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Vorticity patterns *vis-a-vis* rainfall distribution over India during July 1979

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सार – माह जुलाई 1979 को समुद्र तल से 0.9 कि० मी० ऊपर और 300 मि० बार स्तर पर आपेक्षित भ्रमिलता का अगले दिन के 03 ग्री० मा० स० तक का 24 घंटेवारी से अंकित वर्षा के साथ संबंध का अध्ययन किया गया है। परिमिति अंतर विधि का उपयोग कर 2 डिग्री अक्षांश/देशान्तर ग्रिड दूरी पर अभिलक्षी विश्लेषित पवन क्षेत्र से भ्रमिलता क्षेत्र की व्युत्पत्ति की गई है। समुद्र स्तर से 0.9 कि० मी० पर चक्रवाती भ्रमिलता और 300 मि०बार स्तर पर प्रति चक्रवात या चक्रवाती भ्रमिलता का अगले दिन की वर्षा के साथ गहरा संबंध पाया गया है।

ABSTRACT. The association of relative vorticity patterns at 0.9 km asl and at 300 mb level with the 24-hourly rainfall recorded upto 03 GMT of the next day has been studied for the month of July 1979. The vorticity field is derived from objectively analysed wind field at 2 degrees latitude/longitude grid length by using finite difference technique. It is found that cyclonic vorticity at 0.9 km asl with anticyclonic or cyclonic vorticity at 300 mb level has very high association with rainfall of next day.

1. Introduction

Cyclones and anticyclones are important features of large-scale atmospheric flow. The cyclones are characterised by positive vorticity and convergence in the lower and middle troposphere and negative vorticity and divergence in the upper troposphere. The relative intensity of lower level convergence and upper level divergence or lower level positive vorticity and upper level negative vorticity generally provides a measure for the intensity of cyclonic system. The synoptic forecaster, in the absence of any quantitative estimates of divergence or vorticity, looks for troughs or ridges, position of the jet stream, velocity gradients along the flow etc to assess the vorticity or divergence in a rather subjective way. These observations though provide important information in the decision making process of the forecaster, yet do not have the required amount of objectivity. For the computation of divergence and vorticity, it is considered appropriate to use the wind field in the tropics where the pressure field adjusts to the wind field (Houghton and Washington 1969). Several authors (Das 1951, Dutta and Baghare 1968 and Sajnani 1968) have computed divergence and vorticity over the Indian region from the observed winds. However, the use of observed winds for determining divergence is beset with difficulties. The magnitude of the error in the observed winds is considered to be only one order less than that of the winds themselves. Hence, the errors in computing the large scale divergence, it is argued, should be of the same order as the divergence values themselves. Charney (1948) has shown from scale analysis of atmospheric motions that the two terms $\partial u/\partial x$ and $\partial v/\partial y$ comprising the horizontal divergence are of the opposite sign and of the same order of magnitude $\sim 10^{-5}$ sec^{-1}. On the other hand, in the computation of vorticity, the errors in the two terms $\partial v/\partial x$ and $\partial u/\partial y$ perhaps cancel each other on subtraction or one of the two terms is one order higher than the other, and more reliable estimates of vorticity are obtained.

In the Northern Hemisphere Analysis Centre, New Delhi we are preparing daily on a routine basis divergence and relative vorticity charts. As estimates of the vorticity are more reliable, in this study, we have made an attempt to examine the distribution of vorticity at 0.9 km asl and 300 mb in relation to the occurrence of 24-hour rainfall recorded upto 03 GMT of the next day. The study for the present has been confined to the month of July 1979.

2. Analysis scheme

The objective analysis scheme for wind field consists of finding by the method of least square, the quadratic surfaces which best fit the resolved zonal (u) and meridional (v) components of reported winds. The surfaces of best fit become indeterminate if there are less than six observations surrounding a grid point. We have overcome this difficulty by using in addition to the reported wind observations, earlier wind analysis at the grid points as base wind field. The use of the base field serves the dual purpose of ensuring that the family of surfaces is determinate even in data sparse regions and that analysis maintains time continuity. The equation of the quadratic surface which best fits the observations and the base field is written as :

$$H_s = F(x, y)$$
$$= \sum_{j,k} a_{jk}\, x^j\, y^k \text{ such that } j \geqslant 0,\ k \geqslant 0 \text{ and } j+k \leqslant 2$$

where x and y are the rectangular cartesian coordinates. The expression E which we minimise in order to obtain the best fitting surface is given by :

$$E = \sum_{r=1}^{l} p(H_s - H_0)_r^2 + \sum_{j=1}^{m} q(H_s - H_p)_j^2$$

where, H_0 represents the observations 'l' in number, and H_p the base field values m in number, used for determining the surface of best fit. p and q are the weighting factors depending upon the distance of the observations from the grid points. We determine a_{jk} by solving the following set of simultaneous equations :

$$\frac{\partial E}{\partial a_{jk}} = 0$$

3. Computation of vorticity

Vorticity computations were made using the method of finite differences. The equation used in the computation of vertical component of relative vorticity (ζ) is given by :

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

4. Methodology

In order to study the association between rainfall distribution and vorticity patterns, we divided the country into three broad zones, *viz.*, northwest, northeast and Peninsula. The demarcation of these zones is shown in Fig. 1. The boundaries of these zones do not agree exactly with those of established meteorological subdivisions. The delineation of the zones is based primarily on latitude/longitude grid. Each zone is further subdivided into 4×4 degrees latitude/longitude squares except the southernmost square which is of 6×4 degrees to accommodate adjacent land area.

On these three zones, we superimposed the vorticity patterns at 0.9 km and at 300 mb for 00 GMT of each day of July 1979. These two levels have been taken to represent the lower and upper troposphere respectively. The lower level has been taken as 0.9 km because it has more data coverage. A frequency distribution was prepared separately for each zone by considering for each square, eight possible permutations of cyclonic or anticyclonic vorticity at lower or upper level with or without rainfall. The bar diagram showing frequency distribution for each zone is given in Figs. 2 (a-c).

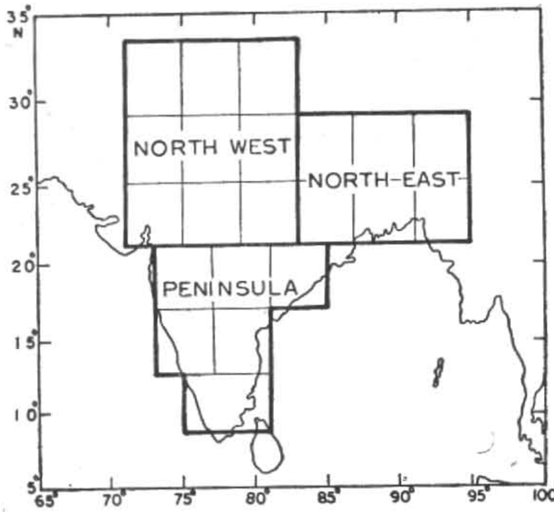

Fig. 1. Demarcation of three zones

5. Discussion of the results

It is seen from Fig. 2 that considering the three zones collectively, maximum frequency of rainfall is associated with cyclonic vorticity at lower level irrespective of anticyclonic or cyclonic vorticity at the upper level. There are, however, instances of rainfall with anticyclonic vorticity at both the lower and the upper levels. The frequency of such occasions is maximum for northeast zone and minimum for Peninsular zone.

On combining the frequencies shown in Fig. 2, we find that for northwest India, of the total cases considered, if we exclude the cases of no rainfall, there are 77 per cent cases associated with rain. 76 per cent of these are associated with cyclonic vorticity at the lower level. The remaining 24 per cent cases of rain are associated with anticyclonic vorticity at the lower level. The corresponding figures for Peninsula are 83, 76 and 24 per cent and for northeast zone are 90, 70 and 30 per cent. We, thus, see that about 75 per cent of cases of rainfall, over the three zones as a whole are associated with cyclonic vorticity at 0.9 km asl with anticyclonic or cyclonic vorticity at 300 mb. The remaining 25 per cent cases of rainfall are associated with anticyclonic vorticity at 0.9 km asl.

It is interesting to note that even with anticyclonic vorticity, both at 0.9 km and 300 mb levels, the number of cases of rainfall are more than the number of cases without rain. Some of the cases of rainfall have been looked into individually. It is found that the anticyclonic vorticity at the 300 mb level is much higher in magnitude than the anticyclonic vorticity at 0.9 km asl, *i.e.*, anticyclonic vorticity is increasing in magnitude with height. In case of no rainfall, it was observed that the vorticity at the lower level was mostly anticyclonic and at the upper level it was

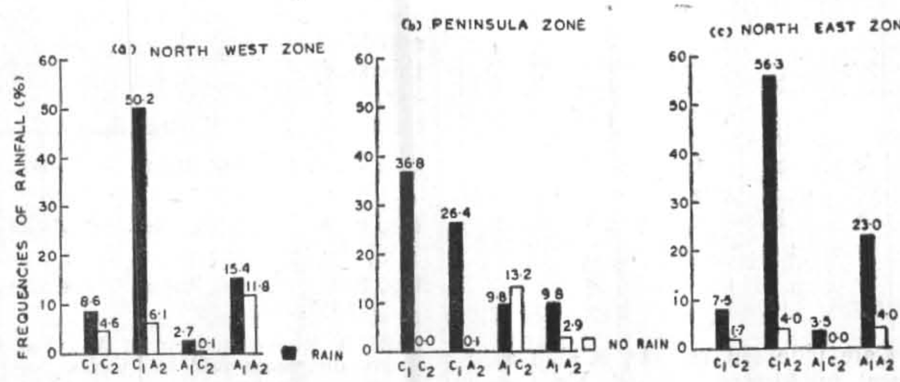

Fig. 2. Percentage occurrence of rainfall associated with vorticity patterns

C_1C_2. — Cyclonic vorticity at 0.9 km asl & cyclonic at 300 mb
C_1A_2. — Cyclonic vorticity at 0.9 km asl & anti-cyclonic at 300 mb
A_1C_2. — Anticyclonic vorticity at 0.9 km asl & cyclonic at 300 mb
A_1A_2. — Anticyclonic vorticity at 0.9 km asl & anticyclonic at 300 mb

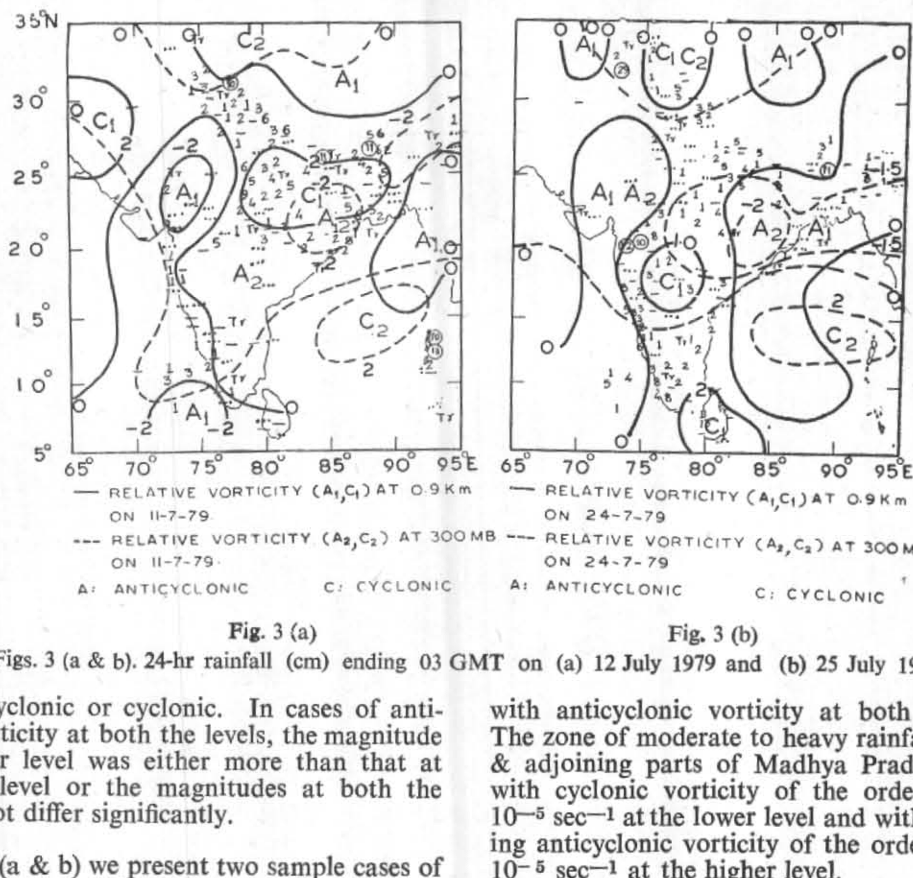

Fig. 3 (a) Fig. 3 (b)

Figs. 3 (a & b). 24-hr rainfall (cm) ending 03 GMT on (a) 12 July 1979 and (b) 25 July 1979

either anticyclonic or cyclonic. In cases of anticyclonic vorticity at both the levels, the magnitude at the lower level was either more than that at the higher level or the magnitudes at both the levels did not differ significantly.

In Figs. 3(a & b) we present two sample cases of distribution of vorticity patterns at 0.9 km asl and at 300 mb with the 24-hour rainfall recorded at 03 GMT of the succeeding day. In Fig. 3(a) it may be seen that major amount of rainfall recorded at 03 GMT of 12 July 1979 is over the area north of 20° N besides that over west coast. Most of the rainfall is associated with cyclonic vorticity at the lower level and anticyclonic vorticity at higher level. However, there are small pockets of light rainfall over the Gujarat and some portion of west coast which are associated with anticyclonic vorticity at both these levels. The zone of moderate to heavy rainfall over Bihar & adjoining parts of Madhya Pradesh coincides with cyclonic vorticity of the order of $+2.0 \times 10^{-5}$ sec^{-1} at the lower level and with corresponding anticyclonic vorticity of the order of -2.0×10^{-5} sec^{-1} at the higher level.

Fig. 3(b) showing rainfall of 25 July 1979 and vorticity of 24 July 1979 also corroborates this finding of low level cyclonic with upper level anticyclonic vorticity over areas of major rainfall. However, rainfall over northeast India, Gangetic West Bengal and neighbourhood is associated with anticyclonic vorticity at both the levels. It will, however, be seen that the anticyclonic vorticity at higher level is more than the anticyclonic at lower level.

6. Conclusions

Cyclonic vorticity at 0.9 km asl with anticyclonic or cyclonic vorticity at 300 mb and rainfall recorded upto 03 GMT of the next day are associated on 75 per cent cases of occurrence of rainfall. Anticyclonic vorticity at 0.9 km with more anticyclonic vorticity at 300 mb is also associated with occurrence of rainfall, especially in northeast zone.

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