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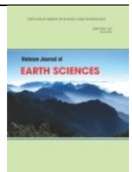

Effects of jetstream on seasonal variations of tropical cyclone tracks in the East Sea

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ABSTRACT

Tropical cyclones (TCs) frequently occurs and result in substantial socio-economic consequences for the countries around the East Sea. In this study, the Joint Typhoon Warning Center (JTWC) best tracks and the NCEP/NCAR reanalysis data are employed to investigate the effect of jetstream on the seasonal variations of the TC tracks. The results reveal four primary directions of the tracks: northeastward, northwestward, westward and southwestward. A low-level anomalous cyclone moving from the Western North Pacific (WNP) to the Indochina Peninsula (IP) plays a significant role in guiding the movement of the TCs. This anomalous cyclone is strongly modulated by the development of a wavetrain along the subtropical jetstream. In May, the wavetrain induces strong anomalous divergence to the east of China, leading to the northeastward expansion of the low-level anomalous cyclones, thereby directing the TCs to the northeast. From June to August, the jetstream shifts to higher latitudes, reducing its impact on the TC tracks. From September to December, the jetstream moves back to the south; however, its effect on the TC tracks is opposite to that in May. During this time, the wavetrain accelerates an anomalous anticyclone in Southeast China and the Western North Pacific, which in turn pushes the anomalous cyclone to the south and promotes westward and southwestward movement of the TCs in the East Sea.

Keywords: Tropical cyclone track, the East Sea, intraseasonal oscillation, jetstream, wavetrain, Western North Pacific, monsoon trough, subtropical high.

1. Introduction

The East Sea is located in the transitional region of three monsoon systems and it is frequently influenced by tropical cyclones (TCs) (Ding, 2007; Chen et al., 2017; 2020). The TCs might originate locally in the East Sea or traverse into the sea from the Western North Pacific (WNP) (Ling et al., 2016). From 1950–2010, there is an average of 10.3 TCs impacting the East Sea annually (Wang et al., 2007; Chen et al., 2017), resulting in substantial socio-economic consequences. Therefore, exploring the controlling factors of the TC tracks becomes of utmost importance, offering valuable tools in TC forecasting.

While the TCs can occurs in the East Sea throughout the year, the majority of them concentrate in the period from midsummer to fall. The TCs tend to form in the southern basin of the East Sea in May then shift northward in the following months. From September to December, the forming locations of the TCs shift back to the southern basin of the East Sea (Wang et al., 2007). This change

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in forming locations is found to be consistent with the seasonal fluctuations of sea surface temperature, humidity and the southward propagation of monsoon trough over the East Sea. Other studies (Lee et al., 2006; Lin and Lee, 2011) emphasized the important role of vertical wind shear in the TC genesis in the East Sea. They suggested that strong vertical wind shear prohibits TC formation during May to June, while decreasing vertical wind shear, caused by the weakening of northeasterlies creates a favorable environment for TC development during November to December., creates a favourable environment for the TC development during November to December.

In addition to the changes in the forming location, TC tracks also exhibit clear seasonal variations. Fudeyasu et al. (2006) pointed out that the typical paths of westward-propagating disturbances originating from typhoons over the WNP tend to move more southward from summer to fall. Chen et al. (2020) divided the tracks of the TCs forming in the East Sea into four major paths: a northeastward path towards the Philippines and Taiwan, a northward path heading for southern China, and a westward-northwestward trajectory towards the Indochina Peninsula and southwestern China. In May, the dominant track type is northwestward but it switches to a west-northwestward direction in June. From July to September, the TC track changes to west-northwest and north, finally settling on west-northwest from October to November.

Large-scale circulation is generally considered the primary factor modulating the TC movements. This fundamental concept serves as the basis for the development of various TC forecasting schemes (Riel and Shafer, 1944; Miller and Moore, 1960). In a comprehensive study, Chan and Gray (1982) pointed out that the direction and speed of TCs exhibit their highest correlations with winds at the levels of 700, 600, and 500 hPa. Typically, the TCs tend to move approximately 10–20° to the left of the surrounding wind within around 600-kilometer radius from the TC center. Additionally, the TCs also exhibit faster moving, approximately 1 m s^{-1} compared to the surrounding mid-troposphere wind. Other factors deflecting the TCs from the steering flow include the Coriolis force (the beta effect) and the horizontal vorticity gradient of the surrounding flow (Rossby, 1948; Holland, 1983; 1984; Wu and Wang, 2000; Chan, 2005). In short-term forecasts, state-of-the-art dynamical models adeptly predict large-scale circulations, leading to a notable improvement in predicting TC tracks over recent decades.

In the WNP region, steering flows associated with monsoon trough and Western Pacific Subtropical High (WPSH) are the controlling factors modulating TC movements (Harr and Elsberry, 1993; 1995; Chen et al., 2009). Chen et al. (2009) showed that straight moving TCs are associated with the intensification of the WPSH while recurving TCs are related to the deepening of the monsoon trough. Lander (1996) emphasized that there are two distinct patterns of the monsoon trough, each associated with a different type of the TC tracks. In normal conditions, the monsoon trough extends southwestward from the northern part of the Indochina Peninsula (IP) to Guam, and the TCs tend to move northwestward, along the southern periphery of the WPSH. In some specific periods, the axis of the monsoon trough might reverse, becoming southwest to northeast oriented. In such cases, the TCs are steered more northward and they might interact with other TCs along the trough axis. From a long-term perspective, Nakazawa and Rajendran (2006) pointed out that the circulation over the WNP can be characterized by two dominant modes: the first mode is linked to the ENSO while the second one is related to the fluctuations of the WPSH. When the WPSH moves westward, the TCs are driven more straight to the west and when the WPSH retreats eastward, the TCs tend to recurve northward toward Japan.

Recently, there has been significant attention towards subseasonal forecasting of tropical cyclone activities (Xiang et al., 2022). This extended forecasting enables early preparation, notably minimizing potential loss of life and property. The dominant factors controlling TCs on this timescale are intraseasonal oscillations (ISO) in the tropics. Gray (1985) and Miller et al. (1988) showed that two typically types of TC tracks (straight-moving and recurving TC tracks) tend to occur at different periods of time in a season, implying the influence of intraseasonal oscillation (ISO) on the TC tracks. Harr and Elsberry (1991) emphasized the association between these track types and specific anomalous large-scale circulation patterns. Further research has affirmed that the TCs tracks over the WNP are predominantly governed by ISO. For instance, Kim et al. (2008) showed that more eastward (westward) TCs tracks occur in the phases when the convection is enhanced near the equatorial Indian Ocean (tropical WNP). Li and Zhou (2013) observed that during the active phase, the TCs tend to move westward and northwestward, while in the inactive ISO phase, the TC tracks shift towards the recurving type. Yang et al. (2014) provided further insights, showing that eastward-moving TCs often appear during the most active phases of ISO (specifically, phases 5-6), when associated anomalous westerly winds override the background easterly flow. In contrast, westward-moving TCs tend to occur during the weaker active phases of ISO (phases 3–4), when the anomalous westerlies are insufficient to overcome the prevailing easterly background winds.

While the ISO in the tropics is considered the major source of predictability for TCs at the subseasonal timescale, it is important to emphasize that the ISO in the East Sea is significantly influenced by Rossby waves along the upper-level jetstream (Tuan, 2019; Compo et al., 1999). Understanding the impact of these waves on TCs might provide a basis for evaluating the capability of models in simulating and predicting the subseasonal variability of TCs. Therefore, our objective is to identify the effect of the Rossby waves along the jetstream on the variations of TC tracks. Section 2 describes the data and methodology, and findings are presented in Section 3. Finally, the study concludes with summarized results in Section 4.

2. Data and methodology

2.1. Data

The 6-h data from the Joint Typhoon Warning Center (JTWC) best tracks (Chu et al., 2002) are employed to investigate the characteristics of the TC passing through the East Sea region. The seasonal changes in large-scale circulation are illustrated by using atmospheric data from the NCEP-DOE reanalysis 2, obtained from NOAA/OAR/ESRL PSL, Boulder, Colorado, USA (Kanamitsu et al., 2002). The reanalysis data are provided at a 2.5°×2.5° latitude-longitude resolution, and the climatological mean of each atmospheric variable is computed in the period from 1990 to 2020.

2.2. Methodology

The composite technique is a popular method for determining the specific large-scale patterns associated with each type of TCs tracks (Harr and Elsberry, 1991; Chen et al., 2017; 2020). However, this method has limitations, as the resulting patterns only comprise the time sections during the storm periods; therefore, they do not completely describe the seasonal characteristics of large-scale circulation. Furthermore, the use of the composite technique also leads to the contamination due to the superposition of many TCs circulations at the same time (Harr and Elsberry, 1991). Therefore, regression is employed in this study as an alternative method to address these issues.

At first, anomalies circulation is derived by subtracting the u- and v-component winds by their first three harmonics. A detailed description of the harmonic analysis can be found in the study by Kristina and Sultan (1989). To assess the influence of large-scale circulation on the TC tracks, the average of 700 hPa anomalous vorticity in the East Sea region (108–120°E, 5–22°N) is calculated (Fig. 1). It is expected that the positive anomalous vorticity will drive the TC anticlockwise, while negative values produce the opposite effect. The anomalous vorticity is preferred over geopotential height because the latter exhibits weak gradients in tropical regions. We elucidate the characteristics of the large-scale patterns associated with changes in anomalous vorticity through regression analysis each month. Here, the average anomalous vorticity serves as the dependent variable, and anomalous wind and geopotential height serve as independent variables. Days -3, 0, and +3 indicate the lagged days on which the dependent variable is regressed on the independent variables. Since these regressed fields are computed using data from entire days of each month, they offer a reasonable representation of the seasonal variation of large-scale circulation. Importantly, these regressed fields are not contaminated by the superposition of multiple TCs because they donot only include the time sections during the storm periods.

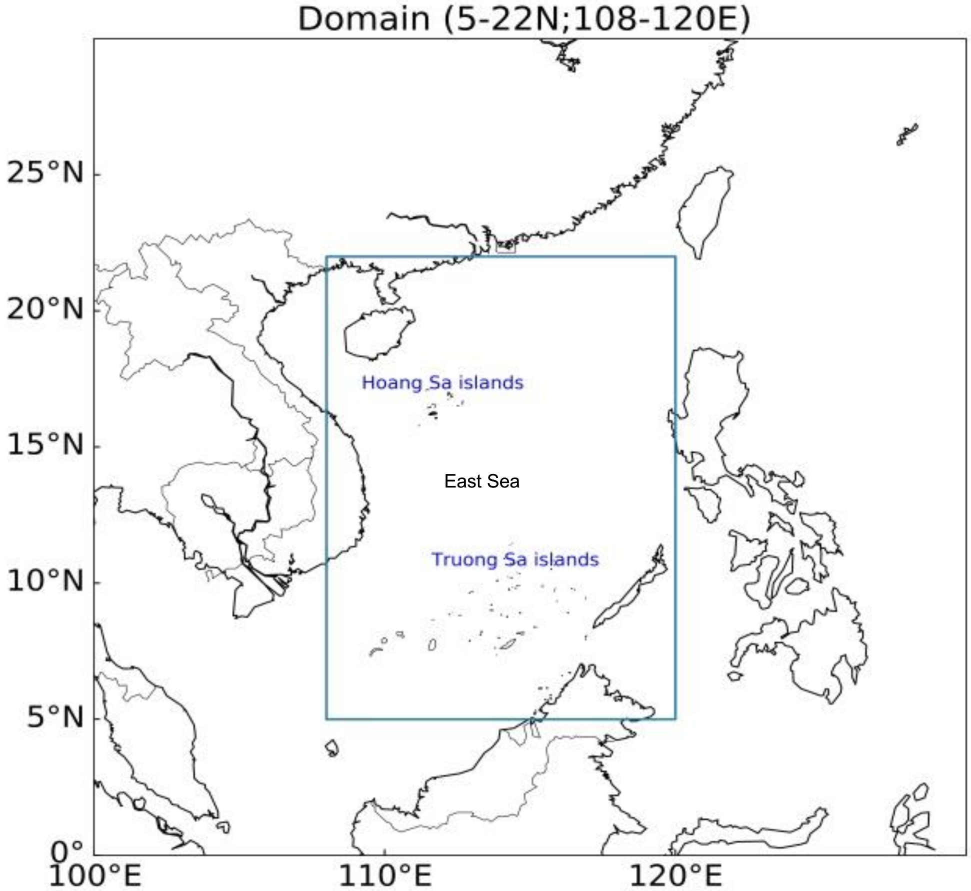

Figure 1. The East Sea domain for calculating the anomalous vorticity is marked by rectangular box

3. Result

3.1. Seasonal variation of the TC traversing the East Sea

Figure 2 displays the patterns of formation locations and tracks of the TCs for each month during the period 1991-2020. It is evident, the formation locations exhibit significant variations throughout the year. In May, the number of the TCs is relative small and most of them originate in the southern basin of the East Sea and WNP. The number of TCs increases rapidly in the following months, accompanied by a northward shift in formation locations. The TC genesis reaches its northernmost locations around the latitude of 20°N in August. During this time, the number of TCs generated locally in the East Sea becomes comparable to that in the WNP. As fall approaches, the formation locations shift back to southern areas, with notable changes in the proportions of local and non-local TCs. By October, non-local TCs rapidly outnumber their local counterparts. From November to December, approximately 90 percent of the TCs originate in the remote areas of the WNP.

The TC track patterns also exhibit distinct seasonal variations. In May, the TCs move in a northeastward direction towards Taiwan and the East China Sea (Fig. 2a). While two TC initially form outside the East Sea with northwestward directions, they are later steered northeastward after entering the East Sea. Progressing from June to August, the prevailing tracks switch to a northwestward direction, heading towards the Southern China and Northern Vietnam (Figs. 2b–d). From September to October, the tracks patterns become more diverse, characterized by various directions (Figs. 2e–f). While the majority of the TCs follow a northwestward or westward path, some TCs still move northeastward and westward during this period. Divergent track patterns persist from November to December with a significant proportion of TCs moving southwestward; however, some northwestward paths are still observed during this time (Figs. 2g–h).

3.2. Seasonal variation of large-scale circulation

The seasonal variations of large-scale circulation are investigated to explor their relationships with the TC tracks (Fig. 3 and Fig. 4). The circulations at the levels of 700 hPa and 500 hPa were chosen because they are considered the most significant factors influencing TC tracks (Chan and Gray, 1982). In May, the southern regions of the East Sea are influenced by a weak anticyclonic circulation associated with the WNPH which can be illustrated by the geopotential height line of 3160 m (Fig. 3a). Meanwhile robust southwesterly winds prevail in the northern areas, that is principally related to the extratropical system. In June, the southwesterly winds expand further into the East Sea even though the WNPH remains unchanged (Fig. 3b). Transitioning into July, the subtropical high retreats northeastward, concurrent with the southeastward expansion of a monsoon trough across the East Sea. Consequently, southwesterly winds establish and dominat the entire East Sea (Fig. 3c). The withdrawal of the WNPH is more noticeable at the 500 hPa level (Fig. 4). From August to September, the monsoon trough orients more zonally, and noticeable southwesterly winds are only observed in the southern areas of the East Sea. In the northern areas, the wind is relatively weak. By October, the WNPH rapidly extends westward, reversing the low-level circulation from southwesterly to northeasterly winds. The WNPH continues to deepen and extend southward in the following months, enhancing the northeasterly winds across the East Sea.

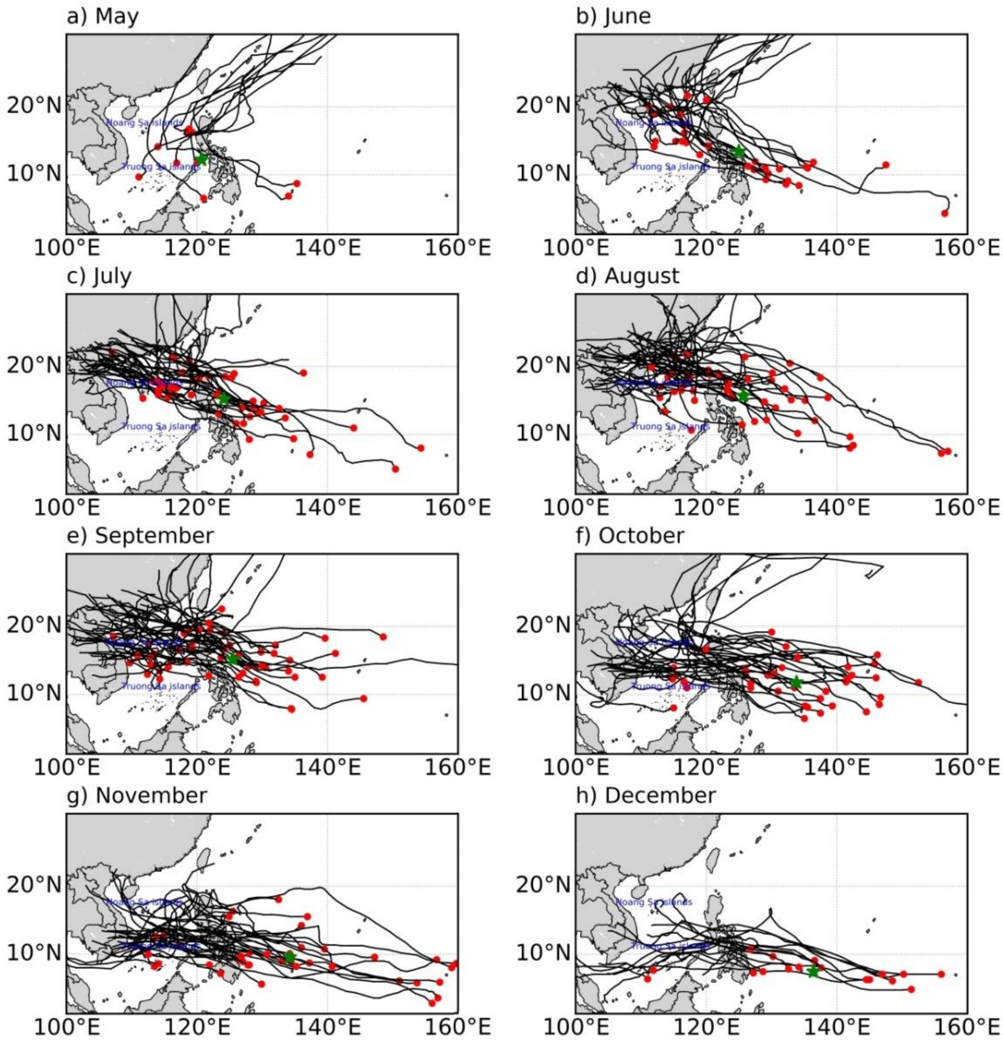

Figure 2. Track distribution of the TCs affecting the East Sea from May to December in the period of 1991–2020. The star symbol indicates the average position of tropical cyclone formation

The TCs are generally generated along the monsoon trough and the southern periphery of the WNPH (Chen et al., 2017); therefore, their formation locations are consistent with the seasonal migrations of these systems. However, the relationships between the TC tracks and the climatological mean of the large-scale flows are not evident. For instance, during June to August, the monsoon trough deepens, significantly enhancing southwesterly winds over the East Sea; however, the TCs primarily move northwestward during this time. In September, when the southwesterly wind weakens considerably, the prevailing tracks are still northwestward and westward. Moving into October to December, the westward expansion of the WNPH induces strong northeasterly winds in the northern East Sea, which might align with the southwestward movements of the TCs. However, it remains unclear why some TCs continue propagating northwestward or even northeastward during this time.

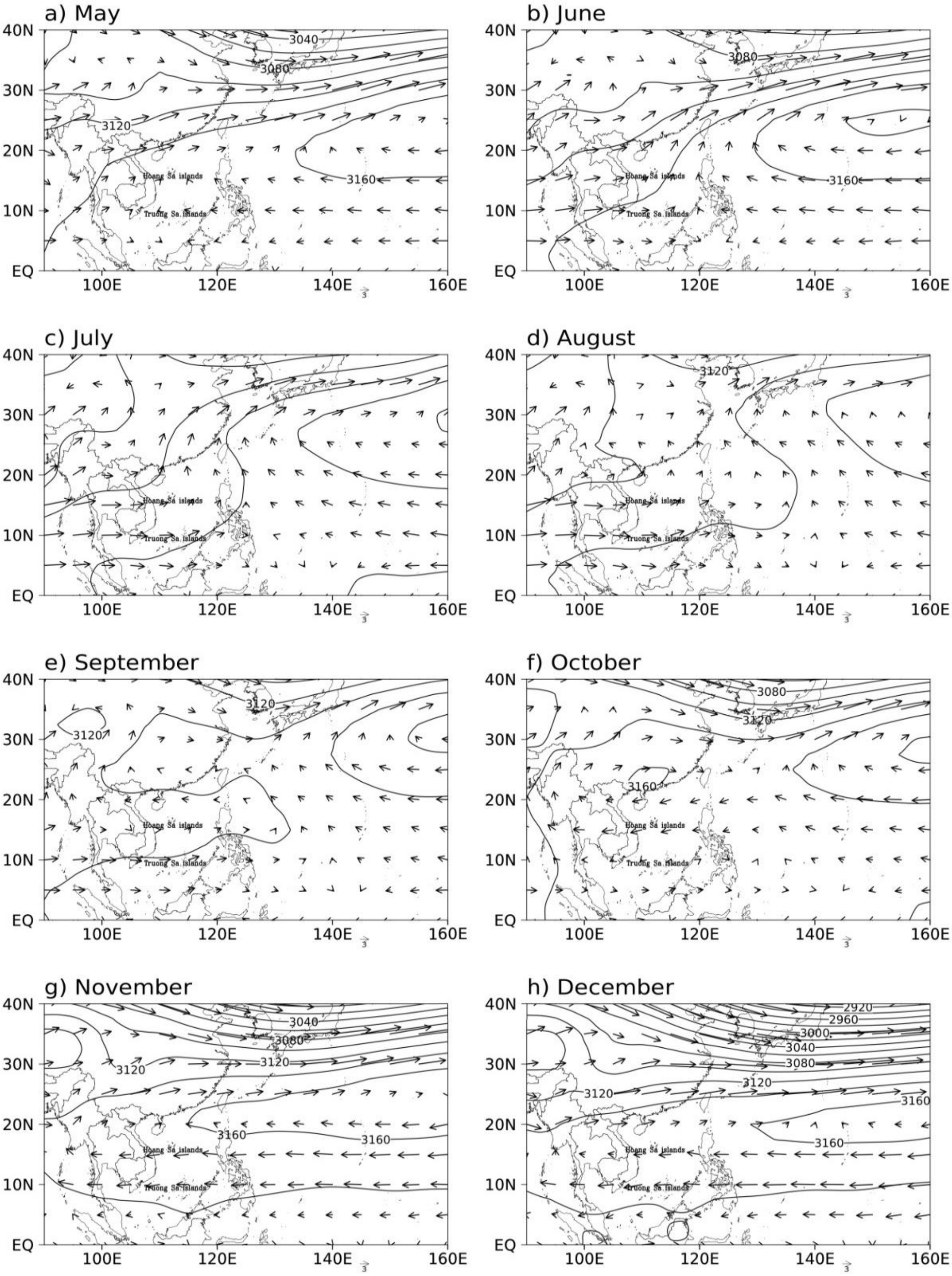

Figure 3. Climatology monthly mean of 700 hPa geopotential height (contour, *m*) and wind (vector, $m\ s^{-1}$) in the period of 1991–2020

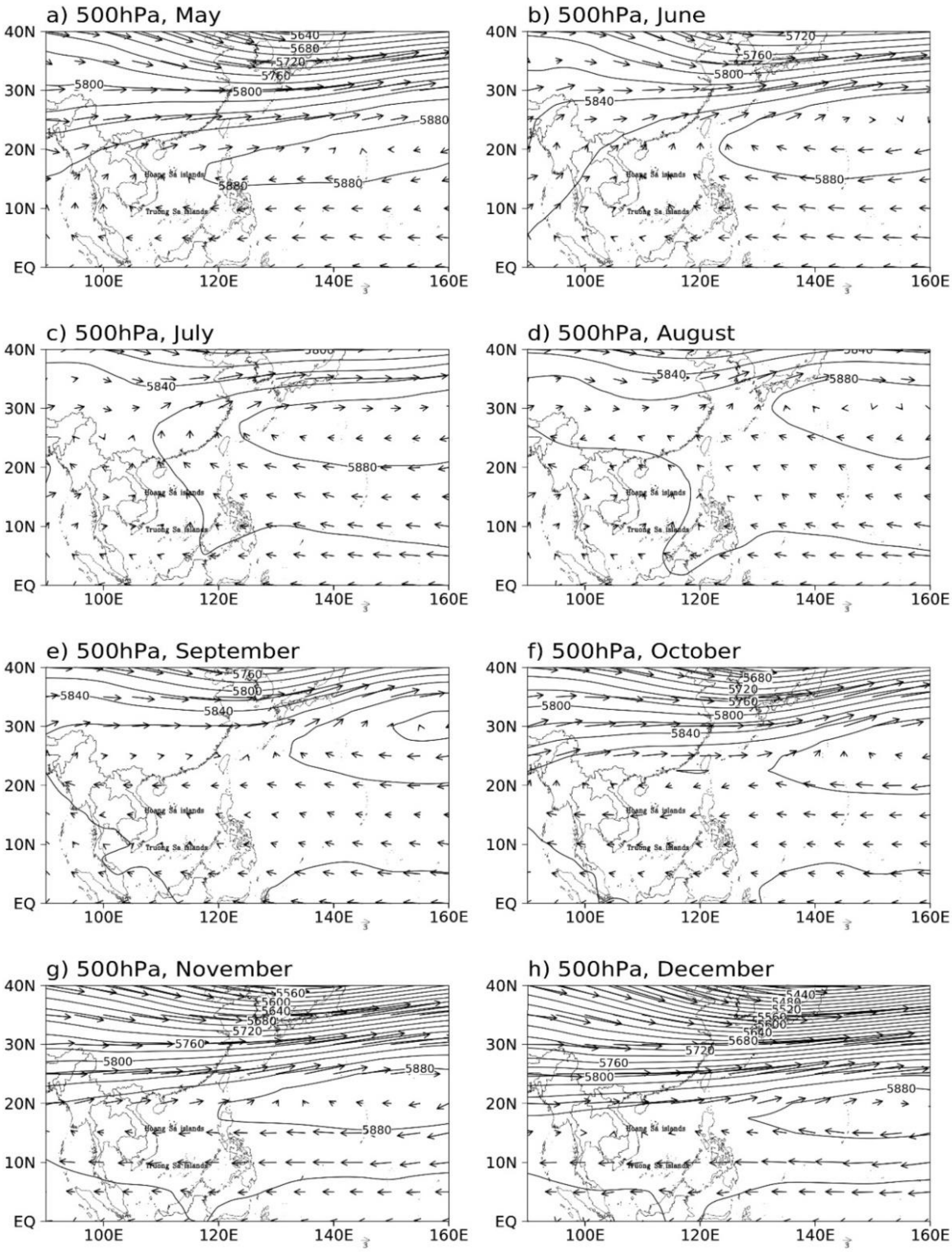

Figure 4. Same as Fig. 3, except for 500 hPa

3.3. Associated large-scale anomalous pattern

As revealed in previous studies (Harr and Elsberry, 1991; Chen et al., 2017; 2020), anomalous circulations are considered important factors contributing to the variabilities of tropical cyclone (TC) tracks. In this study, the associations between anomalous circulation and TC tracks are re-investigated using the regressed method. To identify the dominant modes of the anomalous relative vorticity over the East Sea, power spectrum density analysis is applied to the average variable within the region of 108–120°E, 5–22°N from May to December (Fig. 5). It can be observed that the spectrum of the anomalous vorticity displays significant year-to-year variability. However, three spectral peaks that exceed the 95% confidence level are clearly observed, that is associated with periods of 6 days, 14 days and 20 days. Spectral peaks with periods greater than 25 days are not statistically significant, implying weaker activities of ISO modes greater than 25 days. This observation is also consistent with Tuan (2019), indicating that the ISO in the East Sea is principally depicted by submonthly variations.

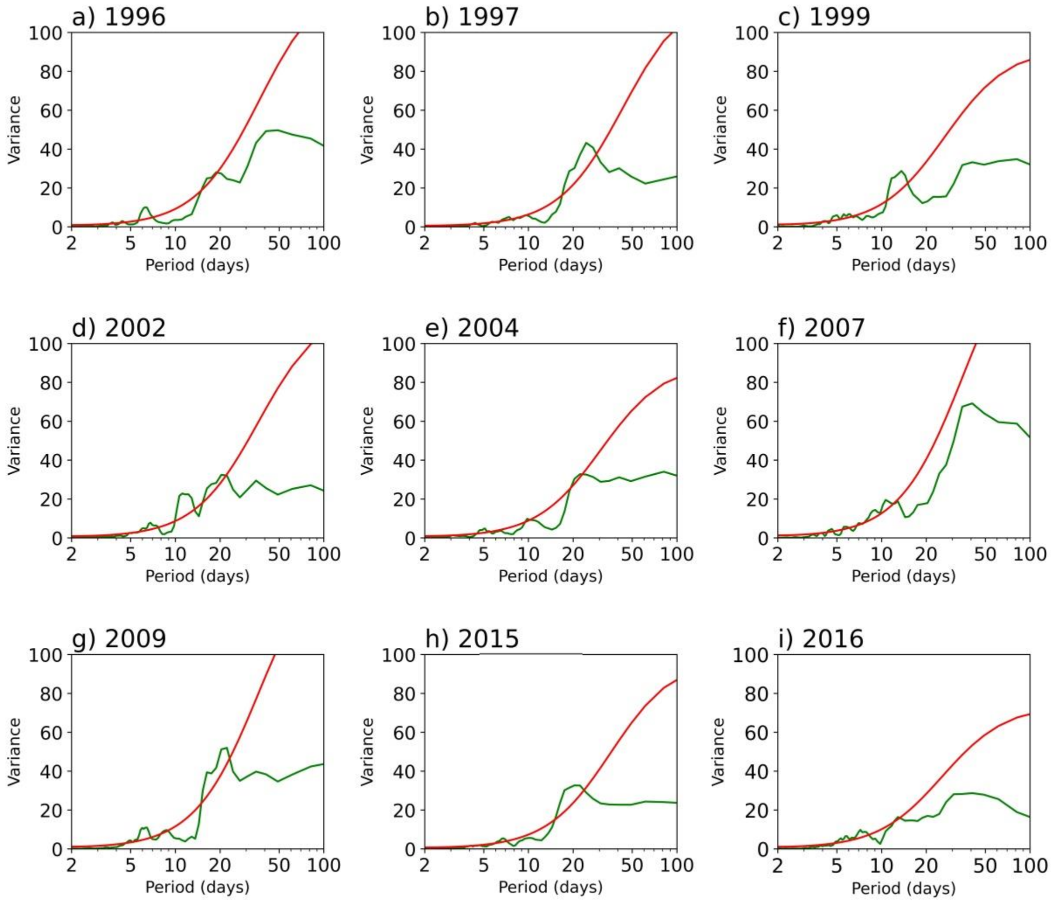

Figure 5. Power spectral density of the anomalous vorticity over the East Sea from May to December (green line) and the red line indicates statistical significance at the 95% level

The anomalous circulation patterns regressed on the anomalous vorticity in each month are displayed in the Fig. 6 and 7. To highlight the significant, only the anomalous winds exceed the 95% significance threshold are plotted. A common feature observed among these regressed patterns is a northwestward propagation of a synoptic-scale cyclonic anomaly from the WNP towards the IP. On day -3, the center of the anomalous cyclone is found over the northern areas or the west of the Philippines. Moving to day 0, the anomalous cyclone dominates over the East Sea and it then affects the northern IP on day -3. Along the westward propagation of the anomalous cyclone, anomalous westerly wind is significantly enhanced to the south of it, consistent with the interaction between convection and circulation (Gill, 1980). Note that, the anomalous cyclone moves slower and more northwestward oriented in summer than in fall, that is potentially linked to the influence of extratropical factors.

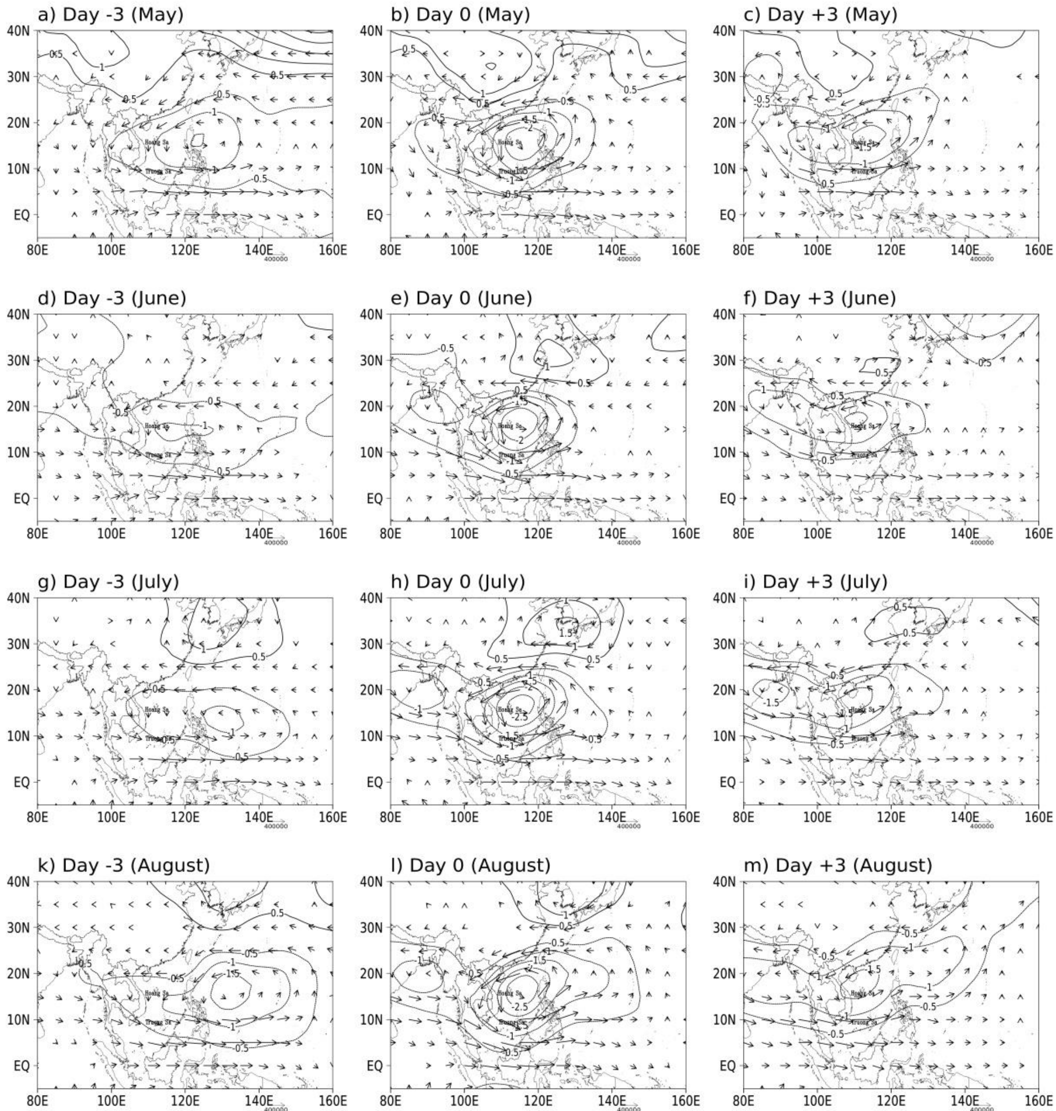

Figure 6. 700 hPa anomalous wind (vector, $m\ s^{-1}$) and geopotential height (contour, *m*) regressed on the anomalous vorticity from May to August during 1991–2020

In May, the anomalous cyclone exhibits slow movement (Figs. 6a–c) while the TCs are primarily generated in the southern basin of the East Sea (Fig. 2a). As a result, the TCs are steered in a northeastward direction, following their surrounding flows in the southeast of the anomalous cyclone. It is worth emphasizing that, while moving westward, the anomalous cyclone also expands slightly to the northeast from day -3 to 0, maintaining strong anomalous northeasterly wind to the southeast (Figs. 6a–c). Even on day 3, the anomalous low-level flow is still observed over the Philippines despite the anomalous cyclone already approaching northern Vietnam. The prevalence of the anomalous northeasterly wind increases the likelihood of northwestward movement for the TCs in this period, explaining for the distinct patterns of the TC tracks in May.

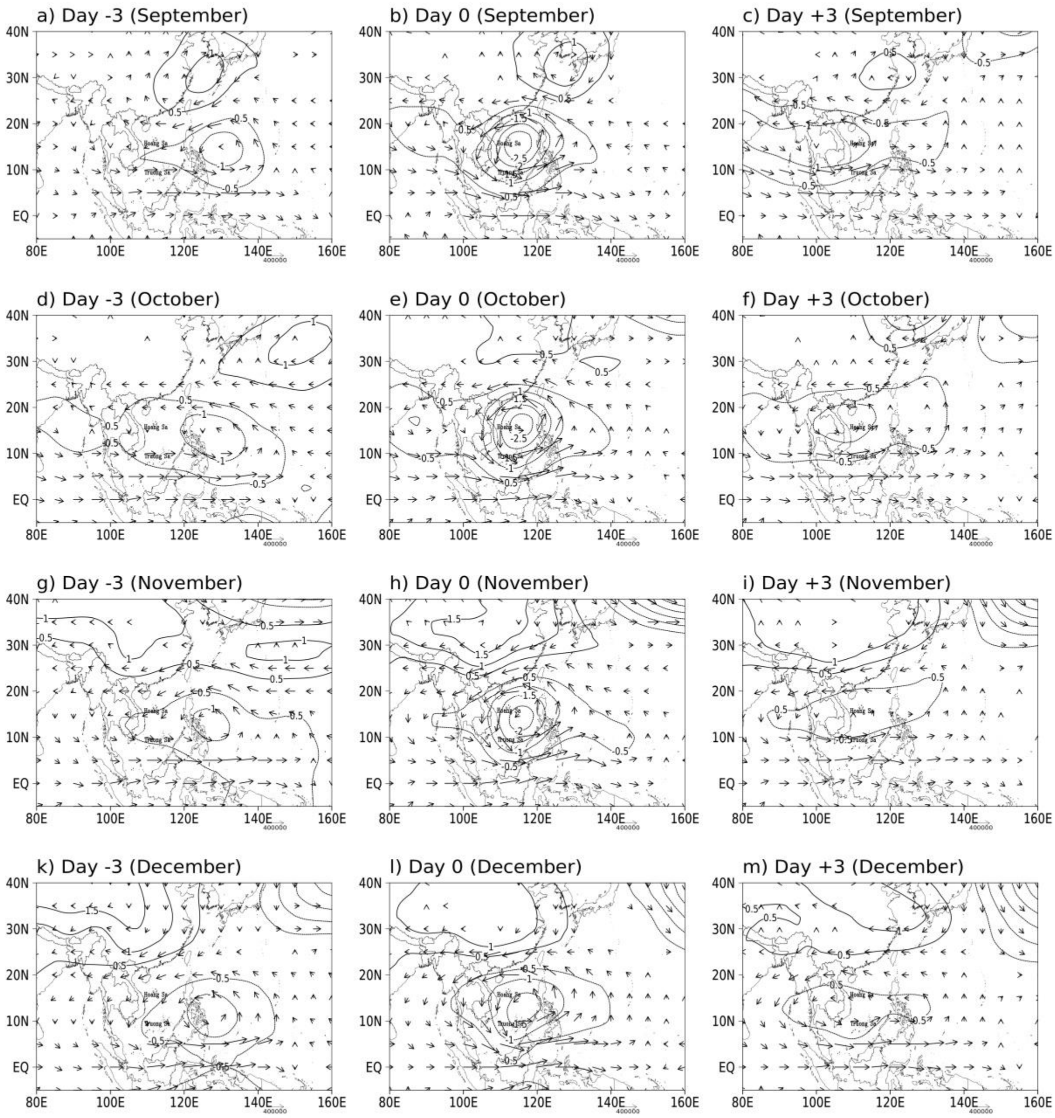

Figure 7. Same as Fig. 6, except for September to December

From June to August, the anomalous cyclone primarily moves northwestward while the TCs are generated in the oceanic regions of higher latitudes. Consequently, the TCs typically move northwestward, guided by the southeasterly wind towards the northern part of the anomalous cyclones. Additionally, since the formation locations of the TCs are relatively close to each other during this period, they are influenced by the similar steering flows; therefore, resulting in relatively uniform TC paths (Figs. 2 b–d). Note that, there is a presence of an extratropical anomalous anticyclone over the east China, which restrains the TCs from propagating too far northward (Figs. 6e–f, g–i). However, this extratropical anomalous anticyclone tends to shift northward from June to August, promoting a more northerly movement of the anomalous cyclone the TCs over the East Sea.From September to December, TCs are generated in lower latitudes while the synoptic-scale anomalous cyclone direction is primarily westward instead of northwestward as in the previous months. This change aligns with the southward migration of the anomalous anticyclone in the extratropic. As winter approaches, the extratropical anomalous anticyclone gains strength, exerting more influence and pushing the anomalous cyclone further southward (Figs. 7g–m). Therefore, the TCs are principally steered in the westward and southwestward directions, following the cyclonic circulation in the northern part of the anomalous cyclone. However, the formation locations of the TCs are much farther apart, and the anomalous cyclone moves faster than that in the previous months. Consequently, the TCs display a wider range of directions due to the different effects of the anomalous cyclone. The TCs forming far from the East Sea tend to enter the East Sea after the anomalous cyclone and are steered northwestward towards the Southern China and Northern Vietnam. On the other hand, locally formed TCs in the East Sea tend to move westward or southwestward following the cyclonic circulation.

3.4. Effect of upper-level jet stream

The subtropical jetstream plays a role as a waveguides for upper-level Rossby wave (Hoskins and Ambrizzi, 1993). The wavetrain, in turn, exerts influence on lower weather conditions through both barotropic modes (Tuan 2019; Compo et al. 1999) that means an anomalous low (high) upper-level pressure is associated with a low (high) pressure at lower levels. The upper-level wavetrain typically propagates eastward along the jetstream but the Tibetan Plateau deflects the low-level wavetrain southward (Tuan, 2019). Therefore, despite the East Sea being situated far to the south of the jetstream, the low-level wavetrain still impacts its weather conditions. In this study, the upper-level anomalous circulations are regressed on the anomalous relative vorticity in East Sea to explore how the wavetrain affect the anomalous circulation in the East Sea. By establishing this connection, we aim to uncover how the TC tracks are modulated by the seasonal variations of the jetstream.

In May, the jetstream expands in a wide range of latitudes, from 20°N to 40°N, that is close to the East Sea regions (Fig. 8a). An eastward-moving wavetrain along the jetstream is clearly observed, marked by alternating patterns of anomalous cyclone and anticyclone. Simultaneously, there is another eastward-propagation wavetrain originating from Kazakhstan, that is associated with polar jetstream (Tuan, 2019). These two wavetrains eventually merge with each other over the southeast China and the WNP, resulting in strong cyclonic and anticyclonic circulations. In the region between these to anomalous cyclone, specifically over the East China Sea (120–140°E; 15–25°N), the wind diverse significantly on day 0 and day +3 (Fig. 8b, c) due to the intensification of the wind to the north of the regions. This upper-level divergent wind probably induces ascending motion and favors the development of anomalous cyclone at the lower levels, that effectively accounts for the northeastward expansion of the synoptic-scale anomalous cyclone in the East Sea in May, as illustrated in Fig. 6c.

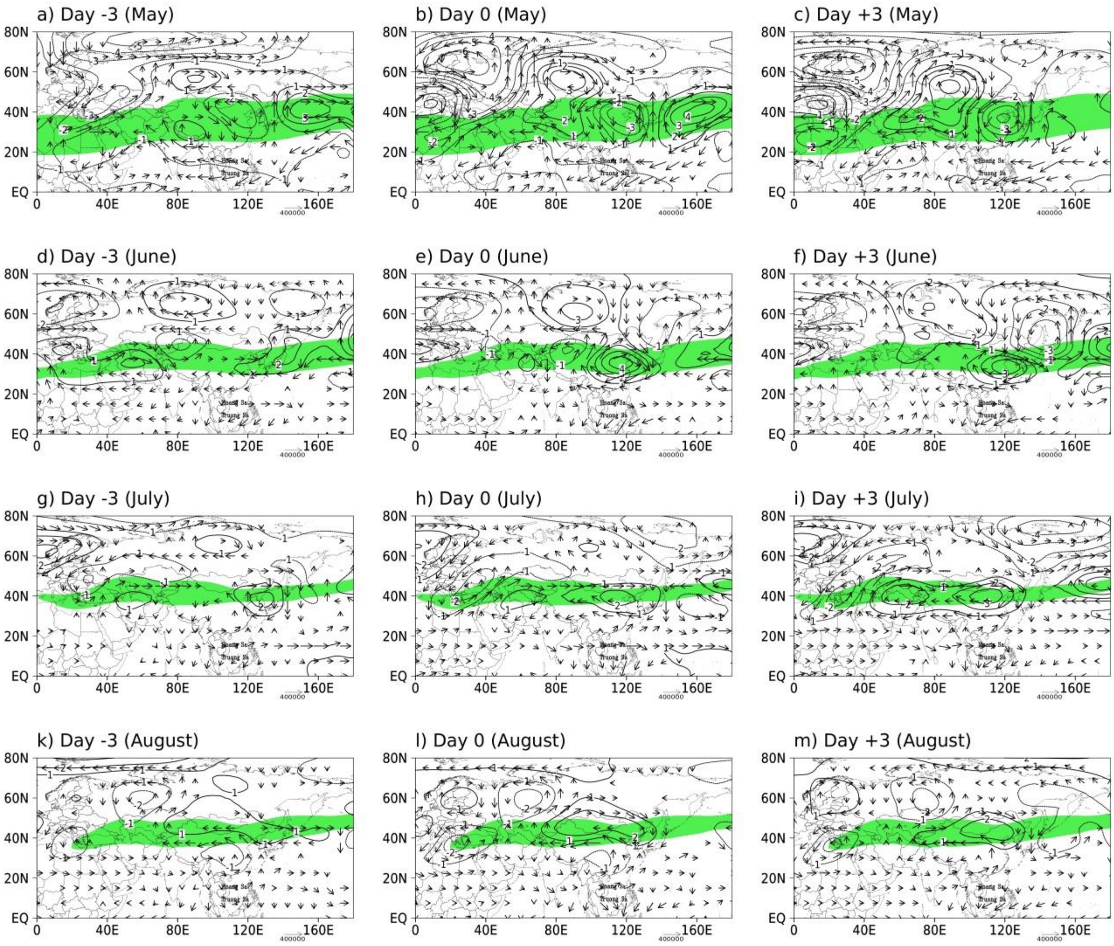

Figure 8. 200 hPa anomalous wind (vector, *m* s^{-1}) and geopotential height (contour, *m*) regressed on the anomalous vorticity from May to August. The shaded areas indicating the regions of zonal wind speed at higher 20 m s^{-1}

From June to August, the rise in surface temperatures across the Eurasian continent diminishes the air temperature difference between extratropical and tropical regions. As a result, upper-level horizontal pressure gradient weakens (Figure not shown), resulting in the narrowing down and the northward propagation of the jetstream. While the wavetrain along the subtropical jetstream is still observed, its effect on the TC tracks is not as directly as in May. As the wavetrain moves eastward, an upper-level anticyclonic circulation is generated over the East China from day 0 to day 3 (Figs. 8 e, f, h, i, l, m). At the lower levels, another anticyclonic circulation is also induced due to the barotropic nature of the wavetrain (Figs. 6 e, f, h, i, l, m). The lower-level anticyclonic circulation strengthens the anomalous easterlies over the southern China, that help to direct the TCs westward as discussed in the previous section. Note that, the effect of the Tibetan Plateau on the wavetrains is minimal as the jetstream predominantly resides to the north of the plateau in this period.

From September to December, the cooling of the Eurasian continent enhances the upper-level pressure gradient, leading to the southward movement and meridional expansion of the jetstream. However, the effect of the wavetrain on the TC tracks is opposite compared to that in May. A most important feature of the upper-level patterns in this period is the enhancement of an anomalous anticyclone over the southeast China and WNP (Figs. 9 e, f, h, i, l, m). As winter approaches, the anomalous anticyclone become more prominent and extends farther to the northern East Sea. This development of the upper-level anomalous anticyclone is associated with a formation of an anomalous anticyclone at lower levels, as mentioned in the previous section (Figs. 7 e, f, h, i, l, m). Note that, due to the influence of the Tibetan Plateau, the upper and lower anomalous anticyclones are out of phase, resulting in incomplete overlap between them. The low-level anomalous anticyclone, in turn, pushes the pre-existing anomalous cyclone over the East Sea further southward. Therefore, the TCs are mostly steered in the westward and southwestward directions in this period.

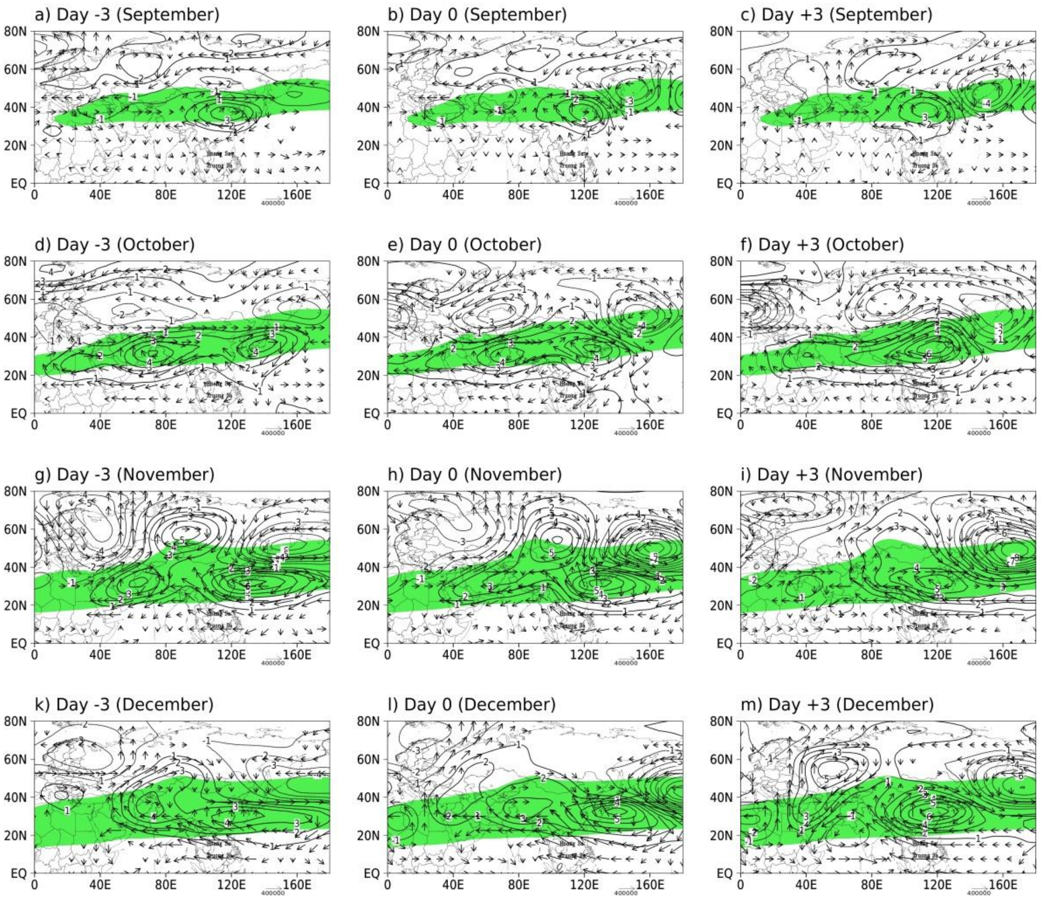

Figure 9. Same as the Fig. 8, except for September to December

4. Discussions

Previous studies employed a composite technique to explore the characteristics of large-scale circulation associated with specific TC track type (Harr and Elsberry, 1991; Chen et al., 2020). The composite patterns typically represent averaged patterns from the formation days of the TCs. Their findings highlighted the presence of a synoptic-scale cyclonic anomalies over the East Sea with distinct cyclonic patterns varying among different TC track types. It is important to note, however, that the cyclonic anomalies are essentially induced the superposition of many TCs circulations at the same time. Therefore, the centers of the the cyclonic anomalies are nearly coincident with the locations where the TCs are generated. These contaminated patterns lead to difficulty in identifying how the steering flows drive TC movement. Chen et al. (2020) suggested that the anomalous vorticities propagate in different directions, guiding the TCs along different movements. This argument is evidently not reasonable, as the movements of the resulted cyclonic anomalies apparently aligned with the TC tracks, as determined by constructing composite.

Our regressed fields are computed using data spanning a 31-year period, ensuring that anomalous circulation is unaffected by the overlapping presence of multiple TCs. As a result, a totally different mechanism in which the TCs are modulated by the anomalous circulation is pointed out. First, the anomalous cyclones do not propagate in multiple directions as suggested by Chen et al. (2020) but only propagate westward/northwestward (Fig. 5 and Fig. 6). This feature is more consistent with previous studies on the characteristics of the submonthly oscillations over the East Sea (Tuan 2019; Mao and Chan 2005). Second, the TC tracks depend on the relative positions of the TCs to the anomalous cyclones, rather than directly following the anomalous cyclone's movements. When the TCs are located to the south or southeast of the anomalous cyclones, they tend to move northeastward. Conversely, if the TCs are situated at the center or the northern parts of the anomalous cyclones, they are driven northwestward and westward.

The regressed fields also revealed how the TC tracks are modulated by the extratropical wavetrains along the jetstream, helping to explain the seasonal variations of the TC tracks. Broadly, the evolutions of the wavetrains lead to the formation of anomalous anticyclonic cyclones over the East China. As a result, low-level anomalous anticyclonic cyclones are generated at lower levels due to the barotropic nature of the wave. In turn, the anomalous circulation intensifies low-level easterly wind over the northern East Sea, steering the TCs northwestward. From October to December, the jetstream moves further to the south, driving the anomalous cyclone and the TCs more westward and southwestward. In a different manner, the wavetrain triggers the northeastward expansion of the anomalous cyclones over the East Sea, leading to the northeastward tracks of the TCs in May. Although this statistical approach with a limited sample size might introduce uncertainties, it enhances the understanding the sources of TC predictability at the subseasonal timescale. The findings offer a basis to identify the weaknesses of dynamical models in simulating and predicting TC activities. To reinforce the conclusions, the dynamical simulation of the effect of the jetstream on the TCs is absolutely needed in future studies.

5. Conclusions

In this study, the effect of the jetstream on the movements of the TCs in the East Sea is investigated using TCs track data from JWCM and NCEP/NCAR reanalysis data. Our focus is on how the wavetrain along the jetstream influences the lower-level circulation, which in turn affects the TC tracks. The main findings are as follows:

The TC tracks in the East Sea display clear seasonal variations. In May, the TCs typically move northeastward toward Taiwan and the East China Sea. From June to August, the TCs tend to move northwestward towards the southern China and northern Vietnam. From September to December, direction of the TC tracks becomes more divergent witha large number of TCs moving westwards and southwestwards while some TCs propagate northwestward heading towards the northern Vietnam.

In general, the TCs in the East Sea are steered by the circulation associated with the anomalous cyclones propagating from the WNP to the IP. However, the particular TC path depends on the TC formation location and the development of the wavetrain along the jetstream. In May, the wavetrain induces an anomalous cyclone over the east of China, leading to the northeastward expansion of the pre-existing anomalous circulation over the East Sea. Therefore, the TCs are directed northeastward towards Taiwan and the East China Sea. From June to August, the jetstream shifts to higher latitudes and the wavetrain does not directly affect the TC tracks. From September to December, the jetstream moves back to the south, but its effect is opposite to that in May. During this time, the anomalous anticyclones are enhanced over the southern China and WNP pushing the anomalous cyclone over the East Sea southward. As a result, the TCs tend to move westward and southwestward during this period.

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