13.1 EXAMINING MODEL SENSITIVITIES TO CLOUD MICROPHYSICS USING A SINGLE-COLUMN MODEL, NCEP FORECASTS AND ARM DATA

Sam F. Iacobellis* and Richard C. J. Somerville

Scripps Institution of Oceanography
University of California, San Diego

1. INTRODUCTION

For the last several years it has been recognized that much of the uncertainty in numerical simulations of potential climate scenarios (i.e., doubling CO_2) is due to incomplete and overly simplistic parameterizations of clouds and cloud microphysical properties. In response, many modeling centers have developed prognostic cloud and cloud microphysical parameterizations and incorporated them into their climate simulation models. Cloud parameterizations continue to be developed today, becoming increasing complex with the addition of more detailed cloud microphysics.

In this study we address the latter issue using a single-column model (SCM) located at the ARM program site in the U.S. Southern Great Plains (SGP) to address the question of how sensitive are basic quantities such as atmospheric radiative heating rates and surface and top-of-atmosphere (TOA) radiative fluxes are to the various parameterizations of clouds and cloud microphysics. The ARM program sites are providing a wealth of observational data that can be used to constrain and evaluate the SCM results and thus are ideal testing locations for examining these parameterizations. This study concentrates on the SGP site. The methodology can be applied to the other ARM sites located in the tropical west Pacific and the north slope of Alaska.

2. MODEL DESCRIPTION

The SCM represents an isolated column of atmosphere extending upwards from, and including, the underlying surface. Unlike a three-dimensional general circulation model (GCM), the isolated atmospheric column within the SCM does not have any horizontally adjacent columns. As a result, time-dependent horizontal advective fluxes of heat, moisture and momentum (used to derive vertical velocity) must be supplied to SCM.

The necessary forcing data for the SCM was obtained from a version of the National Center for Experimental Predictions (NCEP) Global Spectral Model (GSM) (Roads et al, 1999). The forcing data was produced using the 0 - 24 hour fields from each daily forecast made by the GSM. These individual 24-hour forecasts were concatenated to produce a 3-month long forcing data set extending from June through August, 2000. In addition to the horizontal advective fluxes of heat, moisture and momentum, the surface temperature and surface heat fluxes were also specified from the GSM forecast products.

The SCM utilizes 53 layers (Lane et al, 2000) and thus has a relatively high vertical resolution. The horizontal extent of the SCM domain is approximately 200 x 250 km and represents the Cloud and Radiation Testbed (CART) at the ARM SGP site. The SCM incorporates relaxation advection (Randall and Cripe, 1999) to keep the modeled temperatures and humidities from drifting towards unrealistic values.

3. RESULTS

3.1 *Control Run*

The control SCM run utilized a prognostic cloud parameterization (Tiedtke, 1993) together with interactive cloud optical properties for both liquid (Slingo, 1989) and ice (McFarquhar, 2001b) clouds. The effective radius is also calculated interactively using the schemes of Bower et al (1994) for liquid droplets and McFarquhar (2001a) for ice particles.

Time series of surface and TOA radiative fluxes, cloud fraction and precipitation from the SCM control run were compared to ARM observations. Overall, the model results reproduce much of the observed temporal variability. The model appears to do a better job at capturing the observed trends on the timescales of 3-4 weeks than at the shorter timescales of days to a week.

3.2 *Prognostic vs. Diagnostic Clouds*

An experiment run (EXP-DC) of the SCM was performed in which the prognostic cloud scheme of the control run was replaced with the diagnostic parameterization from CCM3 (Slingo, 1987). The results from this experiment run produced a mean vertical profile of cloud fraction markedly different from the control run (Figure 1). Compared to Millimeter Cloud Radar (MMCR) measurements, EXP-DC produced an overabundance of low clouds with a peak at approximately 2km, whereas the control SCM run underestimated cloud frequency throughout the lower troposphere. While EXP-DC produced a relative maximum of cloud frequency near 12 km, it generally underestimated the amount of high (ice) clouds. The results from the control run produced more realistic values of high clouds with a maximum at 10-11 km similar to the MMCR measurements in both magnitude and height.

* Corresponding author address: Sam F. Iacobellis, Scripps Institution of Oceanography, La Jolla, CA 92093-0224; e-mail: siacobellis@ucsd.edu.

The mean values of ice cloud extinction from these two runs are also shown in Figure 1. In general, the values of ice cloud extinction from EXP-DC exceed those from CON, the difference being close to an order of magnitude between 6 and 10 km. Also displayed in Figure 1 is the mean ice cloud extinction during the model integration period from Jay Mace's ice cloud properties data set derived from MMCR measurements (see www.met.utah.edu/mace/homepages/mace.html for description of the data set). The Mace data only examines ice clouds that are optically thin and occur with no underlying low clouds. The model data shown includes all ice clouds regardless of optical thickness or underlying cloud amount, thus comparison between the model data and measurements is difficult at best. However, it is interesting and worthwhile to note the good agreement between the results from CON and the measurements.

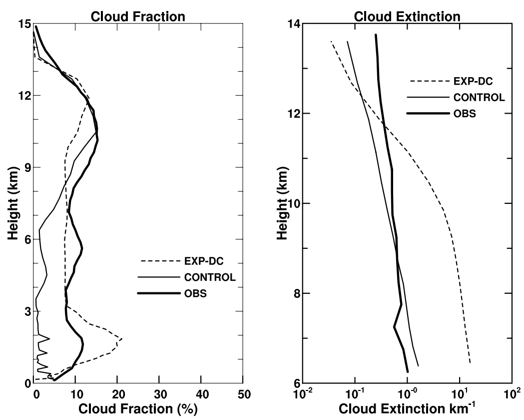

Figure 1. Vertical profiles of model cloud fraction and cloud extinction from runs CON and EXP-DC together with ARM observations.

As one might expect these differences in cloud properties between CON and EXP01 have important effects on the modeled radiative fluxes at the surface. The mean DSSR from EXP01 is 221 W m^{-2} compared to 293 W m^{-2} from CON (observed mean = 267 W m^{-2}).

3.3 *Effect of Ice Particle Radius Parameterization*

The ice particle effective radius parameterization used in the control run was replaced with the scheme of Wyser (1998) (EXP-ICE1) and Suzuki et al (1993) (EXP-ICE2).

The fractional cloud amounts produced by these two new model runs did not vary significantly from the control run. However, each run produced quite different mean vertical profiles of ice particle effective radius R_{eff} and consequently different ice cloud optical properties. Figure 2 shows the mean vertical profiles of ice particle effective radius from these model runs and from the Mace ice cloud properties data set. The width of the horizontal bars is equivalent to +/- $\sigma(z)$, where σ is the standard deviation. While the mean R_{eff} from all three model runs decreases with increasing height, each profile is notably different and it is difficult to determine which compares most favorably with the observational data.

The same parameterization of shortwave cloud optical properties was used in these runs and comparing results from these model runs can illustrate the sensitivity of modeled radiative fluxes to the parameterization of R_{eff}. The maximum magnitude of the difference in longwave cooling rate is on the order of 0.3 °K day^{-1}. The mean value of OLR varied by 5-7 W m^{-2}, while the mean value of DSSR varied between 3-4 W m^{-2}. These variations due to alternate parameterizations of effective ice particle radius are generally less than those found in the tropical cloud modeling study of Iacobellis and Somerville (2000) and may be due to the generally lower amount of convective cirrus anvil cloud cover found in the mid-latitudes relative to that found in the tropics.

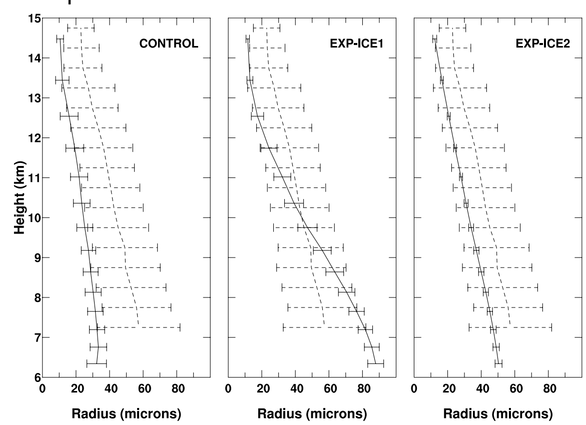

Figure 2. Vertical profile of ice particle effective radius from SCM runs CON, EXP-ICE1 and EXP-ICE2. Observations from the Mace ice cloud properties data set are shown by the dashed lines. The width of the horizontal bars is 2σ.

The variability of R_{eff} at any given level, as measured by the standard deviation, is underestimated by all three parameterizations examined. The IWC variability is approximately equal in magnitude to the mean values for both the model and measured values. The radiative flux parameterizations, both longwave and shortwave, are highly non-linear and an underestimation of the variability of cloud microphysical properties such as R_{eff} could have important consequences on model calculated mean radiative fluxes. To help quantify the effect that the narrow range of R_{eff} has on the modeled radiative fluxes, the control version of the SCM was rerun with a random ΔR_{eff} added to the model calculated value of R_{eff} (model run EXP-WIDE). This was a conservative procedure such that the mean value of R_{eff} at each model level did not change from the control run. Figure 3 shows the probability distribution of effective particle radius from run EXP-WIDE for clouds occurring from 8-9 km and 12-13 km. The width of the distribution from EXP-WIDE more closely matches, albeit not perfectly, the distribution from the Mace ice cloud property data set.

The results from model run EXP-WIDE indicate that the change in the distribution of R_{eff} can alter the solar and longwave radiative fluxes at the surface and TOA by up to 5 W m^{-2} relative to the control run. However, at the TOA level it appears that increases in the outgoing solar radiative flux are largely offset by decreases in the outgoing longwave flux resulting in little change in the heat budget for the earth-atmosphere system. The wider distribution of R_{eff} in model run EXP-WIDE results in optically thicker ice clouds (on average) that reflect more sunlight. The optically thicker ice clouds also have a higher mean emissivity compared to the control run thus essentially increasing the effective radiative cloud height and decreasing the outgoing longwave radiation.

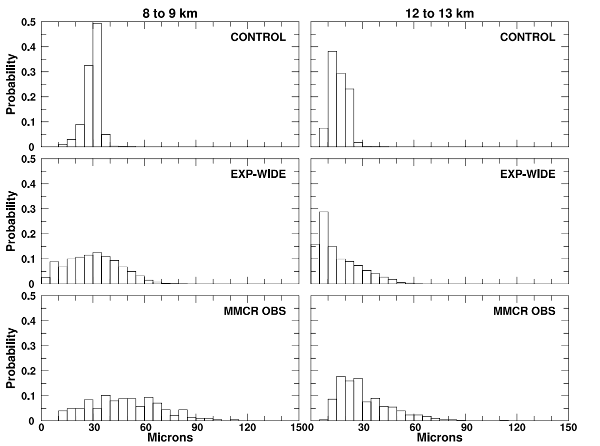

Figure 3. Probability distribution of effective ice particle radius from SCM runs CON and EXP-WIDE. and from ARM MMCR measurements.

4. SUMMARY AND FUTURE WORK

• SCM control run captures much of the observed temporal variability when forced with NCEP forecasts.

• Diagnostic cloud scheme produces much less realistic cloud properties compared to interactive prognostic cloud parameterization.

• The different parameterizations of ice particle effective radius produced wide range of results. However, each scheme underestimated variability of ice particle radius compared to observations.

• Underestimation of R_{eff} variability may affect individual surface or TOA flux by up to 5 W m-2. However, differences largely offset resulting in little change in the earth-atmosphere heat budget.

• Further examine sensitivities of ice-cloud microphysical parameterizations at SGP site.

• Apply methodology developed here at other ARM sites in tropical west Pacific and north slope of Alaska.

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