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THE SEASONAL ROLE OF ENSO AND MONSOON ON THE INTERANNUAL VARIATIONS OF RAINFALL EXTREMES IN THE PHILIPPINES

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Abstract The interannual relationships between indices representing the El Niño–Southern Oscillation (ENSO), the monsoon, and extreme precipitation in the Philippines during boreal summer (July–September, JAS), and fall (October–December, OND), was revealed using the nonparametric measure of monotonic relationship between two variables. The extreme precipitation indices were calculated from the observed daily rainfall data from 35 meteorological stations during a 60-year (1951–2010) period of study. Results show that the wet (dry) indices of extreme precipitation are significantly negatively (positively) correlated with the Niño 3.4 index during OND; whereas only few stations have significant correlations during JAS. It was found that the strength of the monsoon, which is measured by the western North Pacific summer monsoon index (WNPMI), is highly correlated with precipitation indices for stations located in the western section of the country during JAS. These findings suggest that while the ENSO controls much of the interannual variation of precipitation indices during OND, the governing influence of monsoonal activity is well-pronounced during JAS, particularly in the western section of the Philippines.

Key words: extreme precipitation indices, ENSO, western North Pacific summer monsoon, Philippines

1. Introduction

The El Niño–Southern Oscillation (ENSO) is a well-known phenomenon that alters precipitation in several regions across the globe. For instance, Curtis *et al*. (2007) found that the warm phase of ENSO (El Niño) contributes to dry conditions over the tropical land areas, while the cold ENSO-phase (La Niña) brings wet conditions. Similarly, Lyon *et al*. (2006) showed above-median (below-median) July–September (October–December) rainfall over the Philippines for a developing El Niño, and in a recent study Villafuerte *et al*. (2014) showed the consistency of the ENSO-influence, not only on median levels of rainfall, but also on extreme rainfall over the Philippines.

The western North Pacific summer monsoon has a southwesterly prevailing wind as it approaches the Philippines, bringing wet conditions over the western section of the country. It is locally known as the southwest monsoon or "*Habagat*", which usually begins as early as May and lasts until September sometimes reaching early October (Flores and Balagot 1969). The Philippines is an agricultural country; thus, agricultural activities in the country rely on the rainfall brought by the southwest monsoon. However, some of the recent major weather-related disasters that occurred in the Philippines coincided during the southwest monsoon season when it brought excessive rains (Yumul *et al*. 2011).

Although previous studies have investigated the influence of ENSO on rainfall in the Philippines (e.g., Lyon *et al*. 2006; Villafuerte *et al*. 2014), in addition to the country's monsoonal rainfall characteristics (e.g., Cruz *et al*. 2013; Yumul *et al*. 2011), the seasonal role of ENSO and monsoon on rainfall extremes over the country has not yet been investigated. Thus, this study aims to examine the roles of these phenomena on seasonally defined rainfall extremes in the Philippines. It is considered that the results contained herein will provide significance for society, in particular for minimizing the impact of rainfall extremes and possible recurrences in relation to the ENSO and monsoonal activities.

2. Data and Methodology

Daily rainfall data observed at 35 meteorological stations of the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) are utilized in this study (Fig. 1). These rainfall data were collected, quality controlled, and compiled by the Climatology and Agrometeorology Division of PAGASA. The selected stations shown in Fig. 1 have minimal missing data (less than 10%) during the 1951 to 2010 period of study. Moreover, these selected meteorological stations were also used in Akasaka *et al*. (2007), and passed the homogeneity test performed by Endo *et al*. (2009). Rainfall extremes are described following Villafuerte *et al*. (2014), which are partly based on the extreme precipitation indices defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) (Table 1).

The Met Office Hadley Centre's sea ice and sea surface temperature dataset HadISST1 (Rayner *et al*. 2003), is used to calculate the sea surface temperature (SST) anomaly index over the Niño 3.4 region (averaged SST anomaly within the region 5°N–5°S, 120–170°W; Barnston *et al*. 1997). The western North Pacific summer monsoon index (WNPMI), which is taken as the difference of averaged zonal wind anomalies at 850 hPa (U850) over the regions (5–15°N, 90–130°E) and (22.5–32.5°N, 110–140°E) following Wang and Fan (1999), is computed from the mean monthly U850 provided by the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis (Kalnay *et al*. 1996).

Then, the monotonic relationships among the seasonal Niño 3.4 index, the WNPMI, and the extreme precipitation indices are measured using the nonparametric Kendall's τ coefficient (Kendall 1938). The Niño 3.4 index is compared simultaneously with the seasons of extreme precipitation indices (i.e., JAS averaged Niño 3.4 index for extreme precipitation indices in JAS). In addition, seasonal lag correlations are also provided in the latter part of section 3.

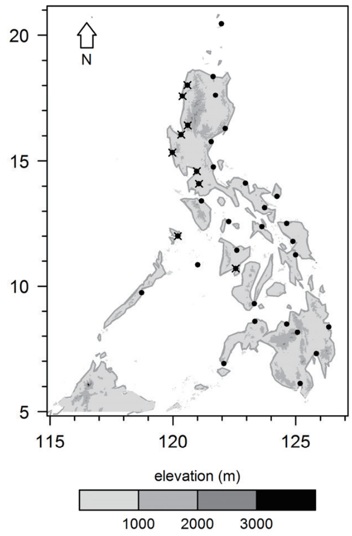

Fig. 1 Topographical map of the Philippines, and the geographical distribution of the 35 meteorological stations used in this study (black dots); the nine stations where there is a pronounced-influence of the southwest monsoon are marked with crosses.

Table 1 List of extreme precipitation indices used in this study (adapted from Villafuerte *et al*. 2014); each of the indices was computed seasonally (i.e., July–September and October–December)

Index	Definitions	Units
P95	95th percentile of wet days	mm/day
RX1d	1-day maximum rainfall	mm/day
RX5d	5-day maximum rainfall	mm
PTOT	Seasonal wet days' total rainfall	mm
P95d	Count of days exceeding the base period's p95	days
WSDx	Maximum length of wet spell*	days
DSDx	Maximum length of dry spell**	days

* wet spell refers to consecutive days with rainfall ≥ the base period's seasonal mean daily rainfall

** dry spell refers to consecutive days with rainfall < the base period's seasonal mean daily rainfall

3. Results

Figure 2 shows the simultaneous correlation coefficient τ obtained between the Niño 3.4 index and the maximum 5-day rainfall (RX5d) at every station. Significant negative correlations ($p < 0.05$) are found at several stations during OND, while only a few stations have significant positive correlations during JAS. This seasonal reversal of rainfall response to ENSO is consistent with the findings of Lyon *et al*. (2006) when they examined the seasonal response of median precipitation with ENSO. However, as this present study examines extreme precipitation, only few stations have showed significant correlations with ENSO during JAS. The same relationships are obtained in the remaining six extreme precipitation indices (not shown). This finding suggests that ENSO plays an important role in the interannual variability of rainfall extremes in the Philippines during OND, but is not the major contributor during JAS. Because ENSO is generally at its peak in winter (November–January) and only at its developing phase in JAS, this is considered as the possible reason for its weak influence on extreme precipitation during JAS.

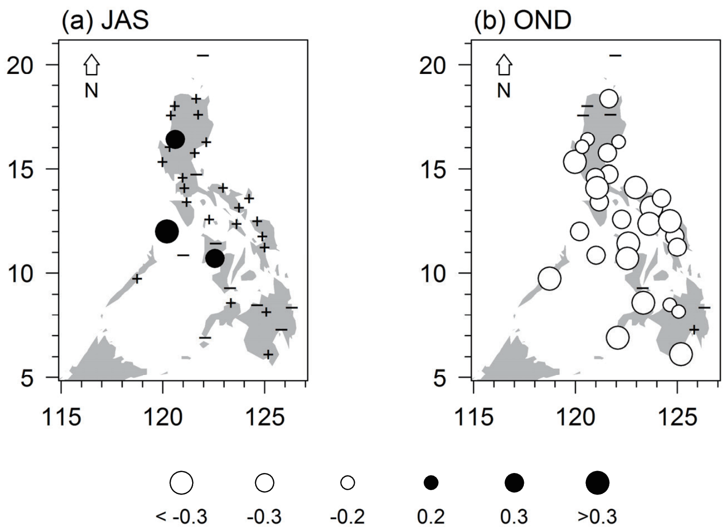

Fig. 2 Simultaneous correlation coefficients obtained between the Niño 3.4 index and the RX5d during: (a) July–September (JAS); and (b) October–December (OND) seasons. Circles denote significance at the 5% level, while "+" or "–" are not statistically significant.

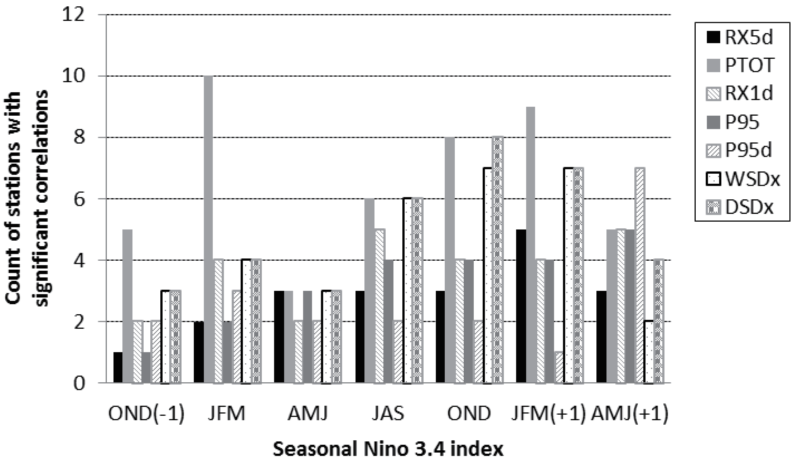

Fig. 3 Number of stations with significant correlation obtained between the JAS RX5d and the seasonally-lagged Niño 3.4 index; "(-1)" and "(+1)" denote seasons of the previous year and the following year, respectively.

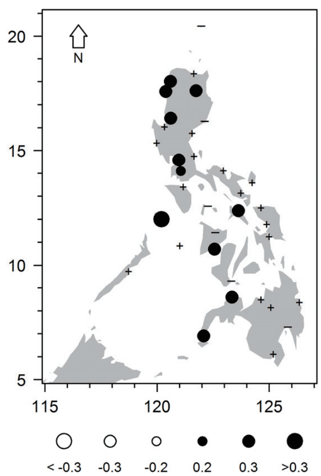

Fig. 4 Correlation coefficients τ between the WNPMI and the JAS RX5d (circles denote significance at the 5% level, while "+" or "–" are not statistically significant).

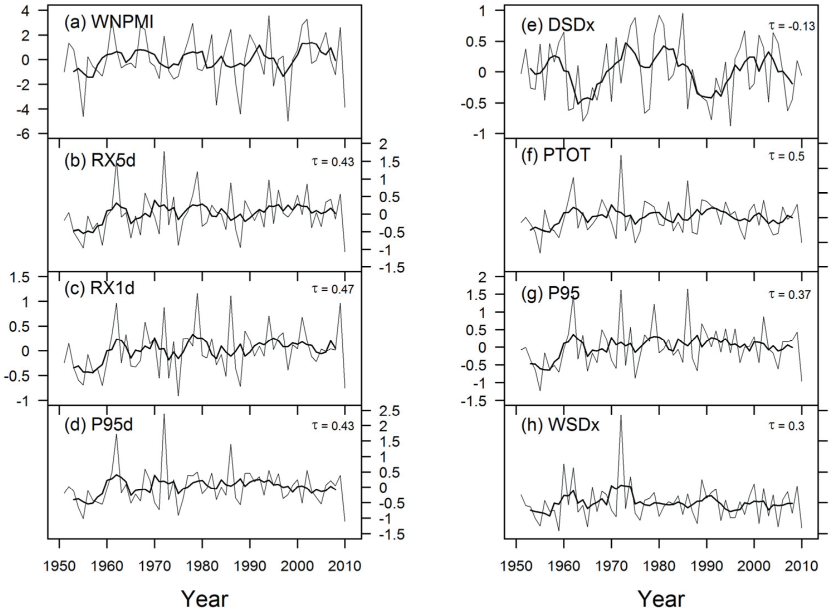

Fig. 5 Time series of: (a) western North Pacific summer monsoon index; and (b)–(h) mean of the normalized extreme precipitation indices representing the western Philippines (the nine stations used to represent the western Philippines are shown in Fig. 1; normalization is performed by subtracting their long-term mean and dividing by the standard deviation). The thick curves denote the 5-year running mean; extreme precipitation indices are defined in Table 1.

We then further investigated whether our choice of selecting seasons to define the Niño 3.4 index is the main reason for the weaker influence of ENSO during JAS as compared to OND. The Niño 3.4 index is taken as the average SST anomaly during the previous ENSO event (i.e., OND(-1)), two seasons behind (JFM), one season behind (AMJ), and the remaining non-overlapping seasons until April–June of the following year (AMJ(+1)) (Fig. 3). It is noted that the number of stations that showed a significant correlation between the extreme precipitation indices and the seasonally-lagged Niño 3.4 index did not vary greatly except for the seasonal total wet day's rainfall (PTOT), which showed the largest number of stations with significant correlation during JFM. This suggests that regardless of the seasons where the ENSO index is based, the extreme precipitation indices in JAS are apparently less affected by ENSO for most of the stations in the Philippines. This result is consistent with the findings of Curtis *et al.* (2007) who examined the impact of ENSO on extreme precipitation using gridded and satellite rainfall estimates.

Since the southwest monsoon is prevalent in the Philippines during JAS (Cruz *et al*. 2013), it is possible that a relationship exists between the strength of the monsoon and the extreme precipitation indices. Figure 4 shows the correlations between the WNPMI and the RX5d in JAS. There are at least 11 stations with a significant correlation ($p < 0.05$), and seven of these stations are among the nine stations used in Cruz *et al*. (2013) to define the southwest monsoon rainfall anomaly index (see, Fig. 1). Following their earlier study, we then used the same nine stations to obtain the mean of normalized extreme precipitation indices to represent the western Philippines and to compare the time series with the WNPMI. Figure 5 shows the time series of the obtained mean of the normalized extreme precipitation indices for the western Philippines. Significant correlations ($p < 0.05$) were obtained in most of the extreme precipitation indices, except for the maximum length of dry spell (DSDx; Fig. 5e). A strong interdecadal variability is also apparent for DSDx, denoting a drier JAS seasons in the 1950s, mid-1970s to 1980s and in 2000s, while wetter conditions were experienced in the mid-1960s and 1990s. On the other hand, the indices representing one- and multi-day extreme precipitation reflect strong interannual variations.

4. Discussion

The results that we obtained imply a weak influence of ENSO, but a strong influence of the western North Pacific summer monsoon on extreme rainfall in JAS over the Philippines. However, this appears to contradict the findings of Chou *et al*. (2003), who found that a strong western North Pacific summer monsoon tends to occur when there is a developing El Niño, and that the opposite is true for a developing La Niña condition. We need to consider therefore why our results imply a weak influence of ENSO on extreme rainfall during JAS in the Philippines. To address this issue, we compared the WNPMI with the Niño 3.4 index during its peak phase (i.e., averaged November–January SST anomaly); their time series are shown in Fig. 6a. The first comparison between the two series employs a 21-year running correlation (Fig. 6b). It can be noticed that the relationship between the WNPMI and the Niño 3.4 index is very weak until the early 1970s, and significant correlations are only detected from the mid-1970s until the 2000s, with a weak relationship developing again from the early 1990s. This multidecadal variation in the relationship between the WNPMI and the Niño 3.4 index partly explains why ENSO showed a weak influence on extreme precipitation indices during JAS over the Philippines.

However, analyses that involve running correlations can be biased by the chosen length of sliding window, which is 21 years in this case. We therefore employed a cross wavelet analysis, wherein the two time series were viewed in a time frequency space (e.g., Grinsted *et al*. 2004). Figure 6c shows the cross wavelet transformed series of the Niño 3.4 index and the WNPMI. The analysis confirms a significant co-variation between the two series in the early 1970s to 1990s, primarily at the 4–6 years period of the cross wavelet spectrum. Moreover, the cross wavelet analysis reveals a phase difference between the two time series (denoted by the arrows pointing upward), which means that the WNPMI reaches its peak a quarter of cycle ahead (i.e., pi/2) than the Niño 3.4 index. This temporal lag between the two time series is the reason why the instantaneous running correlation coefficients obtained between them is low, generally less than 0.5 (see, Fig. 6b). It also supports the influence of the developing- and decaying phases of ENSO on the western North Pacific summer monsoon (e.g., Chou *et al*. 2003).

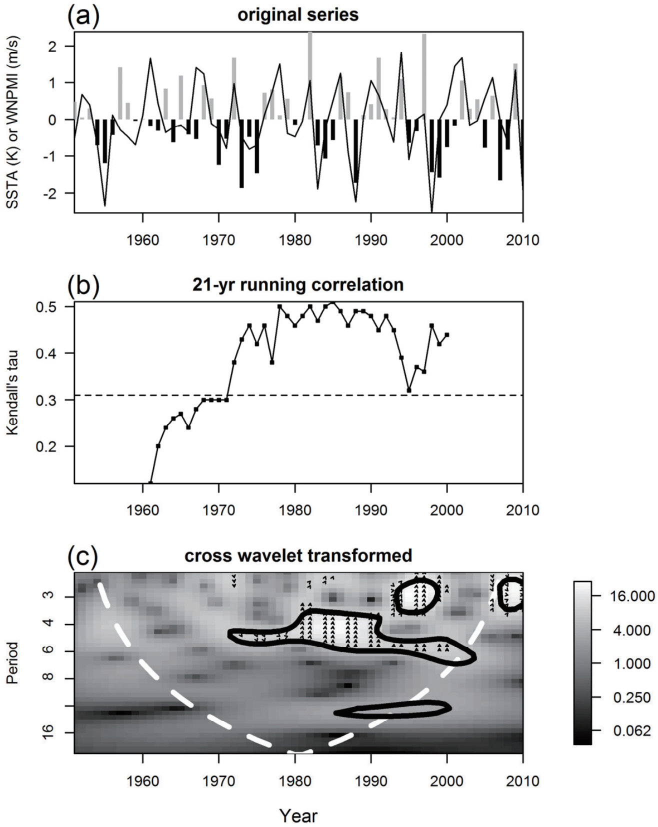

Fig. 6 (a) Time series of the averaged November–January Niño 3.4 index (bars), and WNPMI (solid line); and (b) their 21-year sliding correlation (dashed line marks the 5% significance level); and (c) the cross wavelet transformed time series. The shadings in (c) denote the common power between the two series, with areas inside the thick contours indicating significance at the 5% level; arrows indicate relative phase relationships (those pointing upwards mean that the WNPMI leads the Niño 3.4 index).

5. Conclusion

By employing a nonparametric measure of monotonic relationship between two variables (the Kendall's τ coefficient), this present study has identified significant relationships between the ENSO (and monsoon) and the seasonally-defined extreme precipitation indices in the Philippines. It has been shown that a significant negative correlation ($p < 0.05$) exists between the Niño 3.4 index and the wet extreme precipitation indices for almost all of the stations across the country during OND, and that the reverse is true for the single dry index (i.e., DSDx). In contrast, no substantial influence of ENSO was found on the extreme precipitation indices during JAS. Several factors possibly affect the interannual variation in JAS extreme precipitation, and one of these is the strength of the western North Pacific summer monsoon. Significant positive correlations ($p < 0.05$) were obtained between the wet extreme precipitation indices and the WNPMI, primarily at stations situated on the western coasts of the Philippines, thereby suggesting that strong (weak) southwest monsoons are associated with wet (dry) conditions during JAS.

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