Further Analysis of CSU SCM Results From the SGP CART Site

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Introduction

Randall et al. (1996) summarized a strategy for testing parameterizations in single-column models (SCMs). The SCM is driven with observations and the results produced by the SCM are compared with additional observations of the same meteorological events. When the SCM's parameterizations are judged to have performed satisfactorily in tests against observations, they can be transplanted into a three-dimensional atmospheric general circulation model (GCM).

Model and Forcing

The SCM used here is a single-column version of the Colorado State University (CSU) GCM. The model uses a stretched vertical coordinate in which the top of the planetary boundary layer (PBL) is a coordinate surface (Suarez et al. 1983). The PBL is then identically the lowest layer of the model. The depth and turbulence kinetic energy of the PBL are prognostic (i.e., time-stepped) variables of the model.

The cumulus parameterization is based on the ideas of Arakawa and Schubert (1974), but with the prognostic convective closure described by Randall and Pan (1993) and Pan and Randall (1998), and with multiple cloud-base levels as reported by Ding and Randall (1998). Except as noted, for all runs described in this paper, the parameters α and τ_D, used in the convection parameterization and discussed in detail by Pan and Randall (1998), were set to 10^8 m^4 kg^{-1} and 10^3 s, respectively. The model results do depend significantly on the value of α used, although no one particular α setting is optimal for all cases. We have found that $\alpha = 10^8$ m^4 kg^{-1} often gives the most realistic simulations. This study is not about cumulus parameterization, and the physical interpretation of α will not be discussed here; such a discussion is given by Pan and Randall (1998). Nevertheless, we will discuss the results of experiments in which the value of α is varied. The purpose of these experiments, in the context of this study, is to investigate how the results depend on the method by which the SCM is forced. This allows us to illustrate some important differences among the forcing methods.

The stratiform cloud parameterization used in the model was developed by Fowler et al. (1996) and Fowler and Randall (1996 a, b). The radiation parameterization is that of Harshvardhan et al. (1987). The model also includes a land-surface parameterization, but it is not used in the Atmospheric Radiation Measurement (ARM) SCM runs described here; instead, we prescribed the surface fluxes of sensible and latent heat according to observations. For detailed descriptions of the GCM and its performance, see the papers cited above, and Randall et al. (1991).

Since it operates in isolation from all adjacent grid cells, an SCM cannot determine the horizontally domain-averaged horizontal advective tendency of temperature and moisture. It is therefore necessary to prescribe some information about the horizontal advection of these quantities. One approach to specifying the large-scale advective forcing is simply to compute the horizontal and vertical advective tendencies of temperature and moisture from the observations and then use them to prescribe the SCM. We refer to this as “revealed forcing.” With this simple approach, errors in the predicted vertical distribution of temperature or moisture have no effect on the advective tendency of these variables. A slight modification of revealed forcing, which we call “horizontal advective forcing,” consists of prescribing horizontal temperature and moisture advection based on the observations, and then using the predicted profile of these variables, together with the prescribed, to evaluate vertical advective tendencies of temperature and moisture as the model runs. Horizontal advective forcing allows the tendency of temperature and/or moisture due to vertical advection to depend on the predicted profile of these variables, as it does in nature and as it would in a full three-dimensional model; this dependency is missing with revealed forcing. A third method of forcing utilized here we refer to as “relaxation forcing,” in which the SCM is relaxed to observed temperature and moisture values upstream from the Cloud and Radiation Testbed (CART) site, based on an advective timescale computed from observed winds across the site. A complete description of these forcing methods can be found in Randall and Cripe (1999).

Discussion

Our results for the July 1995 Southern Great Plains (SGP) Intensive Observation Period (IOP) showed that relaxation forcing produces the most realistic soundings. Nevertheless, in many cases, relaxation forcing gives the least realistic surface precipitation rate. We have found that in general, the model tends to produce more humid (in the sense of precipitable water) soundings when α is large, and drier soundings when α is small. In particular, this is true for the relaxation forcing runs. Further, this tendency holds not only for the present July 1995 SGP IOP case, but also for five other SGP IOPs as well as runs completed with Global Atmospheric Research Program’s (GARP) Atlantic Tropical Experiment (GATE) and the Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE) data sets. When convection is active, the simulated atmosphere becomes drier as α decreases. For $\alpha = 10^7$ m^4 kg^{-1}, the simulated atmosphere is considerably drier than observed, while for $\alpha = 10^9$ m^4 kg^{-1}, it is slightly more humid than observed. In short, for small α the model “runs dry,” while for large α it “runs wet.” The physical explanation for this is discussed by Pan and Randall (1998); for purposes of the present study, this explanation is irrelevant. Here we simply take advantage of the fact that we can make the model run wet or run dry by altering the value of α.

As already discussed, the precipitation rate tends to be very unrealistic in the relaxation forcing runs, despite the fact that the relaxation forcing-simulated soundings are generally more realistic than simulations using the other forcing methods. We found that, for the relaxation forcing runs, the precipitation rate is higher with a small α, while with a larger α it is lower. This is particularly true for those IOPs in which convection was active, such as the July 1995 SGP IOP. The interpretation of these results is very simple: In a model that tends to run drier than observed (i.e., with small α), relaxation forcing fights back against this drying by trying to moisten the sounding, and the parameterizations of the model, in turn, fight back against the relaxation by drying the sounding through precipitation. As a result, relaxation forcing leads to excessive precipitation in a model that tends to run dry. In a model that tends to run wet, relaxation forcing tends to dry out the sounding, and so inhibits precipitation.

These results indicate that "error is conserved." With revealed forcing and horizontal advective forcing, the precipitation rates are relatively realistic but the soundings deviate substantially from the observations, and this tells us that something is wrong with the model. With relaxation forcing, the soundings are guaranteed to be relatively realistic, but the precipitation rates deviate greatly from the observations, telling us again that there are problems with the model. This indicates that relaxation does not hide the problems of a model; it only changes the way in which those problems manifest themselves.

Conclusions

We have explored several approaches to prescribing observed forcing for use in SCMs, and the results obtained with the various methods for several different observed cases indicate, perhaps not surprisingly, that each approach has certain advantages and disadvantages.

The results discussed here, based mainly on the July 1995 SGP IOP, indicate that the revealed and horizontal advective forcing simulations are only modestly successful in reproducing the observed fluctuations of temperature and water vapor on a level-by-level basis. The observed precipitable water variations are more successfully simulated in these runs, as are the observed surface precipitation variations. Although the temperature and water vapor soundings obtained with relaxation forcing are much more realistic than those obtained with revealed forcing or horizontal advective forcing, the simulated precipitation rate in the relaxation forcing run is actually much less realistic than in the revealed and horizontal advective forcing runs. We have found that this counter-intuitive behavior generally holds, not just for the particular case discussed here. Our results further suggest that revealed forcing gives larger errors in the soundings, while horizontal advective forcing gives larger errors in the precipitation rate. The differences are fairly small and may not be significant. Further study is needed on this point.

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