

Seasonal variation of SST and mean OLR distribution over Indian Ocean warm pool

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ABSTRACT

In order to examine the seasonal variation of SST distribution over Indian Ocean warm pool (IOWP), a recent climatological atlas is consulted. It is seen from SST distribution of (a) annual mean and (b) August monsoon mean that the temperature distribution is more or less similar in both. Examination of the seasonal distribution of SST has revealed that the small scale changes in convection of shorter duration, i.e. diurnal and synoptic basis, appear to be operating independently, irrespective of warm and cold core water masses. The seasonal mean OLR distribution over the domain of 10°N-15°S, and 60°-100°E for the seasons (a)winter, (b)spring, (c)summer monsoon and (d)post monsoon has been studied. The OLR can be used as a proxy for rainfall. It is interesting to note that the eastern equatorial Indian Ocean seems to be highly convective during all the seasons as compared to western equatorial Indian Ocean. It is clearly revealed that there exists always a relationship between the processes that take place in the IOWP and the rainfall distribution over the Indian sub-continent. Attempt has been made to bring out the coherent relationship that exists among the three parameters of SST, rainfall and cloud cover.

INTRODUCTION

It is well known that the eastern equatorial Indian Ocean (10°N-15°S, 60°-100°E) is identified as one of the highly energetically active zones of the Indian Ocean, and the others being the eastern Arabian Sea, head Bay of Bengal, the Somali Basin and the Mascarene High region of the southern Indian Ocean. The reason for this activity is that, this part of the ocean surface water maintains warm temperatures of the order of 28°C and on some occasions 29°C throughout the year (Fig.1). However, the seasonal variations are part of the anomalies from this value. This region is termed as an Indian Ocean Warm Pool (IOWP) by Vinayachandran & Shetye (1991) due to its warmth of about 28°C, which is a minimum SST required for an active convection to occur over open oceans (Gadgil, Joshi & Joseph 1984 & Graham & Barnett 1987). Convections in the geophysical fluids (ocean and atmosphere) necessarily involve in a hierarchy of structures and length scales. Over a warm ocean surface, small scale turbulence, longitudinal roles and other boundary layer structures tend to increase buoyancy within the confined thickness of the marine Planetary Boundary Layer (PBL). Similar processes convert an upward surface buoyancy flux into a mean density increase of the oceanic mixed

layer. Together with the confined thickening of PBL and the entrainment, they cause a gradual increase of convection instability at its other boundary. The buoyancy anomaly is advected by low-level winds into areas of convergence over the warm sea surface areas. Within the ocean, dense surface water is similarly advected towards the most strongly cooled regions. The accumulated convective instability can be realized by random fluctuations, by the effect of boundary irregularities, or by synoptic-scale perturbations that cause additional convergent Ekman transports resulting in deep convection in the form of relatively large fluid particles or of more persistent plumes, which "Cream off" the buoyancy and transport it vertically away from the boundary layers. These convective elements tend to become organized in large rotating structure. Further, it has been observed (Pai 1997) that the organized convective activity over the IOWP has a large seasonal variation in the surface area as covered by the pool and, hence, it is the area of active zone of ocean-atmosphere coupling. Vinayachandran (1991) speculated that the interaction of IOWP with the Asian monsoons is important. The factors that control the variability of IOWP, are the fluxes of heat and momentum and ocean currents with the fluctuations spreading over a wide range of spatial and temporal scales. Generally, the warming

phase of the IOWP commences by February when the pool begins to extend on both sides of the equator and continues through April. The northern boundary of the pool merges with the south Indian coastline during April in the Bay of Bengal and by May in the Arabian Sea. The first signal of cooling is observed in the southern Indian Ocean during May. The summer monsoon cooling begins during June in the western equatorial Indian Ocean and by July in the Arabian Sea, and continues through September. In the Bay of Bengal side of the IOWP, surface temperature does not fall below 28°C during the summer. Soon after withdrawal of monsoon, a secondary warming takes place in the Arabian Sea during October and is followed by winter cooling of the Indian Ocean (north of equator). The summer warming of the southern Indian Ocean and a warm pool in the Bay of Bengal are part of the IOWP and recedes during October-November. The above changes in the surface temperature may be seen in a recent Atlas (Reddy & Kumari 1993). Further, the formation of warm pool over equatorial Indian Ocean in May and marked by June with its intensity with a good monsoon activity (Bal Krishnan, Jaiswal & Srivastava 1993). In good monsoon years the warm pool over the equator extends from 60°E to 80°E longitude, while during poor monsoon years it centers at 60°E and 75°E.

Pai (1997) reported the inter-annual variability of Indian summer monsoon using OLR data for the period 1979-92 and pointed out the negative relationship between Indian rainfall and cloud cover in Southern Hemispheric Equatorial Trough (SHET) and indicating thereby the strong oceanic tropical convergence zone and depressed convective activity over Indian continental region. During good monsoon years (1983 and 1988) the continental tropical

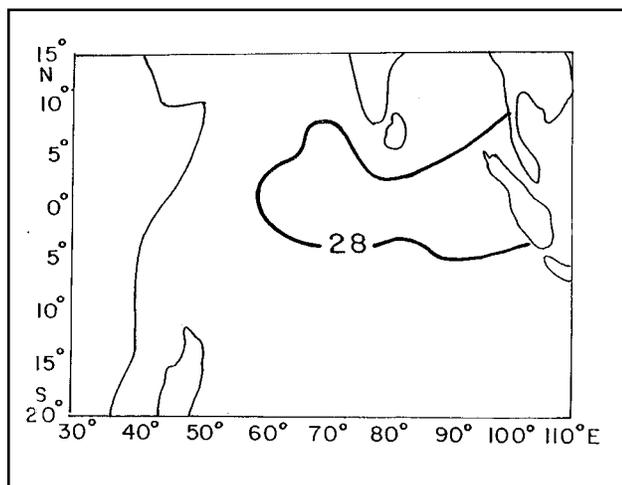


Figure 1. Contour of 28°C isotherm

convergence zone over Indian region was active as inferred from prevailing negative OLR anomalies (Kutzbach 1967).

Kondragunta (1990) has studied the intra-seasonal variations of the Asian summer monsoon using OLR data from NOAA polar orbiting satellites, covering the summers (1May-30 September) for the period 1975-83 and identified two regions of high standard derivations of OLR, one in the equatorial Indian Ocean (lat. 5°S-10°N, long. 65°-95°E) and the other over north-west Pacific (lat. 10°N-25°N; long. 110°-140°E) with a 40-day dominant mode in the equatorial Indian Ocean. The first eigen-vector clearly shows two centre of action with out-of-phase relationship – one centre located over the IOWP around 90°E and the other is located north-west Pacific around 140°E and the feature is similar to east-west dipole pattern noticed by Lau & Chan (1986) and unfolding the east-west dipole patterns near the equator propagate from the Indian Ocean towards western central Pacific. This feature indicated that when the equatorial Indian Ocean is at its dry phase, the north-west Pacific is at its wet phase and vice-versa.

A review of all the above studies has clearly revealed that there exists always a relationship between the processes that take place on IOWP and rainfall distribution in situ and over the Indian sub-continent within a coherent relationship among the parameters, SST, rainfall and cloud cover/OLR over the IOWP. The present study attempts to find a relationship between the three parameters to understand the ocean-atmosphere interface processes in the range of pentadal (five-day-mean) in climatological time scale.

DATA

The 5-day mean data of OLR for the period 1979-1990 in the domain 10°N-15°S; 60°-100°E and GPCP rainfall estimates for the period 1986-93 in the domain 11.25°N-16.25°S; 61.25° -101.25°E along with the seasonal climatological SST atlas of Reddy and Kumari (1993) are procured and consulted respectively.

RESULTS AND DISCUSSION

The seasonal pattern of SST over the area of study is presented in Fig.2. The isotherm of 28°C covers a vast area in both the hemispheres, right from 14°S to 10°N (Fig. 2a). This isotherm represents the extent of warm pool over this region. There exists two high warm pool islands at Indonesian coast at 8°S between 65°E and 70°E and are embedded with a relatively low warm water pool (28.5°C). The colder water (less than 27°C)

is found to lie close to the southern rim of the grid with a maximum cooling (26.5°C) in the south-east corner of the grid. In spring Fig. 2(b) the equatorial Indian Ocean further warmed up very rapidly and attained maximum temperature of the order of 30°C in the north-west Indian Ocean. The highest temperature (30.5°C) is seen over eastern equatorial (equator 5°S; 95°E) Indian Ocean where the winter maximum is found. In summer, the ocean has cooled down relatively by about 1°C. The warm waters of the spring are now decentralized and pool up into eddies covering a small area (Fig.2). The equatorial region between 3°S and 5°N seems to be warmest (29°C) part of the ocean. Coldest temperatures of the order of 25°-25.5°C are now seen along the southern rim of the grid. North-south temperature gradient is strong over the southern hemisphere and weak in northern hemisphere. The post monsoon temperature distribution is more or less similar to that of winter, but the central equatorial Indian Ocean between 75°E and 80°E seems to be colder (28°C) than in the summer (Fig.2). The two pools of warm water (29°C) are located near equator at 60°E and 65°E and between 90°E and 100°E. The southern hemisphere water temperatures are now slightly improved, as 25.5°C isotherm disappeared from the region, except over a small region in south-west corner of the area between

60°E and 65°E but the gradients of temperatures are similar to that of in the south-west monsoon season (Fig.2). It is of importance to note that the area enclosed by 28.5°C isotherm supports the convective activity (Saji et al., 1999) and in the Indian Ocean this isotherm confined to the equator and its excursion depends on the season by transferring convective activity across the equator.

Fig. 3 shows the sea-surface temperature distribution of annual mean and August month mean. It is seen from Figure 3 that the temperature distribution is more or less similar in both annual and August month. The main features of August month are reflected in the annual mean, except for the area 80°-87°E and 4°S-1°N (Fig.3), where the SSTs of August are warmer (29°C). This warm core appears to have shifted to the east along the equator in the annual mean. The fairly well mixed warm waters enclosed by the 28.5°C isotherm are confined to the equator in both annual mean chart and August mean. The double broken lines seen in Fig. 3(b) represent the mean positions of the Southern Hemispheric Easterly Trough (SHET) south of the equator and Northern Hemispheric Easterly Trough (NHET) north of the equator orienting in an east-west direction. It is interesting to note that these two lines (double broken lines) more or less coincide with the alignment

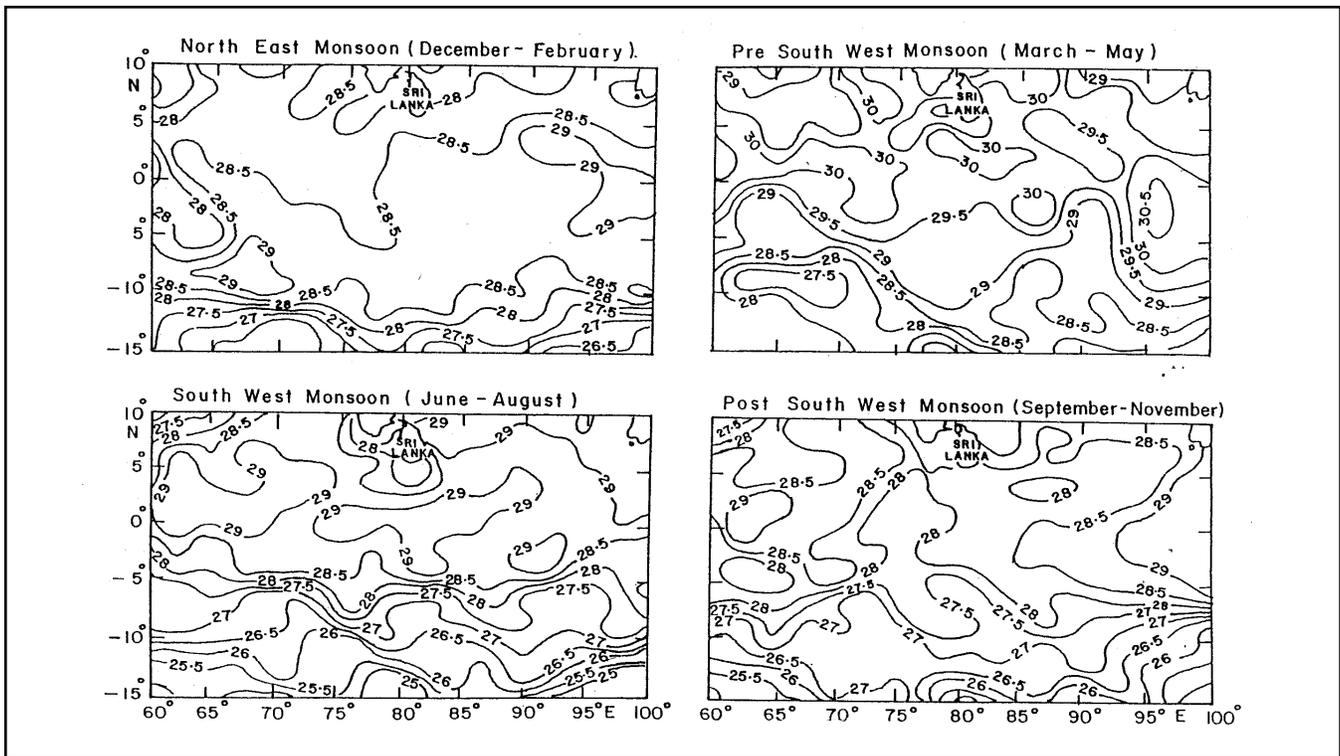


Figure 2. Sea Surface Temperature

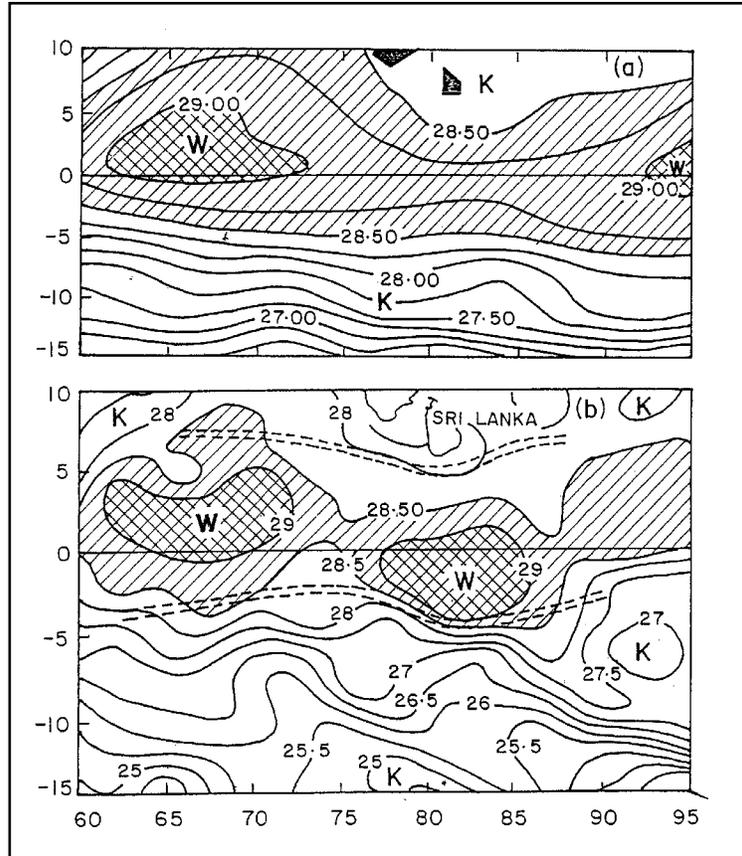


Figure 3. Indian Ocean Sea Surface Temperature Distribution - Annual mean and August month mean

of the 28.5°C isotherm in the month of August. Figs. 3 a & b is reproduced here to show the concurrent relationship between SST (28.5°C isotherm) and the meteorological weather systems within the SHET and NHET and the related cloud and rainfall distribution.

The seasons mean OLR distribution over the study area is presented in Fig 4. The OLR pattern can be used as a proxy for rainfall. It is interesting to note that the eastern equatorial Indian Ocean seems to be highly convective during all the season as compared to western equatorial Indian Ocean. The OLR varies from 210 W/m², the lowest value being the representative for the region of maximum cloud cover to the highest value of 270W/m² cloud-free region. It is observed that the in south Indian Ocean, in contrast to the north displayed that the isopleths of OLR that run east-west direction and show a strong north-south gradients irrespective of seasons. The isopleths are always making an angle with the equator implying the movement of cloud across the equator. Kripalani, Singh & Arkin (1991) by analyzing the OLR fields, has brought out the importance of the oceanic cloudiness zones that form near the equatorial latitudes. It is

reported the probability of occurrence of rainfall of 2.5 mm/day exceeds 0.9 mm/day when OLR is less than 180 W/m² and is very low (0.0mm/day) when OLR is greater than 280 W/m² (Kripalani, Singh & Arkin 1991).

In winter Fig. 4(a), the area of lowest values of OLR (210 W/m²) is close to 100°E and in between equator and 6°S and the axis of trough of minimum of OLR is located from north-east to south-east in southern hemisphere (3°S, to 9°S, and 60°E to 100°E). This trough line appears to coincide with the ridge warm SST Fig. 2(a). There are three areas of very high values of OLR (260-270 W/m²) along the northern rim of the Arabian Sea and Bay of Bengal and the south-east corner of the south Indian Ocean where relatively colder water is also present. Two ridges of maximum OLR are found in the Arabian Sea and Bay of Bengal. Further, the area of lowest OLR and the axis of the OLR trough line appear to have coincided with a ridge of water at 29°C during this period in the southern Indian Ocean. The ridges of OLR coincide with relatively low values of SST 28°C Fig.3a. In spring Fig. 4b, the contours of OLR are organized in parabolic

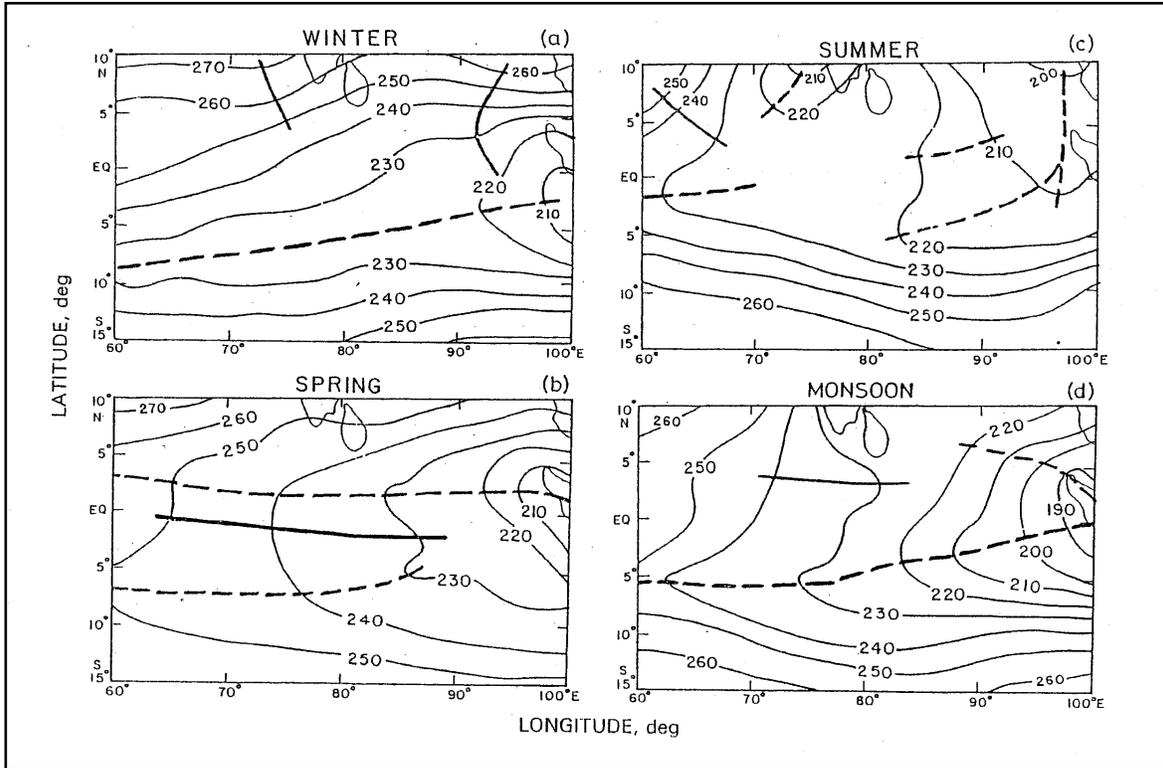


Figure 4. Seasonal mean OLR distribution

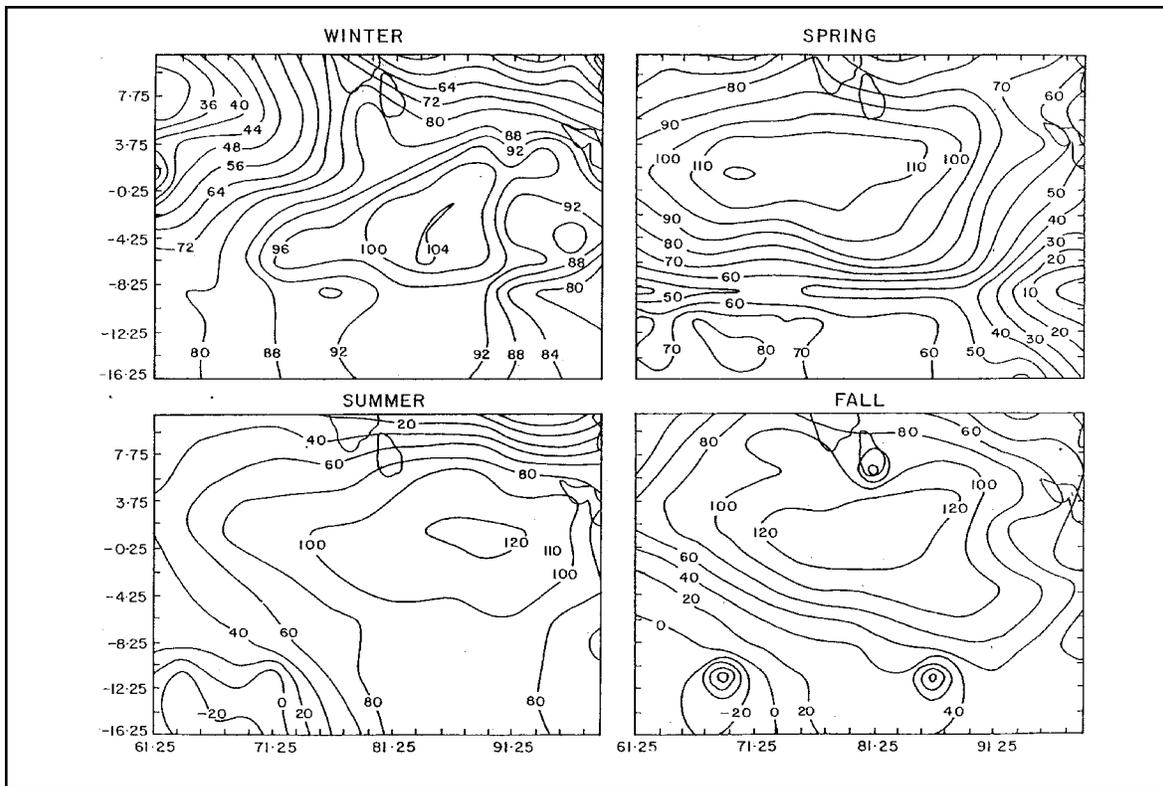


Figure 5. Seasonal mean GRCP rainfall distribution

form and symmetrical about the equator, with an orientation from east-west direction on either side of the equator. The low values of OLR (210 W/m^2) that were found along 100°E around 3°S in winter now appear to have moved northward and lie around 2°N . The winter axis, which was found in the southern hemisphere is now bifurcated into two branches. One branch remains in the same position in the south-western Indian Ocean 60°E and 90°E south of 5°S , whereas the second part of the trough has shifted to north (2°N in the north Indian Ocean). Very high values of OLR (270 W/m^2) are observed along the north-west corner of the grid in the Arabian Sea (Fig.4). A strong ridge of OLR that runs from east-west approximately along 3°S separates the above two trough lines. In summer Fig.4c, the isopleths have further re-organized and dislocated from the spring structure. A flat plain area of OLR is seen near the equator between 4°S and 5°N , 68°E - 82°E that displays a low OLR (220 - 230 W/m^2). These are the low OLR and appeared to have coincided with the August warm pool in Fig.3b. The area of lowest value of OLR (220 W/m^2) is further moved northward along the eastern rim up to the northern rim in the Bay of Bengal and lying around 10°N , 95°E . The trough axes found in spring are now split into multiple trough lines and lie randomly in both the hemispheres. The prominent among these lines in eastern equatorial Indian Ocean lie in a north-west to south-east direction. The area of higher OLR (260 W/m^2) is seen in the south-west corner of the grid and a secondary area of high values of OLR (250 W/m^2) in the north-west corner of the grid over the Arabian Sea. During this period, one feeble ridge of OLR is seen in the Arabian Sea near 5°N and between 60°E and 70°E . All the trough lines seen in this area during this period are very well-aligned with areas of warm water pools (29°C). The ridge in the Arabian Sea has coincided with cold water (27.5° - 29°C); Fig. 4c. In Fig. 4d, the isopleths of OLR of monsoon resembles to those observed in spring. The area of low values of OLR (190 W/m^2) of this season is approximately coincides with the area of low OLR during spring. A trough line of OLR lies in the southern hemisphere running in a north-east to south-west direction from equator (90°E to 5°S , 60°E). A secondary feeble trough line is also seen in the northern hemisphere between equator and 5°N and east of 90°E . A strong ridge appeared around 4°N between 70°E 90°E . Two prominent areas of high values of OLR (260 W/m^2) are noted in both the hemispheres along 60°E on either extreme end of rims. The trough line is now coinciding with axis of warm surface waters (28° - 29°C) in south Indian Ocean

Fig. 4d. The examination of the seasonal distribution of SST has revealed that the small changes in convection of shorter duration, i.e., diurnal and synoptic basis appear to be operating independently, irrespective of warm or cold core water masses. Similarly, the seasons mean GPCP rainfall estimates over the study area are presented in Fig5.

CONCLUSIONS

In this study the author addressed the issue of the structure of tropical convection over the equatorial Indian Ocean warm pool (IOWP: 10°N - 15°S ; 60° - 100°E), using the seasonal mean OLR, GPCP rainfall and sea surface temperature patterns. The analysis revealed the following features:

- i) It is seen from SST distribution of (a) annual mean and (b) August month mean that the temperature distribution is more or less similar in both.
- ii) It is interesting to note that the eastern equatorial Indian Ocean seems to be highly convective in all the seasons compared to western equatorial Indian Ocean.
- iii) In southern Indian Ocean, it is to be noted that the isopleths of OLR always run east-west direction and show a strong north-south gradients in all the seasons. The isopleths are always making an angle with the equator implying the movement of cloud across the equator.
- iv) Examination of the seasonal distribution of SST has revealed that the small scale changes in convection of shorter duration, i.e. diurnal and synoptic basis appear to be operating independently, irrespective of warm or cold core water masses.
- v) A comparison of the loadings of the GPCP rainfall and OLR with the seasonal distribution of SST over study area revealed that maximum loadings of GPCP, minimum loadings of OLR coincide with warm SST with certain extent. In other way, more SST means more convection, implies more rainfall, indirectly more clouds. Clouds reduce the OLR, the higher and thicker the cloud, the greater the decrease.

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