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An experiment in objective analysis for 500 mb

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ABSTRACT. The present report gives the results of an experiment in objective analysis with Indian data. The technique is similar to Cressman's method, with an additional check for horizontal consistency of data.

The average of 5-day normals and the previous 24-hr forecast were used as the first-guess field. The first-guess was then improved with the available current data by using suitable weighting factors.

The results of using successive scans of radius 5, 10 and 15 degrees (latitude/longitude) are presented in this report.

1. Introduction

In objective analysis we are concerned with the problem of generating data at grid-points from irregularly spaced observations. Research on this subject has followed two broad lines of approach. On the one hand, polynomials have been fitted to observed data by the method of least squares, and grid point values have been obtained from these polynomials. This technique was designed by Panofsky (1949) and subsequently used with modifications by Gilchrist and Cressman (1954), Johnson (1957) and others.

Bergthorssen and Döos (1955) suggested a different approach. A first-guess field was first prepared with the help of a number of predictors, such as, the previous day's forecast and climatological normals. Subsequently, the first-guess field was improved by using the latest observations. Cressman (1959) designed a convenient system of weighting factors for this purpose. A useful horizontal check for the consistency of data was devised with the help of similar weighting factors by Masuda and Arakawa (1960).

In this paper, we present the results of an experiment based on the latter technique. We used this method because there are two large data holes adjoining the Indian region. We refer to the Arabian Sea on the west and the Bay of Bengal to the east. The regions adjoining Pakistan, Iran and Iraq form yet another region of sparse data. In such regions where data are difficult to come by it is difficult to fit polynomials with reasonable confidence. On the other hand, climatological normals provide one with some basis, albeit unsatisfactory, for a first-guess field. We felt, therefore, it would be preferable to conduct this pilot study with a first-guess and subsequent corrections, although it was realised that success would depend on how good the first-guess was in reality.

2. Analysis of data

2.1. *The first-guess field* — On the basis of experience gained in day-to-day subjective analysis, we took the first-guess to be the mean of 5-day normal of the 500-mb contours and the 24-hr forecast of the previous day. Five-day normal, which is a short term mean based on 5 years of data provides a good tool for creating data over the areas of sparse network. The previous day's 24-hr forecast also enables one to maintain continuity with the earlier analysis.

2.2. *Horizontal check for data* — It was soon realised that before we could use raw data from teleprinter tapes, some form of horizontal check for internal consistency would be necessary.

For this purpose, we compared the 500 mb reported height with a weighted mean value from all neighbouring stations lying within a circle of radius 10° latitude or longitude. If the difference between the reported height and the weighted mean exceeded a certain value, then the reported value was considered to be in error and rejected. More specifically, we adopted the following procedure.

Let Z represent the 500-mb height reported by a station, and Z_i are the heights reported by neighbouring stations situated at distances R_i from Z. We compute the mean value of Z_i and R_i by —

$$\overline{Z} = [\sum_{i=1}^{n} W_i \; Z_i \;] \;/\; [\sum_{i=1}^{n} W_i] \qquad (2\cdot1)$$

$$\overline{R} = [\sum_{i=1}^{n} W_i \; R_i] \;/\; [\sum_{i=1}^{n} W_i] \qquad (2\cdot2)$$

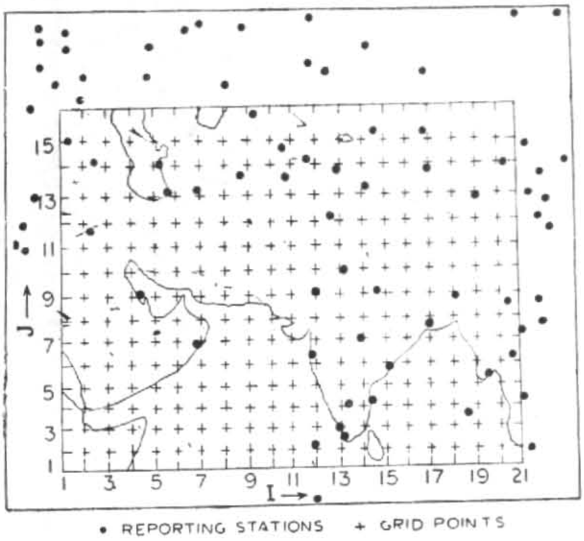

Fig. 1. The distribution of reporting stations and grid points

The weighting factor W_i is,

$$W_i = (N^2 - R_i^2) \, / \, [N^2 + R_i^2] \qquad (2\cdot3)$$

where N is the distance at which the weighting factor is zero. In actual practice, we found it necessary to take N as the distance at which W_i is approximately 10^{-5}, *i.e.*, an extremely small positive value.

It is to be noted that the weighting factor is not entirely empirical. It is a parameter designed to give the highest weightage to observations nearest to the grid-point, and the least weightage to data which are farthest away from the grid-point, as defined above and also used subsequently in Section 3. In this respect it acts as a band-pass filter which preserves the features revealed by the nearest observations, but does not take much notice of distant stations.

After computing $\overline{Z}$, we evaluate

$$\triangle Z = | Z - \overline{Z} | \qquad (2\cdot4)$$

$$\text{and} \quad \triangle Z_c = \triangle Z_p \times \overline{R} \qquad (2\cdot5)$$

where $\triangle Z_p$ is a permissible mean error between two observing stations separated by a distance of 100 km. We thus see that $\triangle Z_c$ is a measure of the permissible error at a grid-point taking into account the influence of all stations within a circle of radius $\overline{R}$. If $\triangle Z$ is greater than $\triangle Z_c$ then we infer that the reported height exceeds the weighted mean of all neighbouring stations by the permissible error. The observation is, therefore, rejected. For the purpose of this study we took $\triangle Z_p$ to be 15 gpm.

As pointed out by Masuda and Arakawa (*loc. cit.*), it is possible for erroneous data reported in the neighbourhood to cause the rejection of correct reported data. Thus, a gross error will be reflected in the calculated value of $\overline{Z}$ which in turn, may affect $\triangle Z$. To avoid such a situation two scans were made. The reported data which do not pass the first scan were separated from the rest. In the second scan these separate points were re-checked with respect to those which were declared as passed in the first scan. If the difference was still greater than $\triangle Z_c$ the reported values were rejected.

3. Objective analysis

The distribution of reporting stations and the grid selected for study is shown in Fig. 1. The grid consists of 21 × 16 nodal points with a unit grid length of 300 km. After the horizontal check, the analysis is performed in a series of scans over the field. In each scan, the grid-points were considered one by one and the first-guess field was improved by applying corrections based on values observed at reporting stations.

We considered stations which report both wind and height or only height. Stations which report only the wind observations were not considered in this study. Thus, for stations which report only the 500-mb height we have, initially, (*i*) a first-guess field from which we can interpolate a value Z_M corresponding to the station and (*ii*) the reported height, say, Z_o, at the station. From this basic information we work out a correction term for each grid-point adjoining the reporting station. The correction term is —

$$\triangle Z_H = - W \, (Z_M - Z_o) \qquad (3\cdot1)$$

where Z_M is the interpolated guess field and Z_0 is the height reported by the station. The weighting factor is defined by (2·3).

For stations which report both wind and height, a similar correction term $\triangle Z_V$ is computed for all nearby grid-points. This correction term (Cressman 1959) is

$$\triangle Z_V = W \, [Z_o + \frac{kf}{mg}(v \triangle x - u \triangle y) - Z_F] \qquad (3\cdot2)$$

In equation (3·2), u, v are respectively the eastward and northward components of the reported wind, f is the Coriolis parameter and $\triangle x$, $\triangle y$ represent the distance between the reporting station and the grid-point along the X and Y axes respectively. We represent the first-guess field at the grid-point by Z_F and k is a constant to express the ratio of the geostrophic to the actual wind. In this study we put $k = 0\cdot80$.

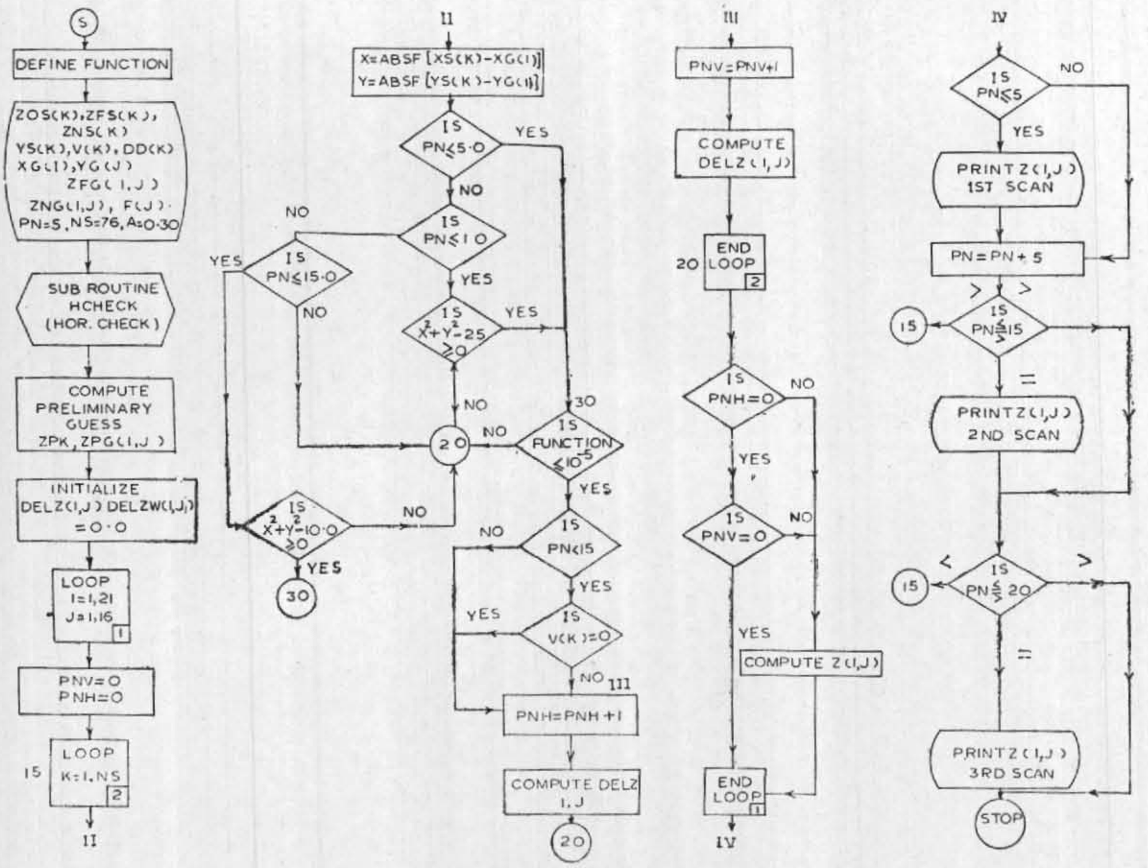

Fig. 2. Flow diagram for objective analysis

It will be observed that the factor kf/mg is a function of latitude only. It was, therefore, calculated at the beginning for all latitude belts and introduced as input data in the computer programme.

When all data within a radius N from the grid-point have been scanned each reporting station yields a contribution to either $\triangle Z_H$ or $\triangle Z_V$. The final correction $\triangle Z$ that is applied at each grid-point to the first-guess is given by —

$$\triangle Z = \frac{A \Sigma \triangle Z_H + \Sigma \triangle Z_V}{AN_h + N_V} \qquad (3\cdot3)$$

where N_h & N_V are the number of $\triangle Z_H$ and $\triangle Z_V$ corrections. A is a constant factor to give weightage to the lateral gradient of the first-guess. In this study we have put $A = 0\cdot30$.

It may thus be observed that in each scan we determine the correction for each grid point within a radius N of a reporting station. For the first scan we took N to be 5 degrees. Subsequently for the second and third scans $N = 10$, 15 degrees respectively. For the first and second scans we have used both height and wind data, while for the third scan only height data were used.

4. Flow diagram for objective analysis

In Figs. 2 and 3 we present flow diagrams for objective analysis and horizontal check respectively.

The main details of the programme are as follows.

(*i*) *Input* — This consists of the following information:

(*a*) The latitude and longitude of observing stations and grid-points,

(*b*) 500-mb observed heights,

(*c*) Observed wind speed and direction and

(*d*) The first-guess for Z at each observing station and grid-point.

(*ii*) *Variables* — The following variables have been introduced in the programme:

(*a*) ZOS (K)	This is the observed height at each station.
(*b*) V(K), DD(K)	Observed wind speed and direction.
(*c*) XS(K), YS(K)	Geographical coordinates (longitude and latitude) of reporting stations.
(*d*) ZFS(K), ZNS(K)	Previous day's forecast and 5-day normal height at each reporting station.
(*e*) ZFG(I, J), ZNG (I, J)	Previous day's forecast and 5-day normal height at each grid-point.

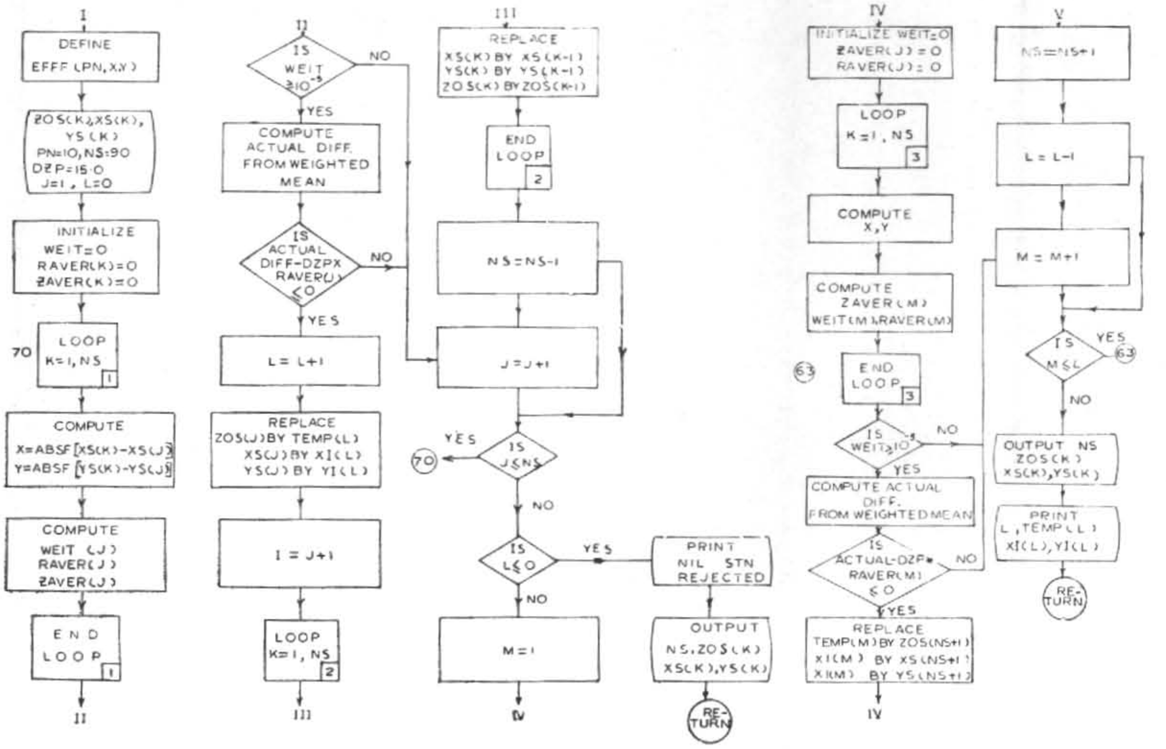

Fig. 3. Flow diagram for horizontal check

(*f*) XG(I), YG(J)	Geographical coordinates (longitude and latitude) of each grid point.
(*g*) DELZ (I, J), DELZW (I, J)	Correction terms for stations reporting only height and both height and wind respectively. The correction terms are given by equations (3·1) and (3·2).
(*h*) PNH, PNV	Number of correction terms given by variables DELZ, DELZW.
(*i*) PN	Radius of the scan.
(*j*) ZAVER(J)	Weighted mean contour height.
(*k*) DZP	Permissible mean observational error.
(*l*) RAVER(J)	Weighted mean distance.

(*iii*) *Output* — We start the first scan with a value of PN=5 degrees and increase it by 5 degrees after each scan. In the third scan, we have given no weight to the wind observations and only reported height values were considered for computing the corrections. For the second scan, the *Z*-field computed in the first scan becomes the preliminary *Z*-field and similarly for the third scan the output of the second scan becomes the preliminary field. It may further be added that in the second scan only the stations within 5° and 10° radius and similarly for the third scan only those stations falling between 10° and 15° radius have been considered for determining the correction at the grid-points. For the purpose of comparison the computer was programmed to print the height values at each grid-point after each scan. To study the difference, we also programmed to get the results after a single scan of ten degrees.

5. Results and conclusions

In Fig. 4 we present the results of an analysis based on a single scan with PN = 10 degrees. For comparison, we show in Fig. 5 the conventional analysis for the same day. It may be noted that the central value of the low pressure given by machine analysis is lower by 40 gpm from the conventional analysis. The low pressure in the former analysis is centred about 1·5 degrees northwest of its position obtained by conventional means.

In Fig. 6 we show the results of objective analysis after a single scan of 5 degrees and Fig. 7 shows the cumulative effect of the first scan coupled with a second scan. As mentioned earlier, the radius of the second scan was 10 degrees. Similarly, Fig. 8 shows the cumulative effect of the first

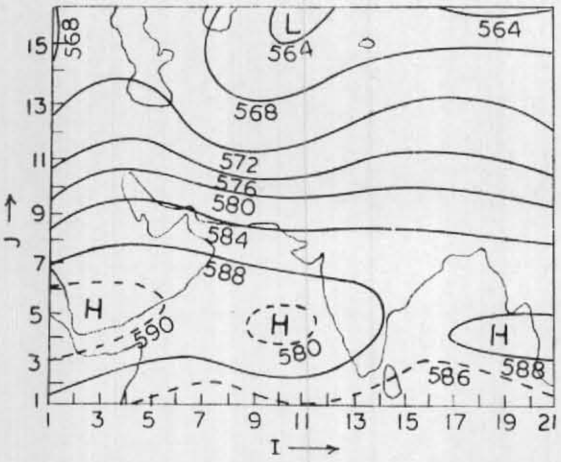

Fig. 4. Objective analysis of 500 mb on 27 April 1969 (00 GMT) with scan radius of 10 deg.

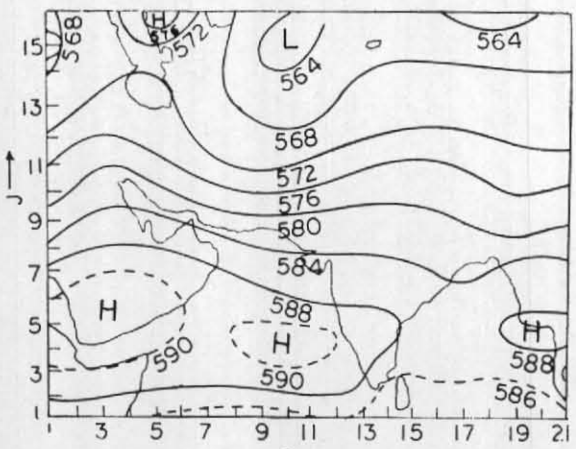

Fig. 7. Objective analysis of 500 mb on 27 April 1969 (00 GMT) with scan radii, 5 & 10 deg.

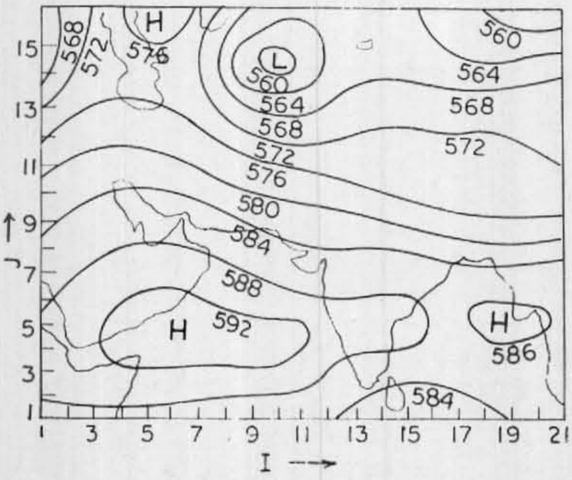

Fig. 5. Conventional analysis of 500 mb contours on 27 April 1969 (00 GMT)

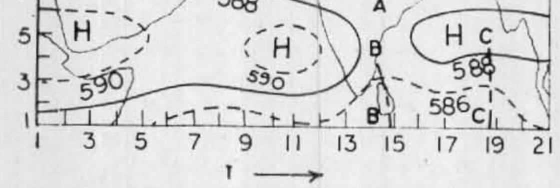

Fig. 6. Objective analysis of 500 mb on 27 April 1969 (00 GMT) with a scan radius of 5 deg.

two scans coupled with a third scan of radius 15 degrees.

It is interesting to note that the results of a single scan of 5 degrees (Fig. 6) depicts prominently the small features of troughs and ridges like AA, BB, CC and DD shown on Fig. 6. Comparing this with the conventional analysis, it may be seen that the ridge south of Caspian Sea and the trough over south peninsular India are also prominent in the conventional analysis. But, the other troughs depicted by machine analysis can be located by conventional method only after a careful analysis. If we take special care of the winds at Singapore, Songkhla and Port Blair, then only it is possible to locate the trough CC of Fig. 6. The low pressure system off NW India shows a shift of about 2° northwestwards from its position in conventional analysis.

There seems to be an interesting change when we study the results of scan of radii 5 and 10 degrees (Fig 7). Of the three troughs of Fig. 6, only the trough over south peninsular India appears in machine analysis, whereas the rest of the troughs have been smoothened out. The centre of the low pressure area is much more in agreement with the position obtained by conventional analysis. The position of the cut-off high is also in agreement.

The results with scan of radii 5, 10 and 15 degrees (Fig. 8) indicate excessive smoothening of the Z-field. The low pressure area of NW India is also shifted by about 3 degrees northwest of its position in conventional analysis. The ridge south of the Caspian Sea indicates sharp curvature,

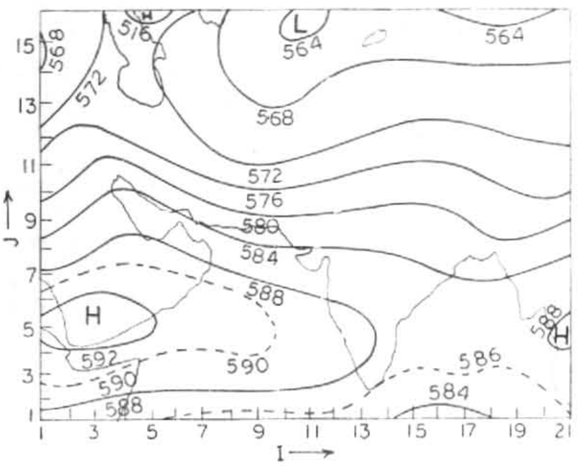

Fig. 8. Objective analysis of 500 mb on 27 April 1969 (00 GMT)with scan radii 5, 10 and 15 deg.

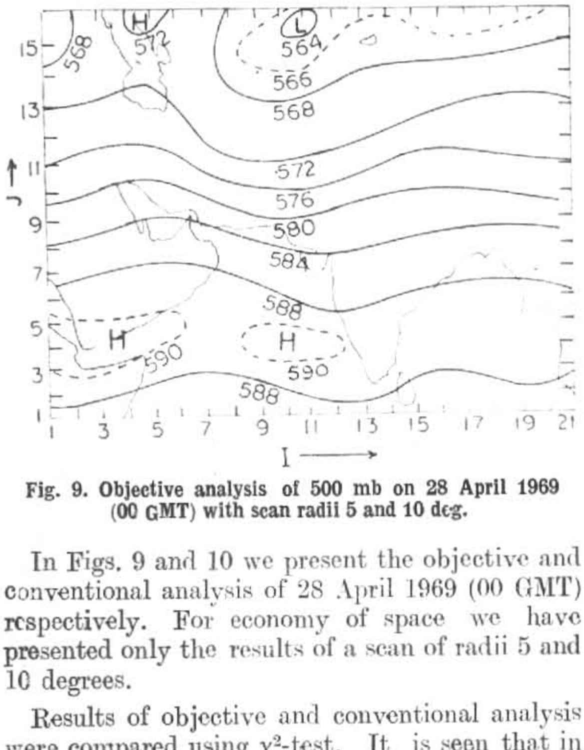

Fig. 9. Objective analysis of 500 mb on 28 April 1969 (00 GMT) with scan radii 5 and 10 deg.

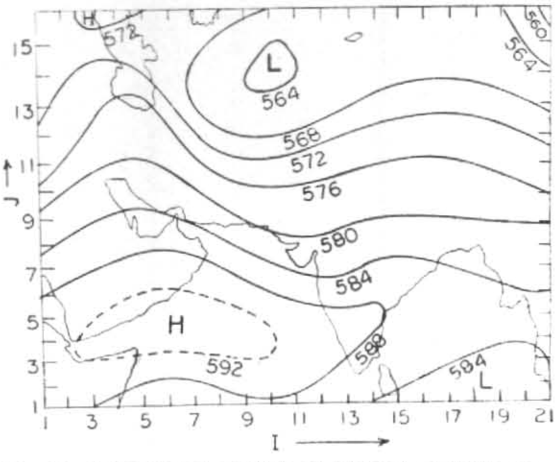

Fig. 10. Conventional analysis of 500 mb contours on 28 April 1969 (00 GMT)

In Figs. 9 and 10 we present the objective and conventional analysis of 28 April 1969 (00 GMT) respectively. For economy of space we have presented only the results of a scan of radii 5 and 10 degrees.

Results of objective and conventional analysis were compared using χ^2-test. It is seen that in both the cases the computed values of χ^2 at 5 per cent level of significance for desired degrees of freedom are smaller than the corresponding tabulated values. Hence we conclude that there is good agreement between the objective and conventional analyses.

6. Summary

The main results of the study may be summarised as follows :

1. We find that the 5-day normal heights and the 24-hr forecast of the Z-field provide a fairly good basis for the first-guess field.

2. The 'method of correction' reflects different scales of disturbances if the radius of the scan is not too large. Results of a single scan of 5 degrees radius brings out small disturbances, such as, minor troughs rather well, while a scan of 10 or 15 degrees smoothens out small scale features and only retains the large scale ones.

3. It was found that two scans, first of 5-degree and the second of 10-degree radius, give us a fairly good Z-field which is comparable to conventional analysis.

7. Acknowledgements

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