GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L21815, doi:10.1029/2006GL027449, 2006

Correction published 20 January 2007

Impact of ENSO on landfall characteristics of tropical cyclones over the western North Pacific during the summer monsoon season

H. Fudeyasu,[1] S. Iizuka,[1] and T. Matsuura[1]

Received 4 July 2006; revised 29 September 2006; accepted 18 October 2006; published 15 November 2006.

[1] We investigate the impact of ENSO on the landfall characteristics of tropical cyclones (TC) over the Western North Pacific (WNP) during the summer monsoon season. During the early monsoon period (late May–late July), an increase in the numbers of TCs that make landfall in the Korean Peninsula or Japan is associated with an increase in the Niño-3.4 SST anomalies. During the peak monsoon period (late July–mid September), the number of TCs that make landfall in the Indochinese Peninsula is greater in El Niño years than in La Niña years. Furthermore, in El Niño years, the TCs that make landfall in the Korean Peninsula or Japan tend to have longer lifespan and greater intensities. These changes can be primarily attributed to the change in the mean TC formation location as a result of ENSO.

Citation: Fudeyasu, H., S. Iizuka, and T. Matsuura (2006), Impact of ENSO on landfall characteristics of tropical cyclones over the western North Pacific during the summer monsoon season, *Geophys. Res. Lett.*, *33*, L21815, doi:10.1029/2006GL027449.

1. Introduction

[2] The interannual variability in tropical cyclones (TCs) over the Western North Pacific (WNP) and its relationship with the El Niño/Southern Oscillation (ENSO) has been examined by several studies [e.g., *Chan*, 1985, 2000; *Lander*, 1994]. These studies have shown that a longitudinal shift in the mean TC formation location occurs in ENSO years. In El Niño (La Niña) years, the TCs tend to form in more eastward (westward) locations than the climatological mean TC formation location. During the fall from September through to November, in strong El Niño years, this longitudinal shift in the mean TC formation location is associated with TCs that tend to curve more northeastward, while in strong La Niña years, this longitudinal shift is associated with more TCs that tend to take a westward course [*Wang and Chan*, 2002]. Furthermore, *Wu et al.* [2004] have shown that the mean number of TCs that make landfall in southern China and the Indochinese Peninsula during the fall in El Niño years is significantly less than normal.

[3] On the other hand, *Chen et al.* [1998] have shown that the frequency of TC formation during the summer from June through to August in La Niña (El Niño) years increased (decreased) in the northern part of the WNP. However, *Wu et al.* [2004] have reported that there is no significant difference in the mean number of TCs that make landfall in East and Southeast Asia during the summer between El Niño and La Niña years. Thus, ENSO does not affect the frequency of TCs that make landfall in East and Southeast Asia during summer, although the mean TC formation location in the WNP is dependent on the ENSO.

[4] In general, the spatial and temporal variation in TC formation is primarily influenced by a large-scale circulation [e.g., *Gray*, 1998; *Ritchie and Holland*, 1999]. In the WNP during summer, the large-scale circulation pattern changes abruptly in accompaniment with the seasonal change in the Asia monsoon [e.g., *Matsumoto*, 1992]. Previous studies [e.g., *Ueda et al.*, 1995] have shown that the seasonal change in the location of the monsoon trough related the Asia monsoon over the WNP strongly affects the formation and tracks of the TCs in the WNP. This seasonal change in the monsoon trough does not depend on monthly changes. Consequently, using calendar months in this study would be inappropriate for describing the seasonal variability in TC activity in the WNP.

[5] During the summer monsoon season from late May through to mid-September, which is also the most active season for TC formation in the WNP, many TCs approach and make landfall in East and Southeast Asia where they can cause severe damage. An understanding of the interannual variability in the landfall location of TCs during the summer monsoon season may therefore be useful for reducing the risk of damage and for improving water resource management. In this study, we examine the difference between El Niño and La Niña years in terms of the TC landfall characteristics during the summer monsoon season.

2. Data and Definition

[6] The best track data compiled by the Joint Typhoon Warning Center (JTWC) was used to identify the TC tracks. It should be noted that the results using the data acquired from the Regional Specialize Meteorological Center-Tokyo Typhoon Center of the Japan Meteorological Agency were essentially the same as the results obtained using the JTWC data. The JTWC data includes locations and maximum wind speeds of TCs for successive six-hour intervals. In this study, the TC formation location was defined as the location where a TC first reached tropical storm intensity (maximum sustained wind speeds of greater than 17 m s^{-1}), while the end location was defined as the location where the TC had for the last time tropical storm intensity. Thus, the TCs that were analyzed were both tropical storms and typhoons. The landmasses that encompass the WNP are divided into Area 1, which includes the Korean Peninsula and Japan; Area 2, which includes China; and Area 3, which includes the Indochinese Peninsula (Figure 1). This is the same

---

[1] Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan.

0094-8276/06/2006GL027449$05.00

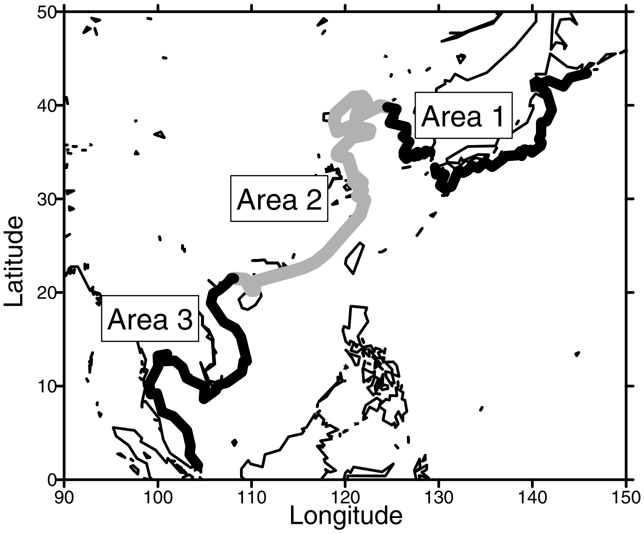

Figure 1. Delineation of the three study areas. Area 1: the Korean Peninsula and Japan; area 2: China; area 3: the Indochinese Peninsula.

definition as that employed by *Wu et al.* [2004], except that the Philippines have been excluded from the present study.

[7] Similar to *Wu et al.* [2004], we analyzed the TCs that formed in the 40-years period between 1961 and 2000. ENSO years were defined as in the work by *Wu et al.* [2004] using the mean sea surface temperature (SST) anomaly in the Niño-3.4 region (5°S–5°N, 120°–170°E) during the June–November TC season in the WNP. This meant there were nine El Niño years (1963, 1965, 1969, 1972, 1982, 1987, 1991, 1994, 1997), and six La Niña years (1964, 1971, 1973, 1975, 1988, 1999).

[8] We defined the analysis period, taking into consideration the spatial and temporal changes in the Asia monsoon over the WNP. The lower-level easterlies are dominant in the tropics of the WNP until late May. The westerly region then begins to appear in the tropics in mid June, which is consistent with the onset of the Asian monsoon in Southeast Asia [e.g., *Matsumoto*, 1992]. In late July, the westerly region shifts abruptly northward with the eastward extension of monsoon trough over the WNP [e.g., *Nakazawa*, 1992]. From mid September, a gradual retreat of the westerly region begins, together with a westward penetration of the trade easterlies in the lower latitude. For these reasons, the periods from late May through to late July (145–204 Julian days) is defined as the early monsoon period, while the period from late July through to mid September (205–265 Julian days) is defined as the peak monsoon period. It should be noted that the climatological mean number of TCs is 4.9 in the early monsoon period and 10.7 in the peak monsoon period (Table 1). Furthermore, there is no significant difference in the mean number of TCs between ENSO and neutral years.

3. Result

[9] Figure 2 shows the TC tracks during the early and peak monsoon periods in El Niño and La Niña years. During the early monsoon period, there is a difference in the TC formation locations between El Niño and La Niña years (Figures 2a and 2b). The number of TCs that form in the southeast of the climatological mean TC formation location (132.7°E, 15.6°N) increases (decreases) in El Niño (La Niña) years. In El Niño years, many TCs that form in the southeastern part of the WNP tend to move northwestward, and, thus, make landfall in Area 1. Table 2 shows the mean numbers of TCs that make landfall in Areas 1, 2, and 3 during the early and peak monsoon periods in ENSO years, neutral years, and climatological mean. The difference in the mean number of TCs that make landfall in Areas 2 and 3 during the early monsoon period between El Niño and La Niña years is not statistically significant. On the other hand, the mean number of TCs that make landfall in Area 1 is greater in El Niño years than in La Niña years. A Student's t-test shows that this difference is statistically significant at the 95% level.

[10] Figure 3 shows the relationship between the numbers of TCs that made landfall in Area 1 during the early monsoon period for 1961 and 2000 and the Niño-3.4 SST anomalies in July. The increases in the numbers of TC landfalls are found to be associated with the Niño-3.4 SST anomalies. We find a correlation coefficient of 0.51, which does not agree with *Wu et al.* [2004] that considered summer to be from June through to August.

[11] During the peak monsoon period, the mean TC formation location in El Niño years is different from those in La Niña years (Figures 2c and 2d). In El Niño years, the number of TCs that formed south of the climatological mean TC formation location (138.1°E, 19.3°N) and in the South China Sea (SCS) increases, while the number of TCs that formed north of the climatological mean formation location decreases. The reverse situation occurs in La Niña years. This south-north difference in the active region for TC formation between El Niño and La Niña years is in agreement with a previous study [*Chen et al.*, 1998] that

Table 1. Mean Numbers of TCs That Form in the WNP During the Early and Peak Monsoon Periods in El Niño Years, La Niña Years, Neutral Years, and Climatological Mean

El Niño	La Niña	Neutral	Mean
	Early Monsoon		
5.8	5.0	4.5	4.9
	Peak Monsoon		
11.5	10.2	10.6	10.7

Table 2. Mean Numbers of TCs That Made Landfall in Areas 1, 2, and 3 During the Early and Peak Monsoon Periods in El Niño Years, La Niña Years, Neutral Years, and Climatological Mean

Area	El Niño	La Niña	Neutral	Mean
		Early Monsoon		
1	1.3	0.2	0.6	0.7
2	1.6	1.7	1.1	1.3
3	0.3	0.6	0.4	0.4
		Peak Monsoon		
1	2.0	1.8	2.3	2.2
2	2.2	2.5	2.4	2.4
3	1.7	0.7	0.8	0.9

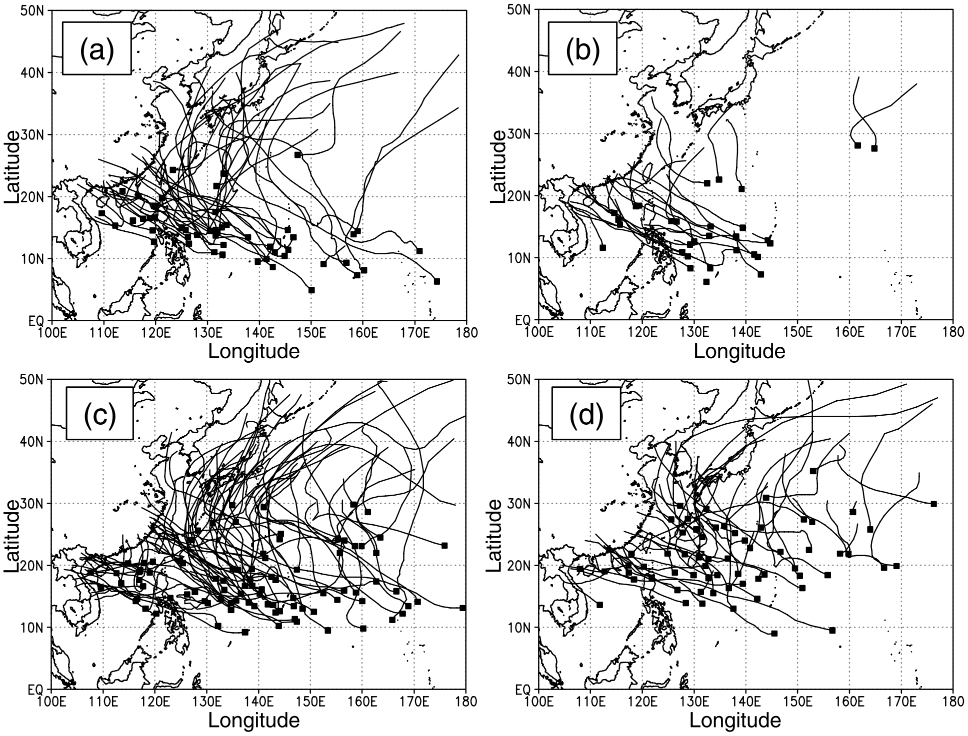

Figure 2. Tracks and formation locations for TCs that form during (a) the early monsoon period in El Niño years, (b) the early monsoon period in La Niña years, (c) the peak monsoon period in El Niño years, and (d) the peak monsoon period in La Niña years, respectively. The track is shown using a line, while the formation location is shown with a square. El Niño years were defined as 1963, 1965, 1969, 1972, 1982, 1987, 1991, 1994, and 1997, while La Niña years were defined as 1964, 1971, 1973, 1975, 1988, and 1999.

considered summer to be from June through to August. *Chen et al.* [1998] suggested that the increase in TC formation in the northern part of the WNP in La Niña years is related to the appearance of an anomalous cyclonic cell situated in a summer teleconnection wave train emanating from the western tropical Pacific that progresses along the edge of the WNP.

[12] During the peak monsoon period in El Niño years, most of the TCs that form in the SCS and the Philippine Sea take a straight track towards the Indochinese Peninsula and southern China (Figure 2c). The mean number of TCs that make landfall in Area 3 during the peak monsoon period is, thus, larger in El Niño years than in La Niña years (Table 2). This difference between El Niño and La Niña years is statistically significant at the 95% level. *Harr and Elsberry* [1991] found that most of the TCs that formed in the SCS and the Philippines Sea tended to take a straight track, that is, they moved westward and finally made landfall in the Indochinese Peninsula and southern China. Therefore, in El Niño years, the increase in the number of TCs that made landfall in Area 3 during the peak monsoon period could be primarily attributed to an increase in the TC formations in the SCS and the Philippine Sea, which corresponds to a

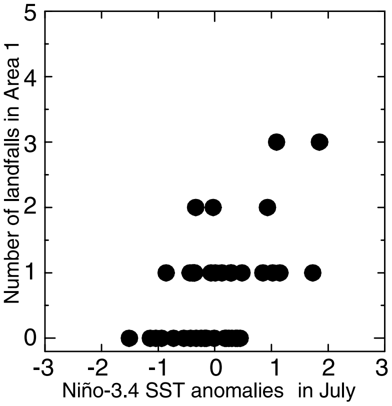

Figure 3. Scatter diagram showing the relationship between the Niño-3.4 SST anomaly in July and the numbers of TCs that make landfall in Area 1 during the early monsoon period for 1961 and 2000.

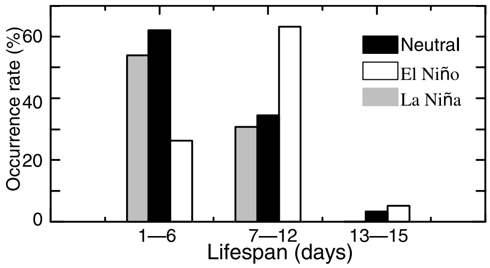

Figure 4. Occurrence rate for TCs that make landfall in Area 1 during the peak monsoon period based on lifespan in El Niño years, La Niña years, and neutral years.

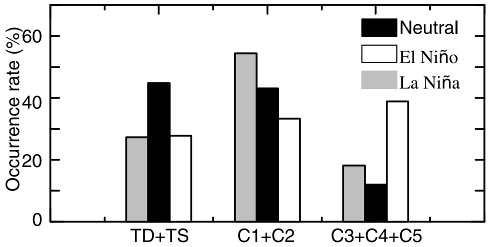

Figure 5. Same as Figure 4 except the occurrence rate of TCs making landfall in Area 1 based on the Saffir-Simpson scale. TD: tropical depression; TS: tropical storms; C1–C5: Category 1–5 typhoons.

southward shift in the mean TC formation location. It should be noted that the correlation between the numbers of TCs that made landfall in Area 3 and a Niño-3.4 SST anomaly during the years surveyed was not observed to differ markedly due to the large variability in the number of TCs that formed in the Philippine Sea during the neutral years.

[13] On the other hand, during the peak monsoon period, more than 20% of all TCs that form over the WNP move northward and make landfall in Area 1. Thus, as has been shown previously (Table 2), no significant difference is apparent in the mean numbers of TCs that make landfall in Area 1 between El Niño and La Niña years, which is consistent with the previous studies [*Wu et al.*, 2004; *Saunders et al.*, 2000]. However, the landfall characteristics of TCs in Area 1 differ between El Niño and La Niña years. Figure 4 shows the percentage of total TCs with a given lifespan that make landfall in Area 1 during the peak monsoon period. The climatological mean lifespan of TC that make landfall in Area 1 is 6.3 days. The occurrence rate of TCs with a lifespan of between 7 and 12 days in El Niño years is more than that in neutral or La Niña years, while the occurrence rate of TCs with a lifespan of between 1 and 6 days in El Niño years is smaller. The difference in the occurrence rate of TCs that have a longer lifespan between El Niño and La Niña years is statistically significant at the 95% level. Since lifespan and TC formation location are related [*Wang and Chan*, 2002], an increase in the number of TCs that form in the southern part of the WNP in El Niño years causes an increase in the occurrence rate of TCs that have a longer lifespan.

[14] For TCs that make landfall in Area 1 during the peak monsoon period, the occurrence rate of intense TCs, which are defined as TCs that can be classified as being category 3–5 on the Saffir-Simpson scale [*Simpson*, 1974], is greater in El Niño years than in La Niña years (Figure 5). This difference in the occurrence rate of intense TC between El Niño and La Niña years is statistically significant at the 90% level. *Chia and Ropelewski* [2002] have statistically studied the relationship between the TC intensity and the formation locations during the periods from July through to October. They demonstrated that intense TCs (category 3–5 on the Saffir-Simpson scale) were more likely to develop from TCs that formed in the southeastern part of the WNP than from those that formed in the northwestern part of the WNP. Thus, TC intensity is related to their formation locations. During the peak monsoon period in El Niño years, TCs that form in the southeastern part of the WNP and make landfall in Area 1 tend to have a longer lifespan and develop into more intense TCs. The south-north difference in the TC formation location during the peak monsoon period between El Niño and La Niña years does not affect the number of TCs that make landfall in Area 1. Instead, the characteristics of TCs are different between El Niño and La Niña years. However, there is no difference in the characteristics of TCs that make landfall in Area 2 between El Niño and La Niña years.

4. Summary

[15] We investigated the impact of ENSO on the characteristics of TCs that made landfall during the early monsoon period (late May–late July) and the peak monsoon period (late July–mid September). It was found that an increase in the numbers of TCs that made landfall in Area 1 during the early monsoon period was associated with an increase in the Niño-3.4 SST anomalies. This increase during El Niño years could be primarily attributed to an increase in TCs that formed in the southeastern part of the WNP.

[16] During the peak monsoon period, the number of TCs that made landfall in Area 3 was greater in El Niño years than in La Niña years. This was caused by an increase in the formation of TCs in the SCS and the Philippine Sea, which corresponded to a southward shift in the mean TC formation location. Furthermore, in El Niño years, those TCs that made landfall in Area 1 were found to have longer lifespan and greater intensities. This increase could be attributed to an increase in the number of TCs that formed in the southeastern part of the WNP.

[17] The findings of this study suggest that ENSO not only affect the characteristics of TCs during the fall, but also have an effect on the landfall characteristics of TCs during the summer monsoon season.

[18] **Acknowledgments.** The authors would like to thank S. Suzuki and K. Ichiyanagi for their helpful discussions and suggestions. This work is partly supported by the Research Project for Suitable Coexistence of Human, Nature, and the Earth under the Ministry of Education, Sports, Culture, Science and Technology.

References

Chan, J. C. L. (1985), Tropical cyclone activity in the northwest Pacific in relation to the El Niño/Southern Oscillation phenomenon, *Mon. Weather Rev.*, *113*, 599–606.

Chan, J. C. L. (2000), Tropical cyclone activity in the western North Pacific associated with El Niño and La Niña events, *J. Clim.*, *13*, 2960–2972.

Chen, T. C., S. P. Weng, N. Yamazaki, and S. Kiehne (1998), Interannual variations in the tropical cyclone formation over the western North Pacific, *Mon. Weather Rev.*, *126*, 1080–1090.

Chia, H. H., and C. F. Ropelewski (2002), The interannual variability in the genesis location of tropical cyclones in the northwest Pacific, *J. Clim.*, *15*, 2934–2944.

Gray, W. M. (1998), The formation of tropical cyclones, *Meteorol. Atmos. Phys.*, *67*, 37–69.

Harr, P. A., and R. L. Elsberry (1991), Tropical cyclone track characteristics as a function of large-scale circulation anomalies, *Mon. Weather Rev.*, *119*, 1448–1468.

Lander, M. A. (1994), An exploratory analysis of the relationship betweem tropical storm formation in the western North Pacific and ENSO, *Mon. Weather Rev.*, *122*, 636–651.

Matsumoto, J. (1992), The seasonal changes in Asian and Australian monsoon regions, *J. Meteorol. Soc. Jpn.*, *70*, 257–273.

Nakazawa, T. (1992), Seasonal phase lock of intraseasonal variation during the Asian summer monsoon, *J. Meteorol. Soc. Jpn.*, *70*, 597–611.

Ritchie, E. A., and G. J. Holland (1999), Large-scale patterns associated with tropical cyclogenesis in the western Pacific, *Mon. Weather Rev.*, *127*, 2027–2043.

Saunders, M. A., R. E. Chandler, C. J. Merchant, and F. P. Roberts (2000), Atlantic hurricanes and NW Pacific typhoons: ENSO spatial impacts in occurrence and landfall, *Geophys. Res. Lett.*, *27*, 1147–1150.

Simpson, R. H. (1974), The hurricane disaster potential scale, *Weatherwise*, *27*, 169–186.

Ueda, H., T. Yasunari, and R. Kawamura (1995), Abrupt seasonal change of large-scale convective activity over the western Pacific in the northern summer, *J. Meteorol. Soc. Jpn.*, *73*, 795–809.

Wang, B., and J. C. L. Chan (2002), How strong ENSO events affect tropical storm activity over the western North Pacific, *J. Clim.*, *15*, 1643–1658.

Wu, M. C., W. L. Chang, and W. M. Leung (2004), Impacts of El Niño–Southern Oscillation events on tropical cyclone landfalling activity in the western North Pacific, *J. Clim.*, *17*, 1419–1428.

H. Fudeyasu, S. Iizuka, and T. Matsuura, Japan Agency for Marine-Earth Science and Technology, JAMSTEC Yokosuka headquarters, 2-15, Natsushima-Cho, Yokosuka-city, Kawakawa, Japan. (fudeyasuh@jamstec.go.jp)