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SATELLITE OBSERVED WIND FORCING OVER THE SOUTHWEST EQUATORIAL INDIAN OCEAN DURING INDIAN SUMMER MONSOON

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Abstract: In this paper, satellite-observed wind forcing in the form of strong surge of cold air through Mozambique channel and along east African coast, under the influence of eastward propagating baroclinic wave disturbances over southwest Indian ocean has been studied during various summer monsoon seasons. Further, its impact on the intensification of monsoon systems over the Arabian sea through the excitation of low-level jet and associated cross-equatorial flow has been illustrated. For this purpose, satellite-observed cloud imagery, obtained from TIROS-N, NOAA, DMSP, GOES and INSAT satellites during 1979 and 1988-95,have been utilized for finding latitudinal positions of the cold fronts across south African-Malgassy region (i.e. 30°S, I -40°E), GOES(IO) and INSAT derived low level cloud drift winds in the domain 2.5°S to 2.5°N and 40°50°E have been used to observe the triggering of low level jet and associated cross equatorial flow. Daily rainfall of ten stations viz. Tiruvananthapuram, Alleppy, Cochin, Kozikhode, Mangalore, Karwar, Goa, Ratnagiri, Bombay and Dahanu have been used for finding the modulation of the rainfall activity along the west coast of India.

From the results of the study it is inferred that there is an abrupt increase in the strength of low-level wind flow along east African coast 2 to 3 days after the first appearence of northward propagating cold front across south African-Malgassy region. This is followed by intensification of the rainbearing monsoon systems (e.g. ITCZ, lows, off shore troughs etc.) over the Arabian sea giving increase in rainfall activity along the west coast of India. Therefore it is suggested that above association between northward-propagating cold front across south African-Malgassy region and excitation of low-level cross-equatorial flow can be linked to forecast increase in rainfall activity along the west coast of India 5-7 days in advance.

INTRODUCTION

During the months of the northern summer, strong surface heat troughs form over the desert areas surrounding the Arabian sea. At the same time high mountains like Himalayas inhibit the area of the cold air outbreaks and high lands over east Africa act as a barrier to low level wind flow. As a consequence of these radiational and topographic features, a strong low level southerly flow occurs along the east African coast and broad southwesterly monsoonal flow dominates over the Arabian sea. This low level air current which is well organised and very strong in a narrow belt known as low level jet or Somali jet is considered to be the main artery and the major component of monsoon gyre transporting moisture in the lower troposphere over the Indian sub-continent. Therefore, the fluctuations appearing in the intensity of low level jet and associated cross equatorial flow has very much importance as it is related to rainfall activity over India and particularly along the west coast of India (Findlater, 1969, Krishnamurti and Bhalme, 1976, Findlater, 1978, 1981, Sikka and Gray, 1981, Kumar et al., 1983, Mahajan et al., 1986, Mahajan et al., 1989, Prasad and Lal, 1990).

In this paper, the intensity of the cross equatorial flow is analysed using low level winds inferred from the images of the GOES(IO) and INSAT satellites during monsoon periods of 1979 and 1988-1995. The analysis demonstrates the influence of the northward propagating frontal systems across south African Malgassy region on the intensification of the cross equatorial flow and the modulation of the rainfall along the west coast of India through the enhancement of rainbearing monsoon systems over the Arabian sea.

DATA

During summer monsoon 1979 one of the geostationary satellites, GOES belonging to United States of America was specially brought from Atlantic ocean over the Indian ocean and deployed at about 60 degree E for monitoring the monsoon circulation over the Indian ocean, particularly in terms of wind observations. GOES measurements were ideal because they possessed both high spatial and high temporal resolution,i.e. 1 km in visible range, 8 km in infrared range and with half-hourly sampling frequency. This satellite had produced images of the earth and its cloud cover in the spectral bands 0.5-0.9 micro meter (visible) and 11-12 micro meter (infrared) respectively. Based on the sequences of cloud photographs transmitted from GOES-IO (Indian Ocean) satellite wind vectors at two levels in the troposphere were determined by several groups in USA and France. Wind data produced by these groups have been utilized in this study. Good quality of satellite derived wind data were available from INSAT satellites from 1988 onwards. Hence cloud motion winds obtained from INSAT satellites have been used for the period 1988-1995. These satellites provided images in the spectral bands 0.55-0.75 micro meter in visible range and 10.5-12.5 micro meter in infrared range with resolutions 2 and 8 km respectively. Estimates of low level wind field deduced from cloud motion vectors were extracted at MDUC (Meteorological Data Utilization Centre), New Delhi (Kelkar and Khanna, 1986). Satellite derived low level wind data used in this study have been taken from weather charts of India Meteorological Department. Daily rainfall of ten stations viz. Tiruvananthapuram, Alleppy, Cochin, Kozikhode, Mangalore, Karwar, Goa, Ratnagiri, Mumbai and Dahanu have been utilized for finding the modulation in rainfall activity along the west coast of India. Satellite imagery obtained from GOES, INSAT and DMSP satellites have been used to find out the latitudinal positions of cold fronts across south African Malgassy region. Sea surface pressure charts of India Meteorological Department have been used for finding the variations in pressure pattern during the northward passage of cold front over the southwest Indian ocean.

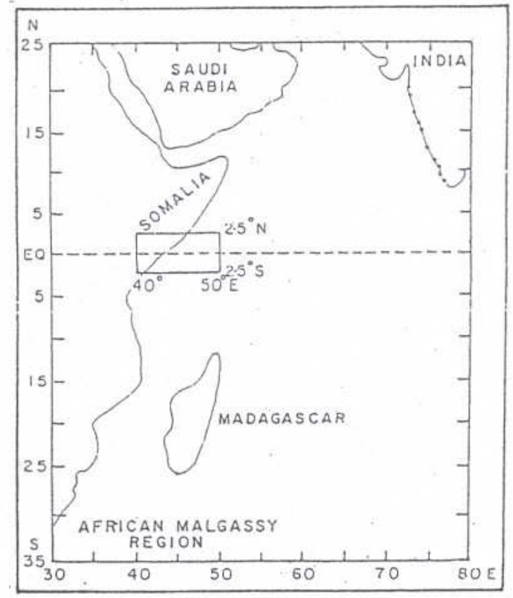

Fig. 1 Schematic diagram of the region of the study

METHODOLOGY

The mean values of v component of low level winds derived from the cloud motion vectors were computed for each day in the domain 2.5°S-2.5°N and 40°50° E during the period 16 May to 7 July for the year 1979 and June to September for the years 1988-1995 respectively, This region is depicted in figure 1. Latitudinal positions of the cold fronts as seen in satellite observed cloud imagery and sea-level pressure charts of south Indian ocean across south African Malgassy region were noted and only those cold fronts were considered favourable for the physical linkage which penetrated northward of 30°S and in the belt 30°-50 E. Such cold fronts in this category (Table 1 and 2) were considered responsible for the surge of cold air through the Mozambique channel during the period of the study. Lag correlations between the intensity of low level cross equatorial flow in the above domain and mean rainfall of ten stations along the west coast of India were computed.

Table 1

Synoptic features of the region during 1979

Date of observation of cold front in south African Malgassy region	Intensity of cross-equatorial flow after 2-3 days Speed (ms^{-1})	Intensity of cross-equatorial low after 2-3 days Date Speed (ms^{-1})	Intensity of cold front	Northern most Lat of penetration of cold front	Intensity of high pressure cell following the cold front
22 May	3.8	24 May 7.4	Feeble	24	1026
26 May	6.1	29 May 9.3	Moderate	22	1028
1 June	4.9	4 June 8.7	Feeble	20	1024
12 June	10.1	15 June14.9	Very deep	20	1040
21 June	12.1	24 June14.2	Moderate	23	1030
26 June	8.9	28 June15.1	Moderate	20	1030

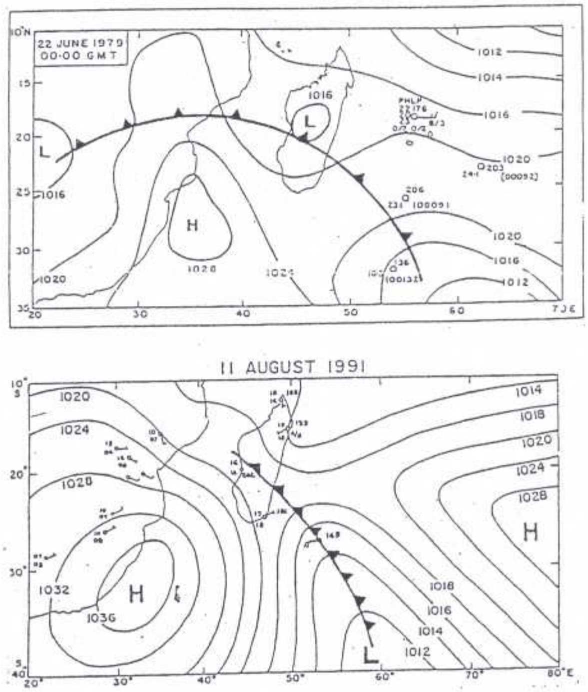

Fig2. Sea level pressure field on 22 June 1979 and 11 August 1991 during northward propagation of cold front over western Indian Ocean.

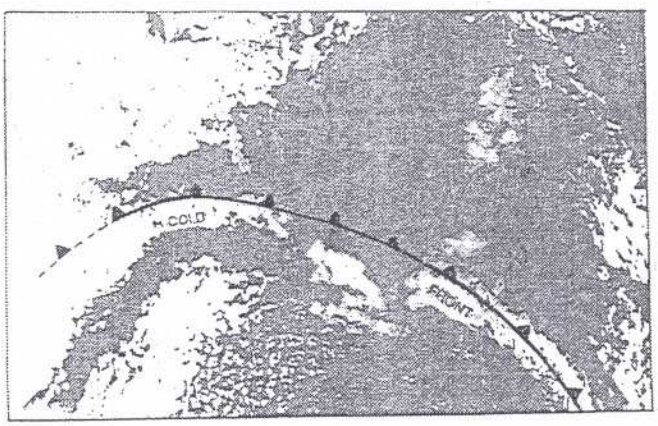

Fig 3 TIROS-N Visible picture of cold front propagating northward across Mozambique Channel and Madagascar on 22 June 1979.

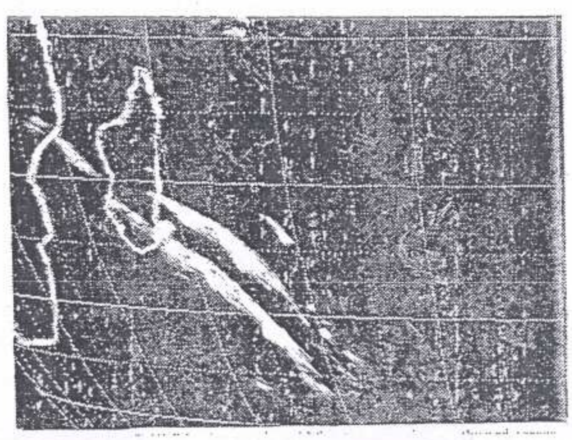

Fig 4 INSAT-1D Visible picture of a cold front propagating northward across Mozambique Channel and Madagascar 11 August 1991.

ANALYSIS OF THE WEATHER CHART

Sea surface weather charts of India Meteorological Department were examined over the western Indian ocean. Figure 2 illustrates the examples of the sea-level pressure field during the northward propagation of cold front over western Indian ocean on 22 June 1979 and ll August 1991 respectively. In these diagrams, high pressure cells are seen following the cold fronts. It is considered that these cells are responsible for the surge of cold air through the Mozambique channel. Figures 3 and 4 show the visible cloud imagery of northward propagating cold front on 22 June 1979 and 11 August 1991. These satellite photographs give a view of the cold fronts accelerating through the Mozambique channel and across Madagascar. The cold fronts which are seen in the form of well organised cloud bands agree fairly well with the cold front seen on the sea surface pressure charts.

Table 2

Synoptic features of the region during 1991

Date of observation of cold front across South African Malgassy region	Intensity of cross-equatorial flow on that day Knots	Intensity of cross-equatorial flow after 2-3 days Knots	Northern most lat penetration of cold front	Intensity of high pressure cell following cold front
10 June	10.0	12 June 29.2	25	1028
14 June	10.2	17 June 19.8	24	1026
20 June	10.1	22 June 29.2	22	1030
27 June	20.3	29 June 30.2	25	1026
4 July	13.2	7 July 33.0	24	1028
16 July	20.0	19 July 37.1	26	1032
2 August	21.3	5 Aug 33.2	26	1034
11 August	15.0	13 Aug 33.0	20	1036
27 August	25.1	29 Aug 38.0	24	1030
19 Sept.	10.0	21 Sept 30.2	25	1032

ANALYSIS OF THE EQUATORIAL WIND FIELD

Figures 5 and 6 show the time series of the intensity of the cross equatorial flow in the domain 2.5°S- 2.5°N and 40°-50° E during 16 May to 7 July 1979 and June to September 1991 respectively. In these figures thick arrows are marked against the dates on which first appearance of northward propagating cold fronts across south African Malgassy region were observed. The intensity of low level cross equatorial flow increases abruptly in each case after the northward passage of cold front. This intensification of low level cross equatorial flow could be related to the funneling effect of strong southerly winds through Mozambique channel associated with cold front which drastically increased the air inflow in the area of the western equtorial region. Here, it is significant to note that the intensity of low level cross equatorial flow reaches its maximum value 2-3 days after the first appearence of northward propagating cold front across south African Malgassy region. Tables 1 and 2 highlight the details of the intensity of cross equatorial flow before and after the passage of northward propagating cold front, northernmost latitudinal penetration of cold front and intensity of high pressure cells following the cold fronts.

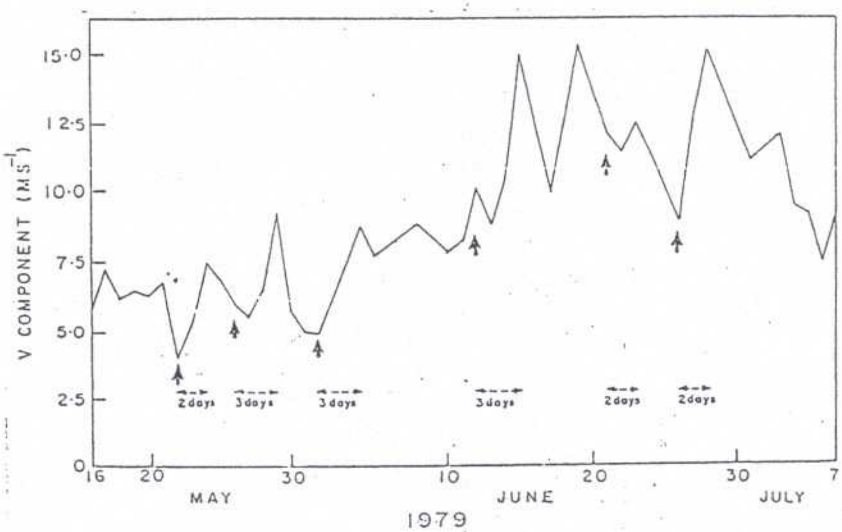

Fig 5. Time series of the intensity of satellite derived cross equatorial flow in the domain 2.5°S-2.5°N and 40°-50°E during 16 May to July 1979.

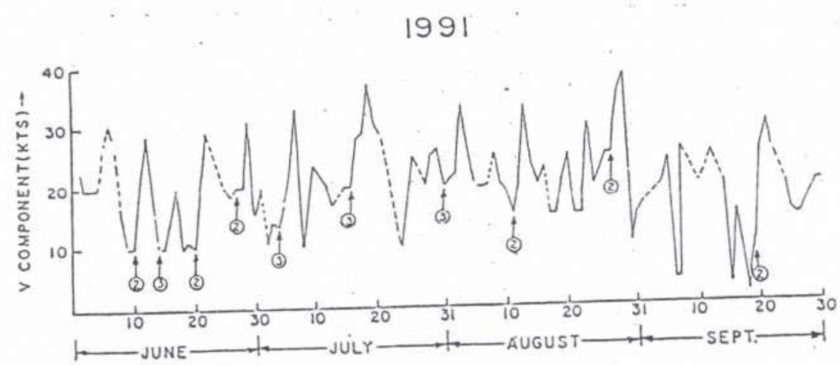

Fig 6. Time series of the intensity of satellite derived cross equatorial flow in the domain 2.5°S-2.5°N and 40°-50°E during June to September 1991.

MODULATION IN CONVECTIVE AND RAINFALL ACTIVITY ALONG THE WEST COAST OF INDIA

Some of the earlier researchers have found a good correlation between the intensity of cross equatorial flow and rainfall along the west coast of India. However, for this purpose they have used wind data obtained from Garissa station located near the equator in Kenya. But data from one station is not sufficient to represent the intensity of cross equatorial flow in true sense. Hence, this relationship has been once again examined using satellite derived winds obtained from GOES(IO) and INSAT satellites ovcr the western equatorial Indian ocean. A highly significant correlation between the intensity of low level cross equtorial flow in the domain 2.5°S-2.5°N and 40°-50°E and rainfall of ten stations along the west coast of India was obtained with a lag of 3-4 days (r = .85 & .87, degree of freedom = 316 and level of significance = 1%).

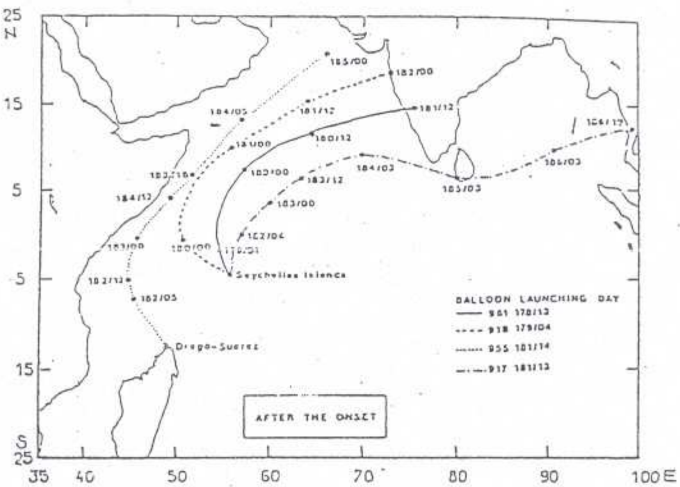

Fig 7. Constant balloon trajectories during summer Monex 1979.

The wind from western equatorial Indian ocean normally takes 3-4 days to reach the west coast of India as shown by constant pressure balloon trajectories (figure 7) during summer Monex 1979 (Cadet, et al. 1981). Figures 8 and 9 depict time series of mean rainfall of ten stations along the west coast of India for the years 1988-1991.

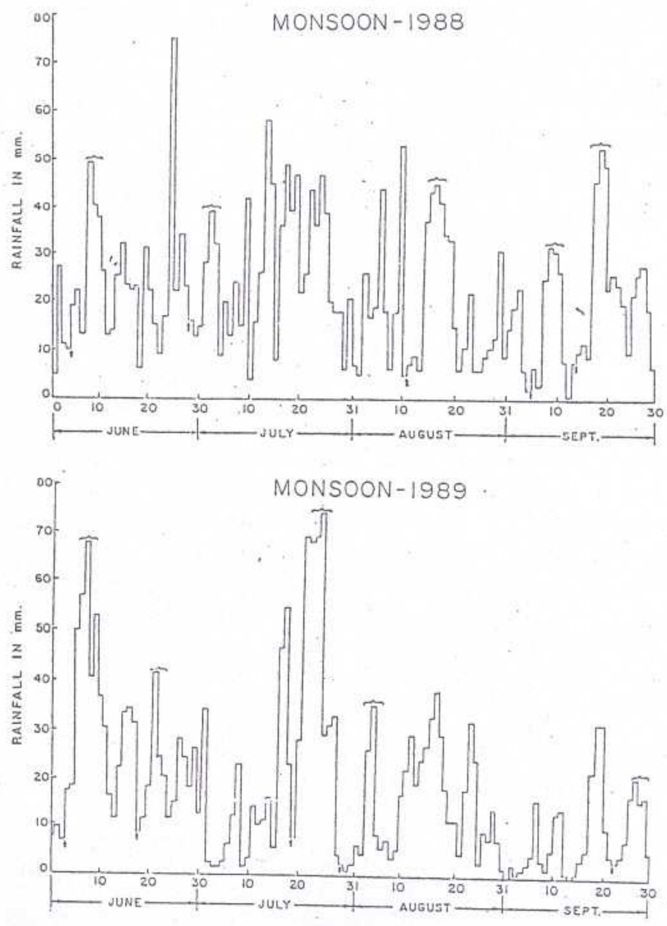

Fig 8. Time series of mean rainfall of ten stations along the west coast of India for the years 1988-89.

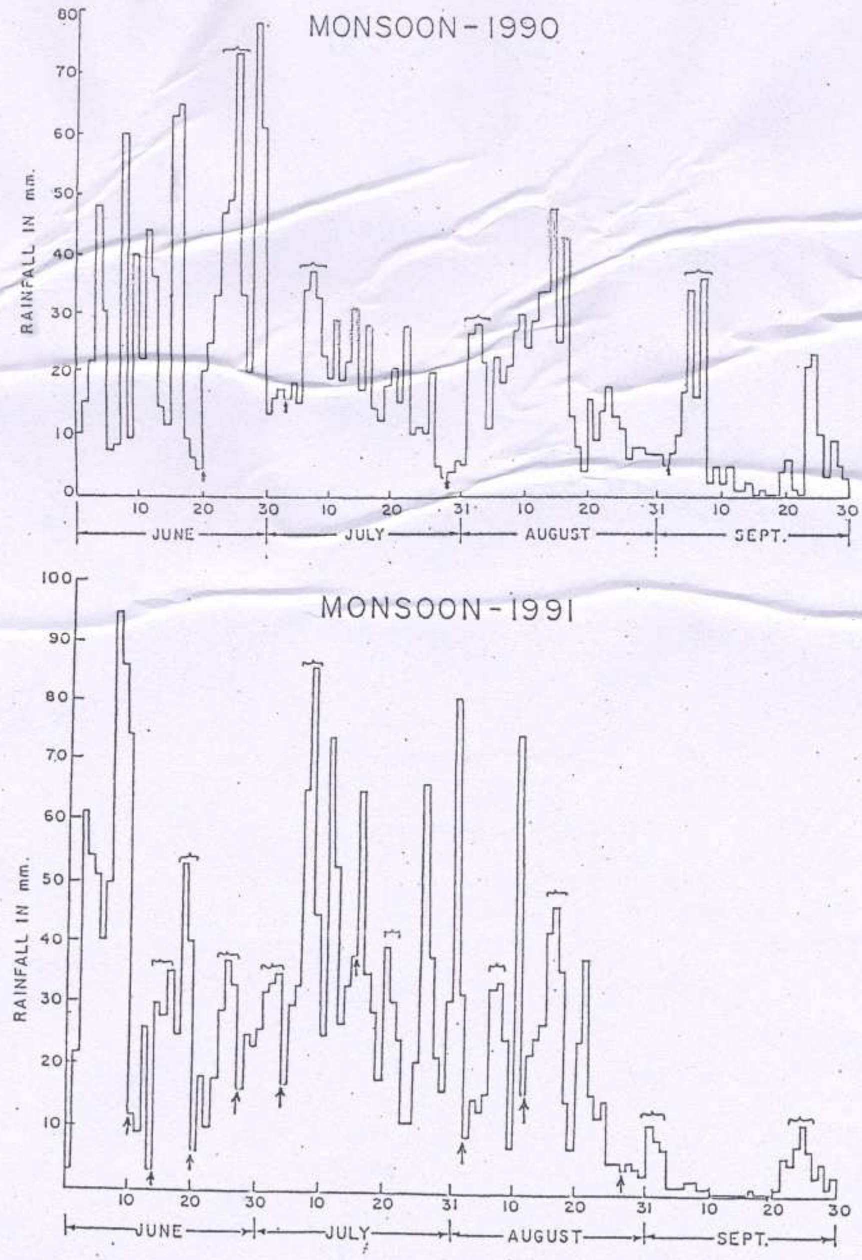

Fig 9. Time series of mean rainfall of ten stations along the west coast of India for the years 1990-91.

In these diagrams also thick arrows are marked against the dates on which the first appearance of northward propagating cold front across south African Malgassy region were observed. With reference to such dates existing pattern of mean rainfall has been found to be increased suddenly (as indicated by rainfall peaks) with a lag of 5-7 days. This may be due to the fact that triggering of cross equatorial flow is caused due to the onrushing of strong low level air inflow through the Mozambique Channel under the influence of northward propagating cold front after 2-3 days and this is followed by incursion of a lot of moisture to enhance the convective activity along the west coast of India with a lag of 3-4 days. Thus, 5-7 day period is required to modulate the rainfall along the west of India. This feature is excellently reflected in the mean rainfall pattern of ten stations along the west of India.

CONCLUSION

In this paper the influence of northward propagationg baroclinic wave disturbances across south African Malgassy region has been studied, on the modulation of the rainfall along the west coast of India through the excitation of cross equatorial flow as revealed by GOES and INSAT satellites during various summer monsoon seasons. This may not be the only reason by which strengthening of cross equatorial flow and modulation of rainfall along the west coast of India take place. But the analysis of the weather charts and examination of satellite imagery suggest that northward propagating cold front across African Malgassy region exercises a marked influence on the intensification of low level cross equatorial flow after 2-3 days. This leads to the strengthening of monsoonal westerlies causing the enhancement of convective activity of weather systems over the Arabian Sea. This convective activity modulates rainfall along the west coast of India after 3-4 days. Therefore, it is suggested that above association can be used to forecast increase in rainfall activity along the west coast of India 5-7 days in advance.

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REFERENCES

FINDLATER, J. (1969). A major low level air current near the Indian Ocean during the northern summer, Q. J.R.Meteor.Soc., 95: 362-380.

FINDLATER, J. (1978). Observational aspects of low level cross equatorial jet stream of western Indian Ocean in: Monsoon Dynamics (Ed) T.N.Krishnamurti, Birkhauser Florida State University, USA: 1251-1262.

FINDLATER, J. (1981). Low level air flow over Kenya and rainfall over India, in Monsoon Dynamics (Ed) T.N.Krishnamurti, Birkhauser Florida State University, USA: 309-313.

KELKAR, R.R. and KHANNA, P.N. (1986). Automated extraction of cloud motion vectors from INSAT-IB imagery, Mausam, 37: 495-500.

KRISHNAMURTI, T.N. and BHALME, H.N. (1976). Oscillation of Monsoon system, Part I: Observational aspects, J. Atmos. Sci., 33: 1937-1954.

KUMAR, S., SETHUMADHAVAN, K. and RAO, M.K. (1983). Influence of frontal system moving across south Africa and southwest Indian Ocean on the onset of southwest monsoon over west coast of India, Mausam, 34: 405-410.

LAL, A. and PRASAD, R. (1990). Influence of southern hemispheric frontal system on the southwest monsoon rainfall over the west coast of India during Monex-1979, Mausam, 41: 375-380.

MAHAJAN, P.N., MUJUMDAR, V.R. and GHANEKAR, S.P. (1986). The burst of Indian summer monsoon as revealed by GOES satellite during Monex 1979, Adv. Atmos. Sci., 3: 514-519.

MAHAJAN, P.N., MUJUMDAR, V.R. and GHANEKAR, S.P. (1989). Excitation of low level jet as seen

by GOES-IO satellite off the Somali coast, Adv. Atmos. Sci., 6: 475-482.
SIKKA, D.R. and GRAY, W.M. (1981). On the linkage of the genesis of monsoon disturbances and Cyclones over the Indian ocean with the passage of baroclinic waves across the southwest Indian Ocean, International Conference on scientific results of monsoon experiment, Denpassaar, Bali, Indonesia: 4.29-4.34.

GREAT BALLS OF FIRE!
Ball Lightning in Dublin, Ireland, on 31 August 1992

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Reading, Berkshire

INTRODUCTION

The meteorological situation on August 31,1992 was dominated by a deep depression (976mb) located off NW Scotland. A cool and unstable maritime-polar airflow covered the whole of the British Isles with heavy showers falling in most regions. It was during the afternoon that one of these cumulonimbus shower clouds passed over Dublin in the fresh and gusty west to south-westerly wind. The shower was by no means exceptional, but it brought a short downpour of heavy rain and hailstones together with several flashes of lightning and rumbles of thunder. It was during this brief storm that the infamous ball lightning was observed by several witnesses in an area of south-east Dublin, which is coincidentally named 'Ballsbridge'

SEQUENCE OF EVENTS

As luck would have it, I was very fortunate to be using the Main Library at University College Dublin (UCD) that afternoon and I had placed myself beside the large glass window on the top floor of the library - which commands a full view over Ballsbridge and the whole south-east portion of Dublin city. This allowed me to observe the weather during the course of the afternoon (instead of studying with my books as previously planned!).

At around 3:30pm, a large cumulonimbus approached from the south-west. It had a very dark base which was obscured in places by the heavy rain and hail. A brilliant white cirrus anvil spread out both ahead and behind the storm.

UCD is less than 2km due south of Ballsbridge, but since it only caught the edge of the storm precipitation, a good visibility was maintained throughout from my viewing platform. I observed two flashes of white forked cloud-to-ground (CG) lightning at around 3:45p.m, followed by some very loud thunder. Of these, I estimated the nearest lightning strike to be about 1.5km away. Indeed, I actually saw the second CG strike hit directly to ground somewhere in the Ballsbridge area. By 4:00pm, it was all over, and the storm had pushed out eastwards into Dublin Bay.

Later that evening, I heard news reports of damage at the Cerebral Palsy of Ireland Clinic (CPI) on Sandymount Avenue (in centre of Ballsbridge, 2km north of UCD) where a large 'fireball' was reported to have exploded during the height of the storm. Was this the infamous ball lightning? Or were the reports just exaggerations of a simple CG lightning strike? So, with my curiosity unsatisfied, I decided to get some first hand reports for myself and cycled down to the centre on the following day to interview the witnesses.