Why is the Tropical Cyclone Activity over the Western North Pacific so Distinct in 2016 and 1998 Following Super El Niño Events?

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Abstract

Although both the tropical cyclone (TC) peak seasons in 2016 and 1998 are in the decaying stage of a super El Niño, TC activities over the western North Pacific (WNP) exhibit vast differences. The TCs in 2016 were greater in number and intensity and had distinct monthly variations in TC activity in contrast to those in 1998. The detailed comparison shows that the warm sea surface temperature anomaly over the WNP in 2016 had higher magnitude and a more eastward extension than that in 1998. In August, coincident with the enhanced Madden–Julian oscillation westerly phase, more TCs clustered within the eastward-extending convective belt caused by the southwesterly surge. The mean longitude of TC genesis in 2016 shifted more eastward, which is favorable for the longer lifetime and greater intensity of the TCs. In terms of the extratropical influences, the cyclonic circulation anomaly associated with the Silk Road Pattern from the middle latitude penetrated southward and split the WNP subtropical high (WNPSH) into two components in August of 2016, thus causing deep-tropospheric southerly steering flows in between and TC northward-prone tracks. During the boreal autumn in 2016, the WNPSH strengthened and stretched westward, producing the robust easterly steering flows that led to successive TCs affecting the coastal areas of East Asia.

Keywords tropical cyclone; western North Pacific; super El Niño

1. Introduction

The destruction caused by tropical cyclones (TCs) can be catastrophic. According to the World Meteorological Organization (De and Joshi 1998), TCs rank second among all natural disasters in loss of life behind drought. A better understanding of the mechanisms responsible for the interannual variation of TC activity will help improve planning and management for TC disasters.

The western North Pacific (WNP) is the most TC-frequent basin in the world with an average of 26 TCs each year. A considerable number of studies in past decades have been devoted to the interannual variability of TC activity over the WNP, which is generally regarded to have a close relationship with El Niño and Southern Oscillation (ENSO) (e.g., Chan 1985; Chia and Ropelewski 2002; Wu et al. 2004; Camargo and Sobel 2005; Chen and Tam 2010). It has been commonly accepted that the frequency of TC formation significantly increases and decreases in the southeast and northwest quadrant of the WNP, respectively, during the boreal summer and autumn of El Niño year. This situation is reversed during La Niña. On the basis of the statistical analysis and composite of large-scale fields, it has been found that TC activity over the entire WNP would be largely suppressed because of the large-scale anticyclonic circulation anomaly dominating the WNP during TC peak seasons in the year following an El Niño event (e.g., Chan 2000; Wang and Chan 2002; Xie et al. 2009). For instance, there are only 16 named TCs occurring over the WNP...
in 1998 preceded by the super El Niño event in late 1997, significantly less than the climatological average (Nakazawa 2001).

By comparison, the TC activity in 2016 poses a surprise to TC seasonal prediction. The Niño 3.4 index reached its peak in the winter of 2015, with the sea surface temperature (SST) anomaly over the equatorial eastern Pacific larger than 2°C, which has comparable intensity to the 1997/1998 El Niño event. On the basis of the conventional statistical prediction, it was anticipated that there would be suppressed TC activity over the WNP in the TC peak seasons of 2016 given the unfavorable environmental background during the decaying phase of El Niño, similar to the case in 1997/1998. However, the fact shows that there were 26 named TC occurrences in 2016, equivalent to the climatological mean; this phenomenon is out of the precedent expectation. Moreover, the TC activity in 2016 also exhibits distinctive monthly variations. Specifically, after the quiet TC activity before July, the first named TC, Nepartak, formed on 3 July. This TC is the second latest on record behind 1998, in which the first typhoon formed on 9 July. In August, the TCs suddenly became unusually active; moreover, most of them displayed northward-shifting tracks with less TC occurrences around East Asia. Through September and October, successive strong typhoons attacked the southeast coast of China; this phenomenon is rare in boreal autumn.

Therefore, the intriguing issue of what contributed to the remarkable discrepancy in TC activity in 2016 and 1998 preceded by similar super El Niño events remains to be addressed. Recently, Zhan et al. (2017) examined the salient differences in TC activity over the WNP between 1998 and 2016. They stated that the pattern of SSTA anomalies and the Pacific meridional mode play a key role in the discrepancy in TC genesis between these two years. However, the monthly variation of tropical intraseasonal variability and the extratropical zonal mode, as well as their effects on TC formation and track, have not been clearly addressed yet. Therefore, in the present study, the monthly evolution of the background fields from July to October in 2016 and 1998 will be examined to shed light on the role of tropical and extratropical systems in the vast differences of TC activity between these two years. The rest of the paper is organized as follows: Section 2 describes the data and methodology used in this study. Section 3 presents the overview of TCs in 2016 and 1998, as well as the influences associated with tropical and extratropical systems. Section 4 summarizes the conclusions.

### 2. Data and methodology

The TC data record over the WNP employed in this study was obtained from the Regional Specialized Meteorological Centers of the Japan Meteorological Agency (JMA), which mainly contains the information of date, location, and minimum surface level pressure at 6 h intervals. Furthermore, the daily SST anomaly was derived from the National Oceanic and Atmospheric Administration (NOAA) optimum interpolation SST V2 data. Other conventional atmospheric variable fields were obtained from National Centers for Environmental Prediction/National Center for Atmospheric Research reanalysis with a horizontal resolution of 2.5° × 2.5°. The daily outgoing longwave radiation (OLR) from the NOAA satellites was used as a proxy for deep convection (Liebmann and Smith 1996).

Considering that the cyclonic circulation related to TCs may contaminate the composite of the background field discussed in the following section, the TC-related circulation is first removed on the basis of the algorithm proposed by Kurihara et al. (1993). After this procedure, the impact associated with TC circulation on the monthly mean fields can be diminished, and the pure background field was retained.

Furthermore, the space-time filter was employed to examine the influence of Madden–Julian oscillation (MJO) (Madden and Julian 1994) on the convection and zonal winds over the WNP. This filtering method can effectively extract the waveband of interest based on both the specified period and wavenumber (positive and negative wavenumbers denote eastward- and westward-propagating modes, respectively). This filtering tool has been extensively used in the analysis of tropical waves (e.g., Wheeler et al. 2000; Roundy and Frank 2004; Chen and Chou 2014). In this study, the MJO regime covers periods from 30 to 60 days and eastward-propagating wavenumbers of 0–6.

### 3. Results

#### 3.1 Overview of TCs in 2016 and 1998

According to TC data from JMA, the total number of TC genesis is 22 from July to October 2016, including 11 tropical storms and 11 typhoons, among which 6 typhoons achieved super typhoon intensity with the maximum azimuthal-mean near-surface wind greater than 51 m s\(^{-1}\). By contrast, there are only 11 named TCs forming during this period in 1998. Among them, seven TCs achieved typhoon intensity but without a super typhoon, thus suggesting that the TCs in 2016 are more likely to upgrade to super typhoons. In addi-
tion to TC frequency and intensity, the TC formation location also displays evident differences in 1998 and 2016. As shown in Fig. 1, although the mean latitudes of TC formation between the two years are comparable, the mean longitudes are 131°E and 141°E in 1998 and 2016, respectively, indicating that the large-scale environment favorable for TC formation is present in the more eastern portion of the WNP in 2016 than in 1998. This finding partly explains the high super typhoon occurrence in 2016 due to the longer TC duration over the warm sea surface.

TC characteristics exhibit distinct monthly variations in 2016 (Fig. 1a). In July, four TCs formed over the WNP, among which three TCs moved northwestward and made landfall in southeast China. Eight TCs occurred in August; moreover, it is unusual that seven TCs displayed nearly coherent northward-migrating tracks. The averaged latitude of TC formations in August is approximately 20°N higher than the counterparts in other months. During September and October, the total number of TC genesis is 10, most of which were displaced northwestward and struck the countries in East Asia. By contrast, TC activity in 1998 took on less pronounced monthly variations because of fewer TC occurrences from July to October (Fig. 1b). In July, only one TC formed near the offshore sea of China. In August, there were three TC formations. During September and October, a total of seven TCs formed, and most of them tended to move northeastward and affected Japan.

### 3.2 The influence from tropical systems

To examine the tropical influence, Fig. 2 depicts the evolution of the Niño 3.4 index and the Hovmöller diagram of SST anomaly and zonal wind in the tropical region. As shown in Fig. 2a, both the Niño 3.4 indices exhibit almost identical evolutions before June in the year following a super El Niño; after June, the index in 1998 was smaller than that in 2016, representing the lower SST anomaly over the central-to-eastern Pacific in 1998. The longitudinal distribution demonstrates clearly the spatial differences. Figure 2b demonstrates that the positive SST anomaly occupied the whole equatorial Pacific before July of 2016, indicating that the warm SST related to the super El Niño lasted for a long period. The strong easterly flows at 850 hPa can be observed to prevail over most of the tropical Pacific with a minimum of $< -8 \text{ m s}^{-1}$, whereas the westerly winds retreated to the west of 120°E prior to July, thus inferring a predominant anticyclonic anomaly over the tropical WNP (not shown). It is also consistent with the findings in a number of previous studies in which an anomalous anticyclonic circulation was found to exist over the WNP during the decaying phase of El Niño (e.g., Chan 2000; Wang and Chan 2002; Du et al. 2011). As a result, this unfavorable environmental background is hostile to TC formation, thus leading to the vacancy of TC activity prior to July in 2016. After July, the SST anomaly over the tropical East Pacific turned from positive to negative, indicating a transition from El Niño to La Niña. However, the SST anomaly over the whole tropical western Pacific was still positive and increased in magnitude until November; this phenomenon tended to generate more near-surface moisture and upward heat flux, which are conducive to spawning TCs.

On the other hand, the 850 hPa westerly flows had an oscillatory eastward extension, with the mean westerly and easterly flow interface located to the east of 135°E after August. Correspondingly, most of the TCs formed within the westerly dominant region or near the convergent region between the westerly and easterly winds. Therefore, in contrast to the case in 1998, the eastward-extending high SST and zonal westerly flows in 2016 have a more eastward extension and
are responsible for the more eastward mean location of TC genesis. In particular, the lower-level westerly flows penetrated eastward up to 165°E in August. These westerly flows accounted for the most frequent TC occurrences in this month; thus, the total number of TCs in 2016 increased.

By contrast, most of the WNP was dominated by the negative SST anomaly before June in 1998, and the SST anomaly to the east of 180°E is positive (Fig. 2c). As the El Niño signal faded, the SST anomaly over the central-to-eastern Pacific rapidly transited to negative deviation after June, whereas the positive SST anomaly over the WNP was only confined to the west of 150°E. Similarly, the tropical easterly flows were prevalent over the major portion of the WNP during the transition from El Niño to La Niña, thus resulting into a late TC genesis. Together with the westward retreat of positive SST anomaly over the WNP in 1998 as opposed to the case in 2016, the tropical westerly flows, which reflect the strength of monsoon

![Fig. 2. (a) SST evolution of Niño 3.4 index for 2015/2016 (red) and 1997/98 (blue) super El Niño from the preceding October to the following September. Longitude-time Hovmöller diagram of SST anomaly averaged from −5°S to 10°N (shaded, °C) and 850 hPa zonal wind averaged from 5°N to 15°N (contour, m s⁻¹) in (b) 2016 and (c) 1998.](image-url)
trough (MT), were less robust than those in 2016 and were responsible for the inactive TC occurrences over the WNP in 1998.

Over the WNP, more than 80% of TC genesis occur within the MT circulation (e.g., Frank 1987; McBride 1995). To substantiate the evolution of convection and lower-level circulation, Figs. 3 and 4 show the monthly mean OLR and 850 hPa winds in 2016 and 1998, respectively. The figures show that in July 2016, the anticyclonic circulation appeared over most of the WNP, whereas the MT-related cyclonic circulation and convection were confined around the Philippines (Fig. 3a). Of interest is that the circulation pattern varied abruptly in August (Fig. 3b). The southwesterly surge penetrated anomalously eastward, giving rise to a robust convection belt centered at 15°N from the Indochina Peninsula to the west of the dateline with the maximum convection located at 155°E, where the southwesterly and easterly flows converged. As a result, TC occurrences became considerably active in August, with eight TCs forming within or near this zonal convection belt. Subsequently, the anticyclone associated with the WNP subtropical high (WNPSH) was established again over the WNP. Meanwhile, the convection associated with the MT concentrated on the southwestern side of the WNPSH had six TC geneses in September (Fig. 3c). In October, the anticyclone expanded more southward and westward such that the MT-related convection was confined close to the equatorial region, and the mean location of TC formations shifted relatively equatorward (Fig. 3d).

By comparison, the anticyclonic circulation during July in 1998 was stronger than that in 2016 (c.f., Figs. 3a, 4a), resulting into only one TC genesis in July. This pattern persisted through October (Figs. 4b–d), except in September when the WNPSH slightly retreated eastward, and the MT extended eastward in agreement with the enhanced westerly surge in Fig. 2c together with five TC geneses. Overall, the monsoonal westerly flows related to the MT over the WNP from July to October 1998 are less vigorous than those in 2016; thus, the tropical cyclogenesis in 1998 was inactive.

Similarly, the monthly anomalies of OLR and 850 hPa winds in Figs. 5 and 6 also support the above argument. In July and August 1998, there existed
the pronounced suppression of convection over the tropical WNP, along with the anomalous anticyclonic circulation (Figs. 6a, b). By comparison, the significant anomalies of cyclonic circulation and convection emerged in August 2016 (Fig. 5b). From September through October, the discrepancy in the anomalies of circulation and convection decreased, thus causing small difference in TC number in this period (c.f., Figs. 5c, d, 6c, d).

As described in Figs. 2a and 3b, August in 2016 was an unusual month in which the enhanced westerly surge reached up to 150°E, forming a strong convection belt with the clustered TC formations. The low-frequency MJO may play an important role in the westerly anomaly in August 2016. A great deal of research has revealed that MJO can facilitate tropical cyclogenesis by enhancing low-level cyclonic horizontal shear and convergence and increasing midlevel moisture (e.g., Liebmann et al. 1994; Maloney and Hartmann 2000; Frank and Roundy 2006). On the other hand, MJO can also promote higher-frequency waves to amplify through scale contraction and energy accumulation by establishing a convective envelope. For instance, Maloney and Dickinson (2003) found that the perturbation kinetic energy corresponding to a synoptic disturbance is significantly high during the active phase of MJO and acts as a precursor of TC genesis. Figure 7 depicts the MJO-band filtered zonal wind and the OLR averaging between 5°N and 15°N in 2016 and 1998. One strong MJO life cycle can be found in July and August 2016 (Fig. 7a), with the zonal westerly (easterly) wind anomaly lagging behind the OLR negative (positive) anomaly by one quarter period because of the response of zonal wind anomaly to the convection anomaly. The striking feature is that the strong MJO-related easterly anomaly persisted over the WNP from mid-July to late-July in 2016, thus largely contributing to the westward-shifted MT westerly flows and few TC occurrences during this period (as inferred from Figs. 2a, 3a). During August, the MJO transited to the westerly phase. The strong MJO westerly anomaly induced the eastward penetration of monsoonal westerly surge and the enhancement of TC activity during August of 2016. During September and October, the MJO envelop was notably weakened. TCs mainly formed in the MJO easterly phase and the corresponding easterly region to the south of the WNP SH (Figs. 7a, 8c, d), where the SST still maintained large warm anomaly, which is favorable for TC genesis (Fig. 2a). By contrast, the MJO amplitudes in
Fig. 5. The monthly anomalies of OLR (shaded, W m$^{-2}$) and 850 hPa winds (vector, m s$^{-1}$) in (a) July, (b) August, (c) September, and (d) October in 2016. Typhoon symbols stand for TC formation locations.

Fig. 6. Same as Fig. 5 except in 1998.
Fig. 7. Longitude-time Hovmöller diagram of MJO-band filtered OLR (shaded, W m$^{-2}$) and 850 hPa zonal winds (contour, m s$^{-1}$) averaged from 5°N to 15°N in (a) 2016 and (b) 1998.

Fig. 8. The monthly mean 500 hPa geopotential height (shaded, gpm) and winds (vector, m s$^{-1}$) averaged from 850 to 300 hPa in (a) July, (b) August, (c) September, and (d) October. Typhoon symbols stand for TC formation locations.
terms of zonal wind and convection through the TC peak seasons in 1998 were significantly smaller than those in 2016 (Fig. 7b). As a consequence, the mean westerly flows only reached to the west of 135°E (Fig. 2b), accompanied by the inactive TC occurrences in boreal summertime of 1998.

3.3 The influence from extratropical systems

As mentioned above, more TCs clustered in August 2016, and the TC tracks demonstrated a distinctive monthly variation in contrast to the case in 1998. To interpret this discrepancy, the multi-level mean winds are estimated as a surrogate for the steering flows. Figure 8 displays the 500 hPa geopotential height, and wind vectors averaged from 850 to 300 hPa in 2016. In July, the region encompassed by 5880 gpm was zonally elongated with the westernmost ridge located around 110°E (Fig. 8a). Correspondingly, the easterly steering flows on the southern periphery of the WNPSH extended to the South China such that the three TCs forming on the southern side of the WNPSH made landfall in the southeast coast of China. Comparatively, the ridge of the WNPSH in August was displaced to the north of 30°N in such a way that it was readily influenced by the mid-latitude systems. Xue and Fan (2016) documented that owing to the influence from the higher-latitude system, the WNPSH in August exhibited an opposite pattern in 1981 and 2013 with a similar SST anomaly distribution in the tropical Pacific. In August of 2016, the WNPSH was disrupted by the mid-latitude westerly trough, which split the WNPSH into two isolated parts: the weak part was located to the west of 120°E, and the strong part was located to the east of 150°E (Fig. 8b). A vigorous mid-latitude trough penetrated southward in between, thus contributing to a discernible cyclonic circulation centered at 135°E. Note that the TC-related cyclonic circulations have been removed before composite; thus, the cyclonic circulation sandwiched by the two separate WNPSH components was not caused by the frequent TC occurrences in August. It is this cyclonic circulation that generates the mean northward steering flows, which advect the TCs forming or entering within 130°E and 150°E northward. As a result, most of the TCs in August occurred farther away from the Asian coasts, as exhibited in Fig. 1. During September and October (Figs. 8c, d), the mid-latitude westerly belt shifted southward and became flat. Meanwhile, the strengthened WNPSH retreated southward and remarkably expanded westward. The strong easterly flows on its equatorward flank prevailed in the boreal autumn of 2016, which caused all of the TCs forming to the south and southwest of the WNPSH to migrate northwestward. As a result, four typhoons made direct landfall in the southeast coast of China, and three typhoons passed by the coast of China, significantly greater than the TC climatology influencing China in this season.

Different from the anomalous pattern in August 2016, the main body of the WNPSH in 1998 encompassed by 5880 gpm was strong from July to August (Figs. 9a, b), with the westernmost edge to the west of 105°E. As a result, TC activity was largely suppressed with only three TC geneses in August 1998 as opposed to eight TC geneses in August 2016. As exhibited in Figs. 9c, d, another striking difference is that the WNPSH during September and October 1998 was less zonally elongated and shifted more eastward in 1998 than in 2016, leading to most of the TCs moving northward and affecting Japan; this finding is consistent with the data shown in Fig. 1b.

As discussed above, the distinctive circulation pattern in August 2016 contributes significantly to the enhancement of TC activity. The mid-latitude westerly trough played a crucial role in interrupting the WNPSH around 140°E, as shown in Fig. 8b. To evidently exhibit the effect of mid-latitude circulation, the anomalies of 500 hPa geopotential height and wind averaging over 850 to 300 hPa in August are depicted in Fig. 10. A zonal wave-like pattern can be clearly detected in 2016 (Fig. 10a), with alternating positive (anticyclonic) and negative (cyclonic) geopotential height (circulation) anomalies whose major axis was located around 40°N. This wave-like pattern is similar to the Silk Road Pattern (SRP) or the circumglobal teleconnection in some other studies), which is geographically phase-locked from the source region around the Caspian sea and extends eastward to East Asia (Lu et al. 2002; Enomoto et al. 2003). Yasui and Watanabe (2010) defined the SRP index as the first leading empirical orthogonal function mode of meridional wind anomalies. The linear regression of mid-to-upper geopotential height onto the SRP index can identify the spatial distribution of geopotential height related to the SRP (Li et al. 2017), which is in good agreement with the pattern shown in Fig. 8a. It is this pronounced SRP-like pattern that essentially modulated the WNPSH structure in August 2016. It is clear that a strong negative geopotential height anomaly, along with a cyclonic circulation anomaly, had a southward shift with the center located at (30°N, 140°E), which was roughly flanked by two positive geopotential height anomalies to its northeast and northwest. This sandwich structure in terms of the
Fig. 9. Same as in Fig. 8 except in 1998.

Fig. 10. The anomalies of geopotential height (contour, gpm) and wind (vector, m s$^{-1}$) averaged from 850 to 300 hPa in August of (a) 2016 and (b) 1998.
geopotential height anomaly split the main body of the WNPSH into two detached components, as shown in Fig. 8b. It is this cyclonic circulation anomaly over the WNP related to the SRP that facilitated more TC genoses and northward migration in August 2016, as displayed in Fig. 1a.

In contrast to the zonally extending SRP pattern in August 2016, there was no evident wave-like SRP structure along the zonal belt of 40°N in August 1998. Instead, a rather weak negative geopotential height anomaly was located over northeast Asia, whereas an enhanced positive geopotential height anomaly occupied the central Northern Pacific (Fig. 10b). Correspondingly, the main body of the WNPSH prevailed over the WNP (as shown in Fig. 9b), thus suppressing the TC activity in August 1998. It should be noted that the initiation and interannual variation of SRP is not yet understood well. Some previous studies have suggested that the Indian summer rainfall can play a role in triggering the SRP downstream (Ding and Wang 2005; Chen and Huang 2012). However, Sato and Takahashi (2006) argued that there are no statistically significant heating anomalies in the tropics associated with the SRP, thus emphasizing the importance of internal atmospheric dynamics. On the other hand, the SRP-ENSO relationship has been found to be vague in some studies (Yasui and Watanabe 2010; Kosaka et al. 2012). On the interannual time scale, the mid-latitude SRP may affect TC activity over the WNP by modulating the structure of the WNPSH; this topic will be further investigated in our follow-up work.

To quantify the integrated effect of dynamic and thermodynamic environments on TC genesis, a modified version of genesis potential index (GPI) (Murakami and Wang 2010; Hsu et al. 2014) in which the vertical motion effect is incorporated into the original GPI formula (Emanuel and Nolan 2004) is employed:

$$ GPI = 10^{0.5} \eta \left( \frac{R H}{50} \right)^{0.5} \left( \frac{V_{pot}}{70} \right)^{3} \cdot \left(1 + 0.1 V_s \right)^{-2} \frac{-\omega + 0.1}{0.1}, $$

where $\eta$ is the absolute vorticity at 850 hPa, $RH$ is the relative humidity at 700 hPa, $V_{pot}$ is the maximum TC potential intensity, $V_s$ is the magnitude of the vertical wind shear between 850 and 200 hPa, and $\omega$ is the vertical pressure at 500 hPa. The definition of $V_{pot}$ is based on the work of Emanuel (1995) and the modifications of Bister and Emanuel (1998). Figures 11 and 12 clearly show that the large GPI regions have good correspondence to those of main tropical cyclo-

### 4. Summary

On the basis of statistical analysis, previous studies revealed that TC activity can be significantly suppressed in the year following a super El Niño, such as in 1997/1998. One exception occurred in 2016, in which the TC frequency is equivalent to the climatology with 22 TC formations during the TC peak seasons in contrast to 11 TCs in 1998. Moreover, the mean TC intensity in 2016 is notably greater than that in 1998. Furthermore, the TC activity exhibits a distinctive monthly variation in 2016, with the clustered TC genoses and northward-prone tracks in August, as well as the coherent westward migration of TCs in boreal autumn. Therefore, this study aims to examine the factors responsible for the vast differences in TC activity between 2016 and 1998.

Although both experiencing a quiet TC activity before July in 2016 and 1998, the subsequent TC activity in the TC peak seasons in 2016 started to emerge. In contrast to the case in 1998, the warm SST in 2016 had an eastward extension over the tropical western Pacific, whereas the weaker SST cooling existed over the tropical central-to-eastern Pacific during the ENSO transition. Correspondingly, the lower-level westerly flows can penetrate more eastward in 2016 than in 1998. In August 2016, the southwesterly monsoonal surge associated with the strong MJO event was strengthened, forming a vigorous convection belt centered roughly at 15°N and promoting the frequent TC formations. Furthermore, the mean location of TC genesis shifted eastward in 2016 in contrast to that in 1998. Owing to the longer duration over the warm SST and more favorable atmospheric conditions, the TCs in 2016 tended to attain higher intensity than those in 1998.

The extratropical influence can also make joint contributions to the unique TC characteristics in 2016. In August, the WNPSH was suddenly separated into two anticyclonic components between which cyclonic circulation was pronounced. This sandwich-like struc-
Fig. 11. The distribution of monthly mean GPI (shaded) and 850 hPa winds (vector, m s\(^{-1}\)) in (a) July, (b) August, (c) September, and (d) October of 2016.

Fig. 12. Same as Fig. 11 except in 1998.
ture can be partly ascribed to the apparent SRP-like wave train, in which the large anomalies of negative geopotential height and cyclonic circulation shifted southward and dominated over the western portion of the WNP. As a result, the primary WNPSH component retreated to the east of 150°E, producing the prevalent southerlies to the west of it and facilitating the northward movement of most of the TCs in August 2016. Through September and October 2016, the zonally elongating WNPSH was strengthened, thus enhancing the deep-tropospheric westward steering flows causing the TCs to make successive landfall in the southeast coast of China in boreal autumn. By comparison, the WNPSH in 1998 varied less because of the lack of potent tropical and extratropical influences. Comparatively, the overall large-scale background conditions in 1998 were hostile to TC genesis.

This study further provides an implication that TC seasonal forecast over WNP that excessively depends on tropical ocean signals, such as ENSO, is largely limited. The circulation evolution related to tropical intraseasonal oscillations and extratropical climatic modes should be comprehensively taken into consideration to improve TC seasonal prediction.

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