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# Seasonal changes in satellite observed cloudiness and radiometric measurements in the tropical belt of Africa and Asia

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ABSTRACT. Monthly mean analysis of the TIROS-VII 8-12 micron radiation data for the period 1963-1964, global satellite observed cloudiness for the year 1965 and 1966 and the global brightness charts for the year 1967 published by different workers are studied in detail for the monsoonal belt of Africa and Asia. The discussion highlights seasonal changes in the cloudiness with respect to atmospheric circulation features of the region grouped in to more or less different homogeneous belts. The study of the data over the Indian belt suggests a connection between the advance and retreat of the southwest monsoon cloudiness with changes of cloudiness over southwest Bay of Bengal, northeast India and Eastern China. Variations in the westward and eastward extent of the cloudiness over the equator in the Indian Ocean and Pacific Ocean respectively are discussed.

## 1. Introduction

Several research workers have used satellite television cloud data for the preparation of monthly mean cloud cover charts on global basis using either subjectively computed grid point cloud amounts from the operational nephanalysis prepared by National Environmental Satellite Centre, Washington (Arking 1964, Clapp 1964, Sadler 1968 and Bjerknes *et al.* 1969) or by objective representation of the brightness patterns (Taylor and Winston 1968). Monthly mean values of Planetary scale outgoing long wave radiation as obtained by satellite measurements have been computed by Bandeen *et al.* (1965), Winston (1967) and Allison *et al.* (1969) for different periods. Winston (1969) has given an extensive review on the results obtained by the TIROS series of satellites on the global distribution of cloudiness and radiation.

The purpose of the present paper is to highlight some of the climatological features in cloudiness/brightness and radiation charts over different sections of the tropical belt between 0°E to 140°E and explain them in the light of known climatological features of the atmospheric circulation. Towards this end, we have primarily used the cloudiness charts prepared by Sadler (1968) for the years 1965 and 1966, the brightness charts prepared by Taylor and Winston (1968) and charts of outgoing long wave radiations prepared by Allison *et al.* (1969) for the year 1963-1964. Generally brightness levels four and above appear to correspond well with the heavily clouded regions over active monsoonal regimes of West Africa, India and South-east Asia while brightness level one overlies the areas of clear skies. Over the Sahara and Arabian deserts brightness level 3-4 is found to correspond with the clear areas due to high reflectance of the deserts.

## 2. General features of satellite cloud and outgoing long-wave radiation climatology over the tropical belts 0-140°E

Major features which emerge out of studying these charts are the following—

(*i*) A pronounced belt of nearly zonally oriented maximum cloudiness in the region of equatorial trough which shows seasonal migration north or south of the equator. The northward migration of this belt during the northern hemisphere summer is, in general, more than the southward migration in the southern hemisphere summer. A marked break in this belt occurs over the west Arabian Sea and adjoining East Africa and Arabia during the northern hemisphere summer.

(*ii*) Secondary belt of equatorial cloud maximum in the northern or the southern hemisphere is not marked in their respective winter months. However, double equatorial maximum cloudiness is discernible in the transition months along certain longitudinal belts.

(*iii*) Orographic features are found to influence the cloudiness over Borneo and Celebes regions throughout the year and over the west coast of India and Burma during the southwest monsoon months.

(*iv*) A belt of generally zonally oriented minimum cloudiness in the sub-tropical region associated with the large-scale subsidence in the belt of sub-tropical ridge. This belt also shows characteristic poleward/equatorward movement in summer/winter months. This inter-seasonal migration is also greater in the northern hemisphere. A break in the sub-tropical minimum cloudiness occurs over India during summer, thus showing a great contrast between the heavily clouded Indian and Southeast Asian region and almost clear skies over the Sahara and Arabia, which make the effect of southwest monsoon so strikingly clear. During September and October with the equatorward migration of the equatorial trough in the northern hemisphere, the sub-tropical belt of minimum cloudiness gets bridged across India near about 20°N.

(*v*) In the outgoing longwave radiation charts the areas of maximum and minimum equivalent black body temperature ($T_{BB}$) are also zonally oriented. Since the radiation values depend upon cloudiness, the maximum in radiation are associated with the cloud free conditions of the sub-tropical ridge and minima in radiation with the clouded regions of the equatorial trough. Seasonal migration of the regions of minima and maxima in radiation are noticed in response to the shift in the equatorial trough and subtropical ridge but the migration in the northern hemisphere is larger than in the southern hemisphere.

### 3. Latitudinal variations in cloudiness along different longitudinal belts

In view of the variations in cloudiness along the longitudes within the monsoon belt under consideration we have examined the average along the following six longitudinal belts, *i.e.,* (*i*)0°—40°E, (*ii*) 40°—60°E,(*iii*)60°—90°E (*iv*) 90°—100°E, (*v*) 100°—120°E and (*vi*) 120°—140°E separately. These belts were grouped on the basis of certain features observed in the mean monthly distribution of cloudiness during the monsoon months. The cloud amounts and brightness values for each of the six longitudinal belts for 2·5° latitude/longitude intersections were picked up from the isopleths drawn in the charts by Sadler (1968) and Taylor and Winston (1968) respectively and latitudinal averages were prepared for each belts and plotted as monthly time sections from February 1965 to December 1967. Although the important features observed in these sections are discussed below for each belt, only three sections are shown in Figs. 1 to 3, *i.e.*, 60°-90°E, 90°-100° E and 100°-120°E in order to restrict the number of diagrams.

3.1. *0°-40°E*—This region is dominated by the continent of Africa both to the north and south of the equator. The axis of the maximum cloudiness / brightness remains well south of the equator till March. It reaches farthest from the equator (10°—12°S) in February and begins to recede towards the equator in March and lies very close to it in April. The cross-sections along 15°—24°E prepared by Flohn (1960) shows equatorial westerlies in January—February between the equator and 12°S from surface to about 700 mb. The cloud maximum in southern summer thus lies within the zone of westerly winds. May is the transition month in which the cloudy belt (> 4 octas) lies within about five degrees latitude on either side of the equator although the axis of the maximum cloudiness may lie within the northern hemisphere. The axis moves gradually northward with the advance of the northern summer and attains its northernmost position of about 8°N in August. Southward movement of the axis is noticed in September and it lies again very near the equator in October and moves south of it with the season. The cloud amounts over the equator throughout the year remain over 4 octas.

The position of the axis during the northern hemisphere summer is nearly 10° south of the surface position of the Intertropical Convergence Zone (ITCZ). The gradient in the cloudiness poleward of the axis is more in the northern hemisphere summer compared to the southern hemisphere summer. The limited poleward extension of the maximum cloudiness and its sharp reduction to its north during the northern hemisphere summer is due to the fact that dry Saharan air percludes development of clouds. Only at a distance significantly south of the surface ITCZ the southwest air from the Atlantic Ocean is significantly deep and the weather activity is mostly contained in this zone.

The axis of the subtropical minima in the cloudiness shows somewhat larger annual variation in the northern hemisphere (12°—15°) in comparison to the southern hemisphere (10°—12°) generally. The axis in both the hemispheres is nearer the equator in winter (15°—20°N/S) in comparison to summer (25°—30° N/S). There is no significant increase of cloudiness along 30°N/S in winter indicating very little extension of the effect of winter time westerlies in the mean in producing large scale weather in the sub-tropics over this belt.

3.2. *40°-60°E* — The striking abnormality in this region is evidenced by the lack of cloudiness in the equatorial region where normally cloudiness should prevail as over other equatorial regions in association with the equatorial trough. The abnormality is still more puzzling during the northern hemisphere summer when the whole monsoonal belt over West and Central Africa to the west of this dry region and the Indian and Southeast Asian region to the east of it are abundantly clouded. This is due to several factors, one of which being the difluence of the southeast trades into two currents; one branch approaching the African coast and moving westwards, while the other branch turns northward and blows parallel to Somali coast as shallow southwest monsoon. Besides the shallowness of the southwest monsoon current, it is overrun by the stable air of Sahara origin. The subsidence is also helped by the dynamic effects of the upper tropospheric easterly jet stream. The pronounced upwelling along the coast of Somalia also suppresses cloud development. There seems to be year to year variation during the northern hemisphere summer in the equatorial cloudiness within this belt since significant cloud (> 4 octas) are observed in June-July 1966 between 5°S and 5°N in comparison to less clouds in 1965 and 1967.

During the northern hemisphere winter northeast trades blow over the Arabian Sea and although the aridity of west Arabian Sea north of 10°N is expected but what is surprising is that there is no appreciable build up of clouds right upto equator and even southward upto 5°S. The circulation in the northern hemisphere in January in this region at 850-mb level is controlled by the Arabian anticyclone centred near 20°N and 50°E between 10°—30°N with north-south ridge along about 50°E (Thompson 1965). The ridge is, however E-W oriented at 700 mb and is well south of the 850 mb position. The NE current in the lower levels of Arabian anticyclonic origin is subsident and has very small sea trajectory which may contribute to almost clear skies in this belt during northern hemisphere winter. The northerly low-level current moving southward crosses the equator without any turning in this region thus extending less cloudy conditions till about 5° south of the equator.

The cloud maximum in the southern hemisphere summer in association with the equatorial trough is best developed in February when it lies near about 8°—10°S and weakens by April as the SE trades begin to strengthen and extend toward the equator. There is marked minimum in cloudiness with axis about 15°S in the southern hemisphere between June to September in association with the subtropical ridge. The brightness data for the year 1967 shows this minimum to be very pronounced. No significant increase of clouding along 30°N in winter is noticed in this belt too.

3.3. *60° — 90°E* — Month to month changes in average cloudiness in this belt are shown in Fig. 1. The seasonal migration of cloud maximum is marked in this belt. The axis of the maximum cloudiness lies near about 10°S in January-February and the cloud amounts decrease northward

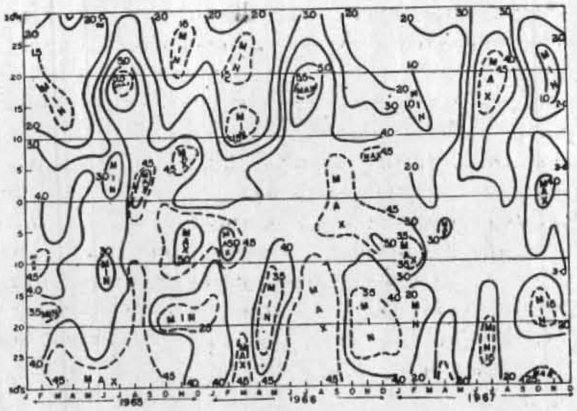

**Fig. 1. Longitudinal belt 60-90°E**

Zonally averaged cloudiness for 1965 and 1966 and zonally averaged brightness values for the same belt for 1967. The isopleths have not been joined between Jan and Feb 1967 since the data from Feb 1967 pertains to brightness values. The units are octas of cloud and brightness in tens.

across the equator. By April this maximum moves nearer the equator and shows relative weakening while simultaneous increase of cloudiness is noticed at the equator and upto 5°N. This results on the average in a relatively flat field of cloudiness with amounts ranging between 4 to 4·5 octas during 1965 and 1966 and a brightness field of 2·5 to 3·0 during 1967. Such conditions prevail in May too though the northern hemisphere cloudiness relatively increases up to 10°N. These changes may be occurring under the combined influence of (*i*) the development of continental thermal lows over Peninsular and central India and over South Arabia (Ethiopia and Somalia) during April—May as well as (*ii*) the equatorward migration and weakening of the surface equatorial trough in the south Indian Ocean in April in comparison to what it was in the early part of the year and its becoming rather diffuse in May. However, with the intensification of the continental lows over western parts of Indo-Pakistan and Arabia and the setting up of the SW monsoon season there is sudden increase of cloudiness in the belt 10°—20°N between May and June and the axis of the maximum cloudiness lies near 12°—15°N. The maximum intensifies and approaches its northern most position of about 18°N during July-August. The decrease of cloudiness to the north of the maximum is also rather marked in July-August. The maximum begins to weaken in September and shifts southward to about 12°N. However, in the transition month of October, the field of cloudiness again becomes flat between 10°N to 10°S and remains so in November and December. This occurs in association with (*i*) the sea surface level positioning of the seasonal low pressure area

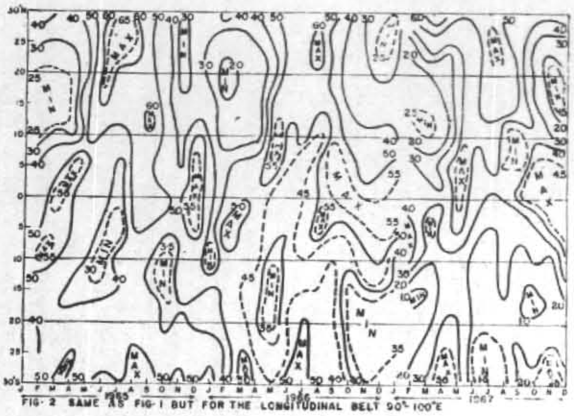

Fig. 2. Longitudinal belt 90-100°E

[Explanation same as Fig.1]

over the Bay of Bengal and (*ii*) the development of the sea surface level equatorial trough in the south Indian Ocean. Whereas the data for November and December during 1965 and 1966 suggest the existence of two maxima in cloudiness on either side of the equator, the brightness data for 1967 shows only a single maximum which is centred very near the equator in November and shifts south of the equator in December. In general equatorial belt from 5°N to 5°S is covered by about 4 octas of clouds from April to December except for June and July 1965 when the cloud cover was about 3 octas only and a minimum lay near about 5°N. Thus the monthly changes in cloudiness do not conclusively suggest that the cloudiness maximum migrates across the equator twice in the course of a year during the transition months. What is observed in the average picture is that the field of cloudiness becomes flat in the transition month in the equatorial belt due to weakening of the maximum of the winter transition belt and increased cloudiness in the summer transition belt. However, advance and retreat of summer is accompanied by poleward and equatorward migration of the cloud maxima in both the hemispheres though this shift is more marked in the case of the northern hemisphere. The cloud census study under Global Atmospheric Research Programme (WMO 1970) has also shown that cloud clusters may form and move westward along 5°—10°N/S in the winter hemisphere although the major cloud belt lies in the summer hemisphere.

The axis of the minimum cloudiness shows larger seasonal migration in the northern hemisphere in comparison to that in the southern hemisphere. Data for 1965 and 1966 do not suggest any significant increase in cloudiness during winter months along 30°N whereas the brightness data show increase for the year 1967 which may be due to snow cover over the Himalayan belt. There is increased cloudiness along 25—30°S in comparison to 25—30°N in their respective winters which show greater influence of the subtropical westerlies in the southern hemisphere oceanic belt.

3.4. *90° — 100°E* — The variation in cloudiness in this belt are shown in Fig. 2. An important feature of this belt is that although the maximum in cloudiness lies along about 10°S in January-February and about 25°N in July-August in the respective summer hemisphere, significant cloud amounts (> 4 octas) extend upto the equator and even across it upto 5°N/5°S respectively. During the transition months of April and October a broad zone of maximum cloudiness lies between 5°N and 5°S. Whereas, in May the maximum lies along about 10°N and shifts further northward in June with the advance of the SW monsoon, a broad maximum between 5°N and 5°S is noticed during November and December although during December a more detailed examination of the data may place the axis of the maximum along about 3°S. Thus it is rather difficult to say from the mean monthly data whether there is a progressive shift of maximum in this belt from the winter transition hemisphere to summer transition hemisphere in the transition months. This is due to the fact that these averages are based on daily data which show on several occasions simultaneous existence of cloud band on either side of the equator although their intensity may vary from one transition to the other in the respective hemisphere. Another important feature is the significant increase of clouds in May along 7°—12°N which is in association with the substantial increase in the frequency of SW winds at the sea level south of 20°N. This occurs with early season extensions of low-level SW monsoon flow over Bay of Bengal and the formation of a low pressure area over Burma. During the same month (May) cloud amounts also increase over NE India due to the influx of low-level moisture and favourable position of the belt of stronger upper tropospheric subtropical westerlies. These regions of maximum cloudiness are separated by a region of less cloudiness along about 15°N which is the position of the middle tropospheric ridge. With the advance of the southwest monsoon the equatorial maximum rapidly shifts northward and by the same time the stronger upper tropospheric westerlies also move north of the Eastern Himalayas. Thus a single broad belt of maximum cloudiness extending NE/SW from NE India to SE Arabian Sea results in June as a dominant feature of the SW monsoon cloudiness over the whole Indian region. Northernmost position of this maximum is in July and August along about 25°N. With the withdrawal of the SW monsoon over NW India in September and the associated eastward extension of the mid-tropospheric subtropical ridge toward Burma the cloudiness maximum shifts toward the equator in October and the subtropical belt of minimum cloudiness is again bridged from Africa to Burma across about 20°N. However, the cloud amounts in this region within the belt of northern hemisphere subtropical minimum cloudiness are 2-3 octas (brightness values 1-2) which are about an octa more than in the zone between 60°—90°E.

3.5. *100°—120°* — Fig. 3 shows the variation along this belt. The maximum cloudiness axis shows a regular seasonal progression from the southern to northern hemisphere and *vice versa* and the axis crosses the equator in April-May and November-December. The mean southern hemisphere equatorial band is prominently seen during January-February and lies rather close to the equator near about 5°S. The data for all the three years suggest presence of significant clouding in the northern hemisphere equatorial belt too during January and February. This may be again due to the existence of a separate equatorial belt in the northern hemisphere on a quite a few days during winter which in the average picture results in weak gradient in cloud amounts in the near equatorial belts of both the hemispheres. Similarly during the northern hemisphere summer (July and August) although the axis of the maximum cloudiness lies near about 10°N, 4 to 4·5 octas of clouds are observed in the southern hemisphere near equatorial region. Thus a feature of this belt is also the existence of significant cloudiness (>4 octas) at the equator throughout the year.

In the case of the northern hemisphere, the cloud data suggest two maxima during June, July and August—one showing northward shift up to 25° to 30°N in June and then gradual southward shift commencing in August, whereas the other running along about 10°N from June to September. The latter shifts southward across the equator with the progress of the season in December.

A separate maximum appears along the northern boundary of the area in September-October and remains there till May. This is no doubt due to southward extension of the cloudiness associated with the extratropical disturbances passing over China and North China Sea. Whereas the maximum along about 10°N from June to September is associated with the position of the middle tropospheric trough, the maximum at the northern boundary in the same months is associated with position of the surface ITCZ. The merging of the cloudy belt near 25°-30°N due to the northward

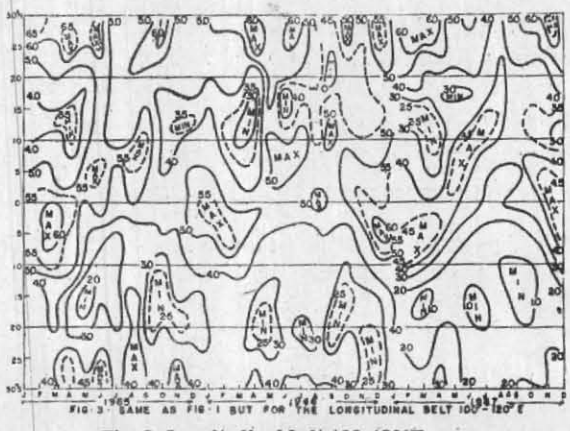


**Fig. 3. Longitudinal belt 100-120°E**

[Explanation is same as Fig. 1]

extension of ITCZ in June and their separation again in August-September suggest that over China in June and July, it is difficult to distinguish between the cloudiness of the ITCZ and that due to disturbances of extra-tropical nature. The above suggestions are also supported by the brightness data for the 1967 except for the month of August 1967 which shows a broad single maximum near about 10°-15°N with extension upto 30°N.

The seasonal variation in the position of the subtropical minimum cloudiness is rather small both in the northern and southern hemisphere. Another important feature which is observed in this region is that in contrast to Indo-African region the subtropical minimum belt of cloudiness in the northern hemisphere is associated with cloud amounts of about 3-4 octas (brightness value 2-3) which may be due to (*i*) pulsatory character of the northeast monsoon and (*ii*) influence of low level E/SE winds which emanate from the Pacific anticyclone and the passage of tropical disturbances of varying intensity.

3.6. *120°—140°E*—In the northern hemisphere this region lies in the eastern fringe of the monsoonal regime. It is characterised by mostly oceanic areas in the northern hemisphere, a chain of islands near the equator and major portion of the Australian continental region in the southern hemisphere. The axis of the maximum cloudiness shows the seasonal inter-hemispheric migration but its southernmost extent in the southern hemisphere summer is near 5°S whereas in the northern hemisphere summer it migrates to about 10°N. There may be considerable year to year variations in the position of the maximum and its latitudinal extension during the summer months in both the hemispheres. For example, the brightness data for 1967 suggest that the position of maximum during February lay near

10°-12°S and during July to September 1966 the cloudy belt extended upto 20°N. The following features are similar to those observed in the case of the belt 100°-120°E.

(*i*) Equatorial region being clouded throughout the year on an average by about 4 octas of clouds.

(*ii*) The subtropical minimum zone of cloudiness having 3-4 octas of clouds and showing expected seasonal migration in the northern hemisphere between 15°N in winter to 25°-30°N in summer.

(*iii*) Presence of another cloud maximum belt along 25°—30°N in all the months except summer which is due to the influence of the disturbances in the subtropical westerlies.

In the southern hemisphere the region of subtropical minimum cloudiness over the continental Australia shows significantly less cloudiness in all the months in comparison to other longitudinal belts over the south Indian Ocean. Even during the winter the disturbances in this subtropical westerlies do not seem to significantly affect the belt between 25°—30°S.

The radiation data interpreted in terms of cloudiness for the year 1963-64 also shows features similar to what have been described above for the different belts.

#### 4. Year to year variations

In order to study year to year variations in the cloudiness the data was examined in two different ways, *i.e.*, (*i*) variations of the average cloudiness with latitude and longitude for the representative months of each year; (*ii*) variations in the position of the maximum cloudiness and minimum cloudiness associated with the position of the equatorial trough and the subtropical ridge respectively. It was noticed that the cloud amounts during February 1966 were somewhat higher compared to February 1965 for the longitudes between 0° to 60°E whereas, they were more or less the same in case of other longitudes. In case of July there was greater cloudiness in 1966 compared to 1965 for the longitudes between 40° to 100°E whereas no significant differences existed between the two years for other belts. It was also observed that whereas the average cloudiness in the south Indian Ocean subtropical minimum belt was generally about 3 octas for all the months in 1965 and 1963 (Sadler's charts) the brightness value for the year 1967 for the same belt was much lower. It is difficult to say at this stage whether this consistent difference between the brightness values in 1967 and the cloud amounts in 1965 and 1966 for the south Indian Ocean subtropical belt are due to the inter-annual changes or due to the difference in the method of basic data processing employed in the preparation of the corresponding charts.

Longitudinal variations in the axis of the maximum cloudiness/minimum $T_{BB}$ values for July (northern hemisphere summer) and February (southern hemisphere summer) were found to be significantly different (5°—7° in latitudes) from year to year along some longitudes. In the case of northern hemisphere the difference was more prominent in the West African and the Western Pacific sectors whereas the difference was the least over the belt between 60°—100°E. Thus on the average the position of cloud maximum in association with the summer monsoon trough over India did not show any significant year to year variation. In the case of southern hemisphere the year to year variation was again the least for the sector 60°—100°E and maximum for the sector 100°—120°E. The axis of the maximum cloudiness in the summer hemisphere lay in general equatorward of the climatological position of the ITCZ, embeded in the zone of the westerlies in the lower troposphere. The axis of the minimum outgoing long wave radiation for July 1963 and February 1964 was in general found to be equatorward of the axis of the maximum cloudiness in other years. Due to lack of satellite cloudiness averages for the years 1963 and 1964 it is difficult to say whether this could be due to year to year variations or whether it implies that more convective clouds occur equatorward of the cloudiness maximum.

The axis of the cloudiness minimum also varied significantly from year to year in both the hemispheres, the variation being larger in the corresponding winter months. In the northern hemisphere the maximum variation (10°—12° in latitudes) was observed in February over the African regions and minimum over the Indian and 100°—120°E regions (3°—5° in latitudes) suggesting thereby that year to year fluctuations in the middle tropospheric subtropical ridge axis is larger over the former in comparison to the latter regions.

#### 5. Month to month variations of cloudiness over the equator

Bjerknes (1966, 1969) has brought out some interesting features of the air-sea interactions over the eastern Pacific Ocean region. According to his hypothesis warmer equatorial ocean temperatures lead to increase convective rain and the consequent greater release of latent heat may accelerate the meridional circulation of the Hadley cell which may in turn cause greater transport of heat and momentum to middle latitudes leading to stronger zonal westerlies. Krueger and Gray (1969) examined satellite cloud observations, and found important longitudinal variations near the equator which they explained were due to the probable presence of three major centres of action (standing eddies) zonally oriented in the vicinity of the equator. They are of the view that these eddies may be the seat of weather activity and may provide the major part of the condensation heating necessary for driving the Hadley circulation. According to them such eddies occur over Indonesia, New Guinea and Northern Australia, and somtimes may extend as far east as Canton Island (02° 46′S, 171° 43′W) which is located at the western edge of the equatorial dry zone of the eastern Pacific.

On examining the cloud data over the equator in the Indian Ocean region in relation to the Pacific region it was found that there is evidence that the equatorial cloudy zone of the Western Pacific extends further westward over the Indian Ocean and its westernmost boundary shows month to month longitudinal variations. Similarly the easternmost boundary of the cloudy region over the Pacific also shows month to month longitudinal variations. Fig. 4 shows the month to month variations in the eastward and westward extent of four octas isoneph/brightness value of 4 over the equator in the Indian Ocean and the Pacific Ocean for the period 1965—67. The westward extent of the cloudy belt has shown large longitudinal variations from about 100°E to 50°E. The eastward extent also has shown large longitudinal variations from about 180°E to 120°E. However, the relationship between the two is not very clear and further work is required.

Sea surface temperature data for the Indian Ocean region for the years 1965—1967 is not yet available to the author. However, this data was available for the year 1963—1964 (IIOE period) and was examined in relation to the variation in westward extent of the longitudinal position of the 0°C isotherm in the equivalent black body temperatures (TBB) in the outgoing long wave radiation charts of Allison *et al.* (1969) for the

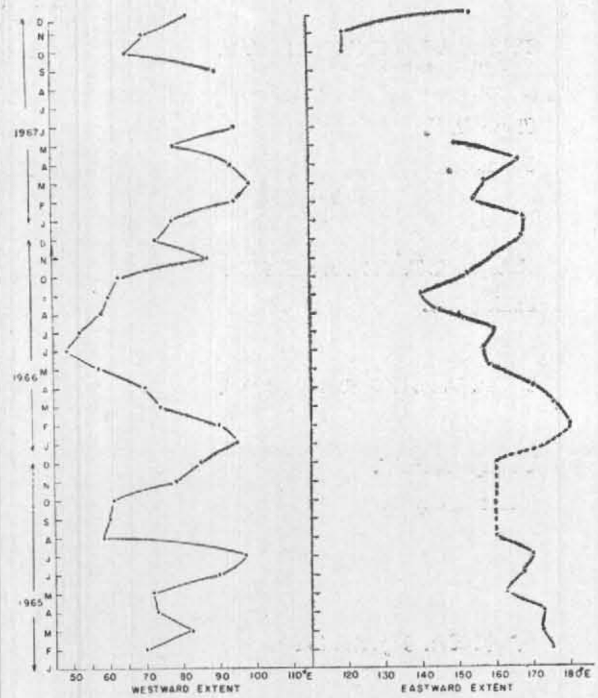


**Fig. 4**

Month to month variations in the westward and eastward extents of 4/8 isoneph across equator in the Indian Ocean & the Pacific Ocean respectively for 1965—67

period June 1963 to December 1964. It is thought that 0°C isotherm would correspond to cloudy regions. The data showed that the longitudinal variation in the 0°C isotherm of the TBB charts are generally in phase with the longitudinal variations in the 82°F (≈28°C) isotherm in the sea surface temperature over the equator. Further aspects of any possible link between the average sea-surface temperature variations and cloudiness over the equator in the Indian Ocean are still under study.

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## DISCUSSION

Dr. P.R. Pisharoty : Was the area of equatorial cloudiness to the higher temperature side of the 80°F isotherm ?

Shri D.R. Sikka : Yes.

Prof K.R. Ramanathan suggested that it would be worthwhile to study the east-west displacement of the cloudiness with the thickness and strength of the equatorial westerlies.