ON THE MAINTENANCE OF BLOCKING ANTICYCLONES OF NORTHERN HEMISPHERE—PART I: QUASI-GEOSTROPHIC POTENTIAL VORTICITY ANALYSIS

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ABSTRACT

Four observed blocking anticyclones in different regions of the Northern Hemisphere are investigated. Analyses show that there exist distinct differences in the maintenance of the time-mean quasi-geostrophic potential vorticity (PV) low in 300 hPa within blocking areas. In two Pacific blocking cases, the PV advection by time-mean flow tends to flow the PV low to northwestern part of the blocking highs, and thus is beneficial to the maintenance of the blockings' strength. The transfer by transient eddies acts to balance the effect of the time-mean flow. In the Atlantic and Alaska blocking cases, however, the advection of mean flow tends to flow the PV low eastward. The PV transfer by transient eddies acts to flow potential vorticity low to the western part of the blocking ridges and also to balance the time-mean flow's effect. Thus, in the latter two cases, it is the transfer by the transient eddies that acts to maintain the blockings.

Key words: blocking anticyclone, potential vorticity (PV), quasi-geostrophic analysis

I. INTRODUCTION

Since late 1970s, several diagnoses and theoretic studies have suggested that the vorticity transfer by synoptic scale eddies may contribute to the maintenance of the blocking. In a case study of the July 1976 European block, Green (1977) showed that the westerly momentum transfer by transient synoptic eddies ($u'v'$) acts to attract westerly momentum out of the blocking ridge area and thus to maintain the monthly mean blocking jet split. In a diagnosis of the same blocking case in terms of the potential vorticity (PV), Illari (1984) presented that at 300 hPa the potential vorticity transfer by transient eddies acts to maintain the monthly mean potential vorticity anomaly within the blocking ridge against the advection downstream of it due to the time-mean blocking flow itself.

In a study of observed composite blocking in either Atlantic or Pacific, however, Mullen (1987) has shown that the net quasi-geostrophic geopotential tendencies due to transports by the synoptic transient eddies exhibit an approximate quadrature relationship with the blocking pattern in the Atlantic, but this displacement is somewhat less in the Pacific case. Further clues about this can be got from the work of Metz (1987). He ran a simple quasi-geostrophic barotropic model forced by an observed transient vorticity flux arising from the interactions between planetary waves and synoptic eddies for wintertime condition in the Northern Hemisphere. He found that the low frequency response to this forcing, i. e., from 10 to 90 days, is well simulated with regard to the position and intensity of the low frequency variance maximum over the Atlantic, but over the Pacific the maximum is much weaker and shifted to the west than the observed. This suggests that this kind of synoptic forcing may be more important for the low frequency variance in Atlantic than in Pacific. Tibaldi and Molteni (1990) also showed that the predictability of observed blocking during the period of 1980—1987 in ECMWF model has big regional dependent differences between Atlantic and Pacific with regard to the phase and amplitude errors and skill in predicting the duration of blocks. This implies that the responsible mechanism for the observed blocking may be quite different and regional dependent.

In this paper we try to reveal the differences in the maintenance of quasi-geostrophic PV of blocking highs in different regions of the Northern Hemisphere. A diagnostic study is presented of four blocking cases, one in North Atlantic, one in East Asia, and two in North Pacific. Some possible causes of the differences will be discussed in Part II of this paper.

II. DIAGNOSTIC EQUATION

The quasi-geostrophic PV equation is adopted here. At pressure coordinates, it has the following form:

$$\frac{\partial q}{\partial t} + \boldsymbol{v}_h \cdot \nabla q = S, \tag{1}$$

where $q = f + \zeta + f\frac{\partial}{\partial p}(\theta''/\frac{\mathrm{d}\theta_0}{\mathrm{d}p})$, $f = 2\Omega\sin\varphi$, $\zeta = \boldsymbol{k} \cdot \nabla q \times \boldsymbol{v}_h$, $\theta'' = \theta - \theta_0(p)$.

The equation for time-mean PV is as follows:

$$\frac{\partial \bar{q}}{\partial t} + \bar{\boldsymbol{v}}_h \cdot \nabla \bar{q} = - \nabla \cdot \overline{\boldsymbol{v}'_h q'} + \bar{S}, \tag{2}$$

where the bar refers to the time-mean and the prime to the transients relative to the time-mean.

According to Eq. (2), the maintenance of PV is controlled by the PV advection of both transient eddies and time-mean flow, as well as the effect from small scale systems. Here only the former two terms will be analysed. The static stability is calculated from the vertical profile of the time-mean temperature which is horizontally averaged over the whole area of 20—82.5°N. The data used here are derived from daily 00 GMT ECMWF analyses, including the geopotential height, wind and temperature on a 2.5°×2.5° regular horizontal grid, covering the whole domain of 20°N to 82.5°N at 7 standard pressure levels from 1000 hPa to 100 hPa.

To minimize the effects of the noises in the divergence of PV transfers and the advection by time-mean flow, we define two special stream functions, for a clearer representation, as

$$\begin{aligned} \psi_m &= \nabla^{-2}(-\bar{\boldsymbol{v}}\nabla\bar{q}), \\ \psi_{fb} &= \nabla^{-2}(-\nabla\,\overline{\boldsymbol{v}'\zeta'}). \end{aligned} \tag{3}$$

These stream functions are set equal to zero at the two boundaries of 20°N and 82.5°N, meaning that the influence of these boundaries is not considered.

III. SYNOPTIC SITUATION

One of the Pacific blocking episodes started at February 5, 1980, with a weak ridge

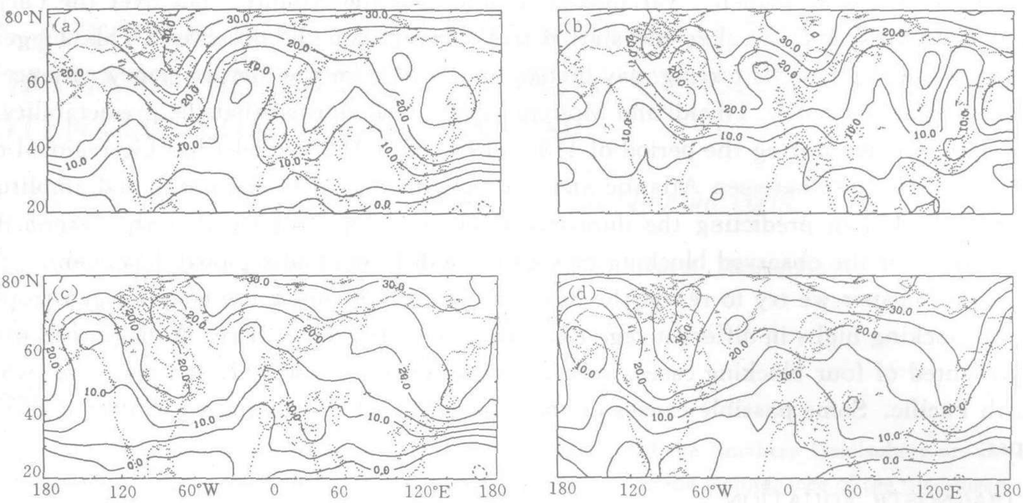

Fig. 1. Time-mean quasi-geostrophic PV at 300 hPa for (a) Atlantic case, Feb. 5—20, 1983, (b) East Asia case, June 19—30, 1982, and (c)—(d) Feb. 5—17, 1980 and Dec. 17—29, 1983 Pacific blocking cases. Contour interval: $5.0\times10^{-5}\mathrm{s}^{-1}$.

placed near 120°W at 300 hPa. This ridge developed gradually in later days and became a strong high with its center placed around (130°W, 55°N) on February 10. From that time onward, the ridge remained almost at the same place until the end of its life, that is, February 17. At its time-mean (February 5—17) geopotential height, a very strong time-mean blocking ridge is found near 130°W at 300 hPa. Another Pacific case has similar characteristics.

The Atlantic case started on February 5, 1983. A weak ridge appeared near 25°W, 45°N at 300 hPa. This ridge developed gradually from that time onward and reached its strongest intensity on February 11. During this period this ridge remained quasi-stationary around 30°W, and then from February 15 to 18 it remained stationary near 0°W. After February 18, the ridge became decaying gradually. At time-mean (February 5—20) 300 hPa geopotential height, a very strong time-mean blocking ridge is found near (25°W, 60°N).

The time-mean PV patterns at 300 hPa of the four blocking cases are shown in Figs. 1a—1d, respectively. An obvious feature is that the PV is a minimum in the centres of the time-mean blocking highs. Therefore, we can investigate the maintenance of the blocking by means of the PV.

IV. BALANCE OF PV AT 300 hPa

1. *Atlantic and East Asia Cases*

Figure 2a shows the advection of time-mean PV by time-mean blocking flow at 300 hPa for the Atlantic blocking. The major feature is that three strong negative centers are found at (30°W, 75°N), (50°W, 65°N), and (45°W, 50°N), respectively, which are located approximately in the northwestern part of the time-mean blocking ridge. Two

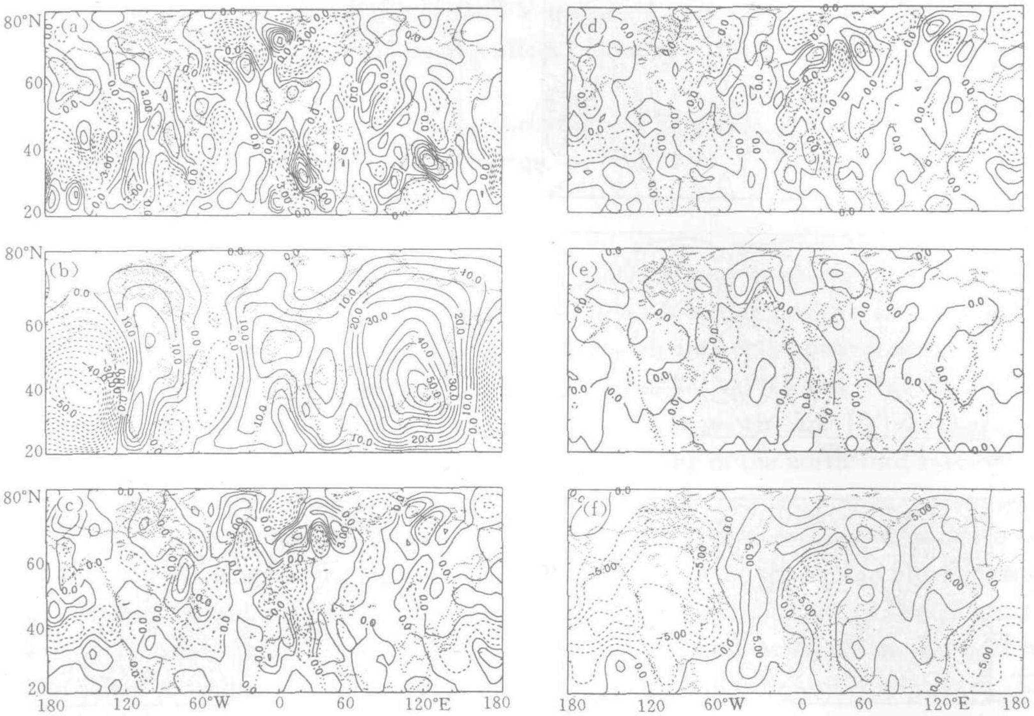

Fig. 2. The Atlantic blocking case, at 300 hPa: (a) the advection of time-mean PV by time-mean blocking flow, (b) ψ_m, (c) the divergence of PV transient transfer, (d) the divergence of transient relative voticity transfer, (e) the divergence due to transient heat transfer, ($\nabla \mathbf{v}'b'$, $b = f\frac{\partial}{\partial p}(\theta''/\frac{d\theta_0}{dp})$), and (f) ψ_{fb}. Contour interval: (a), (c), (d) and (e): $1.5\times10^{-10}\,\mathrm{s}^{-2}$, (b): $5.0\times10^{-10}\,\mathrm{m}^2\,\mathrm{s}^{-2}$, (f): $2.5\times10^{-10}\,\mathrm{m}^2\,\mathrm{s}^{-2}$. Dashed lines refer to negative.

strong positive centers are found at (10°E, 75°N) and (20°W, 65°N), approximately in the southeastern part of the ridge. This means that the advection of time-mean flow has a tendency to move the time-mean PV low southeastward. This phenomenon is even more clear in the stream function ψ_m (Fig. 2b).

Figure 2c shows the divergence of the PV transfer by transient eddies. It can be seen that it has a tendency to balance the effect of the time-mean flow. Thus, it is beneficial to the maintaining of the blocking around the same area. This result is similar to the result obtained by other studies (for example, Illari 1984). From the two components of the divergence (Figs. 2d and 2e), that is, the ones due to the transfers of vorticity and heat transfer, we see that the effect of vorticity transfer dominates the PV transfer. The stream function ψ_{fb} has a large positive value in blocking area, its center is located at the western part of the blocking high. This also approves that it is the vorticity transfer by eddies that causes the PV low to move westward and has the tendency to balance the effect of time-mean flow.

The East Asia blocking high case is quite similar to the former one. The advection of time-mean PV by time-mean blocking flow at 300 hPa has two strong negative centers in the western part of the blocking and two strong positive centers in the eastern part

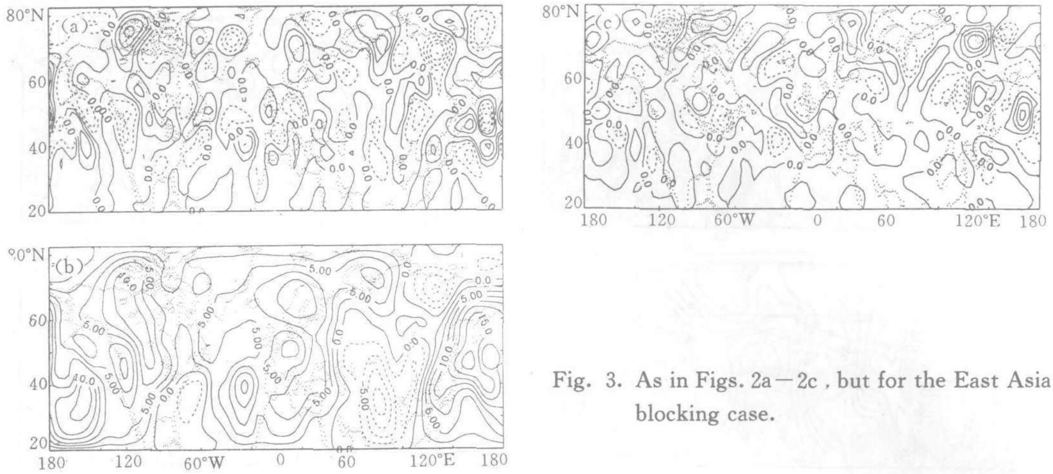

Fig. 3. As in Figs. 2a—2c, but for the East Asia blocking case.

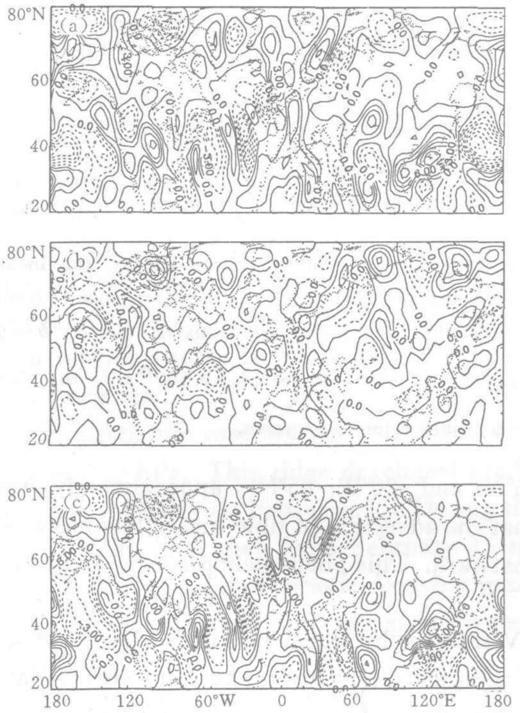

Fig. 4. The Pacific blocking case of Feb. 5—17, 1980, at 300 hPa: (a) the advection of time-mean PV by time-mean blocking flow, (b) the divergence of transient PV transfer, (c) the advection of time-mean relative vorticity by time-mean flow. Contour interval: $1.5\times10^{-10}\mathrm{s}^{-2}$.

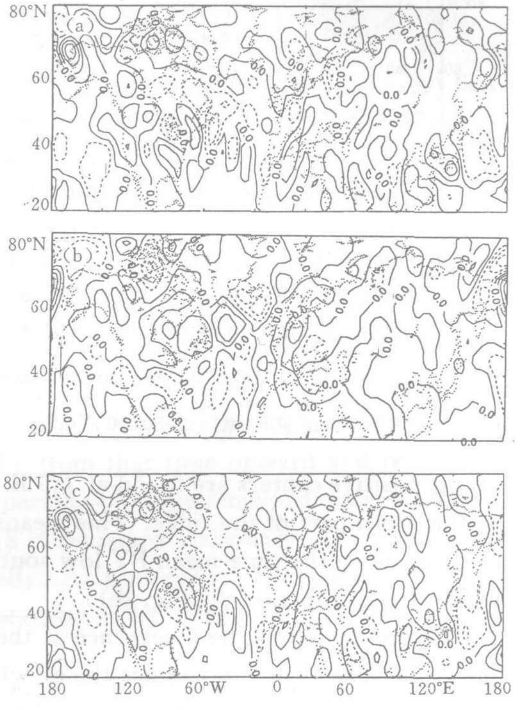

Fig. 5. As in Fig. 4, but for the Pacific blocking case of Dec. 17—29, 1983. Contour interval: $3.0\times10^{-10}\ \mathrm{s}^{-2}$.

(Fig. 3a). In ψ_m (Fig. 3b), there are also two negative centers in the western part, and one strong positive center in the eastern part. Therefore, the effect of the time-mean flow makes the PV low move eastwards, too.

Figure 3c shows the divergence of the PV transfer by transient eddies. It can be seen that it also has a tendency to balance the effect of the time-mean flow, especially in the northern part of the blocking.

From the above mentioned two cases (Atlantic and East Asia cases), we see that it is the transient eddy that maintains the blockings.

2. *North Pacific Cases*

Let us first look at the case of Feb. 5—17, 1980. Figure 4a shows the advection of time-mean PV by time-mean blocking flow at 300 hPa. A strong positive area is found in the northern part of the time-mean blocking ridge with its center placed near (160°W, 70°N), and two negative centers south of it, near (165°W, 60°N) and (120°W, 48°N). This suggests that this advection term has a tendency to move the low PV northward instead of southeastward. Thus it is helpful to the maintaining of the northward extension of the time-mean blocking.

The transient eddy has an opposite effect. A strong cyclonic circulation (negative value), instead of an anticyclone, exists in the northern part of the time-mean blocking ridge with its centers placed at (145°W, 70°N) and (165°E, 55°N) (Fig. 4b). Therefore, the transient PV transfer has a tendency to weaken the time-mean blocking ridge and does not have an effect to strengthen the time-mean blocking ridge and to move it westward, like that in the Atlantic and Alaska blocking cases.

Figure 4c is the advection of time-mean relative vorticity by time-mean blocking flow at 300 hPa. Comparison with Fig. 4a shows that the advection of the time-mean PV by time-mean blocking flow is dominated by its advection of the relative vorticity.

Another Pacific blocking case (Dec. 17—29, 1983) has very similar characteristics to the former Pacific case (Figs. 5a—c).

V. CONCLUSION

From the above four blocking cases, we see that the time-mean flow and the transient eddy are important in the maintenance of PV in blocking areas, and their effects are different in different regions. The Pacific blockings are maintained by time-mean flow. The Atlantic and East Asia cases, however, are maintained by transient eddy. Therefore, these facts reveal that the maintenance mechanism of blockings in the Northern Hemisphere is different in different areas.

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