Precipitation Characteristics and Mechanisms over Sri Lanka against the Background of the Western Indian Ocean: 1981–2020

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Abstract: In the current environment of climate change, the precipitation situation of marine islands is particularly valued. So, this study explores precipitation characteristics and mechanisms over Sri Lanka in the background of the western Indian Ocean using satellite and reanalysis datasets based on 40 years (from 1981 to 2020). The results show that the highest precipitation occurs between October and December, accounting for 46.3% of the entire year. The Indian Ocean sea surface temperature warming after 2002 significantly influences precipitation patterns. Particularly during the Second Inter-Monsoon, the western Indian Ocean warming induces an east–west zonal sea surface temperature gradient, leading to low-level circulation and westerly wind anomalies. This, in turn, results in increased precipitation in Sri Lanka between October and December. This study used the Trend-Free Pre-Whitening Mann–Kendall test and Sen’s slope estimator to study nine extreme precipitation indices, identifying a significant upward trend in extreme precipitation events in the Jaffna, arid northern Sri Lanka, peaking on 9 November 2021. This extreme event is due to the influence of weather systems like the Siberian High and intense convective activities, transporting substantial moisture to Jaffna from the Indian Ocean, the Arabian Sea, and the Bay of Bengal during winter. The findings highlight the impact of sea surface temperature warming anomalies in the western Indian Ocean and extreme precipitation events, anticipated to be more accentuated during Sri Lanka’s monsoon season. This research provides valuable insights into the variability of tropical precipitation, offering a scientific basis for the sustainable development of marine islands.

Keywords: precipitation; sea surface temperature; water vapor transport; Sri Lanka; western Indian Ocean

1. Introduction

Long-term variation characteristics of precipitation are crucial for managing water resources, studying the global water cycle, and developing effective climate-mitigation strategies. Against the background of current climate change, the precipitation situation of marine islands is particularly valued [1]. Threatened by ocean warming and rising sea levels from glacier melting, marine islands face diverse challenges from ocean and climate change, impacting the ecological environment and sustainable development [2]. At present, more research is focusing on the analysis of precipitation characteristics and related physical processes in the Maritime Continent (MC) [3]. For example, the daily cycle of precipitation and convection across the MC demonstrates a pronounced difference between land and
ocean [4–8]. At the same time, some studies have analyzed the physical mechanism of MC precipitation spatial distribution, focusing on Java Island and Indonesia, discussed the local precipitation process related to land and sea winds, and discussed its impact from the perspective of global climatology [9]. However, current research scarcely addresses the topic of precipitation on marine islands, and these macroclimate drivers greatly affect many sectors, including agriculture, hydrology, marine resources, infrastructure, and tourism; they also cause disasters [10–13]. For example, an increase in precipitation can lead to heightened stratification of water bodies, potentially limiting the nutrient supply to surface water and thereby affecting the ecological environment on marine islands [14,15]. A current study indicates that during El Niño years, Sri Lanka experiences monsoon rainfall below the average levels, whereas the opposite occurs during La Niña years [11]. Some previous studies have also found that when El Niño occurs in the Pacific Ocean, its associated changes in circulation patterns tend to reduce moisture availability around Sri Lanka, specifically resulting in a decrease in daily rainfall in the spring (March and April) north of Sri Lanka. Conversely, when La Niña occurs in the Pacific Ocean, daily rainfall in the spring (March and April) north of Sri Lanka increases [16]. This has important implications for Sri Lanka’s agriculture and water resources [17,18]. Meanwhile, climate change is causing higher sea surface temperatures, rising sea levels, and more intense tropical cyclones and storms, impacting marine island ecosystems like the Andaman and Nicobar Islands in India [19]. Monsoon depressions and tropical storms in the Bay of Bengal have caused widespread precipitation in Bangladesh, causing huge losses of life and property [20].

Situated in the southern extremity of the Indian subcontinent, Sri Lanka is a compact island covering 65,610 square kilometers. The island spans between 5°55′ and 9°50′ N and 79°41′ and 81°53′ E. Given its tropical location, except in mountainous areas, the temperature exhibits limited variation throughout the year. Consequently, the predominant climatic changes in the region are intricately associated with variations in precipitation patterns [21,22]. The precipitation climate of Sri Lanka is predominantly influenced by the seasonal variations in the monsoon pattern [23]. Sri Lanka’s large-scale changes in wind and precipitation patterns characterize the island’s four distinctive monsoon periods. These include the North–East Monsoon (NEM: December to February), the First Inter-Monsoon (FIM: March to April), the South–West Monsoon (SWM: May to September), and the Second Inter-Monsoon (SIM: October to November) [24–26]. During Sri Lanka’s two inter-monsoon periods (FIM and SIM), the phenomenon is intricately linked to the motion of the Intertropical Convergence Zone (ITCZ) [27], which moves across Sri Lanka from south to north during the FIM and from north to south during the SIM [28,29]. Moreover, the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) also have a substantial influence on precipitation changes in Sri Lanka [13,30–33].

Previous studies have shown that there are currently two views on tropical precipitation changes. One theory anticipates heightened precipitation in currently wet regions (wet becomes wetter) [34,35], while another proposes increased precipitation in areas where the rise in sea surface temperature (SST) outpaces the average surface warming in the tropics (warmer becomes wetter) [36–38]. The wet-becomes-wetter pattern is typically induced by seasonal precipitation anomalies [37]. Sri Lanka is heavily dependent on seasonal precipitation [24], and the SIM registers the highest average daily precipitation [26]. Studies have used weather stations to scrutinize precipitation patterns in Sri Lanka and proposed that local diurnal variations in convective precipitation are more active during the inter-monsoon period than during the monsoon [39]. Especially during the SIM, Sri Lanka is prone to catastrophic inundations and landslides [40]. This indicates that seasonal precipitation anomalies have the potential to initiate extreme precipitation events. Studies have indicated that Sri Lanka is impacted by severe precipitation events annually, leading to inundations, landslides, and substantial economic repercussions [41,42]. As an illustration, numerous regions in Sri Lanka encountered precipitation surpassing 200 mm on 15 May 2016 [16,43]. In May 2017 alone, Sri Lanka experienced 35 significant landslide events [44]. Subsequently, on 1 September 2020, a sudden heavy precipitation event occurred in southwestern Sri
Lanka, exceeding 250 mm within 24 h. This led to localized flooding, impacting more than 7000 individuals [45].

Another pattern is the warmer-becomes-wetter phenomenon, which is induced by SST anomalies. Research proves that the Indian Ocean (IO) SST significantly impacts Sri Lanka’s precipitation [46]. The IOD, as the second dominant climate mode in the tropics, represents a distinctive and intrinsic atmospheric–oceanic interaction within the IO, linked to the east–west SST anomaly gradient in the tropical IO [47]. During the positive IOD phase, characterized by warmer waters in the western IO and cooler waters in the east, precipitation in East Africa and the western IO area rises substantially, while precipitation weakens in Indonesia and the eastern IO region [48]. Conversely, during the negative IOD phase, intensified equatorial westerlies lead to increased precipitation in Australia and Indonesia, resulting in decreased precipitation in Africa [49]. Consequently, the IOD notably influences the climate of countries along the IO, including India, East Africa, and Indonesia [50]. Particularly notable was the severe impact of the IOD in 2019. In June of that year, forest fires erupted in northeastern Australia, resulting in extensive devastation. By March 2020, the affected area spanned approximately 180,000 square kilometers, with 59,000 buildings destroyed, and a tragic loss of at least 34 lives, including 10 firefighters [51]. Explorations have found that between 1869 and 2000, the positive IOD events led to increased precipitation in Sri Lanka NEM periods. The positive IOD phase is characterized by higher SST anomalies in the western regions, which lead to extensive convergence in the lower layers of the atmosphere. This convergence reached Sri Lanka, where the convection generated by this atmospheric convergence resulted in increased autumn precipitation in northern Sri Lanka [52].

The explanation above indicates that despite numerous studies on precipitation variability in Sri Lanka, there is a paucity of research on the long-term precipitation characteristics and causes in the region. While most studies on extreme precipitation in Sri Lanka have focused on the humid southwest region, there is a scarcity of research concerning the relatively arid northern region. Existing studies indicate a significant trend of extreme positive precipitation anomalies in Sri Lanka’s arid areas [53], underscoring the need for further research on extreme precipitation events in these regions. Meanwhile, certain tropical cyclones have impacted the Sri Lanka region, resulting in excessive precipitation and flooding [54]. Nevertheless, persistent water shortages endure as a chronic issue in this area. Additionally, there are still many uncertainties regarding the precipitation characteristics of marine islands at sea and land confluence, requiring further analysis and study. Hence, the research objective is to explore the key characteristics and mechanisms governing long-term and short-term precipitation in Sri Lanka. Additionally, this study aims to comprehend precipitation patterns against the background of the western IO, with a particular focus on IO SST anomalies and extreme precipitation events. The examination of these characteristics and their underlying causes holds significant scientific importance, contributing to a deeper understanding of tropical precipitation studies.

2. Data and Methodology

2.1. Datasets Used in the Study

2.1.1. Precipitation Data

Sri Lanka’s annual precipitation typically varies between approximately 1283 mm and 3321 mm, with most precipitation occurring during the SWM and the NEM periods [55]. Sri Lanka meteorological stations from 2010 to 2022 were derived from comprehensive weather statistics provided by the Met Office Weather [56]. Data were recorded every 3 h. To ensure data quality, this study adopted strict criteria to check the limit values, including eliminating data exceeding the limit and excluding stations with over 3 days of missing data. The climatological boundary range is typically set between 0 and 150 mm [57]. However, given that the meteorological station recorded data every three hours, the boundary range for this study was adjusted to 0–300 mm. Additionally, a time consistency check was performed, and the statistical analysis revealed a data error rate of
0.09% across nine meteorological stations. Subsequently, 9 sites were retained for subsequent analyses. Figure 1 depicts the study region and illustrates the spatial distribution of the nine weather stations on the Sri Lankan topographic map. Supplementary Table S1 lists basic information about the coordinates and elevation of Sri Lanka’s nine weather stations (see Supplementary Table S1).

Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) is the main daily precipitation dataset for this study [58]. The dataset has the advantage of higher spatial resolution (0.05° × 0.05°) and site correction, which gives this study of Sri Lanka’s long-term precipitation from 1981 to 2020 (40 years) higher reliability. To supplement the analysis of precipitation over the ocean, the study also used the Global Precipitation Climatology Project (GPCP), with a spatial resolution of 2.5° × 2.5° [59], which is commonly used to study precipitation pattern changes in tropical regions [60]. Version 2.3 has undergone multiple integrated analyses, such as data calibration, algorithm correction, and time overlap [59]. And, we used observational data to verify them and found that the results based on the same period of the datasets are basically consistent (see statistical methods for details). Furthermore, this study used the Global Precipitation Measurement Dual-Frequency Precipitation Radar (GPM DPR) to measure the reflection and scattering properties of precipitation particles. Its algorithm’s performance has been physically evaluated [61]. It provides crucial insights into the vertical distribution, size, and type of precipitation particles. Additionally, it offers data with greater spatiotemporal resolution, facilitating the precise evaluation of precipitation intensity, distribution, and duration. The DPR radar operates in two different frequency modes: Ka frequency and Ku frequency. Ka frequency modes offer high spatial resolution, typically around 5 km × 5 km. Ku frequency modes provide relatively lower spatial resolution, typically around 25 km × 25 km [61].

2.1.2. Reanalysis Data

In this study, the ERA5 data were utilized from the European Centre for Medium-Range Weather Forecasts (ECMWF) [62]. They have been globally available at an hourly resolution since 1940, and they are presented on a 0.25° × 0.25° grid. Bandara et al. [63] evaluated various precipitation datasets in Sri Lanka and found that ERA5 can well replicate climate change. This study intended to utilize the ERA5 to examine the difference in the IO SST and to investigate the correlation among SST anomalies, precipitation anomalies, and wind anomalies. It also has relatively high performance in characterizing extreme
climate phenomena [64]. Therefore, this study selected the ERA5 to investigate information from 9 November 2021, with an emphasis on examining the factors contributing to extreme precipitation occurrences. The atmospheric variables examined encompass the surface pressure, precipitation, near-surface temperature, etc.

2.2. Definition of Extreme Precipitation Events

The Climate Extremes Indices, defined by the Expert Team Climate Change Detection and Indices (ETCCDI) [65], have been widely used to investigate variations in intense precipitation severity, occurrence rates, and contributions to total precipitation across various regions globally [66–73]. In this study, the long-term trends of extreme precipitation indices were calculated using nine ETCCDI extreme precipitation indices (Table 1) combined with CHIRPS daily precipitation data in Sri Lanka from 1981 to 2020.

Table 1. ETCCI-recommended climate indices used in this study.

<table>
<thead>
<tr>
<th>Index</th>
<th>Descriptive Name</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRCPTOT</td>
<td>Wet day precipitation</td>
<td>Annual total precipitation from wet days</td>
<td>mm</td>
</tr>
<tr>
<td>SDII</td>
<td>Simple daily intensity index</td>
<td>Average precipitation on wet days</td>
<td>mm/d</td>
</tr>
<tr>
<td>RX1day</td>
<td>Maximum 1-day precipitation</td>
<td>Annual maximum 1-day precipitation</td>
<td>mm</td>
</tr>
<tr>
<td>R10mm</td>
<td>Precipitation days</td>
<td>Annual count of days when RR \geq 10</td>
<td>Days</td>
</tr>
<tr>
<td>R20mm</td>
<td>Precipitation days</td>
<td>Annual count of days when RR \geq 20</td>
<td>Days</td>
</tr>
<tr>
<td>R95p</td>
<td>Very wet day precipitation</td>
<td>Annual total precipitation when RR &gt; 95th</td>
<td>mm</td>
</tr>
<tr>
<td>R99p</td>
<td>Extremely wet day precipitation</td>
<td>Annual total precipitation when RR &gt; 99th</td>
<td>mm</td>
</tr>
<tr>
<td>CWD</td>
<td>Consecutive wet days</td>
<td>Maximum number of consecutive wet days</td>
<td>Days</td>
</tr>
<tr>
<td>CDD</td>
<td>Consecutive dry days</td>
<td>Maximum number of consecutive dry days</td>
<td>Days</td>
</tr>
</tbody>
</table>

Amongst the various statistical methodologies available that can be used to define extreme precipitation, the most straightforward and widely utilized approach is non-parametric statistical techniques relying on fixed values or percentiles to establish thresholds for severe occurrences [74]. Following this approach, the ETCCDI formulated a series of 27 indices based on daily temperature and precipitation records, extensively utilized for identifying and tracking shifts in climate patterns [72,75–77]. From the compilation, Table 1 in particular highlights nine indices associated with precipitation. Consequently, the majority of researchers utilize percentile-based metrics, with percentiles spanning from 90 to 99 [78]. Therefore, the analysis identifies extreme precipitation events by examining the daily average precipitation recorded at all stations in Sri Lanka. Extreme precipitation events are defined as whenever the daily precipitation (above 0.1 mm/day) surpasses the 95th percentile level across every precipitation day over a continuous period [79].

2.3. Statistical Methods

Figure 2 shows the main process of the study, including research data, research methods, and the corresponding research content.

The availability of CHIRPS data is verified using observational data [22]. Firstly, the temporal and spatial consistency was ensured. By aligning and transforming the data, the weather station data were reindexed to match the time index of the CHIRPS data, and missing values were filled with zeros. Secondly, the percentage bias (PBIAS), the root mean square error (RMSE), and the Willmott Index of Agreement (Willmott d) were used for validation. As shown in Supplementary Figure S1, the combined results of these indicators show that although there is a certain underestimation trend and a large prediction error in CHIRPS data, the prediction results closely match the actual observations, indicating that the model can better capture the actual precipitation in most cases.
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The Standardized Precipitation Index (SPI) was proposed by McKee et al. [80]. In this study, the continuous precipitation time series on a three-month time scale is regarded as obeying the Gamma distribution. The corresponding cumulative probability function is derived and then transformed into a standard normal distribution. Firstly, the Gamma distribution is defined as follows:

\[ g(x) = \frac{1}{\beta^\alpha \tau(\alpha)} x^{\alpha-1} e^{-x/\beta} \]  

\( \hat{\alpha} \) is the shape parameter, \( \hat{\beta} \) is the scale parameter, \( x \) is the precipitation, and \( \tau(\alpha) \) is the Gamma function, and we use the maximum likelihood estimation method [81] to calculate the \( \hat{\alpha} \) and \( \hat{\beta} \), that is

\[ \hat{\beta} = \frac{\bar{x}}{1 + \sqrt{1 + 4(\ln \bar{x} - \frac{1}{n} \sum_{i=1}^{n} \ln x_i)/3}} \]  

\[ \frac{4(\ln \bar{x} - \frac{1}{n} \sum_{i=1}^{n} \ln x_i)}{3} \]  

where \( x_i \) is the precipitation, \( \bar{x} \) is the mean precipitation, and \( n \) is the length of the time series. The cumulative probability function is calculated as

\[ G(x) = \int_{0}^{x} g(x)dx = \frac{\int_{0}^{x} x^{\alpha-1} e^{-x/\hat{\beta}}}{\beta^\alpha \tau(\alpha)} \]  

and it can be converted when the independent variable is 0:

\[ H(x) = q + (1 - q)G(x) \]
where \( q \) is the probability of 0 value appearing in the precipitation sequence. Then, \( H(x) \) is standardized, and the result is

\[
SPI = S \left( t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right)
\] (5)

The values of \( c_0, c_1, c_2, d_1, d_2, \) and \( d_3 \) are 2.515517, 0.082853, 0.010328, 1.432788, 0.189269, and 0.001308, respectively. Where

\[
t = \sqrt{\ln \frac{1}{H(x)^2}}
\] (6)

\( H(x) \) is the probability obtained by \( \tau \) distribution, and when \( H(x) > 0.5, S = 1; \) when \( H(x) \leq 0.5, S = -1. \) And, Table 2 shows the range of SPI values and the corresponding classification.

**Table 2. SPI values’ range and classification.**

<table>
<thead>
<tr>
<th>SPI Range</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 or more</td>
<td>Extremely wet</td>
</tr>
<tr>
<td>1.5–1.99</td>
<td>Very wet</td>
</tr>
<tr>
<td>1–1.49</td>
<td>Moderately wet</td>
</tr>
<tr>
<td>0.99–0.0</td>
<td>Normal</td>
</tr>
<tr>
<td>0.0 to −0.99</td>
<td>Near normal</td>
</tr>
<tr>
<td>−1 to −1.49</td>
<td>Moderately dry</td>
</tr>
<tr>
<td>−1.5 to −1.99</td>
<td>Severely dry</td>
</tr>
<tr>
<td>−2 and less</td>
<td>Extremely dry</td>
</tr>
</tbody>
</table>

In this study, the Pearson correlation coefficient and t-test are used to analyze the impact of SST anomalies on precipitation anomalies [82]. The data used are the ERA5 and GPCP data (OND) from 1981 to 2020. The parameters are SST variables and precipitation variables. The precipitation variables of latitude and longitude (5–10° N to 79–82° E) are screened, and the precipitation anomaly values are calculated. The SST variables of latitude and longitude (20° S–20° N to 30–120° E) are screened, and the SST anomaly values are calculated. The correlation and significance between SST anomalies and precipitation anomalies are calculated for each period (the FIM, SWM, SIM, and NEW) and each position (latitude and longitude (20° S–20° N to 30–120° E) using a cycle. The correlation coefficient of each position is stored in the correlation matrix, and the significance matrix stores the significance mark. By studying the correlation between SST across different time periods and precipitation during future time periods, the lead–lag relationship can be explained, which means that the change in one variable precedes the change in another variable over time, indicating that the former may have a predictive effect on the latter. In this study, we used SST anomalies during four different monsoon periods to conduct a correlation analysis with OND precipitation anomalies, with the aim of exploring whether SST anomalies during different periods have an impact on subsequent precipitation and to determine whether these impacts are significant. The formula is as follows [83].

\[
 r = \frac{\sum (X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum (X_i - \overline{X})^2 \sum (Y_i - \overline{Y})^2}}
\] (7)

where \( X_i \) is the SST anomaly and \( Y_i \) is the precipitation anomaly. \( \overline{X} \) and \( \overline{Y} \) are the corresponding means. This formula calculates the linear relationship between the two variables in the range \([-1, 1]\).
To determine whether the correlation is significant, we use a \( t \)-test.

\[
t = r \sqrt{\frac{n-2}{1-r^2}} \tag{8}
\]

Here, \( r \) is the Pearson correlation coefficient and \( n \) is the sample size, and we use the \( p \)-value to assess the significance of the \( t \)-test.

\[
p = 2 \times \left( 1 - CDF_{t \times (n-2)}(|t|) \right) \tag{9}
\]

\( CDF_{t \times (n-2)} \) is the cumulative distribution function of the \( t \) distribution, with \( n-2 \) degrees of freedom, and \(|t|\) is the absolute value of \( t \). The \( p \)-value designed in this study is significant when it is less than or equal to 0.5.

Simple Linear Regression is applied to investigate the correlation between SST anomalies in the western IO and precipitation in Sri Lanka between October and December (OND) \[83\].

\[
y_i = \beta_0 + \beta_1 x_i + \epsilon \tag{10}
\]

where \( y_i \) is the precipitation anomaly, \( x_i \) is the sea surface temperature anomaly, \( \beta_0 \) is the intercept, \( \beta_1 \) represents the slope, and \( \epsilon \) indicates the error term. The standard error of the regression coefficient is calculated as follows:

\[
SE(\beta_1) = \sqrt{\frac{\sum(y_i - (\hat{\beta}_0 + \hat{\beta}_1 x_i))^2}{(n-2)\sum(x_i - \bar{x})^2}} \tag{11}
\]

Here, \( SE(\beta_1) \) is the standard error of the regression coefficient, \( \bar{x} \) is the mean of precipitation anomalies, and \( n \) is the number of samples. The \( t \) statistic is further calculated to test the significance of the regression coefficient:

\[
t = \frac{\hat{\beta}_1}{SE(\hat{\beta}_1)} \tag{12}
\]

\[
|t| > t_{\text{critical}} = t_{(1-\alpha/2,(n-2))} \tag{13}
\]

where \( \alpha = 0.01 \), which means the confidence level is 99%. If the significance test passes \(|t| > t_{\text{critical}}\), the regression coefficient is significant. In this study, the Trend-Free Pre-Whitening Mann–Kendall (TFPW-MK) test is used to analyze the trend of the extreme precipitation index in Sri Lanka from 1980 to 2020. It combines pre-whitening and the Mann–Kendall test to improve the accuracy of trend detection in auto-correlated data \[84\].

Firstly, remove the trend term in the sample data through \( \hat{\beta} \) (Theil–Sen regression estimator) to obtain \( Y_i \):

\[
\beta = \text{Median} \left[ \frac{(X_j - X_i)}{(t_j - t_i)} \right] \forall i < j \tag{14}
\]

\[
Y_i = X_i - \hat{\beta} \tag{15}
\]

where \( x_i \) and \( x_j \) are the data values at times \( t_i \) and \( t_j \), respectively.

Then, calculate the first-order auto-correlation coefficient \( (r_i) \) of \( Y_i \) \[85,86\]:

\[
r_i = \frac{1}{n-1} \sum_{i=1}^{n-1} \frac{[X_i - E(X_i)][X_i+1 - E(X_i)]}{\frac{1}{n} \sum_{i=1}^{n} (X_i - E(X_i))^2} \tag{16}
\]

where \( E(X_i) \) is the mean value.

\[
Y_i' = Y_i - r_1 \times Y_{i-1} \tag{17}
\]

\[
Y_i'' = Y_i' - \hat{\beta}_i \tag{18}
\]
3. Results and Discussion

3.1. Long-Term Precipitation Characteristics

3.1.1. Spatiotemporal Changes in Precipitation in Sri Lanka

Figure 3 shows a spatial gradient with precipitation rates gradually increasing from southwest to northeast in Sri Lanka from 1981 to 2020. This reflects the fact that Sri Lanka experiences the SWM and NEM periods throughout the year. Specifically, from April to September, large-scale precipitation begins to occur in the southwest of Sri Lanka and gradually extends to the northeast. The amount of precipitation in October, November, and December (OND) is relatively high, accounting for 46.3% of the annual precipitation. Notably, the OND precipitation is influenced not only by the monsoon factor but also by the ITCZ, tropical depressions, and cyclones in the Bay of Bengal (BOB) and orographic effects [12]. With this premise, this work further uses the concept of the rainy season OND [87], which describes the precipitation pattern in Sri Lanka from October to December. This redefined season better captures the dynamics of precipitation in the region.

![Spatial distribution of average monthly precipitation over Sri Lanka between 1981 and 2020. The amount of precipitation in October, November, and December (OND) is accounting for 46.3% of the annual precipitation. The precipitation data come from the CHIRPS data.](image-url)

The data clearly show that precipitation in Sri Lanka peaks during OND, with November being the peak period. Recognizing the importance of these major precipitation seasons, we conducted a comprehensive examination of the SPI time series and its 5-year moving average during the Sri Lankan OND season. The SPI can determine whether Sri Lanka is dry or wet over a long-time scale [88]. When the SPI is negative, it indicates drought. When the SPI is positive, it indicates wetness (see Table 2). Figure 4 shows the trends...
of Sri Lanka’s precipitation and IO SST during the OND around 2002. As illustrated in Figure 4a, whether they are CHIRPS data or GPCP data, the results revealed a noteworthy trend: around 2002, the SPI shifted from a negative to a positive trend. This shift implies a substantial increase in precipitation during the OND, exceeding the long-term average. Numerous modeling analyses indicate that heightened precipitation intensity and reduced precipitation frequency are predominantly linked to warming [89–93]. Prior studies have examined how the IO SST affects precipitation in Sri Lanka [94]. In this study, we extend this understanding by conducting a comparative analysis of the IO SST between two different time frames: 1981–2001 and 2003–2020. This analysis provides valuable insights into the changing relationships between these key climate variables.

Examining Figure 4b, the study observed the contrast in IO SST anomalies between two distinct time periods (i.e., 1981 and 2001 and 2003 and 2020), and clear differences can be found. The IO SST anomalies during 2003–2020 were significantly higher than those observed during 1981–2001. That is, the IO SST is significantly warmer. Additionally, increased IO SST anomalies extend into the more central regions from the western tropical IO area. This shift underscores the strong correlation between warming anomalies in IO SST and increased precipitation during OND in Sri Lanka.

To further explore the link between SST anomalies in the IO and precipitation during OND period in Sri Lanka, while fully considering its lead–lag relationship [95], the precipitation in Sri Lanka during the OND period and the IO SST anomalies during the four monsoon periods were studied. Additionally, we conducted a correlation analysis to explore the relationship.

Figures 5 and S2 indicate the correlation between IO SST anomalies and Sri Lanka precipitation during OND across the four monsoon periods. The correlation coefficient ranges from −0.29 to 0.32 in NEM, from −0.38 to 0.30 in FIM, from −0.51 to 0.45 in SWM, and from −0.48 to 0.59 in SIM, respectively. And, significant changes in the degree of correlation are observed during different monsoon periods. Specifically, there is a weak correlation between IO SST anomalies and OND precipitation in Sri Lanka during the NEM and FIM, with no significant observed connection. This implies that IO SST anomalies’ influence on subsequent OND precipitation during these two monsoon periods is limited. In contrast, there is a moderate correlation between western IO SST anomalies and Sri Lanka OND precipitation during the SWM. This indicates that IO SST anomalies during SWM may significantly influence Sri Lanka’s OND precipitation. It is essential to observe that the western IO SST anomalies showed a strong correlation with OND precipitation anomalies in Sri Lanka during the SIM (r ≥ 0.5). This implies that, compared with other seasons, the
western IO SST anomalies during the SIM are likely to exert a greater influence on OND precipitation in Sri Lanka. This correlation pattern aligns with the positive correlation pattern in IOD SST [48]. Based on the findings, it is evident that IO SST anomalies exert a strong and noteworthy influence on OND precipitation patterns in Sri Lanka during the SIM. Increased SST during the SIM may act as a catalyst for increased precipitation in OND, thereby playing a key role in precipitation in Sri Lanka.

Figure 5. The correlation (shading) from 1981 to 2020 between OND precipitation anomaly and IO SST anomaly in (a) the North–East Monsoon (NEM: December to February), (b) the First Inter-Monsoon (FIM: March to April), (c) the South-West Monsoon (SWM: May to September), and (d) the Second Inter-Monsoon (SIM: October to November), respectively. The contour lines delineate areas where correlation coefficients surpass 0.4, and the significant regions at a 95% confidence level are marked with black dots. (d) The square (1° S–7° N and 50–62° E) defines the SST parameter.

Figure 5d reveals a correlation in the area from (1° S–7° N to 50–62° E), with the correlation reaching 0.5. Despite the calculated correlations being statistically significant, they remain relatively small, implying the involvement of other influencing factors in precipitation changes. But, our results underscore the significant impact of increased IO SST. Specifically, the central and western IO SST growth in the SIM demonstrates a substantial and noteworthy influence on precipitation changes during OND in Sri Lanka. Based on these insights, this study presents an SST parameter derived from SST anomalies within designated square regions in Figure 5d (1° S–7° N and 50–62° E) to elucidate the link between western IO SST anomalies and Sri Lanka’s OND precipitation. To deepen our understanding of this intricate relationship, the study conducts a comprehensive exploration of differences in atmospheric circulation, broadening our understanding of the intricate interactions between these key climate variables.

Figure 6 illustrates the clear relationship between western IO SST anomalies and IO precipitation anomalies during the OND period, particularly against the background of the SIM. Specifically, the significant increase in precipitation in the central and western IO, along with the suppression of precipitation in the eastern IO, is attributed to the rise in the western IO SST. This distinctive pattern may be due to the fact that the cold SST anomalies off of the coast of Sumatra suppress convection, while the warm SST anomalies on the west side enhance convection [96], leading to enhanced low-level easterly winds and subsequently tilting convective activity anomalously towards the central IO [97]. Consequently, this shift enhances the availability of water vapor transport, ultimately resulting in increased precipitation over Sri Lanka during OND.
To sum up, the western IO SST increase during the SIM has a noteworthy effect on precipitation dynamics in Sri Lanka during the OND period. This impact plays a vital role in determining Sri Lanka’s precipitation patterns by enhancing precipitation and causing intense periods of rain during the rainy season.

Although strides have been made in linking IO warming to OND precipitation patterns, the complexity of tropical climate dynamics leaves many uncertainties regarding the underlying mechanisms. One such influencing factor is the Madden–Julian Oscillation (MJO), which exerts a considerable influence on seasonal precipitation changes. The SWM and SIM are particularly prone to substantial precipitation anomalies driven by MJO dynamics [26]. Furthermore, the Walker Circulation contributes significantly to shaping the climatic conditions in Sri Lanka. During the OND period, it induces increased convection in the region, as well as increased subsidence during the remainder of the year [98]. During the OND period, there is an increase in convection across Sri Lanka and the south of India [99]. Additionally, studies indicate that precipitation patterns in tropical regions may experience notable alterations during extreme occurrences like the IOD and ENSO. For example, during summer, the ENSO events tend to trigger droughts in the north of Sri Lanka, while the IOD phenomena lead to excessive precipitation in the southern parts of the country [46]. However, current studies primarily focus on the direct impact of IO warming on OND precipitation, without fully quantifying how the OND precipitation changes in response to major climate phenomena, including the ENSO, IOD, Indian Ocean Basin (IOB), MJO, etc. The relationship between ENSO and IOD is also worthy of attention. Studies have shown that nearly 40% of IOD occurs at the same time as ENSO. Yue et al. [100] observed that favorable IOD conditions boost the progression of El Niño. Ashok et al. [101,102] found that a negative IOD is usually related to the La Niña phenomenon. The IOB is traditionally recognized as the IO’s response to the ENSO via atmospheric teleconnections, as highlighted in studies by Xie and Marathe et al. [103,104]. Notably, recent findings [105] introduced a novel perspective that revealed the importance of IOB. This multifaceted aspect represents an interesting and complex area that deserves further comprehensive study.

3.2. Spatial Variability of Extreme Precipitation Indices

The extensive documentation of the global surge in severe weather occurrences since 1950 has been carried out by the Intergovernmental Panel on Climate Change (IPCC). This comprehensive effort undertaken by the IPCC has aimed to provide thorough insights into the escalating frequency and severity of extreme weather phenomena worldwide [73].

Figure 6. Regression map of the SIM SST parameter, OND precipitation, and 850 hPa wind anomaly; contour lines delineate areas where the precipitation response is amplified due to warming in the western IO.
Precipitation in Sri Lanka has increased significantly in the past few years, which is not only responsible for the IO warming anomaly but also for an escalation in extreme precipitation events. Significantly exacerbating climate change, evolving patterns of extreme precipitation impact key sectors, such as agriculture and water resource management [106]. Therefore, this study further examined the trends in Sri Lanka’s extreme precipitation indices, aiming to understand their influence on the country’s overall precipitation patterns.

As depicted in Figure 7, the study uses the TFPW-MK test and Sen’s slope to study the spatial variation of the extreme precipitation index trend at nine meteorological stations in Sri Lanka from 1981 to 2020 [22]. The indices associated with heavy precipitation were calculated for these stations (as listed in Table 1), and the summarized outcomes are presented in Supplementary Table S2. One noteworthy finding is that the PRCPTOT showed a significant upward trend at all stations. Among them, Ratnapura had the highest increase of 29.63. The noticeable transition primarily stems from the increased incidence of intense precipitation events [107]. The SDII in most areas showed a significant downward trend, but the rate of decline was very small. This is because as precipitation increases, so do the number of wet days. Among them, Jaffna and Trincomalee exhibited a negligible downward trend of only $-0.06$ and $-0.02$. When analyzing RX1day, it was found that all stations demonstrated a decreasing trend. Except for the three stations in the southwest, the rest of the stations showed a significant decline, among which Jaffna had the largest decline of $-0.82$ [103]. In addition, R10 and R20 showed a significant upward trend as a whole, while for R20, only the two stations in the central region (Mahailluppallama and Badulla) showed an insignificant increase, and the rate of increase was very small.

![Figure 7. Cont.](image_url)
Figure 7. Spatial distribution of extreme precipitation indices. Mark (I) includes (1) PRCPTOT, (2) SDII, (3) RX1day, (4) R10mm, and (5) R20mm, respectively; (II) includes (1) R95p, (2) R99p, (3) CWD, and (4) CDD, respectively. Blue coloring indicates an increasing trend and red coloring indicates a decreasing trend. The circle represents significant correlations at $p < 0.05$. The star represents a slope value of 0 (for details, see Figure 1 for the base map). And, the data come from CHIRPS data.

Using the R95P, it can be seen that the northern regions and the southern regions show different spatial distributions. The extreme precipitation high-value area is located in the north, and the extreme precipitation low-value area is located in the south. The results show that Jaffna and Trincomalee have an upward trend of 7.91 and 6.87, while Galle has a decrease of $-3.25$, reflecting spatial variability. This indicates that precipitation is shifting from the humid southwest to the dry northern regions. For R99P, it shows almost the opposite result to R95P, especially in Jaffna, where the upward trend changes to a significant decrease. This is worth considering, highlighting an increase in Jaffna’s extreme precipitation events (R95P), while severe precipitation events (R99P) are slightly decreasing.

For CWD continuous wet days, all stations show a significant upward trend, while for CDD continuous dry days, all stations show a downward trend, especially in the southwest.

Taken together, these results highlight that precipitation is highest in the southwest and lower in the north. However, for extreme precipitation, the southwestern humid region shows a clear downward trend, while the northern dry region shows an upward trend, especially in the Jaffna region. This not only shows that Jaffna is leaving the arid zone but also proves the increase in extreme precipitation events, further confirming that Jaffna has become an important research area for extreme precipitation events. Several research endeavors have demonstrated that the share of extreme and heavy precipitation events within the overall precipitation is anticipated to rise throughout the 21st century compared
to moderate and gentle precipitation occurrences [93]. Consequently, these findings are crucial for formulating effective water resource management strategies [71].

3.3. Case Study
3.3.1. Environmental Conditions

Figure 7 reveals a clear trend in the indices of Jaffna area’s extreme precipitation, which is significantly different from other regions, indicating a clear upward trajectory. The marked rise in extreme precipitation indices holds considerable importance for investigating severe precipitation events, prompting this study to designate the Jaffna region as the focus of an in-depth study of such events.

Meanwhile, detailed data analysis was conducted using weather station data in the Jaffna region between 2010 and 2022. According to the data in Figure 8a, the analysis suggests that the Jaffna region experienced a total of 56 extreme precipitation events from 2010 to 2022. The most serious event was on 9 November 2021, with precipitation of 295 mm. According to the previously defined extreme precipitation event standards, days when the daily precipitation exceeds 95% of all rainy days for one or more consecutive days (daily precipitation > 0.1 mm/day) are extreme precipitation events. Therefore, the event that occurred in the Jaffna region on 9 November 2021 was chosen as an extreme precipitation event, providing an object for further exploration of the mechanisms of such phenomena.

![Figure 8](image-url)

*Figure 8. (a) Time series of Jaffna region’s extreme precipitation events between 2010 and 2022. (b) Spatial distribution of precipitation and (c) vertical profile of precipitation in Sri Lanka on 9 November 2021.*

Furthermore, as shown in Figure 8b,c, a comprehensive examination of the precipitation intensity and its vertical distribution confirmed the weather conditions in the Jaffna region on 9 November 2021 as an extreme precipitation event. The regions experiencing heavy precipitation are primarily distributed across central and northern Sri Lanka, with an extension towards the south, notably in the Jaffna region (refer to Figure 8b). These intense local precipitation events often arise from various processes, such as monsoonal processes, cyclonic or frontal processes [108], convective processes, and the expansion of the ITCZ [109]. A closer look at the vertical profiles in Figure 8c reveals a trend. The precipitation rates increase with decreasing altitude, which sets the Jaffna region apart from other regions. This remarkable feature means there is convective activity in the atmosphere. This instability in the state of the atmosphere is often associated with rapid fluctuations in temperature or humidity. These changes promote the rise of updrafts, leading to cloud formation and subsequent precipitation [110]. It was further observed that heavy precipitation was significantly concentrated, with the heaviest precipitation occurring at lower elevations where temperatures were above freezing. At the same time, the precipitation distribution in the area is uneven, with more precipitation in some longitudinal areas. This may be due to local atmospheric conditions or terrain effects, such as mountains, which can enhance precipitation through terrain uplift.
3.3.2. Mechanistic Analysis

We delve deeper into the mechanisms of this extreme event, considering three fundamental aspects: near-surface characteristics, tropospheric atmospheric conditions, and vertical structures. Figure 9a indicates that during an extreme precipitation event in Sri Lanka, the most notable positive precipitation anomaly is observed near Sri Lanka, with a significant increase in precipitation also noted east of Sri Lanka. This pattern suggests regional consistency in extreme precipitation events in Sri Lanka, indicating regulation by large-scale circulation rather than localized factors \[111,112\]. In Figure 9b, the temperature in northern Sri Lanka experienced a significant cooling effect during the extreme precipitation event, while the temperature in the south exhibited positive anomalies. This temperature variation may be attributed to the influence of topographic features, particularly the central mountains. And, extreme precipitation is closely related to temperature \[113,114\]. Figure 9c depicts near-surface low-pressure anomalies in the latitude range of approximately 5° to 10° near Sri Lanka, representing ITCZ \[115\]. This phenomenon is typically generated by the convergence of air masses and associated large-scale updrafts. At the same time, combined with Figure 9b, the ocean area warming, combined with the notable cooling observed in the continental region, promote the movement of northeasterly winds in the BOB. Therefore, the moisture transported from the BOB fosters ideal circumstances for the growth of the NEM over Sri Lanka \[116\].

![Composite image of precipitation, temperature, and surface pressure](image)

Figure 9. Composite image of (a) precipitation, (b) surface temperature, (c) surface pressure, and surface wind anomalies for Sri Lanka's extreme precipitation event on 9 November 2021. Sri Lanka's borders are indicated by red outlines (the same is true below).

This study extends its investigation to the tropospheric synoptic characteristics associated with extreme precipitation events. Figure 10 illustrates the distribution of geopotential height anomalies and corresponding wind fields across the troposphere.

In accordance with Figure 10b, it can be seen that the low-pressure circulation near Sri Lanka in the mid-level is enhanced, and its force extends to the lower levels, forming two obvious circulation centers in the Arabian Sea and the BOB at 850 hPa \[117\]. And, the center is stronger over the BOB and extends east and south \[118\] (refer to Figure 10a). Simultaneously, obvious easterly waves appeared above 250 hPa (noted in Figure 10a), which was the result of the strengthening and upward extension of the mid- and low-level circulation. Concurrently with the emergence and progression of the low-level westerly jet at 850 hPa, an easterly jet materialized on the northern side of the low-pressure system (see Figure 10b). Situated at approximately 500 hPa, the center of the easterly jet stream is higher than that of the westerly jet stream. As the low-pressure circulation evolves and intensifies, the easterly jet progressively approaches the central region of the low-pressure...
circulation (as shown in Figure 10c) and ultimately becomes part of the low-pressure circulation. Simultaneously, in the middle and lower troposphere, the distribution of low-level northeasterly winds and terrain elevation anomalies create favorable conditions for wind penetration into Sri Lanka and contribute to the effective transport of clouds to Jaffna. Additionally, it is clear that nearer to the surface the wind speed escalates, accentuating the low-pressure system. The synergistic effect of strengthened mid- and low-level northeasterly winds and low-pressure systems promoted large-scale updrafts, leading to the manifestation of this significant precipitation event. This aligns with the evaluation of [42] that the cyclonic circulation centered over eastern Sri Lanka leads to a rise in the convergence of water vapor flux in the lower troposphere.

![Composite plots in Sri Lanka on 9 November 2021 of geopotential height anomalies and their corresponding wind fields at (a) 250, (b) 500, and (c) 850 hPa, and (d) vertically integrated moisture flux divergence and water vapor flux for the extreme precipitation event.](image)

In winter, the NEM is predominantly influenced by the Siberian High and originates from interior Asia, extending to the Indian subcontinent, Sri Lanka, and the BOB. The NEM typically occurs around the last week of November, with a gradual fading observed from the final week of February. The monsoon is pivotal in delivering precipitation to the east and north regions of Sri Lanka. As delineated in Figure 10d, a mild cyclonic circulation characterized by horizontal wind shear was observed in proximity to Sri Lanka [119]. This circulation facilitated the convergence of winds towards Sri Lanka, engendering a distinct convergence area within the BOB. At the same time, the existence of horizontal wind shear in this area is favorable for cloud formation and thus precipitation. Concurrently, the monsoon, traversing the Indian subcontinent, exhibited a transition from northeasterly to westerly winds upon reaching the Arabian Sea. This transition led to the creation of a distinct low-level convergence zone, extending from the Arabian Sea to the western periphery of Sri Lanka. Furthermore, this westerly wind continued its trajectory towards Sri Lanka, ultimately amalgamating with the winds in the BOB. The emergence of these two convergence zones is attributed to the interplay between the prevailing low-level monsoon winds and the regional topography. This interaction results in the augmented wind and moisture convergence of Sri Lanka. Additionally, the dynamic interplay of meteorological phenomena, such as convergence, convection, and depression, act synergistically to promote uplift and enhance the moisture supply. The amalgamation of these factors markedly enhances the incidence of precipitation events, particularly in the Jaffna region.

Based on the aforementioned investigations, it is evident that the Siberian High, robust convective activities, and alterations in wind fields exert a substantial influence on the vertical structure of the atmosphere. At the same time, there is a critical need to delve into the study of the vertical atmospheric structure concerning extreme precipitation events.

Figure 11a illustrates that negative geopotential height anomalies commonly signify lower atmospheric pressure, fostering updrafts. Such updrafts frequently lead to height-

As shown in Figure 11b, vertical profiles of water vapor flux divergence offer insight into how water vapor is transported and distributed vertically in the atmosphere. Previous research has elucidated that extreme precipitation areas occur with low-level convergence, positive vorticity perturbations, and upper-level divergence. The Jaffna region exhibits high levels of divergence accompanied by low levels of convergence. Observe the change in wind direction from 1000 hPa to 500 hPa, where there is an updraft and the air masses converge to form a convergence zone. As the altitude continues to rise, the 400 hPa wind direction and water vapor flux divergence change significantly, from updraft to downdraft, accompanied by air dispersion. Such rapid changes in wind direction and water vapor flux often occur near jet streams or shear layers, which are known to cause airflow instability. In particular, vertical shear plays a crucial role in promoting upward motion and convection; this, consequently, triggers the onset of intense precipitation.

Zooming into the area surrounding Sri Lanka, based on the chart in Figure 11c, the Jaffna region exhibits significant negative vertical velocity anomalies, indicating significant upward motion. These atmospheric circumstances play a pivotal role in the incidence of severe precipitation occurrences.

To sum up, Sri Lanka’s continuous heavy precipitation results from the combined influence of favorable low-level water vapor in the IO, the Arabian Sea, and the BOB, horizontal and vertical wind shear, low-level convergence, high-level divergence, and unusually strong updrafts in the surrounding areas of Sri Lanka.

4. Conclusions

In this study, precipitation characteristics and mechanisms over Sri Lanka are comprehensively analyzed by taking into account the broader background of the western Indian Ocean using a 40-year database (from January 1981 to December 2020), which includes the CHIRPS, GPCP satellite data, GPM DPR data, reanalysis data, and weather stations’ data. The primary findings of this study are outlined below.

1. Sri Lanka exhibits unique spatial precipitation patterns from 1981 to 2020. Precipitation gradually increases from the southwest to the northeast of Sri Lanka. It is worth noting that there is a substantial and evident upward trend in precipitation in both summer and winter, with the OND period having the wettest months. These changes...
in precipitation distribution under changing climate conditions have significant implications for meteorologists and climate researchers.

2. This study finds that the IO SST increased significantly after 2002, with significant warming from western to central tropical IO. Subsequent investigations highlighted the rising IO SST influence on precipitation patterns in Sri Lanka. The increase in the western IO SST also results in the development of an east–west zonal pattern of the SST gradient, which fosters the reinforcement of low-level circulation and the onset of anomalous westerly winds in the equatorial western IO. The anomalous westerlies in turn induce extensive convergence of the western IO in the SIM, causing increased precipitation over Sri Lanka during the OND period. These findings provide valuable insights into the mechanisms by which changes in the IO SST affect precipitation patterns in Sri Lanka.

3. Simultaneously, the study observes a notable increase in extreme precipitation in the arid northern part of Sri Lanka in recent years. The study further focused on the extreme precipitation event in Jaffna in arid northern Sri Lanka on 9 November 2021. The results showed that in terms of precipitation relative to the climatic norms over an extended period, the Jaffna region has low-level convergence, high-level divergence, increased humidity, and anomalies in near-surface low pressure. These climate systems result in the anomalous convergence of northeasterly and westerly winds in the Jaffna region, transporting substantial quantities of water vapor to the region from the IO, Arabian Sea, and BOB. These dynamics are considered key factors in the incidence of severe precipitation events. Furthermore, negative anomalies in geopotential height, horizontal and vertical wind shear, and vertical velocity over the Jaffna region indicate the presence of a convective system that promotes intense convective activity, thus creating dynamic circumstances for extreme precipitation incidents in the area.

Hence, the investigation underscores the critical importance of western IO warming SST anomalies for precipitation over Sri Lanka. This warming trend may lead to more pronounced rainy seasons in the future. Furthermore, we discovered the significant impact of extreme precipitation events on the regional distribution of precipitation in Sri Lanka. Thus, we should not only pay attention to the southwestern provinces of Sri Lanka but also focus on the northeast in the future. Supported by extensive long-term observational studies and in-depth short-term case studies, our findings have significant implications for improving our comprehension of precipitation changes in the tropics and the sustainable development of marine islands. Small island countries are more vulnerable to climate change, such as extreme precipitation, compared with other regions worldwide. They are relatively fragile and have limited capacity to cope with extreme events. Therefore, this work provides a solid scientific basis for mitigating the adverse consequences of extreme-precipitation-related disasters, especially those related to the ecological environment and agricultural production. This in turn helps to enhance the protection of human life and property. Concurrently, this study found that GHIPRS precipitation data can be used as a substitute for observational data to analyze extreme precipitation trends. In this way, it can be applied to developing countries, such as tropical and subtropical areas, where there are no observation stations or the observation station data do not highlight good spatial variability. However, the research methods used in this study are relatively single. In the following sections, we will add other methods, such as deep learning, to further study the complexity of precipitation-formation mechanisms.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/atmos15080962/s1, Figure S1: Cross-validation statistical plots of weather station data and CHIRPS data from 2010 to 2020. (a) Monthly average time series plot, (b) Correlation scatter plot ($R^2 = 0.75$), (c) Box plot, (d) Error distribution histogram; Figure S2: The maximum, minimum and average values of the correlation coefficient between sea surface temperature anomalies and precipitation anomalies in NEM, FIM, SWM, SIM periods, respectively; Table S1: Weather stations
details; Table S2: Trends in precipitation indices over the Sri Lanka. The * represent significant correlations at $p < 0.05$.


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**Data Availability Statement:** The CHIRPS data (https://data.chc.ucsb.edu/products/CHIRPS-2.0/) (accessed on 19 July 2024), the GPCP Monthly product (https://psl.noaa.gov/data/gridded/) (accessed on 10 January 2023), the ERA5 data (https://www.ecmwf.int/en/forecasts/datasets/reanalysisdatasets/era5 (accessed on 19 July 2024)), the DPR data (https://gpm.nasa.gov/missions/GPM/DPR) (accessed on 15 April 2023), and the meteorological stations’ data (https://rp5.ru/) (accessed on 1 March 2023) are available online.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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