Tropical Cyclone Activity over the Western North Pacific Associated with El Niño and La Niña Events

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ABSTRACT

This paper presents the results of an investigation on the variations of tropical cyclone (TC) activity over the western North Pacific (WNP) associated with both El Niño (EN) and La Niña (LN) events. The study is based on the monthly number of TCs that occurred during the period 1959–97. Anomalies within each 5° lat × 5° long box from the year before (EN−1 and LN−1) to the year after (EN+1 and LN+1) are examined.

During an EN−1 year, more (less) TCs are found in September and October over the South China Sea (southeast of Japan). In an EN year, TC activity is below normal during these two months over the South China Sea (SCS) but above normal especially in the late season in the eastern part of the WNP. After the mature phase of the warm event (i.e., during an EN+1 year), TC activity over the entire ocean basin tends to be below normal.

No significant anomalies are found during an LN−1 year. However, in an LN year, the SCS tends to have more TCs in September and October, but for the rest of the WNP, TC activity tends to be below normal from August to November. During the year after an LN event, the entire basin generally has more TCs. Such a situation is especially true over the SCS from May to July.

All these anomalous activities are apparently linked to anomalies in the large-scale flow patterns at 850 and 500 hPa. Because the 850-hPa flow is related to TC genesis and development, areas with anomalous cyclonic (anticyclonic) flow are generally found to be associated with above- (below-) normal TC activity. Anomalous 500-hPa flow is identified as responsible for steering TCs toward or away from a region, thus rendering the TC activity in that region above or below normal.

1. Introduction

It has long been recognized that tropical cyclone (TC) activity in most ocean basins has a strong interannual signal [see, e.g., the review in Landsea (1999)]. Over the western North Pacific (WNP), this signal has been found to be related to the warm phase[1] of the El Niño–Southern Oscillation (ENSO) phenomenon [Chan 1985 (hereafter C85); Dong 1988; Lander 1993, 1994] and the quasi-biennial oscillation in the stratosphere (Chan 1995). Most of these studies suggested that the changes in the TC activity in the WNP associated with the warm phase of the ENSO are due to a longitudinal shift in the upward and downward branches of the Walker Circulation (e.g., C85; Wu and Lau 1992). Lander (1993, 1994) further noted that changes in the large-scale circulation during warm events are responsible for the variations in TC activity. Chen et al. (1998) (hereafter C98) extended these studies by comparing the locations of TC formation during years between warm and cold phase years. They found substantial differences in the genesis locations especially during the summer months and attributed these differences to zonal and meridional shifts in the location of the monsoon trough.

While results from these studies have greatly advanced our knowledge on the interannual variations of TC activity, the focus has mostly been on the activity during warm events except in the C98 study. To provide a more complete picture of such variations requires an investigation of TC activity prior to, during, and after the occurrence of the warm and cold phases, which is the first objective of the present study. The other ob-

[1] The "warm" and (later) "cold" phases of the ENSO refer to the magnitudes of SST anomalies (SSTA) in the central and eastern equatorial Pacific. In previous studies, a warm (cold) phase of the ENSO is generally a year in which the SSTA is above (below) normal, although various magnitudes of the anomalies have been used. See Philander (1990) for a detailed description of the phenomenon. In this study, the SSTA over the Niño-3.4 region (5°S–5°N, 170°–120°W) is adopted. A warm (cold) phase, i.e., El Niño (La Niña), year will refer to one in which the SSTA increases to >0.5°C (decreases to <−0.5°C) sometime during that year (generally either in the spring or summer). Such a definition is also used by the Climate Analysis Center to identify the occurrence of either an El Niño or La Niña.

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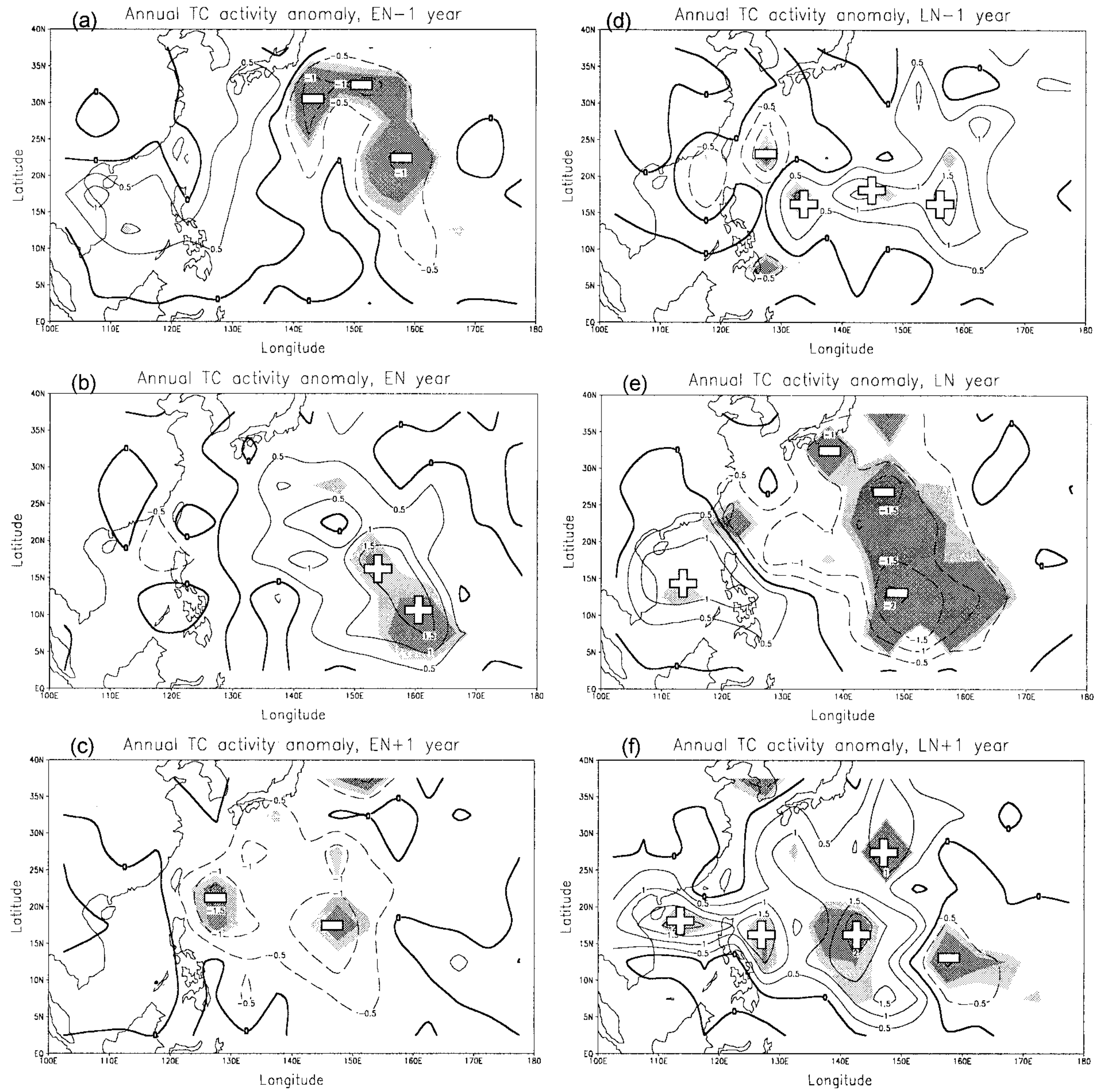


FIG. 1. Composite anomalies of the annual TC activity during (a) EN−1, (b) EN, (c) EN+1, (d) LN−1, (e) LN, and (f) LN+1 years over the western North Pacific. Solid (dashed) lines indicate positive (negative) anomalies, with the plus (minus) signs indicating the approximate locations of the maximum (negative maximum) values. Contour interval: 0.5. Light and dark shades indicate areas where the *t* test is significant at the 90% and 95% level, respectively.

jective is to understand these variations in TC activity in terms of the large-scale conditions associated with such activities. It will be shown that not only do the locations of TC genesis differ between warm and cold events, the tracks of the TCs also tend to be different. Furthermore, because the large-scale conditions associated with these events vary with seasons, it is necessary to examine the variations in TC activity from month to month, or season to season. All these results should be of value for short-term climate forecasts, at least for the year after either a warm or cold event. If reasonably accurate forecasts of the occurrence of a warm or cold event can be made, the TC activity during that year or even the year before may also be estimated. Indeed, Chan et al. (1998) have made use of the sea surface temperature conditions over the equatorial central and eastern Pacific as one of the predictors of the seasonal TC activity over the WNP.

Section 2 describes the data used and lists the warm (El Niño, or EN) and cold (La Niña, or LN) years. The

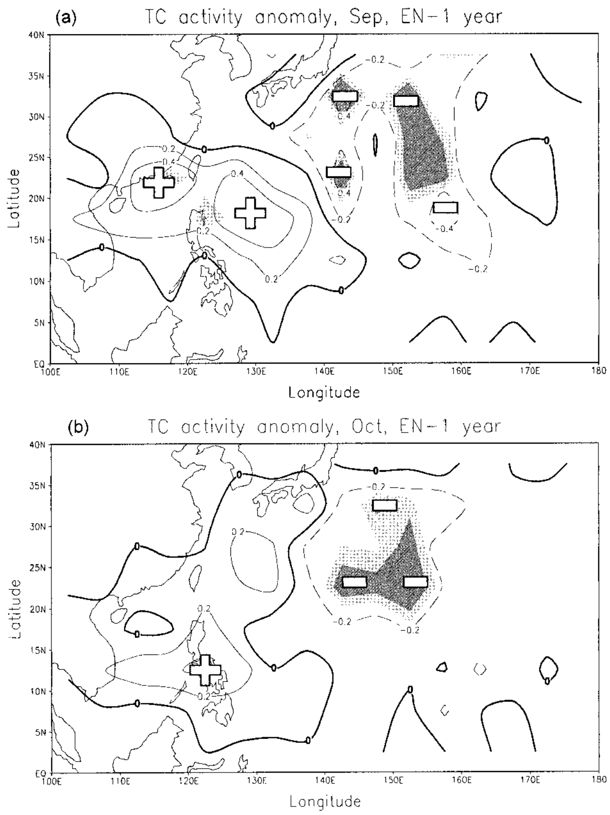


FIG. 2. Composite anomalies of TC activity in (a) Sep and (b) Oct during EN−1 years over the western North Pacific. Solid (dashed) lines indicate positive (negative) anomalies, with the plus (minus) signs indicating the approximate locations of the maximum (negative maximum) values. Contour interval: 0.2. Light and dark shades indicate areas where the *t* test is significant at the 90% and 95% level, respectively.

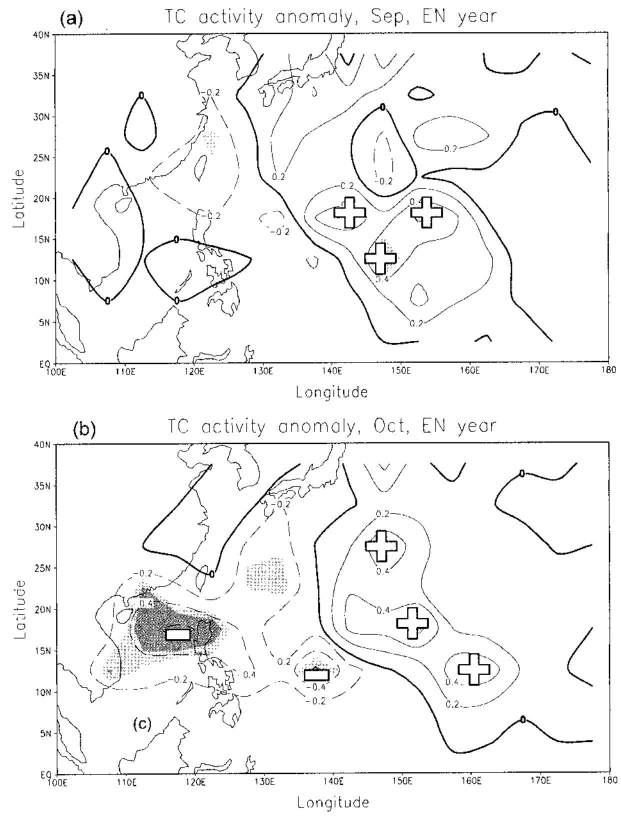


FIG. 3. As in Fig. 2 except for the EN year composite and the months (a) Sep and (b) Oct.

methods of computing the anomalies of TC activity and those of the composite flow patterns associated with such anomalies are also presented. In addition, techniques to evaluate the veracity of these anomalies are described. The distributions of the annual and monthly anomalies in TC activity in each event category are examined in section 3. To understand these distributions, anomalies in the composite flow patterns at various levels associated with the areas in which the TC activity anomalies are significantly above or below normal are analyzed in section 4. A summary and discussion are then given in section 5.

2. Data and methodology

a. Data

Tropical cyclones over the WNP during the period 1959–97 form the basic dataset for this study. Their best-track positions are obtained from the Joint Typhoon

TABLE 1. Standardized anomalies of the number of tropical cyclones (TCs) and tropical storms and typhoons (TSTYs, i.e., without TCs that only reached tropical depression intensity) over the South China Sea averaged between Sep and Oct in each of the EN−1 years.

Year	TCs	TSTYs
1964	2.29	2.51
1968	−0.18	−0.11
1971	0.12	0.19
1975	0.19	0.27
1981	−0.62	−0.58
1985	1.43	1.58
1990	0.19	0.27
1993	0.62	0.35
Mean	0.50	0.56

TABLE 2. As in Table 1 except for the EN years.

Year	TCs	TSTYs
1965	−0.55	−0.50
1969	−1.42	−1.43
1972	−0.55	−0.50
1976	−0.99	−0.96
1982	−0.18	−0.11
1986	−0.31	−0.28
1991	−0.18	−0.11
1994	−0.62	−0.58
Mean	−0.60	−0.56

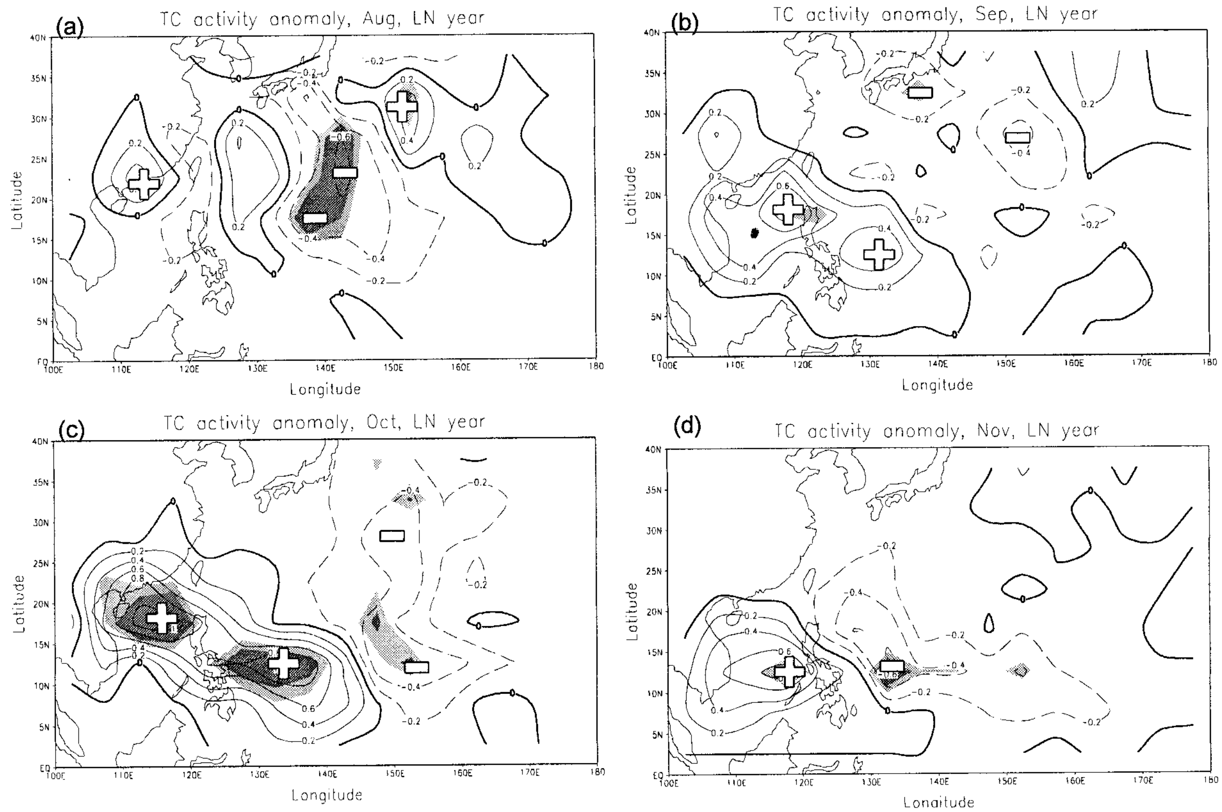


FIG. 4. As in Fig. 2 except for the LN year composite and the months (a) Aug, (b) Sep, (c) Oct, and (d) Nov.

Warning Center in Guam. Although some of the TC activity over the ocean before the satellite era might not have been detected, it would only slightly affect the results since the majority of the EN and LN events occurred from the 1960s onward.

To study the large-scale flow patterns, the monthly reanalyses of the National Center for Environmental Prediction (NCEP) for the period 1958–97 are used.

TABLE 3. Standardized anomalies of the number of tropical cyclones (TCs), tropical storms and typhoons (TSTYs), and typhoons (TYs) over the entire western North Pacific (including the South China Sea) averaged for the whole year (annual) and for the period May–Nov in each of the EN+1 years.

	Annual			May–Nov		
Year	TCs	TSTYs	TYs	TCs	TSTYs	TYs
1966	1.02	0.44	0.52	0.55	0.24	0.22
1970	−0.78	−0.82	−1.57	−0.18	−0.16	−0.62
1973	−1.43	−1.46	−1.57	−0.49	−0.42	−0.56
1977	−1.76	−1.88	−1.83	−0.72	−0.72	−0.69
1983	−1.1	−1.03	−1.57	−0.42	−0.35	−0.50
1987	−1.1	−0.82	0	−0.51	−0.36	−0.11
1992	0.21	0.87	0.78	0.23	0.47	0.40
1995	0.37	−0.4	−0.78	0.15	0.03	−0.26
Mean	−0.57	−0.64	−0.75	−0.17	−0.16	−0.26

The EN and LN years are extracted from the homepage of the Climate Prediction Center. The EN years are 1965, 69, 72, 76, 82, 86, 91, and 94 and the LN years are 1964, 70, 73, 75, 88, and 95. The year before, of, and after an EN (LN) event will be labeled as EN−1, EN, and EN+1 (LN−1, LN, and LN+1), respectively.

b. Methodology

1) TC ANOMALIES

The climatology of TC activity is first determined. This is obtained by counting the annual number of TCs occurring in each 5° long × 5° lat grid box within the domain 0°–40°N and 100°E–180° and then computing

TABLE 4. As in Table 1 except for the LN years for the months of Sep–Nov.

Year	TCs	TSTYs
1964	2.40	2.58
1970	1.20	1.28
1973	0.99	1.09
1975	0.25	0.08
1988	0.25	0.33
1995	1.32	0.59
Mean	1.07	0.99

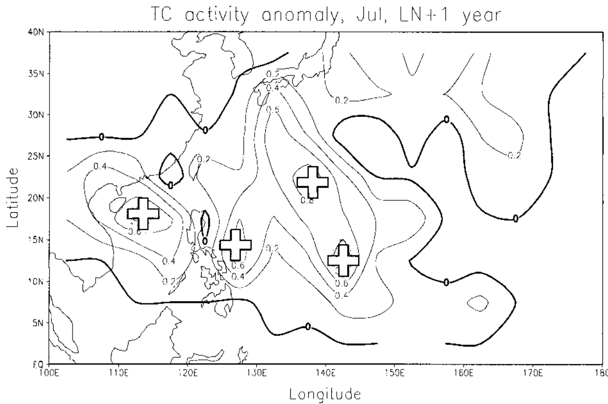


FIG. 5. As in Fig. 2 except for Jul of the LN+1 year.

the average. In this study, TC activity includes all tropical cyclones from tropical depressions to typhoons, unless otherwise stated. The annual anomalies of TC activity during each of the EN±1, LN±1, EN, and LN years are obtained by subtracting the climatological mean in each grid box from the annual number in that year. The anomalies are then averaged for each category. A similar procedure is used for the monthly anomalies. The significance of the anomaly in each box is tested using the Student t-test (the null hypothesis being that the anomaly is not significantly different from zero). However, the results from such a test should be interpreted with caution because of the small sample size. A large area with t values significantly above the threshold suggests that a coherent signal may have been identified. In other words, the anomalies in that area are likely to be true in most individual years.

It will be shown in section 3 that annual anomalies in TC activity within one particular area are generally contributed by monthly anomalies during certain months. To study whether the composite results are applicable to individual years, an average of the TC activity within these months is made. However, because the variation in TC activity in each month is different, the standardized anomalies, instead of the anomalies, are averaged. The standardized anomaly for a given month is simply the anomaly (as defined above) divided by the standard deviation of TC activity in that month derived from the entire data sample.

TABLE 6. As in Table 1 except for the LN+1 years for the months of May–Jul.

Year	TCs	TSTYs
1965	0.28	0.48
1971	2.10	2.49
1974	−0.02	−0.29
1976	1.68	2.03
1989	0.98	1.25
1996	−0.42	−0.29
Mean	0.77	0.94

2) Circulation anomalies

The number of TCs occurring in each grid box is contributed by the genesis of TCs within the box and by TCs moving into the box. Therefore, the investigation of the variation in TC activity must consider processes responsible for both genesis and movement. For this reason, the monthly NCEP wind analyses at 850 and 500 hPa are examined through compositing. These levels are chosen since the low-level flow is well correlated with TC genesis and intensification[2] (e.g., McBride and Zehr 1981; Chan and Kwok 1999), while the midtropospheric flow can be considered as the steering flow for TC motion (e.g., Chan and Gray 1982). To highlight the differences in circulation patterns between these years and the ''normal'' (climatological) conditions, anomalies of the patterns are discussed. These are calculated by subtracting the climatology derived from the (1959–97) NCEP reanalyses from the composite monthly patterns associated with each of the events.

Because the anomalies are wind vectors, two tests are performed to ascertain the veracity of the composite flow anomalies. One is applying the Student t-test to the magnitude of the composite wind speed anomaly (with the same null hypothesis, i.e., that the anomaly is not significantly different from zero). The second test is to examine the steadiness of the composite wind vector anomaly. Both Chan and Kwok (1999) and Li and

[2] The upper-level flow has also been examined. However, all of the anomalies in TC activity related to development appear to be explainable by the 850-hPa flow anomalies. Therefore, the upper-level flow is not discussed.

TABLE 5. As in Table 3 except for the LN+1 years.

	Annual			May–Nov		
Year	TCs	TSTYs	TYs	TCs	TSTYs	TYs
1965	1.35	1.29	0.78	0.42	0.24	0.37
1971	0.86	1.5	1.57	0.48	0.67	0.70
1974	0.53	0.87	−0.78	0.19	0.25	−0.07
1976	−1.1	−0.61	−1.05	−0.70	−0.50	−0.29
1989	0.53	0.65	0.78	0.24	0.33	0.43
1996	1.84	1.08	0.78	0.68	0.41	0.31
Mean	0.67	0.8	0.35	0.22	0.23	0.24

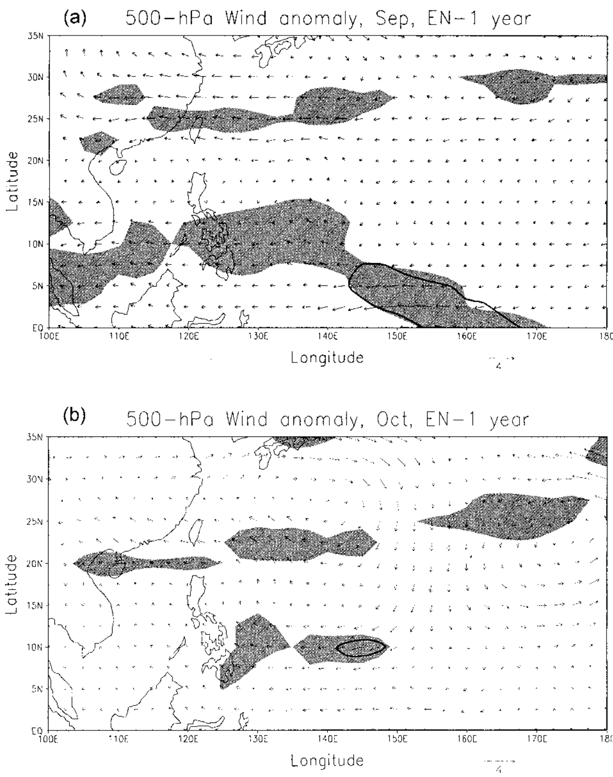


FIG. 6. Anomalous 500-hPa wind vectors during an EN−1 year for the months of (a) Sep and (b) Oct. Shadings indicate areas where the *t* test indicates significance of 95% or greater. Contour lines indicate steadiness of 80%.

Chan (1999) have demonstrated the usefulness of applying this concept to test the validity of composite results. The steadiness *S* is defined as

$$S = \frac{[(\text{mean zonal anomaly})^2 + (\text{mean meridional anomaly})^2]^{1/2}}{\text{magnitude of the composite wind vector anomaly}} \times 100\%.$$

A high value of the steadiness implies that most of the wind anomalies in the composite are pointing in the same general direction. In other words, the direction of the composite wind anomaly is representative of that of most of the individual cases. With these two tests, areas with significant anomalies can be identified.

3. Distribution of TC activity

a. Associated with EN events

In the EN−1 year, TC activity tends to be above normal over the South China Sea (SCS) and within the 120°–135°E longitude band but significantly less southeast of Japan (Fig. 1a). This pattern mainly results from anomalous TC activities in the months of September and October (Fig. 2). While it is difficult to define a boundary for the area ''southeast of Japan,'' it is easier to examine the TC activity over the SCS. Throughout the rest of the paper, the SCS will be defined as the area bounded by (0°–23°N, 105°–120°E). Six of the eight EN−1 years in the sample had TC activity above normal over the SCS during September and October (Table 1). Thus, it is likely that in the year before a warm event, TC activity over the SCS would be above normal during these two months.

Consistent with previous results (C85, C98), TC activity is significantly above normal in the eastern part of the WNP (EWNP) during an EN event (Fig. 1b). A small negative anomaly can also be found over the SCS, although the anomaly is not statistically significant. A coherent increase in activity over the EWNP is found starting from September (Fig. 3a). In October, TC activity remains above normal in this region while a large area of negative anomalies is found west of ~140°E, especially over the SCS (Fig. 3b). A similar situation occurs in November (not shown). These results also imply that during EN years, TC activity tends to be especially below normal in the late season over the SCS, which is consistent with the findings of C85 and C98. Indeed, during the months of September and October, TC activity in *all* the EN years in the sample was below normal over the SCS (Table 2).

In the EN+1 year, TC activity over almost the entire WNP is below normal (Fig. 1c), with two major centers of minimum, one over the area southeast of Taiwan and another farther east near 150°E. This basinwide below-normal TC activity during an EN+1 year is consistent with the result found by C85. Differences between early- or late-season occurrence do not seem to be as obvious as in the previous two categories. This composite result is found to be true in most of the individual years (Table 3). Other than 1966 and 1992, all other EN+1 years had near-normal or below-normal annual TC activity, irrespective of the maximum intensity of the TC. A similar situation occurs during the active season of May–November.

b. Associated with LN events

Similar to the EN years, TC activity during LN−1 years appears to be above normal over most parts of the WNP east of ~130°E (Fig. 1d). Slightly fewer TCs tend to occur near Taiwan and the northern part of the SCS. Among the six categories, TC activity anomalies in LN−1 years are the least significant, despite the fact that half of the cases here are actually EN years (1969, 1972, and 1994). This result suggests that perhaps the conditions required to trigger a cold event have large variability. For this reason, the situation in LN−1 years will not be investigated further.

TC activity during an LN event is almost exactly the reverse of that in EN years, with significantly below (above) normal activity over the WNP (SCS) (Fig. 1e). Tropical cyclones that contribute toward these anomalies mostly occur during August–November (Fig. 4). Notice the particularly significant positive anomaly in September, and especially in October, from east of the

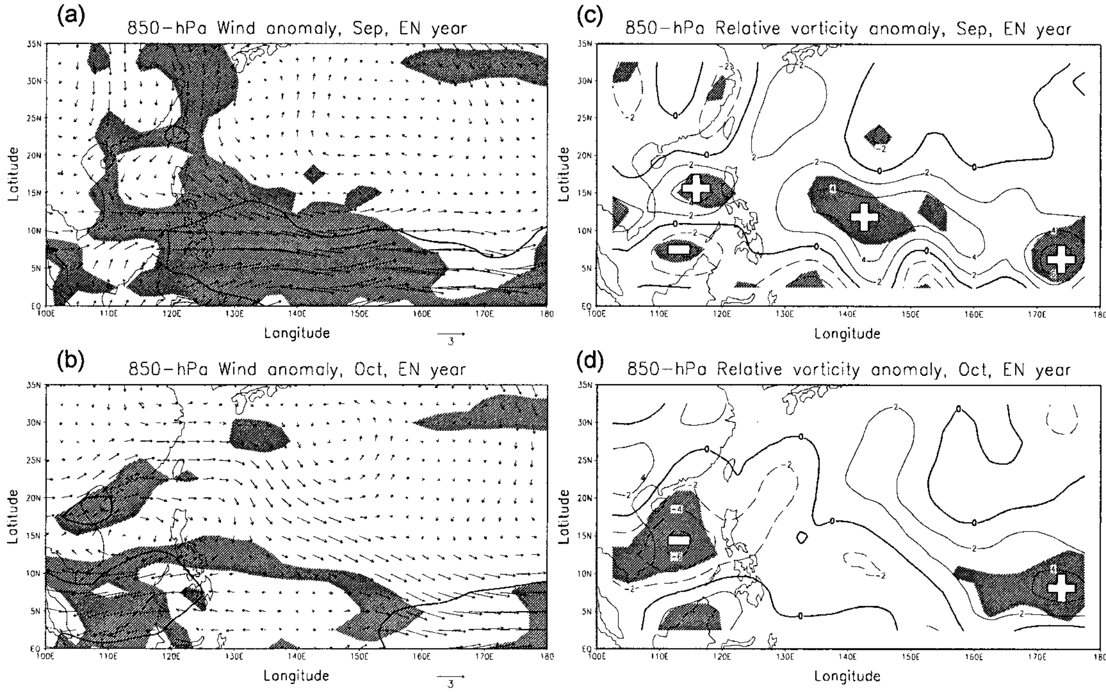


FIG. 7. 850-hPa flow anomalies during an EN year. Anomalous wind vectors are shown for the months of (a) Sep and (b) Oct. Corresponding anomalies in relative vorticity are shown in (c) and (d), respectively. Shadings in all diagrams indicate areas where the *t* test indicates significance of 95% or greater. Solid (dashed) lines in the vorticity plots indicate positive (negative) anomalies, with the plus (minus) signs indicating the approximate locations of the maximum (negative maximum) values. Contour lines in wind vector anomaly plots indicate steadiness of 80%. Contour interval in relative vorticity plots is 2×10^{-6} s^{-1}.

Philippines to the South China coast (Figs. 4b and 4c). Indeed, in all the six LN years in the sample, TC activity is above normal in these two months (Table 4). A similarly significant, though not as large, negative anomaly can be identified east of 150°E.

During LN+1 years, positive anomalies cover much of the region west of 155°E (Fig. 1f). Such a pattern persists throughout much of the season, which suggests that TC activity is expected to be above normal throughout most of the WNP during LN+1 years. This statement is valid for all such years in the sample except for 1976 (Table 5). Note also from Fig. 1f the two areas of significantly positive anomalies over the northern part of the SCS and just east of the Philippines. An examination of the monthly anomalies shows that these are contributed by increases in activity in the early season from May to July (Fig. 5 shows the distribution in July). Indeed, for individual years, TC activity over the SCS was near or above normal in all the LN+1 years in the sample except 1976 (Table 6).

c. Summary

Over the SCS, TC activity is completely opposite in the months of September and October during the warm and cold years (see Table 7 for a summary). This flip-flop also occurs over the entire basin between EN+1 and LN+1 years. Since the development of warm and cold events is related to changes in the large-scale circulation, such changes should also explain these observed anomalies in TC activity, which will be discussed in the next section.

4. Circulation anomalies

Although TCs can occur throughout the year in the WNP, the main activity lies between May and November. Therefore, only the circulation anomalies in these months will be considered in this study. Further, only those anomalies that relate to the anomalous TC activities described in section 3 are discussed in detail. The main focus will be on the low-level (850 hPa) flow since it relates to the genesis of TCs (e.g., Chan and Kwok 1999). Therefore, unless otherwise stated, the anomalies and flow patterns to be discussed below will be assumed to mean those at 850 hPa. When studying the steering or movement of the TCs, the 500-hPa flow is analyzed. This will be specifically mentioned.

a. EN−1 years

The increase (decrease) in TC activity over the SCS (in the area southeast of Japan) in September and October during EN−1 years can readily be explained by

Table 7. Summary of significant anomalies in tropical cyclone activity relative to climatology (normal) during EN, EN±1, LN, and LN±1 years.

Year	Area(s) with significant anomalies
EN−1	SCS: above normal
	Southeast of Japan: below normal
	(both in Sep and Oct)
EN	SCS: below normal in Sep and Oct
	Eastern part of WNP: above normal especially in late season
EN+1	Entire basin: below normal
LN−1	No clearly identifiable significant anomalies
LN	SCS: above normal in Sep and Oct
	Rest of WNP: below normal from Aug to Nov
LN+1	SCS: above normal from May to Jul
	Entire basin: above normal

the anomalies in the 500-hPa flow in these two months (Figs. 6a,b). Anomalous easterlies along 20°–30°N in both months would tend to steer most TCs westward into the SCS and the east China coast. The anomalous northerly flow to the southeast of Japan in October (Fig. 6b) further explains the below-normal TC activity in that region (see Fig. 2b).

These anomalous flows are part of the anomalous anticyclone that is present over the WNP. A similar anomalous anticyclonic circulation is also found at 850 hPa (not shown), which appears to be the one that has been proposed to be responsible for the initiation of the warm event (e.g., Wang 1995). In other words, conditions that would trigger a warm event would likely cause TC activities over certain regions of the WNP to become anomalous sometime prior to the start of a warm event. Therefore, if these conditions can be predicted in advance, short-term seasonal forecasts of TC activity should be possible.

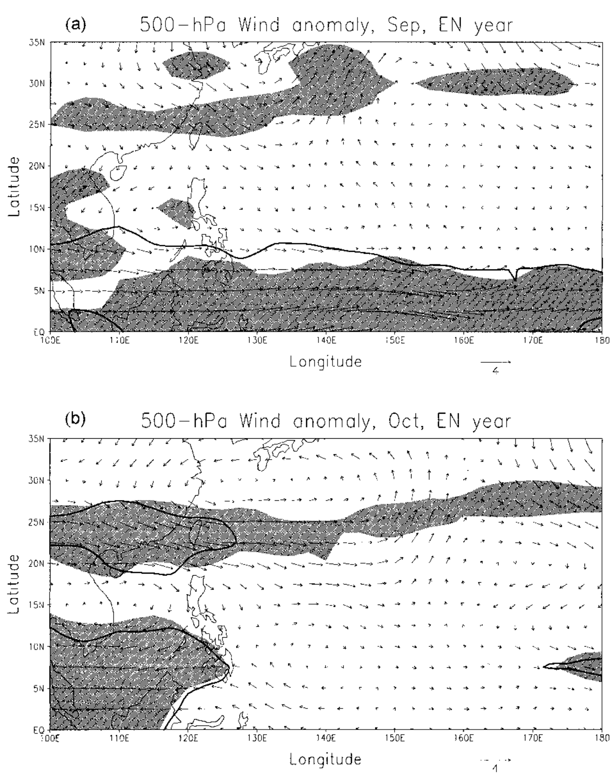


Fig. 8. As in Fig. 6 except for the EN year for the months of (a) Sep and (b) Oct.

b. EN years

In September, a large area of steady and significant anomalous westerlies can be identified south of ~10°N (Fig. 7a). This, of course, corresponds to the conditions prior to the mature phase of the warm event. These westerly anomalies give rise to large positive anomalies in relative vorticity east of ~130°E (Fig. 7c), which therefore favors TC development in this region. Note that over the SCS, relative vorticity anomalies are positive in the north and negative in the south. By October, the westerly anomalies have propagated eastward and now easterly anomalies dominate the southern part of the South China Sea (Fig. 7b). This flow pattern corresponds to the downward branch of the anomalous Walker circulation associated with warm events. Such a distribution of wind anomalies lead to negative (positive) relative vorticity anomalies over the SCS (EWNP) (Fig. 7d), which explains the result summarized in Table 7.

The 500-hPa anomalous flow in September and October also contributes to the observed TC activity anomalies. Anomalous westerlies over the East China Sea and the Sea of Japan (Fig. 8a) would likely steer any TC that develops in the Tropics northward instead of moving into the Asia mainland. This situation continues into October when a large anomalous cyclonic circulation dominates the area south of Japan (Fig. 8b), which results in strong westerly anomalies within the 15°–25°N lat band.

c. EN+1 years

The region east of the Philippines has large anticyclonic anomalies at 850 hPa as early as May of EN+1 years (Fig. 9c) due to the strong anomalous easterlies in the Tropics (Fig. 9a), which of course corresponds

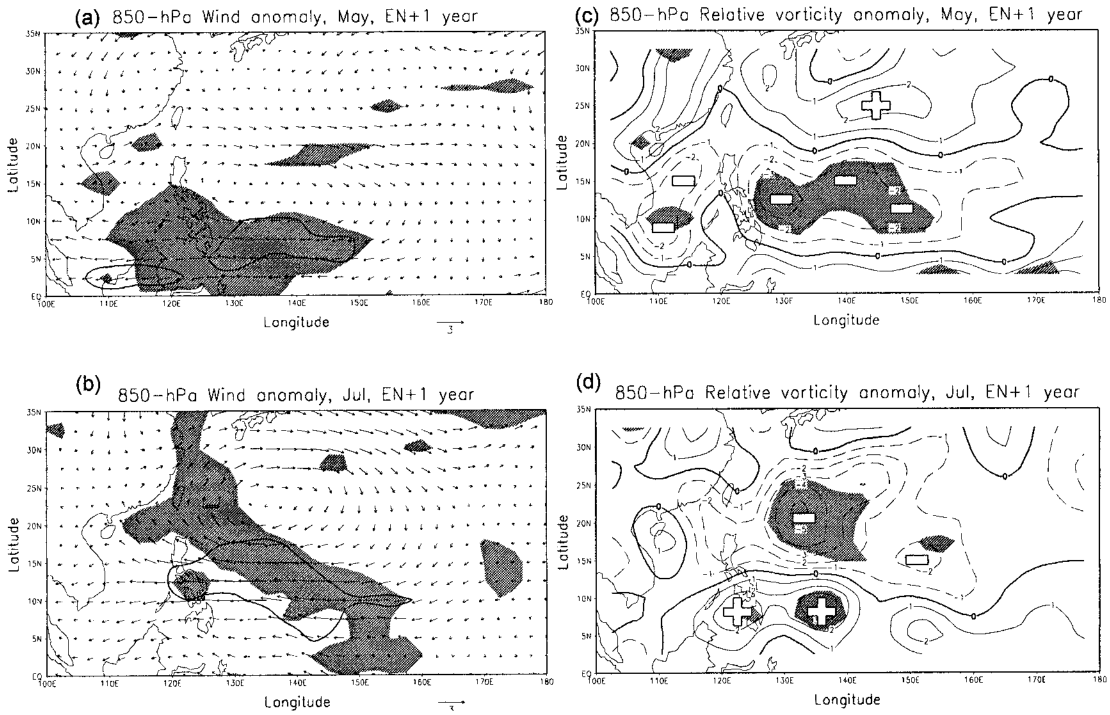
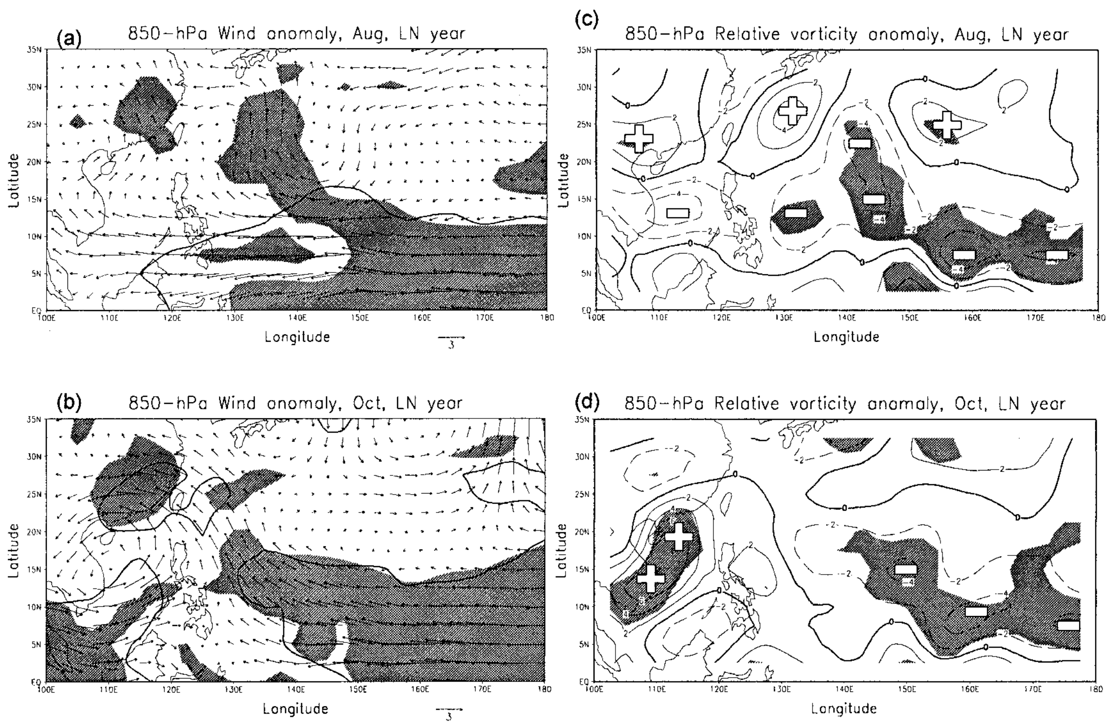


FIG. 9. 850-hPa flow anomalies during an EN+1 year. Anomalous wind vectors are shown for the months of (a) May and (b) Jul. Corresponding anomalies in relative vorticity are shown in (c) and (d), respectively. Shadings in all diagrams indicate areas where the *t* test indicates significance of 95% or greater. Solid (dashed) lines in the vorticity plots indicate positive (negative) anomalies, with the plus (minus) signs indicating the approximate locations of the maximum (negative maximum) values. Contour lines in wind vector anomaly plots indicate steadiness of 80%. Contour interval in relative vorticity plots is 1×10^{-6} s^{-1}.



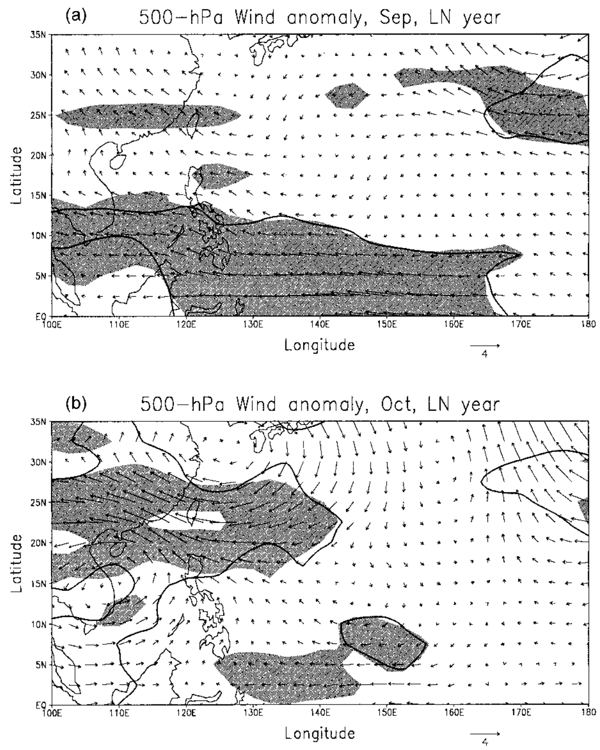


FIG. 11. As in Fig. 6 except for the LN year for the months of (a) Sep and (b) Oct.

to the typical conditions in the year after a warm event. The anticyclonic anomalies actually extend from the SCS to almost the date line. This situation persists into June (not shown). Such conditions are therefore unfavorable for TC formation or development. By July, the band of anomalous easterlies has shifted northward (Fig.

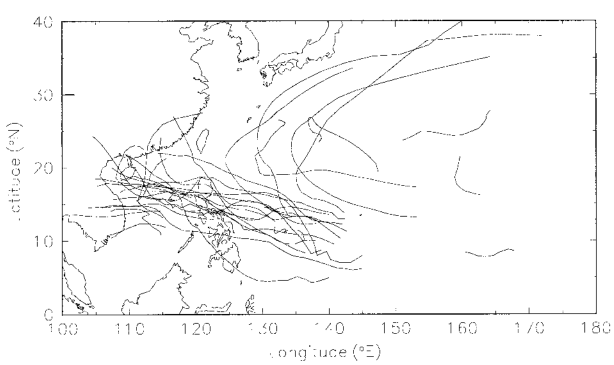


FIG. 12. Tracks of TCs in Oct of all the LN years in the data sample.

9b), which results in a region of cyclonic anomalies south of ~10°N (Fig. 9d). Thus, other than at low latitudes, these conditions are not conducive to TC development. Similar situations continue throughout much of the season. These anomalous flow features are therefore consistent with the below-normal TC activity found during EN+1 years.

d. LN years

Flow features in LN years are almost the exact reverse of those found in EN years (cf. Figs. 7 and 10). For example, at the height of the season (August), steady and statistically significant anomalous easterlies dominate over the entire WNP south of ~15°N (Fig. 10a). As a result, large areas of negative relative vorticity anomalies are found throughout the Tropics (Fig. 10b) where TCs are most likely to form climatologically. This feature is typical throughout most of the early and midseason. However, the flow field in October changed such that cyclonic anomalies are especially strong over the SCS (Figs. 10c,d). The positive relative vorticity anomalies result from strong anomalous easterlies over the Asia mainland and strong anomalous westerlies from the Indian Ocean (Fig. 10b), the latter being a condition corresponding to an enhanced Walker circulation over the maritime continent during an LN event. Such a pattern is therefore partly responsible for the late-season increase in TC activity over the SCS during an LN year.

Another reason for such an increase can be identified from the 500-hPa flow pattern during September and October (Figs. 11a,b). Steady and statistically significant easterly anomalies are found throughout the latitude band 15°–27.5°N west of 140°E in October (Fig. 11b). A similar though less prominent feature is also found in September (Fig. 11a). Therefore, any TC that forms east of the Philippines is likely to be steered into the SCS. This is in fact the case for most of the TCs in the six LN years in the sample (Fig. 12). Notice that most of the TCs developed around 140°E and crossed Luzon into the SCS.

e. LN+1 years

In sharp contrast to the other categories, a prominent cyclonic anomaly is found over the SCS and the area to the east of the Philippines in May during LN+1 years (Fig. 13d). Such anomalies mostly result from anomalous westerlies from the Indian Ocean (Fig. 13a). A similar situation is found in June and July (not shown). This pattern therefore favors TC formation over the SCS

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FIG. 10. 850-hPa flow anomalies during an LN year. Anomalous wind vectors are shown for the months of (a) Aug and (b) Oct. Corresponding anomalies in relative vorticity are shown in (c) and (d), respectively. Shadings in all diagrams indicate areas where the *t* test indicates significance of 95% or greater. Solid (dashed) lines in the vorticity plots indicate positive (negative) anomalies, with the plus (minus) signs indicating the approximate locations of the maximum (negative maximum) values. Contour lines in wind vector anomaly plots indicate steadiness of 80%. Contour interval in relative vorticity plots is 2×10^{-6} s^{-1}.

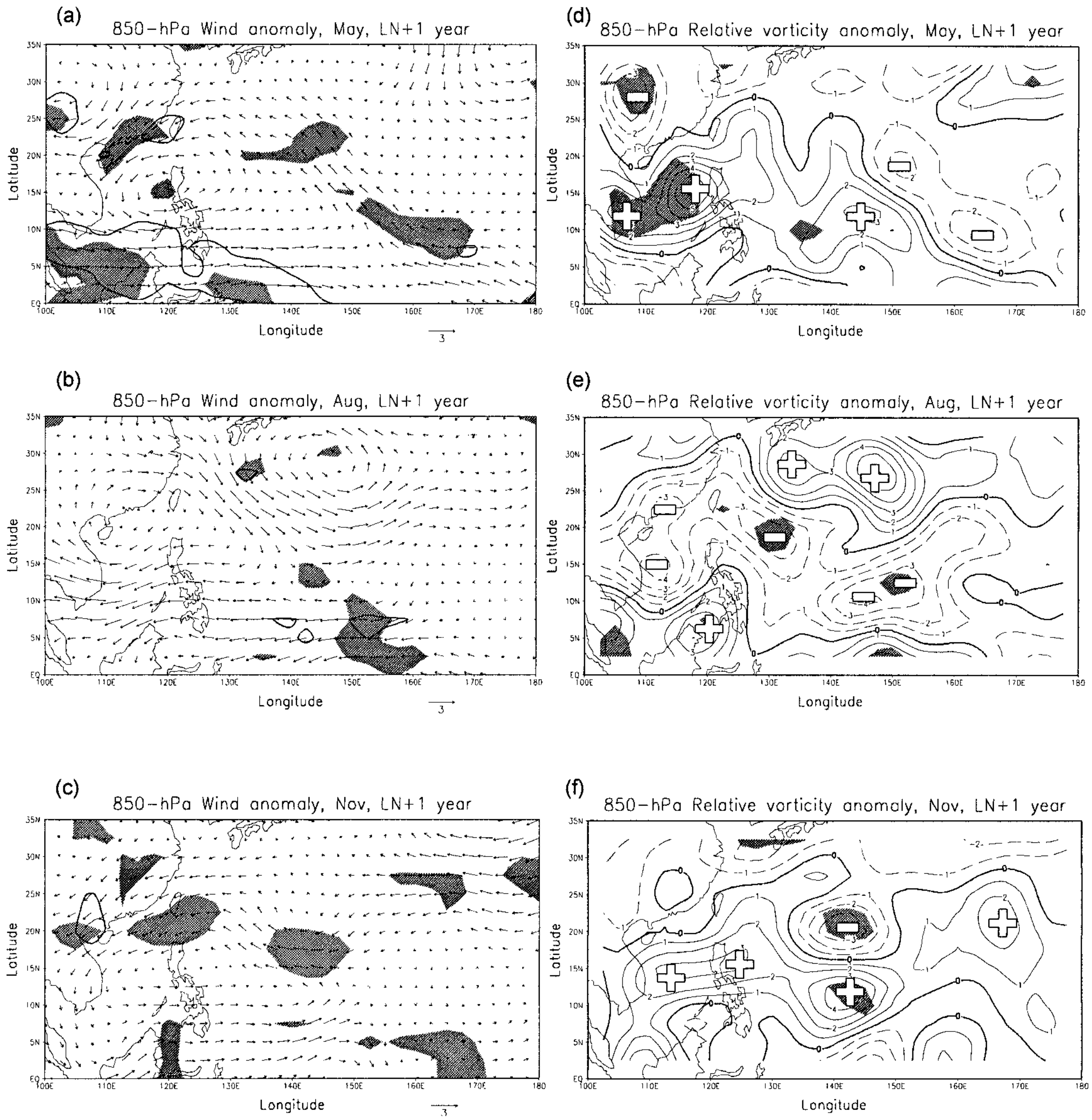

FIG. 13. 850-hPa flow anomalies during an LN+1 year. Anomalous wind vectors are shown for the months of (a) May, (b) Aug, and (c) Nov. Corresponding anomalies in relative vorticity in (d) to (f), respectively. Shadings in all diagrams indicate areas where the *t* test indicates significance of 95% or greater. Solid (dashed) lines in the vorticity plots indicate positive (negative) anomalies, with the plus (minus) signs indicating the approximate locations of the maximum (negative maximum) values. Contour lines in wind vector anomaly plots indicate steadiness of 80%. Contour interval in relative vorticity plots is 1×10^{-6} s^{-1}.

and in the region east of the Philippines during the early season. An anticyclonic anomaly south of Japan at 500 hPa also helps steer any TC that forms east of the Philippines westward into the SCS (Fig. 14 shows the anomalous flow pattern in June). By August, the 850-hPa anomalies change such that a large anomalous cyclonic circulation is found southeast of Japan (Fig. 13b) so that anticyclonic anomalies are found over a large part of the WNP (Fig. 13e). This situation continues into September and October (not shown). By November, cyclonic anomalies return over the tropical WNP (south of 15°N) and in the northern part of the SCS (Figs. 13c and 13f).

f. Summary

Anomalies in TC activity in each of the EN±1, LN+1, EN, and LN years over various regions of the WNP are apparently linked to those in the large-scale circulation associated with these events. It is important to note that *both* the low-level circulation (which is used as a proxy to represent the characteristics of genesis and

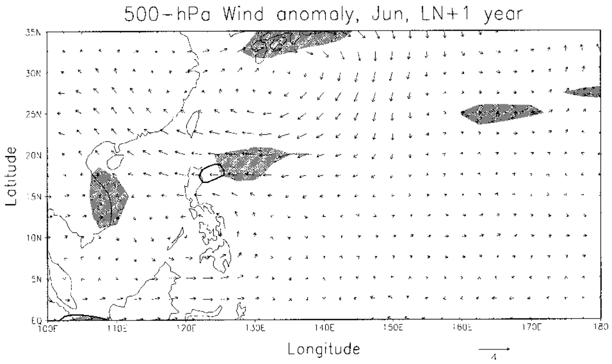

FIG. 14. As in Fig. 6 except for the LN+1 year for the month of Jun.

development) and the midtropospheric flow (which correlates well with TC movement) have to be used to describe the anomalies in TC activity.

5. Summary and discussion

This paper presents a comprehensive study on the variations of tropical cyclone (TC) activity over the western North Pacific (WNP) associated with both El Niño (EN) and La Niña (LN) events. Investigations are made on such activities from the year before (EN−1 and LN−1) to the year after (EN+1 and LN+1). Significant anomalous activities are found in different regions of the ocean basin, which are generally opposite in sign between the two types of events.

During an EN−1 year, more (less) TCs are found in September and October over the South China Sea (southeast of Japan). In an EN year, TC activity is below normal during these two months over the South China Sea (SCS) but above normal especially in the late season in the eastern part of the WNP. Such a result is consistent with previous studies of Chan (1985) and Chen et al. (1998). After the mature phase of the warm event, TC activity over the entire ocean basin tends to be below normal.

No significant anomalies are found during an LN−1 year. However, in an LN year, the SCS tends to have more TCs in September and October but for the rest of the WNP, TC activity tends to be below normal from August to November. During the year after an LN event, the entire basin generally has more TCs. Such a situation is especially true over the SCS from May to July.

All the anomalous activities are apparently linked to the anomalies in the large-scale flow patterns at 850 and 500 hPa. Because the 850-hPa flow is related to TC genesis and development, areas with anomalous cyclonic (anticyclonic) flow are generally found to be associated with above- (below-) normal TC activity. Anomalous 500-hPa flow is identified as responsible for steering TCs toward or away from a region, thus rendering the TC activity in that region above or below normal.

To summarize, TC activity over the WNP is found to have large variations not only in EN and LN years, but also during the year before and the year after. Such variations occur because the large-scale flow patterns associated with these events are anomalous in different regions. These anomalies cause TCs to develop in different areas and/or move to different areas within the ocean basin. These results must be taken into consideration in any seasonal forecast of TC activity, which was done by Chan et al. (1998). However, it should also be noted that while the EN or LN effect may be significant, it is not the only factor that determines the anomalies in TC activity. In fact, Chan et al. (1998) have found that other flow features may also be important in predicting the number of TCs over the WNP. Such features are related to the atmospheric circulations over Eurasia in the previous winter, which apparently create ''memories'' over the land area through snow cover or soil moisture to modify the circulation in the following summer. How such ''memories'' actually occur and how they might affect the summer flow patterns are the topic of another investigation.

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