A climatological study of typhoons over the Philippine Area of Responsibility from 1989–2018

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Abstract. The Philippines is in the Western North Pacific region, where it is a recipient of several weather disturbances such as tropical cyclones. This study aims to determine trends and periodicities of typhoons (TY) within the Philippine Area of Responsibility (PAR), and the rainfall they brought in a 30-year period (1989–2018) for future forecast and disaster risk mitigation efforts of these TY. These TYs are raised when TC's sustained winds are 118 kph and above. Frequency analysis of TY is done to determine the trends and periodicities in terms of the yearly total occurrence, number of TY that made landfall, distribution of TY classification, and their seasonal variation. The results showed that with PAR the yearly total occurrence of TY seems to have an approximately 12-year periodicity where maximum occurrence was observed around the years 1994, 2004, and 2014 while minimum occurrence was observed in years 1989, 1999, and 2010. Also, track data shows that only 32 % of these TY made a landfall within PAR. Out of the three regions in the Philippines, Luzon Island is the region where most of the severe typhoons made landfall at 80 %. Moreover, TYs occurred mostly during September to November where the transition period between the northeast monsoon and south west monsoon usually occurs. Also, rainfall during which these TYs have occurred were obtained from five synoptic stations across the Philippines. It showed from 1989 to 1998, the total yearly rainfall brought by these TYs ranged from 804 mm to 1 912 mm. But from 1999 to 2018, these TYs brought more rain where their total yearly rainfall ranged from 2 844 mm to 4 941 mm.

1 Introduction

The Philippine terrain is determined by the islands on which it is located and for the most part contains mountain ranges in conjunction with coastal plains. Tropical cyclones (TC) are low pressure systems that form over bodies of ocean which have an air and surface temperature of more than 26 °C and generally progresses at latitudes of more than 5 °C from the equator [1]. They develop from high ocean temperatures. TCs that form in Western North Pacific are also known as typhoons and are categorized by their maximum sustained winds. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) developed the public storm warning system to alert the government and community to prepare for the possible impacts of an impending typhoon. Table 1 shows the updated tropical cyclone classifications from PAGASA.

During the 1902 to 2005 (has a 32-year dominant periodicity) and years after 1945 (has a dominant periodicity of 10 yr to 22 yr), there are no trends found in their annual tropical cyclone landfall numbers (TLP). Instead, the annual TLP has a significant difference between ENSO phases during a low Pacific Decadal Oscillation phase, with a higher number during La Niña [2].

Table 1. Updated Tropical Cyclone Classifications [1]

Category	Sustained Wind Speed (kph)
Tropical Depression	winds up to 61 kph
Tropical Storm	62 kph to 88 kph
Severe Tropical Storm	89 kph to 117 kph
Typhoon	118 kph to 220 kph
Super Typhoon	>220 kph

A tabulated form of global tropical cyclone activity was utilized using "best track" data sets from 1986–2004 for all tropical cyclone (TC) basins. Despite an increase of warming sea surface temperatures throughout the years, a study by [3] shows that in the increase of accumulation of cyclone energy, there have been no established trends. In category 4–5 hurricanes, only around a 10 % increase have been shown over the past 20 yr. A study about the typhoons from 1996 to

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2014 originating in the Western North Pacific was done by gathering the best track data from JWTC and conducted a sub-domain analysis to find trends and patterns. A total of 588 tropical cyclones were examined with a focus on the track and intensity of the typhoons. The results showed that the tropical cyclone genesis have a preferred region and the direction of movement is affected by the presence of tropical cyclones [4]

As far as the authors are concerned, there has been no established literature in these previous studies regarding the trends in frequency, intensity, tracks, and relation to possessed rainfall of tropical cyclones, specifically typhoons and super typhoons, over the Philippine Area of Responsibility (PAR) that reached the year 2018.

This study aims to study the frequency, intensity, tracks, and possessed rainfall of typhoons (TYs) (sustained winds of more than 118 kph) in the PAR from the years 1989 to 2018. Specifically, this study aims to determine the frequency of TYs in the Philippines from years 1989-2018.

Since these TYs have a definite impact in the social and economic aspects of the country, the findings of this study aims to benefit the local government units in typhoon-prone areas by using frequency distribution methods that could determine any trends and periodicities in terms of the frequency of the typhoons per region, signal and total number, as well as the frequency of rainfall per synoptic station. The data that will be gathered can be used in disaster and risk mitigation as well as disaster preparedness in time for a TYs occurrence [5]. The trends, if correctly identified, can be used for future weather forecasts and prediction of intensity variation and movement of these TYs. This study can help in identifying if there is a relationship between climate change and the increasing number of severe typhoons, and to find if severe typhoons have gained strength throughout the years. For meteorologists and different agencies, the results of this study can help in future weather forecasts and disaster risk reduction and management.

2 Methodology

Figure 1 shows TY tracks gathered from the Joint Typhoon Warning Center (JTWC) for TY *Isang* and TY *Reming* that entered PAR in 2000 [6]. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) uses three domains wherein they analyze, monitor, and forecast tropical cyclones (TC). These are namely: The Philippine Area of Responsibility (PAR), Tropical Cyclone Advisory Domain (TCAD), and Tropical Cyclone Information Domain (TCID) [7]. As shown in Figure 1, PAR is the smallest and innermost area wherein its margins are near to the Philippine landmasses. The researchers will only consider typhoons that entered in the Philippine Area of Responsibility which either made landfall or did not make landfall. TYs that emerged outside of PAR will be disregarded.

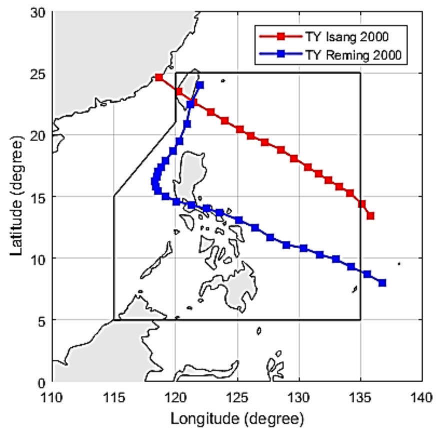

Fig. 1. TY *Isang* (did not make landfall) and TY *Reming* (made landfall) tracks that entered PAR (black border) in 2000

To understand the track records of TYs that entered the Philippine Area of Responsibility (PAR), data was obtained from the Joint Typhoon Warning Center website [8]. The TY data includes tropical cyclone tracks, international names, duration, intensity (wind), minimum and maximum mean sea level pressure (MSLP), and maximum intensity from 1989 to 2018. TYs that made landfall and did not will be determined with the use of these track datasets. With the use of PAGASA's TC list, TYs with weak MSWs are filtered, and only TYs with more than 120 kph are considered.

To investigate the trend in rainfall intensity brought by TYs during this period, the daily rainfall data gathered from PAGASA's synoptic stations namely Quezon City, Cebu Mactan International Airport, Roxas City, Zamboanga del Sur, and Davao City as shown in Figure 2.

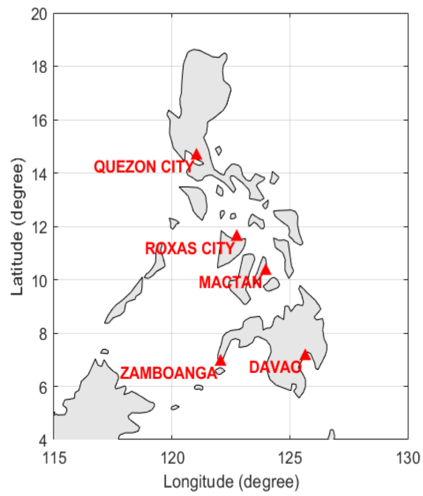

Fig 2. Locations of the surface synoptic stations to be used in the rainfall per region analysis

Rainfall in Luzon is represented by the Quezon City synoptic station while Visayas and Mindanao are represented by Roxas City and Mactan synoptic stations, and Davao City and Zamboanga City synoptic stations, respectively. The researchers deliberately chose different synoptic stations to learn which of the regions experience greater amounts of rainfall. Daily rainfall data will be obtained from these stations from 1989 to 2018.

Each year is divided seasonally: northeast monsoon season (DJF), summer season (MAM), southwest monsoon season (JJA), and transition from southwest to northeast monsoon season (SON) [9]. The average daily rainfall intensity for a month and the average for a quarter was computed. To determine the periodicity of the frequency of TYs from 1989 to 2018, the circular Auto Correlation Function (ACF) is used. ACF is given by:

$$ACF\ (\tau) = \frac{\sum_{i=1}^{n} Y_i \times Y_{i+\tau}}{N} \qquad (1)$$

where Yi is the value of the data in the time series, τ is time lag which provides the periodicity (1 yr to 20 yr) and N is the number of entries with an offset of 1 each entry. In this study, the predicted periodicity is determined by identifying which time lag has the greatest value of ACF [10].

3 Results and discussion

Figure 3 shows the total number of occurrences per year from 1989 to 2018. It is sub-divided into TYs that made landfall (in black) and did not make landfall (in red). It shows the year 2004, as the year with the greatest number of TYs that did not make landfall, with a total of 10 and the year 1998 with the least number with one. The year where most of the TYs made landfall was in 2006, with a total of 6 TYs while there were no TYs that made landfall in 2002. It shows that, on average, there were more TYs that did not make landfall than TYs which did landfall where the average yearly occurrence of TYs throughout the data set that made landfall is 2.3, while there is an average of 5.3 TYs that did not make landfall.

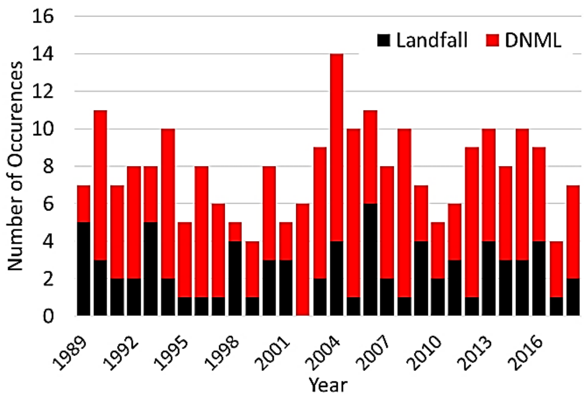

Fig. 3. Yearly Count of Severe Tropical Cyclone Occurrences

Moreover, of the total TYs per region, Luzon has the highest number, Visayas being the second, and Mindanao being the last. Using the best track data from 1989 to 2018 from JTWC, TYs tracks were seen. With over 235 TYs, and only 76 of them making landfall in the Philippines, only 32 % of all TYs recorded have made landfall in the country. Luzon is the most hit region in the Philippines, tallying over 61 TY occurrences in 30 yr. Visayas has 12 TY occurrences, and Mindanao, having the least TY occurrence with 3.

A recent study in 2014 that was focused on the climatology of landfall characteristics of tropical cyclones from various countries states that the North Western Pacific (NWP) basin has the greatest average quantity of tropical cyclone (TC) formations. They included countries which have a mean number of at least one landfall a year. Their findings reveal that China has the greatest frequency of TC landfall. The Philippines came second and Japan as third. In addition, they also stated that TCs that made landfall in the Philippines were more severe compared to any other country [11]. Another study observed that no significant trend was analyzed in the time series of TCs, as well as tropical depressions that had made landfall or crossed over the Philippines from 1948 to 2010. Nevertheless, it was identified that there was a decreasing trend on the number of landfalling or crossing TCs in the country [12]. In another recent study, the researchers observed interdecadal variations regarding the frequency and intensity of TCs in the NWP. The findings show that there was an increase in TC occurrence, including landfalls, in the regions of East China, Japan, and Korean Peninsula [13]. In a study on typhoons that made landfall in Guangdong Province of China between the years of 1470–1931, an increasing trend is found. It has also been observed that centennial and decadal oscillations exist [14].

In the 235 recorded TYs that entered the Philippine Area of Responsibility (PAR), there are 226 typhoons (29.36 %) of which made landfall. Also, there are 9 super typhoon occurrences where 78 % of which made landfall, and 4 of which made landfall in the first decade of the study (1989–1998), and 3 more occurred in the third decade (2009–2018). A study suggested that the total number of TCs annually shows a slight decreasing trend of the number of TYs but increased in intensity [15]. However, for severe typhoons, there is an increase in the number of occurrences. This is because in the WNP, TYs journey longer westwards which is favorable for the development of severe TYs, resulting in an increase of occurrences in 20 yr. However, in the 1990s, TY occurrences decreased, due to negative tendencies shown when TYs entered the South China Sea [16]. This is consistent with the results of this study, seeing that in the first decade (1989–1998), there were only 75 occurrences, but then increased by ten TY occurrences per succeeding decade. TYs will travel a longer trajectory during an El Niño year, since the formation of TYs occur in the southeast basin, therefore generating more intense TYs [17].

Using Equation 1, the ACF calculated to determine periodicity of occurrence of TYs inside the PAR in shown in Figure 4. It shows that there is a 12-year dominant periodicity in TY frequency. This means that in approximately every 12 yr, TY occurrences have been more frequent. A study showed that in a decadal scale, there is a peak that occurs at around 25 yr in their unadjusted Cat45 TC frequency, however there is a 12 to 18-year cycle in the adjusted Cat45 TC frequency. Each adjusted and unadjusted Cat45 TC frequency has different spectral peaks [18], the former of which varied with the results of this study, while the latter is consisted with the results of this study.

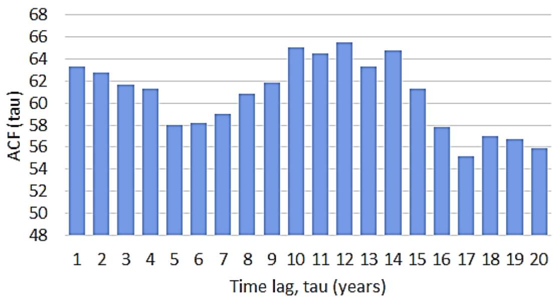

Fig. 4. Circular Autocorrelation Analysis Showing Dominant TY Occurrence Period in Years

Time series analysis of the TY occurrences per season per year is shown in figure 5. The study is based in 4 seasons, namely the northwest monsoon season (December to February), summer season (March to May), the southeast monsoon season (June to

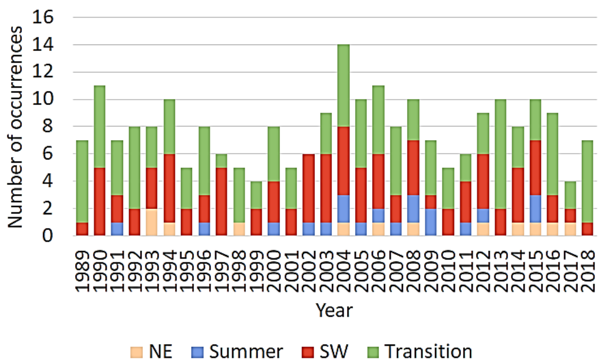

Fig. 5. Seasonal TY Occurrence per Year

September), and the transition period from the southeast monsoon to the northeast monsoon (October to November). It shows that the transition period from southwest monsoon season to northeast monsoon season is the season where most TY occurs, with 118 occurrences, and averaged 3.9 occurrences in 30 yr.

The Northeast monsoon season has the least number of occurrences, with 12 and an average of 0.4 occurrences. The summer season only has 18 occurrences and averaged 0.6 occurrences. The southwest monsoon season has 87 occurrences and has an average of 2.9 occurrences. The year with the most TY and STY occurrence is the year 2004, with 14 occurrences, and the year with the least TY and STY occurrence are the years 1999 and 2017, each with 4 occurrences.

Here, transition period as the season with the most TY occurrence. The NE Monsoon, usually occurs from January to February, summer season (denoted in the table as Summer, usually occurs from March to May), the SW Monsoon, usually occurs during June to September, and the transition period (a transition period from southwest to northeast monsoon season; from months October to December). The season where most TYs occur is the transition period with 118 occurrences. Following the transition period is the Southwest monsoon, with 87 occurrences. The summer season comes next with 18 occurrences, and the northeast monsoon tallied the least with 12 occurrences.

According to Cinco et. Al (2013), projected in 2020 and 2050, the southwest monsoon and the transition period are expected to have an increase in rainfall in Luzon and Visayas. There will be a decrease in rainfall during the summer season and the rainfall for northeast monsoon will increase. Also, the months of July to October have the greatest number of TCs, and from July onwards is where stronger TCs occur. The months of January through May saw less TC occurrences [9].

Figure 6 shows a time series of annual rainfall per region from 1989 to 2018 from the 5 synoptic stations in the Philippines. The region with most accumulated rainfall is Luzon, followed by Visayas, and Mindanao. Luzon averaged 632 mm of rain in 30 yr, experiencing its highest rainfall count in 2000, with over 1 800 mm of rain. Rainfall in Visayas averaged 441 mm of rain, wherein 2008 experienced its highest rainfall count with over 1 300 mm of rain. However, in Mindanao, its rainfall count averaged less than 400 mm, and its highest rainfall topped in 2013 with 890 mm of rain.

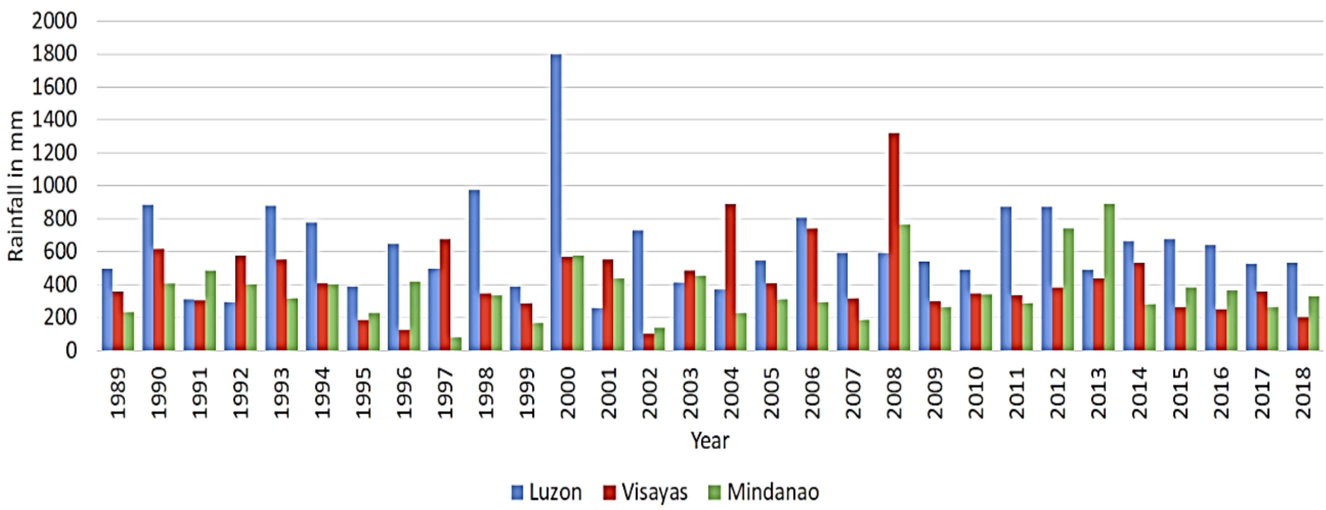

Fig. 6. Annual Rainfall Count of TYs per Region

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The total annual rainfall during TY occurrence from 1989 to 2018 from the 5 synoptic stations in the Philippines is shown in figure 7. The graph shows the year 2000 as the year with the most accumulated rainfall from TYs. The year where most rainfall occurred was in 2000, tallying a total of 4 941.4 mm. Observed also were decadal differences. From the years 1989 to 1998, rainfall totals ranged from 804 mm to 1 912 mm. Two decades later, from the years 1999 to 2018, saw a spike in the totals, ranging from 2 844 mm to 4 941 mm.

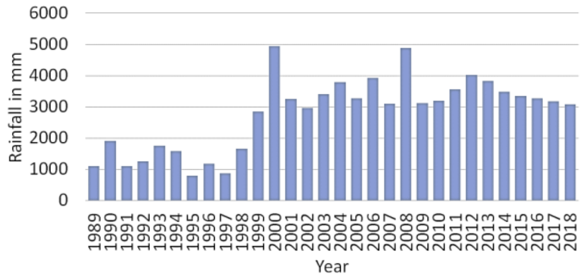

Fig. 7. Rainfall Totals per Year during TY Occurrence from 1989 to 2018

Climate projection consensus of future TC behavior shows that the number of TCs will continue to decrease. However, it strengthens in terms of the TCs intensity and rainfall. Their study identified the correlation between the intensifying TC related rainfall with mostly an increase in moisture convergence - mostly from an increase in water vapor and evaporation [19]. In comparison, the findings of their study regarding the strengthening of TCs is consistent with the results gathered, evidently shown in the decadal differences in terms of rainfall quantity. This can be supported by a study in 2012 which stated that from 1958 to 2010, trends regarding TC rainfall frequency were found to be decreasing, while increasing in TC rainfall intensity to the south China monsoon region [20].

In a previous study, extreme rainfall is not related to typhoon intensity. However, it is related to the typhoon duration and translation. The slower typhoon translation and longer duration time contribute to larger rainfall count. In the last 51 yr in Taiwan, TY tracks north (north of 23 degrees latitude) occur 3 hours longer than southern TY tracks, likely producing three times as much rainfall [21]. In Vietnam, a study has reported that from 1961 to 2008, there is an increasing trend in TC rainfall along the central coastlines [22].

Highest among the regions is Luzon, with an approximate of 19 000 mm of rain. It is followed by Visayas, with an approximate of 13 000 mm. and Mindanao with just over 11 000 mm. As for the TY rainfall share, 44 % is from Luzon, 31 % is from Visayas, and 25 % comes from Mindanao. A study further supported this, since Luzon is the most hit region in the country, its high rainfall count follows that. The north-eastern part of the country from 1951–2013 is the most hit area, while TY occurrence in the south-western part is either few to none [15].

4 Conclusion and recommendations

From 1989 to 2018, there is an apparent 12-year cycle on the annual occurrence of TY within the PAR. Also, track data shows that only 32 % of these TY made a landfall within PAR. Luzon Island is the region out of the three identified regions in the Philippines where hit with the greatest number of the TYs. TYs is experience most of the time during the transition from northeast monsoon to southwest monsoon (September to November). While there is an noticeable periodicity in TY occurrence, there was an significant increase in the annual rainfall brought by these TYs where it only ranged from 804 mm to 1912 mm in 1989 to 1998, to a range of 2844 mm to 4941 mm in 1999 to 2018. This study shows that TYs bring more rain even if their overall occurrence did not significantly change.

It is recommended that the period of student be increased to earlier years to see the extent of the change that had happened. So that any response to this seemingly climate change derived phenomena be fully studied.

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References

1. PAGASA, Retrieved from http://bagong.pagasa.dost.gov.ph/information/about-tropical-cyclone (n.d.-a).
2. H. Kubota, J.C.L. Chan, Geophys. Res. Lett., **36**, 2–5 (2009).
3. P.J. Klotzbach, Geophys. Res. Lett., **33**, 229–237 (2006)
4. T. Khurana, S.K. Bhattacharya, S.D. Kotal, Trop. Cyclone Res. Rev., **6**, 82–93 (2017)
5. I.L. Corporal-Lodangco, L.M. Leslie, Int. J. Climatol., **37**, 3525–3539 (2017)
6. Naval Meteorology & Oceanography Command, Joint Typhoon Warning Center (JTWC) (n.d.)
7. PAGASA, Retrieved from http://bagong.pagasa.dost.gov.ph/learningtools/philippine-area-of-responsibility (n.d.-b).
8. C. Choy, S. Chong, D. Kong, E.O. Cayanan, Trop. Cyclone Res. Rev., **4**, 1–11 (2015)
9. T.A. Cinco, F.D. Hilario, R.G. De Guzman, E.D. Ares, *Climate trends and projections in the Philippines*, in Paper presented at the 12th National Convention on Statistics (NCS), Mandaluyong City, Philippines, October 1–2 (2013)
10. M. Vlachos, P. Yu, V. Castelli, *On Periodicity Detection and Structural Periodic Similarity*, in Proceedings of the 2005 SIAM International Conference on Data Mining, 449–460 (2005)
11. H. Fudeyasu, S. Hirose, H. Yoshioka, R. Kumazawa, S. Yamasaki, Trop. Cyclone Res. Rev., **3**, 178–192 (2015)

12. T.-C. Lee, T.R. Knutson, H. Kamahori, M. Ying, Trop. Cyclone Res. Rev., **1**, 213–235 (2012)
13. T.-C. Lee, T.R. Knutson, T. Nakaegawa, M. Ying, E.J. Cha, Trop. Cyclone Res. Rev., **9**, 1-22 (2020)
14. J.C.L. Chan, J.E. Shi, Int. J. Climatol., **20**, 183–190 (2000)
15. T.A. Cinco, R.G. de Guzman, A.M.D. Ortiz, R.J.P. Delfino, R.D. Lasco, F.D. Hilario, E.L. Juanillo, R. Barba, E.D. Ares, Int. J. Climatol., **36**, 4638–4650 (2016)
16. L. Wu, B. Wang, J. Clim., **21**, 1432–1439 (2008)
17. P.J Klotzbach, M. Ballester, T. Barnston, G. Bell, J. Camp, J. Chan, D. Jones, Y. Kuleshov, T. LaRow, M. Saunders, O. P. Singh, F. Vitart, *Tropical Cyclone Variability on Seasonal Time Scales (Observations and Forecasting).* 1–22 (2010).
18. H. Zhao, L. Wu, R. Wang, Adv. Atmos. Sci., **31**, 57–65 (2014)
19. K.J.E. Walsh, S.J. Camargo, T.R. Knutson, J. Kossin, T.-C. Lee, H. Murakami, C. Patricola, Trop. Cyclone Res. Rev., **8**, 240–250 (2019)
20. C.P. Chang, Y. Lei, C.H. Sui, X. Lin, F. Ren, Geophys. Res. Lett., **39** (2012)
21. S.H. Su, H.C. Kuo, L.H. Hsu, Y.T. Yang, J. Meteorolog. Soc. Jpn., **90**, 721–736 (2012)
22. H.A. Nguyen-Thi, J. Matsumoto, T. Ngo-Duc, N. Endo, SOLA, **8**, 41–44 (2012)