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Rainfall over Bombay associated with cyclonic storms striking Saurashtra coast

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ABSTRACT. Normally heavy rain is expected over the field of depressions and cyclonic storms. On this basis, it is comparatively easy to issue heavy rainfall warnings sufficiently in advance, whenever disturbances in the Arabian Sea and Bay of Bengal show a tendency to move towards the coast. It was observed by Mukherjee *et al.* (1966) that cyclonic disturbances striking south Tamil Nadu coast during October bring adequate supply of moisture to cause heavy rainfall in far away coastal Andhra Pradesh. Applying the same analogy, this paper tests the theory whether the cyclonic storms striking Saurashtra coast can cause heavy rainfall in Bombay. It is found that during the last 85 years, seven cyclonic storms struck Saurashtra coast during the pre-monsoon months April and May and the post-monsoon months October and November. All of them caused good rainfall over Bombay. This has been tested for Bombay due to its importance as a metropolis. The results were always found to be positive. The phenomenon has been explained taking into consideration the characteristics of air flow connected with these systems.

1. Introduction

It was observed by Mukherjee *et al.* (1966) that cyclonic disturbances striking south Tamil Nadu coast during October cause heavy rainfall over distant coastal Andhra Pradesh. The frequency of occurrence of cyclonic disturbances in the Arabian Sea is less than in the Bay of Bengal. Nevertheless, with a view to find out whether any such phenomenon exists on the west coast also, all the cyclonic disturbances that crossed Saurashtra coast during the last 85 years have been studied, to see whether they caused any rain on distant Maharashtra coast. Rainfall recorded at Bombay, because of its position as an important metropolis on the west coast, has been studied. Since the cyclonic disturbances moving northwards close to the west coast would have caused heavy rain over the west coast, those that moved within 200 km of the coast have been excluded. Also, the depressions and storms that struck Saurashtra coast during the monsoon season have not been taken into account, since moisture always exists on the west coast during this season and it is difficult to attribute the rainfall solely due to the cyclonic disturbances. Only those cyclonic storms that struck Saurashtra coast roughly west of Long. 71.0° E have been considered here. It is noticed that during the period 1890-1976, only seven cyclonic storms struck the Saurashtra coast, 3 in the pre-monsoon and 4 in the post-monsoon seasons. The rainfall caused by these systems at Bombay within 24 hours of their crossing the Saurashtra coast has been studied and the results presented.

2. Data utilised

"*Tracks of Storms and Depressions in the Bay of Bengal and the Arabian Sea 1877-1960*" published by the India Meteorological Department in 1964 and its "addendum for the period 1961-1970" published in 1972 have been consulted. Tracks of storms and depressions for each of the years 1971 to 1976 published in the *Indian Journal of Meteorology and Geophysics*, have also been studied. Rainfall recorded at Bombay was taken from the Bombay volumes published by the erstwhile Colaba Observatory (now Indian Institute of Geomagnetism) upto 1970. Rainfall data for later years have been collected from the *Indian Daily Weather Reports*.

3. Cases studied

(a) *Pre-monsoon season*

(*i*) *Severe cyclonic storm of 28 April to 2 May 1892* — A depression formed in the west Arabian Sea near Lat. 17.0° N and Long. 60.5° E

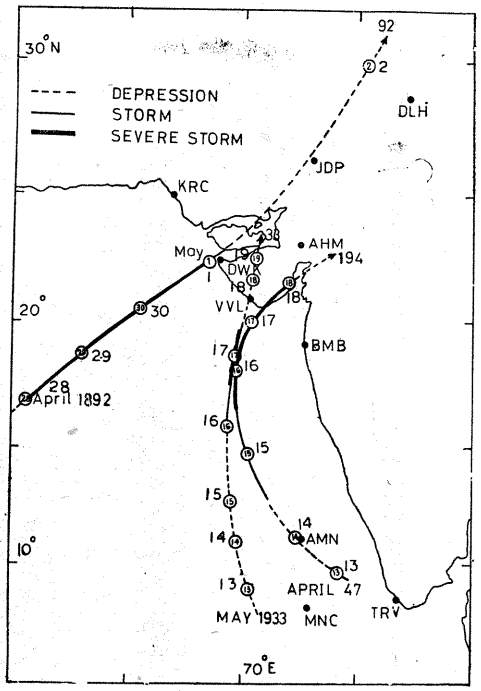

Fig. 1(a). Tracks of cyclonic storms in the pre-monsoon season

on 28 April 1892, rapidly intensified into a severe cyclonic storm, moved northeastwards and crossed Saurashtra coast near Dwarka on 1 May 1892. It weakened into a depression and moved away northeastwards later. Bombay recorded 2.8 mm of rainfall on 1 May 1892. The storm moved northeastwards and there was no recurvature.

(*ii*) *Severe cyclonic storm of 13-19 May 1933* — A depression formed in southeast Arabian Sea on 13 May 1933 near Lat. 9.0° N and Long. 70.5° E, moved northwards and intensified into a cyclonic storm on 16th and severe cyclonic storm by 17th. It weakened into a depression and crossed Gujarat coast near Veraval on 17th evening and moved away northwards later. 18.8 mm of rainfall was recorded at Bombay on 18th and 5.3 mm on 19th. It may be mentioned that recurvature in this storm was not prominent and it moved roughly northwards throughout.

(iii) *Severe cyclonic storm of 13-18 April 1947* — On the morning of 13 April 1947 a depression formed off Kerala coast, with its centre near Lat. 9.5° N and Long. 74.5° E. The depression moved initially northnorthwestwards and intensifying into a cyclonic storm, lay with its centre near Lat. 12.0° N Long. 71.5° E on the morning of 14th. Rapidly intensifying into a severe cyclone with a core of hurricane winds and adopting a northerly course, it was centred on 16th morning about 320 km westsouthwest of Bombay. The cyclone then recurved towards northnorthest and was centred about 80 km eastsoutheast of Veraval on the 17th morning. Thereafter it crossed Saurashtra coast on 17th evening and weakening at the same time filled up near Surat by the night of 20th. Bombay recorded 46.5 mm of rain on 17th.

(b) *Post-monsoon season*

(*i*) *Severe cyclonic storm of 12-20 November 1893* — A depression formed in Lakshadweep area on 12 November 1893 near Lat. 12.0° N and Long. 73.0° E, moved northwest, intensified into cyclonic storm by 14th and severe cyclonic storm by 15th. It continued to move northwestwards till 17th and recurved northeastwards later. It crossed Saurashtra coast near Veraval on 20th and weakened later. Bombay recorded 0.8 mm rainfall on 20th and 38.6 mm on 21st.

(*ii*) *Severe cyclonic storm of 14-21 November 1896* — A depression formed off Sri Lanka coast on 14 November 1896 near Lat. 6.0° N and Long. 79.5° E, moved northwest, intensified into a cyclonic storm by 18th and severe cyclonic storm by 19th. It then moved northwards and recurved northeastwards and crossed Saurashtra

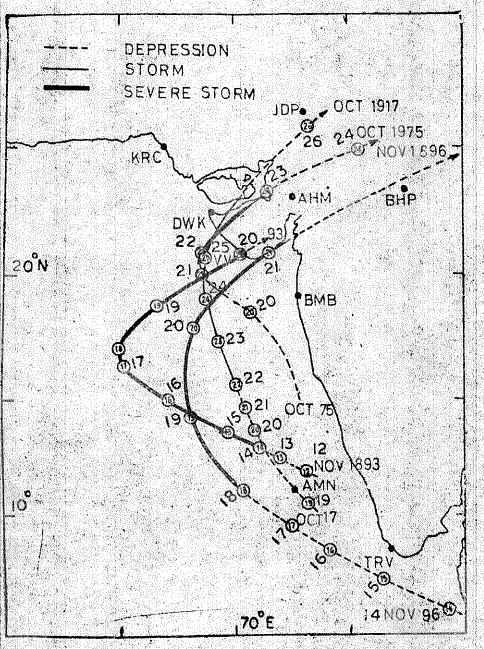

Fig. 1 (b). Tracks of cyclonic storms in the post-monsoon season

coast near Mahuva on 20th, weakened and moved away northeastwards later. Bombay recorded 6.1 of rainfall on 21st.

(*iii*) *Cyclonic storm of 19-26 October 1917* — Weather was disturbed in the southeast Arabian Sea on 18 October 1917 and a depression formed the next day with centre near Lat. 11.0° N and Long. 73.0° E. Moving in a northwesterly direction, it intensified into a cyclonic storm on 22nd when it was about 400 km to the west of Goa. The storm moved initially northnorthwestwards and then northwards. After recurvature, it crossed coast between Dwarka and Veraval on the morning of the 25th. Moving northeastwards, it broke up against the hills of east Punjab. Bombay recorded 1.0 mm of rainfall on 24th, 9.4 mm on 25th and 42.4 mm on 26th.

(*iv*) *Severe cyclonic storm of 19-24 October 1975* — A low pressure area formed over east central Arabian Sea with central region near Lat. 14.0° N and Long. 73.0° E on the morning of 18 October 1975. A depression from the Bay of Bengal crossed the Andhra coast near Ongole on 18th afternoon, weakened into a low pressure area and moved northwest to central parts of Madhya Maharashtra by 19th morning. The low pressure area in the Arabian Sea also moved northwestwards. The low pressure area over Madhya Maharashtra subsequently moved into the Arabian Sea between Harnai and Ratnagiri. The two systems merged together and concentrated into a depression by the evening of the 19th, centred about 75 km southwest of Harnai. The depression intensified into a deep depression by 20th morning, and to a cyclonic storm by the same evening. Continuing to move northwestwards, it was centred near Lat. 19.5° N and Long. 69.0° E by 21st morning. It then moved northnorthwest and concentrated into a severe cyclonic storm by the 21st evening. The system intensified further into a severe cyclonic storm with a core of hurricane winds and lay centred near Lat. 20.8° N and Long. 69.0° E on 22nd morning. It then recurved northeastwards, and crossed the Saurashtra coast about 15 km northwest of Porbandar by about 0930 GMT of the 22nd. The system continued to move in a northeasterly direction, weakened into a cyclonic storm and was centred near Radhanpur on the 23rd morning. It further weakened into a depression with centre near Kota on the 24th morning. It lay as a well-marked low pressure area over west U.P. by the 24th evening and became less marked on the morning of the 25th. Rainfall (in mm) recorded on Maharashtra coast was as follows — 23rd Dahanu 1.4 and Bombay (Santacruz) 18.9, 24th : Bombay (Colaba) 26.8, Bombay (Santacruz) 13.9 and Alibag 15.2.

Tracks of all the storms discussed above are given in Figs. 1(a) and 1(b).

4. Discussion

It is seen that considerable amounts of rainfall have occurred at Bombay within about 24 hours of the systems striking the Saurashtra coast. Table 1 gives the details of rainfall associated with striking cyclonic storms.

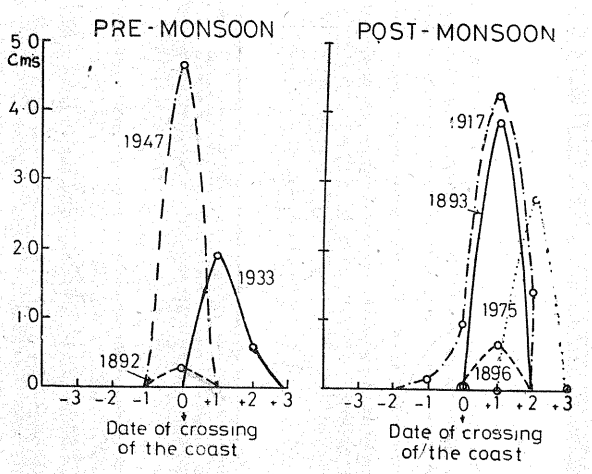

Fig. 2(a). Daily rainfall recorded at Bombay

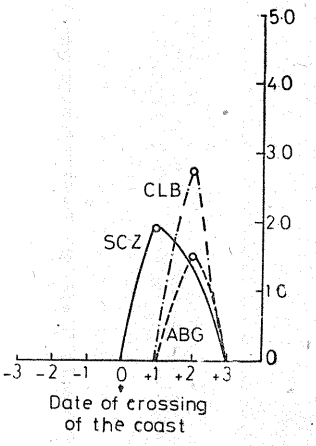

Fig. 2(b). Daily rainfall recorded at Colaba, Santacruz and Alibag in respect of 1975 storm.

It can be easily seen that the maximum rainfall occurred at Bombay within 24 hours of the storm crossing the Saurashtra coast. The daily rainfall that occurred at Bombay (Colaba) during the preceding and the following 3 days period of the date of crossing is graphically shown in Fig. 2(a). Though the rainfall recorded from 0300 to 1200 GMT of 23 October 75 at Bombay (Colaba), within 24 hours of crossing of the storm over Saurashtra coast, was 26.8 mm, the same had to be shown as though occurred on two days since rainfall recorded at 0300 GMT next day only was considered. Data in respect of Santacruz and Alibag which are about 30 km north and south of Colaba respectively are also graphically represented along with Colaba rainfall data in Fig. 2(b) for the 1975 storm. It is seen from the records that on 23rd, Santacruz had experienced rainfall from 0700 to 1340 IST, Colaba from 0826 to 1305 IST, Alibag from 0948 to 1115 IST. Thus the system first affected northern parts and later southern parts. It can also be seen that all three stations reported good amounts of rainfall within 24 hr of the storm crossing Saurashtra coast.

Heavy rain can be expected over a particular area if three conditions are satisfied, *viz.*, (1) Convergence in the lower levels over the area, (2) Divergence in the upper troposphere over the same area and (3) Adequate supply of moisture in the lower levels. Each of these conditions is discussed in detail below in relation to the cases under study.

(1) *Convergence in the lower troposphere*

Due to increased frictional drag over land, a stationary zone of convergence tends to occur over land areas at some small distance from the coast with on-shore winds. Even when winds

TABLE 1

Period of disturbance	Classification of disturbance	Date of crossing the coast	Nearest place of crossing the coast	Amount and time of maximum rainfall recorded in Bombay
		(a) Pre-monsoon		
i. 28 Apr-2 May 1892	Severe cyclonic storm	1/5	Dwarka	1/5 2.8 mm
ii. 13-19 May 1933	Do.	17/5	Veraval	18/5 18·8 mm
iii. 13-18 Apr 1947	Do.	17/4	Diu	17/4 46.5 mm
		(b) Post-monsoon		
i. 12-20 Nov 1893	Severe cyclonic storm	20/11	Veraval	21/11 38·6 mm
ii. 14-21 Nov 1896	Do.	20/11	Mahuva	21/11 6·1 mm
iii. 19-26 Oct 1917	Cyclonic storm	25/10	Porbandar	26/10 42·4 mm
iv. 19-24 Oct 1975	Severe cyclonic storm	22/10	Do.	23/10 (Santacruz) 18.9 mm 24/10 (Colaba) 26·8 mm

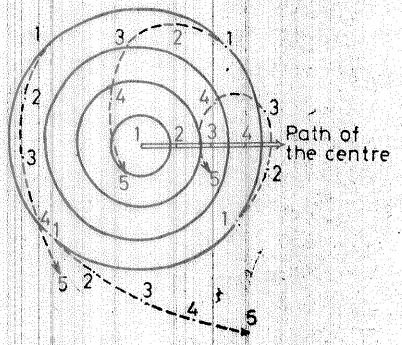

Fig. 3. Typical trajectories in the vicinity of cyclonic centres in northern hemisphere. Numbers indicate successive positions (*After* Petterssen).

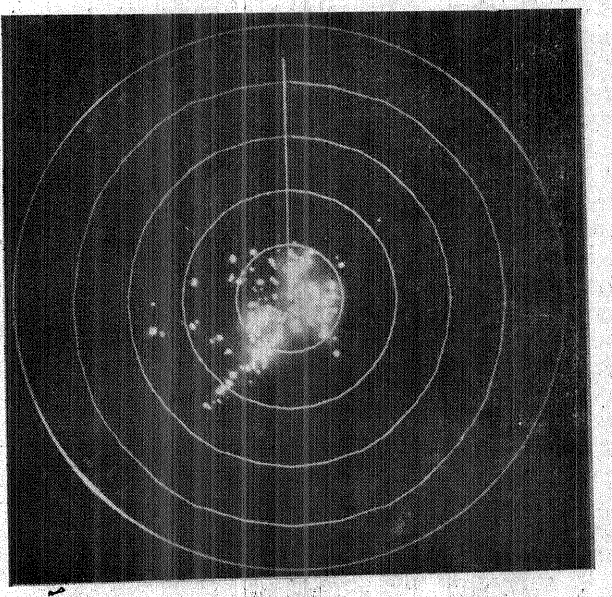

Fig. 4. Radarscope picture taken by the cyclone warning radar at Bombay at 0237 GMT of 23 Oct 1975

are blowing along a coast line with land to the right, there may be a zone of frictional convergence and upward motion along the coast. Although the vertical velocities associated with these frictional effects are not very large, their influence on clouds and weather may be noticeable, if the air is saturated or nearly so. Both these factors apply in the case of Maharashtra coast. Also, the effect of orography is significant in the case of coastal Maharashtra. The Western Ghats run nearly parallel to the coast almost over the west coast of India. When the maritime air from the field of the storm arrives over coastal Maharashtra, the combined effect of all the three processes mentioned above may produce sufficient upward motion in the lower troposphere. Only the relative importance of the three processes may vary depending on the direction from which moist winds are blowing.

(2) *Divergence in the upper troposphere*

According to current ideas, divergence in the upper troposphere over a region of low level convergence is a very favourable condition of heavy rainfall. An analysis of the 500 mb and 250 mb level upper air charts of 1200 GMT on 21st and 0000 GMT on 22nd in connection with the severe cyclonic storm of 19-24 October 1975 has revealed the presence of a westerly trough between Long. 62° E and Long. 65° E thus indicating prevalence of an area of divergence over the Maharashtra coast on these days. It is possible that similar mechanism operated also in all the other cases presented in this paper. In fact, the movement of cyclone towards east, points to that conclusion.

(3) *Adequate supply of moisture in the lower levels*

In most of the cases considered, the cyclonic storm which was responsible for the rain was quite far away from the area of rainfall. It is, therefore, difficult to visualise that system so far away as coastal Saurashtra could bring in adequate supply of moisture to cause good rainfall as has been observed at Bombay.

However, when we consider the relation between stream lines and trajectories in a moving cyclonic storm, it is possible theoretically to visualise the process by which maritime air from the field of the cyclone could move away towards Maharashtra coast and replace the comparatively dry air mass there. Considering circular concentric streamlines, the relation between the steamlines and trajectories may be expressed as in Fig. 3 (Petterssen 1956).

When a cyclonic storm in the Arabian Sea is moving in an easterly or northeasterly direction and striking Saurashtra coast, the trajectory of the maritime air parcels in the field of disturbance will be towards Maharashtra coast. It is thus theoretically possible for the moist maritime air from the field of the disturbance to affect weather over Maharashtra coast.

In the case of the severe cyclonic storm of

19-24 October 1975, release of moisture after the system crossed the Saurashtra coast near Porbandar on 22nd evening, was actually observed by the Cyclone Warning Radar at Bombay. When the system was out in the sea, the radarscope pictures showed only a small portion of the outermost spiral band which got separated from the main system after the cyclone entered land and it gradually moved eastwards. The radar-scope picture taken on 23rd morning is given in Fig. 4. This moisture release caused good rainfall over north Konkan and south Gujarat region. This type of release of moisture occurs generally in the eastern sector of a north or northeastward moving system as mentioned by Petterssen (1956), specially when the speed of movement of the centre of the system is less than the wind velocity in the outer periphery of the cyclonic wind field.

5. Conclusion

A study of the cyclonic storms striking Saurashtra coast roughly west of Long. 71.0° E shows that good amounts of rainfall do occur over Maharashtra coast. They commence within 24 hours of the disturbance crossing the coast. About 3 to 4 cm of rain can occur over Maharashtra coast unless the disturbance originates in west Arabian Sea and moves straight towards the Saurashtra coast as in case (a.i) or when it crosses the Saurashtra coast nearer to Maharashtra coast as in case (b.ii) of Table 1, when rainfall may be less than 1 cm only. The facts mentioned in this paper thus appear to provide a useful tool to forecasting personnel in predicting the occurrence of good rainfall amounts at Bombay during post monsoon and pre-monsoon seasons when otherwise the weather is dry.

Acknowledgements

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