THE BURST OF INDIAN SUMMER MONSOON AS REVEALED BY GOES SATELLITE DURING MONEX 1979

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ABSTRACT

During FGGE year 1979, low-level air flow over the western Indian Ocean was determined from the analysis of GOES images (5—20 June). The wind pattern shows sudden change in low-level air circulation over western Indian Ocean during the initial burst of summer monsoon. The burst of monsoon is characterized by sudden establishment of low-level jet and strong cross-equatorial flow. This abrupt change signals the beginning of southwest monsoon over India and it is associated with the first monsoon rainfall over the southern part of western coast of India. Sudden change in low-level air flow is followed by the burst of monsoon within 3—5 days.

I. INTRODUCTION

During the months of northern summer, intense heat lows form over the desert areas surrounding the Arabian Sea. High mountains to the north, like Himalaya, inhibit the cold air outbreaks and the East African highlands act as a barrier to low-level wind flow. As a con-s sequence of these radiational and topographic features, a strong low-level air current occur along the East African coast and a broad monsoonal southwesterly flow dominates the Arabian Sea. Thus, the low-level air flow circulating over the western Indian Ocean is characterized by southeasterly trade winds of the Southern Hemisphere, cross-equatorial flow along Somali coast and southwesterly flow over the Arabian Sea. The cross-equatorial flow is the main artery and major component of the monsoon gyre, transporting moisture in the lower troposphere. The gyre originates from the outflow of the Mascarene anticyclone and it is well known as southeast trades. These trades after crossing the equator turn eastward mainly under the influence of Coriolis force. The major low-level air current, most pronounced at the height of 1—1.5 km (known as Somali jet), with the speeds reaching about 30 m s^{-1} is one of the most intriguing phenomena (Findlater, 1969)[1]. The real start of southwest monsoon is usually signalled by a sudden increase in cross-equatorial flow which occurs abruptly over the western Indian Ocean and is known as the burst of monsoon. Statistical study of this burst has been done along African coast and over the Arabian Sea (Fieux and Stommel, 1977)[2]. However, the relationship between the dynamical burst (establishment of low-level jet and associated large cross-equatorial flow) over the western Indian Ocean and rainfall burst along the western coast of India (Kerala coast) is not well documented.

In the present study the burst of monsoon during the summer of MONEX 1979 is discussed using satellite-derived winds inferred from the analysis of GOES images. The period of the study extends from 5 to 20 June. The geographical area covered extends from 30°S to 30°N and from 30° to 90°E. The results of the analysis presented in the study stress the relationship between the dynamical burst over the western Indian Ocean and the rainfall burst along the west coast of India.

II. THE DATA

1. *Satellite Data*

During FGGE year 1979, Indian Ocean geostationary satellite GOES was specially stationed at 60° E to observe the atmospheric activity and this provided researchers first opportunity to continuously view the monsoon circulation over the Indian Ocean. GOES measurements are ideal because they possess both high spatial and high temporal resolution (1 km visible, 8 km infrared and half hourly sampling frequency). GOES produces images of the earth and its cloud cover in the spectral bands 0.5—0.9μm (visible) and 11—12μm (infrared) respectively. Wind fields deduced from cloud motions are extracted in L. M. D. (Laboratory de Meteorology Dynamique), using the sequences of cloud photographs transmitted from GOES satellite. Low-level wind fields have been inferred from GOES images during the period 16 May—7 July 1979. However, the data used in the study is dated from 5 to 20 June for which the initial burst of monsoon along the west coast of India occurred.

2. *Ship Data*

During summer MONEX, research ships recorded meteorological data at their stationary positions as well as during their transit over the tropical Indian Ocean. In this study we have mainly used surface wind data from stationary positions of Russian research ships in the polygon formation over the Arabian Sea, which were centred near 7.0°N, 69.0°E (UHQS), 7.0°N, 64.5°E (UMAY), 9.2°N, 66.7°E (EREB), 4.7°N, 66.7°E (EREC) during the period 2—14 June 1979.

III. WIND FIELD ANALYSIS

Fig. 1 depicts GOES images taken at 0930 GMT on 11 June (Fig. 1a is the visible channel and Fig. 1b the infrared channel). A feeble southwest monsoon current south of 12°N is clearly seen over the Arabian Sea. This sets in southwest monsoon along the west coast of Indian (monsoon onset data as declared by India Meteorological Department). Fig. 2 shows the GOES images taken at 1000 GMT on 14 June (both visible and IR), when the onset vortex formed in the strong monsoon current. Large convective clouds covering most of the central Arabian Sea are seen off the western coast of India. The satellite imagery relates the evolution of monsoon cloud cover to the flow fields obtained from cloud motion vectors.

Figs. 3, 4, 5 and 6 depict examples of wind fields on 5, 8, 11 and 14 June respectively. On 5 June, winds of the order of 2—3 m s^{-1} over Mozambique Channel do not show any specific direction. Southeast trade winds (10—15 m s^{-1}) east of the northern tip of Madagaskar penetrates African coast where their intensity is about 10 m s^{-1}. Here, corss-equatorial flow is not established. Winds over the southeast Arabian Sea are northwesterly which show a typical pre-monsoon situation. On 8 June, the situation suddenly changed and strong southeast trade winds of the order of 20—25 m s^{-1} east of the northern tip of Madagaskar are seen. Winds over Mozambique Channel show south/southwesterly direction with slight increase in wind speed. The low-level air flow off Somali coast seems to be well established. As a consequence of this situation a feeble monsoon current over the Arabian Sea south of 12°N (Fig. 1) off Kerala coast is established on 11 June.

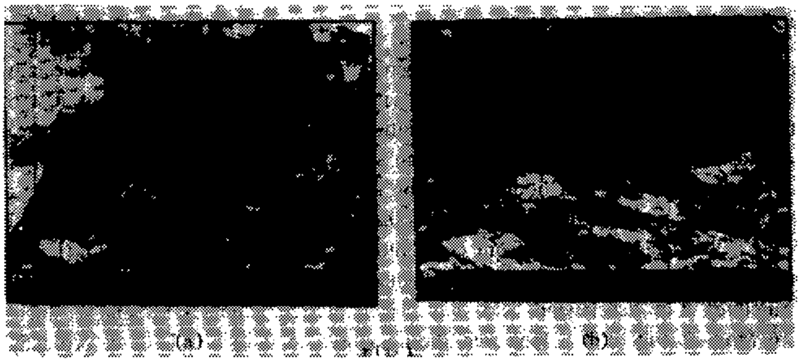

Fig. 1. GOES images at 0930 GMT on 11 June 1979.
(a) visible; (b) infrared.

Fig. 2. As in Fig. 1 except on 14 June 1979.

During the next few days, cross-equatorial flow strengthens and westerly winds dominate the Arabian Sea. On 14 June the intensity of Somali jet reaches 15 m s^{-1} and southerly winds are observed near the equator, off East African coast. Strong winds are found over the Arabian Sea between 50° and 60°E, where the intensity reaches 20 m s^{-1}. These strong winds may correspond to an intensification of low-level jet over the Arabian Sea (Desai et al., 1976)[3]. Strong southerlies of the order of 20 m s^{-1} are noticed over the Mozembique Channel. Broad-scale forcing of low-level winds over the Mozambique Channel seems to be related to the passage of cold fronts observed on 12 and 13 June, to the south of Mozambique Channel (around 30°S and 40°E).

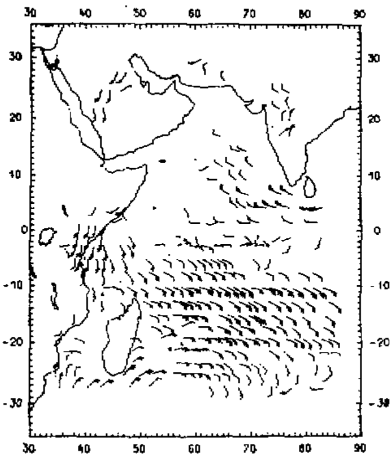

Fig. 3. Low-level wind vectors determined from cloud displacements at 0930 GMT 5 June 1979. Each full barb represents 5 m s^{-1}.

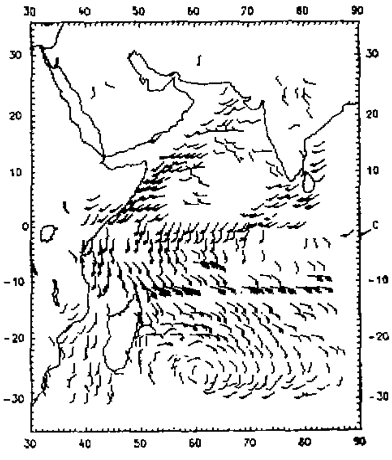

Fig. 4. As in Fig. 3 except on 8 June 1979.

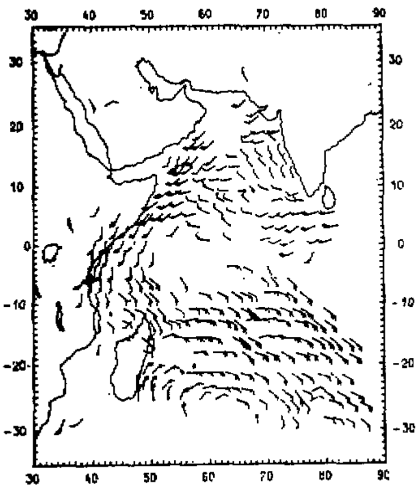

Fig. 5. As in Fig. 3 except on 11 June 1979.

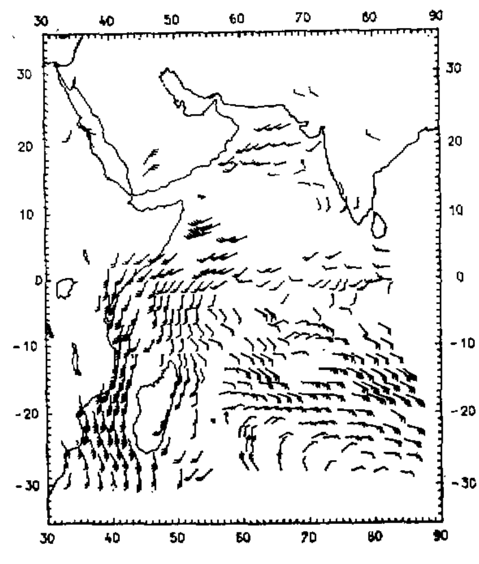

Fig. 6. As in Fig. 3 except on 14 June 1979.

IV. RELATIONSHIP BETWEEN LOW-LEVEL AIR FLOW AND RAINFALL BURST ALONG THE WEST COAST OF INDIA

The southwest monsoon of India is usually signalled by a "burst" of rainfall along the west coast of Kerala. Sudden increase in rainfall occurs abruptly and is characteristic of the beginning of southwest monsoon. Afterwards northward progression of rainfall front generally covers whole India within one and half months.

During the summer of MONEX 1979, monsoon burst was noticed on 12 June and on the following days. Fig. 7 depicts the mean rainfall of three stations, namely Trivandrum, Alleppey and Cochin, along the west coast of south Kerala (mean latitude 9°N). Rainfall < 2.5 cm occurred before 11 June and it can be related to local storms (pre–monsoon activity). Abrupt increase in rainfall occurred on 12 June, and on the following days rainfall was significantly greater except on 13 June. The decreased rainfall on 13 June is probably due to the northward shift of trough line over the southeast Arabian Sea (Nyenzi, 1980)[4].

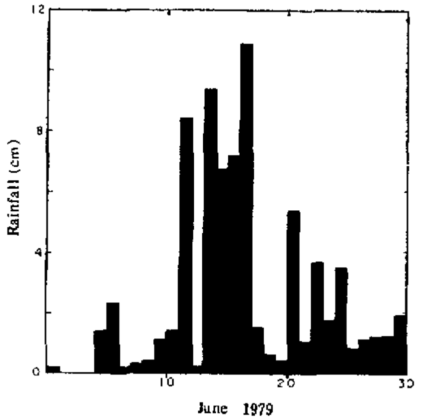

Fig. 7. Mean rainfall at three stations (Trivandrum, Alleppey, Cochin) along the southern part of the western coast of India.

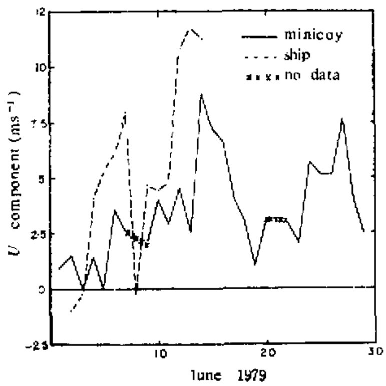

Fig. 8. U component of wind at Minicoy (solid line) and mean U component of wind at ships (dashed line) located off western coast of India.

This sudden increase in rainfall along south Kerala coast can be associated with increase in the intensity of southeast trade winds and cross–equatorial flow off Somali coast as observed on 8 June. The air flow crossing the equator along the East African coast reached the Indian coast after 3—5 days, as shown by constant–level balloon trajectories obtained during MONEX 1979 (Cadet et al., 1981). Increase in the wind intensity over the western Indian Ocean must have reached the Indian coast during 11—13 June. Rushing of cross–equatorial flow and its spreading towards the central and eastern Arabian Sea is one of the main causes for the intensification of ITCZ during the pre–onset phase (Sikka et al., 1980) which ultimately results in an increase in rainfall along the west coast of India. Fig. 8 depicts the U component of surface wind at Minicoy (an island off the Indian west coast) and research ships over the southeast Arabian Sea. It is clearly seen that westerly component over the southeast Arabian Sea increased on 12 June for both ships and Minicoy more than any other day before 12 June. This can be associated with the establishment of low–level jet and intense rainfall occurred that day along the west coast of south Kerala. Thus, there exists a strong relation between the dynamical change over the western Indian Ocean and the rainfall burst along the west coast of India.

V. CONCLUSION

In this paper, the relationship between the dynamical change over the western Indian

Ocean and the monsoon rainfall burst along the west coast of India has been illustrated. The analysis of GOES images during the first burst of summer of MONEX 1979 has been made. The dynamical change over the western Indian Ocean signals the beginning of monsoon season over India. Within a few days cross-equatorial flow and low-level jet were established. At the same time strong trade winds of the Southern Hemisphere crossed the equator and spread orderly over the Arabian Sea. After 3—5 days, the surface winds at the four research ships and Minicoy island increased significantly. As a consequence of this situation the first monsoon rainfall burst was noticed along the south Kerala coast of India. Our result shows the important role of Somali jet in the dynamics of monsoon circulation as observed by previous investigators (Findlater, 1969, Krishnamurti et al., 1976)[1,7]. Thus, satellite-derived wind data are of potential use for forecast of monsoon rainfall burst along the west coast of India.

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