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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Following a spin-up simulation in the previous year, we have performed several few-week simulations of global atmosphere using a T639L216 global climate model, which extends from the surface to the lower thermosphere. We particularly focus on the wave-mean flow interactions associated with atmospheric gravity waves with horizontal wave length of O (10-100 km), which cannot be directly simulated with conventional global climate models. The first T639L216 simulation was not successful, in which too strong gravity wave forcing destroyed the meridional structure of polar night jet soon after the simulation started. Comparisons of gravity wave characteristics simulated in the T213 and T639 models suggest that the T639 model may generate too many gravity waves with large wave amplitude. Thorough theoretical considerations, additional sensitivity studies, and observational constraints would be required to obtain more realistic simulation of gravity waves using such an unprecedented high-resolution global climate model, and we would continue those efforts next year.

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 in the previous year for more details; Watanabe [1]).

The main goals of this year were to perform several few-week simulations using our gravity wave resolving global climate model at a target resolution (T639L216: corresponding to 20 km horizontal resolution and 500 m in vertical), and for the first time compare simulated gravity waves to those observed with the PANSY radar which has been under construction at the Antarctic Syowa station. Unfortunately, weather and sea-ice conditions in last two Antarctic summertime (2011/2012 and 2012/2013) were worst in the history of Syowa station, which prevented the ice-breaker Sirase from approaching the Syowa station. Due to difficulties in transport of necessary materials, the full operation of PANSY radar was postponed. Therefore, we concentrated our attention to results of the high-resolution model simulations.

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 the previous year (Watanabe [1]). The model contains 216 levels between the surface and a 150 km height (500 m vertical resolution through 0 – 100 km), and has two configurations for horizontal resolution, that is, T213 (about 60 km) and T639 (about 20 km). Following a one-year T213 simulation, we performed a four-day (1-4 June) spin-up simulation using the T639 model during last year. This year we perform several few-week simulations of the T639 model, and compare characteristics of mean wind structures and gravity waves simulated in the T213 and T639 models. Results of the first T639 simulation would be highlighted in this report, which extends from June 5 to June 15 in a certain (virtual) model year.

3. The first T639L216 simulation

Figure 1 compares the zonal mean zonal wind in June among observed monthly climatology, T213 monthly mean from the one-year pilot simulation, and T639 one-day average in June 12, which corresponds to the 8th day after the beginning of simulation (June 5). Obviously, the T639 model fails to reproduce the observed meridional structures of the wintertime polar night jet and summertime easterly jet in the middle atmosphere, while the T213 model qualitatively simulates those structures. This has not been expected because an increase in horizontal resolution had continuously improved realization of the mean wind structures in the middle atmosphere (e.g., Hamilton, et al. [3]; Hamilton et al. [4]; Kawamiya et al. [5]). In principle, the higher resolution gives more realistic result. Why not?

It has turned out by comparing wave-mean flow interactions in the T213 and T639 models that the T639 model generates too much gravity wave forcing in the upper stratosphere and lower mesosphere (40-60 km), which destroys the mean wind structure of the polar vortex (Fig. 2). Here, eastward gravity wave forcing is approximately calculated as vertical divergence of upward flux of zonal momentum. Therefore, it is natural to consider that the T639 model may generate too many gravity waves with large wave amplitude. Another possibility is that the wave dissipation processes which weaken upward propagating gravity waves, e.g., turbulent dissipation due to unresolved motions which is often represented by numerical diffusion, in the T639 model may not sufficiently work. Anyhow, our first T639 simulation was not successful, which further motivated us to understand behaviors of gravity waves in the real atmosphere.

4. Possible comparison to observation

Ideally, we should have appropriate observation of the real world, which can be used to constrain our model (as directly as possible). Here, we would present a few example of our basic ideas on how we utilize observation data to improve the T639 model. As for the wave generation issue, recent

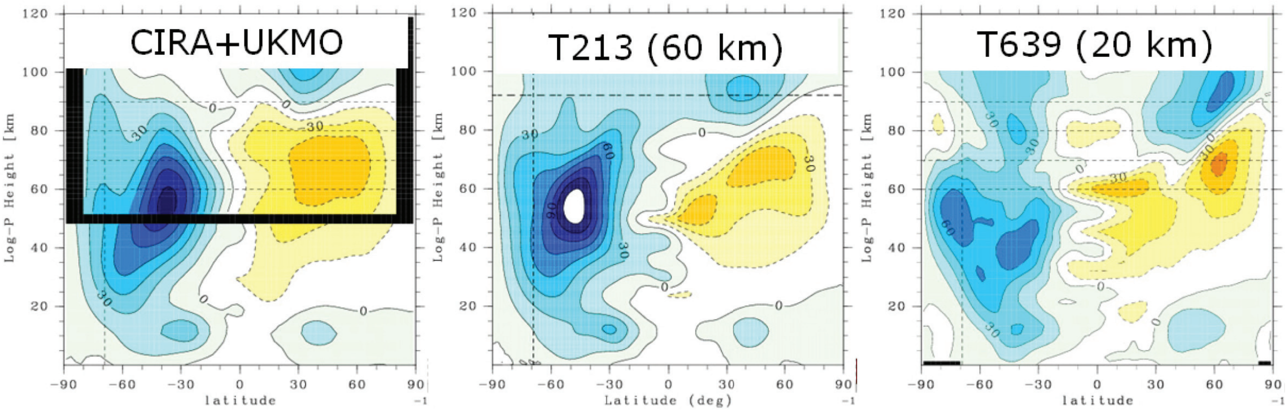

Fig. 1 The zonal mean zonal wind in June. Left: monthly climatology of the Met Office assimilation data (below 50 km) (Swinbank and O'Neill, [6]) and the 1986 Committee on Space Research (COSPAR) International Reference Atmosphere (CIRA) data (above 50 km) (Fleming et al. [7]). Center: T213 monthly mean. Right: T639 result which is a one-day average on June 12 (see text).

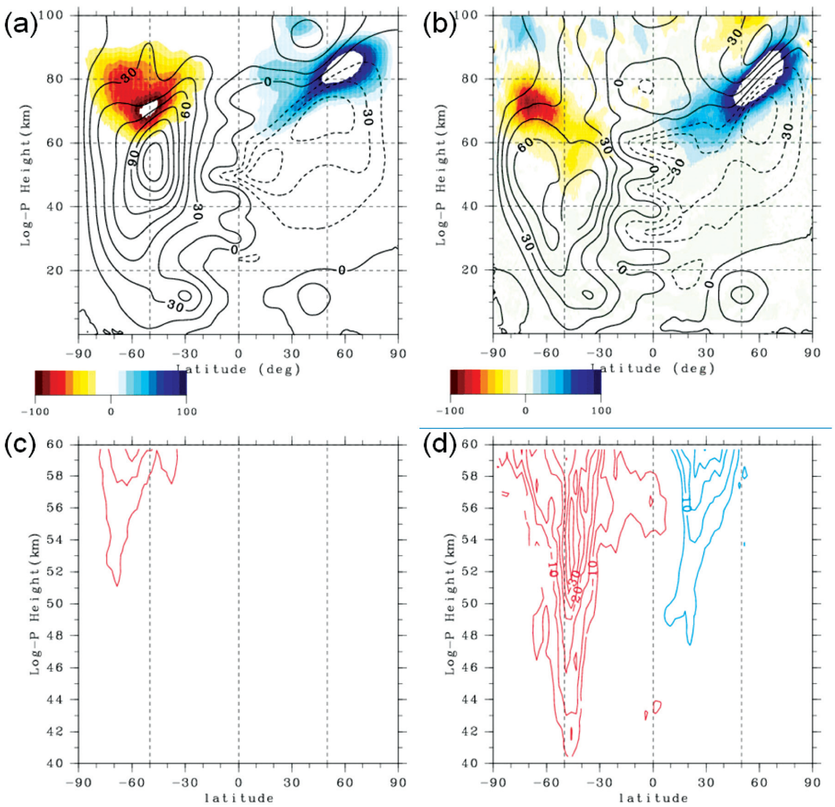

Fig. 2 The zonal mean zonal wind (contours with an interval of 15 ms^{-1}) and eastward gravity wave forcing (color shading with an interval of 10 $ms^{-1}day^{-1}$) in the T213 model during June 1-30 (a) and the T639 model during June 10-15 (b). Close up views of 40-60 km for the T213 (c) and T639 (d) models with the contour interval of 5 $ms^{-1}day^{-1}$.

satellite observations do provide global estimates of gravity wave amplitude (a few of them further estimate gravity wave momentum flux) in the lower stratosphere, where is near source altitudes of gravity waves (e.g., Alexander et al. [8] and reference therein). However, each satellite instrument measures only a portion of gravity wave spectrum, e.g., a limited range of frequency and wavelength, which can potentially be simulated in our model. We may need to observe our model's wave field from a virtual satellite orbit with similar field of view (nadir or limb scan) and weighting function that satellite instrument employs. This is so-called 'satellite simulator'. We once experienced such a collaboration study with satellite people using the T213 model (not published), and further work with T639 model would be promising.

On the other hand, the dissipation (turbulent diffusion) issue could be addressed with ground based instruments which have high-vertical and temporal resolutions in the upper stratosphere and mesosphere, such as radars and lidars. For example, MST (Mesosphere-Stratosphere-Thermosphere) radars provide estimations of eddy vertical diffusion coefficient (e.g., Fukao et al. [9]), which can be compared with model's one. Model's vertical profiles of minimum and maximum eddy vertical diffusion coefficient could be constrained through such an effort. Lidar may provide important information; that is a probability for occurrence of turbulent mixing as a function of height. In other words, we need to know when (how frequent?) and where (altitude?) gravity wave dissipation occurs in statistical sense, because this is the fundamental difference we found between the T213 and T639 models (Fig. 3).

5. Possible sensitivity studies

Another way to improve the T639 model is to perform any useful sensitivity tests using the model. If we just want to obtain realistic mean wind structures, it might be reasonable to tune (strengthen) eddy diffusion parameters, which arbitrarily alter (weaken) gravity wave amplitude in the middle atmosphere. This is, however, quite meaningless to us, because we want to simulate physically realistic behaviors of gravity waves, as well as the mean wind structures. One candidate of helpful sensitivity tests would be to increase/decrease vertical resolution of the model. It has been pointed out that increasing only horizontal resolution (from T213 to T639 in our case) should not be appropriate in gravity wave modeling (Lindzen and Fox-Rabinovitz [10]). We have started addressing this issue, and the results would be reported in the near future.

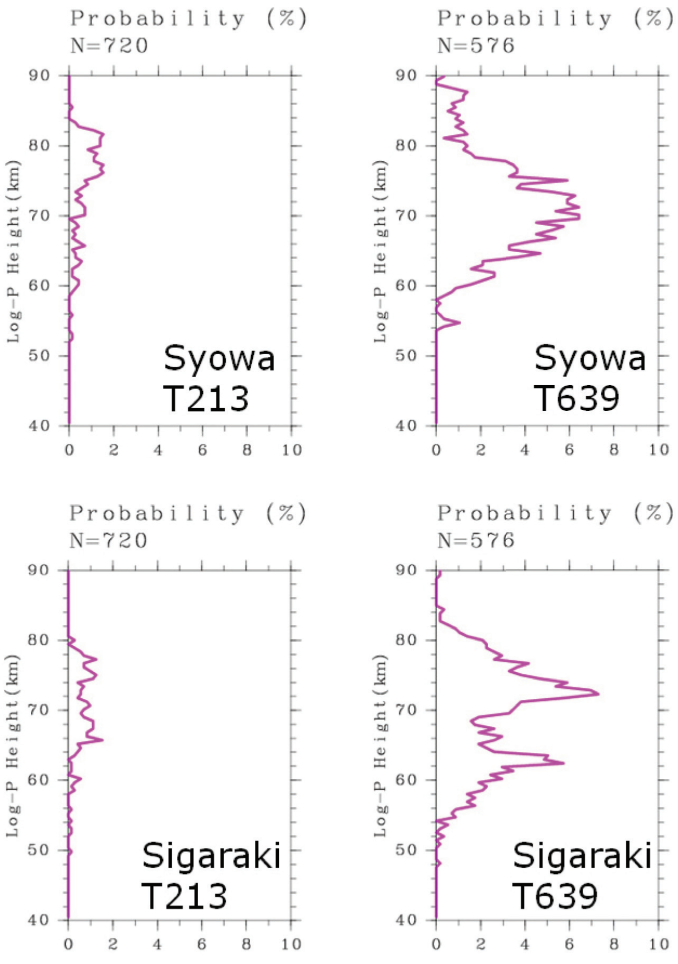

Fig. 3 Provability profiles for detection of turbulent mixing, which is mostly caused by gravity waves, at model's grid points close to Japanese lidar observation sites; the Antarctic Syowa station and the MU radar site in Sigaraki, Japan. The analysis period for these statistics is June 1-30 (June 10-15) for the T213 (T639) model.

6. Summary

We have performed several few-week simulations using the T639 model. The first simulation of the T639 model was not successful, in which too strong gravity wave forcing destroyed the meridional structure of polar night jet very soon. The comparisons of gravity wave characteristics between the T639 and T213 models have revealed that the strong gravity wave forcing in the T639 model occurs at lower altitude than that in T213. This implies that the T639 model may generate too many gravity waves with large wave amplitude. Thorough theoretical considerations, additional sensitivity studies, and observational constraints would be required to obtain more realistic simulation of gravity waves using our high-resolution global climate model, and we would continue those efforts next year.

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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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前年に行ったスピンアップ実験に引き続き、地表から下部熱圏までを含んだ T639L216 全球気候モデルを用いて、数週間スケールの全球大気シミュレーションを実施した。とくに注目したのは、通常の気候モデルが表現できない水平波長 10-100 km スケールの大気重力波に関する波と平均流の相互作用である。最初に行った T639L216 モデルによるシミュレーションは「成功」とは呼べないものであり、重力波による平均流への過剰な波動強制（ここではブレーキ作用）が、極夜ジェットの子午面構造を実験開始から短期間のうちに破壊してしまった。T213 モデルと T639 モデルでシミュレートされた重力波の性質を比較したところ、T639 モデルは大振幅の重力波を数的に過剰に生成していることが示唆された。理論的考察をはじめ、モデルを用いた感度実験や、観測事実からモデルの拘束条件を導くなどの努力が、T639L216 という前例のない高解像度気候モデルを用いて現実的な大気重力波のシミュレーションを行うためには不可欠であることが分かった。来年にかけて、こうした努力を積み重ねていく必要がある。

キーワード : 高解像度気候モデル , 大気内部重力波