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Interaction of mid-latitude systems in the southern hemisphere with southwest monsoon

S. KUMAR

Regional Meteorological Centre, Bombay

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सार — दक्षिण अफ्रीका तथा सम्बद्ध दक्षिण पश्चिम हिन्द महासागर में वर्ष 1977 से 1981 तक निम्न वायुमंडल में बहने वाले शीत वाताग्र तथा सम्बन्धित पश्चिमी तरंगों के प्रवाह का मई से अगस्त के महीनों में दक्षिण पश्चिम मानसून के मुख्य लक्षणों पर पड़ने वाले प्रभाव का अन्वेषण किया गया है, तथा यह पाया गया है कि सघन वाताग्र जो 25° दक्षांश से उत्तर में प्रवाह कर जाते हैं, दक्षिण अफ्रीका तथा मेसकरन उच्च दाब के पूर्वी तट पर दक्षिण से उत्तर की ओर बने दाब कटक (रिज) में काफी उतार चढ़ाव पैदा कर देते हैं।

सघन वाताग्र के प्रवाह के समय दक्षिण अफ्रिका के पश्चिमी तट से मोजाम्बिक चैनल तक दाब सूचांक गिरता है। जिससे भूमध्य रेखा को पार कर आने वाले प्रवाह में कमी हो जाती है। लेकिन शीत वाताग्र के और आगे बढ़ जाने पर दाब सूचांक, भूमध्यीय पश्चिमी प्रवाह तथा क्षैतिज कर्तन भी बढ़ने लगता है। शोध कार्य यह भी स्पष्ट करता है कि दाब सूचांक के बदलाव का मानसून हवाओं की बहुत सी प्रवास्थाओं तथा आरम्भ में पक्का सम्बन्ध है। यह सम्बन्ध मानसून के इन तत्वों के पूर्वानुमान तथा उनके समझने में सहायक होगा।

ABSTRACT. The movement of cold fronts with associated westerly waves in the lower troposphere across southern Africa and adjoining southwest Indian Ocean during the months of May to August for the years 1977 to 1981, has been examined in relation to the chief features of southwest monsoon. The deep frontal systems which penetrate north of latitude 25° S cause considerable fluctuations in the intensity of south to north pressure ridge along the east coast of southern Africa and Mascarene high.

During the period of movement deep frontal systems from the west coast of South Africa to the Mozambique channel, the pressure index falls leading to decrease in cross equatorial flow. With further eastward movement of the system across Mozambique channel the pressure index rises and causes increase in cross equatorial flow in Arabian Sea, strengthening equatorial westerlies and increase in horizontal shear. The study has revealed a definite association between variation of pressure index with onset and various phases of the monsoon circulation. This association could be of help in understanding and forecasting of these monsoon features.

Key words — Atlantic ocean anticyclone (AOA), Frontal system, Mascarene high, Pressure index, Cyclonic storm, Indian ocean anticyclone (IOA), Cross equatorial flow.

1. Introduction

During the southern hemisphere winter season, the deep frontal systems move across southern Africa and adjoining oceanic areas penetrating north of latitude 25° S, cause considerable variations in the intensity of pressure patterns and pulsations in the speed and direction of the southeast trades in the region. Ramaswamy and Pareek (1978) showed that there are teleconnections between the activity of the southwest monsoon over India and the middle and upper tropospheric flow patterns in the southern hemisphere between 50° E and 160° E. Malurkar (1958) conceived that shallow westwards moving low pressure areas south of equator were responsible for the air stream to cross the equator from south to north in "pulses" which according to him, strengthens the monsoon over various parts of Indian region. The possible relationship between the surges in the southeast trades of the south Indian Ocean and the strengthening of the southwest monsoon was suggested by Desai (1966). During the onset phase of MONEX-79, Kumar *et al.* (1983) have found that the passage of moderate/deep frontal systems across southern Africa followed by intense Atlantic Ocean anticyclone and period of sustained strong pressure ridgs over southeast Africa determine the strength of crose equatorial flow into south Arabian Sea and south Bay of Bengal leading to organisation of ITCZ and onset of monsoon over west coast of India.

In the present study, the influence of frontal systems moving across southern Africa and adjoining southwest Indian Ocean on the monsoon for five seasons have been examined to establish cross hemispheric linkages.

2. Pressure index

During the southwest monsoon season there exists a trough-ridge system over Africa south of equator, with a trough running north-south over central parts and a north-south oriented ridge along the east coast. Through the basic flow is easterly, this trough-ridge system which generally extends upto equator, introduces a meridional component in the basic flow.

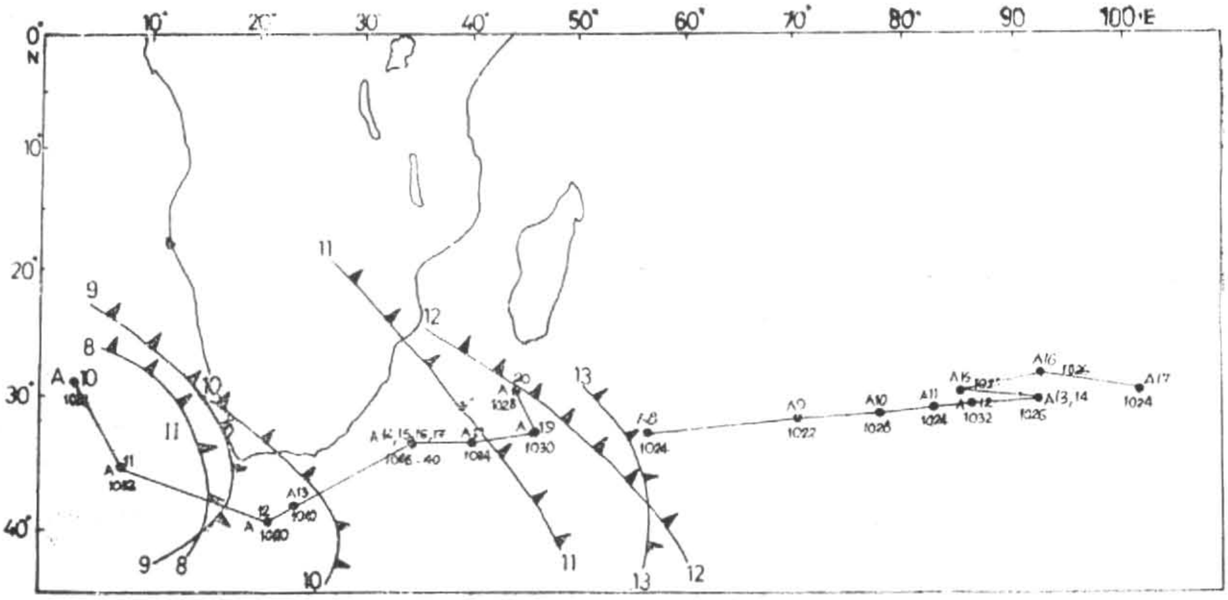

Fig. 1. The position of the cold front and centre of the anticyclones with central pressure from 8 to 17 June 1979

Johnson and Morth (1960) have shown that the pressure distribution with low pressure area to the north of equator and high pressure area to the south is favourable for causing cross equatorial flow and termed this as "Equatorial drift". On occasions when the pressure gradient becomes large, it leads to the cross isobaric explosive drift (jet) of air from south to north across the equator.

The most noteworthy surface synoptic feature of the region under study is the rythmic eastward movement of troughs and ridges across the south and east coasts of Africa. The associated pressure changes lead to weakening/intensification of the pressure ridge over southeast Africa and consequent decrease/increase in the cross equatorial flow from the southern hemisphere. The normal variation of pressure at 25°S along the southeast coast of Africa over periods of 4 to 7 days is from 1010 to 1025 hPa, but extreme variation from about 1005 to 1035 hPa occur once in a month or two Taljaard (1972). Generally the sequence of changes in the pressure pattern in association with the eastward movement of frontal system across southern Africa lasts for about one week.

During the southwest monsoon season the Mascarene high has generally a ridge extending into southeast coast of southern Africa between latitudes 25° S and 30° S. The intensity of pressure ridge along east coast of southern Africa undergoes significant variations between 25° S and 30° S in association with the passage of deep frontal system across the region between 10° E and 55° E. These consideration alongwith the fact that surface data is reliable in this area led us to define, "the highest pressure value at 1200 GMT between 25° S and 30° S along the southeast coast of southern Africa" as an index to measure the intensity of south to north pressure ridge along the east coast of southern Africa.

3. Sequence of changes in the pressure pattern in association with the movement of frontal system

As the frontal system moves from west coast of southern Africa to Mozambique channel, it causes the weakening of the pressure ridge over southeast Africa. Generally the cold front is found extending northward when it is at Natal coast and is oriented northwest-southeast. The mountain ranges of South Africa constrains the movements of these systems and the gap along the Natal and south Mozambique coasts between the mountain ranges and Indian Ocean anticyclone offers a favourable routes for northward penetration (Torrance 1972).

In the rear of the cold front the Atlantic Ocean anticyclone ridges eastward over and off the southern and southeastern coast of South Africa, resulting in the strengthening of pressure ridge over southeast Africa.

Feeble/moderate cold fronts (with intensity of rear high $\geq$ 1024/1030 hPa) generally do not penetrate north of 25°S and are seen slipping southeastward between longs. 35°E and 45°E. In the rear an elongated ridge from, Atlantic Ocean anticyclone extends up to south Mozambique channel and invariably forms a new anticyclonic cell. The parent cell tends to retract westwards and northward to the area of quasi-permanent position of. Atlantic Ocean anticyclone. The new anticyclone cell, then merges with the Mascarene high resulting in increase in its intensity.

Thus, the feeble/moderate cold fronts while moving southeastward cause only insignificant/slight variation in intensity of Mascarene high and its movement east or northeastward by few degrees.

The deep/very deep cold fronts (with intensity of rear high upto 1035 hPa/more than 1035 hPa) generally move further eastward across Mozambique channel. Along with it, the Mascarene high also moves eastward from its normal position long. 55°-60° E. As the frontal system further moves eastwards beyond 45°-50° E, the Atlantic Ocean anticyclone crosses into southwest Indian Ocean and stagnates over oceanic area south of Malagasy establishing the pressure ridge again. A typical case of movement of a deep cold front is shown in Fig. 1.

4. Data and analysis

Study is based on the 1200 GMT surface and upper air charts of Meteorological Office, Bombay Airport and surface charts of southern hemisphere published in *Daily Weather Bulletin of Republic of South Africa* for the period May to August from 1977 to 1981. This also includes the extensive data of Monex-79.

The Monthly mean pressure index was also worked out from the normal sea level charts of southern hemisphere and is given as mean pressure index (hPa) May-1017, June- 1021, July-1022, August-1019.

5. Discussion

Surface and upper air charts alongwith other available data were examined in details to determine the influence of frontal system moving across southern Africa and adjoining southeast Indian Ocean on the various features of southwest monsoon.

5.1. *Chief features of the region in May and June*

5.1.1 *May 1979* — Six cold fronts during May moved across the region. Their details are given below :

Period of passage	*Northern most latitude of penetration (°S)*	*Intensity of rear anticyclone (hPa)*	*Intensity*
1-3 May	24	No rear high	Feeble
3-8 May	19	1034	Deep
11-13 May	22	1027	Moderate
17-20 May	24	1026	Do.
21-27 May	22	1028	Do.
28 May to 1 June	20	1025	Do.

It is found that in the month of May, there was considerable variation in the pressure index in first fortnight and insignificant in the second fortnight (Fig. 2).

During the passage of a deep cold front, a low pressure area in southeast Bay of Bengal was noticed on 3 May which rapidly concentrated into a depression (7° N, 90° E) on 5 May, a deep depression on 6 May and a cyclonic storm (7° N, 88° E) on 7/8 May and

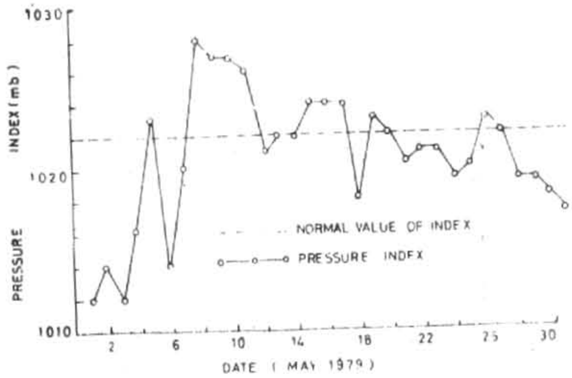

Fig. 2. Index for the intensity of pressure ridge for May 1979

into a severe cyclonic storm (7° N/85° E) on 9 May. The equatorial ITCZ remained weak during the rest of the period.

5.1.2. *June 1979* — During this month five cold fronts were noticed over southern Africa and south Indian Ocean as detailed below :

Period of passage	*Northern most latitude of penetration* (°S)	*Intensity of rear anticyclone* (hPa)	*Intensity*
4-7 June	26	1024	Feeble
8-17 June	20	1040	Very deep
18-22 June	22	1030	Moderate
21-23 June	23	1030	Do.
23-29 June	20	1030	Do.

Pressure Index fell rapidly from the normal value on 7 June to 1005 hPa by 10 June. Thereafter, it rapidly increased to 1036 hPa by 13 June and continued to be above normal up to 24 June.

The following significant features noticed during this period :

(*i*) *Abrupt organisation of ITCZ and onset of monsoon over Kerala on 12 June*

The ITCZ intensified abruptly and advanced northwards ushering in the onset of monsoon along the west coast of India. The influence of frontal system on organisation of ITCZ and onset of monsoon have been studied in details by Kumar *et al.* (1983).

(*ii*) *Strengthening of Somali jet and rainfall over west coast of India*

On 12 June, the jet with speed more than 30 kt at 850 hPa was observed for the first time. With increase in pressure index, the jet has strengthened and moved gradually northward from the latitude 7 °N to 19 °N by 30 June. It is seen that the fluctuations in the strength of Somali jet are associated with variation in the pressure index with the lag of 1-3 days (Fig. 3).

Jet core at 850 hPa and associated maximum rainfall of the day over the west coast of India is shown in the Fig. 4. Findlator (1974) has shown that in the case of

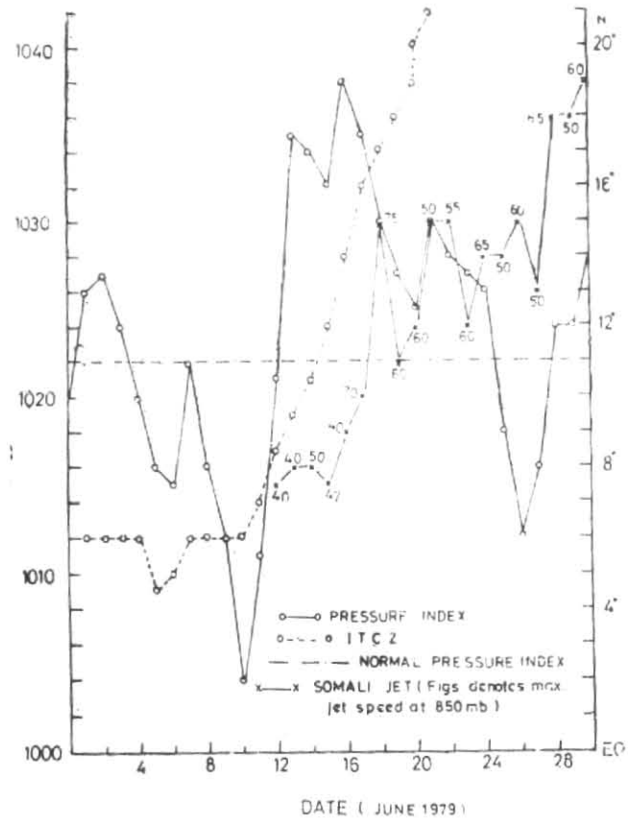

Fig. 3. Index for the intensity of pressure ridge advance of ITCZ and position of Somali jet during June 1979

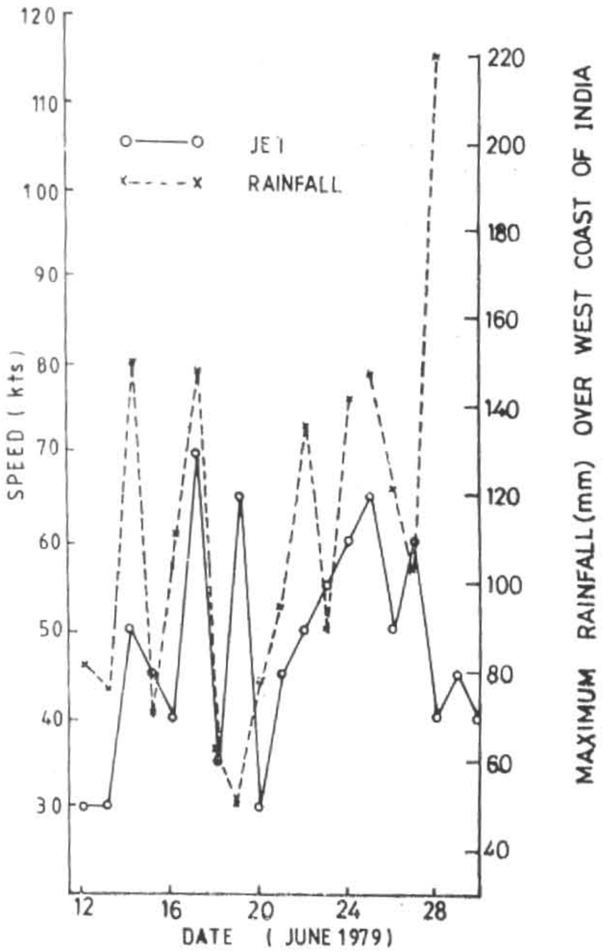

Fig. 4. The speed of Somali jet at 850 hPa and daily maximum rainfall over west coast of India during June 1979

low level jet excessive rainfall occurred over east coast of Africa near Mumbasa close to the position where the axis of maximum flow approached the coast. In this study it is found that during the period of strong winds excessive rainfall occurred over west coast of India close to the position where the jet axis approached the coast. The maximum rainfall occurred within 3-4 degrees of latitude on either side of the jet core.

(*iii*) *Formation of vortex over southeast Arabian Sea and northward movement of ITCZ*

On 12 June an increase in cross equatorial flow was noticed. A trough of low was seen forming over Lakshadweep and adjoining southeast Arabian Sea on 13 June. The ITCZ has further organised and lay between 9°N and 10°N.

By 14 June the trough of low had concentrated into low pressure area off the Kerala-Karanataka coast. The ITCZ appeared to have further intensified and moved to 11°N. The low pressure became well marked by 15th and concentrated further into depression on 16th and into deep depression by 17 June. The deep depression became a cyclonic storm by 18 June and moved westnorthwards.

(*iv*) *Formation of depressions in Bay of Bengal (23-26 June and 28-30 June)*

First depression formed over northwest Bay on 23 June and second over north Bay on 28 June in association with the passage of frontal systems across Mozambique channel on 20 June and 26 June respectively.

5.1.3. *May and June 1977, 1978, 1980 and 1981*

Six to seven frontal systems moved across the southern Africa during May and four to six in June. These caused rise in pressure index by 3 hPa to 16 hPa over a period 3 to 8 days with an average period of 4.8 days in May, and by 4 hPa to 19 hPa over a period of 4 to 9 days with an average period of 6.1 days in June. The monsoon arrived over Kerala two days in advance in association with deep to very deep cold fronts in later half of May in 1977 and 1981. The monsoon advanced early over entire west coast in 1978 and 1980.

5.2. *Chief features during July and August*

5.2.1. *July 1979* — The pressure index, horizontal shear between Lat. 10°N and 20°N along Long. 90°E and chief features of monsoon are shown in Fig. 5. During the month of July, seven cold fronts moved across the region.

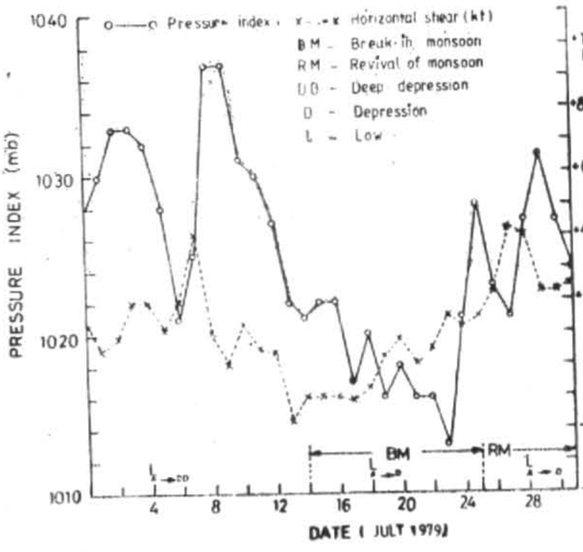

Fig. 5. Index for the intensity of pressure ridge, Horizontal shear over Bay of Bengal and chief monsoon features during July 1979

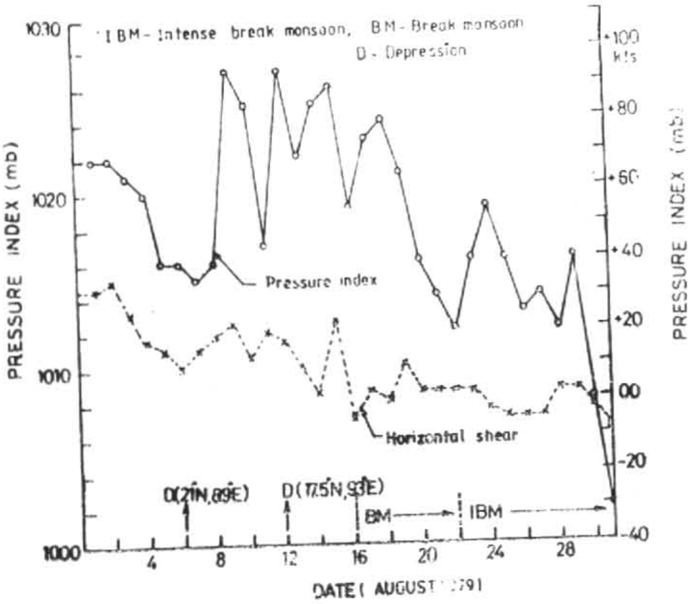

Fig. 6. Index for the intensity of pressure ridge, Horizontal shear over Bay of Bengal and chief monsoon features during August 1979

The chief features of southwest monsoon were

(*i*) *Monsoon depression* (*4-10 July*)

Two very deep frontal systems passed between 30 June and 8 July, causing large variation in the pressure index. The horizontal shear over Bay of Bengal also increased between 1 and 3 July, thus, providing favourable conditions for formation of depression.

(*ii*) *Break monsoon period* (*14-25 July*)

During this period three cold fronts of feeble to moderate intensity moved across the region in quick succession resulting in insignificant variation in pressure index which remain below normal. The horizontal shear over Bay of Bengal was generally negative.

(*iii*) *Revival of monsoon* (*26-30 July*)

During this period two deep fronts moved across the region, causing significant variation in pressure index. The horizontal shear over Bay of Bengal also increased between 26 and 27 July and a low formed on 28 July which concentrated into a depression by 31 July. The strength of westerlies over Arabian Sea and Peninsula increased resulting in the revival of monsoon.

5.2.2. *August 1979*

The pressure index, horizontal shear between Lat. 10°N and 20°N along Long. 90°E and chief features of the monsoon are shown in Fig. 6. During the month of August, nine cold fronts moved across southwest Indian Ocean in quick succession and were of feeble to moderate intensity except for two deep fronts which also did not penetrate north of Lat. 27°S.

The following features of monsoon were noticed :

(*i*) *Monsoon depressions* (*6-9 August and 12-15 August*)

First depression formed at 21°N, 89°E when the pressure index was falling. However, the horizontal shear was positive (10-15 kts). As this depression has formed near Head Bay, it appears to have not been influenced by the frontal system. Again the pressure index rose above normal from 9 August and shear was also positive (15-20 kt), when the depression formed on 12 August with centre at 17.5°N, 93°E.

(*ii*) *Break Monsoon* (*16th August onward and intense break from 22nd August*)

Pressure index was nearly normal to above normal between 16 and 19 August and was very much below normal from 20 to 31 August. The shear was also insignificant during the whole period.

5.2.3. *July and August 1977, 1978, 1980 and 1981*

Six frontal system moved across the region (10°E-55°E) during July and 6 to 8 in August. These caused rise in pressure index by 4 hPa to 13 hPa over a period of 3 to 11 days with an average period of 5.1 days in July and 3 hPa to 17 hPa over a period of two to eight days with an average period of 4.5 days in August. Three depressions formed during August and weak monsoon conditions prevailed over the country from 15 to 18 August when pressure index fell to 1016 hPa.

In association with high pressure index one depression each formed in July 1977, 1978, & 1980 and three depressions in August 1977, two in 1978 and one in 1980 and three in 1981. During the periods when pressure index was below normal the weak monsoon/break monsoon conditions occurred for 5 days in July 1978, 2 days in July 1980, 4 days in July 1981, 3 days in August 1977 and 7 days in August 1981.

6. Conclusions

The passage of deep cold fronts across southern Africa and adjoining oceanic areas exercise marked influence on the strength of cross equatorial flow into Arabian Sea and Bay of Bengal. The following salient features emerge from the study :

(*i*) During the period of movement of the deep frontal system from the west coast of South Africa to the Mozambique channel, the pressure ridge over southeast Africa remains weak or disappears for 2-3 days and the pressure index falls rapidly leading to decrease in cross equatorial flow. Along with the frontal system, the Indian Ocean anticyclone also moves eastwards from its normal position (55°E-60°E). The velocity maximum in southeast Trades over south Indian Ocean is generally seen moving eastwards in sympathy with Indian Ocean anticyclone. It is likely that the trajectory of the cross equatorial flow from the periphery of this anticyclone may also shift eastwards causing increase in cross equatorial flow into north Indian Ocean east of Long. 60°E. With further eastward movement of frontal system across Mozambique channel, the Atlantic Ocean anticyclone ridges into south Africa, establishing the pressure ridge over southeast Africa which causes rise in pressure index and southerly surge of cold air through the channel and increase in cross equatorial flow in Arabian Sea. This in turn leads to strengthening of equatorial westerlies and increase in horizontal shear.

(*ii*) The sequence of changes in the intensity of pressure ridge over southeast Africa in association with passage of deep frontal systems can be monitored by variations in pressure index .This lasts for about seven days and is generally broken with the arrival of another frontal system from the west.

(*iii*) During pre-onset phase the passage of each deep frontal system causes surge of relatively cold air leading to intensification of equatorial ITCZ and conditions become favourable for advance of monsoon. If the intensity of pressure ridge is sustained for five to seven days, invariably a low pressure area forms in the zone of ITCZ and concentrates into a depression due to increase in horizontal shear. As this system moves northwards the onset of monsoon occurs over the west coast of India. However, if the pressure ridge weakens the cross equatorial surge disappears and advance of monsoon halts temporarily. With the arrival of another strong surge the monsoon starts progressing again.

(*iv*) The absence of moderate/deep frontal systems in the second fortnight of May, can lead to a delay in the onset of monsoon.

(*v*) The formation of tropical depression may be attributed to increase in the horizontal shear in the lower level westerlies over north Indian Ocean which fluctuates with variation in pressure index.

(*vi*) If the cold fronts across southeast Africa move in quick succession with overlapping period of one or two days the pressure ridge is not maintained and the cross equatorial flow becomes insignificant. As a result the strength of monsoon westerlies decreases and horizontal shear over Indian seas becomes insignificant or negative leading to break-monsoon conditions.

(*vii*) The revival of monsoon generally occurs with the movement of deep frontal system during the period of sustained strong pressure ridge over the southeast Africa.

(*viii*) The period of variation of pressure index in association with the passage of frontal systems across the region 10°E to 55°E has range of 3 to 7 days on an average.

Thus, the intensity of frontal system and frequency of their passage across southern Africa and adjoining southwest Indian Ocean have cross hemispheric linkages with various features of southwest monsoon. This fact can be used for prediction of monsoon.

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