1.1 The concept of SCM

A single-column model (SCM) is a one-dimensional (vertical) computational model of a specific columnar region of the atmosphere. It may be thought of as being extracted from the array of such columns which make up the atmospheric portion of a global climate model or general circulation model (GCM). In the GCM, this atmospheric model column would interact at each vertical level and at every time step with neighboring columns, providing horizontal fluxes of heat, water and momentum to and from these neighbors. By contrast, a SCM requires these fluxes to be specified, either from model data or observations or some combination of the two. If the fluxes are set to zero, the SCM becomes one type of a radiative-convective model (RCM). One way to think of a RCM (Ramanathan and Coakley, 1978) is as a horizontally averaged GCM, with the horizontal averaging over a global domain resulting in zero horizontal flux convergence.

Many climate modeling research groups have developed and used single-column models (SCMs) as tools for parameterization development. These SCM efforts have sometimes not been published in the open scientific literature, remaining instead as technical reports in the “grey literature.” ARM has historically been a significant source of support to the small community of SCM modelers, by providing research grants, observational data, and computational resources. In particular, observational data from the ARM Southern Great Plains (SGP) site has been a major stimulus to the development and use of SCMs. The ARM success with research involving SCMs has encouraged several modeling groups to make their own internally developed SCMs publicly available, sometimes with professionally programmed and well-documented codes. The NCAR climate modeling group, for example, has made single column versions of its global climate models available for many years.

A great deal of experience has been gained in using single-column models with ARM data, and over time, the role of SCMs in climate research has been expanded and clarified. SCMs clearly have a valuable place in the hierarchy of modeling approaches which is needed to improve the realism and trustworthiness of climate models. Of course, a wide variety of techniques has long been employed to test and validate physical process parameterizations in both weather and climate models. One straightforward method is to compare the results of full three-dimensional GCM simulations, using different parameterizations, against global observations. Another is to carry out numerical weather prediction (NWP) experiments initialized with realistic data and to compare the effects of different parameterizations on short- and medium-range forecast skill. Both of these approaches have provided valuable information. However, carrying out a carefully coordinated model parameterization intercomparison program with 3-dimensional models, even when the same basic model is used as the vehicle, is time-consuming and computationally expensive.

1.2 Early studies using SCMs

The semi-prognostic model of Lord (1982) and the convective adjustment tests of Betts and Miller (1986) are early examples of the idea of using a model of a single atmospheric column. The basic concept of an SCM is to force and constrain an isolated time-dependent atmospheric GCM column with estimates of observed advective flux convergences, then to compare the output with observations to judge the realism of the parameterizations. Because the SCM has only one space dimension (vertical), it is very fast, and it is practical to explore large segments of parameter space by making hundreds or even thousands of integrations, which is impossible with a full GCM. In ARM, SCMs have been widely used to investigate parameterizations of cloud-radiation processes.

This approach typically involves evaluating parameterizations directly against measurements from ARM field programs, and using this validation to tune existing parameterizations and to guide the development of new ones. The single-column model is thus used to make the link between observations and parameterizations. Surface and satellite measurements are both used to provide an initial evaluation of the performance of the different parameterizations. The results of this evaluation are then used to develop improved cloud-precipitation schemes, and finally these schemes are tested in GCM experiments (e. g., Lee et al., 1997). An early example of using a single-column model in this way is described by Iacobellis and Somerville (1991a,b).

The SCM thus is a versatile and economical one-dimensional model, containing the full set of parameterizations of subgrid physical processes that are normally found in a modern GCM. The SCM is applied at a specific site having a horizontal extent typical of a GCM grid cell. Its input is typically an initial state, plus the time-dependent advection terms in the conservation equations, provided at all model layers. Its output is a complete heat and water budget for the study site, including temperature and moisture profiles, clouds and their radiative properties, diabatic heating terms, surface energy balance components, and hydrologic cycle elements, all specified as functions of time.

Single-column models may be looked on as a means of isolating the behavior of a model atmosphere over a single horizontal grid cell. Viewed in this way, they enable one to study the comparative merits and drawbacks of alternative parameterizations of physical processes, for example, or the sensitivity to errors in advective forcing. When detailed observational data are available, they provide a way to evaluate local model behavior comprehensively. In brief, they are a means of zooming in microscopically onto the model grid scale itself, to diagnose both the GCM physics and the actual atmosphere.

By perturbing the advective forcing, for example, one can explore the dependence of the diabatic heating rates and other subgrid parameterization outputs on the accuracy of the horizontal flux convergences. Similarly, for a given advective forcing, one can test how these model products depend on the choice of parameterizations. For a discussion of limitations of single-column modeling, including issues of sensitivity to errors in forcing data and consequences of constraining the SCM temperature and humidity profiles from departing too far from observations, see, e. g., Randall et al. (1996), Lee et al., 1997, Iacobellis and Somerville (1991a,b) and references therein.

A major result in ARM is that SCMs have proven themselves capable of directly validating parameterization results against ARM measurements. Because climatically critical observable quantities such as column liquid water and downwelling surface shortwave and longwave radiation can be both derived from SCM results and inferred from observations at the SGP site, it is safe to say that with extensive examples of this type of research in ARM, a major step has been achieved in fulfilling the original promise of the SCM approach.

The SCM is a convenient testbed for examining many aspects of the ways in which GCMs treat subgrid physical processes. For example, Lane et al. (2000) found strong sensitivity to vertical resolution in several test integrations in which they increased the number of layers substantially. Several possibilities are raised by this result. One is that the parameterizations are constructed around implicit assumptions as to how many layers are involved, so that they do not generalize to arbitrary vertical resolution and converge at sufficiently small vertical grid size. Another is that typical GCM and NWP vertical resolutions are simply inadequate for some aspects of parameterized subgrid physics, although they may generally be satisfactory from the viewpoint of large-scale dynamics.

It is now well-recognized in the GCM and NWP communities that single-column models (SCMs) are tools which have a valuable role to play in testing and improving parameterizations by evaluating them empirically against field observations. Early surveys of SCM research have been published by Randall et al. (1996) and Somerville (2000). Large multi-author efforts to compare many models include those of Ghan et al. (2000) and Xie et al. (2002).

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