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Satellite-observed upwelled region and prime eddy off Somali coast during Monex-79

P N MAHAJAN
Indian Institute of Tropical Meteorology, Pune 411 005, India

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Abstract. An upwelled region as seen through satellite imagery off the Somali coast is compared with sea surface temperature during summer Monex-79. The relationship between satellite-derived low-level cloud drift winds and the sea-surface temperature is studied. Cloudiness associated with a prime eddy off the Somali coast is also studied. It is observed that the upwelled region has a unique crescent shape and reflects the sea-surface temperature that is driven by low-level strong winds. The prime eddy, as observed through a satellite imagery, shows that low cloud convection tends to be greater over the warm waters of the prime eddy, and the upwelled cold water tends to encircle the eddy leading to the identification of its outer boundary.

Keywords. Prime eddy; crescent-shaped upwelled region; satellite-derived low-level winds; Somali current; Monex.

1. Introduction

During the months of northern summer, the Somali current commences south of equator by late April and flows along the east African coast (Leetmaa 1972, 1973). It then progresses northward during May and reaches its full strength during July and August (Swallow and Bruce 1966). Large anticyclonic eddies (diameter 400–600 km) are formed off the Somali coast during monsoon season and is termed as prime eddies (Bruce 1979). Generally, these eddies are formed between 4 and 12°N and between the Somali coast and 58°E. In some years, an eddy of small size forms adjacent to and south of the prime eddy. Using SST reports from ships and satellite-sensed SST data Evans and Brown (1981) showed that prime eddy occurred each year with some variation in the location of the southern eddy. A cloud-free area is seen off the Somali coast during each monsoon season, and it remains prominent during the established phase of the monsoon season. During the summer Monex-79, a crescent-shaped cloud-free area and the prime eddy were seen through satellite imagery off the Somali coast. In this paper an attempt has been made to investigate the oceanic features and the cloudiness patterns associated with these phenomena.

2. Data

2.1 *Satellite data*

During FGGE year 1979, Indian ocean geostationary satellite (GOES-IO) was specially brought to a new location of 60°E to observe the atmospheric activity.

This gave investigators their first opportunity to view the monsoon circulation over the Indian ocean. At the same time, the TIROS-N polar orbiting satellite also provided useful information over the Indian ocean. Satellite-derived low-level cloud drift winds were obtained from GOES satellite during May–July 79 (Crozet *et al* 1979). GOES measurements were ideal because they possessed both high spatial and high temporal resolution (1 km in visible, 8 km in infrared and half hour sampling frequency). GOES-IO 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. Based on the sequence of cloud photographs, wind vectors at two levels in the troposphere were determined by several groups in USA and France. Satellite-derived wind vectors along the sea lane (figure 1) were averaged for each day to see its relation with the sea surface temperature (SST).

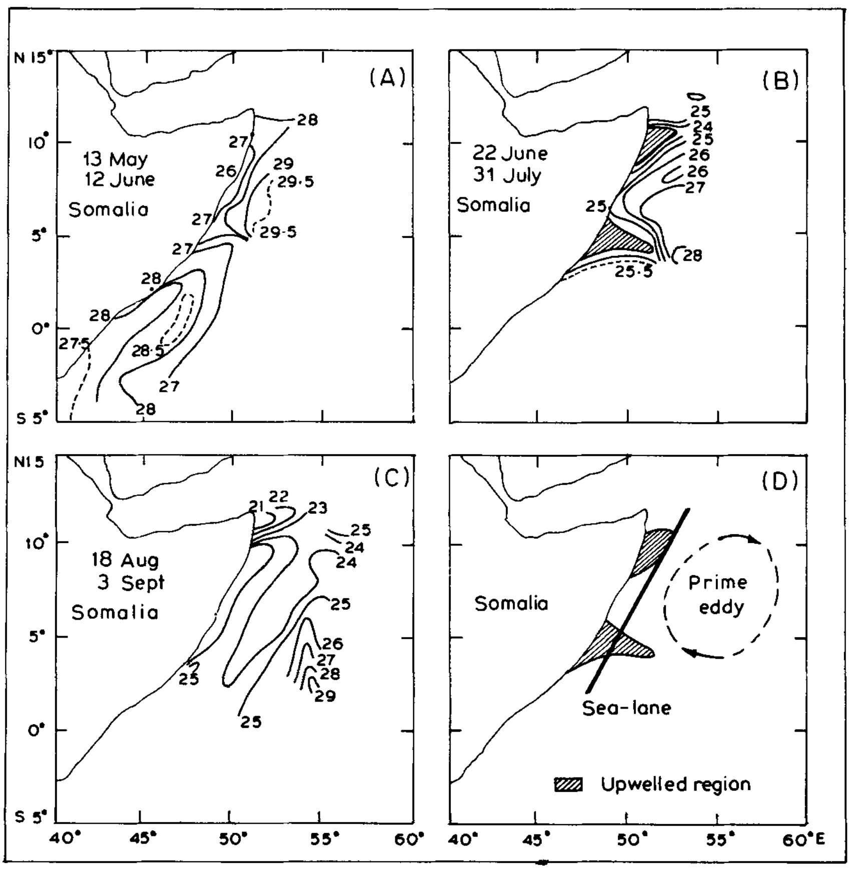


Figure 1. Time sequence of ship-observed SST fields for oceanic response to the southwest monsoon 1979 (From Brown *et al* 1981). The schematic drawings indicate probable circulation pattern of the prime eddy and regions of upwelling (shaded triangular areas off Somali coast).

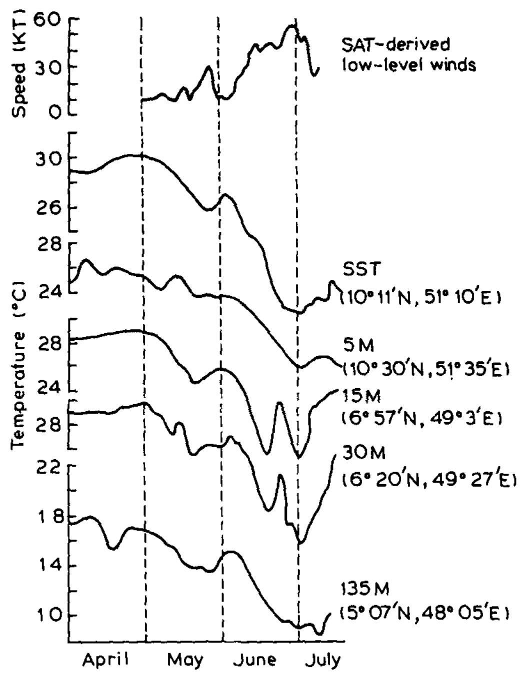


Figure 2. Time series of satellite-derived low-level cloud drift winds and temperature records at different locations off Somalia; sensor depths as indicated.

2.2 *Moored station data*

During Monex-79 a plan was designed to investigate the spatial and the temporal development of the Somali current and its associated cloudiness, upwelling and eddy fields. Moored stations were deployed off the Somali coast with instruments recording currents and temperatures at several locations. Shipboard observations of the vertical profiles of temperatures were made by several research ships taking part in the FGGE experiment. Temperatures and satellite-derived low-level cloud drift winds at different locations off the Somali coast are shown in figure 2.

3. Sea temperature and satellite-derived winds

Time series of coastal temperatures and satellite-derived low-level cloud drift winds at different locations off Somalia (figure 2) reflect the immediate near coastal surface response during different phases of monsoon. With the onset of the southwest monsoon and the development of strong southerly surface winds, the offshore transport of water increases, compensating upwelling increases and significant SST drops occur off Somalia. Intercomparison of ship wind estimates and satellite-derived low-level winds showed that both methods agreed reasonably well in describing the large-scale monsoon wind changes off east Africa (Schott and

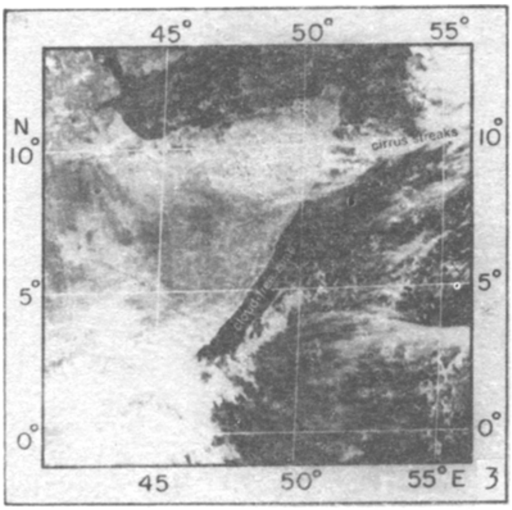
Fernandez-Partagas 1981). However, there seemed to be a noteworthy effect of cold water upwelling areas on the cloud level wind data. It is significant to note that the number of cloud level vectors off northern Somalia decreased drastically after the monsoon onset. This was caused due to the reduced convection over the cold water areas. Onset of summer monsoon 1979 was of a multiple type (Sikka 1980) with a temporary onset in early May accompanied by moderate southerly winds off Somalia. This temporary onset resulted in an inphase cooling at the coastal stations. Abrupt increase in wind intensity and drastic decrease in sea temperature during mid-June followed the regular onset (Brown and Schott 1981).

Figure 1A depicts the time sequence of ship observed sea surface temperature fields. During late May and early June, light to moderate winds off Somalia produced upwelling and resulted in the coastal cooling northward from near the equator to near 10°N. During late June and the whole of July (figure 1 B), the configuration of wedge-shaped regions of cold upwelled water and crescent shape of the ocean thermal front resulted from the advection of large oceanic anticyclonic eddies.

4. Crescent-shaped unwelled region and prime eddy

Figure 3 depicts the visible picture of 18 June 1979. Low cloud-free zone extends from 2°N to 8°N. Some portion of the north Somali coast is obscured by cirrus clouds. This period represents the early stage of the southwest monsoon. Figures 4 and 5 depict the visible and IR pictures of 5 July 1979 and illustrate the continuity of a cloud-free zone from mid-June to early July. Figure 6 depicts the cloud-free zone with a more pronounced crescent shape than in June. The visible picture once again gives an indication of inhibited low cloud development in the upwelled region. Figures 4 and 5 show the upwelling and thermal pattern off Somalia. A crescent-shaped region in the thermal pattern correlates directly with SST (figure 1B). It is significant to note that the thermal pattern, which resembles upwelling and advection pattern in the infrared picture, is largely free of low clouds in the visible picture. This indicates that the temperature pattern of the infrared image is in fact that of the ocean surface and not of the clouds. There is an indication to suggest that the development of low clouds is inhibited by cold-upwelled water. Therefore, an upwelled crescent-shape is observed in the visible picture.

A northward flowing alongshore Somali current is a part of an eddy field found during each southwest monsoon season off the Somali coast (Swallow and Bruce 1966; Bruce 1968, 1973). The current diverges from the coast turning eastward around 9°N to 10°N each year. In some years it turns eastward around 3°N to 5°N to form a southern eddy. It turns southward at about 55°–58°E and then back towards the shore. Past measurements indicate that during the southwest monsoon, a clockwise 'warm' eddy (prime eddy) of this general description occurs within the Somali basin. Figure 7 depicts the IR photograph of a TIROS-N satellite showing the prime eddy on 18 August 1979. We observe that the Somali current prime eddy is warm and anticyclonic. Low cloud convection tends to be greater over the warm waters of the prime eddy. Upwelled cold water tends to encircle the eddy leading to



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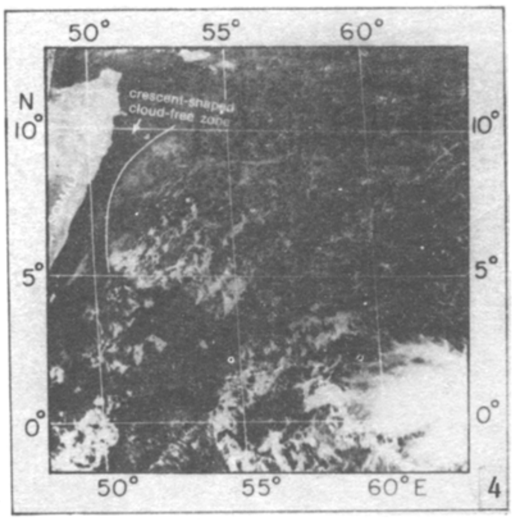

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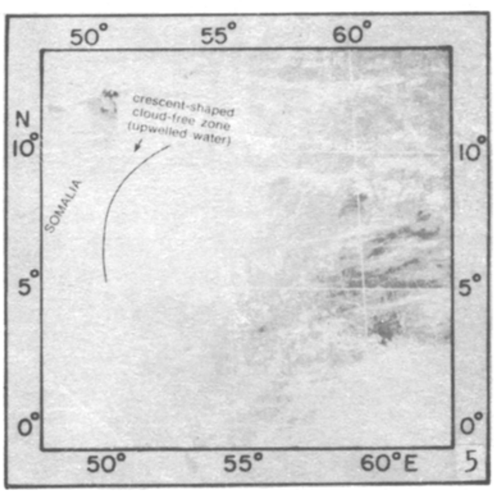

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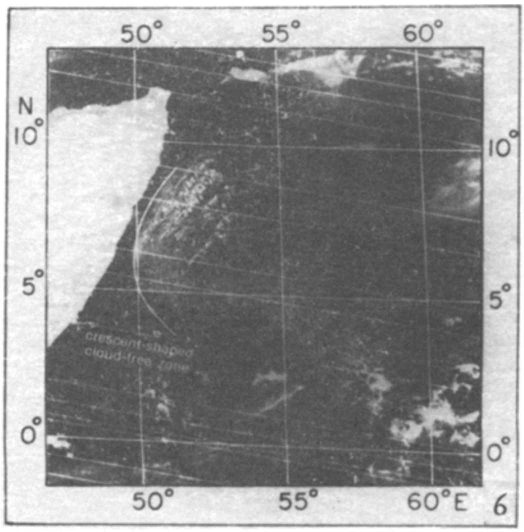
Figures 3–5. DMSP visible picture **3.** 18 June 1979. **4.** 5 July 1979. **5.** DMSP infrared picture of 5 July 1979.



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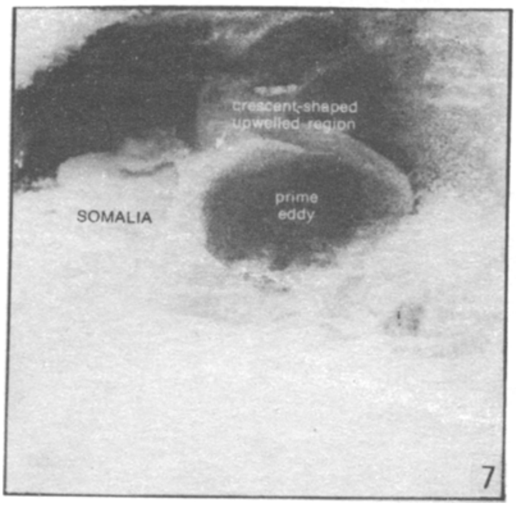

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Figures 6 and 7. 6. DMSP visible picture of 14 July 979. **7.** TIROS-N infrared picture of 18 August 1979. (Photo Courtesy R. Whritner, Scr)ps Institution of Oceanography).

the identification of its outer boundary. Cloud formation is inhibited in the upwelled region, creating a crescent-shaped clear area as depicted in satellite visible imagery.

5. Conclusions

In this paper the relationship between a crescent-shaped upwelled region, satellite-derived low-level cloud drift winds and SST has been illustrated. Similarly, oceanic features and cloudiness patterns associated with a prime eddy off the Somali coast has been illustrated. The following are the main conclusions of the study. (i) Satellite-observed cloud-free area off the Somali coast persists throughout the monsoon season. (ii) The upwelled region has a crescent shape and reflects a cold SST pattern that is driven by strong low-level winds. (iii) Air and sea temperatures are markedly lower in cloud free area. (iv) Low-cloud convection is greater over warm waters of the prime eddy. (v) Upwelled cold water tends to encircle the eddy to mark its outer boundary.

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