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

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 weakening amplitude of the quasi-biennial oscillation (QBO) in the lower stratosphere was discovered by long-tern radiosonde observation and several climate model simulations. The results provide strong support for the existence of a long-term trend of enhanced upwelling near the tropical tropopause.

We analyzed the result of the Last Millennium experiment using MIROC-ESM and MIROC. The winter air temperature trend over the circum-arctic region shows unsynchronous variation over the arctic. A grounding-line flux parameterization was introduced to the parallel version of IcIES in order to better simulate transient behavior of grounding line migration and its performance was checked under some ideal configuration.

The advanced sub-grid snow fraction scheme (SSNOWD) was implemented in MIROC5.2. The expected reduction in the low bias of snow fraction was confirmed, but the cold biases in spring were enhanced in some regions. Further adjustment is needed for prolonged snow cover, besides inclusion of the improved soil physical properties.

Madden-Julian Oscillation represented by the Chikira-Sugiyama cumulus scheme was compared with observation and reanalysis. Furthermore, a new method to understand moisture variation associated with MJO was proposed. It was revealed for the first time that a vertical heating profile which maximizes moistening is selected.

Keywords: Atmosphere-Ocean-Land coupled model, offline biogeochemical model, stratospheric QBO, ice-sheet model, MJO

1. Introduction

This project is a successor of one of the previous ES-joint projects named “Development of a High-Resolution Coupled Climate Model for Global Warming Projection Study”. 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 weakening amplitude of the QBO by increased tropical upwelling

In the lowermost stratosphere, the vertical structure of the quasi-biennial oscillation (QBO) is linked to the mean upwelling. We analyzed 60 years of observational data, and discovered that the strength of the equatorial Quasi-Biennial Oscillation (QBO) has been weakening over the past several decades. Figure 1 shows time variation in the amplitude of observed and modelled QBO and in modelled annual mean tropical upwelling at 70 hPa. The QBO amplitudes are found to be dropped by about 30% over 60-years. This trend is also apparent in the global warming simulations of the CMIP5 models that realistically simulate the QBO and consistent our previous studies by MIROC-AGCM [1, 2]. The weakening is most reasonably explained as resulting from a trend of increased

mean tropical upwelling in the lower stratosphere. The discovery of a significant trend in the lower stratosphere QBO amplitude provides strong support for the existence of a long-term trend of enhanced upwelling near the tropical tropopause [3].

3. Improvement and development of an ice-sheet/ ice-shelf model IcIES

We analyzed the result of one of the experiments, the Last Millennium (LM) using MIROC-ESM (Sueyoshi et al. 2013) and MIROC, to verify the response of the cryosphere to the century-scale climate change. As preliminary results, winter warming during 20th century over the Eastern Siberia is clear. Signatures are shown in rise of temperature in February, decrease in snow amount, and increase in runoff during spring. We have also analyzed the winter air temperature trend over the circum-Arctic region, which shows unsynchronous variation over the Arctic. Variability is large in North Europe and Alaska, small in Siberia and Greenland. It also shows an anti-phase response to the volcanic forcing between Alaska and North Europe.

Simulating position of grounding-line is a key issue for ice-sheet modeling especially for Antarctic ice sheet. Following Schoof (2007 [4]), we introduced a grounding-line flux parameterization into the parallel version of IcIES. We performed a series of experiment presented in Marine ice-sheet model intercomparison project (MISMIP, Pattyn et al 2012 [5]) using the new version of IcIES and check the efficiency of the parameterization method (Fig. 2). Under this configuration (linear down-slope bedrock toward the ocean), the grounding line positions are expected be reversible along the changes

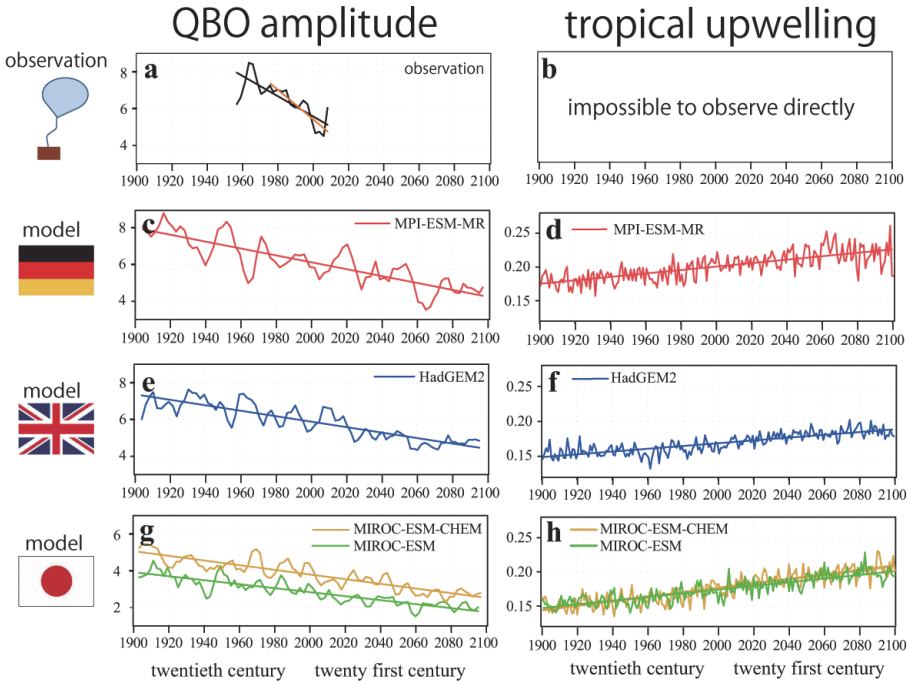

Fig. 1 Changes at altitude of about 19 km in (left) QBO and (right) equatorial upwelling. (a,b) are monitoring data; (c,d), (e,f), and (g,h) are German, British, and Japanese modeling results, respectively. The larger the value of the vertical axis, the larger the speed of westerly and easterly winds that accompany QBO (left) as well as the upwelling (right). From the 20th to 21st century, the QBO has weakened and the equatorial upwelling strengthened.

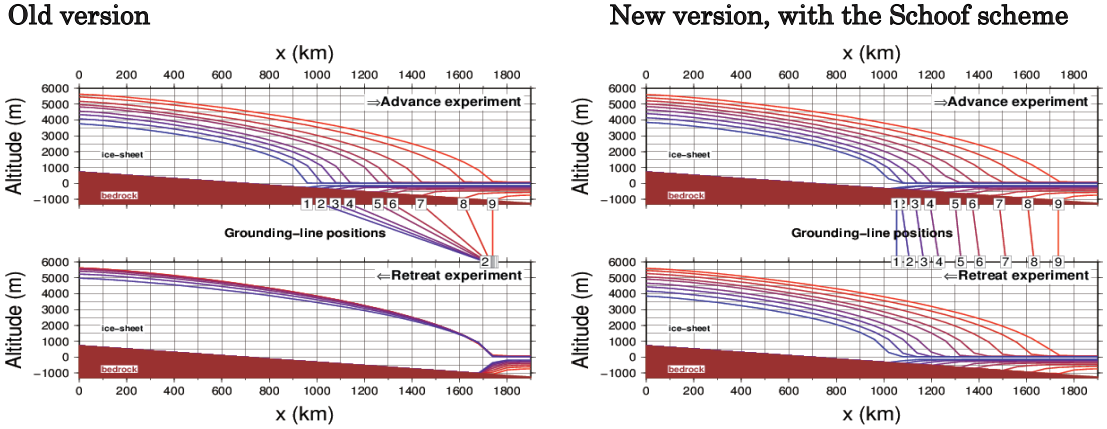

Fig. 2 An idealized ice-sheet/shelf/grounding line simulation following MISMIP (Pattyn et al. 2012). Left panels are results using the old model (before implementation of the Schoof parameterization scheme) and right are those using the new model. There are nine configuration for ice rate-factor (inverse of viscosity), from 1 to 9 which are expected to have reversible grounding positions when advance case (1 to 9) and retreat case (9 to 1). Grouding line retreat cannot be simulated using the old version.

in the environment. Upper panels are simulated ice-sheet topography along some environment change (number from 1 to 9) and the boxes are corresponding grounding line positions. Lower panels are simulated ice-sheet topography starting from the environment 9 to 1 and their grounding positions. Without the grounding line parameterization, the reversibility cannot be achieved, while it is successfully simulated with the parameterization. Although we implement this method using MPI parallel method, we only examine on serial case. Parallel efficiency of the new implementation is being examined.

4. Evaluation and improvement of the land-surface scheme

The advanced sub-grid snow fraction scheme (SSNOWD), which has been validated in MIROC5, was implemented in MIROC5.2. The expected improvement in snow fraction was confirmed, which has been underestimated in early winter in the regions with small snow amount. That led to reduction in the warm biases in mid-latitudes in early winter, but led to enhancement in the cold biases in some regions in spring. That could be related to the prolonged snow cover, which should be adjusted in the next step. The improved schemes for the soil thermal property including the organic layer have been tested in MIROC3.2, and are in preparation to be implemented in MIROC5.2. The dependence of soil surface albedo to soil moisture was coded, and realistic parameters were examined.

5. Understanding moisture variation in MJO represented by MIROC5 with the use of the Chikira cumulus scheme

Madden-Julian Oscillation (MJO) is a major variation of the atmospheric system in the tropics. However, the understanding of its mechanism has been remaining to be a challenging issue for decades. This fiscal year, a thorough analysis of the MJO represented by MIROC5 with the use of the Chikira-Sugiyama cumulus scheme was made digging into the mechanism of MJO (Chikira 2014 [6]) as well as a detailed comparison with observations and a reanalysis dataset (Chikira and Sugiyama 2013 [7]).

In particular, the work of this fiscal year includes a

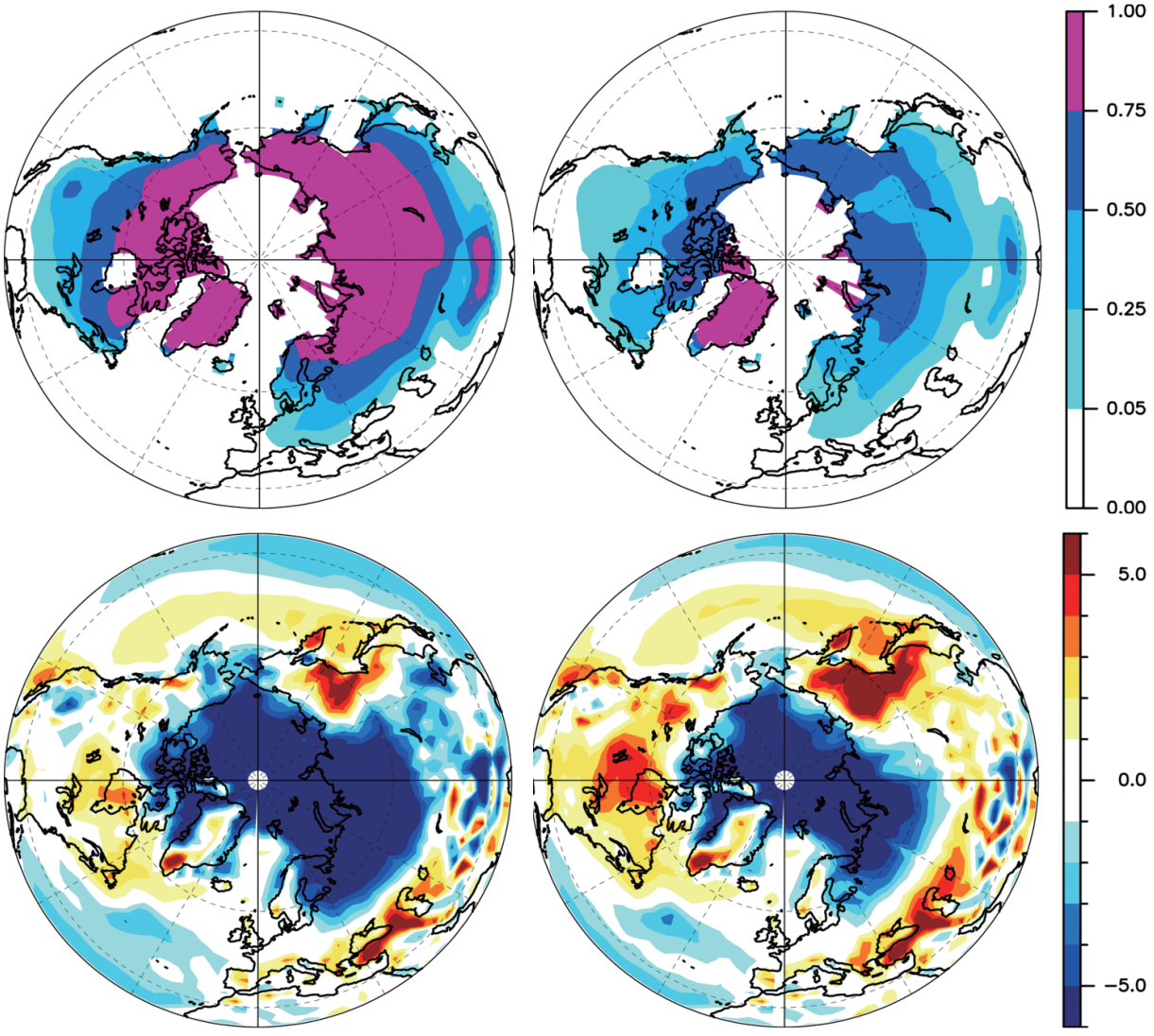

Fig. 3 Snow cover (upper) and surface air temperature (lower) in Oct.-Dec. with (left) and without (right) SSNOWD by MIROC5.2.

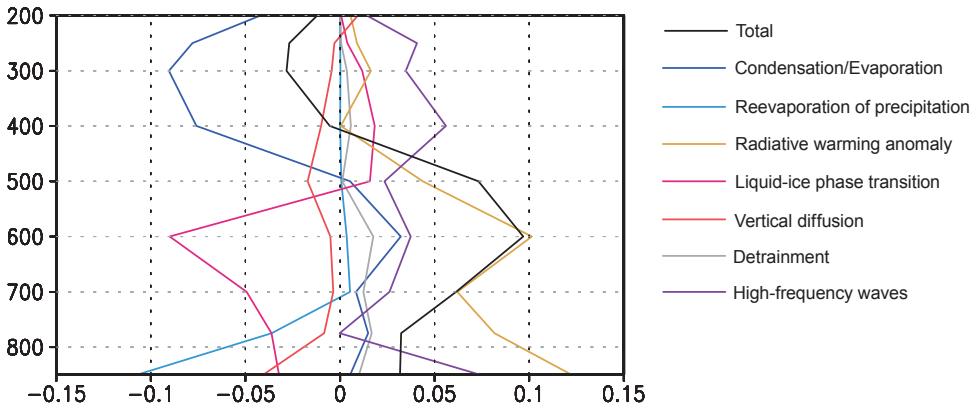

Fig. 4 Contribution of each factor to the amplification of the moisture over the convective area of the model MJO. Ordinate is pressure (hPa). Unit of abscissa is g $kg^{-1}day^{-1}$.

quantitative evaluation of physical factors which contribute to amplification of moisture (Fig. 4). The analysis showed that a primary factor for the amplification in the middle and lower troposphere is radiative warming anomaly. Besides, it was pointed out for the first time that the snow melting and the reevaporation of the precipitation suppress the moistening, and a cumulus heating profile which maximizes the moistening is selected

References

[1] Kawatani, Y., K. Hamilton, and S. Watanabe, "The Quasi-biennial oscillation in a double CO_2 climate", J. Atmos. Sci., 68, 265-283, 2011.

[2] Kawatani, Y., K. Hamilton, and A. Noda, "The effects of changes in sea surface temperature and CO2 concentration on the quasi-biennial oscillation", J. Atmos. Sci., 69, 1734-1749, 2012.

[3] Kawatani, Y. and K. Hamilton, "Weakened stratospheric Quasibiennial Oscillation driven by increased tropical mean upwelling", Nature, 497, 478-481, doi:10.1038/nature12140, 2013.

[4] Schoof, C., Ice sheet grounding line dynamics: Steady states, stability, and hysteresis. J. Geophys. Res., 112, F03S28, 2007.

[5] Pattyn, F. et al., "Results of the Marine Ice Sheet Model Intercomparison Project, MISMIP", The Cryosphere 6, 573-588, 2012.

[6] Chikira, M., "Eastward-propagating intraseasonal oscillation represented by Chikira-Sugiyama cumulus parameterization. Part II: Understanding moisture variation under weak temperature gradient balance", J. Atmos. Sci., 71, 615-639, doi:10.1175/JAS-D-13-038.1, 2014

[7] Chikira, M. and M. Sugiyama, "Eastward-propagating intraseasonal oscillation represented by Chikira-Sugiayama cumulus parameterization. Part I: Comparison with observation and reanalysis", J. Atmos. Sci., 70, 3920-3939, doi:10.1175/JAS-D-13-034.1, 2013.

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、数年から数千年に及ぶ気候変動を再現できる大気・海洋・陸面結合大循環モデルを改良するとともに、氷床モデル等の開発を行い、最先端の気候システム研究を実施する。より具体的には（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。

重力波抵抗パラメタリゼーションのない気候モデルを用いて、温暖化時の赤道準 2 年振動（QBO）を再現させた成果を参考に、本年度は観測データと気候モデルを組み合わせた考察を行った。地球温暖化時に成層圏子午面循環が強まる事と下部成層圏の QBO 振幅が弱まる事の関連性を明らかにし、現実大気でも子午面循環が強まっている事を立証した。

MIROC-ESM を用いた過去 1000 年実験の解析を行い、100 年スケールの気候変動に対する寒冷圏の変化を調査した。その結果、北極圏における冬の気温応答は、場所により異なることが分かった。昨年度に引き続き、氷床モデルの改良と並列化を進めた。今年度は、棚氷と氷床の境界（grounding line）の parameterization を導入した。実装した過程を理想的な条件下で試験運用し、grounding line 位置の時間発展がよく再現されることを確認した。

陸面モデルの積雪過程については，これまで MIROC5 で検証・感度実験を進めてきたサブグリッド積雪被覆率スキームを MIROC5.2 に実装し、冬季前半に降雪量が小さい地域での積雪被覆率の過小評価が軽減することを確認し、秋から冬の中緯度での高温バイアスは改善したが、低温バイアスが増大する地域や季節もあった。今後、土壌の熱物性値やアルベドの改良、有機層の導入と合わせてパラメタ調整を進める。

MJO に関しては、Chikira-Sugiyama 積雲対流スキームによって表現された MJO を観測・再解析データと詳しく比較するとともに、MJO に伴う自由大気の水蒸気変動の鉛直構造を精確に理解することを可能にする新しい方法を提案した。大気の湿潤化を最大化する鉛直加熱モードが選択されていること等が初めて示された。

キーワード : 大気海洋陸面結合モデル, オフライン地球生態化学モデル, 成層圏準二年振動 (QBO), 氷床モデル, MJO