SEVERE AND CATASTROPHIC FLOODS IN THE TAPI AND THE NARMADA

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ABSTRACT

14 cases of Severe and Catastrophic floods in the Tapi and the Narmada have been studied in great detail with far greater emphasis on the synoptic aspects than on other aspects. The conclusion is drawn that study of the synoptic aspects in depth would lead to more timely warnings against heavy rainfall which leads to these floods.

INTRODUCTION

THE Tapi and the Narmada are two of the longest rivers in India which flow from east to west. These two rivers are highly liable to floods during the southwest monsoon period.

Floods are caused by many factors but one of the most important among them is heavy rainfall. A very good paper on the hydrometeorological aspects of the floods in the Tapi and the Narmada has been published by Pant, Abbi and Gupta[1]. They had however dealt with the meteorological aspects, only in a general way. Dhar *et al.*[2] and Abbi *et al.*[3,4] have also studied the hydrometeorological aspects with brief references to the synoptic situations. A perusal of the available published literature thus gives the impression that no study in depth has so far been made on the meteorological (synoptic) aspects of the floods in these two rivers.

The present authors have attempted to fill in this lacuna in our knowledge. Their objective has been not only to probe into the *basic meteorological* mechanism of these floods but also to provide forecasters with additional tools, if possible, for the issue of more timely warnings against heavy rainfall which leads to these floods. The present article is a very brief summary of the authors' detailed study of these aspects.

CASES SELECTED FOR STUDY

Tables I and II show the cases during the period 1923–74 selected for study. The classification of the floods in the tables as severe or catastrophic is based on the damage caused by them as reported in the press or by scientific workers. The data contained in the tables are based on the figures given by UNESCO[5] or by other scientific workers[6–8].

Figure 1 shows the track of the cyclonic storm/depression which caused severe floods in the Upper Narmada in September 1926. It will be seen that the storm moved from North Orissa through East Madhya Pradesh by the 18th and reached the neighbourhood of Sutna in Madhya Pradesh where *it*

TABLE I

Severe and Catastrophic floods in the Tapi (1923–1974)

River discharge measurements made at Kathore which is about 25 km upstream of city of Surat

Sl. No.	Maximum discharge Q_{max} M^3/sec (cumecs)	Date	Total duration of the floods (hours)
1.	13600	14–7–1941	288
2.	21500	6–8–1942	216
3.	25500	24–8–1944	360
4.	37300 (at Ukai)*	17–9–1959	120
5.	42500 (at Ukai)*	6–8–1968	120

* Ukai is 109 km upstream of Surat.

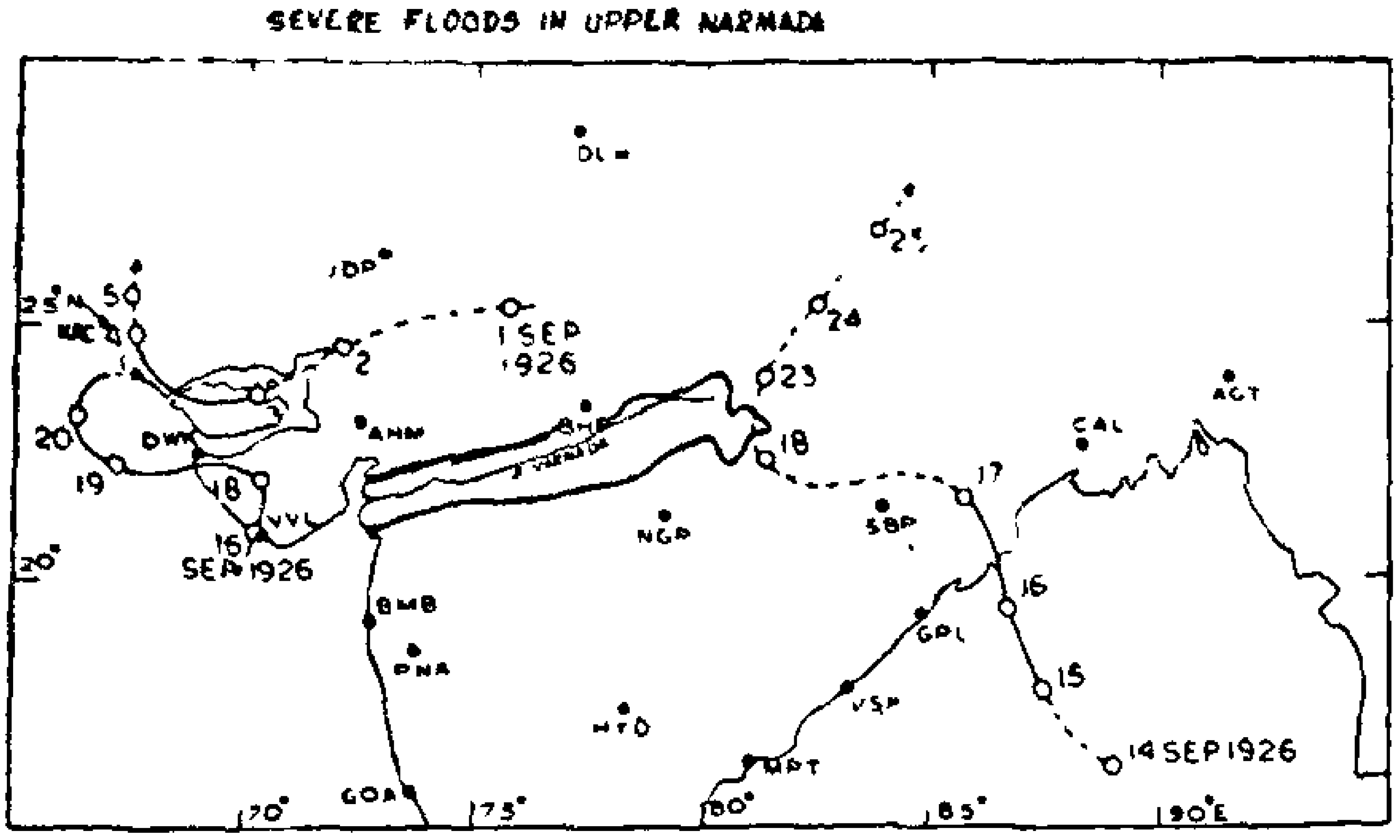
TABLE II

Severe and catastrophic floods in the Narmada (1923–1974)

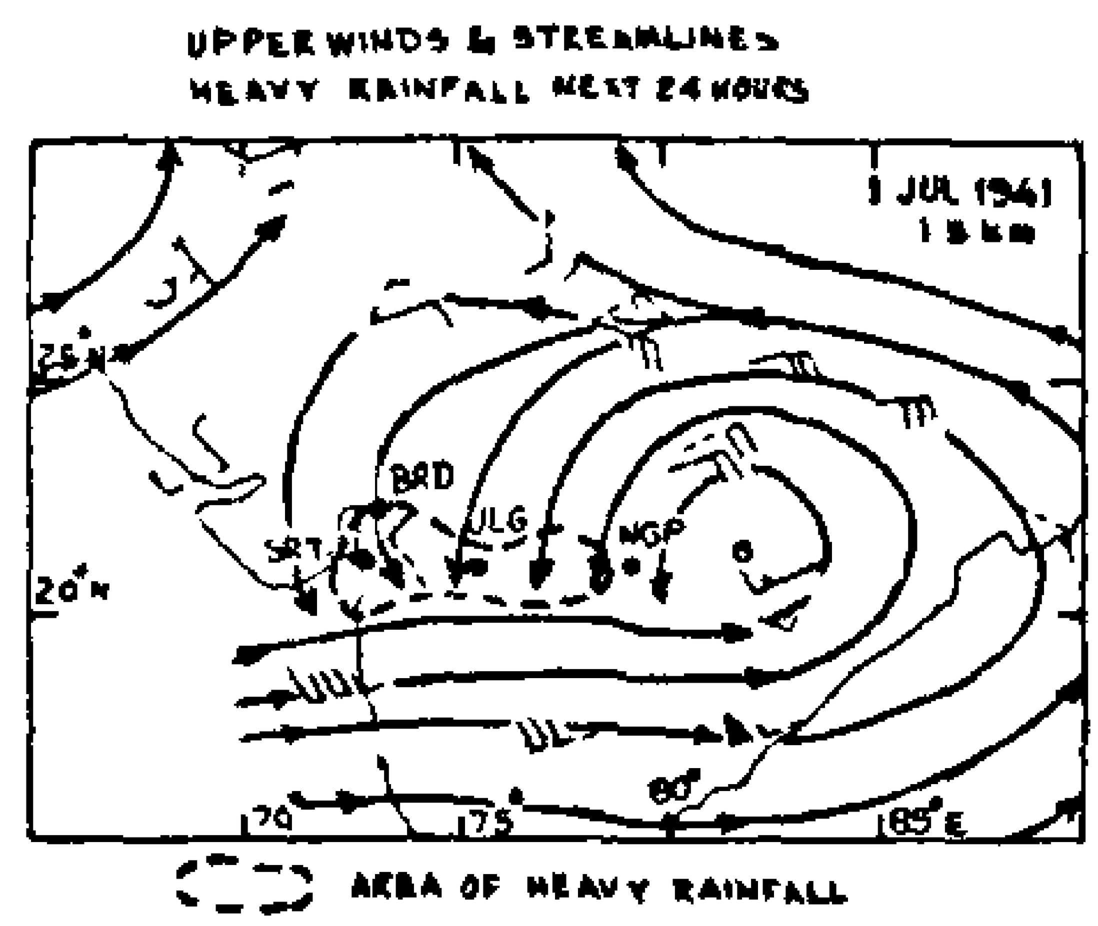
River discharge measurements made at Garudeshwar which is 105 km upstream of Broach.

Sl. No.	Maximum discharge Q_{max} M^3/sec (cumecs)	Date	Total duration of the floods (hours)
1.	..	Sept. 1926	..
2.	..	July 1937	..
3.	30000	24–9–1954	336
4.	43200	15–9–1959	696
5.	47700	17–9–1961	576
6.	22900	13–8–1964	696
7.	58000	6–8–1968	312
8.	59000	6–9–1970	144
9.	..	August 1973	..

N.B.—The dates in thick print in Tables I and II refer to catastrophic floods. All other floods have been classified as severe.



(1)



(2)

FIGS. 1–2. FIG. 1. Shows the Narmada basin and the tracks of the cyclonic systems which had their origin in the Bay of Bengal and the Arabian Sea. Dashed lines indicate the depression-stage while continuous lines indicate the cyclonic-storm stage. Note the persistence of the Bay of Bengal depression over Madhya Pradesh between 19 and 23 September just near the eastern extremity of the Narmada basin. Note also the abrupt curving of the depression towards north-northeast after 23rd. FIG. 2. Arrows with barbs as dashed lines show the direction and speed of the winds at $1 \cdot 5$ km, early in the afternoon. Those shown as continuous lines indicate direction and speed of the upper winds in the morning. The small circle east of Nagpur shows the position of the centre of the depression at 0330 IST on 1 July 1941, *i.e.*, 24 hrs prior to the world-record of rainfall just south of the city of Surat.

remained almost stationary as a deep depression between the 19th and 23rd. It was this unique feature which led to very heavy rainfall and severe floods in the Upper Narmada. A fundamental question therefore arises as to why the deep depression persisted over the same region for such a long period and did not move west or westnorthwestwards as it would have normally done. An explanation of the same is attempted below.

Besides the above-mentioned depression, there was a cyclonic storm over Kathiawar on the 18th (Fig. 1). The coexistence of two deep cyclonic systems only about 1100 km away from each other, resulted in the formation of an inverted V-shaped ridge between the two low-pressure systems. Consequently, the depression over Madhya Pradesh had to remain stationary until the Kathiawar storm dissipated. It has also to be remembered that both the systems had developed in the second half of September when the westerly circulation was becoming more and more pronounced over Pakistan and further north, Consequently, the Madhya Pradesh depression could not move westwards or westnorthwestwards as it would otherwise have done.

The floods in the Tapi in July 1941 are of great interest as they were associated with a world-record of rainfall in the plains (1058 mm in 24 hrs ending at 8 A.M. on 2-7-1941) at a place known as Dharampur in Surat District. This station is just south of the catchment of the Tapi near Surat.

Figure 2 shows the upper winds and stream lines at $1 \cdot 5$ km level on 1 July 1941, *i.e.*, 24 hrs prior to the record rainfall. By far the most important point in this case is that the heaviest rainfall occurred very far away from the centre of the monsoon depression at sea-level in the region just south of the monsoon northerlies. It may be added that similar features had developed sufficiently ahead in other cases also (*e.g.*, in the case of August 1968).

The September 1954 floods in the Narmada are of special interest as a succession of 5 cyclonic systems continuously kept up the activity of the monsoon over the Narmada basin right upto the end of September. The monthly mean 700 and 500 mb charts for the Indian region for September 1954 are in striking contrast to the corresponding charts for September 1957—a month in which the performance of the monsoon was poor and the mosoon itself withdrew from the country very early (the charts have however not been reproduced here).

The factual evidence presented above suggests that sustained monsoon activity (over the Narmada basin) associated with a succession of monsoonal cyclonic systems is intimately connected with the General Circulation of the atmosphere not only over India but over Asia as a whole. There also appears to be

ISOHYETAL PATTERN FOR MAX 2-DAY (14-15 SEP 1959) RAINSTORM IN THE TAPI CATCHMENT

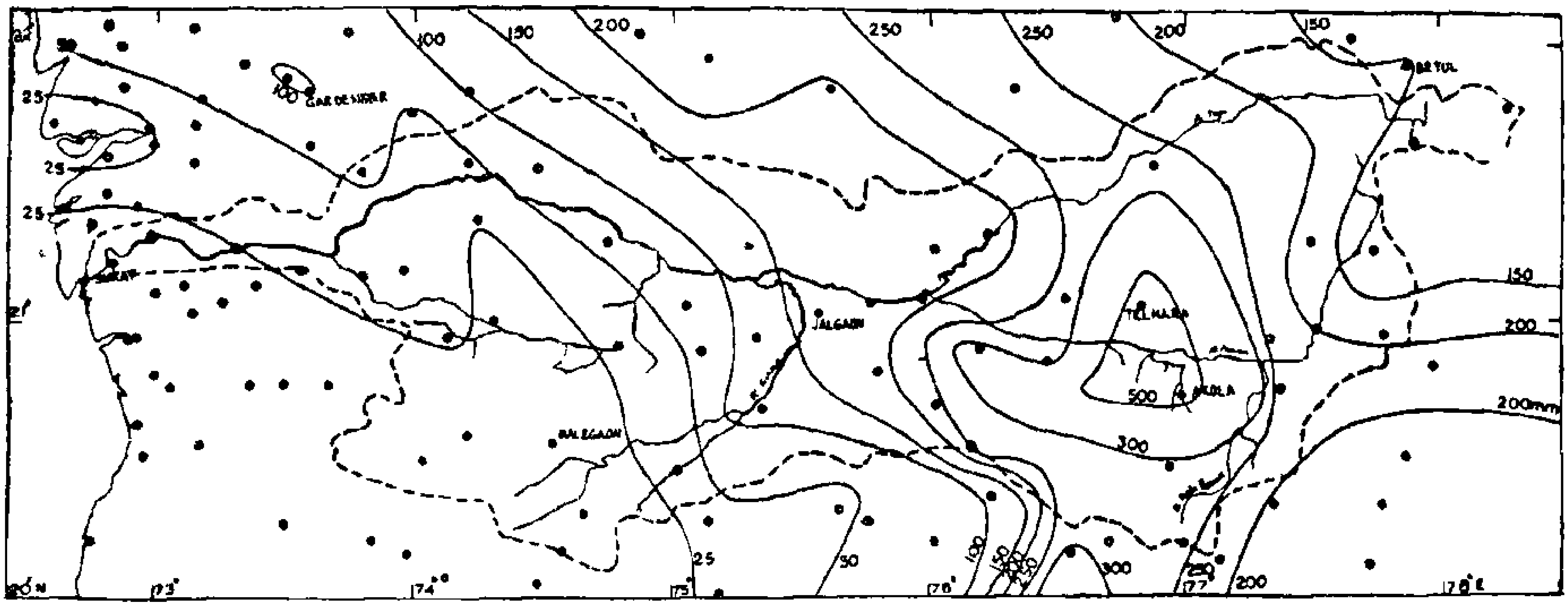


FIG. 3. Shows lines of equal amount of rainfall (isohyets) over the Tapi basin. Note that the rainstorm centre is near the extreme eastern and of the basin and that the isohyets are crowded east of 75° E. Shaded circles indicate the positions of the State Raingauge stations.

atmospheric teleconnections between vigorous monsoon developments over India and weather developments over the Polar and Arctic regions. The authors do not however claim to have established the link between the developments in these two areas far separated from each other. The subject is being pursued further.

The catastrophic floods in the Tapi in September 1959 were associated with good antecedent rainfall followed by an abnormal westsouthwestward movement (I.Met.D.)[8] of a monsoon depression. This direction of movement is well-brought out, not only by the 24 hrs pressure change chart but also by what we may call as the "steering effect" of the flow patterns *above* the field of the monsoon depression (charts not reproduced here). These two parameters therefore provide additional tools for forecasting abnormal direction of movement of the monsoon depressions as in the present case.

Figure 3 shows the isohyetal patterns delineated by the present authors for a maximum 2-day rainstorm over the Tapi basin in association with the catastrophic floods in that river in September 1959. The most interesting feature in these patterns is that the rainstorm centre lay not far from Akola in the upper reaches of the river while there was very little rainfall downstream west of 75° E. Hence the catastrophic floods experienced at Surat were mainly caused by the flood-waters from the upper reaches flowing downstream to Surat. Tidal effects[6] near Surat might also have aggravated the flood situation.

Rao[8] has worked out the time-lag between flood-levels at the various gauging stations across the Tapi and the flood-levels at Kathore as well as at Hope Bridge at Surat itself. According to Rao, an advance warning of 24 to 29 hrs would be possible for floods generated *in the upper basin* as indicated by the gauge-levels, to reach Hope Bridge. Now, we have pointed out on the basis of our synoptic studies that the meteorological parameters should enable us to foresee earlier, the abnormal direction of movement of monsoon depressions similar to those in September 1959, in future. Our studies have also brought out that but for the abnormal direction of movement, catastrophic floods of the observed magnitude would not have occurred in September 1959. Thus we see that the new tool we have provided *would facilitate the issue of even more timely warnings than envisaged by Rao*[8].

One of the most important points connected with the floods in the Tapi and the Narmada is that the courses of these two rivers and the tracks of the monsoon depressions, both, run from east to west. Consequently, the heavy rainfall associated with the progressive westward movement of the depressions aggravate[2] the flood situation.

The severe floods in the Narmada in August 1964 were associated with a series of low pressure waves which moved from the east into the Bay of Bengal and activated the monsoon over the upper reaches of the Narmada. These facts are consistent with the mean 700 mb chart for August 1964 for the Northern Hemisphere[10] published by the U.S. Weather Bureau which shows a significance mean low pressure area east of the Philippines (diagram not produced here).

Figure 4 brings out a comparative analysis of the meteorological factors which produced catastrophic floods in the Tapi and the Narmada in August 1968 and in the Narmada in September 1970. The winds

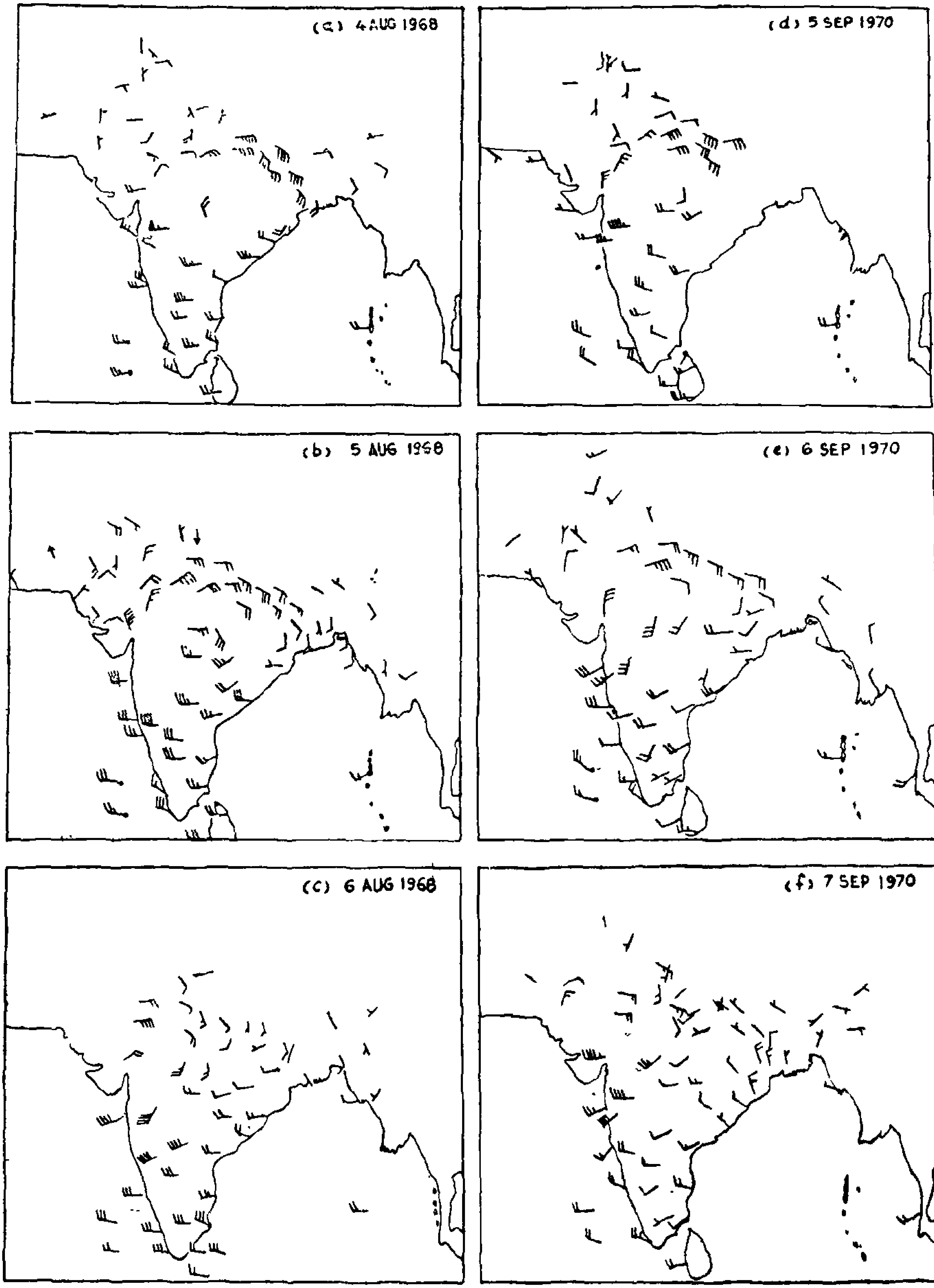


FIG. 4. Arrows with barbs are winds plotted according to international practice. Note the comparative degree of convergence of wind-streams over the Narmada basin (see Fig. 1) in August 1968 and September 1970.

at 1·5 km asl and the associated lower tropospheric convergence on each diagram should be compared with the rainfall distribution during the subsequent 24 hrs, as our main objective is to bring out the prognostic value of the flow-patterns. Without going into details, we would point out that cyclonic vorticity and wind convergence is very high in the lowermost reaches of the Narmada on 5 September 1970. In contrast, the winds over the same area on 4 August 1968 were lighter and the area of convergence and cyclonic vorticity were diffuse. *Subsequently however the conditions became reversed* in the two cases. This explains why the isohyetal averages contributed by the maximum 2-day and 3-day rainstorms in August 1968 over the Narmada[1] were higher than in the corresponding cases in September 1970[4] *vide* Table III.

TABLE III

Storm period over Narmada	Maximum 1-day (mm)	Maximum 2-day (mm)	Maximum 3-day (mm)
4–6 Aug. 1968	76 (5 Aug.)	145 (5–6 Aug.)	174 (4–6 Aug.)
5–7 Sept. 1970	87 (6 Sept.)	127 (5–6 Sept.)	160 (5–7 Sept.)

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1. Pant, P. S., Abbi, S. D. S. and Gupta, D. K., *Proc. Seminar on Flood Control and Use of Water Resources*, 1970, p. 151.
2. Dhar, O. N., Bhattacharya, B. K. and Ghose, G. C., *Ind. Jour. of Power and River Valley Development*, 1975, pp. 405, 406 and 408.
3. Abbi, S. D. S., Gupta, D. K. and Subramanian, S. K., *I.J.M.G.*, 1970, **21**, 539.
4. —, Srivastava, K. K., Hemraj and Brij Bhushan, *Met. Monograph. Hydrology*, No. 2, 1972.
5. UNESCO, *World Catalogue of Very Large Floods*, UNESCO Press, 1976, p. 126.
6. Parmar, F. H. and Shelat, R. N., *Proc. Seminar on Flood Control and Use of Water Resources*, 1970, p. 36.
7. Purohit, M. U., *Ibid.*, 1970, p. 50.
8. Rao, B. S., *Ibid.*, 1970, p. 60.
9. India Met. Dep., *Tracks of Cyclonic Storms and Depressions*, 1964, *and Supplement*, 1972.
10. U.S. Weather Bureau, *Mon. Weather Rev.*, 1964, **92**, 536.