Eddy-resolving Simulation of World Ocean Circulation using the PFES
– Toward the Sophisticated J-COPE Project –

Group Representative
Takashi Kagimoto Frontier Research System for Global Change, Researcher

Author
Takashi Kagimoto Frontier Research System for Global Change, Researcher

We carry out the development of the PFES (Princeton Ocean Model for the Earth Simulator). The hybrid-type parallelization technique using the Message Passing Interface library for the internode communication and the microtasking method for the intranode communication enables us to attain a satisfactory level of the parallelization performance. We also establish a 33years climatological eddy-resolving simulation of the global ocean using the PFES forced by the NCEP/NCAR reanalysis data. A preliminary simulation provides many realistic features in terms of the global aspect, while the representation of the Kuroshio path south of Japan is not so good. This serious problem in the Kuroshio path is common in many ocean general circulation model. Therefore we will be able to clarify what is the cause by comparing our model results to others.

Keywords: ocean circulation, Kuroshio, POM, GCM

Report of our result

Model development

We develop the parallelized ocean general circulation model called as the PFES (Princeton Ocean Model For the Earth Simulator). This model is based on the Princeton Ocean Model (POM), because it is certainly preferable to the simulation of the coastal ocean. The original code of the POM is fully vectorized and thus we need to do less thing for the vectorization. More than 99.5% vectorization ratio is easily attainable. Of course this value depends strongly upon the average vector length of the program code. On the other hand, the POM should have been parallelized in order to utilize it on the Earth Simulator. We apply a hybrid-type parallelization technique, that is, a combination of an internode communication with the Message Passing Interface (MPI) library and an intranode communication with a microtasking method.

Although the program code parallelized with the hybrid-type strategy becomes quite complex, the adoption of the microtasking method might be effective to attain a good parallelization performance particularly on the SMP (Symmetric MultiProcessing) type parallel computers such as the Earth Simulator. On such the computer, data exchange between neighbor processors are not necessary because the memory space is shared by all processors in a processing node. Besides the memory space that each process requires can be reduced. Thus the microtasking method has great merits in parallelizing the program code.

Other thing that we did is to rewrite the program code with Fortran90. Specifically the data object of most variables is changed from a simply array to a structure. This structure has three members: two-dimensional or three-dimensional array data itself; and widths of the shadow area in the lower and the upper sides of the second index of the data (we adopt one-dimensional domain decomposition method). This enables us to easily change the width of the shadow area. This means that the replacement of a numerical scheme is quite easy with least modification of the code. It is also easy to change one-dimensional domain decomposition method to two-dimensional one by including two additional members into the structure, that is, widths of the shadow area in the lower and the upper sides of the first index of the data.

Parallelization performance

We check the parallelization performance of our program code with the problem size 3604x1502x55. The wall clock time is evaluated from the 5days simulation with 10, 32 and 188 processing nodes. Figure 1 shows the speed-up with respect to the wall clock time with 10 processing nodes. It is clear by comparing to that with 10 processing nodes that the parallel computation with 32 processing nodes does not deteriorate the performance. The parallelization effciency is about 92.12%. As the number of processing nodes that the program code utilizes increases, the parallelization effciency, as you expect, becomes worse. In our case, the speed-up

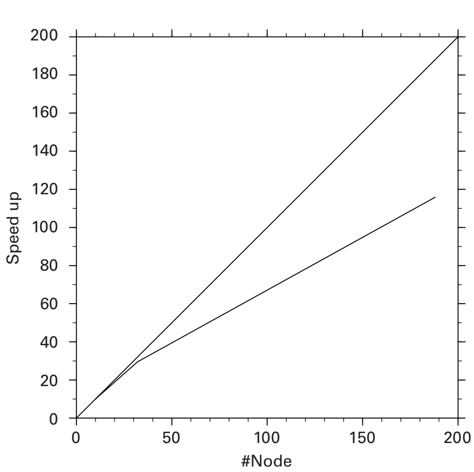

Fig. 1 Speed-up with respect to the wall clock time with 10 processing nodes. This solid line is 100% speed-up line and the thick solid line indicates measured values.

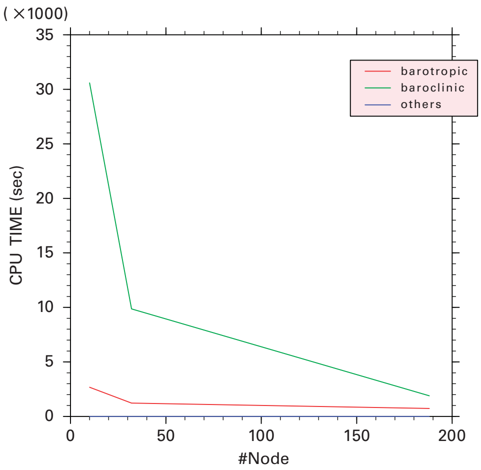

Fig. 2 Wall clock time of three major procedures in the ocean model. Red line indicates the wall clock time of the three-dimensional baroclinic calculation, the green one for the two-dimensional barotropic calculation and the blue one for others.

value with 188processing nodes is approximately 120. This corresponds to 61.72% parallelization effciency. Note that we do not use all processors of 188 processing nodes (1504 processors) for this evaluation, because the one-dimensional domain decomposition method that we adopted is applied to the meridional direction in which there are 1502 grid points.

Figure 2 shows the cost of three major procedures in the ocean model with various number of processors. It is not surprising that three-dimensional calculation costs more than 90% of the total calculation in the ocean model. As the number of processing nodes increases, the cost of the three-dimensional calculation is extremely reduced up to approximately 72% with 188 processing nodes. On the other hand, the cost of two-dimensional calculation increases from 8% to 29% as the number of processing nodes increases from 10 to 188. This is due to appearance of communication time between neighbor nodes. Although the program is coded so ingeniously that communication procedures as much as possible are hidden behind the actual calculation by adopting the non-blocking communication method, it cannot be effective in the two-dimensional calculation because the actual calculation time is, in some case, shorter than the communication time.

Model results

We carry out a climatological simulation of the global ocean circulation using the PFES (the Arctic Ocean is excluded from the calculation in order to avoid the polar problem). The horizontal resolution is 0.1 degree in both zonal and meridional directions. The number of vertical levels is 55 sigma levels. The model is forced by the long-term average of the atmospheric condition based on the NCEP/NCAR (National Center for Environmental Prediction/National Center for Atmospheric Research) reanalysis data. So far 33 years integration is established. In this report, we will describe a couple of examples of the model results. One is a global feature and the other in the western North Pacific.

The sea surface height (hereafter SSH) of the global ocean is shown in Fig.3. The contrast of the SSH associated with

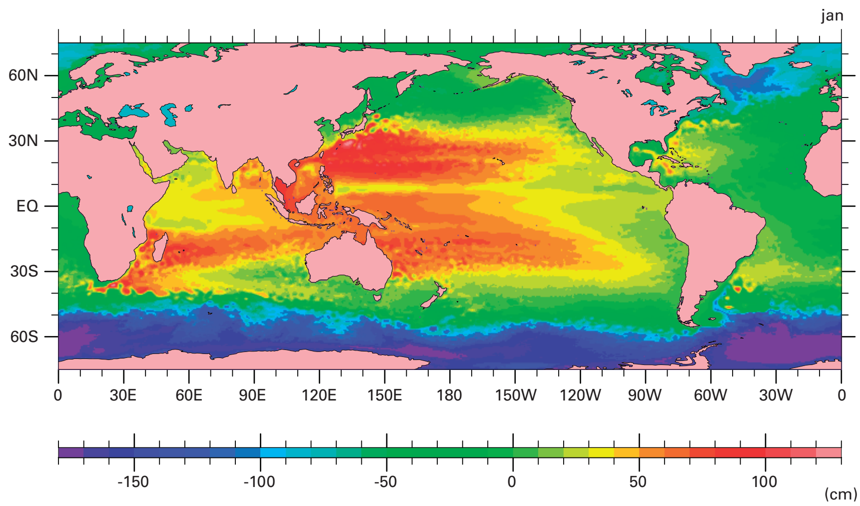

Fig. 3 Monthly mean sea surface height on January of 33rd year. Contour interval is 10cm.

the subtropical gyre such as the Kuroshio and the Gulf Stream (higher regions) and the subpolar gyre such as the Oyashio and the Labrador Current(lower regions) is represented well. The large gradient of the SSH associated with the Antarctic Circumpolar Current is also clear. Some traces of meso-scale eddy passages can intriguingly be seen in the Gulf of Mexico (eddies shed from the Loop Current) and in the southwest of the African Continent (the Agulhas Rings). These features are quite similar to the real ocean.

Figure 4 shows the monthly mean sea surface temperature in the western North Pacific on January of 33rd year. The subtropical and subpolar fronts are simulated well. However path of the Kuroshio is not realistic. Specifically the Kuroshio detaches the coast at the south tip of Kyushu Island, flows eastward to 138˚E and attaches the coast south of Kii Peninsula (In Fig.4 the Kuroshio path can be traced by 21–22 ˚C isotherm). As far as we know, this path has not been observed in the real world. Therefore some defect may exist in the model. But it is not only in the PFES, but in others. In fact, the OFES (the MOM3-based Ocean model for the Earth Simulator), CCSM2 POP (the Community Climate System Model Ver.2 Parallel Ocean Program) and other models, which are run on the Earth Simulator with a high horizontal resolution comparable to ours, represent similar feature in the Kuroshio path. Therefore it seems a common feature in the ocean general circulation model.

Since our final goal is to construct the more sophisticated "ocean weather forecast system" for the Kuroshio than the current J-COPE system, the representation of the Kuroshio path is a serious issue. We need to investigate what is the cause as soon as possible. The clue to solve this problem is perhaps provided by the analysis of the dynamical balance particularly near the Japanese coast. In the onshore side of the Kuroshio, the positive vorticity is generally fed by the coast through the viscous process. If the positive vorticity is not dissipated enough, a cyclonic circulation might be generated in the onshore side of the Kuroshio. This means that it is quite important to pay attention to the dissipation process of the vorticity. In the PFES, the horizontal viscosity is evaluated by the Smagorinsky model (the viscosity is proportional to the total strain rate), while the biharmonic viscosity is used in others. This suggests that the subgrid scale parameterization is insuffcient, especially to simulate the realistic western boundary current such as the Kuroshio. This will be a research subject in the future.

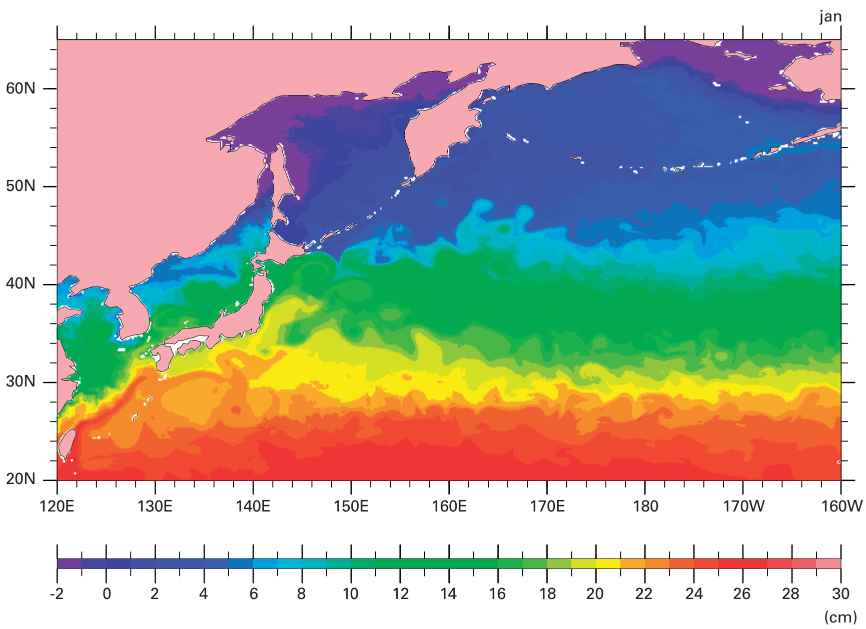

Fig. 4 Sea surface temperature in the western North Pacific on January of 33rd year. Contour interval is 10cm.

日本近海予報実験を念頭においた超高解像度世界海洋大循環モデル実験

利用責任者
鍵本　崇　地球フロンティア研究システム　研究員
著者
鍵本　崇　地球フロンティア研究システム　研究員

プリンストン大学海洋大循環モデルを地球シミュレータ用に並列化したPFES(Princeton Ocean Model for the Earth Simulator)を開発した。並列化手法は、MPI(Message Passing Interface)によるノード間通信とマイクロタスキングによるノード内並列を組み合わせたハイブリッド型の方法を採用した。これにより、ある程度満足のいく並列性能を得ることができた。このPFESを用いて、渦解像度の全球海洋循環のシミュレーションを行った。海洋の水温および塩分の気候学的状態から、NCEP/NCARの再解析大気データセットを外力としてモデルを駆動し、これまでのところ33年間の積分を完了している。大規模循環場については観測と符合する現実的な海洋の状態が再現されているのに対し、黒潮の流路については観測とは一致しない非現実的な結果であることが分かった。しかもこの非現実的な流路はPFESだけではなく、その他の高解像度海洋大循環モデルにおいても見られる共通の問題であることがモデル間相互比較で分かった。詳細についてはまだ検討中であるが、サブグリッドスケールのパラメタリゼーションが鍵となっているのではと現在では考えている。

キーワード：海洋大循環、黒潮、POM、GCM