Development of an Integrated Earth System Model for Prediction of Environmental Changes

Project Representative

Taroh Matsuno Frontier Research Center for Global Change/Japan Agency for Marine-Earth Science and Technology

Authors

Michio Kawamiya [*1], Kengo Sudo [*1], Chisato Yoshikawa [*1], Yukio Tanaka [*1], Motohiko Tsugawa [*1], Masaki Satoh [*1, 2], Hirofumi Tomita [*1], Tomoe Nasuno [*1], Shin-Ichi Iga [*1], Hiroaki Miura [*1] and Taroh Matsuno [*1]

＊1 Frontier Research Center for Global Change/Japan Agency for Marine-Earth Science and Technology

＊2 Center for Climate System Research, University of Tokyo

This project consists of three themes that are relatively independent. The corresponding three teams develop an integrated earth system model, a cloud-resolving atmospheric general circulation model with the icosahedral grid system, and an eddy-resolving ocean general circulation model with the cubic grid system, respectively. On the first theme, results are introduced from a preliminary experiment with fully-coupled climate - carbon cycle model, experiments on climate - chemistry interactions with the atmospheric chemistry component model, and an attempt to improve gravity wave drag parameterization. On the second, global cloud-resolving simulations are performed with an aqua planet setup using Nonhydrostatic ICosahedral Atmospheric Model (NICAM). It is found that the simulations with grid intervals of 7 km and 3.5 km well capture observed hierarchical structure of clouds from cloud resolving to global scale and show realistic properties such as eastward moving super cloud clusters. On the third, results from the eddy-resolving ocean model, which is computationally more efficient than models with the traditional lat-lon grid system, are shown. Analysis on the eddy buoyancy flux convergence indicates that eddies act to flatten the tilting of isopycnal surfaces in the Southern Ocean.

Keywords: earth system model, carbon cycle, icosahedral grid, global cloud-resolving model, global eddy-resolving model, cubic grid

1. Introduction

This project is developing three different models, namely, an integrated earth system model that includes both physical and biogeochemical components forming the earth's climate, a cloud-resolving atmospheric general circulation model with the icosahedral grid system, and an eddy-resolving ocean general circulation model with the cubic grid system. Since the development of the three models is being conducted in a relatively independent manner, the objectives and backgrounds of model development are described separately in the following sections devoted to the respective models.

2. Development of an integrated earth system model

The first theme corresponds to Kyousei-2, a MEXT project to develop a model where biogeochemistry and physical climate system interact with each other. The development is conducted by coupling existing biogeochemical component models with an atmosphere-ocean coupled climate model. As of March 2005, the current version of the integrated model includes carbon cycle for both land and ocean, and tropospheric chemistry. The resolution for the atmosphere is T42L20. The ocean model has 44 vertical levels, a zonal resolution of 1.4°, and a spatially varying meridional resolution of 0.5°-1.4°. It is planned to extend the model top, which is currently ~ 30 km, to the upper stratosphere with a sophisticated parameterization of gravity wave drag. Results from a preliminary experiment for climate - carbon cycle feedbacks show

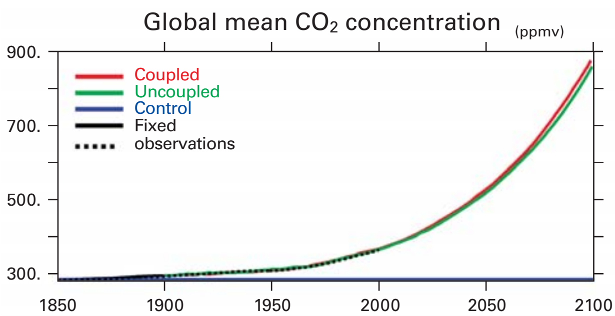

Fig. 1 Development of atmospheric CO2 concentration obtained by providing CO2 emission data as model input after 1900. The red line shows the case where interactions between climate and carbon cycle are considered, and the blue line not. Units are ppmv.

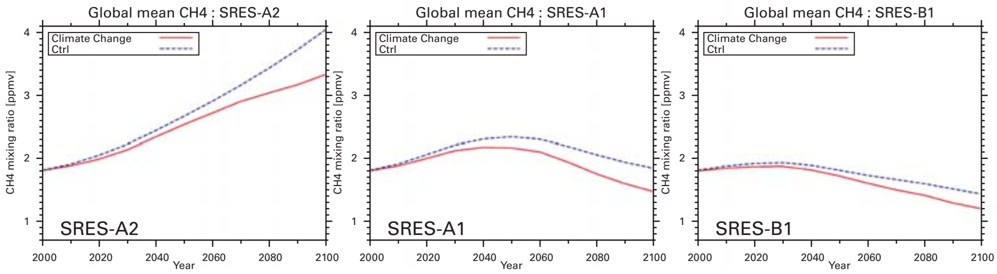

Fig. 2 Temporal evolution of global mean methane concentrations projected for SRES (left) A2 which is a high case, (middle) A1 which is an intermediate case, (right) B1 which is a low case from 2000 to 2100. Solid lines show results from the simulations with climate change as well as emission changes, with dashed lines for the control simulations with emission changes only (using present climate).

significant differences from those of two preceding studies [1, 2] in that our model exhibits much weaker feedback between carbon cycle and climate change (Fig. 1). Experiments with the atmospheric chemistry component model CHASER show that there are significant differences in future atmospheric composition projected by the model depending on whether one considers interactions between climate change and chemical reactions in the atmosphere (Fig. 2). While attempting to improve gravity wave drag parameterization for the stratosphere, it has been revealed that gravity wave drag directly derived from explicitly resolved gravity waves shows significant dependence on the resolution.

As a whole, Kyousei-2 exhibits a steady progress. It is expected that the integrated model, when completed, will profit the entire community for climate research by enabling direct researches on interactions among sub-systems that have formerly been studied in separate disciplines.

3. Global cloud resolving calculations for aqua planet experiments

The aim under this theme is to develop a super-high resolution atmospheric generation circulation model that explicitly resolves cloud motions with a few-kilometer grid interval in the horizontal directions. To achieve this goal, we are developing a new model based on quasi-uniform grids, which is suitable for the Earth Simulator. The new atmospheric model is based on the nonhydrostatic equations and the icosahedral grid (Fig. 3) [3], and is called Nonhydrostatic ICosahedral Atmospheric Model (NICAM).

We have run a global cloud resolving run on the aqua planet [4]. This is a statistical run including moist processes: direct calculations of radiative-convective equilibrium on a prescribed sea surface temperature on the globe. This experiment is a first step to evaluate climate sensitivity with explicit cloud calculation. We performed a 3.5km-grid model run for 10days, which compares the run with the 7km-grid model for 30days after the spin-up run with a 14km-grid model for 60days [5]. Fig. 4 shows a snapshot of the global precipitation obtained with the 3.5-km mesh model. This captures a multi-scale structure of clouds from a few km to the global scale. The super cloud clusters, whose longitudinal size is about 3,000 km, are propagating eastward with a phase speed about 30-40days traveling around the equatorial circle, and shows the convectively-coupled Kelvin wave structure (Fig. 5). These properties are similar to observations. This experiment is a first global cloud resolving run and can be used as a study of direct interaction of clouds and radiation, which is one of the most ambiguous factors of the current climate simulation.

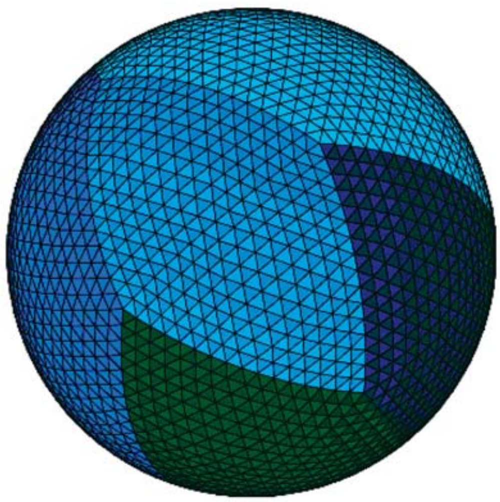

Fig. 3 Icosahedral grid.

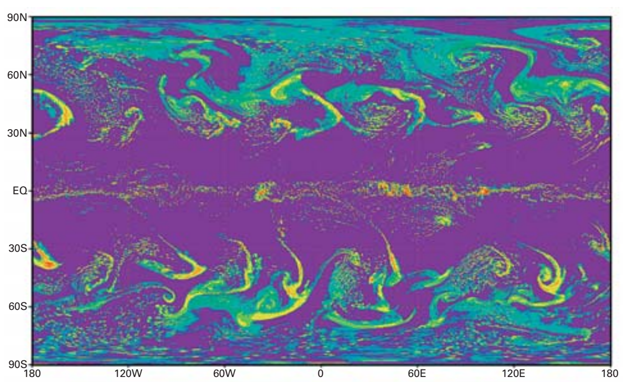

Fig. 4 Global distribution of precipitation obtained with the 3.5km-mesh model at day 85 for the aqua planet experiment. Units are log (precipitation/(mm day^{-1})).

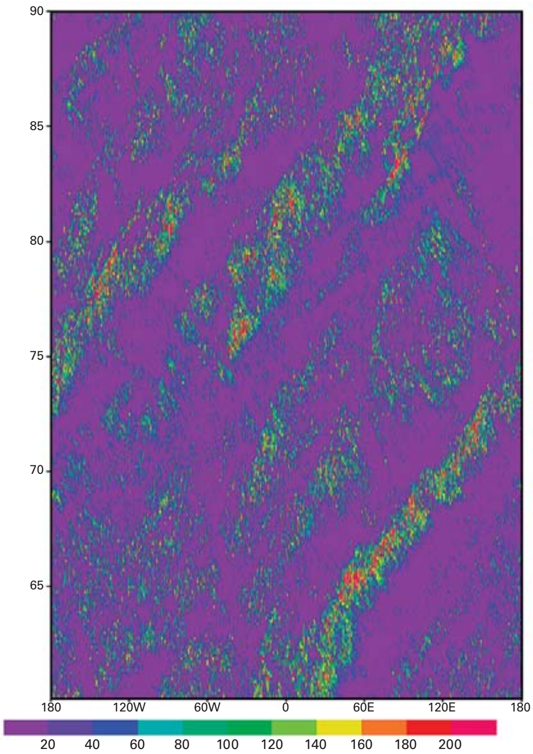

Fig. 5 Hovmoller section of precipitation averaged over 2N-2S latitudes for the 7km-run.

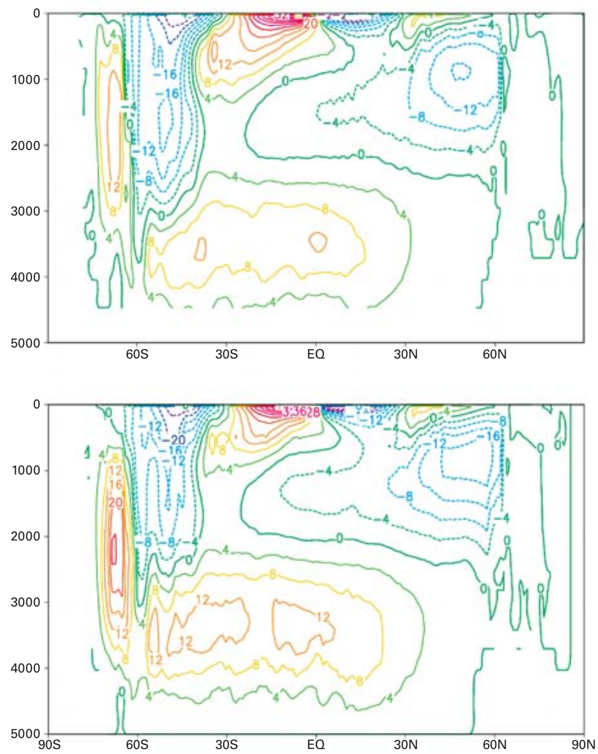

Fig. 6 Meridional stream function in Sv of cubic (top) and longitude-latitude (bottom) grid systems after 1000 yr integration.

4. Cubic-grid ocean model for long-term integration with an eddy resolving resolution

In order to study mesoscale eddy activities in the ocean, an ocean general circulation model which has high physical and computational performance has been developed. The model employs a cubic-grid system to improve the computational performance. A long time-integration is carried out to evaluate the physical performance. Fig. 6 shows the calculated meridional stream function after 1000 year integration. For comparison, that of a lon-lat model is also shown. The result of the cubic model agrees very well with that of the lon-lat model. Fig. 7 shows the relation between the maximum grid size and time step width. The time step width of the cubic model is at least 5 times longer than that of a rotated lon-lat one and the high computational performance of the new model is clearly shown.

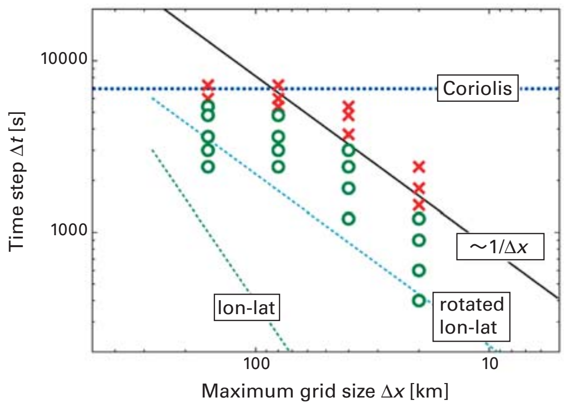

Fig. 7 Relation between maximum grid size and time step width . The circles denote the time step width of successful integration, while crosses denote that of failed integration.

By using high computational capability of the Earth Simulator, the distribution of the eddy buoyancy flux convergence (EBFC) in the Southern Ocean (Fig. 8) is obtained in detail for the first time in the world by using the COCO model. The distribution contains rich information regarding the role of eddies to large scale ocean current. It shows that the intensity is strong in the ACC and Agulhas Retroflection region. In the ACC, the EBFC is positive on the poleward flank and negative on the equatorward flank of it. In Drake Passage and Argentine Basin, the negative EBFC regions are located on the north of Subantarctic Front and the positive regions are located on the south of Polar Front. In the east of the Kerguelen Plateau, the strong negative (positive)

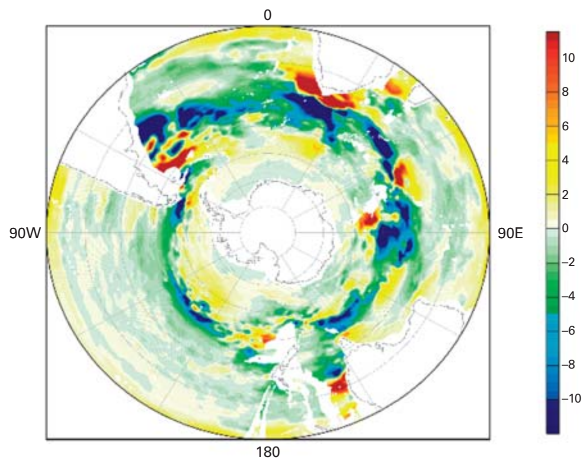

Fig. 8 The eddy buoyancy flux convergence at 2000 m depth. Units are 4×10^{-13} ms^{-3}.

region exists on the north (south) of Polar Front. In Agulhas Retroflection region, the EBFC is positive on the north side of the Agulhas Current and negative on the south side of it. The EBFC distribution contributes to flatten the tilting of isopycnal surfaces in these regions.

Bibliography

1) P. Cox, R. Betts, C. Jones, S. Spall and I. Totterdell, Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model, Nature, vol.408, pp.184-187, 2000.
2) P. Friedlingstein, L. Bopp, P. Ciais, J.-L. Dufresne, L. Fairhead, H. LeTreut, P. Monfray and J. Orr, Positive feedback between future climate change and the carbon cycle, Geophysical Research Letters, vol.28, pp.1543-1546, 2001.
3) H. Tomita and M. Satoh, "A new dynamical framework of nonhydrostatic global model using the icosahedral grid," Fluid Dyn. Res., 34, pp.357-400, 2004.
4) R.B. Neale and B.J.Hoskins, "A standard test for AGCMs including their physical parameterizations: I: The proposal," Atmospheric Science Letter, 1, doi:10.1006/asle.2000.0019, 2001.
5) H. Tomita, H. Miura., S. Iga, T. Nasuno, and M. Satoh, "A global cloud-resolving simulation: Preliminary results from an aqua planet experiment," Geophys. Res. Let., 32, L08805, doi:10.1029/2005GL022459, 2005.

地球環境変化予測のための地球システム統合モデルの開発

プロジェクト責任者
松野　太郎　　海洋研究開発機構 地球環境フロンティア研究センター

著者
河宮未知生*1，須藤　健悟*1，吉川　知里*1，田中　幸夫*1，津川　元彦*1，佐藤　正樹*1, 2,
富田　浩文*1，那須野智江*1，伊賀　晋一*1，三浦　裕亮*1，松野　太郎*1
＊1　海洋研究開発機構 地球環境フロンティア研究センター
＊2　東京大学 気候システム研究センター

本プロジェクトは比較的独立した3つのテーマからなっており、それぞれのチームに分かれモデル開発にあたっている。開発しているモデルは「地球システム統合モデル」、「正二十面体格子を用いた全球雲解像大気モデル」、および「立方体格子を用いた全球渦解像海洋モデル」の3つである。1つ目のテーマに関しては、気候－炭素循環結合モデルによる予備的実験の結果や、大気化学コンポーネントモデルを用いて行った気候と大気化学の相互作用に関する実験、成層圏の重力波抵抗パラメタリゼーションを改良する試みについて紹介する。2つ目に関しては、正20面体格子非静力学大気モデル(NICAM)とよぶ全球雲解像モデルを開発し、水惑星条件で格子間隔3.5 kmの全球雲解像シミュレーションを実施した。本実験は世界で初の全球雲解像実験である。格子間隔7 kmおよび3.5 kmの実験では積雲スケールから全球スケールまでの積雲の階層的な構造をとらえることができた。東向きに伝播するスーパークラウドクラスターなど観測事実によく似た特徴が再現された。3つ目のテーマに関しては、従来型の緯度経度グリッドに比し高い計算効率を持つ全球渦解像モデルを用いた実験結果を紹介する。渦浮力フラックスの収束･発散に関する解析を行った結果、南極海において渦は等密度面の傾きを弱めより水平にする働きがあることが示唆された。

キーワード：地球システムモデル，炭素循環，正二十面体格子，全球雲解像モデル，全球渦解像モデル，立方体格子