Toward high-resolution simulation of planetary atmospheres—Model dependencies of a QBO-like oscillation.

*Hiroki Kashimura[1], Hisashi Yashiro[2], Seiya Nishizawa[2], Hirofumi Tomita[2], Kensuke Nakajima[3], Masaki Ishiwatari[4], Yoshiyuki O. Takahashi[1], Yoshi-Yuki Hayashi[1]

1. Kobe Univ./CPS, 2. RIKEN AICS, 3. Kyushu Univ., 4. Hokkaido Univ.

Scales of atmospheric motions in Earth range from a few meter to the planetary scale, and multi-scale phenomena interact with each others. This is a reason for promoting an atmospheric simulation with higher resolution. The situation must be same in other planets such as Mars and Venus. Higher resolution is required for better understanding of the planetary atmosphere. However, especially for the planetary atmospheres, we should advance carefully on a higher resolution simulation, because there is almost no observations for small scales.

On the way to higher resolution, there are some gaps both in governing equations and in calculation methods.

For large-scale motions, the atmosphere keeps the hydrostatic balance, and it is assumed in the governing equations. On the other hand, for small-scale (a few tens of kilometers) motions, the assumption of the hydrostatic balance is not valid, and we need to calculate a prognostic equation of vertical momentum. Hence, the making the resolution higher requires change in the governing equations.

To achieve a high performance in massive parallel computers, calculation methods also must be revised. A spectral method has been widely used for numerical simulation of the atmosphere in a spherical geometry. This is because the spectral method has an advantage of a high precision and avoiding inequality in the resolution on a sphere. However, it is not suitable for the parallel computing due to spectral transformation. To benefit the power of the massive parallel computers, an icosahedral grid systems has been constructed (Tomita et al. 2001, 2002). Difference in calculation methods may influence numerical solutions in a significant scale, though it is undesirable.

To overcome the above gaps—to understand the dependency of numerical solutions on governing equations and calculation methods and to obtain robust results and knowledge, which are independent on them—comparative studies are important. In this study, we use two numerical models: DCPAM and SCALE-GM. DCPAM assumes the hydrostatic balance and uses the spectral methods. SCALE-GM is a non-hydrostatic model using a finite volume method in the icosahedral grid systems. Optionally, SCALE-GM can be used with the hydrostatic assumption.

We have performed an idealized experiment of the Earth-like atmospheric circulation (Held and Suarez 1994) with an extension of the model top to around 50 km, by using both models. In the lower atmosphere (< 15 km), similar atmospheric circulation was obtained in both models; whereas the behavior of zonal wind in the upper atmosphere differs significantly. SCALE-GM showed QBO-like oscillation, that is, the direction of the mean zonal wind above the equator changes with a period of about two years. However, DCPAM did not show such oscillation. Such QBO-like oscillation and its model dependency were reported by Yao and Jablonowski (2013, 2015), but is not well investigated.

To explore the model dependency of the QBO-like oscillation, we have performed numerical experiments

with a variety of horizontal eddy diffusion and model resolution. Numerical results show that a QBO-like oscillation also occurs in DCPAM when the horizontal diffusion is weak. For both models, the weaker horizontal diffusion results in shorter period of the QBO-like oscillation. In addition, the finer resolution makes the period shorter. An analysis of the momentum transport shows that the vertical transport of zonal momentum by disturbances from the zonal mean is stronger in the shorter oscillation cases. Such vertical transport would be caused by vertical propagation of atmospheric gravity waves. Hence, the horizontal eddy diffusion and model resolution influence the occurrence of QBO-like oscillation and its period via the excitation, propagation, and/or breaking of the gravity waves.

Keywords: atmospheric general circulation model, Held and Suarez (1994) experiment, quasi-biennial oscillation

