13.4 EVALUATION OF CLOUD-RADIATION SENSITIVITIES TO ALTERNATIVE CLOUD AND CONVECTION SCHEMES

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1. INTRODUCTION

We have developed a single-column model (SCM) to investigate the sensitivity of cloud-radiation interactions to various cloud and cumulus convection parameterizations. Results from a control version of the SCM are first evaluated for realism by comparing model produced clouds and radiative fluxes against surface and satellite observations taken at the Atmospheric Radiation Measurement (ARM) Program Southern Great Plains (SGP) site. The sensitivity of model radiative fluxes to the cloud and cumulus convection parameterizations is then analyzed.

2. MODEL DESCRIPTION

The SCM is a diagnostic model resembling a single vertical column of a 3-dimensional general circulation model (GCM).The SCM contains a full set of parameterizations of subgrid physical processes that are normally found in a modern GCM and is applied at a specific site having a horizontal extent typical of a GCM grid cell. Since the model is one-dimensional, the advective terms in the budget equations must be specified from observations or operational numerical weather prediction analyses. For a more complete discussion of SCMs, the reader is referred to Randall et al. (1996).

The configuration of the single column model used in this study has 53 vertical layers and a timestep of 7.5 minutes. A diurnally varying solar signal dependent on the latitude and time of year is applied at the top of the model atmosphere. The SCM is modular in design allowing for easy switching between alternative parameterizations. The control version of the SCM contains the longwave radiation parameterization of Morcrette (1990) and the solar radiation parameterization of Fouquart and Bonnel (1980). Cloud water and cloud amount are calculated using the formulation of Tiedtke (1993). This cloud scheme introduces two new prognostic equations for cloud liquid water/ice and cloud amount. Terms representing the formation of clouds and cloud water/ice due to convection, boundary layer turbulence and stratiform condensation processes are included in these equations. Cloud water/ice is removed through evaporation and conversion of cloud droplets and ice to precipitation. The visible cloud optical depth is calculated using the parameterizations of Slingo (1989) for water clouds and Ebert and Curry (1992) for ice clouds. The effective cloud droplet radius (R_e) is computed using the parameterizations of Bower et al (1994) for liquid water clouds and Wyser (1998) for ice clouds.

The SCM employs the cumulus convection parameterization of Zhang and McFarlane (1995) and the scheme of Hack (1994) for shallow convection. This is the same cumulus convection parameterization package contained in the NCAR community climate model (CCM3). In this study, the land surface temperature and surface heat fluxes are specified from observations.

The SCM is operated in a 'relaxation mode' in which the temperature and humidity profiles are relaxed to the observed profiles using a specified time constant,

$$\tau_a = D \big/ 2\sqrt{u^2 + v^2}$$

where D is the distance across the SCM domain (370 km), and u and v are the horizontal wind components. Use of this relaxation helps to insure that model errors in the temperature and humidity profiles remain small without seriously distorting the atmospheric profiles. The magnitudes of the correction terms are usually small compared to other budget components. Further, results from SCM runs which used no relaxation correction have shown that the conclusions derived from the SCM results with relaxation are not dependent on the inclusion on the correction terms.

3. MODEL EXPERIMENTS

Numerical experiments were performed by applying the SCM in the atmospheric column directly over the ARM SGP site. The SCM was forced with horizontal advection tendencies and vertical velocities calculated using the constrained

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variational scheme of Zhang and Lin (1997). This forcing data was derived from measurements gathered by radiosondes and wind profilers at the ARM SGP site during the four week period Intensive Observing Period (IOP) in the Summer of 1997. We have assumed maximum overlap of clouds due to the strongly convective atmospheric environment at the ARM SGP site during summer.

3.1 *Control Run*

The time series of model produced cloud fraction, downwelling surface shortwave radiation (SW↓), downwelling surface longwave radiation (LW↓), outgoing longwave radiation (OLR), precipitation and cloud water path from the SCM control run (solid lines) are shown together with observed values (dashed lines) in Figure 1.

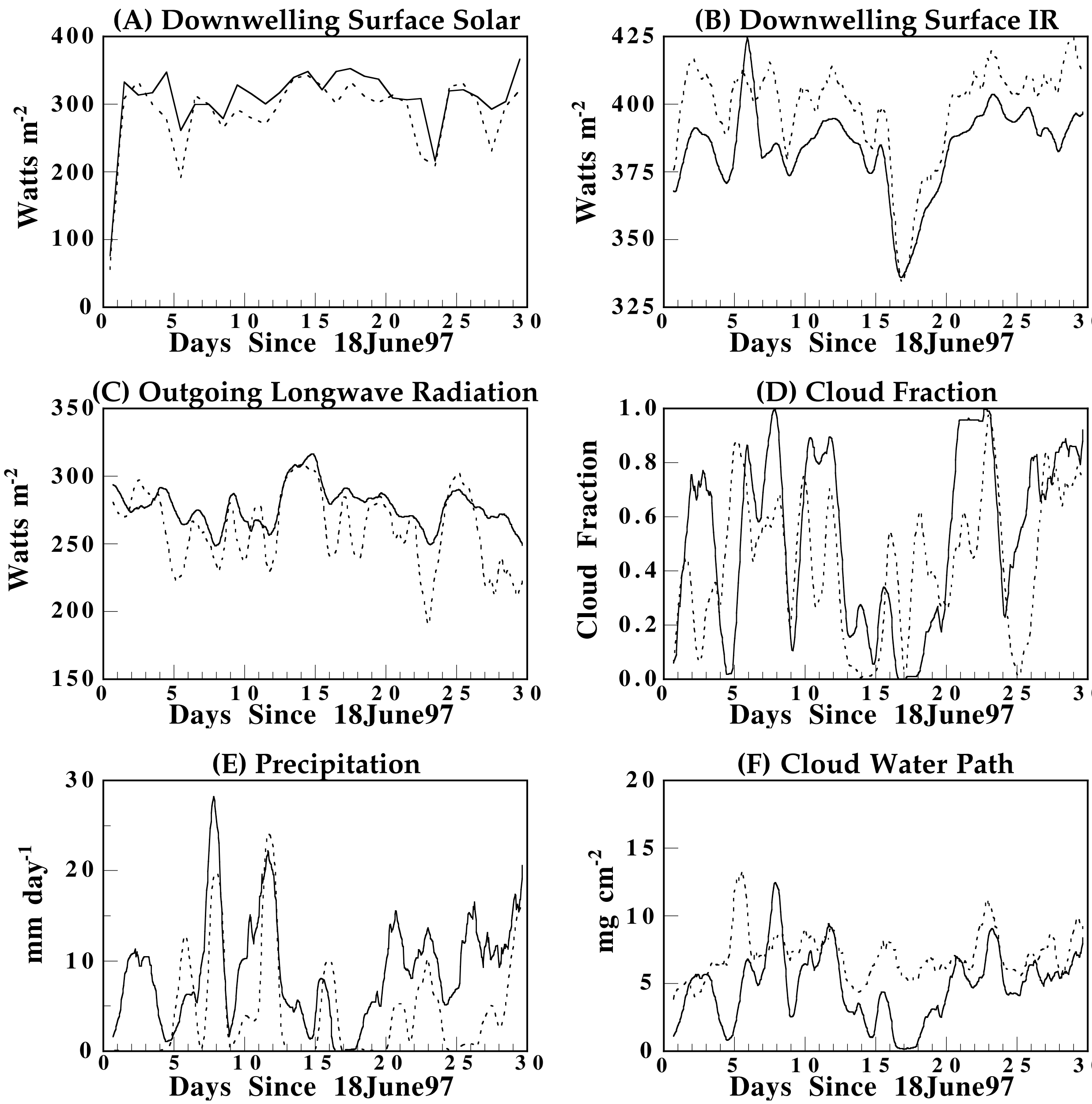

Figure 1. Time series of a) downwelling surface shortwave flux; b) downwelling surface longwave flux; c) outgoing longwave radiation; d) cloud fraction; e) precipitation; and f) cloud water path. Solid lines are model values and dashed lines are from observations at the ARM SGP site.

Overall, the model values compare reasonably well with most of the observations. The SCM appears to simulate most of the significant temporal variations in the observed data, however, there are some systematic differences worth noting. First, the mean LW↓ produced by the SCM is lower than the observations by 10-20 W m^{-2}. Other differences are that the mean model OLR and SW↓ are higher than observed by approximately 15 W m^{-2} and 10 W m^{-2} respectively.

These differences between the SCM and observed radiative fluxes are probably due to a combination of model errors in the cloud amount, the vertical distribution of clouds and/or the cloud optical properties. Since the modeled total cloud fraction also appears to be higher than observed (Figure 1d) and since a lower cloud fraction would further decrease the LW and increase the SW and OLR, it would appear that errors in the vertical distribution of clouds and/or cloud optical properties are primarily responsible for the errors in the SCM radiative fluxes.

Since the model temperatures are very close to observed due to relaxation and because nearly all low clouds are black in the infrared, the low LW↓ most likely indicate that the SCM is not producing enough low clouds. This suspicion is reinforced when on compares the model produced low clouds (defined as clouds occurring between the surface and 700 mb) to an average of low cloud measurements made by ground observers at 5 locations within the ARM SGP site as shown in Figure 2. Comparison of the model cloud heights to Micropulse Lidar (MPL) cloud base height data from the ARM SGP site (not shown) also indicates that the SCM underestimates the amount of low optically thick clouds.

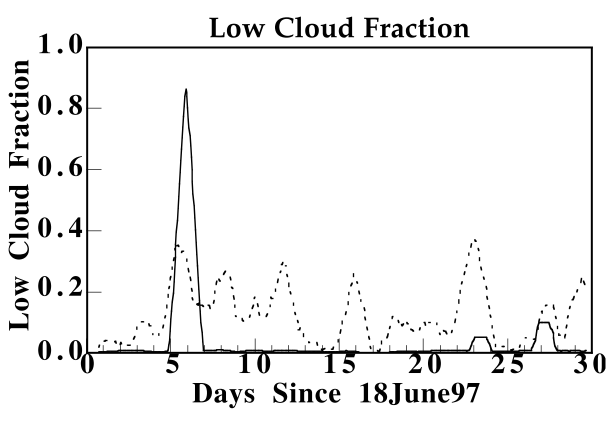

Figure 2. Low cloud fraction (surface to 700 mb) from the SCM (solid line) and from surface observations (dashed line).

In the Tiedtke cloud scheme, clouds arising from convective activity are produced from the detrained cloud water calculated by the cumulus convection scheme. The mean vertical profile of detrained cloud water from the control run is shown in Figure 3. There is very little detrained cloud water below the 600 mb level. In the Zhang-McFarlane convection parameterization, detrainment of cloud water from the cumulus towers is restricted to regions of decreasing cloud mass flux with height. The lack of low clouds in the control run may be due to this restriction.

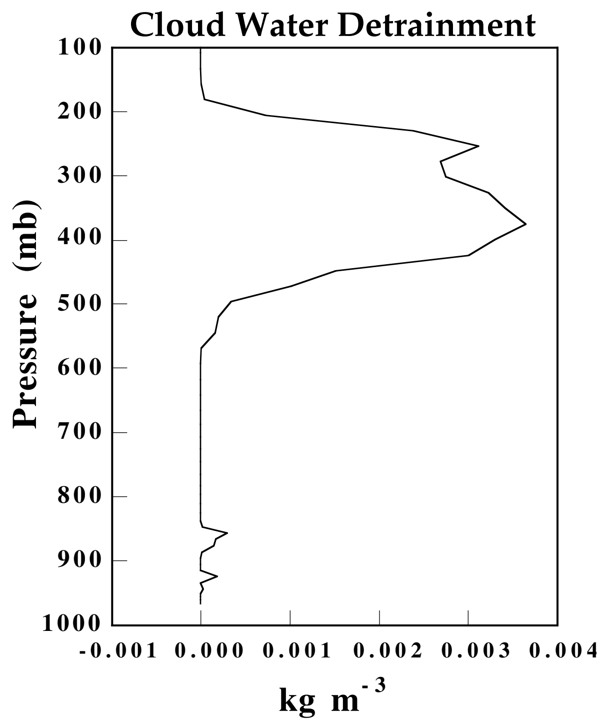

Figure 3. Vertical profile of model calculated cloud water detrainment from the control run.

In our presentation we will show results from several additional model experiments. Some of these experiments employ other convection schemes. The results from these experiments will be used to determine if the lack of low clouds in the SCM is due to the particular convection scheme or due to other missing physics. Results from other model experiments will be used to determine the sensitivity of the model radiative fluxes to changes in the parameterization of the cloud optical properties. Of particular interest is the parameterization of ice cloud microphysics such as the effective particle radius.

4. CONCLUSIONS

• SCM successfully reproduces most of the significant observed temporal variability in several radiative fluxes.

• Some SCM biases in these radiative fluxes appear due to a lack of modeled low clouds.

• The results from additional SCM experiments will be used to determine if this lack of low clouds is due to the particular convection scheme.

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