551.577.37 : 551.553.21 : 551.571.4

SOME EXCEPTIONALLY HEAVY RAINFALL CASES DURING INDIAN SOUTHWEST MONSOON ASSOCIATED WITH CONTRASTING MOISTURE DISTRIBUTION IN THE VERTICAL

1.1. Typical cases reminding of cloud bursts in the Indian summer monsoon field are discussed, when sudden and rapid exceedingly heavy rains were localized in a small area. In some of the cases there was no major monsoon system like monsoon depression and, in some, when attended by a major monsoon system like monsoon depression, particularly in a small area the rainfall far exceeded the usual expectations. The flash floods and severe inundations took a heavy toll of human life and property, besides severe dislocations.

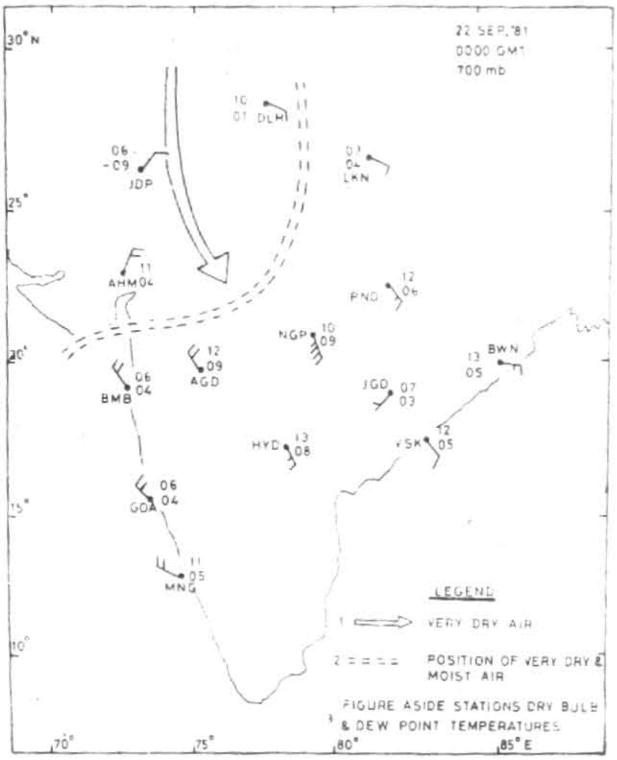

Fig. 1.

1.2. The cases discussed are those of (1) the Bombay area of 22/23 September 1981 : Santacruz, Colaba and Alibag reporting 32, 24 and 22 cm rain respectively as on the morning of 23rd, (2) the Bombay area of 21/22 June 1982, Alibag (Bombay) recording 22 cm as on the morning of 22nd, and (3) the Sand heads area of 19 to 21 June 1981, Sandheads reporting 47 and 63 cm respectively for two successive days as on the mornings of 20th and 21st. In all the events the exceedingly heavy rains were localized in only a small area with neighbouring places far less amounts or no rain. In the first two events there was no major monsoon system and, in the next two events a monsoon depression system was moving across the area.

2.1. *The events of the Bombay area of September* 1981 *and June* 1982 — In the September 1981 event, as on 22nd, the monsoon trough extended from south Gujarat to the Andaman seas with an embedded migratory monsoon low that weakened from a depression moving earlier across the Andhra coasts, when in the extreme north western disturbances were moving, one such being over south Pakistan (Fig. 2). Considerably dry air in the wake was drawn across Rajasthan to south Gujarat, and the lowest 850 hPa level still with monsoon air, the partition of this very dry and moist air was seen pronounced at 700 hPa level (Fig. 1) passing between Bombay and Ahmedabad. In the upper troposphere, at the representative level of 200 hPa (Fig. 2), two wave troughs were propagating close to each other — the westerly extended to Saurashtra coasts and the easterly amplified to north Konkan coasts —the ridge line passing approximately around 20°N. As on the next day morning, with moderate to heavy rains distributed in almost the entire Maharashtra and parts of Gujarat, exceedingly heavy rains were localized around Bombay, the amount from Santacruz being 32 cm (Fig.2). In June 1982 event (not shown), as on 21st, an off-shore sea level trough in the monsoon field extended southwards from Gujarat coasts to the east Arabian Sea, in the presence of a western disturbance moving across Pakistan — the resultant partition of very dry and moist air at 750 hPa level passing through an area between Bombay and Goa, when in the upper troposphere ridge line out of the propagation of a westerly and an easterly wave was around 22°N. As on the next day morning, with distributed rainfall, one or two heavy, a small area of Bombay received exceedingly heavy falls, the amount from Alibag being 22 cm.

2.2. *The events of the Sandheads area of June 1981*— On 19th, a well marked low pressure area of north Bay of Bengal was underlying the divergent sector of an upper easterly wave at a time, when western disturbances were moving across extreme north of the country and moderate to severe heat wave conditions prevailed in central India the consequent partition of very dry and moist air, pronounced at 650 hPa level passing through an area between Sandheads and the Sunderban coasts (not shown). On 20th the well marked low became a deep depression, still underlying the divergent sector of the upper easterly wave and, the partition of very dry and moist air at 650 hPa level continued to run slightly southwest of Sandheads area (Fig. 4). Along with the distributed rainfall, rather heavy to heavy at places, as on the morning of 20th and 21st, a small area of Sandheads recorded exceedingly heavy falls of 47 and 63 cm respectively, against far less amounts elsewhere in the field (Fig. 4).

3.1. *Discussion*—Several Indian authors have earlier attributed the heavy rains of Indian summer monsoon to either well defined synoptic systems or orography. Rao (1976) and Koteswaram & George (1958) discussed several combinations of rain bearing systems with upper air features in westerlies and easterlies. Dominated although by upper westerly and easterly waves, there was no major monsoon system except for a migratory monsoon low around Marathwada in September 1981 and an off-shore sea level trough in the June 1982 event, the proximity of the upper ridge lines been also far from near the seats of lower convergences contributing towards the cause of such exceedingly heavy falls confined only around the Bombay area. Even then, in the light of the discourses of Sengupta (1986) on the small scale accentuations leading to flash floods in Rajasthan, the conventional method of superimposition of vergence and vorticity (Millar and Keshavamurthy 1968) is tried. It is seen, that, allowing participation of favourable vergence and vorticity for appreciable rainfall in parts of the western peninsula, the presence of lower divergence $+1 \times 10^{-5}$/sec in the September 1981 event (Fig. 2) and lower anticyclonic vorticity—1×10^{-5}/sec in the June 1982 event (not shown) vitiated the prospect of any favourable conjunction over the Bombay area for delineating an area of such high accentuation. Same way, in the case of the two events of the Sandheads area of June 1981, far excelling the usual expectations from so many monsoon depressions of the past underlying upper divergent sectors, despite appreciable lower convergence-cum cyclonic vorticity of the depression field, the order of

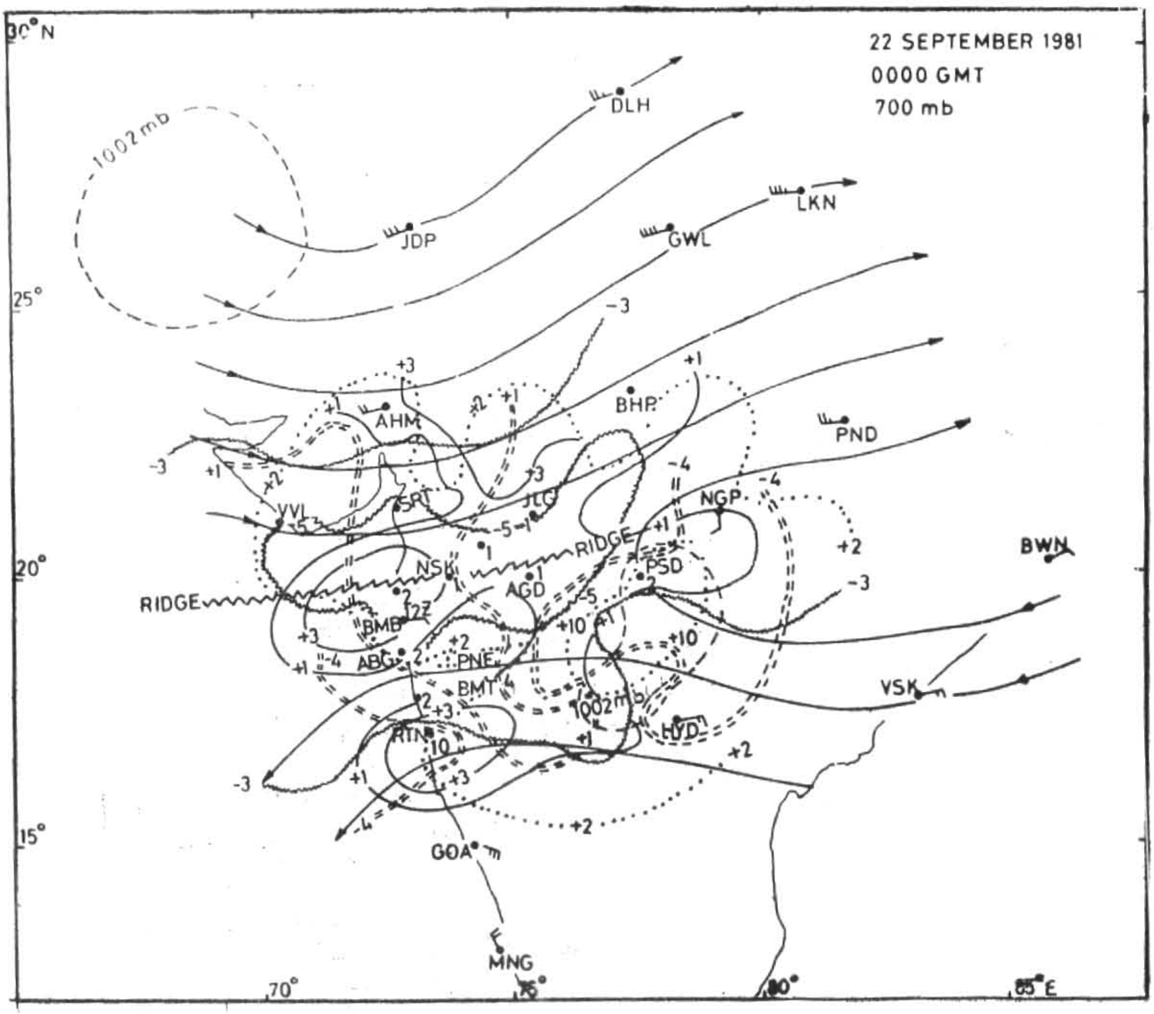

Fig. 2.

superimposing upper divergences +2 (not shown) and $+6\times10^{-5}$/sec (Fig. 4) drawn from the upper divergent sectors of 19th and 20th respectively does not appear to be commensurate with the development that can release such exceedingly heavy falls like 47 and 63 cm when read with the table of Petterssen 1956. An identifying feature for such a typical situation is, therefore, necessary. A further examination of the synoptic field reveals the presence of a common feature — the infringement of very dry air in the wake of far north western disturbances and the associated upper westerly waves marking clear partition of very dry and moist air in the middle part of the lower troposphere, keeping the lowest levels with moist monsoon air. From the point of view of thermodynamics such a contrast of moisture distribution prompts vertical motion and convective development, that can lead to sustained heavy rainfall rates accumulating to heavy amounts when acted further by triggers aloft.

3.2. *Isentropic method* — With the contention of Hill (1969), that a distinct humidity regime can also be taken as a participant of a front when clear thermal fronts are less conceived in the tropics (much more so in the Indian summer monsoon), Sengupta and Marathe (1988, 1990) discussed certain weather developments in central India during winter and also in the break monsoon period by the isentropic method, elaborating in the light of Byers (1974) and Petterssen (1940) on the delineation of ascending moist air of condensation of estimated vertical velocity and its further stimulation towards generation of higher vertical velocities (Panofsky 1946) through upper triggering agencies required for intense developments of exceedingly heavy rains.

4. *Determination of accentuation* — Accordingly, isentropic charts for chosen potential temperatures are

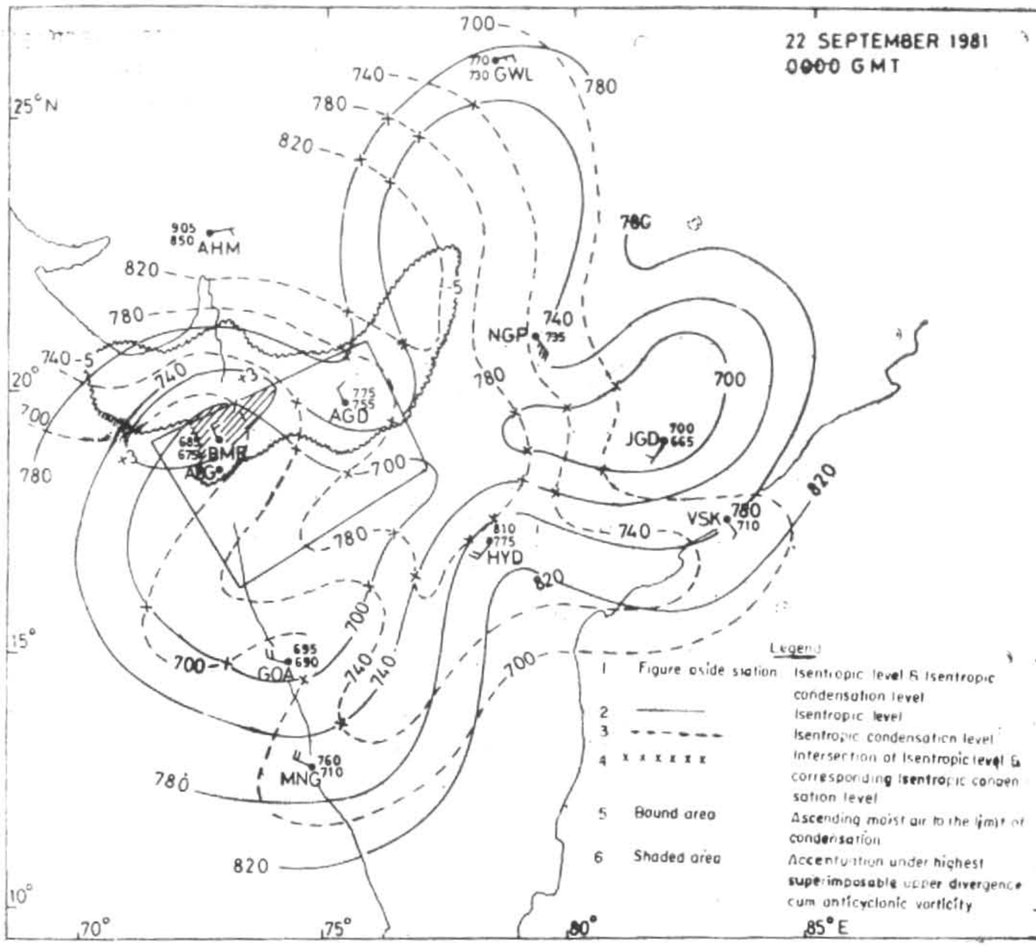

Fig. 3. 22 September 1981, 0000 GMT Isentropic analysis potential temperature 310° K

drawn, vertical velocities computed from the normal components of wind in the upgradient of the isentropic surfaces and, from the intersection of the isentropic levels and the corresponding isentropic condensation levels, the area of ascending moist air of condensation demarcated. The estimated vertical velocities are found to be about 5 cm/sec (Fig. 3) and 2.5 cm/sec respectively for the two Bombay events and, 2.5 cm /sec and 3 cm/sec respectively for the two Sandheads events (Fig. 4). For delineating areas of highest accentuated rainfall, the optimum conjunction of superimposing upper divergence-cum-anticyclonic vorticity of the field is tried aloft the area of ascending moist air of condensation. Reading *plus* for upper divergence and *minus* for upper anticyclonic vorticity, it comes out to be with + 3 cum — 5 (Fig. 3) and + 2 cum — 3 (not shown) respectively for the two Bombay events and with +2 cum —2 (not shown) and +6 cum —2 (Fig. 4) respectively for the two Sandheads events — delineating only small areas of highest accentuation.

5. *Conclusion* — The study clearly brings to light the utility of a kind of frontal assumption in the Indian summer monsoon field, involving isentropic method, for explaining some of the exhorbitantly heavy rains localized in small areas — hitherto discussed in more or less, a synoptic scale. The identifying feature remains as a clear partition of very dry and moist air around the middle of the lower troposphere, with reference to a source of considerable upper divergence and anticyclonic vorticity aloft that can trigger the ascending moist air of condensation towards an intense development around the partition of air.

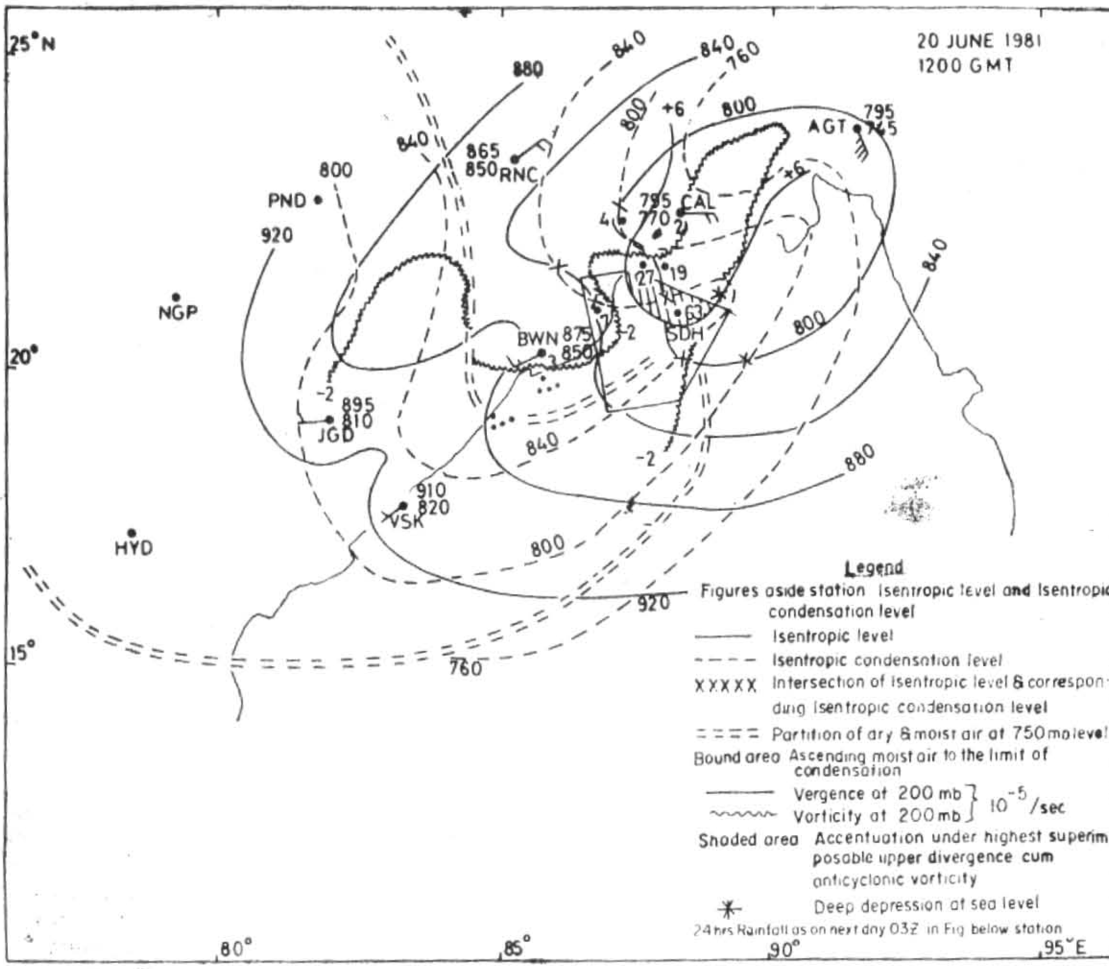

Fig. 4. 20 June 1981, 1200 GMT Isentropic analysis potential temperature at 310° K

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S. SENGUPTA
R. N. CHOWDHURY

Meteorological Office, Nagpur

3 February 1984