Variation of the Tropical Cyclone Season Start in the Western North Pacific

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ABSTRACT

The variation of the tropical cyclone (TC) season in the western North Pacific (WNP) was analyzed based on the percentiles of annual TC formation dates. The results show that the length of the TC season is highly modulated by the TC season’s start rather than its end. The start of the TC season in the WNP has large interannual variation that is closely associated with the variation of the sea surface temperature (SST) in the Indian Ocean (IO) and the central-eastern Pacific (CEP). When the SSTs of the IO and CEP are warm (cold) in the preceding winter, anomalous high (low) pressure and anticyclonic (cyclonic) circulation are induced around the WNP TC basin the following spring, resulting in a late (early) start of the TC season. These results suggest that a strong El Niño in the preceding winter significantly delays the TC season start in the following year.

1. Introduction

The western North Pacific (WNP) is the most active tropical cyclone (TC) basin on Earth. About 30% of global TCs develop in the WNP and the lowest central pressure of TCs is observed in this area as well. Every year, many TCs in the WNP threaten coastal countries, resulting in enormous socioeconomic damages and loss of lives. Thus, it is important to know when the TC season will start to try to prevent possible damages from the TCs. Normally, TC activity is modulated by large-scale environmental parameters such as sea surface temperature (SST), vertical wind shear, low-level vorticity, and relative humidity (Gray 1979; McBride and Zehr 1981). These environmental parameters vary seasonally and thus can induce changes in the seasonality of TC activity including the start, end, and length of the TC season.

Previous studies on changes in the TC season have largely focused on the Atlantic basin, which has an apparent active hurricane season from June to November. Kossin (2008) examined the Atlantic hurricane season using quantile regression analysis and suggested that this season is possibly getting longer in association with an increase in the SST in the main region where the hurricanes develop. In addition, Karloski and Evans (2016) suggested that low-level vorticity, El Niño–Southern Oscillation (ENSO), and the Pacific decadal oscillation are related to the long-term trends of the hurricane season.

Climatologically, it is known that TCs in the WNP, unlike Atlantic hurricanes, form throughout the year, so the variation in the TC season in the WNP has been of less concern. However, the major period that TCs are active in the WNP has varied year to year. In particular, the start of the TC season in the WNP has shown large interannual variation. For example, no TC formed before July in 2016, whereas nine named TCs occurred before July in 2015. Thus, it is worthwhile to examine the variations of the TC season in the WNP and the large-scale environmental parameters affecting them. In this paper, the analysis of the characteristics of the variation in the TC season in the WNP is described in section 2.
and the investigation concerning large-scale environmental parameters affecting the start of the TC season is presented in section 3. The data and methodologies used are described in each section. Finally, a discussion regarding the results of this study occurs in section 4.

2. Variation of the TC season in the WNP

We analyzed the TC season in the WNP based on the annual TC formation dates. The observed TC data were obtained from the best-track data of the Regional Specialized Meteorological Center (RSMC) Tokyo–Typhoon Center. These data include 6-hourly location and intensity information of TCs over the WNP collected since 1951. In this study, the TC formation date is defined as the day when the TC was first labeled as a tropical storm, which is defined as having a maximum sustained wind speed of more than 17 m s$^{-1}$. In the WNP, the monthly mean number of TCs is at its annual minimum in February (Kim et al. 2014). Thus, we defined a “TC year” in the WNP as the period from 1 February in the corresponding year to 31 January the following year.

Figure 1 shows the box-and-whisker plots for annual TC formation dates from 1951 to 2015. The boxes cover from the 25th to 75th percentiles (lower to upper quartiles, respectively) and the whiskers extend to the 5th and 95th percentiles, of the annual TC formation dates. The first and last TC formation dates are marked with dots. The lower and upper dashed lines denote the linear trends for the 5th and 95th percentiles, respectively, for the 1951–2015 period.

![Figure 1. Box-and-whisker plots for the western North Pacific (WNP) tropical cyclone (TC) formation dates for 1951–2015. The boxes cover from the 25th to 75th percentiles (lower to upper quartiles, respectively) and the whiskers extend to the 5th and 95th percentiles, of the annual TC formation dates. The first and last TC formation dates are marked with dots. The lower and upper dashed lines denote the linear trends for the 5th and 95th percentiles, respectively, for the 1951–2015 period.](https://journals.ametsoc.org/jcli/article-pdf/30/9/3297/4094109/jcli-d-16-0888_1.pdf)
suggest that the variation in the length of the TC season is mainly associated with the start of the TC season rather than its end. Meanwhile, the start and end of the TC season in the WNP had long-term variations as well as the interannual ones. The linear trends for the start and end of the TC season are plotted on Fig. 1. The start of the TC season was delayed (0.26 day yr$^{-1}$), whereas the end occurred earlier (−0.23 day yr$^{-1}$), indicating that the length of the TC season in the WNP is getting shorter (−0.49 day yr$^{-1}$) (Table 1). However, these long-term trends are not statistically significant at the 90% confidence level. Because of the weak signal in the long-term trends in this study, we paid attention to interannual variation of TC season rather than the long-term variations. In addition, further analysis focused on the variation of the start of TC season, which is a main factor modulating the variation of TC season.

### Table 1. Statistics for the start, end, and length of the TC season over the WNP. The ordinal date is the count of days from 1 February. The asterisk (*) denotes the correlation coefficient is significant at the 99% confidence level. The season start and end are 5th and 95th percentiles of TC formation dates in the TC year and the season length is the period between the season start and end.

<table>
<thead>
<tr>
<th>Season start</th>
<th>Ordinal date</th>
<th>Calendar date</th>
<th>Average Standard deviation (days)</th>
<th>Correlation coefficient with Trend (days yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Season start</td>
<td>107</td>
<td>18 May</td>
<td>35.1</td>
<td>0.26 $^{*}$</td>
</tr>
<tr>
<td>Season end</td>
<td>300</td>
<td>27 Nov</td>
<td>18.6</td>
<td>0.27</td>
</tr>
<tr>
<td>Season length</td>
<td>193 days</td>
<td></td>
<td>35.1</td>
<td>0.12</td>
</tr>
<tr>
<td>Annual TC counts</td>
<td></td>
<td></td>
<td></td>
<td>0.26</td>
</tr>
</tbody>
</table>

3. Large-scale environmental parameters related to the variation of TC season start

We analyzed large-scale environmental parameters that modulate the start of TC season using the extended reconstructed sea surface temperature version 4 (Huang et al. 2015) and the National Centers for Environmental Prediction (NCEP)–National Center for Atmospheric Research (NCAR) reanalysis dataset (Kalnay et al. 1996). Figure 2 shows the correlation maps between the ordinal date of the TC season start and the large-scale environmental parameters (SST, 850-hPa geopotential height, and 850-hPa vorticity and horizontal winds) for the months December–February and March–May. The solid (dashed) line of contour represents positive (negative) correlation coefficients. The contour interval is 0.1 and the zero line is omitted. The light (dark) shading regions indicate statistical significance at the 90% (95%) confidence level. The correlation coefficients with the zonal and meridional winds are illustrated as vectors. The correlation vectors are drawn only if the correlation coefficients with either the zonal or meridional winds are significant at the 95% confidence level.

**FIG. 2.** The correlation coefficients between the start day of TC season and (a), (b) SST, (c), (d) 850-hPa geopotential height, and (e), (f) 850-hPa vorticity and horizontal winds in (left) December–February and (right) March–May. The solid (dashed) line of contour represents positive (negative) correlation coefficients. The contour interval is 0.1 and the zero line is omitted. The light (dark) shading regions indicate statistical significance at the 90% (95%) confidence level. The correlation coefficients with the zonal and meridional winds are illustrated as vectors. The correlation vectors are drawn only if the correlation coefficients with either the zonal or meridional winds are significant at the 95% confidence level.
height, relative vorticity, and horizontal wind). In the figures, the positive (negative) correlations indicate that the TC season starts later (earlier) when the environments’ anomalies are positive (negative). To examine the factors affecting TC season start, we considered the environmental parameters during the preceding winter (December–February) and spring (March–May) of each TC season.

Figures 2a and 2b show that the ordinal date of the TC season start was positively correlated with the tropical SSTs in the Indian Ocean (IO), South and East China Seas, and tropical central-eastern Pacific (CEP) but negatively correlated with those in the southeastern Philippines Sea. The correlation pattern was strong in the preceding winter (Fig. 2a). The positive correlations in the IO and tropical CEP remained until spring (Fig. 2b). The correlation patterns between the TC season start and SST reflect the variability associated with ENSO (Harrison and Larkin 1998). Thus, we examined the start of the TC season following strong ENSO phases that are selected when the Niño-3.4 anomaly from December to February exceeds one standard deviation from the mean. The selected TC years following strong ENSO events in winter and their start dates of the TC season are shown in Table 2. The mean start date of the TC season following a strong El Niño was 21 June whereas for one following a strong La Niña it was 5 May. It is noted that because of the increasing trend in the TC season start, the TC start dates in early years of El Niño are slightly earlier than those in late years. Despite of the trend, the mean start date of the TC season following El Niño was delayed more than one and a half months from the mean start date after La Niña and the difference is statistically significant at the 99% confidence level based on both the Student’s t test and Mann–Whitney U test. This suggests that the TC season in the WNP is significantly modulated by El Niño–related SST variations.

Along with the ENSO-like SST variation, atmospheric environmental parameters closely varied with the start of the TC season. Figures 2c–f illustrate the correlation coefficients between the low-level atmospheric environmental parameters in the WNP and the ordinal date of the TC season start. The ordinal date of the TC season start was positively correlated with the 850-hPa geopotential height in the western Pacific and eastern IO during winter (Fig. 2c). In spring, the positive correlation area was smaller but the strong positive correlations were sustained over the WNP TC basin (Fig. 2d). In addition, the correlation coefficients with 850-hPa vorticity and horizontal wind show that anomalous anticyclonic circulation prevailed over the WNP TC basin in spring in association with the late-starting TC season (Fig. 2f). The anomalous high geopotential height and low-level anticyclonic circulation over the WNP provided unfavorable conditions for TC formation in spring, resulting in a delay of the TC season start over the WNP.

Many previous studies have pointed out that the ENSO-related SST anomalies over the tropics affect the anomalous circulation over the WNP basin. Anticyclonic flow develops in the Philippine Sea during the boreal winter of El Niño and is sustained until the following spring by a Rossby wave response to El Niño–induced subsidence over the Maritime Continent and an increase in westerlies over tropical western Pacific, which is forced by the SST warming over the CEP (e.g., Wang et al. 2000; Wang and Zhang 2002; Wu et al. 2010a). In addition to this process in the tropical Pacific sector, the El Niño–related warm SST anomalies over the IO also intensify and sustain the anomalous Philippine Sea anticyclone by a Kelvin wave response that forces surface divergence and descent over the WNP (e.g., Watanabe and Jin 2002; Lau and Nath 2003; Annamalai et al. 2005; Yang et al. 2007; Wu et al. 2010b; Zhan et al. 2011a,b; Zhan et al. 2014; Yuan et al. 2012). Thus, the correlation patterns shown in Fig. 2 can be attributed to a similar physical process as the aforementioned ENSO-related variations. In summary, when the warm SST anomalies occurred in the CEP and IO in the preceding winter, anomalous high pressure was induced over the vicinity of the Philippines Sea by the atmosphere–ocean coupled processes. The anomalous high pressure over the Philippines Sea was maintained until spring, suppressing TC formation in the spring and causing a late start of the TC season.

4. Summary and discussion

In this study, the variation of TC season in the WNP was analyzed based on the percentile analysis on the TC
formation days in each TC year, which is defined from 1 February in the corresponding year to 31 January the following year. The TC season is defined as the period from the 5th to the 95th percentiles of annual TC formation days. The results show that the length of TC season was highly dependent on its start, which has large interannual variation. The start of the TC season was significantly associated with the ENSO-related variations in oceanic and atmospheric environmental parameters during the preceding TC season. When the El Niño–like tropical SST anomalies (i.e., anomalous warming over the IO and CEP) occurred in the preceding winter and anomalous high pressures and anti-cyclonic circulations were induced and maintained around the WNP TC basin until the spring, TC formations over the WNP were suppressed in the spring, resulting in the late start of the TC season.

The statistics for the start of the TC season following a strong El Niño and La Niña also supported the relationship between the ENSO-related SST variation in the preceding winter and the start of the TC season (Table 2). It is notable that the start of the 2016 TC season in the WNP was extremely late. A named TC was not reported until 3 July by the RSMC-Tokyo Typhoon Center. Meanwhile, the El Niño of 2015–16 had the strongest El Niño events observed since 1950 (L’Heureux et al. 2017). Thus, the relationship between the strong El Niño and late start of the TC season analyzed in this study was valid for the 2016 TC season of the WNP.

As mentioned in section 2, the long-term trends show that the length of TC season has been slightly shortening as the start of the season is occurring later and the end is occurring earlier. Although the trends are very weak and statistically insignificant, it is notable that the reduction in the TC season length in the WNP is different from the positive trends in the Atlantic hurricane season length reported by Kossin (2008). They interpreted that the increases in local SST warming in the hurricane-developing region might affect the longer hurricane season. However, the simple linkage between the long-term trends in the local SST and length of TC season may not be valid for the WNP. In fact, the local SSTs in the WNP TC basin have also increased in the last several decades, whereas the length of the TC season has shortened slightly. From the results of this study, we speculate that the long-term variation of the TC season over the WNP might be associated with the remote SST variations over the IO and CEP and related atmospheric conditions of the WNP TC basin. Unfortunately, because of the large uncertainty in the insignificant long-term variations of the TC season over the WNP, the environmental factors affecting the possible long-term trends of the WNP TC season remain unknown.

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REFERENCES


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