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Localized floods in Rajasthan owing to exceedingly heavy rains : Case study of small scale accentuations in the Indian summer monsoon field associated with intense upper anticyclonic shear zones

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सार — अधिकांश राजस्थान में वार्षिक वर्षण बहुत कम होता है और वहां की मृदा व भूतल भी उससे जुड़ा हुआ है । अकस्मात तेज व भारी वर्षा से , चाहे वह एक या दो दिन ही हो, स्थानीय रूप से भारी बाढ़ आ सकती है तथा उससे बहुत अधिक क्षति हो सकती है । भारतीय ग्रीष्म-कालीन मानसून क्षेत्र में इनमें से कुछ स्थितियों के अध्ययन से पता चलता है कि वास्तव में भिन्नात्मक अध्यारोपण और इसलिए पहले ही से मौजूद निम्न क्षोभमण्डलीय चक्रवाती भ्रमिलों के आंशिक बलाघात के कारण ही छोटे-छोटे या स्थानीय क्षेत्रों में इतनी अधिकता से भारी वर्षा होती है । ये चक्रवाती भ्रमिल ऊपरी प्रति चक्रवाती अपरूपण क्षेत्रों में बनते है और ये अपरूपण क्षेत्र एक ऊपरी पछुआ पवन तथा एक पुरवा पवन के फैलने व बढ़ने के कारण बनते हैं ।

ABSTRACT. Most of Rajasthan being an area of less annual rainfall, soil and topography adhered to the condition, sudden, rapid and exceedingly heavy rains for even a day or two, in a localized area can cause severe floods with natural calamity of very high order. Study of some of these situations in the Indian summer monsoon field reveals, that, fractional superimposition and, therefore, fractional accentuation of pre-existing lower tropospheric cyclonic vortices by upper anticyclonic shear zones formed out of propagation and amplification of an upper westerly and an easterly wave, in close proximity, is actually responsible for such exceedingly heavy falls in meso or small areas.

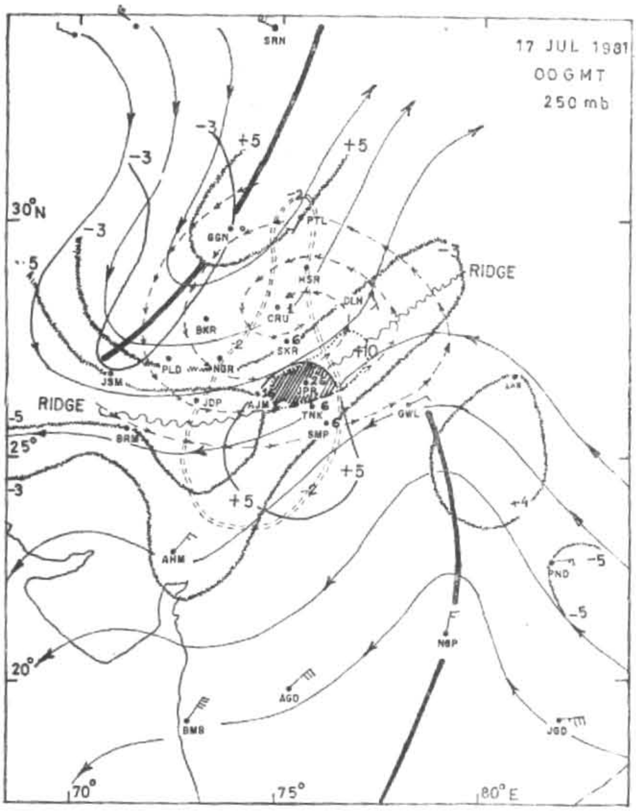
1. Introduction

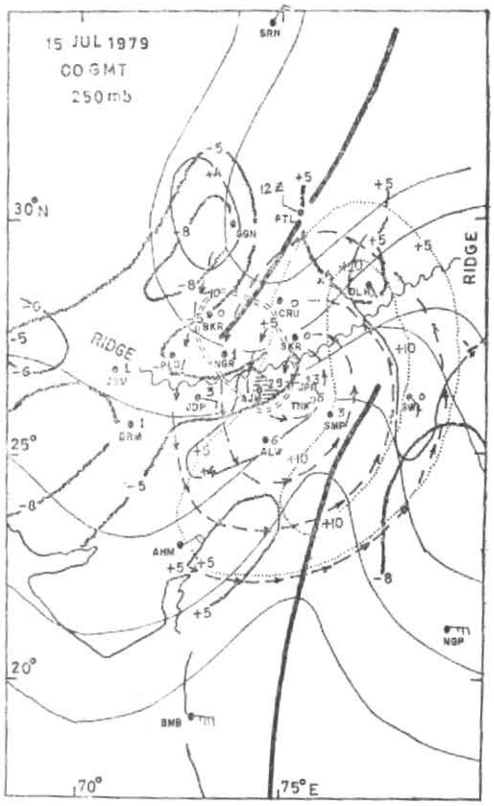
1.1. In this case study, intense meso/small scale accentuations in Rajasthan, during the Indian summer monsoon are discussed, because of the great importance and desired interest on the issue of a situation created by severe and devastating floods from sudden, rapid and exceedingly heavy rains localized in small or meso areas of a so called desert region. The cases taken up are those of July 1981 and July 1978, when unattended by any monsoon disturbance and that of July 1979 when attended by a migratory monsoon low.

1.2. In all the three cases, there had been, of course, a fairly wide area of light to moderate rains, but, embedded in it, were spectacularly defined meso or small areas of exceedingly heavy falls that brought in natural calamity of very high order. In the case of 17 to 19 July 1981, the city of Jaipur remained in the onslaught of incessant exceedingly heavy downpour for successive two to three days, bringing in unprecedented floods and devastation for Jaipur and around. In the case of 18 to 20 July 1978, small areas in northeast Rajasthan, around Pilani-Sikar-Churu remained under exceedingly heavy rains for successive days, resulting into heavy loss and devastation. In the case of 14-16 July 1979, exceedingly heavy rains were localized in parts of central Rajasthan, starting from around Swai Madhopur to Ajmer to Jodhpur areas, bringing in severe floods in the river *Luni* and leaving about 600 people dead or missing.

2. Qualitative survey

2.1. *Case of 16-18 July 1981* — In association with western disturbances moving across extreme north of the country, in the lower troposphere, cyclonic vortices were present in northwest India. On 15th, these vortices were over Jammu & Kashmir, central Rajasthan and northwest Madhya Pradesh. In the upper tropophere, around 300/200 mb level, one westerly wave was already in the exit across Western Himalayas when another one was advancing across Iran, at a time, when, one easterly wave was already in the exit across Gujarat and the west coast, whilst another one was advancing across east Madhya Pradesh. On 16th, the lower cyclonic vortex over northwest Madhya Pradesh was absent and, the one over central Rajasthan, at the representative level of 700 mb became well marked. In the upper troposphere, at the representative level of 250 mb, the advancing westerly wave moved into central Pakistan and the approaching easterly wave to central Madhya Pradesh, both the waves amplifying and gaining latitude, the amplified easterly trough possessed by a captive cyclonic vortex over west Uttar Pradesh. The resultant





—— STREAM LINES 250 mb; → — → STREAM LINES 700 mb; FIGURES ASIDE STATIONS 24 Hr. RAINFALL AS ON NEXT DAY 03 GMT;
—— UPPER VERGENCE 250 mb; ~~~~ VORTICITY 250 mb; ==== LOWER VERGENCE 700 mb; ...... VORTICITY 700 mb (10^{-5}/ Sec);
SHADED AREA HIGHEST ACCENTUATION; UNITS OF VERGENCE AND VORTICITY 10^{-5} sec^{-1}

Fig. 1

Fig. 2

wind profile at the extreme forward ends of the two upper wave troughs in close proximity presented an almost zonal anticyclonic shear zone, ridge line passing close through Jaisalmer-Phalodi-Nagaur-Churu-Ambala, superimposing a part of the lower cyclonic vortex. Rainfall activity started all around the upper ridge line, marked with a spectacularly very heavy fall for a meso area around Bikaner; Bikaner recording 13 cm next day morning against far less amounts in the vicinity. On 17th, the lower cyclonic vortex moved northeast near Sikar and, in the upper troposphere, the westerly wave moved fast amplifying upto central Rajasthan, whilst the easterly wave moved slight, losing the captive cylconic vortex (Fig. 1). Ridge line of the resultant upper anticyclonic shear zone now passed close through Barmer-Ajmer-Jaipur-Moradabad, superimposed on a part of the lower cyclonic vortex (Fig. 1). Along with other less significant rains either side of the ridge line, a spectacularly small area of exceedingly heavy rains was marked around Ajmer-Jaipur; Jaipur and Ajmer recording 26 and 16 cm respectivly next day morning (Fig. 1). On 18th, the lower cyclonic vortex moved futher northeast near Mathura and, both the upper tropospheric waves moved considerably fast, about to cross each other with ridge line of the resultant upper anticyclonic shear zone passing close through Jailsalmer-Jaipur-Alwar-Bulandhsar superimposed on a part of the lower cyclonic vortex. A meso area of Jaipur again recorded exceptionally heavy fall of 36 cm next day morning. On 19th, the upper wave troughs moved away crossing each other and the upper shear zone was less prominent. Rainfall activity decreased abruptly except for remnant exceedingly heavy falls of 24 to 13 cm in the Jaipur-Tonkraj area.

2.2. *The case of* 18-20 *July* 1978 — On 17th, in association with a western disturbance, a lower tropospheric cyclonic circulation was lying around north Pakistan, when, the seasonal trough in the subcontinent was near the foot hills of the Himalayas. In the upper troposphere, one westerly wave was in the exit across Nepal Himalayas and another one was advancing across Afghanistan, at a time, when an easterly wave was also progressing across eastern Peninsula. On 18th, the lower cyclonic vortex at the representative level of 850 mb moved near Lyalpur (Pakistan) and at the upper representative level of 200 mb, both the westerly and the easterly waves moved fast, coming to a close proximity and representing an upper anticyclonic shear zone of ridge line close through Bahawalpur-Bikaner-Sikar-Moradabad superimposed on a part of the lower cyclonic vortex. A small area between Nagaur and Churu recorded exceedingly heavy falls : Churu reporting 16 cm and Jhunjhunu and Nagaur 11 cm each next day morning. On 19th, the lower cyclonic vortex moved between Ganganagar and Churu when both the upper tropospheric waves were considerably amplified, the easterly wave moving fast with a captive cyclonic vortex over the hills of Uttar Pradesh and, ridge line of the resultant upper anticyclonic shear zone passing close through Nawabshah-Shergarh-Nagaur-Sikar-Moradabad (Fig. 3) imposed on a part of the lower cyclonic vortex. A meso area around Pilani recorded exceedingly heavy *fall of 18 cm* next day morning against far less amounts in the vicinity (Fig. 3). On 20th, the lower cyclonic vortex moved near Churu, both the upper tropospheric waves retaining the high amplification, the easterly wave progressed further, losing the captive cyclonic vortex; presenting upper anticyclonic shear zone of ridge line almost the same as the day before imposed on a part of the lower cyclonic vortex. A small area of Pilani-Sikar close to the upper ridge line recorded exceedingly heavy falls; Pilani and Sikar reporting 22 and 17 cm respectively next day morning. On 21st, the upper wave troughs moved away considerably crossing each other and, the upper anticyclonic shear zone was less perceptible for a superimposition resulting into abrupt end of rainfall activity.

2.3. *The case of* 14-16 *July* 1979 — On 13th a migratory monsoon low as reminiscence of a monsoon depression was lying over north Madhya Pradesh with associated cyclonic circulation extending to mid-troposphere, at a time when in the upper troposphere, a westerly wave over Jammu & Kashmir extended to west Pakistan and an easterly wave was progressing across east Uttar Pradesh, representing an upper anticyclonic shear zone across central Rajasthan to north Uttar Pradesh. There was no favourable superimposition and no heavy fall of any distinction. On 14th, the lower cyclonic vortex at the representative level of 700 mb moved near Tonkraj and, in the upper troposphere, at the representative level of 250 mb, with very slight progression both the waves amplified considerably, the easterly one possessing a captive cyclonic vortex over west Uttar Pradesh : presenting an upper anticyclonic shear zone of ridge line passing close through Radhanpur-Udaipur-Tonkraj-Aligarh imposed on a part of the lower cyclonic vortex. A meso area around Swai Madhopur recorded exceedingly heavy fall of 19 cm next day morning compared to far less amounts in the vicinity. On 15th, the lower cyclonic vortex moved between Ajmer and Jaipur, the upper tropospheric waves moved considerably forward and damped, almost approaching each other, the ridge line of the resultant upper anticyclonic shear zone passing close through Pokran-Merla Road-Alwar-Moradabad, imposed on a part of the lower cyclonic vortex (Fig. 2). A meso area around Ajmer recorded an exceptionally heavy fall of 29 cm next day morning (Fig. 2). On 16th, the lower cyclonic vortex moved near Bhilwara, both the upper tropospheric waves moving fast crossed each other; the ridge line of the resultant upper anticyclonic shear zone passing close through Pokran-Jalore-Udaipur-Swai Madhopur and imposed on a part of the lower cyclonic vortex. A small area between Jodhpur and Mount Abu received very heavy falls; Jodhpur and Mount Abu recording 12 and 13 cm respectively next day morning. On 17th, there was no upper anticyclonic shear zone for superimposition and rainfall activity decreased abruptly.

3. Discussion

3.1. *Type of accentuation and its identification* — Isolated heavy rains do occur in the Indian summer monsoon field associated with depressions, cyclonic storms, orography etc, as also in association with western disturbances and upper westerly waves activating monsoon lows and quite often ushering advancement of monsoon in Rajasthan (Rao 1976), similar discussion also made by Gupta (1984), while referring situations relating to July 1979 events. These discussions, so far, had been in the synoptic scale only, no mention made of the meso or small scale. So, in the absence of any

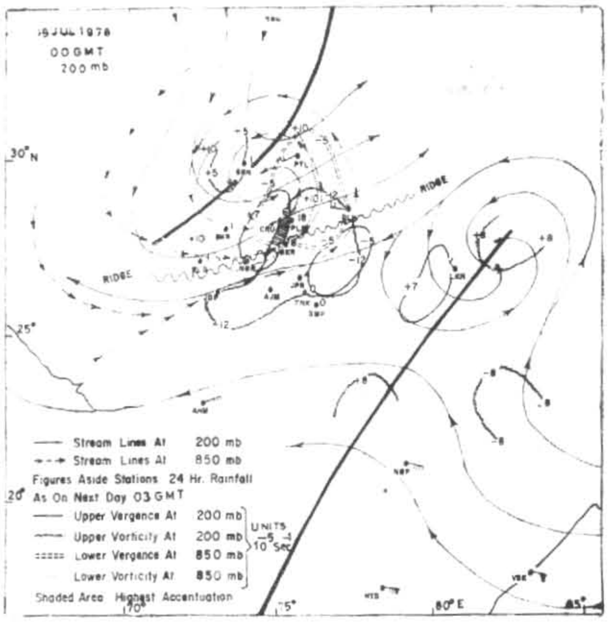


Fig. 3

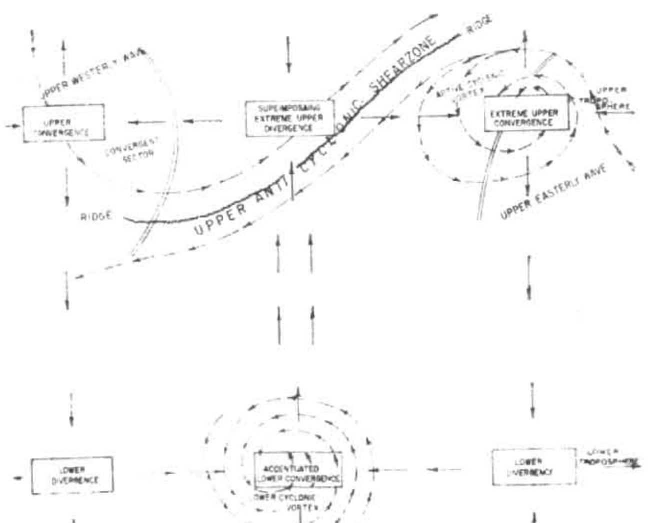


Fig. 4. Schematic model : Accentuation process for superimposing upper anticyclonic shear zone with lower cyclonic vortex

major system or orography, to account for such sudden, rapid and exceedingly heavy rains typically confined in only a meso or small area, causing localized floods and devastation, it requires a separate discussion and identification. The participants in the lower troposphere are the pre-existing convergences in the form of : (1) cyclonic vortices out of western disturbances for the events of July 1981 and July 1978 cases (Figs. 1 & 3) and (2) cyclonic vortices in the form of migratory monsoon lows for the events in the July 1979 case (Fig. 2). In the upper troposphere, typically, for all the events of the three cases there is a common feature; an elongated, narrow, almost zonal anticylonic shear zone (Figs. 1-3). This upper anticyclonic shear zone is also seen to be fractionally imposed on a part of the lower cyclonic vortex. Intense development in a small or meso area, corresponding to the superimposition, is triggered off, where localized exceedingly heavy rains occur. We thus get a typical situation where a synoptic scale, by and large, is condensed into a small or meso scale; the upper anticyclonic shear zone serving as the forerunner, whose recognition with reference to the lower cyclonic vortex becomes a tool for identification; the process of development, obviously being the favourable superimposition of upper divergence aloft lower convergence.

3.2. *The upper anticyclonic shear zone and its role in the development*—It can be seen in all the events of the cases that the upper anticyclonic shear zones are created under progression and amplification of a westerly and an easterly wave, coming to a close proximity and allowing the farthest ends of the respective wave troughs present an almost zonal, narrow and elongated zone of high anticyclonic shear. Application of the equation of potential vorticity $\zeta = f + \frac{v}{r_s} - \frac{\partial v}{\partial n} \Big/ \triangle p$ = constant into this shear zone shows that the curvature term v/r_s vanishes because of $r_s \approx \infty$, the shear term $\partial v/\partial n$ assumes very high positive value immediately around the ridge line and the coriolis parameter f is almost unchanged for the zonal narrow zone. The numerator of the equation, therefore, decreases enormously and for constancy of the equation, the denominator $\triangle p$, the vergence term also decreases abruptly as to signify extreme divergence around the ridge line. Further, the presence of cyclonic vortex at the peak of the upper easterly trough (Fig. 3) and the convergent sector of the upper westerly trough, respectively to the east and west of the upper anticyclonic shear zone act as the seats of high upper convergence, that facilitates strengthening and, therefore, enhancing the process of divergence in the upper anticyclonic shear zone. In fact, in each of the cases of July 1981, July 1978 and July 1979, there are events (Figs. 2 & 3) to show that highest accentuational activity of rainfall started with the assumption of this captive cyclonic vortex in the upper easterly trough. The upper anticyclonic shear zone being narrow and elongated, the high divergence out of it can, however, be favourably imposed on only a part of the lower convergence. Moist air of the lower troposphere appropriate to this optimum conjunction is only subjected to the intense development, marking only a meso or small area of exceedingly heavy falls. Sengupta (1977) discussed on certain such cases outside the Rajasthan area, but, for a quantitative substantiation.

4. Quantitative survey

4.1. *Object of the quantitative survey and the method used* — The qualitative view, however, gives a fair approximation of the superimpostion and for delineating the exact area of accentuation and substantiation of the result, a quantitative treatment is necessary. This is done by evaluating vergence and vorticity at the representative upper and lower layers. The area of highest accentuation is delineated by trying for an optimum conjunction of highest upper divergence *cum* anticyclonic vorticity aloft highest lower covergence *cum* cyclonic vorticity (Miller and Keshavamurthy 1968), preference given to the highest deployable upper divergence that governs the degree of accentuation (Petterssen 1956).

4.2. *Results of the quantitative survey* — Vergence and vorticity in the units of 10^{-5}/sec for the representative upper and lower layers of all the events of the cases are plotted on a map, as can be seen in Figs. 1-3. An examination of the values of vergence and vorticity in all the events reflect very clearly on the progression and amplification of the upper tropospheric waves as also the upper anticyclonic shear zones, around the ridge line of which the highest upper divergence *cum* anticyclonic vorticity is mostly located. Same way, vergence and vorticity in respect of the lower cyclonic vortices and their movements are reflected in the map.

4.3. *Delineation of the exact aress of accentuation and substantiation of the result* — For favourable superimposition, an optimum conjunction is tried on the map of the highest upper divergence *cum* anticyclonic vorticity aloft lower convergence *cum* cyclonic vorticity. The meso or small areas delineated are seen to be corresponding precisely to the localized areas of exceedingly heavy falls and located very close to the upper ridge line. For the July 1981 events, it can be seen, where, 700 mb level is the lower representative layer and 250 mb level the upper representative layer. The delineated areas are seen to be corresponding to : the meso area of Bikaner of 16th under optimum conjunction of upper divergence +2 cm *cum* anticyclonic vorticity —5 with lower convergence —2 cm *cum* cyclonic vorticity +3; the small Ajmer-Jaipur area of 17th under optimum conjunction of highest upper divergence +5 *cum* anticyclonic vorticity —5 with lower convergence —2 *cum* cyclonic vorticity + 5 (Fig. 1) and, the meso area around Jaipur of 18th under optimum conjunction of upper divergence +3 *cum* anticyclonic vorticity —6 with lower convergence—4 *cum* cyclonic vorticity +6. The July 1978 events can be seen where 850 mb level is the lower representative layer and 200 mb level the upper representative layer. The delineated areas are seen to be corresponding to : the small area between Nagaur and Churu of 18th under optimum conjunction of highest upper divergence +2 *cum* anticyclonic vorticity —5 with lower convergence —2 *cum* cyclonic vorticity +4; a meso area around Pilani of 19th under optimum conjunction of upper divergence +4 *cum* anticyclonic vorticity —8 with lower covergence —2 *cum* cyclonic vorticity +5 (Fig. 3) and, the small Pilani-Sikar area of 20th under optimum conjunction of upper divergence +2 *cum* anticyclonic vorticity —6 with lower convergence —2 *cum* cyclonic vorticity +8. The July 1979 events can be seen where, 700 mb level is the representative lower layer and 250 mb level the representative upper layer. The delineated areas are seen to be corresponding to : the small area around Swai Madhopur-Tankraj of 14th under optimum conjunction of upper divergence +4 *cum* anticyclonic vorticity —5 with lower convergence —2 *cum* cyclonic vorticity +5; a meso area around Ajmer of 15th under optimum conjunction of upper divergence +4 *cum* anticyclonic vorticity —5 with lower convergence +3 *cum* cyclonic vorticity +8 (Fig. 2) and, a small area between Mount Abu and Jodhpur of 16th under optimum conjunction of upper divergence +2 *cum* anticyclonic vorticity —10 with lower convergence —2 *cum* cyclonic vorticity +4. In all the events of the cases, however, far less amounts of rainfall are seen to be distributed in a wider area appropriate of lower orders of conjunction.

5. Conclusion and a model thereof

5.1. It can now be concluded that some of the localized severe floods of Rajasthan in the Indian summer monsoon are the result of fractional accentuation of a part of pre-existing lower cyclonic vortex by a created upper anticylonic shear zone; the lower cyclonic vortex being either from a western disturbance or a migratory monsoon low and the upper anticylonic shear zone formed out of progression and amplification of a westerly and an easterly wave in close proximity. The process is unique in the sense that the field is synoptic, but the product is in the meso or small scale. The forerunner of such typical case is the upper anticyclonic shear zone coupled either side by two convergent zones of the two progressing wave troughs, remarkably the captive cyclonic vortex of the amplified easterly trough.

5.2. A schematic model outlining this upper anticyclonic shear zone is appropriate enough for the favourable conjunction that takes place with a part of the lower cyclonic vortex. Supported by both qualitative and the quantitative discussions, a schematic model on the formation of this upper anticyclonic shear zone and the processes involved in the development under conjunction with the lower cyclonic vortex is shown in Fig. 4. the diagram and the notes therein being self illustrative.

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