Original Research Article

The influence of the Indian ocean warm pool on extreme precipitation over the Tibetan Plateau

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Abstract: This study investigates the influence of sea surface temperature (SST) anomalies in the Indian Ocean Warm Pool, represented by the Indian Ocean Warm Pool Strength (IOWPS) index, on extreme precipitation (RX1day) over the Tibetan Plateau. Using daily precipitation data from the Climate Prediction Center and SST data from the National Climate Center, we assess the relationship between IOWPS and extreme precipitation from 1994 to 2023. Results show a strong positive correlation (r = 0.610) between IOWPS and regionally averaged RX1day. Spatial analysis indicates that the strongest positive correlations are located in the southeastern and southern parts of the plateau, where the South Asian monsoon, modulated by the Indian Ocean warm pool, brings substantial moisture. The findings highlight the significant role of the Indian Ocean warm pool in driving extreme precipitation, particularly through monsoonal moisture transport. This research underscores the importance of understanding ocean-atmosphere interactions for predicting extreme precipitation events in this climate-sensitive region.

Keywords: Tibetan Plateau; Extreme precipitation; Indian ocean warm pool

1. Introduction

Extreme precipitation events over the Tibetan Plateau (TP) have profound impacts on the region's hydrology, ecosystems, and the millions of people living in downstream areas. The TP plays a crucial role in shaping the climate and water resources of Asia, acting as a source of major rivers that support some of the world's most populous regions. Understanding the factors that influence extreme precipitation on the plateau is critical, particularly as climate change continues to intensify weather extremes globally.

Among the key factors affecting precipitation patterns over the Tibetan Plateau is the variability of sea surface temperatures (SSTs) in the Indian Ocean.[1-3] The Indian Ocean Warm Pool (IOWP), which encompasses the region of the Indian Ocean with the highest SSTs, is a crucial driver of atmospheric circulation patterns and moisture transport. [4] Variations in the strength of the IOWP, as quantified by the Indian Ocean Warm Pool Strength (IOWPS) index, significantly impact the South Asian monsoon, which is the primary source of precipitation for much of the Tibetan Plateau.

The South Asian monsoon, driven by the thermal contrast between the Indian Ocean and the Asian continent, transports large amounts of moisture from the ocean to the land. During the summer monsoon season, this moisture is carried over the TP, contributing to both regular rainfall and extreme precipitation events.[5] SST anomalies in the Indian Ocean can strengthen or weaken the monsoon circulation, thereby affecting the intensity and frequency of precipitation events on the plateau. For example, a stronger IOWP, indicated by warmer SSTs, increases moisture availability and evaporation, intensifying the monsoonal flow and enhancing precipitation over the TP, particularly in its southeastern regions.

While several studies have explored the relationship between the South Asian monsoon and Tibetan Plateau precipitation, the specific role of the IOWP in influencing extreme precipitation events remains an area of active research. Extreme precipitation, often measured as the annual maximum daily precipitation (RX1day), has significant implications for regional water resources, flash flooding, and disaster preparedness.[6] Understanding how SST anomalies in the Indian Ocean influence these extreme events is essential for improving climate models and predicting future changes in precipitation patterns.

This study aims to investigate the influence of the IOWPS on extreme precipitation over the Tibetan Plateau from 1994 to 2023. Using gridded daily precipitation data and SST indices, we analyze the correlation between IOWPS and RX1day, focusing on spatial variability across the plateau. We hypothesize that stronger IOWP conditions will lead to enhanced extreme precipitation, particularly in regions of the plateau most directly influenced by the South Asian monsoon. This research will contribute to a deeper understanding of the ocean-atmosphere interactions that drive extreme weather events in the Tibetan Plateau region and help improve predictions of future climate impacts.

2. Data and method

The extreme precipitation data used in this study is obtained from the Climate Prediction Center (CPC) Daily Gridded Precipitation dataset, which provides global precipitation estimates at a 0.5° × 0.5° resolution. The dataset covers the period from 1994 to 2023 and includes daily precipitation measurements that allow for the calculation of extreme precipitation events over the Tibetan Plateau.

For the purpose of this study, extreme precipitation is defined as the annual maximum daily precipitation (RX1day), calculated for each grid point on the Tibetan Plateau. RX1day represents the highest recorded daily precipitation amount in a given year, making it a suitable metric for assessing extreme weather events. We compute the RX1day values for each year and grid point, resulting in a time series of extreme precipitation events across the entire Tibetan Plateau. Additionally, the regionally averaged RX1day values are computed to assess the overall trend and regional variability in extreme precipitation across the plateau.

To analyze the influence of Indian Ocean sea surface temperatures (SSTs) on extreme precipitation over the Tibetan Plateau, we use the Indian Ocean Warm Pool Strength (IOWPS) index. The IOWPS index is derived from the area-averaged SST anomalies over the Indian Ocean warm pool region, which extends from 50°E to 90°E and 10°S to 10°N. This region encompasses the warmest waters of the Indian Ocean, which are critical in driving the South Asian monsoon system.

3. Results

The correlation analysis between the Indian Ocean Warm Pool Strength (IOWPS) index and the regionally averaged extreme precipitation (RX1day) over the Tibetan Plateau from 1994 to 2023 reveals a significant positive relationship. The Pearson correlation coefficient is calculated as 0.610, indicating a strong positive association between warmer sea surface temperatures (SSTs) in the Indian Ocean warm pool and increased extreme precipitation over the plateau.

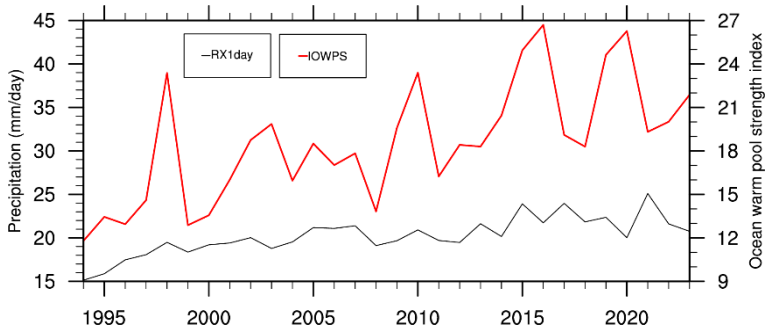

Figure 1. Regionally averaged maximum daily precipitation (RX1day, black line) over the Tibetan Plateau, alongside the Indian Ocean Warm Pool Strength Index (IOWPS, red line) from 1994 to 2023.

Figure 1 shows that years with higher IOWPS values, representing a stronger Indian Ocean warm pool, tend to coincide with higher RX1day values. For example, prominent peaks in IOWPS, such as those in 1998, 2010, and 2015, align with elevated extreme precipitation levels over the Tibetan Plateau. This suggests that increased SSTs in the Indian Ocean warm pool enhance moisture availability and monsoon strength, leading to more intense precipitation events on the plateau. Conversely, years with lower IOWPS values, such as 1993 and 2005, are associated with lower RX1day values, further supporting the positive correlation between these two variables. Overall, the trend analysis suggests that fluctuations in the Indian Ocean warm pool significantly influence the intensity of extreme precipitation events on a regional scale.

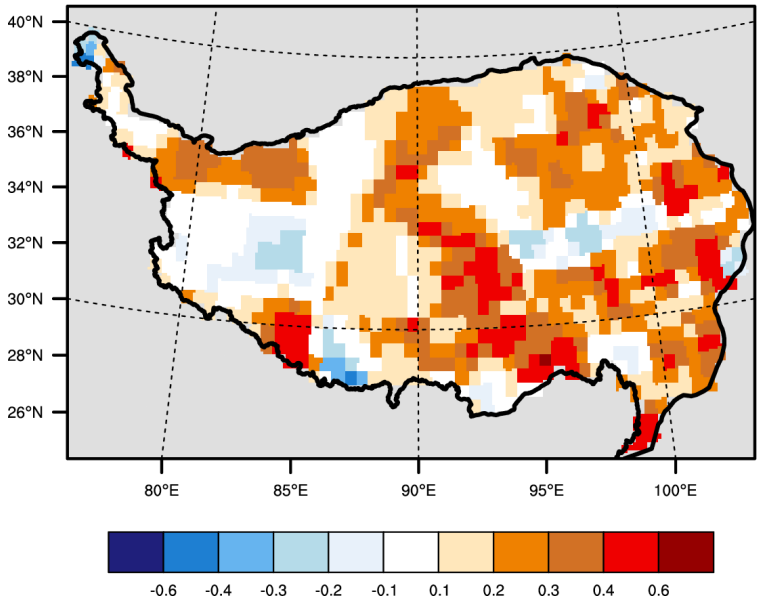

Figure 2. The spatial distribution of the correlation coefficients between the Indian Ocean Warm Pool Strength (IOWPS) index and the extreme precipitation (RX1day).

Figure 2 reveals that the influence of the IOWPS on extreme precipitation is not uniform across the Tibetan Plateau. The strongest positive correlations between IOWPS and RX1day (up to 0.6) are found in the southeastern and southern regions of the plateau. These areas are directly influenced by the South Asian monsoon, which transports moisture from the Indian Ocean. When the IOWPS is higher, the warmer SSTs in the Indian Ocean result in increased moisture supply and stronger monsoonal flows, leading to enhanced extreme precipitation in these regions. The correlation is particularly strong near the southern and southeastern slopes of the plateau, where monsoonal moisture interacts with the complex topography, causing intense rainfall.

4. Conclusion and discussion

This study explores the relationship between the Indian Ocean Warm Pool Strength (IOWPS) and extreme precipitation (RX1day) over the Tibetan Plateau from 1994 to 2023. A strong positive correlation ((r = 0.610)) exists between the IOWPS and regionally averaged extreme precipitation over the Tibetan Plateau, indicating that warmer sea surface temperatures (SSTs) in the Indian Ocean warm pool lead to more intense extreme precipitation events. This correlation is particularly strong in the southeastern and southern regions of the plateau, where monsoonal moisture transport from the Indian Ocean is most prevalent.

The positive relationship between IOWPS and extreme precipitation over the Tibetan Plateau can be attributed to several key atmospheric mechanisms. As the Indian Ocean warm pool strengthens, indicated by higher IOWPS values, there is an increase in SSTs, which enhances evaporation and moisture availability. This additional moisture is transported by the South Asian monsoon to the Tibetan Plateau, particularly affecting the southeastern and southern regions, where monsoonal precipitation is most intense.

While this study provides valuable insights into the relationship between IOWPS and extreme precipitation over the Tibetan Plateau, there are several limitations that should be addressed in future research. The use of 0.5° × 0.5° resolution data may not fully capture the local variability of extreme precipitation, especially in regions with complex topography. Future studies could benefit from using higher-resolution datasets to examine more localized precipitation patterns and their drivers. This study focuses primarily on the influence of the Indian Ocean warm pool. However, other factors such as the Indian Ocean Dipole (IOD), El Niño-Southern Oscillation (ENSO), and westerly winds also play important roles in shaping the Tibetan Plateau's climate. Future research should explore how these additional climate drivers interact with the IOWPS to influence extreme precipitation over the plateau.

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