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Mean model of western depression*

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ABSTRACT. The mean structure of wind, divergence, vorticity and vertical motion at different levels in the various sectors of a western depression over north India during winter season has been studied by pooling together the observations pertaining to six such disturbances in a moving coordinate system. The model thus obtained has been compared to similar model for extra-tropical depressions.

1. Introduction

The earlier studies of the western depression made by Malurkar and Desai (1943), Mull and Desai (1947), Pisharoty (1956), Mooley and Gupta (1967) and Seth (1968) were confined to individual case studies. These studies have been handicapped due to lack of adequate upper air data in each individual case. The present distribution of rawin/radiosonde stations over northwest India is not sufficient to give a complete picture of the various features associated with a western depression. It was therefore considered necessary to pool data from a number of western depressions of a fairly homogeneous characteristic and thus obtaining a mean vertical structure of the western depression with sufficient observations in the different sectors.

2. Technique

Hughes (1952) and Jordan (1952) used moving coordinate system in the study of tropical storms where they were confronted with a similar problem of inadequate upper air data. In a moving coordinate system, the centre of the coordinate system was considered to be coincident with the surface centre of the storm and direction; and the speed of moving coordinate system was considered to be the same as that of the storm. In the case of western depression, this technique of averaging winds with the help of a moving coordinate system was adopted.

3. Data used

Six western depressions were selected for the purpose of study. The dates and the location of the centres at various hours are given in Table 1. All the western depressions were fairly similar in their behaviour and had nearly homogeneous characteristics. Even though the directions of motion varied to some extent, it was thought that the system of moving coordinates would retain the major characteristics in proper perspective.

4. Procedure

A grid at 1 degree interval of latitude and longitude, covering an area of 10- degree of latitude and longitude was prepared as a transparent overlay. The grid squares were numbered as shown in Fig. 1. On a chart of the upper winds at a given level the grid was placed in such a way that the centre of the grid coincided with the surface centre, and the latitude line passing through the grid centre coincided with the tangent to the direction of motion. Wind observations falling in the different squares were noted. The process was repeated for different positions of the western depression in all the six cases. Thus, for the given level each grid square had one or more observations. The observations in each grid square were vectorially averaged. These vectorial means were plotted at the centre of the respective grid squares and a mean wind pattern was obtained. This process was carried out for all the standard levels from 0.9 to 9·0 km a.m.s.l.

5. Computation of divergence and vorticity

Bellamy (1949) chose geographically fixed triangle for computation of divergence. In the present study, equilateral triangles were chosen. The grid area was divided into 45 equilateral triangles, such that height of each triangle was 100 n. miles on the scale of grid and the base of each triangle had a west-east orientation (Figs. 2 and 3). The interpolated values of winds were read at the vortices of each triangle. The values of divergence and vorticities were calculated using a direct reading table (Table 2) and were plotted at the centroid of each triangle on a chart. The charts were analysed by drawing isopleths (Figs. 2 and 3).

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TABLE 1

List of the western depressions selected for the study

Case No.	Date	Time (GMT)	Position of centre of western depression: Lat. (°N)	Long. (°E)	Case No.	Date	Time (GMT)	Position of centre of western depression: Lat. (°N)	Long. (°E)
1	4 Jan 1959	0300	31·0	70·0	4	25 Jan 1962	0300	25·0	74·0
		1200	31·5	70·0			1200	27·0	75·0
	5 Jan 1959	0300	31·5	74·0		26 Jan 1962	0300	30·5	73·0
2	3 Feb 1959	0300	29·0	73·0	5	23 Feb 1962	1200	29·0	73·0
		1200	30·0	73·0		24 Feb 1962	0300	29·0	73·0
	4 Feb 1959	0300	31·5	73·0			1200	26·5	75·0
3	20 Jan 1962	0300	31·0	71·0	6	19 Jan 1965	0300	30·0	72·0
		1200	32·0	74·5			1200	29·0	74·5
	21 Jan 1962	0300	30·0	75·0		20 Jan 1965	0300	26·5	80·0

TABLE 2

Computation of derivatives of wind field using equilateral triangle

(Values are $V\cos\theta$ along the ordinate of the triangle)

	Direction (deg.) at A	B	C	Speed (kt) 1	2	3	4	5	10	Direction (deg.) at A	B	C	
	360	120	240	1·00	2·00	3·00	4·00	5·00	10·00	180	300	060	
Read as such with negative sign	350/010	130/110	250/230	·98	1·97	2·95	3·94	4·92	9·85	190/170	290/310	050/070	Read as such with Positive sign
	340/020	140/100	260/220	·94	1·88	2·82	3·76	4·70	9·40	200/160	280/320	040/080	
	330/030	150/090	270/210	·87	1·73	2·60	3·46	4·33	8·66	210/150	270/330	030/090	
	320/040	160/080	280/200	·77	1·53	2·30	3·06	3·83	7·66	220/140	260/340	020/100	
	310/050	170/070	290/190	·64	1·29	1·92	2·57	3·31	6·43	230/130	250/350	010/110	
	300/060	180/060	300/180	·50	1·00	1·50	2·00	2·50	5·00	240/120	240/360	360/120	
	290/070	190/050	310/170	·34	0·68	1·03	1·37	1·71	3·42	250/110	230/010	350/130	
	280/080	200/040	320/160	·17	0·35	0·52	0·69	0·87	1·74	260/100	220/020	340/140	
	270/090	210/030	330/150	0	0	0	0	0	0	270/090	210/030	330/150	

Instructions for use of Table

(1) Choose equilateral triangle in such a way that one of its side has W-E orientation.

(2) Mark the vortex of the triangle as A and other corners B and C moving clockwise.

(3) If the triangle is upright-one, read the values in the above table against the given wind velocities at point A, B and C. In case the triangle is an inverted one, then change the algebraic sign of the values.

(4) The algebraic sum of the three values obtained in (3) above will give Divergence (Unit hr^{-1}) when divided by the altitude of the triangle measured in n. miles.

For calculation of vorticity add 90° in the clockwise direction to the values of wind at A, B and C. The repetition of process given above in (3) and (4) will give the value of vorticity.

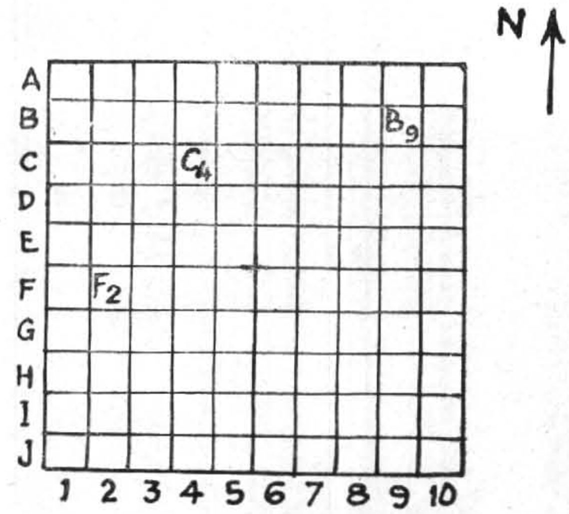

Fig. 1. Grid used for upper air data. Each square is equal to 1° Lat. & 1° Long.

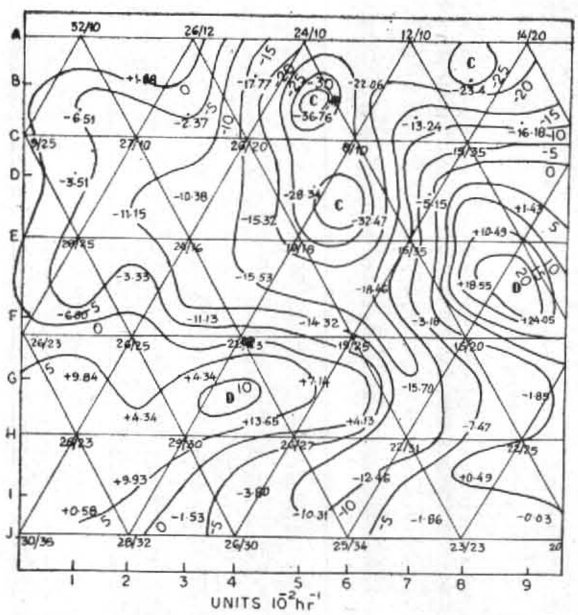

Fig. 2. Divergence-convergence pattern at 3·0 km. Winds are read at vortices of each triangle and values of divergence and vorticities calculated from Table 2. Curved lines are isopleths. Ht. of each triangle is 100 n.m. and base has W-E orientation

6. Computation of vertical velocity

The vertical velocity was calculated for all the triangles of the grid for various standard levels using the formulae:

$$\rho_2 w_2 - \rho_1 w_1 = -\bar{\rho} \int_{z_1}^{z_2} \nabla . \mathbf{V} \, dz \qquad (1)$$

or $\rho_2 w_2 - \rho_1 w_1 =$

$$-\bar{\rho} \left| \frac{\text{Div } z_2 - \text{Div } z_1}{2} \right| \triangle z \qquad (2)$$

where, ρ_1 = Air density of z_1 level

ρ_2 = Air density at z_2 level

$\bar{\rho}$ = Mean air density of layer between z_1 and z_2

Div z_1 = Divergence at z_1

Div z_2 = divergence at z_2

w_1 = Vertical velocity at lower level z_1

w_2 = Vertical velocity at higher level z_2

$\triangle z$ = Thickness of the layer between z_1 and z_2

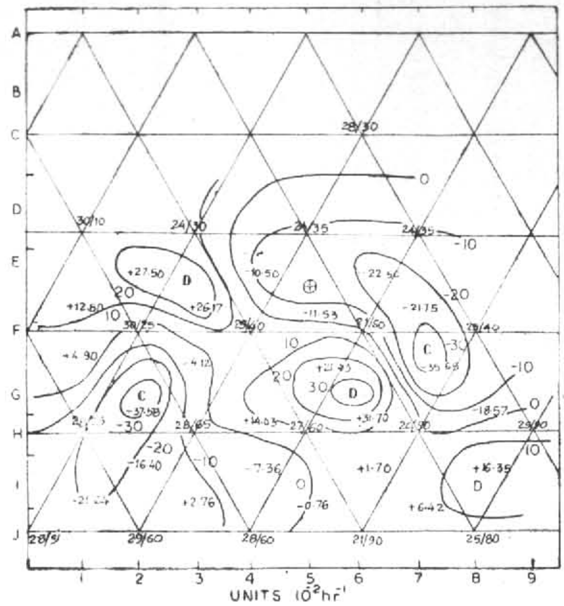

Fig. 3. Divergence-convergence pattern at 9·0 km. Winds are read at vortices of each triangle and values of divergence and vorticities calculated from Table 2. Curved lines are isopleths. Ht. of each triangle is 100 n.m. and base has W-E orientation

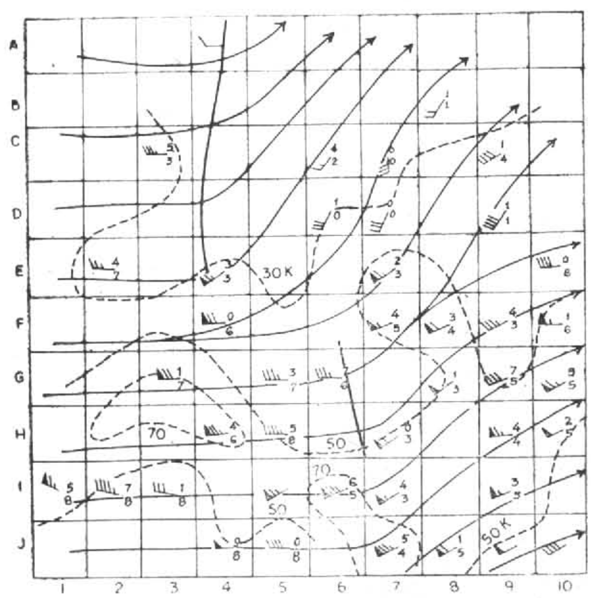

Fig. 4. Upper air pattern at 6·0 km. (Streamlines & isotachs)

The values of the vertical velocity thus obtained were plotted for different standard levels and analysed to deliniate the areas of upward and downward motion.

7. Upper wind patterns

(*a*) *Streamlines* — Spiralling cyclonic circulation is obtained upto 3 km with centre shifting towards north. At 4·5 and 5·4 km a trough is observed, oriented from northeast to southsoutheast. Two separate trough lines are seen at 6·0 km with orientation from north to south (Fig. 4). At higher levels, upto 9·0 km, fairly similar pattern is observed.

(*b*) *Isotachs* — Relatively stronger winds are seen in the south and southwest sectors from 0·9 to 3·0 km. It is noticed that from 4·5 km upward, winds are much stronger in the southern half of the grid as compared to the northern half. The average wind speed at 9·0 km in the south sector is of the order of 80 to 100 kt (Fig. 5).

8. Divergence pattern

The convergence maximum at 0·9 km is very close to the surface centre of the western depression. At 1·5 km the centre of maximum convergence has shifted to the northwest and the area of convergence is elongated in northwest/southeast direction. A second maximum of convergence is observed in the northnortheast sector. The area covered by divergence appears to be larger than what is seen at 0·9 km.

At 3·0 km the centre of convergence maximum appears to have shifted towards northnortheast sector (Fig.2). The magnitude of divergence maxima and convergence maxima are comparable. The convergence zone at 6·0 km covers northern half of the grid with a trough covering some portion of southwest and southsoutheast sectors. The two distinct zones of divergence can be seen in western and eastern sectors. At 9·0 km a complete reversal of the pattern as seen at 6·0 km, is noticed (Fig. 3).

9. Vorticity pattern

At 0.9 km maximum cyclonic vorticity is seen very close to the surface centre of the western depression. This centre shifts to east of the surface centre at 1·5 km and to the southsoutheast sector at 3·0 km. There are five distinct areas of cyclonic vorticity at 6·0 km. The pattern remains similar at 9·0 km.

10. Vertical velocity pattern

The centre of maximum upward velocity is seen close to surface centre upto 3·0 km. The magnitude of vertical velocity is found to be increasing with height. The magnitude of downward velocity surrounding the upward motion is relatively very weak. The upward motion occupies more than three-fourth of the area of the grid around the surface centre.

11. Discussion

(1) Fig. 6(a) gives the vertical profile of the divergence pattern on a W-E vertical plane passing through the surface centre of the western depression. On comparing it with similar profile for extra-tropical depression (Fig. 6 b) obtained by Fleagle (1948), it is seen that the pattern in the core of western depression is somewhat more complex.

(2) The jet axis is found to lie about 250 km south of the surface centre in the core of western depression whereas in an extra-tropical depression the jet axis is located almost at the latitude of surface cyclonic vortex as found by Boyden (1963),

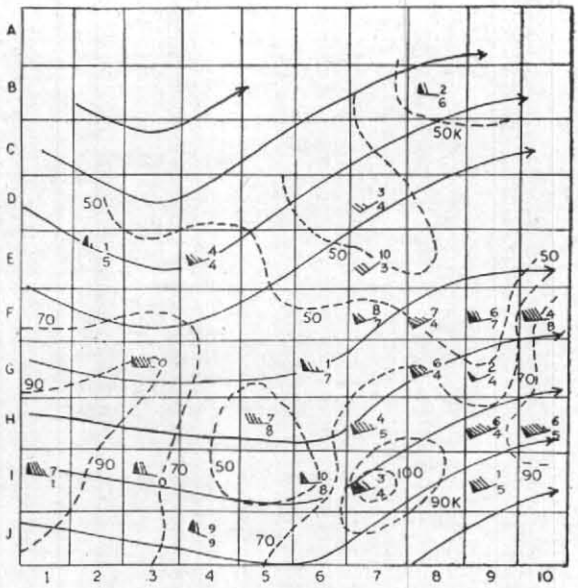

Fig. 5. Upper air pattern at 9.0 km. Streamlines and isotachs

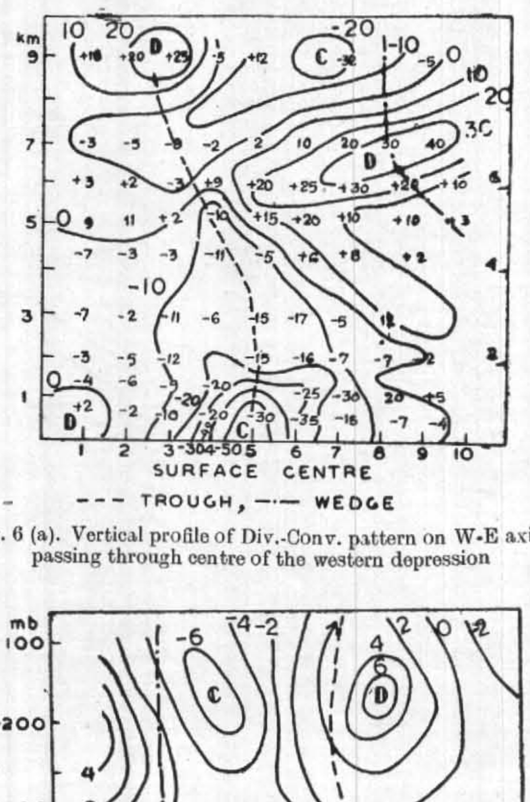

Fig. 6 (a). Vertical profile of Div.-Conv. pattern on W-E axis passing through centre of the western depression

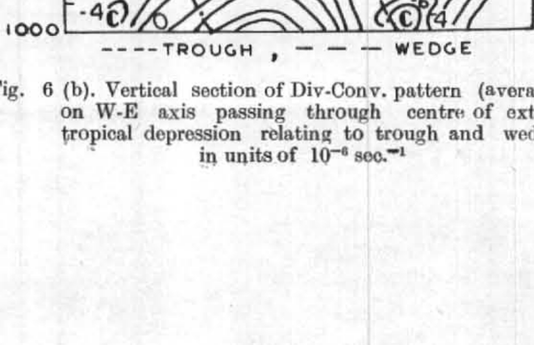

Fig. 6 (b). Vertical section of Div-Conv. pattern (average) on W-E axis passing through centre of extra-tropical depression relating to trough and wedge in units of 10^{-6} sec.$^{-1}$

(3) Marked convergence is noticed at 7·2 km near the axis of upper level trough in western depression. but according to Bjerknes and Holmboe (1944) there is a convergence behind and divergence ahead of the upper level trough in an extra-tropical depression. This difference may be due to the fact that in the western depression troughs are very nearly vertical, whereas in extra-tropical depression troughs are found tilting westward.

(4) The upper winds are found to be veering with height in the eastern half and backing in the western half in western depression upto 3·0 km. This shows that upto that level there is a warm air advection ahead and cold air advection at the rear of a western depression.

12. Conclusion

(*a*) The vertical profile of divergence in a western depression does not conform to a simple two-layer model as observed in extra-tropical depressions but it is somewhat more complex.

(*b*) The axis of sub-tropical jet stream is located to the south of the surface centre of the western depression. The speed of the jet is higher than the normal speed indicating that jet speed increases when a disturbance is affecting the area.

(*c*) Vertical upward velocity near the centre of western depression extends atleast upto 9·0 km, and at that height it is found to be of the order of 75 cm/sec.

(*d*) Western depression shows two well marked troughs above 6·0 km with a longitudinal separation of about 3°. It is possible that the northern portion is retarded due to orographic features, while the southern portion moves unimpeded with the result that two distinct troughs are found in the case study of the western depressions.

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