Mausam, (1992), **43,** 1, 71-76

556.166.2 : 556.047 (545)

A diagnostic study of flood producing rainstorm of September 1988 over northwest India with the aid of a fine mesh numerical analysis system

K. PRASAD

Meteorological Office, New Delhi

(*Received 21 June 1990*)

सार — सितम्बर 1988 के दौरान पंजाब तथा समीपवर्ती राज्यों में आई भयंकर बाढ़ से सम्बन्धित सिनॉप्टिक स्थिति का संख्यात्मक विश्लेषण किया गया है। यह विश्लेषण त्रिआयाम बहुचर ईष्टतम अंतर्वेशन विधि द्वारा $1^\circ \times 1^\circ$ अक्षांश/रेखांश ग्रिड पर किया गया है। अनेक व्युत्पन्न प्राचलों के अभिकलन के लिये सॉफ्टवेयर तैयार किया गया है और इसको मूल प्राचलों के विश्लेषण के साथ जोड़ दिया गया है। दिन प्रति की वर्षा का संख्यात्मक विश्लेषण किये हुए ग्रिड बिन्दुओं पर समेकित क्षैतिज जलवाष्प फ्लक्स अपसरण के साथ नैदानिक अध्ययन किया गया है । इस अध्ययन से पता चलता है कि कुल जलवाष्प फ्लक्स अभिसरण के क्षेत्र तथा अगले दिन रिकार्ड की गई भारी वर्षा के क्षेत्र में काफ़ी हद तक परस्पर स्थानिक सम्बन्ध है। अध्ययन यह दर्शाता है कि संख्यात्मक विश्लेषण किये गये चार्टों से भारी वर्षा के पूर्वानुमान में सिनॉप्टिक पूर्वानुमान विज्ञानी को काफ़ी मदद मिल सकती है ।

ABSTRACT. A numerical analysis of the synoptic situation leading to devastating floods in Punjab and adjoining states during September 1988 has been carried out. The analysis is done by three dimensional multivariate optimum interpolation (OI) scheme cast on $1^\circ \times 1^\circ$ Lat./Long. grid. Software has been developed for computation of several derived parameters and linked with the basic flow variable analysis. A diagnostic study of day to day rainfall *versus* the objectively analysed grid point fields of integrated horizontal flux divergence of water vapour is carried out. The study brings out a close spatial correspondence between the area of net moisture flux convergence on the analysis day and the area of heavy rainfall on the following day. The study suggests that the numerical analysis products can be of a good predictive value to a synoptic forecaster in heavy rainfall predictions under difficult and uncertain synoptic situations.

Key words — Integrated horizontal flux, Divergence of water vapour, Multivariate optimum interpolation, Objective analysis, Vorticity advection.

1. Introduction

The prediction of rainfall associated with tropical weather disturbances, especially the heavy rainfall extremes which cause floods and other damages, is a central problem in tropical meteorology. The common approach followed in tropical weather predictions is through the synoptic methods of forecasting by a human forecaster, though computerised methods of numerical weather prediction are also being increasingly used. The synoptic methods have their inherent limitations in that a human forecaster, who bases his inferences and forecasts on manual analysis of weather charts, can not visualise the four-dimensional structure of the atmosphere beyond a certain limit. The forecaster's difficulty is compounded in the situations of extreme weather events.

In order to make a comprehensive diagnostics of the state of atmosphere at a given initial time, it is necessary to look at not only the distribution of the so called flow variables the wind, geopotential height and temperature, but also some of the derived parameters of atmospheric circulation such as vorticity, convergence, divergence, vertical motion, moisture distribution etc. The latter are possible to compute and represent only with the help of computerised methods of numerical (objective) analysis.

In view of the fact that some of the rain producing disturbances in the tropics are of meso-scale (100-1000 km) and even small scale (< 100 km) dimensions, such numerical analyses should be carried out on fine meshes of the order of 100 km or less so as to resolve these disturbances properly. Keeping the above aspect in view, a fine mesh numerical analysis system cast on $1^\circ \times 1^\circ$ Lat./Long. grid has been designed and implemented. The analysis is carried out by a three-dimensional statistical multivariate optimum interpolation (OI) scheme. Software has been developed for computation of a number of derived parameters and linked with the analysis scheme.

This paper discusses the usefulness of the fields of derived parameters as an aid to the synoptic forecaster in enhancing his capability and confidence towards accurate weather prediction. The efficacy of the numerical products in this context is demonstrated with reference to one of the most severe flood producing rainstorm of the recent past the prolonged extremely heavy rainfall over northwest India during 22-27 September 1988 — which resulted in a catastrophe over the area, particularly Punjab and, therefore, deserves a thorough investigation from the meteorological point of view. Since moisture plays the crucial role in the rainfall process, attention is focussed on the distribution of moisture parameter in the form of horizontal flux divergence of water vapour. The analysis shows encouraging results and brings out the importance of the above parameter as a potentially useful tool in rainfall predictions.

The main features of the optimum interpolation scheme are described briefly in section 2. Section 3 contains a short synoptic history of the atmospheric disturbances which led to the heavy rainfall and floods. In section 4 derivation of a suitable parameter for rainfall diagnostics is made. In section 5 the occurrence of rainfall is discussed with reference to the derived numerical products, section 6 gives the concluding remarks.

2. The optimum interpolation scheme of objective analysis

The objective analysis scheme used in this study is based on three dimensional multivariate optimum interpolation as described by Mc Pherson *et al.* (1979), Di Mego *et al.* (1985), Dey and Morone (1985), Prasad and Bansal (1987). The analysis is performed for the geopotential height, u and v components of wind and specific humidity. Temperature is obtained from geopotential through the hydrostatic relationship. The analysis for geopotential and wind components is multivariate in that the analysis of one parameter is influenced by the other parameters. The computed corrections to the first guess for the mass and motion variables are geostrophically coupled poleward of 25° Lat., partially decoupled between 25 and 10 deg Lat. and fully decoupled equatorward of 10° Lat. The analysis of specific humidity is univariate.

The data input for the analysis are the upper air (TEMP/PILOT), surface (SYNOP/SHIP), satellite derived winds (SATOB), satellite thickness profile (SATEM) and aircraft (AIREP) obtained on the Global Telecommunication System (GTS). The data are sorted, decoded, preprocessed into the format required by the analysis scheme and passed through the usual quality control checks before being used for the OI analysis.

3. The observed atmospheric evolution and severe rainstorm of 22-27 September 1988 over northwest India

Towards the end of the monsoon season in 1988 a monsoon low pressure area moved from Bay of Bengal to Rajasthan across Madhya Pradesh. The low originated in Bay of Bengal on 19 September 1988. Moving northwestward across Madhya Pradesh from 20-22 September, it remained practically stationary between 22 and 23 September over southwest Madhya Pradesh and neighbourhood. Thereafter it took a north northwesterly course across Rajasthan and continued moving

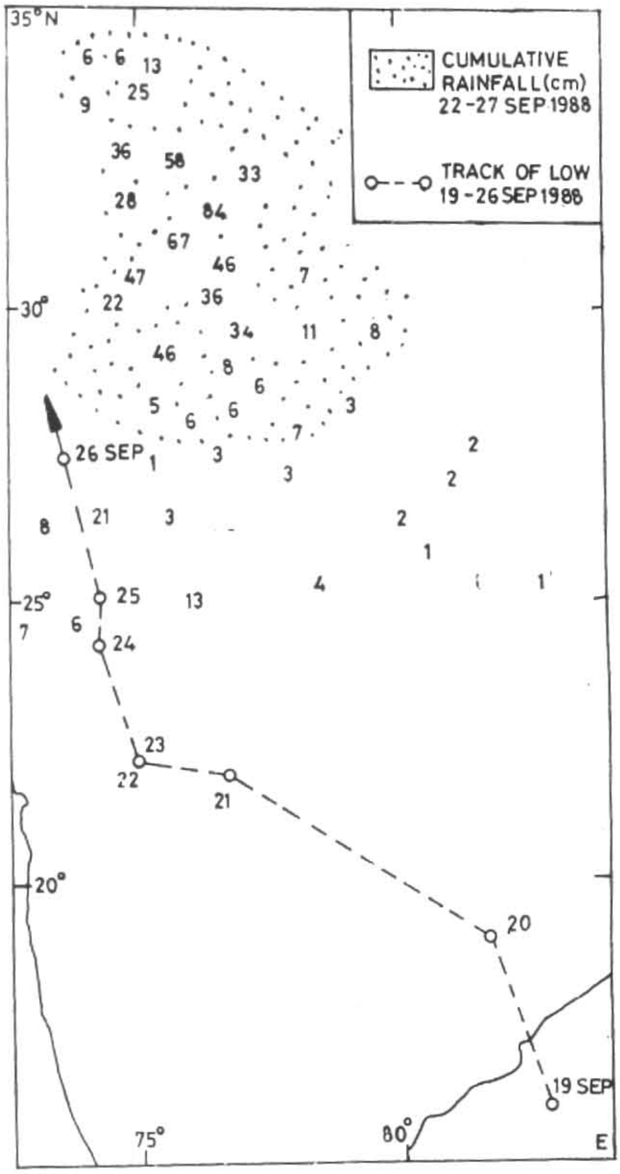
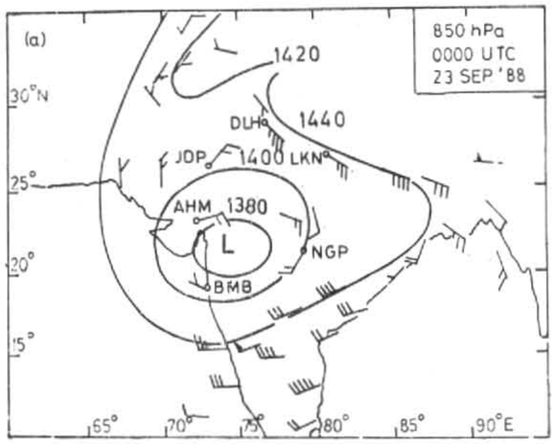


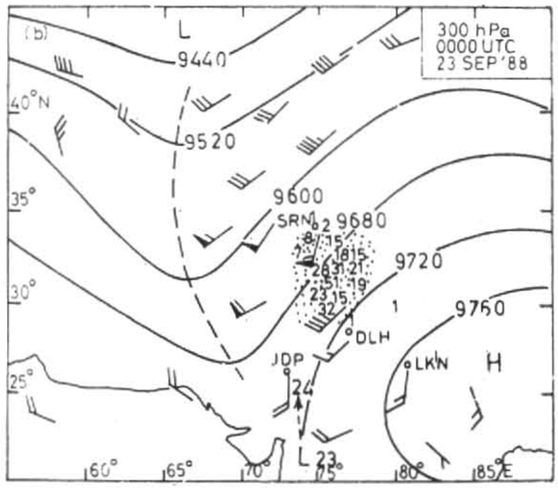
Fig. 1. Track of low pressure area, 19-26 Sep. 1988, and cumulative rainfall, 22-27 Sep 1988 over northwest India

in that direction up to 26th. The low dissipated subsequently. The track of the low pressure area alongwith the cumulative rainfall of the period 22-27 September are shown in Fig. 1. Fig. 2 (a) shows the flow pattern analysis at 850 hPa on 23 September 1988.

At the same time a middle latitude westerly wave trough in the upper troposphere was approaching north India from west during 22-23 September. The trough was extending from 25° N to 45° N between 65° E & 70° E on 23 September and was well marked and deep. The trough weakened and moved away eastward later. The flow pattern analysis at 300 hPa is shown in Fig. 2(b).

The low spawned an unusually heavy and prolonged spell of rainfall from 22 to 27 September over parts of northwest India, *viz.*, Punjab, Himachal Pradesh and





Figs. 2 (a-b). Flow pattern analysis of the synoptic situation on 23 September 1988 (00 UTC): (a) 850 hPa and (b) 300 hPa. Dotted area of heavy rainfall on 24 Sep 1988

adjoining areas of Haryana and Jammu & Kashmir. Exceptionally heavy falls of the order of 30-50 cm in 24 hours occurred at a few places on 24 September. Amount exceeding 20 cm continued to be reported on other days. The rain spell brought catastrophic floods in Punjab.

The interaction between a tropical low and upper tropospheric trough is usually a favourable combination for occurrence of exceptionally heavy rainfall over north India during the monsoon season. This type of situations do occur occasionally over northern parts of the country and are one of the most important synoptic events causing flood producing rainstorms over the north Indian river basins, generally during the late monsoon period. The area ahead of the wave trough being an area of upper divergence is most liable to heavy falls. The rainfall in the present case followed this general pattern, as may be seen in Fig. 2(b).

A notable feature of the rainfall distribution was that the heavy rainfall area was far to the northnortheast of the position of the low on all the days of the rainstorm which is reflected in the cumulative rainfall pattern and the track shown in Fig. 1. Another noteworthy feature was the heavy rainfall in a very small areal extent. This pattern of rainfall is typical of the monsoon disturbances during the late monsoon month of September (Rao 1976). An interesting aspect of the present case, however, was that heavy rainfall continued over the same area even after passing away of the upper trough after 23 September and only the low level circulation sustaining the rainfall. These typicalities of the rainfall distribution can best be examined with the aid of numerical analysis, which is the subject matter of the succeeding section.

4. Diagnostic numerical products

The optimum interpolation scheme of numerical analysis discussed in section 2 gives us the grid point fields of only the basic flow variables, the geopotential height, temperature, u and v components of wind and humidity. Once the fields of basic parameters have been obtained, the fields of derived parameters can be constructed. The derived parameters of most common interest are the vorticity, vorticity advection, divergence and vertical motion. A suitable parameter which could be related to rainfall is the vertically integrated horizontal water vapour flux divergence which is defined as :

$$\mathrm{Div_{flux}} = -\frac{1}{g}\int_{p_T}^{p_B} \nabla.\, q\mathbf{V}\, dp \qquad (1)$$

where, q is the specific humidity, $\mathbf{V}$ is the horizontal wind vector, p_B and p_T are the pressure levels at the bottom and top of the atmosphere. For the purpose of computations the integrated water vapour flux divergence may be evaluated as follows :

$$\mathrm{Div_{flux}} = -\frac{1}{g}\left[\int_{p_T}^{p_B} q\nabla.\,\mathbf{V}\, dp + \int_{p_T}^{p_B} \mathbf{V}.\,\nabla q\, dp\right] \qquad (2)$$

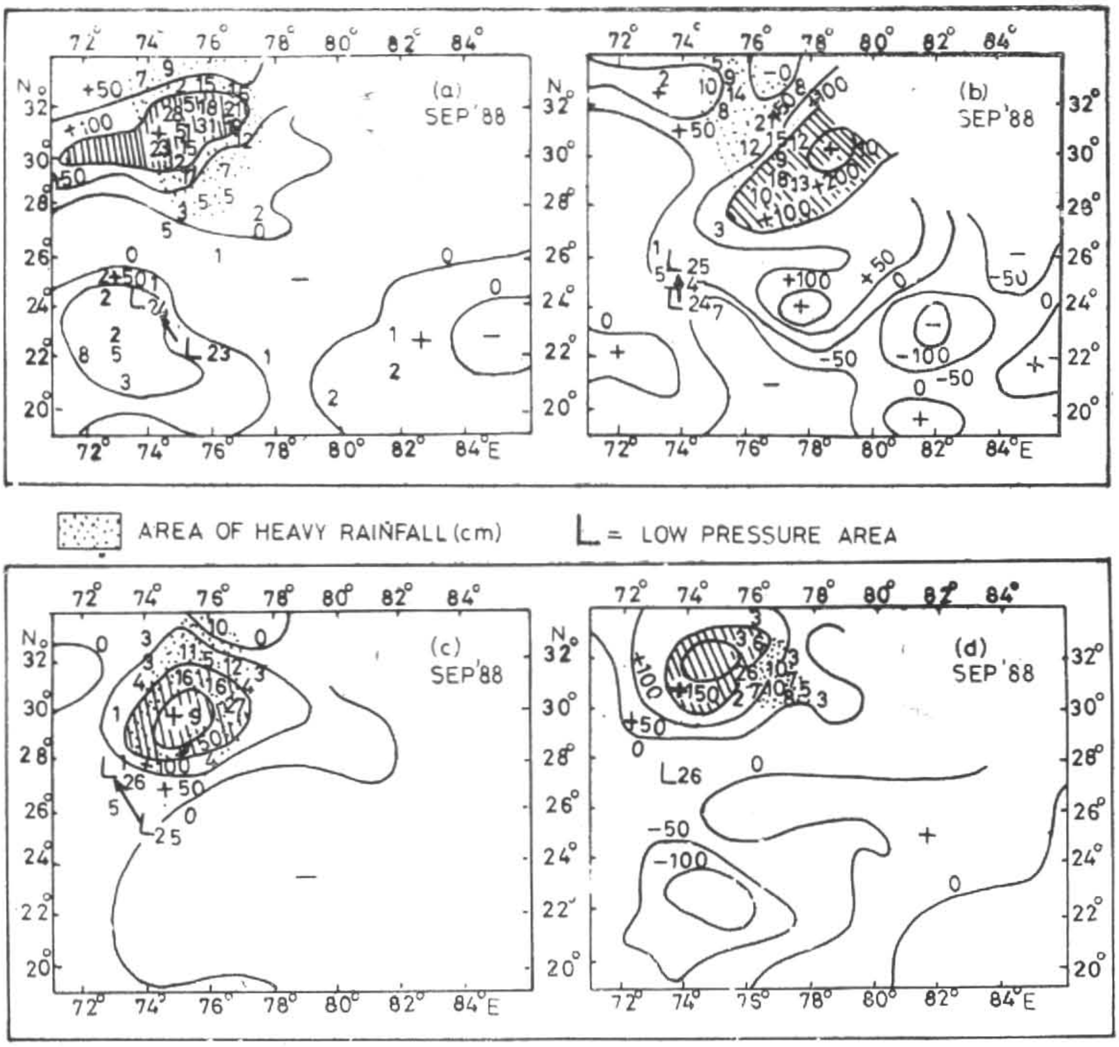
The expressions in Eqn. (2) are computed at the individual standard isobaric levels from 1000 to 300 hPa and then integrated. The divergence term and the moisture advection terms are computed from the analysed fields of u and v components of wind and specific humidity q provided by OI. 300 hPa is the last level where humidity analysis is available.

5. Discussion

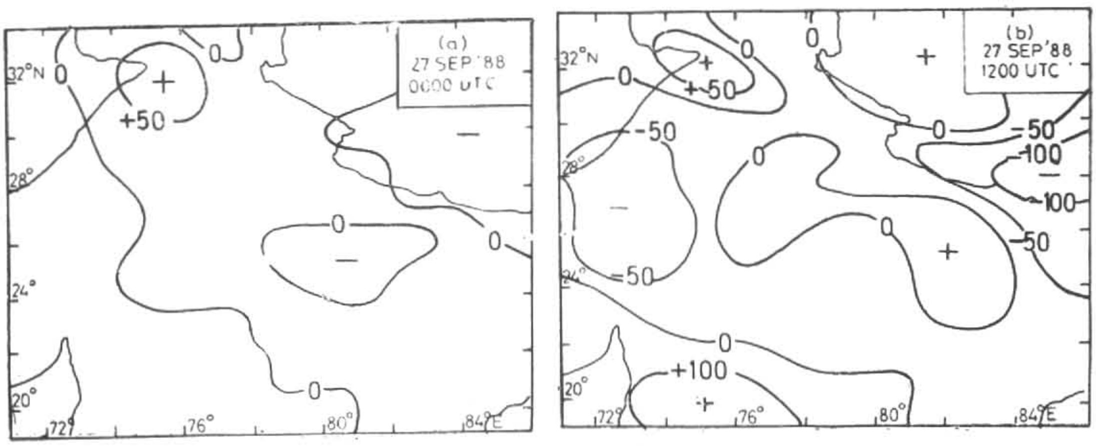
5.1. The analysis of water vapour flux divergence and upper vorticity advection vis-a-vis rainfall from 23 to 27 September 1988

The daily analysis of integrated horizontal water vapour flux divergence for the period 23 to 27 September 1988 are presented in Figs. 3(a-d). Superimposed on these are the 24-hour rainfall amounts (cm) recorded the next day.

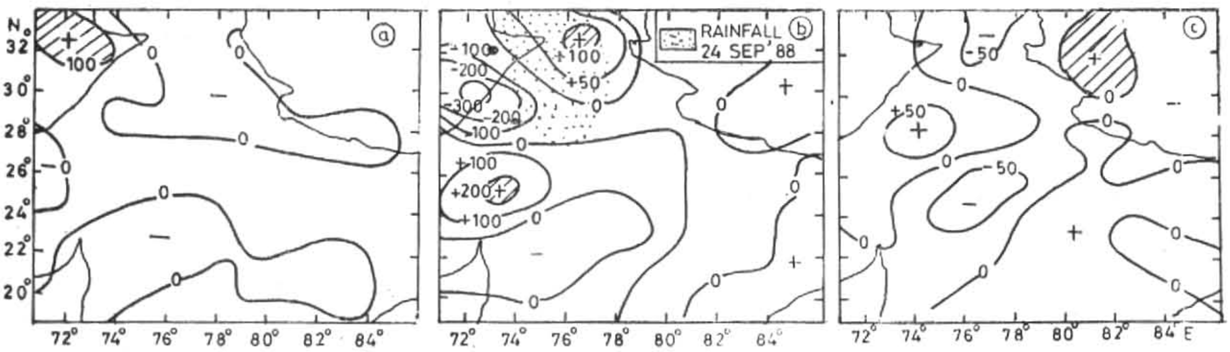
The flux divergence pattern as shown in Fig. 3 is marked by the presence of a positive maximum (net flux convergence) of the order of 100 to 200$\times10^{-6}$ gm



Figs. 3(a-d). Integrated horizontal water vapour flux divergence (Surface-300 hPa); (Unit: 10^{-6} gm cm^{-2} s^{-1}); Positive values indicate net moisture convergence and dotted area of heavy rainfall next day (a) 23 Sep, (b) 24 Sep, (c) 25 Sep and (d) 26 Sep (00 UTC)



Figs. 4(a-b). Same as in Fig. 3 except (a) 27 Sep 00 UTC and (b) 27 Sep 12 UTC



Figs. 5(a-c). Advection of absolute vorticity at 300 hPa; (Unit : 10^{-10} s^{-2}) (a) 22 Sep, (b) 23 Sep and (c) 24 Sep 1988 (00 UTC)

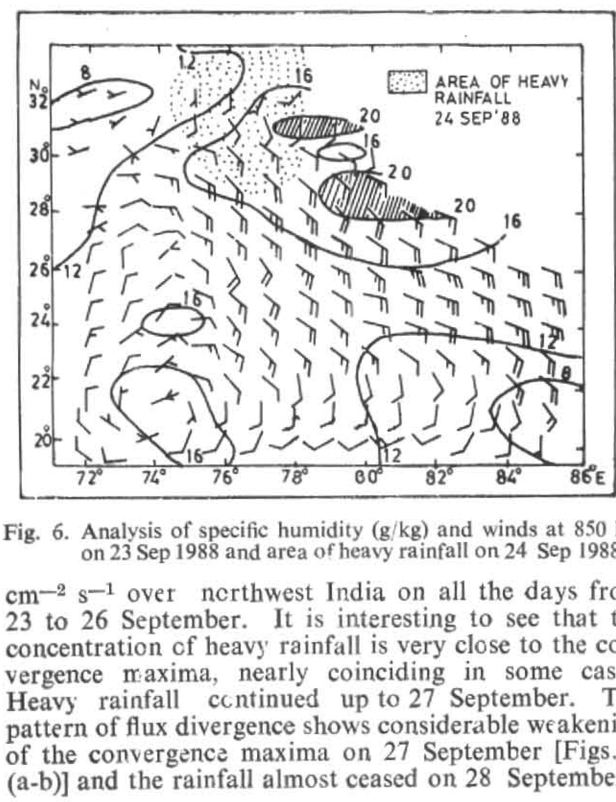


Fig. 6. Analysis of specific humidity (g/kg) and winds at 850 hPa on 23 Sep 1988 and area of heavy rainfall on 24 Sep 1988

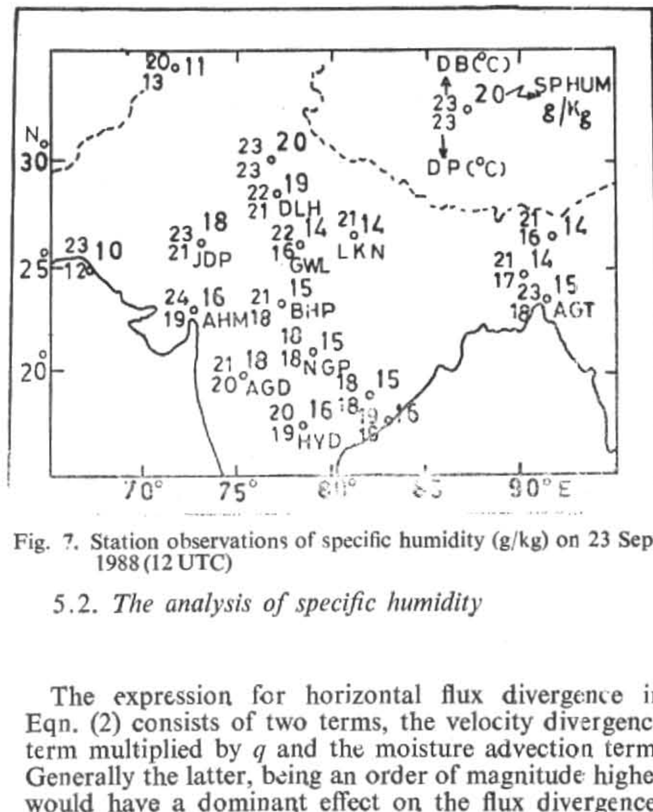


Fig. 7. Station observations of specific humidity (g/kg) on 23 Sep 1988 (12 UTC)

cm^{-2} s^{-1} over northwest India on all the days from 23 to 26 September. It is interesting to see that the concentration of heavy rainfall is very close to the convergence maxima, nearly coinciding in some cases. Heavy rainfall continued up to 27 September. The pattern of flux divergence shows considerable weakening of the convergence maxima on 27 September [Figs. 4 (a-b)] and the rainfall almost ceased on 28 September.

The rainfall was the heaviest on 24 September. It may be recalled from section 3 that the upper tropospheric flow pattern was characterised by the synchronous movement of a westerly trough across north India [Fig. 2 (b)]. The area ahead of the trough is usually associated with positive vorticity advection (PVA) and divergence. In order to look at the role of vorticity advection in the present case, the field of this parameter was derived from the analysis of u and v components at 300 hPa. These are presented in Figs. 5(a-c). Eastward movement of a PVA maxima across northern parts of India from 22 to 24 September may be noticed. On 23 September the PVA maxima happened to overlay the moisture flux convergence shown earlier in Fig. 3(a). The superimposition of PVA over the low level moisture convergence would have enhanced the latter between 23 and 24 September resulting in the exceptionally heavy falls on 24 September.

5.2. *The analysis of specific humidity*

The expression for horizontal flux divergence in Eqn. (2) consists of two terms, the velocity divergence term multiplied by q and the moisture advection term. Generally the latter, being an order of magnitude higher would have a dominant effect on the flux divergence. In order to examine the observed pattern of flux divergence *vis-a-vis* the advection of moisture (specific humidity), the analysis of latter at 850 hPa of 23 September is shown in Fig. 6. The chart shows a cell of high specific humidity amounting to 20 g/kg over the area covering Himachal Pradesh, hills of west Uttar Pradesh and neighbourhood. Superimposed on the specific humidity isopleths are the winds at 850 hPa. Also shown is the area of heavy rainfall (stipled with dots). The southeasterly winds over the area are seen cutting across the maxima of specific humidity causing strong moisture advection downstream where heavy rainfall has actually occurred. Fig. 7 shows the actual station observations of specific humidity for verifying the grid point analysis of the same parameter shown in Fig.6. The specific humidity figures at Delhi and a neighbouring station, north of it, do suggest existence of pockets of high specific humidity in this area as brought out in the grid point analysis.

6. Concluding remarks

It has been possible to demonstrate with the help of numerical analysis that the area of flood producing heavy rainfall over northwest India during September 1988 had a close spatial correspondence with the area of net moisture flux convergence. The synchronous movement of an area of positive vorticity advection in association with an upper tropospheric trough provided an additional trigger to produce exceptionally heavy falls on 24 September. The study suggests that availability of such numerical products on a routine basis can be of a good predictive value to a synoptic forecaster in rainfall prediction under difficult and unusual synoptic situations.

Acknowledgements

The author is indebted to Dr. N. Sen Roy for guidance and encouragement. The author is also grateful to Dr. S.K. Ghosh, Shri B.M. Chhabra and Shri G.S. Mandal for useful discussions from time to time. Sincere thanks are due to Smt. Usha C. Balani for handling the wordprocessing work and Shri D. Joarder for assistance in data processing and running the computer programs.

References

Dey, Clifford H. and Morone, Lauren L., 1985, "Evolution of the National Meteorological Centre Global Data Assimilation System . January 1982- December 1983", *Mon. Weath. Rev.*, **113**, 3, pp. 304-318.

Di Mego, Geoffrey, J., Patricia, A.Phoebus and James, E. Mc Donell. 1985,"Data Processing Quality Control and Selection for Optimum Interpolation Analyses at the National Meteorological centre" Pro. of the Workshop on the use and quality Control of Met. obsns, 6-9 November 1984, ECMWF, pp. 325-368.

Mc Pherson, R.D., Bergman, K.H., Kistler,R.E. Raseh G.E. and Gordon, D.S., 1979, "The NMC operational global data assimilation system, *Mon. Weath. Rev.*, **107** pp. 1445-1461.

Rao, Y.P., 1976, *Southwest Monsoon*, Chapter 7, India Met. Dep. Met. Monograph, Synop. Met. No. 1/1976, p. 132.

Prasad, K. and Bansal, R.K., 1987, "Objective analysis by optimum Interpolation", India Met. Dep. Pre-publ. Sci. Rep. No. 87/1.