A Comparison of Three Different Modeling Strategies for Evaluating Cloud and Radiation Parameterizations

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Introduction

The Atmospheric Radiation Measurement (ARM) Program is collecting measurements useful for evaluating cloud parameterizations in regional and global circulation models (GCMs). However, the most widely used testbed for evaluating cloud parameterizations in the ARM Program is the single-column model (SCM), which is essentially a single-column version of a GCM, driven by observed lateral boundary conditions. Unfortunately, the measurements necessary to drive an SCM are difficult to obtain with adequate accuracy. We are therefore exploring the use of alternate cloud parameterization testbeds, namely regional and GCMs that assimilate observed winds throughout their model domains. We evaluate the cloud parameterization in the GCM because that is the model the cloud parameterization is ultimately designed for. We evaluate the cloud parameterization in the regional circulation model (RCM) to demonstrate that, given the same treatment of model physics, the regional model can be used as a faster testbed for the cloud parameterization.

Approach

We have applied simple nudging of winds and temperature to the Pacific Northwest National Laboratory (PNNL) versions of both the National Center for Atmospheric Research (NCAR)/The Pennsylvania State University Mesoscale Model (MM5) and the NCAR Community Climate Model (CCM2), the RCM and GCM, respectively. Note that we do not nudge humidity because that would compromise the independent evaluation of the simulated moisture balance. Both models have been run with the same model physics, namely the Colorado State University (CSU) Regional Atmospheric Modeling System (RAMS) cloud microphysics parameterization (Ghan and Easter 1992; Ghan et al. 1997), the CCM2 treatment of cumulus parameterization (Hack 1994), the CCM2 radiation parameterization (Kiehl et al. 1994), the Holtslag and Boville (1993) non-local mixing scheme, and the Biosphere-Atmosphere Transfer Scheme Version 1e (BATS1E) land surface transfer scheme (Dickinson et al. 1993). The RCM and GCM are run at approximately the same horizontal (300 km and T42, respectively) and vertical resolution, but it must be recognized that the two models are quite different in their numerical representation of large-scale dynamics and moisture transport.

We also have run an SCM for the same period, namely October 24 - November 13, 1994. The SCM is essentially a single column of the GCM, but with vertical velocity and lateral boundary conditions prescribed rather than interacting with adjacent columns. The same code is used in both the SCM and GCM, except for the prediction of winds (which are prescribed from observations in the SCM), the treatments of horizontal advection (which is prescribed from observations in the SCM), and horizontal diffusion (which is neglected in the SCM). The large-scale forcing for the SCM is from Zhang and Lin's (1997) variational analysis of Cloud and Radiation Testbed (CART) observations rather than from the European Center for Medium-range Weather Forecasting (ECMWF) analysis used to drive the RCM and GCM. To treat the feedback of the simulated temperature and water vapor on the horizontal advection of those fields, nudging of temperature and water vapor toward the observed fields is applied, using the advective time scale for the nudging coefficient. The advective time scale is based on the observed wind speed and an assumed grid scale of 300 km.

Results

Figure 1 compares the simulated and observed daily mean column water vapor, column liquid water, column cloud ice, precipitation, outgoing solar radiation, outgoing longwave radiation, surface downward solar radiation, and surface

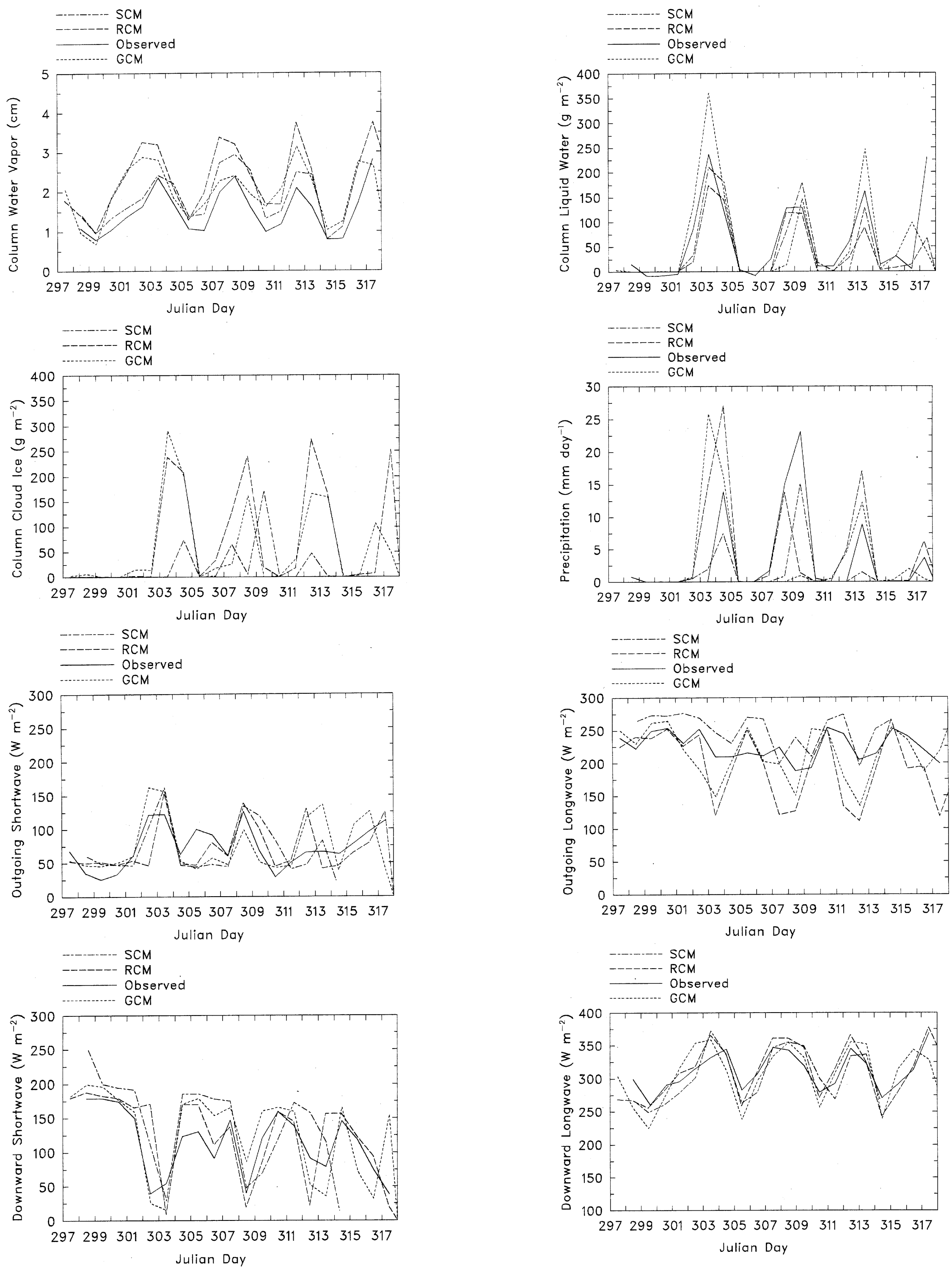

Figure 1. Daily mean column water vapor, column liquid water, column cloud ice, precipitation, outgoing solar radiation, outgoing longwave radiation, surface downward solar radiation, and surface downward longwave radiation observed at the ARM Southern Great Plains (SGP) site (solid line) and simulated by the SCM (dash-dot line), the GCM (short dash line), and by the RCM (long dash line) at the ARM SGP site, for the period October 25 – November 14, 1994.

downward longwave radiation at the SGP site during the 21-day Fall 1994 Intensive Observation Period (IOP). Column water vapor and liquid water measurements are from the microwave radiometer (MWR) at the central and two boundary facilities. Column ice measurements are not available. Observed precipitation is from the network of Oklahoma and Kansas mesonet stations. Outgoing longwave and solar radiation are from the Minnis et al. (1995) analysis of Geostationary Operational Environmental Satellite (GOES-7) measurements. Downward solar and longwave radiation at the surface are from the network of Solar and Infrared Radiation Observing System (SIROS) broadband instruments at the central and extended CART facilities. All three models simulate the timing of the day-to-day variability of the column water vapor fairly well, but the simulated column water vapor is consistently higher than observed. No simulation of column water vapor is consistently closer to that observed than the other simulations. Each model simulates the column liquid water well at some times and not at other times. However, all three models reproduce the timing of the cloud events fairly well. The agreement between the cloud ice simulated by the RCM and GCM, is generally much better than the agreement between the SCM ice and the other simulations.

Consistent with the cloud simulation, all three models simulate the timing of the precipitation quite well. However, the three models yield quite different precipitation amounts. The lower precipitation rate simulated by the SCM in the first and third cloud systems is related to the lower cloud ice simulated by the SCM. The precipitation simulated by the GCM in the second cloud system is weak because the cloud ice is simulated prior to, rather than concurrent with, the cloud water, so that the seeder-feeder mechanism cannot operate.

The models simulate the temporal variability of shortwave and longwave radiation with some skill, but biases are evident. In particular, the outgoing longwave radiation during cloud events is consistently too low in the RCM and GCM simulations.

These results are significant improvements over previous results. Agreement among models is improved due to efforts to ensure common resolution and model physics. Remaining intermodel differences are due to differences in the treatment of moisture transport, differences in the simulation domain, and differences in the large-scale analyses used to drive the models. Differences between simulated and observed fields are due to a combination of errors in observations, assimilation of observations, and in model physics.

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