Use of Surface Observations to Estimate Upper Air Humidity for the Objective Analysis of Relative Humidity over Indian Region①

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ABSTRACT

In the present study objective analyses of relative humidity (RH) at surface and at the levels of 850, 700 and 500 hPa have been made using Gandin's (1963) optimum interpolation scheme. As the horizontal resolution of the radiosonde stations is rather inadequate for upper air humidity analysis, a scheme has been developed, following Rasmussen (1982) to estimate the upper air RH from the surface observations like surface RH, present weather and cloud cover. The relative humidities at the levels 850, 700 and 500 hPa were related to the surface observations through three separate regression relations. The RH values at 850, 700 and 500 hPa levels were estimated from the surface RH, cloud coverage and present weather using the above regression relations and subsequently the objective analyses at 00 GMT for the period from 4 July to 8 July 1979, were made using these estimated data along with the observed radiosonde data. Objective analyses were also made for the same period using only the radiosonde data for comparison to study the impact of those estimated data. Root mean square errors were computed for all the five days by interpolating RH at the observing stations from the objectively analysed field and comparing them with the actually observed RH to examine how best the analyses (with and without estimated data) fitted the observations. Lastly they were compared with satellite cloud pictures. This study shows that the estimated upper air RH values have positive impact on the analysis of upper air RH and could be used over radiosonde data sparse region and even over oceanic regions.

I. INTRODUCTION

Atmospheric moisture is extremely non–homogeneous, streaky in the horizontal and highly stratified in the vertical. There may be relatively large area of saturation or near saturation with adjacent areas of very low moisture content. Such strong gradient imposes severe strains on the objective analysis method. It is more so over the Indian region because ot the surrounding data sparse regions, viz. the Arabian Sea, the Bay of Bengal and the Indian Ocean. However, Atkins (1974), Perkey (1976) and Lejenas (1979) have demonstrated that the precipitation forecasts are sensitive to the initial moisture conditions and it is essential to develop an objective analysis scheme for relative humidity (RH).

Since some surface observations are statistically related to the upper air RH, a number of schemes (some of them are reported below) have been put forward and tested by several authors to estimate upper air RH in order to augment the existing radiosonde data. They have

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made different approaches to the objective analysis of RH using upper air humidity data diagnosed from surface or satellite observations. Ball and Veigas (1968) estimated the upper level humidity from surface reports and made objective analysis using Cressman's (1959) scheme. Atkins (1974) described the objective analysis of RH using successive correction method with two scans using surface two scans using surface observations to diagnose upper level humidity. The weighting functions used in this study depend, not only on the distance between the grid points being analysed and the observation points, but also on the magnitude and direction of the gradient of the background humidity field. Jonas (1976) used Atkins' method to analyse upper air RH. Chu and Parrish (1977) have described the analysis technique used at the National Meteorological Center, U. S. A. They also used radiosonde data, surface observations and bogus observations obtained from satellite cloud photographs. Their algorithm was later refined by Tibaldi (1982) for use at the ECMWF. Tibaldi used surface observations of clouds, present weather, surface temperature and dew point measurements to estimate upper level RH. Bergman and Gordon (1979) described an analysis scheme which is three dimensional. The correlation function is modeled as the product of a horizontal correlation and a vertical correlation. The horizontal correlation depends on separation, wind speed and wind direction while the vertical correlation depends on separation and stability. Stephen and Thomas (1981) developed an analysis procedure which used surface specific humidity data to infer specific humidity aloft by the use of first order linear regression equations. Resmussen (1982) while describing the objective analysis of relative humidity for regional–scale Numerical Weather Prediction showed that RH is a reliable variable, however, RH^* which is the square root of (1–RH) is better variable. Norquist (1988) conducted a set of experiments to assess the impact of several alternative sources of humidity informations in the RH analysis. The different sources are (i) satellite layer precipitable water retrievals with accompanying temperature retrievals, (ii) surface observations and (iii) cloud amount from AFGWC (Air Force Global Weather Central).3–D Nephanalysis. He found that the latter two cases yeilded acceptable RMS errors and hence can be used in data assimilation. Over Indian region, Begum et al (1987) have developed a scheme to estimate empirical vertical profiles of RH from the surface observations etc.

In the present study, a scheme for the objective analysis of RH following Gandin's optimum interpolation method is formulated and the analyses are made at the surface, 850, 700 and 500 hPa levels for the period 4 July to 8 July, 1979. In view of the inadequate horizontal resolution of radiosonde data, they are supplemented by estimating RH at 850, 700 and 500 hPa levels by the technique of linear multiple regression following Rasmussen (1982) and the impact of these estimated upper air RH on the analysis was subsequently examined.

II. DATA

For this study daily data at surface, 850, 700 and 500 hPa temperature and dew point temperature, cloud amount, present weather for four July months (1976 to 1979) were used, for developing the regression equations. The analyses of ECMWF for the period 3 July to 8 July were used as initial guess field. The radiosonde data for the period 4 to 8 July and the surface data, present weather etc. were also used in the actual analysis of RH. Since we want to focus our attention on the development of a scheme to estimate upper air RH and its usefulness on the analysis, land region alone was considered for this study. Consequently, the special MONEX data like dropsonde data from research aircrafts and surface data from research ships were not utilized.

III. METHODOLOGY

As mentioned earlier, for regional scale moisture analysis the initial specification of moisture analysis is important. Since the surface observations are dense and more accurate and also as they are statistically related to upper air RH, the regression relation between them was determined. Then upper air RH is estimated at number of stations well distributed over the region by using the just developed regression equation. In the present study three different regression equations for threee levels viz. 850, 700 and 500 / hPa were developed. These estimated RH data along with the radiosonde data were used for the objective analysis.

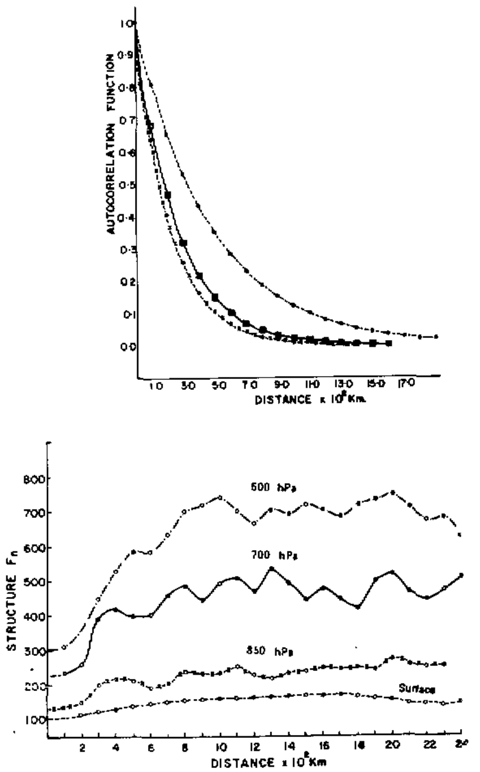

Fig.1(a). Autocorrelation functions of relative humidity at surface (0———0), 850 (0———0), 700 (0—*—*—0), 500 (□———□).
(b). Structure functions of relative humidity at surface.

1. *Objective Analysis using Optimum Interpolation Scheme*

The analysis scheme used in this study is based on Gandin's (1963) optimum interpolation method. He had derived an expression for the weighting function for the observing stations with respect to the grid points incorporating the physical characteristics of the parameter over the region. This is done by computing structure funtions and autocorrelation functions. Here, the covariances over the analysis domain were assumed to be both homogeneous and isotropic and the variances to be homogeneous. For the Indian region, Rajamani et al.

(1983) and Sinha et al. (1989) have applied this optimum interpolation (O.I.) scheme of objective analysis for the wind field and Sinha et al. (1987) for the mixing ratio respectively. Details about O.I. scheme are given there and so only a few important points regarding the scheme are given here and not the derivation of the complete set of equations. The O. I. scheme utilizes an analysis equation of the form

$$A_g = F_g + \sum_{i=1}^{n} w_i (O_i - F_i) \tag{1}$$

where n is the number of observations affecting a particular grid point. $(O_i - F_i)$, the observed minus the first guess at the ith location, F_g is the first guess value at the grid point, and A_g is the resulting grid point analysis. The w_i is the so called "weights" which were chosen in such a manner that the mean square of the analysis errors is minimized. The weights satisfy the n equations

$$\sum_{j=1}^{n} (\mu_{ij} + \delta_{ij} \lambda^2) w_j = \mu_{0i}, \quad i = 1,2,\cdots\cdots n \tag{2}$$

where μ_{ij} is the autocorrelation function, λ^2 is the normalized total random error, and δ_{ij} is the Kronecker delta.

The computed autocorrelation functions and the structure funtions of the RH field for the surface, 850, 700 and 500 hPa levels and for the July month are shown respectively in Fig.1 (a,b). The autocorrelation between points separated by a distance ρ was formulated in terms of positive definite correlation coefficient function. The particular form of correlation coefficient function used for the four levels is

$$\mu(\rho) = \exp(-b \cdot \rho) \tag{3}$$

where b, the fitting constant whose value for different levels are given in Table 1 and the estimated values of the mean random observational errors which were obtained by extrapolating the structure function curves to zero distance are given in Table 2.

Table 1. Values of the Constant of the Modeling Curve Fitted to the Autocorrelation Functions

Period	Level (hPa)	Fitting Constant (b)
July	Surface	0.2087
	850	0.3769
	700	0.4477
	500	0.3797

Table 2. Estimates of Random Errors of Relative Humidity

Period	Level (hPa)	Extrapolated Value of Structure Functions at Distance $\rho=0$	$\sigma_{a_i}^2$	Random Error σ_{ai}
July	Surface	106.0	53.0	7.28
	850	132.0	66.0	8.12
	700	226.0	113.0	10.63
	500	312.0	156.0	12.49

2. *Regression Relation and Estimation of Upper Level Relative Humidity*

Our main objective is to estimate the upper air RH from the surface observations. Rasmussen (1982), as mentioned above, used multiple regression technique to estimate the upper air RH. Following Rasmussen we have used this technique to estimate the RH at the upper level. As the reported present weather codes (00–99) are physically meaningless for direct use in the regression equation, the present weather was split into three categories, dry , showery and wet following Jonas (1976). The values for above three different categories for their use in regression equation are shown in Table 3.

The daily 00 GMT data of four July months (1976 to 1979) were used to develop the regression relation between the upper air RH and surface observations. Three different pre diction equations for the above three different levels were obtained and they have the form

$$RH_E + A \cdot (RH_S) + B \cdot (WW) + C \cdot (NL) + D \cdot (N) + E \tag{4}$$

where RH_E is the estimated value, RH_S is the surface RH, WW is the present weather code which has the value 1,2 or 3 depending on whether it is dry, showery or wet. NL and N are the amount of low cloud and total amount of cloud in octas. The values of constants A, B, C, D, and E in the regression relation for different levels are given in Table 4.

Table 3. Weather Types Assigned to Present Weather Codes Together with Their Respective Dummy Variables

Present Weather Code (India Met. Department)	Weather Type	Dummy Variable
0—12 28 30—37 40—49	Dry	1
13—19 25—27 29 80—99	Showery	2
20—24 38—39 50—79	Wet	3

Table 4. Values of Regression Constants for Different Levels

Levels (hPa)	A	B	C	D	E	Variance Explained %
850	0.385	1.308	1.477	−0.333	45.473	92
700	0.153	3.881	* * * * *	1.289	48.951	90
500	0.244	4.857	−0.638	3.911	14.823	85

III. ANALYSIS OF RELATIVE HUMIDITY

RH analyses were made at 00 GMT for an interesting period from 4 to 8 July, 1979. During this period, a low was formed over the head Bay of Bengal and moved west–northwestward. It moved slowly at the beginning, intensified into a depression on 7 July and crossed the Indian coast on 8 July. Due to this movement of the depression, the rainfall pattern changed everyday as could be seen from the cloud pictures (Fig.2a–e). The maximum rainfall region associated with the depression has moved westwards. Whether the analyses with and without estimated *RH* data reflect these features will be examined in a latter section.

In this study the area covered for the analysis extends from 10°N to 30°N and from 70°E to 100°E. In the first part of the experiment the objective analyses were made for the surface RH as well as for the surface RH^*. The previous day's analysis is used as the initial guess. After the objective analyses were made for RH^*, RH values were recovered via the inverse transformation. In the second part of the experiment, the analyses were made for the upper levels. In this case also, ECMWF analyses of the corresponding previous days were used as the initial guess. First, the analyses were made with only radiosonde data as the input (Analysis–A) and then the analyses were made with the estimated data along with the radiosonde data (Analysis–B). Lastly these experiments were carried out using climatology as the initial guess.

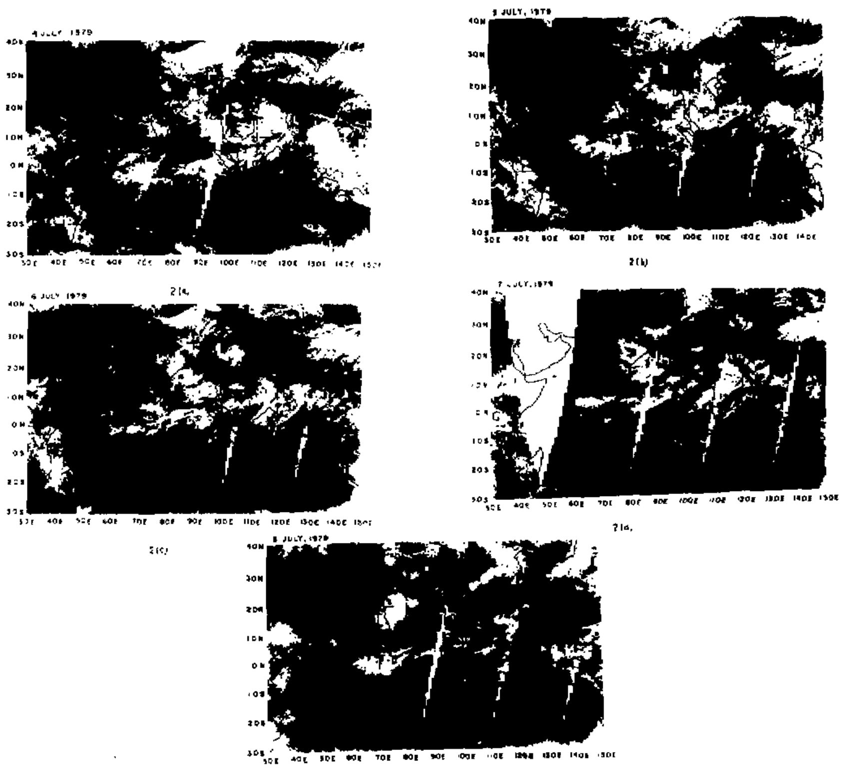

Fig.2(a). Satellite cloud picture of 4 July, 1979. (b) Satellite cloud picture of 5 July, 1979. (c) Satellite cloud picture of 6 July, 1979. (d) Satellite cloud picture of 7 July, 1979. (e) Satellite cloud picture of 8 July, 1979.

IV. DISCUSSION OF RESULTS

A comparative study made between analyses of RH and RH^* showed that there were no major differences in the two analyses. Further, quantitative assessment of these analysed fields was made through the computation of RMS errors. It was found that RMS errors for all the five days for RH field were less than the RH* field and is shown in Fig.3(a) and Table 5. This suggests that RH analyses are closer to the observations than RH* analyses. However, both analyses are acceptable as the RMS errors in both cases vary between 6 to 10% (Table 5).

Table 5. Root Mean Square Errors in % by Comparing the Observed Value of RH with the Analyzed Value

Date	Surface		850		700		500	
	RH	RH*	R.S. + Esti-mated	Only R.S.	R.S + Esti-mated	Only R.S.	R.S. + Esti-mated	Only R.S.
4.7.79	7.5	8.3	10.9	12.3	11.6	13.7	14.1	9.2
5.7.79	6.9	7.2	12.5	11.6	13.2	13.7	14.0	14.4
6.7.79	6.0	6.4	11.4	11.6	10.2	11.5	13.9	17.5
7.7.79	8.9	9.5	13.1	13.1	12.6	12.2	13.5	8.9
8.7.79	8.0	8.2	12.8	15.3	10.3	10.5	13.7	15.8

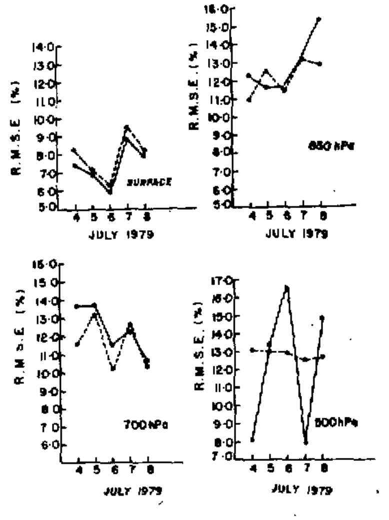

Fig.3(a). Root Mean Square Errors in % for surface RH(0———0) and RH*(0————0). (b) Root Mean Square Errors in % for 850 hPa level for the analysis with only radiosonde data (0——0) and for the analysis with radiosonde along with estimated data (0————0). (c) Same as Fig.3(b) but for 700 hPa level. (d) Same as Fig.3(b) but for 500 hPa level.

Next, let us examine whether these analyses reflect the actual synoptic conditions. High relative humidity values in both the analyses of RH and RH* were in the region of the depression on all the days, agreeing with synoptic conditions. For example, Fig.4 (a, b) shows that the regions of higher isopleths of RH and RH* respectively agree with position of the depression on 7 July, 1979. Similar agreement is also seen in the satellite cloud pictures Fig.2 (a–e). To sum up, as far as the surface analyses are concerned, we found taht the objective analyses have a good agreement with the observations as well as with synoptic conditions.

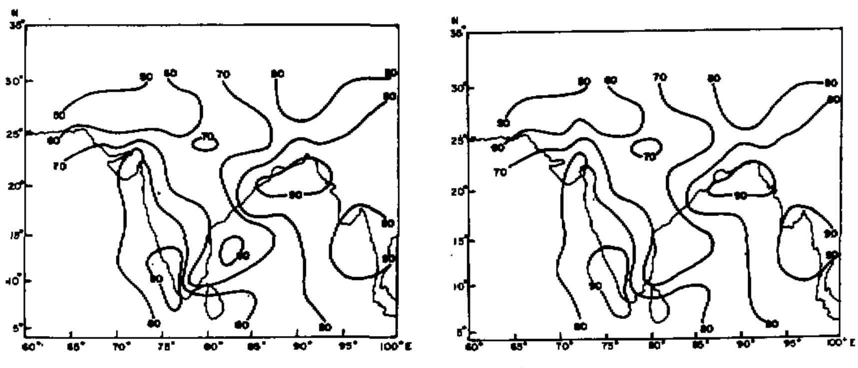

Fig.4(a). Objective analysis of surface RH of 7 July, 1979. (b) Objective analysis of surface RH* of 7 July, 1979.

In the second part of the study, the objective analyses of upper air RH have been made. Here the objective as mentioned earlier, has been to improve RH analysis by supplementing the available radiosonde data with RH data estimated from surface observations. Accordingly RH at 850, 700 and 500 hPa levels were estimated from surface observations using regression relations and supplemented to radiosonde data for making objective analyses. The analyses of these days were also made with only radiosonde data as input and compared with the other analyses in order to examine the impact of the inclusion of the estimated RH data on the analysis.

First look at the two sets of analyses (Fig.5 and Fig.6) which show that they are qualitatively similar and agree fairly well with the synoptic conditions (movement of the depression etc.) as well as with the satellite cloud pictures. Both the analyses at all the three levels show three maxima, one over the Bay of Bengal corresponding to the monsoon depression, second over the foothills of the Himalayas and third over the west coast of southern peninsula. The first maximum in RH moved with the monsoon depression, while the second remained stationary on all days. However, the third maximum decreased in intensity as the convective activity decreased on 6 and 7 July (Fig.2c and 2d). However, a closer examination of the two sets of analyses shows that the magnitudes of analyses are marginally greater in case of analysis B. This suggests that the inclusion of the estimated RH data tends to make the analyses more moist.

Next, to carry out quantitative examination of the two sets of analyses A and B, the RMS errors were computed for these analyses comparing them with the observed data for all the days at all the levels. Here, RH values were interpolated back to the observing stations from the objectively analyzed values at the surrounding grid points and were compared with the actual station observations to compute the RMS errors. Table 5 and Fig.3 (b–d) show that the RMS errors for analysis B are less than for analysis A on most of the days at 850, 700 and 500 hPa levels. At 850 and 700 hPa levels, the difference is marginal. From this, it could be inferred that the analysis B has been closer to the actual observation. Hence the impact of the inclusion of the estimated RH data is to improve the analysis marginally and certainly not to deteriorate the analysis and so it is possible to use with advantage the estimated RH data in the radiosonde sparse region or in the absence of radiosonde data or even over the oceanic region where reliable ships' observations would be available.

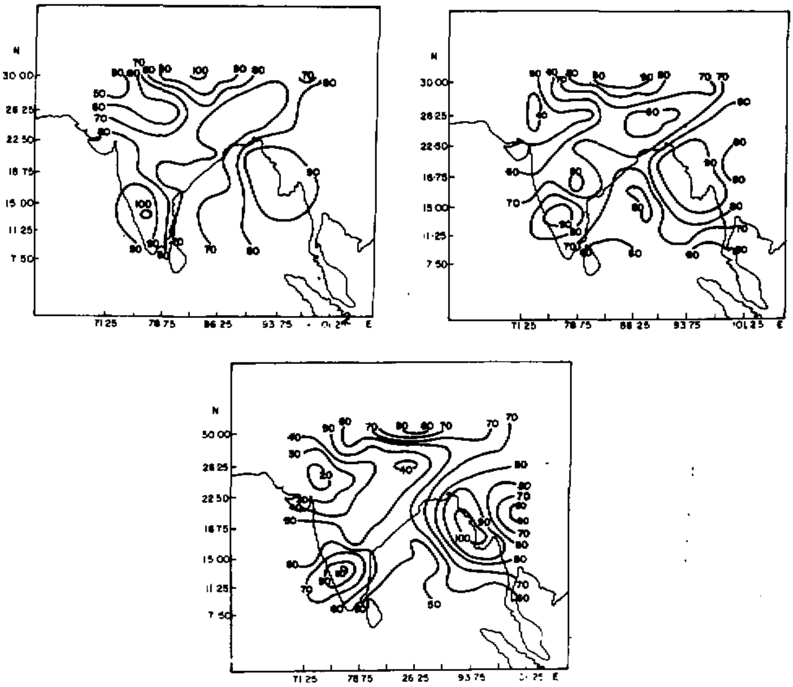

Fig.5(a). Objective analysis of 850 hPa level with estimated data of 5 July, 1979. (b) Same as Fig.5(a) but for 700 hPa level. (c). Same as Fig.5(a) but for 500 hPa level.

V. CONCLUSIONS

It is found that the analyses of surface RH and surface RH* using univariate optimum interpolation scheme are found to be good when compared with the synoptic conditions as well as with the cloud pictures. The RMS errors comparing the observations vary from 6 to 10%, which are low and acceptable.

The univariate optimum interpolation scheme yields fairly satisfactory analyses of upper air RH at 850, 700 and 500 hPa levels. Also, the estimated RH data from surface observations using regression relations improve the analysis, although the improvement is only marginal.

Thus, this study shows that the surface observations can be used in the analysis of upper air RH, in radiosonde sparse regions, or where the radiosonde data are absent or even over oceanic regions where reliable ships' observation would be available.

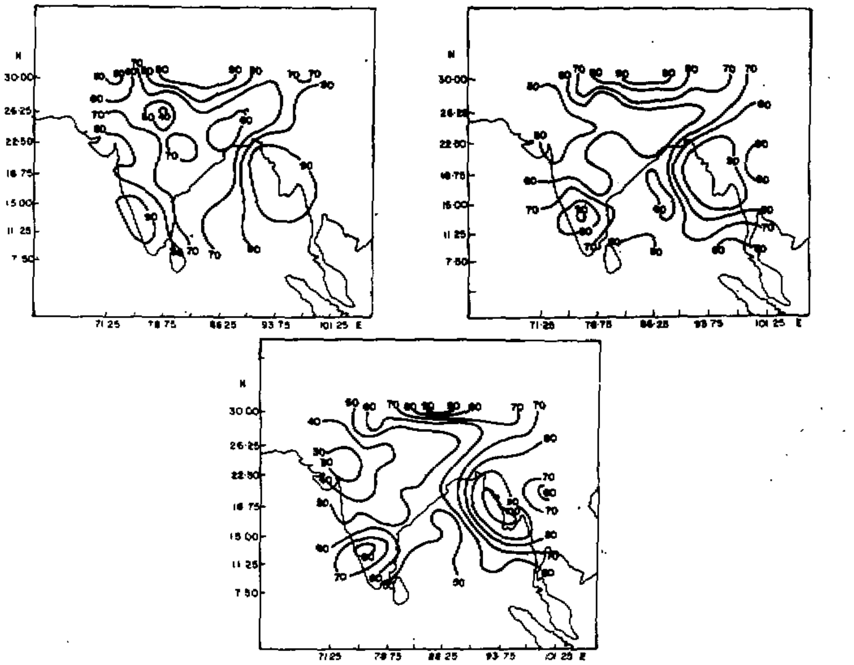

Fig.6(a). *Objective analysis of* 850 hPa levels without estimated data of 5 July, 1979. (b) same as Fig.6(a) but for 700 hPa level. (c) Same as Fig.6(a) but for 500 hPa level.

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