The Impact of Summertime North Indian Ocean SST on Tropical Cyclone Genesis over the Western North Pacific

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Abstract

In this study, we investigate the impact of interannual variability of boreal summertime (June-September) north Indian Ocean (NIO) sea surface temperature (SST) on the distribution of tropical cyclone (TC) genesis over the western North Pacific (WNP) using observational datasets. The boreal summers with warm (cold) SST in the NIO, fewer (more) than normal TCs form over the entire WNP, with fewer (more) TCs forming north of 10°N and more (fewer) TCs forming south of 10°N. The warm (cold) SST in the NIO induces anomalous anticyclonic (cyclonic) vorticity north of 10°N and cyclonic (anticyclonic) vorticity south of 10°N, which contributes to the meridional seesaw-like distribution of WNP TC genesis. This study provides a new perspective to understand TC activities over the WNP and may help seasonal TC prediction.

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1. Introduction

The western North Pacific (WNP) has the highest fraction of tropical cyclone (TC) genesis globally. TC activities, such as genesis number, genesis location, intensity, and moving track, show strong interannual variability (e.g., Chan 1985; Chia and Ropelewski 2002; Camargo and Sobel 2005; Wu et al. 2006; Camargo et al. 2007; Li et al. 2013; Wang et al. 2013a). The interannual variation of TC activities over the WNP is affected by the WNP monsoon trough (Chen et al. 1998), canonical El Niño-Southern Oscillation (ENSO) (Wang and Chan 2002), ENSO Modoki (Wang et al. 2013b), the joining area of Asian and Indian-Pacific Ocean (AIPO) (Li et al. 2011a, 2011b), the Antarctic Oscillation (Ho et al. 2005), and others.

The impacts of ENSO on the spatial distribution of TC genesis over the WNP has been extensively studied (e.g., Chen et al. 1998; Chia and Ropelewski 2002; Wang and Chan 2002; Wang et al. 2013b). Chen et al. (1998) found that the TC genesis number north of 15°N shows a significantly negative correlation with sea surface temperature (SST) over the Niño 3 region during summer. Wang and Chan (2002) indicated that the total TC genesis number over the entire WNP has no close relationship with ENSO events; however, the TC genesis number over the southeast (northwest) quadrant is positively (negatively) associated with strong ENSO events. Chia and Ropelewski (2002) suggested that the interannual variability of TC mean genesis position over the WNP is mainly affected by the ENSO events. Wang et al. (2013b) found that central Pacific warm events have no distinct effect on the TC genesis over the WNP, while central Pacific cold events suppress the TC genesis over the southeast quadrant of the WNP during summer.

2. Data

The TC data used in this paper are obtained from the Regional Specialized Meteorological Center of the Japan Meteorological Agency. To verify the results, the TC data from the Shanghai Typhoon Institute of China Meteorological Administration (CMA) is also used. The SST data are the Extended Reconstructed SST V3b on 2° × 2° grid from the National Oceanic and Atmospheric Administration (NOAA) (Smith et al. 2008). The atmospheric variables are from the National Centers for the Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis, including zonal and meridional winds on 2.5° × 2.5° grid (Kalnay et al. 1996). The CPC Merged Analysis of Precipitation (CMAP) dataset on 2.5° × 2.5° grid (Xie and Arkin 1997) is also used. The analysis is based on the boreal summertime (June to September, or JJAS) mean data for the period of 1979–2014.

3. Results

Figure 1a shows the correlation map between the total TC genesis number over the WNP and SST in the Indo-Pacific during JJAS for the study period. It shows that in the Indo-Pacific, only the SST in the NIO has a statistically significant correlation with TC genesis number over the WNP in JJAS. The total TC genesis number over the WNP is negatively related to the SST in the NIO. This result is consistent with Du et al. (2011). Based on the correlation distribution in Figure 1a, the NIO region in this study is referred to the region of 50°E–100°E and 6°N–20°N. To emphasize the interannual variability of TC genesis number over the WNP associated with the NIO SST, a nine-year high-pass filtering (Zheng et al. 2014) is applied to the time series of the NIO SST.
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The TC genesis number south of 10°N over the WNP is positively correlated with the NIO SST, while that north of 10°N is negative and minimum. The WNP is therefore divided into two sub-regions meridionally (north sub-region and south sub-region), using 10°N as the boundary, to study different influences of the NIO SST on TC genesis over different sub-regions of the WNP. As shown in Table 1, the correlation between the TC genesis number over the north (south) sub-region and the NIO SST is −0.57 (0.38), which are both significant at the 95% confidence level. The correlation using the TC data from the CMA exhibits a similar distribution (figure not shown), indicating that it is robust for the opposite effects of the NIO SST on the WNP TC genesis north and south of 10°N.

According to Fig. 2, we further divide the WNP into four sub-regions longitudinally (east sub-region and west sub-region) and latitudinally (north sub-region and south sub-region), using 135°E and 10°N as the boundaries, respectively. The correlation between the TC genesis number east of 135°E over the WNP and the NIO SST is not statistically significant. We thus divide the WNP into two sub-regions (west sub-region and east sub-region), using 135°E as the boundary. As shown in Table 1, the correlation between the TC genesis number over the west sub-region and the NIO SST is −0.36, which is significant at the 95% confidence level; while the correlation coefficient between the TC genesis number over the east sub-region and the NIO SST is only −0.23, which is statistically insignificant. It implies that the NIO SST may have more influence on the TC genesis over the west sub-region of the WNP.

Table 1. Correlation coefficients between the NIO SST and JJAS TC genesis numbers over different regions of the WNP for the period of 1979–2014.

| Region                        | Correlation Coefficient |
|-------------------------------|-------------------------|
| entire WNP                    | −0.48*                  |
| west sub-region (west of 135°E) | −0.36*                  |
| east sub-region (east of 135°E) | −0.23                   |
| north sub-region (north of 10°N) | −0.57*                  |
| south sub-region (south of 10°N) | 0.38*                   |
| northwest sub-region (north of 10°N, west of 135°E) | −0.36*                  |
| northeast sub-region (north of 10°N, east of 135°E) | −0.41*                  |
| southwest sub-region (south of 10°N, west of 135°E) | 0.05                     |
| southeast sub-region (south of 10°N, east of 135°E) | 0.38*                   |

The * indicate significant at the 95% confidence level using the Student’s t-test.
sub-regions (northwest, northeast, southwest, and southeast sub-regions), using 10°N and 135°E as the boundaries (Fig. 3a). As shown in Table 1, the correlation between the TC genesis number over the northwest (northeast) sub-region and the NIO SST is −0.36 (−0.41). They are both significant at the 95% confidence level, suggesting that the northwest sub-region and northeast sub-region both contribute to the negative correlation between the TC genesis number over the north sub-region and the NIO SST. Moreover, the correlation between the TC genesis number over the northeast (southeast) sub-region and the NIO SST is −0.41 (0.38), significant at the 95% confidence level. Due to the opposite correlations over these two sub-regions, the correlation between the TC genesis number over the east sub-region and the NIO SST is not statistically significant. It shows that the NIO SST also influences the TC genesis over the east sub-region of the WNP, although the effect of the NIO SST varies with latitude.

The TC genesis locations in the whole study summers, during the warm NIO summers and the cold NIO summers are shown in Fig. 3. We can see that the TC genesis number over the WNP during the warm NIO summers is fewer than that during the cold NIO summers. The average TC genesis number over the WNP are 13.8 during the warm NIO summers, 18.6 during the cold NIO summers, and 16.0 when the NIO SST is under the climatological mean condition. Apart from the TC genesis number over the entire WNP, the TC genesis has a meridional seesaw-like distribution: the average TC genesis number over the north sub-region during the warm and cold NIO summers are 11.4 and 17.6, respectively; while the average TC genesis number over the south sub-region during the warm and cold NIO summers are 2.4 and 0.9, respectively. More (fewer) TCs form south (north) of 10°N during the warm NIO summers than during the cold NIO summers, indicating that the NIO SST evidently affects the meridional distribution of TC genesis over the WNP.

To illustrate how the NIO SST influences TC genesis distribution over the WNP, the correlations between the NIO SST and JJAS atmospheric variables are analyzed (Figure 4), including 850-hPa winds, precipitation, 850-hPa relative vorticity, 1000-hPa divergence, zonal-mean relative vorticity, and zonal-mean divergence. At 850 hPa, the easterlies appear around 10°N over the WNP (Fig. 4a), which largely reduces (enhances) the cyclonic shear of zonal wind north (south) of 10°N. Consequently, there are an anomalous anticyclonic circulation centered north of 10°N and two anomalous cyclonic circulations centered south of 10°N (Fig. 4c). The zonal-mean 850-hPa relative vorticity shows obvious north-south seesaw characteristic associated with different phases of the NIO SSTA (Fig. 4e). At 1000 hPa, the region north (south) of 10°N is dominated by an anomalous divergence (convergence) (Figs. 4d and f ). Since the negative (positive) relative vorticity and low-level divergence (convergence) is unfavorable (favorable) for TC genesis (Elsberry 2004), the WNP TC genesis north (south) of 10°N is suppressed (promoted). These results reveal that the NIO SST affect the TC genesis distribution through atmospheric circulation over the East Asia-western Pacific, which can be explained by the Kelvin wave-induced Ekman divergence (WIED) mechanism proposed by Xie et al. (2009). In the warm NIO summers, convective activities over the western tropical Indian Ocean could be enhanced by warm SST in the NIO (Fig. 4b). The anomalous heating induced by enhanced convection excites a baroclinic Kelvin wave propagating into the Pacific, which induces easterlies around 10°N and an anomalous anticyclonic (cyclonic) north (south) of 10°N. In the cold NIO summers, the situation is reversed.

4. Concluding remarks

This paper reveals the impact of interannual variability of boreal summertime (JJAS) NIO SST on the spatial distribution of TC genesis over the WNP. The NIO SST not only modulates the total TC genesis over the entire WNP, but also affects the spatial distribution of TC genesis, especially its meridional distribution. In the summers with warm (cold) SST in the NIO, fewer (more) TCs form over the entire WNP; more specifically, fewer (more) TCs form north of 10°N and more (fewer) TCs form south of 10°N. The warm (cold) SST in the NIO induces anomalous anticyclonic (cyclonic) vorticity north of 10°N and cyclonic (anticyclonic) vorticity south of 10°N, which suppresses (promotes) TC genesis north of 10°N and promotes (suppresses) TC genesis south of 10°N.

Since the TC genesis north of 10°N has more contribution to the total TC genesis number over the WNP in summer than the TC genesis south of 10°N, the total TC genesis number over the WNP has a negative correlation with the NIO SST. Furthermore, the meridional seesaw atmospheric anomalies associated with different phases of the NIO SSTA is significant. Therefore, the NIO SST also has a distinct effect on the meridional distribution of TC genesis over the WNP.

Unlike previous studies (Du et al. 2011; Zhan et al. 2011), this
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This paper emphasizes the impact of the NIO SST on the meridional distribution of TC genesis over the WNP. In this study, we used 10°N as the boundary between the north and the south, which is different from 17°N used in the WNP TC genesis associated with ENSO events by Wang and Chan (2002). Our results provide a new perspective, which promotes the understanding of the TC activities over the WNP, and suggests that accurate forecast of the NIO SST in summer may help to improve seasonal TC prediction over the WNP.

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