# Testing Cloud-Radiation Schemes with Single-Column Models and ARM Observations

*R.C.J. Somerville, S. F. Iacobellis, and D. E. Lane*
*Scripps Institution of Oceanography*
*University of California*
*San Diego, California*

## Introduction

Several ongoing sensitivity studies using a single-column model (SCM) and Atmospheric Radiation Measurement (ARM) observations are briefly described. These studies investigate the sensitivity of model results to 1) various interactive cloud droplet radius parameterizations, 2) the vertical resolution, and 3) various shortwave and longwave radiation parameterizations.

Our SCM results indicate

- an interactive cloud droplet radius decreases the cloud optical thickness and cloud infrared emittance of high clouds, which acts to increase both the downwelling surface shortwave flux and outgoing longwave flux.

- cloud-radiation parameterizations are strongly sensitive to vertical resolution in our SCM.

- surface and top-of-atmosphere (TOA) mean radiative fluxes may vary up to 10 W $m^{-2}$ depending on radiation parameterization.

## Model

The SCM is a diagnostic model resembling a single vertical column of a three-dimensional general circulation model (GCM). The one-dimensional SCM is forced with horizontal advection terms derived from either observations or numerical weather prediction analyses. In this paper the horizontal advective terms were derived from observations taken during the Summer 1995, the Spring 1996, and the Summer 1997 Intensive Observation Periods (IOPs) at the ARM Southern Great Plains (SGP) site.

### SCM Control Version

Shortwave Radiation: Fouquart and Bonnel (1980)
Longwave Radiation: Morcrette (1990)
Cumulus Convection: Zhang and McFarlane (1993)
Prognostic Clouds and Cloud Water: Tiedtke (1993)

Shortwave Cloud Optical Properties, f(CWP, $R_{eff}$):
Liquid water clouds: Slingo (1989)
Ice water clouds: Ebert and Curry (1992)
Effective Cloud Droplet Radius ($R_{eff}$):
Liquid water clouds: Bower et al. (1994)
Ice water clouds: Wyser (1998)

## Sensitivity to Cloud Microphysics

Model realizations were performed using six different schemes to parameterize the effective cloud droplet radius ($R_{eff}$). These schemes are summarized in Table 1. Note that the run using the parameterization denoted by IRE=5 is the control run. In each of these six runs, the SCM was forced with advective tendencies from the Summer 1995 IOP. Model profiles of temperature and humidity were relaxed to observed values using a time constant of 24 hours.

**Table 1**. Various parameterizations of effective cloud droplet radius used by the SCM. LWC = liquid water content; IWC = ice water content; T = temperature.

| | **Water Clouds** | **Ice Clouds** |
|---|---|---|
| IRE=0 | $R_{eff}$=10μm (constant) | $R_{eff}$=10μm (constant) |
| IRE=1 | $R_{eff}$=f(LWC) Bower et al. (1994) | $R_{eff}$=10μm (constant) |
| IRE=2 | $R_{eff}$=f(LWC) Bower et al. (1994) | $R_{eff}$=f(T) Suzuki et al. (1993) |
| IRE=3 | $R_{eff}$=f(LWC) Bower et al. (1994) | $R_{eff}$=f(IWC) McFarlane et al. (1992) |
| IRE=4 | $R_{eff}$=f(LWC) Bower et al. (1994) | $R_{eff}$=f(T) Ou and Liou (1995) |
| IRE=5 | $R_{eff}$=f(LWC) Bower et al. (1994) | $R_{eff}$=f(T,IWC) Wyser (1998) |

The different parameterizations result in a wide range of mean $R_{eff}$ between 600 mb and 100 mb as shown in Figure 1a. The different values $R_{eff}$ result in very little difference in the mean model cloud fraction or cloud water content, while there are significant variations in the model calculated cloud optical properties (Figures 1b and 1c). The mean values of outgoing longwave radiation (OLR) and downwelling surface shortwave flux are shown in Figures 1d and 1e, respectively, for each value of IRE. The different parameterizations of the $R_{eff}$ result in variations in the model OLR of up to 20 W $m^{-2}$ and variations in the downwelling shortwave flux of up to 30 W $m^{-2}$. Additionally, there are differences in both the solar and longwave radiative heating rates of up to 0.3 °C $day^{-1}$ (not shown).

## Vertical Resolution Experiments

In general, GCMs resolve the atmosphere with 19 or fewer layers. We examine the importance of vertical resolution by testing 12 different resolutions with our SCM. The model layers are equally spaced in pressure, with 16 layers in the lowest resolution model and 60 layers in the highest. We simulate three time periods using forcing terms calculated from observations made at the ARM Cloud and Radiation Testbed (CART) site. Cloud-radiation variables are examined for the Spring 1996 IOP (Figure 2) and compared to observations from the Oklahoma Mesonet and Goestationary Operational

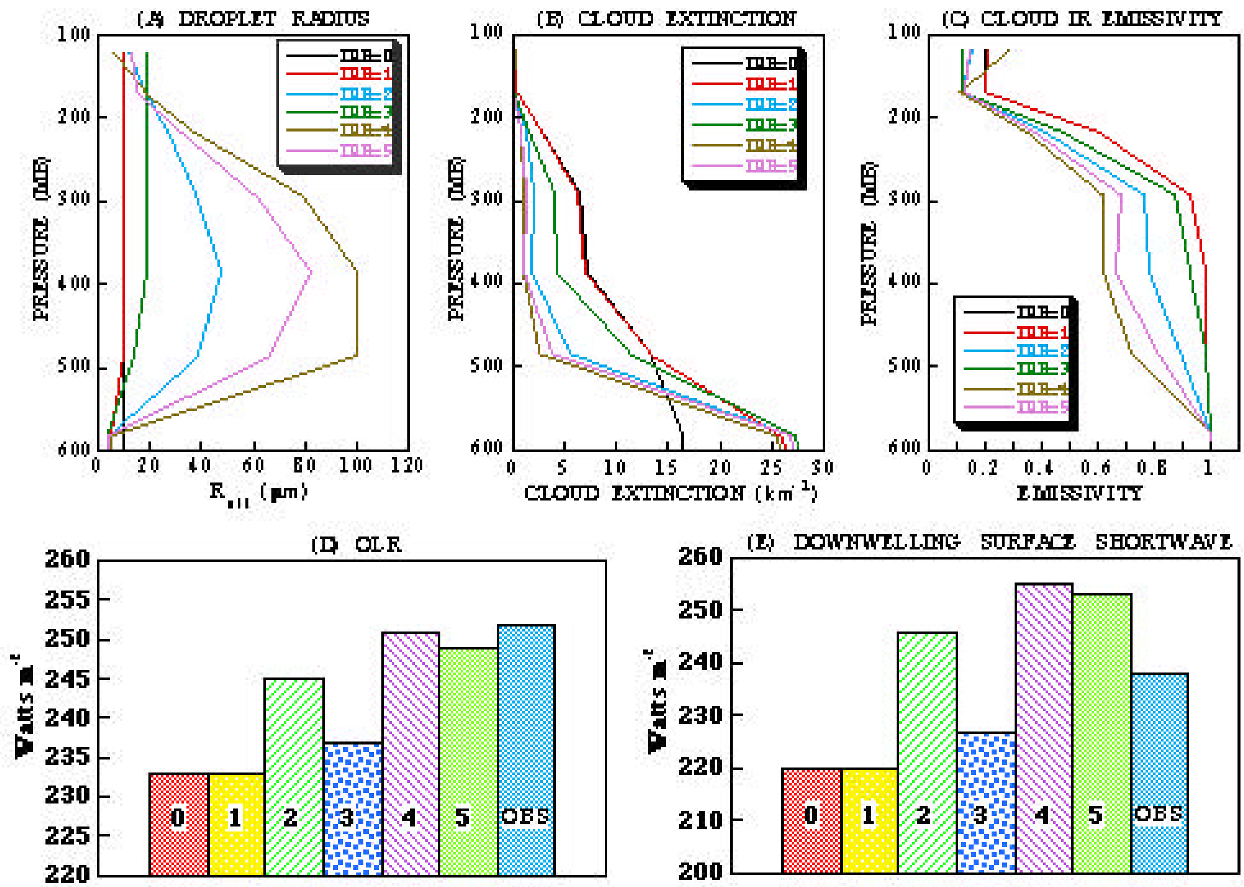


**Figure 1**. SCM cloud droplet radius sensitivity results. Time-averaged model results of a) effective cloud droplet radius, b) cloud extinction, c) cloud infrared (IR) emissivity, d) OLR, and e) downwelling surface shortwave flux are shown for the six model runs utilizing different parameterizations of cloud droplet radius.

Environmental Satellite (GOES)-8 data products. We investigate how variations in scale alter the realism of the model representation of cloud processes. We also study the influence of these changes on parameterizations of convection.

Figure 2a shows the average cloud fraction for the Spring 1996 IOP. The bars indicate the total cloud fraction, with the light blue demonstrating the cloud fraction due to convection. As resolution increases from 16 to 60 layers, the total amount of cloud increases slightly, but the convective cloud amount increases dramatically. Figure 2b indicates that there is a corresponding decrease in outgoing longwave radiation with increasing vertical resolution. This occurs because the increase in convective cloud is occurring fairly high in the atmosphere. Figure 2c illustrates the average profile of cloud amount per layer for each resolution when there is cloud present. It is apparent that the maximum in cloud amount shifts to a higher pressure-altitude in the atmosphere as resolution increases, accompanied by a small increase in low level cloud as well. There is no indication that the results are converging with finer resolution.

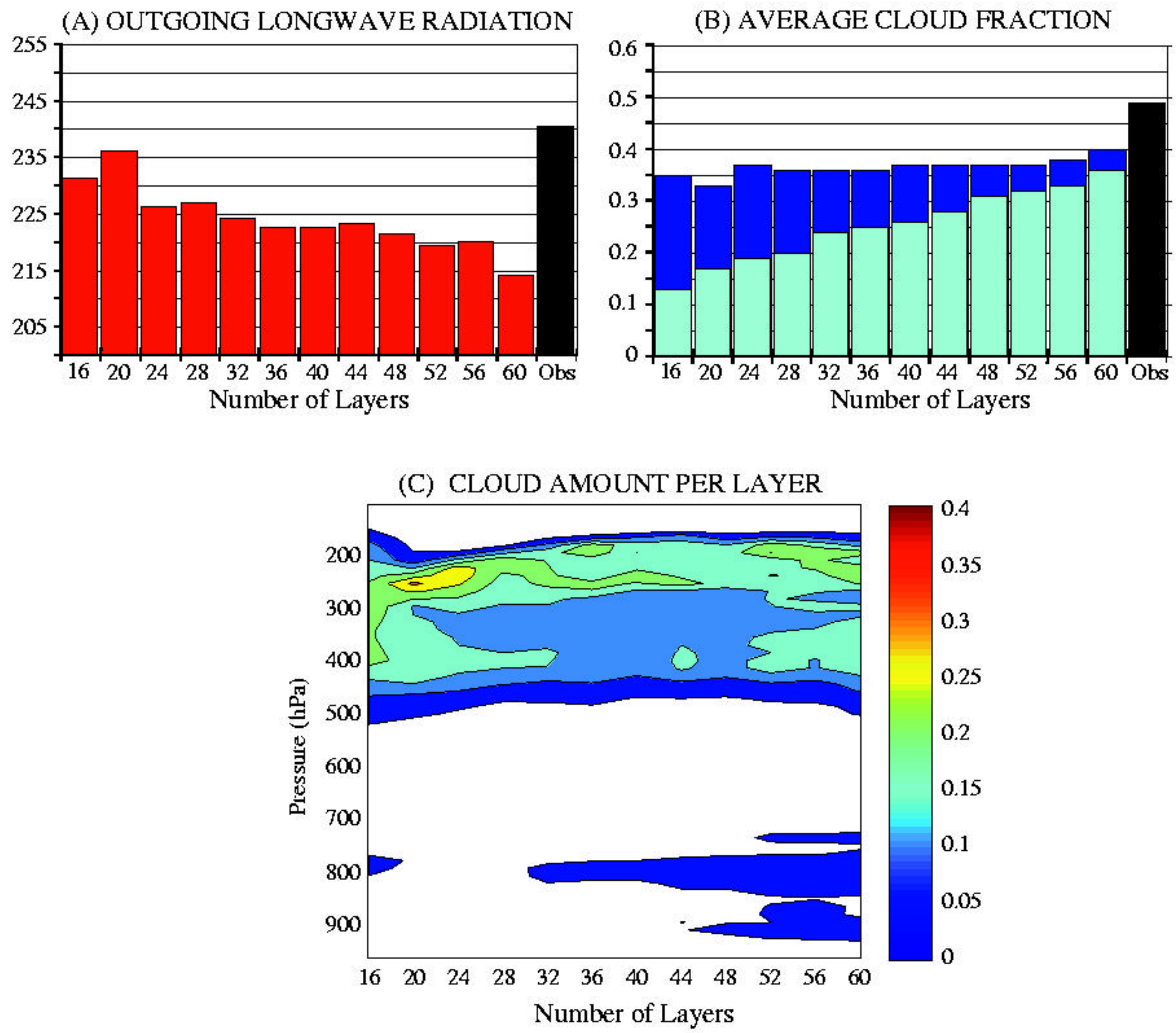


**Figure 2**. Results from the 12 model simulations of the Spring 1996 IOP. The time-averaged a) OLR (W m$^{-2}$), b) cloud fraction (fraction), and c) the cloud amount per layer when cloud is present (fraction).

## Radiation Parameterizations

The control version of the SCM utilizes the shortwave parameterization of Fouquart and Bonnel (1980) and the longwave parameterization of Morcrette (1990) (M90). Additional SCM runs were performed using the longwave parameterization of Mlawer et al. (1997) (rapid radiative transfer model [RRTM]) and with the gamma-weighted two-stream approximation (GWTSA) of Oreopoulos and Barker (1999) applied to the shortwave parameterization. SCM runs were performed using ARM forcing data from the Summer 1995 and Summer 1997 IOPs.

For both time periods tested, the mean OLR produced using the RRTM parameterization is reduced (11 W $m^{-2}$ to 17 W $m^{-2}$) compared to that obtained with M90 of the control version. The downwelling surface longwave flux obtained from the RRTM scheme is higher (6 W $m^{-2}$ to 8 W $m^{-2}$) than that found with M90. Analysis has shown that these flux differences are not due to changes in model cloud fraction. The difference in the IR heating rate profile (RRTM –M90) from these runs are shown in Figures 3a and 3b for both clear-sky and all-sky conditions. Most of the difference between the RRTM and M90 profiles does not appear to be due the presence of clouds.

The incorporation of the GWTSA into the FQ shortwave parameterization produces an increase in the downwelling shortwave flux (4 W $m^{-2}$ to 7 W $m^{-2}$) and a corresponding decrease in the shortwave cloud forcing. Figures 3c and 3d illustrate that significant differences in the shortwave heating rate arise when the GWTSA is incorporated and are primarily related to the model cloud fraction maximum located near 300 mb (not shown). For both time periods tested, the shortwave heating rates decrease above 250 mb and increase below 250 mb due to the inclusion of the GWTSA. This “crossover” appears to be due to the changing cloud optical thicknesses, which become quite small (< 2.0) above 250 mb.

# Conclusions

## Microphysics

- Alternative schemes produce a wide range of effective radius, especially for ice particles.
- Cloud radiative properties are sensitive to microphysics (20 W $m^{-2}$ OLR; 30 W $m^{-2}$ solar).
- In situ data need to resolve this issue.

## Vertical Resolution

- Cloud-radiation effects are sensitive to vertical resolution (20 W $m^{-2}$ OLR; 10 W $m^{-2}$ solar).
- Convergence is not found, even at 60 layers.
- Layer spacing is critical at coarse resolution.

## Radiation Parameterization

- Radiative fluxes are sensitive to the inclusion of the RRTM longwave radiation scheme and the GWTSA (5 W $m^{-2}$ to 5 W $m^{-2}$ OLR; 5 W $m^{-2}$ to 8 W $m^{-2}$ solar).
- Differences appear during both clear-sky and cloudy-sky conditions.

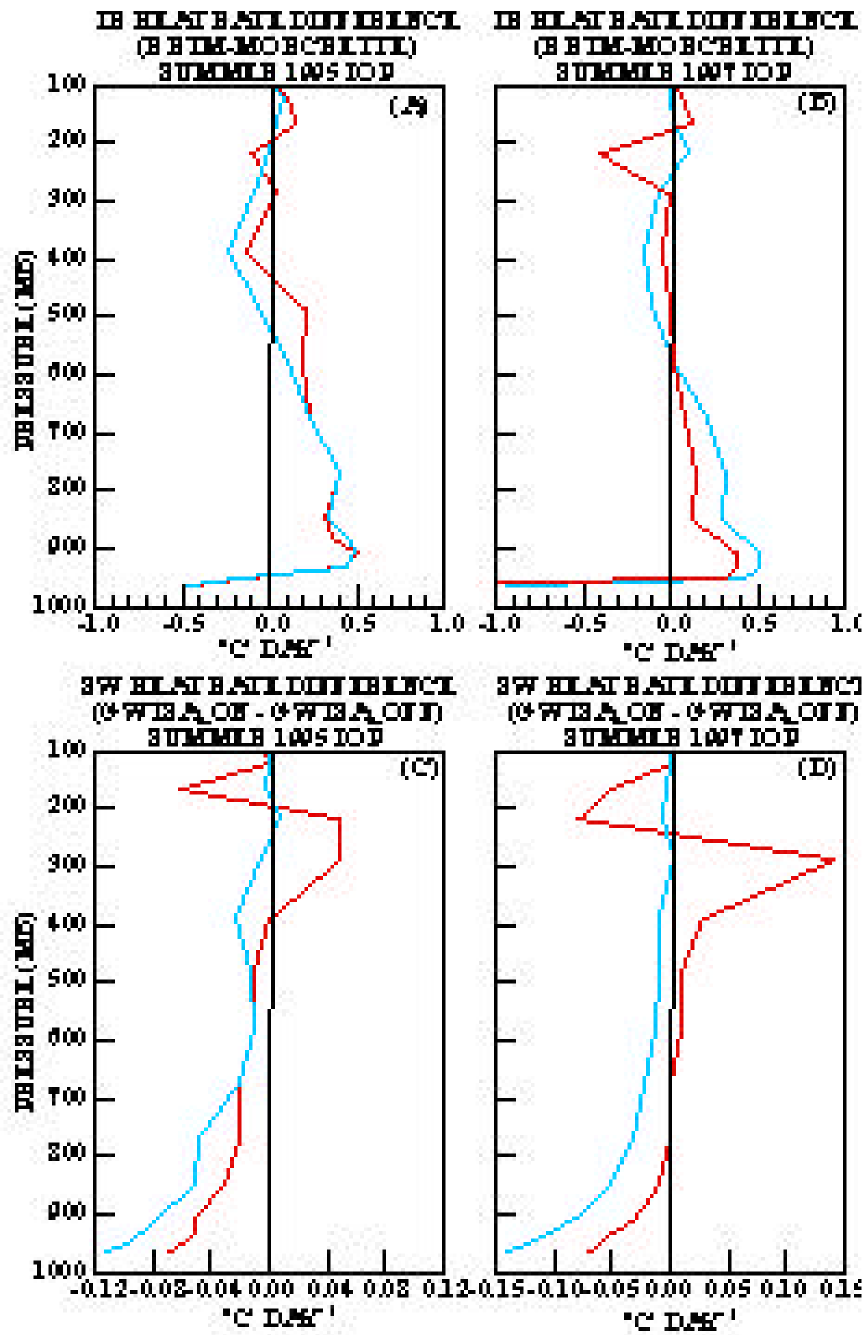


**Figure 3**. Time-averaged model produced vertical profiles from the SCM radiation parameterization sensitivity experiments. Clear-sky heating rates are shown by the blue curves, while the red curves denote all-sky conditions.

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