Improving Convection Parameterization Using ARM Observations and NCAR Community Atmosphere Model

Contributors
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Research Highlight

Cloud radiative forcing is an important component of the Earth's radiation budget, and El Niño represents the most prominent mode of interannual climate variability. Thus, it is imperative that global climate models (GCMs) simulate the radiative response to El Niño well in order for them to be useful for climate variability studies and future climate prediction. In this regard, the simulation of the shortwave cloud radiative forcing (SWCF) response to El Niño in the NCAR CAM3 is far from satisfactory. For example, at T42 resolution the model's shortwave cloud radiative forcing response to El Niño-Southern Oscillation (ENSO) is much too weak compared to that observed. This was a well known bias in earlier versions of the NCAR model as well. Since tropical clouds in warm sea surface temperature (SST) regions are associated mainly with convection, it is natural to expect that simulation of cloud radiative forcing response to El Niño may be sensitive to changes in the convection parameterization scheme in GCMs. By using a revised Zhang-McFarlane convection parameterization scheme based on ARM research, this study attempts to drastically improve the shortwave cloud forcing response to ENSO in CAM3. It examines, by comparing with the standard CAM3 simulation and observations, the physical mechanisms that lead to the improved simulation of the SWCF response to El Niño.

We use the NCAR CAM3 primarily at the T42 resolution, which is equivalent to 2.8° x 2.8° in Gaussian grid. For limited comparison, we also use T85 resolution (1.4° x 1.4° in Gaussian grid). Two versions of the Zhang-McFarlane convection scheme are used. One is the original version for the control simulation, and the other is the modified version. The major difference between them is in the closure assumptions. Both simulations start from September 1, 1979, and run for 22 years ending on August 31, 2001, using observed monthly-varying SST as boundary conditions. Output is used from January 1980 through December 2000. For the T85 resolution, output is used from the Atmospheric Model Intercomparison Project (AMIP) simulation archived by NCAR over the same period. The simulation period covers several El Niño and La Niña events, including the strongest El Niño of 1997/1998. Since SWCF depends on cloud optical and physical properties, we systematically examine the simulation of cloud amount, liquid water path (LWP), and ice water path (IWP) in the model in response to El Niño.

The observations show strong SWCF anomalies in the central and eastern equatorial Pacific during the 1986/1987 and 1997/1998 El Niños. The standard NCAR CAM3 fails to reproduce such anomalies during these and other El Niño periods, with an even wrong sign in the eastern Pacific. The simulation that uses the revised Zhang-McFarlane convection scheme, on the other hand, reproduces the observed SWCF response well in the western and central equatorial Pacific. Comparison with observations shows that the SWCF response to SST variations, or cloud shortwave feedback, is nonlinear. For positive SST anomalies, SWCF anomaly decreases with SST anomaly; but, for negative SST anomalies, SWCF anomaly increases with

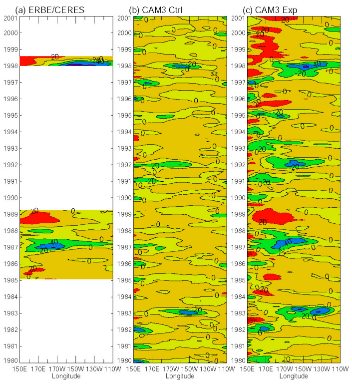

Figure 1: SWCF anomalies from Earth Radiation Budget Experiment (ERBE) and Clouds and Earth's Radiant Energy System (CERES) observations and CAM3 simulations (Ctrl is the standard model and Exp is with improved convection scheme). The anomalies are obtained by subtracting the mean SWCF at each longitude over the period of interest, which is from Feb 1985 to Apr 1989 for ERBE and from Jan 1980 to Dec 2000 for CAM3. Contour intervals are 20 Wm-2 with dotted lines for positive values.

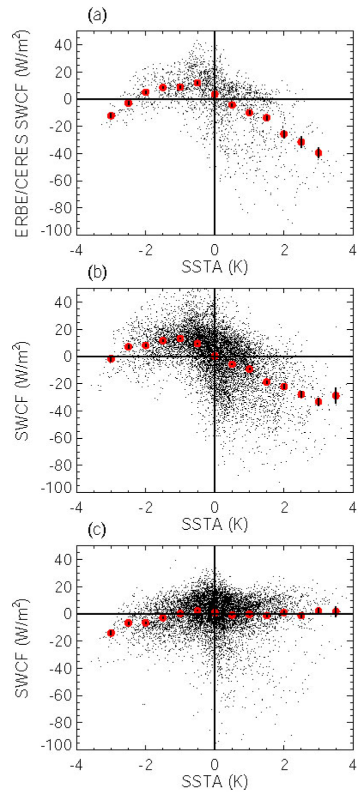

Figure 2: Scatter plots of SWCF anomaly versus SST anomaly from (a) ERBE and CERES data, (b) CAM3 Exp and (c) CAM3 Ctrl over the central and eastern equatorial Pacific (150°E-110°W, 5S-5N). Each point represents

SST anomaly. The former is attributed to enhanced convection, while the latter is attributed to increased low-level cloud at colder SSTs. The simulation with the revised convection scheme simulates the observed SWCF versus SST relationship well, while the standard CAM3 fails to do so. Examination of the relationships among simulated cloud ice water path, liquid water path, cloud amount, and SST anomalies shows that differences in cloud LWP anomalies between the simulations are responsible for the differences in SWCF response. Further analysis of cloud amount and in-cloud liquid water path indicates that excessive decreases of cloud amount and cloud liquid water path for low-level clouds, both of which contribute to the negative LWP anomalies, during El Niño in the CAM3 control simulation lead to weak SWCF anomalies. It is shown that the reduced shallow convection may have contributed to the negative cloud amount LWP anomalies in the control run. When the modified Zhang-McFarlane convection scheme is used, shallow convection is more active compared to the control. The liquid water content anomalies are higher due to enhanced transport of water vapor by shallow convection to the lower-middle troposphere. Comparison with a higher-resolution simulation at T85 confirms the importance of LWP anomalies in improving the SWCF simulation.

Reference(s)

Li, G, and GJ Zhang. 2008. "Understanding biases in shortwave cloud radiative forcing in the National Center for Atmospheric Research Community Atmosphere Model (CAM3) during El Nino." Journal of Geophysical Research 113, D02103, doi:10.1029/2007JD008963.

Working Group(s)

Cloud Modeling

a monthly mean value over a CAM3 grid point. The large red dots are averages within each 0.5 K SSTA bin when there are at least 10 points, and the error bars give the error of the mean.