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MODULATION OF TC GENESIS OVER THE NORTHWESTERN PACIFIC BY ATMOSPHERIC INTRASEASONAL OSCILLATION

TIAN Hua (田　华)[1, 2], LI Chong-yin (李崇银)[1, 3], YANG Hui (杨　晖)[1]

(1. LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029 China; 2. Graduate University of Chinese Academy of Sciences, Beijing 100049 China; 3. Institute of Meteorology, PLA University of Science and Technology, Nanjing 211101 China)

Abstract: The influence of intraseasonal oscillation (ISO) on TC genesis over the northwestern Pacific is studied through comparing analyses of the more and less TC years from 1979 to 2006. It is indicated that the ISO strongly affects the TC genesis. In the years for more TC genesis, the ISO is weak and propagates insignificantly in the area to the west of the Philippines, but the ISO is strong in the area to the east of the Philippines and propagates significantly northwestward. In this situation, the Walker cell shifts gradually westward from the tropical western Pacific to the tropical eastern Indian Ocean. Convergent winds appear in the lower atmosphere while divergent winds in the upper atmosphere, suggesting the presence of enhanced ascending flow over the 140–160°E region and a favorable condition for TC genesis. Moreover, in the years for less TC genesis, the ISO gradually becomes stronger in the area to the west of the Philippines and significant eastward propagation prevails from the eastern Indian Ocean to the area around 120°E; the ISO is weak in the area to the east of the Philippines. During these years, the Walker circulation gradually moved eastward, with convergent winds in the upper troposphere and divergent winds in the lower troposphere. Sinking motion was significant, unfavorable for the TC genesis over the Northwestern Pacific.

Key words: tropical intraseasonal oscillation (ISO); influence; TC genesis; composite analysis

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1 INTRODUCTION

The atmospheric intraseasonal oscillation (ISO) was discovered at first in the wind and pressure fields over the tropics by Madden and Julian[1, 2], so that sometimes the ISO in the equatorial atmosphere is called the Madden-Julian oscillation (MJO). The ISO, as a phenomenon or circulation with intraseasonal time scale (30-60 days) in the atmosphere, is regarded as an important system of atmospheric circulations. Because of the structural features and regular activity, ISO will have significant impacts on the weather and climate via the activity and anomaly. The ISO has drawn much of our attention in recent years because its time scale (month to season) is closely related to long-term weather and short-term climate variations. Some studies showed that the onset of the Asia-Australian monsoon, East Asian summer monsoon activity and precipitation anomalies are all modulated by the ISO[3, 4], which also plays a certain role in the occurrence of ENSO[5, 6].

Gray[7] indicated that the occurrence of tropical cyclones (TCs) has different phase features, with an active stage being about 1 to 2 weeks and an inactive stage for 2 to 3 weeks between two active stages. This periodicity of TC activity brings more attention to the impact of intraseasonal variability (such as MJO) on TCs. There are some studies for the relationship between the TC and atmospheric ISO. For example, Nakazawa[8] indicated that most TCs over the Western Pacific are easy to develop during the wet phase of the MJO. Liebmann et al.[9] found that most TCs over the Western Pacific and the Indian Ocean occur in the wet phase, suggesting an important, though not crucial, influence of the MJO on TC occurrence. Maloney et al.[10] divided the phase of MJO based on the filtered zonal wind at 850 hPa for 20–80 days and found that the number and intensity of hurricanes over the east part of the Northern Pacific are all modulated by the MJO. For the named tropical systems, the number of genesis for westerly anomalies at 850 hPa is twice

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Corresponding author: TIAN Hua, e-mail: tianhua@mail.iap.ac.cn

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as many as that in easterly anomalies at the same level, but with stronger intensity. Sobel et al.[11] showed that there is more wave energy in the active phase of the MJO. Through the wave energy flux tropical disturbances can be enhanced into TCs; Hall et al.[12] studied the relationship between TC activity around Australia and the MJO. They found that the MJO plays an important role in the development of TCs. The number of TCs forming in the active period of the MJO is obviously more than that in the inactive period. Bessafi et al.[13] analyzed TCs over the southern Indian Ocean and found that TCs tend to occur over the southern Indian Ocean to the west of 100°E during the active phase of the MJO. The study about TC occurrence over the Mexican Gulf and Caribbean Sea regions also came to the same conclusion[14]. By analyzing TCs over the western Pacific and Indian Ocean, Zhu et al.[15] found that more than half of them occur in the wet phase of the eastward propagating MJO except over the northwestern Pacific, while the occurrence of TCs over the Northwestern Pacific is affected by both eastward and westward propagating MJO. Wang et al.[16] analyzed the influence of summer monsoon variation on the TC genesis and found that the summer monsoon also has obvious impacts on TC development over the Northwestern Pacific through the atmospheric intrseasonal oscillation.

The TC occurs over the Northwestern Pacific most frequently. China is one of the countries affected greatly by the TC in the world. In China, there are a series of studies on the TC over the Northwestern Pacific[17-19]. Recently, studies on the influence of the ISO on TCs mainly focus on the ISO phase. The study about the influence of ISO's interannual variation on TC occurrence is relatively rare. Moreover, in tropical atmosphere the ISO is mainly an eastward propagation in winter. In summer[20] , however, there are three propagation cases: the eastward propagation along the equator, the northward propagation over the Indian monsoon / East-Asian monsoon regions, and westward propagation outside the equator[21-23]. It remains unclear whether or not the different propagating features of the ISO have different impacts on the TC occurrence. In this study, we investigate the influence of the MJO intensity on the TC occurrence over the Northwestern Pacific from an interannual variation point of view. Meanwhile, the relationship between the propagation of the ISO and the TC occurrence over the Northwestern Pacific is analyzed. Some possible reasons and mechanisms are also discussed.

2 DATA

The atmospheric circulation data were obtained from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR, USA) and the reanalysis daily data. Data used in the study include sea level pressure, geopotential height, and horizontal wind velocity. All of these variables are at 2.5°×2.5° grids (from 1979 to 2006). The TC data compiled by the Joint TC Warning Center (JTWC) were also used. The data include TC center position and the maximal wind speed available every six hours. When the wind speed of a TC is $\geqslant$34 m/s (64 km/h), the time and position of the cyclone are defined as the growth time and position of the TC. The Outgoing Longwave Radiation (OLR) data used were retrieved from National Oceanic and Atmospheric Administration (NOAA, USA), covering the period of 1979 to 2006.

In order to study the influence of the intensity of ISO on the genesis number of TCs over the Western North Pacific on an interannual scale, an ISO index is defined. The index can describe both the intensity and space distribution of TCs. Two approaches are used to describe the intensity of atmospheric ISO activity. One is to use the band-pass filtered wind data (u', v') to calculate the ISO kinetic energy $K=(u'^2+v'^2)/2$[24, 25]; the other is to calculate the deviation contribution of the kinetic energy[26, 27]. We used the band-pass filtered wind data to calculate the deviation. The deviation has the maximum value at middle latitudes, which is not consistent with the real circulation. In order to avoid this disadvantage in describing the ISO intensity, the radio of ISO deviation to the total deviation (that is, deviation contribution) was used.

Three indices were used to describe the intensity of the ISO: the ISO kinetic energy at 850 hPa, the deviation contribution of ISO zonal wind at 850 hPa, and the deviation contribution of OLR. In this study, the band-pass filter was used to display the 30-60 day low-frequency oscillation because the main intraseasonal variation of tropical circulation has a 30-60 day period[28, 29]. The ISO kinetic energy, ISO deviation and total deviation were averaged from June to October to represent the situation in the TC season.

According to the genesis number of TCs over the Western North Pacific from June to October against an absolute value of 0.7 (normalized deviation), we screened out 1992, 1993, 1994, 1996, 1997, 2001 and 2004 as the years of more TCs and 1979, 1981, 1983, 1988, 1998, 1999 and 2006 as the years of less TCs. A composite study in the following sections is based on the above screening. Figure 1 delineates the growth TC numbers over the Western North Pacific in the TC season (June to October) from 1979 to 2006.

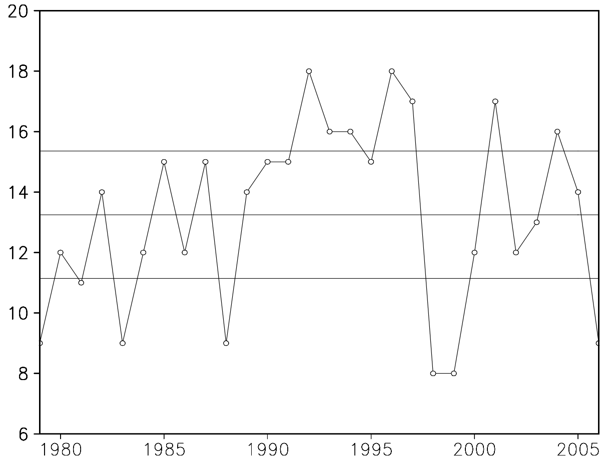

Figure 1. TC numbers over the western North Pacific in June–October from 1979 to 2006.

3 CIRCULATION CHARACTERISTICS OF TC GENESIS

3.1 *Sea surface temperature in the WNP*

Figures 2a and 2b show the composite sea surface temperatures (SSTs) in the Western North Pacific (WNP) averaged from June to October for the years of more and less TCs respectively. For the year of more TCs, the 29°C contour moves eastward to the longitude at about 160°W. By contrast, in the year of less TCs, the 29°C contour only arrives at about the International Date Line (IDL). Although the SSTs in the Western Pacific satisfy the thermal condition for TCs developing into typhoons in both of the more and less TC years, the eastward expansion of the warm pool is apparently favorable to the growth of TCs. The maximum difference in SSTs between the more and less TC years is not in the WNP, but in the tropical Pacific. For the more TC years, the SSTs in the Western Pacific to the west of 150°E are lower than those for the less TC years. The growth number of TC over the WNP bears a significant positive correlation with the SST in the middle Pacific. The positive correlation coefficients are dominant to the east of 140°E. The association between the number of TCs over the WNP and SSTA is consistent with the SST difference between the more and less TC years. This means that the SST in the Western Pacific has significant impacts on TC genesis.

In general, the SSTs in the Western Pacific satisfy the thermal condition for TC genesis. The interannual variation of the number of TCs over the WNP is mainly dependent on the dynamical condition of TC growth and development provided by the air-sea interaction, which is related to the activity of ISO and monsoon troughs over the tropical Pacific.

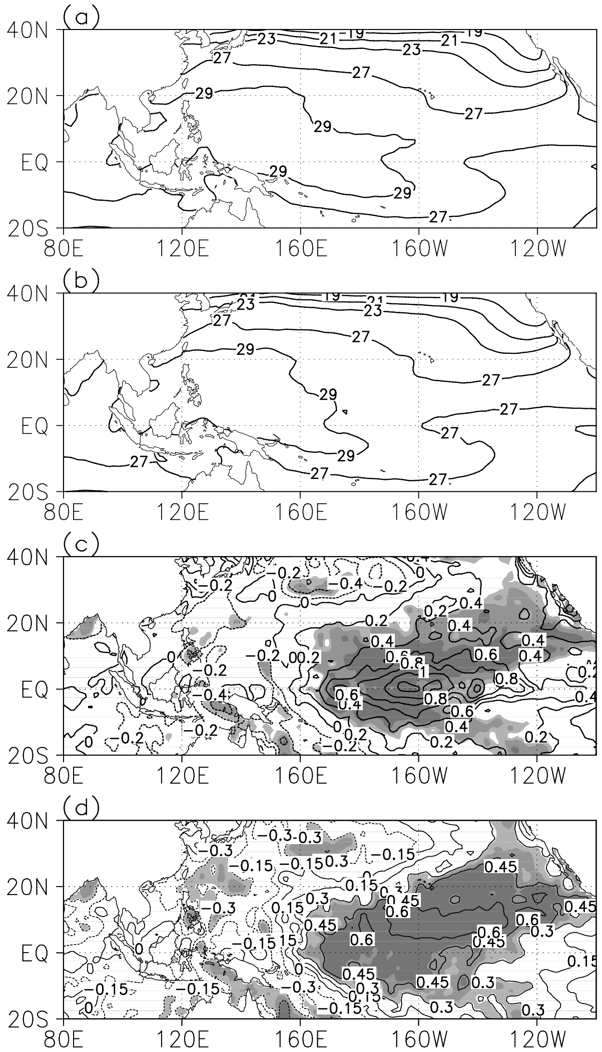

Figure 2. The composite SST in the Western North Pacific (WNP) averaged from June to October; a: more TCs years; b: less TCs years; c: more TCs years minus less TCs years. d: distributions of the correlation between SSTA and TC genesis in WNP. Areas with 95% (99%) confidence level are with dark (light) shades, treated similarly hereinafter.

3.2 *Atmospheric circulation*

The monsoon trough over the WNP is a convergence zone (i.e. the ITCZ) formed by the southeasterly wind at its southern side and the easterly wind at its northern side. It has clear cyclonic vorticity, which facilitates the development of initial disturbances into TCs. Figure 3a shows the composite wind field at 850 hPa during June to October for the more TC year. It can be seen that the monsoon trough in the direction of northwest-southeast stretches to 150°E. The subtropical high in the Western Pacific region is weaker and situated eastward and northward. In contrast to the more TC year, the eastern end of the monsoon trough withdraws westward in the less TC year (Figure 3b). The curvature of the trough is unclear. The subtropical high over the Western Pacific is stronger and situated westward and southward. Comparing the position of the TC growth, we found that TCs form mainly in the monsoon trough at the southwest side of a subtropical high over the Western Pacific. Both the monsoon trough and the position and intensity of the subtropical high over the Western Pacific have great impacts on the TC growth. In the more TC year, quite a number of TCs form in the area from 150°E to 170°E for the more TC year (Figure 3a); while in the less TC year, TCs generally form in the area to the west of 150°E (Figure 3b).

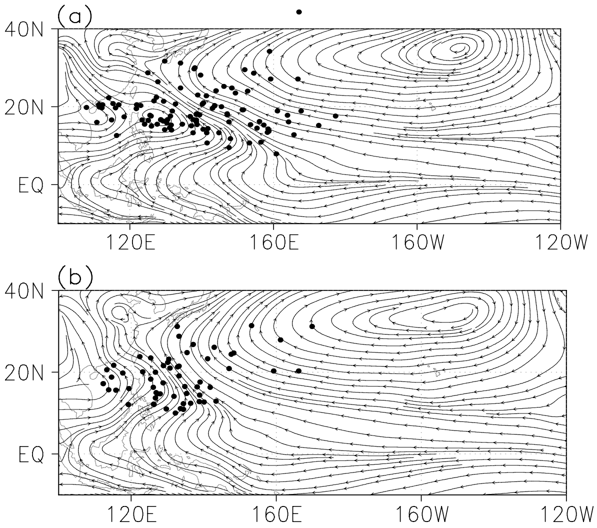

Figure 3. The composite wind field at 850 hPa during June–October for the (a) more and (b) less TC years. The dark spots are the locations of TC genesis.

4 INTENSITY OF TROPICAL ISO AND TC GENESIS

In order to study the modulation of ISO in TC genesis, we made composite analyses of the low-frequency kinetic energy anomalies at 850 hPa for the more and less TC genesis years and found a distinct difference between them. In the years of more TC genesis (Figure 4a), there are two regions with large positive values. The most prominent one locates from the east of the Philippines to the south of 15°N, which is just the location of the monsoon trough. This means that strong low-frequency activity can enhance the monsoon trough and is favorable for the TC genesis. In addition, the low-frequency kinetic energy anomalies are also positive over the Indian Ocean south of the equator, but the intensity is much weaker. The low-frequency kinetic energies in most regions north of the equator (from the Indian Peninsula to the South China Sea) are similar to those in the normal years. Negative anomalies occur locally, suggesting that the low-frequency activities are similar to that in the normal years but weaker in local areas. The situations for the less TC genesis yeas are just the opposite (Figure 4b). There are large values of low-frequency kinetic energy from the east part of the Arabian Sea to the south part of the South China Sea, indicating abnormal activities of the low-frequency oscillation. By contrast, in the western North Pacific east of the Philippines and the monsoon trough areas are negative anomalies of low-frequency kinetic energy and weaker low-frequency oscillations. The differences figures between the more and less TC genesis years highlight the different distribution of low-frequency kinetic energy. There is a dipole mode of low-frequency kinetic energy in the tropics of North Hemisphere. The prominent negative value regions show much weaker low-frequency activity in the years of more TC genesis from the east part of the India Peninsula to the South China Sea. The positive value areas are located in the WNP around 130°E to 170°E, indicating that the activities of low-frequency oscillation in monsoon troughs play an important role in TC genesis. The positive value center in the east part of the southern Indian Ocean may imply an association between the Indian Ocean Dipole and TC genesis but further studies are necessary for validation.

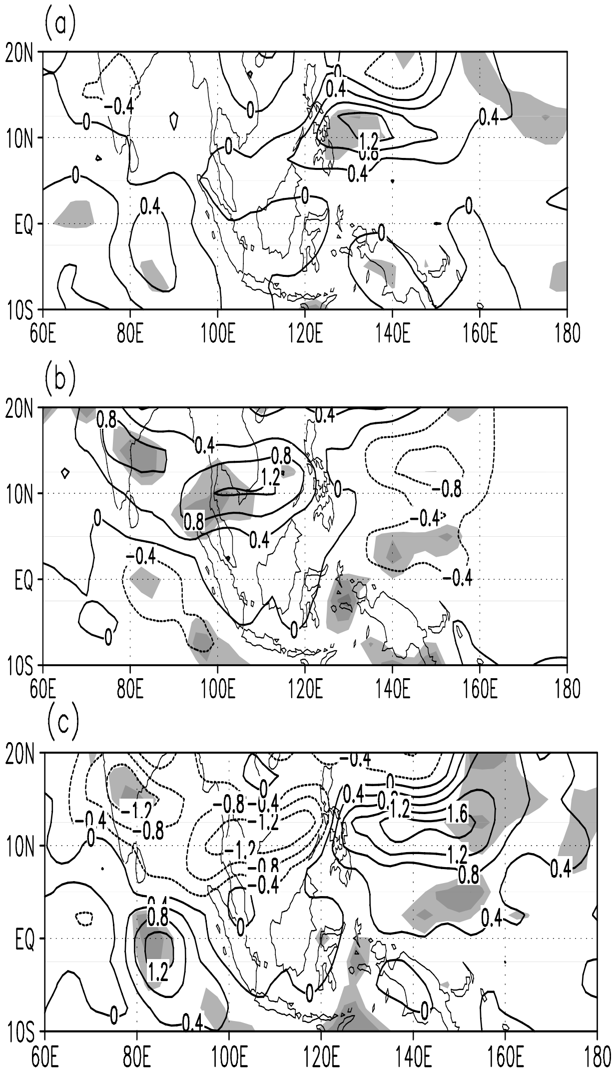

Figure 4. 850 hPa low-frequency kinetic energy for the years of more (a) and less (b) TC genesis and their difference (c).

From the time-longitude sections of the low-frequency kinetic energy averaged from 5°N to 15°N during June to October (Figure 5), we can see that the low-frequency kinetic energy is strong in the region to the east (west) of 120°E for the years of more (less) TC genesis. In the years of more TCs (Figure 5a), there are positive kinetic energy anomalies in the area to the east of 120°E and they usually occur from June to October (much obvious during June, early July, and September, but relatively weak during late July and early August). In the years of less TCs (Figure 5b), strong kinetic energy is noticeable in the area to the west of 120°E during the entire TC season, especially in the monsoon area to the west of 120°E in September.

The variance contributions of 850-hPa low-frequency zonal wind and OLR are used as the indexes to describe the intensity of ISO. The indexes show the proportion of the low-frequency activity to the overall change. Figures 6a and 6b are the variance contribution anomalies of 850-hPa low-frequency wind in June to October. For the years of more TC genesis (Figure 6a), the positive region of zonal wind variance contribution is in the WNP to the east of 120°E, with the maximum being around 10°N in 120°E to 140°E. This pattern indicates that the intensity of low-frequency wind is stronger than the one in the normal years (most remarkable in the areas east of the Philippines). The negative values are mostly in the areas west of 120°E and north of the equator. The negative region around 60°E to 80°E is above the 90% significance level, indicating weaker intensity of low-frequency wind in the years of more TCs. However, for the years of less TC genesis (Figure 6b), there are negative anomalies of low-frequency wind variance contribution over the WNP to the east of 120°E. The anomalies around 135–160°E to the north of the equator show that the weight of low-frequency wind is weaker than the one in the normal years. There are positive anomalies in areas to the west of 120°E and to the north of the equator. The anomalies in areas to the east of the Indian Peninsula indicate stronger weights than normal. The distributions of variance contribution of OLR are similar to that of low-frequency wind. For the years of more TC genesis (Figure 6c), there are two large value variation regions of OLR variance contribution: one is over the WNP; the other is near the equator around 120–140°E. The negative regions are located in the areas to the west of tropical Indian Ocean, indicating weaker low-frequency convection there. For the years of less TC genesis (Figure 6d), the low-frequency convection is active in the areas to the east of 120°E but is not in the areas to the west of 120°E.

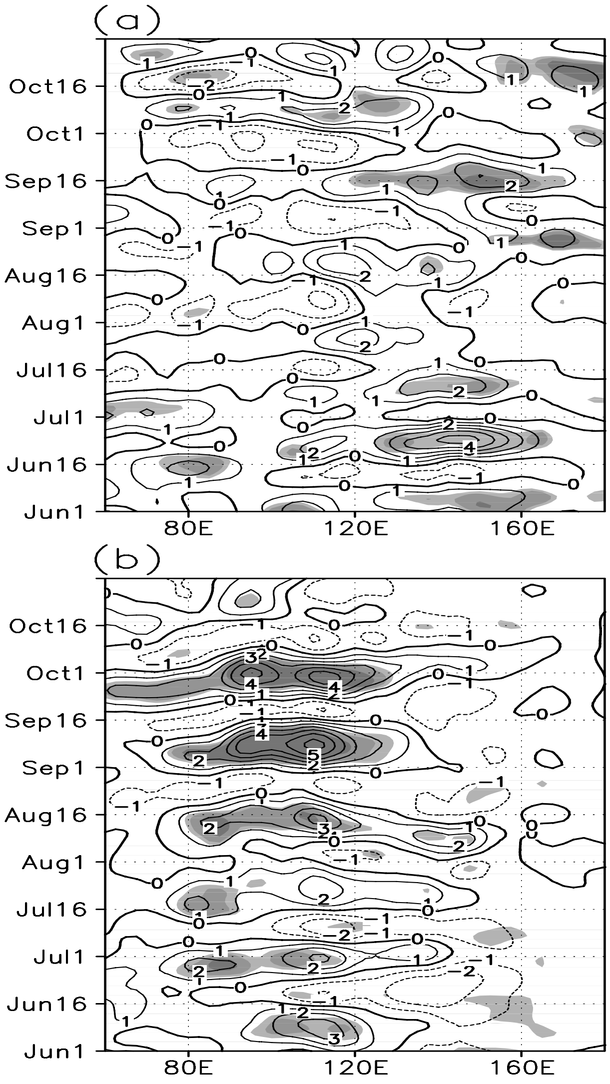

Figure 5. Time-longitude sections of the low-frequency kinetic energy averaged from 5°N to 15°N during June to October for the years of more (a) and less (b) TC genesis.

It seems that the tropical ISO patterns are extremely different between the years of more and less TC genesis. For the years of more TC genesis, the activities of strong low-frequency (30–60 days) oscillation over the WNP east of the Philippines, which are corresponding to the position of the monsoon trough, are favorable to TC genesis; while for the years of less TC genesis, the activities of low-frequency oscillation are weaker over the WNP east of the Philippines, with most of the strong interseasonal oscillations being in the South China Sea and Indian Monsoon regions. This pattern is unfavorable for the TC genesis over the WNP.

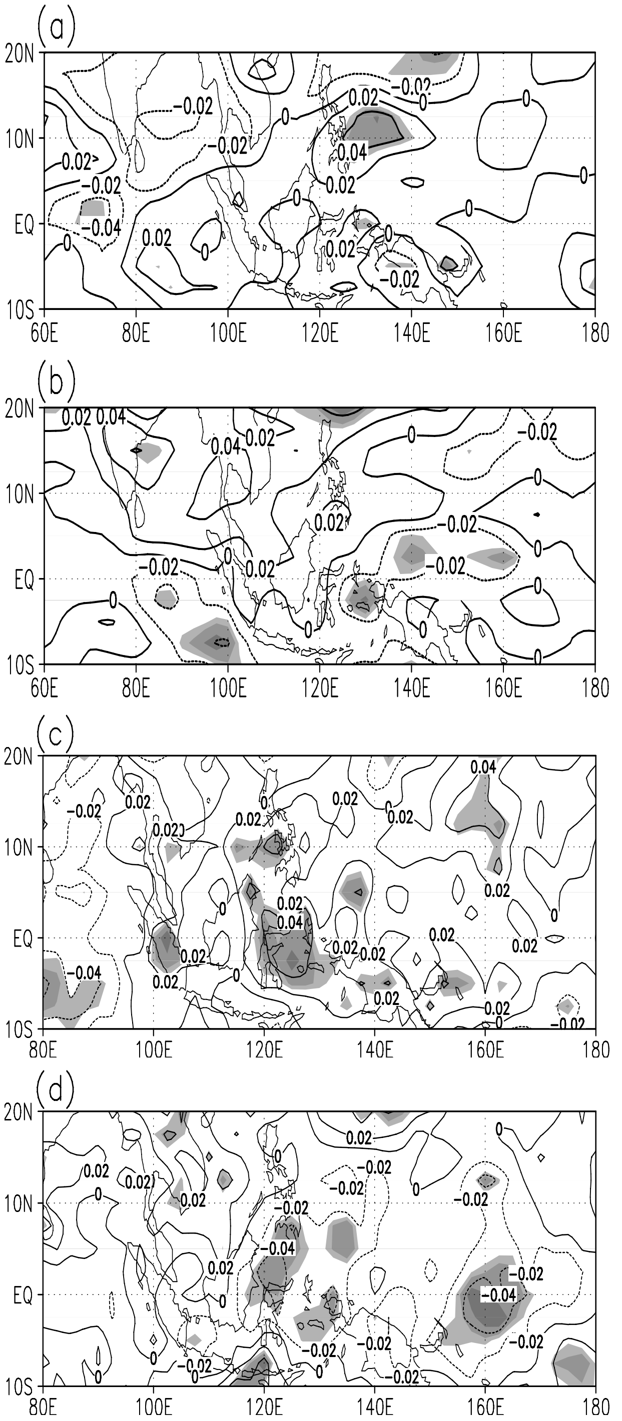

Figure 6. Variance contributions anomalies of 850 hPa low-frequency zonal wind (a, b) and OLR (c, d) for the years of more (a, c) and less (b, d) TC genesis.

5 PROPAGATION OF ISO AND TC GENESIS

Recent studies suggest that the tropical ISO principally propagates eastward during the winter half-year. However, the characteristics of ISO during the summer half-year in the Northern Hemisphere are significantly different from that during the winter half-year and are more complicated. Liebmann et al.[9] found that the tropical depressions/cyclones are affected by the westward and eastward propagation of the ISO respectively, but the analysis is not specific and adequate. In this section we will make a step forward to discuss the effect of the ISO propagation on the numbers of TC genesis.

For the seven years of more and less TC genesis, 119 and 64 TCs (excluding the TCs to the east of 160°E or in the South China Sea) are respectively selected to make the lead-lag composite analysis. The day of TC genesis is marked by Day 0. The time-longitude sections from Day 30 to Day –30 (averaged in 5–15°N) are showed in the Figure 7. The figures show that regardless of the more or less TC genesis years, the TC growth (Day 0) is generally in the westward phase of the ISO. This is in accordance with the finding from other studies. For the years of more TC genesis (Figure 7a), the ISO mainly propagates westward along latitude. On day 10, the low-frequency west wind occurs around 140°E at first. The wind is then strengthened and starts to propagate westward. The westerly wind anomalies reach their maximum strength around 120–130°E on Day 0. Later, they will gradually weaken during the westward propagation, which can reach to areas west of 80°E. On Day –10, the easterly wind anomalies occur around 130°E and then propagate eastward. The distribution patterns are similar for both Day 20 and Day –25. The propagation can be regarded as a cycle of about 45 days. However, for the years of less TC genesis, the main feature of ISO propagation spreads eastward. On day 10, the low-frequency westerly wind anomalies develop around 80°E and start to propagate eastward while strengthening continually. The low-frequency westerly wind anomalies reach their maximums around 100–120°E on Day 0. Afterwards, the wind anomalies will be constantly weakened during the eastward propagation. On day –10, the low-frequency easterly wind anomalies develop around 80°E, start to propagate eastward, and reach the area around 120°E on Day –20. The distribution patterns are similar for both Day 25 and Day –15. The propagation can also be regarded as a cycle of about 40 days. On Day 10 and Day –15 westerly wind anomalies develop around 140°E and propagate westward. However their intensities are much weaker than that around 80°E and they propagate eastward. Therefore, eastward propagation is the fundamental characteristic of the ISO in the tropical Indian Ocean.

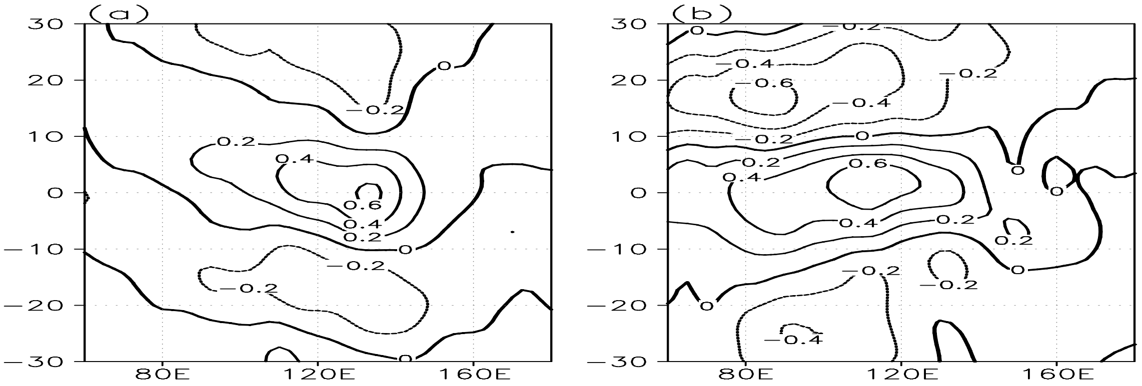

Figure 7. Time-longitude, 5–15°N-averaged sections for the years of more (a) and less (b) TC genesis from 30 days prior to and 30 days after the climatologically mean day of genesis.

The ISO can also propagate along longitude in the summer half-year of the Northern Hemisphere. For the years of more and less TC genesis, the time-latitude sections from Day 30 to Day –30 (averaged in 5–15°N) are showed in Figure 8. In the years of more TC genesis, the ISO mainly propagates northward along longitude. The low-frequency westerly wind anomalies are strengthened on Day 5 around 5°N, start to propagate northward, and continue to intensify during their propagations. The westerly wind anomalies reach its maximum strength around 12°N on Day –5. The anomalies propagate at a speed about 1°/day and reach 20°N before dissipating. The low-frequency easterly wind anomalies develop around the equator on Day –10 and then propagate northward. The distribution patterns are similar for both Day 15 and Day –30. The process can be regarded as a cycle of about 45 days. In the years of less TC genesis (Figure 8b), the ISO along longitude is characterized by standing waves without distinct northward propagation. There are westerly wind anomalies from the equator to 18°N from Day 10 to Day –10. The maximum wind anomalies are around 10–15°N. During the same period the easterly wind anomalies are around 18–30°N. The easterly wind anomalies exist to the north of 20°N with the maximum around 10–15°N during Days –10 to –30.

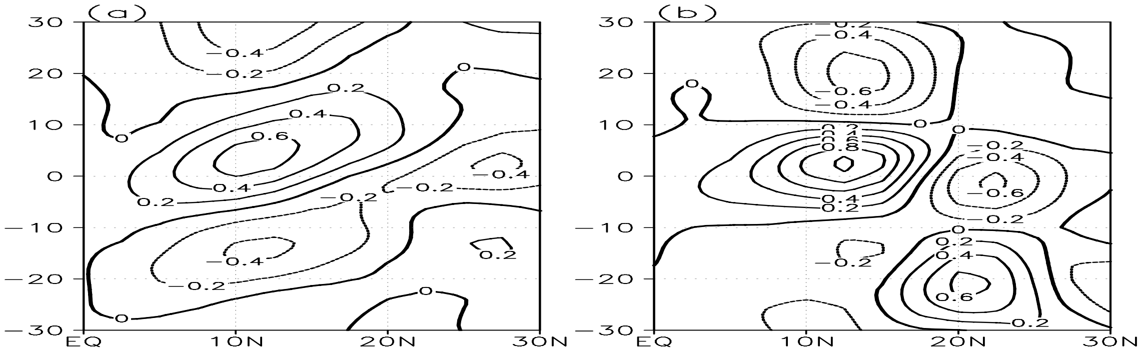

Figure 8. Same as Figure 7, but for the time-latitude sections along 120°E.

As a result, in the years of more TC genesis, the northwestward propagation of ISO from 140–160°E is favorable to the TC genesis. By contrast, in the years of less TC genesis, the propagation of ISO associated with TC genesis is generally eastward. The ISO originates around 60–80°E in tropical Indian Ocean, propagates to the east, and reaches its maximum strengthen to the west of 120°E. It weakens gradually afterwards. The westward propagation of ISO is relatively weak without a northward component. Therefore, the low-frequency activities are very active near the areas to the west of the Philippines but are weak in areas to the east of the Philippines, especially around 140–160°E to the north of the equator.

6 LOW-FREQUENCY STREAM PATTERN AND TC GENESIS

In order to make further study on the influence of ISO on TC genesis, we composited the low-frequency stream fields for the more and less TC years during June to October. For the years of more TCs, the composite results show a widespread cyclonic circulation extending to the north part of the South China Sea and a prominent belt with cyclonic circulation to the east of the Philippines. Strong low-frequency westerly winds develop near the equator from 80°E to 160°E. The low-frequency stream field in areas to the east of the Philippines extends to 160°E, which is consistent with the areas of the monsoon trough in the years of more TC genesis. Therefore, in the years of more TC genesis, the low-frequency stream fields strengthen the cyclonic vorticity. This favors the genesis of TCs and is also the major reason for the strengthening and eastward extension of the monsoon trough. In the years of less TCs, anticyclonic circulations control the most areas from the Arabian Sea to East Indian Ocean and South China Sea. The equatorial areas in 60–120°E are dominated by the low-frequency easterly winds. There is a long and narrow cyclonic stream zone to the south of the West Pacific subtropical high and the north of the equator. The low-frequency westerly winds prevail in the area from 130°E to the IDL near the equator. The low-frequency winds at 850 hPa present a divergence pattern from 120°E to 130°E near the equator, which is unfavorable to TC genesis. Comparing the circulation patterns between the years of more and less TC genesis (Figure 9), we can see that in the years of more TCs there is a cyclonic stream belt from the eastern tropical Indian Ocean to the western Pacific. Low-frequency westerly winds prevail to the west of 120°E in the tropics while the easterly winds are in areas to the east of 140°E. The westerly and easterly winds produce a low-frequency convergence zone near the 120–145°E region that favors TC genesis.

Besides the 850-hPa low-frequency stream patterns analyzed above, the patterns at 200 hPa are discussed as follows. The analyzed result (Figure 10) shows that the low-frequency velocity potential at 200 hPa displays a divergence pattern from there to the east of the Philippines in the years of more TC genesis. This means that ascending motions exist over the WNP east of the Philippines and facilitate TC genesis. By contrast, in the years of less TC genesis, positive anomalies of the velocity potential at 200 hPa show a notable low-frequency convergence near the Indian Ocean and central Pacific. This pattern is unfavorable to the TC genesis over the WNP.

The time-longitude sections of OLR anomalies averaged in 5–15°N for the years of more or less TC genesis (Figure 10) show that convections are induced in the most areas from 120°E to 140°E during the propagation of OLR anomalies along the equator in the years of more TCs, while the convections over the central Pacific to the east of 140°E are anomalously strengthened. The convergence pattern originates around 60–80°E, but its eastward propagation is restrained. The negative anomaly of OLR takes up most areas from 120°E to 140°E. The convections are strengthened once more to the east of 140°E with a westward propagation of the convergence zone around 160°E. Thus it can be seen that for the years of more TC genesis, the low-frequency (30–60 days) oscillation east of the Philippines is quite strong, making positive feedback to the surrounding circulation to strengthen the cumulus convection that favors the genesis of TCs. In the years of less TCs, the ISO in areas to the west of the Philippines is strong, but the low-frequency oscillations are weak to the east of the Philippines. Therefore, strong convections develop mainly in the areas to the west of the Philippines while convections in the areas to the east of the Philippines over the WNP are weak and unfavorable to TC genesis.

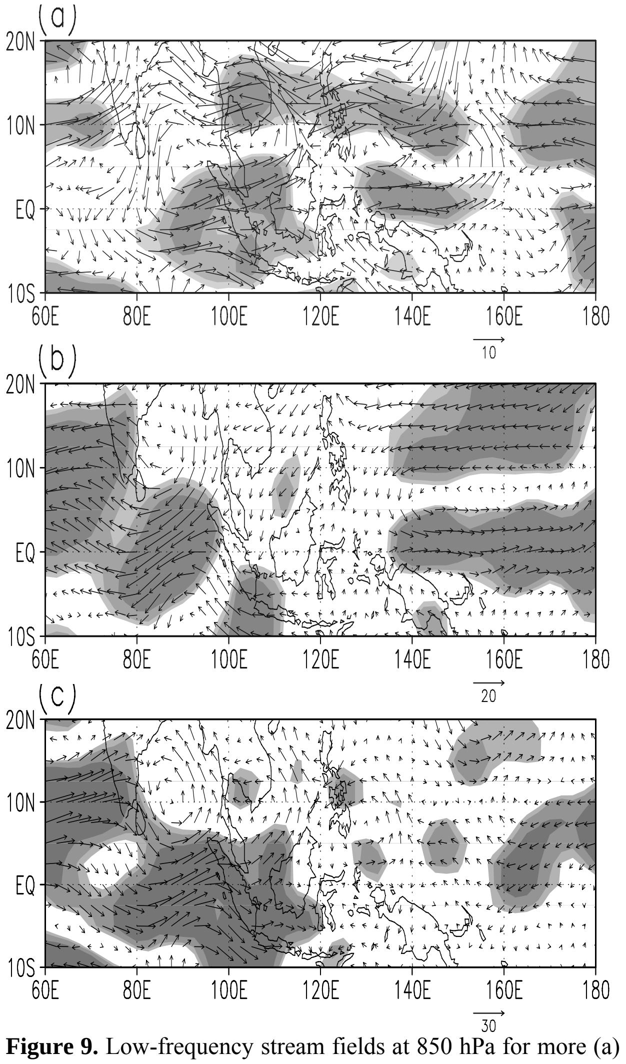

Figure 9. Low-frequency stream fields at 850 hPa for more (a) and less (b) TC years during June to October and their difference (c). The shades from light to dark show the areas above the 90%, 95%, and 99% significance level, respectively.

As a result, the ISO modulates the TC genesis by changing the Walker cell. The latter produces an anomalously upward or downward motion over the main genesis region of TCs, favorable or unfavorable for TC genesis respectively. In the years of more TC genesis, uniform low-frequency westerly wind anomalies develop along the tropics. The low-level convergence and high-level divergence to the east of the Philippines induced by the low-frequency wind field causes the anomaly of Walker circulation and strengthen upward motions to the east of the Philippines, favoring TC genesis. In addition, there is a positive feedback between the ISO and cumulus convections. The strengthened convections to the east of the Philippines are beneficial to ISO activity, further facilitating TC genesis. However, in the years of less TC genesis, there are low-frequency easterly wind anomalies from there to the area west of 130°E and low-frequency westerly wind anomalies to the east of 130°E. The corresponding low-level divergence and high-level convergence are unfavorable for the genesis of TCs.

7 CONCLUSIONS AND DISCUSSION

(1) The intensity of the ISO strongly affects the TC genesis. For the years of more TC genesis, the ISO kinetic energy is weak in the area to the west of 120°E but is strong in the area to the east of 120°E where the kinetic energy intensifies the cumulus convection and supports TC genesis. By contrast, in the years of less TCs, the ISO kinetic energy is strong in the area to the west of 120°E but weak to the east of it, unfavorable to TC genesis

(2) The propagation of ISO also influences the TC genesis. In the years of more TCs, the ISO propagates northwestward in the areas from 140°E to 160°E to the north of the equator, while in the years of less TCs, the ISO propagates dominantly eastward, rarely westward and no northward. As a whole, the northwestward propagation of ISO over the Western North Pacific is favorable to TC genesis.

(3) For the years of more (less) TC genesis, there is ISO convergence (divergence) flow in the lower level and divergence (convergence) flow in the upper levels over the Western North Pacific to the east of the Philippines. The enhanced (weakened) ascending flow is (not) favorable to TC genesis.

The modulation of ISO for TC genesis can be shown as follows. The ISO kinetic energy is mainly produced in the area to the east of the Philippines. The ISO westerly winds develop over the areas from 140°E to 160°E to the north of the equator and propagate northwestward. Thus, the activity of ISO is strengthened and the ISO cyclonic circulation dominates over the lower troposphere. The monsoon trough is influenced and intensified by the ISO cyclonic circulation while stretching eastward. The presence of an enhanced ascending flow in areas to the east of the Philippines makes cumulus convection stronger. These are all in favor of TC genesis over the WNP. There is interaction between the ISO and the surrounding circulation. The ISO ascending flow in areas to the east of the Philippine results in strong cumulus convection, which induces anomalous equatorial west wind. The process of positive feedback further helps in the TC genesis. For the years of less TC genesis, the stronger activity of ISO dominates to the west of the Philippines and the ISO zonal wind propagates eastward. Generally, the ISO forms over the equatorial Indian Ocean about 60°E and intensifies while propagating eastward. It achieves its maximum around the South China Sea and then weakens. Such activities of ISO cause the ISO-associated easterly wind anomaly at 850 hPa in areas to the east of the South China Sea. The ISO energy is weakened in areas to the east 130°E, which results in the westerly wind anomaly in lower troposphere. Then the divergence at lower levels is unfavorable to the genesis of TCs. Moreover, the study by Huang and Chen[20] indicated that the relationship between the interannual variation of MJO and the number of TC genesis is based on the barotropic energy transfer from low frequency to high frequency. The activity of MJO in areas to the east of the Philippines transfer larger barotropic energy, which offers favorable dynamic environment for the formation of TCs. This suggests that the strong activity of ISO in areas to the east of the Philippines is critical for the years of more TC genesis.

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