Parallel Ocean General Circulation Model for Distributed Memory Computer Systems

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Introduction.

One of the most actual problems of a modern science is the problem of global changes of environment, including global changes of a climate. The important part of this problem is investigation of World Ocean, its meso-and large- scale hydro physical variability. The important directions of this research are mathematical modeling and the computer experiment that can be performed using the numerical models of the general circulation of ocean. For the adequate description of currents structure, eddies, coastal and deep dynamics of oceanic processes the high spatial resolution is required. In research of long-period dynamic of ocean it is necessary to carry out integrations over many decades or even centuries. These tasks require large computational resources. Therefore modern models of the general ocean circulation are implemented on multiprocessor computers [1-3] that allow considerably to speed up computations.

At the Institute of Numerical Mathematics, Russian Academy of Sciences (INM RAS) consecutive model of ocean dynamics has been developed [6]. In contrast to the most of widely used ocean models INM RAS model is based on a splitting method and implicit schemes to solve the model equations in [4]. Due to this algorithm it is possible to imply large time steps with saving numerical stability For uniprocessor systems model INM RAS is one of the fastest among existing ocean dynamics models.

At the present time the consecutive model of ocean general circulation allows to make calculations for a long period with the spatial resolution 2,5°x2° (on longitude and latitude) and 33 irregular vertical levels [6]. Also this model is the oceanic part in coupled model of atmosphere and ocean circulation INM RAS.

However for the resolving eddies in ocean and their contribution into large-scale circulation it is necessary to make calculations at the spatial resolution not less than 1/2°x1/2° [3] for hundreds years. Adjustment of model parameters also needs a large number of experiments. Due to the computational cost of running a 3-dimensional OGCM these applications are far from having been exhaustively run.

In INM RAS has been developed the parallel version of model of World Ocean for computers with the shared memory [5]. This work is devoted to development of the parallel program for general ocean circulation model of the INM RAS for multiprocessor computational systems with the distributed memory.

Model Equations and its Solution Method.

The model is based on primitive equations [4][6] on a sphere using of vertical σ-coordinate. The equations are discretized on a staggered Arakawa-C-type grid. The grid is regular in longitude and latitude and irregular in vertical coordinate. Prognostic variables are: *u,v* - the horizontal velocity components, *T* - the temperature, *S* - the salinity.

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The procedure of solution model equations is based on splitting method on physical processes and space coordinates [7]. Its idea is the representation of the full operator of the problem as a sum of simple operators. Every particular operator corresponds to any "elementary" physical process. The main modules in this algorithm are following: the solution transport-diffusion equations, stream function module, parameterization of the convection and geostrophic adaptation fields of speed and density.

Parallelization technique.

The single program multiple data (SPMD) approach with the master process for I/O is used. Data exchanges between processes are implemented with MPI (Message Passing Interface).

The main difficulties in parallelization of program are connected with the solution of transport-diffusion equations and calculation of stream function. The additional difficulties are caused to the data shift on a grid "C" and the complexity of computational area.

In parallel program one-dimensional domain decomposition is applied. Each of sub domains is calculated on single processor.

Such selection of domain decomposition is connected with using tridiagonal solver to obtain the solution of one-dimensional transport-diffusion equations. It is necessary to keep all needed data for solver on the one processor. The one-dimensional equations are obtained because implicit coordinate splitting method for 3-dimensional transport–diffusion equations is applied. One-dimensional decomposition is also needed for solving linear equations in stream function evaluation, because block-diagonal preconditioner is used.

In transport-diffusion module algorithm with data transposition is implemented. At first longitude data decomposition is applied and one-dimensional tasks in latitude and vertical coordinates are solved. Then we have to transpose data to latitude decomposition and to solve tasks in longitude coordinate. After that the data are transposed again for the subsequent calculations. Thus two operations of transposition are required at each timestep.

The task of stream function evaluation is reduced to the solution of linear system equations with size (NX*NY)*(NX*NY), where NX and NY - number of points on longitude and latitude. The system matrix is block tridiagonal but it has no a symmetry. In consecutive algorithm the successive overrelaxation successive method was applied to the solution of this system. In case of cyclical boundary conditions this method does not enable the parallelization. For the parallel program this method was exchanged by a method of the Jacobi. The number of iterations has grown twice but this method, from the point of view of the parallelization, is identical to matrix vector multiplying and can be effectively implemented into multiprocessing systems.

Another problem is the automatic choice of the decomposition of complex computational area into one-dimensional subregions, in order to balance load on the processors. If to apply an uniform distribution on a latitude and longitude, then, for example, for world ocean computational area it is able to appear, that the load on one processor is more than on others by some times. The uniform distribution on number of calculation points was applied to solve this problem. The more advanced algorithm of automatic partitioning is also designed, which takes into account the shift of grids for different data types (temperature, speeds and flow function).

For parallelization procedures of geostrophic adaptation fields of speed and density, calculations of vertical diffusion coefficients and convection parameterization are enough to exchange neighbour with each subdomain data elements.

Performance.

Parallel program of ocean dynamics model of INM RAS was developed and tested on supercomputer MVS-1000M. It is possible to exploit the program on different types of modern computers.

During the development of the model it was possible to satisfy the requirement of coincidence of all significant figures of machine representation calculations results of work of the parallel program on several processors, with results received on one processor. Due to applying the "master" processor for input-output, three-dimensional fields models variables and also average characteristics of these fields completely coincide. Such requirement allows to test the parallel program quickly. The first message about mistakes is discrepancy of average of temperature, salinity, speeds and energy in the model.

In parallel program total speed up 12 was received on 32 processors on the resolution 2.5°x2°x33 (144x88x33) and speed-up 68 on 180 processors on the resolution 0.5°x0.4°x33 (720x420x33) (efficiency 36%). At the further increase of number of processors speed-up will increase slightly or even decrease.

Conclusions.

In comparison with other models of ocean dynamics and models of atmosphere, it is possible conclude that usage of the locally one-dimensional implicit schemes makes worse parallel properties of a solution method. It is explained by the necessity to apply one-dimensional area decomposition, which has the worse properties as contrasted to 2D-decomposition.

Despite of worse parallel properties of an implicit method to solve the ocean dynamic equations, the total speed of computations may appear higher than in models with the explicit schemes due to the larger step on time.

With the help of the parallel program the calculations of world ocean dynamics with the spatial resolution 0.5°x0.4°x33 are provided.

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