Development of Coupled Ocean-Atmosphere-Sea ice Model with Optimized Computational Performance on the Earth Simulator

Group Representative

Keiko Takahashi The Earth Simulator Center, Research Scientist

Author

Keiko Takahashi The Earth Simulator Center, Research Scientist

In this project, we have been developed a coupled atmosphere-ocean-sea ice model for the Earth Simulator (CFES), which can show good computational performance for high-resolution simulation on the Earth Simulator (ES). CFES is composed of AFES and OFES that both of them were optimized to archive high parallel efficiency on the ES. Sea ice model, which has been developed under collaboration among Frontier Research System for Global Change, International Arctic Research Center and the Earth Simulator Center, was introduced to OFES in this project. CFES is characterized by fully parallelized and distributed coupler to transfer physical data from one component to the other and back again. That brought us good cost performance on the ES due to reduction in communication overhead. I/O interaction was also distributed to reduce communication cost by dealing with distributed files. CFES is able to control parallel performance efficiency and amount of resources to be used by changing the number of nodes which employed AFES and OFES with sea ice. Interpolation scheme had been improved to well conserve the physical values throughout coupling interface. In addition, tiling scheme was introduced to calculate physical values on a grid which was composed by sea and land attribution. Physical performance of CFES was validated in cases of resolution with T106, T319 and T639, those results were reasonable by comparing with observed data.

Keywords: Coupled atmosphere-ocean GCM, the Earth Simulator, high-resolution simulation, parallel optimization, concurrent computation

1. Introduction

Coupled atmosphere-ocean GCM (CGCM) provides the most powerful tool to reproduce, understand and project main features of climate change. It is necessary scheme for research interaction between atmosphere and ocean. However, the great expense of running CGCM has been hesitated of development by limiting the number of calculations and by prohibiting the use of the reasonable resolution for satisfying physical requirements. The Earth Simulator (ES) makes it possible to carry out the huge scale simulation. Our

	4	5	6	7	8	9	10	11	12	1	2	3
Development of CFES												
Multi-process programming & implementation	→	→										
Parallelization, Distribution for I/O of couplipng	→	→										
Extension of coupling scheme for mosaic grids	→	→	→	→	→	→						
Validation and Estimation of coupling scheme					→	→	→	→	→	→		
Parallel optimization of CFES	→	→	→	→				→	→	→		
Inplementation of sea-ice component on OFES	→	→	→	→	→							
Computational optomization of sea-ice component					→	→	→	→				
Validation of OFES with sea-ice component				→	→	→	→	→	→	→	→	→
Progress of river runoff and models					→	→	→	→				
Improvement of interpolation schemes								→	→	→		
Arrangement of manuals for users									→	→	→	→
Physical Validation												
For T106, T319 resolution cases of CFES												
long time scale integration, phyisical validation				→	→	→	→	→	→	→	→	→
For T639 resolution cases of CFES												
long time scale integration, phyisical validation										→	→	→

Table 1 Annual schedule for developing CFES

objective here is to develop a coupled atmosphere-ocean-sea ice model for the Earth Simulator (CFES), which can carry out century time integration with high resolution within reasonable turnaround.

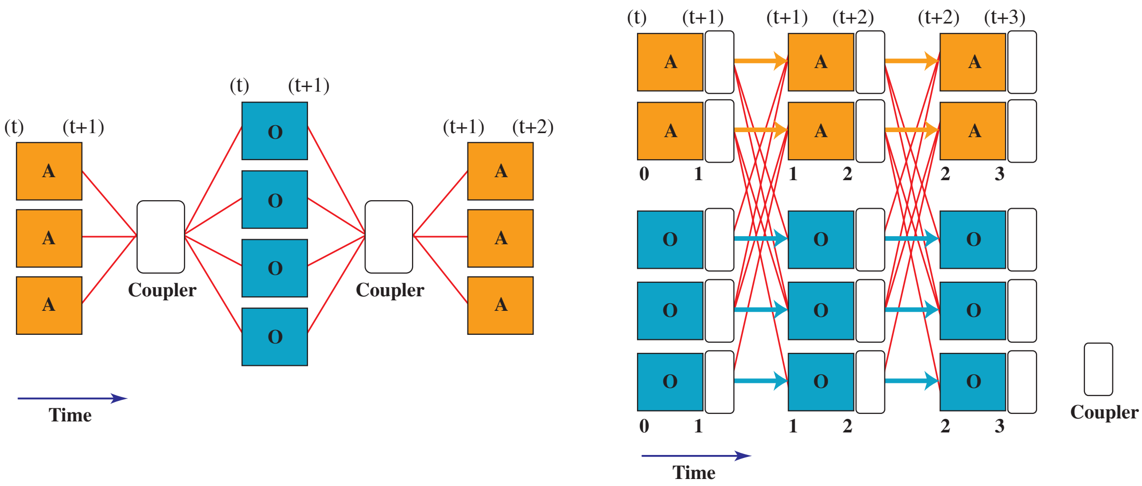
CFES is composed of ocean general circulation model for the Earth Simulator (OFES) with sea-ice model and atmospheric general circulation model for the Earth Simulator (AFES). Both of component models have been optimized for computational performance to be run on the ES. CFES has been designed so that computational efficiency of each component is employed in the maximum on the ES. From a physical viewpoint, coupling mechanism remains still unclear. Therefore, interface between atmosphere and ocean should be modeled and implemented taken into account to maintain a self consistent representation. To remove causative artificial factor of the inconsistent through sequential coupling scheme, CFES has been developed so that individual component can run in parallel with fully parallelized coupling scheme.

This project has been promoted with annual schedule as shown in Table 1. All of the tasks have been finished on the schedule, which included introduction of sea-ice component, extension of coupling scheme for any longitude-latitude grid systems and modification of run-off model. Environments for executions by using CFES and manuals for users have been ready for use. In this report, summary of the progress on developing CFES in FY2002 is described. In section 2, characteristics of CFES are presented, especially, regarding as coupling scheme and computational performance. Short summary of validation results for CFES is shown in section 3.

2. Characteristics and computational performance of CFES

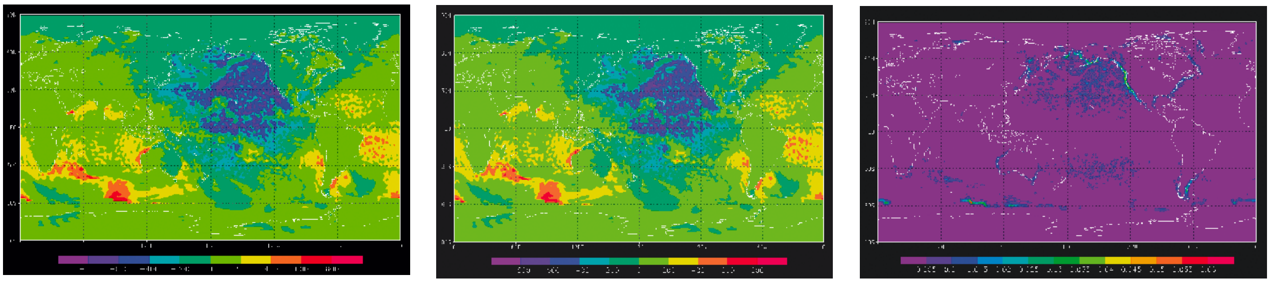
2.1. Coupling interface

In coupling frame work, AFES and OFES components are linked for exchanging physical parameters such as heat flux, fresh water flux, and momentum flux, without flux correction. Ordinarily, each component was coupled with simple serial scheme, as shown in Fig.1(a), so that it does not allow us to model a self consistent interaction between air and sea. In CFES, parallelized structure of CFES was adopted by assigning separate groups of nodes to AFES and OFES. At the same time, interface for coupling was also parallelized and distributed. This framework enables us to archive by



(a) Ordinarily coupling scheme (b) communication for coupling in CFES

Fig. 1 Structure of coupling interface between atmospheric and ocean GCMs.



(a) (b) (c)

Fig. 2 Residual estimation between AFES component with T106 and OFES component with half of T106 resolution. (a): Three hours averaged heat flux distribution data from AFES component, which was used as input data before interpolation, (b): data obtained from OFES component after interpolation, and (c) shows residual between AFES (a) and OFES (b). Residual was converted on AFES grid system.

allowing concurrent execution for exchanging data between AFES and OFES. This entails executing all components from time (t) to (t+1) at the same time as shown in Fig.1(b). From results of implementation, CFES could remove one of causes of the drift due to order of execution. Distributed data exchange implementation of coupling has also achieved reduction of communication costs.

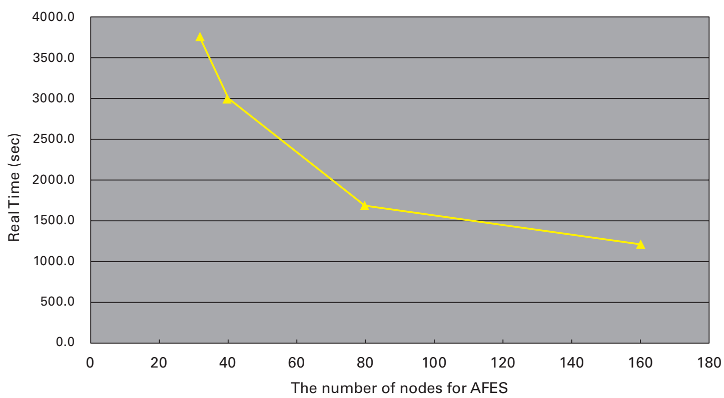
In coupling interface, total amount of physical value transformed from AFES to OFES component has to be conserved. After one step interpolation for heat flux, residual of total sum of heat flux was within 2.48D-10% in cases that the number of grids in OFES component was divided into two times of AFES component with T106 resolution, as shown in Fig.2. Along the east coast of North American continent, error shows maximum value due to steep distribution of heat flux.

Further modification and progress were made, for example, improvement of calculation of radiation on mosaic grids that contains atmospheric and oceanic attribution, extended interpolation schemes to conserve physical value, introduction of river-runoff model, although details of those results were not described in this report due to limited space.

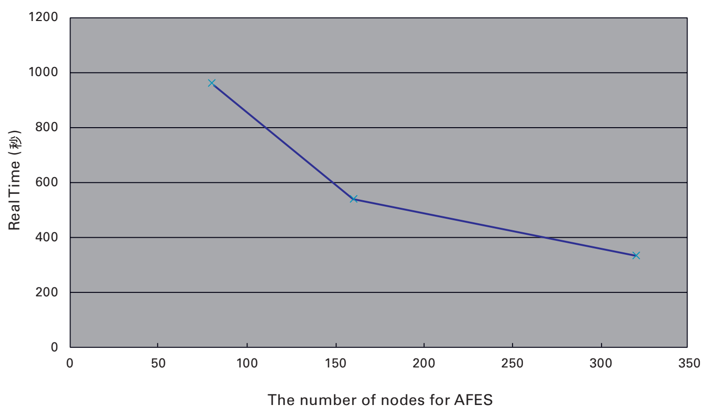
2.2. Computational performance

The target resolutions of AFES/OFES components are T106, T319 and T639 for horizontal. For vertical levels, AFES/OFES components have 48/37 levels, respectively. In this report, results from CFES with T639 and T319 for horizontal with 1-2-1 filtering in the polar region (85°N-90°N, 85°S-90°S) are presented. For polar region of ocean part, micro tasking was introduced to avoid load imbalance between nodes of polar region and others.

Fig.3(a) shows parallel performance of CFES with T319 (about 40km) under condition that 11 nodes were fixed for OFES component. It takes about 1.0 CPU hour for 30 days integration on 171 nodes of ES that include 160 nodes for AFES component and 11 nodes for OFES component. Fig.3(b) presents computational performance for T639 (about 20km) horizontal resolution cases. In the best performance case of T639, 381 nodes were used for estimation of parallel efficiency, which include 320 nodes for atmosphere component and 61 nodes for ocean component. For both cases of T319 and T639, rate of parallelism have reached 99.99%. Especially, for the case of T639, performance corresponds to 32.64% of theoretical peak performance 24.38 Tflops has been achieved on 381 nodes of the ES. The sustained performance of 7.93 Tflops was achieved for CFES with T639 resolution by utilizing 381 nodes. From the results of 10 days integration by using CFES with T639 horizontal resolution, it takes 2088.70 seconds as elapsed time which includes cost for I/O procedures. Therefore, it is estimated that 1 year integration for T639 resolution cases requires about 21.2 CPU hours by using 381 nodes of the ES.



(a) performance of 10 days integrations for T319.

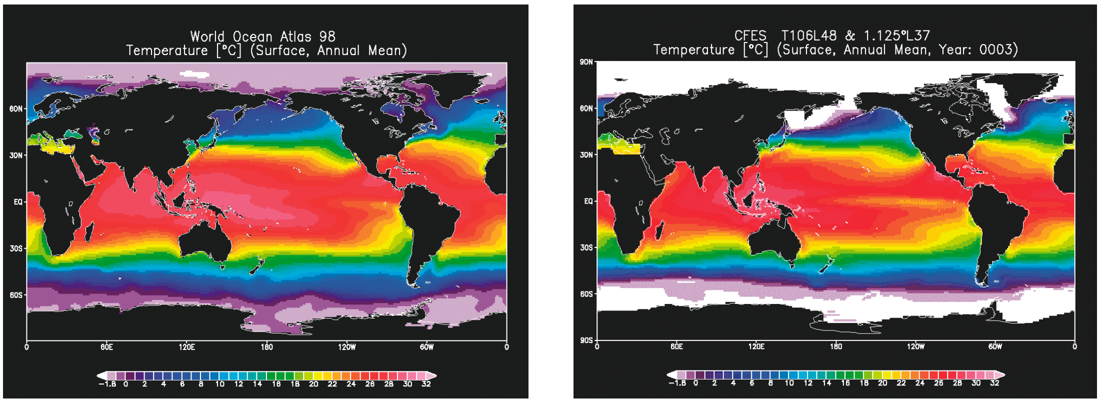


(b) performance of T639 for 1 day integration

Fig. 3 Parallel performance of CFES.

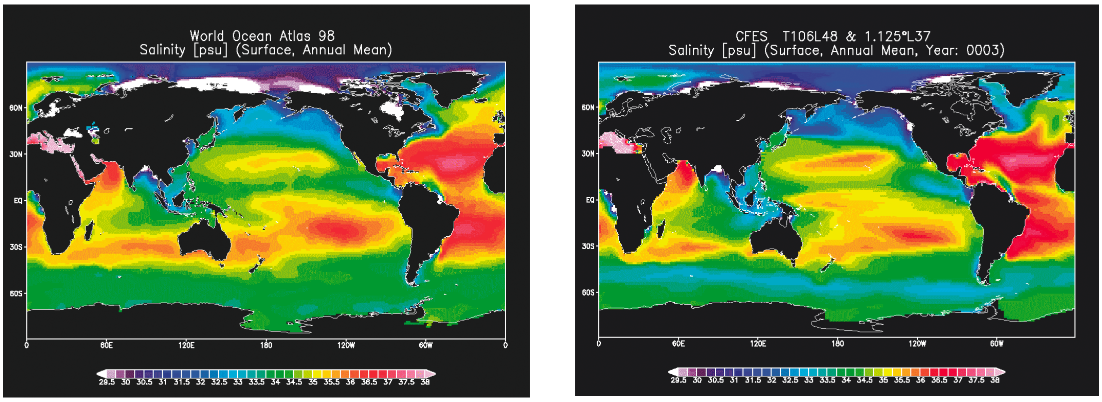
3. Summary of validation for CFES

We show preliminary results of CFES with T106 after three years integration on the ES. Fig.4 and Fig.5 present annual mean distribution of sea surface temperature and sea surface salinity, respectively. Although integration term is too short to validate its physical performance, those distributions are reasonable comparing with observed data. In Figure 6, vertical distribution of temperature on equator band between 2 degree of North and 2 degree of South is showed. Those distributions are also acceptable at present state. For details of results, several informal reports in the Earth Simulator Center are introduced as references.



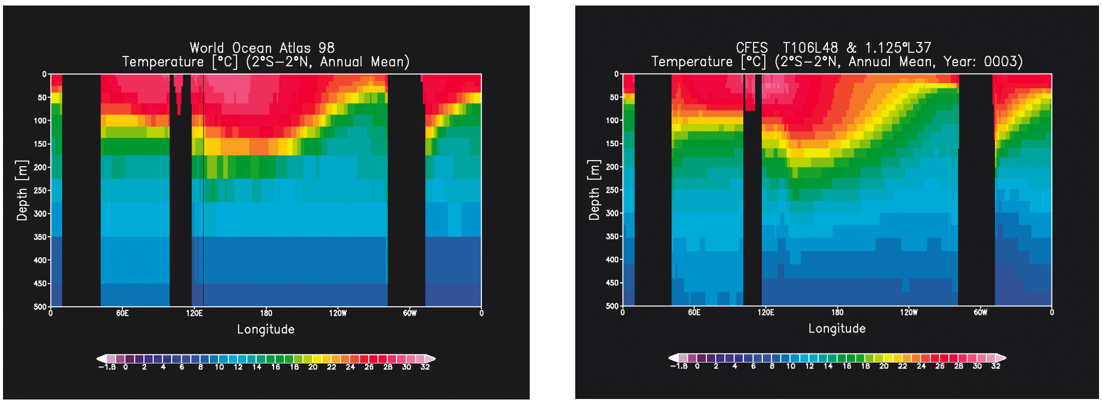
(a) observed data. (World Ocean Atlas '98) (b) results from CFES.

Fig. 4 Annual mean distribution of sea surface temperature. (a) show observational data from WOA98, and (b) present results from CFES with T106 horizontal resolution.



(a) observed data. (World Ocean Atlas '98) (b) results from CFES.

Fig. 5 Annual mean distribution of sea surface salinity.



(a) observed data. (World Ocean Atlas '98) (b) results from CFES.

Fig. 6 Annual mean of vertical distribution of temperature.

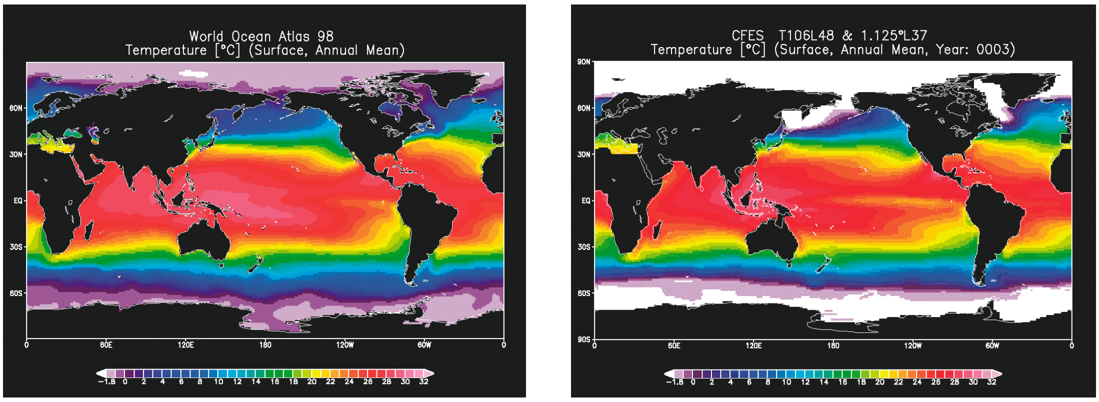
地球シミュレータの特性を活かした
大気－海洋－海氷結合モデルの開発と気候変動予測のための基礎的実験

利用責任者
高橋　桂子　　地球シミュレータセンター　研究員

著者
高橋　桂子　　地球シミュレータセンター　研究員

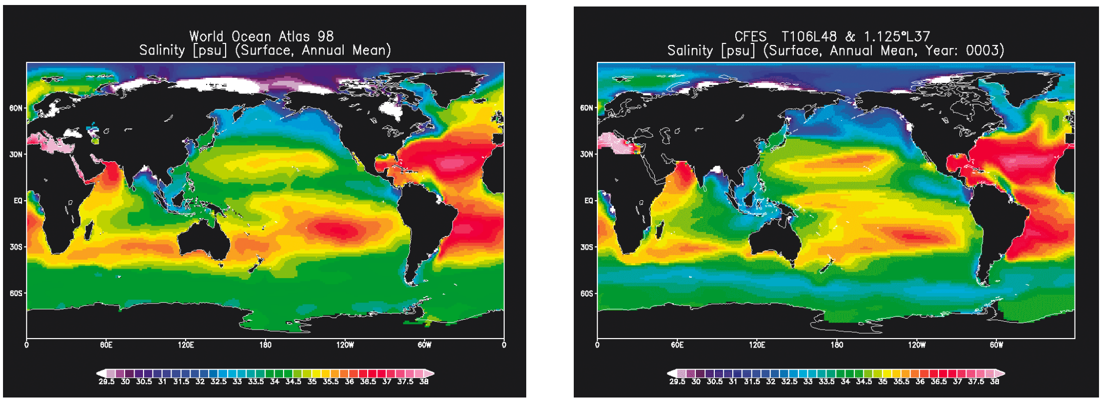
AFESと海氷モデルを含むOFESを、本結合モデルのコンポーネントとし、地球シミュレータの計算能力を最大限に利用可能な大気・海洋・海氷結合モデル(Coupled Atmosphere-Ocean-Sea Ice Model for the Earth Simulator: CFES)を開発した。大気、海洋・海氷の各コンポーネントは独立に実行可能であり、その並列性をコンポーネントごとに制御できる。コンポーネント間の物理量の交換は、MPI通信を介して完全に並列化した分散処理により行う。緯度－経度座標系であれば、異なる任意の解像度をもつコンポーネント同士を結合することが可能であり、全球総和フラックスを保存する。各コンポーネントの解像度がT639(水平約20km)の場合、1年積分を実行するために地球シミュレータ381ノード上で、約21時間必要である。現在さらにモデルの改良を進め、物理的性能検証中であるが、海面水温が寒冷化する傾向があるものの、現時点においてはほぼ妥当な結果を得ている。

キーワード：大気海洋結合モデル、地球シミュレータ、高解像度シミュレーション、並列化性能、並列同期処理



(a)観測値(World Ocean Atlas '98より)　(b)CFESのシミュレーション結果(解像度：T106)

図1　海面水温の年間平均分布



(a)観測値(World Ocean Atlas '98より)　(b)CFESのシミュレーション結果(解像度：T106)

図2　海面塩分の年間平均分布