Single-Column Model Sensitivity to Changes in Horizontal and Vertical Resolution

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Introduction

We examine the importance of vertical and horizontal resolution to parameterization of subgrid scale physical processes. We have developed a one-dimensional, diagnostic model of the atmospheric column overlying a region the size of a single general circulation model (GCM) grid cell. The model is similar in concept to the one described by Iacobellis and Somerville (1991a,b). The most recent version of the model contains simulations of physical processes typical of contemporary GCMs. These algorithms are representations of processes that occur on smaller scales than the horizontal extent of the column. Using the single-column model (SCM), we investigate how variations in scale alter the realism of the model representation of clouds. In addition, we study changes in resolution and the consequent influence on parameterizations of convection.

Model Description

The SCM is a stand-alone model that can be pictured as a single vertical array of gridpoint cells taken from a GCM and placed at a specific geographical location. The model atmosphere is divided into multiple layers in which the vertical fluxes of heat and moisture are calculated. Because of the computational efficiency of the model and the ability to isolate a column of atmosphere for study, the SCM is an ideal environment in which to develop and test parameterizations (Randall et al. 1996). A list of the parameterizations used for these simulations can be found in Table 1. The SCM has been used to validate GCM tests of several different cloud-radiation schemes with observational data (Lee et al. 1997).

Table 1. Model parameterizations.

Parameterization:	Source:
longwave radiation	Morcrette (1990)
shortwave radiation	Fouquart and Bonnel (1980)
cloud radiative properties	Slingo (1989)
convection	Zhang and McFarlane (1995)
cloud prediction	Tiedtke (1993)

The necessary initial values and advection terms are provided from data taken at the Atmospheric Radiation Measurement (ARM) Program's Southern Great Plains (SGP) site. For these trials, observational soundings from the perimeter of the ARM SGP site are used for the standard 2.5° x 2.5° grid spacing. For horizontal scales greater and smaller than this resolution, the horizontal flux data will be calculated from Rapid Update Cycle (RUC) model data. The output of the SCM is the complete heat and moisture budgets for the study site, in our case the atmospheric column above the SGP site. We validate these model products against observational data from the ARM Program. Preliminary results suggest that the model physical parameterizations are somewhat sensitive to the vertical resolution of the forcing data (Iacobellis et al. 1998).

The RUC is a high-frequency data assimilation and analysis/ forecast system provided by the National Centers for Environmental Prediction (NCEP). The RUC analysis that is provided to the ARM Program uses a hybrid isentropic-sigma vertical coordinate as described by Bleck and Benjamin (1993). The model uses a Northern Hemisphere polar stereographic grid with approximately one gridpoint every 60 km at 40°N. Nearly all of the atmosphere is resolved using constant potential temperature surfaces coordinate, except for a layer near the ground where terrain-following coordinates are used. Data are saved once every 3 hours as isobaric variables. There are 37 pressure levels in the model ranging from 1000-100 hPa.

Vertical Resolution Experiments and Results

For the vertical resolution experiments, the SCM was applied over the ARM SGP region during the Summer 1995 SCM Intensive Observation Period (IOP). Standard vertical resolution for the Scripps SCM is 19 layers. A total of 33% of the levels fall below 850 hPa and 67% are above. The advective terms used to force the model are derived from data obtained by wind profilers and balloon sonde sites located along the perimeter of the ARM SGP site. The vertical resolution was increased from the standard 19 layers to 53 layers while maintaining the ratio of layers within and above the boundary layer (Figure 1). The same forcing data set, with a resolution of 10 hPa, is used for all model resolutions, from 19 layers to 53 layers. The SCM interpolates linearly between the observations.

Outgoing longwave radiation (OLR), downwelling solar radiation, cloud fraction and total precipitation modeled by the four different vertical resolutions of the SCM were time-averaged for the entire IOP and compared to ARM observations averaged over the same period (Figure 2). Observational values of OLR and cloud fraction were taken from Pat Minnis' Geostationary Operational Environmental Satellite (GOES)-8 satellite products, while measurements from the Oklahoma Mesonet were used to specify the observed precipitation and downwelling solar radiation. In general, the OLR increases with increasing vertical resolution, while downwelling solar radiation increases between the 19 and 26 layer models but then changes relatively little as vertical resolution increases. There are nominal differences between the two intermediate resolutions. However, all model values are too high when compared with observations. Note that there is a minimum value in both total precipitation and cloud fraction for the 26-layer model. However, the modeled precipitation value is higher than the observational value, and the total cloud fraction is lower. There is little difference between the models in heating rate (Figure 3); the only significant difference is in the convective heating rate where there is a 1° to 2° per day difference between the 19 layer model and the 53 layer model at 650 mb. It is likely that the different profiles of convective heating are responsible for the changes in the time-averaged quantities in Figure 2.

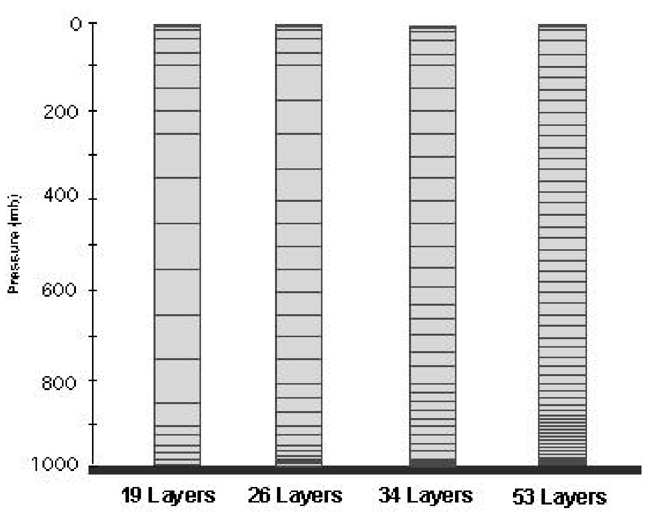

Figure 1. Description of the vertical resolution experiment.

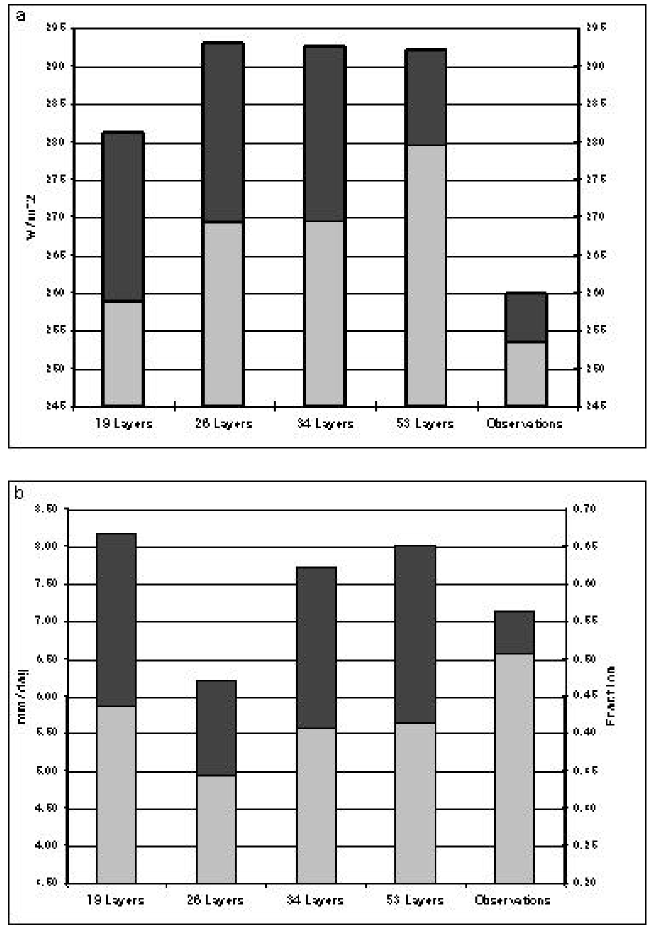

Figure 2. a) Vertical resolution experiment: downwelling shortwave radiation (dark grey) and outgoing longwave radiation (light grey) at the surface. b) total precipitation (dark grey) and total cloud fraction (light grey).

Horizontal Resolution Experiments and Results

The Summer 1995 IOP was also used to test the sensitivity to changes in horizontal resolution. The RUC mesoscale model provided initial data and advection terms were calculated for scales larger and smaller than the standard (Figure 4). For this experiment the three horizontal extents studied are 1.1°, 3.3°, and 5.5° on a side, with the intermediate size approximating the extent of the SGP site.

There is not a significant difference between the model with the intermediate horizontal extent and that with the largest extent. When making the same comparisons as above with observational values of OLR, downwelling solar radiation, total precipitation and cloud fraction, only a change in cloud

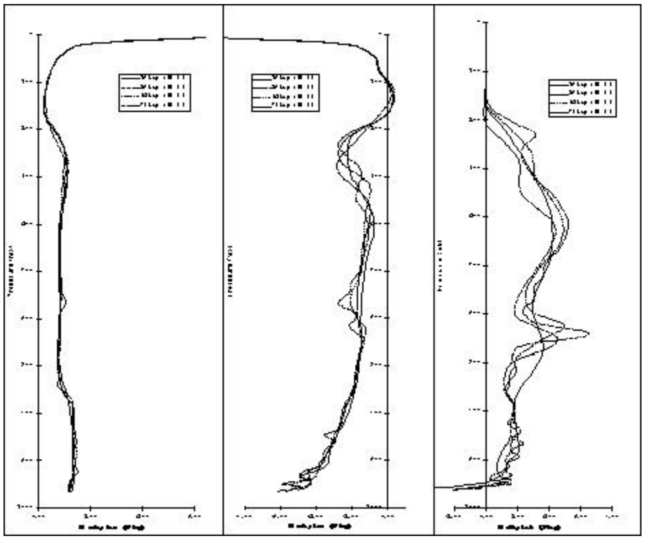

Figure 3. Vertical resolution experiment: a) shortwave heating rate, b) longwave heating rate, and c) convective heating rate.

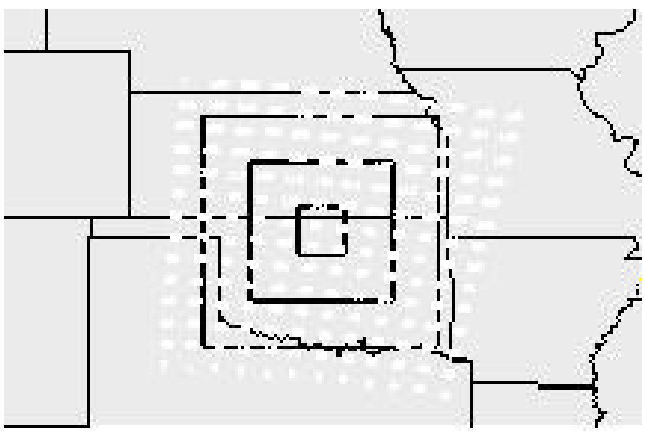

Figure 4. Description of the horizontal resolution experiment.

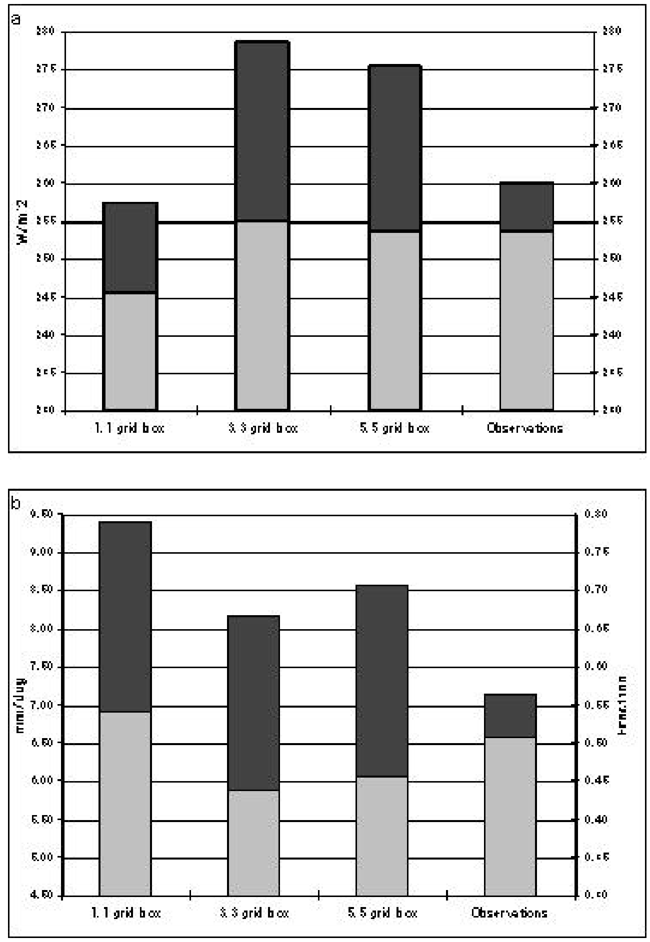

Figure 5. a) Horizontal resolution experiment: downwelling solar radiation (dark grey) and outgoing longwave radiation (light grey) at the surface. b) total precipitation (dark grey) and total cloud fraction (light grey).

fraction is perceptible (Figure 5). It is easily seen that the simulation with the smallest increment is markedly different from the other two. Both the downwelling solar radiation and OLR are noticeably lower than the other simulations with a corresponding increase in cloud fraction. This difference can also be seen in the longwave and convective heating rates in Figure 6.

Conclusions

The SCM demonstrates little sensitivity to changes in vertical resolution. The most significant differences may be related to calculations of convection. The physical parameterizations are realistic for grid boxes larger than 2.5°. However, caution should be exercised when using these algorithms for smaller horizontal extents. Overall, the SCM proves to be a very robust tool for testing parameterizations utilized in modern GCMs. The relative insensitivity of the SCM results to changes in vertical and horizontal resolution indicates that the SCM is a reliable testing ground for algorithms used in GCMs of varying resolutions.

Further study is needed to determine whether the SCM maintains the demonstrated robustness for other seasons and with alternate resolutions. Prospective work includes analyzing additional IOPs, increasing the number of vertical layers, and verifying the results of the horizontal tests with the use of another model, such as the European Centre for Medium-Range Weather Forecasting (ECMWF) GCM, to provide the advection terms.

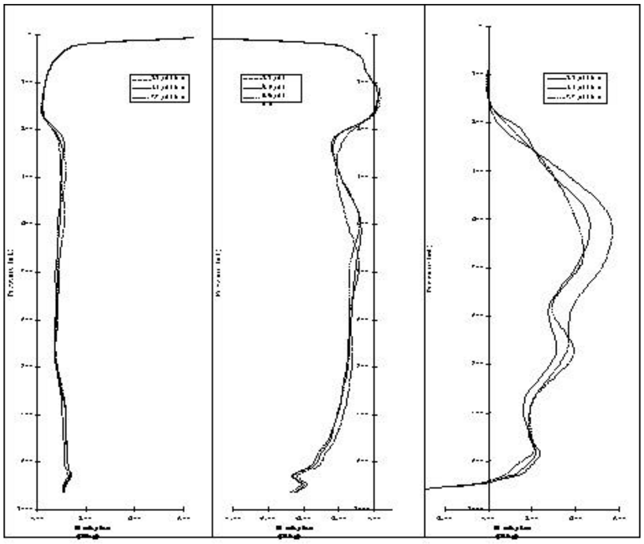

Figure 6. Horizontal resolution experiment: a) shortwave heating rate, b) longwave heating rate and c) convective heating rate.

Acknowledgments

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