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Influence of southern hemispheric frontal systems on the southwest monsoon rainfall over the west coast of India during Monex-79

ASOI LAL and RAJENDRA PRASAD

Meteorological Office, Pune

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सार — मोनेक्स-79 के दौरान भारत के पश्चिमी तट पर वर्षा की सक्रियता पर पड़ने वाले दक्षिण अफ्रीका और संलग्न दक्षिणपश्चिम हिन्द महासागर को पार करने वाले वाताग्र प्रणालियों के कारण पड़ने वाले प्रभाव का सहसम्बन्ध और समाश्रयण तकनीक का प्रयोग करते हुए अन्वेषण किया गया। इन परिणामों से मोनेक्स-79 के दौरान भारत के पश्चिमी तट के मध्य और दक्षिणी भागों में वाताग्र प्रणालियों और वर्षा के मध्य संभावित पार-गोलार्धीय सम्बन्धों का संकेत मिलता है।

ABSTRACT. The possible influence of frontal systems moving across southern Africa and adjoining southwest Indian Ocean on the rainfall activity over west coast of India during MONEX-79 has been investigated by using correlation and regression technique. The results suggest possible cross hemispheric linkages between the frontal systems and rainfall over the middle and southern parts of the west coast of India during MONEX-79.

1. Introduction

A number of studies have been made relating to the prediction of date of onset and activity of southwest monsoon over India. Ananthakrishnan and Ramakrishnan (1965), Ramaswamy (1965) and Rao (1976) studied the synoptic features in relation to the southwest monsoon. Malurkar (1958) conceived the idea of "pulses" comprising of shallow westward moving low pressure areas south of equator. According to him, these "pulses" were responsible for south to north cross-equatorial flow and helped to strengthen the monsoon current. Desai (1966) suggested that a possible relationship existed between the movement of troughs and ridges in the lower troposphere and the strengthening of southwest monsoon over India.

Kumar *et al.* (1983) investigated the influence of frontal systems moving across southern Africa and adjoining southwest Indian Ocean on the onset of southwest monsoon over west coast of India. Southern Africa is almost completely within the sub-tropical high pressure belt. The effect of vast land-mass is quite contrasting in summer and winter and splits the high pressure area into two separate cells, the Atlantic Ocean Anticyclone (AOA) and Indian Ocean Anticyclone (IOA). During southern hemisphere winter, a pressure trough and ridge, both oriented north-south, run over central parts and east coastal regions of southern Africa respectively. Generally, these troughs and ridges move rhythmically eastward across the south and east coasts of Africa. Fig. 1 shows the mean pressure distribution in the southern hemisphere in the month of July which may be taken as representative for the months of May and June also. Locations of AOA & IOA are also shown therein.

The frontal systems traversing over east coast of southern Africa cause weakening of pressure ridge of IOA. The pressure ridge over east coast slowly disappears and IOA moves further eastward. The eastward movement of frontal system along southern Africa is followed by the intensification of AOA. As the frontal system advances eastward, rear AOA starts ridging over southern Africa and results in pressure rise and finally a strong pressure ridge appears over east coast of southern Africa. The stagnation of pressure ridge further enhances the cross-equatorial flow leading to increased activity of southwest monsoon, particularly, over west coast of India. Usually, the position of frontal system, *i.e.,* its northernmost latitudinal penetration and intensity of rear AOA play the most important role in strengthening/weakening cross-equatorial flow and consequent increase/decrease in the activity of southwest monsoon.

In the present study an attempt has been made to investigate the influence of the passage of frontal systems across southern Africa and adjoining southwest Indian Ocean on the southwest monsoon rainfall during MONEX-79 over west coast of India by using correlation and regression technique.

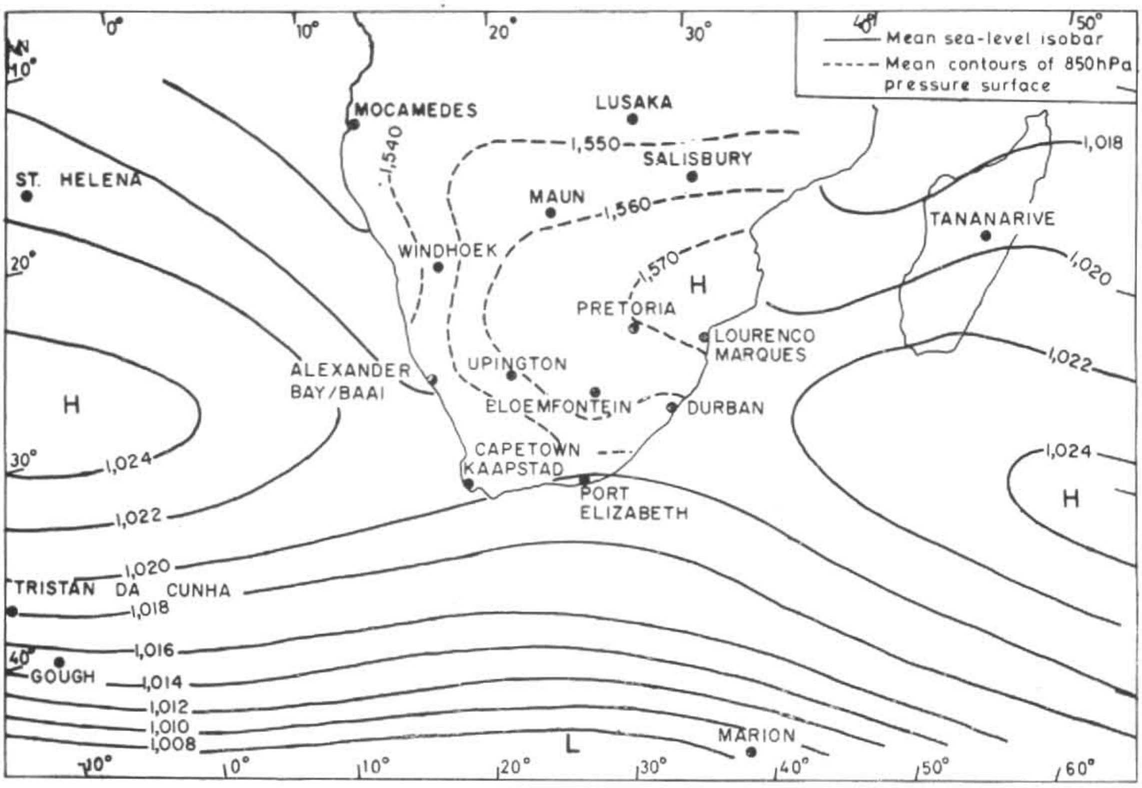

Fig. 1. Mean sea level isobars (full lines) and mean contours of the 850 hPa pressure surface (broken lines) and positions of Atlantic Ocean Anticyclone (AOA) and Indian Ocean Anticyclone (IOA) during July

(*After* B. R. Schulze 1972, *World Survey of Climatology*)

Fig. 2. Location of frontal systems over southeast coast of south Africa and stations along the west coast of India

2. Data and method

The data relating to cold fronts, northernmost latitudinal penetration and presssure of rear AOA was obtained from the surface and upper air synoptic charts of 1200 UTC of MONEX-79, for the months from June to August. Daily rainfall data of five stations located along the west coast of India, *viz.*, Bombay, Karwar, Mangalore, Cochin and Trivandrum was extracted from the *Indian Daily Weather Report* (IDWR) published by India Meteorological Department (IMD), Pune. Fig. 2 shows the frontal systems over southern Africa as well as stations located along the west coast of India which have been considered in the present study. Daily rainfall of these stations on the 2nd, 3rd, 4th and 5th day of frontal passage was used as a dependent parameter. The northernmost latitudinal penetration of front and intensity of rear AOA, denoted by X_1 and X_2 respectively, were used as independent parameters. The intensity of south to north pressure ridge over east coast of southern Africa was determined by using an index defined by Kumar *et al.* (1983). The maximum pressure at 1200 UTC between 25°S and 30°S along southeast coast of southern Africa was taken as an index to measure the intensity of the south to north pressure ridge along the east coast of southern Africa. The daily values of the above index were worked out for the

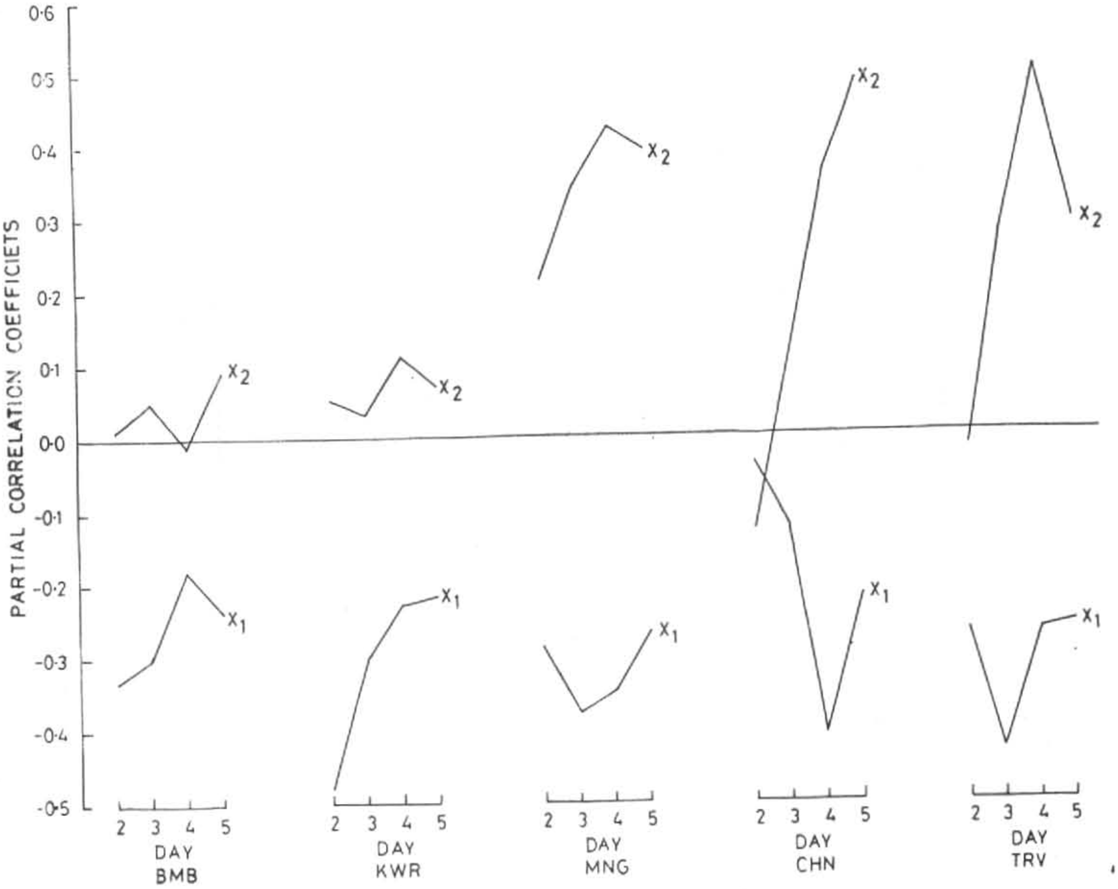

Fig. 3. Partial correlations between rainfall and (a) northernmost latitudinal penetration of front (X_1) and (b) intensity of rear AOA (X_2)

months from June to August 1979. Partial and multiple correlation and regression technique was used to establi:h statistically significant relationships between the rainfall over west coast of India and the independent parameters.

Partial regression equations were obtained in the following form ;

$$Y = a_0 + a_i X_i \qquad (1)$$

where,

Y = dependent parameter

X_i = i^{th} independent parameter

a_0 = constant term

a_i = coefficient of i^{th} independent parameter.

Multiple regression equations were developed in the form given below :

$$Y = b_0 + \sum_{i=1}^{2} b_i X_i \qquad (2)$$

where, Y, X_i, b_0 and b_i have usual meaning.

Percentage variation in rainfall explained by partial and multiple regression equations was also computed.

3. Results and discussion

3.1. *Fronts and monsoon activity*

In all 20 frontal systems traversed across southern Africa and adjoining southwest Indian Ocean during three months (June to August) of MONEX-79. Thirty per cent of the fronts formed during each of the month of June and August and 40% during July. The northernmost latitudinal penetration fluctuated between 20°S and 35°S. Maximum number (25%) of fronts penetrated up to 20°S. A secondary maxima (15%) reached up to 32°S. The highest pressure of rear AOA was detected as 1046 hPa in the frontal system during 4-7 July.

TABLE 1

Partial regression equations

Station	Day	Partial regression eqn. $Y=a_0+a_i X_i$	PCC	't'	Significance level (%)
Bombay	2nd	$Y=7.125-0.219X_1$	-0.33	1.47	20
Karwar	2nd	$Y=12.586-0.395X_1$	-0.48	2.31	5
Mangalore	3rd	$Y=9.035-0.232X_1$	-0.36	1.66	20
		$Y=-138.293-0.137X_2$	0.34	1.52	20
	4th	$Y=9.945-0.246\ X_1$	-0.35	1.56	20
		$Y=-194.956-0.193X_2$	0.42	1.99	10
	5th	$Y=-249.725-0.247X_2$	0.39	1.82	10
Cochin	4th	$Y=7.926-0.224\ X_1$	-0.41	1.91	10
		$Y=-129.061+0.127X_2$	0.36	1.66	20
	5th	$Y=-206.230+0.202X_2$	0.48	2.35	5
Trivandrum	3rd	$Y=2.877-0.093X_1$	-0.43	2.02	10
	4th	$Y=-72.454+0.071\ X_2$	0.50	2.46	5

Y = Estimated daily rainfall (mm),

X_1 = Northernmost latitudinal penetration,

X_2 = Intensity of Atlantic Ocean anticyclone

TABLE 2

Multiple regression equations

Station	Day	Multiple regression equation $Y=b_0+\sum_{i=1}^{2} b_i X_i$	MCC	% variation explained
Bombay	2nd	$Y=114.445-0.305X_1-0.102X_2$ (1.72)* (0.90)	0.39	15
Karwar	2nd	$Y=78.018-0.528X_1-0.157X_2$ (2.63) (1.23)	0.54	29
Mangalore	4th	$Y=-150.393-0.117X_1+0.153X_2$ (0.64) (1.30)	0.45	20
Cochin	5th	$Y=-219.340+0.034X_1+0.214X_2$ (0.21) (2.03)	0.49	24
Trivandrum	4th	$Y=-72.865+0.001X_1+0.071X_2$ (0.02) (2.02)	0.50	25

*t-values, Y, X_1, X_2 have same meaning as in Table 1

3.2. *Partial correlation and regression analysis*

Fig. 3 shows Partial Correlation Coefficients (PCC) between rainfall on 2nd, 3rd, 4th and 5th day of the passage of cold fronts and the northernmost latitudinal penetration (X_1) and intensity of AOA (X_2). It will be seen that X_1 maintained negative correlation on all the days at all stations under study. This indicates that the movement of fronts southward, away from equator, appears to inhibit rainfall activity over west coast of India. X_2 was generally found to display positive correlation at all stations suggesting a favourable contribution by the increasing intensity of AOA.

Stationwise significant observations are discussed below. The level of significance up to 20% only has been considered.

(a) *Bombay* —The highest correlation of X_1 appeared on 2nd day which was significant at 20%. X_2 did not emerge significant.

(b) *Karwar* — X_1 showed highest correlation on 2nd day and had the significance at 5%. X_2 did not appear significant.

(c) *Mangalore* — The highest correlation of X_1 appeared significant at 10% level on 3rd and 4th day. X_2 was significant at 20% on 3rd day and at 10% on 4th and 5th day.

(d) *Cochin* — X_1 showed highest correlation on 4th day which was significant at 10% and X_2 on 5th day at 5% level. X_2 also showed significance at 20% on 4th day.

(e) *Trivandrum* — X_1 had highest correlation on 3rd day, significant at 10% and X_2 on 4th day at 5% level.

The above results suggest that the frontal systems have notable influence on the rainfall activity mostly on the middle and southern parts of west coast.

Table 1 gives the partial regression equations for those independent parameters which were found significant at a level of 20% or more.

3.3. *Multiple correlation and regression analysis*

Multiple Correlation Coefficients (MCC) and regression equations were obtained to study the combined influence of X_1 and X_2 on rainfall. Table 2 gives the multiple regression equations for those days when modal MCC had appeared at each of the stations under study. Corresponding figures of MCC and percentage of total variation in rainfall explained by the respective equations are also shown alongwith Student's *t*-values. Stationwise description of the salient features of multiple correlation and regression analysis is given below :

(a) *Bombay* — The highest MCC (0.39) appeared on 2nd day when the regression equation explained 15% of total variation in rainfall. On other days the percentage of total variation was less than 11%.

(b) *Karwar* — Karwar also showed highest MCC (0.54) on 2nd day when the percentage of total variation in rainfall explained was 29% and on remaining days it was less than 11%. The *t*-values indicated that the regression results of Karwar were better than Bombay.

(c) *Mangalore* — The highest MCC (0.45) emerged on 4th day when the regression equation accounted for 20% of total variation in rainfall. On 3rd and 5th day, the regression equations explained 16% of total variation in rainfall.

(d) *Cochin* — MCC (0.49) was highest on 5th day when the regression equation explained 24% of total variation in rainfall, which was 20% on 4th day.

(e) *Trivandrum* — The highest MCC (0.50) appeared on 4th day when the regression equation accounted for 25% total variation in rainfall which was 19% on 3rd day.

The above results indicate that Karwar, which is located in the middle of west coast, displayed highest MCC among all stations and accounted for maximum variation in rainfall. Trivandrum and Cochin, located on the southernmost part of west coast, emerged next in this category. The regression equations can provide an estimation of daily rainfall after the passage of the front with a lag period of 2 to 5 days.

4. Conclusion

Results obtained from the partial and multiple correlation and regression analysis revealed that the frontal systems moving across southern Africa and adjoining southwest Indian Ocean appear to influence rainfall activity during southwest monsoon season of MONEX-79. The northernmost latitudinal penetration of fronts displayed negative correlation and the intensity of Atlantic Ocean anticyclone had positive correlation with the rainfall on 2nd, 3rd, 4th and 5th day after the passage of front. Other important inferences are summarised as follows :

(*i*) The stations located at the middle and southern regions of west coast showed significant partial correlations. The rainfall activity of these stations appears to be influenced by the frontal systems more predominantly.

(*ii*) The highest multiple correlation coefficient appeared for Karwar, which is located in the middle of west coast and it also accounted for the maximum variation in rainfall.

The results of the study give an indication of the cross-hemispheric linkages between the frontal systems of the southern hemisphere and rainfall over middle and southern parts of west coast during MONEX-79. However, a detailed study with more data is needed to establish the conclusions.

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