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Organisation of large-scale clouds over the Indian Ocean as revealed by TIROS-N satellite during June 1979

P. N. MAHAJAN

Indian Institute of Tropical Meteorology, Pune

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सार — जून 1979 के दौरान भूउपग्रह मेघ प्रतिमावली से हिन्द महासागर के ऊपर दीर्घमापी मेघ आकृतियों के संगठन की जांच की गई है। गुणात्मक दृष्टिकोण से ऊर्जा विनिमय द्वारा पृष्ठीय ताप पर वायुमण्डल की प्रतिक्रिया और उष्ण एवं शीत महासागरों के ऊपर बहती वायु संहिताओं में मेघ कोशिकाओं के निर्माण के विवेचन किए गए हैं। भूउपग्रही चित्रों से यह देखा गया है कि दक्षिणपूर्वी व्यापारिक पवनों में विस्तृत मेघ पट्टियों के संगठन 1° द० और 5° द० अक्षांश के बीच दक्षिण गोलार्ध भूमध्य रेखीय द्रोणिका के अक्ष के समीप तेजी से मुड़ जाती हैं। द्रोणिका के अक्ष के आर पार इस मोड़ को भूउपग्रह व्युत्पित निम्न स्तरीय पवन क्षेत्र और प्रेक्षित लघु-मापी मेघ आकृतियों को प्रमुखता से दर्शाते हैं। 10° द० अ० से उत्तर की ओर प्रमुख संवहनी मेघ समूह और उसके दक्षिण में कोशिकीय मेघ आकृतियों से यह प्रदर्शित होता है कि दक्षिण पूर्वाओं में व्यापारिक पवन व्युत्क्रमण है और दक्षिण पछुवाओं में इसका अभाव है।

ABSTRACT. Organisation of large-scale cloud patterns over the Indian Ocean is examined from the satellite cloud imagery during June 1979. From the qualitative consideration, a response of the atmosphere to the underlying ocean surface temperature through energy exchanges and formation of cloud cells in the moving air masses over warm and cold oceans are discussed. It is observed from satellite pictures that the organisation of extensive cloud bands in southeasterly trades curved sharply near the axis of southern hemispheric equatorial trough between 1° S and 5° S. Satellite-derived low-level wind field and the observed small scale cloud features indicated prominently the turning across the axis of trough. Major convective cloud clusters to the north of 10° S and cellular cloud patterns to the south of it indicated trade wind inversion in southeasterlies and its absence in southwesterlies.

1. Introduction

The satellite pictures received from the TIROS-N satellite showed some interesting features of broad-scale cloud distribution over the Indian Ocean during June 1979. It is observed that large-scale cloud patterns forming in the southeasterly trades over the south Indian Ocean curve sharply in the regions of Africa coast and are further oriented from southwest to northeast towards the Indian Peninsula. In this paper, an attempt is made to highlight the characteristic features of large-scale cloud distribution and its relation with the associated wind field, mean sea surface temperature, and the monsoon activity over India.

2. Data

Satellite pictures received from the Advanced Very High Resolution Radiometer (AVHRR) on-board the U.S. weather satellite TIROS-N were utilised in mercator projection. In order to know the mean turning position of low clouds, low level cloud motion vectors were used. These cloud motion vectors were taken from the wind sets derived by Young *et al.* (1980) from the sequences of images of geosynchronous satellite GOES-IO, stationed at Long. 58° E, using MCIDAS (Man Computer Interactive Data Access System). Sea-level pressure charts for the month of June 1979 were used to find the mean position of SHET (Southern Hemispheric Equatorial Trough). Sea surface temperature recorded by Russian research ships in polygon formation (2-14 June 1979) and FGGE ships as well as Russian research ships in the transitory positions were used to determine mean sea surface temperature for June 1979. Interpretations derived from satellite pictures were compared with inferences based on synoptic data.

3. Large-scale cloud features observed in satellite pictures

3.1. Amorphous type convective cloud masses were mostly observed over the oceanic areas north of 25°S and west of 75° E over the Indian Ocean for first ten days of June 1979. These cloud masses showed restricted convection between 25°S and 10°S. More intense convection with embedded *Cb*'s were seen north of 10° S. Elongated band like structure of cloud masses started organising on 3 June over the Indian Ocean between 10°S-5°S and west of 75° E.

3.2. The band structure organised more on 7, 8 and 9 June. The cloud mass north of equator and west of 75° E intensified while getting aligned generally from west to east. More dense convective cloud masses appeared in the southern hemisphere between the equator and 10°S in the form of broken bands.

3.3. On 11 June some of the cloud bands with embedded deep convection extended to Kerala coast leading the commencement of monsoon activity over Kerala. This was the onset period of southwest monsoon over Kerala. A huge convective cloud cluster with deep convection in active ITCZ prevailed with overcast skies over the stationary positions of Russian research ships in the polygon formation 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) for the period of 12 to 14 June and yielded heavy showers almost throughout the day, as recorded by the ships.

3.4. The cloud clusters over the equatorial Indian Ocean progressively formed into broad broken band aligned in SW-NE direction from 3°N, 60°E to 7°N, 75°E on 13 June 1979. The cloud band aligned in SE-NW direction from 15°S, 53°E to 3°S, 45°E with restricted convective activity formed on 15 June, curved sharply near African coast and extended in the northeasterly direction over the Arabian Sea. The satellite picture of 16 June (Fig. 2) shows the prominent features of the bands. A huge cloud cluster extending from 55°E to 75°E and 2°N to 17°N was broadly aligned in SW-NE direction and was associated with intense deep layer convection, which existed on previous four days with small changes in overall shape and size. A depression was located over the Arabian Sea (13°N, 71°E) on 16 June in the massive cloud cluster.

3.5. The convective cloud cluster in the Arabian Sea (south of 20°N) had formed into broad band aligned in SW-NE direction on 24 June (Fig. 3). The satellite picture shows an extensive dense overcast cloud mass in the form of broad band extending into Bay of Bangal. Curving of cloud band at 5°S, 60°E is also observed. Broken bands were seen from 5°N to 5°S and 55°E to 95°E. On this day monsoon had advanced upto 22°N in the NE Arabian Sea and its northern limit ran through Porbunder, Baroda, Nagpur, Balasore and Gangtok. Heavy massive overcast cloud cluster at 18°N, 85°E was associated with the formation of deep depression and its centre on surface chart was located within half degree of 19.5°N, 87.5°E. This extensive cloud cluster was associated with vigorous monsoon conditions in Orissa and active conditions in Vidarbha, Konkan, Goa, Telangana, Coastal Karnataka and Kerala. However, it is important to note that under such active monsoon conditions the overcast monsoon cloudiness was confined to the north of latitude 5°N and southern hemisphere was markedly cloud-free over the whole Indian Ocean.

3.6. Subsequently, cloud organisation south of equator started developing into a broken band after 25 June and was prominent on 30th June (Fig. 4). South of 15°S, clouds consisted of mainly cumulus lines, cellular clouds and multilayers clouds in frontal bands associated with the southern hemispheric mid-latitude disturbances. Major convective cloud masses of the size nearly 5° square with deep convection were seen south of the equator at 15°S, 55°E; 3°S, 72°E and 3°S, 100°E respectively. It showed the increase in south equatorial trough activity around 3° S, while north of equator, mostly over Arabian Sea and Bay of Bengal amorphous clouds were seen. The cloud band had aligned from 3°S, 68°E to 1°S, 98°E and its clear reflection was observed in satellite derived low-level cloud motion vectors (Fig. 1). Further, the heavy convective cloud mass associated with monsoon depression over Bangla Desh close to Dacca was practically stationary on 29 and 30 June.

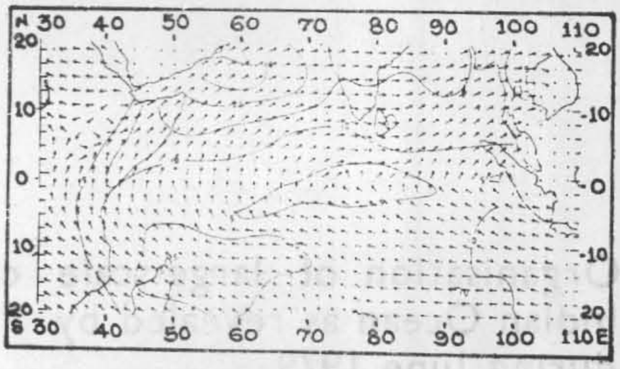

Fig. 1. Satellite-derived low-level cloud motion vectors of 30 June 1979 showing the position of south equatorial trough

3.7. Cloud organisation over the Indian Ocean during June 1979 can be summarised as follows :

(*i*) Cellular patterns, cumulus lines or multi-layer clouds were observed south of 10°S, (*ii*) They had restricted convection, less areal coverage and were less dense as compared to the cloud clusters north of 10°S & (*iii*) The massive overcast cloud bands with embedded *Cb*'s were generally seen to the north of equator only.

4. Distribution of mean ocean surface temperature

Fig. 5 shows the meridional distribution of mean ocean surface temperature along Long. 52°E (western Indian Ocean), '65°E and 90°E' (eastern Indian Ocean) for the month of June 1979. This figure was constructed using sea surface temperatures recorded by different research ships taking part in FGGE experiment. Few data points were taken from climatic atlas of Indian Ocean (Hastenrath and Lamb 1979). Fig. 5 shows that eastern Indian Ocean is distinctly warmer than the western Indian Ocean north of 15°S, and south of this latitude the difference changes sign with the western Indian Ocean becoming warmer than the eastern Indian Ocean. A well known reason for cold western Indian Ocean is that during SW monsoon, upwelling along the Somali coast and the cold Somali current maintains strong zonal temperature anomaly with cold water in the western Indian Ocean and warm water in the eastern Indian Ocean (Saha 1970). It is observed for the month of June 1979 that extreme western part of the Indian Ocean is relatively cloud-free and much more cloudiness is to the east of 60°E. The above distribution of mean sea surface temperature over the Indian Ocean appears to exercise a profound influence on organisation and distribution of large-scale cloud patterns and circulation of overlying atmosphere through ocean atmosphere interaction.

5. Cloud organisation over warm and cold ocean

5.1. Formation and organisation of trade wind clouds are related to the oceanic areas which are warmer than the surroundings (Malkus 1957). After relating satellite pictures with the meteorological data Krueger and Fritz (1961) observed that on an average 3°C higher temperature of the ocean than the surroundings over the north Atlantic and north Pacific anticyclones lead to the formation of cellular clouds. When the mass of cold

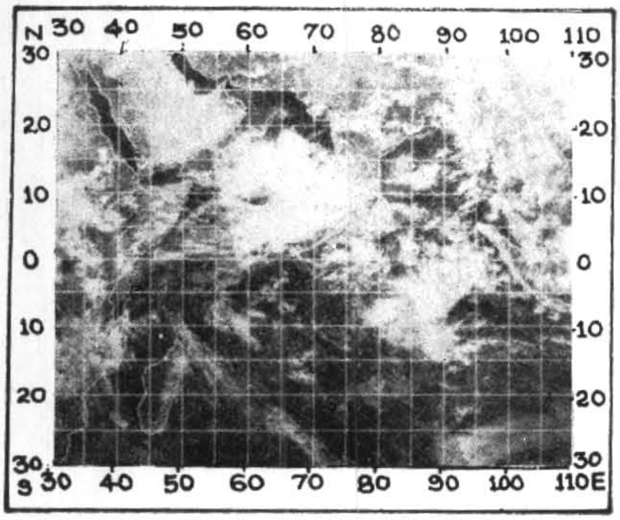

Fig. 2. TIROS-N visible picture of 16 June 1979 showing the turning of cumulus lines in SE trades near east Africa coast

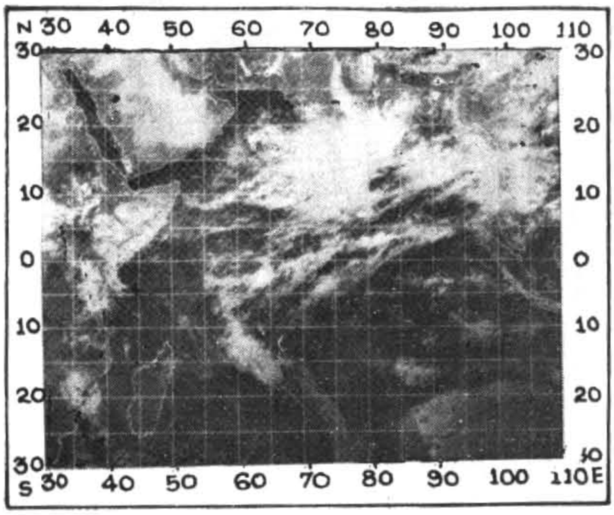

Fig. 3. TIROS-N visible picture of 24 June 1979 showing broad band of extensive dense overcast clouds extending from Arabian Sea to Bay of Bengal across Indian sub-continent

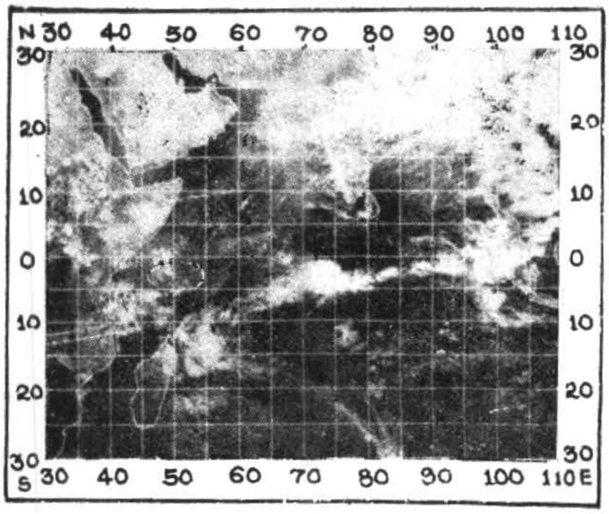

Fig. 4. TIROS-N visible picture of 30 June 1979 showing the increase in south equatorial trough activity around 3° S

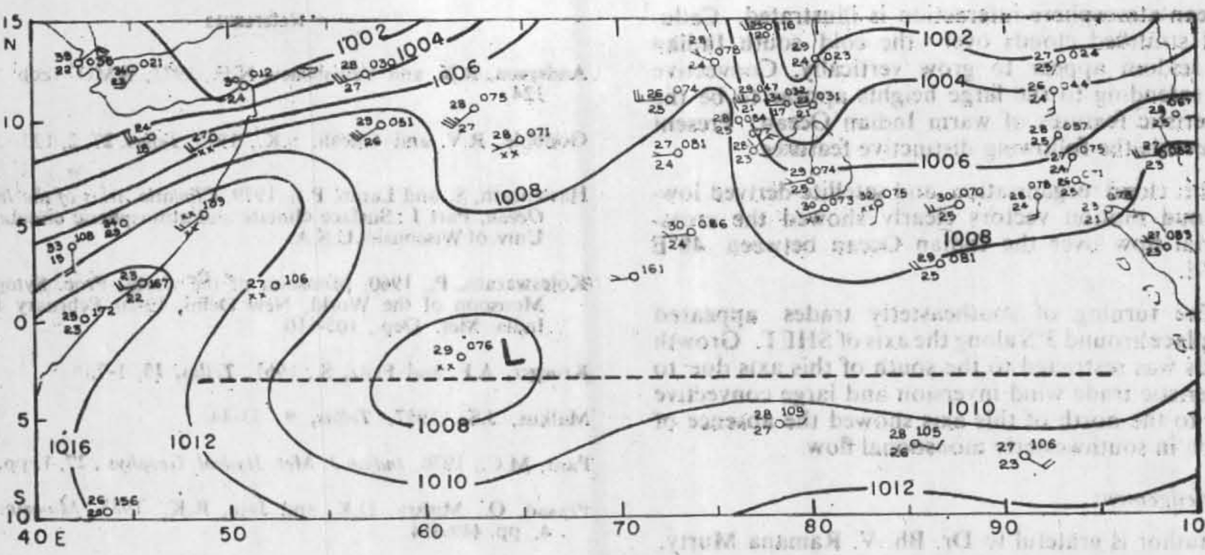

Fig. 5. Mean sea level chart of 20 June 1979 at 1200 GMT showing the position of SHET along latitude 3° S between longitudes 48° E and 70° E

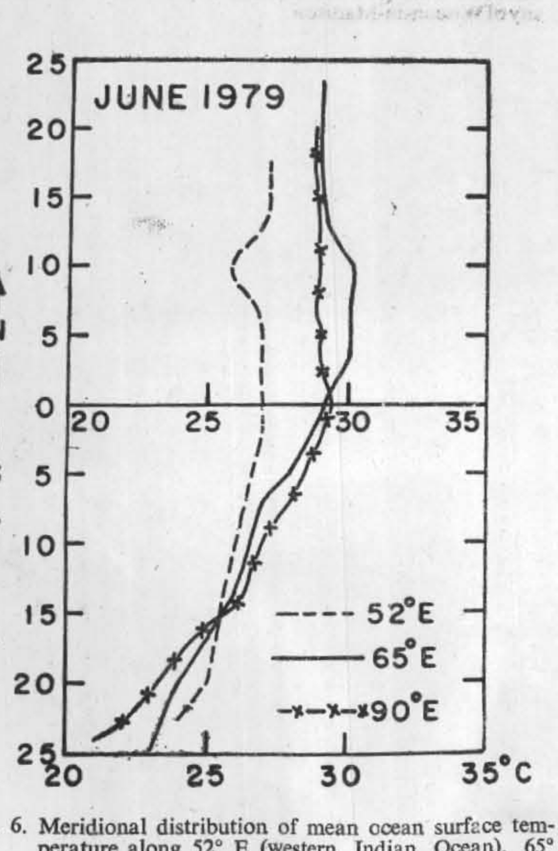

Fig. 6. Meridional distribution of mean ocean surface temperature along 52° E (western Indian Ocean), 65° E and 90° E (eastern Indian Ocean) during June 1979

air moves over the warm sea surface, cumulus lines are organised in the direction of wind (Anderson and Weltishchev 1973). Similar situation prevailed when the cumulus lines oganised in SE trades during June 1979 over the south Indian Ocean.

5.2. Orientation of the cloud lines in the south Indian Ocean has been found to be between 120° and 150° with the average of 135° during the month of June 1979. After crossing the equator, alignment of cloud lines changed from SE-NW to SW-NE. The axis of turning which was almost parallel to latitude lines varied between 1°S and 5°S with mean position at 3°S for the month. The turning of cumulus lines was seen within the longitude range of 48°E to 98°E. The 1200 GMT surface chart of 20 June 1979 (Fig. 6) shows the position of SHET at about 3°S from 48°E to 70°E at sea level. North of the axis of turning, mostly *Cb* clouds were developed restricting one to infer precisely the direction of movement of clouds. Cumulus lines observed to the north of the equator were generally aligned in SW-NE direction.

6. Discussion

A number of workers (Koteswaram 1960, Saha 1971 Prasad *et al.* 1983, etc.,) studied about the existence of southern hemispheric equatorial trough and its orientation in E-W direction. Using the relevant meteorological data collected during ISMEX-1973 Godbole and Ghosh (1975) observed the existence of trough in southern hemisphere from surface upto 500 mb having poleward inclination with height at a mean position near 2°S. The observational study of Godbole and Ghosh is well supported by the findings in this study from the satellite pictures, cloud motion vectors and sea-level pressure pattern inferring the mean position of SHET near 3°S. In the present study mean longitudinal extent of SHET is observed from 48°E to 98°E. Pant (1976) concluded on the basis of ISMEX-1973 data that deep convective activity occurred over both western (west of 56°E) and the eastern (east of 65°E) equatorial region, and central region (56°E to 65°E) was characterised by the subsidence in the middle troposphere. But no such deep convective activity over the equatorial region of west Indian Ocean is seen from satellite pictures, which varies from the conclusion drawn by Pant.

7. Conclusions

In this paper, a qualitative explanation of the distribution of clouds in terms of mean ocean temperature and ocean-atmosphere interaction is illustrated. Cellular and stratified clouds over the cold south Indian Ocean seldom appear to grow vertically. Convective clouds extending to the large heights appear to be the characteristic features of warm Indian Ocean. Present study reveals the following distinctive features :

(*i*) The cloud organisation and satellite-derived low-level cloud motion vectors clearly showed the cross-equatorial flow over the Indian Ocean between 48°E and 98°E.

(*ii*) The turning of southeasterly trades appeared to take place around 3°S along the axis of SHET. Growth of clouds was restricted to the south of this axis due to characteristic trade wind inversion and large convective activity to the north of this axis showed the absence of inversion in southwesterly monsoonal flow.

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