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.

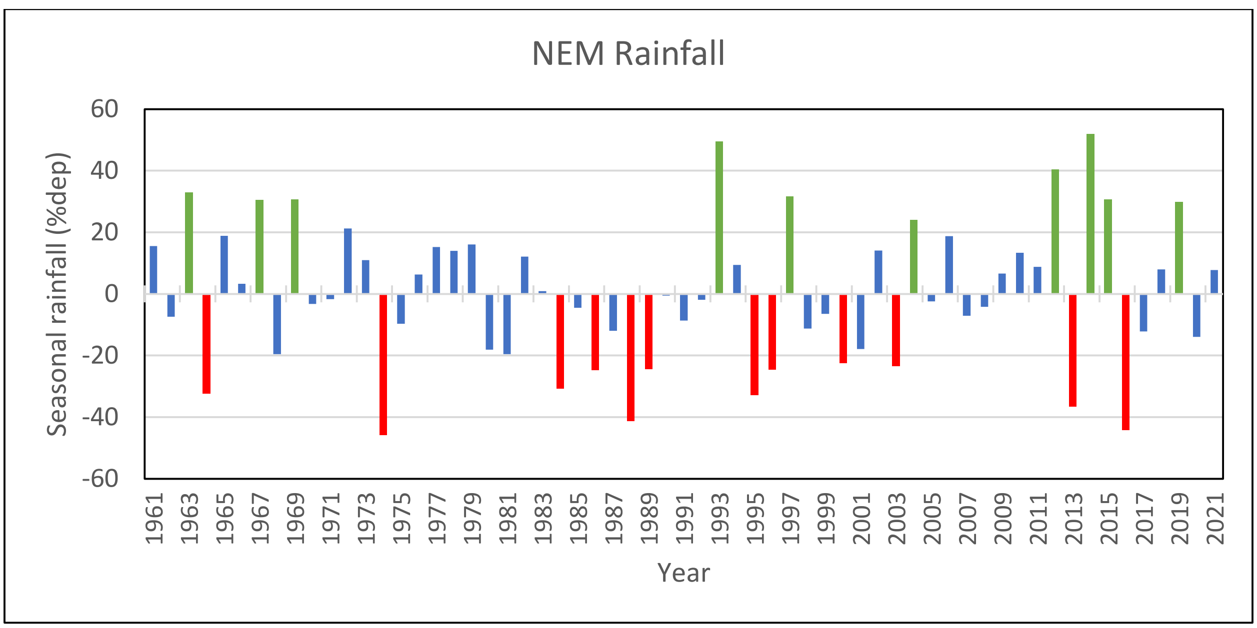
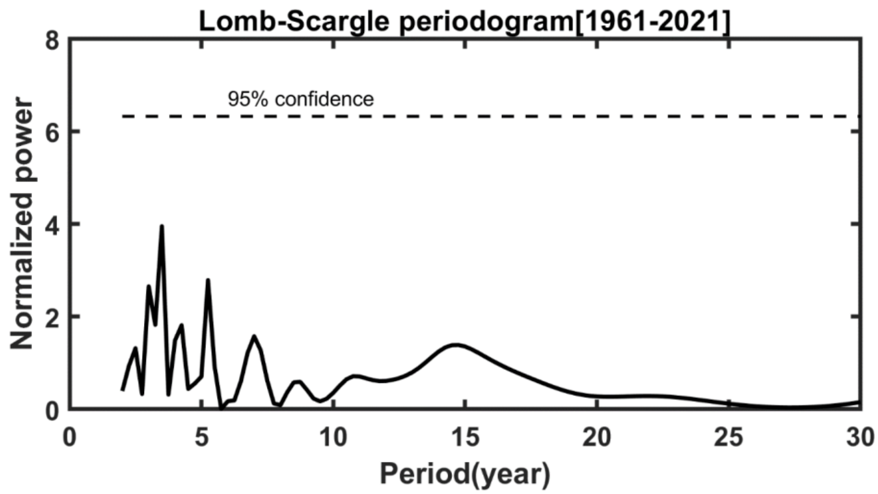


Fig. 7.10. The inter-annual variation of NE monsoon rainfall (OND) over Sri Lanka, expressed as percent departures.

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.



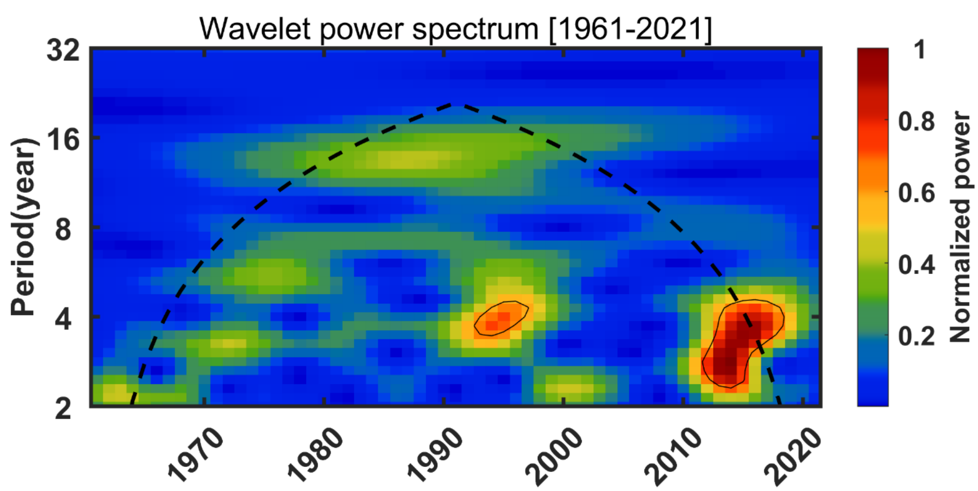


Fig. 7.11. Spectral analysis of NE monsoon seasonal rainfall (1961-2021). a) the normalized power using the Lomb-Scargle periodogram and b) wavelet power spectrum. The 95% significance cone is also shown in Fig. 7.11 b**.**

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.

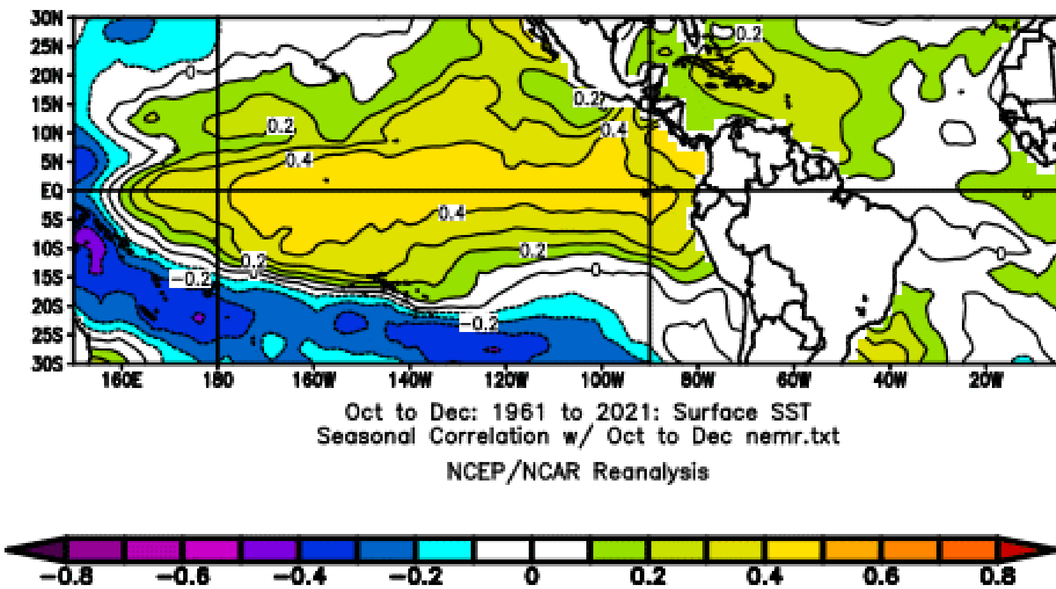


Fig. 7.12 a. Spatial distribution of correlations between OND NE monsoon rainfall and Sea Surface Temperatures (SST) during the period 1961-2021.

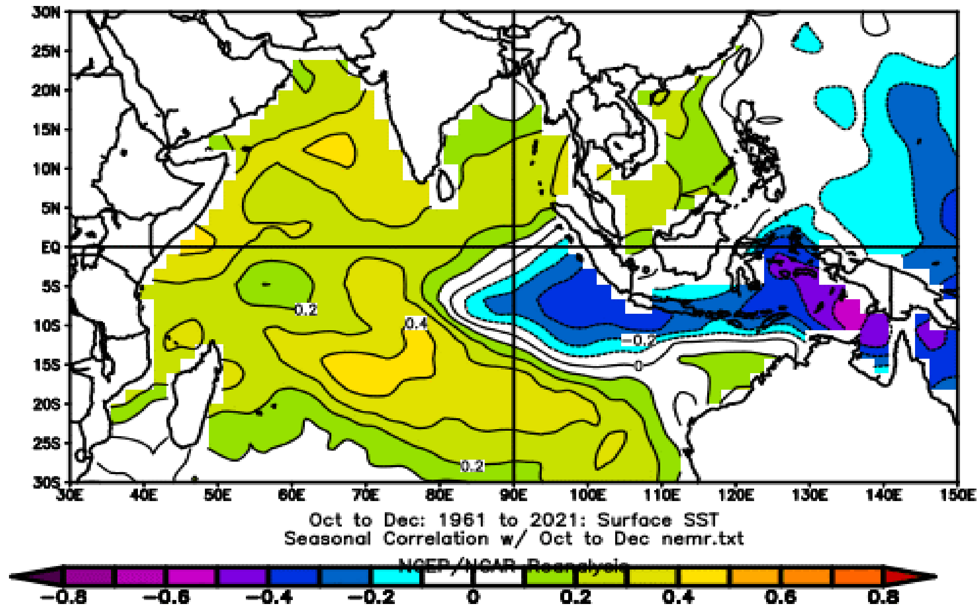


Fig. 7.12 b. Spatial distribution of correlations between OND NE monsoon rainfall and Sea Surface Temperatures (SST) during the period 1961-2021.

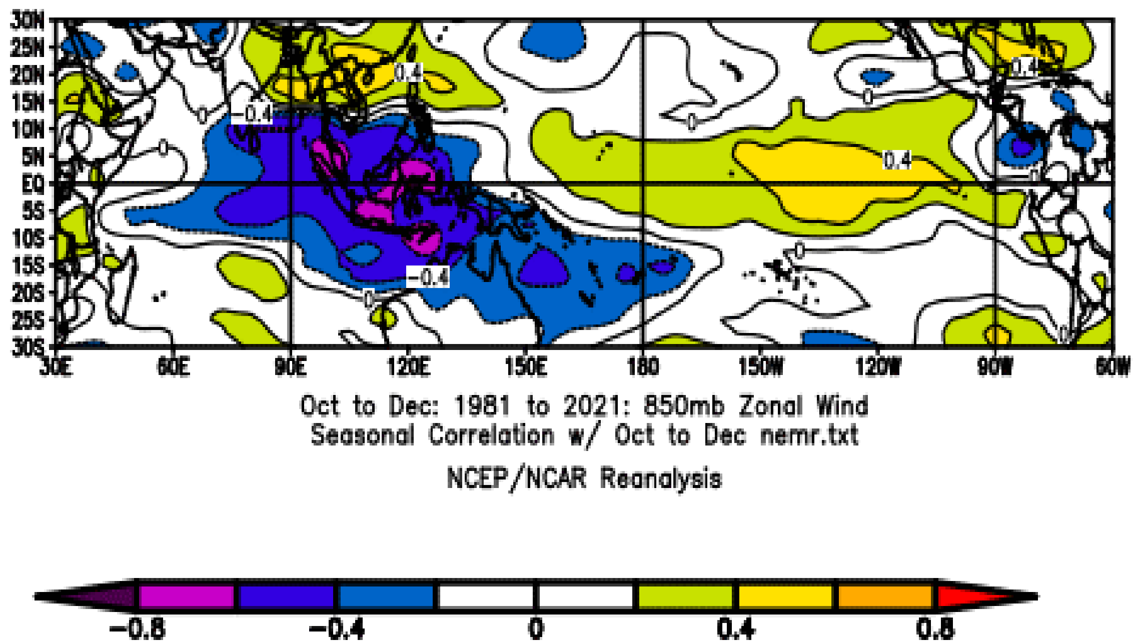


Fig. 7.12 c. Spatial distribution of correlations between OND NE monsoon rainfall and 850 hPa zonal wind during the period 1961-2021.

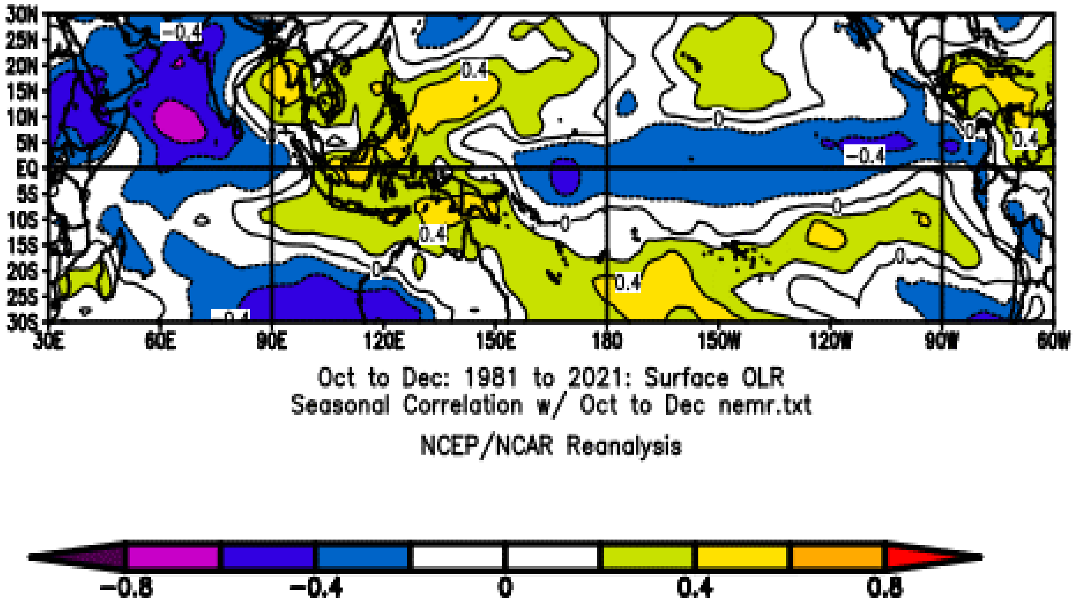
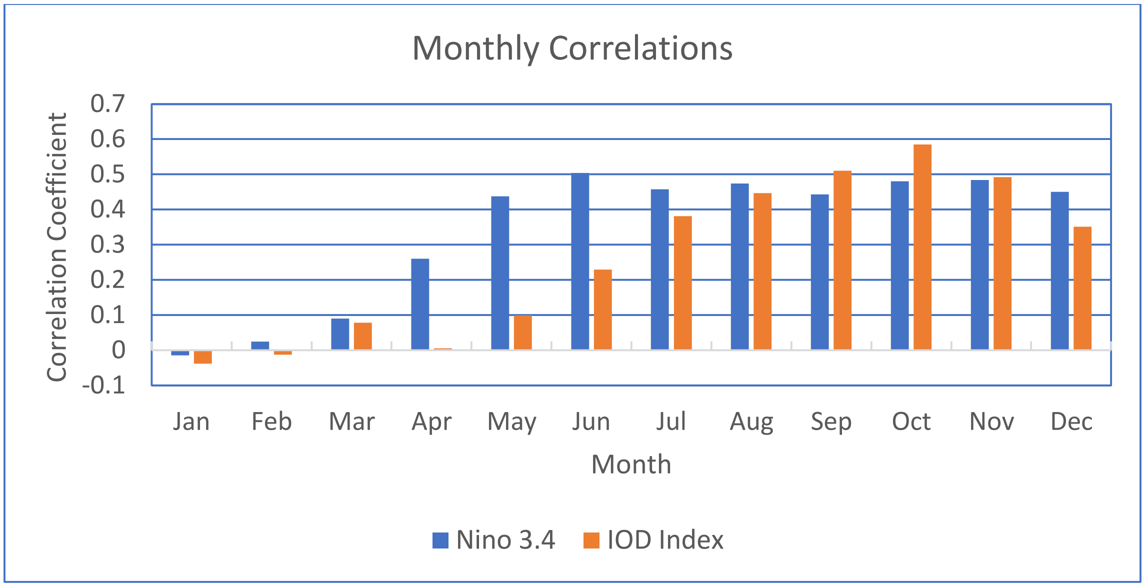


Fig. 7.12 d. Spatial distribution of correlations between OND NE monsoon rainfall and OLR during the period 1961-2021.

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.



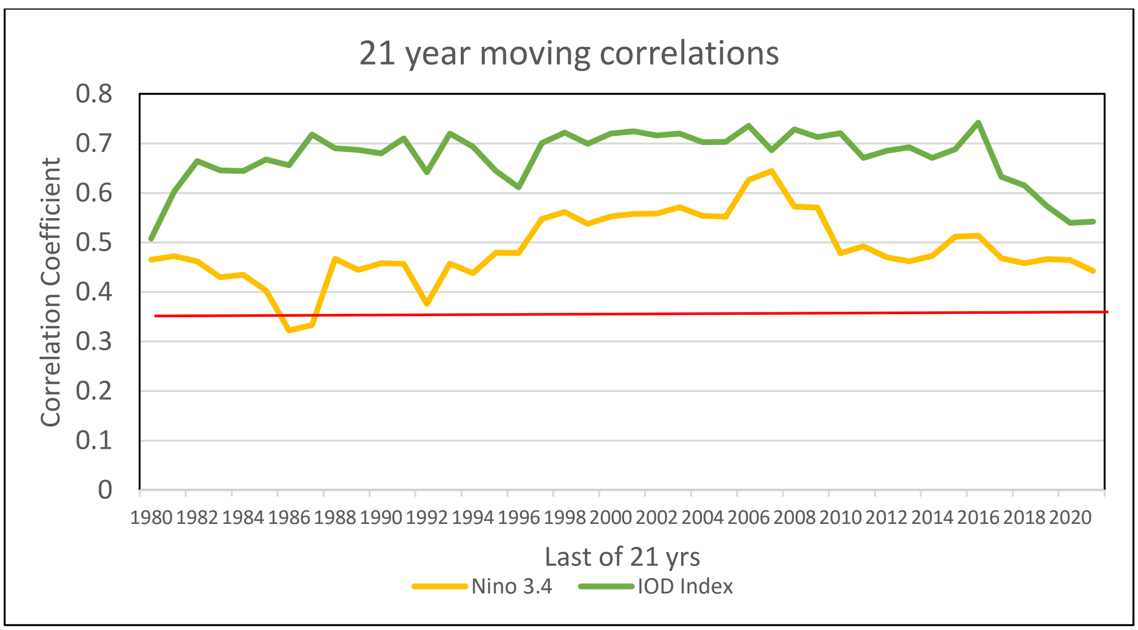


Fig. 7.13. a) Monthly correlations between Nino 3.4 (Blue) and IOD index (red) with OND NE monsoon rainfall. Data of 1961-2021 was used. b) the 21 year moving correlations between OND Nino 3.4 (Orange colour) and OND IOD index with the OND NE monsoon rainfall showing secular variations.

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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.