A CPT for Improving Turbulence and Cloud Processes in the NCEP Global Models

Steven K. Krueger (Lead P.I.), Andrew Gettelman (P.I.), Shrinivas Moorthi (P.I.),
Robert Pincus (P.I.), and David A. Randall (P.I.)

NCAR Final Report

Grant NA13OAR4310101

[UCAR/NCAR Award NA13OAR4310102]

CPT Goals

The hypothesis of the CPT is that the NCEP global models can be improved by installing an integrated, self-consistent description of turbulence, clouds, deep convection, and the interactions between clouds and radiative and microphysics processes. The goal of our CPT is to unify the representation of turbulence and SGS cloud processes and to unify the representation of subgrid-scale (SGS) deep convective precipitation and grid-scale precipitation as the horizontal resolution decreases.

We aim to improve the representation of small-scale phenomena by implementing a PDF-based SGS turbulence and cloudiness scheme that will replace the boundary layer turbulence scheme, the shallow convection scheme, and the cloud fraction schemes in the GFS and CFS. We intend to improve the treatment of deep convection by introducing a unified parameterization that scales continuously between the simulation of individual clouds when and where the grid spacing is sufficiently fine and the behavior of a convectional parameterization of deep convection when and where the grid spacing is coarse. We will endeavor to improve the representation of the interactions of clouds, radiation, and microphysics in the GFS/CFS by using the additional information provided by the PDF-based SGS cloud scheme. The team is evaluating the impacts of the model upgrades with metrics used by NCEP short-range and seasonal forecast operations.

Results and Accomplishments

At NCAR, our primary goal was to provide NCEP with scientific and technical support with the installation of our PDF-based SGS turbulence and clouds scheme called SHOC (Simplified Higher-Order Closure, Bogenschutz and Krueger 2013) into operational versions of the GFS. Working with collaborators at NCEP we were able to offer coupling strategies, bug identification, assistance interpreting results, as well as proposing physical upgrades to the SHOC parameterization. This collaboration was conducted in a series of hands-on telecons and yearly meetings at NCEP. In addition, we worked closely with R. Pincus and collaborators at the U. Colorado to provide global output data of higher-order turbulence moments from a PDF parameterization to assist them in finding efficient strategies for sampling the distribution of cloud condensate described by the SHOC PDF. In addition, we continued to develop and test the SHOC parameterization in other models, the results of which helped to improve the SHOC parameterization and give confidence in the results seen by NCEP.

With partial support from the CPT, we continued development and conducted testing of the SHOC parameterization. While the majority of the SHOC testing and developments were per-

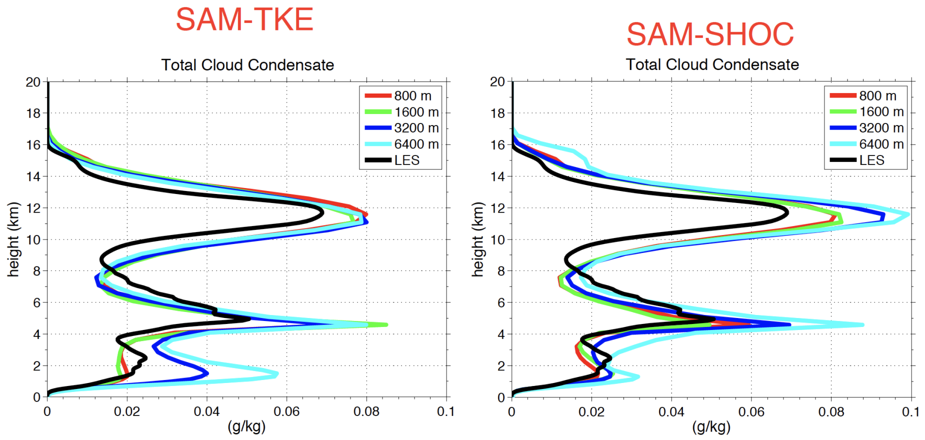

Figure 1: Horizontally averaged cloud condensate profiles from day 20 of the TWP-ICE simulations. The black curve in both panels represents results from the large eddy simulation (LES). Colored curves in the left panel represents results from the SAM CRM using standard 1.5 TKE closure, while colored curves in the right hand panel represents results of SAM using the SHOC parameterization.

formed within a cloud resolving model (CRM) and the Super-Parameterized Community Atmosphere Model (SP-CAM; Khairoutdinov et al. 2005), the CPT benefited from these efforts through a greater understanding of SHOC performance and code upgrades that were attained.

Two primary targets we hoped to gain a better understanding on the SHOC parameterization: 1) How the SHOC parameterization performs in the deep convective regime with various horizontal grid sizes. This had previously been explored with the SHOC parameterization for the simulation of boundary layer clouds, but not as rigorously for the deep convective regime. While SHOC is not expected to parameterize the deep convective circulation (as that is explicitly resolved by the CRM), SHOC must still capture the effects of the smaller scale turbulence. 2) Gain a better understanding how the SHOC parameterization performs globally when coupled to both simple and sophisticated microphysics and aerosol parameterizations. Thus far, much of the results published on SHOC have been focused on idealized CRM cases rather than how the parameterization effects the global simulation of clouds. For these experiments we use a model that SHOC has already been coupled with, namely the SP-CAM.

SHOC Deep Convection Grid Sensitivity

To explore SHOC's grid sensitivity in the deep convective regime, we use the System for Atmosphere Model (SAM; Khairoutdinov and Randall 2003) Cloud Resolving Model (CRM) to simulate an active day from the TWP-ICE campaign. To assist with this effort, a large eddy simulation (LES) was performed for the TWP-ICE campaign (by colleagues Don Dazlich and David Randall), which allows for a useful benchmark to compare our CRM results to. The LES consists of a large grid domain of 2048x2048x256 grid points with 100 m horizontal grid size. The LES uses Smagorinsky turbulence closure, Morrison et al. (2005) microphysics, and interactive radiation. The LES for this case simulated days 18 through 23 of the TWP-ICE campaign and here we focus on the particularly active day 20.

We ran the SAM CRM in two configurations, one with the standard 1.5 TKE turbulence closure, the other with SHOC. We ran each of the configurations with four different horizontal grid resolutions: 0.8, 1.6, 3.2, and 6.4 km. All CRM experiments have 64 vertical layers and are

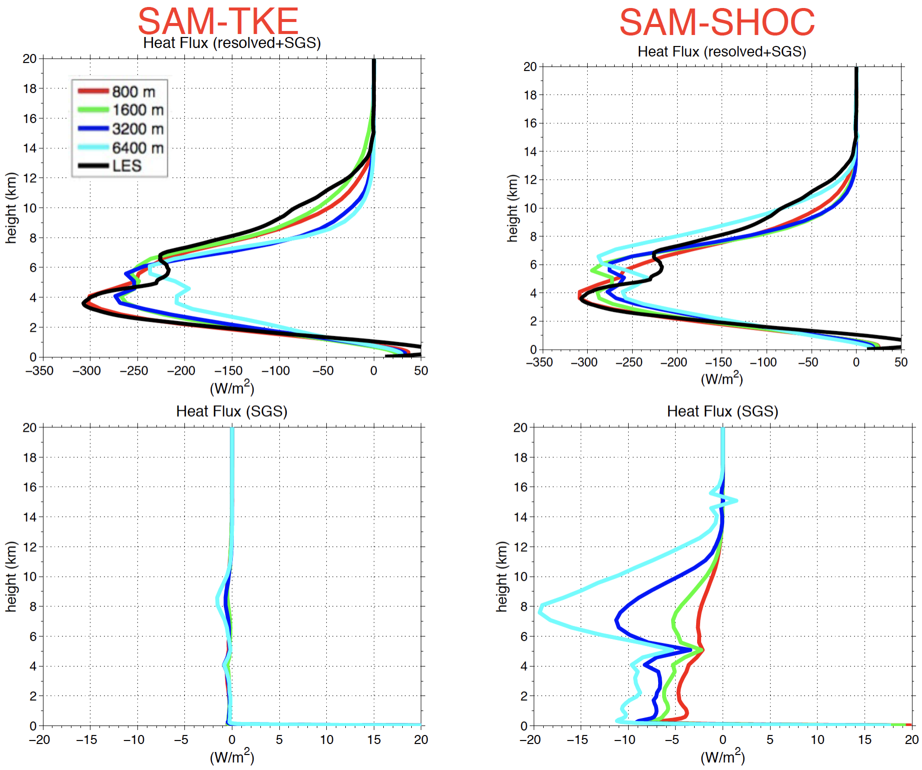

Figure 2: Horizontally averaged heat flux profiles from day 20 of the TWP-ICE simulations. The black curve in both panels represents results from the large eddy simulation (LES). The left column represents results from the SAM CRM using standard 1.5 TKE closure, while the right column represents results from SAM CRM using SHOC. Top row results are for the total (resolved + SGS) heat flux, while the bottom row results are for the SGS contribution only.

run with the Morrison 2005 microphysics. The horizontally averaged cloud condensate profiles for SAM-TKE and SAM-SHOC can been seen in Fig. 1. Here we see that the SAM-TKE simulations show a large sensitivity to the horizontal grid box size for the low-level cloud (clouds below 4 km), while the simulation demonstrated by SAM-SHOC is much more robust at these levels. This is in agreement with earlier work, which demonstrated that SAM-SHOC was much more robust to horizontal grid size for shallow convective clouds. However, we also see that SAM-SHOC simulations are more sensitive to grid size for clouds at the upper-levels, when compared to SAM-TKE. This could highlight the need to explore the coupling between SHOC and the ice microphysics in a bit more detail.

Figure 2 displays the horizontally averaged heat flux (both the total and SGS components) between the SAM-TKE and SAM-SHOC simulations. For the total heat flux the desired result is for robust results for each grid configuration for the CRMs. Here we see that SAM-SHOC exhibits less sensitivity to the grid size, especially at levels lower than 6 km, when compared to the SAM-TKE configuration. In addition, when we examine the SGS contribution, we see that the turbulent transport is being partitioned in a more physical manner for the SAM-SHOC configuration. As the grid resolution becomes more coarse, we would expect that the SGS contribution would increase for the CRMs. However, we see there is very little change in the SGS contribution for the SAM-TKE simulation, indicating that the resolved circulation is attempting to represent all cloud and turbulent processes, even at the coarse grid sizes. SAM-SHOC's ability to partition the turbulence

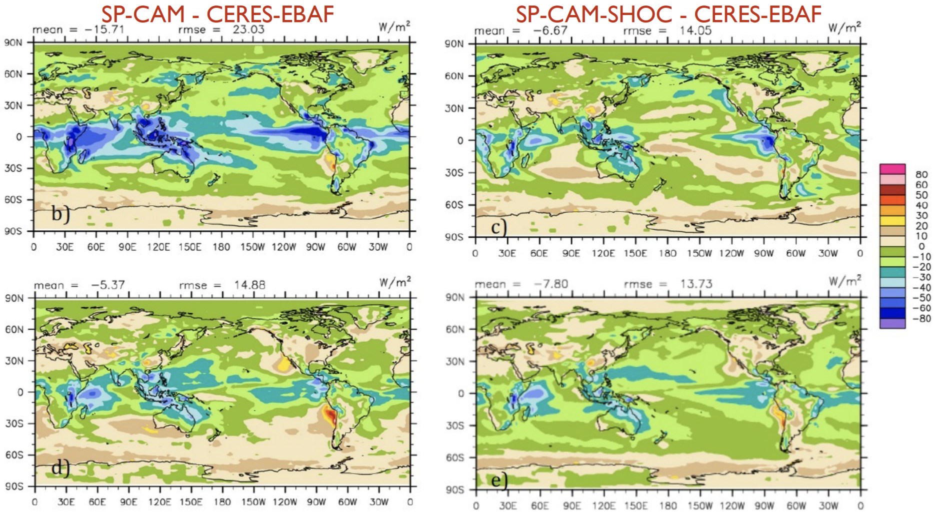

Figure 3: Shortwave cloud forcing biases for each SP-CAM configuration. The left column represents simulations using the default version of SP-CAM while the right column represents simulations using SP-SCAM-SHOC. The top row displays results from configurations using the standard single moment microphysics, while the bottom row represents results from configurations using the advanced double moment microphysics and aerosol model. Results are averaged over the five year simulations.

in a realistic manner is encouraging and a physical improvement over the low order turbulence scheme.

SHOC Performance in Climate Models

To gain further understanding how the SHOC parameterization performs globally, we use the SP-CAM model. This is a configuration where the traditional turbulence and convection parameterizations are removed from CAM and replaced with a CRM in each grid column. The idea is to allow for explicit representation of cloud processes. However, typically these CRMs have horizontal grid sizes on the order of 1 km, which is too coarse to resolve boundary layer clouds and thus must still be parameterized. To ameliorate this we replace the simple Smagorinsky turbulence closure in SAM with SHOC. SHOC has been shown to greatly improve the simulation of boundary layer clouds and to reduce the sensitivity to horizontal and vertical grid spacing compared to simple low order turbulence closures.

We ran SP-CAM and SP-CAM-SHOC each in two five year configurations. The first is with a standard single moment microphysics, while the later is with a double-moment microphysics scheme and advanced aerosol treatment (Wang et al. 2011). For each configuration the finite volume dynamical core is used, with a 2-degree horizontal grid spacing for CAM and a 4 km horizontal grid spacing for the embedded CRM. Each configuration was run using present day forcing and climatological prescribed SSTs.

Figure 3 displays the shortwave cloud forcing (SWCF) biases for each SP-CAM configuration. For the configurations using the single moment microphysics we see that the inclusion of SHOC improves most aspects of the shortwave cloud forcing. The magnitude of the cloud forcing in the tropics is greatly reduced and in better agreement with observations, while the magnitude of the cloud forcing in the stratocumulus regions is increased (namely in the Peruvian regions). In addition, a better distinction between the maritime stratocumulus and cumulus is achieved in the

SP-CAM-SHOC simulations, whereas the SP-CAM simulations tends to have clouds that are too reflective in the cumulus regions and not reflective enough in the stratocumulus regions.

The results for the configurations using the double moment microphysics and aerosol model are similar. However, the differences between the SP-CAM and SP-CAM-SHOC simulations are less drastic. This could be in part because the SP-CAM simulation in this configuration was well tuned. However, we still see improvements in the subtropical stratocumulus regions, as well as the ITCZ in SP-CAM-SHOC. It should be noted that the improvements in clouds in SP-CAM-SHOC do not come at the expense of other skill score metrics as this configuration tends to score just as well, and in many aspects better, as the default SP-CAM simulation.

References

Bogenschutz, P. A., and S. K. Krueger, 2013: A simplified PDF parameterization of subgrid-scale clouds and turbulence for cloud resolving models. *J. Adv. Model. Earth Syst.,* **5,** 195-211.

Khairoutdinov, M. F., and D. A. Randall, 2003: Cloud-resolving modeling of the ARM summer 997 IOP: Model formulation, results, uncertainties and sensitivities. *J. Atmos. Sci.,* **60,** 607-625.

Khairoutdinov, M. F., Randal D. A, and C. DeMott, 2005: Simulations of the atmospheric general circulation using a cloud-resolving model as a superparameterization of physicsl processes. *J. Atmos. Sci.*, **62**, 2136-2154.

Morrison, H., Curry, J. A., and V. I. Khvorostyanov, 2005: A new double-moment microphysics parameterization for application in cloud and climate models. Part I: Description. *J. Atmos. Sci.,* **62,** 1665-1677.

Wang, M., Ghan, S., Easter, R., Ovchinnikov, M., Liu, X., Kassianov, E., Qian, Y., Gustafson, W. I., Larson, V. E., Schanen, D. P., Khairoutdinov, M., and H. Morrison, 2011: The multi-scale aerosol-climate model PNNL-MMF: model description and evaluation. *Geosci. Model Dev.,* **4,** 137-168.

PI Contact Information

Lead P.I.:
Steven K. Krueger, Professor
Department of Atmospheric Sciences
University of Utah
135 South 1460 East, Room 819
Salt Lake City, UT 84112-0110

steven.krueger@utah.edu
phone: (801) 581-3903

P.I.:
Dr. Shrinivas Moorthi, Research Meteorologist
Global Climate and Weather Modeling Branch
Environmental Modeling Center / NCEP
5830 University Research Court - (W/NP23)
College Park MD 20740

Shrinivas.Moorthi@noaa.gov
phone: (301) 683-3718

P.I.:
Dr. Robert Pincus, Research Scientist
CIRES
University of Colorado at Boulder
Box 216 UCB
Boulder, CO 80309-0216

robert.pincus@colorado.edu
phone: (917) 464-3569

P.I.:
David A. Randall, Professor
Department of Atmospheric Science
Colorado State University
1371 Campus Delivery
Fort Collins, Colorado 80523-1371

randall@atmos.colostate.edu
phone: (970) 491-8474

P.I.:
Andrew Gettelman, Scientist III
Climate and Global Dynamics
National Center for Atmospheric Research
P.O. Box 3000
Boulder, CO 80307-3000

andrew@ucar.edu
phone: (303) 497-1887