# Development Research of a High-quality Climate Model for Long-term Climate Change Projection Study

Project Representative

Michio Kawamiya Department of Integrated Climate Change Projection Research, Japan Agency for Marine-Earth Science and Technology

Authors

Michio Kawamiya[*1], Ayako Abe-Ouchi[*2, 1], Yoshio Kawatani[*1], Rumi Ohgaito[*3], Fuyuki Saito[*1], Kazuyuki Saito[*1], Kunio Takahashi[*1], Kumiko Takata[*1, 4]

*1 Department of Integrated Climate Change Projection Research, Japan Agency for Marine-Earth Science and Technology

*2 Atmosphere and Ocean Research Institute, The University of Tokyo

*3 Project Team for Risk Information on Climate Change, Japan Agency for Marine-Earth Science and Technology

*4 National Institute of Polar Research

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.

Sources of spread in multi-model projections of the Greenland ice-sheet are analyzed. The results show that both variation of the initialization methods and the surface mass balance parameterization are key contributors for the divergence. Sensitivity experiment of the Antarctic ice-sheet under past warm climate conditions is performed to show an importance of climate effect rather than ice-sheet dynamics. An Ice-sheet/ice-shelf model IcIES has been developed and tested for the Antarctic ice-sheet simulations.

A simple scheme of snowmelt pond was implemented in the land-surface model of MIRPC5.2. The expected reduction in the warm bias in summer over land in Eurasia was evident, with a reduction in underestimation of precipitation and cloudiness.

We have investigated the interannual variation in equatorial stratospheric water vapor by analyzing MLS Aura satellite. The interannual anomalies in water vapor are strongly related to the dynamical quasibiennial oscillation (QBO). The anomalies display upward propagation below about 10 hPa, but at higher levels show clear downward propagation. We clarified the mechanism of these variations using MIROC-AGCM and CMIP5 models.

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

## 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. Development and application of an ice-sheet/ice-shelf model IcIES

SeaRISE is an international ice-sheet model intercomparison project which focuses on responses of ice-sheet under future global warming (Bindschadler et al. 2013 [1]). The result of SeaRISE/Greenland experiments shows a significant diversion among the participants. In order to evaluate the uncertainties originated from the variation of methods adopted in the ice-sheet models, we introduce some of the methods and parameterization adopted by the other models into an ice-sheet model IcIES to perform sensitivity experiments (Fig. 1). The result shows that main sources of the SeaRISE diversion are the initialization methods and the surface mass balance paramterizations to compute the ice melting from the surface temperature scenarios (Saito et al, submitted to The Cryosphere. [2])

A series of sensitivity experiments of the Antarctic ice

sheet under the past warm climate about 3 million years ago is performed. The results of the multiple climate models as well as idealized climate conditions are introduced to evaluate the sensitivity to the warm climate, which show significant influence to the retreat of the Antarctic ice sheet.

Development of an ice-sheet/ice-shelf model has been continued, and this year we perform its application on realistic Antarctic ice-sheet. Important features of the velocity fields are qualitatively simulated (Fig. 2). Future development subjects (i.e. parallelization algorithms) for practical computation of long-term simulation such as global warming and paleo-climate studies are listed.

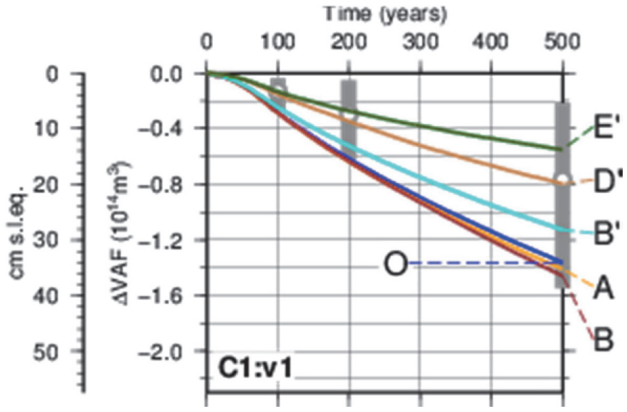


Fig. 1 Simulated changes in Greenland ice-sheet volume under the SeaRISE C1 experiment protocol (Bindschadler et al. 2013), obtained by six different configuration of IcIES. The vertical gray bars indicate the range of results by the SeaRISE 8 participants. Difference between D' and B' is due to the initialization method and that between B' and B is to the surface parameterization, which show dominiant contribution to the spread of multi-model projections.

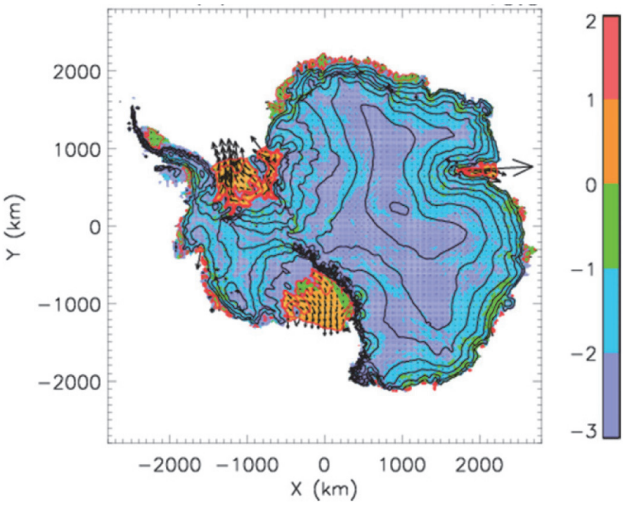


Fig. 2 Simulated surface velocity fields computed by IcIES under the present-day Antarctic ice sheet topography. Contours are the surface topography, colors are the velocity magnitude (km/yr).

## 3. Evaluation and improvement of the land-surface scheme

There have been significant warm biases in summer surface air temperature over land in mid- and high latitudes. That is partly due to lack of consideration for wetlands formed by snowmelt water in spring, leading to dry biases of surface soil moisture. Then, a simple scheme of snowmelt pond (Nitta et al. 2014 [3]) was implemented in MIROC5.2, and the impacts of that are evaluated. As a result, the warm bias in summer over land between 60 N and 70N was significantly reduced (left part of Fig. 3). Similarly, the underestimations of precipitation (right part of Fig. 3) and cloudiness (not shown) are reduced. At the same time, other biases in different seasons and different regions are unchanged.

## 4. Interannual variations of stratospheric water vapor

By analyzing the almost decade-long record of water vapor measurements from the Microwave Limb Sounder (MLS) instrument on the NASA Aura satellite and by detailed diagnostic analysis of the results from state-of-the art climate model simulations, we have confirmed the conceptual picture of the interannual variation in equatorial stratospheric water vapor discussed in earlier papers (e.g. Geller et al. 2002 [4]). The interannual anomalies in water vapor are strongly related to the dynamical quasibiennial oscillation (QBO) and we present the first QBO composite of the time-height structure of the equatorial water vapor anomalies. The anomalies display upward propagation below about 10 hPa in a manner analogous to the annual “tape recorder” effect, but at higher levels show clear downward propagation (Fig. 4a). We then examined these variations in the MIROC-AGCM and in four models in the Coupled Model Intercomparison Project 5 (CMIP5) that simulate realistic QBOs. The models which could simulate the QBO show similar structures of water vapor anomalies (Fig. 4b). Diagnostic budget analysis of the MIROC-AGCM data, as well as comparisons among the CMIP5 model results, demonstrate (i) the importance of temperature anomalies at tropopause induced by the QBO for lower stratospheric water vapor variations, and (ii) that upper stratospheric water vapor anomalies are largely driven by advection of the mean vertical gradient of water content by the QBO interannual fluctuations in the vertical wind (Kawatani et al. 2014 [5]).

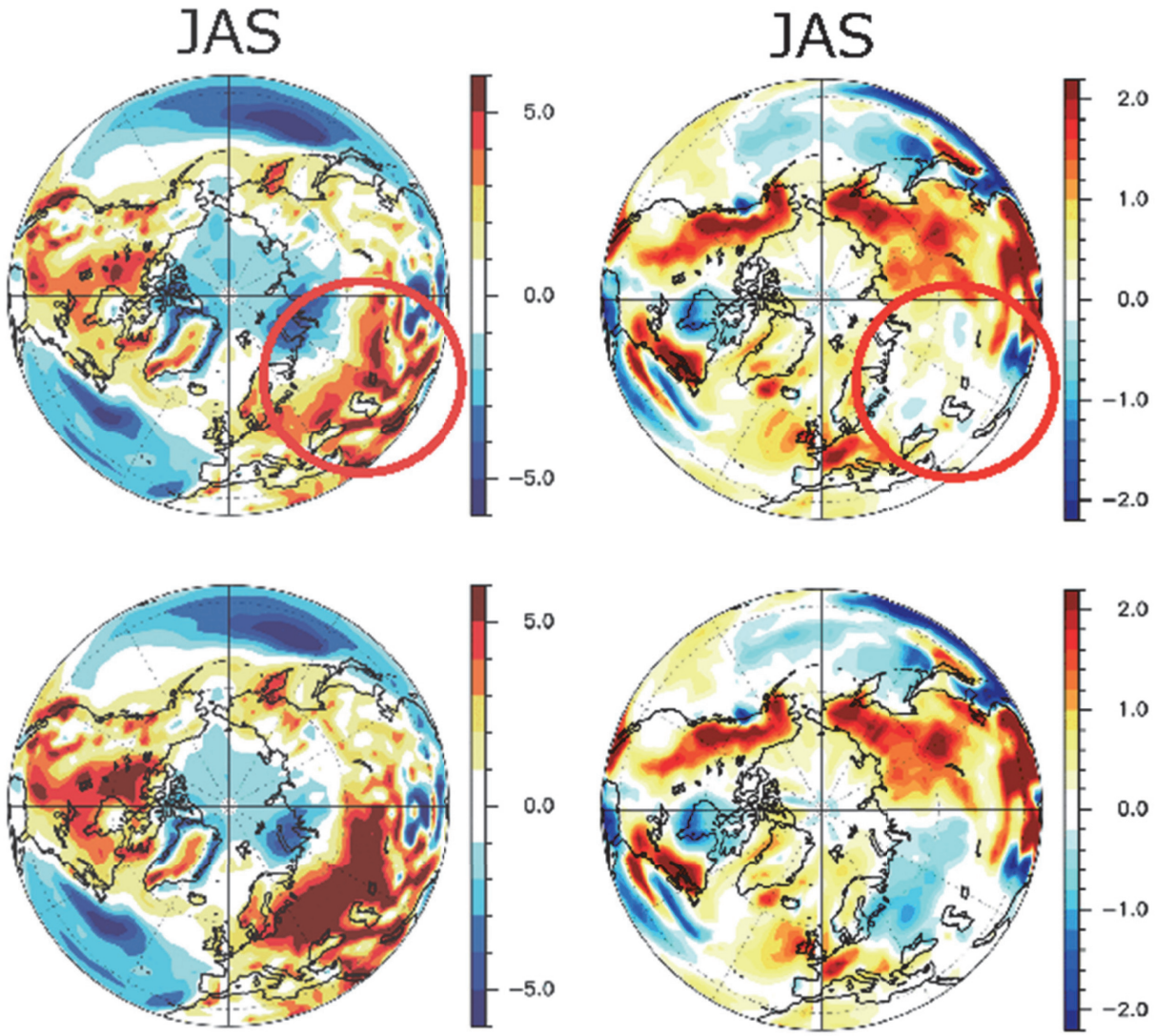


Fig. 3 Biases of MIROC5.2 from ERA interim in July-September. Left panels are surface air temperature, right are precipitation, upper are with snowmelt pond, and lower are without snowmelt pond.

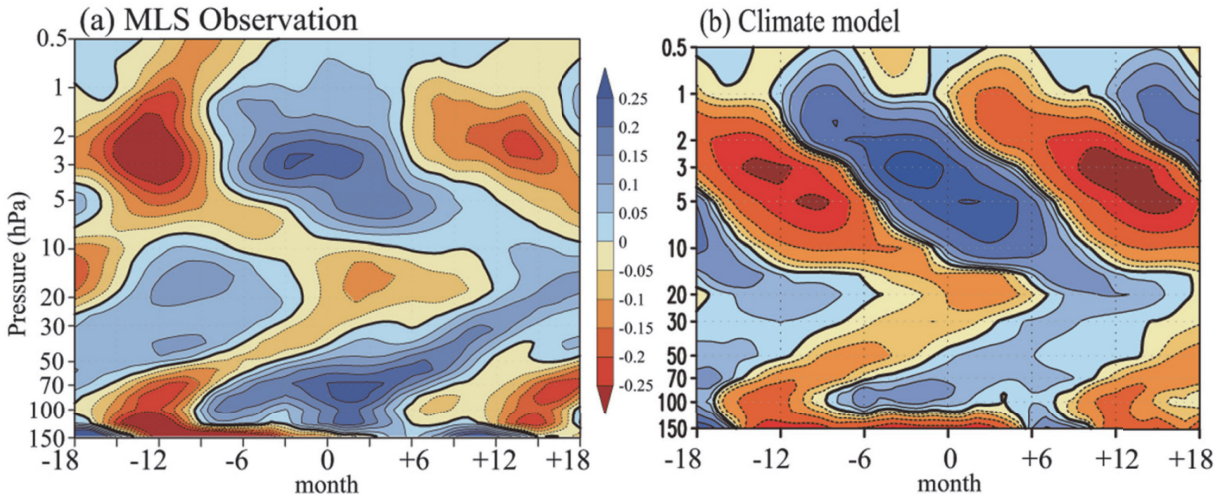


Fig. 4 Composite of the QBO in interannual variation of 12°S–12°N average $H_2O$ where month zero corresponds to westerly to easterly transition of the zonal wind at 30 hPa. (a) MLS observation and (b) climate model simulation. The color intervals are 0.05 ppmv.

## Reference

[1] Robert A. Bindschadler, Sophie Nowicki, Ayako Abe-Ouchi, Andy Aschwanden, Hyeungu Choi, Jim Fastook, Glen Granzow, Ralf Greve, Gail Gutowski, Ute Herzfeld, Charles Jackson, Jesse Johnson, Constantine Khroulev, Anders Levermann, William H. Lipscomb, Maria A. Martin, Mathieu Morlighem, Byron R. Parizek, David Pollard, Stephen F. Price, Diandong Ren, Fuyuki Saito, Tatsuru Sato, Hakime Seddik, Helene Seroussi, Kunio Takahashi, Ryan Walker, Wei Li Wang, Ice-Sheet Model Sensitivities to Environmental Forcing and Their Use in Projecting Future Sea-Level (The SeaRISE Project), Journal of Glaciology, 59, 214, 195–224. 2013.

[2] Fuyuki Saito, Ayako Abe-Ouchi, Kunio Takahashi, and Heinz Blatter, SeaRISE experiment revisited:Sources of Spread in Multi-model Projections of the Greenland Ice-Sheet, The Cryosphere Discussions, 9, 1383–1424, 2015.

[3] Tomoko Nitta, Kei Yoshimura, and Ayako Abe-Ouchi, H13C-1126, A sensitivity study of MATSIRO land surface model with a simple wetland scheme for improvements in the representation of surface hydrology and surface air temperature bias, AGU Fall Meeting 2014, San Francisco, 2014/12/17.

[4] Geller, M. A., X. Zhou, and M. Zhang, Simulations of the interannual variability of stratospheric water vapor, J. Atmos. Sci., 59, 1076–1085, 2002.

[5] Kawatani, Y., J. N. Lee, and K. Hamilton, Interannual variations of stratospheric water vapor in MLS observations and climate model simulations, J. Atmos. Sci., 71, 4072–4085, 2014.

# 長期的気候変動予測のための高精度気候モデルの開発研究

課題責任者
河宮未知生　　海洋研究開発機構　統合的気候変動予測研究分野
著者
河宮未知生 *1，阿部　彩子 *2, 1，河谷　芳雄 *1，大垣内るみ *3，齋藤　冬樹 *1，斉藤　和之 *1，
高橋　邦生 *1，高田久美子 *1, 4
*1 海洋研究開発機構　統合的気候変動予測研究分野
*2 東京大学　大気海洋研究所
*3 海洋研究開発機構　気候変動リスク情報創生プロジェクトチーム
*4 国立極地研究所

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。

グリーンランド氷床の将来の温暖化実験における氷床モデル依存の不確実性を評価するために他のモデルで採用されている手法を実装、効果を検証した。その結果、初期化手法と表面質量収支の違いがモデル間のばらつきに大きく寄与することが分かった。南極氷床の過去の温暖な時代に関する感度実験を行い、複数の気候モデルによる過去の気温や降水量再現下での定常解を計算した。その結果、気温上昇の効果が南極氷床の後退に大きく寄与することが分かった。氷床・棚氷モデルの南極現実地形での運用を行い計算速度についてまとめた。

高緯度陸上での夏季の高温バイアスの一因である融雪時の一時的な湿地帯が、MIROC の陸面過程では考慮されていない。この効果について、融雪時に表面流出の一定割合をためておくプールを追加する簡易湿地スキームを MIROC5.2 に導入し、全球気候への影響を調査した。その結果、北緯 50 度以北の陸上での夏季の高温バイアスや雲量と降水量の過小バイアスが大幅に改善する一方で、他の季節や地域のバイアスは増大させないことが分かった。

気候変動に重要な役割を果たしている成層圏水蒸気の年々変動を、最新衛星観測と気候モデルを組み合わせて精査した。観測データから（1）上部成層圏で時間と共に下方伝播する水蒸気偏差の存在を初めて発見、(2）上部対流圏から下部成層圏にかけて上方伝播する成分が卓越することを示した。次に気候モデル実験を行い（1）と（2）のメカニズムを解明し、(2）に関しては QBO 振幅と相関が高いことが分かった。

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, 海氷厚, 氷床モデル, 成層圏準二年振動（QBO）