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# Some experiments in the objective analysis of the wind-field over India and neighbourhood

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ABSTRACT. As a first step towards preparing input of wind observations for numerical weather prediction work in the Indian region, objective analysis of the wind-field has been made on a number of maps using a variation of Cressman's Scheme. The programme was executed on the CDC 3600 computer adopting a (53 × 17) grid in the region between 20° to 150°E and the equator to 40°N. The stream line patterns obtained by objective analysis for three maps are compared against conventional analyses. Vorticity patterns using the wind obtained from the objective analysis are presented. Root mean square error of the analysed winds, with reference to the station observations is found to be about 8 kt. The stream function patterns, as well as 500 mb 24 hours forecast based on non-divergent barotropic model with the objective and the subjective wind analysis as inputs, do not show any synoptically significant differences.

## 1. Introduction

A need for objective analysis has been recognised with the development of numerical weather prediction. This form of analysis not only avoids personal interpretation of the analyst, but also generates data from observations at equally spaced grid points, and speeds up the analysis through high speed computers.

Various methods of objective analysis have been suggested and tested by different workers in the last 20 years. They can be put in the following broad categories — (*i*) fitting a geometrical surface by polynomials, (*ii*) correction by weighted averages and (*iii*) optimal interpolation.

Surface fitting technique by the method of least squares was first proposed by Panofsky (1949). Variations of this method were attempted by Gilchrist and Cressman (1954), Cressman (1957), Johnson (1957) Bushby and Huckle (1957) and Pfeffer *et al.* (*see* Ref.) . However, this method requires dense data coverage and is generally unsuitable for regions of spares data, such as the tropics. Gandin (1963) suggested a statistical procedure which uses optimal interpolation between the observed values and the climatological values so that errors in the least square sense are minimised. Variations of this method have been attempted by Mashkovich (1964) and Fujiwara and Sagasaki (1966).

Bergthorssen and Doos (1955) first suggested an average correction method by a non-iterative procedure. The basic method was later adopted by Cressman (1959) in an iterative scheme. According to the periodic reports of the World Meteorological Organisation on Numerical Weather Prediction, Cressman's method with suitable variations have been adopted by many meteorological services in their operational objective analysis schemes. Cressman originally employed his method to analyse the contour height field. He had, however, suggested that direct wind analysis could also be made with the same method by resolving the vector wind into $u$ and $v$ components. Different workers have applied Cressman's method for objective wind analysis over extensive areas in the tropics (Yanai 1964; Bedient and Vederman 1964; Shumbera 1966 and Bedient, Collins and Dent 1967). Extensive use of the method is due not only to its flexibility, simplicity of approach, inexpensive use of machine time but also for its suitability in data sparse regions. The method uses a first guess field over all the grid points, and this is subsequently improved by using the data over observing stations. We thought it appropriate to test the Cressman's method and examine its applicability over the Indian region. This region has several data holes due to its geographical location.

## 2. Details of the method applied

In the present study, we have attempted to apply Cressman's method over an area from equator to 40°N and 20°E to 150°E using the first guess to the analysis the previous synoptic hour subjective stream-line-isotach analysis from which the grid point values were obtained by eye estimation. Fig. 1 shows the distribution of wind reporting

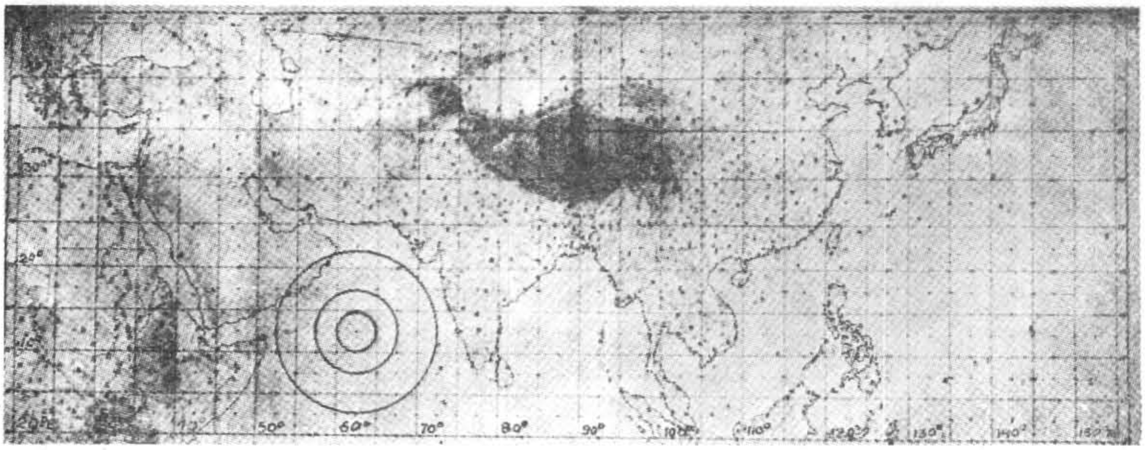



**Fig. 1. Network of wind reporting stations and the grid points**

Solid circles are radiowind/radarwind stations, open circles are pilot balloon stations and cross marks are grid points. The inset concentric circles in the Arabian Sea show the areas examined on each scan

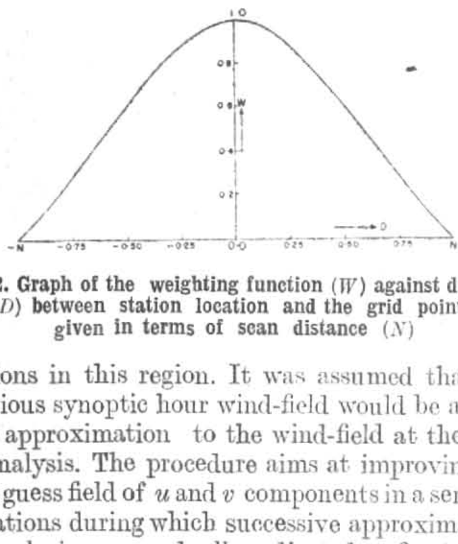



**Fig. 2. Graph of the weighting function ($W$) against distance ($D$) between station location and the grid points, given in terms of scan distance ($N$)**

stations in this region. It was assumed that the previous synoptic hour wind-field would be a good first approximation to the wind-field at the time of analysis. The procedure aims at improving the first guess field of $u$ and $v$ components in a series of iterations during which successive approximations to analysis are gradually adjusted to fit the data of observed winds at reporting stations. The following weighting function, of the same form as used by Cressman, was assigned to each iteration :

$$W = \frac{N^2 - D^2}{N^2 + D^2} \text{ for } D \quad N \text{ and } W = 0 \text{ for } D = N$$

where $N$ is the radius of influence (scan distance) and $D$ is the distance between station location and the grid point. Fig. 2 shows the graph of the weighting function with distance. The scan distance for each iteration defines the lower limit to the analysis scale. The analysis was commenced with the highest $N$ value appropriate to the maximum analysable scale depending upon the data density. Successively lower values of $N$ were then used for each iteration to adjust the analysis to the smaller scales. The analysis proceeds from grid point in each iteration. If there are $n$ observations within a radius $N$ of the grid point in a particular iteration the new approximation of the wind component at the grid point for that iteration is computed as follows :

$$u_g\,(\text{new}) = u_g\,(\text{old}) + \sum_{i=1}^{n} C_u\, W_i \Big/ \sum_{i=1}^{n} W_i$$

$$C_u = u - u_i$$

where $u_g$ (new) and $u_g$ (old) are the new and the previous values of the $u$ component at the grid point, $u$ and $u_i$ are the actual station observation and its interpolated value from the nearby grid points respectively. $C_u$ is the correction to the station observation and $W_i$ is the weight for the station observation appropriate to the scan distance. A similar analysis is performed for the $v$ components separately. The $u$ and $v$ components at the end of the last scan are then combined to get the wind vector at the grid points. For the preliminary results being reported here, we have experimented with three scan distances, *viz.*, 4·0, 2·0 and 1·0 times the grid length which was taken as 2·5° of latitude. The reporting stations in the area of analysis have been indexed according to the station identification numbers and a dictionary of the station numbers and their corresponding latitude and longitude have been prepared. Linear interpolation has been used in the present study to get the station wind from the values at nearby grid points. In order to test the efficiency of the method, the root mean square error between reported winds at the stations and their current interpolated value from the nearby grid points is printed out at the end of each iteration. The most effective scan distance can thus be judged from this statistics. Te output of the analysis programme consists of computed winds at all grid points, error statistics

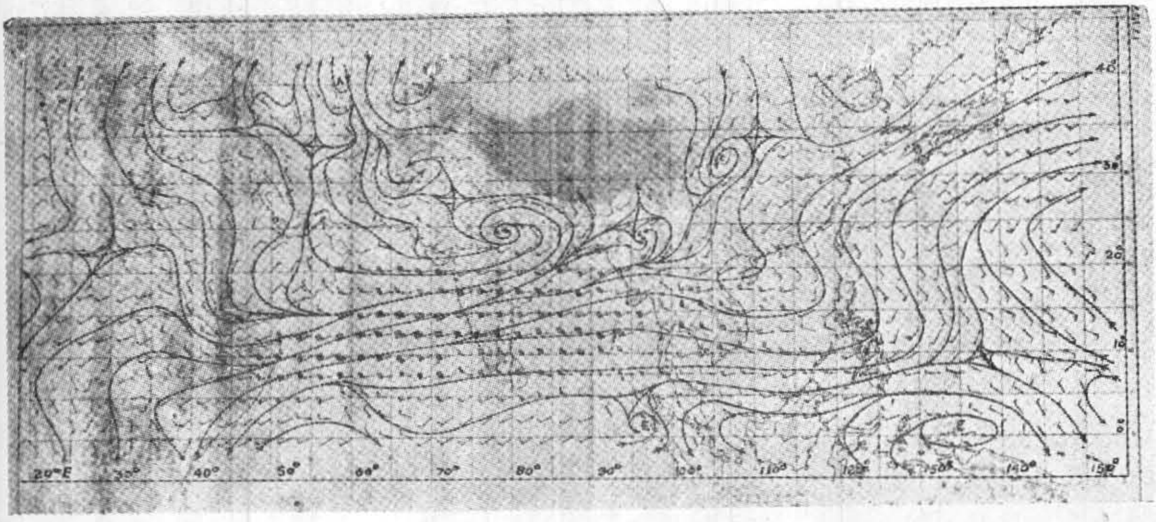


Fig. 3 (a). Objective wind analysis

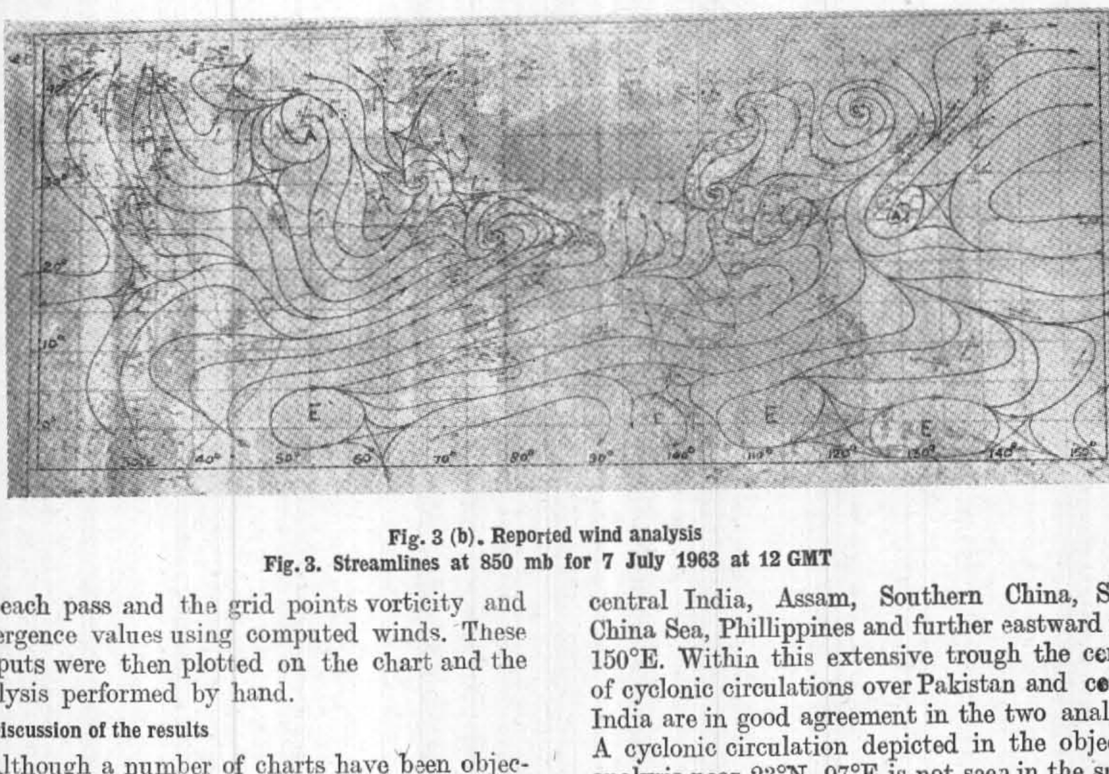


Fig. 3 (b). Reported wind analysis
Fig. 3. Streamlines at 850 mb for 7 July 1963 at 12 GMT

for each pass and the grid points vorticity and divergence values using computed winds. These outputs were then plotted on the chart and the analysis performed by hand.

## 3. Discussion of the results

Although a number of charts have been objectively analysed only three of them are presented here for want of space. For comparison conventional subjective analyses for the same cases are also presented.

3.1. *Case 1: 850 mb chart for 7 July 1963* (12 *GMT*) — The stream lines for the objective and subjective wind analyses are shown in Figs. 3(a) and 3(b) respectively.

There is a good agreement in the two analyses with regard to the position of the trough line through east coast of Arabia, West Pakistan, central India, Assam, Southern China, South China Sea, Phillippines and further eastward upto 150°E. Within this extensive trough the centres of cyclonic circulations over Pakistan and central India are in good agreement in the two analyses. A cyclonic circulation depicted in the objective analysis near 23°N, 97°E is not seen in the subjective version as the available data suggests only well marked trough whose position is about 2° south of the position in the objective version in the same area.

The position of the sub-tropical ridge line over West Pacific Ocean and Eastern China running along about 25°N is in good agreement in the two analyses. But within the ridge line, two anticyclonic centres shown in the subjective analysis near 25°N, 117°E and 25°N, 130°E are not depictable in the objective analysis though the isotach

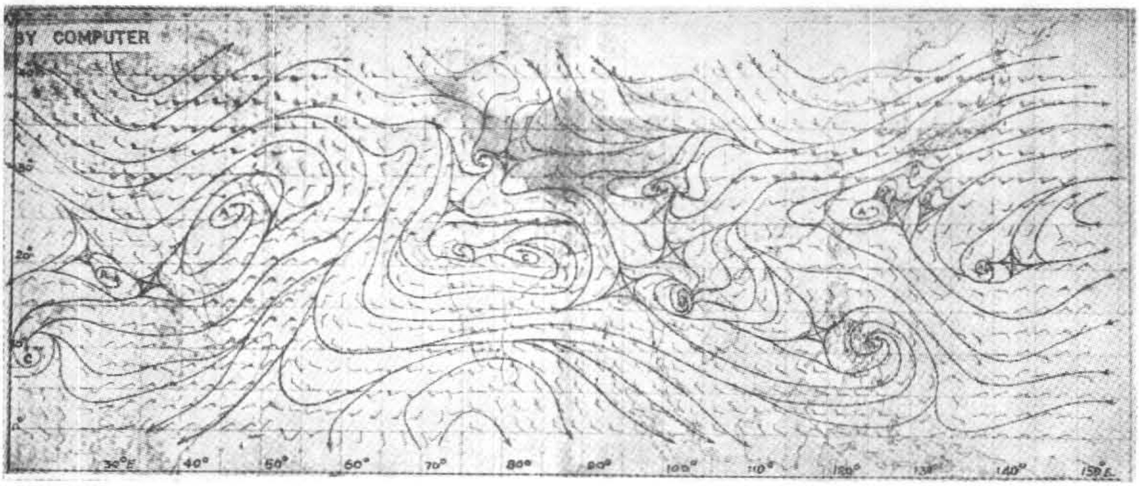



Fig. 4(a). Streamlines of objective wind analysis at 500 mb for 7 July 1963 at 12 GMT

field in the latter has a minimum in the respective areas. It is worth mentioning that the analysis from which the first guess field was derived did not show these anticyclonic cells in the ridge. Evidently the objective analysis maintained a bias towards the first guess field due to data sparsity and weaker wind regimes in the area.

The subjective analysis depicts an anti-cyclonic circulation centred near 36°N, 55°E which seems to have been displaced NE-wards in the objective version. The agreement of the ridge line in the two versions over Iran, Arabia and adjoining regions although generally satisfactory is not exact at places.

The two analyses agree well with regard to centering of the cyclonic circulation near 32°N, 107°E. The trough in the westerlies along about 40°E is in fair agreement in the two versions. However, the subjective analysis shows southward extension of that trough up to 30°N whereas it seems to extend up to 35°N in the objective version. The subjective analysis shows a cyclonic circulation near 37°N, 125°E which is shown as a well-marked trough in the westerlies in the objective analysis with a possible centre near 37°N, 123°E.

The stronger as well as the weaker wind speed regimes in the SW monsoon over the Arabian Sea, India and Bay of Bengal are generally in good agreement in the two analyses. However, the objecttive version shows sudden weakening in the westerly winds near about 10°N and 97·5°E.

3·2. *Case 2: 500 mb chart for 7 July 1963 (12 GMT)* — Figs. 4(a) and 4(b) show the stream lines for the objectively and subjectively analysed winds. There is a good agreement between the objective analysis and the subjective analysis with regard to the location of the monsoon trough over India and the trough over Southeast Asia and Phillippines region. The centres of cyclonic circulation within the trough over Gujarat, east Madhya Pradesh, Thailand are also in agreement. The cyclonic circulation centred near Phillippines in the objective version is placed somewhat eastward in the subjective version.

Location of the sub-tropical ridge line running from Africa to Arabia, Iran, Afghanistan and Tibet is also generally in good agreement in the two versions. The agreement in the location of the ridge line over the West Pacific Ocean is satisfactory. The anticyclonic circulations over Arabia, Tibet and Assam shown in the objective analysis could not be put in the subjective analysis for want of data. The anticyclonic circulation near Rykyu Islands shown in the subjective analysis as a single cell, is seen in the form of three feeble cells in the objective analysis. There is also dissimilarity between two versions of the analysis with regard to the ridge associated with the Rykyu Islands anticyclonic circulation. In the subjective analysis the ridge runs NW/SW from Rykyu Islands towards the South China Sea region whereas the objective analysis puts the ridge in E/W orientation towards Eastern China. This is due to the objective analysis having a bias towards the first guess field in the data sparse regions. The ridge line in the West Pacific which runs from about 26°N, 150°E to about 20°N, 135°E is shown in the subjective analysis to run from along 27°N in the same longitudinal belt. The subjective analysis also shows another ridge along 5°N east of 150°E and a

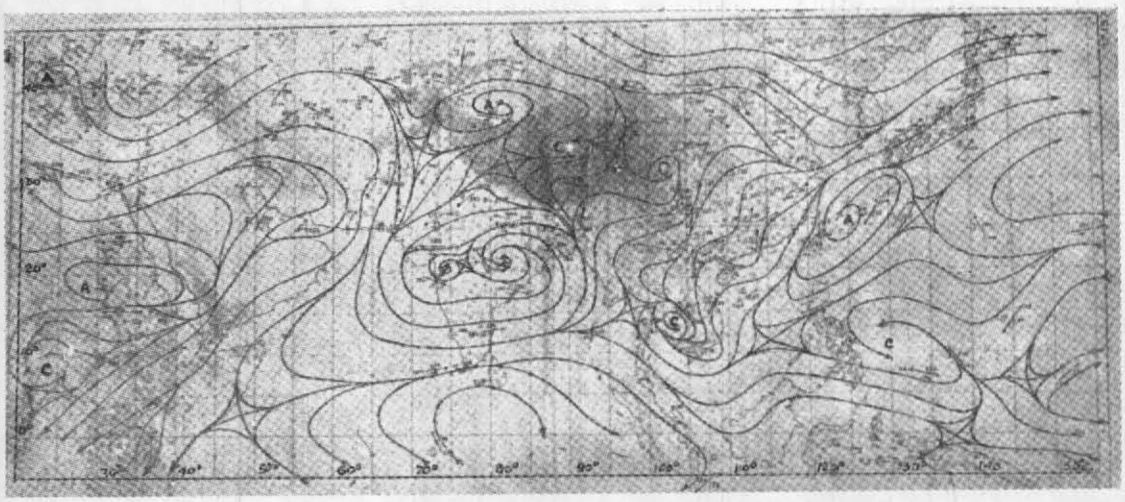


Fig. 4(b). Streamlines of reported winds at 500 mb for 7 July 1963 at 12 GMT

trough line in between the two ridges which have not been brought out in the objective analysis.

In the case of troughs in westerlies there is a good agreement between the two analyses with reference to the trough along 35°E but the trough shown along 125°E in the subjective analysis, is displaced about 2-3° to the west in the objective analysis. The subjective analysis shows a minor trough from 40°N to 35°N along about 70°E which is not shown in the objective analysis. A cyclonic circulation with centre near 31·5°N, 77°E shown in the objective version does not appear in the subjective one.

With regard to the speed field over the data regions positioning of the region of 15 to 20 kt strong winds over India is in good agreement. Same is the case with regard to the stronger regime of winds over Arabian coast. The speed maxima shown over other regions are also in satisfactory agreement.

3.3. *Case 3 : 500 mb chart of 25 March 1967 (00 GMT)* — The objective and subjective wind analyses are shown in Figs. 5(a) and 5(b) respectively. The position of the sub-tropical ridge line is in close agreement between the subjective and objective analysis. The positions of the anticyclones over Africa and Western Pacific are also in agreement. The anticyclonic cell which lies in the subjective analysis over south off Vietnam (near 7°N, 105°E) is shifted a little NE-wards in the objective analysis (near 10°N, 107°E). It may be mentioned that the first guess field also showed this anticyclonic cell NE-ward of the current subjective analysis. Wind changes from the previous synoptic observations being small in the area, the current objective analysis maintained the bias to the first guess. The anticyclonic cells near 10°N, 68°E and 16°N, 120°E, shown in the subjective analysis could not be depicted in the objective analysis. This has been also due to the objective analysis having a bias to the first guess field which did not show these anticyclonic cells.

In the belt of westerlies, good agreement exists between the two analyses in the placement of cyclonic circulation to the east of the Caspian Sea and the associated trough running towards northwest India. The zone of diffluence over northwest India is also in good agreement between the two versions though the wind strength over Kashmir is somewhat weaker in the objective version.

Both the analyses also agree well with regard to the general location of the belt of maximum winds although individual maxima at a few places are not in exact agreement. The zone of the weaker winds over Tibetan region is in fairly close agreement. However, the winds analysed by the machine over Mediterranean region are somewhat weaker than shown in the subjective analysis.

#### 4. General remarks and error statistics

The objective analysis over portions of Africa, Arabian Sea, Bay of Bengal and West Pacific Ocean is unable to alter the first guess winds due to data sparsity over these regions. This is a serious handicap if the previous synoptic analysis is used as the first guess. Therefore, to allow for a change in the analysis from one synoptic hour to the other over such data poor regions, it would be preferable to use the forecast winds as the first guess field. However, in good data regions the adjustment in the

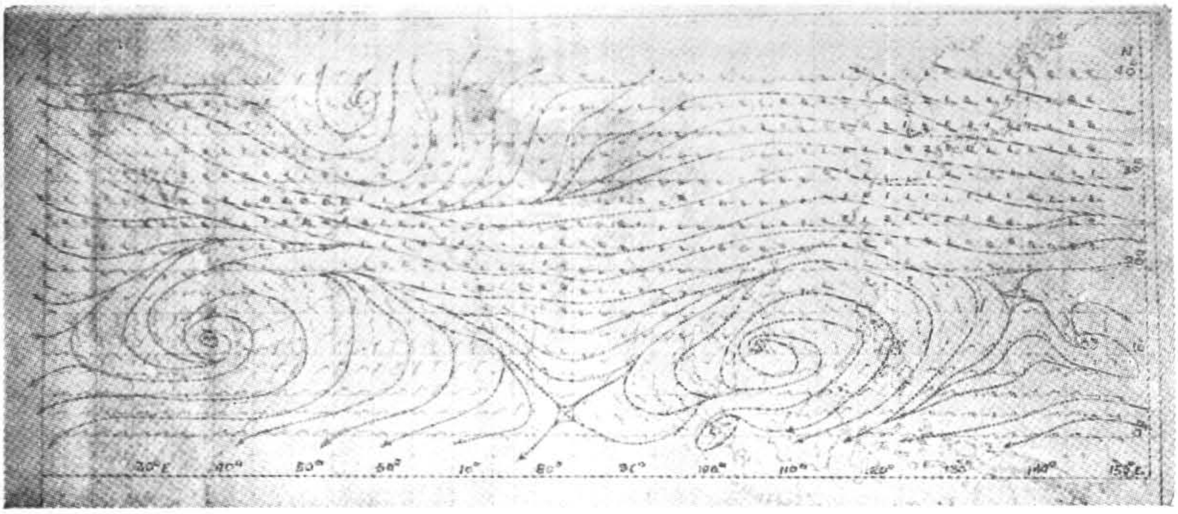


Fig. 5 (a). Objective wind analysis

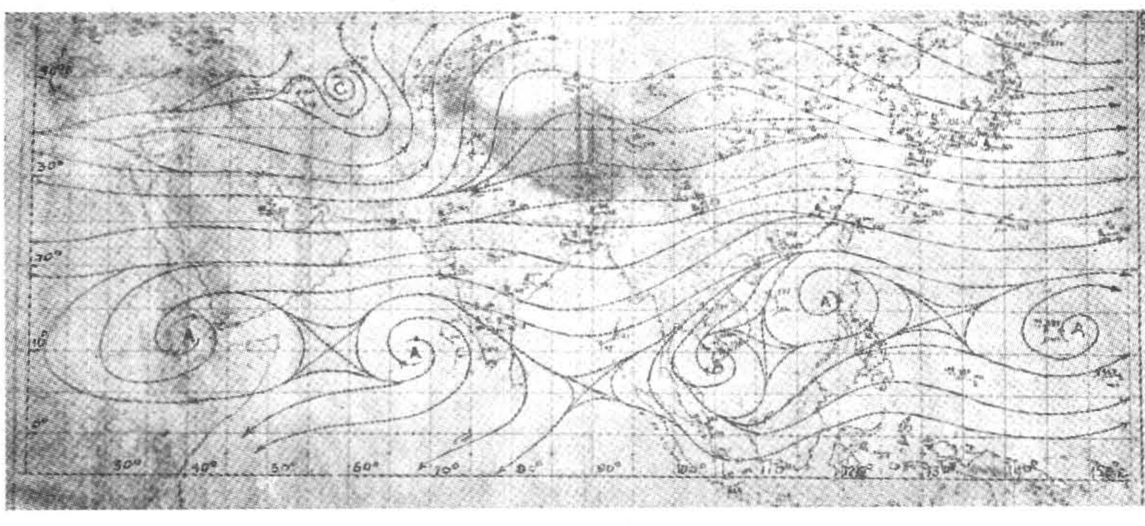


Fig. 5 (b). Reported wind analysis

Fig. 5. Streamlines of objective/reported winds at 500 mb for 25 March 1967 at 00 GMT

machine analysis are quite satisfactory even if the previous synoptic analysis is used as the first guess.

Root mean square errors prior to the commencement of each scan and also at the end of the third scan for the three cases under discussion are shown in Table 1. It is seen that the last scan is most effective in adjusting the analysis to the observations. The root mean square error (R.M.S.) of the objective analysis over the area under discussion is about 8 kt. The magnitude of the error is comparable to the results reported in tropical areas by Bedient and Vederman (1964), and Shumbera (1967).

In the present study trials were also conducted using the analysed winds as the first guess and repeating the analysis process once again but the R.M.S. error was not reduced.

#### 5. Vorticity and divergence computations

Vorticity and divergence fields computed from the objectively analysed winds have been examined. The relative vorticity maps are shown in Figs. 6(a), 6(b) and 6(c) respectively for the cases under discussion. The vorticity field is quite smooth and of acceptable magnitude over good data regions. However, over the data poor regions equatorward of 10°N a few points on each chart

**TABLE 1**

**Root mean square error between the actual station wind and the interpolated winds from the objective analysis**

| Case No | Root mean square errors (kt) | | | |
|---|---|---|---|---|
| | Prior to 1st scan | Prior to 2nd scan | Prior to 3rd scan | After 3rd scan |
| *Case 1* : 850-mb chart | | | | |
| 7 Jul 1963 (12 GMT) | 12·9 | 13·0 | 12·5 | 8·4 |
| *Case 2* : 500-mb chart | | | | |
| 7 Jul 1963 (12 GMT) | 13·3 | 13·3 | 12·6 | 7·9 |
| *Case 3* : 500-mb chart | | | | |
| 25 Mar 1968 (00 GMT) | 15·7 | 15·5 | 14·8 | 8·6 |

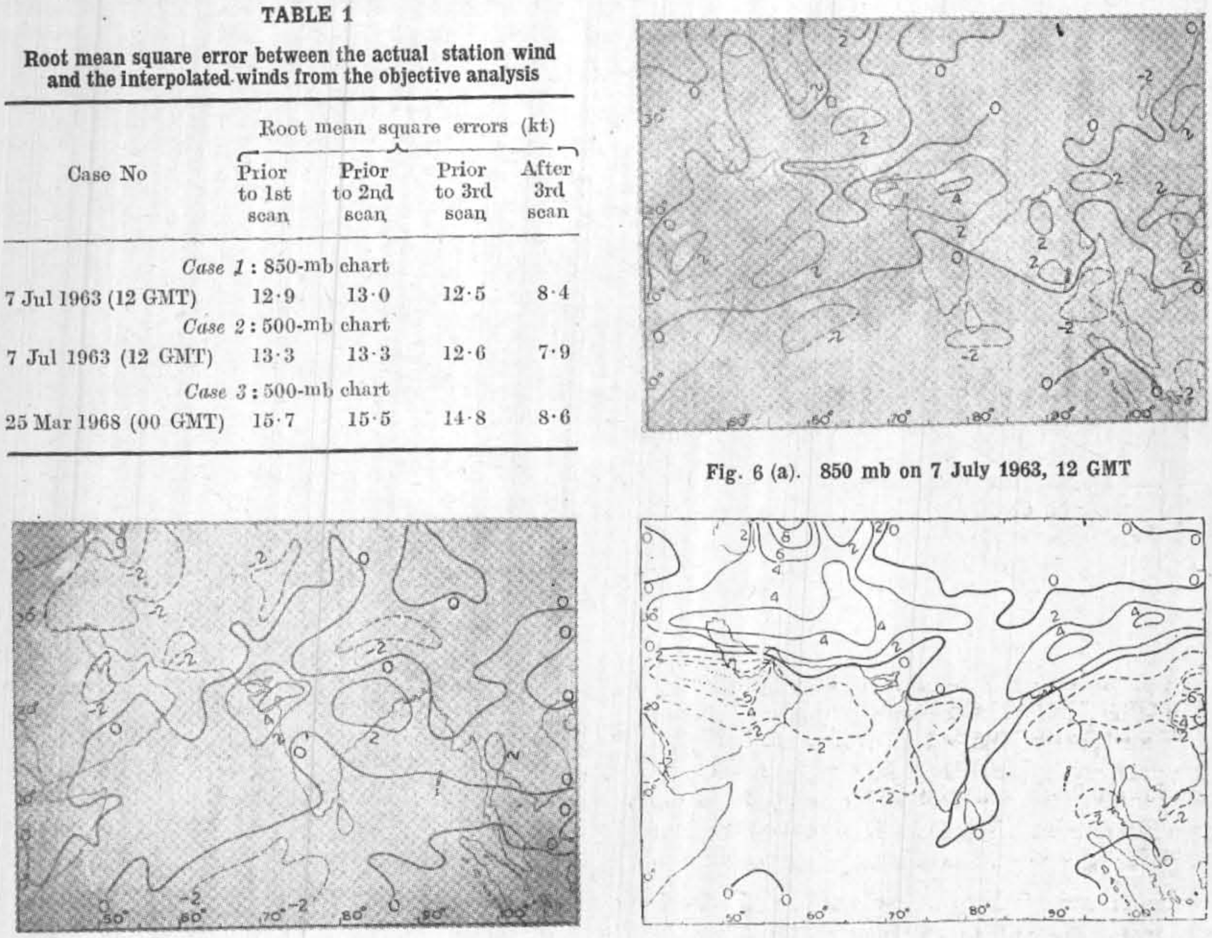


Fig. 6 (a). 850 mb on 7 July 1963, 12 GMT

Fig. 6 (b). 500 mb on 7 July 1963, 12 GMT

Fig. 6 (c). 500 mb on 25 March 1967, 00 GMT

Fig. 6. Relative vorticity ($10^{-5}$/sec)

have negative absolute vorticity. The limitation of the computed divergence from direct winds being well known, these maps are not presented here.

#### 6. Stream function computation

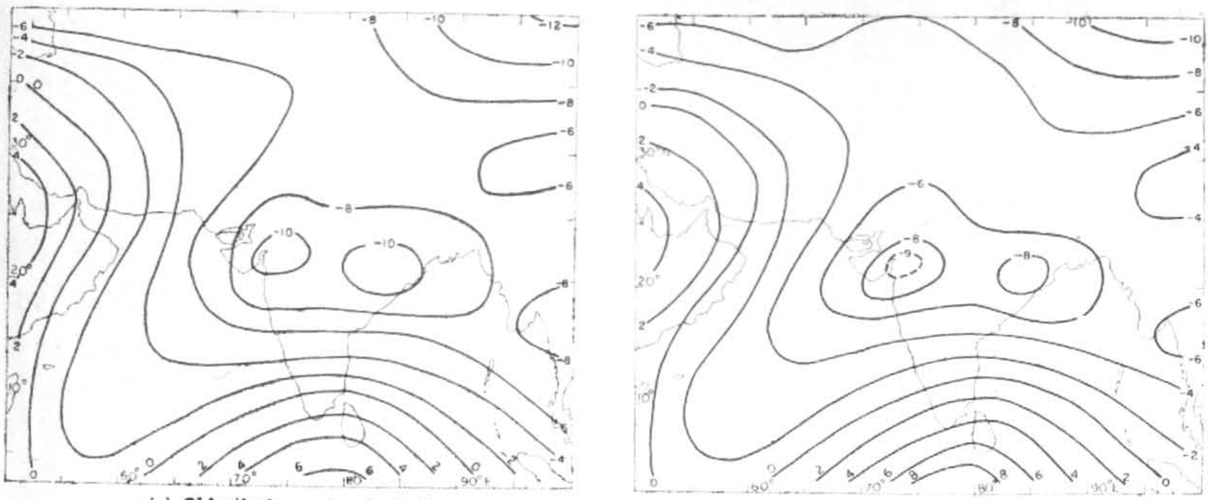
The stream function fields as obtained from the objectively analysed and hand analysed winds by solving the equation $\zeta = \nabla^2\psi$ ( $\zeta$ is relative vorticity and $\psi$ is the stream function) for 500 mb chart for 7 July 1963 (12 GMT) are shown in Figs. 7(a) and 7(b) respectively over a restricted area between 2·5°N to 40°N and 50°E to 100°E. The boundary conditions used for solving the above equation are as suggested by Miyakoda (1960) and the details of the computations are the same as given by Shukla and Saha*. The patterns in the two stream function fields are in good agreement. The positions of the monsoon trough and the subtropical ridge to the north agree in both the cases. Within the monsoon trough the centres of two cyclonic circulations over India are seen in both the analyses though in the objective analysis the centres are about a degree to the west of the respective positions in the hand analysis.

The two stream function fields were also used as input separately for the barotropic model being tested by Shukla and Saha (*loc. cit.*). The forecasts obtained by the two inputs did not show any synoptically significant differences. Actually very little chahge took place during the forecast period and also small changes were indicated by the barotropic forecast. Further testing of the barotropic model with the objective wind analysis as input is planned.

#### 7. Conclusion

The results of the preliminary experiments with Cressman's method o objective wind analysis over the area under discussion are quite encouraging. The agreement between the objective analysis and subjective analysis is closer over data rich regions than over data poor regions. Over some parts of

*"Forecasting flow patterns in the Indian region with barotropic model, by J. Shukla and K. R. Saha, Pre-publ. Sci. Rep., 84, 1968, India met. Dep.



(a) Objectively analysed winds (b) Hand analysed winds

Fig. 7. Stream function field of winds at 500 mb on 7 July 1963 at 12 GMT

(Units : $10^{10}$ cm²/sec)

the oceanic regions devoid of practically any data, the first guess field remains unaffected at the end of the routine analysis. Similar difficulties are also reported by Holopainen (1968). The stream function map for one situation derived from the objective analysis and the hand analysis shows similar patterns at 500 mb and the non-divergent barotropic forecasts based on these initial data separately also do not reveal synoptically significant differences with respect to each other.

8. Acknowledgements

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