THE ROLE OF DEFORMATION AND POTENTIAL VORTICITY IN SOUTHERN HEMISPHERE BLOCKING ONSETS

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1. INTRODUCTION

Theoretical studies (e.g. Shutts, 1983) and observational investigations (e.g. Colucci, 2001) have shown that locally diffluent planetary-scale flow precedes the onset of blocking. According to Shutts (1983), diffluent or deformed flow can interact with the vorticity field so as to initiate and maintain the blocking structure (anticyclonic circulation poleward of a cyclonic circulation). Mak (1991) has shown how the deformation field can interact with the eddy wind field to energetically maintain a blocking system. This energy exchange was shown by Marques and Rao (2000) to account for the distinction between years with low and high blocking frequency over the Southern Hemisphere (SH). From a different perspective, Trenberth (1986) and Marques and Rao (1999) have shown how eddies in the deformed flow associated with a block can locally decelerate the westerly flow, thereby maintaining the block.

In addition, it is known that a local weakening of geostrophic westerlies or increasing of geostrophic easterlies often occurs prior to blocking onset. It would seem from the above considerations that deformation should appear as part of the forcing of the geostrophic u-component wind field during block development. However, to the authors' knowledge, such a diagnostic relationship has not been presented in the literature. We therefore have established a diagnostic quasigeostrophic (QG) tendency model for the u-component of the geostrophic wind, in which forcing functions are expressed in terms of deformation and potential vorticity (PV). Furthermore, considering that SH blocks have not been as extensively investigated as their Northern Hemisphere (NH) counterparts, we have applied this model to SH blocking cases, although our diagnostic model is equally applicable to the Northern Hemisphere. The aim of this paper is to contribute to our understanding of block formation over the SH from the perspective of the interaction between deformation and PV.

2. DIAGNOSTIC MODEL

A diagnostic equation in which the deformation term appears as a part of the forcing to the local change of the u-component of the geostrophic wind can be written as

$$\left[\nabla_p^2 + f_0^2 \frac{\partial}{\partial p}\left(\frac{1}{\sigma}\frac{\partial}{\partial p}\right)\right]\left(\frac{\partial u_g}{\partial t}\right) = \vec{V}_g \cdot \nabla_p\left(\frac{\partial q}{\partial y}\right) + \left(\frac{\partial u_g}{\partial x}\right)\left(\frac{\partial q}{\partial y}\right) - \left(\frac{\partial v_g}{\partial x}\right)\left(\frac{\partial q}{\partial x}\right) - \vec{k} \cdot \vec{D}_g \times \nabla_p q \qquad (1)$$

$\vec{D}_g$ is the geostrophic deformation pseudovector ($\vec{D}_1$, $\vec{D}_2$), where $D_1 = \frac{\partial u_g}{\partial x} - \frac{\partial v_g}{\partial y}$ is the geostrophic stretching deformation and $D_2 = \frac{\partial v_g}{\partial x} + \frac{\partial u_g}{\partial y}$ is the geostrophic shearing deformation.

Due to some cancellation among the second through fourth terms on the RHS of equation (1), alternatively, it may be written as

$$\left[\nabla_p^2 + f_0^2 \frac{\partial}{\partial p}\left(\frac{1}{\sigma}\frac{\partial}{\partial p}\right)\right]\left(\frac{\partial u_g}{\partial t}\right) = \vec{V}_g \cdot \nabla_p\left(\frac{\partial q}{\partial y}\right) + \left[\left(\frac{\partial u_g}{\partial y}\right)\left(\frac{\partial q}{\partial x}\right) + \left(\frac{\partial v_g}{\partial y}\right)\left(\frac{\partial q}{\partial y}\right)\right] \qquad (2)$$

such that the bracketed second and third terms on the RHS of equation (2) represent the net effect of deformation interacting with QGPV in forcing the geostrophic wind tendency. Following the way that Holton (1992) interpreted the y component of $\vec{Q}$ vector as the forcing of the meridional temperature gradient by horizontal shear deformation and stretching deformation respectively, we interpret the bracketed two terms in the RHS of Eq (2) as the forcing of the geostrophic zonal wind tendency by horizontal shear deformation and stretching deformation, respectively. In the present study, we define the first term on the RHS of Eq (2) as the advection effect, and the remaining two terms together as the interaction effect.

The decreasing of the geostrophic westerlies due to the advection effect is schematically illustrated in Fig. 1. The advection of equatorward increasing cyclonic PV, $\left[\vec{V}_g \cdot \nabla_p \left(\frac{\partial q}{\partial y}\right) > 0\right]$, would favor a pattern of cyclonic PV advection (CPVA) equatorward of the anticyclonic PV advection (APVA). This in turn would result in a geostrophic height tendency pattern with height falls situated equatorward of height rises. Thus locally decreasing westerlies would likely result.

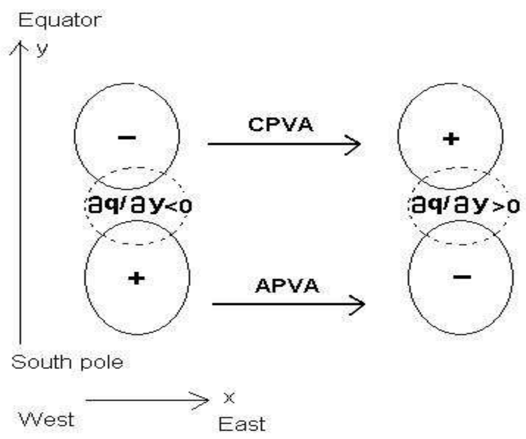

FIG.1. Schematic illustration of formation of decreasing geostrophic westerlies associated with advection of meridional QGPV (denoted as q) gradient in the SH. Positive (negative) signs inside the ellipses indicate the sense of QGPV. The heavy arrows show the background geostrophic wind and thin arrows indicate the local coordinates. The regions of meridional change of QGPV are denoted by the dashed circles. CPVA is the abbreviation of Cyclonic Potential Vorticity Advcetion, and APVA Anticyclonic Potential Vorticity Advection.

Fig. 2 schematically shows how the interaction of PV and deformation can locally weaken the westerlies. Equatorward increasing zonal winds (cyclonic shear in the SH) coinciding with eastward increasing PV would result in a pattern of equatorward increasing CPVA, which could force poleward increasing height rises. Accordingly, the local weakening of westerlies would occur as displayed in Fig. 2 (a). Similarly, anticyclonic shear embedded in an eastward decreasing PV field would also favor local weakening of westerlies (not shown). In Fig. 2 (b) the meridional gradient of PV (i.e. equatorward increasing PV) would be weakened by a purely diffluent background flow, which stretches the PV dipoles along the dilatation axis y and compacts them along the contraction axis x. Thus, the originally existing westerlies would be weakened by the dilution of the meridional PV gradient.

(a) Shearing contribution *(b) Stretching contribution*

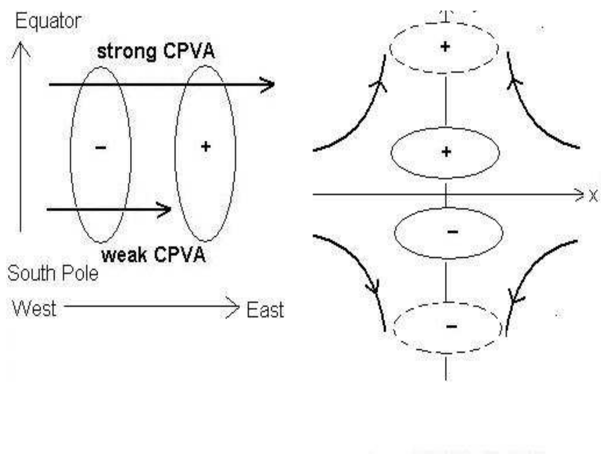

FIG.2. Schematic illustration of formation of decreasing geostrophic westerlies associated with (a) QGPV-shearing interactions and (b) QGPV-stretching interactions in the SH. Every notation is as in FIG.1, except the dashed ellipses in (b) represent the PV fields after being stretched along the dilatation axis, which is denoted as y axis (pointing to the equator). The x axis is the contraction axis (pointing to east).

3. DATA

Fifty years of gridded SH 500-mb heights from the NCEP daily average reanalysis (Kalnay et al. 1996) were screened by the Watson and Colucci (2002) algorithm for block detection. Thirty of these blocking cases were selected and comprehensively examined with the QG wind tendency equation (2). The forcing effects and other quantities were calculated from the NCEP-NCAR reanalysis of six-hourly SH temperatures and geopotential heights at 10 vertical levels (P = 1000, 925, 850, 700, 600, 500, 400, 300, 200, 100) on a 2.5º by 2.5º grid. The geostrophic u-component wind tendencies are resolved into contributions from the advection and interaction effects respectively.

4. THE BLOCKING AND NONBLOCKING CASES

In most blocking cases diagnosed by the QG zonal wind tendency equation, one or the other but not both forcing effects appeared to primarily contribute to the wind tendency fields prior to the block-onset. Two of these cases, July 1999 and December 1965, are discussed in detail due to an apparent dominance of one effect over the other in each case.

The July 1999 blocking event features the advection forcing effect. Following the geostrophic wind vectors from southwestern corner to the eastern side of the block-onset region, the meridional PV gradient changes signs from $\frac{\partial q}{\partial y}<0$ to $\frac{\partial q}{\partial y}>0$. There appears to be an advection of a dipolar pattern with low (cyclonic) PV equatorward of high (anticyclonic) PV, which would locally force a weakening of westerlies from previous arguments and as calculated and analyzed. As expected from the previous discussion, the calculated wind tendencies attributable to the interaction effect offset the advection effect. In fact, the flow is geostrophically confluent $\frac{\partial v_g}{\partial y}<0$, especially over the eastern portion of the block onset region where $\frac{\partial q}{\partial y}>0$. This combination favors a local increase in westerlies, but is overwhelmed by the westerly-decreasing contribution from the advection effect. Compared to the analyzed weakening of westerlies over the block-onset region on 20 July, the total calculated wind tendencies are qualitatively similar.

The December 1965 blocking case is dominated by the interaction effect. Over the western half of the block-onset region on 14 December 1965 (three days prior to the block-onset), cyclonic shear, $\frac{\partial u_g}{\partial y}>0$, coincides with eastward increasing PV, resulting a weakening of the geostrophic westerlies. Meanwhile, a strong diffluent flow $\frac{\partial v_g}{\partial y}>0$ is overwhelming over the equatorward half of the block onset region. An equatorward increasing PV, embedded in this diffluent flow, can weaken the westerlies.

While two types of forcing patterns have been identified as favoring the weakening of westerlies, one may wonder if these forcing signals are unique to the initiation of blocking. Two nonblocking events were thus also examined. Compared to the blocking cases, the calculated and analyzed wind tendencies are both positive, opposing block onset, in the two nonblocking cases.

5. SCALE INTERACTIONS IN BLOCK ONSETS

Scale partitioning was applied to the two forcing effects of Eq (2) and it appears that the weakening of westerlies during block onsets is due primarily to the advection of equatorward increasing cyclonic synoptic-scale PV by the planetary-scale wind, or eastward increasing synoptic-scale PV embedded in a cyclonically sheared synoptic-scale flow and equatorward increasing synoptic-scale PV coincident with a synoptic-scale diffluent flow. In other words, synoptic-to-planetary-scale interactions between PV and deformation appear to often oppose block onsets. Briefly speaking, when geostrophic deformation is contributing to block onsets, it is the interactions between synoptic-scale PV and synoptic-scale deformation or the interactions between planetary-scale PV and planetary-scale deformation that contribute more importantly to block onsets.

6. DISCUSSION AND FUTURE WORK

While deformation is a distinct signature of blocking, it may not always actively participate in the formation of blocking. In addition, due to the fact that the advection and interaction contributions generally opposed to each other in both the blocking as well as nonblocking cases, then we hypothesize that westerlies weaken during block onset when one effect (usually the advection effect) contributes more negatively to the wind tendency than the opposing, positive contribution from the other effect.

There is evidence (e.g. Alberta et al. 1991) for quantitative difference between the total quasigeostrophic and analyzed height tendencies during block evolution, and this suggests that non-quasigeostrophic processes contribute to block formation. For instance, the static stability was regarded only as a one dimensional quantity varying with pressure in present study and the horizontal variations were neglected. Preliminary results from wind tendency equation, with 3-D static stability, show improvements over certain regions, compared to the QG results. Therefore, the nature of the non-quasigeostrophic processes and the relative importance of each need further study.

7. ACKNOWLEDGMENTS

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