Parallel Computational Design of NJR Global Climate Models

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Abstract. An overview of a parallel computational design for global climate models, called NJR, are described. The models consist of two atmospheric general circulation models: the spectral and grid point atmospheric model, and an ocean general circulation model. The spectral atmospheric model describes the equations by using orthogonal spherical harmonic function. The computation domain is decomposed into subdomains along latitudes so that FFT is calculated in parallel without data communication. The complete-data-exchange type of communication is performed after the FFT and Legendre transformation is executed in parallel along longitude without data communication. The grid point atmospheric model and the ocean circulation model employ finite-difference method. The computation domain is decomposed into subdomains along latitude and the boundary data of each subdomain are exchanged between neighboring subdomains in each time step. The NJR global climate model is run efficiently on high performance parallel computers.

keywords: parallel computers, general circulation, NJR

1 Introduction

Computer simulation is essential to studying the global climate changes of the Earth. The climate change is driven by natural causes and human activities. The processes that make up the climate are too large and too complex to be reproduced physically in a laboratory. The computer simulation, which calculates climate evolution by solving basic equations using computers, is crucial for studying global climate change.

The simulation of global climate change requires high performance computing. Equations must be solved on Earth's entire area and integrated in time for several hundred years to simulate global warming due to human activity. Integration over several thousand years is necessary to study glacial epoch climate change. Spatial resolution less than several kilometers is required to resolve convective motion and cloud formation processes which are important factors in determining climate.
Vector-parallel computers can achieve high effective performance for global climate simulation software. Distributed memory parallel computers are categorized into either vector parallel computers, in which vector processors are connected by a high speed network, or scalar parallel computers, in which micro processors are connected by a high-speed network. Vector processors use vector registers which enable fast access to large portion of address space at any instance of time. On the other hand, microprocessors employ cache memory function that is powerful to access relatively small portion of address space repeatedly but is not effective to access large portion of address space at any instance of time. Since global climate simulation software, like any other scientific simulation software, access large portion of their address space, the vector parallel computers therefore can achieve higher effective performance than scalar parallel computers.

The global climate simulation software, structured an optimized for parallel computers, especially vector parallel computers, is an invaluable tool for global climate change study. A project was undertaken by National Space Development Agency of Japan, Japan Marine Science & Technology Center, and Research Organization for Information Science & Technology, to provide parallel global climate simulation software that run efficiently on vector parallel computers. This software is called NJR by taking the first letter of these three organizations.

The NJR consists of atmospheric general circulation and oceanic general circulation model. The simulation software is called model in the meteorology and oceanography community. The atmospheric model is well structured and optimized for vector parallel computers. The atmospheric model is implemented using both spectral and grid point methods for horizontal discretization. The fluid equations, physical processes, and numerical methods in the serial software of the AGCM model [1] developed at Center for Climate System Research of University of Tokyo are used in this model. The ocean model is also well structured and optimized for vector parallel computers. The basic equations and numerical methods of the serial software of the Princeton Ocean Model [2], POM, are employed in this ocean model.

In section 2 and 3, the spectral atmospheric and grid point atmospheric models are described, respectively. Section 4 describes the ocean model. Summary is described in section 5.

2 Spectral atmospheric model

2.1 Basic equations

The atmospheric model consists of two main parts: "dynamics" and "physics". The dynamics part represents advective change and diffusion of the atmosphere. The equations for this dynamics part are called the primitive equations in the meteorology and oceanography community. The vertical component of the pressure gradient force is always balanced by gravity force and the sound wave is eliminated in the equations. This part is represented by five three-dimensional nonlinear partial differential equations. The dependent variables, which are called