Evaluation of a Cloud Microphysics Model Using Simple Nudging in a General Circulation Model

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Introduction

A bulk cloud microphysics model has been implemented in the National Center for Atmospheric Research Community Climate Model (NCAR CCM2) (Ghan and Easter 1992; Ghan et al. 1996; Cotton et al. 1986). The model replaces the temperature and water vapor mixing ratio by the condensation-conserved variable T_c=T-L/$c_p r_c$ and $r_W = r_v + r_c$. Other prognostic variables includes ice mixing ratio and ice number concentration. Snow and rain water mixing ratios are determined from diagnosed precipitation rates and the parameterized bulk terminal velocities. Table 1 compares the observed global mean Cloud Radiative Forcing (CRF) for January and July with that simulated by the CCM2 with (MICRO) and without (NCAR) cloud microphysics. While cloud water concentration was prescribed in the latter simulation, the cloud microphysics model was applied in the former simulation without any tuning.

- In this study, a simple nudging scheme is applied to CCM2. The purpose isto constrain the model simulation of general circulation for an independent evaluation of the cloud microphysics model; and

- to provide global synoptic cloud and precipitation fields for coupling with chemistry and aerosol models.

Table 1. Global mean cloud radiative forcing (W/m^2)

	January			July		
	LW	SW	Net	LW	SW	Net
ERBE	28.3	-51.4	-23.1	28.1	-46.3	-18.2
NCAR	30.6	-51.4	-20.8	29.2	-41.9	-12.7
MICRO	33.0	-34.7	-2.2	34.8	-37.5	-2.7

A Simple Nudging Scheme

To constrain the errors in the general circulation simulated by CCM2, a simple nudging scheme has been implemented in the model. Both temperature and wind are nudged using tendencies calculated from 12-hourly European Centre for Medium Range Weather Forecast (ECMWF) large-scale analyses at 2.5º resolution. Sea surface temperature and sea ice distribution of the ECMWF analyses are used as lower boundary conditions. No nudging is applied inside the planetary boundary layer. The nudging coefficients are determined to be $2.5x10^{-4}$ s^{-1} by sensitivity experiments which minimize the error in water vapor. It was found that nudging of temperature alone has little effect on the water vapor field.

Two Simulations, with and without nudging, were started with initial conditions of July 27 1994 and lasted through the end of August 1994. The simulations were compared with the ECMWF analyses and the root mean square (rms) errors were calculated. Figure 1 shows the error growth in the simulations with and without nudging. In general, the rms errors stabilized after a few days. When nudging is applied, the rms error in column water vapor is reduced by about 10%.

Comparison with ECMWF Analyses

To examine the differences between the simulations with and without nudging, we first compare the August monthly means with ECMWF analyses. With nudging, the zonal mean rms errors in water vapor are generally smaller in the extratropics, but amplified in the tropics and subtropics. When nudging is applied, a much stronger upward motion is found in the tropics. This introduced higher moisture convergence into the tropics and subsequent drying in the subsiding branch in the subtropics.

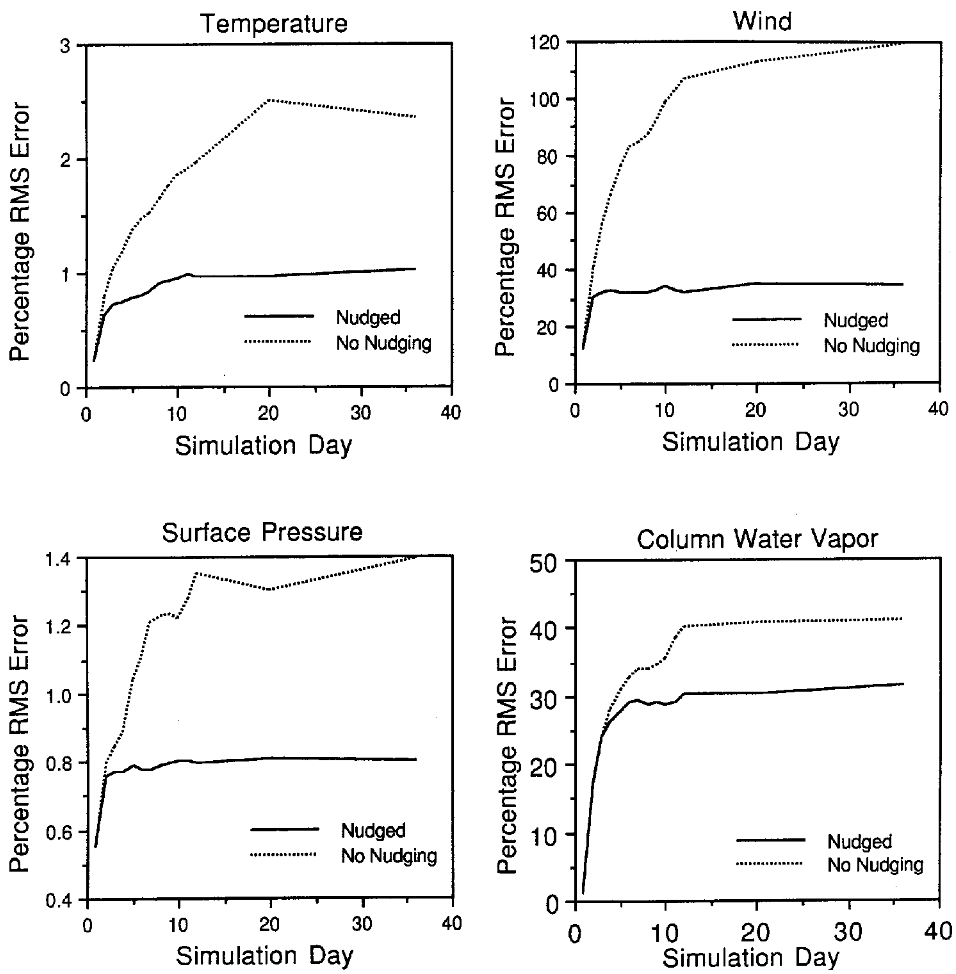

Figure 1. The growth of root mean square (rms) errors in temperature, wind, surface pressure, and column water vapor for the CCM2 simulations with and without nudging.

Figure 2 shows the spatial distributions of the column water vapor. A well organized water vapor band in the Intertropical Convergence Zone (ITCZ) is found in both the ECMWF analysis and the simulation with nudging, but not in the simulation without nudging.

When the large-scale and convective precipitation simulated by the ECMWF model is compared with the CCM2 simulations, the agreement among models is very good for convective precipitation. With nudging, CCM2 simulated a convective rainband in the ITCZ, in close agreement with the ECMWF model. However, the model, with or without nudging, predicts much higher large-scale precipitation in the tropics than the ECMWF model. Over the extratropics, the nudged simulation agrees with the ECMWF model better in the Northern extratropics, but precipitation is somewhat reduced over the ocean in the Southern Hemisphere.

Comparison with Observations

To further evaluate the CCM2 simulations, we compare them with observations. Figure 3 compares the zonal mean simulated liquid water path (only stratiform cloud) with SSM/I measurements for August 1994 (Greenwald et al. 1993). The model simulates too little cloud water in the marine boundary layers. On a separate study, we found that this deficiency can be greatly improved by using higher vertical resolutions. The main difference between the simulations with and without nudging is the spatial structure of cloud. With nudging, the model captures the zonal structure associated with the ITCZ in the tropical Pacific, although consistent with previous discussion, the liquid water path is overpredicted there.

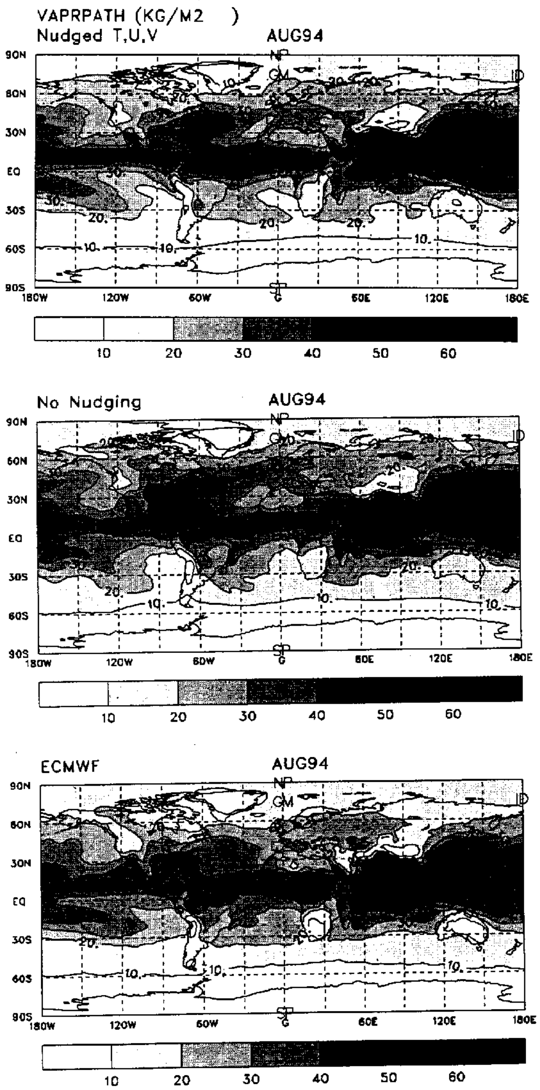

Figure 2. Spatial distributions of the column water vapor in the ECMWF analyses and the CCM2 simulations with and without nudging.

We have also compared the model simulated precipitation with observations from surface stations (~6000 in total). The comparison was made by linearly interpolating the simulations to the locations of the surface stations. The precipitation averaged over all the stations is 2.18, 3.80, and 3.86 mm/day for the observed, simulations with, and without nudging respectively. The correlation coefficient between the simulated and observed precipitation is 0.35 and 0.28 with and without nudging. With nudging, biases are reduced over the Eastern U.S., Alaska, Brazil, East India, and Northern Europe.

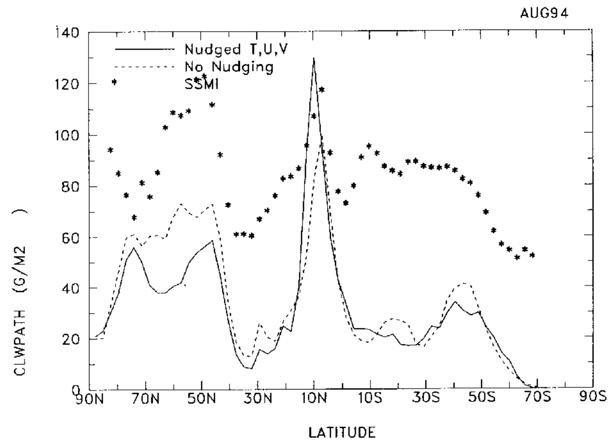

Figure 3. Zonal mean liquid water path of the CCM2 simulations and SSM/I measurements.

To concentrate on a specific region, we compare the model simulations with observations made at the ARM CART site. Figure 4 shows time series of water vapor, liquid water path, and precipitation. Without the use of nudging, CCM2 significantly overpredicts the column water vapor over the CART site. This is accompanied by higher liquid water path and precipitation. When nudging is applied, the water vapor path agrees closely with observations. The model captured the synoptic conditions on August 20 and produced corresponding peaks in liquid water and precipitation.

Conclusion

When nudging is applied, CCM2 produces water vapor and precipitation features in closer agreement with the ECMWF analyses and observations. The spatial feature of the ITCZ becomes more apparent, although water vapor, and hence precipitation is over predicted in the tropics. We will continue to investigate the causes for the overprediction of stratiform cloud and precipitation over the tropics.

With the use of nudging, more sensitivity tests can be performed with month-long simulations to study the different aspects of the cloud microphysics model and their impacts an the model simulations.

Acknowledgments

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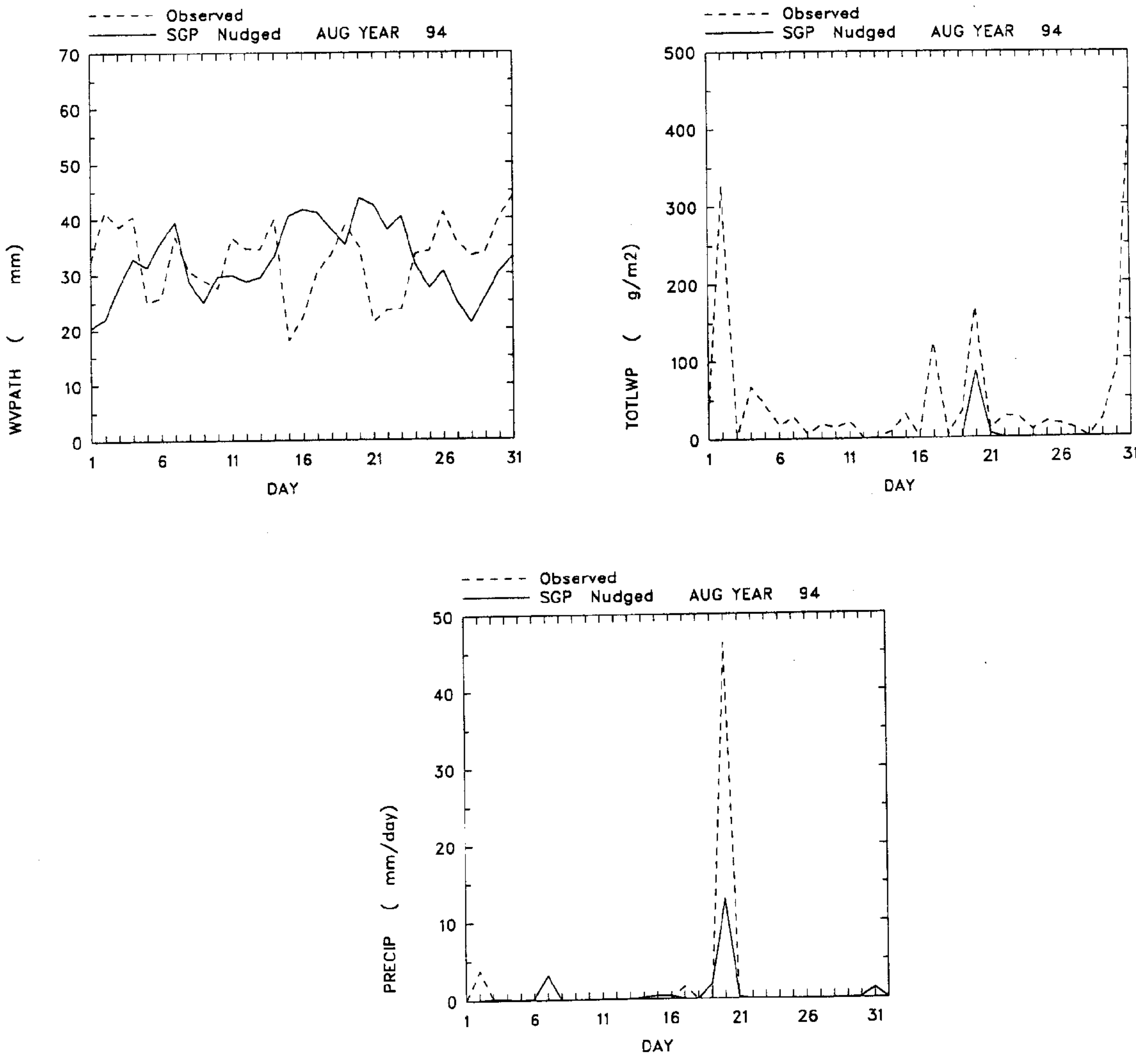

Figure 4. Time series of modeled versus observed water vapor path, liquid water path, and precipitation over the ARM CART site.

References

Cotton, W.R., G.J. Tripoli, R.M. Rauber, and E.A. Mulvhill. 1986. Numerical simulation of the effects of varying ice crystal nucleation rates and aggregation processes on orographic snowfall. J. *Clim. Appl. Meteor*., **25**:1658-1680.

Ghan, S.J. and R.C. Easter. 1992. Computationally efficient approximations to stratiform cloud microphysics parameterization. *Mon. Wea. Rev*., **120**:1572-1582.

Ghan, S.J., L.R. Leung, and Q. Hu, 1996: Application of Cloud Microphysics to NCAR CCM2. In preparation.

Greenwald, T.J., G.L. Stephens, T.H. Vonder Haar, and D.L. Jackson. 1993. A physical retrieval of cloud liquid water over the global oceans using Special Sensor Microwave/Imager (SSM/I) observations. *J. Geophys. Res*., **98**:18471-18488.

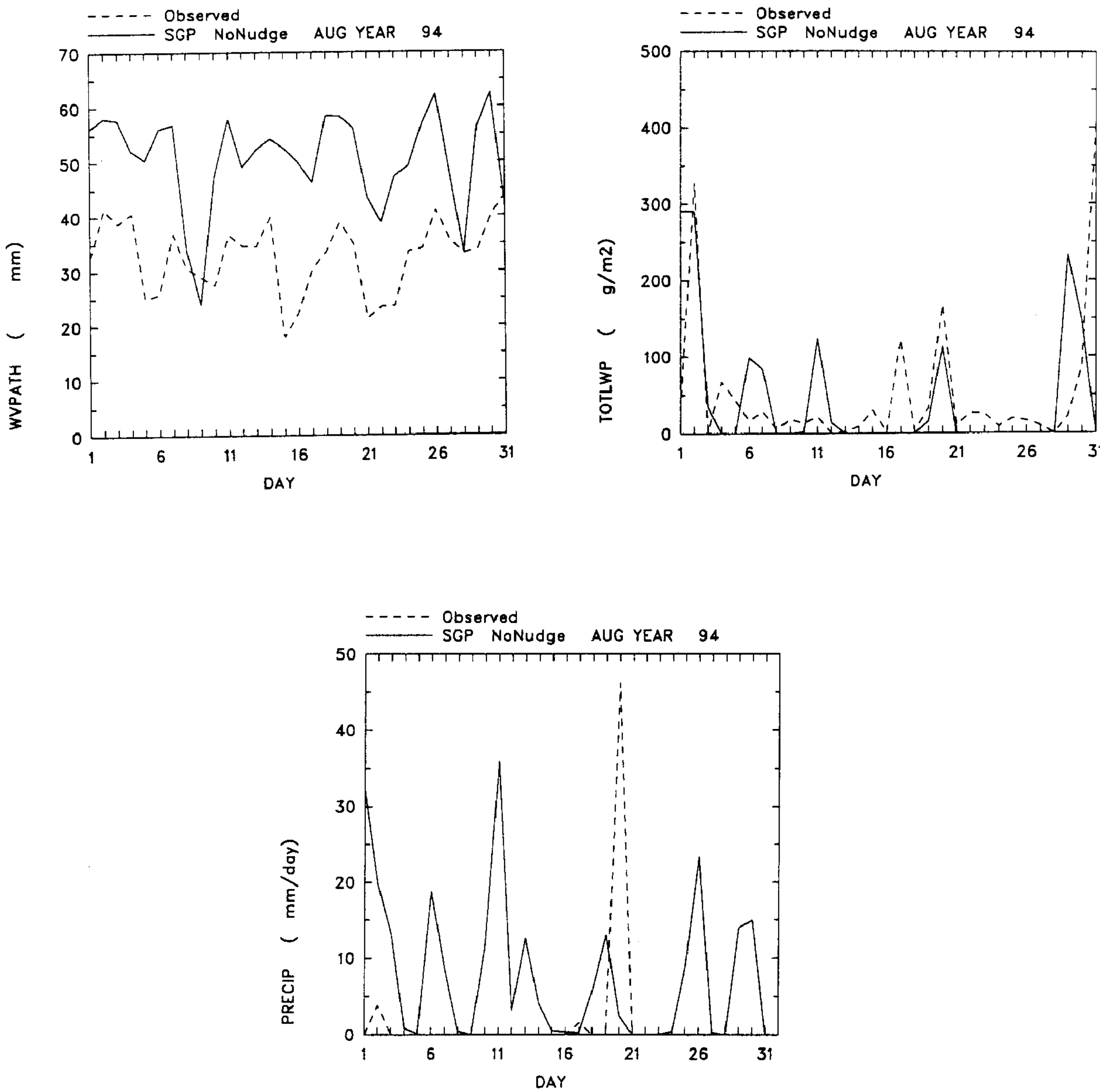

Figure 4. (contd)