Research Development of 4-Dimensional Data Assimilation System using a Coupled Climate Model and Construction of Reanalysis Datasets for Initialization

Group Representative

Toshiyuki Awaji Frontier Research System for Global Change, Group leader

Department of Geophysics, Kyoto University, Professor

Authors

Shuhei Masuda [*1] ・ Toshiyuki Awaji [*1, 2] ・ Wataru Ohfuchi [*3] ・ Nozomi Sugiura [*1]

Keiko Takahashi [*3] ・ Nobumasa Komori [*3]

＊1 Frontier Research System for Global Change

＊2 Department of Geophysics, Kyoto University

＊3 The Earth Simulator Center

We have developed a 4D-VAR ocean data assimilation system which works efficiently on the Earth Simulator (ES). The performed computational speed of our assimilation system reaches 57.4 GFLOPS in the case with 1° horizontal resolution. This system has been used to better define the seasonal change in the state of global ocean. The obtained dynamically consistent time-varying reanalysis dataset exhibits realistic features of ocean circulations, and enables us to qualify the water mass formation and movement process. The sea-ice component of the Coupled Atmosphere-Ocean-Sea Ice Model for the ES (CFES) has been ported to the ocean data assimilation system toward a coupled assimilation system. The sea-ice component works correctly in the test case with low resolution. As an atmospheric component of the coupled assimilation system, the Atmospheric General Circulation Model for the ES (AFES) achieved a computational speed of about 27 TFLOPS with the full configuration of the ES. With AFES on the ES, we performed a set of meso-scale resolving global atmospheric simulations with the T1279L96 resolution (horizontally 10-km grid size) to succeed to reproduce some realistic phenomena in the atmosphere, which cannot be obtained by earlier global models. In addition, adjoint code of AFES is being developed with the use of a semi-automatic differentiation tool TAF. Now, we continue to develop each component and are going to incorporate them into a coupled system based on CFES. Pilot experiments with CFES are conducted successfully to exhibit high computational and potentially physical performance.

Keywords: Data Assimilation, Coupled Model, Climate Variability

1. Parallelization of ocean data assimilation system for the ES

We have developed a 4D-VAR ocean data assimilation system which works efficiently on the Earth Simulator (ES). In our MPI version, domain decomposition is made 1-dimensionally in the latitudinal direction. Besides, as the adjoint calculation needs huge amounts of information from the forward calculation, we applied some efficiency treatments to the data; temporal interpolation method and separate preservation of data for each domain to the disk mounted on each node. The performance of 4D-VAR ocean data assimilation system was tested using 1°×1° global model (Table 1). It measured by assimilation from first guess run to the 8 cycles of the iteration which include 17 forward integrations for 13 months, 8 adjoint integrations and 8 conjugate gradient calculations. One cycle of the iteration can be accomplished within about 1 hour.

This system has been used to better define the seasonal change in the state of global ocean. The obtained dynamically consistent time-varying reanalysis dataset exhibits realistic features of ocean state (Fig. 1), which enables us to clarify not only the distribution of water mass but also its formation and movement process.

Table 2 illustrates the performance of a high resolution North Pacific model (1/4°) which was measured by 1-year integration. A high computational speed of 489 GFLOPS was achieved on the ES.

2. Implement of ice model for coupled system

The sea-ice component of CFES (Coupled Atmosphere-

Table 1 Performance of 1˚ ×1˚ assimilation.

integration period	13	months
number of assimilation cycles	8	cycle
CPU	31	CPUs
elapsed time	8.86	hours
vectorization ratio	98.6	%
floating point performance	57.4	GFLOPS

Table 2 Performance of 1/4˚ ×1/4˚ model.

integration period	1	year
CPU	190	CPUs
elapsed time	1.69	hours
vectorization ratio	99.1	%
floating point performance	489	GFLOPS
parallelization ratio	99.6	%

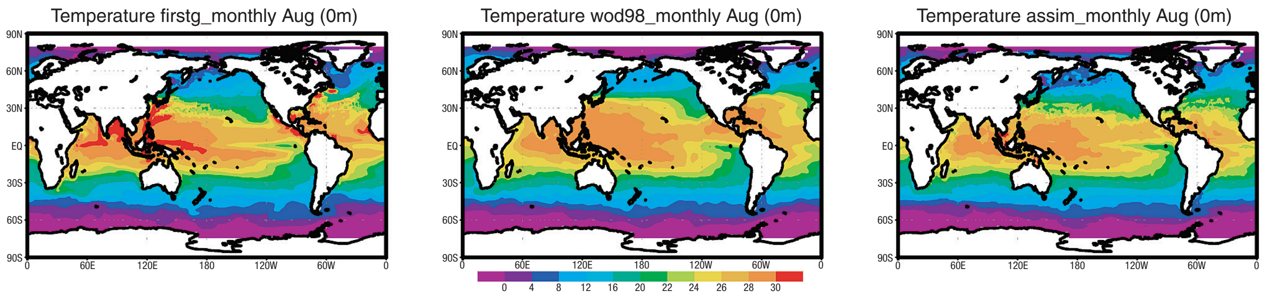

Fig. 1 Summertime SST distribution; (a) simulation, (b) observation, (c) assimilation.

Ocean-Sea Ice Model for the ES) has been ported to the ocean data assimilation system. We execute the system with low horizontal resolution in order to examine the computational and physical performance. The computational domain for the test runs covers a near-global region extending from 75˚S to 75˚N with horizontal resolution of 3˚. The surface forcings that drive the model are the monthly-mean climatologies. Figure 2 compares elapsed time and parallel efficiency between the cases with different number of processor elements (1, 5, 8, 10, 13 and 25) on the ES. As seen in this figure, increase in elapsed time due to introduction of sea-ice process is little. Monthly-mean fields of sea-ice concentration in February and August of the first model year are shown in Figure 3. The seasonal cycle of sea-ice distribution especially in the Okhotsk Sea, the Bering Sea and the Antarctic Ocean is reasonably reproduced. These results show the sea-ice component implemented in the assimilation system seems to work correctly. The adjoint version of the sea-ice component is going to be prepared.

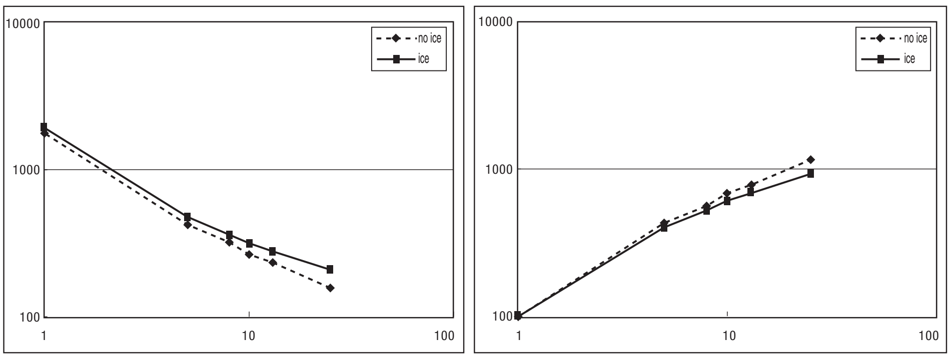

Fig. 2 Comparison between the cases with different number of PE (1, 5, 8, 10, 13, and 25) on the ES for the model with (solid line) and without (dotted line) the sea-ice component; elapsed time (left), parallel efficiency (right).

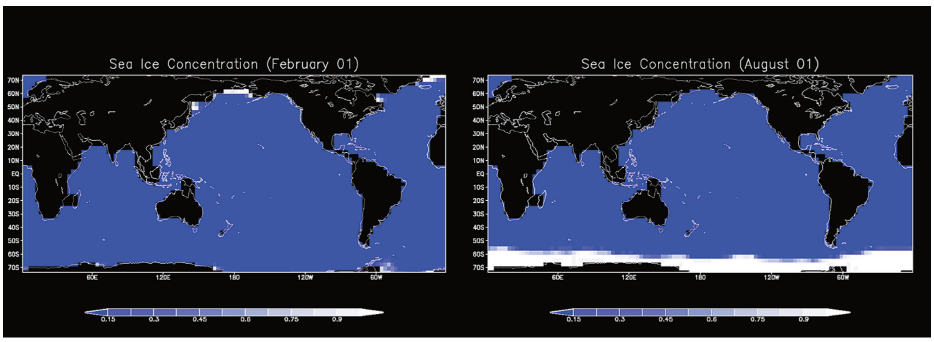

Fig. 3 Monthly-mean fields of sea-ice concentration obtained from the test run in February (left) and August (right).

3. AFES as an atmospheric component

The atmospheric general circulation model (for the ES), (AFES), an atmospheric component of our coupled assimilation system, achieved a computational speed of about 27 TFLOPS (65% of the peak performance) with the full configuration of the ES. This performance was recognized as the fastest computation in the world, and AFES won Gordon Bell Award for Peak Performance at Super Computing 2002. With AFES on the ES, we performed a set of meso-scale resolving global atmospheric simulations with the T1279L96 resolution (horizontally 10-km grid size), targeting typhoon genesis, Baiu (Meiyu) frontal zone and wintertime cyclogenesis. Figure 4 shows a snapshot of global precipitation field from the typhoon experiment. It shows that, for example, a typhoon to the south of Japan, meso-scale tropical disturbances and cyclones over the Antarctic Ocean are well simulated. Figure 5 is a magnified picture of Figure 4 over the Japan-East Asia area. Two typhoons to the south of Japan and to the southwest of Taiwan can be seen. These typhoons started appearing around day 5 of the numerical integrations, and Figures 4 and 5 are for around day 10. This indicates that typhoons were in a sense self-generated in the AFES simulation. Similar results were obtained for other meso-scale phenomena. Even though verification against the observations has yet to be done more carefully, it has been shown that AFES can simulate many aspects of atmospheric circulations of wide range of spatial scales.

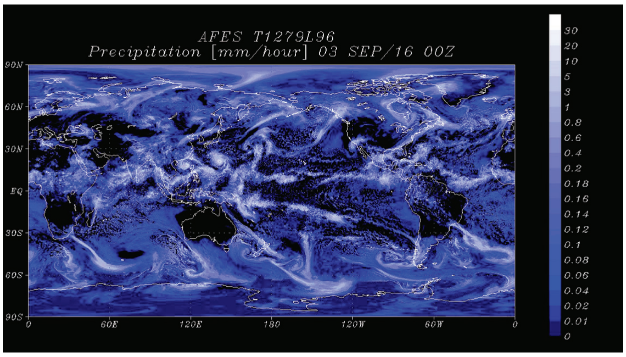

Fig. 4 A snapshot of global precipitat field from AFES T1279L96 typhoon simulation.

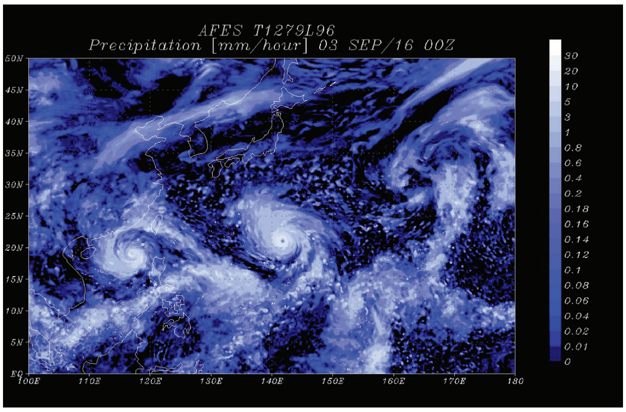

Fig. 5 Magnified picture of Fig. 4 over the Japan-East Asia area.

4. Development of the adjoint code of AFES using TAF

An atmospheric adjoint code is the most important component of our coupled assimilation system. We have developed a prototype adjoint code for dynamical component of AFES with the use of a semi-automatic differentiation tool TAF. Test runs were performed in T21L20 resolution on 1 node as a sensitivity experiment. The distribution of the sensitivity to an artificial fluctuation seems reasonable since it is consistent with previous studies (not shown). Now, we are developing an adjoint code for physical component and extending it to high resolution system.

5. CFES as a platform for a coupled data assimilation system

CFES is composed of oceanic general circulation model for the ES with sea ice component (OIFES) and AFES. In CFES framework, each component is linked by fully parallelized coupling interface, so that each component can run independently. As a result, we are able to control parallel performance with changing the number of processors for each component. At the same time, this framework enables us to archive by allowing concurrent execution for exchanging data between AFES and OIFES. This concurrency entails executing all components from time (t) to (t+1) at the same time as shown in Figure 6. Furthermore, decomposition of data exchange throughout the coupling has achieved reduction of communication costs. In pilot experiments with horizontal resolution of T106 under 1 to 1 grid correspondence between AFES and OIFES as a forward model of a coupled data assimilation system, they took about 10 minutes for one month integration on 48 nodes of the ES. Preliminary results after two years integration are show in Figures 7 and 8, which present SST and SSS, respectively. Although integration term is too short to validate its physical performance, those distributions are reasonable comparing observed data.

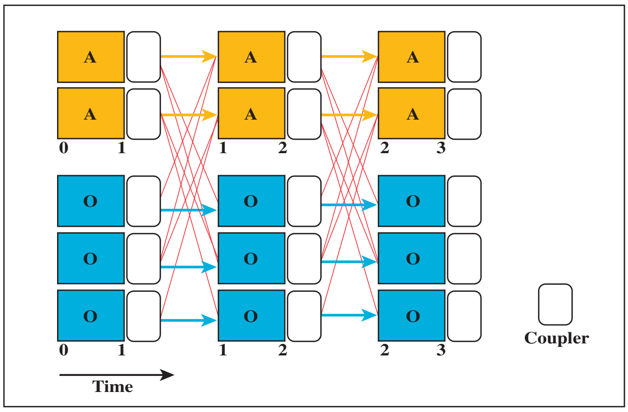

Fig. 6 Structure of coupling schemes of CFES. "A", "O" and "coupler" atmospheric/oceanic, oceanic, and coupling components, respectively.

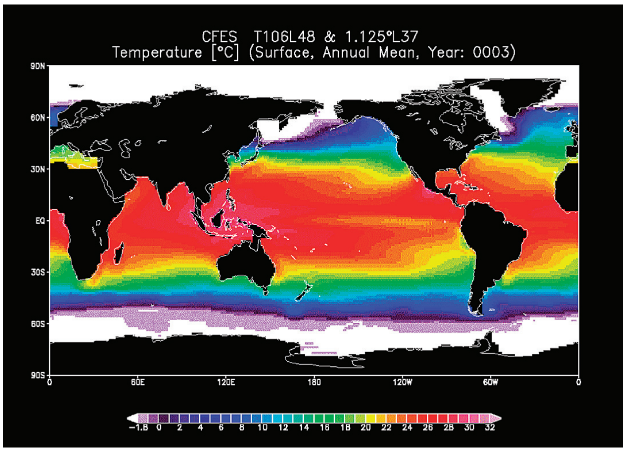

Fig. 7 Annual averaged SST of CFES after 2 years integration of CFES with T 106 horizontal resolution.

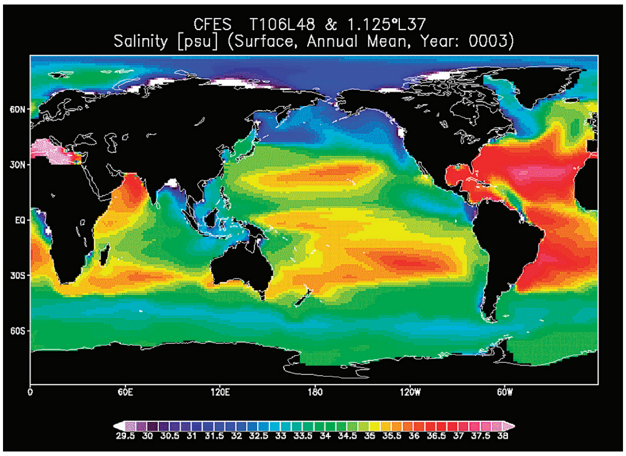

Fig. 8 Annual mean of SSS after 2 years integration of CFES with T 106 horizontal resolution.

6. Concluding remarks

We have developed each component of a coupled data assimilation system. A 4D-VAR global ocean data assimilation system has customized for the use of the ES. This system has been used to better define the seasonal change in the state of global ocean. The obtained reanalysis dataset has greater information and forecast potential than those obtained from earlier studies. The sea-ice component has been ported to the ocean data assimilation system, and confirmed to work correctly at the test case with low resolution. AFES, an atmospheric component in our coupled data assimilation system, achieved a computational speed of about 27 TFLOPS with the full configuration of ES. With AFES on the ES (T1279L96 resolution), we succeed to reproduce some realistic phenomena in the atmosphere which cannot be obtained by earlier global models. In addition, adjoint code of AFES is being developed with the use of a semi-automatic differentiation tool TAF. These components are planed to be incorporated into a coupled system based on CFES which is highly performed on the ES.

Acknowledgments

This study is supported by MEXT RR2002 Project in Japan.

フル結合四次元データ同化システムの研究開発と初期値化・再解析データの構築

利用責任者
淡路　敏之　　地球フロンティア研究システム モデル統合化領域　グループリーダー／
京都大学大学院　理学研究科 地球物理学教室　教授

著者
増田　周平[*1]・淡路　敏之[*1,2]・大淵　　済[*3]・杉浦　望実[*1]
高橋　桂子[*3]・小守　信正[*3]

＊1　地球フロンティア研究システム　モデル統合化領域
＊2　京都大学大学院　理学研究科　地球物理学教室
＊3　地球シミュレータセンター　計算地球科学研究領域

4次元変分法を用いた海洋データ同化システムの計算効率の最適化を行なった。例えば水平解像度1°のモデルでは、気候学的季節変動実験が約一週間で計算可能である。得られた海洋再解析データは観測データとの整合性を持つとともに力学的整合性を持っており、力学解析、予報用初期場推定に優れたパフォーマンスを示す。また、結合同化システムの構築に向け、このシステムに地球シミュレータ用に開発された大気海洋海氷結合モデルCFESに実装されている海氷コンポーネントを移植した。水平解像度が3°のモデルを用いて、地球シミュレータ上でPE数を変化させたテスト計算を行い、移植した海氷コンポーネントが正しく機能していることを確認した。さらに、結合同化システムの大気コンポーネントとなる大気大循環モデルAFESの性能検証のため、地球シミュレータ全体を使用した実験を行い、約27Tflops（ピーク性能約65%）の実行速度を達成した。その高効率性能を生かし，超高解像度メソスケール解像全球シミュレーションをT1279L96（水平約10km）の分解能で行った。その結果、幾つかの現象に対しこれまでのモデルでは不可能だった現実的なシミュレーションを行い得ることを例証した。結合同化システムの最重要コンポーネントの一つとなるこのモデルのアジョイント方程式を作成するため、自動アジョイント化コードTAFを利用して力学過程のアジョイントコードを試作した。これを用いた感度解析を解像度T21L20で行ない、これまでの知見と整合性のある結果を得た。今後、水平解像度1°での予備実験において高い計算効率を示すCFESをプラットフォームとし、各々のコンポーネントを改良しつつこれに組み込むことで結合同化システムを構築していく。

キーワード：データ同化、結合モデル、気候変動