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A Paper on the Tropical Intraseasonal Oscillation Published in 1963 in a Chinese Journal

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Capsule Summary

A study published in Chinese in 1963 documented a 40-50-day oscillation in the Asian monsoon region, eight years earlier than its discovery by Madden and Julian (1971).

Abstract

The Madden Julian Oscillation (MJO) identified by Madden and Julian (1971, 1972) has been well recognized as the most prominent intraseasonal signal in the tropics. Its discovery and its relationship with other weather phenomena such as tropical cyclone (TC) are among the most significant advancements in modern meteorology with broad and far reaching impacts. The original study by Madden and Julian used radiosonde data on the Canton Island and their spectral analysis revealed the signal of a 40-50-day oscillation.

It has come to our attention that an earlier study published in a Chinese journal (Xie et al. 1963, hereafter Xie63) documented an oscillatory signal of 45-day period using radiosonde data from several stations between 70°E and 125°E in the tropics. The 40-50 day signal found by Xie63 is strikingly evident without any filtering. Xie63 identified that the occurrences of TCs are correlated with the 40-50-day variation of low-level westerlies at these stations. The original figures in Xie63 were hand drawn. Their results are verified using data from a longer period of 1958 to 1970. The 40-50-day oscillation in the monsoon westerly and its relationship with the occurrence of TCs are confirmed and further expanded.

This study serves the purpose of bringing recognition to the community the identification of a 40-50-day signal published in Chinese in 1963 and the discovery of the correlation between MJO phases and TC genesis three decades earlier than studies on this subject published outside China.

1. Introduction

Madden and Julian (1971) unveiled a 40-50-day oscillation in the tropospheric zonal wind using radiosonde observation at a single station (i.e., Canton Island) in the central Pacific. This oscillation was later connected to a broad global tropical circulation using observations from multiple stations (Madden and Julian 1972). The intraseasonal signal documented by Madden and Julian is now known as the Madden-Julian Oscillation (MJO). These two articles by Madden and Julian are among the most influential studies in modern meteorology. The originally identified MJO signal is confined in the 40-50-day period with zonal wavenumber one and eastward-propagating characteristics, which were confirmed by later studies using modern observational data (Weickmann 1983; Murakami and Nakazawa 1985; Lau and Chan 1986). The oscillation was also shown to be of more broadband (20 to 90 days) than the original 40-50-day period (e.g., Krishnamurti and Subrahmanyam 1982; Wang and Rui 1990; Hendon and Salby 1994; Annamalai and Slingo 2001; Zhang 2005). Recent theoretical and diagnostic studies indicated that equatorial waves interacting with moisture, convection and boundary layer dynamics build the fundamental mechanism for eastward propagation of the MJO (Hsu and Li 2012; Sobel and Maloney 2013; Jiang et al. 2015; Wang et al. 2016; Wang et al. 2017). Initiation of MJO convection mostly takes place over the western equatorial Indian Ocean (Zhang and Ling 2017), and is caused by anomalous low-level moisture advection (Zhao et al. 2013), warm advection-induced anomalous ascending motion (Li et al. 2015), intraseasonal SST anomaly (Li et al. 2008), and/or extratropical forcing (Hsu et al. 1990; Zhao et al. 2013). Li (2014) provides a comprehensive review on the dynamics of MJO initiation and propagation.

There is pronounced seasonality in MJO intensity (Madden 1986), frequency (Hartmann et al. 1992), and movement (Wang and Rui 1990). In boreal winter, the MJO is dominated by eastward propagation slightly south of the equator, whereas during boreal summer the eastward propagating mode weakens substantially (Madden 1986, Wang and Rui 1990, Hendon and Salby 1994) as the northward propagation prevails in the Indian monsoon region (Yasunari 1979, Hartmann and Michelsen 1989, Wang and Xie 1997, Lawrence and Webster 2002; Jiang et al. 2004) and the northwestward propagation prevails over western North Pacific (WNP) (Lau and Chan 1986). The MJO was identified in connection to the fluctuation and migration of the Asian summer monsoon (Murakami 1976; Yasunari 1979, 1980, 1981; Fu et al. 2003). The Monsoon Experiment in 1978–79 (Krishnamurti 1985) provided an opportunity to explore further the intraseasonal oscillations involved in the Asian summer monsoon activities.

The MJO has been identified to have far reaching impacts on many weather and climate related phenomena and linkages to tropical waves, tropical cyclone (TC) genesis, diurnal cycle, El Niño–Southern Oscillation (ENSO), and monsoon circulations (Zhang 2013). In particular, relationships between the MJO and TC genesis have attracted special attention. Liebmann et al. (1994) indicates that the western north Pacific TCs are twice as likely during convectively active phase of the MJO. Maloney and Hartmann (1998, 2000a, b) suggest that MJO westerlies may set up favorable conditions for TC development by inducing cyclonic low-level vorticity and near-zero vertical wind shear. When MJO 850-hPa wind anomalies are westerly, small-scale eddies grow through barotropic eddy kinetic energy (EKE) conversion from the mean flow, serving as the energy source for TC development (Maloney and Hartmann 2001; Hartmann and Maloney 2001; Hsu et al. 2011). Numerical experiments by Cao et al. (2014) suggested that both circulation and moisture anomalies associated with the MJO affect TC development. In general, all these findings indicate that the MJO can greatly modulate TC activities in most of ocean basins. Operational prediction of the MJO has been improved but remains challenging (Vitart

2014; Xiang et al. 2015, Jiang et al. 2015, Wang et al. 2017). The research on the MJO remains very active to date as more attention is being paid to prediction on subseasonal to seasonal (S2S) time scales to fill the gap between climate and weather prediction.

It has come to our attention that a study published in 1963 (Xie et al. 1963, abbreviated as Xie63 hereafter) in a Chinese journal *Acta Meteorologica Sinica*, documented an oscillatory signal of one-and-a-half month period using raw radiosonde data from several stations between 70°E and 125°E in the Southeast Asian summer monsoon region. Xie63 was mainly devoted to the investigation of the relation between the Southeast Asian flow and the occurrence of typhoons (TCs in the western Pacific). The data covered three years from 1958 to 1960 for the months of June to September. The 40-50-day signal discovered by Xie63 is strikingly strong as revealed by the variation of the zonal wind component at 700 hPa without any filtering. Xie63 identified that the occurrence of TCs was highly correlated with the variation of low-level westerlies at those stations, and was often located in the confluence region where the monsoon westerlies meet the easterly trade winds.

Here is the direct quote, with its English translation, of the abstract of Xie63:

"The relationship between the basic flows of the low latitudes and the occurrence of typhoons was investigated statistically and synoptically by means of recent three-year radiosonde data. It was found that about 80% of typhoons developed in the eastern flank of the tropical confluence zone between the monsoon westerlies and the easterly trade winds. The westerlies are a large-scale and quasi-steady phenomenon. Thus it is probably reasonable to be called the "basic flow" while the typhoons are considered as vortices of smaller scale. There is a quite definite relationship between the time, location and frequency of typhoon genesis and the location and strength of the basic flow in the low latitudes. There was a quasi-periodical

oscillation of strength and position of the basic zonal flow with a period longer than one month. Such an oscillation might be helpful for the extended-range forecast of initiation and development of typhoons."

Irrespective of the importance of these findings more than 50 years ago, the original paper by Xie63 remains mostly unknown to the international research community, mainly because it was published in Chinese. The purpose of this study is to bring attention to the study by Xie63 and its originality to BAMS readers. We analyzed archived radiosonde data for the same three years from 1958 to 1960 to verify the results of Xie63. We also compared the results by Xie63 and Madden and Julian (1971, denoted as MJ71 hereafter) by using a longer period of data (1958-1970) to cover the analysis period of MJ71 (1957-1967). The longer period would allow us to have a better comparison of strength of intraseasonal signals in Southeast Asia Stations found by Xie63 and in Canton Island discovered by MJ71.

This paper is outlined as in the following. Section 2 describes the radiosondes and reanalysis data. The comparison between Xie63 and MJ71 regarding the 40-50-day signals is given in section 3. Section 4 is devoted to the relationship between the MJO and TC genesis as revealed by Xie63. Section 5 provides summary and conclusion.

2. Radiosonde data, reanalysis and typhoon record

The radiosonde data used by Xie63 mainly came from five tropical stations that are roughly evenly distributed from Indian Ocean to the central Pacific. Their World Meteorological Organization (WMO) identification numbers and geographical locations are listed in Table 1. To provide a geographical perspective of the station locations, we marked each of them on the Google map in Fig. 1. They were simply referred to as Station 1 to 5 from west to east. Note that the Station 91701 (or Station 5) located on Canton Island included in one of Xie63's figures was also analyzed by MJ71. The station data used in the current study were retrieved from PANGAEA archive at https://doi.pangaea.de/10.1594/PANGAEA.823608. This dataset merged available collections of upper-air measurements as back as 1920s, including Comprehensive Historical Upper-Air Network (CHUAN) and the Integrated Global Radiosonde Archive (IGRA), which were interpolated to standard pressure levels (Ramella Pralungo et al. 2014). As this dataset provides twice daily observations, we first calculate daily mean result and then conduct linearly interpolation to fill in missing values.

To obtain a more comprehensive picture, the daily three-dimensional wind fields during 1958-1970 from NCEP reanalysis data (Kalnay et al. 1996) are also used. The resolution of the reanalysis data is 2.5 by 2.5 degree. The information on tropical cyclone genesis dates and locations are obtained from http://www.weather.unisys.com/hurricane/.

3. The 40-50-day signals discovered by Xie63 and MJ71

Figure 2 is the original Fig. 2 of Xie63, one of their most important figures. It shows time series of zonal wind at 700 hPa at three radiosonde stations (43371, 48900 and 98836 or Stations 1-3 in Fig. 1). The data covers from first of June to the beginning of September for 1958-1960. Red arrows were added to highlight the periods of the westerlies. Note that the periodicity of the westerlies as revealed by Xie63 in Fig. 2 was based on the 5-day running mean of raw data without any spectral analysis.

Below is an English translation of a direct quote from Xie63, summarizing their major finding relevant to Fig. 2:

"The following are the main results derived from Fig. 2:

1) There is a consistent phase change of the zonal wind from Station 43371 to Station 98836. When the westerlies intensified in India, they also intensified in Southeast Asia, with a slight temporal delay.

2) Total 36 typhoons occurred during the three summer seasons studied. Among them, 28 typhoons happened when a strong westerly appeared over Southeast Asia (at Stations 48900 and 98836). These typhoons appeared mostly to the eastern flank of a confluence zone between the westerlies and the easterly trade winds. About one fifth of the typhoons occurred when easterlies or weak westerlies appeared over the two stations.

3) The change of zonal wind with time at these stations exhibited a wave like oscillatory characteristic, with an average oscillatory period of around one-and-a-half months. Such an oscillatory feature may benefit for extended-range forecast of typhoon genesis frequency."

To confirm their results, we regenerated the time series of the zonal wind at the same three stations shown in Fig. 2 using the time series of 5-day running mean zonal wind at 700 hPa based on the radiosonde data (red) and the NCEP reanalysis data (black) shown in Fig. 3. The time series based on the NCEP reanalysis resembles that of the radiosonde data. Comparing Fig. 3 with Fig. 2 panel by panel indicates that the general patterns are similar with some difference in detail. The difference lies more in the magnitude than in the periodicity. For example, the maxima of the westerly in the middle of July reaches 20 m s^{-1} at Station 48836 in Xie63 (lower left panel in Fig. 2) while our reproduction (lower left panel in Fig. 3) indicates only 10 m s^{-1}, but both of them peak around mid July. The discrepancies may be simply due to the fact that Fig. 2

in Xie63 was hand-drawn. In general, this comparison confirms the low-frequency oscillation in low-level zonal wind with a period longer than one month explicitly stated by Xie63.

A spectral analysis was conducted on the zonal wind at these stations (see Fig. 4), to further confirm the one-and-a-half-month period indicated by Xie63 by visual inspection. To better compare the strength of intraseasonal signals in Southeast Asia Stations shown by Xie63 and in Canton Island discovered by MJ71, a longer analysis period (1958-1970) is used. While most analyses in this present study were applied to the zonal wind at 700 hPa following Xie63, 150 hPa and 850 hPa winds were here used to compare directly to MJ71. Original Fig. 2 from MJ71 for Station 91701 is included in Fig. 4d for comparison.

The power spectrum analysis reveals significant peaks of the MJO variability with a 40-50-day period at all the three pressure levels at Stations 43371 and 48900. By contrast, at Station 91701, the 40-50-day peaks stand out only at 150 hPa and 850 hPa, and they hardly pass the 95% confidence level. This is consistent with later studies (e.g., Li and Wang 2005) that maximum MJO variability appears over the Asian-Australian monsoon and warm pool regions. In comparing the result in Station 91701 with the original result of MJ71, the power spectrum for longer periods (greater than 100 day) appears weaker in the current analysis than in MJ71. The discrepancy may arise from different datasets used and slightly different analysis periods.

A similar power spectrum analysis result was obtained when only the three year (1958-1960) data are used. Figure 5 shows the result for comparison with Fig. 4. This would be what Xie63 might have got if they had conducted a spectral analysis. The strongest 40-50-day signal appears at Station 48900, and this intraseasonal signal is significant at all the three pressure levels. At Station 43371, the lower tropospheric 40-day signal is significant, while the upper tropospheric signal shifts slightly toward a 30-day period.

Then, we calculated the cross-spectra between the upper and lower level winds at different stations (see Fig. 6) to compare with the original Fig. 1 in MJ71. A positive (negative) coefficient indicates an in-phase (out-of-phase) relationship between the upper and lower level winds. As is seen, the panels for Station 91701 reproduce the original Fig. 1 in MJ71, showing an out-of-phase correlation between 150- and 850-hPa zonal wind, with the spectra peak in the 40-50-day band. Panels for Station 43371 and 48900 show a similar characteristic to that at Station 91701.

To compare zonal wind characteristics from the South Asia to the central Pacific, Fig. 7 displays the vertical profile of the zonal wind from 1 June to 30 September in 1958 at each station (Stations 1- 5 marked in Fig. 1) based on radiosonde data. The left panels show unfiltered results as in Xie63. Over the South Asia stations west of 125°E (Stations 1-3), the periodicity of the westerly below the 500-hPa level is distinct, and the period of 40-50 day is clear even without filtering. The span of the westerly in time is largest over the Indian Ocean (Station 1), decreasing towards the east. The upper levels are all dominated by easterlies. Over the central Pacific (Stations 4-5), the prevailing wind is mostly easterly throughout the troposphere. The westerly flow at lower levels at Station 4 (or 91334) is very weak. As we move to Station 5 (or 91701), the westerly is barely discernable. The right panels in Fig. 7 display 30-60-day band-pass filtered signals. A stronger MJO signal appears in upper troposphere than in lower troposphere at Station 5 (central Pacific), while MJO signals at low-levels are as strong as those at the upper level in the monsoon regions (Station 1-3).

Next we examine the evolution patterns of the 700-hPa wind over the summer monsoon region based on NCEP reanalysis data during 1958-1960. Shown in Fig. 8 are 700-hPa wind and relative vorticity anomalies regressed onto the 700h-Pa zonal wind averaged in a reference box enclosing both Stations 2 and 3 (green box in Fig. 8). Prior to the regression, all fields were filtered onto a 30-60-day period. Fig. 8 displays the lagged regression fields from day -15 to day 0, where day 0 corresponds to a time when the zonal wind anomaly reaches a maximum over the box. At day -15, a pronounced easterly anomaly appears over the reference box, and there is an anomalous cyclone south of it. As time progresses, the northwest-southeast tilted cyclonic anomaly moves gradually northward. At day 0, local circulation at 10°N is replaced by a pronounced westerly anomaly. The evolution above indicates that the 40-50-day oscillation of the zonal wind examined by Xie63 is a part of the MJO signal in boreal summer with pronounced northward propagation.

The analysis above using archived data reproduced results from Xie63, which pointed out a strong 40-50-day oscillation in the low-level zonal wind in the monsoon regions during boreal summer. The oscillatory signal is so strong that it can be detected by eye without any filtering. These reproduced results confirm that the oscillatory signals documented by Xie63 were real regardless the short data record used.

4. Relation between MJO and tropical cyclone genesis

Three decades before the studies of Hartmann et al. (1992) and Liebmann et al. (1994), Xie63 pointed out that TC activity in the WNP was modulated by the 40-50-day oscillation of the zonal wind. Figure 2, which is original Fig 2 in Xie63, contains the key finding by Xie63 other than what have been discussed on the periodicity of the zonal wind. The TC occurrence was marked by the small dots at the bottom of the figure for each year of the three years Xie63 investigated. As pointed out by Xie63, about 80% of typhoons in the WNP occurred when strong westerlies appeared in Stations 48900 and 98836. To reproduce the results in Xie63, we calculated how many percentages of TCs in the WNP occurred when total and anomalous (intraseasonal) zonal wind is westerly at Station 48900 during 1958-1970, which covers both the analysis period of Xie63 and MJ71. Out of the total numbers of typhoon occurrence, 92% (60%) of them fell under the total (anomalous) westerly wind period at Station 48900. This compares with 80% reported by Xie63 for 1958-1960.

Another way to demonstrate the MJO impact is to count TC genesis number during its westerly and easterly phases. Figures 9a and b mark the typhoon genesis locations during the MJO westerly phase and easterly phase respectively, which are defined based on the 30-60 day filtered 700-hPa zonal wind anomalies over the reference box of 7.5°N-12.5°N, 105°-125°E (denoted by green rectangles). The ratio of TC genesis number is about 2:1 between the westerly and easterly phase. This number is consistent with the finding by Liebmann et al. (1994), and confirms the assessment that TC activity in the western Pacific is modulated by the MJO.

An additional finding regarding TC activities in Xie63 is the preferred location of TC genesis. Original Figure 3 of Xie63 is displayed in Fig. 10 with our enhancement. The figure depicts the time variation of 700-hPa wind vectors observed at five stations spanning from south of India to the central Pacific. Xie63's assessment on this figure is that the TC genesis in the western Pacific is located mostly at the westerly-easterly confluence zone. The longitudinal distribution of the typhoon genesis locations is mostly between 120°E and 150°E.

To verify Xie63's result on this, we examine the percentage of TC genesis occurred over the westerly-easterly confluence zone, which is defined as a region where the absolute values of 700-hPa zonal wind are less than a given constant. Table 2 shows the percentage of TC genesis occurred within 100°E to 160°E during 1 June to 30 September of 1958-1970 over the westerly-easterly confluence zone defined by different criteria. 75% of TC genesis appears over the westerly-easterly confluence zone, where the absolute zonal wind speed is less than 5 m s^{-1}. If a stricter criterion of 3 m s^{-1} is defined, then the percentage becomes 52%. From a dynamic point of view, energy accumulation (due to wave scale contraction) over a confluence zone may accelerate the development of a TC-like vortex (Kuo et al. 2001).

In summary, the relationship between the zonal wind variability in the Southeast Asia and typhoon genesis deduced by Xie63 has been confirmed with a longer (13-year) dataset. They include the following two results. Firstly, typhoons occurred in the western Pacific mostly when the Southeast Asia is experiencing strong westerly, linking to the monsoon circulation. Secondly, typhoons occurred mostly in the region of a confluence zone where the monsoon westerly meets the trade easterly.

5. Summary

The Madden-Julian Oscillation (MJO) identified by Madden and Julian (1971, 1972) has been recognized as the most significant intraseasonal signal in the tropics and its relationship with other weather-climate phenomena is broad and its impacts are far reaching. The original paper by Madden and Julian (1971) used the radiosonde data on Canton Island with Fourier analysis to reveal the outstanding signal of a 40-50-day oscillation. In their subsequent paper, Madden and Julian (1972) presented a more comprehensive picture of the intraseasonal signal globally using data from multiple stations. These pioneering studies have since brought tremendous attentions of the atmospheric community to this phenomenon and stimulated substantial research efforts on the MJO that have advanced the understanding of tropical dynamics, its mid-latitude impacts, and complex scale interactions.

It has come to our attention that an earlier study published in a Chinese journal (Xie et al. 1963) documented a similar oscillatory signal of one-and-a-half-month period using radiosonde data from three stations between 70°E and 125°E in Southeast Asia. The investigation covered June to September for three years from 1958 to 1960. The 40-50-day signal found by Xie63 was strikingly strong as revealed by the variation of the 700 hPa zonal wind without any filtering. The original focus of Xie63 was to find a possible relation between the Southeast Asian circulation and tropical cyclone (typhoon in the western Pacific) genesis. Xie63 identified that the occurrences of typhoon during these months are closely related to the variation of the low-level westerlies at these stations. Expanding the scope to central Pacific, Xie63's analysis suggested that the western Pacific confluence zone (where the monsoon westerly meets the trade easterly) is the preferred zone of TC genesis.

The purpose of this paper is to bring attention to the recognition of Xie63 pioneer discovery. To verify the results presented in Xie63, in which all the analysis and figures were hand drawn based on a short data record, we first reproduced the original results using available radiosonde data at stations used by Xie63. The analysis was extended to a longer period from 1958 to 1970 so that it can cover the analysis periods of both Xie63 and MJ71 for better comparison of the strength of intraseasonal signals in Southeast Asia Stations found by Xie63 and in Canton Island discovered by MJ71.

The 40-50-day oscillation identified by Xie63 using the unfiltered zonal wind data at several stations from the tropical Indian Ocean to the western Pacific is confirmed to be robust from June to September. Compared to the Canton Island Station (91701), the MJO variability over the Southeast Asian monsoon region is stronger, in both the lower and upper troposphere.

The relationship between the zonal wind variability in the Southeast Asia and the typhoon genesis deduced by Xie63 is also confirmed using a larger data sample: 1) typhoons occur mostly when Southeast Asia is experiencing strong westerlies linked to the monsoon circulation, and 2) typhoons occur mostly in the confluence region where the monsoon westerlies meets the easterly trade winds. For the 13-year (1958-1970) summers, 92% of typhoons occurred when Station 48900 experienced westerlies. Meanwhile, 75% of WNP typhoons occurred in the westerly – easterly confluence zone defined as a region where the magnitude of the zonal flow at 700hPa is less than 5 m s^{-1}.

The pioneering studies of Madden and Julian (1971, 1972) have been widely accepted as the discovery of the MJO. The identification of the 40-50 day periodicity contained in the Xie63 paper is nowhere near as meticulous, comprehensive or rigorous as that done by Madden and Julian (1971, 1972). Xie63 did not do spectral analysis and qualitatively inferred a 40-50 day timescale from unfiltered wind fields over a relatively small number of events. Thus the work by Madden and Julian (1971, 1972) remains a model of how spectral analysis should be used to identify a significant oscillation.

That said, the broader community should recognize the work by Xie et al. (1963) that phenomenologically identified the 40-50-day signal eight years earlier and its discovery of the relationship between MJO and TC genesis three decades earlier than studies on this subject published outside China. With meteorology as a science that impacts people's living globally and is pursued by people everywhere, there must exist many hidden gems published in early days in non-English journals that were unknown beyond their countries. This current paper serves the purpose of bringing out one such gem and to encourage others to do the same.

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Sidebar

Biographic sketch of Prof. Yi-Bing Xie: Prof. Yi-Bing Xie (or pronounced sometime as Yi-Ping Hsieh) was born in 1917. He was a graduate student of Prof. C. G. Rossby and Prof. E. Palman at University of Chicago in 1945-49 and got his PhD from University of Chicago in 1949. He returned back to China afterwards and served as a Professor and Deputy Chair of the Department of Physics in Peking University, Beijing, China in 1952. He became a Professor and Chair of Department of Geophysics in Peking University in 1978 and was elected as an academician at Chinese Academy of Sciences in 1980. He received E. Palman Award in 1988. He passed away in Beijing in 1995 due to cancer.

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Table captions

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Table 2 Percentage of the occurrence of TC numbers over the westerly-easterly confluence zone, which is based on the background 5-day running mean 700-hPa zonal wind speed averaged over 5°-15°N. The analysis period is June to September in 1958-1970.

Figure captions

Figure 1 Locations of the radiosonde stations examined by Xie63. For detailed information about the location and the WMO identification number of each station, readers are referred to Table 1.

Figure 2 Original Fig. 2 from Xie63 showing time series of 5-day running mean zonal wind (m s^{-1}) at 700hPa. Positive (negative) values indicates westerly (easterly). The abscissa represents time from June 1 to September 1. The station number is marked on each panel and the first column is for 1958, the second for 1959, and the third for 1960. Black dots at the bottom denote the occurrence of typhoons each year. Red arrows are added by the authors of the current study to highlight the intraseasonal periods.

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Figure 4 Variance spectra for zonal wind (m^2 s^{-2}) at 150 hPa (blue solid), 700 hPa (black solid) and 850 hPa (red solid) for Station (a) 43371, (b) 48900, and (c) 91701 during 1958-1970. Dotted lines mark the 95% confidence level. The original Fig. 2 from MJ71 is shown in (d) in comparison to the current analysis at Station 91701 (c).

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Figure 8 Lagged regression patterns of 30-60-day filtered 700-hPa wind anomalies (vectors, $m s^{-1}$) and vorticity anomalies (shading, $10^{-6} s^{-1}$) against 30-60-day filtered zonal wind anomalies averaged over the reference box (7.5°N-12.5°N, 105°-125°E) (marked in green) for the period of June-September, 1958-1960. Brown curves are hand drawn to mark the anomalous large-scale cyclonic circulation.

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4 degrees longitude apart). Circles highlight clusters of genesis events and arrows their periods, added by the authors of this current study.

Table 1 Information of the radiosonde stations used in this study.

Station	WMO ID	Location	(Lon, Lat)	NCEP grid point
1	43371	Thiruvananthapuram	(76.95°E, 8.48°N)	(77.5°E, 10°N)
2	48900	Ho Chi Minh	(106.67E ,10.82N)	(107.5°E, 10°N))
3	98836	ZAMBOANGA	(122.07°E, 6.9°N)	(122.5°E, 7.5°N)
4	91334	CHUUK	(151.85°E, 7.47°N)	(152.5°E, 7.5°N)
5	91701	CANTON IS.	(171.21°W, 2.77°S)	(170°W, 2.5°S)

Table 2 Percentage of the occurrence of TC numbers over the westerly-easterly confluence zone, which is based on the background 5-day running mean 700-hPa zonal wind speed averaged over 5°-15°N. The analysis period is June to September in 1958-1970.

abs (zonal wind)	**TC number percent**
Less than 5m s^{-1}	75%
Less than 4 m s^{-1}	65%
Less than 3 m s^{-1}	52%

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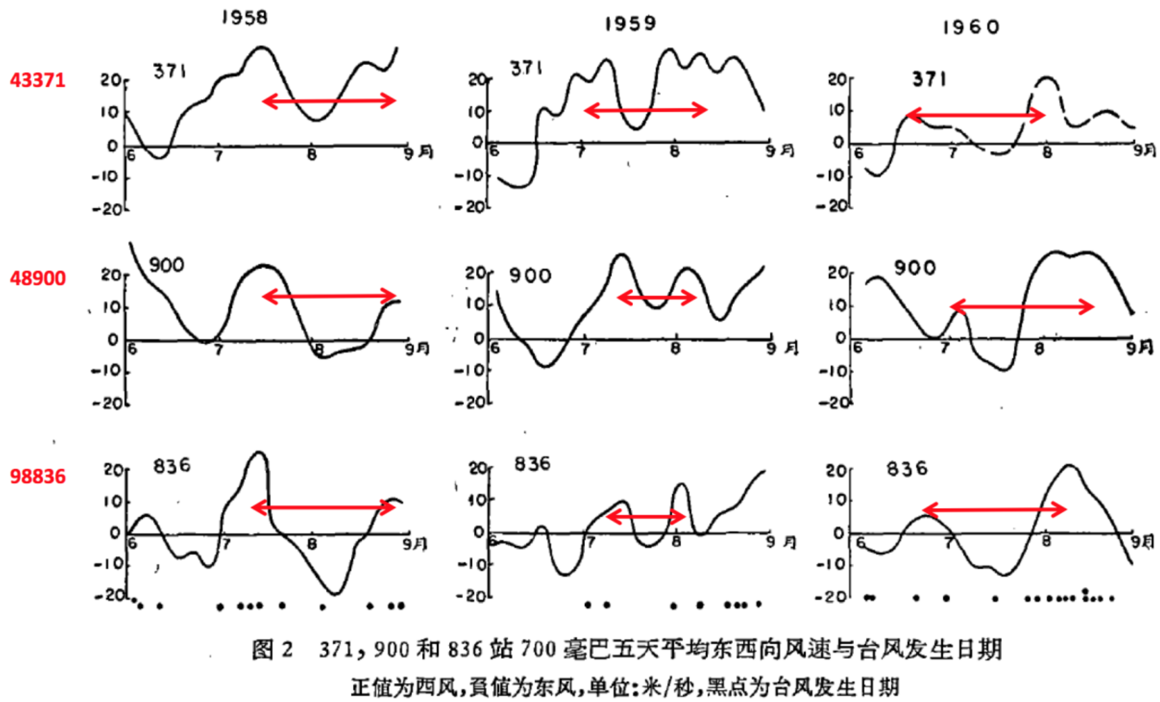

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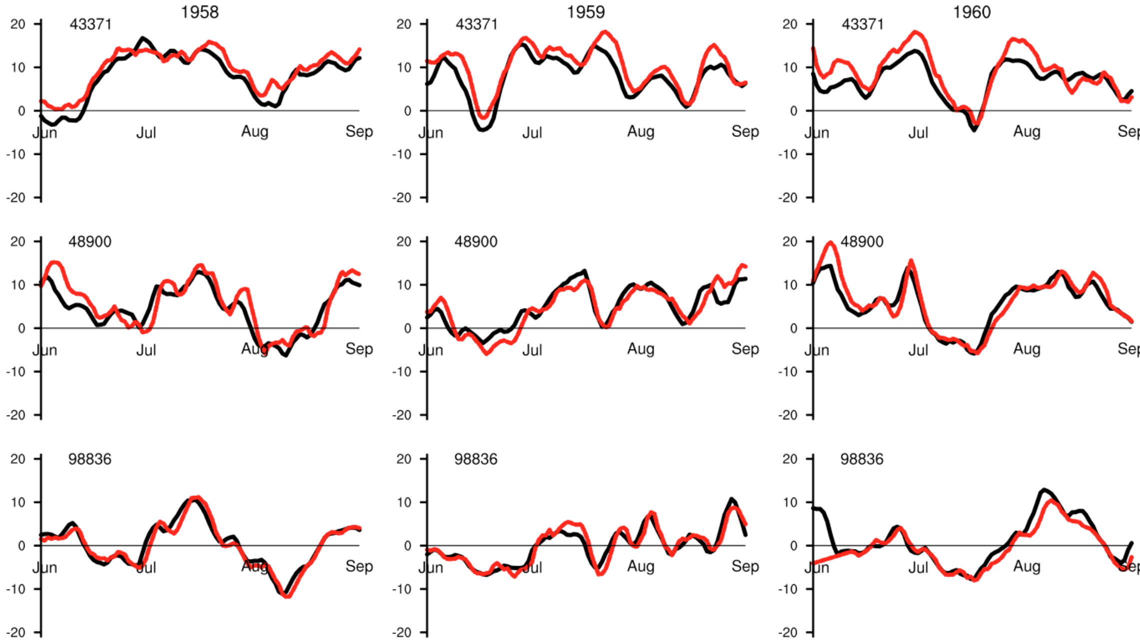

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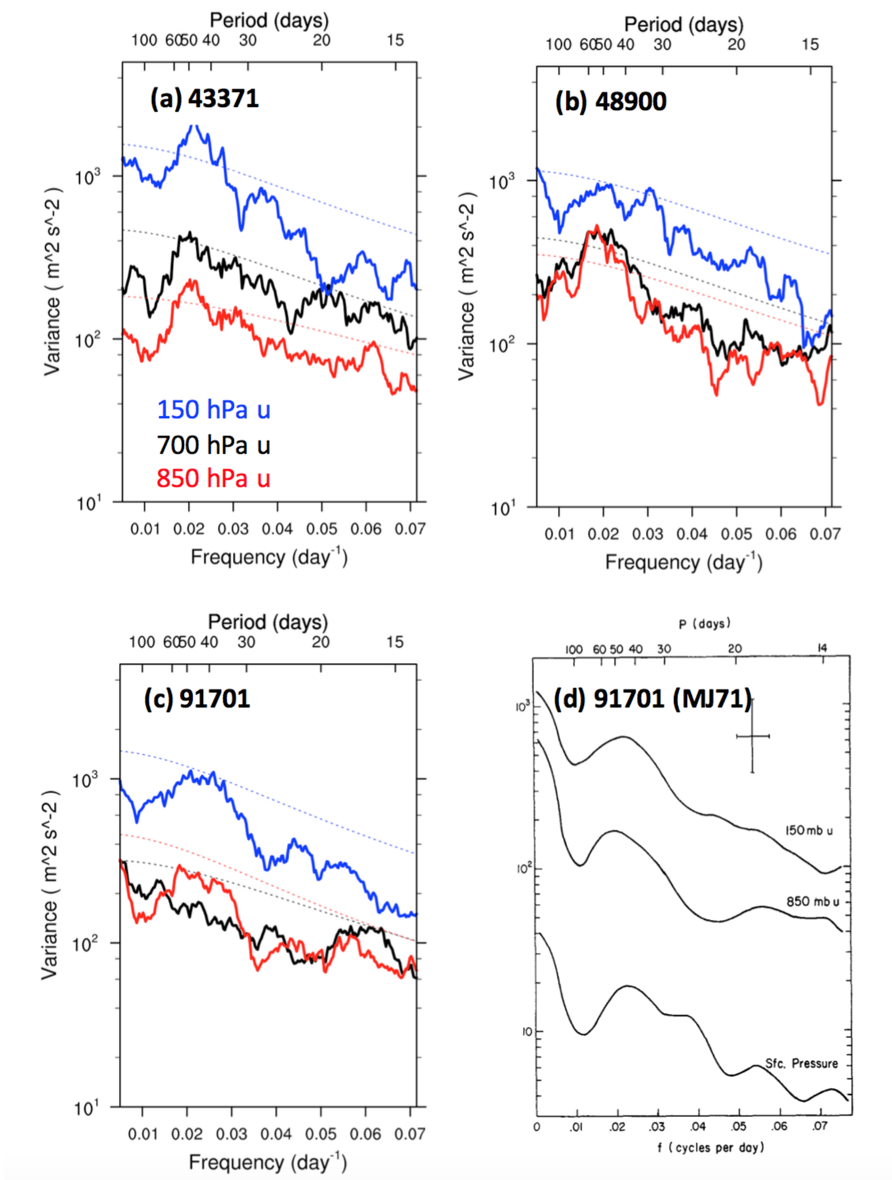

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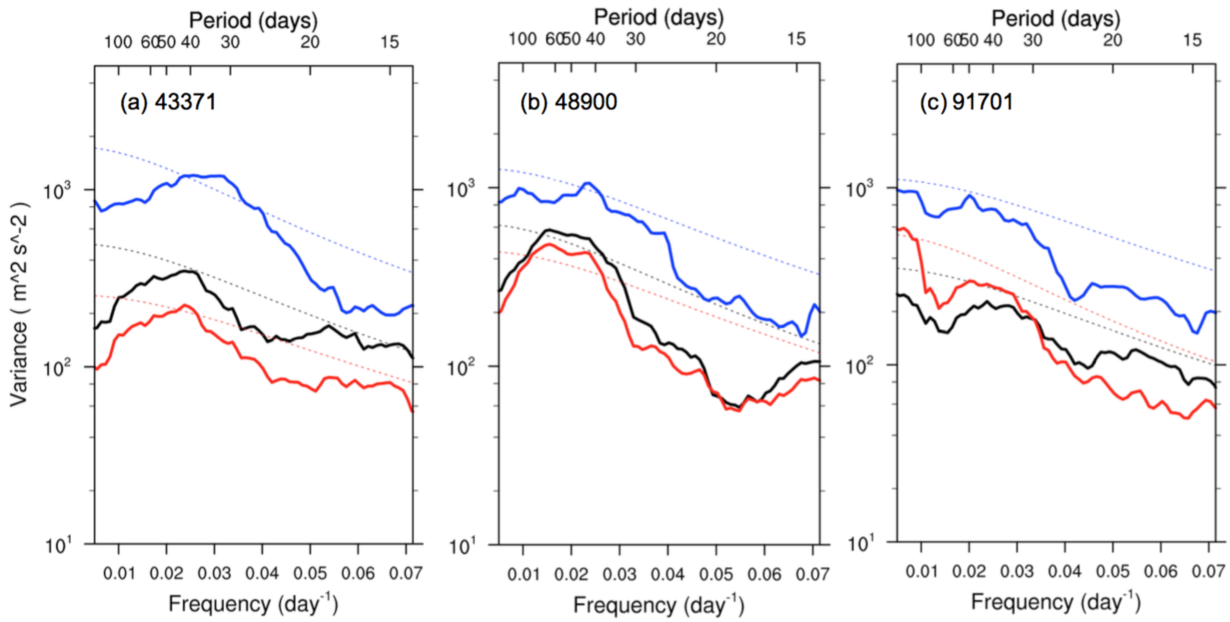

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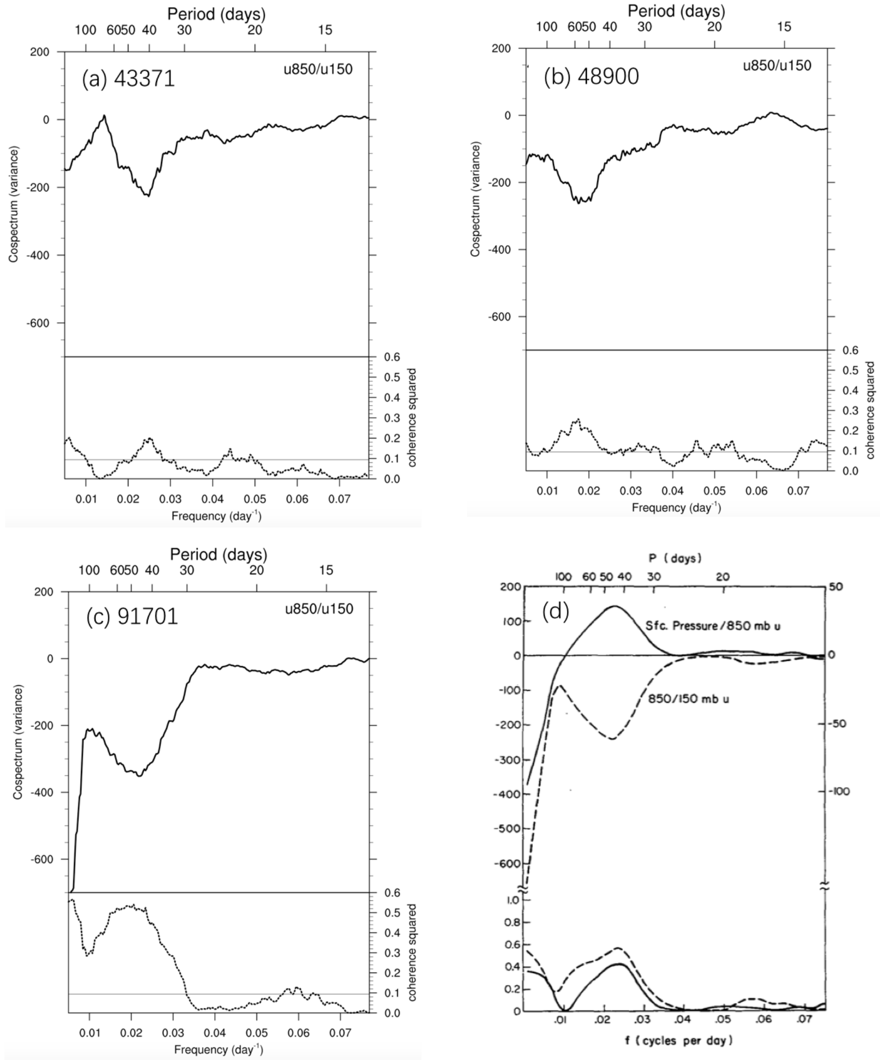

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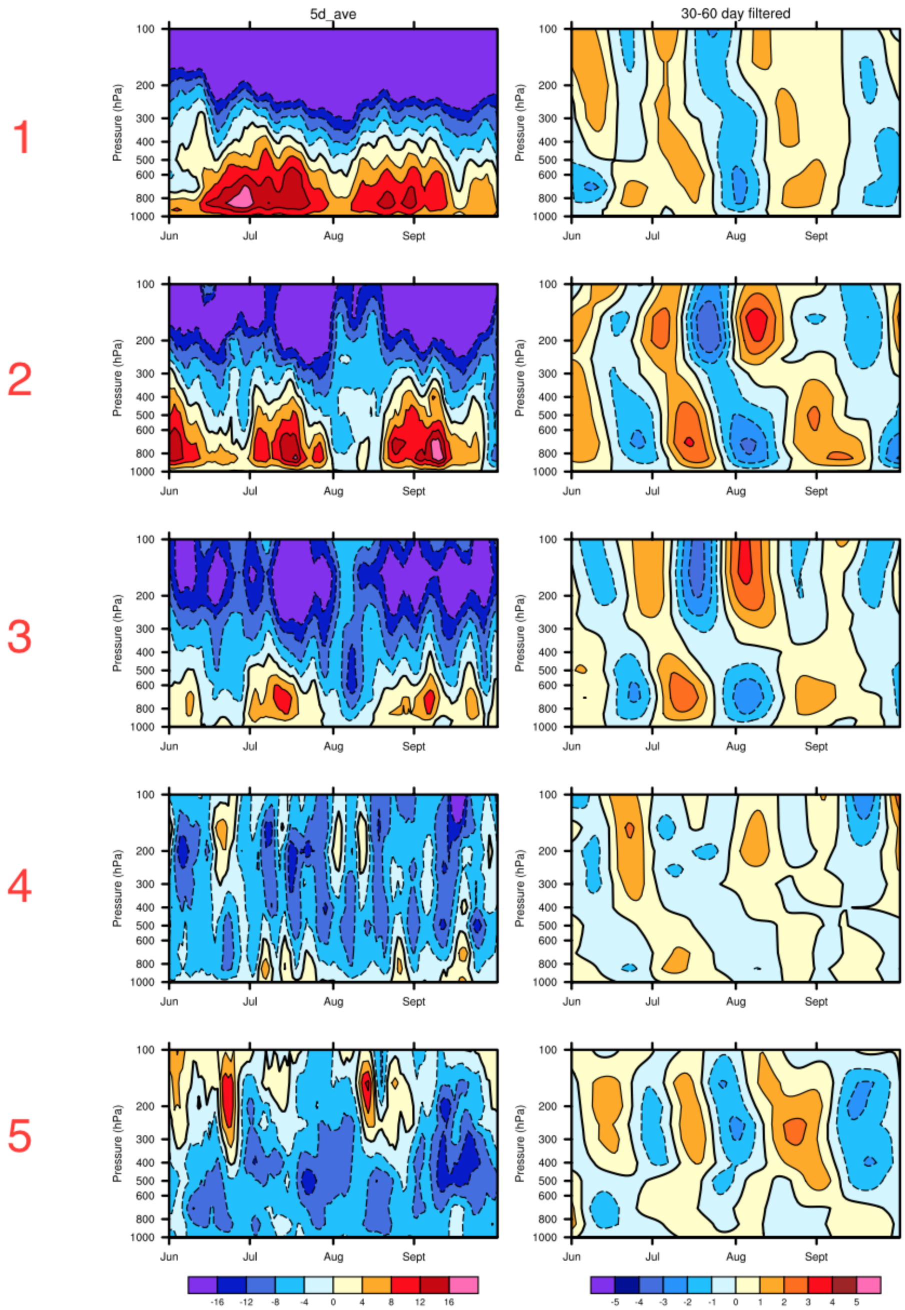

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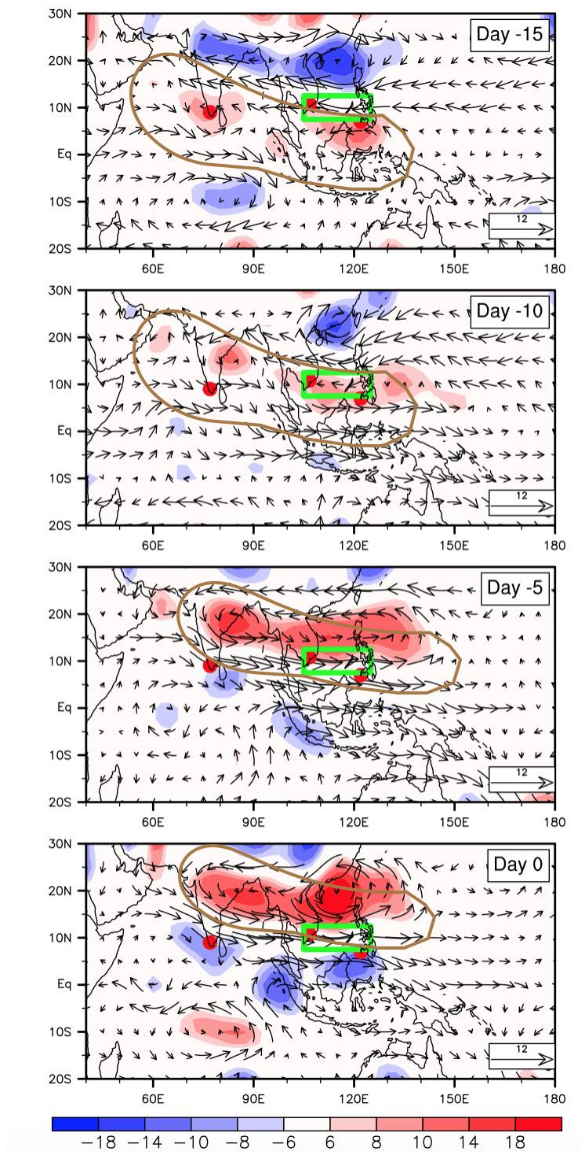

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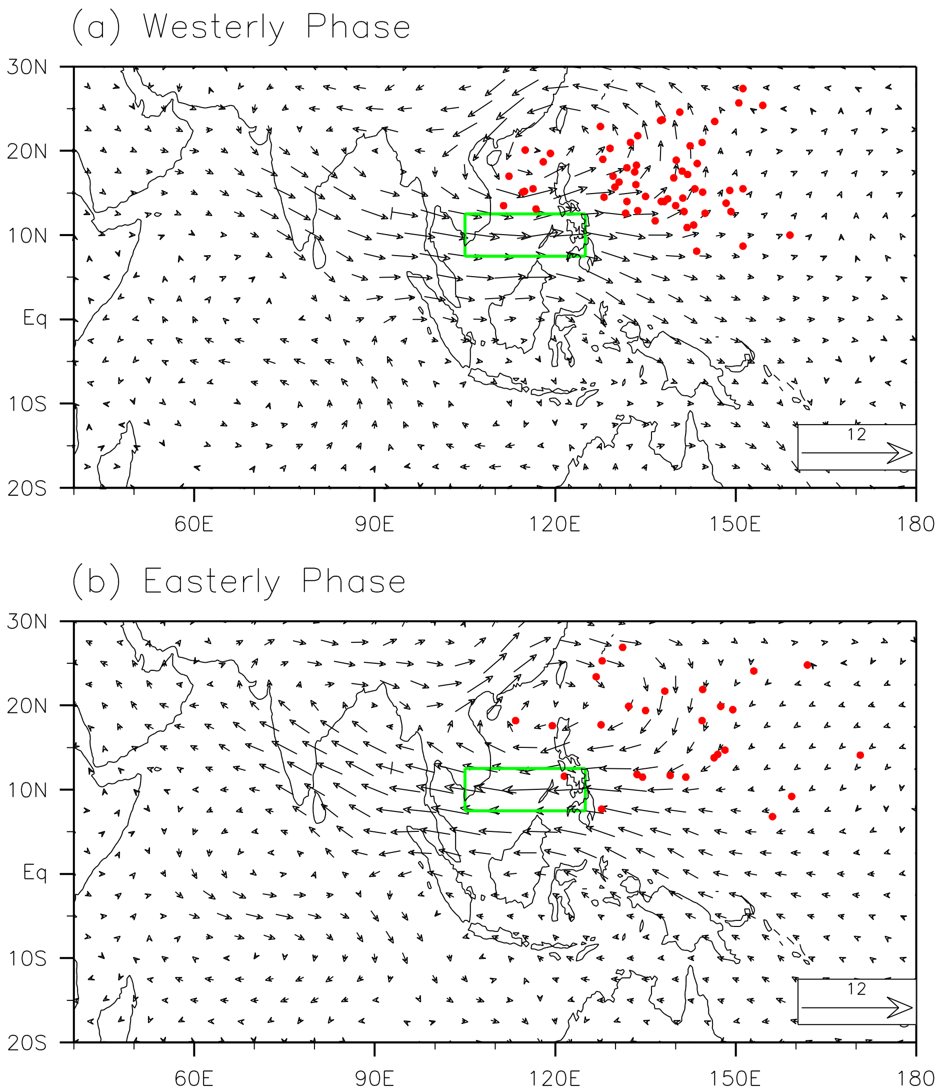

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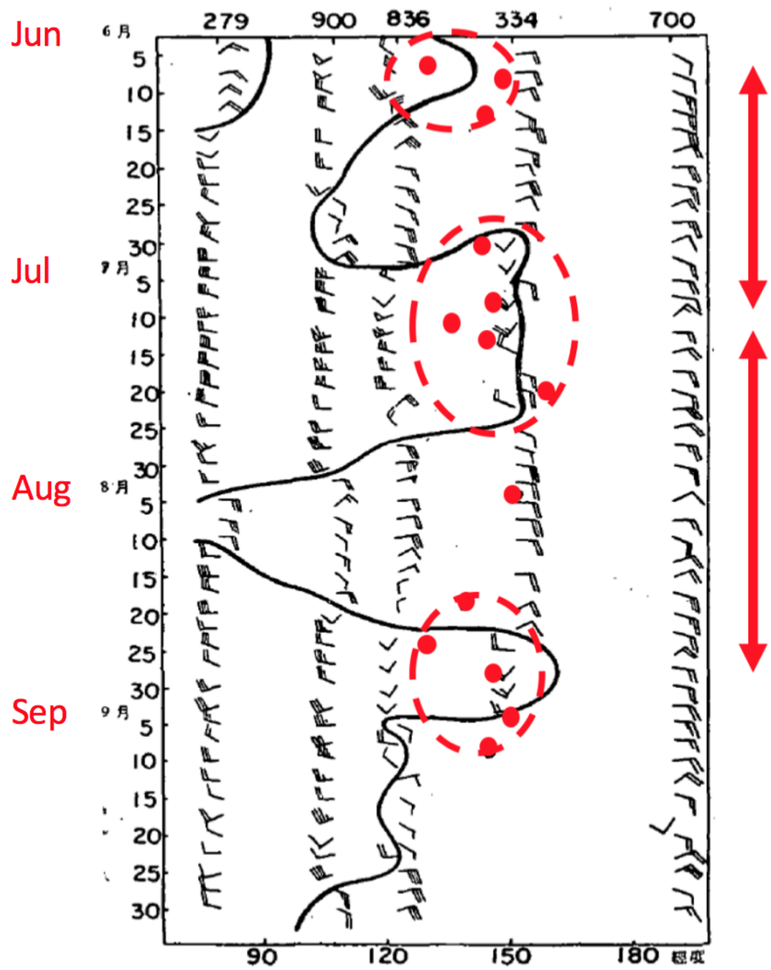

图 3 1958 年 6—9 月 印度南端到太平洋赤道附近 700 毫巴东西风分界綫与台风发生的关系

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