Dynamical analysis on splitting of subtropical high-pressure zone
——Geostrophic effect

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Abstract Based on two simple dynamical models, the preliminary dynamical analysis of the splitting of subtropical high-pressure zone (SHPZ) without land-sea contrast and orographic effect is investigated. Results show that the splitting of SHPZ may be an intrinsic attribute of the earth rotation atmosphere.

Keywords: subtropical high-pressure zone, splitting, inhomogeneity.

THERE is a subtropical high-pressure zone (hereinafter termed SHPZ) between tropical belt and extratropical belt. It is not a continuous belt but splits into some closed high-pressure systems[1, 2]. Why does SHPZ split? To date, the problem has not been solved completely[3]. Some studies[4, 5] hold that the splitting of SHPZ is caused by the external factors, i.e. land-sea distribution and orographic effect. However, these explanations are not satisfactory; for example, they cannot explain the phenomenon that the splitting of SHPZ at middle and upper troposphere is caused by the existence of mid-ocean trough. Thus there are internal dynamical causes in the splitting of SHPZ besides the external causes of land-sea and orographic effect. Nevertheless, dynamical theoretical study is lacking for the splitting of SHPZ. The simple models that describe SHPZ are gotten by the analysis of observational data in this note, and based on them, the preliminary analysis of the dynamical process of splitting of SHPZ is carried out.

1 Dynamical model

For the dynamical study of SHPZ, the importance is not what bearing it has on SHPZ but what are main[1)]. SHPZ existing in the whole year is relatively stable in the planetary-scale system with quasi-stationary property, so the stationary equations of horizontal motion without friction in the spherical coordinate (λ, φ, p) are used in discussion. In order to catch the main characteristics of the system, the orders of the inertial force, the pressure-gradient force and the Coriolis force in the equations need to be compared. Here we do not adopt the method of order estimate in the usual scale analysis but directly calculate and compare with observational data. The method avoids some guesses so that the results are more conformable to the case of the real atmosphere. The data used in this note is the monthly mean data of ten years in European Centre for Medium-range Weather Forecast (ECMWF) seven levels (1980—1989).

Figure 1(a) and (b) show the zonal mean distribution of the ratios between the inertial force,

1) Chou Jifan, Ideas of studied methods for the dynamical mechanism of anomoly of East Asian monsoon, *Paper Abstracts of Academic Discussion on Monsoon*, 1995 (unpublished).

the pressure-gradient force and the Coriolis force at 500 hPa for July in the Northern Hemisphere (we do not consider the case in the equatorial belt, i.e. from 5°S to 5°N). For the large-scale motion except in the equatorial belt, they show that the pressure-gradient force balances basically with the Coriolis force, and that the inertial force is at least one order of magnitude smaller than them. So the stationary equations of large-scale horizon motion in the spherical coordinate (λ, ϕ, p) can be written as follows with high accuracy:

$$f v = \frac{1}{a\cos\varphi}\frac{\partial\Phi}{\partial\lambda}, \tag{1}$$

$$f u = -\frac{1}{a}\frac{\partial\Phi}{\partial\varphi} \tag{2}$$

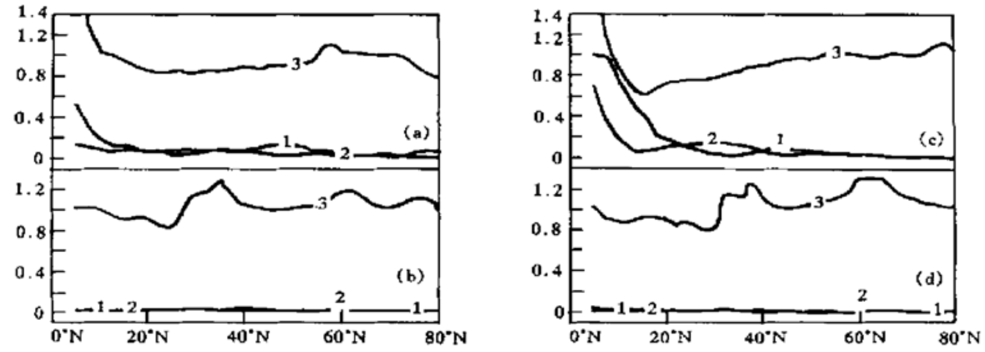

Fig. 1. The zonal mean distribution of the ratios between the inertial force, the pressure-gradient force and the Coriolis force at 500 hPa ((a), (b)), 100 hPa((c), (d)) for July in the Northern Hemisphere. (a), (b), curves 1—3 are $\left[\left|\frac{u}{a\cos\phi}\frac{\partial u}{\partial\lambda}\Big/fv\right|\right]$, $\left[\left|\frac{v}{a}\frac{\partial u}{\partial\varphi}\Big/fv\right|\right]$ and $\left[\left|\frac{1}{a\cos\phi}\frac{\partial\Phi}{\partial\lambda}\Big/fv\right|\right]$ respectively; (c), (d), curves 1—3 are $\left[\left|\frac{u}{a\cos\phi}\frac{\partial v}{\partial\lambda}\Big/fu\right|\right]$, $\left[\left|\frac{v}{a}\frac{\partial v}{\partial\varphi}\Big/fu\right|\right]$ and $\left[\left|\frac{1}{a}\frac{\partial\Phi}{\partial\varphi}\Big/fu\right|\right]$ respectively.

These are just geostrophic balance. They show that for planetary-scale motion the quasi-geostrophic approximation of wind field is effective not only in the middle and high latitudes, but also in the low latitudes[6]. By analyzing and comparing the results of the other six levels, we may conclude that all of the component u may satisfy eq. (2), and that the component v may satisfy eq. (1) at the middle levels, and that although the inertial force is smaller than the Coriolis force at the upper troposphere over the low latitude region, their difference does not reach one order of magnitude. Therefore, for the upper troposphere the following stationary equations need to be discussed:

$$\frac{u}{a\cos\varphi}\frac{\partial u}{\partial\lambda} + \frac{v}{a}\frac{\partial u}{\partial\varphi} - f v = \frac{1}{a\cos\varphi}\frac{\partial\Phi}{\partial\lambda}, \tag{3}$$

$$f u = -\frac{1}{a}\frac{\partial\Phi}{\partial\varphi} \tag{4}$$

In fact, eq. (3) is more general than eq. (1). This shows that even if the motion is of the same scale, all the factors play a main role at different levels.

Additionally, the calculated results show that every level except the equatorial belt at the same latitude has (curve 2 in fig. 1(a) and (b))

$$f > \frac{1}{a}\frac{\partial u}{\partial \varphi}. \tag{5}$$

This is essentially the other form of the case that the Coriolis force is larger than the inertial force for the larger-scale motion.

2 Analysis

First of all, we introduce two concepts of homogeneity and inhomogeneity. If the sign of a physical variable A is everywhere the same on one closed curve (or region), then A is called homogeneous on the curve (or region). Homogeneity is called zonal homogeneity if the closed curve (or region) is a parallel (or zone). On the contrary, inhomogeneity means that a physical variable A is a sign function on a closed curve (or region). First let us discuss equations (1) and (2).

The observations of atmospheric circulation show that westerlies prevail in the troposphere in low latitude areas. The ridge line of SHPZ is just situated on the line where the component of east and west winds are zero[1−5]. Thus, we only discuss the case of line $u = 0$. From eq. (2) we have

$$\left.\frac{\partial \Phi}{\partial \varphi}\right|_{u=0} = 0. \tag{6}$$

So on line $u = 0$, Φ gets its extremum in ϕ direction. The properties of extremum depend on the derivative of two orders:

$$\left.\frac{\partial^2 \Phi}{\partial \varphi^2}\right|_{u=0} = -a\left(\beta u + f\frac{\partial u}{\partial \varphi}\right)\bigg|_{u=0} = -af\left.\frac{\partial u}{\partial \varphi}\right|_{u=0}. \tag{7}$$

If the shear of zonal wind $\frac{\partial u}{\partial \varphi}$ on line $u = 0$ is inhomegeneous, Φ gets maximum at $\left.\frac{\partial u}{\partial \varphi}\right|_{u=0} > 0$ in ϕ direction, and gets minimum at $\left.\frac{\partial u}{\partial \varphi}\right|_{u=0} < 0$. Therefore, SHPZ is split by the trough, and the distribution of ridge and trough must be the pattern as shown in fig. 2. This is just the case of typical mid-ocean trough.

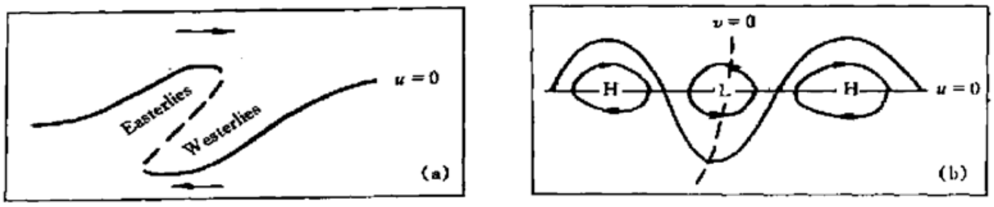

Fig. 2. The distributions of ridge and trough in the splitting of SHPZ caused by inhomogeneity zonal wind shear $\frac{\partial u}{\partial \phi}$. (a) Solid lines are ridge, dashed line trough; arrows indicate the zonal wind direction. (b) Thick solid line is $u = 0$, dashed line is $v = 0$, thin solid lines are isohypse, and arrows point to the direction of air flow. H denotes high pressure, and L low pressure.

For the case that $\frac{\partial u}{\partial \varphi}$ is homogeneous on line $u=0$, we consider that low latitudes are easterlies and high latitudes are westerlies and line $u=0$ is along the parallel. In this case $\left.\frac{\partial^2 u}{\partial \varphi^2}\right|_{u=0}>0$. Thus, Φ gets maximum in φ direction on line $u=0$. From eq. (1), it follows that on line $u=0$, v must be inhomogeneous except the case of $v\equiv 0$. Otherwise, integration over the full parallel gives $\int_0^{2\pi}\frac{1}{a\cos\phi}\frac{\partial \Phi}{\partial \lambda}a\cos\varphi\,d\lambda=0$; but we also have $\int_0^{2\pi} f v a\cos\varphi d\lambda\neq 0$, because the sign of v is the same everywhere. They are contradictory. Hence, v is a sign function and has two zero points at least on line $u=0$. When $v=0$, $\left.\frac{\partial \Phi}{\partial \lambda}\right|_{v=0}=0$, i.e., Φ gets extremum in λ direction. Because $\left.\frac{\partial^2 \Phi}{\partial \lambda^2}\right|_{v=0}=af\cos\varphi\left.\frac{\partial v}{\partial \lambda}\right|_{v=0}$, in λ direction φ gets the maximum at $\left.\frac{\partial v}{\partial \lambda}\right|_{v=0}<0$, and gets the minimum at $\left.\frac{\partial v}{\partial \lambda}\right|_{v=0}>0$. So there exists the minimum of Φ in λ direction on line $u=0$. As a result, SHPZ is split (fig. 3). The case of $v\equiv 0$ on line $u=0$ needs other analysis.

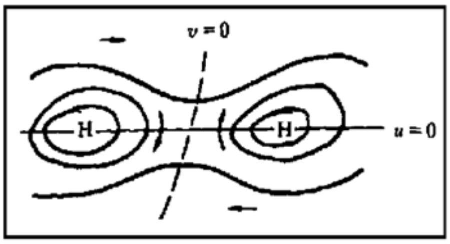

Fig. 3. The splitting of SHPZ caused by the zonal inhomogeneity of the meridional wind v ——the pattern of cat's eye (Symbols are the same as figure 2 (b)).

Similarly, we may have the same conclusions for eqs. (3) and (4). We only discuss the case that $\frac{\partial u}{\partial \varphi}$ is homogeneouson line $u=0$, and consider u distribution in eq. (1). On line $u=0$, $v\left(\frac{1}{a}\frac{\partial u}{\partial \varphi}-f\right)=-\frac{1}{a\cos\phi}\frac{\partial \phi}{\partial \lambda}$. With eq. (5), we obtain that v must be inhomogeneous on line $u=0$ except the case of $v\equiv 0$. Therefore, we may get the conclusion that SHPZ is split.

3 Discussion

The splitting of SHPZ without land-sea contrast and orographic condition is studied on the basis of simple dynamical models. Results show that the discontinuity of SHPZ corresponds with the inhomogeneity of the meridional wind v and the zonal wind shear $\frac{\partial u}{\partial \varphi}$ because of the internal dynamical constraint of SHPZ. So the splitting of SHPZ may be an intrinsic attribute of the earth rotation atmosphere. We should point out that the analysis of this note is preliminary, and that whether or not SPHZ splits depends not only on the Coriolis force but also on other factors. This awaits further study. In addition, it is necessary to state that land-sea and orographic effects are not discussed in this note, but we do not negate the case that their effects can cause the splitting of SHPZ. On the contrary, the complexities and varieties of splitting of SHPZ in real atmosphere are formed just because of the internal dynamical process of subtropical high and the external factors of land-sea distribution and orographic effect.

Acknowledgement This work was supported by the National Natural Science Foundaton of China (Grant No. 49635170).

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(Received November 20, 1997)