Excitation of Low–level Jet as Seen by GOES (I–O) Satellite off the Somali Coast

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ABSTRACT

The intensification of a low–level jet off the Somali coast, as observed through GOES (I–O) satellite during Indian summer monsoon 1979 has been studied. Excitation of Low–level cross–equatorial flow in the western Indian ocean results from an interaction between extratropical perturbations moving eastward across the South African–Malgassy region of the Southern Hemisphere. This excitation occurs 2–3 days after the first appearance of a northward propagation cold front across the South African–Malgassy region. Inten– sification of cross–equatorial flow is followed by an increase in rainfall activity along the west coast of India after 3–4 days. The study reveals that this association can be used to forecast an increase in rainfall activity along the west coast of India 5–7 days in advance.

I. INTRODUCTION

During the summer monsoon season, strong surface heat troughs form over land areas surrounding the Arabian Sea, particularly over North India, Pakistan, Iran and Saudi Arabia. At the same time high mountains to the north like Himalayas seal off the cold air outbreaks and the East African mountains act as a barrier to the low–level wind flow. Strong low–level southerly wind flow occurs along the East African coast and broad monsoonal south–westerly flow dominates the Arabian Sea. This strong low–level flow (known as the Somali jet) which is most pronounced at a height of 1–1.5 km is one of the most intriguing phenomena of the monsoon system (Findlater, 1969). The best match for the satellite–derived low–lever winds is against the observed winds at 900 hPa (~ 1 km) over the Indian Ocean (Mahajan and Deshpande, 1986). A three–dimensional study of jet was made by Hart (1978) and its diurnal oscillation was studied by Ardanuy (1979). On the basis of the spectral analysis, Krishnamurti and Bhalme (1976) showed that the quasi–biweekly oscillation of the intensity of jet might be related to similar oscillation in rainfall over India, associated with active and break phases. The burst of the Indian summer monsoon is characterized by a sudden establishment of the low–level jet and strong cross–equatorial flow over the western Indian Ocean (Mahajan, et al., 1986). A good correlation has been found between the low–level cross–equatorial flow and the amount of rainfall along the west coast of India (Findlater, 1978; 1981). It is also noticed that the cross–equatorial flow is stronger in good monsoon years than bad monsoon years (Krishnamurti, et al., 1976). The low–level jet is an atmospheric western boundary current and is forced by a subtropical high pressure belt (Mascarene high) over South Indian Ocean and low pressure belt (monsoon trough) over North India (Anderson, 1976; Hart, 1978). Cadet and Desbois (1981) showed that the wind discontinuity to the east of Madagascar during eastward propagation of mid–latitude depression in the

Southern Hemisphere causes a weakening of low-level jet. Rao and Haney (1982) studied the kinematic and thermal structure of the low-level surges in Mozambique channel.

A preliminary study by Mahajan et al.(1986) suggests that the satellite-based low-level winds over the western Indian Ocean are of potential use for monitoring large-scale fluctuations of the monsoon circulation over the Arabian Sea. In the present paper, the intensity of cross-equatorial flow is analysed using low-level winds inferred from the images of GOES(I-O) satellite during 16 May -7 July 1979. The analysis demonstrates the influence of frontal systems moving across southern Africa and adjoining south-west Indian Ocean on the intensity of low-level cross-equatorial flow and fluctuations of rainfall along the west coast of India.

II. DATA

During summer MONEX 1979, the Indian Ocean geostationary satellite GOES was specially repositioned from the Atlantic Ocean towards 60°E to observe the atmospheric activity over the Indian Ocean. GOES measurements were ideal because they possessed both high spatial and high temporal resolution (1 km in visible, 8 km in the infrared and half hourly sampling frequency). GOES produced images of the earth and its cloud cover in the spectral bands 0.5-0.9 μm (visible) and 11-12 μm (infrared) respectively. Estimates of low-level wind field deduced from cloud motion vectors were extracted in L.M.D.(Laboratoire de Meteorologie Dynamique). The low-level wind data used in our study were taken from the atlas 'Wind Sets of Geostationary Satellite Data' by Crozet, et al. (1979). Daily rainfall of ten stations along the west coast of India viz. Trivandrum, Alleppy, Cochin, Kozikhode,

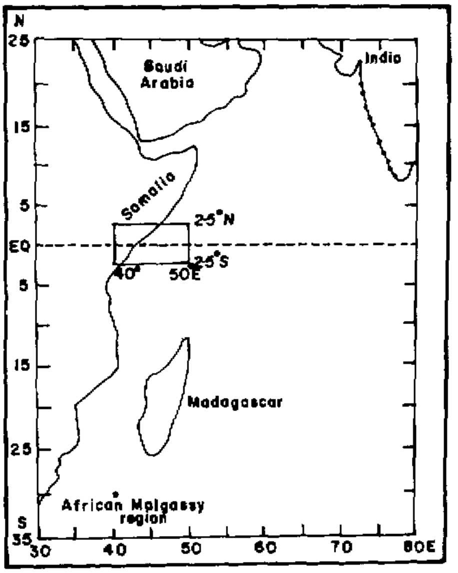

Fig.1. Schematic diagram of the region of study.

Mangalore, Karwar, Goa, Ratnagiri, Bombay and Dahanu were used. The weather charts published by the India Meteorological Department were used to find out the latitudinal position of cold front across south African–Malgassy region. Some satellite photographs obtained from DMSP (Defence Meteorological Satellite Programme) satellite of USA were examined.

III. METHODOLOGY

The mean value of low–level winds derived from cloud motion vectors was computed for each day in the domain 2.5°S–2.5°N and 40°–50°E during the period 16 May – 7 July 1979 (Fig. 1). Latitudinal positions of cold fronts, as seen on sea–level charts of South Indian Ocean across south African–Malgassy region (30°S , 40°E) were noted and only those cold fronts were considered favourable for the physical linkage which penetrated northward of 30°S in the belt 30°–50°E. Such six cold fronts in this category were considered responsible for the surge of cold air across the Mozambique channel during this period of the study. A correlation between the intensity of the low–level cross–equatorial flow in this specified domain, and meanrainfall of ten stations along the west coast of India was examined.

IV. ATLANTIC APPROACHES

The most important surface synoptic feature of the region under study is characterized by the rhythmic eastward propagation of highs and lows from the South Atlantic across the south and east coast of Africa. The associated pressure changes lead to intensification / weakening of a pressure ridge over Southeast Africa which causes the increase / decrease in the intensity of cross–equatorial flow from the Southern Hemisphere. The hypothesis proposed by Sikka and Gray(1981) suggests that an active frontal system from the South Atlantic approaches the western part of South Africa. As this moves eastwards a ridge from the South Atlantic high invades South Africa behind the advancing cold front. Some of the cold fronts have a very strong tendency to penetrate northward or northeastwards. As the front moves across the south African–Maglassy region, a cold high pressure cell forms behind it. This increases the normal west–east pressure gradient in the near equatorial region. A southerly surge of cold air follows through the Mozambique channel and merges with the southeast trades northwest of Madagascar. This intensifies the cross–equatorial flow in the western Indian Ocean. A high pressure cell following the cold front further moves eastward towards Mauritius and merges with the Mascarene high. The pulsation of the Mascarene high causes the intensification of southeasterly trades. The southerly surge through the Mozambique channel and fresh intensified southeastly trades merge together near the equatorial western Indian Ocean, thus triggering the cross–equatorial flow.

V. ANALYSIS OF WEATHER CHARTS AND SATELLITE PHOTOGRAPHS

Sea–surface weather charts of the India Meteorological Department were examined during the period of the study. Fig. 2 illustrates an example of the sea–level pressure field during the northward propagation of a cold front over the western Indian Ocean on 22 June 1979. A high pressure cell following the cold front is seen to the east of African coast. It is suggested that this cell was responsible for the surge of cold air through the Mozambique channel. Fig. 3 shows the DMSP visible image of the southern African coast on 22 June 1979. This figure depicts a satellite view of cold front accelerating through the Mozambique channel and across southern Madagascar. The cold front, which is seen in the form of well–organized cloud band, fairly well fits with the cold front as seen on the sea–level chart. The pattern of cloudiness following the cold front around 30°S, 35°E indicates the area of cold air outbreaks.

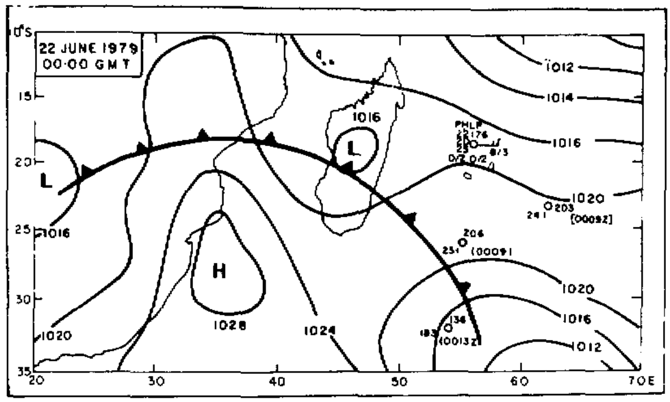

Fig.2. Sea-surface pressure field on 22 June 1979 during northward propagation of cold front.

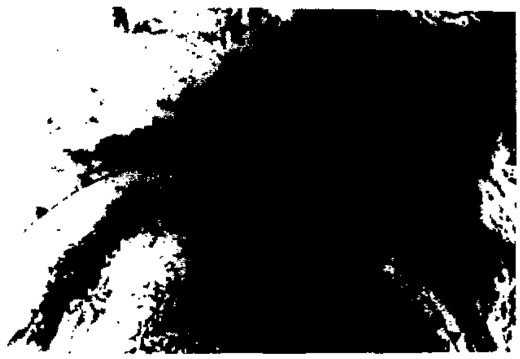

Fig.3. DMSP visual image of cold front on 22 June 1979.

VI. ANALYSIS OF THE WIND FIELD

Fig.4 shows the satellite-derived low-level wind field on 10 June 1979 before the northward passage of a cold front across the south African-Malgassy region. We note that the low-level wind field in the Mozambique channel is weak (~ 5 m s^{-1}) and it has no specific direction. The low-level cross-equatorial flow is also weak and its intensity is about 10 m s^{-1}. Fig.5 shows the satellite-derived low-level wind field on 14 June 1979 after the northward passage of a deep cold front on 11 and 12 June across south African-Malgassy region. In this diagram an abrupt change in the low-level air circulation in the Mozambique channel is observed. Sudden outbreaks of strong southerly winds (~ 20 m s^{-1}) are noticed in the Mozambique channel. Moreover, an increase in the intensity of cross-equatorial flow (~ 15 m s^{-1}) is also noticed.

In all the six cases we found that either moderate or strong southerlies are established in the Mozambique channel within a day or two after the northward passage of cold front across south African-Malgassy region. Sikka and Gray (1981) indicate that the strength of southerlies in the Mozambique channel depends on the amplitude of the trough accompanying cold fronts. Cold fronts which are accompanied by large amplitude troughs in the middle troposphere (500 hPa) lead to strong southerlies in the Mozambique channel but small amplitude troughs lead to moderate southerlies.

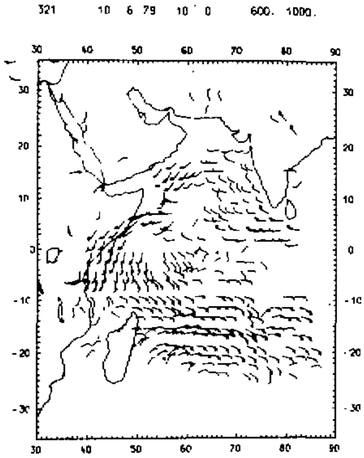

Fig. 4. Satellite–derived low–level wind field on 10 June 1979 before northward propagation of cold front across south African–Malgassy region.

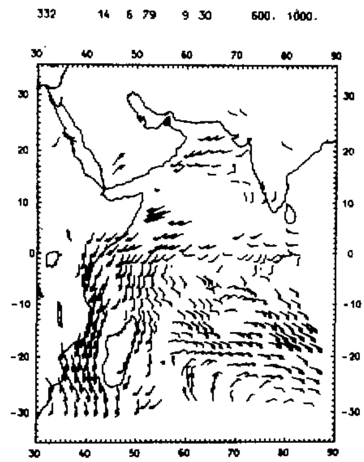

Fig. 5. Satellite–derived low–level wind field on 14 June 1979 after northward propagation of cold front across south African–Malgassy region.

Fig.6 shows a time series of the intensity of cross–equatorial flow in the domain 2.5°S–2.5°N and 40°–50°E during 16 May to 7 July 1979. Each thick arrow shows the day on which the first appearance of a northward propagating cold front was observed in south African–Malgassy region. The intensity of a low–level jet increases abruptly in each case after the northward passage of a cold front. This intensification of the low–level jet could be related to the funnelling effect of strong southerly winds through Mozambique channel, associated with cold front, which drastically increased the air inflow in the area of the jet. Here, it is significant to note that the intensity of the low–level jet reaches its highest value 2–3 days after the first appearance of northward propagation cold front in the south African–Malgassy region i.e., the time required for the surge to reach the western equatorial Indian Ocean. Another noteworthy feature is that before the onset of the monsoon i.e., before 10 June, the mean intensity of cross–equatorial flow was about 6 m s^{-1}, but after onset if was about 12.5 m s^{-1}. Table 1 gives the details about the intensity of the cold front, the northernmost penetration of the cold front, the intensity of the high pressure cell following the cold front and the intensity of cross–equatorial flow. Bannon (1979) theoretically studied the influence of mid–latitude disturbances on the large–scale features of the low–level jet and his study demonstrates that an eastward propagating mid–latitude disturbances can have a significant effect on the flow at the equator. This is confirmed by our results presented in this paper.

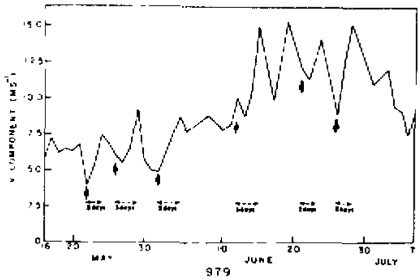

Fig. 6. Time series of intensity of low–level cross–equatorial flow in the domain 2.5°S–2.5°N and 40°–50°E during 16 May–7 July 1979.

Table 1. Synoptic Features of the Region during 16 May–7 July 1979

Date of observation of cold front in south African–Malgassy region	*Intensity of* cross–equatorial flow on that day Speed ($m\ s^{-1}$) (v)	*Intensity of* cross–equatorial flow after 2–3 days Date	 Speed ($m\ s^{-1}$) (v)	Intensity of cold front	Northern most Lat.(° S) of penetration	Intensity of cold pressure cell following the cold front (*hPa*)
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 June*	*14.9*	*Very deep*	20	1040
21 June	12.1	24 June	14.2	Moderate	23	1030
26 June	8.9	28 June	15.1	Moderate	20	1030

VII. MODULATION OF RAINFALL ALONG THE WEST COAST OF INDIA

As stated earlier, there is a strong correlation between the intensity of low–level winds along the Somalia coast and rainfall along the west coast of India. This relationship has been studied during 16 May to 7 July 1979, considering the intensity of low–level cross–equatorial flow in the domain 2.5°S–2.5°N and 40°–50°E, and the mean rainfall of ten stations along the west coast of India. Fig.7 shows the time series of mean rainfall along the west coast of India during 16 May to 7 July 1979. It is significant to note from this diagram that rainfall activity was weak before 10 June and then it suddenly increased. This rainfall activity before 10 June might be related to the pre–monsoon thunderstorm activity because by this time monsoon flow was not set up. When the monsoon current was set up and low–level jet was established, suddenly the rainfall activity along the west coast of India increased. To see the relation between cross–equatorial flow and the rainfall along the west coast of India, we computed the correlation between them, after the set up of monsoon current. We found a significant correlation with a lag of 3–4 days ($r=0.65$ and 0.67, degree of freedom = 51 and level of significance = 1%). To reach the wind to west coast of India, it normally takes 3–4 days, as shwon by constant–level balloon trajectories during MONEX–1979 (Cadet, et al., 1981).

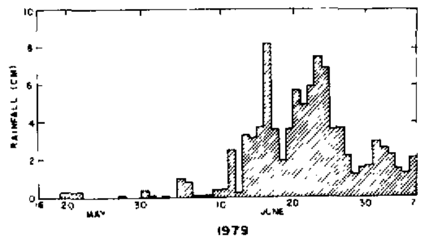

Fig.7. Time series of mean rainfall of ten stations along west coast of India during 16 May–7 July 1979.

VIII. CONCLUSION

In this paper a relationship between the northward propagating cold front across south African–malgassy region and the excitation of low–level jet as observed through GOES (I–O) satellite during the summer monsoon 1979 has been illustrated. This may not be the only reason by which the intensity of low–level jet is increased. However the analysis of weather charts and low–level winds suggests that northward propagating cold front across south African–malgassy region exercises a marked influence on the intensity of cross–equatorial flow which leads to the strengthening of low–level monsoonal westerlies over the Arabian Sea. This makes favourable environment for the intensification of ITCZ and formation of onset vortex during the onset period of monsoon. These weather systems modulate the rainfall activity along the west coast of India. The above association can be used to forecast the increase in rainfall activity along the west coast of India 5–7 days in advance. However the full implications of such monitoring have to be explored in details from INSAT–1B data, as our stusdy is based on the limited data of summer MONEX–1979.

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