

Estimation of divergent wind from OLR data for use in objective analysis over the Indian region

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सार — ऊर्ध्वाधर वेग, अपसरण और तत्पश्चात् भारतीय क्षेत्र में पवन के अपसारी भाग का आकलन करने के लिए, ओ. एल. आर. आंकड़ों के प्रयोग हेतु एक पद्धति को सुलभ किया गया। इस पद्धति में मेघमय क्षेत्र में आरोही गति का आकलन अनुभविक सूत्र से किया गया और मेघमुक्त क्षेत्र में अवरोही गति का आकलन उष्मागतिक ऊर्जा समीकरण द्वारा किया गया तथा दोनों को मिला दिया गया। मिश्रित ऊर्ध्वाधर वेग क्षेत्र से 00 यू. टी. सी. पर, 4 से 8 जुलाई 1979 तक सभी मानक स्तरों पर अपसरण, वेग विभव और अपसारित पवनों का आकलन किया गया। इन क्षेत्रों की तुलना उपग्रह मेघ चित्रों, वर्षा आदि के साथ की गई है और ये मिनाप्टिक स्थितियों को चित्रित करने हेतु वास्तविक पाए गए। कुल पवन को प्रेक्षित पवन क्षेत्र से आकलित किए गए अपसारित और चयीय घटक के जोड़ के रूप में आकलित किया गया। इस पद्धति के मूल्यांकन के लिए, एकल प्राचल अनुकूल अन्तर्वेशन पद्धति में आरम्भिक अनुमानन क्षेत्र के रूप में 850 एच. पी. ए. पर इस कुल पवन क्षेत्र का प्रयोग किया गया और 4 से 8 जुलाई 1979 तक की अवधि के लिए विश्लेषण किए गए। परिणामों से ज्ञात हुआ है कि यह पद्धति वास्तविक विश्लेषणों को प्रतिरूपित करने के योग्य है जिसमें पवन के अपसारी भाग सम्मिलित हैं।

ABSTRACT. A scheme is formulated for the use of OLR data in the estimation of vertical velocity, divergence and then the divergent part of the wind over Indian region. In this scheme, ascending motion over cloudy region is estimated from an empirical relation between the cloud top temperature and descending motion over cloud-free region is estimated from the thermodynamic energy equation and both are blended. From this blended vertical velocity field, divergence, velocity potential and divergent winds at all standard levels from 4 to 8 July 1979 at 00 UTC are computed. These fields are compared with satellite cloud pictures, rainfall etc and they are found to be realistic in depicting the synoptic conditions. Total wind is computed as the sum of the estimated divergent component and rotational component computed from observed wind field. For assessment of the scheme, this total wind field at 850 hPa is used as initial guess field in univariate optimum interpolation scheme and analyses were made for the period 4 to 8 July 1979. Results show that scheme is able to produce realistic analyses which included divergent part of the wind.

Key words — Divergent winds, OLR, Objective analysis, NWP, Equivalent black body temperature.

1. Introduction

Initial specification of divergence is important for realistic forecast of precipitation rate particularly in the tropics. Due to non-divergent initial conditions precipitation rates are underforecast in the first few hours of forecast because model requires several hours to develop a consistent vertical velocity field. This 'spin up' problem in forecast models may be due to inaccurate specification of divergence, moisture and thermal fields etc (Kasahara *et al.* 1988). Many studies have been made to incorporate the divergent wind in analysed winds so that specification of divergence in the initial condition is improved in order to reduce the spin up problem. Sumi *et al.* (1979), Sumi (1981), Tarbell *et al.* (1981), Julian (1984), Krishnamurti *et al.* (1984), Krishnamurti & Low-Nam (1986) and Salmon & Thomas (1986) have attempted to specify the divergent part by different methods. Most of these studies have used OLR data to estimate divergent part of the wind. In our earlier study (Kulkarni *et al.* 1992) also using regression relation between OLR data and the divergence, the latter was estimated. Then the divergent part of wind was obtained and included in the initial guess field of the analysis scheme. Since the divergence at every level

was separately computed the requirement that the vertically integrated divergence is zero, was not ensured in this study.

Kasahara *et al.* (1988) had suggested a scheme in which the ascending motion was more directly computed from OLR data and the descending motion from the thermodynamic energy equation. Following this scheme, in the present study we have computed the vertical motion and subsequently estimated the divergent wind over the Indian region. This divergent wind has been included in the analysis thus improving the initial specification of wind field for NWP. In this scheme, the vertically integrated divergence is made zero with the constraint that vertical velocity is zero at 1000 and 100 hPa.

2. Methodology

2.1. Delineation of cloudy and cloud-free region

The cloudy region is a region of ascending motion and the rest of the cloud-free region is likely to be of descending motion. In this scheme the descending

motion over cloud-free region is computed from the thermodynamic energy equation and the ascending motion is computed in an entirely different way as discussed in section 2.2. This ascending motion is assumed to be of parabolic nature with zero values at 1000 hPa and 100 hPa level and a maximum at 500 hPa. The ascending motion is also computed assuming the vertical velocity to be zero at the top of the cloud (instead of 100 hPa level) and at 1000 hPa level.

Kasahara *et al.* (1988) used a threshold value of Equivalent Black Body (EBB) temperature to delineate the cloudy and cloud-free regions. The EBB temperatures were computed from OLR data using the following relation :

$$F = \sigma T_e^4 \quad (1)$$

where, $\sigma = 5.6693 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$.

The EBB temperature value 258 K is found to delineate cloudy region and cloud-free region or in other words, the region of ascending motion from that of descending motion. This threshold value of EBB temperature has been used in the study by Kasahara *et al.* (1987) on the global distribution of diabatic heating rates based on thermodynamic energy budget. This would mean that the regions are cloudy whenever $(258^\circ - T_e)$ is positive, and cloud-free wherever $(258^\circ - T_e)$ is negative.

2.2. Computation of vertical motion, divergence and velocity potential

2.2.1. *Vertical motion over the cloudy region*—In convective region, greater the vertical velocity (upward motion) taller the cloud is expected to grow, provided the moisture is available. In view of this, in the region of colder cloud top temperature or lower values of OLR, there would be greater vertical velocity. On the basis of this, Kasahara *et al.* (1988) has derived an empirical relation between maximum vertical velocity and OLR data. He further assumed this vertical velocity to be of parabolic nature in the vertical with zero values at 1000 and 100 hPa levels and a maximum at 500 hPa. The extreme value of vertical velocity is given by :

$$\omega_{\max} = \beta (258 - T_e) \quad (2)$$

Kasahara *et al.* (1988) has used a value $-0.675 \times 10^{-4} \text{ hPa s}^{-1} \text{ K}^{-1}$ for β . In this study, a sensitivity study was made to determine the best value for β . Accordingly the values ranging from -0.175×10^{-4} to -1.175×10^{-4} were also used and the vertical velocity fields were computed for all these values of β .

As mentioned above, vertical profile is assumed to be parabolic in the form given by :

$$\omega(P) = 4.0 \frac{(P_L - P)(P - P_u)}{(P_L - P_u)^2} \omega_{\max} \quad (3)$$

where, $P_L =$ Lowest level 1000 hPa,

$P_u =$ Uppermost level 100 hPa,

2.2.2. *Vertical motion over cloud-free region*—As mentioned in section 2.1, wherever equivalent black body temperatures are greater than 258°K, there is cloud-free region or descending motion and it is computed from the thermodynamic energy equation. Over the tropics, the local change of temperature as well as the temperature advection are nearly negligible considering scale analysis of thermodynamic energy equation (Holton 1979). Since there are only small fluctuations in daily temperatures over tropics, in this thermodynamic equation the vertical velocity term has to be compensated by the diabatic heating term \bar{Q} of Eqn. (4) given below. In other words, over this region there is heat balance with radiative cooling being compensated by adiabatic warming because of subsidence. When there is no precipitation, the net diabatic heating or cooling is essentially due to longwave radiation which tends to cool the troposphere. Here, we assume a cooling rate of 1.5°C/day due to longwave radiation from a study by Mani *et al.* (1981), over Indian region during monsoon. The thermodynamic energy equation is given by:

$$\partial T / \partial t + \bar{v} \cdot \nabla T - S\omega = \bar{Q}/c_p \quad (4)$$

When the local change and advection of temperature are neglected, we get :

$$-S\omega = \bar{Q}/c_p \quad (4a)$$

where, S is the static stability,

ω is vertical velocity, and

\bar{Q}/c_p is total diabatic heating rate.

The vertical velocity over cloud free-region is, therefore, determined using Eqn. 4(a).

2.2.3. *Determination of divergence and velocity potential*—The upward motion obtained from Eqn. (3) and the downward motion from Eqn. 4(a) were blended and from this resultant vertical velocity field we obtained the horizontal divergence using continuity equation.

$$\nabla \cdot \bar{v} = -\partial \omega / \partial p \quad (5)$$

Since the condition $\omega = 0$ at 1000 hPa and 100 hPa has been specified as boundary condition, the horizontal divergence integrated in the vertical is zero.

The velocity potential χ was calculated from Poisson equation (Eqn. (6)) by specifying suitable boundary conditions (Hawkins and Rosenthal 1965).

$$\nabla^2 \chi = \nabla \cdot \bar{v} \quad (6)$$

From velocity potential, we computed the divergent component of the wind u_χ and v_χ .

Thus eastward and northward components of wind were obtained as :

$$u = u_\psi \text{ (observed)} + u_\chi \text{ (estimated)} \quad (7a)$$

$$v = v_\psi \text{ (observed)} + v_\chi \text{ (estimated)} \quad (7b)$$

TABLE 1

Maximum value of vertical velocity at 700 hPa for different values of β

S. No.	β (10^{-4} hPa $s^{-1}k^{-1}$)	Vertical velocity (10^{-3} hPa s^{-1})
1	-.175	-62.3
2	-.275	-98.0
3	-.375	-133.6
4	-.475	-169.2
5	-.575	-204.8
6	-.675	-240.5
7	-.775	-276.1
8	-.875	-311.7
9	-.975	-347.3
10	-1.075	-383.0
11	-1.175	-418.6

The new wind field, thus obtained includes the divergent component of wind keeping the rotational part of wind unchanged.

2.3. Quantitative assessment of the scheme by objective analysis.

The new u and v components of wind field obtained from Eqns. 7(a) and 7(b) were used as initial guess fields in objective analysis scheme by univariate optimum interpolation method. The importance of such divergent winds in initial guess fields has been discussed by Julian (1984), Krishnamurti & Low-Nam (1986), Kasahara *et al.* (1988) and Heckley *et al.* (1990) and so this is not elaborated here. This scheme was applied for four consecutive days starting from 4 July 1979. The previous 24 hrs, wind fields by ECMWF analysis and the total wind field corresponding to the same time (previous 24 hrs) by present scheme at 850 hPa were used as initial guess and wind analysis were made for these days. Root mean square (RMS) errors were computed comparing the observed winds in both cases with and without the divergent part of the wind in order to examine the quality of the analyses.

3. Synoptic situation

For the study, we used the data of 4 to 8 July 1979 (00 UTC.) The main synoptic feature during this period was the monsoon depression over Bay of Bengal. The low pressure area which entered northeast Bay across Arakan coast on 4 July lay there without appreciable development till 6 July and concentrated into depression on 7th morning. It crossed north Orissa coast on afternoon of 8 July. Moving westnorthwestwards, the depression weakened into a 'low' over northwest Madhya Pradesh by 10th and merged with the seasonal trough by 11 July 1979.

TABLE 2

Root mean square errors in mps (obtained by comparing station observations) for analyses with and without OLR data

Date (July 1979)	Divergent wind from OLR included		Divergent wind from OLR not included	
	u	v	u	v
5	5.1	3.1	5.0	3.1
6	4.0	3.2	4.0	3.4
7	5.5	3.0	5.6	3.2
8	4.5	4.9	4.2	5.1

4. Data, computation and discussion of the results

4.1. Data and computations

This study is based on FGGE level III-B data (ECMWF) analysis of wind, geopotential height at all standard levels for the period from 4 to 8 July 1979 (00 UTC) and on OLR data obtained from Climate Analysis Centre, NMC, USA. OLR data were used to compute EBB temperatures (Eqn. (1)) and using Eqns. (2) and (3), the vertical velocity (upward motion) was computed in the cloudy region from these EBB temperatures using different values of β (mentioned in section 2) in order to determine the best value of β giving realistic values of upward motion.

For different values of β , the pattern of the vertical velocity field remained the same as expected, but the magnitudes varied. The maximum vertical velocity at the grid point (18.7°N, 82.5°E) in all the cases with the corresponding β values are tabulated (Table 1). According to Holton (1979), the large scale vertical velocity is of the order of 3 cm s^{-1} and in various studies it is generally found that in the region of maximum vertical velocity with respect to the monsoon depression, the upward motion is of the range $2-3 \text{ cm s}^{-1}$. The maximum value obtained in the kinematic method for vertical velocity also is 2.5 cm s^{-1} . The value of $-0.675 \times 10^{-4} \text{ hPa s}^{-1} \text{ k}^{-1}$ for β yielded this value justifying the choice of the value for β in this study.

From the geopotential height data (FGGE) temperatures at the grid points at all the standard levels were computed. These temperature data were in turn used to compute the vertical velocity (downward motion) over cloud-free regions using thermodynamic energy equation (Eqn. 4(a)). The wind data were used for the computation of vorticity, divergence and vertical velocity by kinematic method. The rotational part of the wind, $u\psi$ and $v\psi$ were computed from the vorticity field. The vertical velocity obtained from kinematic method, was used for comparison with that obtained from Eqns. (3) & 4(a). The FGGE wind data at the

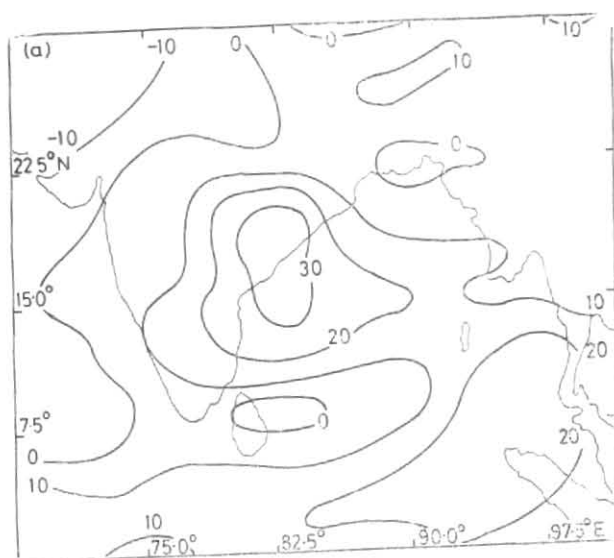


Fig. 1(a). Distribution of $(258 - T_e)$ in K for 7 July 1979

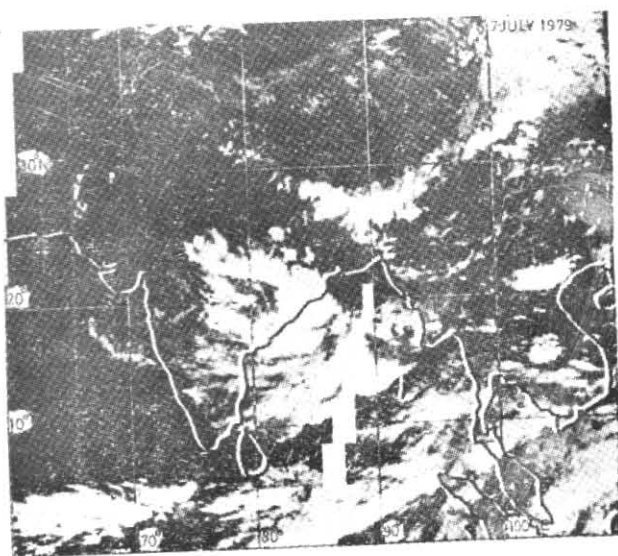


Fig. 1(b). Satellite cloud pictures for 7 July 1979

grid points were used as the initial guess field for the univariate optimum interpolation (OI) scheme of objective analysis.

The winds from radiosonde observations over India and the neighbourhood for the four days from 5 to 8 July were used in the analysis. Using the univariate optimum interpolation scheme, the wind analyses were made for four days. The wind field corresponding to the previous day (persistence) was used as initial field for this analysis scheme. The total wind field which included the divergent part was also used as initial guess field. Analyses for both cases were examined.

4.2. Discussion of results

4.2.1. *Delineation of cloudy and cloud-free region*—For each grid point EBB temperature (T_e) was subtracted from the threshold value 258°K . The positive difference of $(258^\circ\text{K} - T_e)$ represents the cloudy region and negative difference represents the cloud free region. The difference $(258^\circ\text{K} - T_e)$ fields for all days have been plotted and compared with satellite pictures. However, this field for 7 July 1979 is shown in Fig. 1(a). The areas with positive difference are in very good agreement with the satellite cloud imageries as can be seen from Fig. 1(b). For all the other days also this agreement was observed. This suggests that threshold value 258°K of EBB temperature used by Kasahara for delineating cloudy and cloud-free regions holds good over Indian region also during monsoon season.

4.2.2. *Vertical velocity field*—As mentioned in section 4.1, the ascending motion over cloudy region was computed from Eqn. (3) and the descending motion over cloud free region from Eqn. 4(a) and are depicted in Fig. 2 for 700 hPa for 7 July 1979. It was observed that the region of upward vertical velocity at 700 hPa agrees well with the region of rainfall as well as with the cloud imageries from satellite pictures. On the 4 and 5 July in the formative stage of the depression, large upward motion is occurring to the south of the depression while on 6 to 7 and 8 July, it is to the southwest of the depression. When vertical velocity fields computed for all days from 4 to 8 July were examined it was found that, the pattern of the vertical velocity and the magnitudes were consistent with the changes in the intensity as well as position of the system during the period of study.

The vertical velocity computed by kinematic method for comparison is shown in Fig. 3. The general patterns of the vertical velocity fields in both methods are similar and so also their magnitudes. The maximum upward motion is about 2 cm s^{-1} in both methods. The important difference is the upward motion off Goa-Konkan coast in kinematic method which is not seen in the vertical velocity by the other method. This is not supported by the satellite pictures. From this, it appears that the vertical velocity field from OLR data agrees better with satellite cloud pictures and so, is very much acceptable.

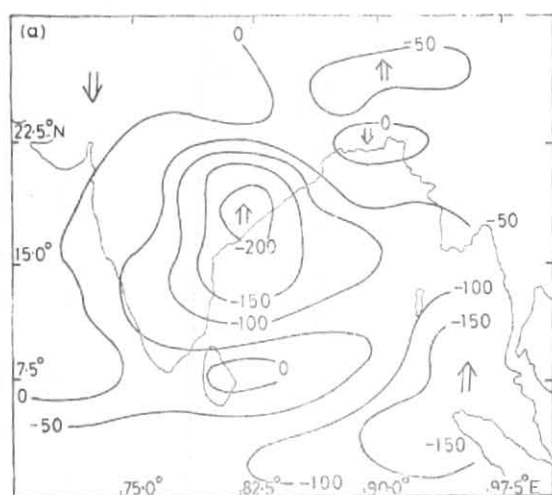


Fig. 2(a). Blended vertical velocity (10^{-5} hPa s^{-1}) at 700 hPa, 7 July 1979 (00 UTC)

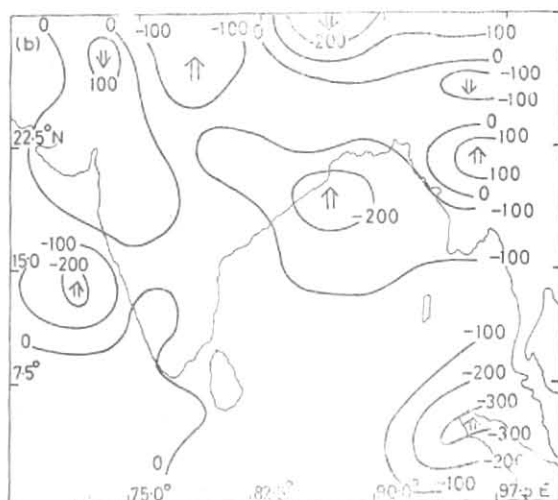


Fig. 2(b). Kinematic vertical velocity (10^{-5} hPa s^{-1}) at 700 hPa, 7 July 1979 (00 UTC)

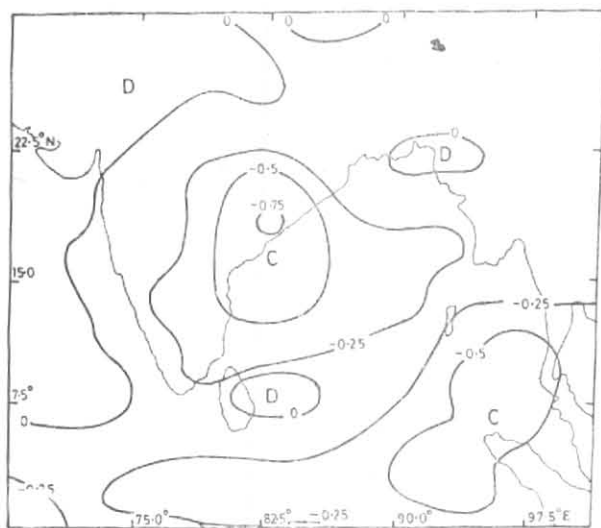


Fig. 3. Divergence (10^{-5} s^{-1}) at 850 hPa, 7 July 1979 (0) UTC)

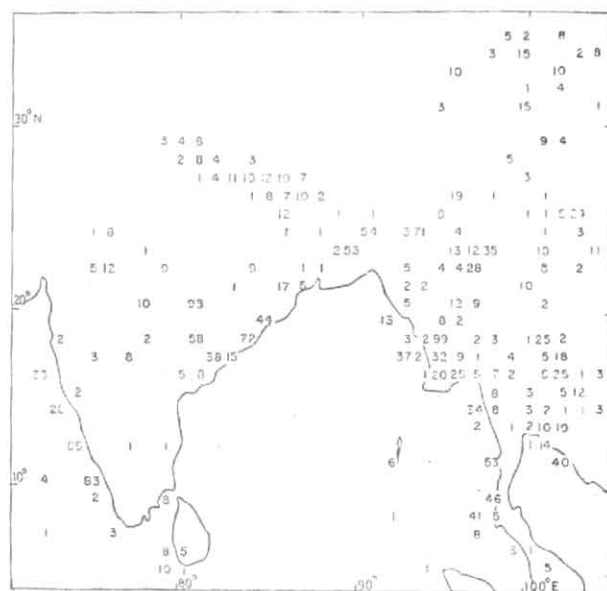


Fig. 4. 24 hrs rainfall (mm/day) ending at 00 UTC (8 July 1979) (raingauge observations)

4.2.3. *Divergence and velocity potential*— We have computed the divergence from vertical velocity (from OLR data) using continuity Eqn. (5). The patterns of divergence/convergence at 850 hPa on 7 July are given in Fig. 4. Maximum low level convergence occurs at 850 hPa with corresponding compensating divergence at 200 hPa. At 850 hPa surface, region of convergence agrees well with the region of convective activity/heavy rainfall (Fig. 5). Maximum value of low level convergence on 7 July is $0.77 \times 10^{-5} \text{ sec}^{-1}$ at the grid point 18.7°N , 82.5°E at 850 hPa, while at the same point the upper level divergence is $0.89 \times 10^{-5} \text{ sec}^{-1}$ at

200 hPa (divergence field at 200 hPa is not shown here). This brings a classic example of low level convergence and upper level divergence.

Velocity potential gives the information about inflow/outflow and magnitude of divergent wind. It was computed for 850, 700, 500, 300 and 200 hPa levels from 4 to 8 July 1979 using Eqn. (6). The daily changes in the intensity and movement of the monsoon depression are depicted in the velocity potential field on all days. Fig. 6 shows the velocity potential and divergent wind at 850

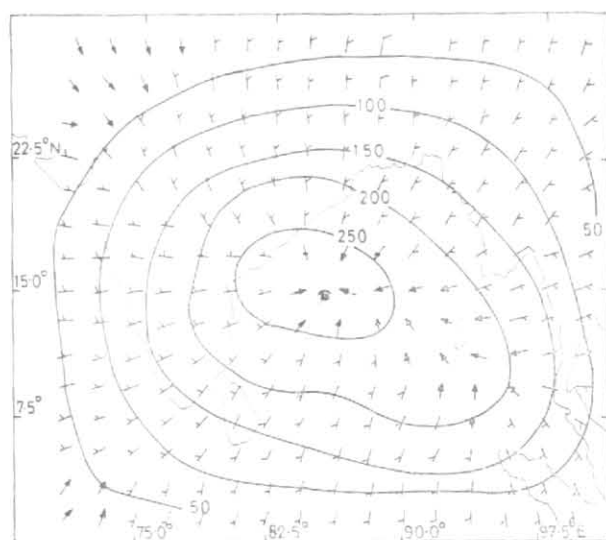


Fig. 5. Velocity potential ($10^1 \text{ m}^2 \text{ s}^{-1}$) at 850 hPa, 7 July 1979 (00 UTC)

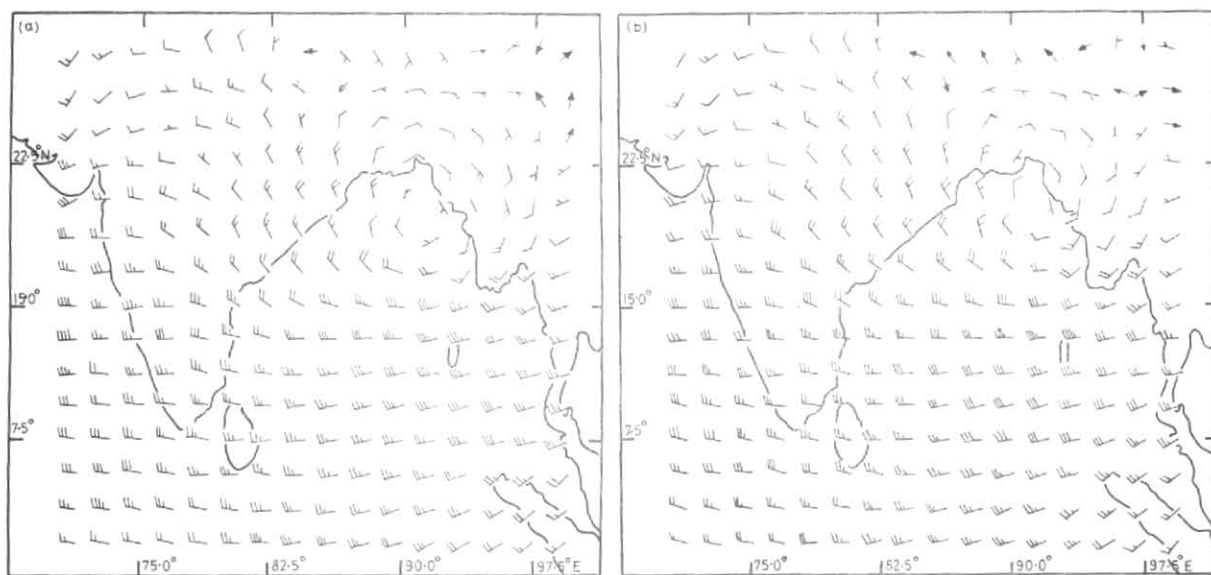


Fig. 6(a). Objective analysis of wind field at 850 hPa, 7 July 1979 (00 UTC) with FGGE III-B analysis as initial guess

Fig. 6(b). Same as in Fig. 6(a) except with FGGE III-B analysis modified by OLR as initial guess

hPa for 7 July 1979. They are also consistent with the cloudiness as seen from satellite pictures in Fig. 1(b). Just like convergence/divergence pattern, region of maximum velocity potential or the inflow is found to be at the southwest sector of the depression. Its magnitude

has increased from 4 to 7 July and decreased on 8 July. On all the days, region of maximum velocity potential coincide with region of maximum upward motion. This shows that the velocity potential obtained using this scheme is realistic.

4.2.4. *Analysis of wind field*— In order to assess the impact of the divergent part of the wind in the final wind analysis, analyses were made with two initial guess fields. Firstly, the total wind which included the divergent part of the wind by this scheme, was used as initial guess field and secondly unmodified analysis (from ECMWF) of the previous day (24 hrs earlier) was used as has been carried out in our earlier study (Kulkarni *et al.* 1992). In that study details of the analysis scheme have been given and hence not included here. The analyses for the two cases at 850 hPa for 7 July are given in Figs. 7 & 8. The RMS errors were computed by interpolating the analyses at the grid points to the observing stations and comparing with actual observations (Table 2). They in both cases are found to be of same magnitude suggesting that both analyses are comparable and the flow patterns in both cases are similar whether divergent part from OLR is included or not. However, the analyses which included the divergent part in the initial guess will have the divergent part added to the rotational part and thus would be the better initial specification of the wind field for the forecasting models since this would reduce spin up problems.

5. Concluding remarks

The threshold value 258°K of EBB temperature used by Kasahara seems to hold good over Indian region during monsoon season since the $(258^{\circ}\text{K}-T_e)$ pattern delineates fairly well the cloudy and cloud-free region. The blended vertical velocity field obtained from OLR data (upward motion) and the thermodynamic energy equation (descending motion) are consistent with the synoptic situations on all five days with maximum vertical velocity in the southwest sector of the depression and also agreeing with rainfall pattern as well as with satellite cloud pictures. The wind field which included the divergent part is found to be satisfactory initial guess field for the objective analysis scheme since the final analyses depict the synoptic situations well and also the RMS errors are within tolerable limits. Thus, it is possible, following the above scheme to estimate the divergent part of the wind from OLR data and to include it in the wind field so as to obtain better specification of initial fields for forecasting models.

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