Parallel Computations in Problems of Climate Modeling

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Our daily lives are influenced greatly by various global scale phenomena occurring in the Earth climate system. On the other hand, we affect adversely the Earth's environment to a considerable extent. One of these phenomena is global warming, which is clearly pronounced in the rise of the Earth's surface temperature occurring during the past century. There is strong evidence that most of the warming over the last 50 years is attributed to human activities changing the chemical composition of the atmosphere. There are also other planetary scale phenomena attracting attention of scientists, for example, El Niño Southern Oscillation, Arctic Oscillation and North Atlantic Oscillation. They are not caused by global warming but impact on the temperature and precipitation patterns in tropics and northern midlatitudes, respectively. Thus, there is a great deal of interest in their prediction and studying.

The problem here is that, the climate system is too complex to be reproduced by any laboratory experiment, urging scientists all over the world to use powerful supercomputers for its numerical simulation. Without exaggeration we can assert that, worldwide, a large number of supercomputers are dedicated to environmental problems today. For instance, the NEC SX-6, TOP500 fastest supercomputer, with peak performance 40 TeraFLOPS installed in Yokohama is supposed to be used as ‘Earth Simulator’ for climate studies as well as seismic data processing. Recently a similar machine, but with less number of processors, was purchased by the German climate computing center (DKRZ) and became the most powerful computing system in Europe dedicated to geosciences applications.

The concept of parallel processing is quite suitable for climate modeling, because the Earth climate system may be regarded as a compound of different components - atmosphere, ocean, land, criosphere, and biosphere living there own ‘lives’ concurrently and interacting from time to time each other through exchange of energy and substance at the boundaries. Moreover, domain decomposition technique is applicable for subsystems of the climate system. In our presentation, we will discuss a parallel implementation of the INM's global atmospheric model on clusters of microprocessors and present some results concerning an ocean model shared memory parallelization.

The atmospheric models is based essentially on the same equations governing the motion of atmosphere as numerical weather prediction models, but they are integrated for much longer time such as decades or centuries. Consequently, grid resolutions of atmospheric climate models are coarser than in numerical weather models, where accurate predictions are limited to about ten days. Thus, achieving high integration rates for climate models on highly parallel clusters is problematic. Operating at low resolutions effectively limits the scalability of climate models on MPP's making the choice of the dynamical algorithm to be crucial. The widespread choice here is either Arakawa-like finite differences, spectral or semi-Lagrangian methods.

The INM AGCM discretized the prognostic fields on an Arakawa staggered C-grid and makes use of semi-implicit time stepping algorithm. The model was coded in Fortran 77. We

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highlight the details of its parallel implementation on distributed memory multiprocessors which exploits two dimensional checkerboard partitioning of computational domain along both longitudes and latitudes. There are two kinds of data dependences in dynamics - one requires the boundary data from the neighboring processors (local dependences), while others all the data along some dimension (global dependences). To deal with them we developed a communication library that performs boundary exchanges and transposition of data.

Implemented in C the library is intermediate between MPI and the Fortran application. The communicated data may have quite general format, which makes it suitable for a wide range of both C and Fortran scientific applications computed on structured grids.

A comparison of explicit and semi-implicit time advancing schemes was undertaken. Besides, we compare also iterative and direct linear solvers for Helmholtz equation arising in the semi-implicit scheme.

The model physical parameterizations, such as long and short wave radiations, deep and shallow convection, vertical and horizontal diffusion, large scale condensation, planetary boundary layer, soil thermodynamics, and gravity wave drag, are mostly parallel in horizontal plane and improve the overall performance on supercomputers. Benchmarking results obtained on the MBC1000M computing system as well as on some other systems will be presented.

Another important aspect, which we would like to raise, is matching of the results of parallel computations with the sequential runs. An illustrative example is the vertical diffusion block of INM AGCM, which was subjected to modification during its parallelization and causes a round-off error. This error is quite reasonable and can be justified.