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# VARIATION OF THE EAST ASIAN SUBTROPICAL WESTERLY JET AND ASSOCIATED QUANTIFIED OBJECTIVE INDEXES

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**Abstract:** In order to understand the role of East Asian subtropical westerly jet (EASWJ) in forecasting summer precipitation in East China, interseasonal pentad characteristics of the EASWJ and their relation to summer precipitation in East China are analyzed with the daily reanalysis data provided by National Centers for Environmental Prediction (NCEP, USA) and daily precipitation data from 714 Chinese meteorological stations during the period 1960–2009. In addition, the daily evolution of the EASWJ and objective quantification of the EASWJ are investigated for the Meiyu season over the middle and lower reaches of the Yangtze River valley. It is found that the EASWJ and summer precipitation bands in East China move simultaneously. Especially, the stationary state and northward shift of the EASWJ are closely associated with the beginning, ending and stabilization of the annually first raining season in South China and Meiyu over these reaches. Analysis on the characteristics of the EASWJ in typical (atypical) Meiyu years over these reaches shows that the EASWJ swings steadily around its climatological position in meridional orientation (with large amplitude). Numerical experiments on an example in 2005 shows that indexes proposed in this study can depict the EASWJ well and should be valuable for application in the operation.

**Key words:** medium-range characteristics; statistical analysis; East Asian subtropical westerly jet

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## 1 INTRODUCTION

As the strongest system at the center of an active zone of subtropical westerly jets[1-3], East Asian subtropical westerly jet (EASWJ) is closely related to seasonal transition of East Asian general circulation, summer monsoon onset in Asia and summer precipitation in East China[4-17]. Initially, Ye et al.[4] and Tao et al.[5] systematically analyzed climatological relationships between the EASWJ and Meiyu over the middle and lower reaches of the Yangtze River and pointed out that the seasonal variations of an upper westerly jet in Asia are closely related to the beginning and ending of Meiyu. Later, many studies investigated the seasonal, interannual, interdecadal variations of the EASWJ and its impacts on summer precipitation in East China from the climatological view[14-17]. For instance, Kuang et al.[14] indicated that when the EASWJ is abnormally displaced southward/northward in summer, the Meiyu front is more/less frequently observed in the middle and lower reaches of the Yangtze River valley and summer precipitation is less/more in the Yellow River valley and North China. In recent years, along with the improvement of numerical models and quality of observations, understanding of the EASWJ has been improved from the interseasonal and annual scale to more detailed daily scale. Now, it is possible to understand the relationships between the EASWJ and medium-range variation of rainfall in China. Li et al.[6] indicated that the upper westerly jet in Asia shifts suddenly to the north twice during its transitory process from winter to summer, which is closely

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related to the activity of summer monsoon in East Asia. In the mean climatological state, the first northward shift of the EASWJ happens around 8th May, seven days earlier than the onset of South China Sea summer monsoon; the second northward shift of the EASWJ (around 7th June) is ten days earlier than the onset of Meiyu in the valleys of Yangtze-Huaihe Rivers and should be regarded as a signal for the onset of Meiyu. This paper studies the interseasonal pentad characteristics of the EASWJ in climatological state and its relationship with the summer precipitation in East Asia. Especially, by investigating the cases in typical and atypical Meiyu years over the middle and lower reaches of the Yangtze River, the daily evolution of the EASWJ in representative drought and flood years and quantified objective indexes of the EASWJ are investigated. It is aimed to understand the relation between the EASWJ and the summer precipitation in East China and the implication for prediction of precipitation by designing characteristic indexes.

## 2 DATA

In this study, a daily dataset of horizontal zonal and meridional wind reanalysis at 200 hPa level, covering the period from 1960 to 2009, is obtained from the National Centers for Environmental Prediction (NCEP, USA). The resolution of the NCEP reanalysis are globally 2.5° latitude×2.5° longitude. Precipitation data at 1200 UTC (Coordinated Universal Time) provided by National Meteorological Information Center of China Meteorological Administration are collected from 714 meteorological stations across China during 1960–2009. The Meiyu intensity index provided by National Climate Center is used in this study to analyze the characteristics of Meiyu over the middle and lower reaches of the Yangtze River. A typical Meiyu year is considered to occur when a standard index of Meiyu intensity exceeds 1.0. Seven typical Meiyu years (1954, 1969, 1980, 1983, 1991, 1996, 1998, and 1999) and four atypical Meiyu years (1965, 2000, 2002, and 2009) are identified according to this standard index.

## 3 MAJOR CHARACTERISTICS OF THE VARIATION OF EASWJ

### 3.1 *Variations of the position and intensity*

Some investigators[11-17] indicated that meridional displacement of the EASWJ is mostly related to summer precipitation in East China. Figs. 1a-1b shows that meridional displacement of the EASWJ mainly occurs from April to October. There are two periods of stable jet position (a period with jet position staying at the same latitude for at least four pentads is defined to be stable) when the EASWJ is moving to the north. One period is from the 25th to the 32nd pentad corresponding to the first rainy season in South China when the jet is stable in 35° N. Prior to it, the first northward jump of the jet with the largest magnitude in a year occurs, namely the jet position jumps from the winter climatological latitude of 30° N to 35° N during the 23rd–24th pentads. The other period is from the 34th to 37th pentad corresponding to the Meiyu rain in Yangtze River valley when the jet is stable in 37.5° N. The third jump of the jet to 40° N in the 38th pentad is corresponding to the ending of the Meiyu season. It is shown that the meridional displacement of the EASWJ can be taken as a signal to predict the onset, persistence and ending of representative rainy seasons.

As for the zonal displacement of the EASWJ (figure omitted), it is found that the center of the EASWJ moves from the West Pacific to Northwest China from winter to summer and then retreats to the West Pacific from summer to winter. The jet center in the West Pacific disappears when the EASWJ center shifts westward to 90° E in the 37th pentad, which is one pentad ahead of the usual ending of Meiyu in the 38th pentad. Zhang et al.[18] pointed out that the upper-level center of EASWJ shifts rapidly from 140° E to 80° E, which is mainly related to the variation of jet intensity in different areas being influenced by the change of longitudinal temperature gradients in East Asia. In addition, the intensity of the EASWJ varies from April to October when it jumps to the north and retreats to the south. The intensity decreases from a value of 40 m/s in spring to 20 m/s in the middle of summer, and then increases from 20 m/s in the middle of summer to 40 m/s in autumn; it does not vary much in the two comparatively stable periods.

Thereafter, cases in heavy and light Meiyu years over the middle and lower reaches of the Yangtze River valley are used to compare and analyze the characteristics of the EASWJ in representative drought and flood years. Monitoring and analyzing the EASWJ from a middle-range prospective is useful for forecasting operation. Thus mean departure of jet position and its standard deviation are analyzed and shown in Fig. 1c. Mean departure of jet position is -0.3 latitudes and its standard deviation is 1.6 in heavy Meiyu years. Mean departure of jet position is 2.2 latitudes and its standard deviation is 4.8 in light Meiyu years. It is indicated that the EASWJ perturbs slightly around the climatological position meridionally in typical Meiyu years; the jet position is more northward drifted with larger amplitude of oscillation in atypical Meiyu years. Daily evolvement of zonal mean wind from 110° E to 120° E at the 200-hPa level in the heavy Meiyu year of 1983 and light Meiyu year of 2002 (Figs. 1d-1e) also clearly show this marked difference. The same conclusion can be obtained when the study area is expanded to 90–140° E. In addition, the jet center is mainly located around 125° E in typical Meiyu years and 142.5–147.5° E in atypical Meiyu years.

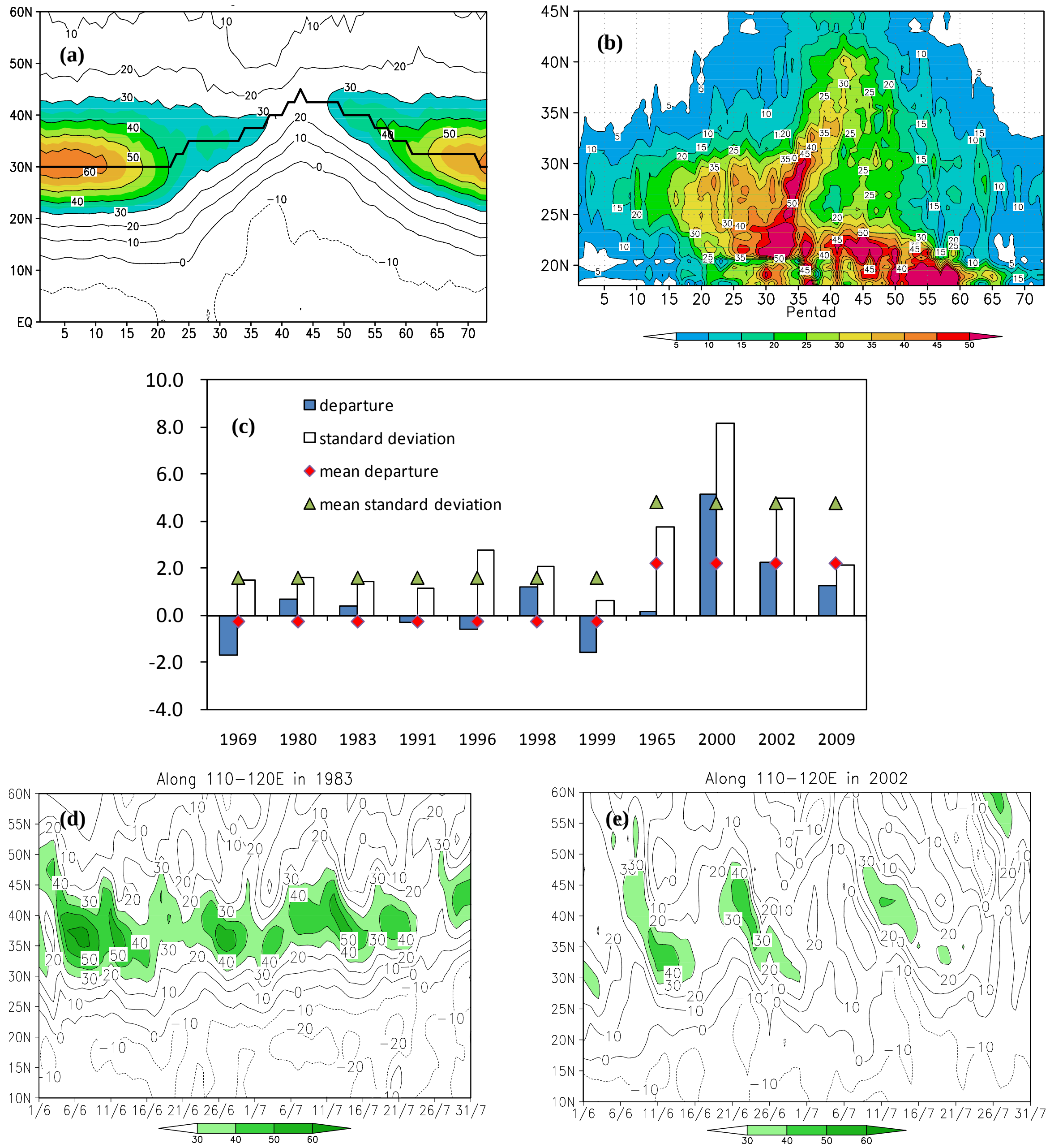


Fig. 1. Pentad evolution of zonal mean wind from 90º E to 140º E at 200 hPa (a, unit: m/s）and summer precipitation of East China from 110º E to 120º E (b, unit: mm) during 1960–2009, departure of jet position and its standard deviation in seven (four) typical (atypical) Meiyu years (c, unit: latitude) and daily evolution of zonal mean wind from 110º E to 120º E at 200 hPa during June–July in the typical Meiyu year of 1983 (d, unit: m/s) and light Meiyu year of 2002 (e, unit: m/s) over the middle and lower reaches of the Yangtze River valley.

### 3.2 *Characteristics of the configuration*

Theory and practice have proved that the EASWJ exhibits all kinds of configuration[19-24]. Recently, Xu et al.[22] and Wang et al.[23] pointed out that a rain storm does not always occur right behind the zonal EASWJ. It sometimes happens right ahead of a non-zonal EASWJ. In this study, 220 cases of EASWJ in heavy Meiyu years over the middle and lower reaches of the Yangtze River valley are analyzed. It is found that the percentage of quasi-zonal cases account for 70% of the total, with the percentage of northeast-southwest (northwest-southeast) taking up 15.5 % (10.9%). Furthermore, 46 regional rain storm cases (with the space scale of rainstorms at five grids at least) in heavy Meiyu years are analyzed. It is shown that 43 cases move with the upper jet, 24 of which are quasi-zonal, accounting for 55.8% of the total, 12 cases are northeast-southwest, 27.9 %, 7 cases are northwest-southeast, 16.3 %. Obviously, the frequency of a non-zonal EASWJ in association with regional rainstorms increases in heavy Meiyu years, accounting for 44% of the total. Further study is required to understand the possible relation between the non-zonal EASWJ and the precipitation intensity.

### 3.3 *Analysis of correlation*

As shown in Table 1, correlation coefficients between jet position and location of rain bands in both heavy and light Meiyu years pass significance tests at the 99% confidence level, suggesting that jet position is mostly related to the location of rain bands. The EASWJ and the rain band move consistently in the same direction. It is shown that the central longitude of the EASWJ is much more related to the rain band in typical Meiyu years than in atypical Meiyu years.

Table 1. Correlation coefficients between the position of the EASWJ and that of the rain band from 110º E to 120º E in East China in seven heavy and four light Meiyu years over the middle and lower reaches of the Yangtze River valley ( parenthesis means correlation coefficient does not pass significance tests at the 99% confidence level)

| | Typical Meiyu years | | Atypical Meiyu years | |
|---|---|---|---|---|
| | daily | 5-day moving mean | daily | 5-day moving mean |
| meridional position of EASWJ (90–140º E) | 0.25 | 0.27 | 0.36 | 0.50 |
| central longitude of EASWJ (80–160º E) | -0.19 | -0.30 | (-0.24) | -0.28 |

In addition, correlation coefficients between the EASWJ intensity and precipitation intensity over the middle and lower reaches of the Yangtze River valley are studied for the heavy and light Meiyu years. The result shows that the correlation coefficients are small and cannot pass significance tests.

## 4 QUANTIFIED OBJECTIVE INDEXES OF EASWJ

### 4.1 *Position index*

Kuang et al.[14] defined mean values of the latitude of the maximum westerly wind at 200 hPa as an index of the EASWJ position. The index defined by Kuang et al. is denoted as $A_1$ in this paper. Using index $A_1$ for reference, position index $Z_1$ is defined in this study as follows. (1) The jet domain is defined as the area with all wind speed above 30 m/s at the 200-hPa level, and position index $Z_1$ is the averaged value of latitudes with the biggest wind speed in every longitude in the jet domain. (2) By considering impacts on the rain bands of summer monsoon in East China, a study domain from 90° E to 140 °E is chosen, which is not restricted in the meridional direction. (3) The EASWJ is identified when a polar front coexists with a subtropical jet.

For the cases for April–October in 2005, index $Z_1$ and $A_1$ are calculated (Fig. 2). It is found that, compared to index $Z_1$, index $A_1$ has poorer ability to distinguish the shift of jet axes to the north of the domain in middle summer as it restricts the domain longitudinally (Fig. 3c). Index $A_1$ also provides clear information about a northern jet when it is significantly stronger than the southern one (Fig. 2a). Index $Z_1$ can eliminate the illusive information determined with index $A_1$.

Table 2 shows that the daily correlation coefficient associated with $Z_1$ is 14% higher than that of $A_1$ and the mean correlation coefficient of five-day-moving average related to $Z_1$ is even 17% higher than that related to $A_1$. The position index of the EASWJ should be valuable in practice.

### 4.2 *Configuration index of jet*

Taking the jet center $(\vartheta_0, \varphi_0)$ from 100° E to 130° E as a centric grid, the point 10 longitudes ahead in the line of the jet axis is denoted as $(\vartheta_1, \varphi_1)$, the point 10 longitudes back in the line of the jet axis is denoted as $(\vartheta_{-1}, \varphi_{-1})$, and the formula to calculate the inclined angle ahead is given as:

$$\alpha_1 = \arctan\frac{a(\varphi_1-\varphi_0)\times\pi/180}{a\cos\varphi_0 10\times\pi/180} \tag{1}$$

where *a* is the mean radius of the earth.

The rearward inclined angle is defined as:

$$\alpha_{-1} = \arctan\frac{a(\varphi_0-\varphi_{-1})\times\pi/180}{a\cos\varphi_0 10\times\pi/180} \tag{2}$$

The jet is configured by using $\alpha_{-1}, \alpha_1$ and its index is denoted by $Z_2$.

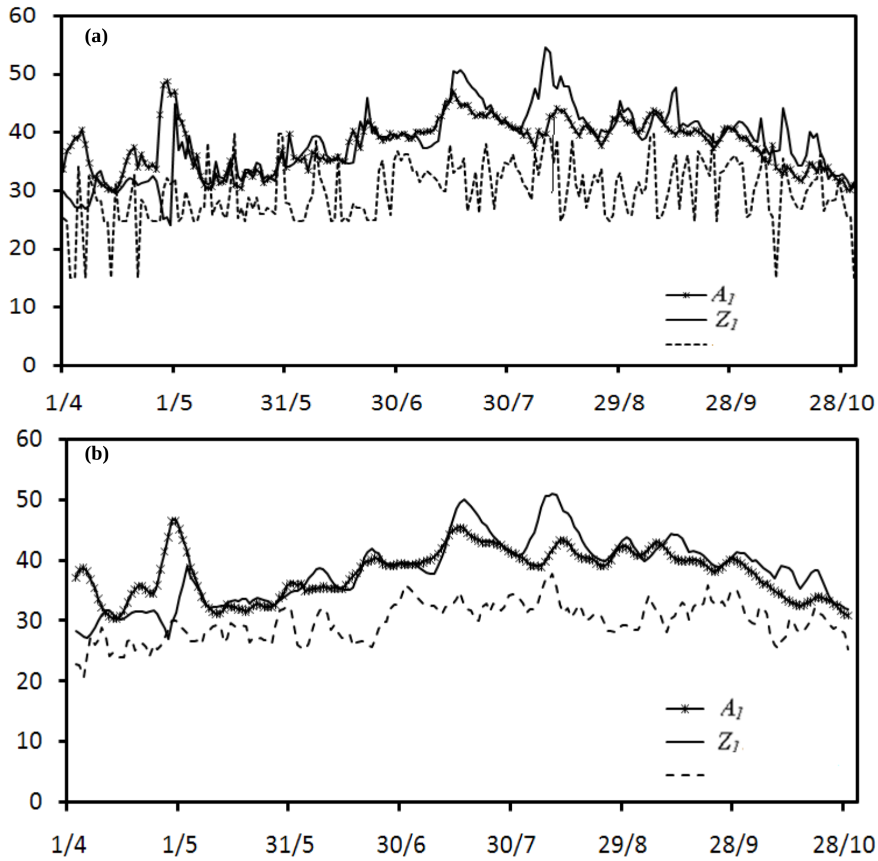


Fig. 2. Daily (a, unit: latitude), five-day moving mean (b, unit: latitude) evolution of index $A_1$, $Z_1$ and axis position of mean precipitation from 110º E to 120º E during April–October in 2005. ---: Center of rain.

Table 2. Correlation coefficients between temporal series of index $A_1$, $Z_1$ and axis positions of mean precipitation from 110º E to 120º E during the same period.

| Correlation coefficient | $A_1$ | $Z_1$ | Confidence test (99%) |
|---|---|---|---|
| Daily precipitation | 0.33 | 0.47 | passed |
| Five-day moving mean precipitation | 0.52 | 0.69 | passed |

According to Eqs. (1) and (2), if $\alpha_{-1}$ and $\alpha_1$ are both less than 20° , $Z_2$ equals to zero and a quasi-zonal configuration is identified; if they are both larger than 20° positively (negatively), the jet is northeast-southwest (northwest-southeast) and $Z_2$ equals to 1(-1); if they are both larger than 20° but opposite algebraically, a curving upwards (downwards) configuration is defined when $\alpha_{-1}$ is negative (positive), $\alpha_1$ is positive (negative), and $Z_2$ equals to 2(-2). It should be noted that this study estimates a quasi-zonal angle with the threshold value at 20° , which is due to the spatial resolution of 2.5° ×2.5° .

The time series of $\alpha_{-1}$ and $\alpha_1$ during April–October in 2005 are drawn to compare with the daily configuration index of the EASWJ (Figs. 3a-3b). In order to validate the reliability of depicting the EASWJ, the index is compared to the real wind field. It is indicated that the configuration identified by index $Z_2$ coincides well with the real situation of the EASWJ. Due to limitation of the text, samples of the EASWJ with the biggest northwest-southeast inclined angle on August 29th, biggest northeast-southwest inclined angle on August 13th and curving upwards configuration on July 28th in 2005 (as shown in Figs. 3c-3e) are compared. The result shows that the three samples are corresponding to configuration index of (-1) with biggest negative angle of -50°, configuration index of (1) with the biggest positive angle of 57° and index of (2) with curving upwards configuration respectively. These three samples reflect the reality and reliability of configuration index to identify the EASWJ.

Comparison between the quantified objective index and the real jet shows matching at 99%.

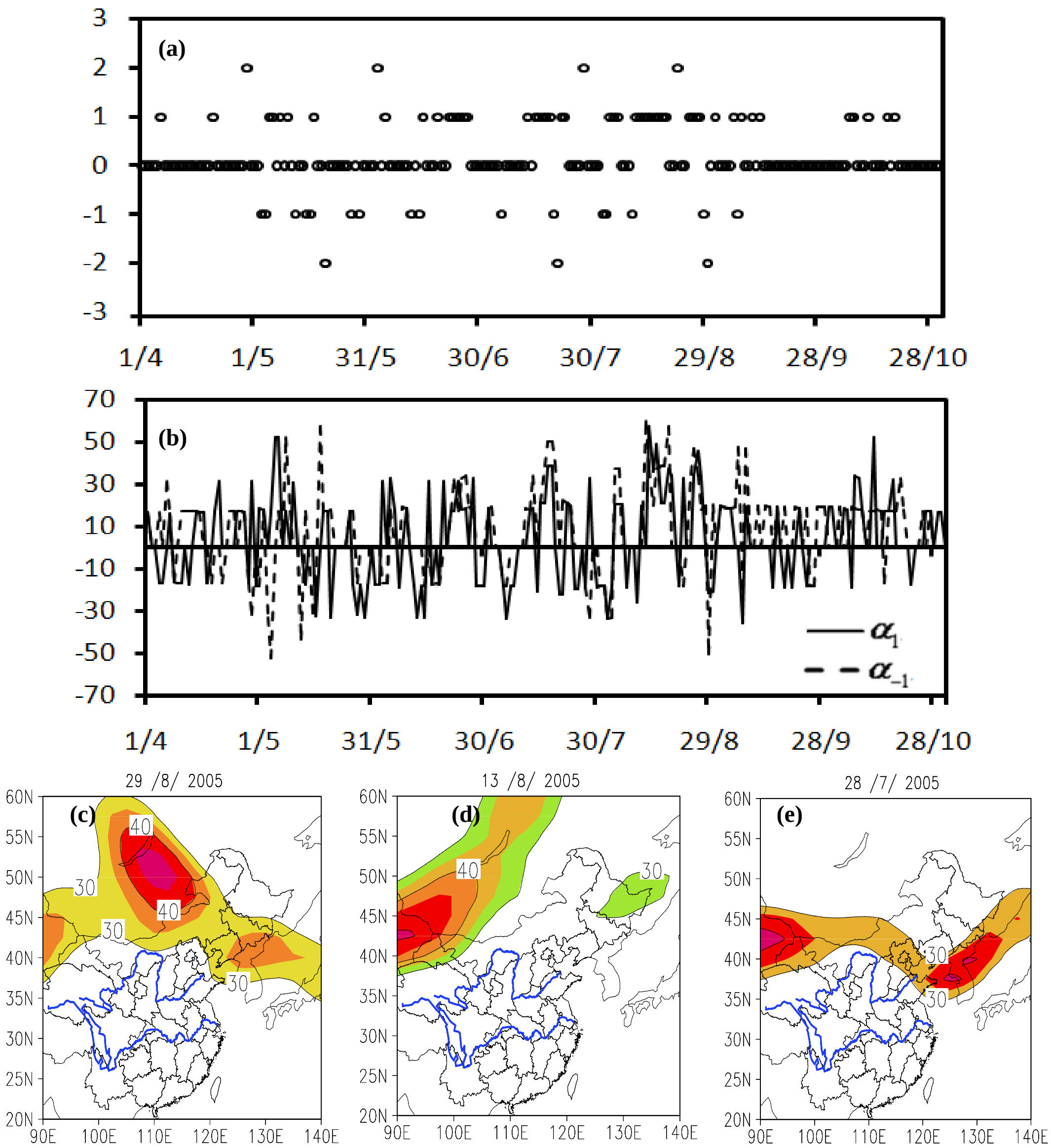


Fig. 3. Daily central configuration index $Z_2$ (a), $\alpha_0$ and $\alpha_{-1}$ (b, unit: angle) of the EASWJ during April–October in 2005 and wind speed field (unit: m/s) at 200 hPa on August 29th (c) , August 13th (d) and July 28th (e), respectively, in 2005.

## 5 CONCLUSIONS AND DISCUSSION

Major results of this study are summarized as follows:

(1) From April to October, the EASWJ and summer precipitation bands in East China move toward the north and retreat to the south simultaneously. The activity of EASWJ is therefore indicative of the beginning, ending and stabilization of the annually first flood season in South China and Meiyu season over the middle and lower reaches of the Yangtze River valley. Middle-range evolution characteristics of the EASWJ in typical Meiyu years are obviously different from that in atypical Meiyu years over these reaches. In typical Meiyu years, the EASWJ swings slightly around the climatological position in the meridional direction and 44% of the rainstorms happen when the EASWJ has non-zonal configuration; in atypical Meiyu years, the EASWJ is more northward drifted with larger amplitudes of oscillation. It is thus implied that the monitoring of EASWJ is also helpful for medium-range forecast of Meiyu over the reaches.

(2) Jet position index different from previous study is simple and unambiguous and capable of representing an appropriate correlation between the EASWJ and the position of summer rainbelt in East China. It is rare to see objective, quantitative methods that depict non-zonal configuration of the EASWJ in previous studies. The index of non-zonal

configuration gained by this study can depict the transition of the EASWJ. However, due to the difference of the subtropical westerly from year to year, universality of the results obtained in this study should be tested with more cases in the future.

(3) There are an almost infinite number of degrees of freedom in the atmosphere to realize a variety of “similar” but in fact quite diverse configurations of the EASWJ. It is therefore extremely ideal to define an algebraic method that will satisfy the free criteria of atmospheric circulation. However, development of modern meteorological science and technique requests imminently such effort on identifying variations of circulation automatically to certain extent. The index of the EASWJ could be improved to be optimal and applicable according to real situation. For example, there is room for improvement in respect of statistically selected area according to seasonal moving mean of the EASWJ.

## REFERENCES:

[1] DING Yi-hui, ZHAO Shen-ming, FU Xiu-qin. Research on multi-year average circulation at 200hPa level in global tropic and subtropics from May to October (Ⅱ) - planetary wind system [J]. Chin. J. Atmos. Sci., 1988, 12(3): 242-249.

[2] NAKAMURA H T. Sample Trapping of synoptic scales disturbance into the North-Pacific subtropical jet core in midwinter [J]. Geophys. Res. Lett., 2002, 29: 1761-1776.

[3] TAN Jie-li, JIANG Jing, YUAN Jun-peng. The seasonal, interannual and interdecadal variations of the intensity of different subtropical upper jet-stream centers [J]. Sci. Meteor. Sinica, 2009, 29(4): 482-489.

[4] YE Du-zheng, TAO Shi-yan, LI Mai-cun. The shift of general circulation in June and October [J]. Acta Meteor. Sinica, 1958, 29(4): 250-263.

[5] TAO Shi-yan, ZHAO Yu-jia, CHEN Xiao-min. The relationship between Mei Yu and up atmospheric circulation over East Asia [J]. Acta Meteor. Sinica, 1958, 29(2): 119-134.

[6] LI Chong-yin, WANG Zuo-tai, LIN Shi-zhe, et al. The relationship between east Asian summer monsoon activity and northward jump of the upper westerly jet location [J]. Chin. J. Atmos. Sci., 2004, 28(5): 641-658.

[7] ZHANG Yao-cun, KUANG Xue-yuan. The relationship between the seasonal shift of the East Asian subtropical westerly jet and Asian summer monsoon onset [C]// 6th Annual Seminar of Chinese Meteorological Society, 2005, 18.

[8] JIN Rong-hua, JIAO Mei-yan, XU Jing et al. Abnormal characteristics and causes analysis of the western Pacific subtropical high activity during the Huaihe flood in 2003 [J]. J. Trop. Meteor., 2006, 22(1): 60-66.

[9] DING Zhi-ying CHANG Yue, ZHU Li, et al. Research on the reason of the double rain-bands’ forming in a sustaining storm rainfall of south China [J]. J. Trop. Meteor., 2008, 24 (2): 117-126.

[10] LIAO Qing-hai, GAO Shou-ting, WANG Hui-jun, et al. Anomalies of the extratropical westerly jet in the north hemisphere and their impact on east Asian summer monsoon climate anomalies [J]. Chin. J. Geophys., 2004, 47(1): 10-18.

[11] XU Shu-ai. Circulation features of the abnormal winter monsoon and their relation with the early summer rainfall over south China [J]. J. Trop. Meteor., 1988, 4(3): 263-271.

[12] LIANG X Z, WANG W C. Association between China monsoon rainfall and tropospheric jets [J]. Quart. J. Roy. Meteor. Soc., 1998, 124(6): 2597-2623.

[13] MIAO Chun-sheng, WANG Jian-hong. On relations between synoptic situation of successive winter precipitating days in south- eastern China and upper circulation of Southern Hemisphere [J]. J. Trop. Meteor., 1993, 9(4): 375-379.

[14] KUANG Xue-yuan, ZHANG Yao-cun. Impact of the position abnormalities of East Asian subtropical westerly jet on summer precipitation in middle-lower reaches of Yangtze River [J]. Plateau Meteor., 2006, 25(3): 382-389.

[15] LIU Fei, HE Jin-hai, DONG Guo-qing. The correlation analysis between variation of the east asian subtropical westerly jet and summer precipitation in China [C]// 26th Annual Seminar of Chinese Meteorological Society, 138-152.

[16] YANG Lian-mei, ZHANG Qing-yun. Anomalous perturbation kinetic energy of Rossby wave along East Asian westerly jet and its association with summer rainfall in China [J]. Chin. J. Atmos. Sci., 2007, 31(4): 586-595.

[17] SHI You-yu, ZHANG Yao-cun. Relationship between subtropical upper-tropospheric westerly jet and its association with summer rainfall in north China [C]// 28th Annual Seminar of Chinese Meteorological Society, 625-634.

[18] ZHANG Y, KUANG X, GUO W. et al. Seasonal evolution of the upper-tropospheric westerly jet core over East Asia [J]. Geophys. Res. Lett., 2006, 33: L11708.

[19] BJERKNES J. Extratropical cyclones. Compendium of meteorology [M]// MALONE T F (Ed.). Amer. Meteor. Soc., 1951, 577-592.

[20] MATTHEW E P. KEYSER D, BOSART L F. A diagnostic study of jet streaks: kinematic signature and relationship to tropopause disturbances [J]. Mon. Wea. Rev., 2004, 132: 97-318.

[21] DING Zhi-ying, ZHANG Xin-qiang, HE Jin-hai et al. The study of storm rainfall caused by interaction between the non-zonal high level jet streak and the far distant typhoon [J]. J. Trop. Meteor., 2001, 17 (2): 144-152.

[22] XU Hai-ming, HE Jin-hai, ZHOU Bing. Role of the NW-SE oriented upper-tropospheric jet axis in rainstorm development [J]. J. Nanjing Inst. Meteor., 2001, 24 (2): 155-161.

[23] WANG Xiao-man, DING Zhi-ying, ZHANG Xing-qiang. Statistic and dynamic analysis to the relation between Meiyu storm and high level jet [J]. J. Nanjing Inst. Meteor., 2002, 25(1):111-117.

[24] HUANG An-li, GAO Kun. Dynamical analysis on the coupling of upper and lower tropospheric jet streaks [J]. J. Hangzhou Univ. (Nat. Sci.), 1982, 9(3): 256-364.

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