



Interdecadal variability of tropical cyclone landfall in the Philippines from 1902 to 2005

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[1] A dataset of tropical cyclone landfall numbers in the Philippines (TLP) is created from a combination of historical observation records of the Monthly Bulletins of Philippine Weather Bureau and Joint Warning Typhoon Center best-track data for the period of 1902 to 2005. Interdecadal variability of TLP is found to be related to different phases of the El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). The annual TLP has an apparent oscillation of about 32 years before 1939 and an oscillation of about 10–22 years after 1945. No long-term trend is found. During the low PDO phase, the annual TLP decreases (increases) significantly in El Niño (La Niña) years. During high PDO phase, however, the difference in annual TLP between different ENSO phases becomes unclear. These results suggest that natural variability related to ENSO and PDO phases appears to prevail in the interdecadal variability of TLP. **Citation:** Kubota, H., and J. C. L. Chan (2009), Interdecadal variability of tropical cyclone landfall in the Philippines from 1902 to 2005, *Geophys. Res. Lett.*, *36*, L12802, doi:10.1029/2009GL038108.

1. Introduction

[2] Tropical cyclone (TC) provides precious fresh water to the land but it can also cause disaster when it makes landfall due to strong winds, heavy rain and storm surge. Recently, the variability of TC activity (including the frequency of occurrence and intensity) has become a great concern because it may be affected by global warming. The number of intense TCs appeared to have increased in association with the increase of sea-surface temperature (SST) during the past 30 years [Webster *et al.*, 2005]. However, TC occurrence also shows natural interdecadal variability [Yumoto and Matsuura, 2001]. Several numerical simulations under the assumption of future global warming suggested that the TC frequency of occurrence would decrease but their intensity would tend to increase [e.g., Oouchi *et al.*, 2006; Gualdi *et al.*, 2008].

[3] To identify the variability of the TC activity associated with climate change, a TC database of more than 100 years of observations over the Atlantic basin was created [Landsea *et al.*, 2004]. Mann and Emanuel [2006] found a positive correlation between SST and Atlantic TC frequency since 1871. However, the reliability of counting TC remains questionable because the areas covered by

observations to detect TC over the Atlantic Ocean were not sufficiently wide until geostationary satellite observations began in 1966 [Landsea, 2007]. For the western North Pacific (WNP) basin, best-track data are available from 1945 from the Joint Typhoon Warning Center (JTWC). The available TC data over the WNP basin is not sufficient to answer the question whether the observed interdecadal variability of TC is natural or anthropogenic, although Chan [2008] pointed out that the natural oscillation is likely dominant based on the data after 1960.

[4] In this study, historical observation records of TC track during the period 1901 to 1940 were collected from the Monthly Bulletins of the Philippine Weather Bureau (MBP). This TC dataset traces TC tracks back to the beginning of the 20th century west of 150°E over the WNP. Weather stations in the Philippines were established and the MBP was published from the late 19th century by Spanish and then American meteorologists [Udias, 1996]. In fact, the historical documents of TCs around the Philippines can be traced back to the 16th century [García-Herrera *et al.*, 2007]. The first observation record of TC was in September 1865 in the first observation year of Manila Observatory [Deppermann, 1939]. However, we had to wait until the beginning of the 20th century when the Philippine Weather Bureau deployed many weather stations in the Philippines to capture the behaviors of typhoons in its vicinity.

[5] We focus on the TC landfall numbers in the Philippines (TLP) in this study because high quality data of the TC tracks near the Philippines is available from the MBP. Saunders *et al.* [2000] showed a significant decrease (increase) in TLP during the autumn of El Niño (La Niña). The decrease in TLP is associated with the eastward shift of TC tracks over the WNP during El Niño according to Wang and Chan [2002]. Over the Pacific, Mantua *et al.* [1997] also identified SST changes over a time scale of 20–30 years, known as the Pacific Decadal Oscillation (PDO). Chan [2008] indicated that intense typhoon frequency over the WNP has oscillations of 16–32 years with a linkage to ENSO and PDO phases during 1960–2005. The question is whether or not TLP changes during different phases of the PDO?

[6] The objectives of this study are to create a unique dataset of TLP from 1902 to 1939, to combine it with the JTWC TLP data during the period of 1945–2005, and to investigate the interdecadal variability of TLP during the past 100 years in order to understand how such variability may be related to different phases of ENSO and PDO. The data used in this study are described in section 2. Definitions of TLP and interdecadal variability of TLP are discussed in section 3. The relationship among TLP, ENSO

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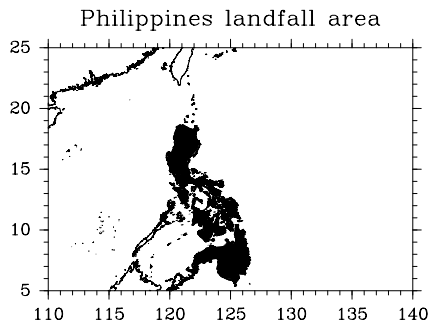


Figure 1. The landfall area in the Philippines used in this study.

and PDO is examined in section 4, followed by a summary in section 5.

2. Data

[7] MBP reported surface weather station data in the Philippines and TC tracks over the WNP region during January 1901–August 1940. The TC track was determined using surface observations (wind, pressure, temperature, rainfall, etc.) at weather stations and ships, reports of calm weather by the passage of TC eye, and damages to ships, houses and other structures on land. TC tracks of MBP used in this study were manually counted from the Bulletins. In this study, the MBP data from 1902 to 1939 are used only when the TC record and station surface data are available throughout an entire year. Surface wind and pressure were available at 43 stations in 1902 and increased to 63 stations in 1939.

[8] After 1945, Philippine weather stations were rebuilt by the Philippine Weather Bureau. Best-track data for TC center locations from 1945 to 2005 are from the JTWC. The JTWC best-track data and the MBP are combined to create a TLP dataset of 100 years. Best track data from 1951 to 2005 are also available from the Regional Specialized Meteorological Center (RSMC) Tokyo-Typhoon Center in the Japan Meteorological Agency (JMA), which are used for validation of the JTWC best-track data. Classification of El Niño and La Niña years follows *Trenberth [1997]*. The PDO index is defined as the leading principal component of North Pacific monthly SST variability poleward of 20°N [*Mantua et al., 1997*].

3. Interdecadal Variability of TLP

3.1. Definitions for TC Landfall Numbers in the Philippines

[9] The targeted area for TC landfall in the Philippines is shown in Figure 1. For 1945 to 2005, TLP is defined by a TC with tropical storm (TS) intensity of 35 kt or higher in the maximum surface wind speed at TC center (based on the JTWC best-track dataset) that passed the Philippines area of Figure 1. For 1902 to 1939, surface wind at TC center is not available. If a TC passed the Philippines area during that period and the nearest minimum station pressure was observed to be less than 750 mmHg (about 1000 hPa), one TLP is counted.

[10] The empirical relationship between pressure and maximum wind speed at TC center was established by *Atkinson and Holliday [1977]*, which was applied in Dvorak Technique for TC analysis [*Dvorak, 1975*]. The threshold of

1000 hPa used for TS criteria before 1939 is consistent with this empirical relationship and therefore reasonable. *Nyomura [1979]* investigated 728 TSs from 1951 to 1977 using the JMA best-track data. The percentage of TSs with a central pressure above 1000 hPa was 5.4 during this period. The data of the two definitions of TLP proposed in this study are available from 1951 to 1978 from the tropical cyclone summaries by *Bonjoc [1978]*. (Tropical cyclone summaries are available from 1948, however many weather stations only reported from 1951 in the Philippines. Station pressure data were used from 1951 in this study.) During this period, the number of TSs that made landfall in the Philippines by the definition of JTWC and JMA best-track data were both 124. Within the 124 TCs, 107 and 105 TSs satisfied the threshold (<1000 hPa) of station pressure in the Philippines for JTWC and JMA best-track data respectively. The definition of the nearest minimum station pressure tends to underestimate the numbers of TCs compared to that of the maximum surface wind speed at TC center. However the difference between these two TLP definitions of the maximum surface wind speed at TC center and the nearest minimum station pressure was 13.7% and 15.3% respectively, for JTWC and JMA best-track data. This kind of difference is equivalent to only about 0.6 TLP per year, and therefore is acceptable.

3.2. Interdecadal Variability

[11] Figure 2a shows annual TLP from 1902 to 2005. After 1945 and 1951, best-track data sets of JTWC and

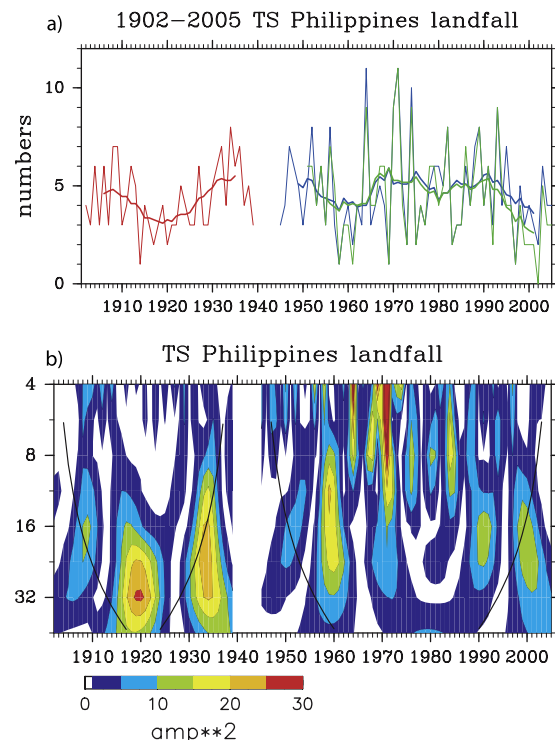


Figure 2. (a) Annual TLP using MBP (from 1902 to 1939; red curves), JTWC (from 1945 to 2005; blue curves), and JMA (from 1951 to 2005; green curves), where the thick curves are for 10-year running mean. (b) Wavelet power spectrum of annual TLP using real-valued Mexican-hat wavelet. Wavelet is performed separately before 1939 using TLP from MBP and after 1945 using TLP from JTWC data. The thick curve indicates the edge effects.

Table 1. Annual TLP From June to the Following May Divided According to PDO and ENSO Phases^a

	1902–1939 High PDO	1945–1976 Low PDO	1977–2005 High PDO
El Niño years	4.1	3.6	4.5
La Niña years	3.9	6.0	4.3
Normal years	4.7	4.3	5.1

^aBold numbers represent they are statistically significant at 95% confidence level of the difference between El Niño and La Niña years.

JMA are plotted. Both best-track data show similar interannual and interdecadal variability of TLP until 1980s. This difference from 1990s is due to the deactivation of the US Air Force aircraft reconnaissance [Kamahori *et al.*, 2006]. We will use the JTWC best-track data for the analysis after 1945.

[12] Before 1939, TLP was low around 1920 and high around 1910 and the mid-1930s. Data are missing between 1940 and 1944. After 1945, the year-to-year variability becomes high from the mid-1960s to the mid-1970s. Since 1990, TLP has been decreasing. However, even considering the difference between the two TLP definitions of the maximum surface wind speed at TC center after 1945 and the nearest minimum station pressure before 1939, no trend can be seen in the annual TLP from 1902 to 2005. A real-valued Mexican-hat wavelet analysis of annual TLP performed separately for the periods before 1939 and after 1945 [Torrence and Compo, 1998] shows a dominant periodicity of about 32 years around 1920, and a 10–22 years periodicity around the 1960s and after the 1990s (Figure 2b). On the other hand, shorter periods of less than 10 years prevailed from the mid-1960s to the mid-1980s. Our results indicate that the 32-year periodicity of TLP was also dominant before 1940.

4. Relationship of TLP to ENSO and PDO

[13] Saunders *et al.* [2000] noted that the TLP has an interannual variability associated with ENSO. However, the effect of ENSO can be modified by that of the PDO [e.g., Chan and Zhou, 2005]. Is TLP then also affected by the PDO? In this section, the annual TLP is estimated from June to the following May based on the combination of Asian monsoon and ENSO [Yasunari, 1991]. The average of annual TLP during low PDO (1945–1976) and high PDO phases (1902–1939 and 1977–2005) are therefore compared (Table 1). (Mantua *et al.* [1997] defined low PDO period until 1925. However our results did not show significant difference before and after 1925.) During the low PDO phase, the difference in annual TLP between El Niño and La Niña years is significant at the 95% confidence level. However, during high PDO phases, such a difference disappears and annual TLP number is slightly higher in El Niño years.

[14] A difference in monthly TLP between different ENSO phases is seen from September to November during both low and high PDO phases (Figure 3), with TLP numbers being generally higher during La Niña years. However, the difference of monthly TLP between different ENSO phases becomes smaller in autumn (October and November) and has opposite signs during summer (June and July) and winter (December and January) of high PDO

phases. These results offset the difference of annual TLP between different ENSO phases.

[15] Interannual variability of TC activity is likely influenced by the intensity of the anomalous Philippine Sea anticyclone. During autumn of El Niño developing year, Philippine Sea anticyclone anomalies are established [Wang and Zhang, 2002], which suppresses the TC activity over this region and reduces TLP. During the low PDO phase before 1976, the contrast of anomalous Philippine Sea anticyclone in autumn between ENSO phases was intensified. However, after 1977 of the high PDO phase, this contrast was weakened; in fact Philippine Sea cyclonic anomaly was strengthened during summer of the El Niño developing year [Wang, 1995]. The modulation of anomalous Philippine Sea anticyclone behaviors between ENSO phases may influence TLP during different PDO phases.

5. Conclusions

[16] A dataset of TLP is constructed by using historical observation records of MBP from 1902 to 1939 and the

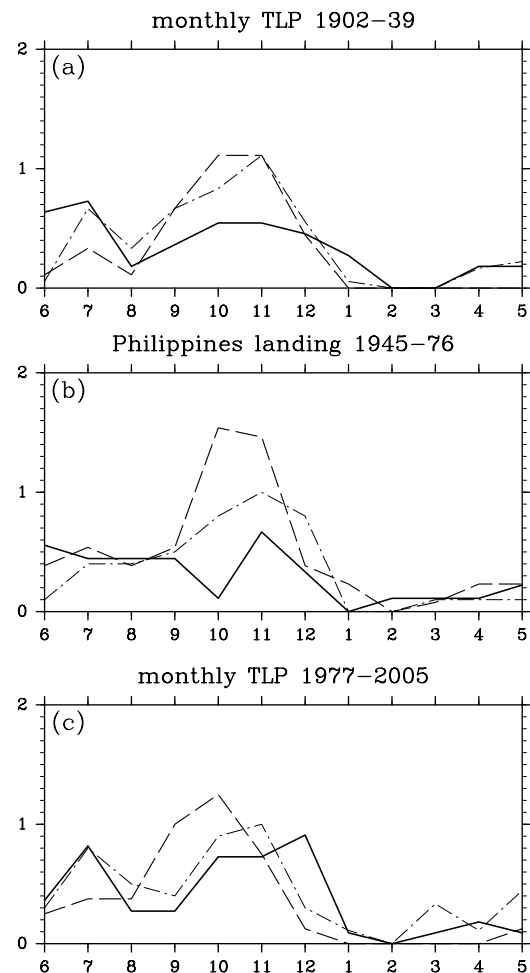


Figure 3. Monthly TLP during high PDO phases of (a) 1902–1939 and (c) 1977–2005 and (b) low PDO period of 1945–1976. In each PDO phase, monthly TLP from June to the following May is averaged in El Niño (solid curves), La Niña (dashed curves), and normal years (dotted-dashed curves).

JTWC best-track data from 1945 to 2005. MBP TC dataset can trace TC tracks back to the beginning of the 20th century. With modern TC best-track data from 1945 over the WNP basin, a unique dataset is created to investigate the interdecadal variability of TLP during the past 100 years. From 1902 to 1939, TLP is defined by TC track that passed over the Philippine area and the nearest minimum Philippines station pressure was observed to be less than 1000 hPa by MBP. After 1945, TLP is defined by TS that passed the Philippines area based on the JTWC best-track data. The difference between the two TLP definitions is less than 16%. Annual TLP from 1902 to 2005 using the two definitions shows dominant periodicity of about 32 years before 1940 and of about 10–22 years after 1945; however, no trend is found. Instead, the annual TLP has a significant difference between different ENSO phases during a low PDO phase, with a higher number during La Niña conditions. However, such differences disappear during high PDO phases. The difference in monthly TLP between different ENSO phases become weaker in autumn (October and November) and has opposite signs during summer (June and July) and winter (December and January) during high PDO phases. Therefore, natural variability related to ENSO and PDO phases appears to prevail in the interdecadal variability of TLP.

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