CHAPTER 3

Spatial Variation of Clouding / Rainfall over Southeast Indian Peninsula and Adjoining Bay of Bengal Associated with Active and Dry Spells of Northeast Monsoon as Derived from INSAT OLR Data

3.1. Introduction

As a continuation of the investigation on characteristics of NEM using OLR data in Chapter 2, the focus in this chapter is to explore some more aspects of NEM like year-to-year seasonal mean OLR variability during 2000-12, spatial variation of mean OLR associated with dry, light and active phases of NEM and land-ocean contrasts in the variability in OLR along CTN during the various phases of NEM - based on INSAT OLR data.

3.2. Data

For the study period 2000-12, the DO and DW of NEM (Table 2.1), OLR data and daily RF data of 27 stations in CTN and 2 in SCAP (Fig. 2.5) are the same as stated in Chapter 2, Section 2.4. The actual RF for TN during the study period is given in Table 2.1. The monthly and seasonal NRF values for the 5 meteorological sub-divisions of SPI during the NEM season (1 Oct to 31 Dec) are given in Table 2.2.

3.3. Methodology of Computation and Analysis

3.3.1. Yearwise Spatial Variability in the Seasonal Mean OLR over SPI during NEM Season

The spatial and seasonal mean variability in OLR over SPI during years of contrasting NEM performance is proposed to be analysed. As seen from Table 2.1, the PDN of RF of NEM was positive for many years, especially over TN where the period 2004-11 manifested continuous run of positive PDNs with several excess years (PDN is + 20% or more). The years 2000 (PDN -29 and -27 for TN and SPI respectively), 2002 (-8, -8), 2005 (79, 71), 2010 (41, 54), 2004 (1, 15) and 2011 (22, -4) were chosen to study the OLR distribution. These six years by and large represent the contrasting performance of NEM over TN and SPI as the realised NEM RF was above normal in quite a number of years.
The daily mean OLR data of 1°×1° lon./lat. grid resolution averaged as stated in Section 2.4.2 over the area under consideration (Fig. 2.4) for the three months (Oct to Dec) of NEM season comprising 92 days was averaged yearwise (which is in reality seasonwise) for all the 13 years of the period 2000-12. Pictorial depiction of the yearly seasonal spatial variability of mean OLR was made using GrADS software, for all the years. The mean OLR spatial variation of the six sample years (2000, 2002, 2005, 2010, 2004 and 2011) considered has been depicted in Fig. 3.1. It is seen that for the years of negative RF PDNs, viz., 2000 and 2002, except for a small area of SPI covered by contours of OLR230, rest of the region manifests higher OLR values. However, values of OLR230 are observed in the oceanic areas of south BoB. In the case of excess RF years 2005 and 2010 which had positive RF PDNs the whole of SPI is engulfed by contours of OLR230. During 2004, the contours of OLR230 enfold SPI up to 11°N while in the year 2011, entire SPI has values of OLR>230 Wm^{-2}. In both these years, PDN of TN is positive whereas that for SPI is negative.

In the years 2005 and 2010, low OLR values correspond to excess RF and in 2000, higher OLR values correspond to a poor NEM. However, in 2011, despite an excess NEM over TN and a near normal NEM over SPI, the spatial OLR distribution has not manifested the expected pattern. So, it is evident from the earlier description based on Fig. 3.1 that the seasonal average OLR variation for a given year does not have a one-to-one direct relation with the seasonal RF realised.

This sort of manifestation can be ascribed to the fact that extremely high OLR values are possible on cloud-free sunny days, representing the contributions to the IR channel from relatively higher temperatures of the land / ocean surfaces sensed by the satellite. Low values of OLR in regions masked by clouding and high values of OLR in cloud-free areas sensed by the satellite contribute to the temporal and spatial OLR variability during an entire NEM season. Further, it is conceded that the value of OLR at a grid point is not directly proportional to the amount of RF realised over the area since that value of OLR is modulated by the amount of moisture in the vertical layer. So, OLR acts as a pointer to the extent of clouding and not necessarily to the quantum of RF actually realised over that location. Despite the contribution of low values of OLR sensed by the satellite over cloud-covered areas, in view of the high OLR values prevalent on dry days which vary from year-to-year, the spatial
variability of yearly NEM seasonal mean OLR might have failed to exhibit the expected OLR patterns associated with the RF PDNs of SPI for a typical NEM season.

The analysis was continued further by identifying NEM days with different types of monsoon activity like dry, light and active phases and deriving separate OLR profiles. For CTN, dry, light and active days of NEM as defined in Table 2.3 are by and large consistent with the RF categorisation used by IMD for each day of NEM. When such an analysis is taken up, the CTN region is well-suited as NEM characteristics including onset and withdrawal are clearly defined in CTN (Raj, 2012). Therefore, the NEM strength is derived based on RF of CTN though the OLR distribution considered is for the entire region as depicted in Fig. 3.1.

3.3.2. Spatial Variation in OLR during Dry, Light and Active Spells of NEM

The DO, DW and duration of NEM as given in Table 2.1 for each year of the study were considered. Based on the DRF of 29 stations, each day of the total duration of NEM season was classified among the three phases of NEM activity as defined in Table 2.3. There were 441 dry days, 75 light and 376 active RF days during the period 2000-12. Out of these, OLR values of 31 dry; 9 light and 26 active days were not available. In all, the OLR values of 410 dry, 66 light and 350 active days were thus classified (Table 3.1) and separately averaged to generate the categorywise spatial mean OLR patterns (Fig. 3.2).

Such an averaging of OLR based on the above defined classifications yielded remarkably contrasting OLR patterns for dry, light and active spells of NEM. Dry spells of duration greater than 20 days were observed in three NEM seasons during 2000-12. In the dry phase of NEM, OLR values are high and vary between 240 and 270 Wm$^{-2}$ over SPI indicating cloud free conditions whereas OLR230 are seen over parts of Sri Lanka and SE BoB. During light RF days, OLR230 is observed up to 9°N confined to south TN, KER and SE sector of BoB and adjoining Comorin areas. In the case of active NEM days, the NLOLR230 over SPI reaches up to 16°N, with distinct presence of contours of OLR200 in CTN and CAP, OLR230 in the SE sector of BoB, adjoining Comorin area and southern parts of Sri Lanka. The trough of OLR isopleths is seen to be oriented closely along CTN and SCAP. This remarkable feature is consistent with two well-known characteristics of normal NEM RF over CTN and SCAP, viz. (a) north of 10.5°N, the RF decreases from S-N and, (b) for a given latitude, longitudinal RF profile manifests a local maximum at the coast. These aspects would come up for further discussions in the forthcoming sections.
In the above analysis, derivation of OLR distributions by the segregation of dates into three different phases of NEM activity viz., dry, light and active has brought out well-structured and contrasting OLR patterns which are amenable to easy and consistent interpretation.

3.3.3. **Spatial Variability of Mean OLR over Land and Ocean**

In this sub-section, we analyse the longitudinal variability of the mean OLR over both land and ocean to perceive how the resulting distribution relates with the mean RF pattern. Firstly, the RF pattern over CTN and SCAP during NEM is presented.

3.3.3.1. **Rainfall during NEM along CTN and SCAP**

The NRF during NEM season (Oct to Dec) at 12 selected stations of SPI, 7 located along the coast and 5 in the interior has been depicted in Fig. 3.3. It is evident that the mean NRF sharply decreases from coast to inland. For example, Chennai-Meenambakkam (MBK) and Vellore (VLR) located more or less at 13°N receive RF of 83 cm and 38 cm respectively. Similarly, Nagapattinam (NPT) and Tiruchirapalli (TRP) at 10°N receive 95 cm and 38 cm respectively. North of 10.5°N where the coast is by and large oriented S-N, the RF also decreases S-N. It is 104 cm at 10.5°N in Vedaranyam (VRM), 83 cm at 12.5°N (MBK, 13.0°N) and 69 cm at 14.5°N [Nellore (NLR)]. In the coastal belt SW of VRM and up to TTC, RF is relatively lower ranging from 45 to 60 cm. The geographical feature of the sheltered nature of the SE parts of TN (Fig. 2.5) with Sri Lankan land mass lying to the east and GoM juxtaposed in between, appears to be the most plausible reason for the lower RF over CTN south of 10°N.

3.3.3.2. **Variability in OLR during Various Phases of NEM**

The mean OLR variability over land and oceanic areas was analysed for latitudes 10.5°, 12.5° and 14.5°N and for the longitudes of 75.5°, 76.5°…85.5°E. The profiles for dry, light and active phases of NEM are presented in Figs. 3.4(a-c).

The inferences drawn are as under:

(i) **Dry**

During dry days [Fig. 3.4(a)] OLR values of 240-265 Wm^{-2} are observed over the area considered, matching with rain-free days over SPI. The existence of values of OLR≥240 Wm^{-2} by and large indicates overall cloud-free conditions. Lowest value of OLR is realised over the ocean at the easternmost longitude of 85.5°E for all latitudes of the area considered. Over CTN / SCAP (79.5°E), the OLR values are 247, 256 and
261 at 10.5°N, 12.5°N and 14.5°N respectively. There is slight increase in OLR values inland at 10.5°N. But in the other two latitudes OLR values remain flat, same as that obtained over the coast. OLR values increase from lower to higher latitudes for a given longitude.

(ii) **Light**

In the case of light RF days, OLR values of 233-255 Wm$^{-2}$ have been observed [Fig. 3.4(b)]. Over CTN / SCAP (79.5°E), the OLR values are 240, 250, 254 at 10.5°N, 12.5°N and 14.5°N respectively, slightly lesser than those in the case of dry days. At 14.5°N, a steep fall in OLR values from 75.5°E to 79.5°E (256 - 248 Wm$^{-2}$) and a near uniform rise (248 - 254 Wm$^{-2}$) eastward of BoB up to 85.5°E are observed. In the other two latitudes, the OLR profiles do not manifest any significant recognisable pattern.

(iii) **Active**

At 79.5°E which is roughly the coastal stretch of TN and SCAP, OLR is lowest in all the latitudes 10.5° (196), 12.5° (207) and 14.5°N (220 Wm$^{-2}$), indicating that the clouding is heaviest along the coast [Fig. 3.4(c)]. From 79.5°E eastwards into BoB, the OLR increases indicating less clouding and justifiably less RF over the BoB oceanic region adjacent to CTN. From 79.5°E westwards inland, the OLR increases rapidly at all the three latitudes 10.5°, 12.5° and 14.5°N, reaching 217, 226 and 242 Wm$^{-2}$ at 75.5°E with the increase of OLR occurring roughly at the rate of 5-5.5 Wm$^{-2}$/°E. At 14.5°N, the benchmark of OLR230 representing NEM clouding is reached near 78.5°E. Thus, even during the active phase of NEM over CTN, clouding extends only up to 100 km inland from the coast at 14.5°N. Over BoB, from 79.5°E to 85.5°E, the rate of increase of OLR is much more gradual [Fig. 3.4(c)], being 4 Wm$^{-2}$/°E at 10.5°N and 3 Wm$^{-2}$/°E at both 12.5°N and 14.5°N indicating that RF over BoB adjacent to CTN though less than that over CTN, is likely to be more than that over interior TN.

The above inferences about the variability in OLR are consistent with the observed decrease of RF from CTN to inland during NEM as discussed in Section 3.3.3 and the presumption that by and large, OLR is a proxy indicator for RF. Whereas the decrease of RF from coast to inland during NEM is a well-known feature of RF climatology of the region, the extent of RF realised over the ocean is unknown. However, the present study based on 13 years of OLR data firmly, authenticates and reiterates the decrease of RF from coast to ocean. Study based on 3 years of TOVS
data by Suresh and Raj (2001) also drew the same conclusion. As such, this important climatological conclusion derived from a fairly large OLR dataset is now fully authenticated.

It is worthwhile to briefly discuss herein the physical mechanisms behind such a variation. At the time of active NEM, the northerly component in the lower tropospheric winds over BoB is less and sometimes a southerly component is present. As the easterlies approach the coast, frictional convergence develops resulting in higher vertical velocity over the coastal belt. This could be the most plausible reason for the OLR variation as derived above. In the inland areas, the sharp reduction of moisture from E-W is a likely reason for the sharp decrease in RF manifested as a sharp increase in the OLR values as well.

3.3.4. Latitudinal Variation of OLR vis-à-vis Variation of SST and Short Wave Radiation

When we reappraise the latitudinal variation of OLR as presented in Figs. 3.4(a-c), it is found that the OLR values are higher in the northern latitudes than in southern latitudes during all the three phases of NEM activity, viz., dry, light and active. As the NEM season advances, SST over BoB decreases in northern latitudes as compared to southern latitudes. The central parts of BoB are cooler than the southern parts by 0.5°C in Dec and by 1°C in Jan with the mean SST ranging from 27°-27.5°C to 26°-27°C between 14°N and 10°N respectively (IMD, 2003a). Along 20°N, the SST over BoB is cooler by nearly 2°C when compared to the southern latitudes. The mean values of undepleted short wave radiation (SWR) received in Dec and Jan at 10°N are 356 and 366 Wm\(^{-2}\) respectively while at 14°N they are 332 and 344 Wm\(^{-2}\) for the same months, calculated based on a standard formula (Haltiner and Martin, 1957).

In order to further explore the latitudinal variation especially for these two months, OLR profiles were generated for 185 and 25 dry days of Dec and Jan respectively (Fig. 3.5). It can be reasonably expected that these days are by and large cloud-free. The same type of OLR gradient with higher OLR values in the northern latitudes and lower values in southern latitudes is evident from Fig. 3.5 despite lesser incoming SWR in northern latitudes and cooler SSTs. Since southern latitudes are closer to the ET and have higher SST during the two months, more moisture is generated which in turn absorbs the OLR in the vertical layers, leading to lower values of OLR. It has been comprehended that in the southern latitudes of BoB,
where high SSTs are prevalent, more moisture is generated and pumped in to upper levels of the atmosphere leading to lower values of OLR compared to northern latitudes.

The results discussed in this chapter have been published [Amudha et al. (2016b)].

3.4. Remarks

In the forthcoming chapter, by adopting an entirely statistical approach, some more finer aspects of NEM are proposed to be analysed using the mean OLR over the oceanic sectors of BoB largely influenced by NEM activity. The linkages between clouding over BoB and RF activity over SPI can thus be effectively understood from an exhaustive study of OLR data by carrying out all possible approaches to understand the causative factors impacting the performance of NEM season over SPI.
TABLE 3.1
Number of days of OLR data used for the three phases of NEM rainfall activity for the period 2000-12

<table>
<thead>
<tr>
<th>Phase of NEM → Month</th>
<th>Dry</th>
<th>Light</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct</td>
<td>45</td>
<td>8</td>
<td>105</td>
</tr>
<tr>
<td>Nov</td>
<td>167</td>
<td>47</td>
<td>179</td>
</tr>
<tr>
<td>Dec</td>
<td>192</td>
<td>17</td>
<td>89</td>
</tr>
<tr>
<td>Jan</td>
<td>37</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>441</td>
<td>75</td>
<td>376</td>
</tr>
<tr>
<td>Missing data</td>
<td>31</td>
<td>9</td>
<td>26</td>
</tr>
<tr>
<td>Actual used</td>
<td>410</td>
<td>66</td>
<td>350</td>
</tr>
</tbody>
</table>

OLR : Outgoing Longwave Radiation
NEM : Northeast Monsoon
Figs. 3.1a-f  Spatial variability of the seasonal mean OLR during NEM, Oct-Dec for the years 2000, 2002, 2005, 2010, 2004 and 2011 (PDN of area weighted average RF for TN and five meteorological sub-divisions of SPI are provided in brackets) 

(shaded areas : OLR≤230 Wm⁻²)
Figs. 3.2a-c. Spatial variability of mean OLR during (a) dry, (b) light and (c) active phases of NEM season, 2000-01 to 2012-13. 

(\textit{shaded areas}: OLR\leq230 \text{ Wm}^{-2})
Fig. 3.3 Normal rainfall (in cm) during NEM season (Oct-Dec) for 12 stations of SPI (*Data source: IMD, 2010b*)
Figs. 3.4a-c  Latitudinal variability in the mean OLR during (a) dry, (b) light and (c) active phases of NEM period from 2000-01 to 2012-13 along the longitudes of 75.5° to 85.5°E
Fig. 3.5 Latitudinal variability in mean OLR over the longitudes of 75.5° to 85.5°E during dry days of Dec and Jan