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A preliminary study of an objective method of forecasting heavy rainfall over Bombay and neighbourhood during the month of July

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ABSTRACT. An objective method to forecast the occurrence of heavy precipitation over Bombay and neighbourhood has been presented in this paper. The various synoptic situations generally favourable for heavy rainfall over the chosen area have been listed and attempts are made to select suitable predictors to cover most of these situations. The predictors should be such that they are capable of lending themselves to objective treatment. A search is also made for the predictor which would provide the maximum possible information concerning the predictand. The result has been the evolution of a Heavy Rainfall Prediction Diagram whose co-ordinates are the latitude of kinematic trough line between the longitudes 70° to 75°E at 7000/10,000 ft and the shear at 10,000 ft between Bombay and Ahmedabad. The isohyets on the diagram have been constructed based on past data for the month of July. If on a certain day the co-ordinates of the predictors intersect within the 7-cm isohyet heavy rainfall should be predicted for Bombay within the next 24 hours.

1. Introduction

During the southwest monsoon accurate forecasting of heavy rainfall over certain areas of the states of Maharashtra and Gujarat is one of the most difficult and challenging problems which the duty forecaster has to contend with in the Storm Warning Section at Bombay. In weather forecasting the experience of the forecaster is one of the major factors contributing to the success of a forecast. However, this experience lies largely in the form of subjective methods used by individual forecasters. It seems desirable to marshall this experience into some suitable objective form with a view to forecast the occurrence of heavy precipitation over an important place like Bombay and neighbourhood.

In this paper the predictand (that which is to be predicted) is the 0300 GMT rainfall at Bombay of next day. For finding out the value of the predictand, certain parameters which will be known as predictors (that which is used for making a prediction) have to be chosen. Only such predictors as can be objectively defined should be used. The month of July has been selected as that is the month when the activity of the southwest monsoon generally reaches its peak over the area chosen.

2. Synoptic situations favourable for heavy rainfall at Bombay

These situations can broadly be divided into (1) Northward movement of troughs of low pressure off the Konkan coast, (2) West-northwestward movement of depressions or low pressure areas across west Madhya Pradesh and to the west of this area, (3) Unsettled conditions in northwest angle of the Bay of Bengal and (4) A presssure gradient of 2 to 4 isobars across the Konkan coast drawn at intervals of 2 mb is also a contributing factor.

(1) *Northward movement of troughs of low pressure off the Konkan coast* — The fact that a trough of low pressure has been located off the Konkan coast does not mean that heavy rainfall should at once be forecasted for Bombay and neighbourhood. If a tangent is drawn at the apex of the trough of low pressure, then this line will roughly represent the northernmost limit of heavy rainfall that may be expected to occur

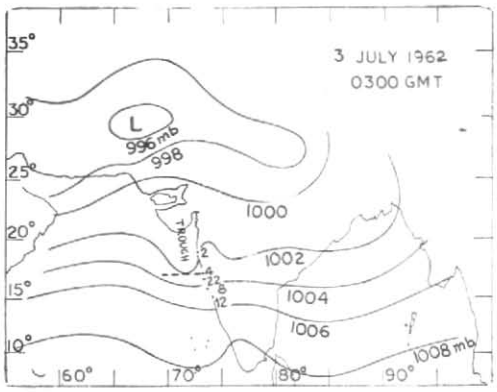

Fig. 1

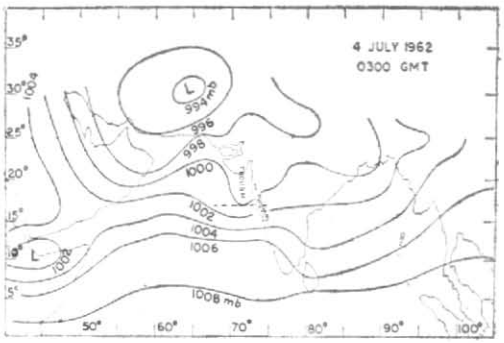

Fig. 2

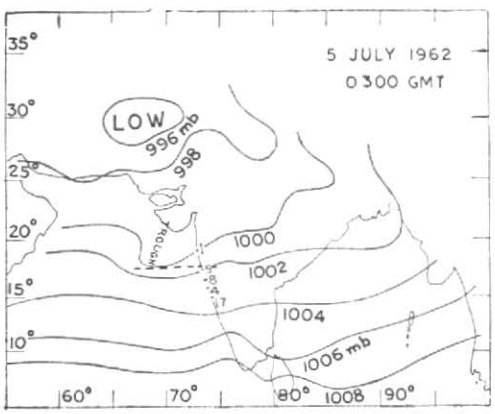

Fig. 3

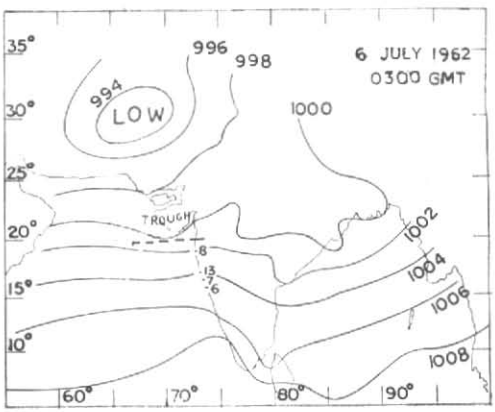

Fig. 4

Figs. 1–4. These figures show the synoptic situation with a trough of low pressure off the Konkan Coast on the sea level charts and the associated rainfall along Konkan Coast. The charts depict vividly the progressive movement northwards of the heavy rainfall area along with the apex of trough (inflexion point of trough). It can be seen that the heavy rainfall area in the four figures lies to the south of the apex along the coast

along the Konkan coast. As the trough moves slowly in a northerly direction the heavy rainfall area which is confined south of the dotted line in Figs. 1 to 4 moves northward.

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With this situation it has been noticed that when the apex of the trough lies in the neighbourhood of Lat. 18°N and progresses slowly northward, heavy rainfall occurs at Alibag earlier than at Bombay, about 24 hours in advance.

This leads us to infer that the daily rainfall at Alibag could serve as good and useful indicator regarding the morrow's rainfall at Bombay under the above mentioned conditions. This inference was confirmed by the correlation coefficient between Alibag rain of the current day to Bombay rain of the next day which came out to be ·58 based on 5 years' data for the months of July (n=150).

(2) *Westnorthwestward movement of depressions or low pressure areas across west Madhya Pradesh and to the west of this area*—For detecting in advance, occurrence of heavy rainfall at Bombay with this situation no suitable station is available except perhaps Dahanu, which lies to the north of Bombay along the Konkan coast. Twentyfour hours earlier rainfall at stations like Jalgaon and Malegaon may not throw any light on the impending heavy rainfall due to occur in Bombay, as the former stations generally receive scanty rainfall even though they may be situated nearer the depression. With this particular type of situation it has been noticed that heavy rainfall first occurs at Dahanu and then spreads southwards towards Bombay in about one or two days time but there were also instances when the heavy rainfall had commenced almost simultaneously both at Dahanu and Bombay. It is thus seen that the value of Dahanu's rainfall as an indicator of the morrow's rainfall at Bombay is definitely less than the Alibag-Bombay relationship. This was confirmed by calculating the correlation coefficient between daily rainfall at Dahanu to Bombay's rainfall of next day which came to ·53, a value which is less than the correlation coefficient between daily rainfall at Alibag to Bombay's rainfall of next day.

When any of the two synoptic situations described earlier prevail, the heavy rainfall activity over Bombay is generally of a prolonged nature lasting anywhere from 3 to 6 days or even longer interspersed sometimes with brief but tantalizing lull of about 24 hours or so during the heavy rainfall spell.

(3) *Unsettled conditions in the northwest angle of Bay of Bengal*—In the absence of the types of situations described earlier unsettled conditions in northwest angle of Bay of Bengal (not northeast angle of Bay of Bengal) can be associated with a brief spell of heavy rainfall activity over Bombay area which may last for about a couple of days. By unsettled conditions is meant the conditions prevailing before the formation of a depression in the head Bay of Bengal. For instance when lows move westnorthwestwards across the Arakan coast we can expect unsettled conditions to develop near the head Bay of Bengal. Once the unsettled conditions concentrate into a depression the heavy rainfall activity over Bombay ceases and it may recur again only when the depression at a later stage is moving westnorthwestwards across west Madhya Pradesh and neighbourhood when we get situations already discussed.

(4) *Pressure gradient off the Konkan coast*—Heavy rainfall seldom occurs in Bombay in the month of July with a lone isobar across

TABLE 1

	Correlation coefficient
(1) Alibag rain (today) to Bombay rain (same day)	·76
(2) Dahanu rain (today) to Bombay rain (same day)	·61
(3) Bombay rain (today) to Bombay rain (tomorrow)	·53
(4) Alibag rain (today) to Bombay rain (tomorrow)	·58
(5) Dahanu rain (today) to Bombay rain (tomorrow)	·53
(6) Higher rain Alibag-Dahanu (today) to Bombay rain (tomorrow)	·63

the Konkan coast. The pressure gradient that is generally favourable for heavy rainfall is about 2 to 4 isobars between the stations Dahanu to Karwar and oriented preferably in WSW'ly direction towards the Konkan coast. But the mere existence of 2 to 4 isobars in this region by itself is not sufficient justification for forecasting heavy rainfall for Bombay unless one of the previously mentioned 3 synoptic situations is already present. In other words the pressure gradient may be taken into account in association with the prevailing synoptic situation. Hence the role of the pressure gradient in being responsible for heavy precipitation is subsidiary.

3. Selection of predictors and search for the most important predictor which would give the highest possible information concerning the predictand

One of the methods of forecasting currently in use by Indian Meteorologists is the persistence method. With a view to see if today's 0300 GMT rainfall at Bombay could be used as predictor for tomorrow's 0300 GMT rainfall at Bombay, the correlation coefficient between the two was calculated making use of 5 years' data for the month of July. The value came to ·53. It may be significant to note that the same value was obtained for the correlation between daily rainfall at Dahanu to Bombay rainfall of next day, whereas the correlation coefficient between the daily rainfall at Alibag to that of Bombay of the next day was higher. This would mean that the daily rainfall at Alibag alone could be a superior index of the morrow's rainfall at Bombay. However, the day's rainfall at Dahanu is not without its own significance, and therefore, an attempt was made to take into account the rainfall both at Alibag and Dahanu by taking the higher rainfall at these two stations of one day and correlating it with the rainfall at Bombay of the next day. The correlation coefficient of the daily higher rainfall between Alibag and Dahanu to Bombay rainfall of next day came to ·63. Amongst the predictors considered so far this combined predictor gives a fairly high correlation coefficient to the predictand.

However, in any objective method of forecasting we should strive to get a predictor which would be able to supply about 75 per cent information concerning the predictand. Measured by this yard stick the higher rainfall Alibag-Dahanu predictor is not satisfactory enough to qualify for the place of the most important predictor.

A list of the various correlation coefficients calculated is given in Table 1.

4. Upper winds over Bombay and neighbourhood

The upper wind chart is undoubtedly the most powerful tool today in the hands of the tropical forecaster and it is to this that we have to look in our quest for important predictors. The upper wind regime over Bombay and neighbourhood should be in a position to provide the key for the occurrence of heavy rainfall or otherwise. But it is extremely awkward to work with upper winds as predictors, since we have to take into consideration both direction and velocity at different heights. The 24-hour upper wind changes over Bombay may be sugges-

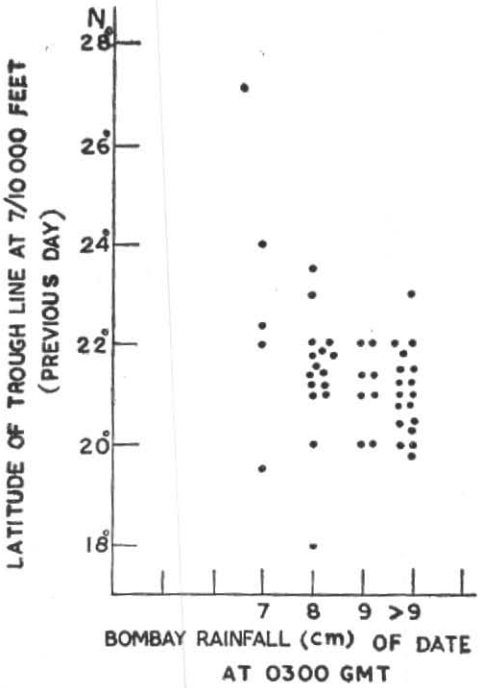

Fig. 5. Heavy rainfall amounts at Bombay at 0300 GMT of today have been plotted against latitude of location of trough line on the previous day

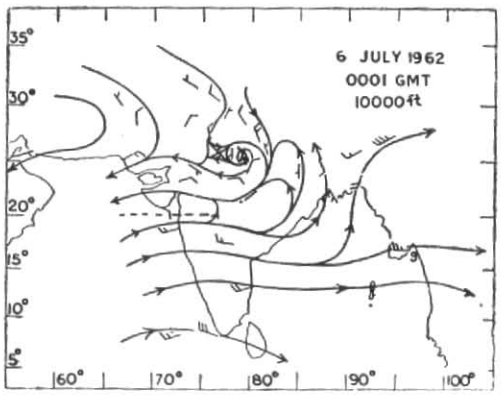

Fig. 6. Upper winds at 10,000 ft showing the west-east trough line running roughly along Lat. 20°N between the longitudes 70° to 75°E on 6 July 1962 (0001 GMT)

tive about the occurrence of heavy precipitation. For example with a trough of low pressure off the Konkan coast upper winds over Bombay at lower levels may be southerly. When these winds change to southwesterly or westerly heavy rainfall may be reasonably expected. This is forecasting with the help of upper winds from a single station. But this method obviously suffers from the handicap in that there is no scope for taking into consideration the upper winds at neighbouring stations like Veraval, Ahmedabad and Aurangabad.

A study of the upper wind regime between 7000—10000 ft during July for the last 5 years has revealed that most cases of heavy rainfall over Bombay are associated with a well defined kinematic trough line with embedded vortices running from west to east between the longitudes 70° and 75°E. The trough line separates the mainly westerly monsoon current from the mainly easterly stream to the north of it. Whether the heavy rainfall is caused by a trough of low pressure moving northwards along off the Konkan coast or whether the heavy rainfall is due to the westnorthwestward movement of a depression or low pressure area across west Madhya Pradesh and to the west of this area, there is invariably a well defined trough line between the latitudes $19\frac{1}{2}°$ and $22\frac{1}{2}°$N at the heights mentioned above (*see* Figs. 5 and 6). If the latitude of the trough line falls outside these limits, chances of heavy rainfall at Bombay are greatly reduced except when there are unsettled conditions in the northwest angle of the Bay of Bengal.

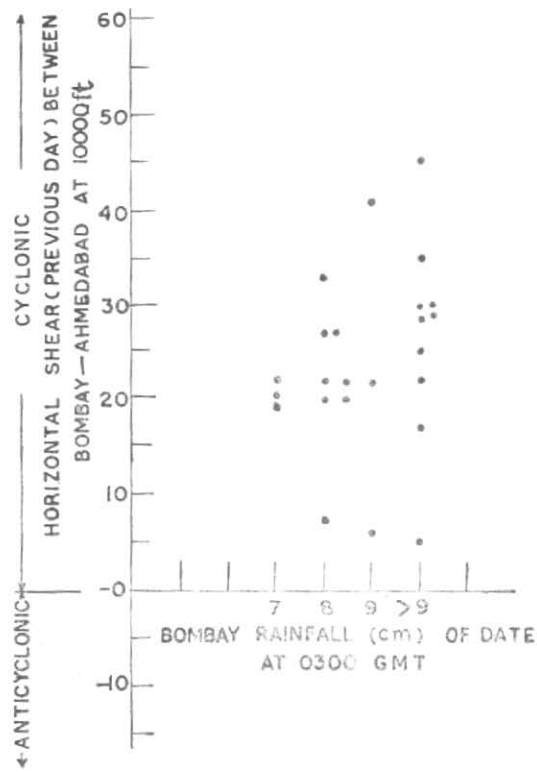

Fig. 7. Heavy rainfall amounts at Bombay at 0300 GMT of today have been plotted against the horizontal shear between Bombay—Ahmedabad at 10,000 ft of previous day

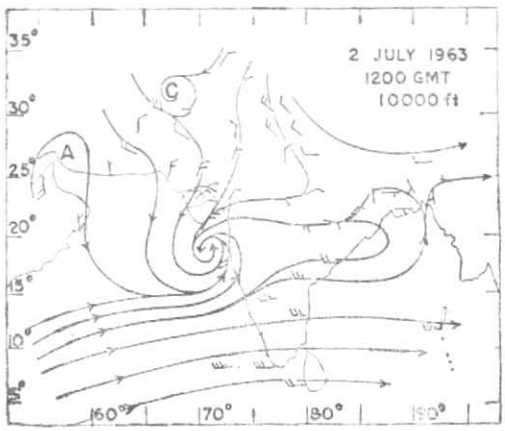

Fig. 8. Upper winds at 10,000 ft depicting a cyclonic circulation between the longitudes 70° to 75°E on 2 July 1963 (1200 GMT). Here the centre of the cyclonic circulation passes through Lat. 19°N which is the latitude to be used in the Heavy Rainfall Prediction Diagram

It has also been noticed that Konkan trough moving northnorthwestwards or low pressure areas over west Madhya Pradesh and neighbourhood moving westwards sometimes develop into depressions in northeast Arabian Sea or over Saurashtra. The movement of these pressure systems over Saurashtra or northeast Arabian Sea is quite often erratic. The trough line between 7000 to 10,000 ft in such cases sometimes shows a tendency to shift southwards and when it moves within the critical limits specified earlier, produces heavy rainfall over Bombay.

5. Unsettled conditions

In the absence of the west-east kinematic trough line described in the previous section heavy rainfall at Bombay can be safely ruled out provided there are no unsettled conditions in the northwest angle of the Bay of Bengal. It is rather difficult to express these unsettled conditions in any objective way. However, when such conditions prevail the wind regime between 7000 to 10,000 ft over the latitudes from Bombay to Ahmedabad will be generally westerly with Bombay winds being stronger than those of Ahmedabad giving rise to a cyclonic shear. A study of the shear between Ahmedabad to Bombay at 10,000 ft for the last 5 years during July has shown that heavy rainfall may generally be expected at Bombay when the shear is 20 kt or more per 300 miles (*see* Fig. 7).

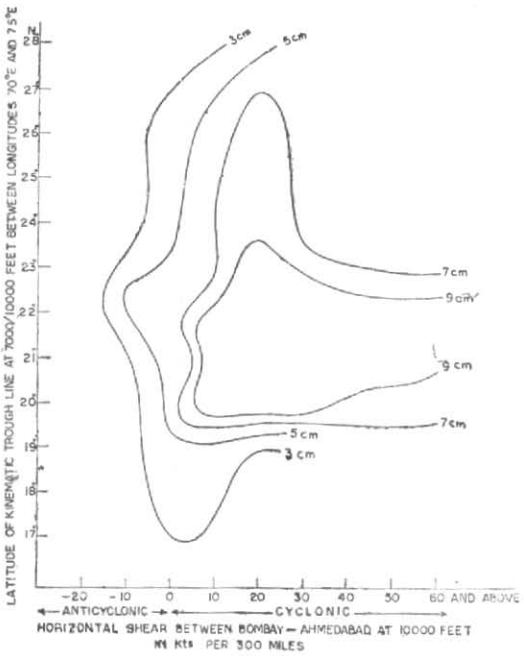

Fig. 9. Heavy Rainfall Prediction Diagram for Bombay

6. How to use the Heavy Rainfall Prediction Diagram (Fig. 9)

The co-ordinates of the diagram (*see* Fig. 9) are the latitude of the trough line between the longitudes 70° to 75°E at 7000/10,000 ft along the y-axis and the shear at 10,000 feet between Bombay and Ahmedabad along the x-axis. In determining the latitude of the trough line between 7000 to 10,000 ft the following should be kept in mind. Choose the height at which the trough line can be demarcated better. If the trough line is well defined both at 7000 and 10,000 ft the latitude at the higher altitude should be preferred. In the case of cyclonic circulation over the concerned areas determine the latitude through which the centre of the circulation passes (*see* Fig. 8). The isohyets on the diagram have been constructed based on past data. The 7-cm isohyet is the most important isopleth on the diagram, for if on any day the co-ordinates corresponding to the predictors intersect within this isohyet heavy rainfall should be predicted for Bombay. To take an example let us suppose that on a certain day the trough line runs along Lat. 21°N and the shear is 20 kt in 300 miles. It is readily seen that the abscissa and ordinate corresponding to these values intersect within the 9-cm isohyet and hence very heavy rainfall should be forecasted for Bombay within the next 24 hours. It is better to use this diagram as a 'Yes" or "No" indicator of heavy rainfall at Bombay rather than as a diagram for obtaining the predicted rainfall in a quantitative way. If on a certain day one of the predictors is absent or not available then determine whether the co-ordinate corresponding to the other predictor passes within the 7-cm isohyet or not. If the co-ordinate does not pass through this isohyet, heavy rainfall need not be forecasted for Bombay.

7. Conclusion

The Prediction Diagram described provides a simple key to the complicated art of heavy rainfall forecasting for Bombay. It is hoped that the methods outlined in this paper will be of benefit in a day-to-day forecasting for Bombay during the month of July. However, the skew distribution of tropical rainfall should not be forgotten. On rare occasions, the synoptic situations are favourable for heavy rainfall but the precipitation does not occur.

8. Acknowledgements

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