Parallel Computing of a Climate Model on the Dawn 1000 by Domain Decomposition Method①

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Received November 26, 1996; revised December 7, 1996

ABSTRACT

In this paper the parallel computing of a grid-point nine-level atmospheric general circulation model on the Dawn 1000 is introduced. The model was developed by the Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (CAS). The Dawn 1000 is a MIMD massive parallel computer made by National Research Center for Intelligent Computer (NCIC), CAS. A two-dimensional domain decomposition method is adopted to perform the parallel computing. The potential ways to increase the speed-up ratio and exploit more resources of future massively parallel supercomputation are also discussed.

Key words: Parallel computing, Climate model, DAWN 1000 MPP computer, Domain decomposition

I. INTRODUCTION

During the last two decades, the understanding of climate has been increasingly progressed. Most of improvements in this field were contributed by the climate model developer, they aim to obtain better understanding of physical processes to make detailed consideration in model physical parameterization and increase the model resolution in the near future. These tasks will use much more CPU time to perform the climate simulation experiments, and the demand for high computing speed is increasing. Now, the technological limits of traditional vector machines seem to have been reached for calculation and memory capacity. Parallelism is a promising way to satisfy the needs to obtain Teraflops at less costs. By using the domain decomposition approach, climate numerical simulation is one of the best fields to exploit the potentials of parallel computing.

As a candidate of the real application, the parallel computing of the IAP nine-level three-dimensional primitive-equation finite-difference atmospheric general circulation model developed by the Institute of Atmospheric Physics, on the Dawn 1000 is introduced in this paper.

The Dawn 1000 is a MIMD massively multi-processor parallel (MPP) computer made by NCIC of the Institute of Computing, CAS. The system consists of 36 processors. Each processor is composed of iPSC860 and 32MB memories. The theoretical peak performance of the total 32 computational processors is 2.56 Gflops in 32-bit precision. Several parallel programming environments, such as NX, PVM, EXPRESS, etc., are provided as the parallel environment to perform FORTRAN (or C) program computing.

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①This work is supported by the Chinese State Key Basic Research Programme "Climate Dynamics and Prediction Theories" and 863 project 863-306-ZD-01-9.

II. IAP 9L AGCM

Since 1984 great efforts have been made to the development of General Circulation Models (GCM) in the Institute of Atmospheric Physics, Chinese Academy of Sciences (Zeng et al., 1995). These efforts are directed to the simulation of the climate system and its variability.

The two-level atmospheric general circulation model (GCM) constructed by Zeng et al. (1987, 1989) was successful in simulating climate characteristics (Liang, 1986; Xue, 1992), in producing sensitivity experiments (Zhang and Liang, 1989), in coupling with other climate subsystems (Zhang et al., 1992) and in predicting short-term climate variability (Zeng, 1990).

From 1991 to 1995 the national key project on basic research "Climate Dynamics and Climate Prediction Theory" has been performed. As one of the most important achievements, a nine-level grid-point global atmospheric general circulation model (IAP 9L AGCM) has been built and employed to carry out numerical climate researches.

The IAP 9L AGCM is the historical descendant of IAP two-level AGCM, but with most dynamical and physical parameterizations qualitatively changed. Its dynamical framework and finite-difference scheme keep the physical coordination of overall property between difference equations and differential equations. The introduction of model standard atmosphere can effectively reduce the large truncation errors in the mountain regions. The model adopts detailed physical parameterization schemes, including both diurnal and seasonal cycle NCAR CCM terrestrial and solar shortwave radiation scheme, fine-tuned Arakawa-Schubert deep convection cumulus parameterization and Albrecht shallow convection scheme, and comprehensive surface and atmosphere interaction module developed by Liang (1996). These detailed considerations improve the physical representation of a wide range of key climate processes in IAP 9L AGCM and raise the model overall performance in numerically simulating climate, which includes the mean observed winter and summer climatology, annual cycle, climatic classification and East Asian monsoon climate (Bi, 1993).

The horizontal resolution of IAP 9L AGCM is 4^0 latitude by 5^0 longitude, the model top is 10 hPa. The model dynamical framework module is well documented by Zhang (1990), and model physics parameterization schemes are documented by Liang (1996). And a detailed description of the model released frozen version is documented by Bi (1993).

In order to facilitate the model parallelization, the whole model code is entirely rewritten with three major objectives: much easier to use and modify; conforming to a plug-compatible physics interface; and easier to modify for efficient execution on a MPP computer.

III. PARALLELIZATION

Like all atmospheric general circulation model, IAP 9L AGCM consists of two main parts: dynamics and physics. The dynamics part is composed of dry dynamics time difference and water vapor advection. As Arakawa-C grid spherical-coordinate variable structure is adopted, most of the variables related to the model dynamics are distributed skippingly in 3 directions.

The process models for radiation, clouds, surface moisture and temperature, which compute the sources and sinks in model governing equation, share the common features that they are coupled horizontally only through the dynamics. We lump all these processes under the general term "physics" and note that the physics calculations are independent for each vertical column of grid cells in the model.

The independence of the physics calculations for each horizontal grid point is the primary source of parallelism in IAP 9L AGCM. By partitioning the horizontal grid into bands and assigning them to processors, a two-dimensional decomposition of the three-dimensional,

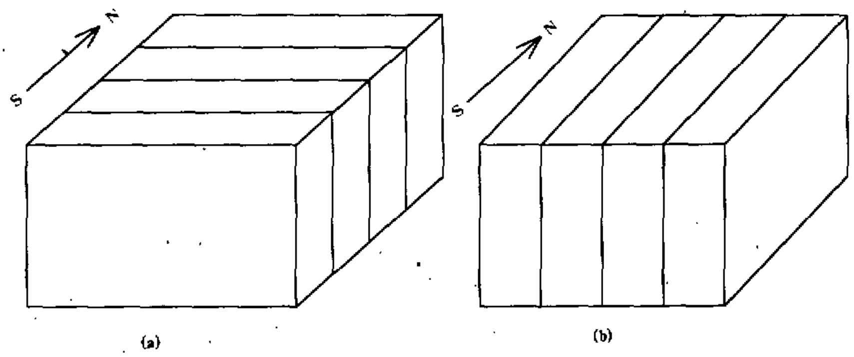

Fig. 1. the XZ and YZ plane by data decomposition along latitude (a) and longitude (b).

physical space data structure is defined. This decomposition allows the physics calculation for each verticalcolumn of grid points to be performed without the need for interprocessor communication. Because the inner loop of most subroutine of the original model dynamics is the longitude cycle, as the first step, we perform data decomposition along latitude. Fig. 1 shows the XZ plane by data decomposition along latitude and the YZ plane by data decomposition along longitude as the next step task.

Suppose we use N nodes, the original array $A(72,46)$ is decomposed to $A(72,M)$, while

$$M = (46+2)/N+2$$

By this rule, we realize the parallel computing on different N value, for example, N= 2, 4, 8, 16 nodes, the programs for different nodes number N are very similar except the subroutine related to the Arakawa's filter operator near the poles. To make full use of the Dawn 1000 by data decomposition along latitude, we have also realized the parallel program on 23 nodes, on this occasion, $M = 46/23 + 2$. To realize the parallel program, about 40 of the total 120 subroutines have been rewritten by adding message passing sentence. Most of these 40 subroutines are related to the model dynamics.

The performance of the parallel computing of IAP 9L AGCM on Dawn 1000 is listed in Table 1. The CPU time is for performing one model day integration. The parallel efficiency is not so good because the data decomposition is only latitudinal, which causes the load imbalance among different nodes. Another fact that would influence it is the memory size occupied by per node being small in contrast with 32 MB owned by per node.

Table 1. Performance of IAP 9L AGCM on Dawn 1000

Model Size 72 × 46 × 9	(72, 46) 1 node	(72, 26) 2 node	(72, 14) 4 node	(72, 8) 8 node	(72, 5) 16 node	(72, 4) 23 node
Memory Size (MB)	25.5	15.9	10.2	7.2	5.9	5.4
CPU time (sec)	4320	2526	1630	1005	732	597
Speed-up	1.00	1.71	2.65	4.30	5.90	7.23
ratio per node	1.00	0.855	0.663	0.538	0.38	0.314

IV. CONCLUSION AND DISCUSSION

The parallel computing of a climate model on Dawn 1000 by domain decomposition method is introduced. We have shown that it is fairly easy to transport the IAP 9L AGCM to the Dawn 1000 parallel MIMD computer, obtaining reasonable sequential and parallel performance by making minor rearrangements of the data and code. As this short time work is just a first step to perform a subproject "climate model parallel computing" supported by the national 863 project in the coming two years, the speed-up ratio listed in Table 1 can be increased by the following method.

1. to pack the message that needs passing between the neighbour nodes and reduce the message passing sentence calling number. By using this method, we can reduce the latency time due to message communication.

2. to reduce the load imbalance among different nodes. As our test is performed on model date January 1, there is no sunshine inside the Arctic Circle in winter, which causes the imbalance of shortwave radiation calculation among different nodes. And the convective precipitation amount and cloud amount are also imbalance among different nodes, which causes the load imbalance of radiation calculation. Our recent research demonstrates that by taking data decomposition along longitude, we can reduce load imbalance greatly.

3. to make full use of the memory supplied. Recent research shows that the parallel performance is improved significantly as the model size becomes large. We are developing a high resolution climate model on Dawn serial MPP computer.

Anyway, these results are very promising in the context of MPP parallel computer development and have confirmed our scientific choices. Further work will consist in the parallel computing of climate models, both component (such as atmosphere, ocean, sea ice and land) and coupled one.

Down 1000 is supplied to use by courtesy of the National Research Center for Intelligent Computing Systems. The author is grateful to Profs. Zhu Mingfa and Qiao Xunzhen for their help and to the engineers at NCIC for their technical support, and also to Prof. Wang Bin for his joining this work.

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