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The influence of ENSO signal reversal episodes on rainfall variability in the Philippines during the monsoon season

Raymund T. Masangya*

Physics Department, Technological University of the Philippines, Manila, Philippines

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Abstract

Research studies on changes in the timing and intensification of the southwest monsoon (SWM) are crucial to the Philippines as SWM primarily affects the rainfall climatology of the country. Rainfall brought by the SWM provides most of the water resource in the Philippines for agricultural, industrial, and commercial use. This study aims to evaluate the potential factors that influence rainfall behavior during the SWM season, including sea level pressure, sea surface temperature, and wind speed. This research will also look at the decrease in rainfall using a composite of El Niño, La Niña, and normal years as potential indicators. The "ENSO signal reversal" during El Niño (EN) and La Niña (LN) events was found from 1998 to 2014 for short term climatological analysis and 1961 to 2014 for long term climatological analysis. The simultaneous correlation for both periods shows weak correlation. This is where the researcher finds another way of analyzing the given indicators. Analysis show that: a) over the Pacific, northeast of the Philippines, the sea level pressure during EN has a distinct negative anomaly, while during LN, the sea level pressure has a distinct positive anomaly; b) wind speed over the West Philippine Sea has a positive (negative) anomaly during EN (LN); and c) SST surrounding the Philippines has a negative (positive) anomaly during EN (LN). This study establishes a pattern for ENSO signal reversal in the Philippines that can help mitigate extreme weather events that can affect the economy and industries in our country.

***Corresponding Author:** Raymund T. Masangya ✉ raymund_masangya@tup.edu.ph

Introduction

Rainfall events are mainly affected by synoptic systems such as monsoons, El Niño Southern Oscillation (ENSO), and mesoscale systems (Francisco *et al.*, 2006; Jose *et al.*, 1996; Delas Alas and Buan, 1986). In the Philippines, precipitation is greatly influenced by the Southwest Monsoon (SWM). Based on Asuncion and Jose (1980), 43% of mean annual rainfall in the Philippines comes from the SWM, which is observed during the boreal summer (July to August). The SWM season is the main rainfall season and also the least variable over the Climate Type 1 in the Philippines. The SWM generally reach the Philippines as a south-westerly stream and originally as trade winds from the Indian Ocean anticyclone (Cruz *et al.,* 2013). Lucero (2012) defines the onset of the SWM based from the daily accumulated and total rainfall, which must not be less than 1 mm and 25 mm respectively. Further, he added that at least four PAGASA stations must satisfy this condition. On the other hand, Moron *et al.* (2009) defines the onset as five days of consecutive rainfall with at least 40 mm of rainfall and should not be followed by 15 days of dry spell (rainfall not less than 5 mm).

Further, some studies define the onset starting from April to August (Lau ans Yang, 1997), but others stated that it starts in mid-June (Wang and Zhang, 2002; Wu and Wang, 2000). Inter-annual variability of the onset in WNP is highly correlated to the difference between the sea surface temperature (between the WNP and equatorial central Pacific), land-sea thermal contrasts, and ENSO (Kucharski *et al.*, 2011; Wu and Wang, 2000). Based on the results of Cruz *et al.* (2013), the SWM rainfall is decreasing over the past 50 years, which will be discussed in the next section. Cruz *et al.* (2013) described the behavior of the southwest monsoon rainfall in the Philippines using PAGASA rainfall data from 1961 to 2010 during the southwest monsoon season (June to September). Furthermore, they found large variability associated with the observed high values of rainfall across all stations. The percentage decline of rainfall per decade has a value of 0.016% to 0.075% in the past 50 years. According to Cruz *et al.* (2013), most of above normal rainfall are observed during El Niño (EN) years while most of the below normal rainfall are observed during La Niña (LN) years. Lyon *et al.* (2006), stated that during EN (LN) the north central Philippines received above median (below median) rainfall. Another study of Lyon *et al.* (2006), concluded that during EN, the rainfall increases due to an increase in moisture flux, which is brought by the zonal elongated band of enhanced low level westerlies on WNP, and vice versa during LN.

The objective of this study is to assess the possible indicators that affect the behavior of rainfall during the SWM season, specifically sea level pressure, sea surface temperature, and wind speed. This study also analyzes the decline in rainfall using composite of El Niño, La Niña and Normal years as potential indicators. Studies on SWM rainfall are crucial for the country's industry, agriculture and energy sectors. One historical case is the extreme rainfall in Metro Manila during typhoon Ondoy in 2009, which caused disastrous flooding in the city. Hence, it is important to analyse and understand trends and behaviour of the Philippine SWM rainfall and assess potential indicators that can lead to establishing a mechanism that affect rainfall during the southwest monsoon season.

Materials and methods

Satellite data used

In this study, four possible indicators of the change in rainfall are analyzed: wind, sea surface temperature (SST), sea level pressure, and large-scale precipitation. Wind, SST and sea level pressure data is obtained from the ECMWF ERA-Interim reanalysis data set from 1979 to present, which was produced with a 2006 version of the Integrated Forecast Model (IFS Cy31r2). ERA-Interim superseded the ERA-40 as a new version of the extended reanalysis. The ERA-Interim data set has 60 vertical levels from the surface up to 0.1 hPa. This study will use monthly surface winds from 1998 to 2014 and the spatial resolution of this data is 0.75° latitude x 0.75° longitude global grid-

(http://apps.ecmwf.int/datasets/data/interim-full-moda/levtype=sfc/, last accessed October 2014). According to Dee *et al.* (2013) ERA-Interim improves the hydrological cycle that results in improving the precipitation and other variables compare to ERA 40.

For comparison in the ERA Interim data, this study used some other reanalysis data that can help in evaluating the behavior of the possible indicators. Another SST data was taken from the NOAA Optimum Interpolation (OI) SST version 2 (V2) from 1998 to 2014 during the southwest monsoon season. The spatial resolution of this data is 1.0° latitude x 1.0° longitude global grid (180×360), which covers an area from 89.5°N – 89.5°S and 0.5°E – 359.5°E. According to Stock *et al.* (2015), NOAA OISST version 2 agrees the data in situ measurements particularly in the large marine ecosystem in the US. We used another mean sea level pressure (mslp) from NCEP/NCAR Reanalysis data set. This 2.5° resolution data has a temporal coverage from 1948 up to present but this study will just use the monthly data from 1998 to 2014 (http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.derived.surface.html, last accessed October 2014) . Finally, the large-scale precipitation was also investigated in this study. The TRMM data set is widely used for validation of rainfall in terms of large-scale system as well as in local scale (Franchito *et al.*, 2009; Lang *et al.*, 2007). Observed rainfall data during the southwest monsoon season was analyzed with large-scale precipitation and check if the behavior was the same in the large area. The inclusion of large-scale precipitation was to have a context of the station data in terms of a spatial map.

Classification of ENSO years

El Niño (EN) and La Niña (LN) events were classified using the SST anomalies in the tropical Pacific basin, which is commonly called the Niño 3.4 region (5°S – 5°N and 120° – 170° W). The threshold value of EN (LN) event is declared at least 0.5 °C (-0.5 °C) over a period of three consecutive months of ERSST.v4 SST anomalies for warm (cold) episode (Kao and Yu, 2009; Moy and Malayang, 2004; Trenberth, 1997). We used the same methodology as that of Cruz *et al.* (2013) and Lyon and Camargo (2009), in classifying the El Niño and La Niña years. The warm or cold episode should last for six or more consecutive overlapping seasons and this episode must start from June to August. Hence, 2007 and 2011 is not included in the LN years because it starts in July. The baseline period (1971-2000) was derived from the Climate Prediction Center of the National Weather Service (http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml, last accessed October 2015). Table 1 and 2 show the list of El Niño and La Niña years from 1998 to 2014.

Table 1. List of the Oceanic Niño Index (ONI) (3-month running mean of ERSST.v4 SST anomalies in the Niño 3.4 region)

Year	AMJ	MJJ	JJA	JAS	ASO	SON
1998	0.5	-0.1	-0.7	-1	-1.2	-1.2
1999	-0.9	-1	-1	-1	-1.1	-1.2
2000	-0.7	-0.7	-0.6	-0.5	-0.6	-0.7
2001	-0.2	-0.1	0	-0.1	-0.1	-0.2
2002	0.4	0.7	0.8	0.9	1	1.2
2003	-0.2	-0.1	0.1	0.2	0.3	0.4
2004	0.2	0.3	0.5	0.7	0.7	0.7
2005	0.4	0.2	0.1	0	0	-0.1
2006	0	0.1	0.2	0.3	0.5	0.8
2007	-0.2	-0.2	-0.3	-0.6	-0.8	-1.1
2008	-0.7	-0.5	-0.3	-0.2	-0.2	-0.3
2009	0.2	0.4	0.5	0.6	0.7	1
2010	0	-0.4	-0.8	-1.1	-1.3	-1.4
2011	-0.3	-0.2	-0.3	-0.5	-0.7	-0.9
2012	-0.3	-0.1	0.1	0.3	0.4	0.4
2013	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
2014	0	0	0	0	0.2	0.4

Philippines ENSO signal reversal and the regional atmospheric circulation

The impacts of ENSO on Philippine rainfall have been investigated by Lyon *et al.* (2006) and Lyon and Camargo (2009). They used composite analysis in order to see the difference in seasonal total rainfall during EN and LN years. The signal reversal was fully investigated by Lyon *et al.* (2006) and Lyon and Camargo (2009). They used composite in order to see the difference between EN and LN years. This method was adapted, which investigates the reversal of the atmospheric circulation during EN and LN years in the Philippines. In Lyon and Camargo (2009), the significance of their results was based on the below and above average in 90% and 95% confidence level.

Table 2. List of classification of years from 1998 to 2014 for normal, La Niña and El Niño years

	Year
Normal Year	2001, 2003, 2005, 2006, 2007, 2008, 2011,2012, 2013, 2014
La Niña	1998, 1999, 2000, 2010
El Niño	2002, 2004, 2009

Also, Lyon *et al.* (2006) used below and above median in their analyses and the statistical significance was 90% and 95% confidence level. However, both of the studies covered the period from 1950 to 2002 and this method was performed in this study in order to have a comparison of the results and also to look for similar patterns from the study of Lyon and Camargo (2009). In this study we will call it as an “ENSO signal reversal”, because this study focuses on the ENSO impacts on Philippine rainfall during the SWM season.

Pearson product-moment correlation

The Pearson product-moment correlation measures the strength of the linear relationship of two variables. This attempts to draw the best fit line linearly and display the Pearson correlation coefficient r. The formula for r is:

$$r = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y)^2]}} \quad \text{(Eq. 1)}$$

Where: x is the values in first set of data, y is the values in second set of data and n is the total number of values. To determine the significance of the Pearson correlation r the critical values are presented in Appendix B of Wiley *et al.*, 2012 (http://onlinelibrary.wiley.com/doi/10.1002/9781118342978.app2/pdf). Most studies like Lyon and Camargo (2009), Moron *et al.* (2009), and Dai *et al.* (2013) used Pearson correlation to measure the interconnection of two variables. Thus, if there is a significant linear correlation then there are five possible situations that can be true. The two variables can have (1) a direct cause and effect relationship, (2) reverse cause and effect relationship, (3) there is another variable that can caused the cause and effect of the two variables, (4) the interconnections of two variables can be caused by complex interactions of some variables, and (5) the cause and effect of two variables are only coincident.

Table 3. Coordinates of the nine PAGASA stations used in this study

Stations	Longitude	Latitude
Ambulong	121.05	14.08
Baguio	120.6	16.41
Coron	120.2	12
Dagupan	120.33	16.05
Iba	119.97	15.33
Iloilo	122.57	10.7
Laoag	120.53	18.18
Science Garden	121.03	14.63
Vigan	120.38	17.57

Simultaneous correlation

The simultaneous correlation was performed by Huo and Jin (2016) to find the relationship between SST and rainfall. In this study, simultaneous correlation was used to determine the strength of linear relationship (using Pearson correlation) between rainfall and the possible indicators (SST, wind and sea level pressure). The analysis was divided into two: (a) short term climatological analysis (1998 to 2014) and (b) the long term climatological analysis (1961 – 2014). The rainfall data that was used in short term climatological analysis was area-averaged at the western part of the country ($118° – 121.5°, 12° – 19°$) and correlated to the gridded data of potential indicators. For long term climatological analysis, we used PAGASA data annual SWM accumulated rainfall from 1961 to 2014 (June to September), taken as an average across all stations and correlated to potential indicators. The summary of data set and location was shown in Table 3.

Results and discussion

The results of this study were focused on the (a) short term climatological analysis and (b) long term climatological analysis using simultaneous correlation in potential indicators, which were SST, wind speed and sea level pressure. We will use statistical tools in testing the relationship and association of rainfall to the potential indicators that can establish a pattern and behavior of these variables.

Short term climatological analysis (1998 to 2014) using simultaneous correlation

The simultaneous correlation is based on the relationship of the time series anomaly data of area averaged rainfall over the western SWM affected regions with the gridded data sets of pressure, SST, and wind speed anomalies. TRMM rainfall data set for precipitation was used and NOI-SST for SST, NCEP-NCAR for sea level pressure and ERA-Interim for wind.

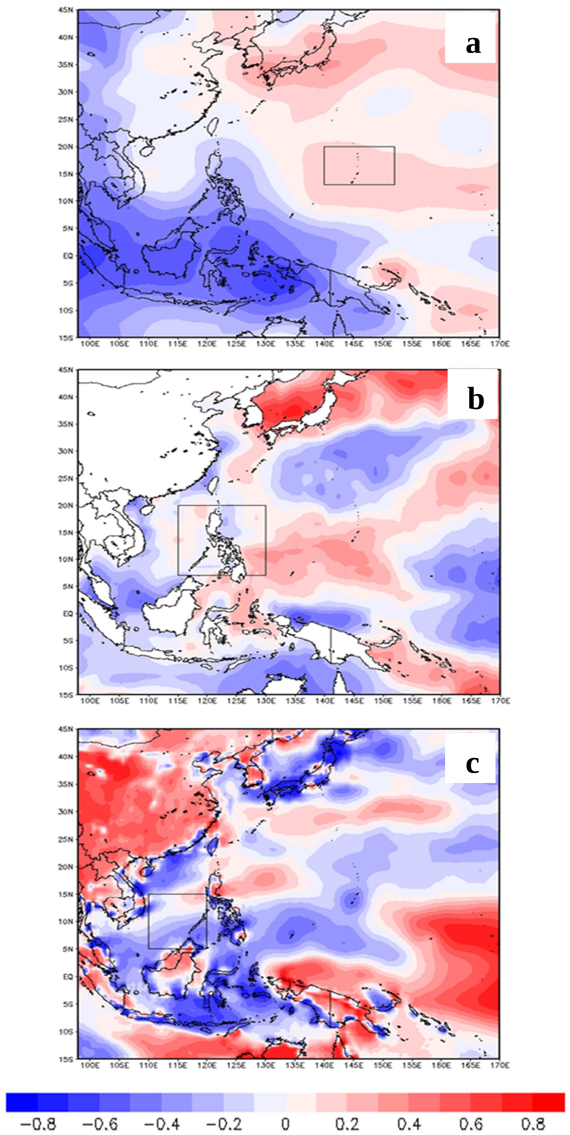

Fig. 1. Simultaneous correlation of precipitation anomaly (TRMM) to (a) sea level pressure anomaly (NCEP-NCAR), (b) SST anomaly (NOI-SST) and (c) wind anomaly (ERA-Interim) from 1998 to 2014 during SWM season

Fig. 1 shows the results of simultaneous correlation of precipitation anomaly to the possible indicators during SWM season. The correlation of the anomaly of precipitation and sea level pressure does not have any significant result especially in the North-eastern part of the Philippines. Also, the correlation coefficient between SST and precipitation anomalies is not conclusive especially at the seas surrounding the Philippines. And this is the same as the result for the wind-precipitation anomaly relationship, which shows weak correlation coefficient.

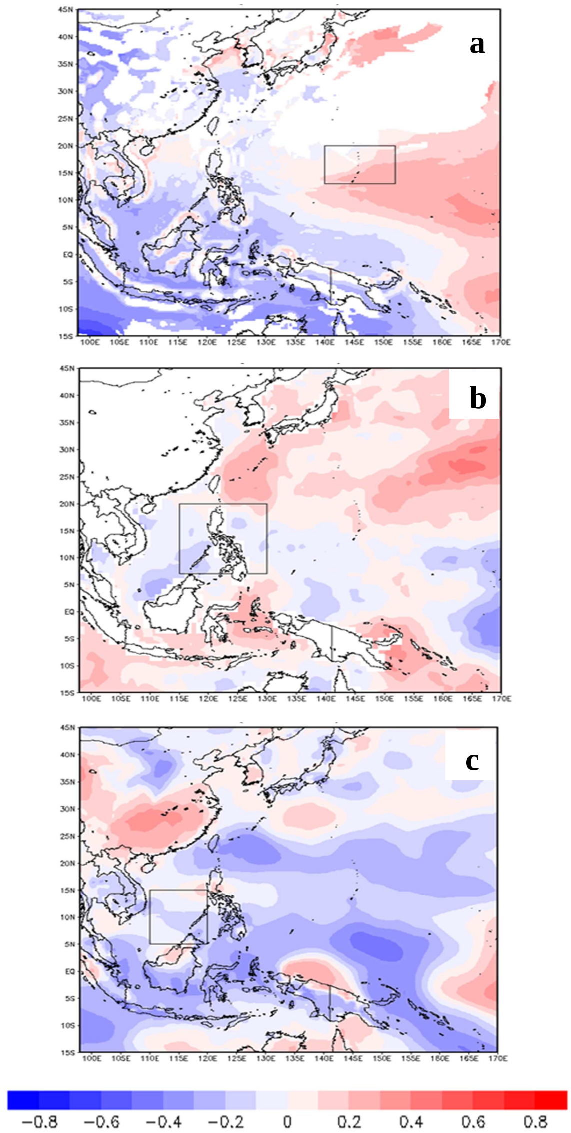

Fig. 2. Simultaneous correlation of rainfall anomaly (PAGASA data) to (a) sea level pressure anomaly, (b) SST anomaly and (c) wind anomaly using ERA data sets from 1961 to 2014 during SWM season

Long term climatological analysis (1961 to 2014) using simultaneous correlation

In this section the rainfall anomalies from the average of the nine meteorological stations (Ambulong, Baguio, Coron, Dagupan, Iba, Iloilo, Laoag, Science Garden and Vigan) in each year (1961 to 2014) are correlated with the anomalies for sea level pressure, wind speed and SST from 1961 to 2014. The data sets for the indicators were downloaded from the ECMWF data sets. This study combines the data of ERA-20C (from 1961 to 1978) and ERA-Interim (from 1979 to 2014) for the indicators. Fig. 2 shows the results of the simultaneous correlation of PAGASA data to possible indicators (SST, wind speed and sea level pressure). All of the relationships do not display significant correlation coefficient and this is consistent with the results in Fig. 1. This shows that in terms of correlation, it may be difficult to determine the behavior of possible indicators for the whole time series data from 1961-2014. Another possible explanation for the non-conclusive results of the correlations analysis is that there are more normal years within the period compared to the ENSO events. From 1998 to 2014 and also from 1961 to 2014, 60% of the data set is considered as normal years.

Signal reversal during ENSO years or ENSO signal reversal

Since the simultaneous correlation did not show significant results, we adopted the methodology of Lyon and Camargo (2009) to inspect the behavior of potential indicators during ENSO events. ENSO signal reversal during ENSO years was investigated by Lyon and Camargo (2009). Their conclusions suggest that there was a decrease (increase) of rainfall during the boreal summer (JAS) during LN (EN) events prior to a "reversal" of higher (lower) rainfall in OND. Lyon and Camargo (2009) used other variables as compared to this study and the analysis covered until the year 2002 only. This study will be based on analyzing the anomaly of the ENSO years and normal years (EN, LN and Normal years). Since this study was only concerned in one season we will call this as an "ENSO signal reversal". The climatological mean is the sum of the annual average of rainfall and potential indicators during SWM season from 1998 to 2014 and divided by the total number of years (17). Hence, the anomaly is the difference between the values of rainfall and potential indicators of ENSO years and Normal years, and the climatological mean. Given the different data sets, as mentioned in the methodology chapter, all of the spatial data were re-gridded into a 0.25 × 0.25 degree resolution. All the spatial maps were re-gridded to this resolution in order to compare in TRMM data, which has this kind of resolution. For example, ERA Interim has 0.75 × 0.75 degree resolution and converts to 0.25 × 0.25 degree resolution.

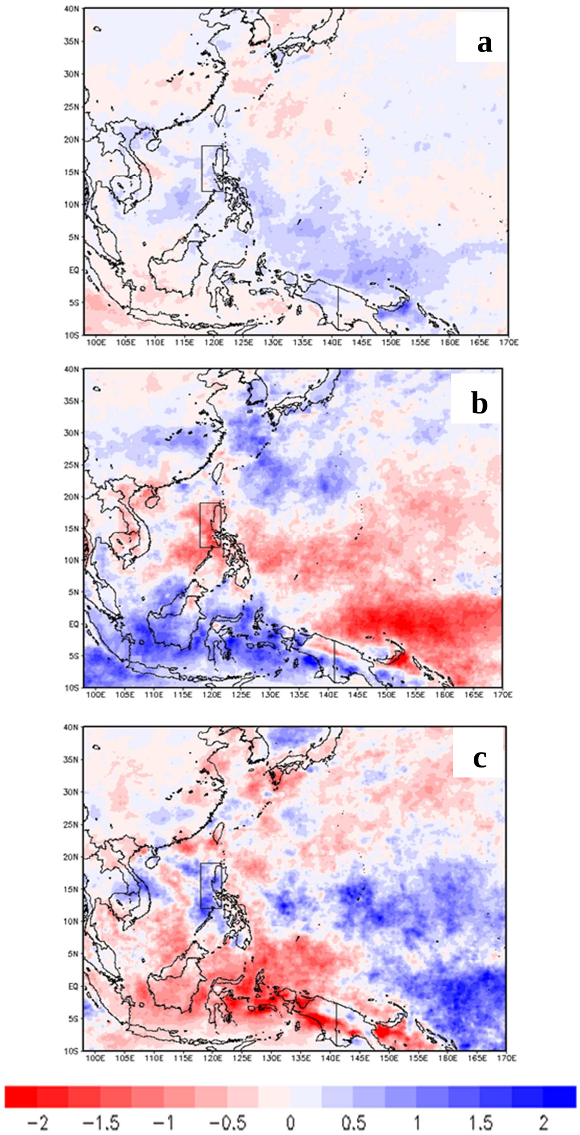

Fig. 3. Composite maps of precipitation anomaly from 1998 to 2014 during southwest monsoon season (JJAS) during (a) normal, (b) La Niña, and (c) El Niño years using TRMM data (unit: mm/day). The box is located at the western part of the country (118° – 121.50° E, 12° – 19° N)

Fig. 3 shows the rainfall anomaly during EN, LN and Normal years. The results show that during EN there is a positive anomaly located at the western part of the country (1180 – 121.500 E, 120 – 190 N), indicating that above normal rainfall occurs during EN events. In contrast, there is negative rainfall anomaly at the same location during LN events, and hence drier conditions and rainfall amounts that are below normal. This is consistent to the study of Lyon and Camargo (2009). According to the National Weather Service of NOAA, El Niño changes the distribution of tropical rainfall from the eastern Indian Ocean to the tropical Atlantic.

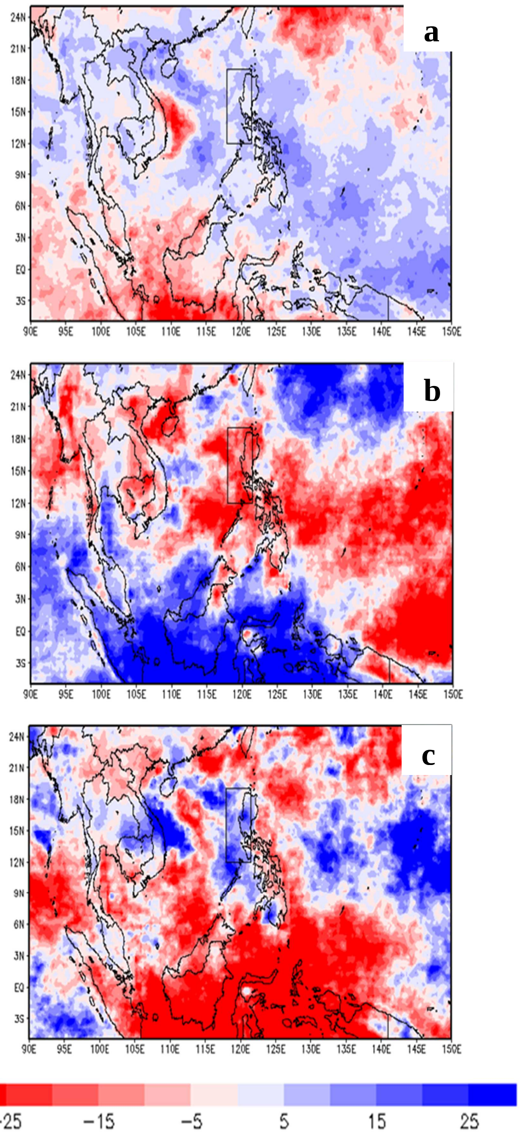

Fig. 4. Composite maps of percentage change from 1998 to 2014 during southwest monsoon season (JJAS) during (a) Normal, (b) La Niña, and (c) El Niño years using TRMM data (unit: %). The box is located at the western part of the country (118° – 121.50° E, 12° – 19° N)

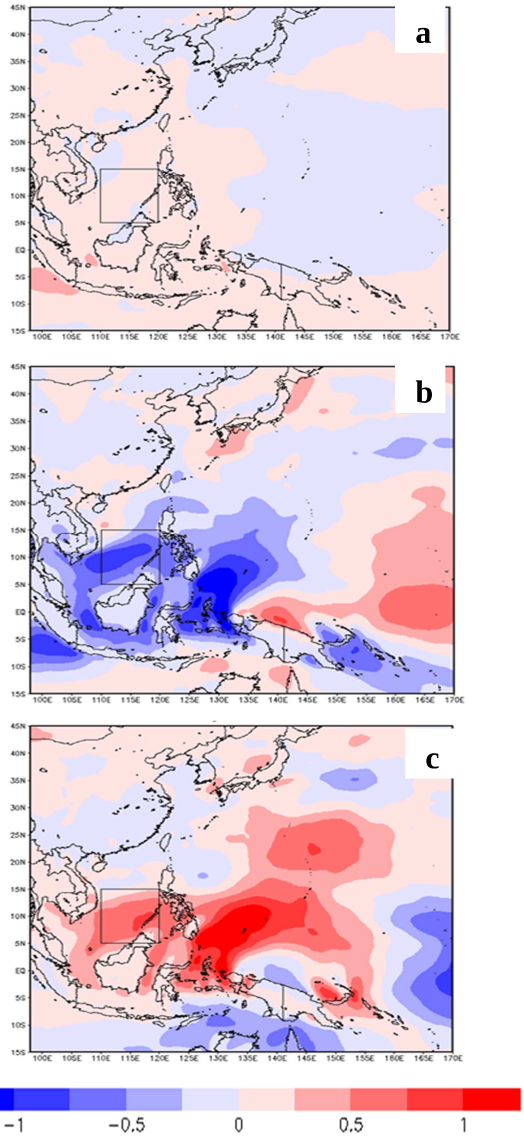

Fig. 5. Composite maps of wind anomaly from 1998 to 2014 during southwest monsoon season (JJAS) during (a) normal, (b) La Niña, and (c) El Niño years using ERA-Interim (unit: m/s). The box is located at the west Philippine Sea (110° – 120° E, 5° – 15° N)

Fig. 4 shows the percentage change of rainfall during SWM season. Since we need to focus on the western part of the country we change the domain and zoom in to this location. In Fig. 4b, the LN events show a negative change, which means there was a decrease in rainfall of about 15% to 25% at the western part of the country. There was an opposite result during EN events, which shows a positive change of about 15% to 25%. This is consistent with Lyon and Camargo (2009). Their study concluded that SWM rainfall is enhanced during EN events and reduced during LN in the western part of the Philippines. Most of the western part of the country shows statistically significant increase (decrease) of rainfall during EN (LN) event with 95% (90%) confidence level in the study of Lyon and Camargo (2009).

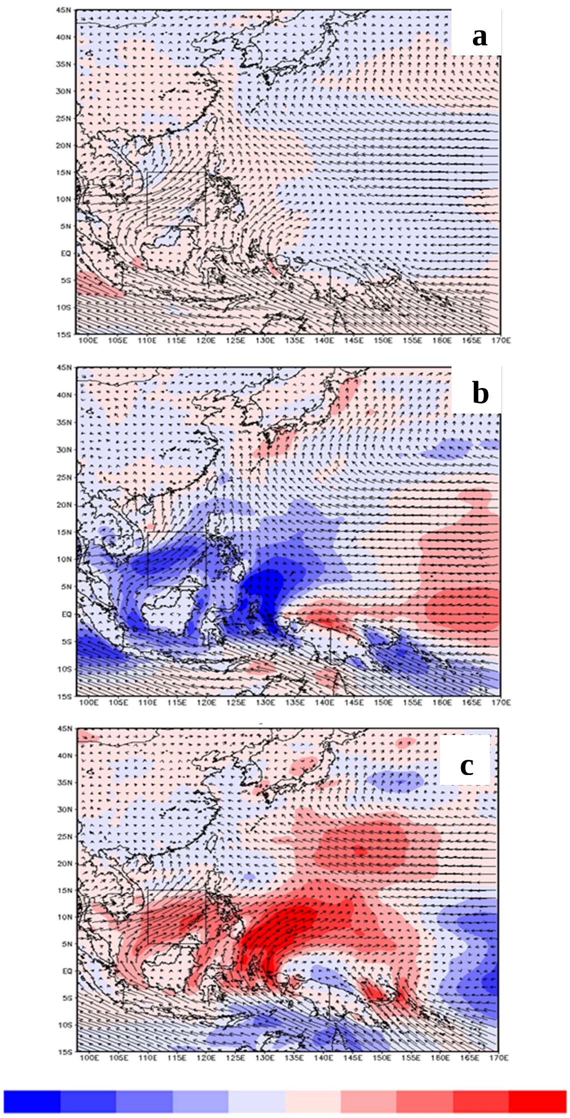

Fig. 6. Composite maps of wind anomaly and wind vector from 1998 to 2014 during southwest monsoon season (JJAS) during (a) normal, (b) La Niña, and (c) El Niño years using ERA-Interim (unit: m/s). The box is located at the west Philippine Sea (1100 – 1200 E, 50 – 150 N).

This study will now analyze wind speed, sea level pressure, and sea surface temperature as possible indicators for the drier (wetter) conditions during LN (EN) events. Fig. 5 shows that El Niño years have stronger winds (with positive anomaly) when compared to La Niña years particularly over the West Philippine Sea (110° – 120° E, 5° – 15° N) and the western regions of the country. During LN events, SWM winds are weaker as shown by the negative anomaly.

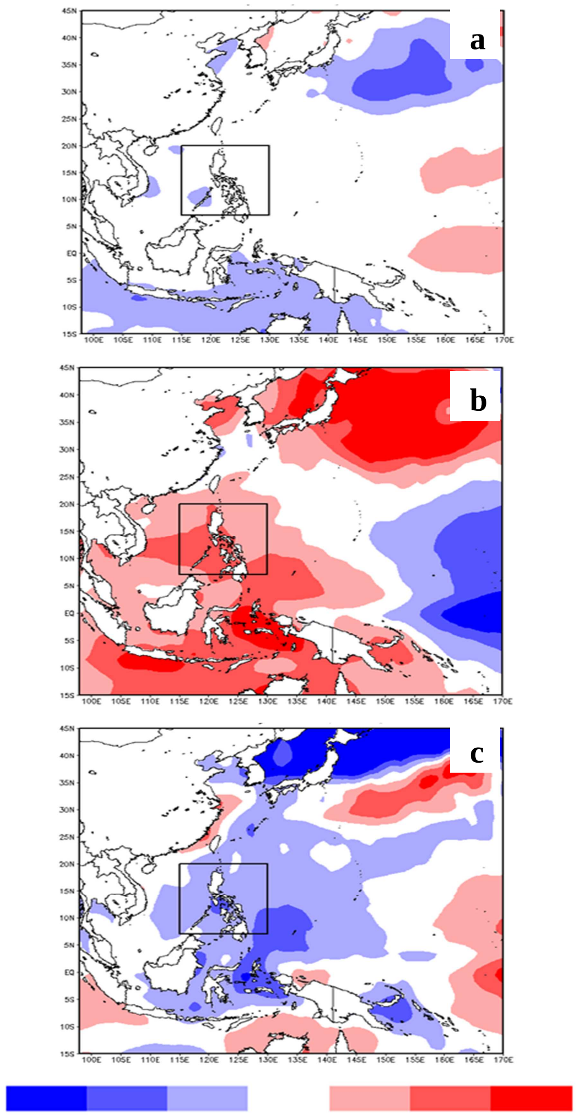

Fig. 7. Sea surface temperature anomaly from 1998 to 2014 during southwest monsoon season (JJAS) during (a) normal, (b) La Niña, and (c) El Niño years using NOI – SST (unit: °C). The box is located at the sea surrounding the Philippines (115° – 130° E, 7° – 20° N)

Fig. 6 shows the wind vector during EN, LN and Normal years. The direction of the wind was from Southwest, which we can say that there was no change in the directions of the wind. Based on Fig. 5 and 6 only the magnitude of wind has a pattern during ENSO events.

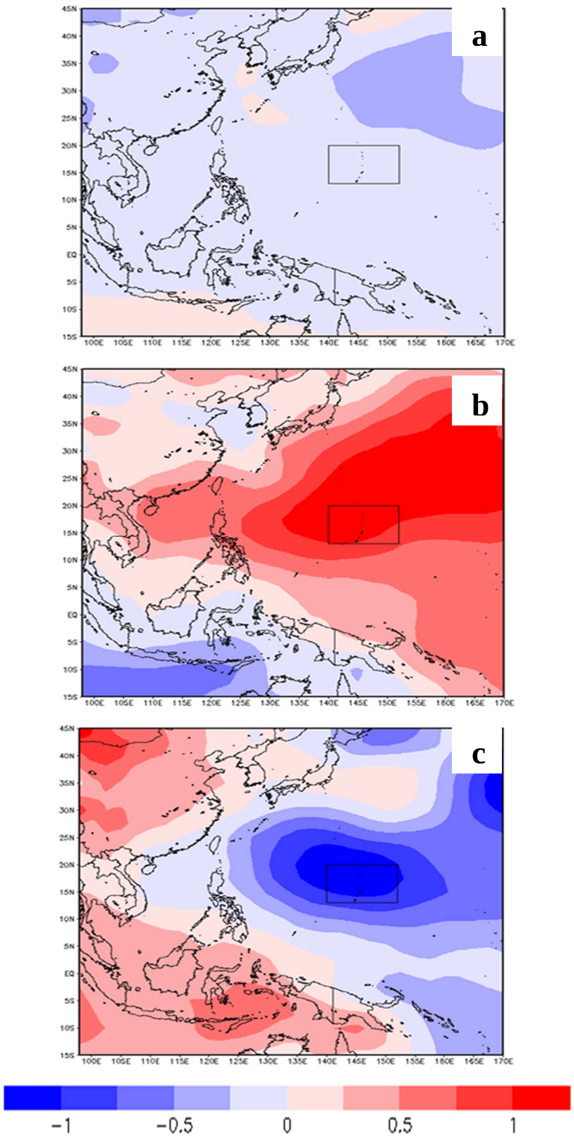

Fig. 8. Sea level pressure anomaly from 1998 to 2014 during southwest monsoon season (JJAS) during (a) normal, (b) La Niña, and (c) El Niño years (unit: hPa). The box is located at the western pacific (1400 – 1520 E, 130 – 200 N)

In Fig. 7 sea surface temperature has a negative anomaly during El Niño and positive anomaly during La Niña years surrounding the Philippines (115° – 130° E, 7° – 20° N). According to Chen and Shih (2008), during El Niño, the negative SST anomalies at the western Pacific help begin and retain a lower – level anticyclone anomaly in the Philippine Sea. The said study also showed an opposite result during La Niña events as compared to El Niño years. Deser *et al.* (2010) states that patterns of non-seasonal SST variability may also result from coupled ocean-atmosphere interactions, most prominently the El Niño-Southern Oscillation phenomenon in the tropical Indo-Pacific sector, but also the tropical Atlantic Niño and the cross-equatorial meridional modes of the tropical Pacific and Atlantic. Our results are consistent with Wu *et al.* (2010) and Wu *et al.* (2009) wherein there is an opposite relation between SST and rainfall during the boreal summer. According to Wu *et al.* (2009), the increase in wind speed can lead to the increase in surface latent heat flux, overcoming cloud shortwave radiation effects and resulting in cold SST anomalies particularly in the Western – North Pacific. The results lead to a negative rainfall-SST relationship in the ENSO-decaying summer. In addition, Wu *et al.* (2009) mentioned that the negative rainfall-SST relationship is due to the anomalous easterly to the south of the Philippine Sea anticyclone. This reduces the mean monsoon westerly and slows down the total surface wind speed, which decreases surface latent heat flux that increases the shortwave radiation that results in the cloud reduction. Since the wind uses ERA – Interim dataset, we also performed the spatial maps of SST using this data set.

Fig. 8a and 8b show that during El Niño years, there is a lower sea level pressure (negative anomalies) at the Western Pacific (140° – 152° E, 13° – 20° N). In contrast, there is positive anomaly (an increase in sea level pressure) during La Niña years. This result is similar to the study of Lyon and Camargo (2009), which showed the same sea level pressure pattern during July, August, and September months in the same location in the Pacific as in this study. Roy and Haigh (2010) concluded that the Aleutian low reduces and the Hawaiian High shifts towards the north that response to a greater solar activity, which results in pressure decrease in the wide area of equatorial region. Yu and Kim (2011) have the same result as Roy and Haigh (2010) but they use Empirical Orthogonal Function as an alternative method for the variations of sea level pressure to the eastern and central pacific types of ENSO. The study states that El Niño enhances the weakening of the Aleutian low with negative sea level pressure anomalies and La

Niña weakens it with positive sea level anomalies. These are consistent with the results of this study. They also state that eastern pacific type was more important than the central pacific type in forcing the extra tropical sea level pressure variability. According to Wang and Zhang (2002), during the summer of El Niño years there was an increase in Central Pacific convection anomaly, which generates cyclonic circulation anomalies in the Philippine Sea, which increases total wind speed and initiate cold SST anomalies. Same as SST, we made also the spatial maps for sea level pressure using ERA Interim.

In summary, if there was a drier condition the sea level pressure in the Western Pacific has a positive anomaly, while there was weaker winds at the West Philippine Sea and there was an increase SST at the surrounding the Philippines, which happens during LN events. From these results, we can say that there was an inverse relationship between sea level pressure and SST to rainfall, and direct relationship to wind speed.

Conclusion

Results further show the ENSO signal reversal in the rainfall during ENSO years from 1998 to 2014. During EN years, the precipitation in the SWM affected regions and the wind speed west of the Philippines has values above normal. In addition, the SST is cooler than normal and sea level pressure in the northeast Pacific is higher than normal. In contrast, during LN years precipitation and wind have negative anomalies. During La Niña, SST are warmer than normal. Also, pressure in the Western Pacific has anomalous high pressure values. The mechanisms for ENSO signal reversal during ENSO events tend to bring drier conditions in the western part of the country based on the composite maps of possible indicators. Results in this study indicate that the effect of ENSO signal reversal on rainfall for the LN events in 1998 to 2010 shows that there are more below rainfall amounts that are occurring during this ENSO event.

The results of simultaneous correlation analysis are not consistent with the results of the composite maps analyzed that showed ENSO signal reversal during ENSO years. For example, the correlation of precipitation anomaly and sea level pressure anomaly has positive correlation coefficient at the Western Pacific but in the ENSO signal reversal the behaviour of the two indicators have an opposite pattern. Because of this, we performed signal-matching method to determine the behaviour of potential indicators in terms of anomaly to rainfall anomaly.

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