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Effect of ENSO on Landfalling Tropical Cyclones Over the Korean Peninsula

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Abstract: The effect of ENSO on landfalling tropical cyclones (TCs) over the Korean Peninsula is examined. It is found that although the landfalling frequency does not show any statistically significant difference among ENSO phases, the landfalling tracks are shifted northward in response to the decrease in Niño-3.4 index. In the neutral ENSO phase, many TCs pass through mainland China before landfalling over the Korean Peninsula due to the westward expansion of the western North Pacific subtropical high. Therefore, the landfalling TC intensity over the Korean Peninsula in the neutral phase is similar to that in the La Niña phase because more than half of those TCs made landfall over mainland China. However, it is found that the preceding winter ENSO phases are not related to the landfalling TC activity over the Korean Peninsula during summer.

Key words: ENSO, tropical cyclones, landfalling, subtropical high

1. Introduction

Studies on the effect of El Niño-Southern Oscillation (ENSO) on landfalling TCs have generally focused on identifying regions that are directly influenced by TCs and statistically analyzing the TC landfalling frequency in each region. Saunders *et al.* (2000) analyzed the landfalling frequency of TCs in the El Niño and La Niña phases in representative regions and countries (Korea-Japan, Taiwan, the Philippines, and Vietnam) influenced directly by TCs in the western North Pacific. They showed that a remarkable change in landfalling TC frequency between the two ENSO phases exists in the Southeast Asia in contrast to change in Northeast Asia (Korea-Japan). Especially, they stressed that the landfalling TC frequency in the Southeast Asian region is higher in the La Niña phase than in the El Niño phase.

Wu *et al*. (2004) conducted analyses similar to Saunders *et al*. (2000) but based on finer spatial and temporal resolution. That is, the TC season was divided into two sub-seasons (June to August and September to November) and the East Asia and the Southeast Asia were divided into four sub-regions (Korea-Japan, China, Indochina Peninsula, and the Philippines). They demonstrated that the landfalling frequency of TCs over Korea-Japan is not significantly influenced by ENSO phases regardless of the sub-seasons. However, they found high landfalling frequency in the other regions in the La Niña phase, but mainly in the latter sub-season (September to November).

Following Wu *et al*. (2004), Fudeyasu *et al*. (2006) divided the TC season into two monsoon seasons (early monsoon season from late May to late July and peak monsoon season from late July to mid September) and analyzed the landfalling TC frequency during the two ENSO phases in three regions except for in the Philippines. Different from the above results, Fudeyasu *et al*. (2006) indicated that difference in the landfalling TC frequency between the two ENSO phases in the Korea-Japan region is larger in the El Niño phase during the early monsoon season than in the later monsoon season. In China, there is no difference in the landfalling TC frequency between the two ENSO phases regardless of the season, and in the Indochina Peninsula region, the landfalling TC frequency during the peak monsoon season is higher in the El Niño phase than in the La Niña phase.

On the other hand, Chan (2000, 2005) examined the variations of the monthly TC frequency within each $5^o \times 5^o$ grid box over the western North Pacific associated with both El Niño (EN) and La Niña events and anomalies for the years before and after the two ENSO events. The results showed that less TCs occur in the late TC season in the southeast of Japan during an EN-1 year.

More recently, Kubota and Chan (2009) analyzed the change of the frequency of TCs making landfall in the Philippines region using data over 100 years (1902-2005). Unlike the above results, they suggested that the difference in landfalling TC frequency in this region among ENSO phases exists only during the low phase of the Pacific Decadal Oscillation (1945-2005).

Therefore, different landfalling TC activities have been documented among ENSO phases in different regions including the Korean Peninsula as part of a large region from different studies. Further, previous studies have not paid special attention to the potential effect of ENSO on the landfalling TC activity over the Korean Peninsula. The objective of this study is to examine the characteristics of the landfalling TC activity over the Korean Peninsula among ENSO phases.

The data and analysis methods used in this study are described in section 2. In section 3, changes in landfalling TC activity (frequency, genesis, track, and intensity of TC and their relationship to the large-scale circulation) over the Korean

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Peninsula among ENSO phases are examined. Finally, the main results are summarized in section 5.

2. Data and definition

The TC information is obtained from the best track archives of the Regional Specialized Meteorological Center (RSMC), Tokyo Typhoon Center. The dataset consists of the TC name, position, minimum central sea level pressure, and maximum sustained surface wind speed at every 6 hour intervals for all TCs occurred during 1951-2008 (58 years). TCs are divided into four categories based on their maximum sustained surface wind speeds (MSSWS), namely tropical depression (MSSWS < 17 m s^{-1}), tropical storm (17 m s^{-1} $\leq$ MSSWS $\leq$ 24 m s^{-1}), severe tropical storm (25 m s^{-1} $\leq$ MSSWS $\leq$ 32 m s^{-1}), and typhoon (MSSWS $\geq$ 33 m s^{-1}). In addition to the above four category TCs, we also include the extratropically transformed cyclones (ETs) from TCs because they also cause damage in the mid-latitudes of East Asia. The results based on the RSMC best track datasets are also compared with the best track dataset from the Joint Typhoon Warning Center (JTWC). While TC data prior to the weather satellite era in 1950s and early 1960s could have some problems (Ho *et al*., 2005). Many studies have already applied data prior to the weather satellite to the TC climate research (Yumoto and Matsuura, 2001; Ho *et al*., 2004) and showed promising results still. In this study, we use all data to get more cases of landfalling TC over the Korean Peninsula.

The reanalysis data of the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR, Kalnay *et al*., 1996) are used to detect features in the large-scale circulation. The dataset has a horizontal resolution of $2.5^{\circ} \times 2.5^{\circ}$ latitude-longitude on 17 vertical pressure levels. This study also uses the NOAA Extended Reconstructed monthly sea surface temperature (SST) with a horizontal resolution of $2.0^{\circ} \times 2.0^{\circ}$ latitude-longitude (Reynolds *et al*., 2002).

A landfalling TC over the Korean Peninsula is defined as any TC with its center crossing the Korean coastline in the RSMC best track dataset at 6 hour intervals. According to this definition, 77 landfalling TCs were found in 58 years. The "TC intensity at landfall" is defined as "the TC central sea level pressure 6 hours before it makes landfall over the Korean Peninsula" based on the RSMC best-track dataset. The TC lifetime is simply defined as the period from the occurrence to the disappearance of the TC.

3. Changes in landfalling TC activity among ENSO phases

a. Landfalling frequency

The frequency of landfalling TCs over the Korean Peninsula from JTWC best track dataset is 69 TCs in 58 years ($r = 0.72$ at the 99% confidence level with the frequency from RSMC best track dataset). Landfalling TCs over the Korean Peninsula from May to October are 1 (1), 8 (5), 24 (23), 31 (32), 12 (8), and 1 (0) in the RSMC (JTWC) best track dataset. Thus, landfalling TCs occur mainly between June and September. To examine the characteristics of the frequency of landfalling TCs over the Korean Peninsula among ENSO phases, we divide the landfalling TC season (June-September) into two sub-seasons: early season (June-July) and late season (August-September). ENSO phases in the entire landfalling TC season and two sub-seasons are defined using the SST anomalies (SSTA) in June-September, June-July, and August-September in the Niño-3.4 region (5°S-5°N, 120°W-170°W) (El Niño: SSTA $\geq$ 0.5°C, La Niña: SSTA $\leq$ -0.5°C, and neutral phase: -0.5°C $<$ SSTA $<$ $+0.5$°C). Here, the climatological SST used to calculate the SSTA is defined as the SST averaged over 58 years from 1951-2008. Years classified by the occurrence of El Niño (La Niña) in the three TC seasons defined above include: 1951, 1957, 1963, 1965, 1972, 1982, 1986-87, 1991, 1994, 1997, 2002, 2004, 2006 (1954-56, 1964, 1970-71, 1973-75, 1985, 1988, 1998-99) for the entire Korea landfalling TC season, 1957, 1963, 1965, 1972, 1982, 1987, 1991-92, 1994, 1997, 2002, 2004 (1954-56, 1964, 1970-71, 1973-75, 1985, 1988, 1998-99) for the early season, and 1951, 1957, 1963, 1965, 1969, 1972, 1976-77, 1982, 1986-87, 1991, 1994, 1997, 2002, 2004, 2006 (1954-56, 1962, 1964, 1970-71, 1973-75, 1985, 1988, 1995, 1998-99, 2007) for the late season.

For the entire landfalling TC season, the landfalling frequency in the El Niño phase is a little higher than not only those in the other two phases but also the mean landfalling frequency (Table 1). However, the differences in the landfalling frequency among the three ENSO phases are not statistically significant. Different from the entire landfalling season, there is little difference in the landfalling frequency among the three ENSO phases in the two sub-seasons. These features of the landfalling frequency among ENSO phases from the RSMC best track dataset are similar to those from the JTWC best track dataset. Fudeyasu *et al*. (2006) pointed out that during the early monsoon season the landfalling TC frequency is higher in the El Niño phase than the other two phases in Korea-Japan. However, the difference between theirs and ours might infer higher TC landfalling frequency in Japan in the El Niño phase.

b. TC genesis and track

To examine the characteristics of the landfalling TC tracks, TCs landfalling over the Korean Peninsula are sorted by the ENSO phases in this study. Because the neutral years for the 58 years greatly outnumber El Niño and La Niña years, features of TC activity in neutral years could be ambiguous. Therefore, the

Table 1. Average frequencies of TCs making landfall over the Korean Peninsula during the entire TC season (June to September), early TC season (June to July), and late TC season (August to September) based on RSMC and JTWC (parenthesis) best track datasets.

Landfall TC season	El Niño	Neutral	La Niña	Mean
Total	1.6 (1.5)	1.3 (1.2)	1.2 (1.0)	1.4 (1.2)
Early	0.6 (0.5)	0.6 (0.5)	0.6 (0.4)	0.6 (0.5)
Late	0.7 (0.9)	0.8 (0.8)	0.8 (0.7)	0.8 (0.8)

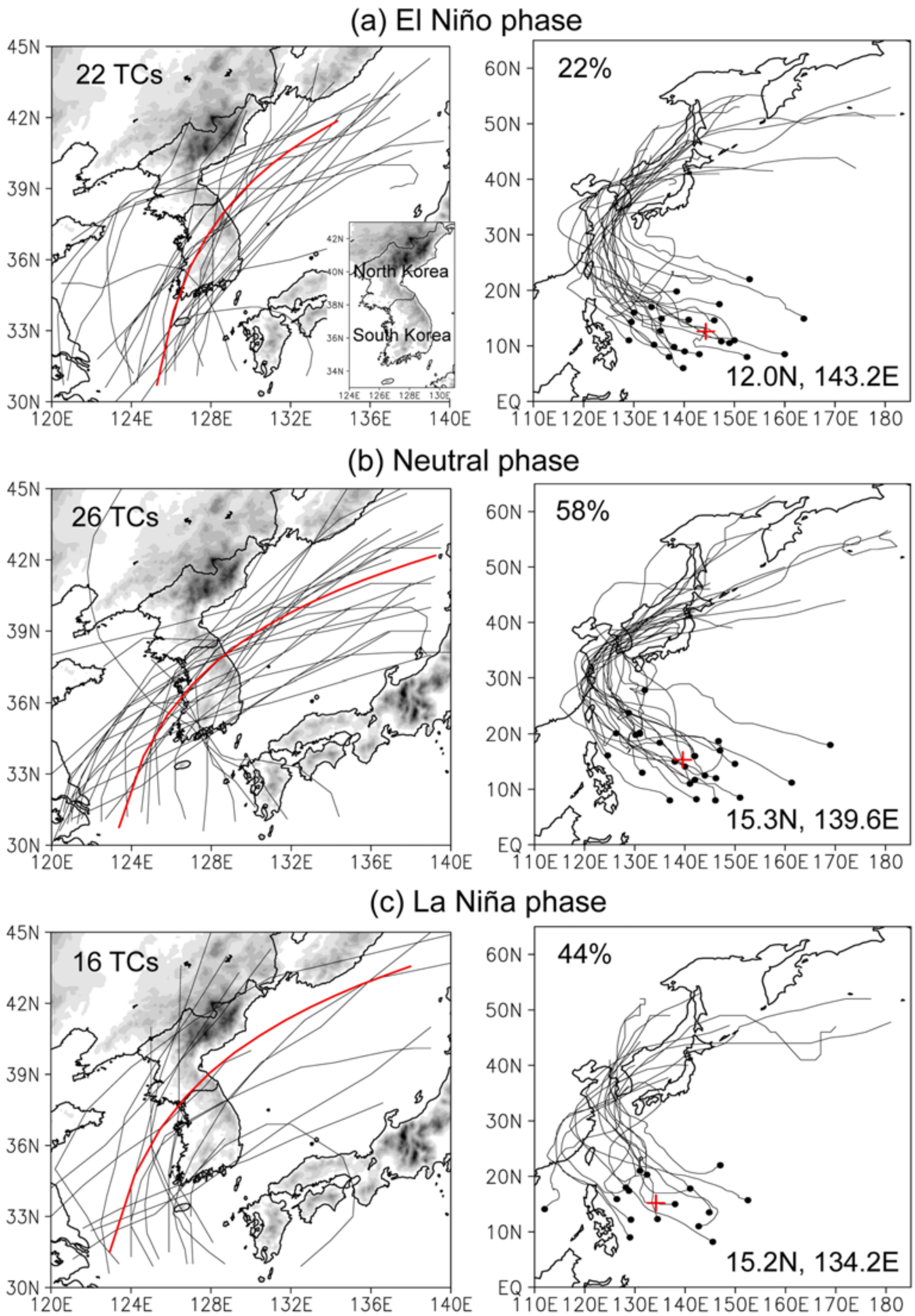

Fig. 1. Landfalling tracks (left) and full tracks (right) of tropical cyclones (TCs) that made landfall over the Korean Peninsula in each of ENSO phases. Red solid lines denote mean regression tracks. In the left panel, numbers in the uppermost left corner indicate frequencies of TCs landfalling over the Korean Peninsula. In the right panel, dots, numbers in the lowermost right corner, and numbers in the uppermost left corner indicate genesis locations, averages of genesis location (red crosses), and rates of frequency that TCs passed through the mainland China to total frequency of landfalling TCs over the Korean Peninsula, respectively.

criterion for the neutral phase for sorting the landfalling TCs is more strengthened, namely the neutral years are defined as −0.3°C < SSTA (June to September) < +0.3°C. Under this restrict condition, the frequencies of landfalling TC over the Korean Peninsula in the El Niño, neutral, and La Niña phases are 22, 26, and 16 TCs, respectively.

Although there are no significant differences in the landfalling TC frequency among ENSO phases, differences in landfalling TC tracks among ENSO phases are evident (left in Fig. 1). TCs in the El Niño phase mainly make landfall along the south coast and the southern part of the west coast of Korea. Most of TCs in the neutral phase make landfall in the southern part of the west coast of Korea. This implies that the TC landfalling location in the neutral phase is more northward than in the El Niño phase. In the La Niña phase, TCs tend to make landfall in the northern part of the west coast of the Korean Peninsula (i.e., western coast in North Korea) in a sharp contrast to those in the El Niño and neutral phases. In particular, more than half of TCs in the La Niña phase make landfall in North Korea, although TC tracks in this phase show a relatively large spread compared to those in the other two phases. As a result, as ENSO phases change from El Niño phase to La Niña phase, the TC landfalling track and landfalling location over the Korean Peninsula tend to shift northward. This northward tendency of the TC landfalling track and location is also clearly seen from the change in the mean regression track among different ENSO phases (red solid lines in Fig. 1). Therefore, this study tested a statistical significance on the latitude of TC landfalling location among the three ENSO phases. As a result, while the differences in latitude location of TC landfalling between El Niño and neutral phases and between El Niño and La Niña phases are significant at the 95% confidence level, the difference between neutral and La Niña phases is significant at the 90% confidence level. The low statistical significance of the latter is because TC tracks in neutral and La Niña phases show a relatively large spread compared to those in the El Niño phase. However, the shift in landfalling TC locations among ENSO phases is very important because the landfalling TC locations are directly related to disasters in the landfalling regions.

To examine quantitatively the relationship between the two phenomena, a scatter diagram of the latitude of the TC landfalling location versus the Niño-3.4 SSTA for months of the landfalling TC activity over the Korean Peninsula is illustrated in Fig. 2a. Although a significant correlation is not obvious (R^2 = 0.28), the scatter diagram shows that as the Niño-3.4 SSTA becomes high (low), the TC landfalling locations tend to shift southward (northward). If exceptional TC cases (square box) between 1-2^{o}C and 36^o-38^{o}N are excluded in the scatter diagram, the correlation would become much higher and significant (R^2 = 0.49). These extreme cases are TCs that made landfall in North Korea in the El Niño phase.

The change in the landfalling TC full tracks is also examined among the ENSO phases (right panel in Fig. 1). There are differences in the frequency of TCs that passed through mainland China before making landfall over the Korean Peninsula among different ENSO phases. While only 22% (5/22) of TCs that made landfall over the Korean Peninsula in the El Niño phase passed through mainland China, about 60% (15/26) in the neutral phase and 44% (7/16) in the La Niña phase did so. In particular, some TCs in the La Niña phase moved farther inland in southern China.

The genesis location of the landfalling TCs over the Korean Peninsula in the El Niño phase occurs dominantly in the southeasternmost region in the subtropical western North Pacific (SWNP) (dots in the right of Fig. 1), consistent with previous studies (Chan, 2000; Wang and Chan, 2002; Wu *et al*., 2004). Differences in the latitude and longitude of the TC genesis locations between the El Niño phase and either of the other two phases are significant at the 99% confidence level from the Student's *t* test. The genesis location of TCs making landfall over the Korean Peninsula in the neutral phase are generally more to the east in the SWNP than those in the La Niña phase (significant at the 90% confidence level), but the difference in the latitude of TC genesis is not statistically significant between the two phases. This indicates that the difference in genesis location of TCs making landfall over the Korean Peninsula among ENSO phases is much larger in longitude than in latitude. This may lead to one to hypothesize that the more to the east (west) a TC forms in the SWNP, the more likely it tends to make landfall in the south (north) of the Korean Peninsula. To test this hypothesis, a scatter diagram of the latitude of TC landfalling over the Korean Peninsula versus the longitude of the TC genesis locations is plotted in Fig. 2b. Although the correlation between the two variables is not statistically significant (R^2 = 0.19), a negative correlation exists.

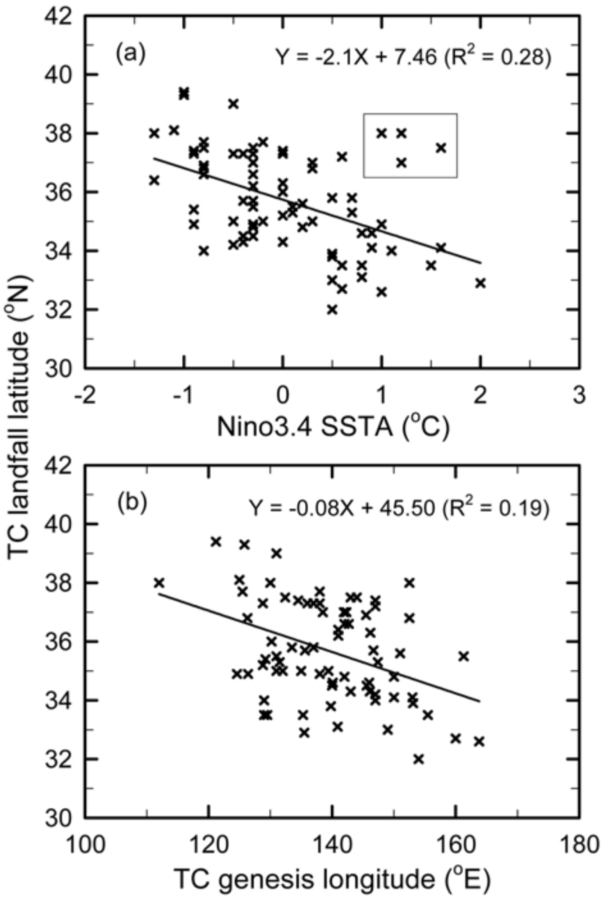

Fig. 2. Scatter diagrams showing the correlation between (a) the latitude of TC landfalling location over the Korean Peninsula and the Niño-3.4 SSTA, and (b) longitude of genesis location of TCs landfalling over the Korean Peninsula.

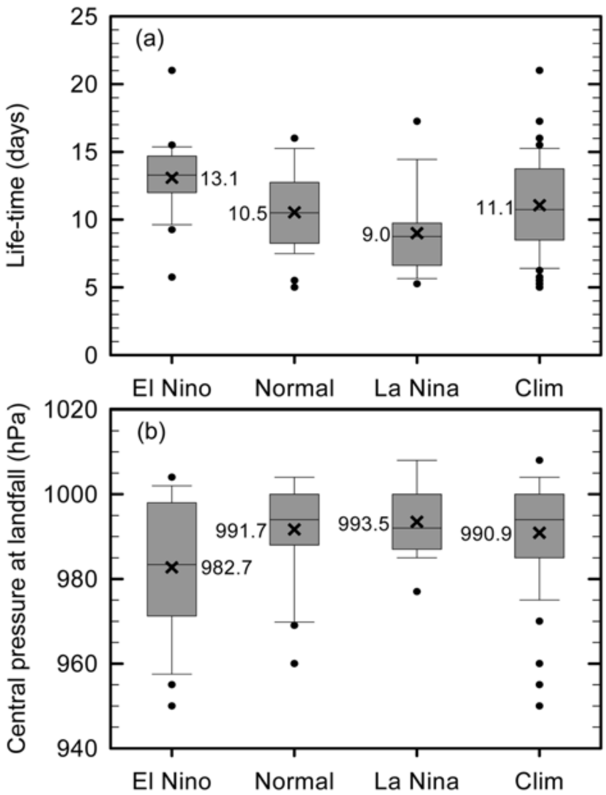

Fig. 3. (a) TC lifetime and (b) central sea level pressure at landfall over the Korean Peninsula in each of the ENSO phases. The boxes show the 25th and 75th percentiles, with lines in the boxes marking the median and the circles for the values below (above) the 25th (75th) percentiles of the distributions. Numbers beside each box denote averages in each ENSO phase. Here, the climatological TC intensity refers to that of all TCs that made landfall over the Korean Peninsula.

c. TC intensity

The change in the track of the landfalling TC among different ENSO phases may affect TC intensity. Therefore, the landfalling TC lifetime and central sea level pressure at landfall over the Korean Peninsula are examined among different ENSO phases. Camargo and Sobel (2005) showed that in El Niño years, there is a large tendency toward more intense typhoons. Chen *et al*. (2006) concluded that the TC lifetime is also proportional to its intensity; strong TCs have a longer lifetime than weak TCs.

As we can see from Fig. 3, the TC intensity is the strongest in the El Niño phase. The differences in the TC intensity at landfall over the Korean Peninsula between the El Niño and La Niña phases are 4 days for the TC lifetime (significant at the 99% confidence level) and 10 hPa for TC central pressure (significant at the 90% confidence level), respectively. This is consistent with the findings of Lander (1994), Wang and Chan (2002), Wu *et al*. (2004), and Camargo and Sobel (2005), who found that as a TC forms in the southeast (northwest) quadrant of the SWNP, it tends to have a much longer (shorter) lifespan and much stronger (weaker) intensity after it moves to the mid-latitudes.

On the other hand, the landfalling TC intensity in the neutral phase is stronger than that in the La Niña phase, but the difference is not statistically significant. Factors leading to such a small difference in the TC intensity between these two phases can be found from characteristics of the full tracks of the landfalling TCs. As shown above, the frequency of TCs passing through the mainland China before they make landfall over the Korean Peninsula is the highest in the neutral phase. Once a TC moves over a large landmass, it tends to weaken rapidly because of the large decrease in moisture flux and the increase in surface roughness.

d. Large-scale atmospheric circulation

To investigate the possible cause of changes in the landfalling TC activity over the Korean Peninsula among ENSO phases discussed above, we examine changes in the western North

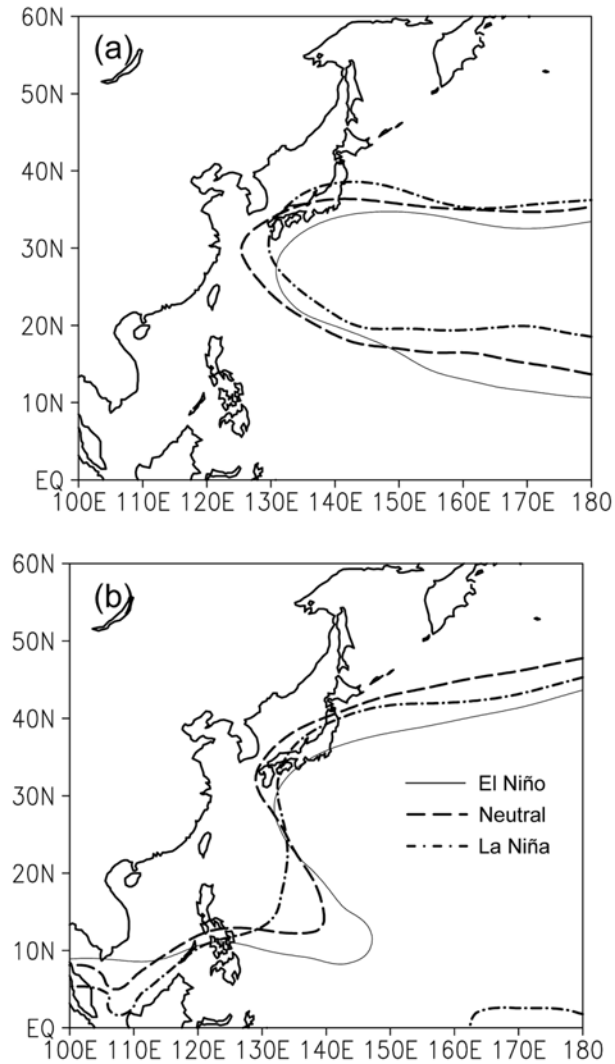

Fig. 4. Contours of 5870 gpm at 500 hPa and 1495 gpm at 850 hPa averaged over months with active landfalling TCs over the Korean Peninsula in each ENSO phase. Solid, dashed, and dot-dashed lines denote the El Niño, neutral, and La Niña phases.

Pacific subtropical high (WNPSH) (5870 gpm contour at 500 hPa, Ho *et al*., 2004) and monsoon trough (1495 gpm contour at 850 hPa, Ramage, 1971) among different ENSO phases (Fig. 4). The two variables are averaged over months for the landfalling TC season over the Korean Peninsula during each of the ENSO phases. While the WNPSH is located in the southeasternmost end in the El Niño phase, it lies in the northernmost end in the La Niña phase (Fig. 4a). In the neutral phase, the WNPSH is located just in between. Generally, the motion of a TC is greatly influenced by the location and strength of the WNPSH (Lander, 1994; Chan, 2000). Therefore, the difference in the location of the WNPSH among different ENSO phases can lead to differences in the tracks of landfalling TCs over the Korean Peninsula as shown above. Note that the WNPSH in the neutral phase extends to the westernmost end. As a result, more TCs in this phase tend to pass through mainland China, which, in turn, results in weak intensity of landfalling TCs over the Korean Peninsula due to the terrain and land effects.

The monsoon trough in the El Niño phase extends to the southeasternmost end in the SWNP (Fig. 4b). Generally, TCs tend to form along the monsoon trough. This trough is characterized by a low-level cyclonic wind shear line between monsoon westerly from its equatorward side and easterly trade winds from its poleward side and is displaced to the east during the El Niño phase (Lander, 1994; Clark and Chu, 2002). In addition to the low-level cyclonic wind shear, the decrease in vertical wind shear is also important for TC genesis in the monsoon trough region (Gray, 1975). As a result, TCs making landfall over the Korean Peninsula in the El Niño phase often form in the southeasternmost end in the SWNP and thus have the longer time over the ocean to intensify before they make landfall over the Korean Peninsula. The monsoon trough in the neutral phase also extends more eastward in the SWNP than that in the La Niña phase, but the difference in the latitudinal location of the monsoon trough is not obvious. This may explain the small differences in both the latitude of the TC genesis location and the TC intensity between the two phases.

e. Relationship with the preceding winter ENSO phase

On interannual time scale, variations in the troposphere tend to follow the changes of SST in the equatorial Pacific, with a lag of 1-2 seasons in the maximum response (Reid *et al*., 1989; Yulaeva and Wallace, 1994; Kumar and Hoerling, 2003). Camargo and Sobel (2005) pointed out that TC intensity in the western North Pacific is strongly lag-correlated with ENSO index up to six months. Fan and Wang (2009) showed that summer TC genesis frequency over the SWNP has a significantly high lag-correlation with the preceding winter (December-February, hereafter DJF) Niño-3.4 index as a predictor of the statistical model for a TC genesis frequency. Therefore, the landfalling TC activity over the Korean Peninsula in the three TC seasons (entire, early, and late TC seasons) is examined among preceding winter (DJF) ENSO phases. For the landfalling frequency, it is shown that there is little difference among ENSO phase in the three TC seasons (Table 2). In addition, the landfalling TC track in the neutral phase is similar to that in the summer neutral phase (Fig. 1b), but the remaining two ENSO phases do not show a distinctive landfalling TC track pattern (not shown). The possible reason on this difference in the landfalling TC activity between the two ENSO seasons (winter and summer) can be found in the Niño-3.4 SSTA time series for the preceding winter (DJF), early (JJ), and late (AS) TS seasons (Fig. 5). It is seen that the sign and amplitude of SSTA during the same year varies with season although the interdecadal variation of SSTA is similar among the three seasons. During the preceding winter El Niño years (e.g., 1958, 1973, 1983, 1992, and 1998), SSTAs in the early and late TC seasons are often near neutral or La Niña phases, and *vice versa* in the preceding winter La Niña years. However, SSTAs in the early and late TC seasons normally have the same sign. Thus, it may not be meaningful to examine the summer TC activity according to the preceding winter ENSO phases, as commented by Wang and Chan (2002).

Table 2. Average frequencies of TCs making landfall over the Korean Peninsula during the entire TC season (June to September), early TC season (June to July), and late TC season (August to September) based on the preceding winter (December-February) ENSO phases.

Landfall TC season	El Niño	Neutral	La Niña	Mean
Total	1.4	1.5	1.5	1.5
Early	0.4	0.5	0.5	0.5
Late	0.9	1.0	1.0	1.0

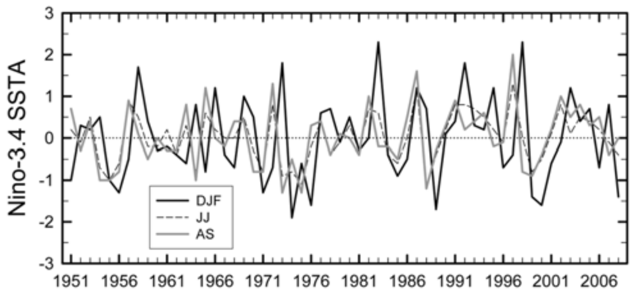

Fig. 5. Niño-3.4 SSTA time series averaged for the preceding winter (DJF), early (JJ), and late (AS) TS seasons.

This difference in the landfalling TC activity between the two ENSO seasons (winter and summer) may be due to the fact that the characteristics of the landfalling TC activity over the Korean Peninsula in the entire TC season are affected by the rapid tropical tropospheric responses to anomalous diabetic effect of SST, with time scale in a week to 15 days rather than the direct ENSO effect from preceding winter (Jin and Hoskins, 1995; Bantzer and Wallace, 1996).

4. Conclusions

This study has analyzed the characteristics of landfalling TC activity over the Korean Peninsula among different ENSO phases, namely El Niño phase, neutral phase, and La Niña phase.

The landfalling frequency in the El Niño phase is a little bit higher than those in the neutral and La Niña phases, although the differences among different ENSO phases are not statistically significant. Tracks of landfalling TCs over the Korean Peninsula are shifted northward as the ENSO phases change from El Niño to La Niña. This implies that latitudes of TC landfalling locations are negatively correlated with the Niño-3.4 SSTA. It is found that more than half of TCs making landfall over the Korean Peninsula in the neutral phase pass through mainland China earlier due to the westward expansion of the WNPSH. This westward expansion of the WNPSH plays a critical role in the dominant tracks and intensity of TCs making landfall over the Korean Peninsula. Therefore, a TC potentially making landfall over the Korean Peninsula is expected to landfall in South (North) Korea with a relatively strong (weak) intensity in the El Niño (La Niña) phase, which is helpful to the seasonal prediction of TC activity in Korea.

This study has also examined changes in the landfalling TC activity over the Korean Peninsula among the winter (DJF) ENSO phases. It is found that the landfalling frequency is similar among ENSO phases and landfalling TC tracks do not show any distinctive patterns among ENSO phases.

Although this study has focused on the TC activity in the small region of Korea, results from this study are important to other East Asian regions (for example, the Philippines, Taiwan, China, and Japan) because the passage frequency and intensity of TCs in these regions prior to landfall over the Korean Peninsula also change with the ENSO phases.

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REFERENCES

Bantzer, C. H., and J. M. Wallace, 1996: Intraseasonal variability in tropical mean temperature and precipitation and their relation to the tropical 40-50 day oscillation. *J. Atmos. Sci.*, **53**, 3032-3045.

Chan, J. C. L., 2000: Tropical cyclone activity over the western North Pacific associated with El Niño and La Niña events. *J. Climate*, **13**, 2960-2972.

______, 2005: Interannual and interdecadal variations of tropical cyclone activity over the western North Pacific. *Meteor. Atmos. Phys.*, **89**, 143-152.

Camargo, S. J., and A. H. Sobel, 2005: Western North Pacific tropical cyclone intensity and ENSO. *J. Climate*, **18**, 2996-3006.

Clark, J. D., and P. S. Chu, 2002: Interannual variation of tropical cyclone activity over the central North Pacific. *J. Meteor. Soc. Japan*, **80**, 403-418.

Fan, K., and H. J. Wang, 2009: A new approach to forecasting typhoon frequency over the western North Pacific. *Wea. Forecasting*, **24**, 974-986.

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.

Gray, W. M., 1975: Tropical cyclone genesis. Dept. Of Atmospheric Science Paper 234, Colorado State University, Fort Collins, CO, 121pp.

Ho, C.-H., J.-H. Kim, H.-S. Kim, C.-H. Sui, and D.-Y. Gong, 2005: Possible influence of the Antarctic Oscillation on tropical cyclone activity in the western North Pacific. *J. Geophys. Res.*, **110**, doi:10.1029/2005JD005766.

______, J. -J. Baik, J. -H. Kim, and D. -Y. Gong, 2004: Interdecadal changes in summertime typhoon tracks. *J. Climate*, **17**, 1767-1776.

Jin, J., and B. Hoskins, 1995: The direct response to tropical heating in a baroclinic atmosphere. *J. Atmos. Sci.*, **52**, 307-319.

Kalnay, E., and Coauthors, 1996: The NCEP/NCAR 40-Year reanalysis project. *Bull. Amer. Meteor. Soc.*, **77**, 437-471.

Kistler, R., and Coauthors, 2001: The NCEP/NCAR 50-year reanalysis, *Bull. Amer. Meteor. Soc.*, **82**, 247-267.

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.

Kumar, A., and M. P. Hoerling, 2003: The nature and causes for the delayed atmospheric response to El Niño. *J. Climate*, **16**, 1391-1403.

Lander, M. A., 1994: An exploratory analysis of the relationship between tropical storm formation in the western North Pacific and ENSO. *Mon. Wea. Rev.*, **122**, 636-651.

Ramage, C. S., 1971: *Monsoon Meteorology.* Academic Press: New York, 296.

Reid, G. C., K. S. Gage, and J. R. McAfee, 1989: The thermal response of the tropical atmosphere to variations in equatorial Pacific sea-surface temperature. *J. Geophs. Res.*, **94**, 14705-14716.

Reynolds, R. W., N. A. Rayner, T. M. Smith, D. C. Stokes, and W. Wang, 2002: An improved in situ and satellite SST analysis for climate. *J. Climate*, **15**, 1609-1625.

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

Wang, B., and J. C. L. Chan, 2002: How strong ENSO affect tropical storm activity over the western North Pacific. *J. Climate*, **15**, 1643-1658.

Wu, M. C., W. L. Chan, and W. M. Leung, 2004: Impacts of El Niño-Southern Oscillation events on tropical cyclone landfalling activity in the western North Pacific. *J. Climate*, **15**, 1419-1428.

Yulaeva, E., and J. M. Wallace, 1994: The signature of ENSO in global temperature and precipitation fields derived from the microwave sounding unit. *J. Climate*, **7**, 1719-1736.

Yumoto, M., and T. Matsuura, 2001: Interdecadal variability of tropical cyclone activity in the western North Pacific. *J. Meteor. Soc. Japan*, **79**, 23-35.