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A study of the Onset of the Monsoon over India during 1962 using TIROS IV Radiation Data

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ABSTRACT. Infrared radiation data collected from the TIROS IV satellite during the months of April, May and the early part of June 1962 have been used to study the onset and advance of the monsoon over India. The data show the northward migration of the intertropical convergence zone with time. A sudden shift of the convergence zone near the equator to the southern tip of India occurs early in May. This apparently corresponds to the "burst of monsoon" over India; this conclusion is supported by other meteorological data. The TIROS IV radiation data also show that the intertropical convergence zone over Africa during the same period shifted northward, but in a more uniform fashion than the convergence zone over the Indian Ocean area.

1. Introduction

The prediction of the onset of the Indian summer monsoon has been one of the challenging problems in meteorology for many years and even now the problem is far from being solved. Several authors (Blanford 1889, Harwood 1924, Wagner 1931, Ramanathan and Ramakrishnan 1938, Pant and Vernekar 1963, Pant 1964) have tried to describe the arrival of the monsoon over India. Their data were collected from land stations over India and the adjacent regions, but very little information was available over the vast areas of the Arabian Sea, the Bay of Bengal and Indian Ocean. Thus, lack of data over the water areas surrounding the Indian Peninsula has hampered studies of the onset of the monsoon and the development of methods for forecasting it.

With sufficient meteorological information becoming available from the weather satellites it is now feasible to study how the monsoon circulation sets in over India and the adjacent regions. The purpose of the present paper is to show the onset of the southwest monsoon in the spring of 1962 by means of radiation measurements made by TIROS IV. This satellite had a medium-resolution scanning radiometer on board (in addition to two television cameras). The radiometer is similar to the one flown on TIROS II and III satellites. These are described in some detail by Bandeen, *et al.* (1961) and Staff Members, NASA.

The outgoing long-wave radiation is largely dependent on the cloud cover, particularly in the subtropics and the tropics. Over areas of substantial cloudiness extending to the middle or high troposphere the outgoing radiation is considerably less than over clear areas. The method of presentation is to show a series of five-day average maps of TIROS IV radiation data and demonstrate the way in which the regions of low outgoing radiation moved northward with time over the Indian region during the spring of 1962. Also, a time-latitude section of the outgoing long-wave radiation is presented to show the average latitudinal advance of the cloudy areas over the region.

2. Data used

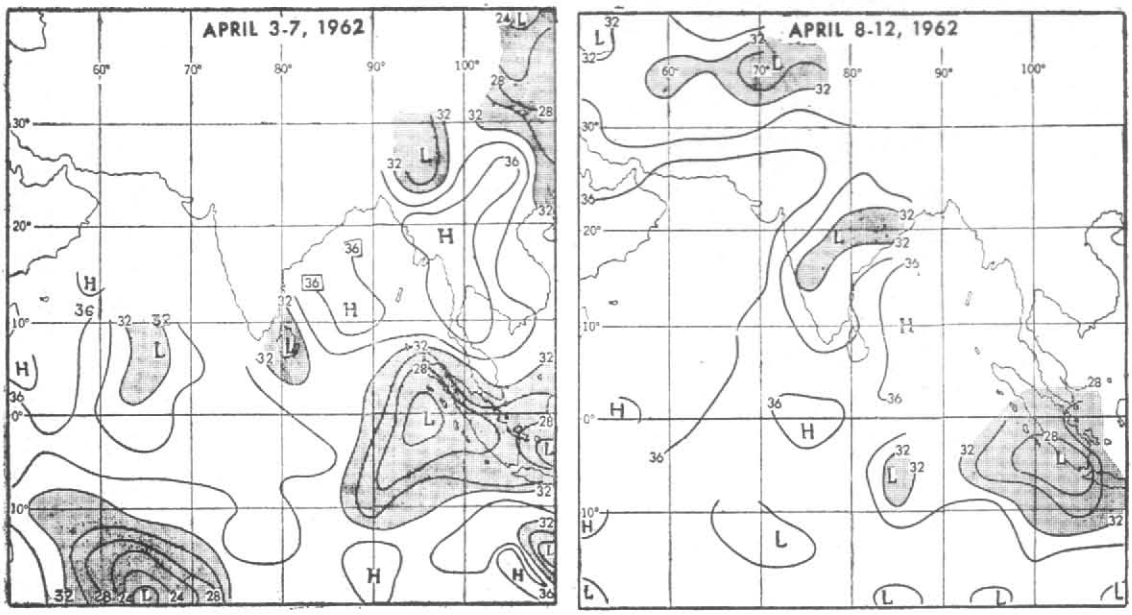
The radiation data used in this study were obtained from channel 2 (8-13 microns) of the TIROS IV satellite. The channel 2 values have been converted to total outgoing long-wave radiation using the technique developed by Wark, *et al.* (1962). These values have been corrected for limb darkening on the basis of an empirical study of the variation of intensity of long-wave radiation with satellite nadir angle (Lienesch and Wark 1965). The maps presented here are portions of large quasi-global Mercator maps of outgoing long-wave radiation averaged over five degree latitude and longitude boxes for five-day periods. The criteria set for data analyzed on these charts were –

(1) the nadir angle of the viewed spot for any datum did not exceed 58 degrees,

(2) at least twenty bits of information had to be in a five degree latitude–longitude box on a given day, and

(3) at least two days of acceptable data had to be at each grid point in the five-day period.

The TIROS IV radiation data were available from February through June, but only data from 5 April to 12 June 1962 have been used, because the main interest was to study the onset of the southwest monsoon circulation. Contours

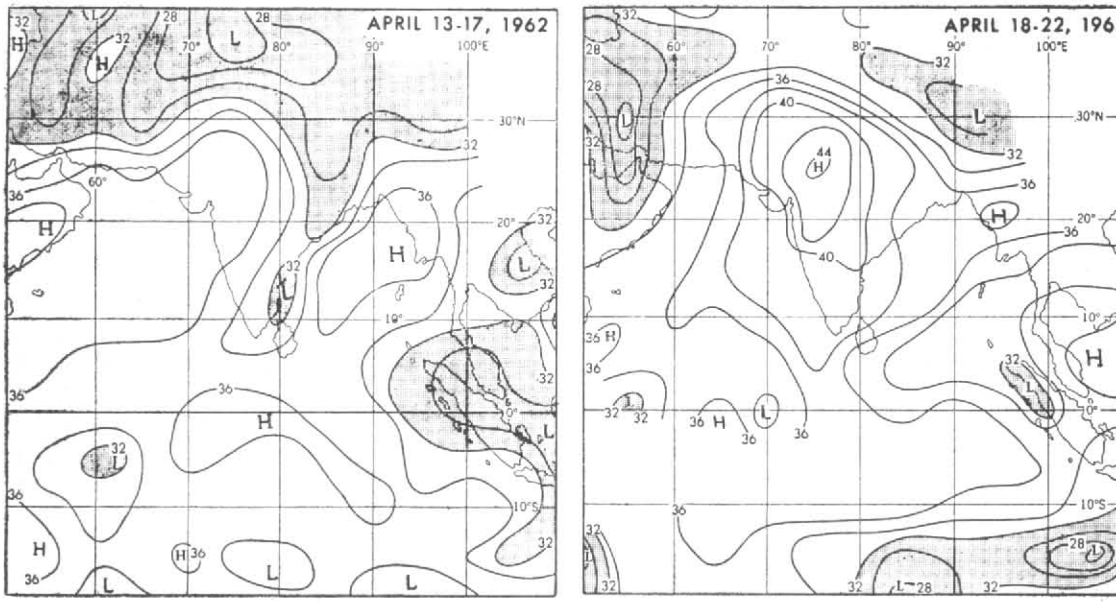


TIROS IV — LONG WAVE RADIATION

< 0.32 Ly/min.

Fig. 1. Outgoing long wave radiation for the period 3-7 April 1962 and 8-12 April 1962, derived from TIROS IV channel 2 data

The units are 10^{-2} ly/min and the isolines are drawn at 2×10^{-2} ly/min. H and L refer to maxima and minima of long wave radiation respectively. The shaded area represents the region where the outgoing long wave radiation is less than 32×10^{-2} ly/min



TIROS IV — LONG WAVE RADIATION

< 0.32 Ly/min.

Fig. 2. Outgoing long wave radiation for the period 13-17 April 1962 and 18-22 April 1962 (see legend to Fig. 1)

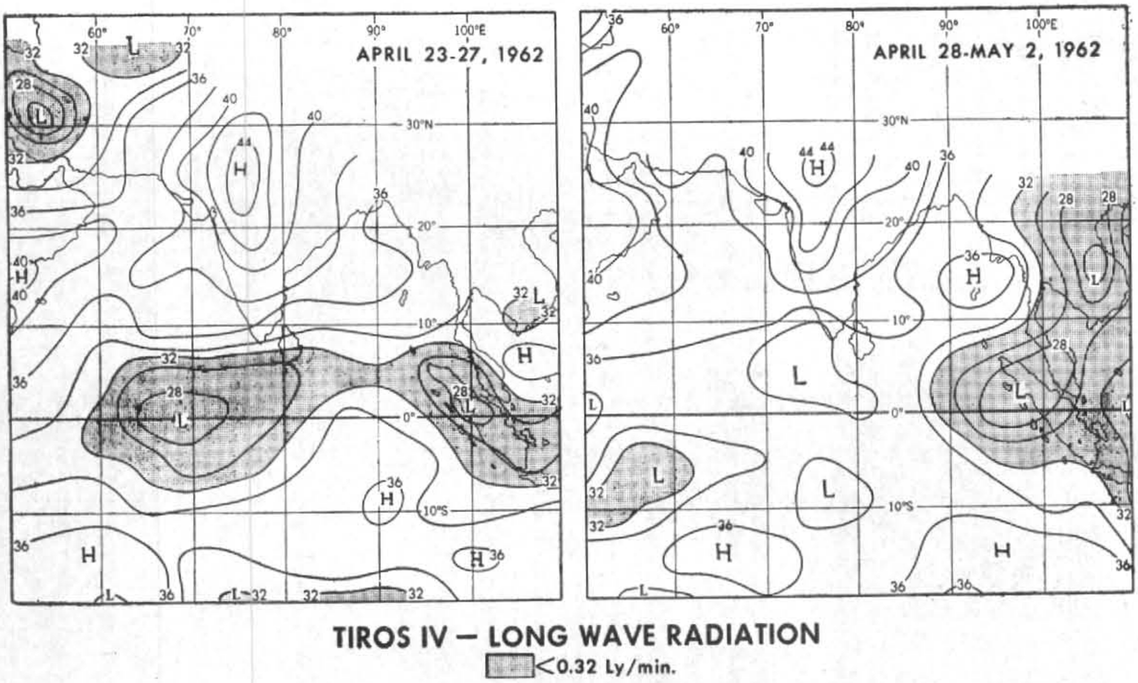


Fig. 3. Outgoing long wave radiation for the period 23-27 April 1962 and 28 April—2 May 1962 (see legend to Fig. 1)

are omitted over regions where the data are missing. The shaded area indicates that the outgoing radiation over these areas is less than 0·32 langleys per minute and this approximately corresponds to 265°K or less over these regions. Such low equivalent radiation temperatures generally must be associated with clouds in this particular region of interest . It is safe to assume that the shaded areas generally correspond either to broken or overcast clouds and that the regions of lowest outgoing radiation correspond to thickest clouds or clouds of large vertical depth. Fritz and Winston (1962), Rao and Winston (1963) have shown a good relationship between radiation values and cloud heights.

3. Description of the Charts

Figs. 1–7 show the average maps for the five-day periods between 3 April to 10 June 1962. The main regions of cloudiness south of 20°N from 3 to 22 April (Figs. 1 and 2) are near and south of the equator and occasional zones of cloudiness appear over India but they are less intense. In general these zones are not elongated zonally between 15°S and 20°S during 18-22 April. Cloudy zones also appear north of 30°N not only in the period 13-17 April, but also throughout the period from 3 April to 10 June. The Arabian Sea and Bay of Bengal regions are predominantly clear or covered with low clouds from 8 to 22 April as indicated by the large values of outgoing radiation. Another interesting feature is the appearance of a centre of high outgoing long-wave radiation over India which persists through 2 May (Fig. 3) . In the period 23-27 April a well organized band of low radiation values establishes itself between 5°N and 5°S, and 60°E and 110°E (Fig. 3). This appears to be the first time that the intertropical convergence zone which was very weak and south of the equator definitely shifted this far northward. During the next period this band becomes weak and disorganized and only a few minor low centres can be noted, indicating that major cloudiness decreased near the equator west of 90°E during 28 April to 2 May, but increased and extended into SE Asia from the east. In general there is a lack of continuity in the low values in this equatorial cloudy zone during this period.

The radiation patterns show some remarkable changes during the early part of May (Fig. 4). The high centres of outgoing radiation values over central and northern India decrease in intensity and a pronounced belt of low radiation values show up over the equatorial regions between 3-7 May. This low radiation area suddenly expands during the next period 8-12 May and covers the equatorial Indian Ocean, the Bay of Bengal, southern tip of India and southeast Asia and advances towards the north extending to about 20°N over India. The westward extension from southeast Asia is

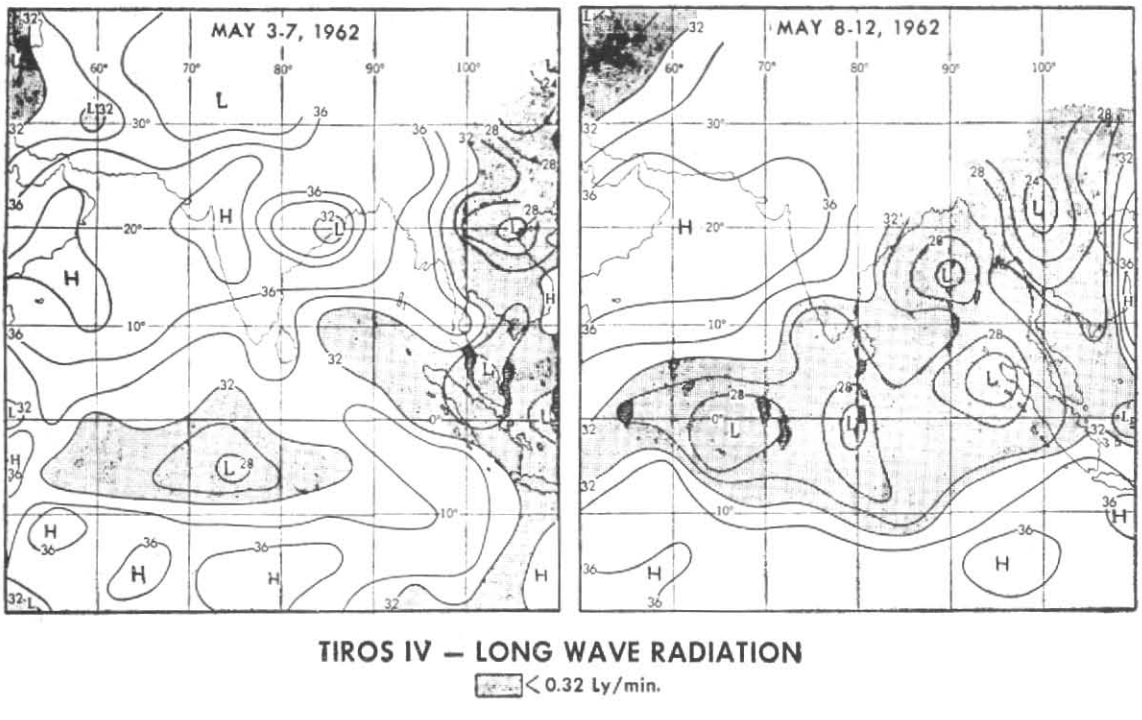
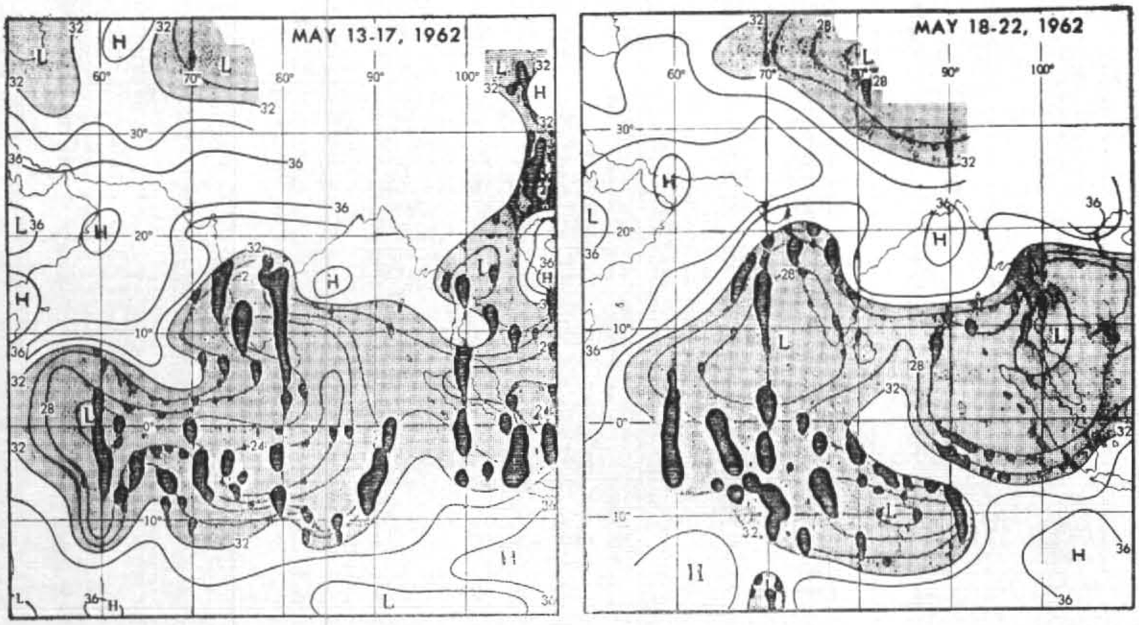


Fig. 4. Outgoing long wave radiation for the period 3–7 May 1962 and 8–12 May 1962 (see legend to Fig. 1)



TIROS IV – LONG WAVE RADIATION

<0.32 Ly/min.

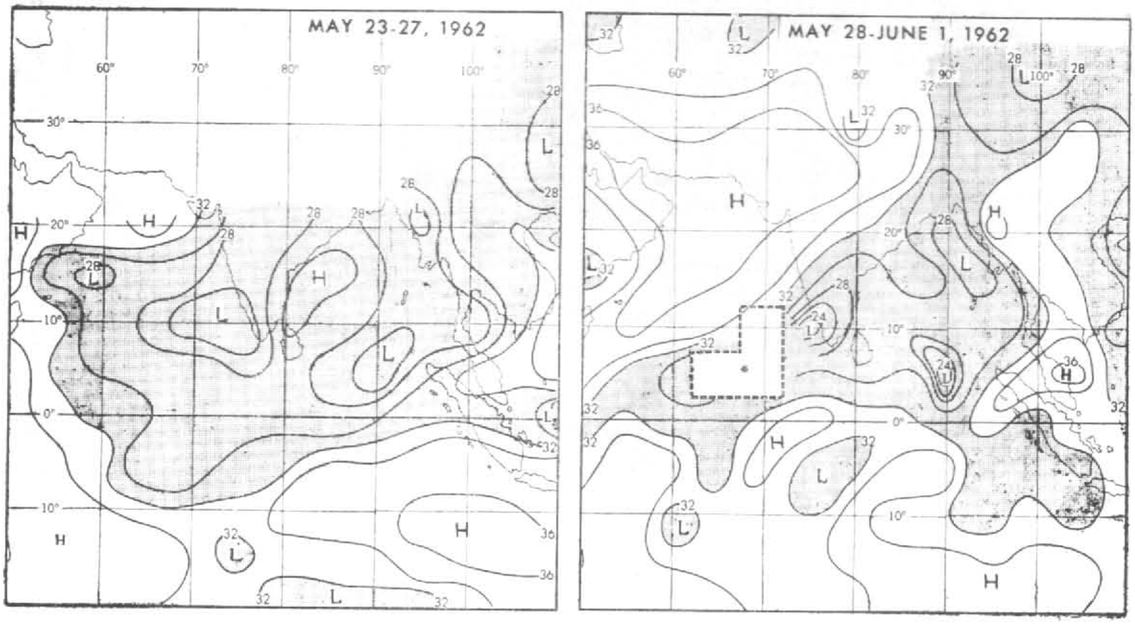
Fig. 5. Outgoing long wave radiation for the period 13–17 May 1962 and 18–22 May 1962 (see legend to Fig. 1)

spectacular and takes place over a very wide area. The southwest monsoon is known to set over southeast Asia early in May and then extend to the Bay of Bengal and to the west coast of India later.

The values in the low centres of outgoing radiation have decreased, indicating increases in the heights of the clouds. These centres intensify even more during the next period 13-17 May (Fig. 5) indicating further increases in cloud top heights. The radiation field shows a double minimum, one north of the equator and another south of the equator. The cloud heights were estimated from the radiation data by using the upper air soundings at Trivandrum for 11 May 1962 to locate the levels at which the equivalent radiating temperatures would be located. The technique used is similar to the one used by Fritz and Winston (1962) and Rao and Winston (1963). The maximum cloud top heights (averaged in 5 degree latitude-longitude boxes of course) were about 30,000 feet during 8-12 May and increased to about 36,000 feet during 13-17 May.

The zone of cloudiness which moved over the Bay of Bengal and the adjoining regions decreased in intensity during 18-22 May (Fig. 5) and again increased in intensity during 23-27 May (Fig. 6). The northern edge of this cloudiness advanced northward at least as far as the data extend (about 22°N), covering a vast region of the Arabian Sea, Indian Ocean, up to 22°N over India, Bay of Bengal and the adjoining countries, except the northern Arabian Sea. By the next period, 28 May and 1 June (Fig. 6), however, a break in the extensive cloudiness occurred over west and northwest India. This first break in the cloudiness over India is shown by the increase in the intensity of the outgoing radiation. Even though the break in the cloudiness occurs, the cloud top heights over the southern tip of India have increased as shown in the radiation field. The Indian Daily Weather Reports for 29-30 May 1962 showed that the monsoon was weak during this period and the northern boundary of the monsoon circulation extended to 18°N.

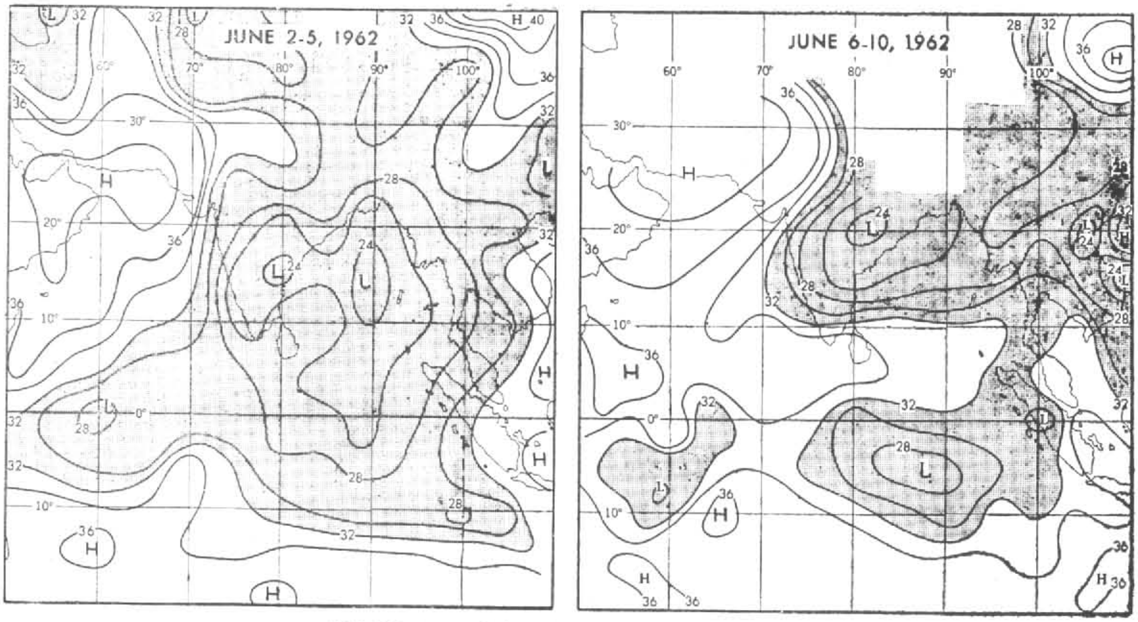
The retreat in the cloudiness protrayed in Fig. 6 does not last long and the period 2-5 June (Fig. 7) shows the most intense stage of the cloudiness over India. Very large sections of India and the adjoining areas are covered by low outgoing radiation values. The low centre near 15°N and 90°E corresponds to a surface low that formed over the Bay of Bengal; the Indian Daily Weather Reports pointed this out on 4 June 1962. This low pressure centre deepened and moved northwest, crossed the coast on 8 June and weakened. The intense and extensive monsoon regime of 2-5 June does not last long and the period 6-10 June (Fig. 7) shows another major change. The intensive



TIROS IV — LONG WAVE RADIATION

< 0.32 Ly/min.

Fig. 6. Outgoing long wave radiation for the period 23–27 May 1962 and 28 May–1 June 1962 (see legend to Fig. 1). There are no data over the region with *



TIROS IV — LONG WAVE RADIATION

< 0.32 Ly/min.

Fig. 7. Outgoing long wave radiation for the period 2–5 June 1962 and 6–10 June 1962 (see legend to Fig. 1)

cloudiness exists only over south and eastern India, but the extreme southern tip of India and the adjoining Indian Ocean areas are relatively clear. The monsoon continues to be active over Burma and southeast Asia. Also, cloudiness remains fairly extensive between the equator and 10°S over the Indian Ocean.

These five-day average charts in Figs. 1-7 showed a definite extension of the low outgoing radiation regions to northern latitudes as time progressed from April to June. In the early periods it was hard to notice any continuity in the radiation fields. The figures also showed the change in the intensities of the radiation indicating the changes in the cloud heights and thicknesses.

A time-latitude section for the entire period is shown in Fig. 8. The radiation values are the averages for each five degree latitude belt averaged for all longitudes between 50°E and 110°E. The shaded region as in the maps corresponds to values less than 0·32 ly/min and generally corresponding to an equivalent blackbody temperature of 265°K. During the month of April the outgoing radiation values were generally higher than 0·32 ly/min at all latitudes except for some occasional low values near the equatorial regions. The low value near 25 April seems to have been the forerunner to the more extensive equatorial convergence development which followed in May. The beginning of May shows the major change. The low values exist mostly between 0° and 5°S and from 8 May show an advance towards more northerly latitudes (and south also), *i.e.*, a general expansion with latitudinal minimum not moving until after 15 May. The India Meteorological Department first used hte word 'monsoon' on 13 May in their Daily Weather Reports. The suggestion from the radiation data is that the increasing cloudiness associated with the monsoon reached the southern tip of India by about 9 May, but due to the unavailability of conventional data south of 4°N, the advancing cloudiness from over the equatorial Indian Ocean area could not be detected earlier.

Several authors (Yin 1949, Staff Members, Academia Sinica 1957) have linked the onset of the monsoon circulation with the extension and the breakdown of the mid-tropospheric westerlies over the northern hemisphere. The mean square zonal wind for the layer 850-500 mb averaged between longitudes 20°W and 85°E for the period April-June 1962 is shown in Fig. 9. These data were already available in the Meteorological Satellite Laboratory. Unfortunately the data do not extend below 20°N and above 500 mb height. The zonal westerlies remained strong between about 35°-40°N until about 10 May and then shifted abruptly to higher latitudes. According to Yin's (1949) hypothesis, as the zonal westerlies shift to higher latitudes the monsoon circulation sets in over India and the adjacent regions. But a comparison of Figs. 8 and 9 suggests that the strong zonal westerlies and the northward advance of the low radiation values occurred at very nearly the same time (Possibly the radiation changes actually set in before the wind changes). Too much emphasis cannot be put on this point because the zonal wind data were not available south of 20°N and the wind data corresponds to a larger area compared to the radiation data. If one were using this wind field alone it is apparent that the monsoon development could not be predicted.

The 500-mb zonal wind component for three Indian stations (New Delhi, Nagpur and Madras) for the same period is shown in Fig. 10. The data above 500-mb were too scanty during this period and so they were not considered. Until 9 May the westerly component was dominant even though a slight eastward component shows up over Madras, about 20-25 April. The easterly component definitely showed up about 9 May and then advanced further north. Again the comparison of Figs. 8 and 10 suggests that the changes in the radiation field and the change in the wind field occurred almost at the same time.

The low outgoing long-wave radiation values shown in Figs. 1-8 near the tropical latitudes can be associated with the Intertropical Convergence zone (ITC). The intertropical convergence zone generally travels only 5 to 10° from the equator but over India it travels up to 25 to 30°N. In Fig. 8 the advance of the low radiation values associated with the cloudiness shows the movement of the ITC over India during the months of May and early June 1962.

For comparison the movement of the ITC over Africa as derived from the radiation data for the same period as in Fig. 8 is shown in Fig. 11. The existence of the ITC between 5°N and 5°S during the month of April is clearly shown in Fig. 11, but it is not so obvious in Fig. 8. The northward progression of the ITC in May occurs at the same time over both regions but the advance over the Indian subcontinent is more pronounced. Perhaps this type of change over the Indian Ocean area is peculiar to the region with its "burst of the Monsoon".

4. Conclusions

Only a limited number of conventional meteorological observations over the Arabian Sea, Bay of Bengal and the Indian Ocean are available through ship reports. Unless other supporting information is available, it is hard to locate the zones of cloudiness associated with the ITC. Until more picture

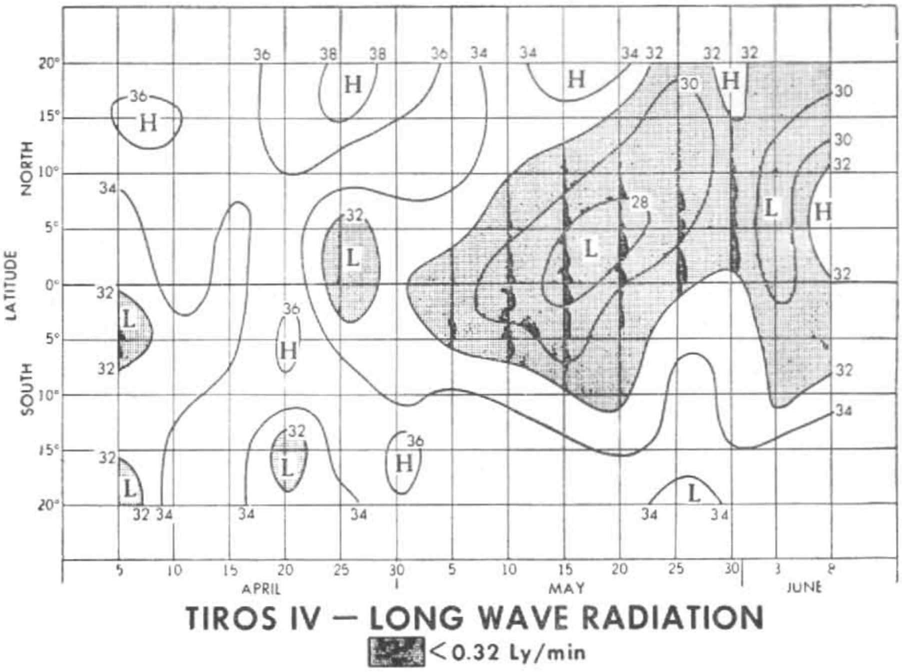


Fig. 8. Time-latitude section of the outgoing long wave radiation derived from TIROS IV channel 2 data, averaged between the longitudes 50°E and 110°E (for other description see legend to Fig. 1)

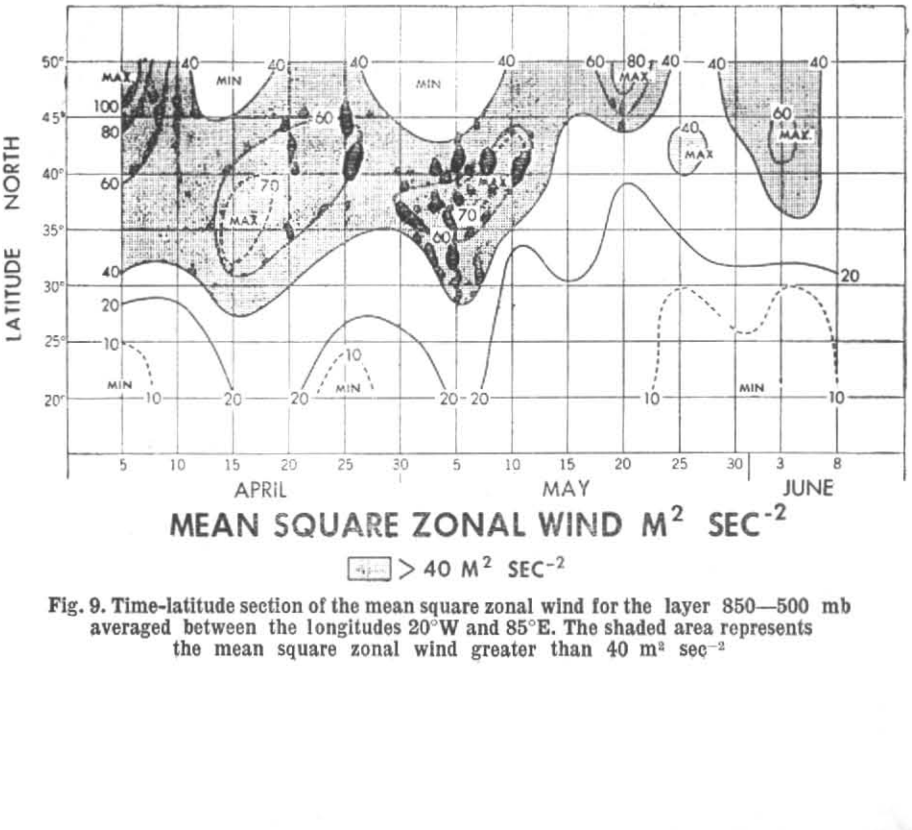


Fig. 9. Time-latitude section of the mean square zonal wind for the layer 850—500 mb averaged between the longitudes 20°W and 85°E. The shaded area represents the mean square zonal wind greater than 40 m^2 sec^{-2}

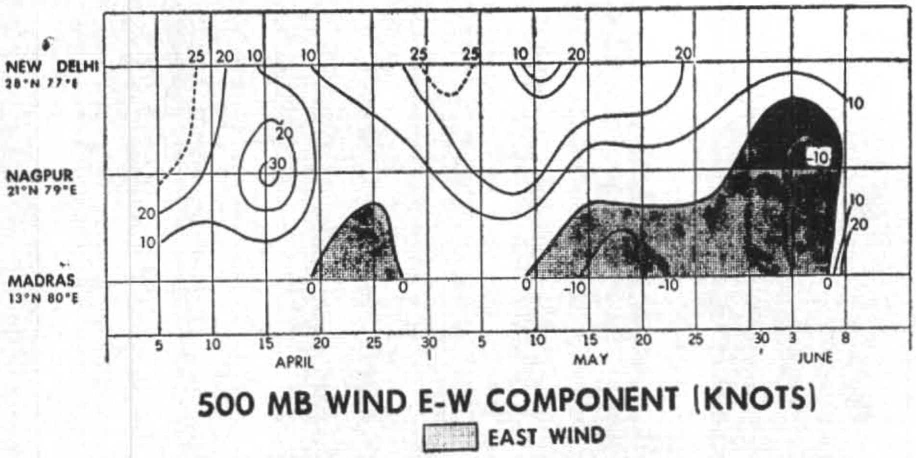


Fig. 10. The 500 mb east-west wind component for the three Indian stations. The shaded area shows the easterly component

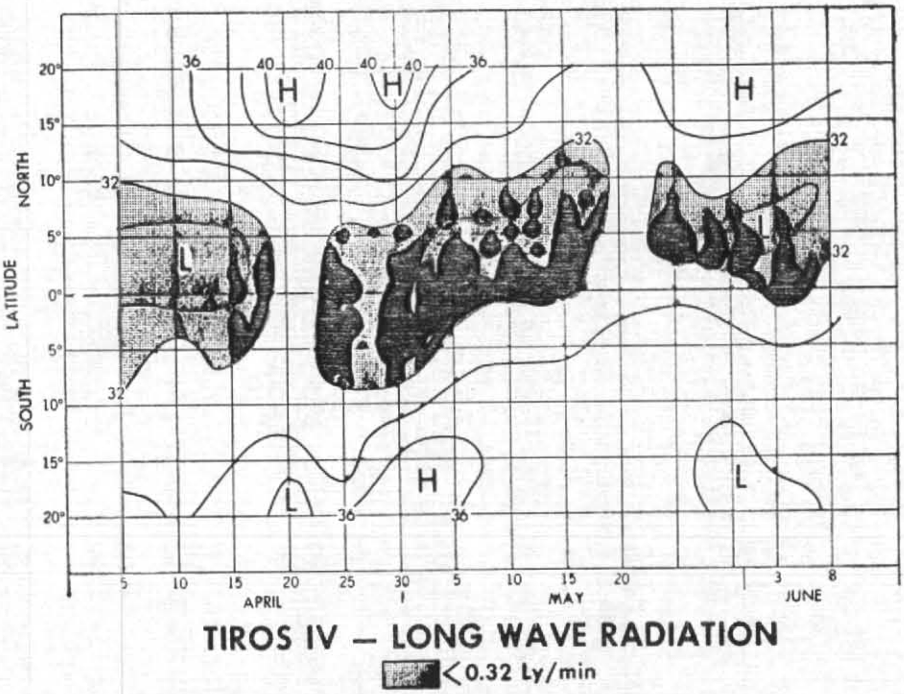


Fig. 11. Time-latitude section of the outgoing long wave radiation derived from TIROS IV channel 2 data, averaged between longitudes 20°W and 40°E (see legend to Fig. 1)

information become available with the polar orbiting satellites, the radiation data are the best source of information to locate the regions of cloudiness associated with the ITC.

It has been shown that the centres of low outgoing long-wave radiation values associated with the cloudiness of the ITC moved northward with time. With the advancement of the cloudiness the monsoon set in over the Indian Subcontinent. The change in the intensities of the radiation values showed the changes in the cloud fields. Also when the data become available from other satellites it is possible to study the variations in the monsoon circulation, the retreat and the redevelopment of the monsoon by observing the changes in the radiation intensities.

It was not possible to establish any lag relationship between the strength and northward shift of the zonal westerlies and the northward migration of the belt of low radiation values. The limited amount of data presented in this paper suggest that changes occurred nearly simultaneously in the radiation and the wind fields.

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