Diagnostic Modeling of the Experimental Site of the Atmospheric Radiation Measurement Program

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Our project is centered around a computationally efficient and economical one-dimensional (vertical) model, resembling a single column of a general circulation model (GCM) grid, applied to the experimental site of the Atmospheric Radiation Measurement (ARM) Program. The model contains a full set of modern GCM parameterizations of subgrid physical processes. To force the model, the advective terms in the budget equations are specified observationally from operational numerical weather prediction analyses. These analyses, based on four-dimensional data assimilation techniques, provide dynamically consistent wind fields and horizontal gradients of temperature and moisture.

Model Description

Our model is diagnostic rather than prognostic. Its input is 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 ARM experimental configuration, 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.

These model products can then be validated against ARM observations. This validation provides a test of the realism of the model's physical parameterizations and a means of evaluating proposed improvements. In addition, it allows an assessment of the sensitivity of the results to individual elements of the parameterizations. The model thus is a computational testbed which allows progress to be made on the problem of modeling cloud formation as well as cloud characterization. Our research effort is a coordinated program of model development, diagnostic modeling, and linkages with GCM experiments and with observations.

Our model has evolved from the one described by Iacobellis and Somerville (1991a,b). These papers describe the theory and conceptual basis of single-column modeling. Virtually all the parameterizations in our model, however, have been replaced or substantially modified since these papers were written.

Code Development

Until very recently, ARM observational data were not available. While awaiting the data, we have developed and extensively revised the current version of the model to incorporate state-of-the-art physical parameterizations. At the same time, we have devoted effort to recoding the model for generality, efficiency, and modularity. As an example of generalizing the code, we want to be able to alter the vertical resolution by simply setting one parameter.

We have succeeded in implementing the model on a workstation in interactive form to facilitate testing and tuning of alternative parameterizations. We have also made substantial progress in developing plug-compatible code for competing algorithms so as to be able to quickly switch between them. Additionally, we have begun to develop and implement effective graphical displays for the model results. Now that the first ARM site has become operational, we have begun receiving ARM data.

We have spent a significant amount of time improving the model code to facilitate future intercomparisons of the physical parameterizations. For example, the code has been modified to allow the time step to be changed by adjusting a single parameter. This is not a trivial change, given the model's dependence on time-dependent observational data. Earlier versions of the model assumed that the observational data would have the same temporal resolution as the model time step. The model can now incorporate observational data with any temporal resolution. Additionally, the different observed variables can have different sampling frequencies, as will be the case in ARM.

The model code and associated software (graphics, data storage, etc.) have been transferred to a high-speed UNIX workstation. The graphics software has been updated to take advantage of the animation and color capabilities of the workstation. Data management procedures are currently being revised to cope with the heterogeneous nature of ARM data. We are also using a data set obtained from the First GARP[(a)] Global Experiment (FGGE) archives as a surrogate to develop and test the effectiveness of these procedures. At the Science Team meeting, we will show sample results based on these data, applied to an area in Oklahoma near the ARM site.

Physical Parameterizations

Our research during the past year has concentrated on improving and supplementing the parameterizations and code in the model and, also, on developing procedures and software to facilitate the use of ARM observational data. We have continued to update and improve the model parameterizations.

During the past year we have incorporated and tested the cumulus convection scheme developed by Emanuel (1991). The current model version now includes a choice of three modern and widely used cumulus convection schemes, those of Arakawa and Schubert, Emanuel, and Kuo. This type of software development is essential to our objective of being able to validate and intercompare competing parameterizations using ARM observations.

Our terrestrial radiation parameterization is based on the one developed by Morcrette (1990) for the European Centre for Medium-Range Weather Forecasts (ECMWF) model. We have initiated work to include Morcrette's solar radiation parameterization into our model. A similar version of this shortwave radiation parameterization is currently being used in the ECMWF model. Earlier versions of our model incorporated the routine of Lacis and Hansen (1974), which at one time was the standard GCM solar radiation algorithm. Currently, we are using the shortwave parameterization of Fouquart and Bonnel (1980).

The parameterization of clouds and cloud radiative properties is the central focus of our research. We have incorporated a treatment of cloud optical properties adopted by the second-generation GCM of the Canadian Climate Centre (McFarlane et al. 1992), in which optical properties are based on cloud liquid water contents, which in turn are parameterized on temperature and pressure following Betts and Harshvardhan (1987), Platt and Harshvardhan (1988), and Somerville and Remer (1984). Our cloud prediction algorithm at present follows Slingo (1987), but we are examining alternatives.

Our intention is not to advocate any particular physical parameterization a priori. Instead, we intend to create a model in which alternative parameterizations can be selected simply by setting a switch. Then, we will use the ARM data to test the different parameterizations within the model so as to determine those respects in which any given parameterization does or does not conform to reality.

We have been collaborating with other groups in an effort to expand and improve the model. Along with a group from Los Alamos National Laboratory (LANL), we are seeking to develop an improved version of the liquid water prognostication treatment of Sundqvist (1978). The current model does not carry liquid water as a prognostic variable, although recent research has demonstrated the value of doing this so as to be able to predict cloud radiative properties. Thus, the inclusion of the Sundqvist-type scheme will give the model added versatility in studying cloud-radiation interactions.

Collaboration has also been ongoing with a group from Science Applications International Corporation (SAIC) headed by N. Byrne. The objective is to implement a statistical treatment of cloud radiative properties within the model (Malvagi et al. 1993). This collaboration includes a graduate student at Scripps Institution of Oceanography, Ms. Yolande Serra, whose Ph.D. dissertation will be based on our ARM research.

The current version of our model incorporates a land surface parameterization based on that of Deardorff (1978). Our boundary layer parameterization follows the approach of Benoit (1976).

(a) Global Atmospheric Research Program.

Recent Publications

Three papers describing recent progress on this project and a closely related ARM project (N. Byrne, principal investigator) appeared in the preprint volume of the *American Meteorological Society 73rd Annual Meeting and Fourth Symposium on Global Change Studies*, Anaheim, California, January 17 - 22, 1993.

F. Malvagi, N. Byrne, G. Pomraning, and R.C.J. Somerville. Stochastic radiative transfer predictions of functional cloud cover, pp. 149-151.

Y. Serra, N. Byrne, S. F. Iacobellis, and R.C.J. Somerville. Effect of varying functional cloud cover on cloud feedback temperature stabilization, pp. 225-227.

R.C.J. Somerville, and S. F. Iacobellis. Single-column diagnostic climate modeling in ARM, pp. 82-85.

Additionally, a paper has been published in the referenced literature:

F. Malvagi, R. N. Byrne, G. C. Pomraning, and R.C.J. Somerville. 1993. Stochastic radiative transfer in a partially cloudy atmosphere. *J. Atmos. Sci.* **50**:2146-2158.

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