Development of an Advanced Finite-Difference Atmospheric General Circulation Model

A. Arakawa and C. R. Mechoso
University of California
Los Angeles, California

Objectives

The goal of this project is to further develop an advanced finite-difference atmospheric climate model for better performance of the simulations of the seasonal cycle and inter-annual variability of Earth's climate. The simulations will be performed with sea surface temperatures (SST) either prescribed (uncoupled mode) or produced by a coupled oceanic general circulation model (coupled mode). Additional objectives include the upgrading of the model's code for high-performance computing.

Accomplishments

We have achieved significant accomplishments in all objectives targeted under this project. In summary, the key components of the University of California, Los Angeles (UCLA) atmospheric general circulation model (AGCM) have been thoroughly revised and the overall model performance has been greatly improved. The model has been coupled to the Princeton/University Modular Ocean Model (MOM), multi-decadal runs have been completed, and several physical aspects crucial to the behavior of the coupled-atmosphere ocean system have been identified. The model code has been parallelized for massively parallel processors (MPP), which has been allowed to double the resolution of the standard version that has a performance of almost 10 Gflops. We have maintained a close collaboration with Computer Hardware, Advanced Mathematics, and Model Physics (CHAMMP) researchers at the Lawrence Livermore National Laboratory (LLNL), and kept them updated on model upgrades. We have also exchanged code components as well as scientific findings with CHAMMP researchers at Colorado State University (CSU). Significant progress has been made towards a new model version based on a generalized vertical coordinate.

This report presents highlights of our accomplishments in the categories of 1) model development, 2) code development, and 3) better understanding of selected climate phenomena. The work on development of the generalized vertical coordinate model is described in a separate paper of this volume.

Model Development

We have developed a scheme to represent the effect of resonant nonhydrostatic waves on the lee side of mountains associated with generation of a nonlinear critical level. The scheme is now a standard model complement, and has contributed significantly to the more realistic simulation of zonal mean flow, sea-level pressure, etc. A substantial effort was also dedicated to revisions of the planetary boundary layer (PBL) parameterization, which improved the simulated surface fluxes as well as stratus clouds.

We explored several key issues relevant to the performance of the tropospheric-stratospheric version of the UCLA AGCM in simulating the stratospheric zonal mean flow. The parameterization of photochemical processes used in the model had a tendency to underestimate the ozone mixing ratios, and to produce substantial biases in zonally-averaged temperatures and winds, as well as errors in planetary wave amplitudes and phases. Those deficiencies were largely alleviated by prescribing ozone mixing ratios from observed climatologies and incorporating a more accurate formulation of shortwave radiation absorption by ozone.

There was significant progress in the development of a prediction scheme for cloud liquid water and cloud ice based on a five-phase bulk microphysics. Our starting point was a methodology for predicting liquid and ice phases separately, as developed at UCLA. The proposed work aimed to extend and refine previous work with emphasis on the parameterization of the effects of microphysical processes on the large-scale flow. Preliminary results of simulations with a model version that includes this scheme are very encouraging.

Efforts in Code Development (in collaboration with LLNL; NASA/JPL; NASA/HPCC)[a]

There are two major components in the AGCM. One is AGCM/Dynamics, which computes the evolution of the fluid flow governed by the primitive-equations. In an MPP, AGCM/Dynamics requires two types of interprocessor communications: 1) message exchanges among neighboring processors in the finite difference component, and 2) non-nearest neighbor exchanges in the spectral filtering component, which is performed only in polar regions. The other component is AGCM/Physics, which computes the effect of processes not resolved by the model's grid on processes that are resolved by the model's grid. The AGCM/Physics computational load varies in both space and time as elements such as cloud distribution and conditional instability of the atmosphere change. We have implemented a static load redistribution algorithm to load balance the filtering step, and a quasi-dynamic scheme to load balance the AGCM/Physics. We have also performed a number of single node optimizations to increase the per-node performance on the CRAY T3D.

The AGCM now boasts an overall parallel efficiency of 50% on 256 nodes of the CRAY T3D. This efficiency is very high for an atmospheric model code because the surface-to-volume ratio for these models is rather high, and there are inherent load imbalances present. The execution rate is nearly 10 Gflops on 512 nodes of the CRAY T3D. The AGCM running side-by-side with the Parallel Ocean Program (POP) can currently achieve a performance of 10.65 GFLOPS when 324 nodes are assigned to the AGCM and 188 nodes to the oceanic general circulation model (OGCM).

We have also developed an Earth System Model Information System (ESMDIS). This is a web-based database application that has the following functions: 1) sets up model runs, 2) loads model output into database, 3) browses metadata information, 4) retrieves datasets, 5) analyzes and validates model output, and 6) visualizes datasets.

(a) The National Aeronautics and Space Administration (NASA)/Jet Propulsion Laboratory (JPL); NASA/High Performance Computing and Communications (HPCC).

Achievements in Climate Simulation

Simulations with the uncoupled AGCM demonstrate that the magnitude of surface evaporation can be affected by the optical properties of high-clouds through interactions between cloud, radiation and dynamical processes. A similar set of simulations with the coupled AGCM show that increasing the emissivity of high clouds results in warmer SSTs. These experiments confirm that the atmosphere-ocean system can be extremely sensitive to the radiative effects of clouds.

The impact of Peruvian stratus clouds on the simulation of the tropical Pacific climate is a major concern in models that attempt to simulate and predict phenomena such as El Niño-Southern Oscillation and its worldwide effects. We performed studies aiming to assess this impact. Our results demonstrate that Peruvian stratus cloud decks are crucial to the maintenance of the asymmetry about the equator of the eastern Pacific climate. Further, the seasonal cycle of these clouds plays an important role in producing the asymmetric features of the annual cycle of the cold tongue in sea surface temperature at the equator.

We are currently performing and analyzing multi-decadal AGCM simulations at different resolutions, and have started preparations for a simulation with the 2.5° lon × 2° lat × 29 layer of the AGCM coupled to the 1/6° lon × 1/6° lat × 60 layer Atlantic version of POP using the CRAY T3D/T3E.

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