang et al. (2015).

Goal 2: *Evaluate the simulation of precipitation by the new model, MMF-CLUBB.*

Simulated surface precipitation was compared to observations of precipitation by the Global Precipitation Climatology Project (GPCP). MMF-CLUBB simulated precipitation with particular accuracy over tropical land masses, such as the Amazon and Borneo (see Fig. 6, Wang et al. 2015). In other respects, MMF-CLUBB's precipitation behaved similarly to a MMF model without CLUBB.

3. Summary of Project Activities

The main project activities involved constructing the MMF-CLUBB model, comparing it to observations of precipitation and other fields, 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.

4. Products Developed Under the Award

2015: “A Multi-scale Modelling Framework model (Superparameterized CAM5) with a higher-order turbulence closure: model description and low-cloud simulations." M. Wang, V. E. Larson, S. Ghan, M. Ovchinnikov, D. P. Schanen, H. Xiao, X. Liu, P. Rasch, and Z. Guo. *J. Adv. Model. Earth Syst.*, **7**, 484–509.

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. CAM is a climate model that contains CLUBB. The MMF version of CAM is stored on the CESM svn repository at NCAR. The intended use of MMF-CLUBB is climate modeling.

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

The main criteria is better representation of surface 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).

The single-column version of CLUBB was tested against ARM observations in Davies et al. (2013) and against large-eddy simulations in Storer et al. (2015). Global simulations by MMF-CLUBB were compared to satellite observations in Wang et al. (2015). In particular, simulated surface precipitation rate was compared with satellite observations analyzed by the Global Precipitation Climatology Project (GPCP) for the years 1979–2003. 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 Wang 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 are expensive and must be run on a large supercomputer. 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 is contained within a README file in the top directory of a checkout of the CLUBB software.