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# On the use of outgoing longwave radiation data in incorporating divergent part of the wind in analysis

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**सार** — वर्तमान अध्ययन में, निर्गमनी दीर्घ तरंग विकिरण (ओ एल आर) और अपसरण के बीच के सम्बन्ध का उपयोग करके 850 एच पी ए पर ई सी एम डब्ल्यू एफ जाल बिन्दु आंकड़ों का उपयोग कर संगणित शुद्धगतिक अपसरण का विस्तार किया गया है। इस नए शोधित अपसरण को वेग विभव संगणित करने और फिर, वेग विभव से पवन का अपसारी भाग प्राप्त करने के लिए उपयोग में लाया गया है। पवन से घूर्णनी भाग प्राप्त करने के लिए हमने पवन आंकड़ों से भ्रमिलता को संगणित किया और बाद में धारा फलन प्राप्त किया गया, फिर उस धारा फलन से पवन का घूर्णनी भाग। संशोधित वेग विभव से (ओ० एल० आर० आंकड़ों का उपयोग करके) प्राप्त अपसारी भाग और असंशोधित धारा फलन के घूर्णनी भाग का जोड़ ही कुल पवन है। प्रारम्भिक अनुमान क्षेत्र में पवन के अधिक यथार्थ अंश होने की दृष्टि से इष्टतम अन्तर्वेशन योजना द्वारा एकविचर उद्देश्य विश्लेषण के लिए प्रारम्भिक अनुमान के रूप में इस कुल पवन क्षेत्र का उपयोग किया जाता है। फलतः विश्लेषित क्षेत्र में भी हवा का अपसारी भाग होगा।

विश्लेषण के लिए चुनी गई अवधि 5 से 8 जुलाई, 1979,स्तर 850 एच पी ए, जो 12 यूटीसी काल के अनुरूप था। यह अवधि एक महत्वपूर्ण अवधि थी क्योंकि बंगाल की खाड़ी पर तब एक मानसून अवदाब था। उपर्युक्त अवधि के लिए प्रारम्भिक अनुमान के दो क्षेत्र समूह लगाए और वस्तुनिष्ट विश्लेषण किए गए। पहले हवा क्षेत्र के विस्तारित अपसारी भाग को समाकलित करके और दूसरी बार प्रारम्भिक अनुमान क्षेत्र में उसे न समाकलित करके किया गया है। विश्लेषण पर पवन के विस्तारित अपसारी भाग के प्रभाव का मूल्यांकन करने के लिए दोनों समूहों से प्राप्त इन विश्लेषणों की तुलना की गई। परिणामों से पता चलता है कि इस तकनीक से यथार्थ परिणाम प्राप्त होने के कारण यह तकनीक पर्याप्त रूप से अच्छा कार्य कर रहा है।

ABSTRACT. In the present study, kinematic divergence computed using ECMWF grid point data at 850 hPa is enhanced by using the relationship between OLR and divergence. This new enhanced divergence is used to compute the velocity potential and then, the divergent part of the wind is obtained from velocity potential. To obtain the rotational part of wind, we computed the vorticity from wind data, and subsequently stream function was obtained and the rotational part of the wind from the stream function. The total wind is the combination of divergent part obtained from modified velocity potential (using OLR data) and rotational part from unmodified stream function. This total wind field is used as initial guess for univariate objective analysis by optimum interpolation scheme so that Initial Guess field contained the more realistic divergent part of the wind. Consequently, the analysed field also will contain the divergent part of the wind.

Objective analysis were carried out for 5-8 July 1979 when there was a depression over the Bay with two sets of initial guess fields. Firstly, with including the enhanced divergent part of the wind field and secondly without including that in the initial guess field. These analyses from the two sets were compared to assess the impact of enhanced divergent part of the wind on the analysis. Results indicate that this technique performs reasonably well since it is able to produce realistic results.

**Key words** — Outgoing longwave radiation (OLR), Stream function, Velocity Potential, Divergent part of the wind, Least square method, Objective analysis, Optimum interpolation scheme.

## 1. Introduction

In most of the operational N.W.P. models, the amount of condensed water and consequently the latent heat released are underestimated during the first few hours of forecast run, particularly in tropics. According to Kasahara *et al.* (1988), this is because of the inaccuracies in the initial specification of the divergence, moisture and thermal fields or because of the problems in parameterising physical processes. The main objective of this study is to improve the initial specification of divergence.

The tropical cloudiness, in the form of very large bright clouds or the cloud clusters have characteristic of synoptic scale waves (Chang 1970, Wallace 1970, & 1971, Reed and Recker 1971). Wallace showed that it is possible to estimate vertical motion field over tropics from cloud brightness data alone. Since the Outgoing Longwave Radiation (OLR) data represents the cloud brightness, they could be used for deriving the divergence field. Chang *et al.* (1975), Sumi (1981), Julian (1984), Krishnamurti and Low-Nam (1986) and Kasahara *et al.* (1988) have used OLR data in incorporating the divergent part of the wind in tropical wind analysis. Their studies are briefly reported below.

Chang *et al.* (1975) used satellite visible brightness and infrared data in analysing the divergence term in linear barotropic vorticity equation and concluded that improved analysis is possible by such a procedure. Sumi *et al.* (1979) designed an analysis scheme to give reliable divergence field through use of satellite brightness data. His scheme was able to produce accurate wind field analysis by incorporating the satellite derived information for enhancement of analysed divergence and vorticity fields. His results indicated that this analysis scheme performed reasonably well. Julian (1984) proposed a scheme in which the rotational and divergent parts of the wind were computed separately. He estimated the divergent component of the wind by transforming satellite observed OLR to a velocity potential field. For objective analysis by optimum interpolation method he used a first guess obtained by adding rotational forecast wind field with the divergent component estimated by above method. Performance of his scheme was compaiable to the optimum interpolation scheme using conventional data.

Krishnamurti and Low-Nam (1986) found a relationship between polar orbitting satellite radiance data and divergent circulation based on 200 hPa wind analysis. He compnted regression relation between divergence and OLR and between the former and the Laplacian of OLR and used to obtain a first guess divergent wind over tropics. He suggested that this relationship may be useful over data sparce regions of tropics for NWP and climate studies. In order to improve the analysis of wind field over tropics, Kasahara *et al.* (1988) proposed a scheme to incorporate OLR data for specifying the initial divergence for global NMC operational model. His scheme was able to produce satisfactory results. The present study is an attempt to examine the problem of improving the wind field analysis over tropics by incorporating divergent part of the wind following the scheme of Sumi *et al.* (1979). The procedure described below is to formulate a scheme to obtain the divergent part of the wind field from OLR data and include that in initial guess field for the objective analysis by optimum interpolation scheme.

**2. Methodology**

2.1. *Computations of the divergence and velocity potential*

In this study, we have followed Sumi *et al.* (1979) to compute the divergence indirectly from OLR data. The divergence was computed by kinematic method (Eqn. 1)

$$\text{Divergence } D = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \qquad (1)$$

where $u$, $v$ are west-east and south-north components of the wind. The divergence ($D$) and OLR values were separated into their respective zonal mean ($\overline{D}$ and $\overline{\text{OLR}}$) and deviation fields ($D'$ and OLR$'$) such that

$$D = \overline{D} + D'$$

$$\text{OLR} = \overline{\text{OLR}} + \text{OLR}'$$

This separation is done because absolute values of OLR may not be accurate but their relative magnitudes are reliable. Hence OLR$'$, the deviations or the anomalies are utilised in computations and not the absolute values. The cloudy regions are associated with the convective regions or in other words with the regions of convergence of wind flow. Thus, the negative divergence ($D$) is related to cloudy regions or very low values of OLR and can be written as (Eqn. 2) :

$$D'_s = \text{SCL} \times \text{OLR}' \qquad (2)$$

where $D'_s$ is the divergence anomaly which is to be estimated from OLR data and SCL represents a regional scaling factor. This scaling factor was determined from known divergence field and the corresponding OLR data by least square method so that the error

$$E = \Sigma\,(D' - D'_s)^2 \qquad (3)$$

is minimum.

The deviation of the enhanced divergent part of the wind $D'_e$, could be obtained as the sum of the $D'$ and $D'_s$

$$i.\,e., \quad D'_e = D' + D'_s \qquad 4(a)$$

The complete enhanced divergence field was obtained as :

$$D_e = \overline{D} + D'_e \qquad 4(b)$$

Velocity potential was computed from the enhanced divergence by solving the Poisson equation

$$\nabla^2 \chi = D_e \qquad (5)$$

2.2. *Computation of the total wind and its inclusion in the objective analysis scheme*

In the present study, for computation of rotational part of the wind, vorticity was first computed from original ECMWF grid point wind data (FGGE IIIB). Stream function, $\Psi$, was then obtained from the following relation :

$$\nabla^2 \psi = \zeta \qquad (6)$$

The $u_\psi$ and $v_\psi$ are obtained from Eqns. (7) :

$$u_\psi = -\frac{\partial \psi}{\partial y} \qquad 7(a)$$

$$v_\psi = \frac{\partial \psi}{\partial x} \qquad 7(b)$$

From the velocity potential obtained from Eqn. (5) (from enhanced divergence), $u_\chi$ and $v_\chi$ are obtained from Eqn. (8) :

$$u_\chi = \frac{\partial \chi}{\partial x} \qquad 8(a)$$

$$v_\chi = \frac{\partial \chi}{\partial y} \qquad 8(b)$$

The final total wind was obtained from combination of rotational part of the wind from unmodified stream function and divergent part of the wind from modified velocity potential (Eqn. 9) :

$$u_{(\text{total})} = -\frac{\partial \psi}{\partial y} + \frac{\partial \chi}{\partial x} \qquad 9(a)$$

$$v_{(\text{total})} = \frac{\partial \psi}{\partial x} + \frac{\partial \chi}{\partial y} \qquad 9(b)$$

This total wind was then used as initial guess for making objective analysis by Optimum interpolation schemes. The objective analysis scheme is given in 2.3.

2.3. *Optimum interpolation scheme of objective analysis*

The analysis scheme used in this study is the univariate optimum interpolation (O. I.) scheme first developed by Gandin (1963). The details of the scheme and computational method for wind field are described by Alaka and Elvander (1972), Davidson and Mc Avaney (1981) and Rajamani *et al.* (1983).

In this scheme the grid point anomaly is computed as a linear combination of the weighted anomalies at the observing stations surrounding the grid point. The weighting factors are computed including climatological characteristics of the parameter '*f*', by solving the following set of equations (Details are given in Rajamani *et al.* (1983).

$$\sum_{j=1}^{n} \mu_{ij} P_j + \lambda^2 P_i = \mu_{oi} \quad i = 1,\ 2 \ldots . n \qquad (10)$$

where, $\mu_{ij} = \overline{f_i' f_j'}/\sigma_0^2; \quad \mu_{oi} = \overline{f_o' f_i'}/\sigma_0^2$

$\lambda^2 = \sigma^2_{\epsilon i}/\sigma_0^2$ and $\sigma_0^2 = \sigma^2_i - \sigma^2 \epsilon_i$

Here $\sigma_i^2$ is the average variance and $\sigma^2\epsilon_i$ is the total mean random error in the observation of wind field, $P_i$ is the weighting factor for the observing station *i*, with respect to the grid point 'o', $\overline{f_i' f_j'}$, $\overline{fo' f_i'}$ are the covariances respectively between the two stations *i* and *j* and between the grid point 'o' and the station '*i*' respectively. The autocorrelation, $\mu$ which is a function of distance is modelled into the following equation (Alaka and Elavander 1972)

$$\mu(\rho) = (Ae^{-B\rho^c} + 1 - A) \cos D\rho \qquad (11)$$

where *A*, *B*, *C* and *D* are constants. This curve becomes 1 at $\rho = 0$ and it decreases exponentially and reaches zero after certain distance.

2.4. *Weighting functions and objective analysis*

The constants *A*, *B*, *C* and *D* mentioned in Eqn. (11) have been computed separately for *u* and *v* components. $\mu_{ij}$ for the pair of stations *i* and *j* and $\mu_{0i}$ for the station '*i*' and grid point '$_0$' were obtained from Eqn. (11). $\sigma^2\epsilon_i$ was obtained from structure function curves separately for *u* and *v* component. After getting $\sigma^2_{\epsilon_i}$ and subsequently $\lambda^2$, the set of Eqn. (10) was formed and solved to get the weighting functions $P_i$ of the station *i*. Knowing the weighting functions, the anomalies at the grid points were computed as linear combination of anomalies at the surrounding stations giving appropriate weights to them. These anomalies were added to initial guess to get the analysed or interpolated value at the grid point.

**3. Data and computation**

3.1. *Data*

FGGE III b data set provided by ECMWF was based on large number of special observations made during SMONEX 1979 in addition to the routine conventional observations and so this is possibly the best data set prepared for the tropical regions. Hence we used for this study the FGGE III b wind field at 850 hPa at 12 UTC, grid size being 1.875 Lat./Long. The OLR data used are daily data from TIROS-N at 2.5 Lat./Long. grid. To match with the ECMWF grid, the OLR data were interpolated bilinearly to 1.875 Lat./Long. grid. The period chosen was 5 to 8 July 1979.

3.2. *Synoptic situation during the period of analysis from 5 July 79 to 8 July 79*

During this period, the main synoptic feature was the presence of monsoon depression over Bay of Bengal. This depression formed on 4/5 July 1979 and reached maximum intensity on 7/8 July 1979. It had a west of northwestward movement. The convective region was in the southwest sector of the depression. Our intension in this study is to examine whether the convective region/cloudy region are well depicted by the enhanced divergence field or the velocity potential field.

3.3. *Computation*

The computations and analyses were made for 5 days from 4 to 8 July 1979 as mentioned above. The level considered was 850 hPa and the time 12 UTC.

As mentioned earlier in Section 2, using wind data divergence *D* is computed. From divergence and OLR data the deviations of divergence, ($D'$) and deviation of OLR (OLR′) from their respective zonal means, $\overline{D}$ and $\overline{\text{OLR}}$ were computed.

Then we obtained the regional scaling factor, SCL, from Eqn. (2), using the OLR data and the divergence for the period from 4 to 9 July 1979 using least square method. The scaling factor for 850 hPa was determined to be $0.2 \times 10^{-7}\ \text{s}^{-1}\ \text{w}^{-1}\ \text{m}^2$. Divergence anomaly, $D'_s$, from OLR was obtained from Eqn. (2) and the resulting divergence anomaly $D'_e$ was obtained from Eqn. 4(a) and further the enhanced divergence was estimated from the Eqn. 4(b). Using this divergence, the velocity potential was computed by solving Eqn. (5) by over relaxation method and similarly using the vorticity, the stream function ($\psi$) was computed from Eqn. (6). The boundary conditions for solving Eqns. 5 and 6 follow :

$$\chi = 0$$
$$\psi_n = v_s - \chi_s$$
$$\psi_s = -v_n + \chi_n$$

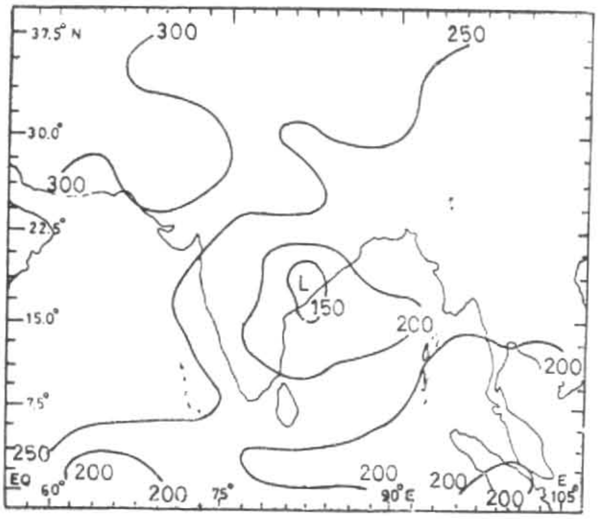



Fig. 1. Outgoing longwave radiation observed from NOAA Polar Orbital Satellite, 7 July 1979 (Units : w/m²)

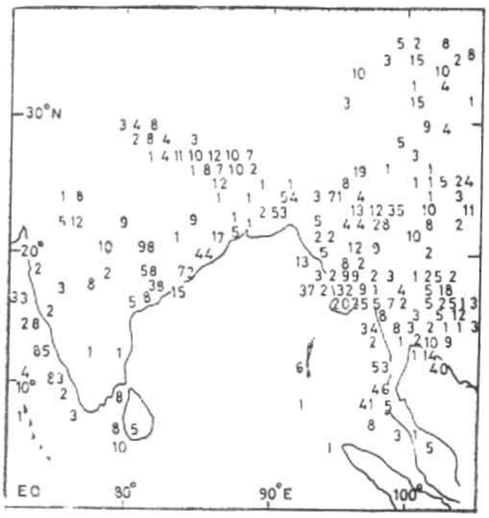
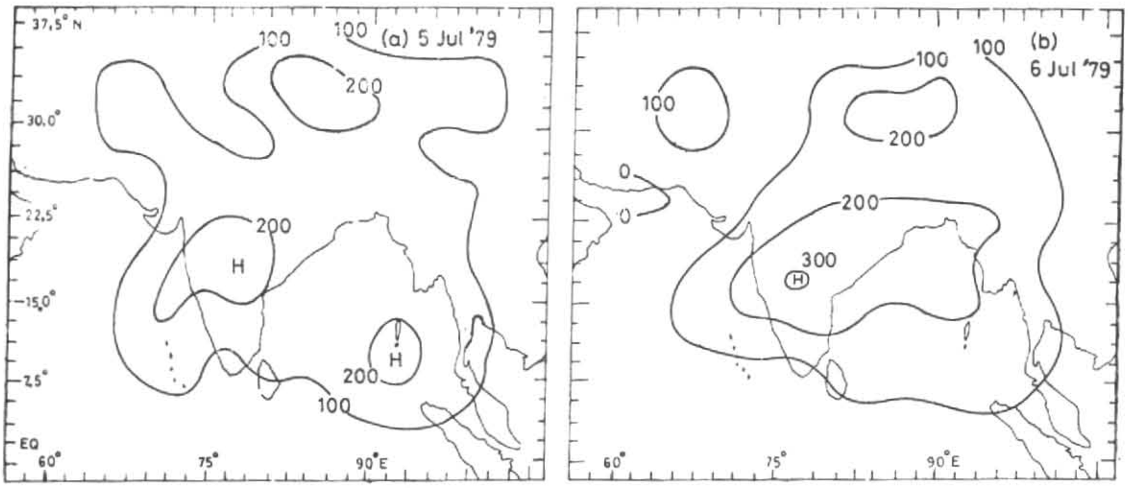



Fig. 2. 24 - hour rainfall (mm/day) ending at 00 GMT, 8 July 1979 (Rain Gauge Observations)




Figs. 3(a-b). Velocity potential computed from FGGE IIIb analysis at 850 hPa, (a) 5 July 1979, and (b) 6 July 1979, 12 UTC (Units : $10^4$ m² s⁻¹)

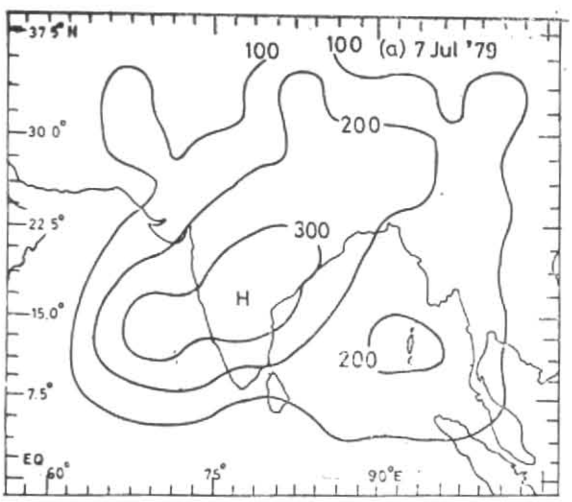



Fig. 4(a). Same as in Fig. 3(a) except for 7 July 1979

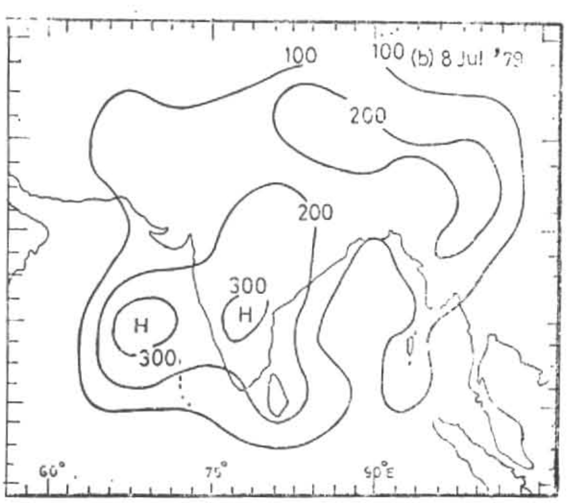



Fig. 4(b). Same as in Fig. 3(a) except for 8 July 1979

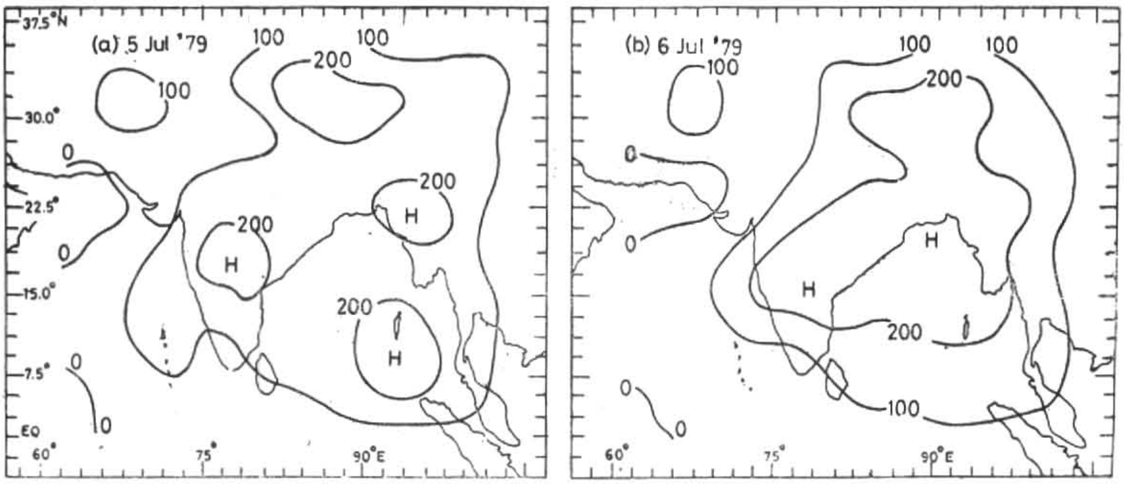



Fig. 5(a). Velocity potential computed from divergence modified by OLR at 850 hPa, 5 July 1979, 12 UTC (Units :$10^4$ $m^2$ $s^{-1}$)

Fig. 5 (b). Same as in Fig. 5(a) except for 6 July 1979

where, $\chi_s = \frac{\partial \chi}{\partial s}$

$$\chi_n = \frac{\partial \chi}{\partial n}$$

$v_s$ = velocity component along the boundary

$v_n$ = velocity component normal to the boundary

$n$ = outward drawn normal

$s$ = distance measured (counter clockwise positive) along the boundary

After obtaining the stream function and velocity potential we obtained the rotational and divergent parts of the wind and then the $u$ and $v$ components were obtained from Eqn. (9). These fields which included the enhanced divergent part, were used as initial guess for the analysis.

### 3.4. *Application of the scheme in objective analysis of wind field*

The major objective of meteorological data analysis is to obtain values of meteorological variables at regularly spaced grid points from randomly spaced observations. In this process use of physically consistent and reliable initial guess field is one of the most essential parts of the analysis scheme. The final analysis field is the result of a mixture of information from observations and from initial guess field. In order to improve the initial guess field, the divergent part of the wind field is included. The wind analysis were made for four days at 850 hPa at 12 UTC. Analyses were also made for the same period with initial guess field not containing the enhanced divergent part *i.e.* unmodified FGGE III b data. For examining the improvement, R.M.S. errors were calculated.

## 4. Discussion of the results

### 4.1. *OLR data, velocity potential and divergence*

Fig. 1 shows the Outgoing Longwave Radiation (OLR) data for 7 July 1979. It is interesting to compare this OLR pattern with 24-hour rainfall reported at 03 : 00 GMT on 8 July 1979. The depression in the head Bay of Bengal was very intense with its centre at 19.7° N, 89.0° E. The heavy rainfall region over the southwest sector of the depression (Fig. 2) compares very well with the region of minimum OLR representing low cloud temperatures or higher cloud tops in the region.

Figs. 3(a & b) and Figs 4 (a & b) depict the velocity potential computed from FGGE IIIb data for 4 days from 5 to 8 July 1979 and Figs. 5(a & b) and Figs. 6 (a & b) the velocity potential computed including the enhanced divergent part of the wind from OLR data. Comparing these two figures, one can easily infer that when the enhanced divergent part of the wind due to OLR was included in the computations, the magnitude increased. Also on 7 July 1979 when the depression was most intense, having maximum amount of convective activity, the velocity potential reached maximum in the southwest sector of the depression compared to the other days. The rainfall region (Fig. 2), agrees well with higher values of velocity potential or the region of inflow in both cases. The magnitude of the divergence ($\nabla . V$) field also was comparable in both cases Figs. 7 (a & b). The objective of this study has been to enhance the divergence of the wind field and this is being accomplished here.

### 4.2. *Assessment of the analysis*

The quantitative measure to test the analysis scheme is the root mean square difference statistics between the observations and analysis. Table 1 shows the root mean sq. (R.M.S.) error between observed value at the station and its interpolated value back from the surrounding grid points.

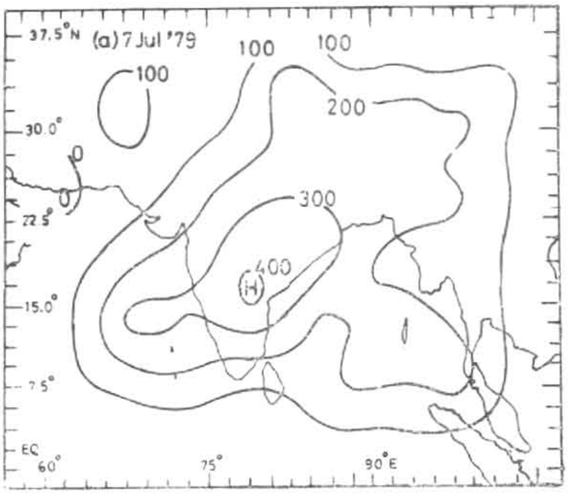



Fig. 6(a). Same as in Fig. 5(a) except for 7 July 1979

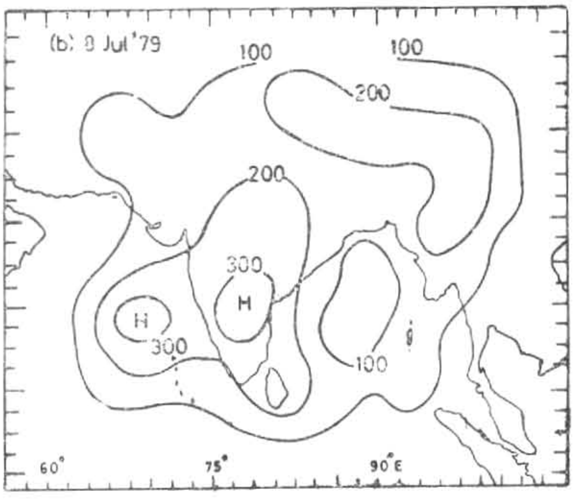



Fig. 6(b). Same as in Fig. 5(a) except for 8 July 1979

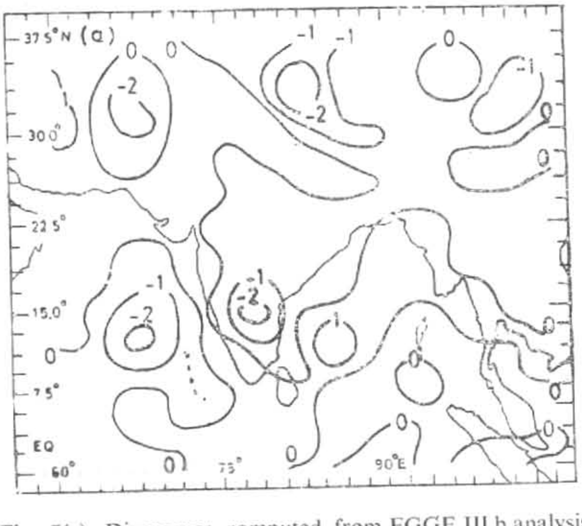



Fig. 7(a). Divergence computed from FGGE III b analysis for 850 hPa, 7 July 1979, 12 UTC (Units : $10^{-5}$ $s^{-1}$)

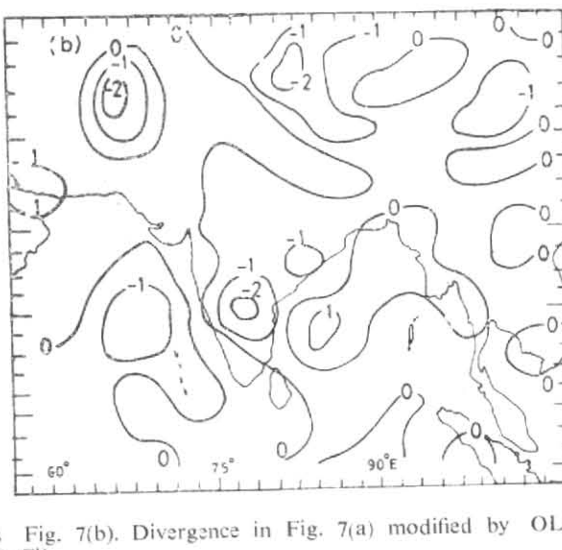



Fig. 7(b). Divergence in Fig. 7(a) modified by OLR

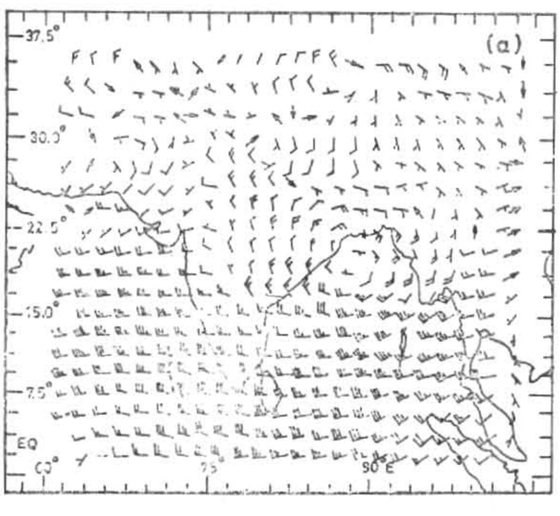



Fig. 8(a). Objective analysis of wind field at 850 hPa, 7 July 1979, 12 UTC with FGGE IIIb analysis as initial guess

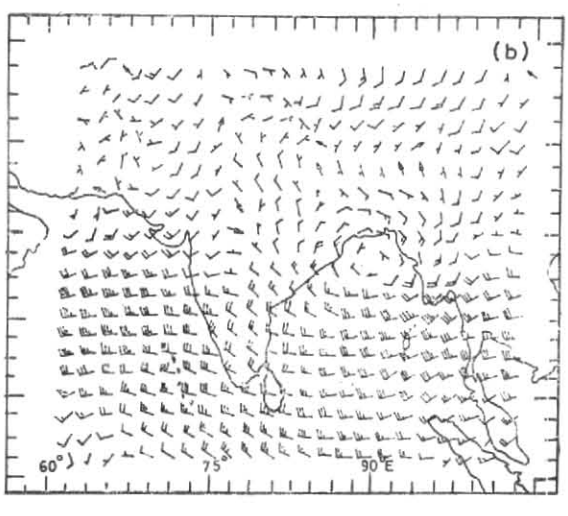



Fig. 8 (b). Same as in Fig. 8a except with FGGE IIIb analysis modified by OLR as initial guess

TABLE 1

**Root Mean Square Errors in m. p. s. (obtained by comparin g station observations) for analyses with and without OLR data**

| Date (Jul 1979) | | With OLR | Without OLR | RMS vector error | |
|---|---|---|---|---|---|
| | | | | With | Without |
| 5 | *u* | 3.79 | 3.39 | 4.92 | 4.65 |
| | *v* | 3.14 | 3.18 | | |
| 6 | *u* | 4.10 | 4.19 | 6.10 | 6.05 |
| | *v* | 4.53 | 4.36 | | |
| 7 | *u* | 4.35 | 4.45 | 5.76 | 5.81 |
| | *v* | 3.75 | 3.74 | | |
| 8 | *u* | 3.86 | 5.37 | 5.85 | 6.71 |
| | *v* | 4.40 | 4.03 | | |

The R.M.S. errors in Table 1 for the two sets of analysis with two different initial guess fields, one having the enhanced divergent part of the wind due to OLR and the other not having it, are comparable. In other words, both the analyses fit the observation with same degree of accuracy. Figs. 8 (a & b) show that the flow patterns are also similar in both cases. The centre of the depression depicted in the analysis when enhanced divergent part is included is closer to the centre, as reported by Indias Meteorological Department.

Although there is no dramatic inprovement in the wind field, the main feature is that the divergent part of the wind field from OLR is introduced in the analysed field.

**5. Concluding remarks**

Since the divergent part of the wind is important in tropical wind field, we formulated a scheme following Sumi *et al.* (1979) to enhance it from OLR data obtained from TIROS-N satellite. On introducing the divergent part of the wind, the velocity potential as well as the divergence field increased in magnitude in the region of convective activity. There was no conspicous improvement in the analysis of wind field, by way of reduction in R.M.S. errors etc. However, the enhanced divergent part of the wind has been included in the final analysis.

When the initial guess wind field contained the divergent part of the wind from velocity potential enhanced by OLR, the position of the centre of the depression was more realistic on all the days. The strength of the system produced by analysis is also reasonable. The results indicate that this technique performs reasonably well and it is fairly successful because it is able to produce realistic results.

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