Development of a High-Resolution Climate Model for Model-Observation Integrating Studies from the Earth's Surface to the Lower Thermosphere

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We investigated a reason why our T639L216 simulation of global middle atmosphere conducted last year was not successful, in which too strong gravity wave forcing destroyed the meridional structure of polar night jet soon after the simulation started. After several sensitivity studies changing the model's vertical resolution and horizontal diffusion parameters, we found that gravity wave forcing simulated in the model strongly depends on the model's vertical resolution. An increase of the model's vertical resolution from 500 m (216 layers) to 300 m (340 layers) dramatically improved the model's reproductively of the jet structures in the middle atmosphere.

Keywords: High-resolution climate model, atmospheric internal gravity waves

1. Introduction

This project aims at further developing gravity wave resolving global climate model and initiating integration studies of high-resolution model simulations and high-resolution observations with various measurement techniques (see our report Watanabe [1] for more details).

The main goal of this year was to investigate a reason why our high-resolution global simulation of the middle atmosphere using T639L216 (corresponding to 20 km horizontal resolution and 500 m in vertical) model was not successful, in which too strong gravity wave forcing destroyed the meridional structure of polar night jet soon after the simulation started. We took two approaches: one was sensitivity test simulation using the model (described later), and the other attempted to obtain observational constraints using a lidar observation dataset, that is, continuous measurements of temperature profiles at the Antarctic Davis station. In short, the former approach leaded to an improvement of the model, and the latter seemed to require further studies. This report particularly describes the former approach.

2. Model and experiment

The high-resolution climate model we are developing in this project is based on JAGUAR (Japanese Atmospheric General circulation model for Upper Atmosphere Research; Watanabe and Miyahara, [2]), and further modifications are outlined in our report in 2012 (Watanabe [1]). The model extends from the surface to a 150 km height. The model's configuration in the previous year was a horizontal resolution of T639 (about 20 km) and a vertical resolution of 500 m (has 216 vertical layers). This year we performed several sensitivity test simulations changing the model's vertical resolution and horizontal diffusion parameters. These sensitivity test simulations were conducted using the both of T213 (about 60 km) and T639 (about 20 km) horizontal resolution. After a series of T213 simulations changing only the model's vertical resolution, we performed a T639 simulation changing its vertical resolution from 500 m (L216) to 300 m (L340). The remaining of this report compares results of those two (T639L216 and T639L340) simulations. An initial condition of the T639L340 simulation was made by a linear interpolation from the T639L216 data of June 21, and the simulation was conducted from June 21 to June 30.

3. Results

Figure 1 compares the zonal mean zonal wind in June among observed monthly climatology, T639L216 one-day average on June 12, and T639L340 five-day average over June 26-30. The T639L216 model fails to reproduce the observed meridional structures of the wintertime polar night jet and summertime easterly jet in the middle atmosphere. In particular, the wintertime westerly jet in the Southern Hemisphere breaks down due to too strong gravity wave forcing in a 40-55 km height region (see Fig. 2c and the previous annual report; Watanabe [3]). On the other hand, T639L340 model better simulates the jet structures. This is mainly due to the fact that gravity wave forcing in the 40-55 km height region simulated by those model versions decreases with increasing model's vertical resolution (Fig. 2). The causal mechanisms of such dependence of gravity wave forcing on the model's vertical resolution is interesting,

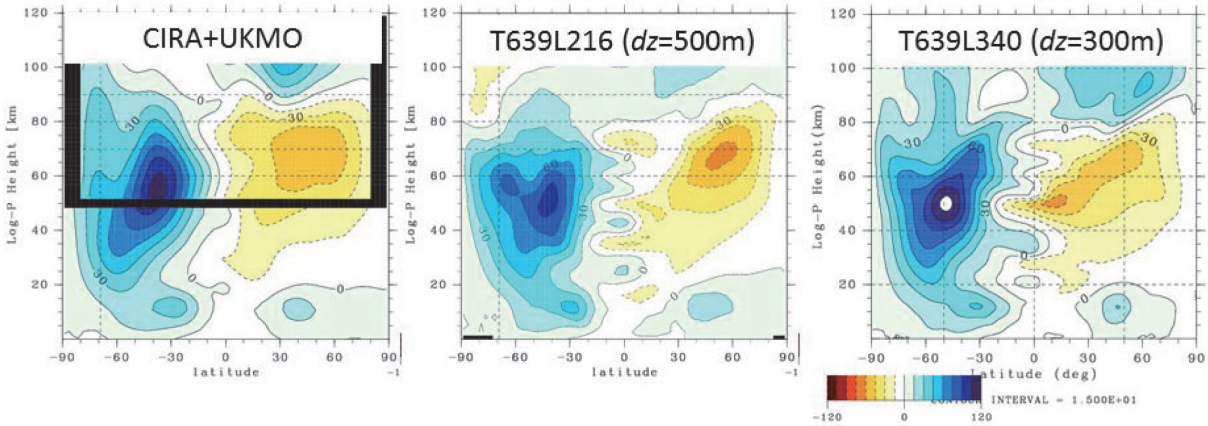

Fig. 1 The zonal mean zonal wind in June. Left: monthly climatology of the Met Office assimilation data (below 50 km) (Swinbank and O'Neill, [5]) and the 1986 Committee on Space Research (COSPAR) International Reference Atmosphere (CIRA) data (above 50 km) (Fleming et al. [6]). Center: T639L216 (*dz*=500m) Right: T639L340 (*dz*=300m). The model data corresponds to a one-day average of June 12 for T639L216, and a three-day average of June 28-30 for T639L340, respectively.

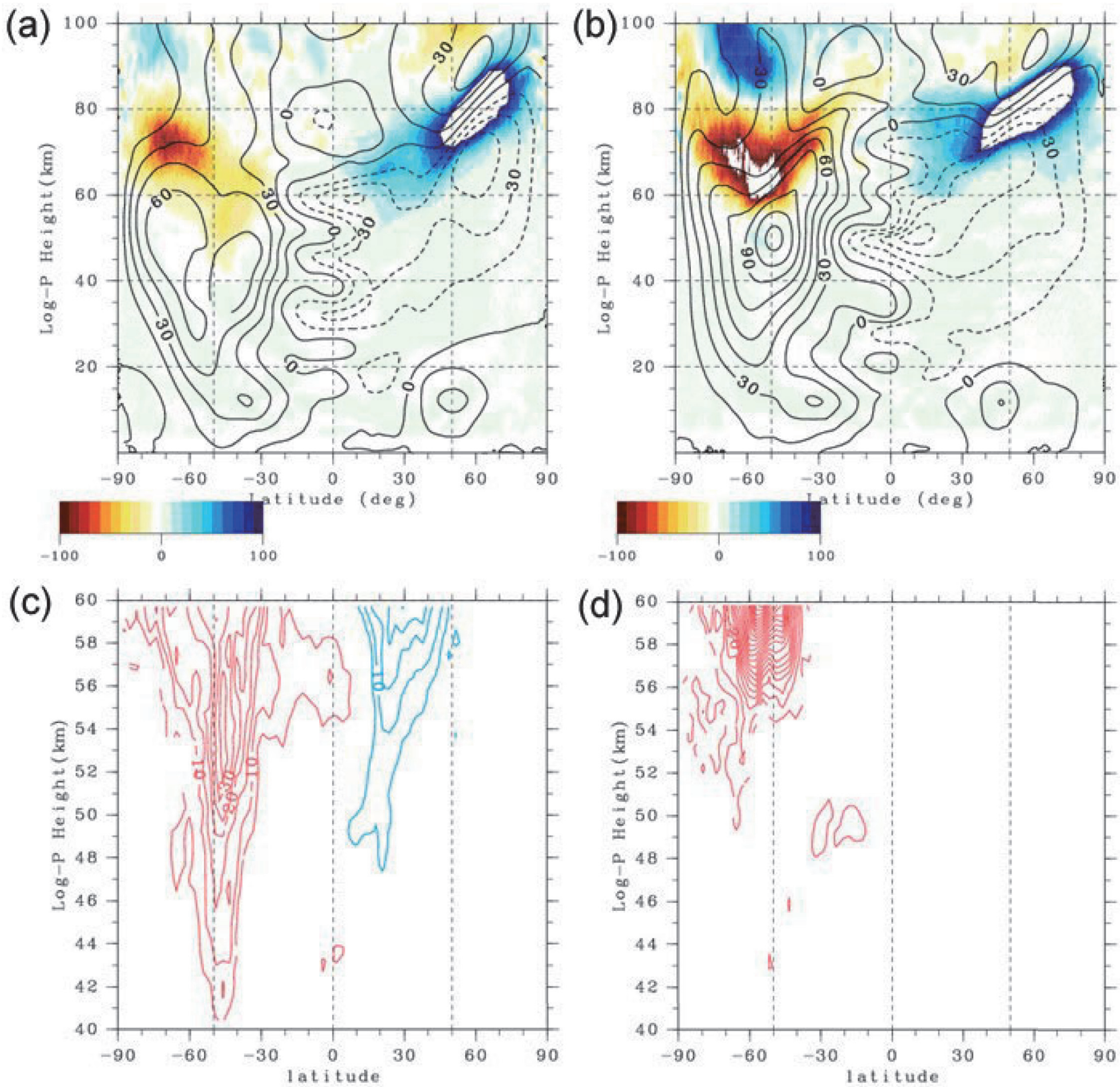

Fig. 2 The zonal mean zonal wind (contours with an interval of 15 ms^{-1}) and eastward gravity wave forcing (color shading with an interval of 10 ms^{-1}day^{-1}) in the T639L216 model during June 10-15 (a) and the T639L340 model during June 26-30 (b). Close up views of 40-60 km for the T639L216 (c) and T639L340 (d) models with the contour interval of 5 ms^{-1}day^{-1}.

and would be reported in the near future (Watanabe [4]).

Another interesting feature in Fig. 2 is that there exists a dipole structure of westward and eastward gravity wave forcing around 60-80 km and 80-100 km height of the SH mid-latitudes. The westward gravity wave forcing decelerates the upper part of wintertime westerly jet, while the eastward gravity wave forcing above that seems to maintain westerly winds along 50S of 80-100 km height. Since this westerly winds are absent in the observed climatology (Fig. 1), the eastward gravity wave forcing could be generated in unrealistic ways. Behaviors of gravity waves in this region must be investigated in the near future.

4. Closing remarks

This three-year project aimed at developing a state-of-the-art high-resolution global climate model which explicitly resolves a major part of vertically propagating atmospheric gravity waves, and initiating integration studies of high-resolution model simulations and high-resolution observations with various measurement techniques (Watanabe [1] and Watanabe [3]). We experienced that the increase of model's horizontal resolution from T213 (60 km) to T639 (20 km) was not successful, unless the vertical resolution was simultaneously increased. We have developed the T639L340 global climate model extending from the surface to about 150 km height with the 300 m vertical resolution, which qualitatively reproduces large-scale wind structures in the middle atmosphere. Our efforts to obtain statistical observational constraints on the model's gravity wave behaviors in the middle atmosphere has just started, and we need further time and new observations. Finally, we would like to thank this ES project, giving us a really good opportunity to start up several model-observation collaboration studies, whose outcomes would be reported in the future.

Acknowledgement

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高解像度気候モデルの開発
－地表から下部熱圏大気のモデル・観測統合研究に向けて

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前年に行った T639L216 シミュレーションがうまく行かなかった（シミュレーション開始直後に、強すぎる重力波強制によって極夜ジェットの構造が壊れてしまった）理由について検討を行った。モデルの鉛直解像度や水平拡散パラメーターを変えながら行った一連の感度実験の結果から、モデルでシミュレートされる重力波強制の大きさが、モデルの鉛直解像度に強く依存することが判明した。モデルの鉛直解像度を 500m から 300m に増やすことにより、中層大気のジェットの構造が大きく改善された。

キーワード : 高解像度気候モデル , 大気内部重力波