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THE NON-STATIONARY CORRELATION BETWEEN SAHEL PRECIPITATION INDICES AND ATLANTIC HURRICANE ACTIVITY

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1. INTRODUCTION

Many regional climates are known to vary on both interannual and interdecadal time scales. Two particularly dramatic examples of this phenomenon in the 20th century have been the significant variations in Atlantic hurricane activity and in West African precipitation. Because of the obvious societal implications, both of these manifestations of climate variability have been the subjects of considerable study. Perhaps remarkably, interannual variations in Atlantic hurricane activity are known to be well-correlated with concurrent rainfall anomalies in the Sahel (e.g., Landsea et al., 1992; Landsea and Gray, 1992).

However, the correlation between the various indices of Sahelian precipitation and the indices of hurricane activity (such as “hurricane days”, “named storm days”, or “accumulated cyclone energy (ACE)”) has proven to be non-stationary. An example of the phenomenon is shown in Fig. 1, which depicts time series of precipitation in the Western Sahel and ACE in the North Atlantic. An examination of the two time series clearly reveals periods in which the two series are strongly related and other periods in which the relationship between the two time series has clearly changed (notably, the period after 1995). This evolving relationship between the two time series can be quantified by statistics such as Kendall’s τ, and the results show that the correlation between Sahelian precipitation and hurricane activity is modulated on several time scales. One possible mechanism for this non-stationary correlation could be the influence of sea surface temperatures, both local and remote.

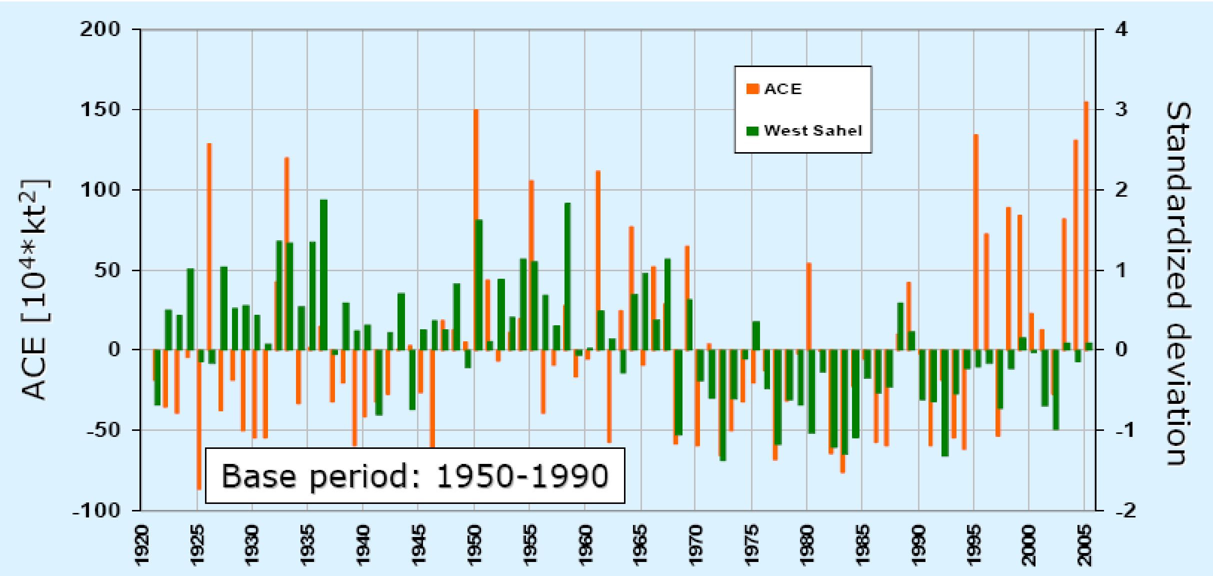


Figure 1. Time series of Western Sahel precipitation index and Accumulated Cyclone Energy (ACE).

2. DATA

2.1 *West African Precipitation Indices*

Based on an eigenvector analysis of annual precipitation at surface stations, Nicholson and Palao (1993) identified three regions with coherent interannual variability of precipitation. These regions are depicted in Fig. 2. A similar analysis was performed independently by Moron (1994), and very similar regions were defined.

Because of the forecasting and research implications of the correlations between West African precipitation and hurricane activity in the Atlantic, Landsea and Gray maintained an archive of West African precipitation indices spanning the period from 1950 to 1995. The present study extends these time series to the period 1921-2005. These time series are depicted in Fig. 3a and 3b.

2.2 *Sea Surface Temperatures*

Monthly values of the sea surface temperature (SST) at 1°x1° resolution were obtained from the Hadley Centre Sea-Ice and Sea-Surface Temperature (HadISST1) data set. For the purposes of the present study, only the values for the month of August were utilized.

3. INFLUENCE OF SST ON THE CORRELATION BETWEEN SAHELIAN RAINFALL AND HURRICANE ACTIVITY

The magnitude of the correlation between Sahelian rainfall indices and the various measures of Atlantic hurricane activity depend to a great extent on the years chosen for the calculation. In this section, correlations between Sahelian precipitation and ACE were performed based on 28-year samples. The lists of years used in the samples were derived based on historical values of SST in August around the world. At each grid point, the 28 warmest years were isolated, and the correlation between Sahelian precipitation and ACE was determined. The procedure was then repeated for the 28 coldest years at the given location. If the SST at the given location does not influence the magnitude of the correlation between the two variables, the two correlation values should be approximately equal. However, if there is a substantial difference between the correlation values obtained for the warmer years versus the cold years, SST clearly plays a significant role in determining the nature of the correlation between these indices.

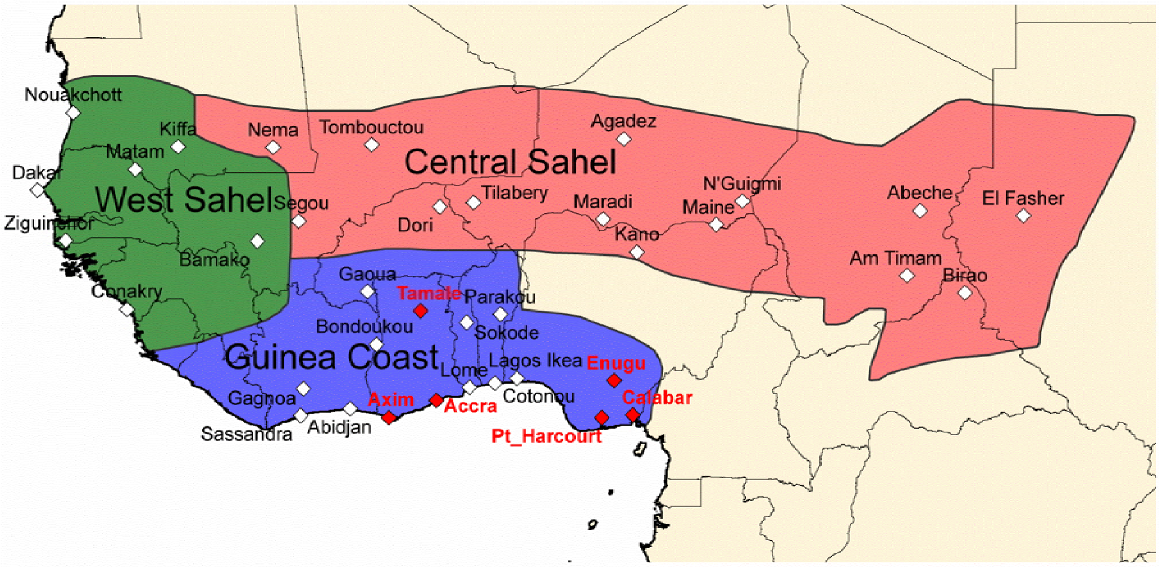
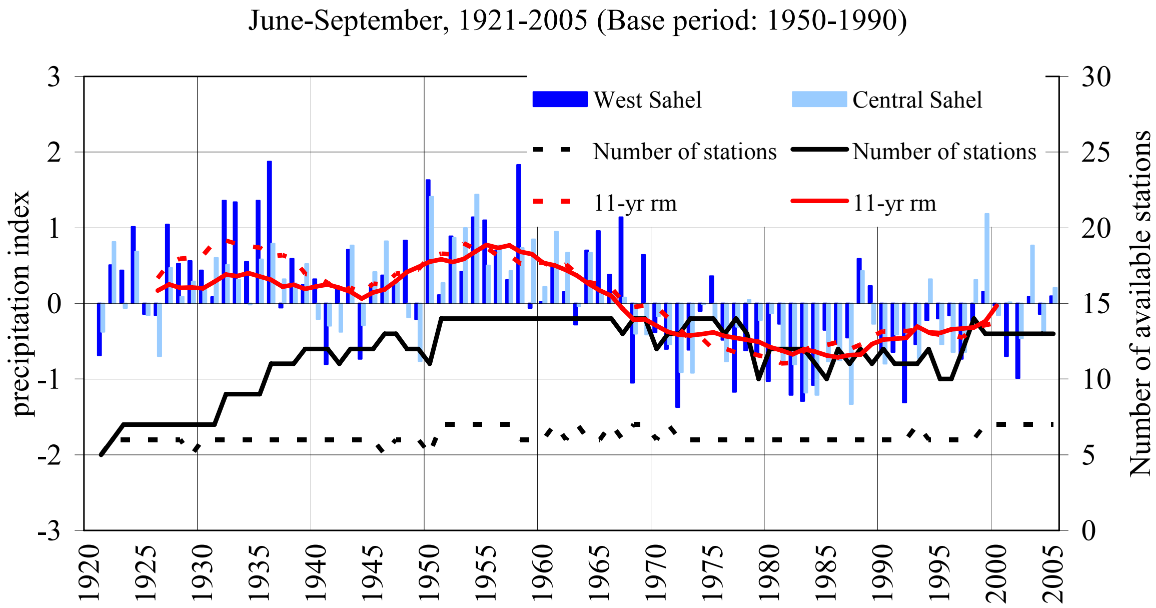


Figure 2. Definition of the regions employed in this study. The synoptic stations written in black letters depict the station sample used in the calculation of the original indices maintained by Landsea and Gray. The synoptic stations written in read and located in Ghana and Nigeria have been added to the Guinea Coast rainfall index by the authors.

a.



b.

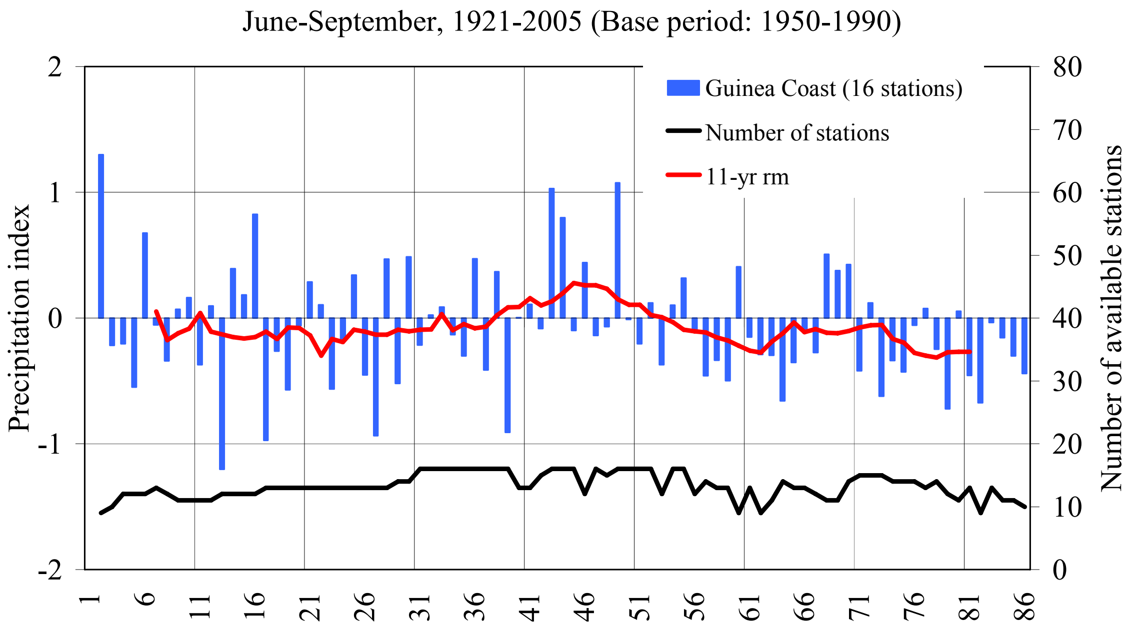
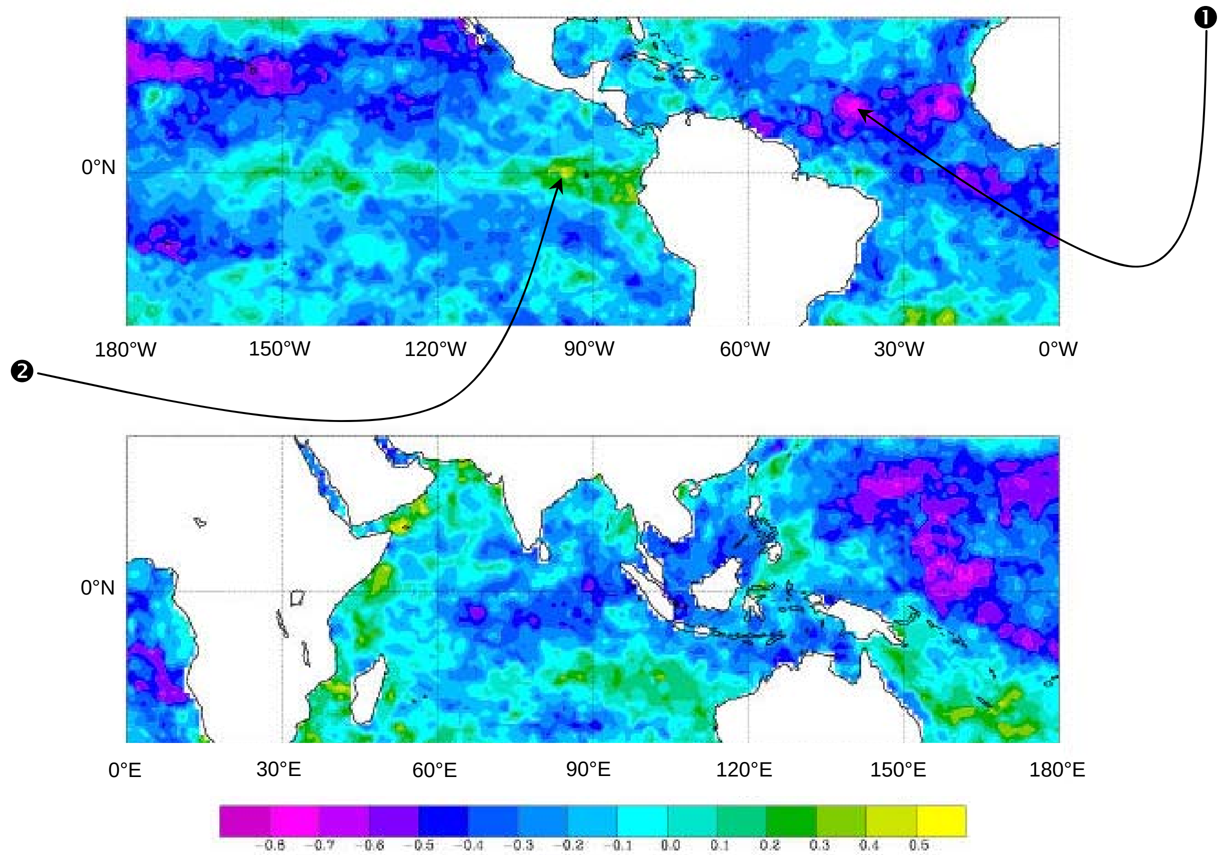


Figure 3. Normalized precipitation indices and 11-year running means for the (a) West Sahel and Central Sahel domain and (b) Guinea Coast domain. Sample sizes in each year's mean value are indicated by the black curves and the right axis.

$r(\text{WSAHEL,ACE})_{\text{warmest 28 years}} - r(\text{WSAHEL,ACE})_{\text{coldest 28 years}}$



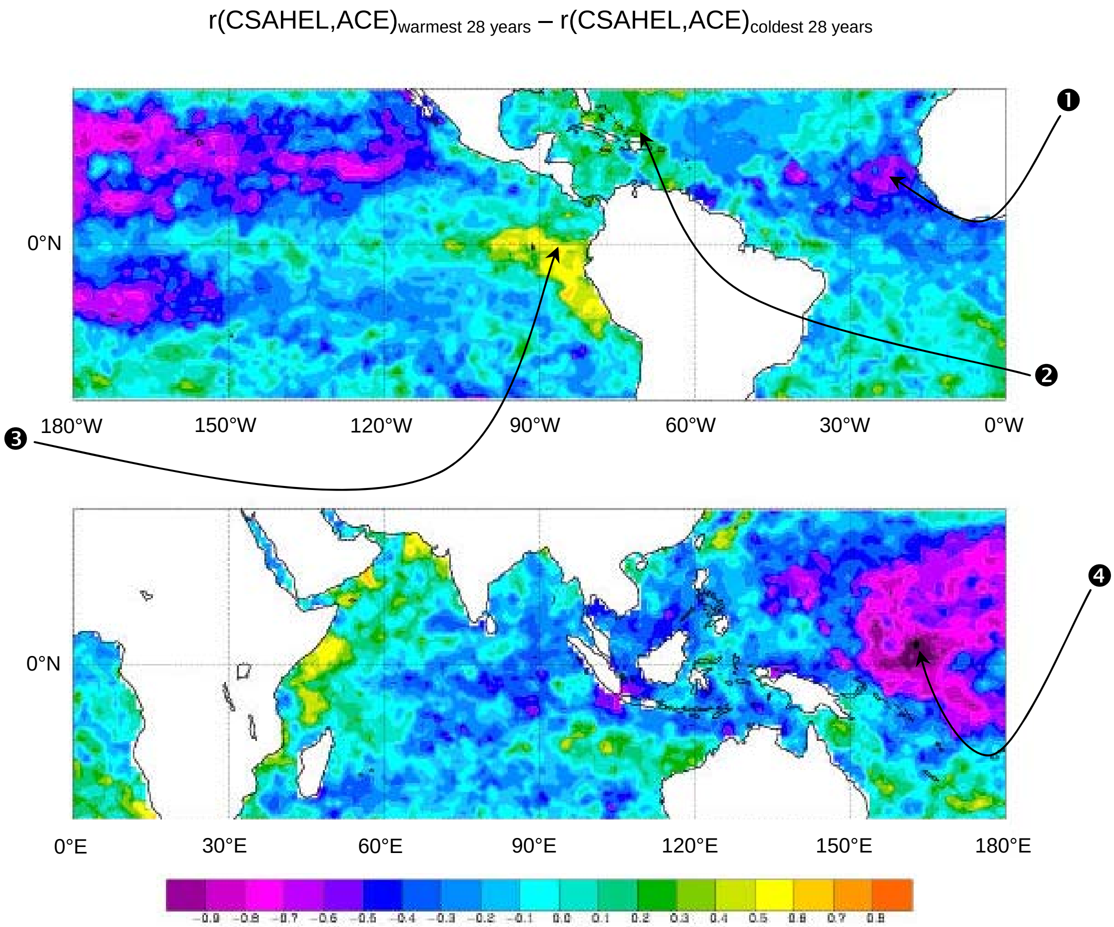
❶ At 13°N, 41°W:

	Warmest 28 Years	Coldest 28 Years
Raw SST:	-0.13	0.67
Detrended SST:	-0.13	0.67

❷ At 0°N, 96°W:

	Warmest 28 Years	Coldest 28 Years
Raw SST:	0.64	0.12
Detrended SST:	0.64	0.12

Figure 4. Correlations between the Western Sahel precipitation index and ACE in the warmest 28 years minus correlations between the Western Sahel precipitation index and ACE in the coldest 28 years, based on detrended SST data.



❶ At 14°N, 23°W:

	Warmest 28 Years	Coldest 28 Years
Raw SST:	0.05	0.43
Detrended SST:	-0.16	0.53

❷ At 20°N, 71°W:

	Warmest 28 Years	Coldest 28 Years
Raw SST:	0.26	-0.12
Detrended SST:	0.23	-0.12

❸ At 1°S, 87°W:

	Warmest 1/3 of All Years	Coldest 1/3 of All Years
Raw SST:	0.64	-0.07
Detrended SST:	0.66	-0.14

❹ At 5°N, 162°E:

	Warmest 1/3 of All Years	Coldest 1/3 of All Years
Raw SST:	-0.40	0.81
Detrended SST:	-0.38	0.81

Figure 5. Correlations between the Central Sahel precipitation index and ACE in the warmest 28 years minus correlations between the Central Sahel precipitation index and ACE in the coldest 28 years, based on detrended SST data.

Figure 4 presents the difference in correlation values for the rainfall in the Western Sahel region and ACE. A broad area of negative values dominates tropical Atlantic. In the warmest 28 years, the correlations between precipitation and ACE were quite low, whereas in the cold years, the correlations were strong and positive (see location ❶ in Fig. 4). Conversely, note that the values are positive in the equatorial Eastern Pacific. Here, the correlations are strong and positive in the years with warm waters, and the correlation becomes statistically insignificant in the cold years (see location ❷ in Fig. 4).

The results for the Central Sahel are indicated in Fig. 5. A more complex pattern is seen in the North Atlantic in Fig. 5 than was the case in Fig. 4. Across the eastern tropical Atlantic, values are negative, suggesting that in years when the waters here are warm (cold) the correlations between Central Sahelian rainfall and ACE are weak (strong), as seen at location ❶ in Fig. 5. In contrast, in the Western Atlantic the values are moderately positive. As demonstrated at 20°N, 71°W (location ❷ in Fig. 5), neither the positive correlations during the warm years nor the negative correlations during the cold years are particularly high, but the difference is consistent over a fairly large part of the western Atlantic. A strong east-west gradient is noted across the equatorial Pacific. Warm water in the Eastern Pacific yields strong correlations between Central Sahelian precipitation and hurricane activity, whereas the correlations are quite weak when the water temperatures are low (see location ❸ in Fig. 5).

Based on these plots, a number of factors that influence the relationship between Sahelian precipitation and hurricane activity can be hypothesized, as discussed in the following subsections.

3.1 *Local SST in the Tropical and Subtropical North Atlantic*

As seen at location ❶ in Fig. 4, the relationships between rainfall indices and indices of hurricane activity break down when the SST is sufficiently high. This can be interpreted to mean that high values of SST are able to provide a local forcing within the Atlantic that is adequate to overcome whatever remote influence there may have otherwise been from the rainfall in West Africa. A similar result was seen at point ❶ in Fig. 5, although the region in which a high SST overrules the influence of West African precipitation was more confined to the Eastern Atlantic. This is interpreted to mean that the Central Sahelian rainfall was a more consistent (i.e., less prone to statistical nonstationarity) predictor of hurricane activity than Western Sahelian precipitation was.

3.2 *El Nino and the Southern Oscillation*

While it is widely understood that El Nino conditions in the Pacific produce an environment that is not favorable for hurricane formation in the Atlantic (e.g., Gray 1984, Shapiro 1987), Figs. 4 and 5 reveal that the nature of this interaction is more complex. Both figures show that the correlations between West African precipitation and hurricane activity in the Atlantic are strongest during El Nino conditions in the Eastern Pacific. When there were warm (cold) waters in the Eastern (Western) Pacific, correlations between rainfall and Atlantic hurricane activity was very high. Therefore, while El Nino years generally have somewhat lower values of ACE, the variability within the population of these warm years is largely explained by variations in the West African precipitation. A pattern of SSTs consistent with La Nina conditions, however, results in weak correlations between Central Sahelian precipitation and ACE, with warm water anomalies in the Western Pacific Warm Pool actually moderately reversing the expected relationship between Sahelian precipitation and ACE (see location ❹ in Fig. 5).

4. CONCLUSIONS

Local SST anomalies in the subtropical and tropical Atlantic were shown to effectively override any influence of Sahelian rainfall when the anomalies are large enough.

For El Nino SSTs, both cold water in the Western Pacific and warm water in the Eastern Pacific are associated with higher correlations between Central Sahelian precipitation and ACE.

For La Nina years, warm water in the Western Pacific is associated with a reversal in the correlation between Central Sahelian precipitation and ACE (i.e., moist years in the Central Sahel are now associated with suppressed hurricane activity). Cold water in the Eastern Pacific, however, results in Central Sahelian precipitation that is uncorrelated with hurricane activity.

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REFERENCES

Gray, W.M., 1984: Atlantic seasonal hurricane frequency. Part 1: El Nino and 30mb quasi-biennial oscillation influences. *Mon. Wea. Rev.*, **112**, 1649-1668.

Landsea, C.W., W.M. Gray, P.W. Mielke Jr. and K.J. Berry, 1992: Long-term variations of western Sahelian monsoon rainfall and intense US landfalling hurricanes. *J. Climate*, **5**, 1528-1534.

Landsea, C.W., and W.M. Gray, 1992: The strong association between western Sahelian monsoon rainfall and intense Atlantic hurricanes. *J. Climate*, **5**, 435–453.

Moron, V., 1994: Guinean and Sahelian rainfall anomaly indices at annual and monthly scales (1933-1990). Int. J. Climatol., 14, 324-341.

Nicholson, S.E. and I.M. Palao, 1993: A re-evaluation of rainfall variability in the Sahel. Part I. Characteristics of rainfall fluctuations. Int. J. Climatol., **13**, 4, 371-389.

Shapiro, L.J., 1987: Month-to-month variability of the Atlantic tropical circulation and its relationship to tropical storm formation. *Mon. Wea. Rev.*, **115**, 1598-1614.

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