6.6 EVALUATING NEW CLOUD-RADIATION AND HYDROLOGIC CYCLE PARAMETERIZATIONS

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

Scripps Institution of Oceanography, University of California, San Diego

1. INTRODUCTION

The availability of new observational data from field programs has yielded new insights into the relationships between cloud microphysics and cloud radiative effects. Tests in single-column mode, carried out in the maritime tropics, in polar regions, and in mid-latitudes, have shown that parameterizations based on these new results can significantly reduce typical model biases in cloud-modulated fields such as surface insolation. One fruitful strategy for evaluating advances in GCM parameterizations is to use short-range numerical weather prediction (NWP) as a testbed within which to implement and improve parameterizations for modeling and predicting climate variability. The work reported here consists of three distinct elements. One element involves the development of new parameterizations for improved treatment of cloud-radiation interactions. A second element concentrates on using a single-column model, which is a process-oriented or phenomenological model, for direct evaluation of the parameterizations against measurements. The third element involves testing the parameterizations in operational NWP models and in a range of GCMs.

In this paper we focus on the second element listed above and present results from recent implementations of our Single-Column Model (SCM) designed to evaluate various parameterizations of cloud-radiation interactions.

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 continuous forcing data set that extends back to May 2000. The SCM was run at the ARM Southern Great Plains (SGP), Tropical West Pacific (TWP), and North Slope of Alaska (NSA) sites using this forcing data. 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.

Each SCM run is for a period of 24 hours. The model results from each 24-hour period were concatenated to produce a temporaly continuous set of model results. An initial set of runs was made using no spin-up period. Each of these runs began at 00 GMT. A second set of runs was also performed using a 12-hour spin-up period. During the spin-up period, the model temperature and humidity profiles were set to observed values. After the 12-hour spin-up period, the SCM was run for an additional 24 hours. The starting time of the 24-hour period in this second set of runs was 00 LST. For both sets of runs, the no relaxation was used during the 24-hour periods.

The SCM utilizes 53 layers (Iacobellis and Somerville, 2000; Iacobellis et al, 2003) and thus has a relatively high vertical resolution (Lane et al, 2000). The horizontal extent represents a single column of a GCM centered on the each of the ARM sites.

The control version of the SCM utilizes a prognostic cloud parameterization (Tiedtke, 1993) together with interactive cloud optical properties for both liquid (Slingo, 1989) and ice (McFarquhar, 2002) clouds. The effective radius is also calculated interactively using the schemes of Bower et al (1994) for liquid droplets and McFarquhar (2001) for ice particles. Ice particle settling is included in the SCM with individual crystal fall speeds calculated from Mitchell (1996). Typical fall speeds range from 0.25 to 1.0 m sec^{-1}. Maximum cloud overlap has been assumed throughout this study. The SCM contains the Rapid Radiation Transfer Model (RRTM) longwave radiation transfer scheme described by Mlawer et al (1997) and the CCM3 shortwave radiation parameterization (Briegleb, 1992). The IR cloud emissivity is calculated internally by the RRTM longwave radiation parameterization as a function of the visible cloud optical thickness. Profiles of aerosol extinction at the SGP site typical for the time period studied were included in the SCM radiative calculations using the data provided in Turner et al (2001). The convection scheme is the CCM3 mass flux parameterization (Zhang and McFarlane, 1995; and Hack, 1994).

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

3. RESULTS

3.1 *Effect of Spin-up*

Figure 1 shows the monthly mean downwelling surface shortwave radiation (DSSR) from the SCM, the GSM and ARM surface observations at each of the three ARM sites for the period May 2000 to December 2002. The results from the SCM runs using no spin-up period appear in the lefthand column while the results from the SCM runs using a 12-hour spin-up period are in the righthand column. At the SGP and NSA sites, the SCM results compare very favorably with the ARM surface observations both with and without the use of a 12-hour spin-up period. Interestingly, the SCM results compare much better with the observations at the SGP and NSA sites than the results from the GSM. Analysis indicates that these flux differences are due to the cloud fields produced by each model. This version of the GSM utilizes diagnostic cloud-radiation parameterizations that appear to be inferior to the prognostic cloud scheme with interactive cloud radiative properties used in the SCM.

However, the SCM results at the TWP site show a significant difference when a 12-hour spin-up period is used. Furthermore, it is difficult to determine whether the SCM or the GSM results are more realistic relative to the ARM surface observations. The remain part of this paper will focus on understanding the difference in the SCM results when a 12-hour spin-up period is imposed.

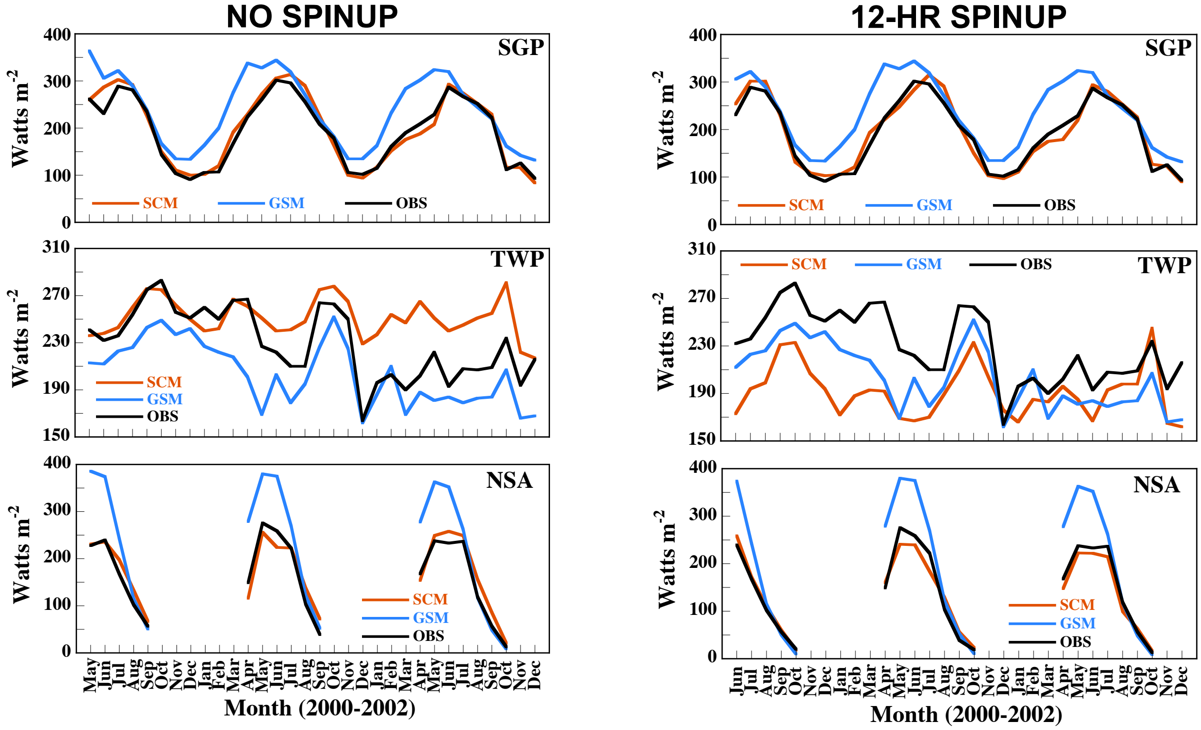

Figure 1. Monthly mean downwelling surface shortwave radiation from the SCM, GSM and surface observations at each of the three ARM Program sites. The column on the left displays SCM results using no spinup period while the column on the right shows SCM results using a 12-hour spinup period.

The main differences between the two sets of SCM runs were i) the use of a spin-up period (no spin-up vs. 12-hour spin-up); and ii) the start time of the SCM (00 Local vs. 00 GMT).

The SCM runs were repeated using a variety of spin-up periods in an effort to understand the differences in the results at the TWP site shown in Figure 1. In these additional runs, the length of the spin-up period was varied between 0 and 24 hours. Figure 2 shows the response in SCM cloud amount as a function of the length of the spin-up period. In this figure, the horizontal axis represents the amount of time after the spin-up cycle.

The top panel in Figure 2 illustrates that the overall SCM cloud amount increases once the spin-up cycle was finished. As one might expect, the runs with a longer spin-up cycle begin with a larger total cloud amount. The differences in total cloud amount between the runs remains significant for about 4-5 hours after the spin-up period.

The middle panel of Figure 2 examines the behavior of the modeled low (surface to 700 mb) clouds, while the bottom panel shows the high (400 to 100 mb) clouds from the SCM. There is very little difference in low cloud amount between the various SCM experiments. The amount of low clouds immediately after the spin-up cycle ends is very close to zero but significantly increases within the first few hours. This suggests that the SCM low clouds amount may be responding to errors in the SCM temperature and humidity fields. Recall, that no relaxation is employed after the spin-up period ends. Conversely, the amount of high clouds remains relatively constant after the spin-up period. Also the amount of high clouds during the time immediately after spin-up depends on the length of the spin-up period. It appears that there is not much difference in high cloud amount for spin-up periods between 6-24 hours.

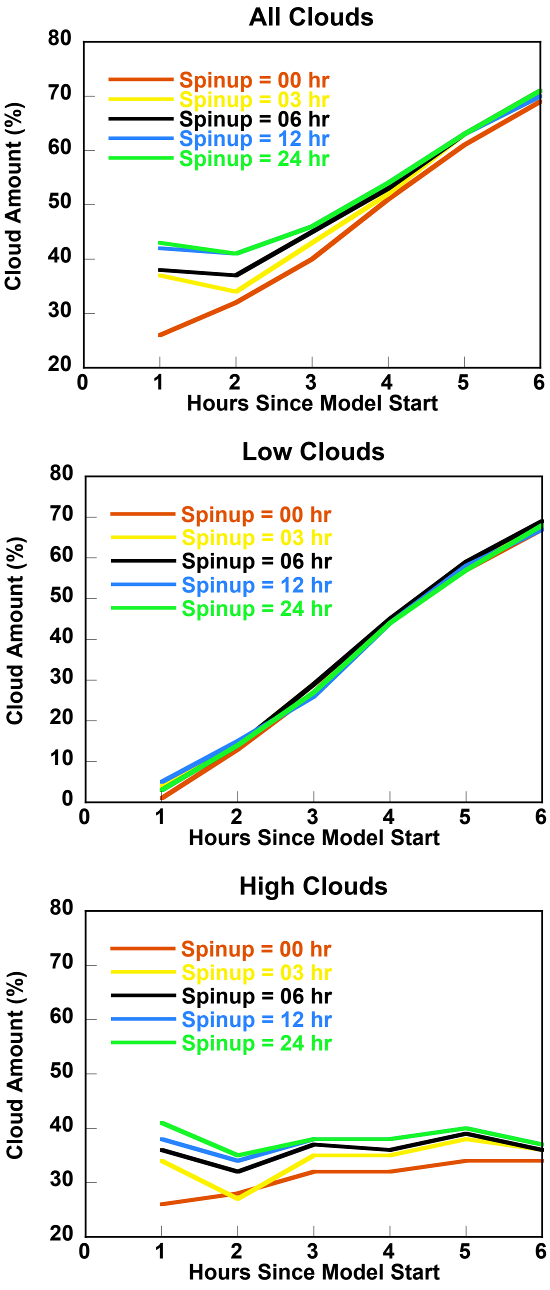

Figure 2. Model cloud amount as a function of time since model start (defined as the time after the end of the spin-up cycle) for several experiments each using a different length of spin-up. The top panel shows the response for all clouds, while the responses of low (surface to 700 mb) and high (400 to 100 mb) are shown in the middle and bottom panels, respectively.

Our analysis indicates that the differences in the high cloud amount between those runs with no spin-up and those with a 12-hour spin-up cycle are not significant enough (in the radiative sense) to account for the differences seen in the downwelling surface shortwave radiation (see Figure 1).

Another difference between the two sets of SCM runs shown in Figure 1 is the start time. The runs with no spin-up started at 00 GMT (1100 hours LST at the TWP), while the runs with spin-up started at 00 LST (here, the model start time refers to the time when the spin-up period ends).

Figure 3 shows the diurnal cycle of the mean total cloud amount from the two sets of SCM runs. Results from the SCM runs with no spin-up are shown in blue, while the clouds from the SCM runs with a 12-hour spin-up are shown in red. Both sets of runs show a similar increase in cloud amount, however due to the shift in start time, the SCM clouds from the runs with a 12-hour spin-up have a larger shortwave radiative effect as they have reached nearly 80% cloudiness during the middle of the day when the solar radiation is highest.

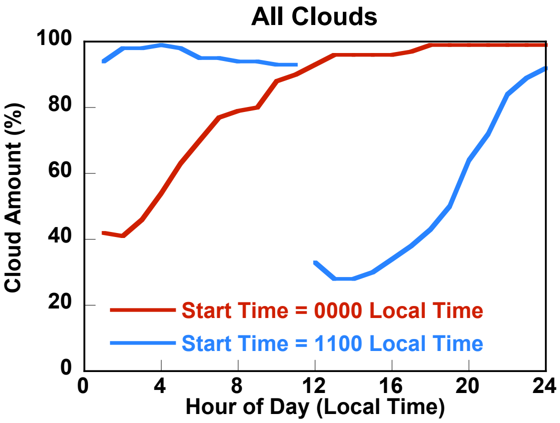

Figure 3. The diurnal cycle of mean model cloud amount from two sets of SCM runs. The blue curve shows the results from the SCM runs with no-spin-up that start at 0000 GMT (1100 LST) and the red curve shows the results from the SCM runs that start at 0000 LST and included a 12-hour spin-up cycle prior to model start.

In the runs with no spin-up that start at 1100 local time, the buildup of low clouds does not reach its maximum until after sunset. However, the low clouds in the runs with the 12-hour spin-up that start at 0000 local time have reached close to their maximum amount by sunrise. Thus, the difference in the downwelling shortwave radiation between the two sets of SCM runs shown in Figure 1 at the TWP is due to an offset in the model start time. This time offset became important because of the increasing low cloud amount seen in both sets of SCM runs. As mentioned earlier, it appears that this drastic increase in low clouds after spin-up is in response to errors in the SCM temperature and humidity fields.

4. FUTURE WORK

We will examine the model results to understand the cause of the drastic increase in low clouds that appears due to errors in the temperature and humidity fields. It is not clear if the cloud parameterizations are responding to model errors or are responsible for the errors through cloud-radiation feedbacks.

At the meeting we plan to show results that examine the response of the model cloud parameterizations as a function of various meteorological parameters such as vertical motion. Examination of these results may help identify failings of the model parameterizations.

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