Chapter-7

NE monsoon over Sri Lanka

Sri Lanka lies within the tropics between 5° 55' to 9° 51' North latitude and between 79° 42' to 81° 53' East longitude, with a tropical climate. The central part of the southern half of the island is mountainous with heights more than 2.5 Km. The remainder of the island is practically flat except for several small hills that rise abruptly in the lowlands. These topographical features strongly affect the spatial patterns of winds, seasonal rainfall, temperature, relative humidity and other climatic elements, particularly during the monsoon season.

7.1. **Mean Rainfall**

Sri Lanka received rainfall due to southwest and northeast monsoons, local convective storms (thunderstorms) and low-pressure systems like lows/depressions moving across the region. The mean annual rainfall varies from 900 mm in the driest parts (southeastern and northwestern) to over 5000 mm in the wettest parts (western slopes of the central highlands). Fig. 7.1 shows the spatial distribution of annual rainfall over Sri Lanka taken from the Sri Lanka Met Department.

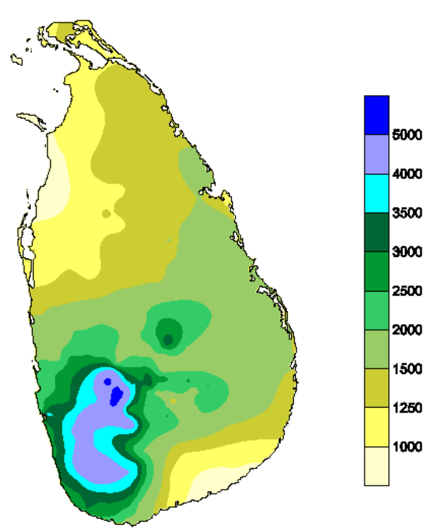


Fig. 7.1. Annual rainfall over Sri Lanka in mm. (Source: Sri Lanka Met Department).

As per the Sri Lanka Met Department, the seasons in Sri Lanka are classified into 1) First inter-monsoon season (March-April) 2) Southwest monsoon (May- September) 3) Second Inter-monsoon season (October-November) and 4) Northeast monsoon (December-February). The spatial distribution of mean rainfall during these four seasons are shown in Fig. 7.2.

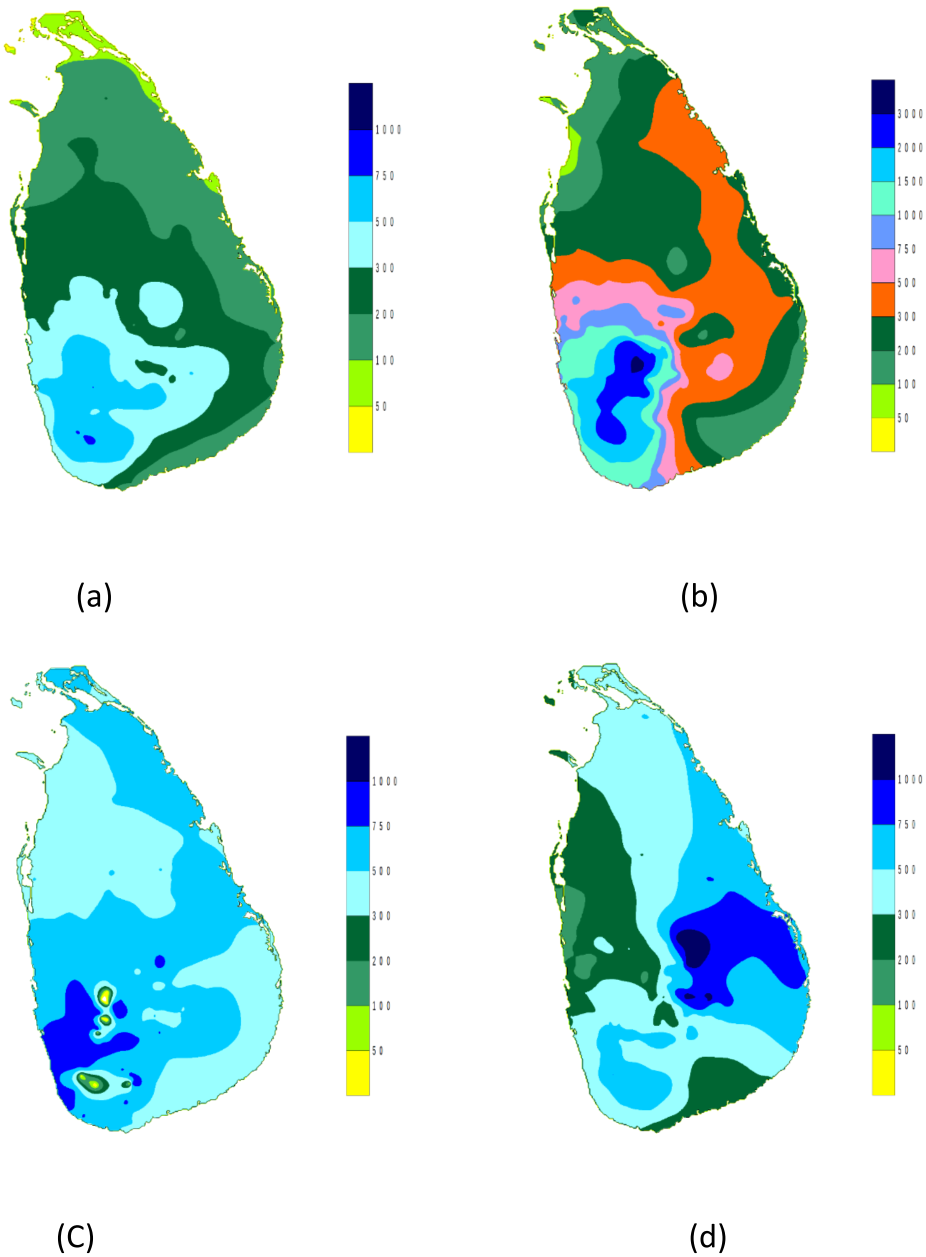


Fig. 7.2. Mean rainfall in mm during a) March-April b) May-September c) October-November and d) December-February. Source: Sri Lanka Meteorological Department.

The months October-November contributes maximum rainfall with the whole country experiencing rainfall more than 300 mm. Except during December-February, maximum rainfall is observed over the western coast, especially the southwest coast. During the December-February season, maximum rainfall is observed over the east coast.

The monthly mean rainfall averaged over the whole Sri Lanka is shown in Fig. 7.3. This time series was prepared using the merged rainfall data of CHIRPS (https://www.chc.ucsb.edu/data/chirps). The Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) is a 35+ year quasi-global rainfall data set ranging from 1981 to near present. This data set incorporates o.05^0 resolution satellite imagery and in-situ station data.

This plot of monthly rainfall clearly suggests that October-December months contribute to maximum rainfall over Sri Lanka. Another smaller peak is observed in April and May. This peak could be associated with the northward movement of ITCZ from the equator and associated convective activity, before the southwest monsoon sets in. During the month of April and May, the ITCZ starts moving northwards and there could be large scale convective activity associated with this movement due to low-level convergence and abundant moisture content.

For the rest of this chapter, we refer to October to December as the northeast monsoon (NEM) season, consistent with the designation of the India Meteorological Department (IMD).

Domroes and Ranatunge (1992) have identified three types of orthogonal structure of the monsoon regime in Sri Lanka using long-term mean monthly rainfall data. Their analysis revealed that a large amount of rainfall occurs from March to October in the southwestern parts of Sri Lanka, from December to February in the eastern parts, and in November in the northern and mid-western parts. Orthogonal factor scores for the first three factors account for 93.6% of the total variance of mean monthly rainfall. Seasonal changes in the monsoon wind system, ITCZ weather phenomena, and topography are the main factors which influence the spatial structure of monsoon rainfall over Sri Lanka.

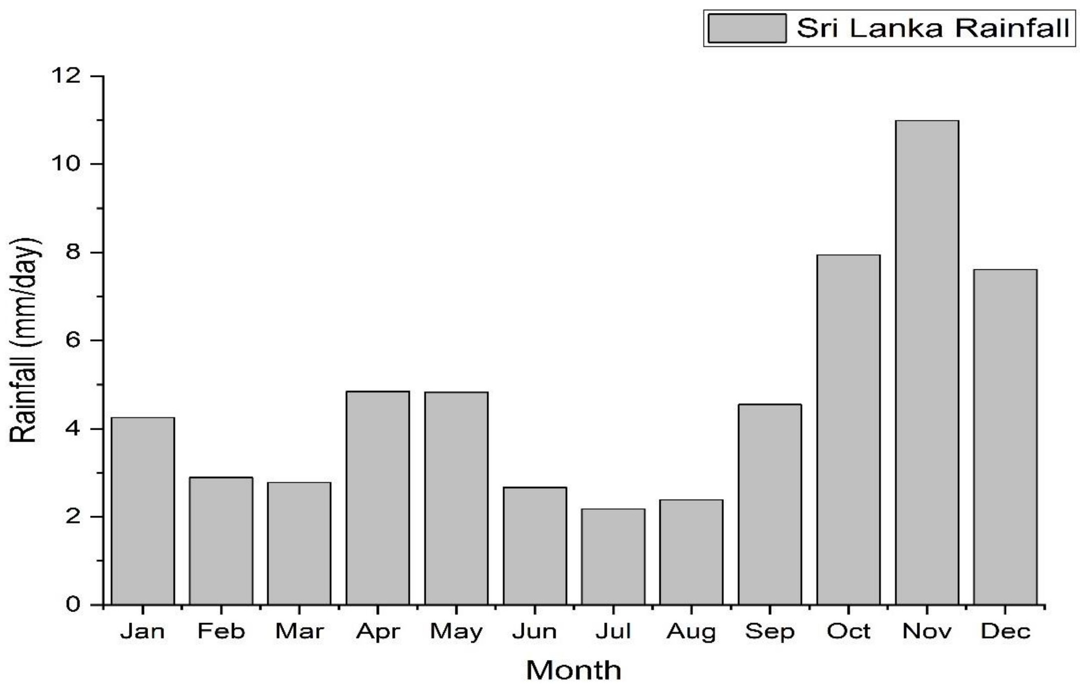


Fig. 7.3. Mean Monthly rainfall (mm/day) averaged over Sri Lanka using CHIRPS data.

Nisansala et al. (2019) analyzed Sri Lanka rainfall using the data during the period 1987-2017. They found increasing trends in annual rainfall at 24 stations with five stations showing significant increasing trend. Annual rainfall at 13 locations (35%) showed decreasing trend, but these trends were not significant ($p < .05$). There is an increasing trend at 76, 51, 32, and 86% of stations during the First Inter-Monsoon (FIM), Second Inter-Monsoon (SIM), South West Monsoon (SWM), and North East Monsoon (NEM) seasons, respectively. In general, the eastern, south eastern, north and north central regions of the country showed increasing rainfall trend over the last 31 years (1987–2017) while western, part of north western and central part of the country indicated a decreasing rainfall trend during the same period. The annual trend in rainfall is shown in Fig. 7.4 below.

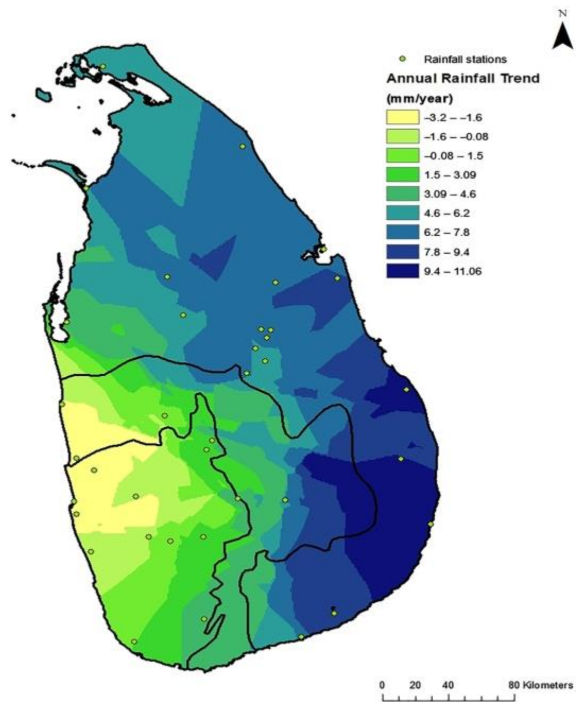


Fig. 7.4. Spatial distribution of linear trends of annual rainfall for the period 1987-2017. This plot is taken from Nisansala et al. (2020).

In Sri Lanka, convective activity with lightning contributes abundant quantity of rainfall. Jayawardhana et al. (2014) studied the lightning activities over Sri Lanka using data Lightning Imaging Sensor of TRMM Satellite. The period 1998-2012 was used for the analysis. The highest occurrence of lighting activities is confined to the highly populated western part of the island while the south eastern and mountain areas have low occurrences. There is a clear spatial polarization of lightning activities during the south-west and north-east monsoon seasons. There is an increasing trend in lightning activities, they appear to be increasing by 50 flashes per year. It has a seasonal dependency with the south-west and first inter-monsoon seasons having the higher increase. The percentage of lightning per month is highest (46%) during the Inter-monsoon-1 period and the lowest (7%) during the Northeast monsoon season. Second highest percentage of lightning per month (25%) can be observed during the inter-monsoon-2 period followed by the Southwest monsoon (22%) period.

During the Oct-Dec season, Sri Lanka receives rainfall, often heavy rainfall due to westward moving depressions and tropical cyclones over the south Bay of Bengal. Fig 7.5 shows the tracks of depressions and tropical cyclones which crossed the coasts of Sri Lanka during the October-December season for the period, 1971-2021.

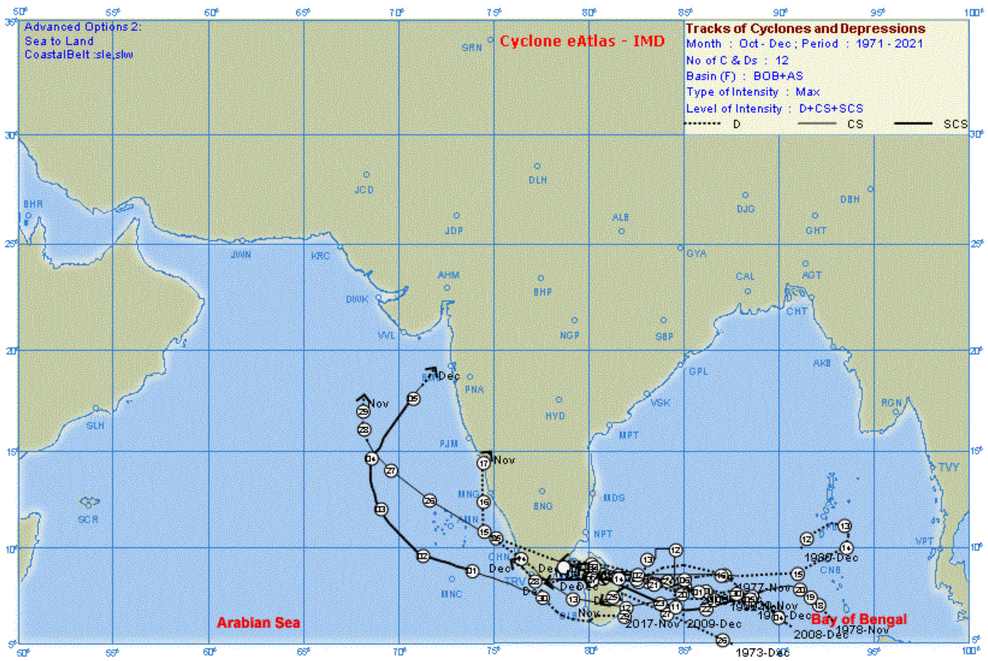


Fig. 7.5. Tracks of Depressions and tropical cyclones crossing the coasts of Sri Lanka during the period Oct-Dec, 1971-2021.

7.1. **Diurnal Variations.**

An analysis of diurnal variations over Sri Lanka was made using sub-daily TRMM data set for the period 1998-2019. Similar results for the NE monsoon season over the south peninsula are discussed in Chapter-6 (section 6.1). The same methodology was followed for this analysis also.

Fig. 7. 6 shows the three hourly mean rainfall over Sri Lanka and adjoining region, averaged during the period 1998-2019. The plot clearly shows that there is significant diurnal variation of rainfall over Sri Lanka and neighborhood during the NE monsoon season. The changes are more evident over the western parts of Sri Lanka, where

rainfall peaks during the evening time (09-12 UTC). Over the eastern parts and adjoining oceanic area, there is hardly any diurnal variation, but a major peak during the early hours (00-03 UTC).

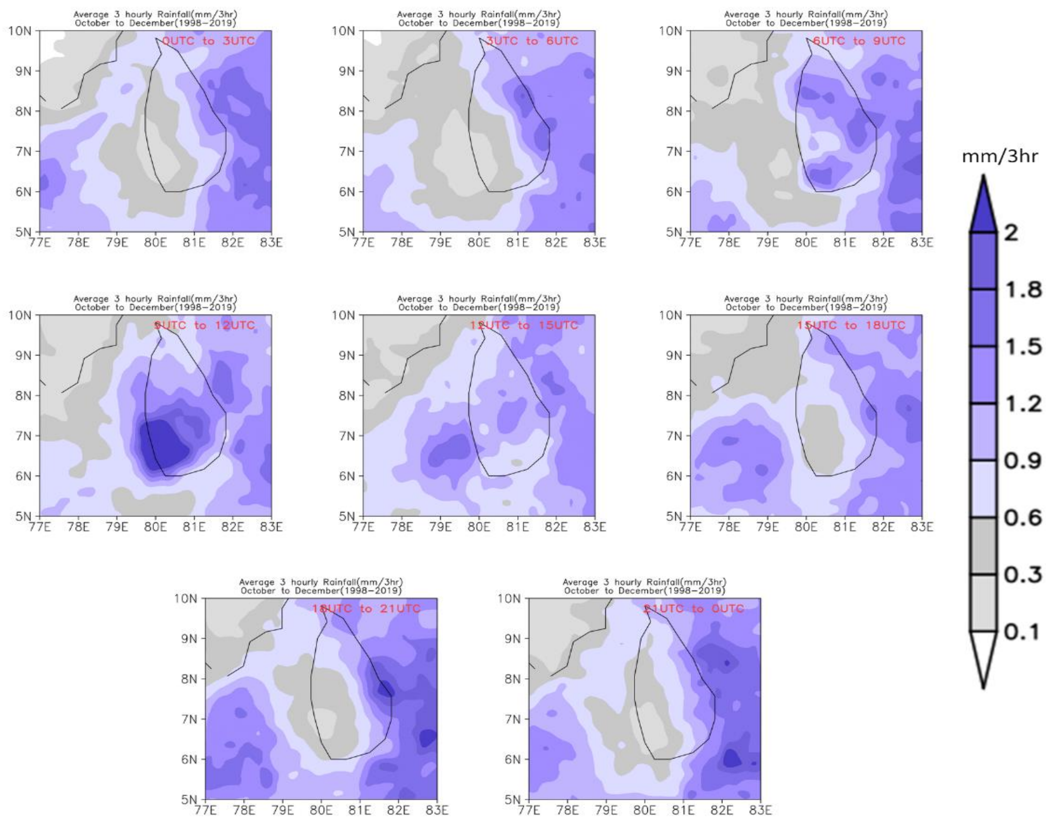


Fig. 7.6. Three hourly mean rainfall over Sri Lanka and neighborhood, averaged using the TRMM satellite data of 1998-2019.

The similar results are revealed in the Phase diagram obtained from the Harmonic analysis as shown in Fig 7.7. The phase diagram shows clear peaking of rainfall during evening and early night hours, which is consistent with Fig 7.6. This peaking could be associated with the solar heating during day time and initiation of convection. More studies are required to establish the physical mechanisms for this observed diurnal pattern. Also, it is important to understand whether the NWP model is capable of predicting this observed diurnal pattern over Sri Lanka.

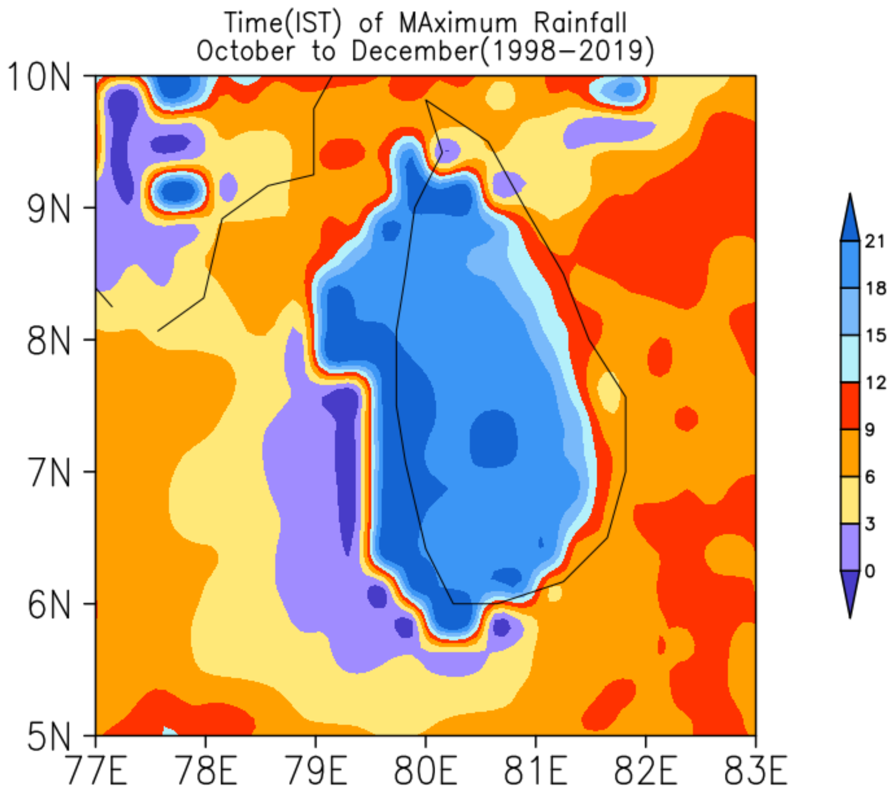


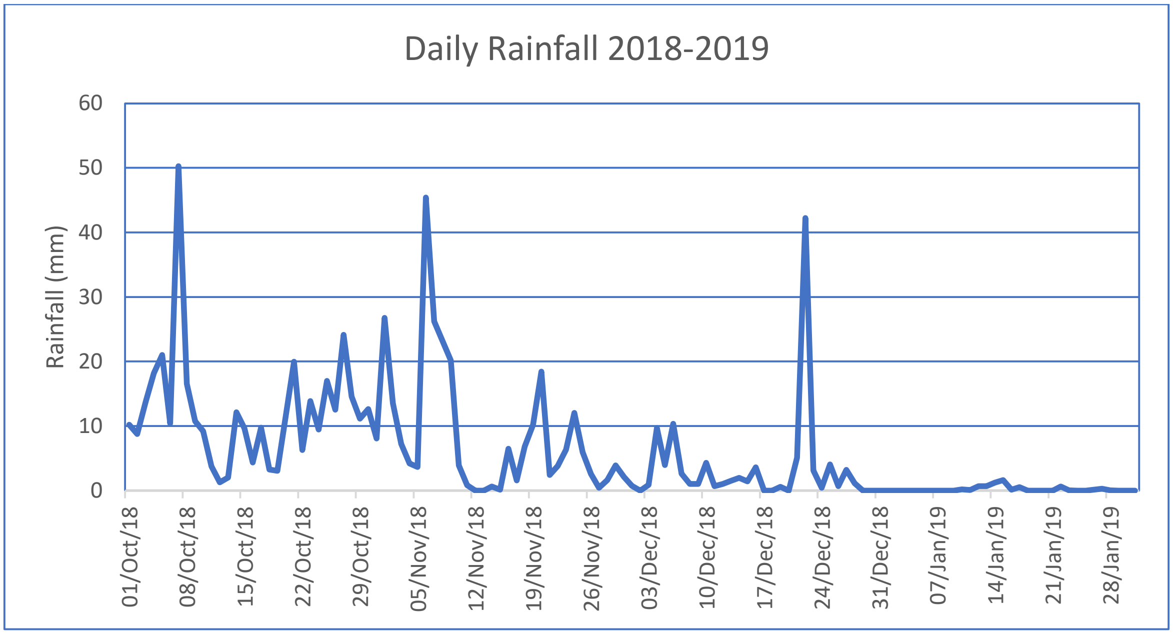
Fig. 7.7. The phase diagram of the harmonic analysis of hourly rainfall using the satellite data of 1998-2019. The phase diagram shows the time (IST) of maximum rainfall.

7.2. **Intra-seasonal variations**

There are not many studies addressing the intra-seasonal variability of the NE monsoon rainfall over Sri Lanka, which is an important component of rainfall variability. Therefore, a preliminary analysis on the intra-seasonal variability of rainfall over Sri Lanka is done and the results are discussed below.

Fig. 7.8 shows the daily rainfall averaged over Sri Lanka during the period 1 Oct 2018- 31 Jan 2019 (above) and 1 Oct 2019- 31 Jan 2020 (below). These two years are selected just as examples to show the rainfall variations within the season. The plot suggests that there is significant rainfall variability within the season, with specific periods of more rainfall, interspaced with little or no rains.

To examine whether daily rainfall has particular periodicity, a spectral analysis of daily rainfall was made for both the years, 2018-2019 and 2019-2020. The results are shown in Fig. 7.9.



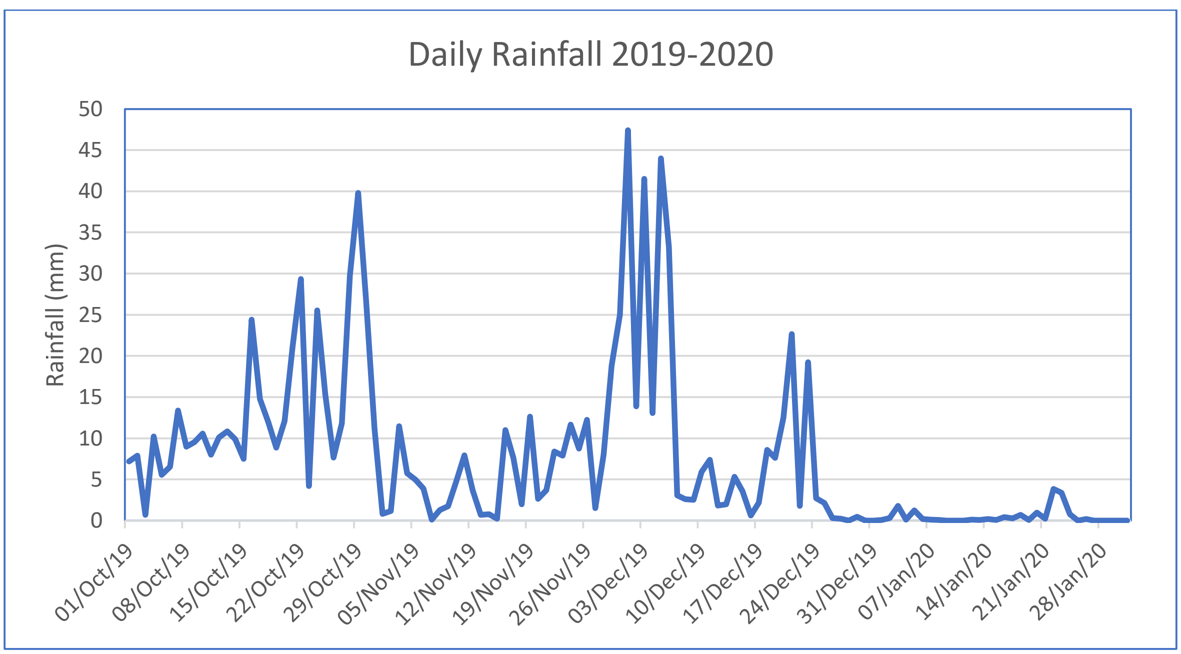


Fig. 7.8. Daily rainfall (in mm) averaged over Sri Lanka during the period 1 Oct 2018- 31 Jan 2019 (above) and 1 Oct 2019- 31 Jan 2020 (below).

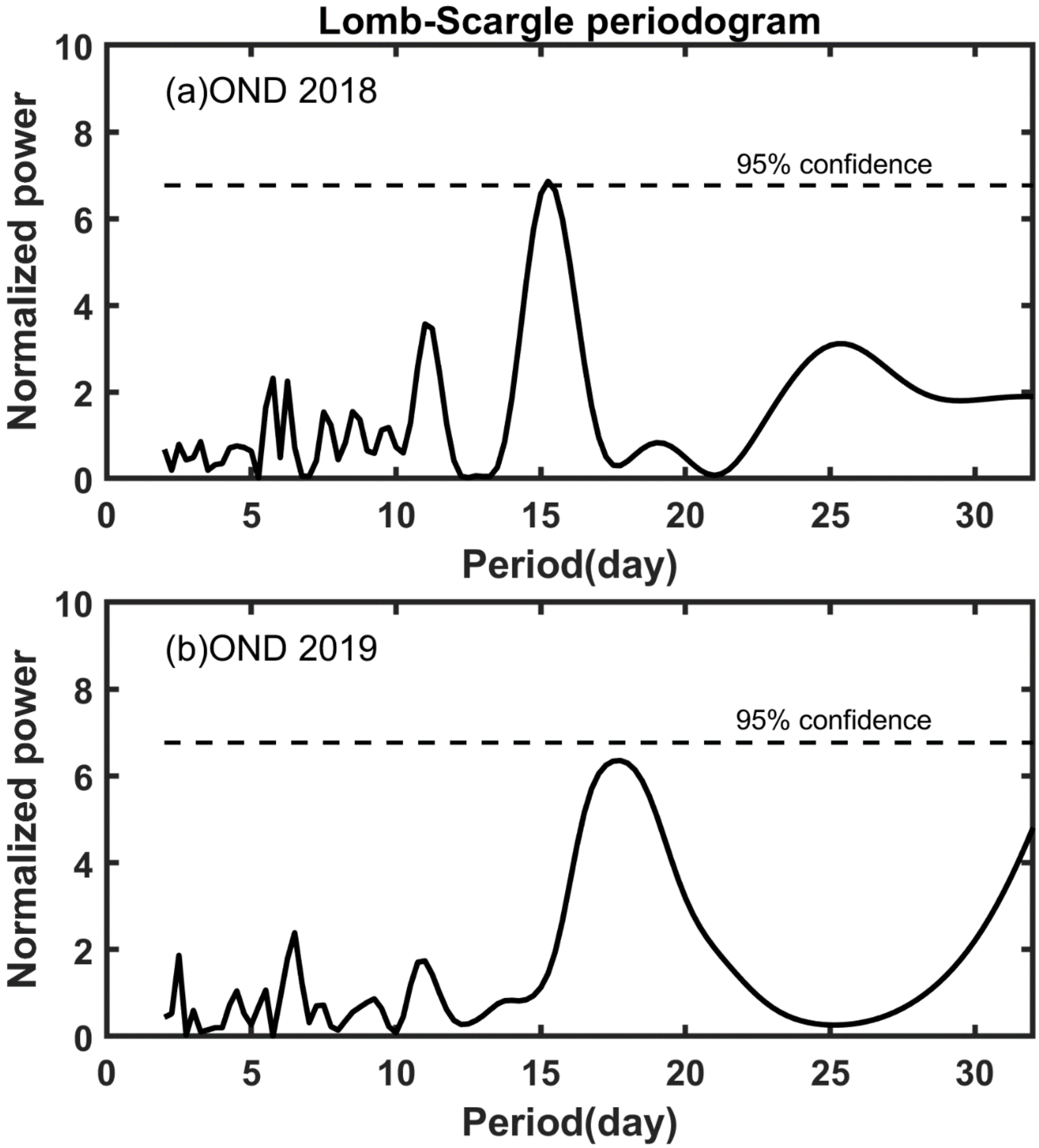


Fig. 7.9. The spectral analysis (Lomb-Scargle periodogram) of daily rainfall for the two seasons. 2018-2019 (above) and 2019-2020 (below). The 95% significance level is shown as horizontal line in both the plots.

The results indicate that there is a strong periodicity of about 15-20 days, which is statistically significant. The physical mechanisms of such periodicity are immediately not known. More studies are required to understand the intra-seasonal variability of rainfall over Sri Lanka and to examine the skill of its predictions using NWP models.

7.3. **Inter-annual variations**

A detailed analysis of year to year variations of NE monsoon over Sri Lanka is discussed in this section. There are only a few studies on the inter-annual variability of NE monsoon rainfall over Sri Lanka.

Suppiah (1996) studied the spatial and temporal variations in the relationships between the Southern Oscillation Index (SOI) and rainfall over Sri Lanka. Major changes in spatial patterns of correlations between seasonal rainfall and the SOI have occurred in Sri Lanka during the Southwest monsoon (SWM) and Second inter-monsoon (SIM) seasons. The periods of strong positive (negative) correlations during the SWM season coincide with weak (strong) negative correlations during the SIM season. This contrasting pattern is clear when the Indian and Sri Lankan summer monsoon rainfalls were out of phase between 1900 and 1960, but not before 1900, or after 1960. The sudden change in correlations around 1960 suggests a change in the coupled ocean–atmosphere system that dominates the climate of these regions.

Suppiah (1997) studied the extremes of the Southern Oscillation (SO) Phenomenon over the equatorial Pacific and Sri Lanka rainfall. There were 27 El Niño and 22 La Niña events, during the period from 1881 to 1990. Positive and negative rainfall anomalies during the south-west monsoon (SWM) season are associated with La Niña and El Niño events, but negative and positive rainfall anomalies are linked to La Niña and El Niño events during the second intermonsoon (SIM) season. These contrasting patterns are dominant in the dry zone of Sri Lanka.

Zubair and Ropelewski (2006) reported that the relationship between ENSO and the northeast monsoon (NEM) in south peninsular India and Sri Lanka from October to December has not weakened. The mean circulation associated with ENSO over this region during October to December does not show the weakening evident in the summer and indeed is modestly intensified so as to augment convection. The intensification of the ENSO–NEM rainfall relationship is modest and within the historical record but stands in contrast to the weakening relationship in summer. There is modestly intensified convection over the Indian Ocean, strengthening of the circulation associated with ENSO (Walker circulation), and enhanced rainfall during El Niño episodes in a manner consistent with an augmented ENSO–NEM relationship.

Zubair et al. (2009) studied the predictability of Sri Lankan rainfall based on ENSO. The El Niño-Southern Oscillation (ENSO) is a primary mode of climate variability of this area. They found that the rainfall is modestly predictable based on ENSO during January–March, July–August and October–December. El Niño typically leads to wetter conditions during October to December and drier conditions during January to March and July to August on average. The correlations of ENSO indices with rainfall are statistically significant for October to December, January to March and July to August and an analysis based on contingency tables shows modest predictability. The use of ENSO indices derived from the central Pacific Ocean improves the predictability from January to June. The predictability based on ENSO for October to December rainfall is robust on a decadal scale.

Abeysekera et al. (2019) studied the relationship between ENSO and rainfall over Sri Lanka. The results clearly revealed a significant reduction of rainfall during both First Inter Monsoon (FIM) and North East Monsoon (NEM) seasons during the El Niño years. The Second Inter Monsoon (SIM) season showed a positive anomaly of rainfall during the El Niño years. However, the effect of El Niño condition on the Southwest Monsoon season (SWM) was not consistent. During La Niña conditions, an above normal rainfall was observed in the FIM, SWM and NEM seasons where the strongest correlation was evident during the NEM season. The SIM season has shown a below normal rainfall during the La Niña period.

Using the seasonal (OND) rainfall over Sri Lanka, a detailed analysis on the inter-annual variability and its teleconnections with ENSO and IOD has been carried out. Fig 7.10 shows the year to year variations of NE monsoon rainfall over Sri Lanka, expressed as percent deviations. The OND mean monsoon rainfall (1971-2021) is 822 mm with 23% as coefficient of variation. Therefore, Sri Lanka receives much more rainfall during the NE monsoon season, compared to the south peninsula and even comparable with the southwest monsoon rainfall over India for four months (June to Sept), which is 870mm.

The green (red) lines suggest excess (deficient) monsoon years. During the period, 1961-2021, there were 12 deficient monsoon years and 10 excess monsoon years. In 1980s and 1990s, Sri Lanka experienced more deficient years. During the recent decade there were four excess years and two deficient years.

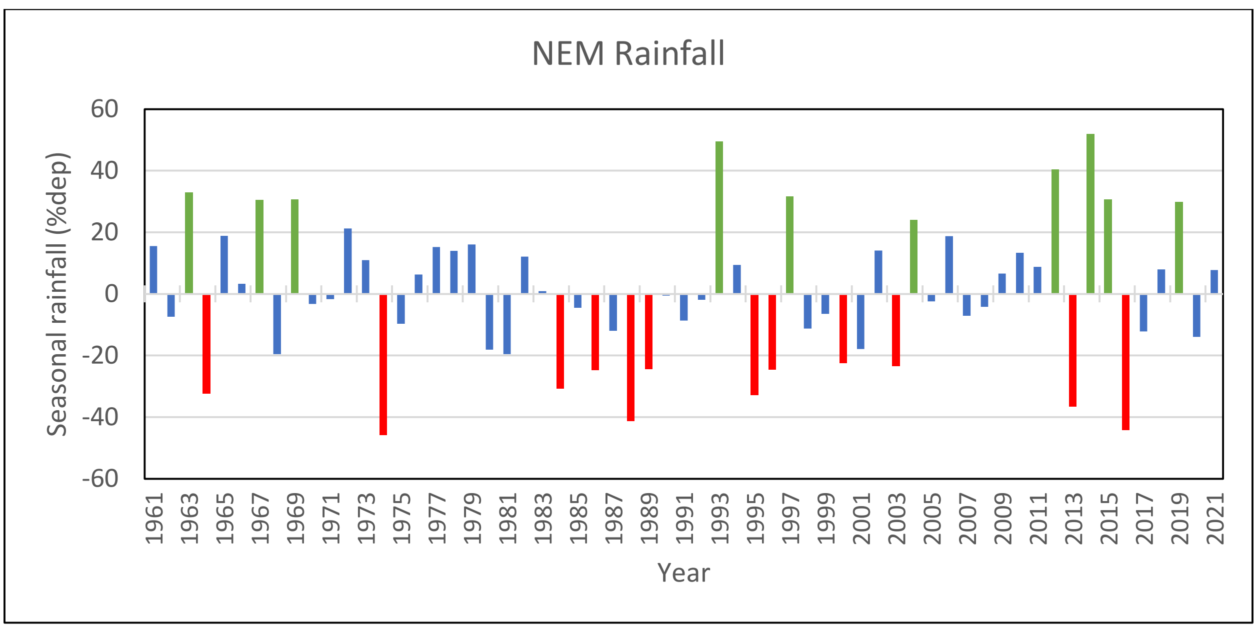
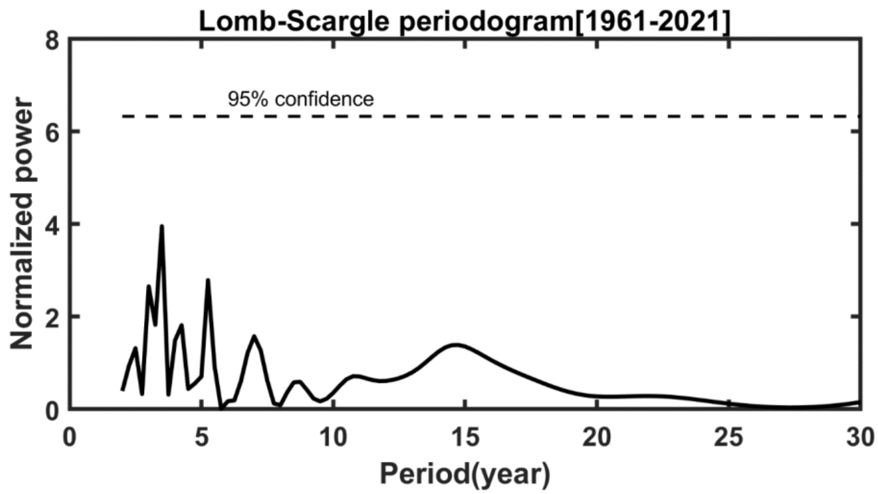


Fig. 7.10. The inter-annual variation of NE monsoon rainfall (OND) over Sri Lanka, expressed as percent departures.

A spectral analysis of seasonal rainfall is made and the results are given below. Fig. 7.11 a shows the spectral normalized power (Lomb-Scargle periodogram) using the data of 1961-2021. It suggests a peak around 2-3 years, but this periodicity is statistically not significant. The wavelet analysis shows the periodicity of 2-4 years during 1990-2000 and in the recent years, 2010-2020 as shown in Fig. 7.11 b.



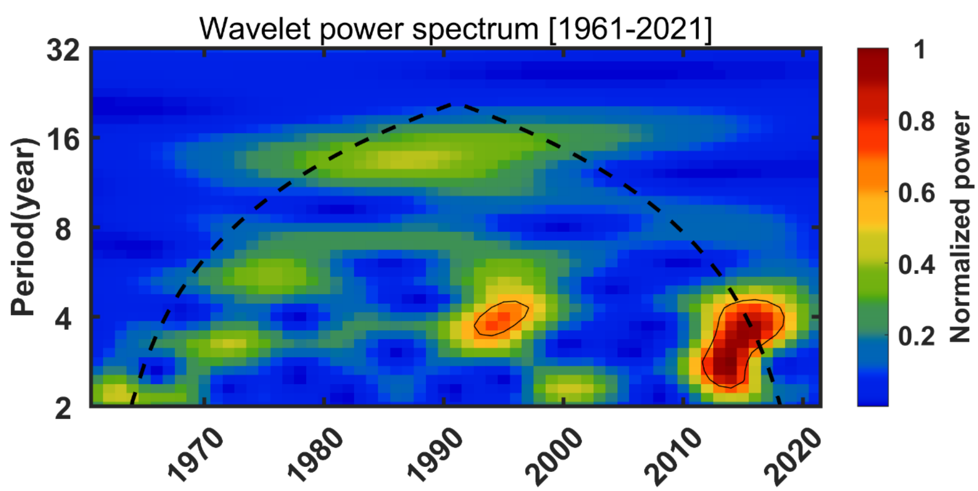


Fig. 7.11. Spectral analysis of NE monsoon seasonal rainfall (1961-2021). a) the normalized power using the Lomb-Scargle periodogram and b) wavelet power spectrum. The 95% significance cone is also shown in Fig. 7.11 b.

Further, to explore the teleconnections with global forcings like ENSO, IOD etc, a spatial analysis of correlations between the NE monsoon rainfall and SST, OLR and 850 hPa zonal winds was done and the results are shown in Fig. 7.12. There is significant correlation between NE monsoon rainfall and SST over the equatorial Pacific (Fig. 7.12 a) and the equatorial Indian Ocean (Fig. 7.12 b), representing the influence of ENSO and IOD events. Please note the dipole like correlation patterns over the equatorial Indian Ocean with negative (positive) correlation over the east equatorial Indian Ocean. Thus, the NE monsoon rainfall is positively correlated to ENSO and IOD. An El Nino event and positive IOD event are likely to enhance seasonal rainfall over Sri Lanka. This relationship is further seen in Fig. 7.12 c and d. The NE monsoon rainfall over Sri Lanka is positively correlated with the zonal winds over the equatorial east Pacific, but negatively correlated with the zonal winds over the equatorial west Pacific Ocean. The same kind of relationship exists with OLR also, suggesting the strong influence of ENSO and IOD events.

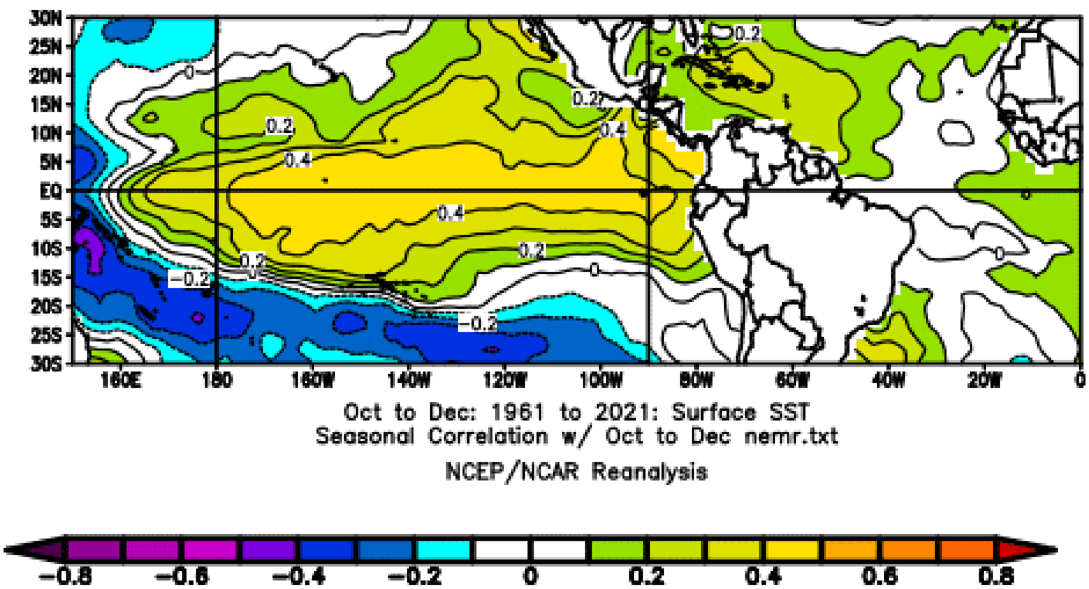


Fig. 7.12 a. Spatial distribution of correlations between OND NE monsoon rainfall and Sea Surface Temperatures (SST) during the period 1961-2021.

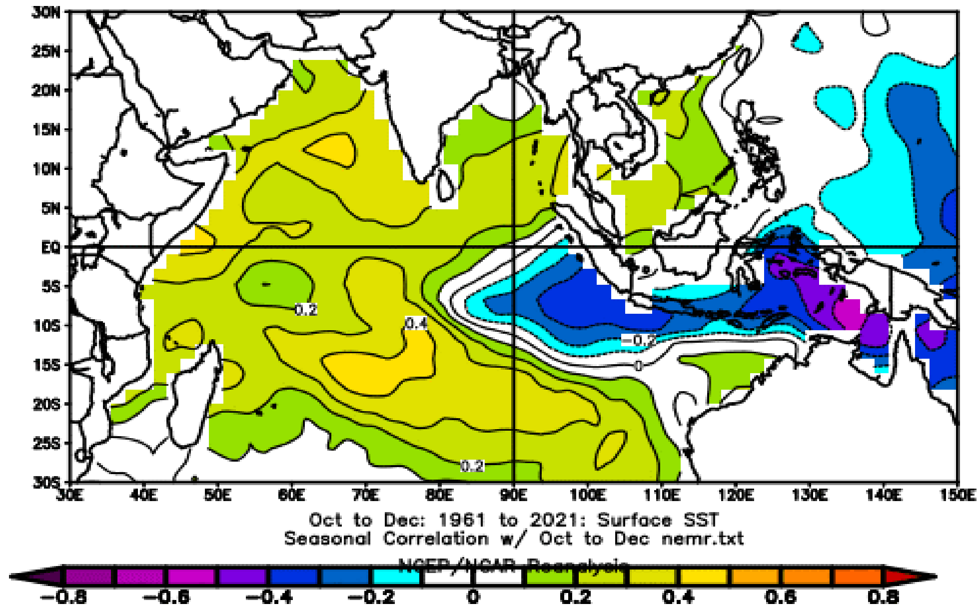


Fig. 7.12 b. Spatial distribution of correlations between OND NE monsoon rainfall and Sea Surface Temperatures (SST) during the period 1961-2021.

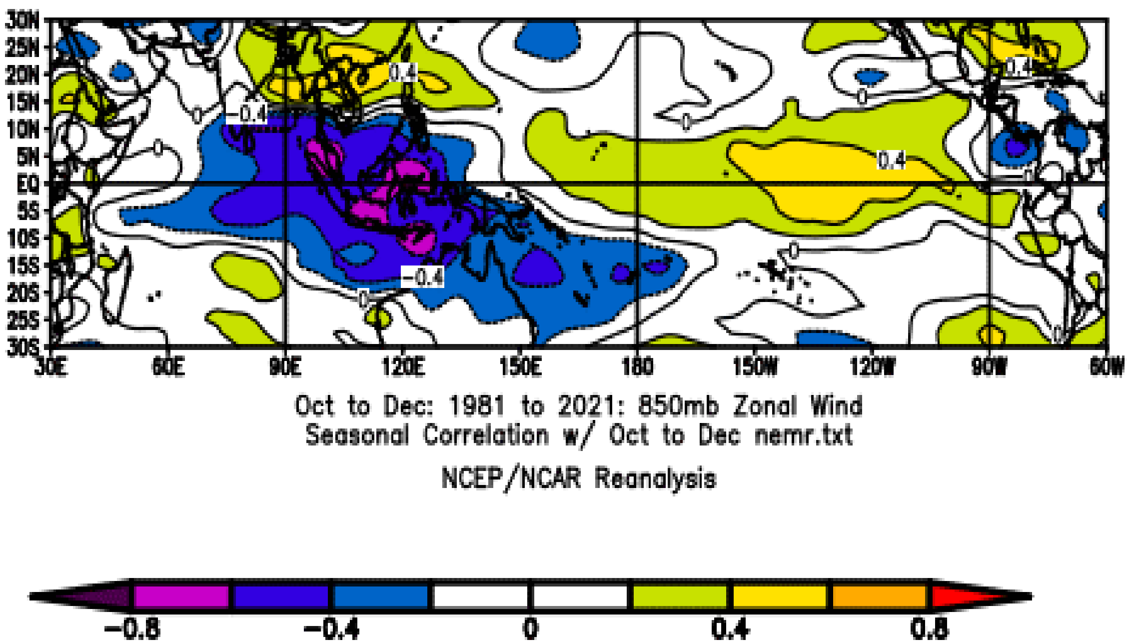


Fig. 7.12 c. Spatial distribution of correlations between OND NE monsoon rainfall and 850 hPa zonal wind during the period 1961-2021.

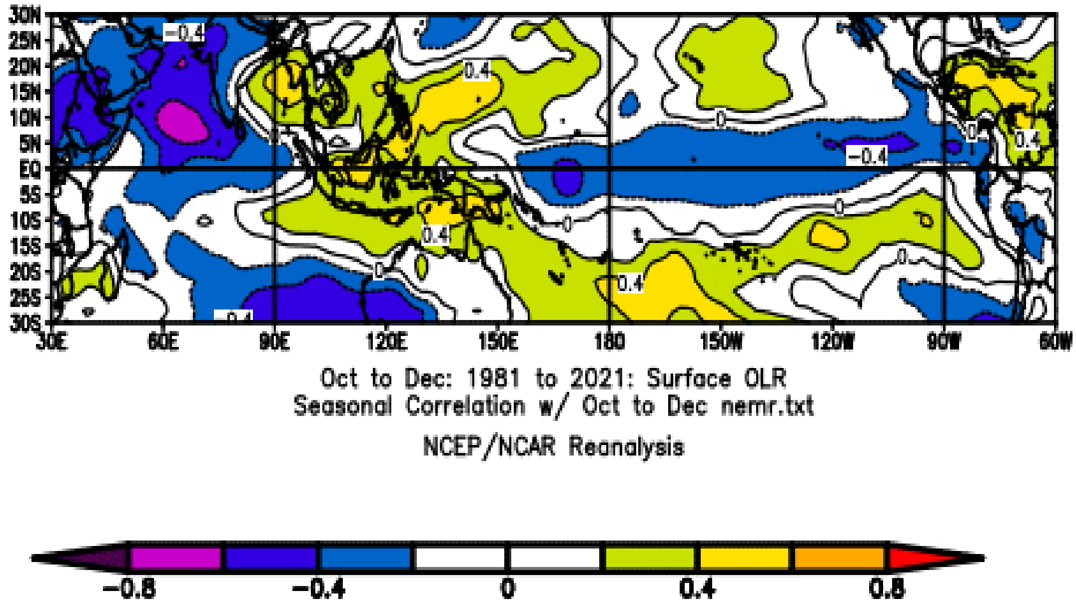
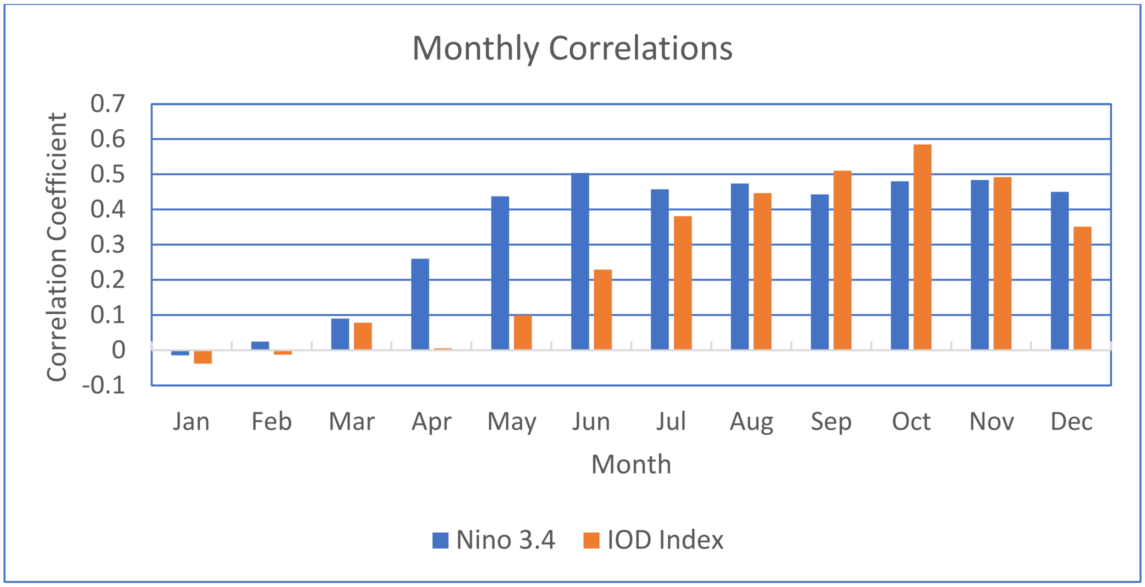


Fig. 7.12 d. Spatial distribution of correlations between OND NE monsoon rainfall and OLR during the period 1961-2021.

Fig. 7.13 a shows the monthly variations of correlations between monthly Nino 3.4 and IOD index with OND NE monsoon rainfall over Sri Lanka. The plot shows the concurrent and strong correlations between Nino 3.4 and IOD Index with monsoon rainfall. Comparatively, IOD index has stronger correlation with NE monsoon rainfall over Sri Lanka compared to the Nino 3.4 during the OND season. But what is more important is that statistically significant correlations are observed even before the NE monsoon season, especially with the Nino 3.4. For example, the Nino 3.4 is significantly correlated right from May onwards with the NE monsoon rainfall over Sri Lanka. Similarly, the IOD index during August and September months is significantly correlated with NE monsoon rainfall. These inferences suggest scope for long range predictability of NE Monsoon rainfall over Sri Lanka. More work is required to explore these relationships and to develop useful long-range prediction methods.



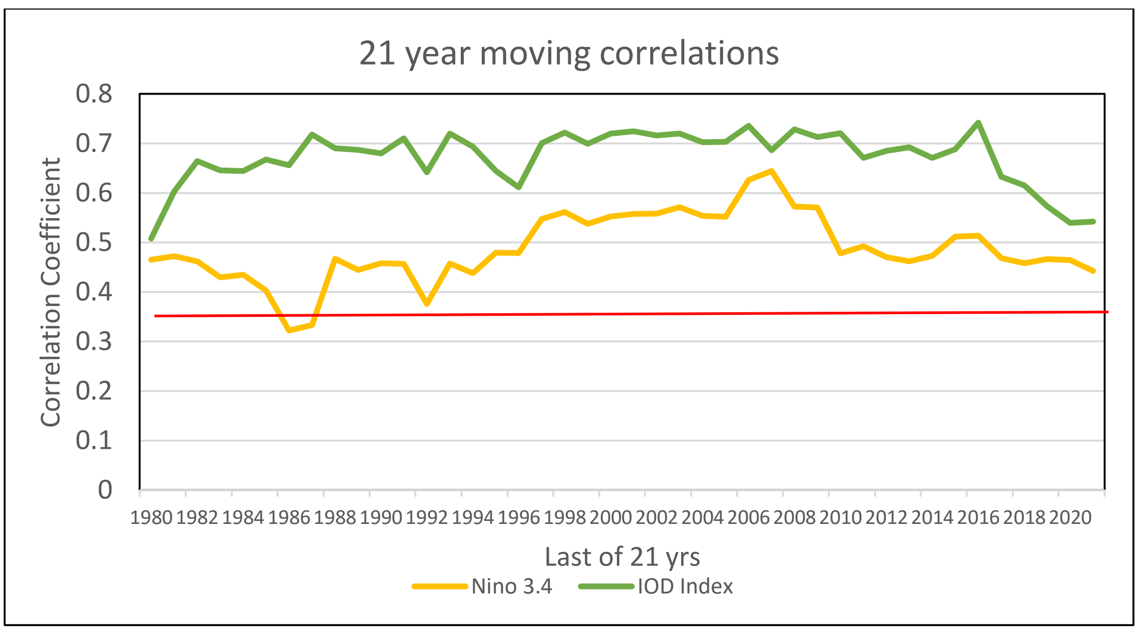


Fig. 7.13. a) Monthly correlations between Nino 3.4 (Blue) and IOD index (red) with OND NE monsoon rainfall. Data of 1961-2021 was used. b) the 21 year moving correlations between OND Nino 3.4 (Orange colour) and OND IOD index with the OND NE monsoon rainfall showing secular variations.

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Fig. 7.13 b shows the 21-year running correlations between the NE monsoon rainfall and the Nino 3.4 and IOD index, showing the secular variations of the relationships. It shows the relationship has been more or less very robust throughout the analysis period (1981-2021). However, during the recent years, the correlation strength is shown as decreasing, especially the IOD Index. More work is required to understand the physical reasons for this observed weakening of the relationships.