Numerical experiments of giant planet surface flows produced by forcings representing thunderstorms

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abstract

It is known that the surfaces of giant planets have the banded structure consisting of eqatorial jets with wide latitudinal widths, mid-latitude jets with a narrow latitudinal widths, and the vortex structure in the polar regions. Large-scale structures such as bands and polar vortices can be formed from small-scale turbulence in the atmospheres due to the inverse cascade effect (Vallis 2017). Thunderstorms are considered to be a candidate for causing such small-scale turbulence (e.g. Ingersoll et al., 2000). Showman (2007) and Brueshaber et al. (2019) restricted the computational domain to a part of the sphere and calculated in the framework of the shallow water equations with the mass forcing representing thunderstorms. Showman (2007) restricted the computational domain to the latitude range of $0° - 70°$ and the longitude range of $0° - 120°$, and the results showed the formation of the banded structures. Brueshaber et al. (2019) found the polar vortex structures were formed in the computational domain from latitude $60°$ to high latitude In addition, their results showed that the number and size of polar vortices, the sign of vorticity significantly depend on the value of Burger number ($Bu = (L_d/a)^2$, L_d : deformation radius, a : planetary radius).

However, their computational domain is only a part of the sphere. It is necessary to confirm their results by calculating on the global domain. Since the structure of jets and vortices may change due to momentum transport from outside the restricted computational domain. The purpose of this study is to perform wheter the jet and polar vortex structures seen on giant planets are formed by the mass forcing representing thunderstorms. Then, compare the global calculation results with the results of previous studies and consider the validity of the results obtained by domain calculation.

In the numerical experiment using the Hierarchical Spectral Models for GFD (SPMODEL; Takehiro et al. 2006, Takehiro et al. 2013). The used equations are a 1.5-layer shallow water equations with the mass forcing representing thunderstorms.

In the standard experimetal ($Bu = 9.72 \times 10^{-5}$) results, the banded structure and the polar vortex structure were formed. It was also found that the structures remained almost unchanged even if the positive / negative ratio of the mass forcing and the spatial size were varied. The characteristics of the polar vortex were found to depend on the value of Burger number: when the Burger number is small, small multiple vortices are formed, as observed Jupiter, and as the Burger number increases, a single cyclonic vortex is formed, observed on Saturn, Uranus, and Neptune. These results are consistent with the results of Showman (2007) and Brueshaber et al. (2019). Moreover, the results using the same parameters as in Showman (2007) show that the zonal wind speed of the equatorial jet is about 10 times larger than their results. The result possibly suggests that the existence of polar reions and/or opposite hemisphere, which was not considered in Showman (2007), affect the strength of the jet.

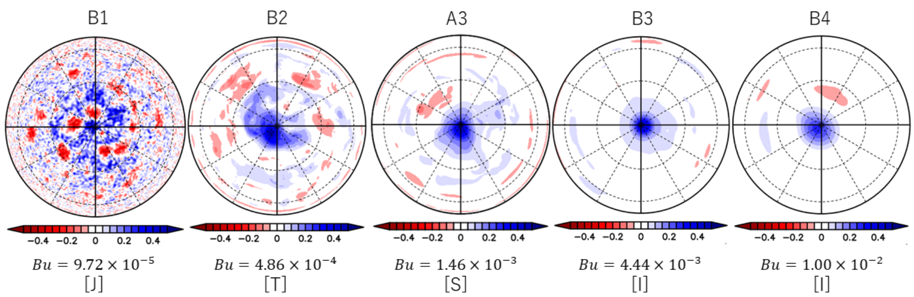

Fig. 1: Nondimensional potential vorticity : Q_e^* for various values of Burger number. Positive (Negative) values of Q_e^* are cyclonic (anticyclonic).