Development of a High-Resolution Coupled Climate Model for Global Warming Studies

Project Representative

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The purpose of this project is to further develop physical models for global warming simulations, and to investigate mechanisms of changes in global environment as a successor of a previous ES joint project. We have obtained the following results this year.

The T106L168 MIROC-AGCM without non-stationary gravity wave parameterization is constructed to investigate future changes of the quasi-biennial oscillation (QBO), semi-annual oscillation (SAO) and stratospheric sudden warming (SSW). These phenomena were well reproduced in the present climate simulation.

The performance of an ocean model with a subgrid scale parameterization for multiple sea-ice thicknesses is investigated. This model reproduced ice-thickness distributions of the Arctic Ocean reasonably well.

A numerical ice sheet model IcIES is extended to include ice-shelf/stream process. The implementation of the parallel ice-shelf model was succeeded, but there remained still many points to be improved. The non-parallel version of IcIES are applied for global warming experiment as well as Eemian experiment.

The surface energy-water balance on land is evaluated by a wetness index (WI) using a global data (GPCC and NNRP) and the 20th century experiments. The mean global distribution of WI was reproduced better with MIROC5 than with CMIP3 GCMs. A simple scheme for the effect of surface soil moisture changes on soil-surface albedo is tested. As a result, surface albedo was increased in the dry regions, which could reduce the warm biases at the surface there.

Keywords: Atmosphere-Ocean-Land coupled model, sea-ice thickness, stratospheric QBO, ice-sheet model

1. Introduction

This project is a successor of one of the previous ES-joint projects named “Development of a High-resolution Coupled Atmosphere-Ocean-Land General Circulation Model for Climate System Studies.” The purpose of this project is to further develop physical models for global warming simulations, and to investigate mechanisms of changes in global environment.

To achieve the purpose, we focus on the development of ice sheet model, permafrost model and sea ice model, improvement of subcomponent models for atmosphere, ocean and land-surface processes in the climate model MIROC, as well as sensitivity studies using climate models relevant to global warming and paleo-climate.

2. The QBO, SAO and SSW simulated in the MIROC-AGCM

The quasi-biennial oscillation (QBO), semi-annual oscillation (SAO) and stratospheric sudden warming (SSW) are reasonably simulated by the T106L168 MIROC-AGCM without parameterized nonstationary gravity wave forcing. The vertical resolution is set 500 m from the upper troposphere to the mesopause (~85 km altitude). The model is integrated for 50-years in the present climate condition. Figure 1 shows the time-height cross section of monthly mean and zonal mean zonal wind over the equator for 15-years. The amplitude and period of the simulated QBO are reasonable. The SAO is well simulated around 1 hPa. This model also successfully simulated the SSW events (not shown). It has been considered that the SSW occurs in the stratosphere. However, recent satellite observation indicated that the SSW also occurs in the mesosphere [1].

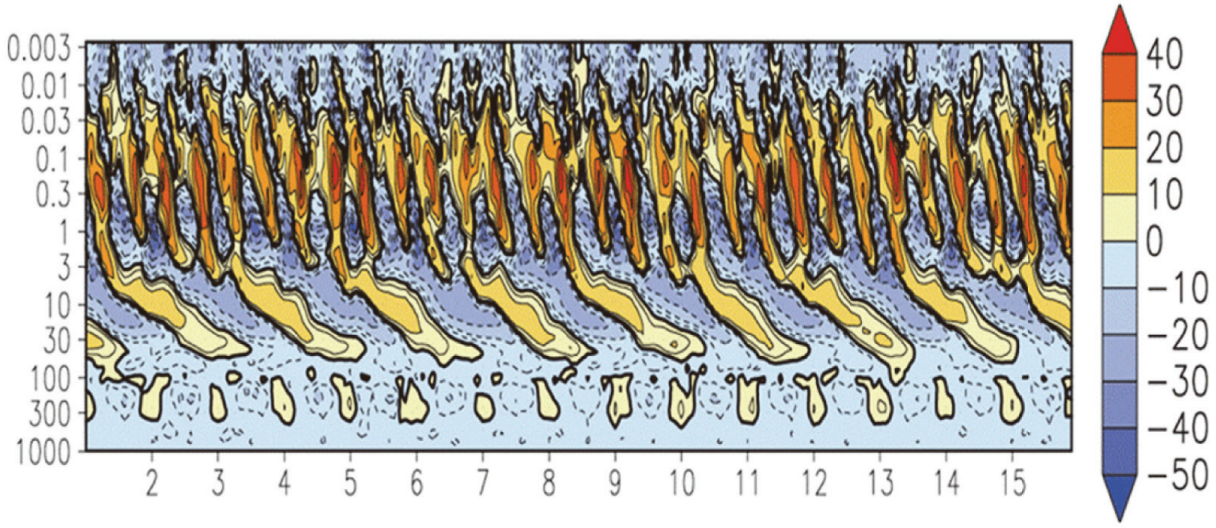

Fig. 1 Time-height cross section of zonal mean zonal wind over the equator simulated by MIROC-AGCM with T106L168 resolution. Red and blue colors correspond to the westerly and easterly, respectively. The contour intervals are 10 ms^{-1}.

Because the number of observational evidences is very small (i.e., only a few cases), the model simulation is needed for its statistical analysis. This is the first time to simulate the QBO, SAO and SSW simultaneously for such a long-term integration in a climate model without the nonstationary gravity wave parameterization. It indicates that the changes of these phenomena in a global warming climate could be investigated using this climate model, which remains in a future study.

3. Performance of an ocean model with a sea-ice thickness distribution parameterization

The performance of the COCO ocean model with the subgrid scale parameterization for multiple sea-ice thicknesses proposed by Bitz et al. [2] is evaluated in the Arctic Ocean. Figure 2(a) shows sea-ice draft distribution of the Arctic Ocean acquired during submarine cruises [3]. Ice draft is the vertical distance form sea level to the bottom of the ice and accounts for about 90% of the ice thickness. These distributions have a local minimum near one meter and it seems to mark the boundary between first-year and multiyear ice. Ice to the left of this minimum is mostly young and recently rafted ice, while ice immediately to the right is mostly second-year ice. Figure 2(b) shows simulated ice thickness distributions using the parameterization with five and fifteen thickness categories. The probability density of the five categories reduces monotonically as the ice thickness increases. On the other hand, that of the fifteen categories has a local minimum around one meter similar to the submarine measurements. The sea-ice thickness parameterization with fifteen thickness categories reproduces the ice draft distribution reasonably well.

4 Improvement and Development of an ice-sheet/ ice-shelf model IcIES

Ice-sheet Model for Integrated Earth-system Studies (IcIES) has been developed in a serial-computing environment. We have started to implement a parallelization method and this year we continue the development. Moreover, we start to implement a new ice-shelf processes to IcIES. Ice-shelf is a floating ice

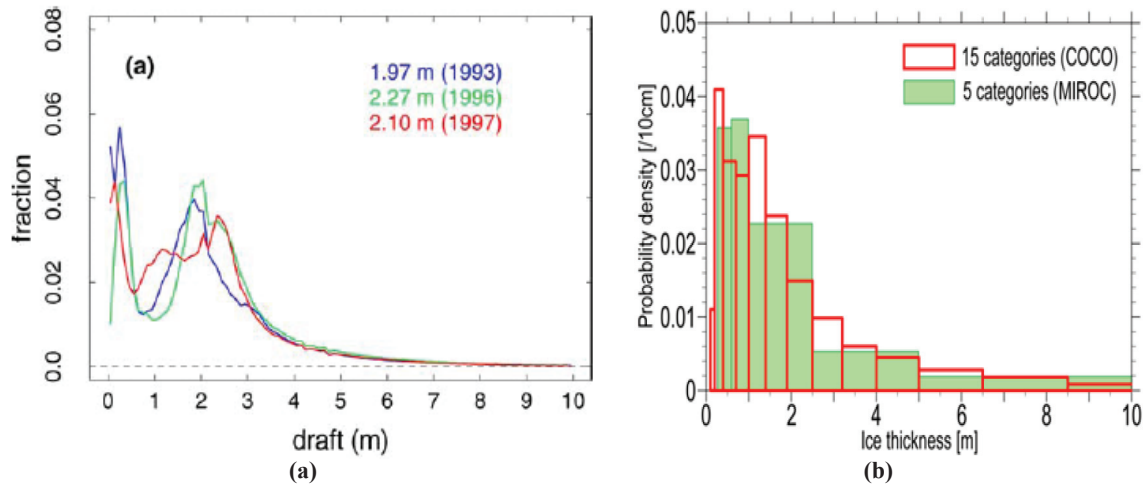

Fig. 2 (a) Ice draft distributions averaged over submarine cruises for each year. (b) The sea-ice thickness distribution simulated by the ocean model.

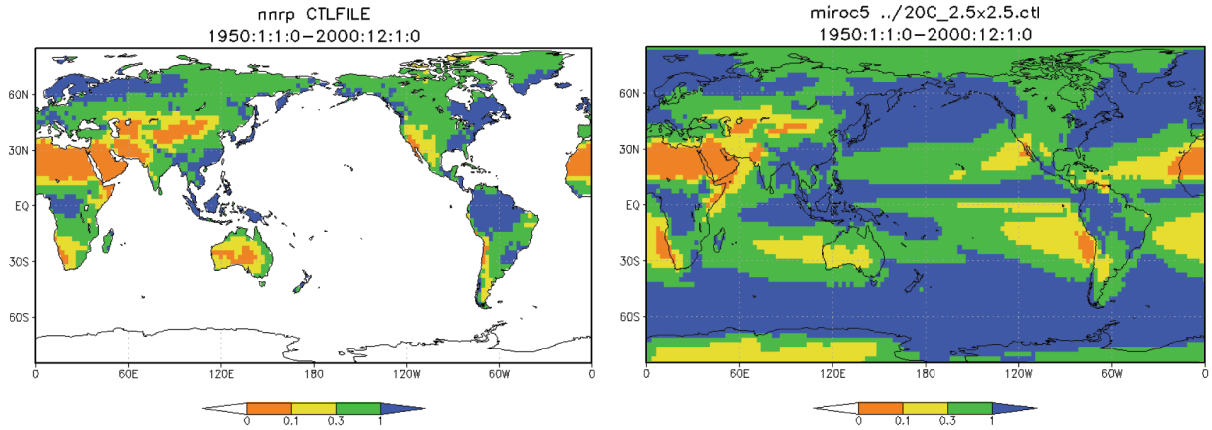

Fig. 3 The global distributions of annual wetness index averaged from 1950 to 2000. Left is by observation (GPCC and NNRP), and right is by MIROC5.

attached to inland ice-sheet, which has different dominant stress components from the ice-sheet part. In order to compute the ice velocity over the ice shelf, a non-linear matrix equation has to be solved, which is technically a challenging matter. Following the parallelization method used in the grounded ice-sheet part, the same block-cyclic domain decomposition method is adopted to describe the ice-shelf velocity. Solution of the matrix equation involves not a small amount of MPI communication in every iteration, and need much careful control to construct the model. We have succeeded to implement the parallel ice-shelf model. Tests of the new ice-shelf model are performed under several idealistic configurations, including not only diagnostic mode (compute the velocity at given ice-sheet geometry) but also prognostic mode (compute ice-thickness evolution with the velocity solution). Since the current framework is just a starting point of development, there remain many points to be improved. In principle the amount of MPI communication is hard to be reduced, but we have to test several different schemes to optimize the matrix solver, which is left for next year.

The previous version of IcIES (non-parallel) is still much efficient to perform a number of sensitivity experiments with low or moderate resolution. This year it is used for sensitivity study of Greenland ice sheet under future global warming (which is submitted to SeaRISE project [4], [5]), as well as under last interglacial condition (Eemian).

5. Evaluation and improvement of the land energy-water balance at a large scale

The energy-water balance at land surface was evaluated with the annual wetness index (WI), calculated by dividing the annual precipitation with the annual potential evaporation. The global observation-based datasets of near surface meteorology (NNRP) and precipitation (GPCC) are used as a reference, to be compared with the 20th-century simulations by CMIP3 GCMs (MIROC3-med, MRI-CGCM, GISS-AOM, CNRM-CM3, and BCCR-BCM2), and MIROC5. The mean global distributions of annual WI, averaged from 1950 to 2000, are compared. The wet-dry contrasts in each GCM roughly agree with observation, but MIROC5 is the best, particularly over Eurasia (Fig. 3).

The soil surface albedo has been fixed on the basis of satellite observation, but in actual, it depends on surface soil moisture. Then a simple scheme for diagnostic soil-surface albedo in accordance with surface soil moisture was tested using the AGCM part of MIROC5. As a result, surface albedo was increased in the dry regions (Fig. 4, lower), e.g., in western North America, northern Africa, and the Middle East, and surface air temperature was decreased by a few degrees Celcius in those regions (Fig. 4, middle). It implies that the surface warm biases could be reduced in those regions (Fig. 4, upper).

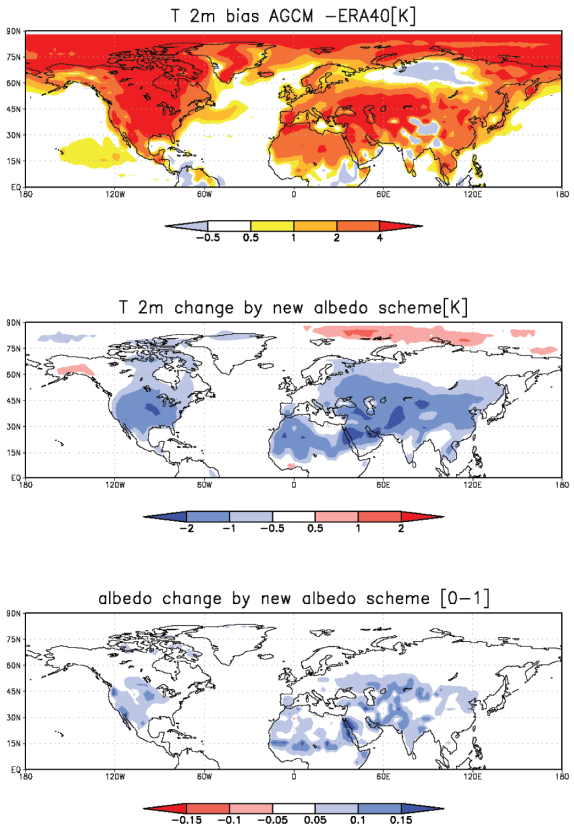

Fig. 4 Change in surface soil albedo (lower) and surface air temperature (middle) by introducing a simple scheme for the soil moisture dependence of soil albedo. The surface air temperature biases with the fixed soil albedo (upper).

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地球温暖化予測研究のための高精度気候モデルの開発研究

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本研究は、地球温暖化予測のための各種物理モデルの開発を進めながら、地球環境の変動メカニズムの解明を行う。具体的には（1）氷床モデル・凍土モデル・海氷モデルの開発、（2）大気、海洋、陸面の物理過程の評価と改良、（3）地球温暖化予測ならびに古気候再現に関わる気候モデルの感度実験、を行う。

本年度は以下の成果を得た。

重力波パラメタリゼーションを組み込まず、かつ長期積分が可能な鉛直高解像度気候モデルを用いて、成層圏準 2 年振動（QBO）、半年振動（SAO）、成層圏突然昇温（SSW）の再現実験を行った。それぞれ観測と類似した結果が得られ、温暖化に伴う現象の変化を解析可能なモデルの構築に成功した。

海氷厚分布を表現するサブグリッドスケールのパラメタライゼーションを組み込んだ海洋モデルのパフォーマンスを調べた。その結果、このモデルは北極海の海氷厚さ分布を良く再現することが示された。

氷床モデル IcIES に棚氷 / 氷流過程を導入した。実装には並列化の枠組みを用い、動作確認を行った。計算の効率にはまだ改良の余地がある。非並列化版 IcIES を温暖化実験や Eemian の感度実験に適用した。

全球データ（GPCC と NNRP）と 20 世紀再現実験結果から気候湿潤度（降水量 / 可能蒸発散量）を算定して地表面熱水収支の再現性を調べたところ、MIROC5 の気候値再現性が CMIP3 モデルよりも良いことが示された。固定値を与えていた土壌表面アルベドに、地表土壌水分の増減効果を考慮したところ、乾燥域でアルベドが増大して、地上気温の高温バイアスが緩和される可能性が示された。

キーワード:大気海洋陸面結合モデル, 海氷厚, 成層圏準二年振動（QBO）, 氷床モデル