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Severe floods in Kathiawar and Kutch caused by a mid-tropospheric disturbance

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ABSTRACT. The paper contains a description of a quasi-stationary cyclonic disturbance in July 1935 which persisted for about 18 days in the mid-troposphere and caused intermittent very heavy rainfall leading to severe floods in Kathiawar and Kutch. The importance of this fact-finding study from the point of view of the Monsoon Experiment 1979, is pointed out.

1. Introduction

The authors are at present engaged in a study of severe floods in the rivers in India during the last 50 years and more. During the course of their investigations, they came across a case of severe floods in Kathiawar and Kutch (Fig. 2a) in July 1935 which caused considerable damage to life* and property (India met. Dep. 1935). A preliminary study of the problem indicated that the floods were *not* caused by the usual monsoon depressions from the Bay of Bengal moving at surface-level across the State of Gujarat (Rao 1976).

The important point which came up from this was whether a cyclonic system whose seat of activity lay only in the upper air could cause severe floods in a big area like Kathiawar and Kutch where there were no major rivers (Rao 1975). The authors felt that the mechanism of occurrence of heavy rainfall was probably similar to that envisaged by Miller and Keshavamurty* (1968) in the so-called mid-tropospheric cyclone over northeast Arabian Sea. The great importance recently given to this mid-tropospheric cyclone in the Global Atmospheric Research Programme and Monsoon Experiment 1979 (ICSU, WMO 1976, Krishnamurthi and Hawkins 1970 and Mak 1975) came in as an additional argument for us to take up this particular case for further study. We were of course aware that we would not have adequate upper air data for an intensive study of this important case but we had no other alternative as we found that there was no other case in recent years of severe floods in Kathiawar and Kutch caused by a cyclonic system in upper air. All the severe floods over this area during the years subsequent to 1935 were caused by the usual cyclonic systems at surface-level (Rao *et al.* 1970). The following is our report on the July 1935 case.

2. Data used in analysis and method of analysis

In July 1935, radiosonde and radiowind data were not being recorded in India. The authors had therefore to work with daily surface charts and with daily upper air charts specially prepared from pilot balloon data (scrutinised data) published by the India met. Dep. The upper wind charts for all the available levels and for both morning and evening were prepared for the period 29 June to 27 July. As the available data were meagre, great care was taken during analysis to maintain continuity in space as well as time. For samples of charts on which this paper is based, Figs. 1(a & b), 2(a & b), 3(a & b) and 4 (a & b) may be seen. The streamlines as drawn in Figs. 2(a), 2(b), 4(a) and 4(b) are merely intended to show the direction of flow. Nothing better could be attempted with the available data. However, as will be seen from later paragraphs, the analysis as done by us, was adequate and reliable enough to justify the conclusions drawn.

3. Mid-tropospheric cyclonic disturbance in July 1935

Our analysis of the daily surface and upper wind charts revealed the following :

*Several villages were washed away in Kutch

†For objective comments on the observational studies of Miller and Keshavamurty, *see* the contribution by Rao (1976)

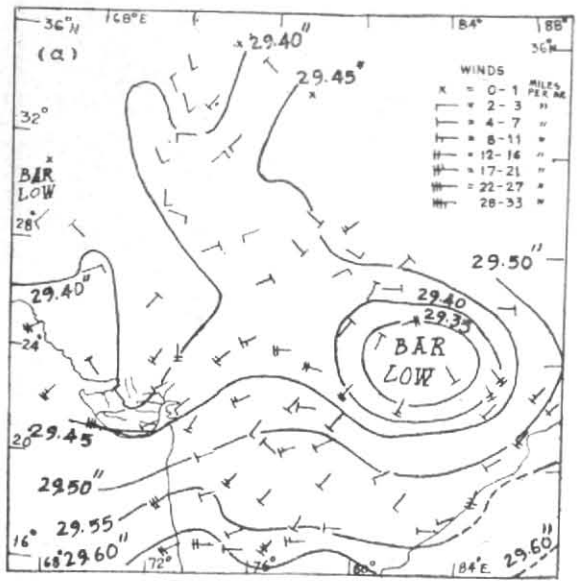


Fig. 1(a). Isobars drawn at intervals of 0·05 inch (reproduced from the *Indian Daily Weather Report* for 10 July 1935). The main rivers in Kathiawar have been shown by the authors on this map

Fig. 1(b). Isopleths of pressure-departure drawn at intervals of 0·05 inch (reproduced from the *Indian Daily Weather Report* for 10 July 1935). Note the significant negative pressure-departures over and near Kathiawar

A quasi-stationary closed cyclonic circulation appeared over south Rajasthan, Kathiawar, Kutch and adjoining areas on 2 July and persisted over that region with varying degrees of intensity and with varying configurations upto 19 July. The circulation occasionally extended downwards upto 1·0 km between 8 and 18 July. A small closed cell was also seen again at 2·0 and 3·0 km on 24 and 25 July.

The closed circulation could be clearly identified at and below 3·0 km on a large number of days. On days on which data were rather insufficient, the deficiency was made up by examining the previous and the next day's charts. The same technique was also followed in the case of the 4·0 km level. Nothing could be identified from the meagre data available at 5·0 km and higher levels.

The centre of the closed circulation lay throughout the period between 24°N and 26°N and between 70°E and 72°E. The error in our determination of the position of the centre was about one degree in latitude as well as longitude. The maximum horizontal extent of the closed circulation at 2·0 and 3·0 km levels was less than 1000 km and the maximum wind in the circulation at and below the 4·0 km level did not generally exceed 25 knots. *By far the most interesting feature observed in this disturbance, was that it did not at any time throughout its life-history, appear as a closed circulation at surface-level.* This disturbance could therefore, perhaps, in the light of what has been stated in the introduction, be categorised as a mid-tropospheric disturbance. Incidentally, the authors would prefer to use the term "mid-tropospheric disturbance" instead of the term "mid-tropospheric cyclone". The reason for this is that the term "cyclone" is used by Indian meteorologists in their storm-warning messages for the Bay of Bengal and the Arabian Sea with reference to devastating cyclonic systems at the surface-level such as the Andhra cyclone in November 1977. And this practice has been in vogue in India at least for seven decades*. It would therefore be only in the interest of clarity in terminology if the term "mid-tropospheric disturbances"** instead of the term "mid-tropospheric cyclones" is brought into use in international meteorological literature at least as far as the Indian monsoon region is concerned.

4. Synoptic situation on 10 July 1935

Figs. 1(a) and 1(b) show the surface winds, sea-level isobars and isopleths of departures of pressure at sea-level from normal at 08 hour local time on 10 July 1935, as published in the *Indian Daily Weather Report* of the India Meteorological Department. Figs. 2(a) and 2(b) show the upper winds and streamlines at 3·0 km and 4·0 km on the same day. The charts for 1·0

*It is interesting to recall that the term "cyclone" itself was coined in India by Piddington near about 1856 to refer to "ocean storms" in the Indian region (India met. Dep. 1975)

** For a definition of the term "Disturbance", *see* "Glossary of Meteorology" published by American Meteorological Society

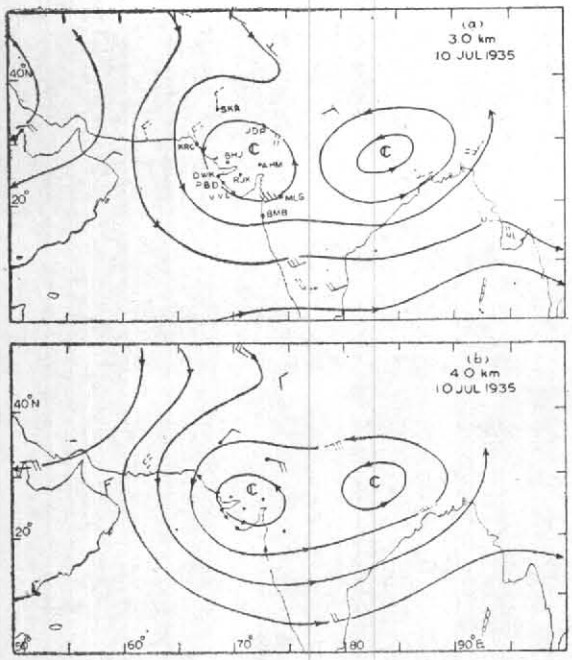


Fig. 2(a). The names of important stations in and around Kathiawar and Kutch have been given in three letters. Arrows and barbs drawn as solid lines are wind directions and speeds based on ascents made in the morning (near about 06 IST). Arrows and barbs drawn as dashed lines indicate wind directions and speeds based on ascents made in the afternoon (near about 15 IST)

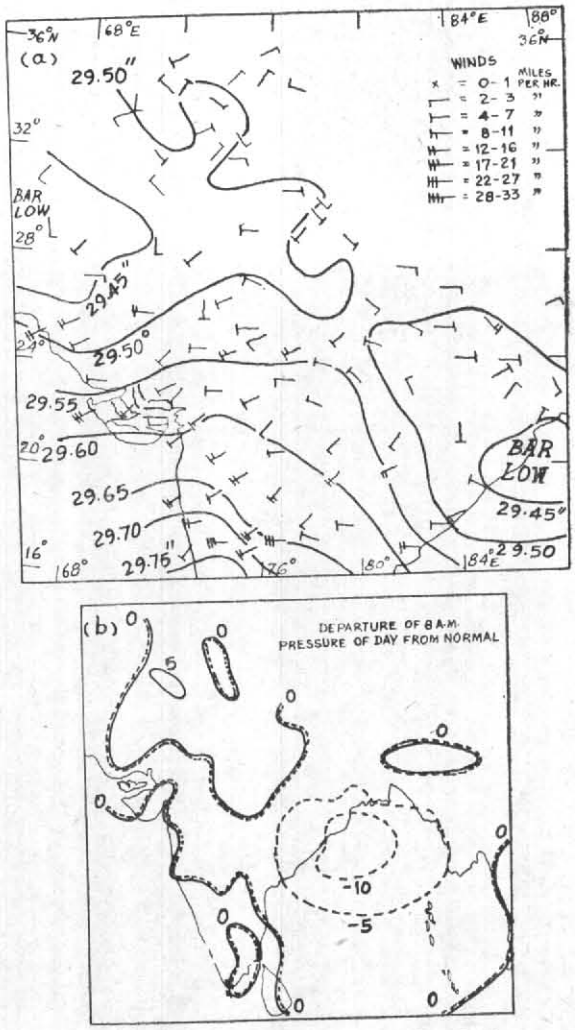
Fig. 2 (b). Shaded, circles are the same stations as in Fig. 2(a)

and 2·0 km for 10 July (not reproduced here) also showed closed cyclonic circulations as at 3·0 km.

It may also be seen from Fig. 1(a) that a depression from the Bay of Bengal lay at sea-level on 10 July over the extreme northeast of Madhya Pradesh. Our study left us with no doubt that the heavy rainfall caused by the Bay of Bengal depression during the subsequent 24 hours was well-separated from that caused by the mid-tropospheric disturbance over and near Kathiawar and Kutch.

5. Synoptic situation on 18 July 1935

Figs. 3(a) and 3(b) show the surface winds, sea-level isobars and pressure departures from normal at sea-level on the morning of 18 July 1935. Figs. 4(a) and 4(b) show the upper winds and streamlines at 3·0 and 4·0 km on the same day. The important difference between the synoptic situations on the morning of 10 and 18 July 1935 was that the mid-tropospheric disturbance did not extend down to sea-level over Kathiawar even as a well-marked trough on 18



Figs. 3 (a)&(b). Same convention in plotting as in Figs. 1 (a) and 1 (b)

July as it did on 10 July. Further, the pressure departure chart at sea-level on 10th (Fig. 1 b) showed a distinct negative anomaly over Kathiawar and the adjoining parts of northeast Arabian Sea which was not the case on 18 July 1935 (Fig. 3 b). Fig. 4(a) shows that a Bay depression lay on 18 July at sea-level off the Orissa coast, *i.e.*, quite far away from the area where the mid-tropospheric disturbance was situated.

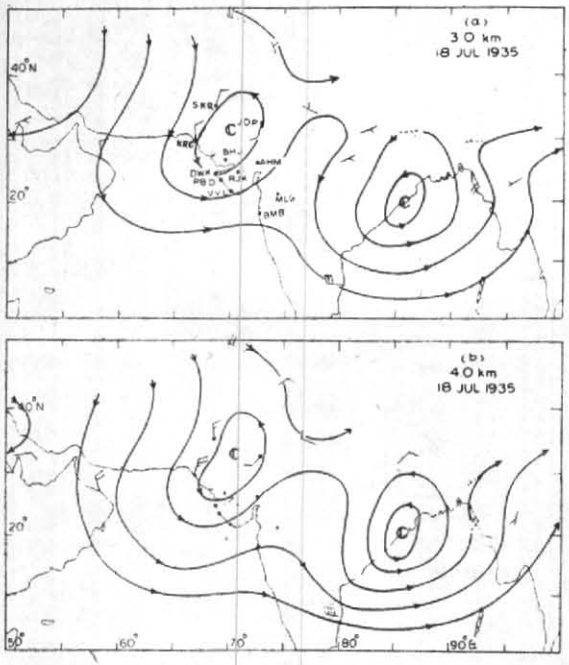
6. Analysis of rainfall

In this section as well as in the subsequent sections, a term such as "rainfall on the 10th" means "rainfall in 24 hours ending at 08 hours local time on the 10th". Similarly, the term "daily rainfall" is intended to mean "rainfall recorded daily during a period of 24 hours ending at 08 hours local time".

TABLE 1

Rainfall of 76 mm or more in 24-hr ending at 08 hr local time, 4 to 22 July 1935

Stations	Lat. (°N)	Long. (°E)	July 1935 4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
(a) Kathiawar and Kutch																					
Tharad	24° 23′	71° 37′							210												
Mehsana	23 37	72 23											92								
Rahapur	23 34	70 38								148	184										
Bhuj	23 15	69 48								81											
Anjar	23 07	70 02								96											
Mandvi	22 50	69 22											112					174			
Morvi	22 49	70 47							116	244											
Wankaner	22 37	70 56								132									115		
Chuda	22 29	71 41				111															
Navanagar	22 28	70 05								90			88						86		
Dwarka	22 22	69 05					110	78					107					140			
Rajkot	22 18	70 47								130			81						79		
Jasdan	22 02	71 12							101												
Gondal	21 58	70 48				86			95	149											
Dhoraji	21 44	70 27						81	87	161											
Porbandar	21 37	69 38								244								99	86		
Amreli	21 36	71 13															102				
Junagad	21 31	70 28					95	84	140								84				
Veraval	20 54	70 22				160				106							81	87			
Jafrabad	20 51	71 22												118				111			
(b) Konkan																					
Umbargaon	20 12	72 46																78			
Dahanu	19 58	72 43			136									92				82	84		
Mokhada	19 56	73 20								137									77		
Mahim	19 39	72 43			115					116				84				108	108		
Vada	19 39	73 08								141								100	102		
Shahapur	19 27	73 20								103											
Bassein	19 21	72 48															77				
Bhivandi	19 18	73 03															92		80		
Panvel	18 59	73 07				93											76			110	
Matheran	18 59	73 17				118	102			97					93		102	76	118	195	
Karjat	18 55	73 20				94									129		102			207	
Colaba	18 54	72 49	88			110														100	
Uran	18 54	72 55															77			109	
Pen	18 44	73 06				80											105			162	
Alibag	18 38	72 53	80														120				
Roha	18 26	73 07															164				87
Mangaon	18 14	73 17				89											102				97
Mahad	18 05	73 25				85											132				140
Mandangad	17 59	73 15				96											173				
Dapoli	17 46	73 12		110													199				
Khed	17 43	73 24															140				
Chiplun	17 32	73 31	95		105												185	79			
Guhagar	17 28	73 12		95	112												132				
Ratnagiri	16 59	73 20		132	96												156				
Rajapur	16 39	73 31		144													136				
Devgad	16 23	73 21		92													107				
Malvan	16 03	73 28		135																	
Kudal	16 01	73 42		150	107												145				
Sawantwadi	15 54	73 49		133	93												130				
Vengurla	15 52	73 38		144	93												91				



Figs. 4 (a) & b). Same convention in plotting as in Figs. 2(a) and 2 (b)

An analysis of the rainfall over Kathiawar and Kutch in July 1935 indicated that except for a few stray cases, daily rainfall exceeding 10 cents (2·5 mm) had occurred only between 3 July and 27 July. There was however a marked increase in the rainfall between 7th and 20th and a marked decrease thereafter. Rainfall slightly increased on 24th and 25th but the amount recorded in 24 hours was generally less than 25 mm.

Table 1(a) shows the 24-hr rainfall at stations lying in the catchments of the rivers and streams in Kathiawar and Kutch, exceeding three inches or 76 mm (*i.e.* heavy rainfall) during the period 4 to 22 July 1935. It will be seen that:

(*a*) Heavy rainfall occurred only between 7th and 20th;

(*b*) Heavy rainfall occurred mainly in 2 spells. The first spell was on 10th and 11th, the peak rainfall occurring on the 11th. The second spell occurred between 18th and 20th, the peak occurring on the 19th. The peak rainfall on the 11th and 19th corresponded to the synoptic situations on the 10th and 18th respectively. The upper winds and streamlines corresponding to these two days may be seen in Figs. 2(a), 2(b), 4(a) and 4(b).

(*c*) Heavy rainfall occurred in the south and west sectors of the mid-tropospheric disturbance.

7. Strong monsoon along the Konkan coast in relation to heavy rainfall over Kathiawar and Kutch in July 1935

Table 1 (b)* shows the occasons of rainfall along the Konkan coast exceeding 76 mm in 24 hours during the period 4 to 22 July, *i.e.*, during the same period as in Table 1(a)*. A comparison of the figures in the two tables shows that there is no direct association between strong monsoon in Konkan and heavy rainfall over Kathiawar and Kutch. In particular, there is no evidence to show that the heavy rainfall in Kathiawar and Kutch was a sequel to strong monsoon conditions in Konkan.

8. Origin of the mid-tropospheric disturbance over south Rajasthan, Kathiawar and Kutch

The synoptic charts and time-sections do not indicate that there was any mid-tropospheric disturbance off the Konkan coast prior to the development of the mid-tropospheric disturbance over south Rajasthan, Kathiawar and Kutch discussed in the present paper. Nor is there synoptic evidence to suggest that any disturbance at sea-level or in the upper air off the Konkan coast moved towards Kathiawar and Kutch in July 1935. And this is supported by our analysis of the rainfall figures in Tables 1(a) and 1(b). It is also definite that the mid-tropospheric cyclonic circulations studied in the present paper was not a remnant of any westward moving monsoon depression from the Bay of Bengal. We therefore arrive at the important conclusion that the *mid-tropospheric disturbance over south Rajasthan, Kathiawar and Kutch developed over that area in situ.* As far as the authors are aware, this is the first case of its kind brought out in meteorological literature pertaining to the Indian monsoon region.

9. Factual findings in relation to the earlier literature on the origin of mid-tropospheric disturbances over the Indian region

Desai (1967) has stated that the development of a mid-tropospheric circulation over the sea area off Bombay is a direct effect of the orography of the Western Ghats. While this argument may be acceptable in the case of a disturbance off the Konkan coast, it does not *prima facie* appear plausible in the case of the mid-tropospheric disturbance discussed in the present paper. It appears unlikely that the orography of the Western Ghats had anything to do directly with

*Tables 1 (a) and 1 (b) have been prepared with the station at the lowest latitude at the bottom of each table and with stations at progressively increasing latitudes higher up. This has been done so that any increase in rainfall over Kathiawar and Kutch as a result of a fresh northward surge of the monsoon current from the Konkan coast could be readily detected.

the development of a disturbance over land whose centre lay between 24°N and 26°N and between 70°E and 72°E, *i.e.*, approximately 700 km away to the northnorthwest of Bombay. On the other hand, the area of precipitation etc associated with this disturbance, fits in reasonably well with the numerical computations made by Mak (1975) on the basis of a theoretical model developed by him.

Rao (1976) has pointed out — to quote is words — that "not infrequently, systems are somewhat more intense in mid-troposphere than at surface" over the Indian region. He has also stated that "systems existent in upper air only are being described by Indian meteorologists as low or trough in upper air". We have considered these points and we are of opinion that a closed cyclonic circulation *over land* as observed by us at 3·0 and 4·0 km *for such a long period as 18 days without a closed circulation at surface level at any stage* and yet causing very heavy rainfall over an arid/semi-arid zone like Kathiawar and Kutch, belongs to a category which has so far not been identified in the Indian monsoon region.

10. Conclusions

In spite of the meagreness of the data on which our investigation is based, our study has clearly brought out the important point that a mid-tropospheric disturbance similar to that over the northeast Arabian Sea studied by Miller and Keshavamurty (1968) could develop over land much further to the north, remain quasi-stationary for nearly 3 weeks and cause heavy rainfall over a wide area leading to severe floods. We have, however, not been able to find out on the basis of the available synoptic data as to how the mid-tropospheric disturbance originated, persisted in a quasi-stationary state for such a long period and finally disappeared *in situ*. We hope that a study of this case and of other similar cases by theoreticians engaged in Monex-79 Experiment will lead to a deeper insight and clearer comprehension of the development mechanism of mid-tropospheric disturbances of the type discussed in the present paper.

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REFERENCES

Desai, B. N.	1967	*J. atmos. Sci.*, **24**, 2, pp. 218-219.
ICSU/WMO	1976	*The Monsoon Experiment* — GARP Publ. series No. 18, p. 15.
India met. Dep.	1935	*India Weather Rev.*, Month. Weather Rep., July 1935.
	1975	*Hundred Years of Weather Service* (1875-1975), p. 13.
Krishnamurthi, T. N. and Hawkins, R. S.	1970	*J. appl. Met.*, **9**, pp. 442–458.
Mak, Man Kin	1975	*J. atmos. Sci.*, **32**, 12, pp. 2246-2253.
Miller, R. Forrest and Keshavamurty, R. N.	1968	*Structure of an Arabian Sea Summer Monsoon System*, Contri. No. 196, Hawaii Inst. Geophys., Univ. Hawaii, pp. 79-91.
Rao, K. L.	1975	*India's Water Wealth*, Orient, Longman, pp. 47-49.
Rao, Y .P.	1976	*Southwest Monsoon*, Met. Monogr. Synop. Met. No. 1/1976, pp. 107, 185, 249, 265-268.
Rao, Y. P., Srinivasan, V., Raman, S. and Ramakrishnan, A. R.	1970	*Active and Weak Monsoon Conditions over Gujarat State*, India met. Dep. FMU Rep. III– 3·1.