Letters to the Editor

ON THE FORMATION OF BLOCKING

1.   The blocking phenomena is widely discussed in synoptic meteorology. Systematic drift of blocking patterns have been observed in earlier synoptic studies. Namias and Clapp, (1944). Namias (1947) described blocking in terms of "retardation" (diminution) of the zonal circulation in a limited sector of the hemisphere at all levels within the troposphere. Blocking is a relatively stationary phenomenon oscillating only a few degrees about a central longitude but they frequently have meridional dipole structure with a high situated to the north of a low. Moreover, blockings persist for a relatively long time compared with the synoptic-scale weather events. There are numerous studies about formation of blocking [Rex, (1950 a,b), Hansen and Sutera, (1993), Colucci and Alberta (1996), and Hafez, (1997)]. In general, blocking is traditionally identified based upon a set of subjective and objective criteria. Obviously, any modification of these criteria changes the classification scheme leading to a degree of arbitrariness. Moreover, subjective criteria may not be immediately suggestive of the physical mechanisms of the underlying processes.

According to Rex (1950 a,b) the blocking is formed when the upper air westerly air current splits into two branches, each branch transports an appreciable mass and the double-jet system extends over at least 45° longitude. The pattern must persist with recognizable continuity for at least ten days. However, Colucci (1985) linked the westward drift of Atlantic blocking with explosive cyclogenesis over eastern America. The fact that transitions are triggered by specific mechanisms was reported in the results of Oartwijn and Barkmeijer (1995). They showed that some flows are more sensitive to blocking onset than others, and that the onset depends crucially on particular small-scale initial perturbations.

The present work attempts to find answers to the questions concerning why, where and when the process of splitting originates.

2.   Although the formation of blocking is still unsolved problem until now, this paper tries to find a physical solution for the blocking formation. In order to study the occurrence of splitting in westerly air current, the equation of motion in natural coordinate system is used. Just before the initiation of the block the main flow could be considered steady. Therefore the horizontal

acceleration is considered zero, ($\frac{dV}{dt} = 0$), V is the actual wind speed. The momentum Equation of motion becomes for anticyclone.

$$0 = fV_G + \frac{1}{\rho}\frac{\partial p}{\partial n} - \frac{V_G^2}{R} \qquad (1)$$

The solution is in the form ;

$$V_G = \frac{fR}{2} - \sqrt{\left(\frac{f^2 R^2}{4} + \frac{R}{\rho}\frac{\partial p}{\partial n}\right)} \qquad (2)$$

$$V_G = -\frac{fR}{2} + \sqrt{\left(\frac{f^2 R^2}{4} - \frac{R}{\rho}\frac{\partial p}{\partial n}\right)} \qquad (3)$$

Where, V_G is gradient wind speed, R is radius of curvature, ρ is density, and $\frac{\partial p}{\partial n}$ is pressure gradient.

The solution of equation (2), could be used to express the air motion within the part of anticyclonic flow of the Rossby wave. Meanwhile equation (3) represents the cyclonic part of the Rossby wave. Rossby waves could be regarded as composed of cyclonic and anticyclonic flow together. For a cyclonic flow there is no restriction for an increased value of gradient wind, because pressure gradient could attain large values without any theoretical restriction. Meanwhile, for anticyclonic flow the situation is completely different. There is a critical maximum limit of gradient wind in the westerly air current. The maximum gradient wind occurs when the terms under the square root in equation (2) becomes zero, *i.e.* $V_{G\max} = \frac{fR}{2}$ when

$$\frac{f^2 R^2}{4} = -\frac{R}{\rho}\frac{\partial p}{\partial n} \qquad (4)$$

Substituting for geostrophic wind V_g in equation (4) then, we get

$$V_{G\max} = 2V_g \qquad (5)$$

When the main westerly air current becomes fast enough so that the value of gradient wind of cyclonic flow
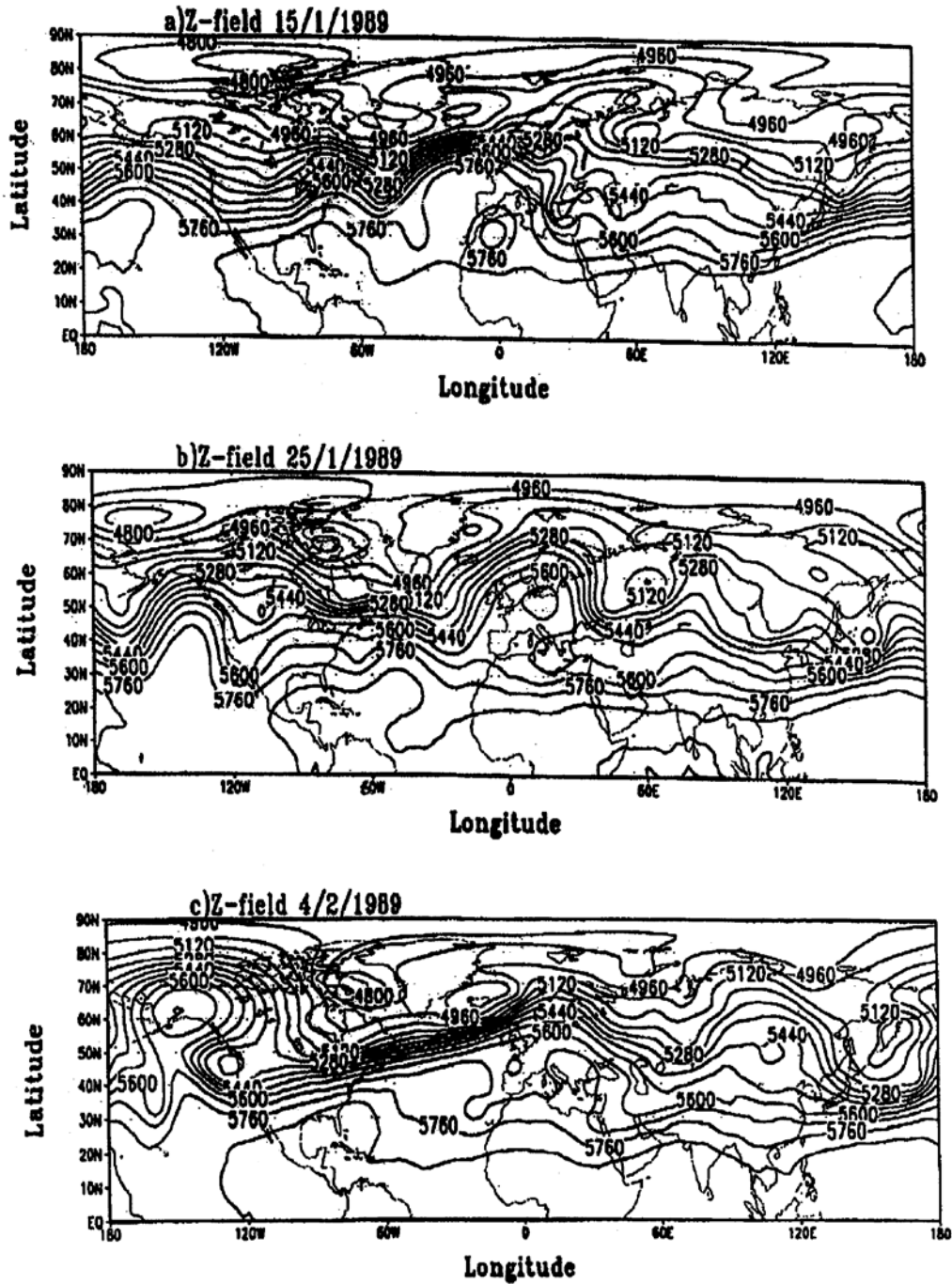
Figs. 1(a-c). The distribution of the geopotential height at 500 hPa level for the Northern Hemisphere during, (a) The initiation of the block, on 15 January, 1989, (b)The mature stage of block, on 25 January, 1989 and (c) The dissipation of the block, on 4 February, 1989

becomes more than the maximum gradient wind of anticyclonic flow. In such a condition the anticyclonic flow can not sustain wind speeds more than its maximum gradient speed $(V_{G\max})$. As a result the main westerly air current splits into two branches leading to the formation of a episode. It is evident that the splitting of the main

a) Z and Y fields 15/1/1989

b) Z and Y fields 24/1/1989

c) Z and Y fields 2/2/1989
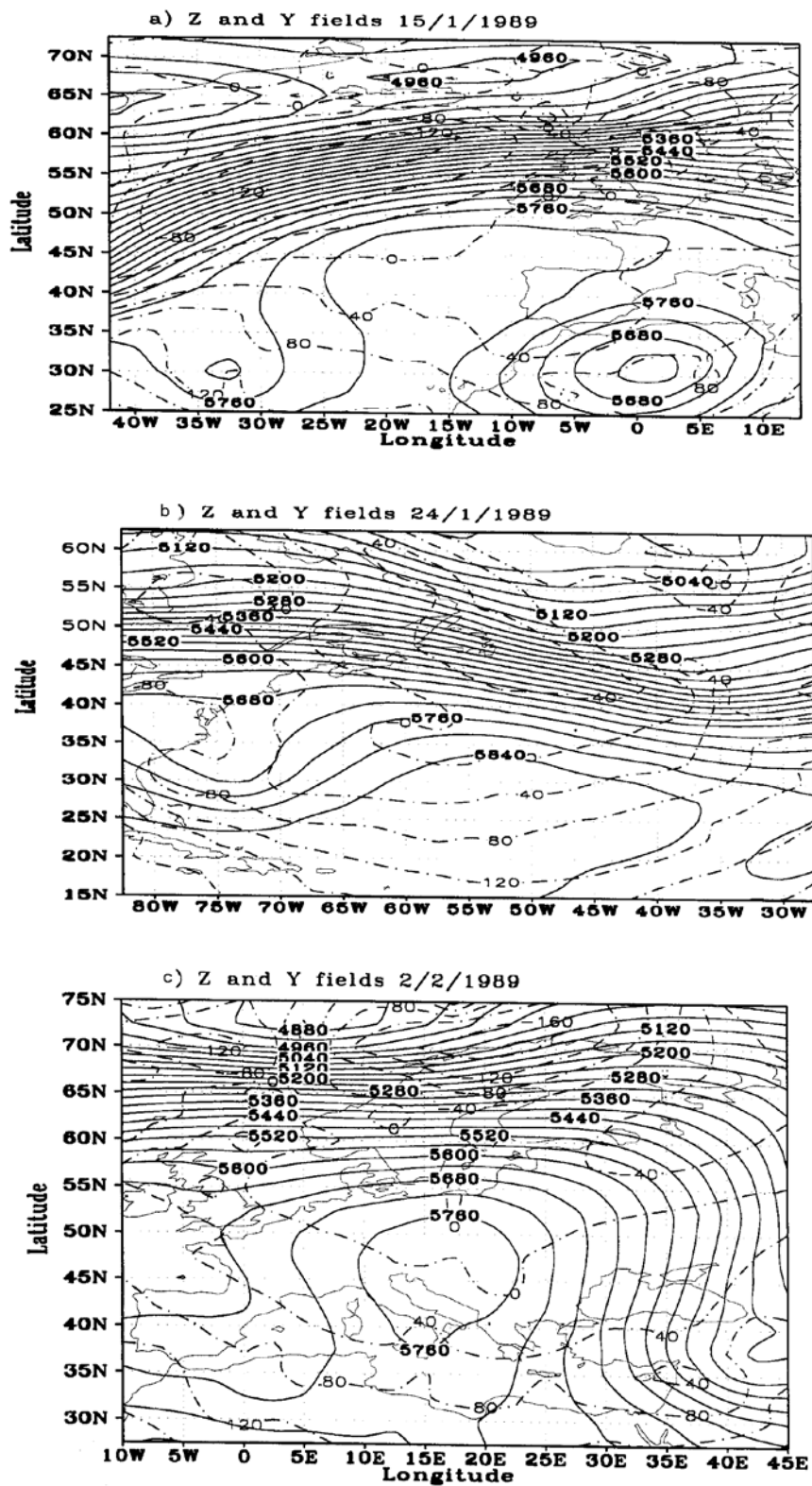
Figs. 2(a-c). The distribution of the geopotential height (solid line), and Y fields (dash line), at 500 hPa level during the initiation, mature, and dacay stages on, (a) 15 January 1989, (b) 24 January 1989 and (c) 2 February 1989 respectively

westerly air current gives the only acceptable solution to prevent the appearance of imaginary term in the solution of gradient wind equation.

In an anticyclonic flow the following criteria could be considered :

$$H = \frac{f^2 R^2}{4} + \frac{R}{\rho} \frac{\partial p}{\partial n} \qquad (6)$$

If, H, is less than zero, the solution of following equation (7) will be imaginary solution.

$$V_G = \frac{fR}{2} - \sqrt{H} \qquad (7)$$

The main air current can not cross the point of negative H. Therefore, it is split into two branches (cyclonic and anticyclonic). This is the only physical solution for the equation (2). *i.e.* The area which have values of $H < 0$ is the area of blocking development). Moreover, the splitting persists untill the value H becames positive. When H is positive at a grid point, then the main westerly air current crosses this point without splitting.

Now, we will try to use an index $Y(\varphi, \lambda)$ to determine the occurrence of the splitting. This index is based upon the characteristics of the air current itself. It is defined as the difference between the gradient wind, V_G and the double of geostrophic wind $2V_g$ at a certain grid point (φ, λ).

$$Y(\varphi, \lambda) = V_G(\varphi, \lambda) - 2V_g(\varphi, \lambda) \qquad (8)$$

So that, if the westerly air current is strong enough and the speed $V_G(\varphi, \lambda)$ for cyclonic curvature is greater than $V_{G_{max}}(\varphi, \lambda)$ for anticyclone, the main westerly air current should be split into two branches. This exist when value H is negative. The strong westerly air current can not penetrate through the area, which has $[Y_H(\varphi, \lambda) \rangle 0]$. Thus the condition for blocking is if $V_G(\varphi, \lambda) \rangle 2V_g(\varphi, \lambda)$. This situation persist in this area untill the gradient wind $V_G(\varphi, \lambda)$ for cyclone does not become greater than the maximum gradient wind $V_{G_{max}}(\varphi, \lambda)$ for anticyclone.

3.   To verify the above methodology one can choose a representative example of blocking that occurred over Europe for 21 days from 15 January 1989 to 4 February 1989. We used 500 hPa geopotential height data

for our study. The northern hemisphere data were obtained from daily 1200 UTC analyses made by the US National Center for Environmental Prediction (NCEP) archived at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, USA. The NCEP data have been interpolated to a $2.5° \times 2.5°$ Latitude-Longitude grid.

3.1. *Synoptic feature* - The situation used here stayed for a long period, and was accompanied with abnormal weather conditions over Europe and Middle East regions. On 15 January 1989 the prevailing westerlies are split over the northern Atlantic and Western Europe sector from 53° W to 3° W approximately *i.e.* 50° longitude in width. However, splitting remains for about 21 days with longitudinal variations. The westerly air current is blocked during that period. Figs. 1(a-c) shows the geopotential height field on 500 hPa level during the initiation, mature and dissipation stages of this block.

4.   The above mentioned methodology is used to study the dynamical and physical mechanisms of the blocking formation. A representative example is the block, which developed over Western Europe on 15 January 1989 and dissipated on 4 February 1989 with a duration of 21 days. Analyses of Y-field as computed by equation 7, section 2 represents difference between gradient wind and double geostrophic wind which is done. As mentioned above, Y-field is negative when gradient wind is less than twice geostrophic wind and *vice versa*. Negative values of Y-field means that there are no dynamical restrictions on the flow. The result shows that higher geopotential height contours create negative values of Y-fields. Meanwhile, positive values of Y-fields indicate that there is a dynamical restriction and the density of contours must not increase beyond a certain limit. The distribution of the geopotential heights and Y-fields at 500 hPa level during the development stage is illustrated in Fig. 2(a). It is clear that the increased positive Y values coincides with the maximum contour intensity region, and *vice versa*. At the same time the negative Y values are associated with low density of contour lines. In fact this area ($Y > 0$) represents the splitting of westerly flows. It may be noticed that the longitudinal extent of the patterns are approximately be 45° or more as reported by Lejenas and Okland (1983). However, the splitting in westerlies is the physical solution for the stream flow, disallowing a non real solution of the momentum equation. Fig. 2(b) shows that the positive Y values exist on the area of low intensity of contours and that maximum contour intensity is associated with negative Y values, during the mature stage of the block. As it is clear from Fig. 2(c), the increasing the geopotential gradient leads to increasing the negative Y values during the dissipation stage of the block. The Y values changes from day to day according to the spatial and temporary changes of the blocking system.

5. Rossby wave breaking (or planetary wave breaking) has long been studied. Recently, the Rossby wave breaking has drawn more attention in conjunction with the onset of blocking in the troposphere. In the light of the present work, one can conclude that, it becomes clear that the mechanism of blocks may be illustrated by studying the characteristics of the cyclonic and anticyclonic flow simultaneously. The splitting in westerlies is the only acceptable physical solution of the momentum equation. Values of the index Y is a switch key of the splitting process and blocking formation. It is noticed that to prevent the imaginary solution of the westerly flow, Y value must be positive. At this time, splitting of westerly into two branches should occur. Splitting in westerly is the main condition of blocking formation.

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