FINAL PERFORMANCE REPORT
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TITLE: Improvement of Moist and Radiative Processes In Highly Parallel Atmospheric General Circulation Models: Validation and Development

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OBJECTIVES:

Develop an economical numerical experimentation environment to facilitate the investigation and improvement of parameterizations of radiative and moist processes in atmospheric general circulation models. Use this computational environment to accelerate the development of a generalized approach to the representation of cloud-scale processes capable of handling shallow nonprecipitating stratiform and convective clouds, and deep penetrative convection in combination with a more complete description of their interaction with the radiation fields. One focus of the parameterization research has been to integrate parameterization schemes through equilibrium assumptions that couple boundary layer processes and convection. The resulting parameterizations will then be more thoroughly tested in a three-dimensional atmospheric general circulation modeling framework.

ACCOMPLISHMENTS:

We have developed one-dimensional time-dependent versions of the NCAR CCM2 and CCM3 atmospheric/land surface models for which the local time-rate-of-change of the large-scale state variables (e.g., temperature, moisture, momentum, cloud water, etc.) depend on specified horizontal flux divergences, a specified vertical motion field (from which the large-scale vertical advection terms will be evaluated), and subgrid-scale sources, sinks and eddy transports. The subgrid-scale contributions are determined by an arbitrary collection of user-selected subgrid-scale physics parameterizations. The overall design includes the provision of a graphical user interface (GUI) to the model. The initial computational environment makes use of a sophisticated Motif-based user interface. This approach has required an integration of the FORTRAN-based CCM physics with the C-based GUI which up until now has restricted the modeling framework to more mature computational environments.

Model namelist parameters are specifiable as command-line data, or via X-Defaults. The point-and-click graphical interface streamlines the control of code flow including: dataset selection; column location (latitude/longitude) selection; modification of control variables (such as termination conditions, update frequencies, specification of history data, etc.); modification of initial data and the associated large-scale

forcing (e.g., modification of vertical structures, amplitudes, etc.); and the visualization of output data (vertical profiles, time series, etc.). In particular, we have emphasized a tight coupling of interactive graphical analysis capabilities with the integration component of the model. Both semi-Lagrangian and Eulerian vertical advection capabilities have been incorporated into the modeling framework, allowing for the accurate solution of vertical advection terms for an arbitrary number of model variables (including the standard state variables).

A generalized netCDF data format has been adopted for describing input and output datasets for this modeling environment, where filters have been created for transparently converting between netCDF and CCM history tape formats. In addition to CCM-generated initial and boundary condition datasets the modeling framework has been constructed to incorporate data (e.g., initial conditions and forcing terms) as diagnosed from various field experiments. The current standard "library" of field program forcing/budget data includes GATE, TOGA COARE, and a number of ARM IOP datasets. These initial condition and forcing data are dynamically specifiable from the GUI, as are global data from ECMWF analyses and CCM climate integrations. This type of data serves a dual role by providing the necessary boundary forcing for the one-dimensional model, and providing validation data for the time-dependent solutions generated by the collection of physical parameterizations.

Research on designing an integrated moist process parameterization package was carried out (in collaboration with a separate project) at the Pennsylvania State University. This work began with a study that coupled an ensemble of cloud models to a boundary layer model (Albrecht, 1979) to examine the feasibility of such a methodology for linking boundary layer and cumulus parameterization schemes (Dean, 1993). The approach proved feasible, prompting research to design and evaluate a coupled parameterization package for GCMs. This research contributed to the development of an Integrated Cumulus Ensemble-Turbulence (ICET) parameterization package. This package incorporates a higher-order turbulence boundary layer that feeds information concerning updraft properties and the variances of temperature and water vapor to the cloud parameterizations. The cumulus ensemble model has been developed, and initial sensitivity tests have been performed in the single column model (SCM) version of CCM2. It is currently being coupled to a convective wake/gust front model, a second major research focus at PSU under support from this CHAMMP project.

The major function of the convective wake/gust front model is to simulate the partitioning of the boundary layer into disturbed and undisturbed regions. It does this by using information on downdraft properties provided by the cumulus parameterization to force a simple wake model in which the various sides of the wake move as gravity currents, and the recovery of wake air to ambient conditions due to surface fluxes is predicted. A second function of this model is to predict the nonlinear enhancement of surface to air sensible heat and moisture fluxes that occur in convective regimes due to correlations between winds and anomalously cold, dry air from downdrafts in the gust front region. The third function of the convective wake/gust front model is to predict the amount of undisturbed boundary layer air lifted by the leading edge of the wake and the height to which this air is lifted. The former quantity is of interest to some types of cumulus parameterizations that predict convection in terms of mass fluxes out of the boundary layer, while the height of lifting is important to any scheme that uses a trigger function to determine whether the boundary layer air is capable of reaching the level of free convection.

The development of the wake/gust front model has been completed, and it has done well in initial testing as a stand-alone component (Qian, et al., 1997). The current task, to be completed by the end of the funding period, is to tie the wake model to a cumulus ensemble model and to install both components into the single column model version of CCM3 for evaluation.

Another area of parameterization research has been focused on the representation of cloud radiative properties. An examination of the CCM2 simulation characteristics (e.g., see Hack et al., 1994) indicated that many surface temperature and warm land precipitation problems were linked to deficiencies in the specification of cloud optical properties, which allowed too much shortwave radiation to reach the surface. In-cloud liquid water path was statically specified in the CCM2 using a prescribed, meridionally and height varying, but time independent, cloud liquid water density profile, which was analytically determined from a meridionally specified liquid water scale height (e.g., see Kiehl et al., 1994). Single-column model integrations were conducted to explore alternative formulations for the cloud liquid water path diagnostic, converging on an approach that employs a similar, but state-dependent technique for determining in-cloud liquid water concentration. The new formulation, results in significant improvements to both the top-of-atmosphere and surface energy budgets. In particular, when this scheme is incorporated in the three-dimensional GCM, simulated July surface temperature biases are substantially reduced, where summer precipitation over the northern hemisphere continents, as well as precipitation rates over most all warm land areas, is more consistent with observations (Hack, 1997). This improved parameterization has been incorporated in the CCM3.

One final example of the CCM SCM utility involved the evaluation of a bulk microphysical scheme using Intensive Observing Period (IOP) data from the ARM Southern Great Plains (SGP) site. In a recent study, Petch and Kiehl (1996) used this framework to illustrate how the interaction of a fractional cloud parameterization with the bulk microphysical scheme of Rutledge and Hobbs (1983) and Lin et al. (1983) produces a better simulation for a synoptically active four-day period during the fall 1994 ARM IOP. This study also demonstrated the importance of forcing a single-column framework with a horizontal flux divergence of hydrometeors, previously thought to have a negligible impact on the solution.

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Ms. Caryn L. Dean, M.S. 1993 (see above for thesis title).

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