Single-Column Modeling: Sensitivity to Initial Conditions and Divergence Forcing

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Introduction

An issue of importance to single-column modelers is that of sensitive dependence on initial conditions. As Lorenz discovered in 1963, slight differences in the basic atmospheric state used to initialize a computer model for weather prognostication can lead to divergent solutions as the model integrates forward in time. These divergent solutions are due to the non-linear nature of the mathematical equations used in the model that govern atmospheric physics and dynamics. In addition to questions regarding correct spatial atmospheric sampling and objective analysis methods, this aspect of non-linearity has obvious implications for climate modeling from the standpoint of instrument error and other dataset irregularities. This is especially true for any climate models, single-column models (SCMs) included, which seek to simulate weather conditions for several months or years into the future by using observational data for both initialization and prescription.

Thus, since one of the motivations for driving SCMs with ARM Intensive Observation Period (IOP) data is to compare the model's predictions against actual weather observations as a means of assessing the SCM's performance, it would be useful to learn if, and to what degree, an SCM can be sensitive to the data used for its initialization and prescription. More generally, the question can be posed as to whether it is even reasonable to expect an SCM to be able to produce atmospheric states that resemble actual weather conditions at the end of a given time period.

In an attempt to shed some light on this question, two experiments have been conducted. In the first, the Colorado State University SCM was driven with ARM Southern Great Plains (SGP) data from the summer 1995 IOP. The model was run 50 times with all of the initializing and forcing data being identical in each case, except for one item: the temperature sounding used to initialize each 17-day run was perturbed slightly (Figure 1). These perturbed profiles were produced by adding to the objectively analyzed temperature observation, provided by Lawrence Livermore National Laboratory (LLNL), a series of temperature increments ranging between +0.5 and -0.5 degrees Celsius as computed by a random number generator. Errors of this magnitude are reasonable approximations of the degree of instrument error one could expect from the radiosonde arrangement used at the SGP Cloud and Radiation Testbed (CART) site. As mentioned above, the moisture and wind profiles, and surface pressure used in the initialization process were the same for each of the 50 runs, as well as the fields used to force the model at each time-step such as horizontal wind divergence, horizontal tendencies due to advection of temperature and moisture, the surface pressure tendency, surface latent and sensible heat fluxes, and profiles of u- and v-wind components.

Additionally, another set of 50 runs was executed using the same forcing and initial conditions as before (Figure 2), including the same set of temperature perturbations to the initial conditions, except that instead of forcing the SCM with horizontal tendencies due to advection of temperature and moisture, relaxation tendencies of horizontal temperature and moisture advection based on physical properties of the data were employed (see abstract by Randall and Cripe for a discussion of the various forcing techniques used). Since the relaxation forcing method is designed to keep the SCM from "wandering" too far from the observed state of the atmosphere at each time-step, it was anticipated that the results from this group of 50 runs should show less disagreement over the course of the IOP than the group where no relaxation was used.

In the second experiment, three SCM runs were conducted in which the only change was the horizontal wind divergence data used to drive the model: all other forcing and initialization data were kept identical. The divergence fields used included the objectively analyzed divergence from LLNL, and analyses from the European Center for Medium-Range Weather Forecasting (ECMWF) for two different regions centered on the SGP CART site. One region, area 27, was slightly larger than the CART site whereas the other, area 29, was slightly smaller (Figure 3). Theoretically, the outcome of these three SCM runs should be quite similar since there is reasonable agreement among these divergence datasets (Figures 4 and 5).

Results

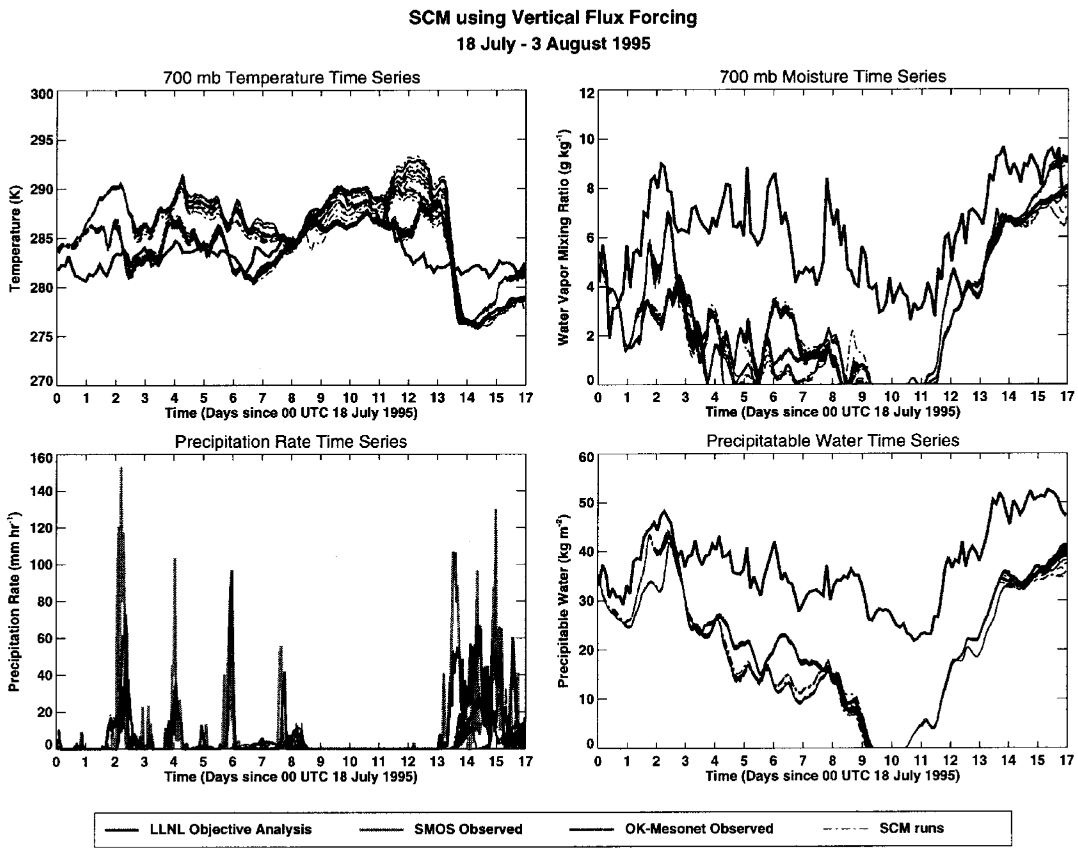

Figure 1. The results of the first group of 50 SCM runs are shown here versus observational data. Each of the SCM runs was initialized with a temperature sounding that was perturbed slightly, at random; all other initialization data were identical. The SCM was driven using vertical flux forcing. The changes that a few tenths of a degree in the temperature profile at initialization can make is evident.

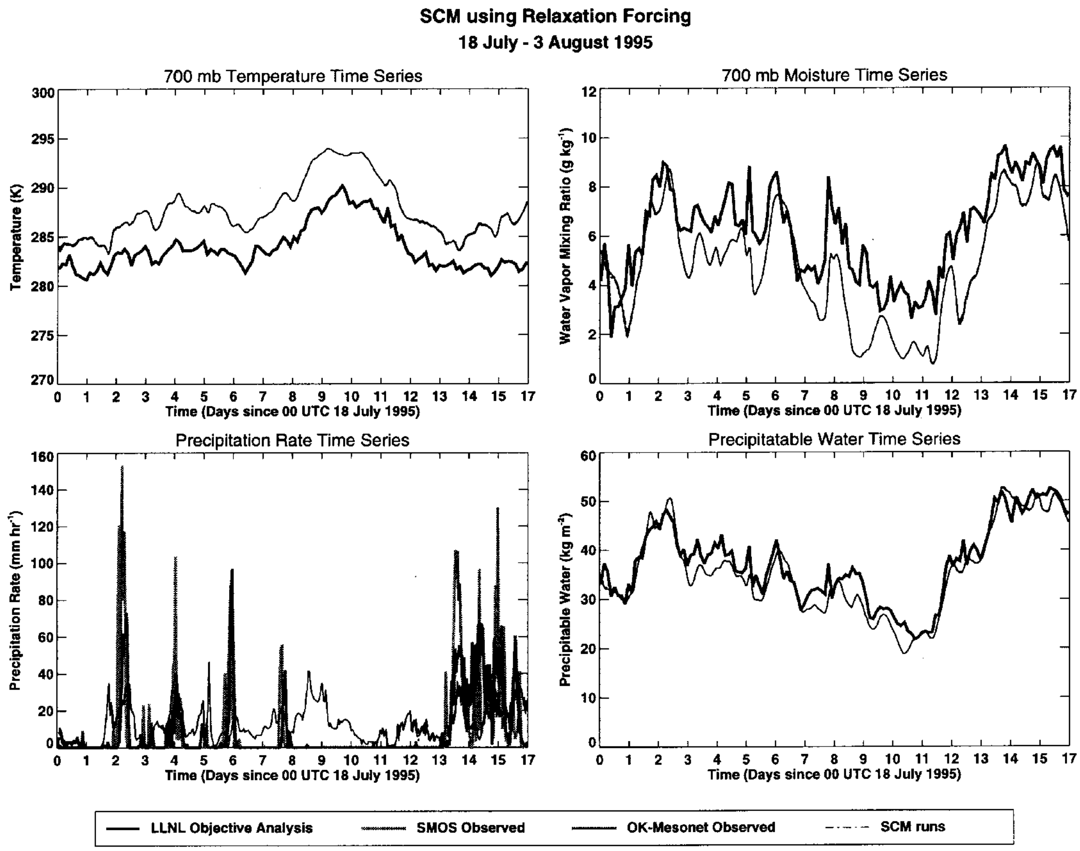

Figure 2. The results of the second group of 50 SCM runs are shown here versus observational data. As before, each of the SCM runs was initialized with a temperature sounding that was perturbed slightly while all other initialization data were identical. However, this time the SCM was driven using relaxation forcing. Clearly, relaxation forcing desensitizes the SCM to fluctuations in observational data.

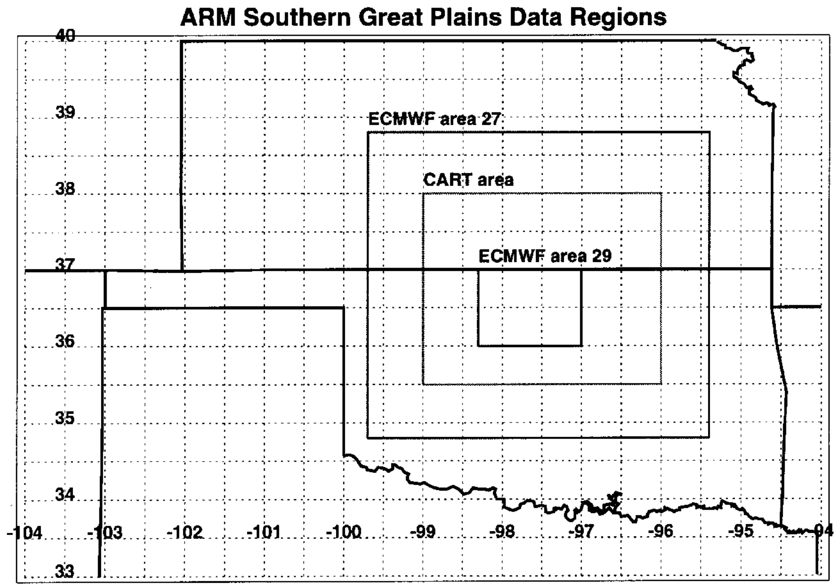

Figure 3. Map showing the location of the SGP CART site in relation to ECMWF areas 27 and 29. Horizontal wind divergence data were used from these three regions to drive the SCM in three independent runs.

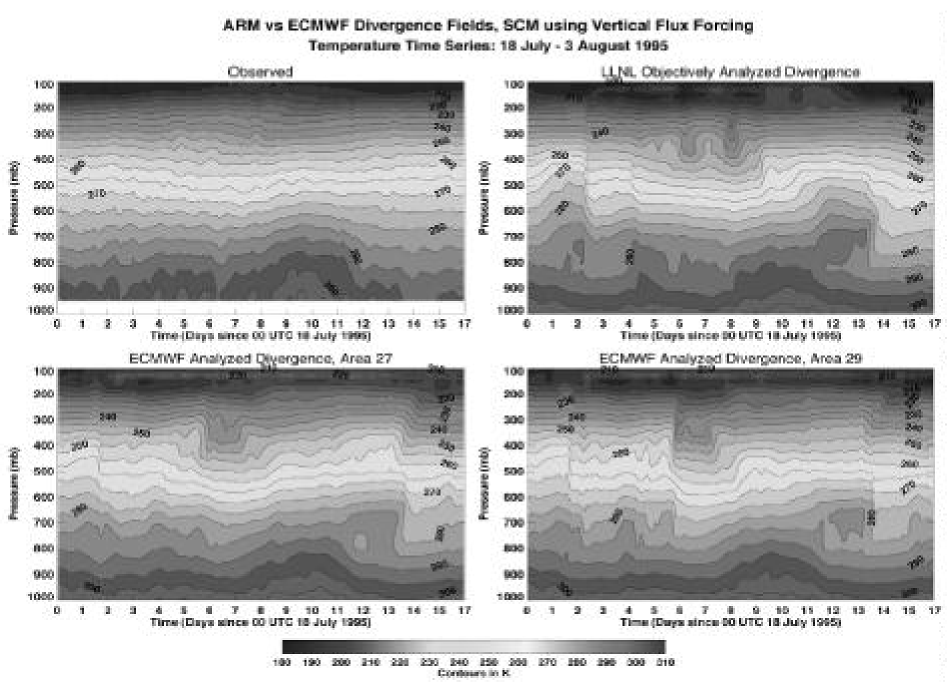

Figure 4. The results of the three SCM runs are shown here versus observational data. Each of the SCM runs was made using identical initialization and forcing data, except for the divergence field. The SCM was driven using vertical flux forcing. The upper left panel is a time-height plot of temperature as objectively analyzed by LLNL. The other three panels show SCM results corresponding to the particular divergence field used.

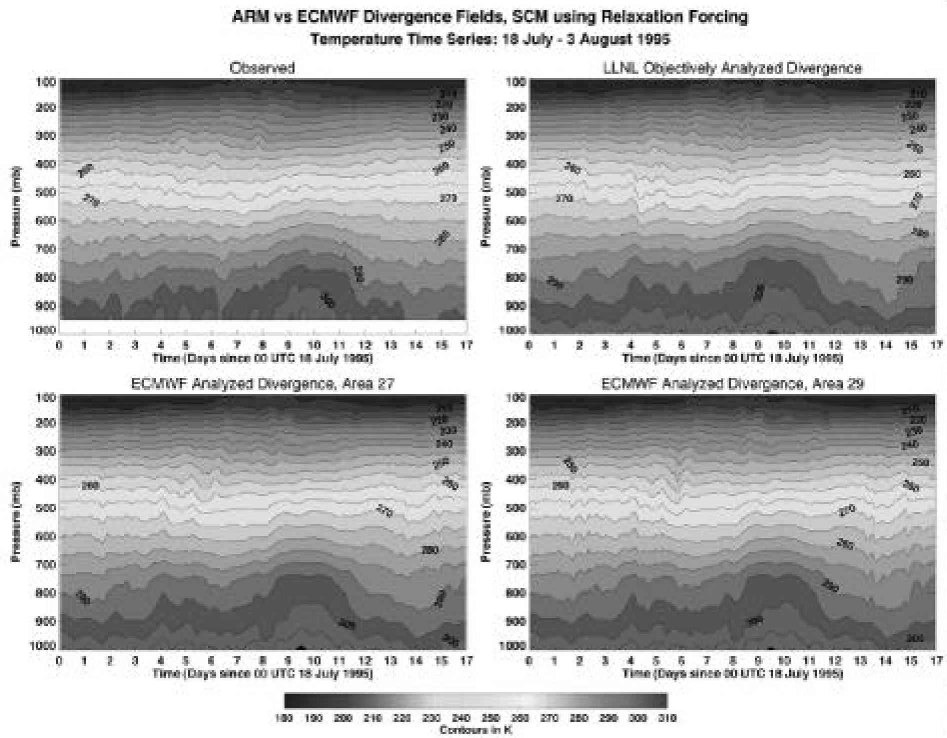

Figure 5. The results of the three SCM runs are shown here versus observational data. Again, each of the SCM runs was made with identical initialization and forcing, except for the divergence field. However, this time relaxation forcing was used to drive the SCM. As expected, the results show much closer agreement, both among themselves and with the observations.

Conclusions

It has been shown that the results of the Colorado State University SCM are sensitive to both initial conditions and forcing data. Although the differences in the prognostic variables among the runs over the duration of the IOP are not enough to completely discredit results from the model, at least for integrations over a 17-day period, the differences are considerable and point to the role that small fluctuations in observational data can play. Similarly, the use of three comparable horizontal wind divergence datasets produced differing results in the prognostic variables, especially toward the end of the period. On the other hand, the greater degree of coherence in the results between the perturbed runs and the observations when relaxation forcing was used to drive the model argues for this type of approach when initializing and driving models with data derived from real-time observations.