An Intercomparison of Single-Column Model Simulations of Summertime Midlatitude Continental Convection

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Introduction

The ultimate goal of the Atmospheric Radiation Measurement (ARM) Program is the improvement of parameterizations of clouds and radiation used in climate models. This goal is being achieved through the use of field measurements to evaluate the parameterizations. One common parameterization testbed is the single-column model (SCM), which is essentially an isolated column of a global climate model. In this study, we have brought together a collection of 11 SCMs and one Cloud Ensemble Model (CEM), and subjected each of them to several alternative analyses of the large-scale forcing observed over the ARM Southern Great Plains (SGP) site during the period July 18 to August 3, 1995. Our goals were as follows:

1. To explore the influence of alternative objective analyses on the SCM and CEM simulations.

2. To investigate alternative strategies for using the objective analyses to force our models.

3. To evaluate the performance of our SCMs in comparisons with the observations, with each other, and with the CEM under midlatitude continental conditions.

As the first in a series of planned intercomparisons using ARM data, this investigation has revealed much about the feasibility of such a study, about the sensitivity to analysis method and to the forcing method, about the value of involving multiple and diverse models, about the model performance, and about the models themselves. Here, we briefly present our most interesting results and summarize our key conclusions. A full description of this study can be found in Ghan et al. (1999b).

One of the notable values of testing multiple models at the same time is that it enables the distinction between errors in the simulation due to deficiencies in the model physics and errors due to problems with the data used to drive the simulations. This point is illustrated in Figure 1, which compares the column mean temperature as observed with that simulated by each model. Differences between simulations are due to differences in the physical parameterizations in each model, although sensitive dependence on initial conditions (Hack and Pedretti 1999) could also play a role in dispersing simulations. Closer examination of Figure 1 also reveals common signatures in the errors, particularly on time scales of 1 to 3 days. These common signatures are most likely due to errors in the lateral boundary conditions used to drive the model simulations. Note that simulations by a single model would not allow such a distinction between errors in physics and boundary conditions.

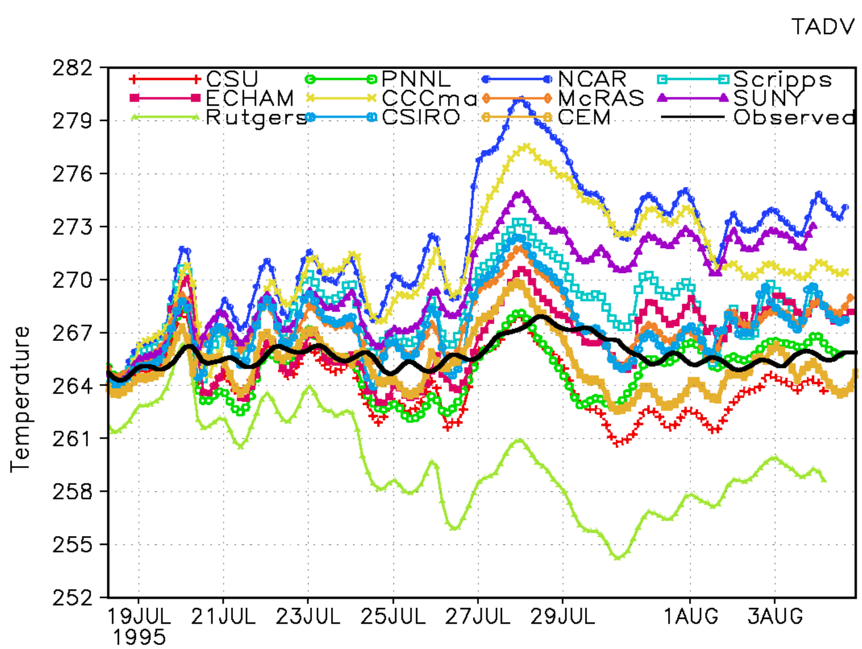

Figure 1. Column (100 hPa to 900 hPa) mean temperature (deg K) as observed and as simulated by each model driven by the State University of New York (SUNY) analysis of the lateral boundary conditions.

To explore the influence of alternative objective analyses on the SCM and CEM simulations, we drove each model with two different objective analyses of the large-scale boundary conditions. One analysis is a modification of the Barnes (1964) objective analysis scheme, which adjusts the winds on the lateral boundaries to ensure mass conservation in the atmospheric column. The second analysis is essentially that of Zhang and Lin (1997), which applies further adjustments to ensure conservation of heat and moisture in the atmospheric column. Figure 2 shows time series of the column water vapor as observed by radiosonde and as simulated by each model driven by each analysis. It is clear from the figure that the simulation of the column water vapor is much more accurate when the models are driven by the Zhang and Lin analysis (SUNY). Similar conclusions apply to many other simulated fields for which there are observations available for evaluation.

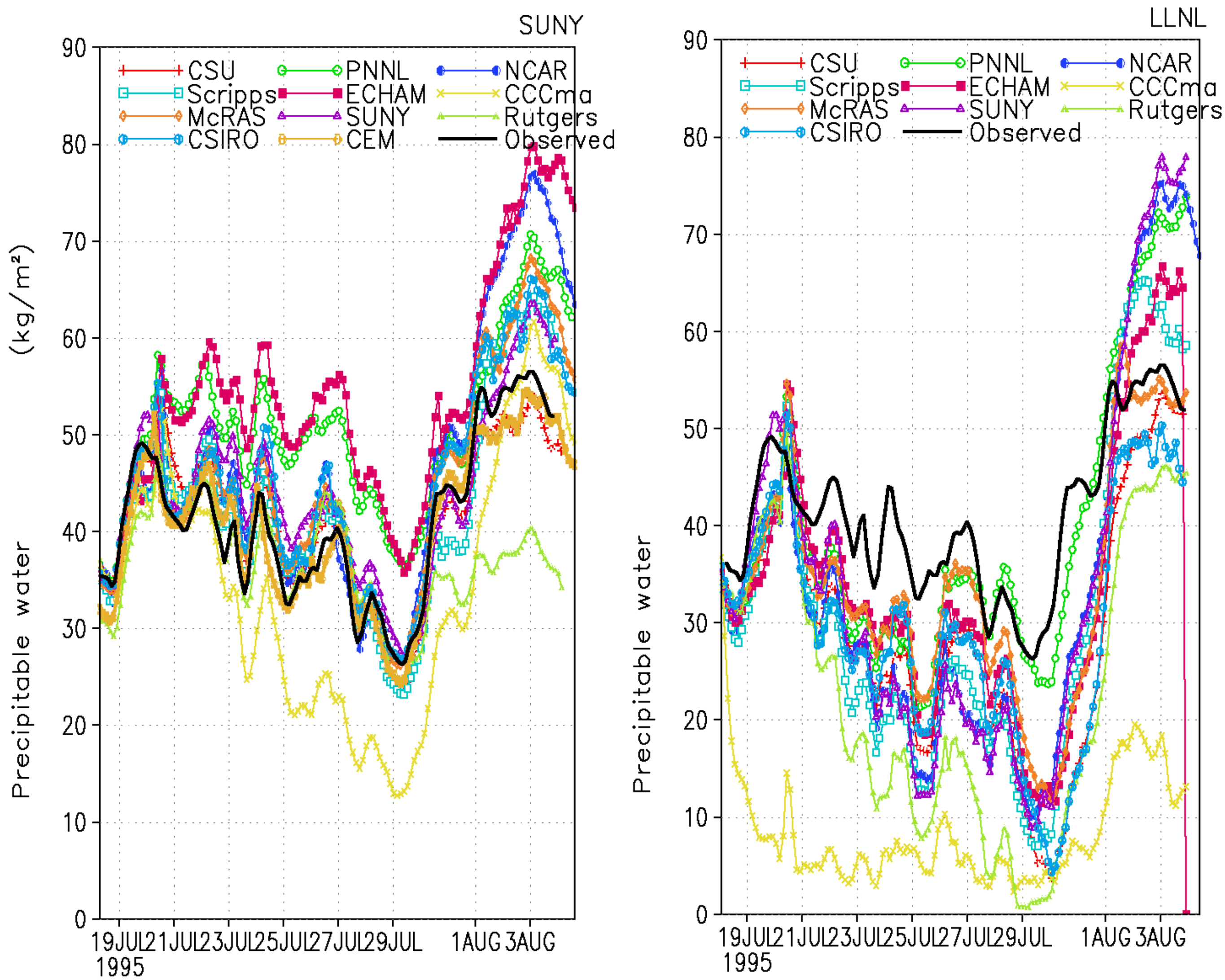

Figure 2. Column total water vapor (also known as precipitable water) (kg/m^2) observed and as simulated by each model driven by the SUNY (left) and Lawrence Livermore National Laboratory (LLNL) (right) analysis of the lateral boundary conditions.

We also investigated the sensitivity of the simulations to two different specifications of the turbulent fluxes of sensible and latent heat at the surface. In one specification, the surface fluxes are derived from Energy Balance Bowen Ratio (EBBR) measurements at some 20 sites in the SGP. In the second specification, the surface fluxes are simulated independently by the Simple Biosphere model using a 6.25 km data set of meteorology measurements, land use data, and soil texture data (Doran et al. 1998). Although these two different specifications of surface fluxes differ considerably, often by a factor of nearly two, the simulations of temperature, humidity, clouds, and radiation by each model are remarkably insensitive to the different lower boundary conditions.

To investigate alternative strategies for using the objective analyses to force our models, we drove each model with two different treatments of vertical advection and two different treatments of horizontal advection. In one treatment of vertical advection, the vertical advective tendencies of temperature and humidity were prescribed from the Zhang and Lin analysis, while in the other treatment the vertical advective tendencies were calculated by each model using the prescribed vertical velocity and simulated profiles of temperature and humidity. Although the sensitivity of the simulations to the treatment of vertical advection were not insignificant for many of the models, the sensitivity was not consistent from model to model (differing in sign). We therefore conclude that vertical advective tendency should be prescribed in all future simulations to ensure that all models are forced by the same vertical advective tendency.

The two treatments of horizontal advection differ in similar respects, with the horizontal advective tendencies of temperature and moisture prescribed from the Zhang and Lin objective analysis in one treatment, but allowed to depend on the simulated temperature and humidity in the second treatment. The dependence on the simulated temperature and humidity is treated by expressing horizontal advection using an upstream scheme. As shown by Ghan et al. (1999a) and Randall and Cripe (1999), this is equivalent to the application of nudging toward the temperature and humidity observed in the column, using the advective time scale for the nudging parameter. Thus, these two treatments of horizontal advection differ only in addition of the nudging term in the budgets of temperature and humidity. As might be expected, the errors in the simulated temperature and humidity are greatly reduced. However, errors in other fields are also substantially reduced. This is illustrated in Figure 3, which shows time series of the outgoing longwave radiation (OLR) as observed and as simulated by each model driven by each treatment of horizontal advection. For most models the OLR errors are significantly smaller when nudging is applied to the simulations.

However, nudging is not so beneficial for other fields, in particular precipitation. Table 1 lists the time mean precipitation simulated by each model with and without nudging. For most models, the precipitation bias is much larger with nudging than without, and the agreement among the models is much worse with nudging than without. This result can be explained in terms of the biases in the temperature and humidity illustrated in Figures 1 and 2. For those models with a warm or dry bias, nudging cools and moistens the atmospheric column, which increases condensation and precipitation. For those models with cool or moist biases, nudging warms and dries the column, which reduces condensation and precipitation.

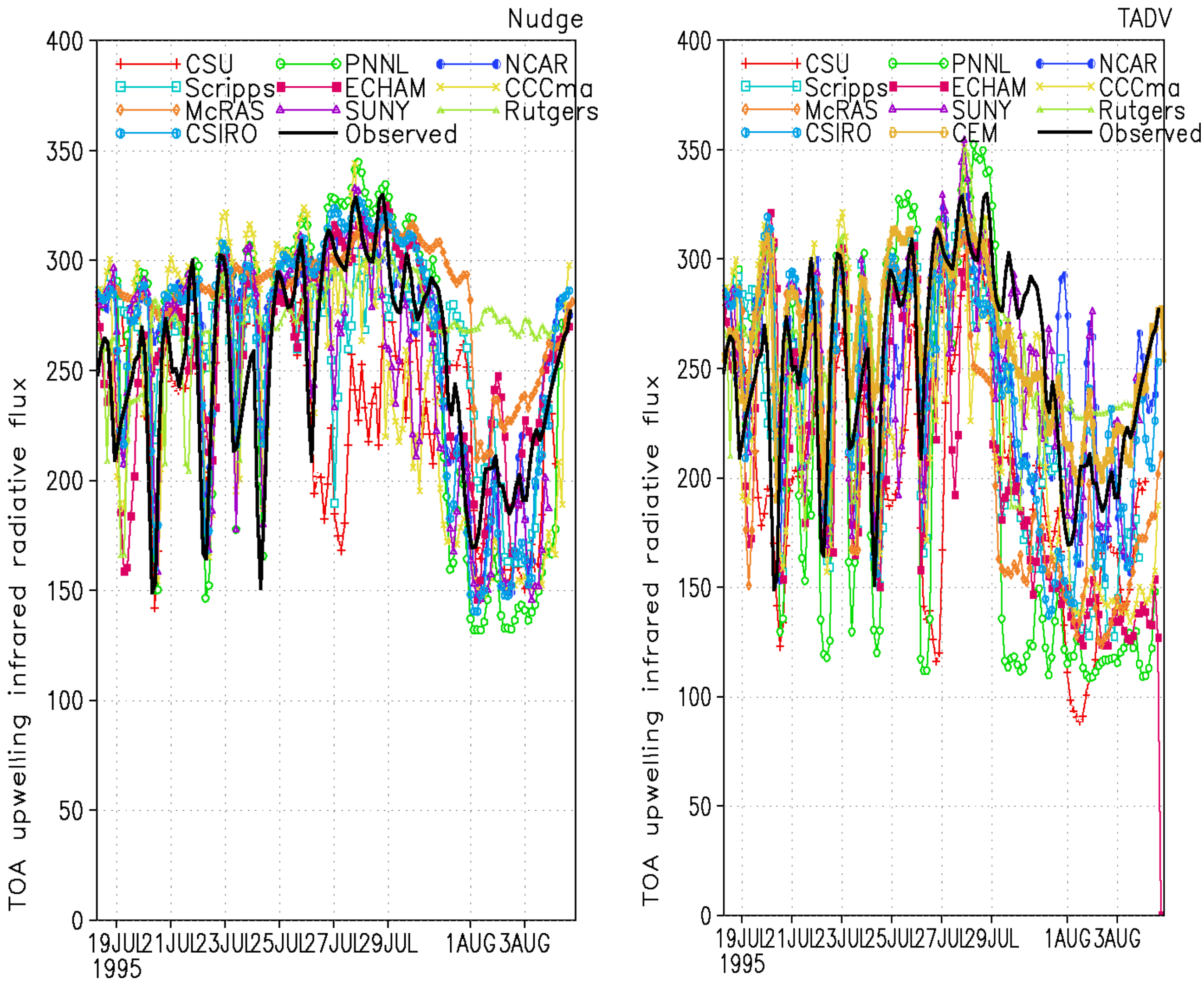

Figure 3. OLR flux at the top of the atmosphere (W/m^2) as observed and as simulated by each model driven by the SUNY analysis of the lateral boundary conditions, with (left) and without (right) nudging of temperature and humidity.

Given the different treatments of a variety of processes in the models, it is often difficult to explain many simulation differences in terms of differences in model physics. However, in some cases model problems were identified and corrected through the process of intercomparison and evaluation. In conventional validation of the models run in three-dimensional climate mode, the problems might have passed unnoticed.

We have also found that the simulations by the CEM are generally superior to those by the SCMs. The errors in simulated temperature and humidity are generally lower at all times and at all levels. The errors in simulated precipitation and longwave radiative flux at the top-of-atmosphere are also lower at all times, but the CEM errors in shortwave flux at the top-of-atmosphere are as large as in the SCM

Table 1. Time mean precipitation rate (kg/m^2/day).

Model	No Nudging	Nudging
Observed	7.81	7.81
CCCma-SCM	6.57	8.49
CSIRO-SCM	7.91	6.69
CSU-SCM	8.17	5.01
ECHAM-SCM	5.96	0.41
McRAS-SCM	7.87	0.40
NCAR CCM3-SCM	9.88	14.4
PNNL/CCM2-SCM	7.33	4.39
Rutgers-SCM	6.97	1.80
Scripps-SCM	7.98	7.71
SUNY/CCM3-SCM	9.13	10.0
UCLA/CSU-CEM	8.19	

CCCma - Canadian Center for Climate Modeling and Analysis
CCM - Community Climate Model
CSIRO - Commonwealth Scientific and Industrial Research Organization
CSU - Colorado State University
McRAS - Microphysics of Clouds with Relaxed Arakawa-Schubert Scheme
NCAR - National Center for Atmospheric Research
PNNL - Pacific Northwest National Laboratory
UCLA - University of California, Los Angeles

simulations. Although the CEM simulations are dependent on the parameterizations of cloud microphysics and cloud optical properties, the ability of the CEM to explicitly resolve convective circulations and its apparent superiority in the simulation of most fields establishes it as a reference model for evaluating SCM simulations of fields not observed or under conditions when the forcing errors are too large to permit evaluation of simulated fields by comparison with measurements. However, the bias in the CEM shortwave fluxes needs to be corrected.

To summarize, we have found that it is possible to do this type of work over midlatitude continents, and specifically at the ARM SGP site. The spatial and temporal density of profiling measurements is as high at the SGP site during intensive operational periods (IOPs) as anywhere. The combination of the profile measurements and surface and top-of-atmosphere measurements of the energy and water balance are critical to the analysis of the forcing required to drive the model simulations.

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