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Diurnal variation of outgoing longwave radiation derived from INSAT-1B data

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सार — इस शोध पत्र में, इन्सैट–1 बी, वी. एच. आर. आर. प्रेक्षणों से व्युत्पन्न वर्ष 1987 से 1990 तक के लिये, हिन्द महासागर क्षेत्र में निर्गमनी दीर्घतरंग विकिरण (ओ. एल. आर.) के 3 घंटेवार मानों का प्रयोग ओ. एल. आर. के दैनिक विविधता के नमूनों के अध्ययन के लिये किया गया। वर्ष के चार प्रतिनिधि महीनों में विभिन्न क्षेत्रों जैसे, रेगिस्तान, समुद्र, मानसून क्षेत्र और भूमध्यवर्ती द्रोणी में दैनिक विविधताओं की प्रकृति पर चर्चा की गई है। ओ. एल. आर. के दैनिक विस्तार में विविधताओं और उसके न्यूनतम और अधिकतम होने के घंटों को भी प्रस्तुत किया गया है।

3 घंटे के सभी आठ नमूनों का प्रयोग करते हुए इन्सैट ओ. एल. आर. के दैनिक मानों और 12 घंटे के नमूमों के चार विभिन्न युग्मों को आकलित किया गया। परिणामों से पता चलता है कि ये अत्याधिक सहसंबंधित हैं। फिर भी 0230 और 1430 स्थानीय समय के अनुरूप ओ. एल. आर. मानो सहित किये गये औसत 8 नमूनों की औसतो की तुलना में कुछ हद तक कम आकलित हैं जबकि 0830 और 2030 स्थानीय समय पर आधारित औसतमान कुछ हद तक अधि-आंकलित है।

ABSTRACT. In this paper, 3-hourly values of Outgoing Longwave Radiation (OLR) for the years 1987 to 1990 over the Indian Ocean region, derived from INSAT-1B VHRR observations, have been used to study the patterns of diurnal variation of OLR. The nature of the diurnal variations over different regions such as desert, ocean, monsoon area and equatorial trough in four representative months of the year is discussed. The variations in the diurnal range of OLR and the hours of occurrence of OLR minimum and maximum, are also presented.

Daily means of INSAT OLR using all eight 3-hour samples and four different pairs of 12-hour samples were computed. Results show that they are highly correlated. However, averages made with OLR values corresponding to 0230 and 1430 local time are slight underestimates compared to the 8-sample averages, whereas averages based upon 0830 and 2030 local time are slight overestimates.

Key words — Diurnal variation, Outgoing longwave radiation, Monsoon region, SHET, Grey shade, Temperature flux.

1. Introduction

The derivation of outgoing longwave radiation (OLR) from window radiance measurements made by polar-orbiting satellites commenced as far back as in 1974. However, in most early studies (Gruber *et al.* 1983), OLR was regarded as just one out of several components which made up the radiation budget of the earth-atmosphere system. Although the importance of OLR in the planetary radiative budget is accepted, in recent years there has been increasing emphasis on the application of OLR as a proxy for other meteorological parameters which are not observed globally. In particular, use of OLR data to determine large-scale precipitation has become quite common (Morrissey 1986, Janowiak and Arkin 1991). Computation of diabatic heating rates and initialisation of moisture fields in numerical weather prediction from satellite OLR data has been attempted (Puri and Miller 1990). Krishnamurti and Low-Nam (1986) have discussed the relationship between OLR and the divergent circulation of the atmosphere. Others have used OLR data to study short-period oscillations in the atmosphere (Lau and Chan 1983).

The NOAA polar-orbiting satellite series from NOAA-2 onwards, and NIMBUS satellites, have provided the basic radiance data for OLR derivation, and it is to be noted that not much effort has been made to exploit the high potential of geostationary meteorological satellites for this purpose, except in India. From INSAT VHRR (Very High Resolution Radiometer) infrared channel data, OLR is being derived routinely from June 1986 onwards at the INSAT Meteorological Data Utilisation Centre, New Delhi. The methodology of OLR estimation and early results have been described by Rao *et al.* (1989) and Arkin *et al.* (1989).

The satellite-derived OLR is modulated by four basic factors : (a) land or sea surface temperature, (b) cloudiness, (c) vertical temperature structure of the atmosphere, and (d) optical depth of the atmospheric water vapour. In the process of averaging OLR over large spatial and temporal scales, effects of the diurnal variation of these parameters get smoothed out to a considerable extent. Particularly in the tropics, large diurnal variations in cloudiness and land surface temperature are known to occur and the diurnal response

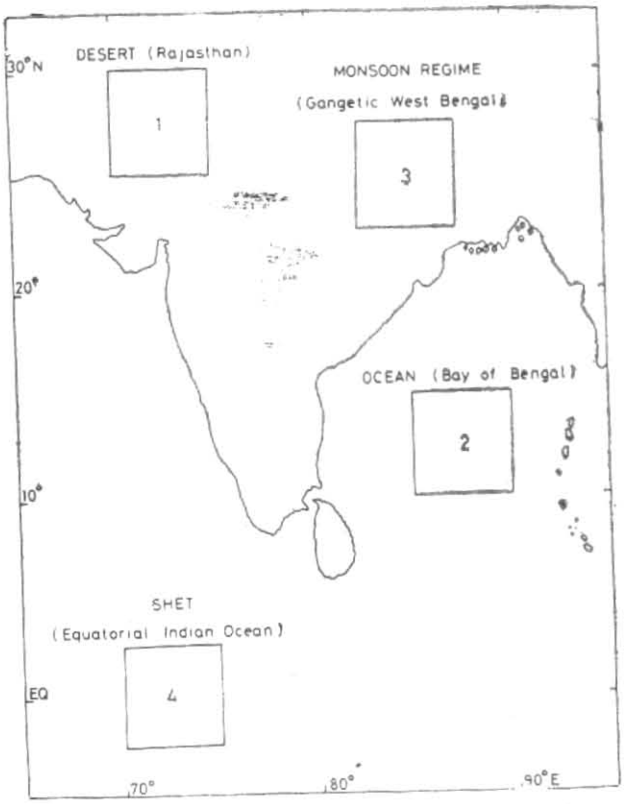


Fig. 1. 5° × 5° areas selected for analysis of diurnal variation of OLR

of the OLR to them could be significant. While this, in itself, calls for a detailed analysis, another important reason for investigating the diurnal variation of OLR is to ascertain whether the daily OLR means derived from twice-a-day sampling provided by the polar-orbiting satellites are realistic or not.

Different NOAA satellites have had different equator-crossing times over the years. Some workers have composited the inhomogeneous data by taking diurnal averages regardless of the equator-crossing times (Janowiak *et al.* 1985). Whereas, others have used the same data set and ignored the inter-annual variations in OLR to isolate the diurnal cycle. There have been some studies based upon METEOSAT (England and Hunt 1984, Duvel and Kandel 1985) and GOES (Hartmann and Recker 1986) observations but the data base used therein has been very limited and window radiances have been directly used instead of OLR.

In the present paper, the authors have derived 3-hourly OLR values for the years 1987 to 1990 over the Indian Ocean region observed by INSAT-1B, the Indian geostationary satellite, located at 74°E on the equator. The use of INSAT OLR has several clear advantages over the data from the polar orbiters in that, (a) a single radiometer is involved in the observations, making them truly comparable, (b) the observation times are fixed and not variable from day to day as in the case of polar orbiters, and (c) OLR values are available for a given place eight times a day at 3-hour interval, providing higher credibility to the daily average.

In this paper, the results are presented as monthly OLR means for fixed hours for four months January, April, July and October representing winter, pre-monsoon, monsoon and post-monsoon seasons respectively. Variations within the month on a day-to-day mode are not discussed. On the spatial scale, 2.5° × 2.5° Lat./Long. averaging has been resorted to.

2. Methodology

The method adopted for deriving OLR from an INSAT-1B infrared image is identical to that described earlier by Rao *et al.* (1989). The area of analysis extends from 40°E to 100°E and 35°N to 25°S and is divided into sub-areas of 2.5° Lat./Long. called 'boxes'. The grey shade value of each infrared pixel (picture element of 11 × 11 km in a box) is read and converted to its corresponding temperature by means of a look-up table. The box mean temperature (T_m) is calculated by averaging the temperatures of all pixels in that box. The flux temperature (T_f) is calculated by :

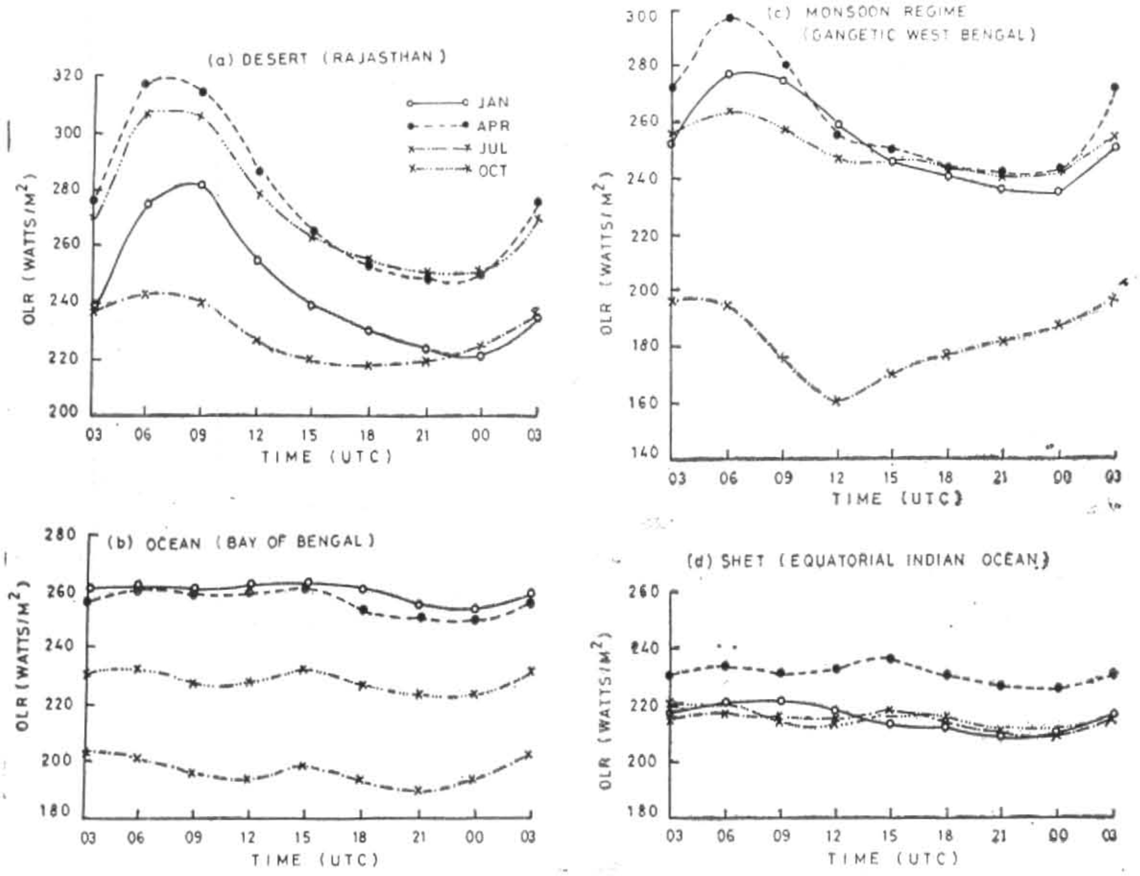
$$T_f = T_m\,(a + bT_m)$$

where, a and b are constants which depend on the spectral response characteristics of the radiometer and zenith angle ($a = 1.1889$ and $b = 0.000989/°\text{K}$ for INSAT-1B for zero zenith angle). OLR is computed from T_f as $\sigma\,(T_f)^4$ where σ is the Stefan-Boltzmann constant.

The OLR values for each box, using 3-hourly INSAT images, are thus computed. For each box, a separate monthly average for each of the eight observation hours is calculated.

The OLR data sets were accordingly built up for the months of January and April for the years 1987 to 1990 and for July and October for the years 1987 to 1989.

After the monthly mean OLR's for different hours of the day were obtained for the different boxes, they were subjected to further analysis like computation of diurnal range of OLR, time of occurrence of maximum and minimum values of OLR, mean of eight 3-hourly values of the day, mean of various pairs of 12-hourly values, *e.g.*, 0000 and 1200 UTC, 0300 and 1500 UTC, etc.



Figs. 2(a-d). Diurnal variation of OLR (monthly mean) over four different regions in four representative months

3. Results and discussion

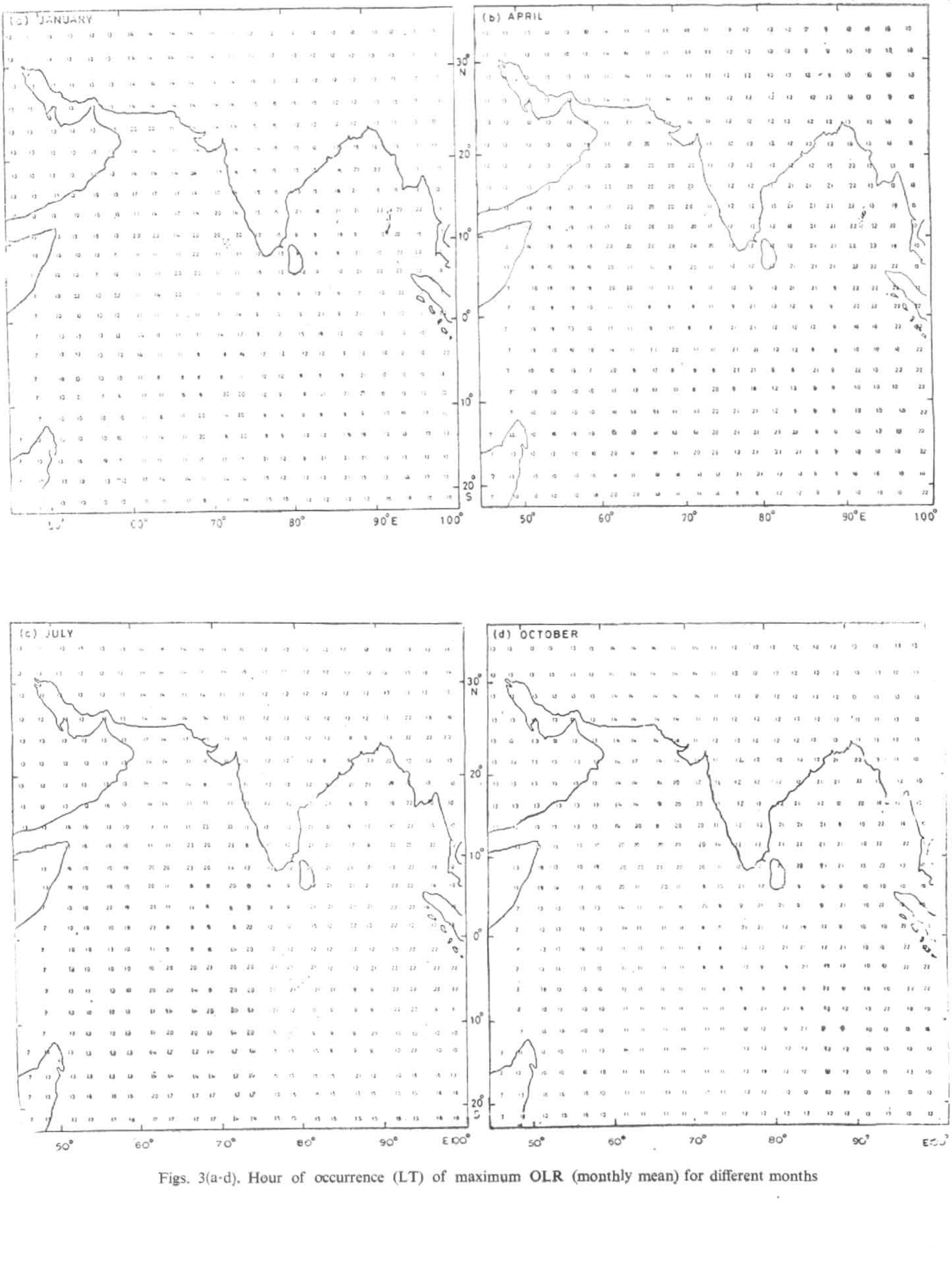
3.1. *Diurnal variation*

Four areas of 5° × 5° Lat./Long. were selected from the INSAT-1B field (Fig. 1) for analysis of the diurnal OLR regime. These are representative of desert region in Rajasthan (27.5°N, 72.5°E), oceanic region over the Bay of Bengal (12.5°N, 87.5°E), monsoon regime over land (25°N, 85°E) and ITCZ region (0°, 72.5°E). The monthly mean OLR derived eight times of the day (0000, 0300, 0600,......2100 UTC) for each of these four different locations is shown in Figs. 2(a-d) for the months of January, April, July and October.

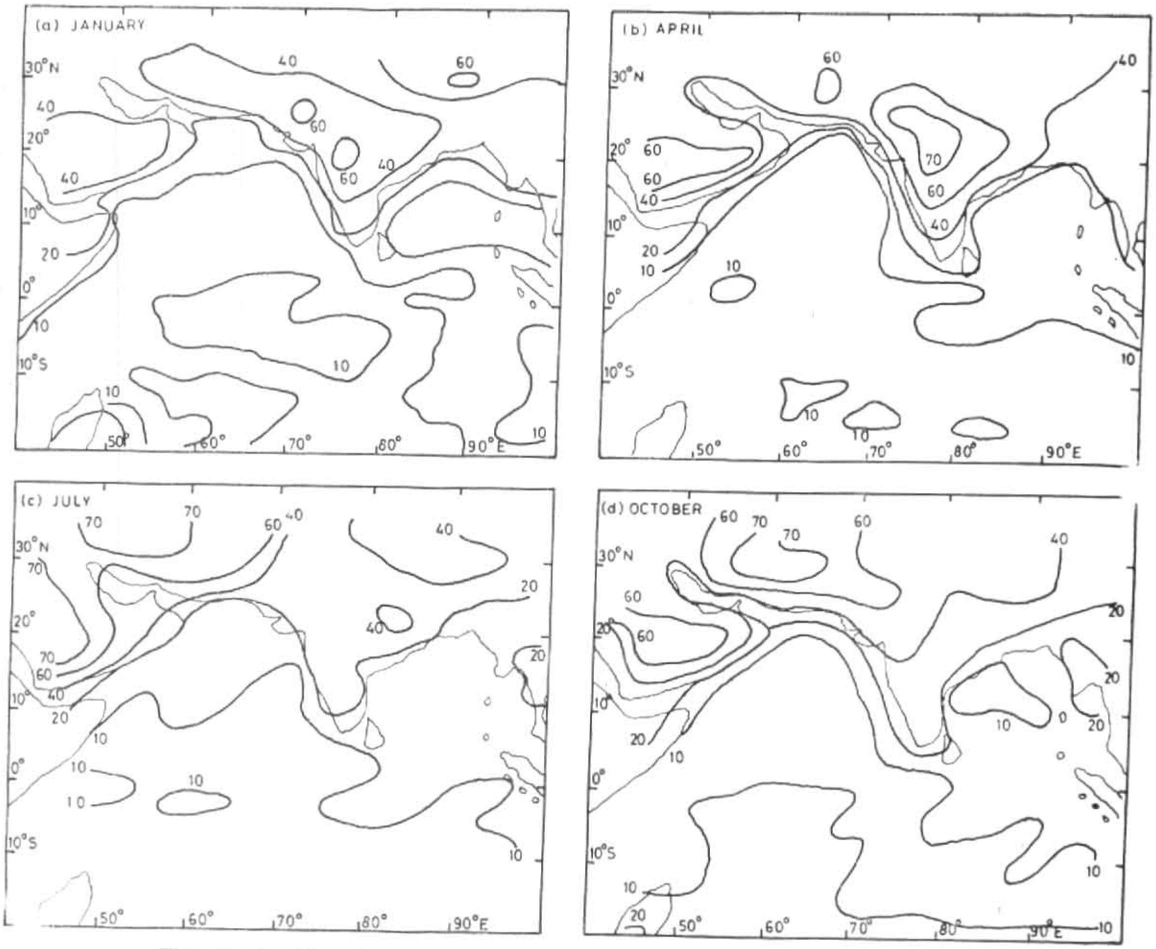
3.1.1. *Desert region* (*Rajasthan*) — Maximum values of OLR occur in this region in April (>320 W/m^2) which decrease to 240 W/m^2 in July, under the influence of the monsoon. The diurnal variation of OLR in April is of the order of 70 W/m^2 while it decreases to 25 W/m^2 in July. The maximum occurs around local noon which shifts slightly to a later time in January than in April. The variations in April and October months are quite similar. Typical of a desert region, the variations are large in all months except in July.

3.1.2. *Oceanic region* — The diurnal variations in the oceanic area are small irrespective of the season. The July values are smaller than those in January and April when the region is practically devoid of cloudiness and the variations are modulated by the sea surface temperature changes only, which are small. The magnitude of OLR in October lies in between those values of July and April because of the monsoon cloudiness.

3.1.3. *Monsoon regime* — In this region, the effect of the summer monsoon cloudiness is clearly brought out. The OLR values decrease to less than 200 W/m^2 in July as compared to those exceeding 240 W/m^2 in the other month. The maximum occurs around noon in all the months except in July when it occurs in the morning hours, this being the epoch of minimum cloudiness. The minimum occurs around 1800 local time in July when the convective activity is maximum over the region. In other months, the minimum occurs early in the morning as the OLR is more controlled by the surface temperature changes.



Figs. 3(a-d). Hour of occurrence (LT) of maximum OLR (monthly mean) for different months



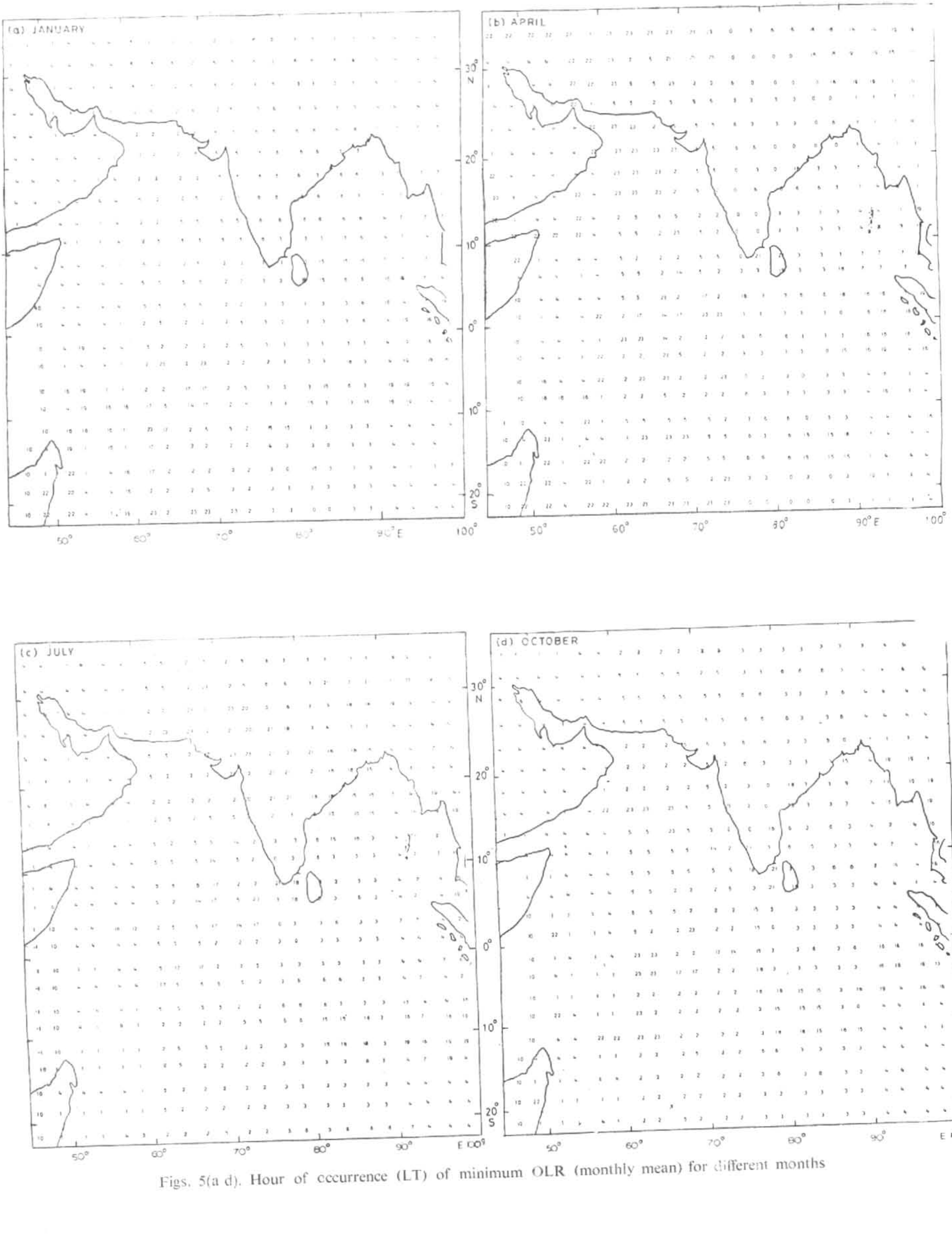
Figs. 4(a-d). Diurnal range of variation of OLR W/m² in four representative months

3.1.4. *SHET* (*Southern Hemispheric Equatorial Trough*) *region* — Though the diurnal variation is similar to that over Bay of Bengal, the seasonal variation also is very small as compared to that region. The seasonal variation is of the order of 25 W/m² while the average diurnal variation is of the order of 8 W/m². The maximum occurs around 2100 and the minimum at 0300 local time.

3.2. *Diurnal range*

As seen in the preceding section, the diurnal range of OLR (*i.e.*, difference between maximum and minimum values of OLR in the 24-hr cycle) varies significantly with place and season. The OLR diurnal range was, therefore, analysed for the four months of January, April, July and October for the entire $2.5 \times 2.5°$ grid of computations. The results are shown in Figs. 4(a-d). In all these months, the diurnal range of OLR is higher over land than that over the oceans. This indicates that whether the OLR changes are modulated by surface temperature changes or cloudiness changes, such variations are more over land than over ocean. The diurnal range is less than 20 W/m² over most of the oceanic regions in all the seasons.

The diurnal range is seen to increase as one goes into continental interiors. It is as high as 70 W/m² over the Arabian desert regions in July and northwest India in April where the surface temperature variations over night and day are very large. In July, the range is suppressed over India under the influence of the monsoon clouding. It is 40 W/m² over Bihar and adjoining Madhya Pradesh and Gangetic West Bengal indicating the large diurnal variability of convective activity over this region. In the month of October, the range increases over the Indian sub-continent, in general, due to increased diurnal range of surface temperature after the withdrawal of the summer monsoon.



Figs. 5(a-d). Hour of occurrence (LT) of minimum OLR (monthly mean) for different months

TABLE 1

Comparison of daily averages of OLR derived from eight and two samples per day

Comparison between average of eight values of OLR in a day and	Correlation coefficient	Regression line	
		Slope	Intercept
(1) Average of 0000 and 1200 UTC	0.99	0.9375	13.283
(2) Average of 0300 and 1500 UTC	0.99	0.9866	5.919
(3) Average of 0600 and 1800 UTC	0.99	1.0506	—10.233
(4) Average of 0900 and 2100 UTC	0.99	1.0277	—8.600

Over Iran and adjoining Afghanistan and Pakistan, high diurnal range 70 W/m² persists in October. It decreases, however, in January as a result of the western disturbance activity.

3.3. *Hours of occurrence of OLR extremes*

The hours of occurrence of maximum and minimum OLR during the diurnal cycle are shown for January, April, July and October in Figs. 3(a-d) and Figs. 5 (a-d) respectively. The hours are in local time, approximated to the nearest whole hour.

A striking feature of the diagrams is that over the Arabian Peninsula, the maximum OLR occurs at 13 local time during all the seasons of the year, because of the sparse cloudiness and predominant effect of surface temperature. Over the Indian land-mass, the maximum OLR generally occurs at local noon or a little before it, but in January when cloudiness is least, 14-15 local time seems to be the preferred time.

The hour of occurrence of minimum OLR is mostly between 01 and 04 local time over the desert regions of Arabia. Over the Indian sub-continent, the minimum OLR occurs generally between 03 and 06 local time but in July the hour of minimum OLR is seen to advance to 18 to 21 local time.

Over the Indian Ocean, the diurnal range of the OLR itself being low [Figs. 4(a-d)] the diurnal curve of OLR against time of day assumes a flat shape [Figs. 2(b-d)] and the sinusoidal nature gets distorted because of cloudiness variations superimposed on the SST variations. As a result, no distinct pattern can be observed in the hour of minimum or maximum OLR over oceanic regions.

3.4. *Daily average of OLR*

The NOAA polar-orbiting satellites view any given place on the earth twice a day, once during a northbound equator-crossing, and again during a southbound pass after about 12 hours. It has been the practice for odd-numbered satellites (NOAA-9, NOAA-11, etc) to have equator-crossing times of 0230 and 1430 local time and for the even numbered ones (NOAA-8, NOAA-10, etc) to cross the equator at 0830 and 2030 local time. The OLR daily means of NOAA are usually based upon the 0230 and 1430 local time radiance measurements.

In the present study, the INSAT OLR daily means were derived from eight observations a day (0000, 0300, 0600,. . . . 2100 UTC). In order to assess the improvement resulting from this refined sampling, pairs of local time 12 hours apart were averaged and compared with the eight-sample average. Correlations and regressions were obtained for all the four representative months January, April, July and October combined together. The comparisons were restricted to grid-points where local times were within 90 minutes of the INSAT observation time for obtaining meaningful results. The results are given in Table 1.

The correlations are 0.99 in all the four cases. Also, the results indicate that the average OLR derived from the pair 0900 and 2100 UTC (0230 and 1430 local times around 82.5° E Long.) has a regression slope of 1.0277 with respect to the 8-value average and an intercept of —8.6. If this situation is considered analogous to NOAA-9, NOAA-11 etc, then NOAA averaging will lead to a slight underestimate compared to an eight-time sampling average. On the contrary, 0300 and 1500 UTC averaging suggests that NOAA-8/10 averaging will cause a slight overestimate.

4. Concluding remarks

Derivation of OLR on a 3-hourly basis from INSAT VHRR radiance measurements has resulted in a better understanding of the diurnal OLR regime over India, Indian Ocean and adjoining regions. The comparison of daily averages based on eight samples a day with those based on various pairs of 12-hour samples, has clearly brought out the need for refined temporal sampling for OLR averaging. Data from the geostationary satellites needs to be fully exploited for this purpose, rather than relying exclusively on polar-orbiting satellites.

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