

Numerical experiments of surface flows on giant planets produced by forcings representing thunderstorms

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Abstract

It is known that the surfaces of giant planets have the banded structures consisting of equatorial jets with wide latitudinal widths and mid-latitudinal jets with narrow latitudinal widths, and the vortex structures in the polar regions. Large-scale structures such as banded structures and polar vortices can be formed from small-scale turbulence 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) performed calculations in the framework of the shallow water system with the mass forcing representing thunderstorms. Showman (2007) showed the formation of the banded structures with restricting the computational domain to the latitude range of $0^\circ - 70^\circ$ and the longitude range of $0^\circ - 120^\circ$. 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, and the sign of vorticity significantly depend on the value of Burger number ($Bu \equiv (L_d/a)^2$, L_d : deformation radius, a : planetary radius).

However, computational domains used by previous studies are restricted to 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 regions outside the restricted computational domain. The purpose of this study is to perform global calculations and to investigate whether the jet and polar vortex structures can be formed by the mass forcing representing thunderstorms. Then, these structures are compared with the results obtained in previous studies to validate the domain calculations.

The model used in this study is 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. The experimentals are performed with changing values of the Burger number. Standard experiment was performed with the values of planetary radius and rotation rate same as those of Jupiter, and $Bu = 9.72 \times 10^{-5}$. In Standard experiment, all of mass forcing was assumed to be positive.

In the Standard experiment, 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 changed according to the value of Burger number (Fig. 1): 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, as 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 existences of polar regions and/or opposite hemisphere, which was not considered in Showman (2007), affect the strength of the jet.

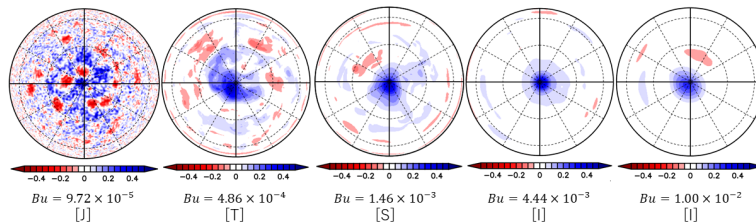


Fig. 1: Nondimensional potential vorticity : Q_e^* for various values of Burger number.

Positive (Negative) values of Q_e^* are cyclonic (anticyclonic).