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Lagged and Timely Effect of ENSO on Summer Monsoon Precipitation over Sudan across 1991-2020

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Abstract: This study investigates the timely and lagged effect of El-Nino Southern Oscillation (ENSO) on the summer monsoon rainfall over Sudan. The analysis was carried out based on zero lag (JJAS), one-month lag (May), two-month lag (April), and three-month lag (March). The study analyzed the dominant modes of the seasonal precipitation to identify the leading pattern and its accountability from the total variance. The EOF analysis revealed that the first mode consists of 52.3% of the total variance and 0.92 consistency recorded between the correspondent PC1 against the raw data field of the seasonal precipitation. The summer monsoon precipitation tends to be strongly correlated with ENSO the smaller the analyzed lag with the highest consistency when the lag is zero. A glimpse of the ENSO correlation with summer monsoon precipitation from March to JJAS suggests shifting in the loading's sign starts by positive sign in March before it gradually turns to negative in JJAS with significant values in El-Nino 3.4 region. Similar responses were shown by the inversed effect, where the timely effect surpassed the lagged ones in particular central parts where significant coefficients exhibit.

Keywords: ENSO, Sudan, Summer Monsoon Precipitation.

Introduction:

The socioeconomic activities in Sudan mainly depend on rainfed agriculture. Roughly 90% of the population relies on the seasonal rainfall and irrigation from the River Nile to secure their living source, agriculture. Moreover, rainfed agriculture is the primary source of the country's income, GDP, and foreign exchanges. The productivity of rainfed agriculture is governed by the magnitude and spatio-temporal distribution of the seasonal rainfall as well as the severe weather events such as droughts and floods, which consider as devastating in almost all cases (Osman and Shamseldin, 2002), (World Bank, 2011), (Salih et al., 2018).

Sudan is characterized by a unimodal pattern of precipitation that dominates the entire country with its peak over August except for the narrow area in the northeast on the Red Sea coast where light rainfall occurs in winter associated with the occasional depression in the Eastern Mediterranean. June-September (JJAS) is the primary rainy season in the entire state, govern basically by the north-south migration of the Inter-Tropical Convergence Zone (ITCZ). This belt is pushed by the South Atlantic High and Mascarene High-pressure systems in the southern hemisphere. As well as the strength and weakness of the Easterly Jet Stream (EJS) at the upper levels, the light impact of the Somali Jet (SJ) was reported as well to have a constructive effect on the summer monsoon precipitation in Sudan in addition to the West African monsoon (Camberlin and Wairoto, 1997), (Fontaine and Louvet, 2006), (Elagib, 2011), (Chen et al., 2013).

Many studies focused on understanding the drivers and the teleconnections of JJAS rainfall over Sahelian Africa; the studies have consensus stated that the ENSO is the main influencer. The positive phase (El-Nino) is associated with deficit conditions in Sudan, while the negative pattern is associated with excess rainfall. These circulations are likely influenced by SSTs around the tropics, determining the amount of atmospheric moisture supported by the circulations. Notably, the El Niño-Southern Oscillation pattern of SST and circulation changes is relevant in most tropics regions, including much of Africa. Tropical circulation patterns over Africa appear to be moderated by SSTs in the Indian and Atlantic Oceans. The highest ENSO signals are found in eastern-equatorial and southeast Africa. Changes in the atmosphere above the seas induced by ENSO have been linked to rainfall variability and droughts in Africa's Sahel area. ENSO is one of the variables that might cause the ITCZ to behave abnormally. These anomalies have an impact on Sudan and its rainfall variability (Hulme and Tosdevin, 1989), (Lélé and Lamb, 2010), (Zhang et al., 2012), (Rhodes, 2012), (Endris et al., 2019), (Kiflie and Tao, 2020).

Objectives:

In this study and based on the findings mentioned above, we aim to investigate the lagged and timely associations of the seasonal rainfall over Sudan and quantify the inversed spatial patterns of the consistency between the ENSO and the study area. The remaining parts of this paper cover: data & methodology, results & discussion, and conclusion.

Data and Methodology:

The gridded Climate Hazards Group Infrared Precipitation with Stations version two (CHIRPS-v2) with a spatial resolution of 5.5 km was employed in this study. CHIRPS-v2 uses the Tropical Rainfall Measuring Mission Multi-Satellite Precipitation Analysis version 7 (TMPA-3B42-v7). It produces a worldwide rainfall product with low latency, high resolution, low bias, and a long record period by interpolating gauge station data with satellite-derived precipitation estimations; this data sets available through: https://iridl.ldeo.columbia.edu/ (Dinku et al., 2018). Reanalysis data from NOAA for Sea Surface Temperature with a grid size of 1°×1° in a row were employed in this study to investigate the associations of the mentioned variable with monsoon rainfall over Sudan; this data sets can be accessed through: https://psl.noaa.gov/data/gridded/data.cobe.html. For ENSO, Nino3.4 index, an average of SST over 5°S–5°N and 170°–120°W, is used to compute the teleconnections, available at: https://climatedataguide.ucar.edu/ (Trenberth, 1997).

To demonstrate the leading mode of the seasonal precipitation and extract the correspondent principal component (PC1), the Empirical Orthogonal Function (EOF) analysis was carried out. Pearson Correlation Coefficient was employed to quantify the consistency and compute the teleconnections. A student T-test was used to determine the significance of the estimated coefficients. The standardized anomaly was used to normalize the time series and remove the influence of dispersion (Elagib and Mansell, 2000), (Hannachi, 2004), (Xin et al., 2020).

Results and Discussion:

Dominant Mode of Summer Monsson Precipitation:

Figure 1a) illustrates the dominant mode of the seasonal precipitation based on EOF analysis; this mode is characterized by positive loading that overwhelms the entire country with 52% of the total variance in the seasonal rainfall. This pattern follows the gradual distribution of the lond-term mean of seasonal precipitation. As the oscillation movement of the ITCZ northward in the onset (June) and southward in September makes the southern areas under the effect of moist air from the Indian and Atlantic ocean for a longer time compared to the northern parts where the ITCZ stays for days to weeks (Camberlin and Wairoto, 1997), (Lélé and Lamb, 2010).

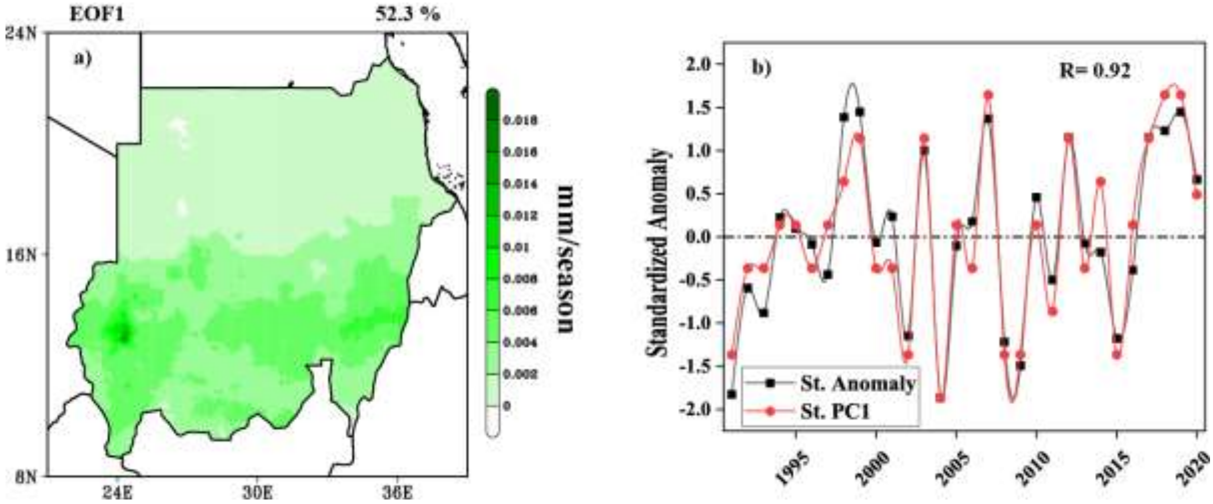

Figure 1a) Spatial pattern of the first EOF of summer monsoon precipitation, b) the standardized interdecadal variability of the PC1 and the precipitation anomaly.

The mode accounts for almost half of the variance of the summer monsoon precipitation, which makes it able to represent the whole variability with more than 50% accountability. This high reliability is proved by the consistency between the analyzed PC1 and raw time series of the precipitation field with 0.92 recorded correlation between the two data fields Figure 1b).

Lagged and Timely Associations with SSTs:

Literature suggests that the sea surface temperatures within the tropics play a critical role in driving atmospheric circulations. On many occasions, the lagged impact exhibits a crucial effect on these circulations' strengths and weaknesses. These effects come basically from the life span of the phenomena, ENSO for instance, it lasts from months to years in an oscillating pattern from negative, neutral to positive phases. Literature suggests that the Mediterranean, Indian, and Atlantic Ocean SST's role could be increasingly important in influencing the atmospheric circulation over east Africa as well (Trenberth, 1997), (Williams and Funk, 2011). Hence, the timely and legged impact of SST's is illustrated in Figure 2.

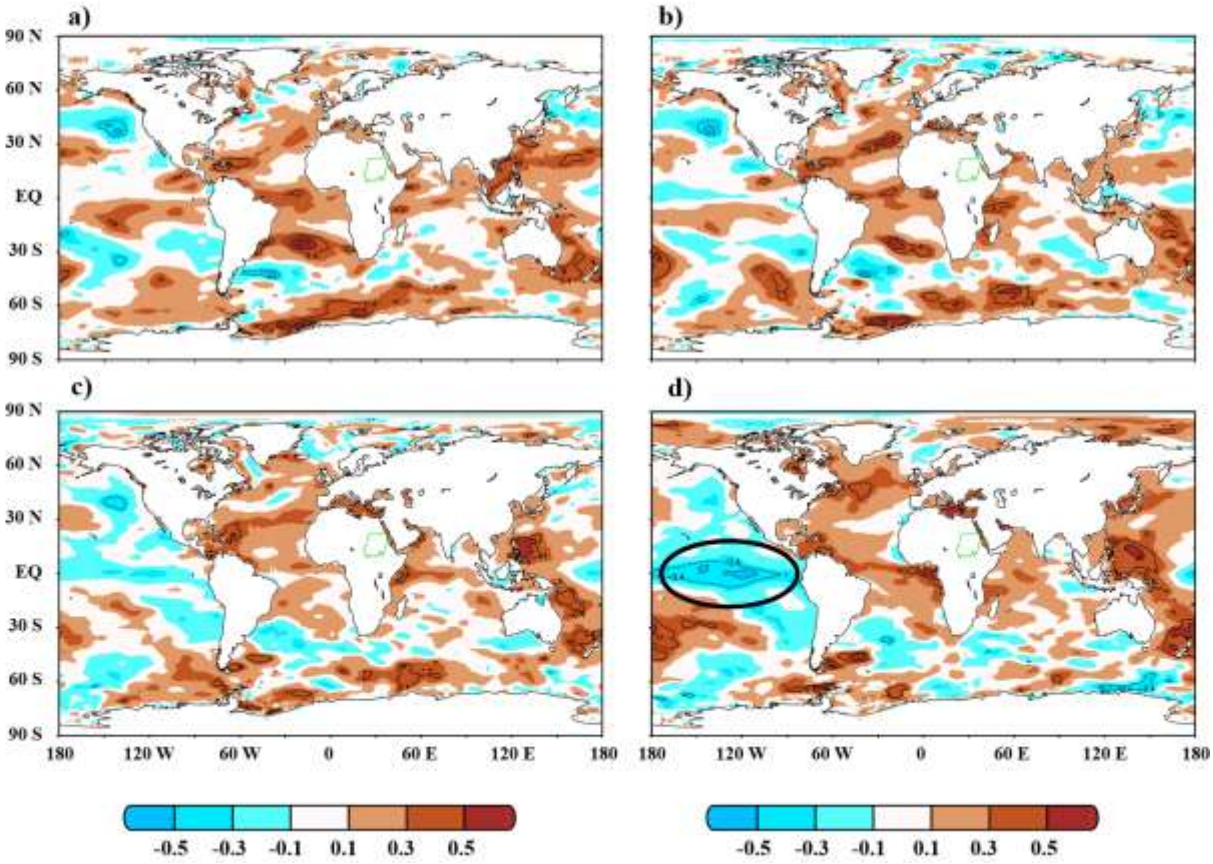

Figure 2 The associations of summer monsoon precipitation with the SSTs in a) March, b) April, c) May, and d) JJAS. The contours signify the areas with a significant coefficient at 95% confidence level.

The associations between SST's and JJAS rainfall over Sudan were investigated in one, two, three months lagged with a one-month interval in addition to the zero-lag. In other words, we investigated the correlation between JJAS rainfall and March, April, May, and JJAS as it is the rainfall occurrence season labeled in this study as the zero lag. Results revealed that starting from March, a mixed pattern in the (northward) from the equator (southward) appears with (decorrelation) positive correlation with the JJAS rainfall over Sudan Figure 2a). Soon after, the decorrelation pattern starts responding negatively to the JJAS rainfall in April associations Figure 2b). By May the negative pattern dominates the whole equatorial pacific except the far west with coefficient failed to pass the significant test at 95% confidence level Figure 2c).

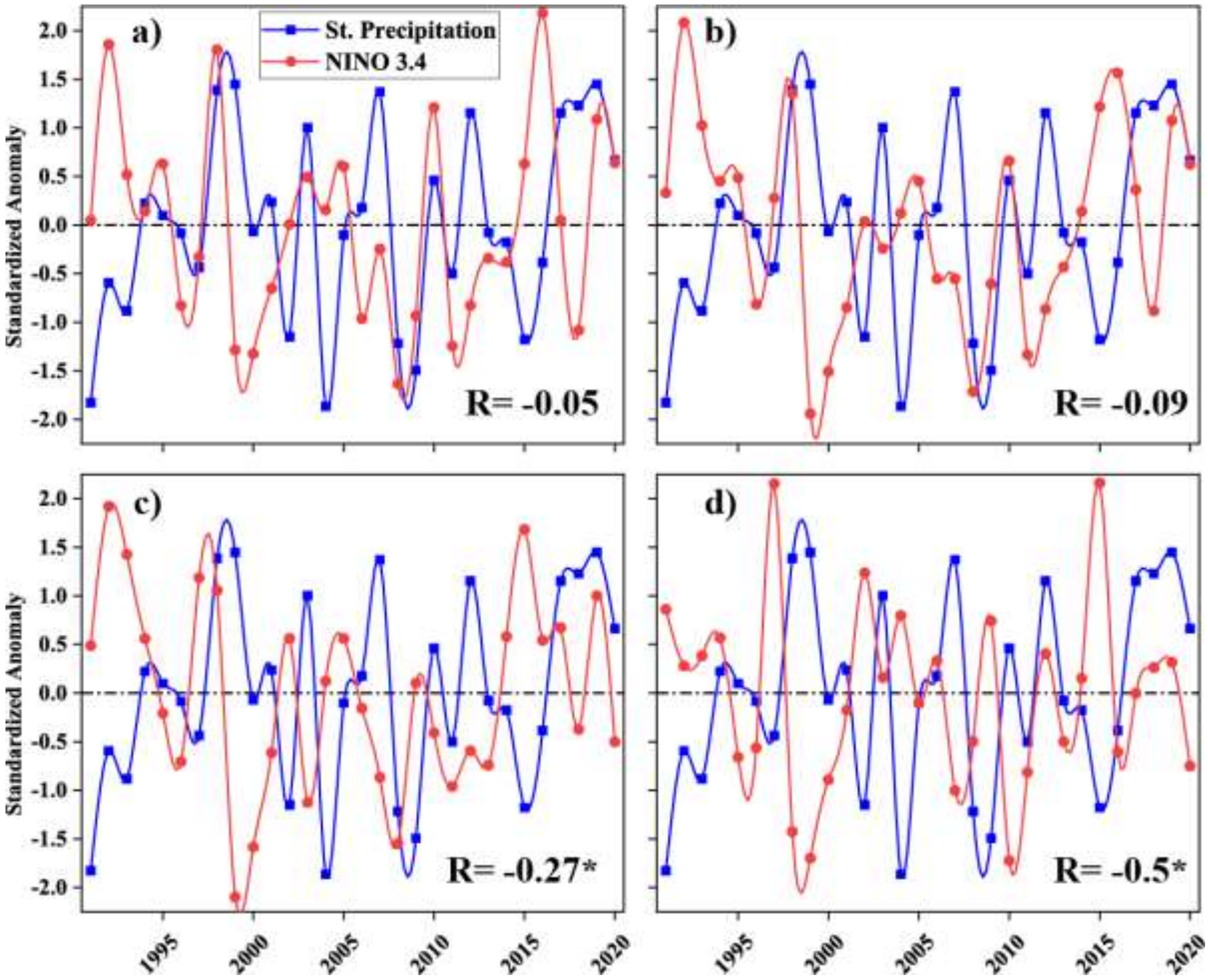

Figure 3 The interdecadal variability of the summer monsoon precipitation against the El-Nino 3.4 index in a) March, b) April, c) May, and d) JJAS. The black stars indicate the values with a significant coefficient at 95% confidence level.

Moving to zero lag associations Figure 2d), summer monsoon precipitation over Sudan is negatively correlated with the SST over tropical central-eastern Pacific and positively correlated with the SST over tropical western Pacific. The positive correlations in the Atlantic Ocean would appear to relate well, supposing that a low Atlantic, high Indian Ocean SST dipole would increase equatorial easterly flows and induce divergence, therefore suppressing convection. However, relatively low level of significance in the Indian Ocean compared with the Pacific during the JJAS months in Sudan.

The associations were further analyzed between the ENSO and summer monsoon precipitation over Sudan. For ENSO, the El-Nino 3.4 index was employed to compute the coefficient. Results suggest that the zero lagged correlation recorded the highest coefficient that passed the significant test at $\alpha = 0.05$ with -0.5 correlation Figure 3d). and lower but notable value exhibits in the one-month lag with -0.27. The larger the lag, the lower the coefficient, hence the lower values recorded in March and April in a row where the coefficients failed to pass the test Figure 3a) and 3b).

Inversed Associations Patterns:

Further, we quantified the spatial distribution of the inversed impact of the ENSO on Sudan's rainy season. Surprisingly, the positive mode with few significant loadings dominates the entire country except the far south in three-month lag, confirming the opposite positive pattern discussed in the previous part Figure 4a). The negative pattern starts expanding northward in April and May before it dominates in the timely occurrence associations (zero lag) with significant loadings in the central parts of the country.

Conclusion:

This study investigates the associations of the rainy season June-September over Sudan with the ENSO on timely and lagged intervals. The lagged impact is critical in the seasonal forecast. Hence we assume that the results of this study could be useful when considering the teleconnections of summer monsoon precipitation to prospect the possible changes in the rainy season. EOF analyzed was employed to quantify the leading mode consistency with the raw filed. The first mode found to be consistent with 0.92 and 52.3% accountability of the total variance of the observed field. The lagged consistency was found to be changing gradually from positive to negative pattern from March to JJAS. The coefficients were more robust and more significant the more we approached the real occurrence time. The inversed effect of El-Nino 3.4 was found to follow the same mode with clear negative loadings in the central parts of the country.

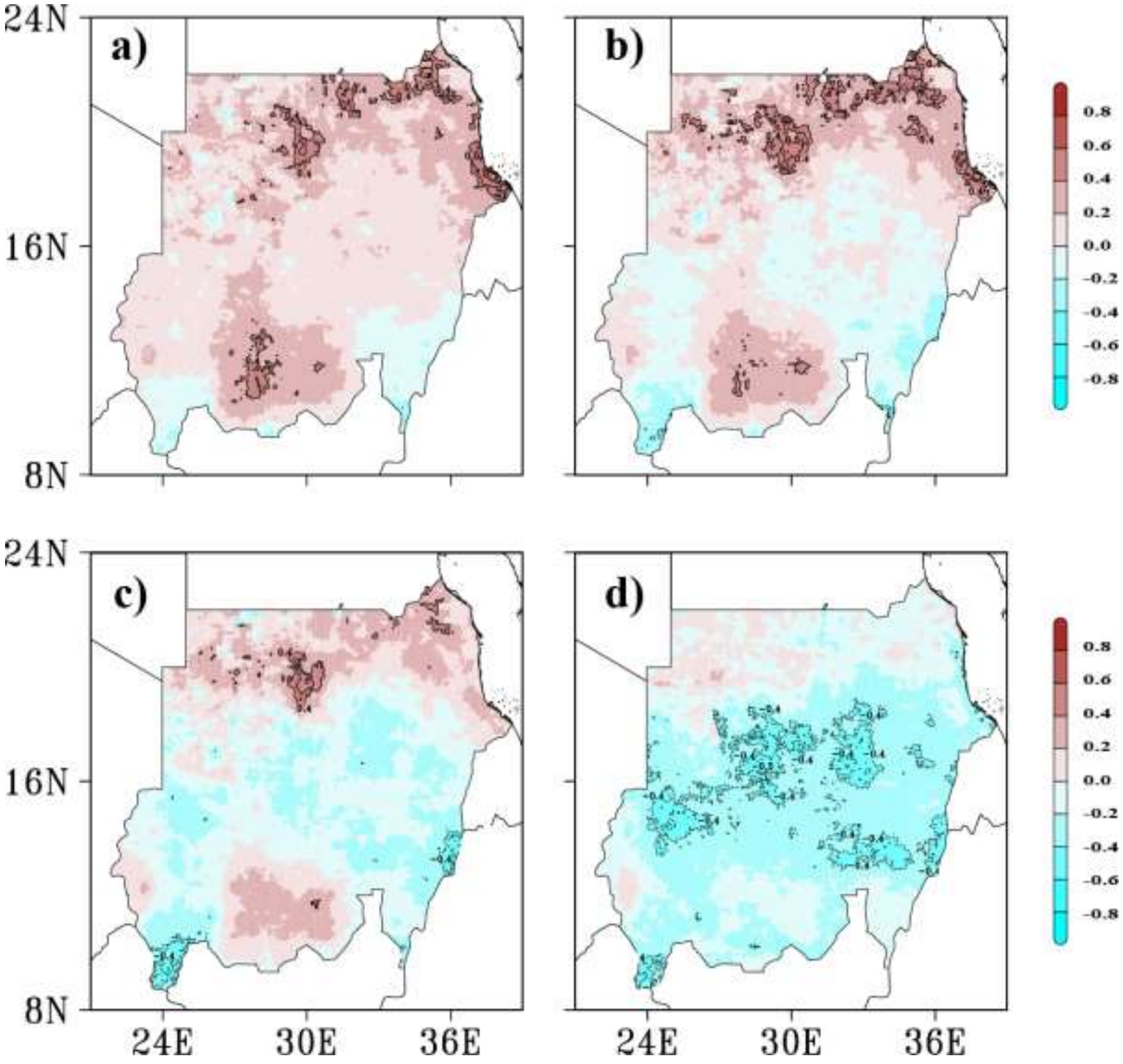

Figure 4 The spatial distribution of a) March, b) April, c) May, and d) JJAS SST's correlation with summer monsoon precipitation over Sudan. The contours signify the areas with a significant coefficient at 95% confidence level.

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