Role of the intraseasonal IPCO in the absence of typhoons in July 2020

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Abstract

The influence of the intraseasonal Indo-western Pacific convection oscillation (IPCO) on the absence of typhoons in July 2020 over the western North Pacific (WNP) was explored. Our observations analysis revealed an unprecedented absence of typhoons over the WNP in July 2020 even though the necessary conditions such as sea surface temperature (SST) and vertical wind shear met the basic requirements of typhoon formation since it began occurring from 1949. Additionally, significant differences were found in the frequency of typhoons between the different phases of the intraseasonal IPCO; the frequency in the positive phase of the intraseasonal IPCO was significantly higher than that in the negative phase of the intraseasonal IPCO. In July 2020, the intraseasonal IPCO was in a strong negative phase, with the third lowest index in history and had the strongest inhibition effect on convection over the WNP on record, leading to large-scale circulation anomalies. The strongest descending movement on record inhibited the upward transport of water vapor and the development of cumulus convection, thereby reducing the release of latent heat of condensation and making it difficult to form a typhoon warm-core structure. In addition, the geopotential height increased over the WNP, and the western Pacific subtropical high moved southerly, which inhibited typhoon formation. Simultaneously, the South China Sea monsoon trough weakened significantly, with increased negative vorticity anomaly in the response scale, which hindered disturbance generation. The lowest genesis potential index confirmed that the large-scale circulation anomaly caused by the intraseasonal IPCO had an unprecedented restraining effect on typhoon generation, leading to the absence of typhoons over the WNP in July 2020.

1 Introduction

Tropical cyclones (TCs) are cyclonic eddies with warm central structures that occur in tropical and subtropical oceans (Zhu et al. 2007a). TCs that occur over the western North Pacific (WNP) and have a maximum wind speed greater than 17.2 m/s in the center are called typhoons, and these cause serious societal and economic impacts (Li et al. 2016a). TCs are accompanied by strong winds and torrential rain, bringing serious disasters to the affected areas. According to the statistics, typhoons kill approximately 453 people in the coastal areas of China annually, resulting in a direct economic loss of more than 26 billion yuan (Niu et al. 2011). However, TCs are also a valuable potential resource that bring abundant fresh water to mankind. In South and Southeast Asia, the precipitation brought by typhoons accounts for most or even all of the local annual rainfall (Elsberry and Tsai 2016). In addition, TCs also play an important role in driving ocean thermohaline circulation, affecting regional and global climate change (Emanuel 2001; Done et al. 2009). Therefore, TC is one of the focuses of weather and climate research, and both too many and too few typhoons have important research significance.

The WNP is one of the main sources of TCs, producing approximately 36% of TCs (Li et al. 2016b), and July, the peak season for TC generation, has approximately four TCs over the WNP every year. However, no typhoon was generated in July 2020 over the WNP for the first time since 1949 as per records. The four well-known necessary conditions for the formation of typhoons are: warm and broad ocean surface (sea surface temperature above 26.5°C), initial disturbance at low level, sufficient Coriolis force, and weak
vertical wind shear. The results in section 3 of this study show that these four necessary conditions meet the requirements of typhoon generation, suggesting that there may be other complex and special drivers behind the absence of typhoons in July 2020. Wang et al. (2021) used the dynamic genesis potential index to show the impacts of large-scale circulation conditions on typhoon genesis, and their numerical experiments showed that warming of the Indian Ocean could trigger abnormal anticyclone over the WNP, leading to the absence of typhoons.

Convection also plays an important role in TC formation. Previous studies on the convective characteristics over the tropical Indo-western Pacific using outgoing longwave radiation (OLR) data showed an out-of-phase relationship in convection variation between the Indian Ocean and the WNP, and the location and phase of convection activities varied in different seasons (Lau and Chan 1985, 1986; Zhu and Wang 1993; Lee et al. 2012). Li et al. (2013) found that this convective dipole phenomenon also has important signals on interannual timescales, but the centers of convective actions remain largely the same and define the out-of-phase convection anomalies over the Indo-western Pacific as the Indo-western Pacific convection oscillation (IPCO). Zhang et al. (2015) found that the IPCO has significant intraseasonal variations, and the average locations of the convection centers of the intraseasonal IPCO change slightly and lie over the eastern equatorial Indian Ocean (EEIO) (5°S–10°N, 70°–100°E) and the WNP (5°–20°N, 110°–160°E), respectively. Wang et al. (2018, 2019) explored the modulation effect of the intraseasonal IPCO on TC genesis location, frequency, and path over the Indo-western Pacific. They found that there tend to be more TCs over the WNP when the intraseasonal IPCO was in its positive phase, whereas the TC genesis frequency is lower in its negative phase. In addition, Wang et al. (2018) explored the possible physical mechanism by which the intraseasonal IPCO affects large-scale circulation and its impact on typhoon generation. In July 2020, the IPCO turns to its strong negative phase. Does the intraseasonal IPCO play an important role in the absence of typhoon in July 2020? What is the physical mechanism of the intraseasonal IPCO inhibiting typhoon formation? These questions are the motivation for the present study.

The remainder of this paper is organized as follows: Section 2 briefly reviews the data and methodologies used in the analyses. Section 3 explores conditions necessary for typhoon genesis over the WNP in July 2020. Sections 4 and 5 show the influence of the intraseasonal IPCO on typhoon genesis and circulation and the absence of typhoons in July 2020, respectively. Section 6 presents a summary of the key results and discussion.

2 Data And Methodology

2.1 Data

Daily datasets analyzed from 1979 to 2020, consisted of reanalysis data (Kalnay et al. 1996) and interpolated OLR data (Liebmann and Smith 1996) from the National Centers for Environment Prediction (NCEP)–National Centers for Atmospheric Research (NCAR), including geopotential height, relative
humidity, vertical velocity, sea surface temperature, wind field, and interpolated OLR, with a horizontal spatial resolution of 2.5°.

The best-track data for typhoon activity over the WNP during 1979–2020 were obtained from the Regional Specialized Meteorological Center (RSMC) of the Japan Meteorological Agency (JMA). Only TCs that reached tropical storm intensity (maximum sustained 10 m wind speed $\geq 17.2$ m $s^{-1}$) were used in our analysis.

### 2.2 Statistical methods

To study the influence of the intraseasonal IPCO, anomalies of the aforementioned meteorological elements, except for typhoon data and sea surface temperature, were applied to a 30–60-day Lanczos bandpass filter using 305 weights, and the response function is shown in Fig. 1. It can be seen that the signals beyond 30–60 days are basically removed.

Based on previous study (Li et al. 2013; Zhang et al. 2015), the intraseasonal IPCO index has been defined as

$$IPCOI = OLR_{EEIO} - OLR_{WNP},$$

where $OLR_{EEIO}$ and $OLR_{WNP}$ are the normalized areal-averaged time series of the OLR anomalies over the EEIO ($5°S$–$10°N$, $70°$–$100°E$) and WNP ($5°$–$20°N$, $110°$–$160°E$), respectively. According to the value of IPCO index (IPCOI), the intraseasonal IPCO can be divided into three phases: positive ($IPCOI > 1$), negative ($IPCOI < -1$), and neutral ($-1 < IPCOI < 1$).

Composite and correlation analyses are performed to explore the possible physical mechanisms. The statistical significance of the correlation between two autocorrelated time series is assessed via the two-tailed Student’s $t$-test using the effective number of degrees of freedom ($N_{eff}$) provided by the following approximation (Pyper and Peterman 1998; Li et al. 2012; Li et al. 2013; Xie et al. 2014; Sun et al. 2017; Xue et al. 2017):

$$\frac{1}{N_{eff}} \approx \frac{1}{N} + \frac{2}{N} \sum_{j=1}^{N} \frac{N-j}{N} \rho_{XX}(j) \rho_{YY}(j),$$

where $N$ is the sample size, and $\rho_{XX}(j)$ and $\rho_{YY}(j)$ are the autocorrelations of the two sampled time series $X$ and $Y$ at time lag $j$, respectively.

### 2.3 Genesis potential index

To further confirm our results, 30–60-day Lanczos bandpass-filtered genesis potential index (GPI) anomalies are employed in this study. Developed by Emanuel and Nolan (2004), GPI has been widely used to diagnose interannual and interdecadal variabilities for TC genesis, and examine the impacts of
large-scale circulation anomalies on TC genesis (Camargo et al. 2007, 2009; Jiang et al. 2012; Zhao et al. 2015a, b; Wang et al. 2018). The GPI is defined as

\[
GPI = \left(1 + 0.1 V_{s\text{hear}}\right)^{-2.0} \left(\frac{\text{rhum}}{50}\right)^{3.0} \left(\frac{PI}{70}\right)^{3.0} 10^5 \zeta_a,
\]

where \(V_{s\text{hear}}\) is the magnitude of the vertical wind shear between 850 and 200 hPa (m s\(^{-1}\)), \(\text{rhum}\) is the relative humidity (%) at 600 hPa, \(PI\) is the potential intensity (m s\(^{-1}\)) and \(\zeta_a\) is the absolute vorticity (s\(^{-1}\)) at 850 hPa. The definition of \(PI\) is defined by Bister and Emanuel (1998), based on Emanuel (1995):

\[
MPi^2 = \frac{C_k}{C_D} \frac{T_s - T_o}{T_o} \left(h_o^* - h^*\right),
\]

where \(C_k\) and \(C_D\) denote the surface enthalpy and momentum exchange coefficients, respectively, \(T_s\) and \(T_o\) are the sea surface temperature and outflow temperature, respectively, \(h_o^*\) is the saturation moist static energy of the sea surface, and \(h^*\) is the saturated moist static energy of the free atmosphere.

### 3 Necessary Conditions For Typhoon Genesis Over The WNP In July 2020

Before investigating the possible impact of the intraseasonal IPCO on typhoons, necessary conditions of typhoon genesis are explored to confirm whether the absence of typhoon genesis is caused by the failure of meeting the basic requirement of these conditions.

The sea surface temperature (SST) is the fundamental thermal condition and should be greater than 26.5°C for typhoon generation. The warm sea surface is the basis of the formation of a warm-core structure, since it contains a large amount of heat, and strong evaporation. Through the turbulence transport between the air and sea, a large amount of warm and wet air is obtained from the lower atmosphere where the disturbance is located, making the atmospheric stratification conditionally unstable. Figures 2a and 3a show the spatial patterns of SST anomalies over the WNP in July 2020 and the time series of the area-averaged SST from 1979 to 2020, respectively. It is seen that the areal-averaged SST over the WNP in July 2020 is abnormally high exceeding 30°C, the highest since 1979. In addition, Fig. 2c shows the generation location of typhoons and tropical disturbances in July, which are basically generated between 5°N and 25°N. It is clear that the SST over the WNP in July 2020 is abnormally warm, providing abundant water vapor and heat supply, conducive to the formation and development of typhoons.

In addition to warm SST, weak vertical wind shear is also crucial for the formation of typhoon. When the vertical wind shear is small, the condensation latent heat produced by the cumulus is concentrated in a
limited space, favoring formation of the warm-core structure of the typhoon. In contrast, the latent heat of condensation will be rapidly transported from the initial disturbance if the vertical wind shear is extremely large, and a large area becomes slightly warm with low pressure, which is unfavorable for the formation of typhoon. Figures 2b and 3b show the spatial patterns of the vertical wind shear anomaly over the WNP in July 2020 and the time series of the areal-averaged vertical wind shear from 1979 to 2020, respectively. In terms of spatial distribution (Fig. 2b), the vertical wind shear south of 15°N is significantly smaller than the climatological normal, and the wind shear north of 15°N is slightly larger. The areal-averaged results (Fig. 3b) show that the vertical wind shear in July 2020 is generally lower than the climatological normal, which means that the condensation latent heat is easier to maintain in a small area and is thus favorable to the formation of the warm-core structure of typhoons.

In addition, tropical disturbances can release the unstable energy of the unstable atmosphere and transform it into the kinetic energy of TC development. The number of tropical disturbances is listed in Table 1. In July 2020, two tropical disturbances occurred over the WNP, less than half the climatological normal. Despite such favorable SST and vertical wind shear conditions, the two tropical disturbances did not develop into typhoons. Thus, other factors must have played a strong role in the process of tropical disturbance and its development into typhoons. As mentioned above, the intraseasonal IPCO could modulate the generation and movement of TCs by influencing the steering flow, energy conversion, and energy propagation during the boreal extended summer (May–October) (Wang et al. 2018, 2019). The following sections explore the possible influence of the intraseasonal IPCO on the genesis of typhoons.

| Number of tropical disturbances in July 2020 and climatological normal over the WNP |
|---------------------------------------------|-----------------|
| Climatological normal | 2020 |
| Tropical disturbances | 4.6 | 2 |

4 Influence Of The Intraseasonal Ipco On The Genesis Of Typhoons And Large-scale Circulation Anomalies

The frequency of typhoon genesis over the WNP changed during the different phases of the intraseasonal IPCO in July. Table 2 shows the composite number of typhoons over the WNP in July during the positive and negative intraseasonal IPCO phases from 1979 to 2020 and their differences. There are significant differences in typhoon generation frequency in the different intraseasonal IPCO phases, and tends to be more typhoons over the WNP during the positive phase of the intraseasonal IPCO (about 1.7 times more than in the negative phases), consistent with the results reported by Wang et al. (2018) on boreal extended summer. The IPCOI could measure the difference in convective intensity between the EEIO and WNP characterizing the phase and strength of the intraseasonal IPCO. In the positive phase of the intraseasonal IPCO, convection over the WNP is strengthened and that over the EEIO is inhibited, while in the negative phase of the intraseasonal IPCO, convection over the WNP is weakened.
and that over the EEIO is strengthened. Figure 4 shows the time series of IPCOI and area-averaged OLR over the WNP (5°–20°N, 110°–160°E) from 1979 to 2020. As can be seen, the intraseasonal IPCO in July 2020 is the one of the strongest negative phases in history, and further indicated by the area-averaged OLR over the WNP was also experiencing the weakest convective intensity on record, which may be closely related to the absence of typhoon.

|                | IPCO (+) | IPCO (−) | Difference (IPCO (+) − IPCO (−)) |
|----------------|----------|----------|----------------------------------|
| Typhoons       | 4.8      | 2.8      | 2.0 *                            |

Note: The asterisk * indicates significance at the 95% confidence level using the Student’s t-test

Previous studies have found that the IPCO could affect large-scale circulation in local and remote areas in a number of ways and modulate the weather and climate of the region (Li et al. 2016b; Zheng et al. 2017; Wang et al. 2019; Zhao et al. 2019). Wang et al. (2018) demonstrated that the anomalies of large-scale circulation are significantly different between the different phases of the intraseasonal IPCO in boreal extended summer (May–October) and proposed possible physical mechanisms of large-scale circulation influencing typhoon generation, including the thermodynamic effect of relative humidity in the middle atmosphere and circulation conditions. In July 2020, the intraseasonal IPCO had an unprecedented strong inhibition on convection over the WNP, which may have inhibited the generation and development of typhoons by influencing large-scale circulation anomalies. This was followed by further investigation on the circulation anomalies in July during the different phases of the intraseasonal IPCO.

The anomalies of large-scale circulation affected by the intraseasonal IPCO could be characterized by the 30–60-day Lanczos bandpass-filtered data. Figure 5 shows the composite difference of the 200 hPa and 850 hPa divergence, 500 hPa vertical velocity and geopotential height, 600 hPa relative humidity anomalies, and vertical wind shear in July between the positive and negative IPCO phases. Significant differences are observed in large-scale circulation under different the intraseasonal IPCO phases, and the large-scale circulation anomalies present in the north–south dipole distribution. Except for the vertical wind shear, other atmospheric factors showing significant difference between the different phases of intraseasonal IPCO are located in the southern part of the dipole 5°N–20°N, corresponding to the key area of the WNP part of the intraseasonal IPCO. Moreover, the significantly different area also covers the main region of typhoon generation (5°N to 25°N), while 20°N to 25°N is basically in the transition region between the northern and southern parts of the dipoles. In the positive phase of the intraseasonal IPCO, the upper-level divergence, low-level convergence, and middle-level ascending motion are enhanced in the
range of 5°N–20°N when the large-scale convection over the WNP is strengthened. Such large-scale circulation anomalies are favorable to the lifting and development of low-level disturbances, and can also enhance the upward movement of water vapor and the development of local cumulus convection. The above atmospheric processes are opposite in the negative phase of the intraseasonal IPCO.

Figure 5d illustrates the composite difference between the positive and negative phases of the relative humidity anomalies at the 600 hPa level. To some extent, relative humidity represents the available latent heat of condensation, further representing the intensity of cumulus convection (Wang et al. 2018). Owing to the strengthening of convection and upward water vapor transport, in the intraseasonal IPCO-positive phase, a larger amount of condensation latent heat will be released by the cumulus convection, contributing to the development of the warm-core structure of the typhoon, than in the negative phase (Fig. 5d).

In addition, in the positive phase of the intraseasonal IPCO, owing to the strengthening of convection (south of 25°N), troposphere heating is dominated by condensation latent heat release. According to the potential tendency equation, as nonadiabatic heating increases with height, the geopotential height decreases (Zhu et al. 2007a). As shown in Fig. 5e, the low-value center of the geopotential height is located in the South China Sea, whereas the high-value center is in the Sea of Japan during the positive phase of the intraseasonal IPCO, which may be favorable to the northward uplift of the western Pacific subtropical high (WPSH) and the development of tropical disturbance over the WNP. In addition, Fig. 5f shows that the distribution of the vertical wind shear anomaly dipole is 5 latitudes south of the other atmospheric circulation anomalies as a whole, with the high-value center located in the south of the South China Sea. In the positive phase of the intraseasonal IPCO, the vertical wind shear is abnormally high south of 15°N, which is not favorable for the maintenance of condensation latent heat and the formation of a typhoon warm heart structure, whereas it is the opposite north of 15°N.

Moreover, tropical disturbance is the embryonic state of TC, which can convert the unstable energy of an unstable atmosphere into kinetic energy of TC development. The intertropical convergence zone is the most concentrated area of heat and water vapor in the tropics and also the main source of tropical disturbances. The monsoon trough is a type of intertropical convergence zone, and more than 80% of tropical disturbances generate from the intertropical convergence zone in the western Pacific and South China Sea.

Figure 6 shows the composite map of the horizontal wind vorticity anomalies at the 850 hPa level. The position and intensity of the South China Sea monsoon trough (SCSMT) are significantly different in the different phases of the intraseasonal IPCO. In the positive phase of the intraseasonal IPCO, the SCSMT is much stronger than that in the negative phase, and the trough line can reach 150°E. In addition, the north–south range of the SCSMT covers the main area of typhoon generation, and water vapor and heat abound in the SCSMT. The airflow easily converges and then rises in this area, which is conducive to the generation and uplifting of tropical disturbances. The positive anomaly of the vorticity at the trough line leads to a decrease in the Rossby deformation radius, which reduces the scale of response and increases
the conversion of latent heat release to rotational motion, thus facilitating the generation of tropical disturbances (Hack and Schubert 1986). In the year of the negative phase of the intraseasonal IPCO, the intensity of the SCSMT is obviously weaker, and the vorticity is a significantly negative anomaly, unfavorable for the generation and development of tropical disturbances.

Previous research has shown that the GPI replicates the interannual variations of TC genesis in several different basins on intraseasonal timescales and reflects the influence of large-scale circulation conditions on TC genesis (Camargo et al. 2007, 2009; Jiang et al. 2012; Zhao et al. 2015a, b). The GPI is mainly influenced by four factors: low-level vorticity, middle-level relative humidity, vertical wind shear, and potential intensity. Table 3 shows the correlation coefficients between IPCOI and GPI and its four elements, and IPCOI is highly correlated with both, indicating that GPI can be used to characterize the influence of environmental conditions caused by the IPCO on typhoon generation, in accordance with a previous study (Wang et al. 2018). Figure 7 shows the composite difference between the positive and negative IPCO phases in the GPI in July. In the key area of the WNP part of the intraseasonal IPCO, positive values indicate that more typhoons tend to be generated in the intraseasonal IPCO-positive phase than in the negative phase.

In general, the intraseasonal IPCO could affect large-scale circulation anomalies over the WNP and further modulate the generation and development of tropical disturbances and typhoons. Except for vertical wind shear, circulation anomalies have a similar effect on typhoon formation. Circulation anomalies in the positive phase of the intraseasonal IPCO are favorable for typhoon formation, but not in the negative phase.

### Table 3

|                | Vshear | rhum | PI   | Vorticity | GPI  |
|----------------|--------|------|------|-----------|------|
| **Correlation coefficient** | 0.72*  | 0.77*| -0.42*| 0.78*     | 0.58*|

Note: The asterisk * indicates significance at the 99% confidence level using the Student’s t-test.

### 5 Role Of The Intraseasonal Ipco In The Absence Of Typhoon In July 2020

As mentioned above, there are significant differences in the number of typhoons and large-scale atmospheric circulation anomalies over the WNP during the different phases of intraseasonal IPCO. Compared with the positive phase, the circulation anomalies in the negative phase of the intraseasonal IPCO were unfavorable for the generation of TCs over the WNP. In addition, the intraseasonal IPCO in July 2020 is a strong negative phase, and the inhibition on convection over its WNP is unprecedentedly strong.
To explain the role of the intraseasonal IPCO in the absence of typhoons over the WNP, three possible influencing pathways are proposed: the influence on cumulus convection, WPSH, and SCSMT.

5.1 Cumulus convection anomalies

Figure 8 shows the anomalies of the aforementioned large-scale atmospheric circulation in July 2020. Figure 8a shows an anomalous anticyclone in the lower troposphere over the WNP, with its center over the South China Sea and the eastern part of the Philippines, and an abnormal cyclone located along the southeast coast of China. The low-level divergence field corresponds well to the position of the wind field, the divergence is strengthened over the South China Sea and the eastern part of the Philippines, and the convergence is strengthened along the southeast coast of China, presenting a north–south dipole distribution. The position of the strongest subsidence movement is consistent with the low-level divergence center and the center of the anomalous anticyclone, whereas the center of the strengthening upward movement is located east of the convergence center (Fig. 8b). Such circulations are not conducive to the lifting and development of low-level disturbances, as the air mass must undergo a considerable amount of forced uplift before reaching the height of free convection and then obtain unstable energy from the atmosphere to continue development. In contrast, the strengthening of the sinking movement inhibits the upward transport of water vapor, leading to a significant negative anomaly in tropospheric relative humidity (Fig. 8c), indicating suppression of cumulus convection and the reduction in the release of latent heat of condensation. Simultaneously, the release of condensation latent heat decreases, which is not conducive to the formation of the warm-core structure of the TC. By simplifying the equations of motion, we obtained the relationship between the radial temperature gradient $\partial T_v / \partial r$ and the vertical tangential wind shear $\partial v / \partial \ln p$ (Anthes 1982; Holland 1987; Zhu et al. 2007; Kepert 2010; Wang et al. 2018):

$$\frac{\partial v}{\partial \ln p} \left(f + \frac{2v}{r}\right) = -R_d \frac{\partial T_v}{\partial r}, \quad (5)$$

where $f$ is the Coriolis parameter, $v$ the tangential velocity ($v > 0$ represents the cyclonic flow), $r$ is radial distance to the center of TC, $p$ is pressure, $R_d$ is the gas constant for dry air, and $T_v$ is virtual temperature. Eq. (5) shows that the TC warm-core structure favors weakening of the TC cyclonic circulation with height, which implies that the warm-core structure plays a vital role in the development of TC. As shown in Fig. 8c, however, the relative humidity in the middle atmosphere is negative anomaly over the WNP, which covers most typhoon-generating areas. Additionally, due to cumulus convection, the latent heat of condensation decreases with weakening of warm-core structure, and the cyclonic circulation associated with the increase in height. These are not conducive for TC formation. Figure 9 shows the time series of the areal-average 600 hPa relative humidity, 500 hPa vertical velocity and geopotential height, vertical wind shear, and 850 hPa absolute vorticity over the WNP in July. It is seen that the vertical velocity and relative humidity in 2020 are the lowest since 1979, indicating that the subsidence movement in July 2020 was the strongest, and the cumulus convection was the weakest, which hindered the development
of the typhoon structure. An approximate half of the vertical wind shear between 5°N and 25°N has a negative anomaly owing to the weakening of cumulus convection releasing latent heat and reducing condensation, resulting in weak vertical wind shear with difficulty in typhoon formation (Fig. 8d).

5.2 WPSH anomalies

Owing to the decrease in cumulus convective intensity and condensation latent heat release, tropospheric heating over the WNP is dominated by surface long-wave radiation heating, which means that nonadiabatic heating increases with decreasing height. According to the potential tendency equation, as nonadiabatic heating decreases with height, the geopotential height increases (Zhu et al. 2007a). As shown in Fig. 8c, the geopotential height over the WNP in July 2020 was abnormally high and conducive to the strengthening of the WPSH. Compared with the climatological normal, the 5880 gpm isoline moved westerly and southerly in July 2007, indicating that the WPSH in July 2020 was southward and stronger. The centers of the above-mentioned circulation anomalies other than the geopotential height are basically located in the South China Sea and the eastern part of the Philippines, explaining the low number or absence of typhoons south of 20°N. A north–south dipole distribution of the circulation anomalies and the location of 20–25°N between the two parts of the dipoles, where the circulation anomalies are small, hinder the formation of typhoons that are mainly influenced by the enhanced WPSH at this latitude.

5.3 SCSMT anomalies

Figure 8f illustrates the horizontal wind field at the 850 hPa level in July 2020, indicating that the intensity of the SCSMT is very weak and the trough line is located west of 120°E, which is unfavorable for the convergence and uplift of airflow. The low-level vorticity over the WNP is a negative anomaly, which increases the scale of the response and reduces the conversion of latent heat release to rotational motion, thus making it difficult for the formation of the initial disturbance. In addition, the southerly and strong WPSH hindered the uplift and development of the disturbances.

In general, the negative IPCO in July 2020 affected large-scale circulation anomalies over the WNP, which reduced the latent heat of condensation released by cumulus convection in the region, strengthened the WPSH, and weakened the SCSMT, hindering the generation of tropical disturbances and typhoons.

5.4 GPI perspective

Figure 10a shows the GPI anomaly over the WNP in July 2020. It reveals that the GPI over the WNP is mostly negative, and the area of the negative GPI anomaly covers most of the generation positions of typhoons over the years, consistent with previous large-scale circulation. As a comprehensive index, the GPI shows that when the strong negative phase of the intraseasonal IPCO occurs in July 2020, the anomalies of large-scale atmospheric circulation have an inhibitory effect on typhoon genesis.

We further areal-averaged GPI over the WNP. Figure 10b shows that the GPI anomalies over the WNP in July 2020 were the lowest on record, indicating that the intraseasonal IPCO negative phase had the
strongest inhibitory effect on typhoon genesis over the WNP by affecting large-scale atmospheric circulation. Previous studies have also shown that relative humidity and vorticity play a leading role in TC genesis compared with the other two factors (Camargo et al. 2009; Wang et al. 2018). Figure 9 shows that the relative humidity and vorticity over the WNP were negative anomalies in July 2020, and the relative humidity was the historical minimum, indicating that the intraseasonal IPCO may inhibit the generation of typhoons by affecting the relative humidity.

6 Conclusion And Discussion

In this paper, the inhibitory effect of the intraseasonal IPCO on typhoon genesis in the “absence of typhoons” over the WNP in July 2020 is discussed. The high SST and small vertical wind shear over the WNP in July 2020 are conducive to typhoon genesis, indicating that it is difficult to explain the absence of typhoons from the conditions necessary for typhoon genesis. In contrast, the intraseasonal IPCO plays an important role in modulating the generation of typhoons during the boreal extended summer over the WNP (Wang et al. 2018). This unprecedented absence of typhoon is consistent with IPCO’s unique suppression of convection and the resulting large-scale circulation over the WNP. The influence of atmospheric circulation anomalies on typhoons, represented by GPI, was the lowest ever recorded. In July 2020, the intraseasonal IPCO turned negative, associated with a strong inhibition on convection over its WNP, leading to large-scale circulation differences and difficulty in generating typhoons.

Three possible ways that affect IPCO typhoon genesis are also presented. Figure 11 shows that the descending movement of the troposphere and low-level divergence were strengthened over the WNP in July 2020, weakening the upward lifting of low-level tropical disturbances and transport of water vapor and inhibiting the development of cumulus convection. Thus, the decrease in the release of latent heat of tropospheric condensation was not conducive to the formation of a typhoon warm-core structure and the development of a cyclone circulation with the increase in height. Due to the inhibition of cumulus convection, tropospheric heating increases by surface long-wave radiation and nonadiabatic heating along with a decrease in altitude, which makes the subtropical high southerly and stronger. This system inhibits the formation and development of typhoons. In addition, when the intraseasonal IPCO was in its negative phase, the following happened, namely: a) significant weakening of SCSMT intensity; b) increase in Rossby deformation radius by increase in the negative vorticity anomaly; c) increase in the response scale; and d) reduction in the efficiency of latent heat release into rotational motion. These are not conducive to the generation and development of tropical disturbances. On further employing GPI to examine the influence of large-scale circulation anomalies on typhoon genesis, the lowest on record was for July 2020, indicating the strongest suppression of typhoons in history. In general, the negative phase of the intraseasonal IPCO may be one of the main reasons for the extreme large-scale circulation anomalies, leading to the absence of typhoons over the WNP in July 2020.

This study provides an understanding of the absence of typhoons in July 2020 and the benefits of operational climate predictions of typhoon activity. Although this study implies that intraseasonal IPCO had an unprecedented inhibitory effect on typhoon in July 2020, various other factors affect its
formation. Wang et al. (2021) found that the extremely warm Indian Ocean SST plays an important role in the generation of abnormal anticyclones over the WNP and further leads to circulation anomalies and the absence of typhoons. The additional factors that are responsible for the absence of typhoons in July 2020 and the influence of other factors, such as ENSO and IOD, remain unknown and require further study.

Declarations

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Data availability

The NCEP–NCAR reanalysis data and interpolated OLR data were obtained from https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html. The best-track data for typhoon activity over the WNP by RSMC of JMA were obtained from http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hppub-eg/trackarchives.html.

Authors’ contribution

FL and JL contributed to the study conception and design. Material preparation, data collection and analysis were performed by FL. JL and HW analyzed and interpreted the physical mechanism of IPCO’s influence on typhoon formation. FL and YD analyzed the influence of IPCO on GPI. The first draft of the manuscript was written by FL, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

References

1. Anthes RA (1982) Tropical Cyclones: Their Evolution, Structure, and Effects. Meteor Monogr, No. 41, Amer Meteor Soc, 208 pp
2. Camargo SJ, Emanuel KA, Sobel AH (2007) Use of a genesis potential index to diagnose ENSO effects on tropical cyclone genesis. J Clim 20:4819–4834. https://doi.org/10.1175/JCLI4282.1
3. Camargo SJ, Wheeler MC, Sobel AH (2009) Diagnosis of the MJO modulation of tropical cyclogenesis using an empirical index. J Atmos Sci 66:3061–3074. https://doi.org/10.1175/2009JAS3101.1

4. Done J, Hu AX, Farmaer EC, Yin J, Bates S, Frappier AB, Halkides DJ, Kilbourne KH, Srimer R, Woodruff J (2009) The thermohaline circulation and tropical cyclones in past, present, and future climates. Bull Amer Meteor Soc 90:1015

5. Elsberry RL, Tsai HC (2016) Opportunities and challenges in the dynamical and predictability studies of tropical cyclone phases. In: Li JP (ed) Special Publications of the International Union. of Geodesy and Geophysics Series, vol 2. Cambridge University Press, pp 133–140

6. Emanuel K (2001) Contribution of tropical cyclones to meridional heat transport by the oceans. J Geophys Res 106:14771–14781

7. Holland GJ (1987) Mature structure and structure change. In: Elsberry RL et al (eds) A Global View of Tropical Cyclones. Office of Naval Research, pp 13–52

8. Lau KM, Chan PH (1986) Aspects of the 40–50-day oscillation during the northern summer as inferred from outgoing longwave radiation. Mon Wea Rev 114:1354–1367. https://doi.org/10.1175/1520-0493(1986)114,1354:AOTDOD.2.0.CO;2

9. Lee JY, Wang B, Wheeler MC, Fu X, Waliser DE, Kang IS (2012) Real-time multivariate indices for the boreal summer intraseasonal oscillation over the Asian summer monsoon region. Clim Dyn 40:493–509. http://doi.org/10.1007/s00382-012-1544-4

10. Li JP, Sun C, Jin FF (2013) NAO implicated as a predictor of Northern Hemisphere mean temperature multidecadal variability. Geophys Res Lett 40:5497–5502. https://doi.org/10.1002/2013GL057877

11. Li JP, Swinbank R, Grotjahn R, Volkert H (2016a) Dynamics and Predictability of Large-Scale, High-Impact Weather and Climate Phases. Special Publications of the International Union of Geodesy and Geophysics Series, vol 2. Cambridge University Press, p 370

12. Li JP, Wang QY, Li YJ, Zhang JW (2016b) Review and perspective on the climatological research of tropical cyclones in terms of energetics (in Chinese). J Beijing Norm Univ Nat Sci 52:705–713

13. Li Y, Li JP, Feng J (2012) A teleconnection between the reduction of rainfall in southwest western Australia and north China. J Clim 25:8444–8461. https://doi.org/10.1175/JCLI-D-11-00613.1

14. Li YJ, Li JP, Feng J (2013) Boreal summer convection oscillation over the Indo-western Pacific and its relationship with the East Asian summer monsoon. Atmos Sci Lett 14:66–71. https://doi.org/10.1002/asl2.418

15. Liebmann B, Smith CA (1996) Description of a complete (interpolated) outgoing longwave radiation dataset. Bull Amer Meteor Soc 77:1275–1277

16. Jiang X, Zhao M, Waliser DE (2012) Modulation of tropical cyclones over the eastern Pacific by the intraseasonal variability simulated in an AGCM. J Clim 25:6524–6538. https://doi.org/10.1175/JCLI-D-11-00531.1

17. Kalnay E, Coauthors (1996) The NCEP/NCAR 40-Year Reanalysis Project. Bull Amer Meteor Soc 77:437–471. https://doi.org/10.1175/1520-0477(1996)077,0437:TNYRP2.0.CO;2
18. Kepert JD (2010) Tropical cyclone structure and dynamics. In: Chan JCL, Kepert JD (eds) Global Perspectives on Tropical Cyclones: From Science to Mitigation. World Scientific Series on Asia-Pacific Weather and Climate, vol 4. World Scientific, pp 3–54
19. Madden RA, Julian PR (1972) Description of global-scale circulation cells in the tropics with a 40–50-day period. J Atmos Sci 29:1109–1123. https://doi.org/10.1175/1520-0469(1972)029,1109:DOGSCC.2.0.CO;2
20. Madden RA, Julian PR (1994) Observations of the 40–50-day tropical oscillation—A review. Mon Wea Rev 122:814–837. https://doi.org/10.1175/1520-0493(1994)122,0814:OOTDTO.2.0.CO;2
21. Niu HY, Liu M, Lu M (2011) Study on loss assessment of typhoon disaster in coastal areas of China. J Catastr 26:61
22. Pyper BJ, Peterman RM (1998) Comparison of methods to account for autocorrelation in correlation analyses of fish data. Can J Fish Aquat Sci 55:2127–2140. https://doi.org/10.1139/f98-104
23. Sun C, Li JP, Feng J, Xie F (2015) A decadal-scale teleconnection between the North Atlantic Oscillation and subtropical eastern Australian rainfall. J Clim 28:1074–1092. https://doi.org/10.1175/JCLI-D-14-00372.1
24. Wang C, Wu K, Wu LG, Zhao HK, Cao J (2021) What caused the unprecedented absence of western North Pacific tropical cyclones in July 2020? Geophys Res Lett 48. https://doi.org/10.1029/2020GL092282. e2020GL092282
25. Wang QY, Li JP, Li YJ, Zhang JY (2018) Modulation of tropical cyclogenesis location and frequency over the Indo-western North Pacific by the intra-seasonal Indo-western Pacific convection oscillation during the boreal extended summer. J Clim 31:1435–1450. https://doi.org/10.1175/JCLI-D-17-0085.1
26. Wang QY, Li JP, Li YJ, Xue JQ, Zhao S, Xu YD, Wang YH, Zhang YZ, Dong D, Zhang JW (2019) Modulation of tropical cyclogenesis tracks over the Indo-western North Pacific by the intra-seasonal Indo-western Pacific convection oscillation during the boreal extended summer. J Clim 52:913–927. https://doi.org/10.1007/s00382-018-4264-6
27. Wu L, Wen ZP, Wu RG (2015) Influence of the Monsoon Trough on Westward-Propagating Tropical Waves over the Western North Pacific. Part II: Energetics and Numerical Experiments. J Clim 28:9332–9349. https://doi.org/10.1175/JCLI-D-14-00807.1
28. Xie F, Li JP, Tian WS, Zhang JK, Sun C (2014) The relative impacts of El Niño Modoki, canonical El Niño, and QBO on tropical ozone changes since the 1980s. Environ Res Lett 9:064020. https://doi.org/10.1088/1748-9326/9/6/064020
29. Xue JQ, Li JP, Sun C, Zhao S, Mao JY, Dong D, Li YJ, Feng J (2018) Decadal-scale teleconnection between South Atlantic SST and southeast Australia surface air temperature in austral summer. Clim Dyn 50:2687–2703. https://doi.org/10.1007/s00382-018-4324-y
30. Zhang JW, Li JP, Li YJ (2015) Intraseasonal characteristics of the Indo–west Pacific convection oscillation (in Chinese). Chin J Atmos Sci 39:221–234
31. Zhao HK, Jiang X, Wu L (2015) Modulation of northwest Pacific tropical cyclone genesis by the intraseasonal variability. J Meteor Soc Japan 93:81–97. https://doi.org/10.2151/jmsj.2015-006

32. Zhao S, Li JP, Li YJ, Jin FF, Zheng JY (2019) Interhemispheric influence of Indo-Pacific convection oscillation on Southern Hemisphere rainfall through southward propagation of Rossby waves. Clim Dyn 52:3203–3221

33. Zhu BZ, Wang B (1993) The 30–60-day convection seesaw between the tropical Indian and western Pacific Oceans. J Atmos Sci 50:184–199. https://doi.org/10.1175/15200469(1993)050,0184:TDCSBT.2.0.CO;2

34. Zhu QG, Lin JR, Shou SW (2007a) Synoptic principles and methods (in Chinese). Meteorological Press, Beijing, pp 508–510

35. Zhu QG, Lin JR, Shou SW, Tang DS (2007b) Principles and Methods of Synoptic Meteorology (in Chinese). China Meteorological Press, p 649

**Figures**

**Figure 1**

The response function of the 30–60-day Lanczos bandpass filter. The filter has 305 weights and cutoff periods of 30 and 60 days.
Figure 2

Spatial patterns of (a) SST anomaly (°C) and (b) vertical wind shear anomaly (m s⁻¹) over the WNP in July 2020 (c) Location of typhoon and disturbance generation. The blue dots indicate the location of tropical disturbances, and the red dots indicate the location of typhoons.

Figure 3
Time series of areal-averaged (a) SST (°C) and (b) vertical wind shear (m s\(^{-1}\)) over the WNP (5°N–25°N, 110°E–160°E) from 1979 to 2020. Dashed lines indicate the climatological normal

**Figure 4**

Time series of IPCOI and areal-averaged OLR over the WNP (5°N–20°N, 110°E–160°E) from 1979 to 2020. Dots indicate the variables in those years that had minimum or maximum values over the study period
Figure 5

Composite difference in (a) 200 hPa divergence (s\(^{-1}\)), (b) 500 hPa vertical velocity (Pa s\(^{-1}\)), (c) 850 hPa divergence (s\(^{-1}\)), (d) 600 hPa relative humidity anomalies (%), (e) 500 hPa geopotential height anomalies (gpm), and vertical wind shear (m s\(^{-1}\)) between the positive and negative intraseasonal IPCO phases in July for the period 1979–2020. The stippled regions denote significance at the 99% confidence level using the Student's t-test. The black rectangle denotes the key areas of the intraseasonal IPCO over the WNP (5°–20°N, 110°–160°E)
Figure 6

(a) Composite map of the 850 hPa horizontal wind (streamline, m s\(^{-1}\)) and vorticity anomaly (shaded, s\(^{-1}\)) over the WNP in July for the period 1979-2020 for the positive intraseasonal IPCO phase. (b) As in (a), but for the negative intraseasonal IPCO phase. The black rectangle indicates the same as in Fig. 5

Figure 7

As in Fig. 5, but for the GPI

Figure 8

Anomalies of the (a) 850 hPa divergence (shaded, s\(^{-1}\)) and horizontal wind (vector, m s\(^{-1}\)), (b) 500 hPa vertical velocity (Pa s\(^{-1}\)), (c) 600 hPa relative humidity (%), (d) 500 hPa geopotential height (gpm), and (e) vertical wind shear (m s\(^{-1}\)) in July 2020. (f) The 850 hPa anomaly vorticity (s\(^{-1}\)) and horizontal wind (m s\(^{-1}\)) over the WNP in July 2020. Thick solid and dashed lines in (d) indicate the 5880 gpm isoline of 500 hPa geopotential height in July 2020 and climatological mean, respectively. The black rectangle indicates the same as in Fig. 5

Figure 9

Time series of areal-averaged 600 hPa relative humidity, 500 hPa vertical velocity and geopotential height, vertical wind shear, and 850 hPa absolute vorticity over the WNP (5°N–20°N, 110°E–160°E) in July. The opposite signs of geopotential height and vertical velocity are used here. Dots indicate that the variables in those years had the minimum value over the study period

Figure 10

(a) Anomalies of the GPI in July 2020. The red dots represent the generation location of typhoon from 1979 to July 2020. The black rectangle indicates the same as in Fig. 5. (b) Time series of areal-average GPI anomalies over the WNP (10°N–25°N, 110°E–160°E) in July. Dot indicates that the variable in that year had the minimum value over the study period
Figure 11

The schematic diagram showing the inhibition of the intraseasonal IPCO on typhoon generation in July 2020