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# Impacts of El Niño–Southern Oscillation Events on Tropical Cyclone Landfalling Activity in the Western North Pacific

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ABSTRACT

The impact of El Niño–Southern Oscillation (ENSO) episodes on the variability in the landfalling pattern of tropical cyclones in the western North Pacific is studied using the bootstrap technique.

It is found that, relative to neutral years, in the months September, October, and November or the late season of El Niño years the number of tropical cyclones landfalling in the landmasses rimming the western North Pacific is significantly reduced. The exception is Japan and the Korean Peninsula. On the other hand, in the late season of La Niña years, China can expect significantly more landfalls. The predictability of the number of landfalling tropical cyclones in the western North Pacific is found to be the highest for China in the late season of La Niña years.

The reduction in the number of landfalls during the late season of El Niño years seems to be related to an eastward shift in the mean tropical cyclone genesis position and a break in the 500-hPa subtropical ridge near 130°E. In contrast, the increase in the number of landfalls during the late season of La Niña years appears to be related to a westward shift in the mean genesis position together with a contiguous 500-hPa subtropical ridge.

## 1. Introduction

The impacts of El Niño–Southern Oscillation (ENSO) events on tropical cyclone activity in the western North Pacific have been considered by Chan (1985), Dong (1988), Lander (1994), and Chan (2000) as well as others. However, the relationship between ENSO events and tropical cyclone landfalling activity in the western North Pacific seems to have received less attention in the literature.

Saunders et al. (2000) studied ENSO's spatial impacts on the landfalling behavior of hurricanes in the Atlantic and typhoons in the western North Pacific. Using the landfalling incidence rate ratio (IRR) they found that ENSO has a significant impact on the landfalling patterns of tropical storms in Vietnam and on typhoons in the Philippines. They also conclude that the impact of ENSO is less in the western North Pacific than in the Atlantic. Recently, Wang and Chan (2002) examined the changes in the life spans and tracks of tropical storms in the western North Pacific during strong ENSO events. Although changes in the landfalling patterns under the influence of ENSO can to some extent be inferred from the tropical cyclone tracks defined in Wang and Chan (2002), the theme of their study is tropical cyclone activity over the western North Pacific Ocean and not landfalls.

Between 1995 and 1999, damages in the Economic and Social Commission for Asia and the Pacific/World Meteorological Organization (ESCAP/WMO) Typhoon Committee[1] member areas in the western North Pacific were estimated to be approximately $3,620 million (U.S. dollars) with average annual human casualties exceeding a thousand (ESCAP/WMO, 2001; more information available online at http://www.wmo.ch/web/www/TCP/ESCAP-Typhoon-Com.html). From the point of view of reducing social and economic impacts, understanding the influence of ENSO events on the variability in tropical cyclone landfalling patterns is therefore equally important.

This note extends the work of Saunders et al. (2000) and Wang and Chan (2002). Using the bootstrap technique (details given in section 2d) and data between 1961 and 2000, it provides a quantitative comparison of landfalling patterns of tropical cyclones in the west-

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[1] The ESCAP/WMO Typhoon Committee was formed in 1968 to promote and coordinate efforts to minimize tropical cyclone damage in the ESCAP region. It has 14 members: Cambodia; China; Democratic People's Republic of Korea; Hong Kong, China; Japan; Lao People's Democratic Republic; Macau, China; Malaysia; the Philippines; Republic of Korea; Singapore; Thailand; Socialist Republic of Vietnam; and the United States.

ern North Pacific in years with ENSO activity (hereafter called ENSO years, and El Niño years for years in which warm events occurred, La Niña years for years in which cold events occurred) with those in years without ENSO activity (hereafter called neutral years). This is an issue not specifically addressed by Wang and Chan (2002). The western North Pacific in this study includes the coastline of mainland China, an area not covered in Saunders et al. (2000). Furthermore, as prior knowledge of the number of tropical cyclones that can be expected to make landfall is useful for planning and disaster mitigation purposes, this note examines the predictability of landfall in the western North Pacific in ENSO years. This topic also seems to be barely addressed in the literature.

This note is arranged as follows. The data and methodology used are described in section 2. The ENSO years used and the delineation of study areas in the western North Pacific for the purpose of this investigation are also given in that section. The confidence intervals for the number of tropical cyclones in different study areas and different ENSO conditions are derived using the bootstrap technique in section 3. The physical basis for the variability in landfalling behavior is examined in section 4. In section 5 an attempt is made at predicting the number of tropical cyclones expected to make landfall in the western North Pacific in ENSO years from Niño-3.4 sea surface temperature anomalies (SSTAs). A summary of the results is given in section 6.

## 2. Data and methodology

### *a. Data on landfalling tropical cyclones in the western North Pacific*

The number of landfalling tropical cyclones in the western North Pacific is extracted from the best-track data published by the Hong Kong Observatory. The period studied is the 40 years between 1961 and 2000. Data before 1961 are not analyzed because the number of tropical cyclones in the presatellite years of the 1950s might be underestimated (Chan 1985).

### *b. ENSO years*

In his investigation of the relationship between ENSO and tropical cyclone activity over the western North Pacific, Chan (2000) stratified ENSO events by years and examined the variation by season within these years. His approach is followed in the present study on landfalls.

The ENSO years between 1961 and 1996 used in this paper are those listed in Trenberth (1997). ENSO years between 1997 and 2000 are identified using the criteria adopted by Trenberth (1997) and the monthly Niño-3.4 SSTA data (available from the Climate Prediction Center's Web site at http://ftp.ncep.noaa.gov/pub/cpc/wd52dg/data/indices/sstoi.indices.) Trenberth (1997) considers an El Niño event to have occurred if the 5-month running mean SSTAs in the Niño-3.4 region (the equatorial Pacific bounded by 5°S–5°N, 120°–170°W) exceed 0.4°C for 6 months or more. La Niña events are similarly defined with an SSTA threshold of −0.4°C.

Of all the ENSO years between 1961 and 2000 thus obtained, only the subset in which ENSO activity began in June or earlier, and ended in November or later are selected for the present study. This is to ensure that during the selected ENSO years the ENSO signal is evident during the June–November tropical cyclone season in the western North Pacific.

This process yields 9 El Niño years (1963, 1965, 1969, 1972, 1982, 1987, 1991, 1994, 1997), 6 La Niña years (1964, 1971, 1973, 1975, 1988, 1999), and 25 ENSO neutral years.

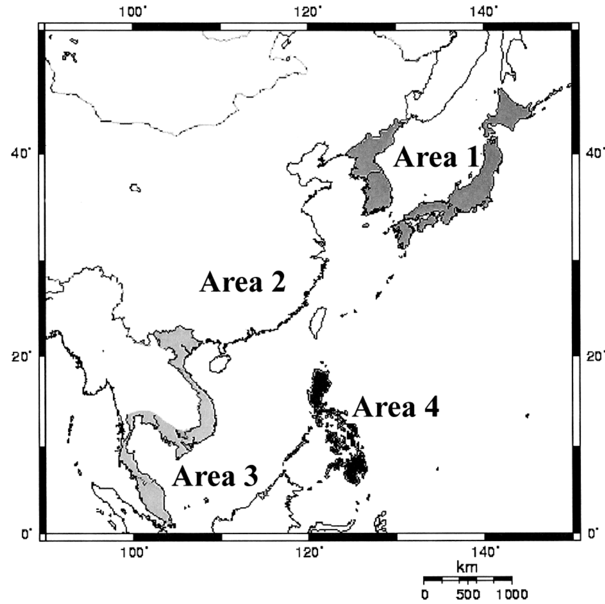



FIG. 1. Delineation of the four study areas. Area 1: Japan and Korean Peninsula; area 2: China; area 3: Indochina and Malay Peninsula; area 4: the Philippines.

### *c. Delineation of study areas in the western North Pacific*

The landmasses rimming the western North Pacific basin are divided into four study areas. Area 1 covers Japan and the Korean Peninsula; area 2 covers China; area 3 is mainly Indochina, Thailand, and the Malay Peninsula; and area 4 the Philippines (Fig. 1).

This delineation is somewhat subjective. The factors taken into account being geographical contiguity or proximity. Consideration is also given to tropical cyclone landfall or track climatologies in the different areas as given in or can be inferred from, for example, Chen and Ding (1979) and Neumann (1993). Area 1 is mainly affected by recurving tropical cyclones, and area 2 by tropical cyclones forming in both the western North

Pacific and the South China Sea and generally moving in a northwest direction. Area 2 has most landfalls in June, July, and September, and area 3 in September and October. Area 4 is rarely affected by tropical cyclones forming in the South China Sea.

### d. Methodology

It is first shown (section 3a) that in ENSO years, for all areas the change in landfalling pattern from neutral years is small in the early season, June–August. Large changes are found mainly in the months September–November or the late season, and only for areas 2, 3, and 4. The bootstrap technique is then used to construct the confidence intervals about the true mean of the number of landfalling tropical cyclones in the late season in these three areas in ENSO and neutral years.

The bootstrap technique belongs to the class of resampling procedures. It allows inferences about a sample to be drawn without assumptions being made on the underlying probability distribution of the data in the sample, or when assumptions about the probability distribution can be made but the confidence intervals cannot be calculated mathematically (von Storch and Zwiers 1999).

The bootstrap technique operates by replicating without replacement a large number of synthetic sets of observations from a single set of actual observations (Wilks 1995). The mean of each of the synthetic sets of observations is calculated and the confidence intervals are obtained from the distribution of these means. For example, if 10 000 synthetic sets are generated, then the 95% confidence intervals are given by the 250th ($10\,000 \times 0.05/2$) ranked mean and the 9750th ranked mean [$10\,000 - (10\,000 \times 0.05/2)$].

The advantages of applying the bootstrap technique to atmospheric observations have been discussed by Nicholls (2001). In regard to tropical cyclones, this technique has been utilized by O'Brien et al. (1996) and Bove et al. (1998) to study the effect of ENSO on landfalling hurricanes in the eastern United States, as well as by Chu and Wang (1997) to study tropical cyclone occurrences in the vicinity of Hawaii.

Because inferences based on resampling techniques are sensitive to the effects of serial correlation (Zwiers 1990), lag-1 autocorrelations are first calculated for the relevant landfalling data series and tested for statistical significance using the Ljung–Box Q test (Box and Jenkins 1976; Vandaele 1983). None of the autocorrelations are found to be significant.

The results of the bootstrap analysis are interpreted in terms of the associated large-scale atmospheric circulations. The National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis data (Kalnay et al. 1996) are used to construct the composites of these circulations at 850 and 500 hPa in ENSO years.

The predictability of the number of landfalling tropical cyclones in the western North Pacific from Niño-3.4 SSTAs is attempted using linear regression methods.

TABLE 1. Average number of landfalling tropical cyclones in El Niño, La Niña, and neutral years.

| | Jun–Aug | | | Sep–Nov | | |
|---|---|---|---|---|---|---|
| Area | El Niño | La Niña | Neutral | El Niño | La Niña | Neutral |
| 1 | 3.0 | 2.8 | 2.8 | 1.2 | 0.8 | 1.44 |
| 2 | 5.1 | 4.8 | 4.9 | 1.7 | 4.0 | 2.8 |
| 3 | 1.8 | 1.3 | 1.5 | 1.7 | 3.8 | 2.9 |
| 4 | 1.4 | 2.0 | 1.9 | 1.3 | 4.3 | 3.2 |

## 3. Landfalling patterns in the western North Pacific

### a. Statistics of observed landfalls

The observed mean number of landfalls in ENSO and neutral years for areas 1, 2, 3, and 4 are given in Table 1. This table shows that in the early season, the differences between the mean number of landfalls in ENSO and neutral years are small for all the four areas. These small differences may be attributed to ENSO not beginning to attain maximum development until September (Chen et al. 1998). In the late season, the differences are large with the exception of area 1.

These differences can be better demonstrated in terms of the standardized anomaly of the number of landfalling tropical cyclones, D, calculated as the ratio of the difference between the mean number of landfalls in El Niño (La Niña) years and neutral years to the standard deviation of the number in neutral years.

In the early season, for all areas D is small, no more than 0.5. In the late season, with the exception of area 1 the value of D generally exceeds 1 (Fig. 2). If D is viewed as a discriminator, then irrespective of whether the value of 0.5 or 1 is selected as the choice of threshold the late season would emerge as that in which ENSO's impacts are likely to be the most evident for all areas except area 1. In the late season, for areas 2, 3, and 4, D takes on negative values for El Niño years, and positive values for La Niña years. These values signify, respectively, fewer landfalls in El Niño years compared with neutral years, and more landfalls in La Niña years.

### b. Confidence intervals

The 95% confidence intervals in ENSO and neutral years in areas 2, 3, and 4 in the late season as obtained from the bootstrap technique are shown in Table 2.

One sees that in the late season, for area 2, the confidence interval is between 1.1 and 2.2 during El Niño years, and between 2.3 and 3.2 during neutral years. For area 3, the respective confidence intervals are 1.0–2.2, and 2.4–3.4. For area 4, they are 0.7–2.1 and 2.6–3.4. The confidence intervals in El Niño years are smaller than those in neutral years. Further, there is little overlap

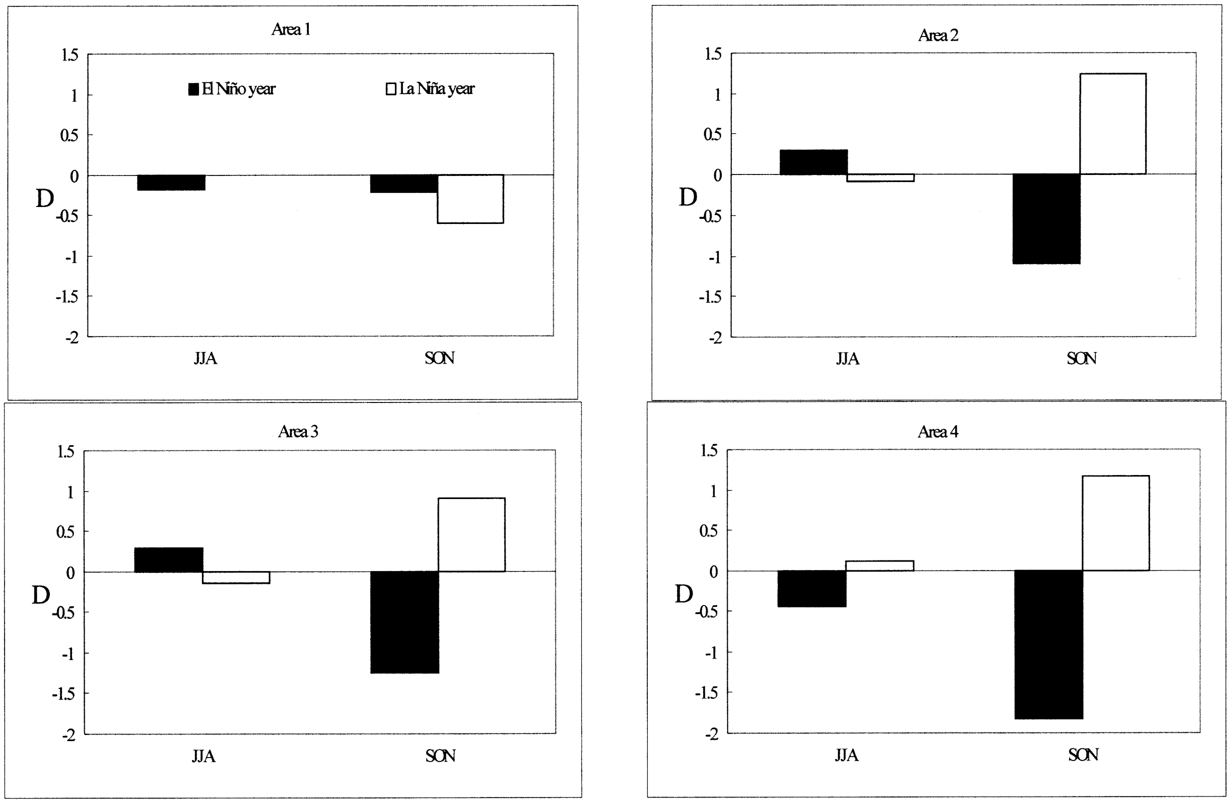



FIG. 2. Departure (D) of the mean number of landfalling tropical cyclones in El Niño and La Niña years from the mean in neutral years, normalized by the std dev of the number in neutral years. Jun–Aug (JJA; early season); Sep–Nov (SON; late season).

between the confidence intervals in El Niño years and in neutral years. This is highly suggestive of the suppressing effect of El Niño on landfalling activity in the late season in areas 2, 3, and 4.

In La Niña years, during the late season the confidence interval for area 2 is between 3.3 and 4.7, for area 3 between 1.7 and 6.3, and for area 4 between 3.3 and 5.7. They are all larger than the respective confidence intervals for neutral years. In particular, for area 2 the confidence intervals do not overlap, and points to the enhancing influence La Niña has on landfalling activity in that area.

The contrast between El Niño and La Niña years is particularly marked. For area 2, the number of landfalling tropical cyclones in La Niña years is almost 2.4 times that in El Niño years. In area 3, it is about 2.2 times. In area 4, it is about 3.3 times.

Results from the permutation test, a two-sample test related to the bootstrap (see, e.g., Wilks 1995 for a description of this test) confirm that the mean number of tropical cyclones landfalling in areas 2, 3, and 4 in the late season of El Niño years differ significantly from the mean number in neutral years (at the 5% level). This test also shows that in the late season of La Niña years, the mean number of tropical cyclones landfalling in area 2 is significantly different (at the 5% level) from that in neutral years. It is insignificant in areas 3 and 4. These results are summarized in Table 3.

ENSO's impacts on landfalling activity found here are generally consistent with those of Saunders et al. (2000) as well as those that might be inferred from the tracks given in Fig. 8 of Wang and Chan (2002).

In particular, in the sense that three out of the four

TABLE 2. Mean and the corresponding 95% confidence intervals of the number of landfalling tropical cyclones in the late season Sep–Nov for El Niño, La Niña, and neutral years.

| | Area 2 | Area 3 | Area 4 |
|---|---|---|---|
| El Niño year | 1.7 | 1.7 | 1.3 |
| | (1.1, 2.2) | (1.0, 2.2) | (0.7, 2.1) |
| Neutral year | 2.7 | 2.9 | 3.2 |
| | (2.3, 3.2) | (2.4, 3.4) | (2.6, 3.4) |
| La Niña year | 4.0 | 3.8 | 4.3 |
| | (3.3, 4.7) | (1.7, 6.3) | (3.3, 5.7) |

TABLE 3. Results of permutation tests. Bold denotes significance at the 5% level. Entries are "$p$" values, and significance at the 5% level is achieved if "$p$" is less than 0.05.

| | Area 2 | Area 3 | Area 4 |
|---|---|---|---|
| El Niño year | **0.008** | **0.000** | **0.006** |
| La Niña year | **0.015** | 0.175 | 0.066 |

delineated areas see a significant impact of ENSO on the number of landfalling tropical cyclones, ENSO's influence in the western North Pacific would seem, in this regard, to be no less than in the Atlantic as found by Saunders et al. (2000). It is ventured that the conclusion reached by Saunders et al. (2000) that ENSO's impacts on landfalling patterns are less in the western North Pacific than in the Atlantic is largely due to landfalls over mainland China in area 2 not being considered in their study.

## 4. Atmospheric circulations associated with the different landfalling patterns

Shifts in tropical cyclone genesis positions together with changes in the steering flow are identified as some of the factors affecting landfalling patterns in the western North Pacific in the late season of ENSO years.

### *a. Shifts in genesis position*

Figure 3 shows that in the late season, the mean tropical cyclone genesis position is at about 14.3°N, 147.3°E during El Niño years, and 14.7°N, 133.0°E during La Niña years. These mean genesis positions are shifted, respectively, eastward and westward from that of neutral years, which is at about 14.5°N, 138.7°E. The correlation coefficient between the mean longitude of the genesis positions in the late season of each year and the mean Niño-3.4 SSTAs in the late season of each year between 1961 and 2000 is 0.67, significant at the 1% level.

These results are broadly consistent with those of Chia and Ropelewski (2002). They show that during the season July–October, tropical cyclone genesis position in the western North Pacific tends to be shifted southeastward during warm ENSO conditions, and northwestward during cold conditions. However, Chia and Ropelewski (2002) note that this is not always the case, and the relationship between genesis position and ENSO is complex. It depends, for example, on the timing and evolution of individual ENSO events. Chia and Ropelewski (2002) further suggest that while ENSO is a dominant factor in changes in genesis position, it is not the only one. The 200–850-hPa wind shear, the strength and position of the western Pacific subtropical high, and the monsoon trough are also involved, all of which may be varying with ENSO in an inter-related way.

The genesis positions of tropical cyclones are closely related to the interannual variations in the monsoon trough (Lander 1994; McBride 1995). The variation in the easternmost position of the monsoon trough in the late season is clearly seen in Fig. 3 (dashed line, left panels). In El Niño years, the eastern end of the monsoon trough stretches to just beyond 170°E, that is, almost to the date line. In neutral years, the eastern end of the monsoon trough does not extend beyond 150°E. In La Niña years, it terminates at about 135°E. That is, in La Niña years the eastern end of the monsoon trough retreats westward by some 35° longitude compared with its position in El Niño years. The eastward shift in the mean genesis position in El Niño years can be explained by the eastward extension of the monsoon trough, and its westward shift in La Niña years by the westward retreat of the monsoon trough. Chen et al. (1998) have attributed the interannual variation in the monsoon trough to an anomalous wave train resulting from SSTAs in the tropical Pacific.

For warm ENSO conditions, it has also been suggested that the shifts in tropical cyclone genesis position are due to a longitudinal shifts in the ascending and descending branches of the Walker circulation (Chan 2000).

### *b. Changes in steering flow*

ENSO-related anomalous flows at 500-hPa flows, which steer tropical cyclones away from or toward a particular region in the western North Pacific basin, have been suggested by Chan (2000) as a reason for the variability in tropical cyclone activity over the western North Pacific.

The right panels in Fig. 3 show that during the late season of El Niño years, the subtropical high at the 500 hPa is split into two separate cells at about 130°E. In contrast, during neutral and La Niña years, the subtropical ridge presents itself as a contiguous entity.

The eastward shift in mean genesis position and the break between the two cells in the subtropical ridge induces tropical cyclones to recurve north or northeast before reaching 120°E (see Carr et al. 1998; Sampson et al. 1998 for the motion of tropical cyclones under different synoptic situations). This may help to explain in part the relatively smaller number of landfalling tropical cyclones in areas 2, 3, and 4 during the late season of El Niño years. Wang and Chan (2002) also found that during the fall of strong El Niño years. Tropical storms tend to recurve northward across 35°N 2.5 times more than in strong La Niña years.

The recurvature at about 130°E is well reflected in the track densities (Fig. 4), which are constructed by counting the number of tropical cyclones passing through grid boxes of 1° latitude and dividing by the number of years. The track density over the South China Sea is, as a consequence, also much lower relative to neutral years. The relatively smaller number of tropical cyclones making landfall in areas 2, 3, and 4 in El Niño years can also be seen in Fig. 4a.

The westward shift in mean genesis position together with the strong subtropical ridge in the late season of La Niña years favor a steering toward the west-northwest. This is reflected in the much higher track densities in the South China Sea in the late season of La Niña years relative to neutral years. Figure 4b also shows the higher number of landfalling tropical cyclones over the

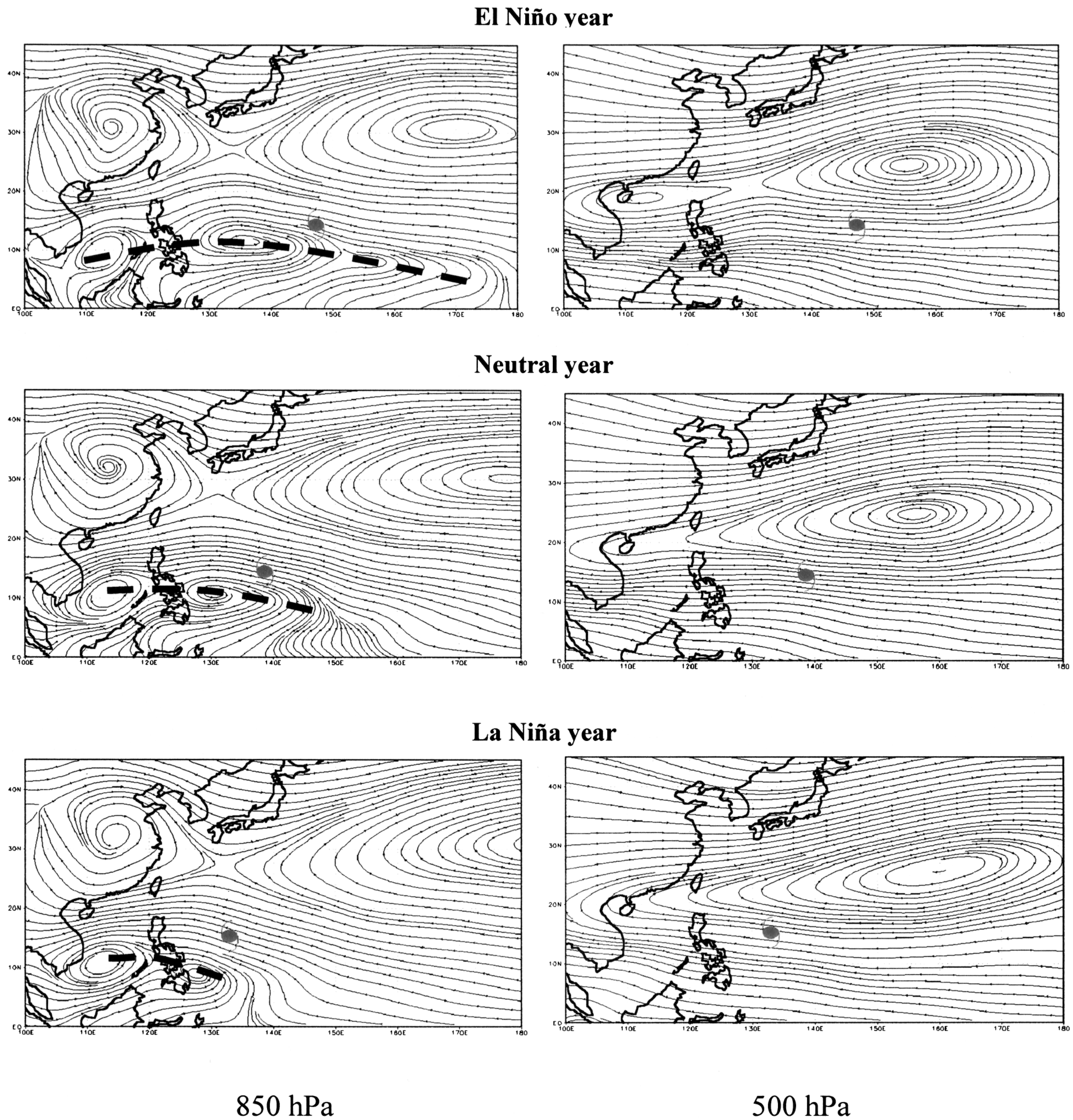


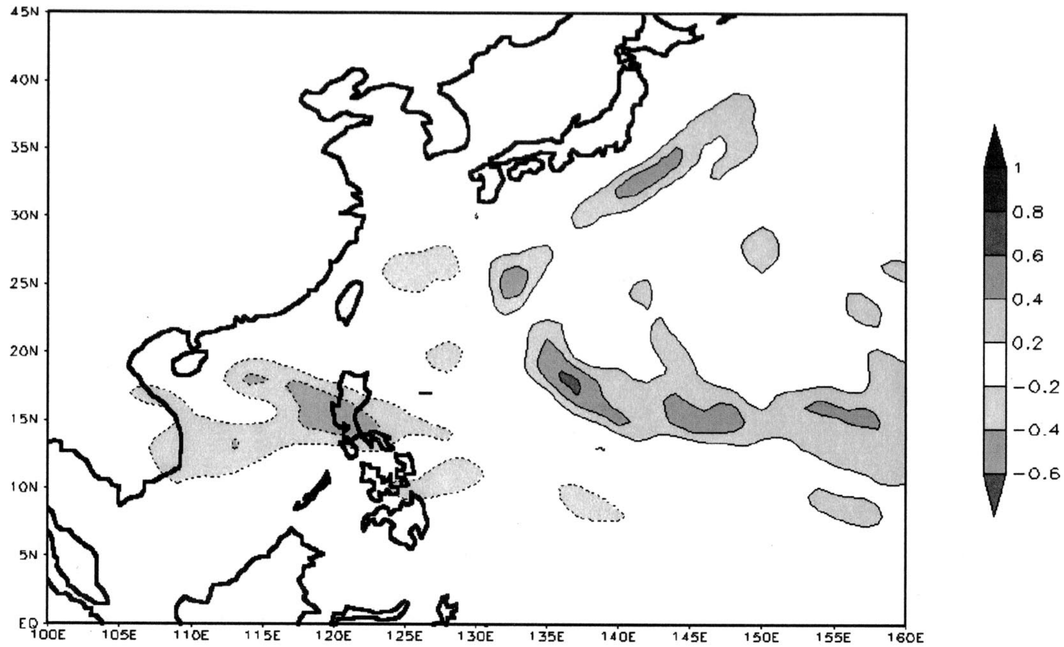

FIG. 3. Composite circulation in the late season at 850 and 500 hPa for (top) El Niño, (middle) neutral, and (bottom) La Niña years. The tropical cyclone symbol and the dashed line represent, respectively, the mean tropical cyclone genesis position and the ITCZ.

Philippines, south China, and northern Vietnam in the late season of La Niña years.

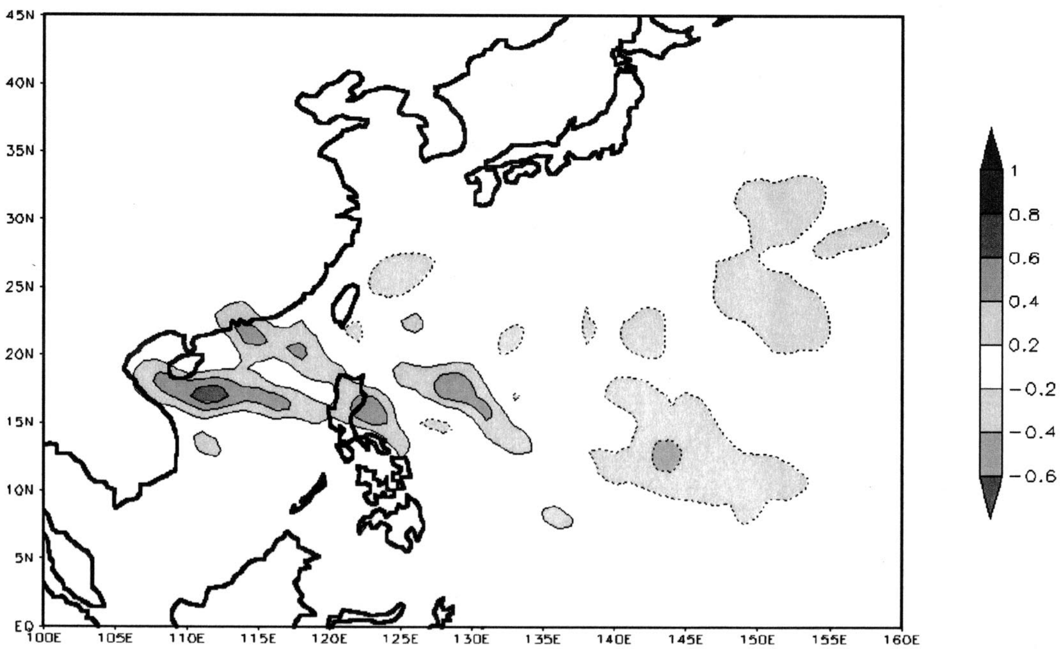
## 5. Predictability

The predictability of the number of tropical cyclones landfalling in the western North Pacific is to some degree afforded by the confidence intervals given in Table 2. That is, the number of tropical cyclones that can be expected to make landfall in the late season of El Niño years is 2 or less in areas 2, 3, and 4. In the late season of neutral years, this number is likely to be between 2 and 3 for areas 2 and 3, and 3 for area 4. In the late season of La Niña years, the number is likely to be between 3 and 5 in area 2, between 2 and 6 in area 3, and between 3 and 6 in area 4.

Wang and Chan (2002) found that the number of tropical storms forming in the months July–September in the southeast (0°–17°N, 140°E–180°) and northwest (17°–30°N, 120°–140°E) quadrants of the western North




(a) El Niño years




(b) La Niña years

FIG. 4. Tropical cyclone track density in the late season relative to neutral years for (a) El Niño and (b) La Niña years.

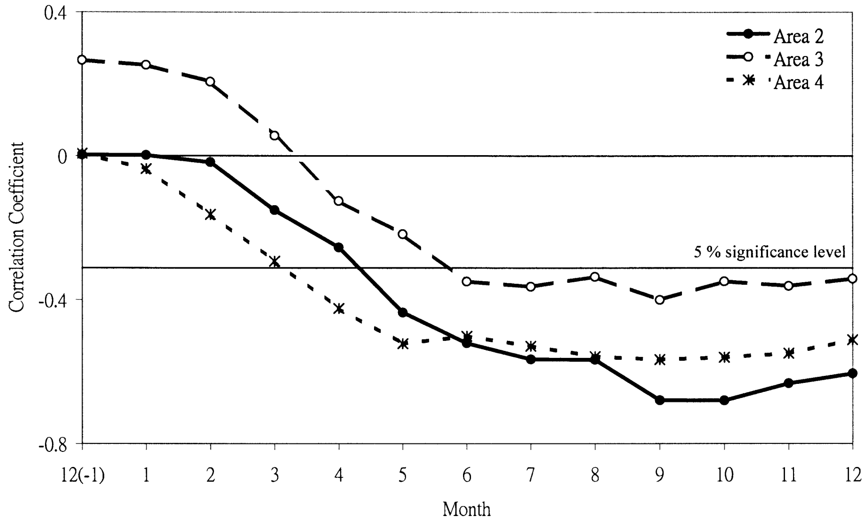



FIG. 5. Correlations of the number of landfalling tropical cyclones in the late season with the monthly Niño-3.4 SSTAs. The 5% significance levels are indicated. 12(−1) on the abscissa denotes Dec in the preceding year.

Pacific is highly correlated with SSTAs in the Niño-3.4 region in that season. A preliminary study of the predictability of the number of tropical cyclones making landfall in the western North Pacific in the late season in terms of late season Niño-3.4 SSTAs for areas 2, 3, and 4 is now attempted.

A lag-correlation analysis shows that for all the three study areas, the correlations between the monthly mean Niño-3.4 SSTAs and the late season landfalling numbers become statistically significant (at the 5% level) from June onward (Fig. 5), suggesting that the summer SSTAs can be a predictive signal for the number of late season landfalling tropical cyclones. Because the highest correlations exist between the late season Niño-3.4 SSTAs and the late season landfalling numbers, the simultaneous correlation approach of Wang and Chan (2002) is adopted in attempting the predictions. This approach also allows prediction with a longer lead time.

Figure 6a shows that for area 2, overall, that is, for all years between 1961 and 2000 considered together, there is a significant (at the 5% level) linear relationship between Niño-3.4 SSTA in the late season and the number of landfalling tropical cyclones in that season. The correlation coefficient $r$ is 0.67. The relationship seems strongest for La Niña years alone, with $r = 0.87$ and significant at the 1% level. It is weaker for El Niño years alone albeit still significant (at the 5% level). Figure 6a also suggests a likely nonlinear relationship between Niño-3.4 SSTAs and landfalling activity for area 2 in the late season.

For area 3, a significant (at the 5% level) relationship between Niño-3.4 SSTAs and the number of landfalling tropical cyclones in the late season for 1961–2000 taken together is also found ($r = 0.37$). This is shown in Fig. 6b. However, the relation is not significant for El Niño years alone ($r = 0.37$) nor for a La Niña years alone ($r = 0.1$).

The case for area 4 is similar to that for area 3 (Fig. 6c) in that the overall correlation is significant at the 5% level, but no significant relationship is found for El Niño or La Niña years alone. The values of $r$ are, respectively, 0.57 for the overall case, 0.07 in El Niño years, and 0.26 in La Niña years.

Thus, it seems predictions for areas 2, 3, and 4 in the late season may be attempted using predicted Niño-3.4 SSTAs, with the case of area 2 in La Niña years seeming to offer the most promise. This predictability should be a subject of further study, given the importance of advance information on the likely number of landfalls in disaster mitigation–related activities. For operational applications, say predicting the likely number of landfalls in the season several months ahead, use can be made of the predicted late season Niño-3.4 SSTAs available online (http://iri.columbia.edu/climate/ENSO/currentinfo/SSTtable.html). Alternatively, the development of empirical equations for predicting late season Niño-3.4 SSTAs can be attempted in the manner of Wang and Chan (2002). This should also be subject of further study.

Wang and Chan (2002) attribute the physical basis of the predictability they found in their study to the formation of an anomalous lower-tropospheric anticyclone (cyclone) over the Philippine Sea in the fall of El Niño (La Niña) years (Wang et al. 2000; Wang and Zhang 2002). This anomalous anticyclone (cyclone) develops as a result of the combined action of ENSO, tropical–extratropical as well as monsoon-ocean interaction. It suppresses (enhances) tropical cyclone formation in El Niño (La Niña) years. Given that many of the tropical cyclones affecting areas 2, 3, and 4 either spawn in or

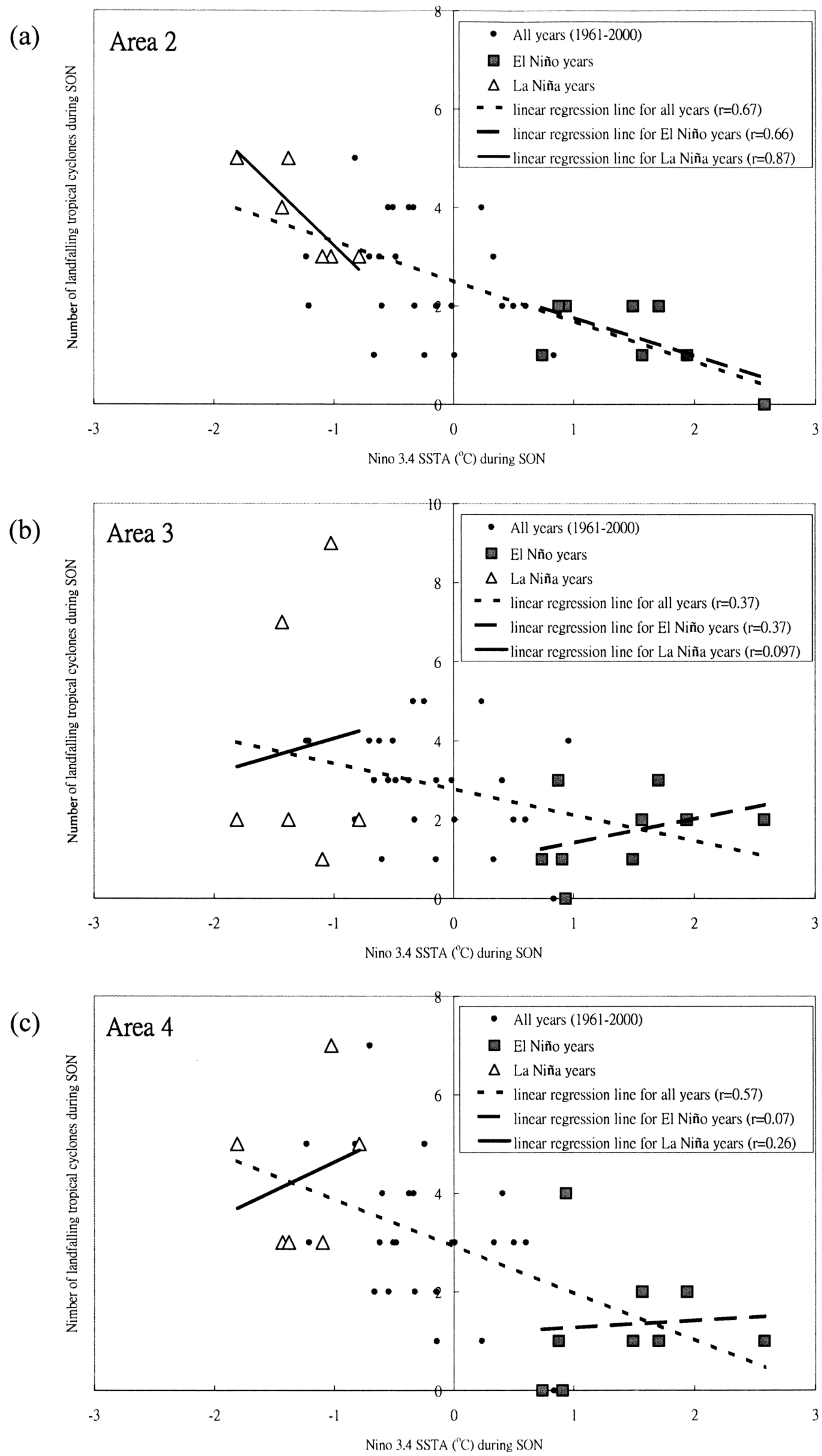



FIG. 6. Scatter diagram showing the relationship between the mean Niño-3.4 SSTA and the mean number of landfalling tropical cyclones during the late season for (a) area 2, (b) area 3, and (c) area 4.

pass through the Philippine Sea, the suppressing/enhancing effects of this anomalous Philippine Sea anticyclone (cyclone) should also be a mechanism for the limited predictability found here.

## 6. Conclusions

Compared with neutral years, in the late season of El Niño years significantly fewer tropical cyclones can be expected to make landfall in the western North Pacific with the exception of Japan and the Korean Peninsula. In the late season of La Niña years, China and expect significantly more landfalls relative to neutral years. For other seasons and other regions, the difference does not appear to be as prominent.

ENSO's influence on landfalling behavior in the western North Pacific can in part be attributed to an eastward shift in tropical cyclone genesis position coupled with a weaker subtropical ridge in El Niño years resulting in generally fewer landfalls, compared with a westward shift in mean genesis position and strong subtropical ridge in La Niña years resulting in generally more landfalls.

The predictability of the number of landfalling tropical cyclones is important for planning and disaster-related activities, and a degree of predictability is offered by the resampling results of this study. In terms of Nino-3.4 SSTAs, the highest predictability is found for the number of tropical cyclones making landfall over China in the late season of La Niña years. The relationship between the number of landfalls in the western North Pacific and SSTAs merits further study so as to effect better predictions, as does the related issue of the development of empirical equations for predicting SSTAs.

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