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STUDY ON THE MAIN CLIMATE MODES OF SHANDONG PRECIPITATION AND THEIR RELATIONS WITH THE EAST ASIAN WESTERLY JET

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Abstract: Summer precipitation patterns of Shandong Province are relatively independent with regard to the whole eastern China region. To study the rules and causes of precipitation variations, three main climate modes—on the annual, seasonal, and climatic intra-seasonal oscillation (CISO) scales—are extracted using a harmonic analysis method based on daily precipitation of Shandong during 1965–2009 and multi-year averaged pentad precipitation at 722 stations in China during 1971–2000. Among the three precipitation climate modes, the annual mode is closely related to the annual cycle of Earth-Atmosphere thermal system, which is characterized by the periodic dry and wet seasons. The seasonal mode reflects the monsoon effect on precipitation and the main flood season's contribution to annual precipitation variations. As an important climatic signal, the CISO mode is more evident during summer monsoon. The gradual modulations of the CISO mode, seasonal mode, and annual mode control the annual variation of precipitation. To study the relationship between precipitation climate modes and atmospheric circulations, an East Asian Westerly Jet Index (EAWJI) is defined in this paper. It is revealed that precipitation of Shandong is closely related to EAWJI in all climate modes. A wet or dry phase of each climate mode corresponds to a specific atmospheric circulation pattern. The phase of the annual mode is reverse to that of EAWJI. During the wet phase of the seasonal mode (weak phase of EAWJI), the atmospheric circulation in and around Shandong is characterized by upper-level divergence and low-level convergence. A reversed atmospheric circulation exists for the dry phase (strong phase for EAWJI). In the summer wet phase of CISO mode (strong phase of EAWJI), Shandong is controlled by upper-level divergence and low-level convergence. Again, the dry phase is corresponding to a reversed circulation structure. The methodology employed in this research, i.e. studying the precipitation climatic variations in terms of independent components of different temporal scales, provides a new approach for annual and seasonal precipitation prediction.

Key words: precipitation of Shandong; climate mode; East Asian westerly jet

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1 INTRODUCTION

Shandong is located in the basins of Yellow River and Huaihe River. Its precipitation has uneven spatial distribution and significant inter-annual variations, which are the typical characteristics of East Asian monsoon climate. Studies on regional precipitation normally focus on the variations of its mean, deviation, and the number of rainy days, especially on their inter-annual variations. In most part of Shandong, the relative variation rate of annual precipitation is 20%–24%, while its counterpart of seasonal precipitation can reach 100% in winter, and reduce to 40%–50% in summer[1]. The variations of precipitation are obvious. If the main climatic components of precipitation are analyzed and their variations and physical mechanisms evaluated, the prediction skill for precipitation anomalies will be greatly improved.

Significant seasonal variations and low-frequency oscillations are the features in monsoon regions[2].The climate of Shandong is cold and dry during winter monsoon and hot and wet during summer monsoon.

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The seasonal variations of precipitation are closely related to the transition of monsoons. For the East Asian monsoon region, its annual climate variations are related to the periodical changes of solar-terrestrial relationships, and its significant seasonal variations and intra-seasonal variations have also drawn wide attention. Rainfall is directly generated by atmospheric circulation through specific weather systems. The variations of precipitation are controlled by many factors, such as annual cycle of Earth-Atmosphere system, atmospheric circulation, ocean-atmosphere interaction, ENSO (El Niño/Southern Oscillation), and topography. Lau et al.[3] pointed out that there are three time scales, i.e. seasonal, intra-seasonal and annual scales in the variations of East Asian monsoon, and the “jump of main rain belt” is related with phase locking of ISO and seasonal cycle. Wang et al.[4] found the statistical significance of CISO of summer monsoon in Northern Hemisphere. Therefore, the variations of weather and climate of East Asia are closely related to the low-frequency oscillations.

Yu et al.[5] analyzed the typical temporal and spatial distribution of intra-seasonal abrupt precipitation changes in the wet season, and pointed out that precipitation in Shandong belongs to a coherent type and has significant low-frequency oscillation. In this paper, main climatic modes were extracted from daily/pentad precipitation series. The relationship between each main mode of precipitation and the strength of East Asian westerly jet is studied. The atmospheric circulation patterns corresponding to the wet or dry phases of each main mode are also revealed. Climatic modes may provide a new perspective on study of climatic variations of precipitation.

2 DATA AND METHODOLOGY

Data sets used in this study consist of: (1) Daily precipitation observation data of 111 stations in Shandong during 1965–2009. (2) NCEP (National Centers for Environmental Protection, USA) reanalysis daily mean wind field (2.5°×2.5°) on 200 hPa and 850 hPa during 1965–2009. (3) Pentad average precipitation data of 722 observation stations in China from 1971 to 2000, and monthly precipitation of 160 stations in China from 1965 to 2009. Daily precipitation series were processed with 5-day moving average filter to remove the effects of synoptic-scale perturbations.

The correlation coefficient of the multi-year averaged annual daily precipitation series between any station and the provincial mean is greater than 0.8, indicating their significant spatial correlation. Summer (JJA) precipitation makes up about 63% of annual precipitation in Shandong, and it belongs to the coherent type in most years from 1470 to 1996[6]. Figure 1 shows the distribution of correlation coefficient of summer precipitation between the provincial mean and any one of the 160 stations in China. It is shown that high significant correlation (statistical reliability greater than 99.9%) region only lies in Shandong. Summer precipitation is affected by various weather systems originating from the tropical region, subtropical region and westerly belt. The variation of summer monsoon and the diversity of weather systems result in significant inter-regional precipitation difference in the East China monsoon region. The summer precipitation of Shandong is weakly positively correlated with that of the north part of North China and weakly negatively correlated with that of south of Yangtze River and north part of Northeast China. The reliability of negative correlation between Shandong and South Xinjiang can reach 95%. As for the adjacent area, the summer precipitation of Shandong has little relationship with that of Huaihe River Basin or north part of North China. Therefore, the variations of summer precipitation have good coherence in Shandong, and are independent from the adjacent area. In this study, the analysis using provincial mean precipitation employed is therefore rational.

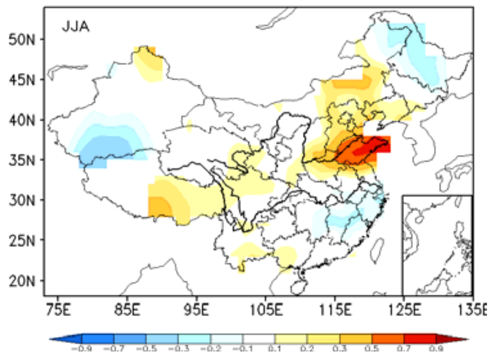

Figure 1. Distribution of correlation coefficients between average precipitation in Shandong and the 160 stations across China in the summers of 1965–2009.

To effectively depict the variation of intensity of East Asian westerly jet, East Asian westerly jet index (EAWJI) was defined in this paper. East Asian westerly jet is composed of a polar-front jet and a subtropical jet. In winter, the polar-front jet is most active and invades southward, lying between 40–60°N or reaches even lower latitudes in some years, while the subtropical jet lies between 20–30°N. In summer, the polar-front jet retreats, and the subtropical jet moves northward for about 15 degrees of latitude[7]. EAWJI is formulated as mean zonal wind speed on 200 hPa in the area of 30–45°N，120–140°E, where most of the seasonal variation of the jets can be captured. The value of EAWJI indicates the intensity of East Asian westerly jet. A 5-day moving average filter was also implemented on the EAWJI series to eliminate the effects of synoptic perturbations.

Harmonics analysis is widely used in multi-scale oscillation research to extract information of specific frequency bands from data series[8]. Previous research on climatic precipitation always focuses on flood season precipitation, summer precipitation, annual precipitation and their inter-annual, inter-decadal variations. In this study, several wave bands are extracted from a regionally averaged 365-day series using a harmonics analysis method based on the basic rules of climatic changes. These wave bands are classified into annual, seasonal, and intra-seasonal cycles, and each of them has specific climatic significance and is one of the intrinsic or common variation periods of East Asian monsoon regions. The 1st harmonics is corresponding to the annual cycle; the periods of the 2nd-4th harmonics are between 180-90 days, covering half-year and seasonal variations; the 5th-12th harmonics have periods of 30-70 days, belonging to climatic intra-seasonal oscillation (CISO).

3 MAIN CLIMATIC MODES OF PRECIPITATION AND EAWJI

Precipitation in the east of China has significant seasonal variations and regional differences. The precipitation decreases from South China, Yangtze River Basin, Huaihe River Basin to North China. For the annual cycle and seasonal variations of precipitation in different regions, the characteristics of northward advancement of summer monsoon precipitation can be clearly distinguished. The peak of the annual cycle shows the northward advancement of the main precipitation belt. As for the seasonal variation, two peaks exist for South China corresponding to the annually first flood season and annually second flood season. There are two peaks for Yangtze River Basin corresponding to Mei-yu and autumn rainfall, and one peak for Huaihe River Basin and North China in summer. Shandong lies in the south part of North China and its main peak of annual precipitation cycle occurs 1 to 2 pentads later than that of Huaihe River Basin and at nearly the same time when the peak occurs in the north part of North China. As for CISO, Shandong and Huaihe River Basin have the same phase from April to mid-July but different phase from late July to late September. In the summer half-year, the CISOs of Shandong and north part of North China have reverse phase.

Harmonics analysis is applied to multi-year averaged daily precipitation series and EAWJI series. The results are shown in Table 1. The multi-year averaged daily precipitation of Shandong is 1.8 mm, and the corresponding EAWJI value is 36.8 m/s. Figure 2 shows the deviation curve of daily precipitation and the fitting curve of the 1st-12th harmonics. The fitting rate of precipitation is 97.7% while the value of EAWJI is 99.8%. The correlation coefficients between the fitting series and the deviation series reach 0.988 and 0.999 respectively indicating that the leading 12 harmonics can capture most components of the variations of precipitation and EAWJI. In this paper, the characteristics of precipitation of the three selected wave bands and their relationship with the East Asian westerly jet were studied in the following context. These bands are defined as annual mode, seasonal mode and intra-seasonal oscillation mode. The fitting degree, i.e. relative variance contribution, of the 1st harmonics for precipitation is 70.4%, while the value of EAWJI reaches 95.4%. Both of them are dominant. Though the variance contribution of intra-seasonal oscillation is small, the signal of CISO is still significant (to be discussed in the following section). The relationship between each component of precipitation variations and atmospheric circulations is further studied next.

Table 1. Results of harmonics between the precipitation in Shandong and the westerly jet index.

Wave number	period /d	Precipitation		EAWJI	
		variance contribution	Fitting degree/ %	variance contribution	fitting degree/ %
1	365.00	2.347	70.363	161.663	95.361
2	182.50	0.542	16.251	4.791	2.826
3	121.67	0.221	6.613	1.441	0.850
4	91.25	0.102	3.069	0.840	0.496
5	73.00	0.025	0.751	0.304	0.179
6	60.83	0.010	0.307	0.062	0.036
7	52.14	0.005	0.140	0.067	0.040
8	45.62	0.002	0.055	0.041	0.024
9	40.56	0.001	0.044	0.005	0.003
10	36.50	0.001	0.029	0.004	0.002
11	33.18	0.000	0.000	0.004	0.002
12	30.42	0.003	0.086	0.040	0.024

3.1 *Annual mode*

Annual cycle is the most basic period for climatic elements, including precipitation. The main energy of Earth-Atmosphere system comes from the solar radiation. The annual cycle of Earth-Atmosphere thermal balance is the basic background for most climate elements. Variations of atmospheric circulation, land-sea heat and water vapor exchanges, features of underlying surface and their interactions all have yearly periods and they are all important factors in the formation of rainfall. As shown in Figure 2a, the annual mode of precipitation exceeds the average daily value in late April and turns to be less in late October. These two dates are one month later than the spring equinox (21 March) and autumn equinox (23 September) respectively. Pervious studies found that from South China to the middle and lower Yangtze regions and to Shandong, the occurrence of the peak of the annual precipitation mode is sequentially delayed (figure omitted). As Shandong is located in middle latitudes, the one-month delay of annual precipitation mode than the astronomical season may result from the delay in Earth-Atmosphere thermal balance. Shandong begins its flood season after the summer solstice (22 June), and starts the dry period after the winter solstice (22 December). Therefore, the period between late April and late October is the wet season of Shandong, and the period from late October to late April is the dry season.

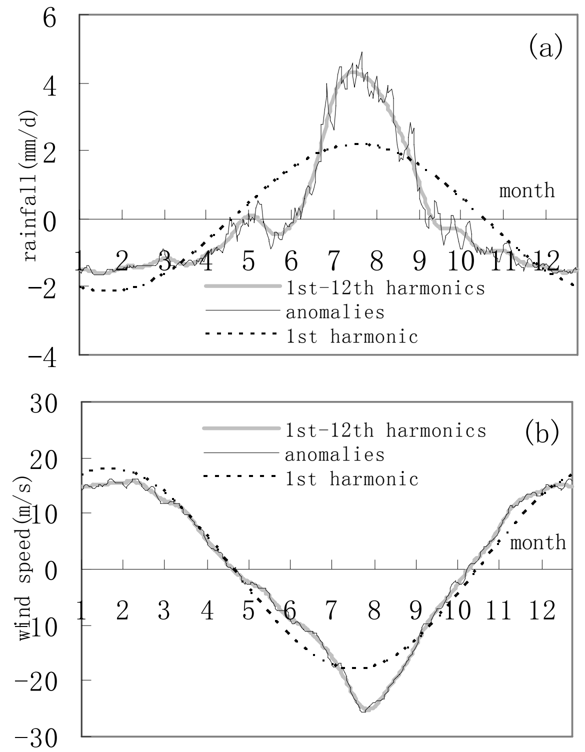

Figure 2. Curves of fitting between the composite series for first 12 harmonics of the precipitation in Shandong (a) and the westerly jet index (b) with their respective anomalous series and curves of the first harmonics.

For the annual mode, the phase of EAWJI is reverse to that of precipitation (Figure 2b), demonstrating the close relationship between precipitation and atmospheric circulation. In winter, the polar-front jet reaches its maximum intensity as it joins with the subtropical jet at about 30°N, leading to the maxima of EAWJI. In summer, the polar-front jet weakens and retreats northward as the subtropical jet gets weaker and the EAWJI reaches its minimum. The annual cycle of atmospheric circulation reflects the Earth-Atmosphere system’s thermal cycle and is the source of annual precipitation variation.

Rainfall in Shandong is usually caused by synoptic systems of the westerly zone like fronts, cyclones and troughs. The northerly shift of cyclone tracks[9] can partly explain the increase of precipitation from spring to summer. However, it should be noted that the fitting rate of annual mode of precipitation is 25% less than that of EAWJI, indicating higher complexity in the variation of precipitation than in that of jet. Furthermore, annual mode is insufficient to reflect the sharp increase of precipitation in summer, especially in the flood season. Within the annual mode, the maximum daily precipitation in July is only 2.2 m/d, while it can reach 6.7 mm/d by observation. It is obvious that the annual cycle cannot provide full information about precipitation in flood seasons, and other modes also play important roles. Though the annual mode of EAWJI has higher fitting rates than that of precipitation, its fitting error is still significant in summer, indicating that the contributions of other modes to climatic variations are non-negligible.

3.2 *Seasonal mode*

Precipitation of the monsoon region in East China has significant seasonal variations. The peak flood seasons for South China, Yangtze River Basin, and Shandong are mid-May, mid-June, and mid-July respectively. These are clearly shown in seasonal modes (figure omitted). Shandong has only one flood season while there are more than one for South China and Yangtze River Basin. The distinct difference of seasonal precipitations in Shandong is the result of alternation between summer monsoon and winter monsoon. During the period of monsoon transition, spring drought or autumn drought frequently occurs in North China.

3.2.1 TEMPORAL CHANGES

The relative variance contribution of the 2nd harmonics is twice the sum of contribution of the 3rd and the 4th harmonics (Table 1), and the sum of these three harmonics still has the basic characteristics of the 2nd harmonics. Besides the 1st harmonics, the others take up 30% of the fitting rate (Table 1) and the seasonal mode plays the main role in it. As the 1st harmonics is filtered out (figure omitted), the precipitation curve has one-valley value both in spring and autumn and one-peak value both in winter and summer. This is the typical characteristic of the seasonal mode, indicating the impacts of East Asian monsoon on precipitation. Precipitation of summer monsoon occurs from late June to late August, (i.e. flood season), accounting for 60% of the annual precipitation. The weak peak of precipitation occurs during the period of winter monsoon between mid-December and end of February. The spring drought and autumn drought are also clearly shown.

The phase of seasonal mode of precipitation is reverse to that of EAWJI (Figure 3). The strongest peak of precipitation in the wet season is in accordance with the weakest valley of EAWJI, while the second peak of precipitation during winter monsoon is in accordance with the second valley of EAWJI. Drought periods in spring and autumn are in accordance with the strong phase of EAWJI. The seasonal mode shows the seasonal adjustment of atmospheric circulation to precipitation. In summer, the polar-front jet weakens and retreats northward, while the subtropical jet is intensified. However, the westerly jet is still weaker than in winter. Previous research[10, 11] found that as season changes from winter to summer, there are three northward leaps of the westerly jet, which are closely related with activities of East Asian summer monsoon and Mei-yu. In accordance with the northward leaps, the seasonal mode of EAWJI changes greatly May through August (Figure 3). EAWJI increases from late April to the end of May and successively decreases from June to the beginning of August. Meanwhile summer monsoon prevails and the upper jet moves northward. After that, the upper jet starts to move southward and EAWJI increases. Though the variation of westerly jet in winter is not as significant as that in summer, its seasonal variation still reflects the activity of winter monsoon[12]. In general, as the westerly jet is intensified, winter monsoon is intensified and precipitation decreases, and vice verse[13, 14].

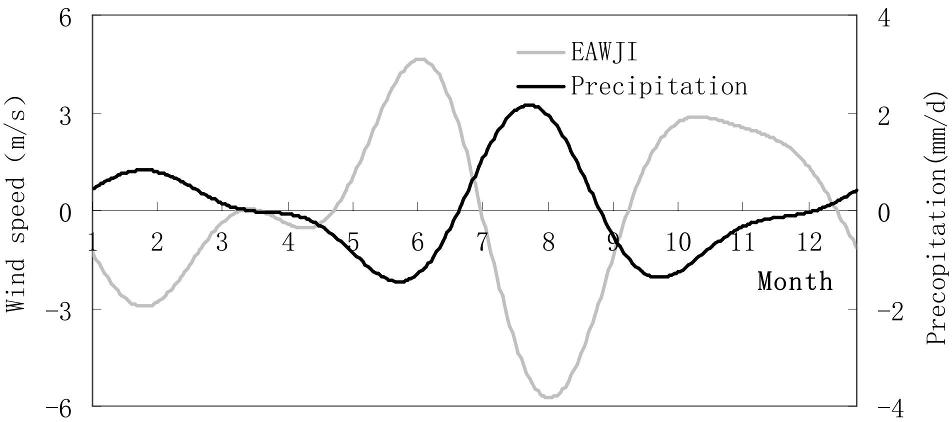

Figure 3. Time series of the seasonal modes of the precipitation in Shandong and the westerly jet index.

3.2.2 DRY, WET PHASE AND ATMOSPHERIC CIRCULATION

The spatial distributions of precipitation during different phases of the seasonal mode are studied. With the 1st harmonics filtered out, the distributions of precipitation of the two dry phases (averaged over 11 May to 10 June, 14 September to 14 October, respectively) and the two wet phases (10 January to 9 February, 13 July to 12 August) are drawn in Figure 4. It is shown that dry phases have coherent negative deviation, while wet phases have coherent positive deviation. For wet phases, the maximum positive anomaly of precipitation in January is 0.8 mm/d, while it is 3.0 mm/d in July. The dry phases of May and September are in the dry periods of spring and autumn, with the least negative precipitation anomaly at −2.2 mm/d and −1.7 mm/d respectively. The spatial distributions of the two dry phases or the two wet phases are similar. However, the average precipitation of the two wet phases differs distinctly, reflecting the different impacts of the circulations of summer and winter monsoons on precipitation.

The dry, wet phases are in accordance with strong, weak phase of EAWJI respectively. The atmospheric circulation patterns during a typical dry phase of 22 May–31 May (strong phase of EAWJI) and a typical wet phase of 23 July–1 August (weak phase of EAWJI) are studied in this section. As shown in the chart of wind vector and diversity on 200 hPa (Figure 5), during the strong phase of EAWJI, the westerly is intensified. A cyclonic shear and convergence center (D<0) lies to the north of the jet, while an anti-cyclonic shear and divergence center (D>0) lies to the south of the jet (Figure 5a). The area from Shandong to Bohai Sea and Yellow Sea is beneath the center of upper-level convergence with divergence at the low level (figure omitted). This circulation pattern is unfavorable for rainfall and leads to a dry phase. On the contrary, during the weak phase, the westerly is weakened and an anti-cyclonic shear and divergence center occur to the north of the jet. Meanwhile a cyclonic shear and convergence center lie to the south (Figure 5b). Over the area of Shandong, Bohai Sea and Yellow sea, there lies a divergence center in upper-level troposphere and convergence at low-level troposphere (figure omitted). The circulation structure is favorable for rainfall and leads to a wet phase. The secondary circulation at the two sides of East Asian jet also changes with the different phases of the seasonal mode. Strong or weak phases of the seasonal mode tend to have reversed secondary circulation structures, which have the characteristics of stationary wave.

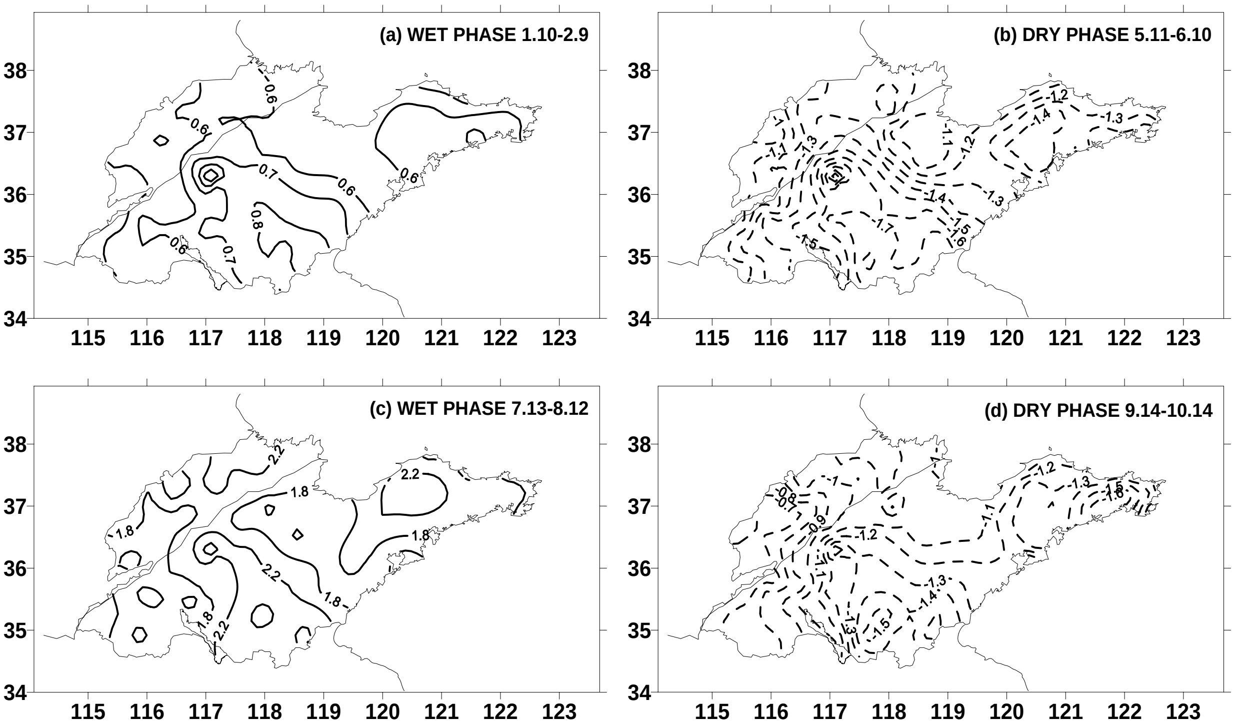

Figure 4. Spatial distribution of the precipitation during the wet phase (a, c) and dry phase (b, d) of the precipitation in Shandong with the 1st harmonics filtered out. (Units: mm)

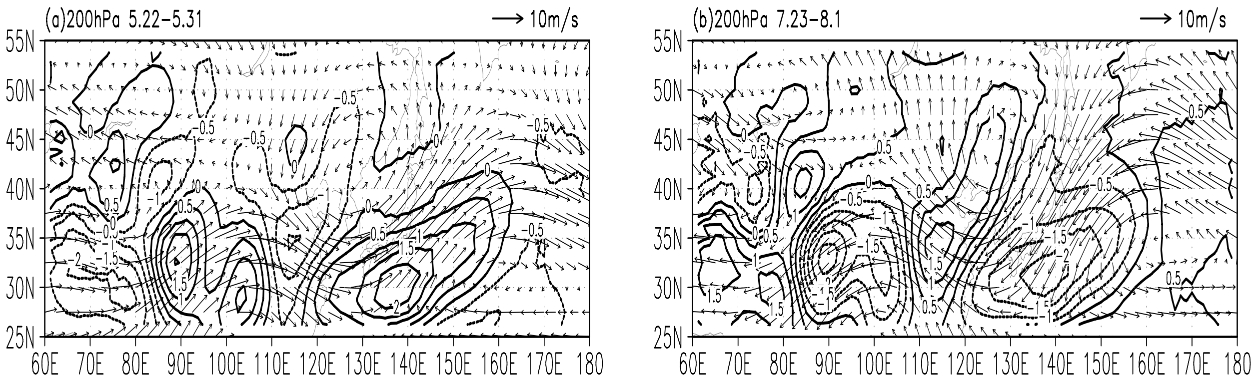

Figure 5. 200 hPa wind vectors (units: m s^{-1}) and divergence (Units: 10^{-5} s^{-1}) during the typical dry (a) and wet (b) phases of the seasonal mode for the precipitation in Shandong.

3.3 *CISO mode*

Low-frequency oscillation is more significant in summer than in winter for the monsoon region of Northern Hemisphere. Compared to seasonal cycles, low-frequency oscillation has greater influence on monsoon onset and monsoon break[2]. The East Asian monsoon has intra-seasonal oscillation (ISO), which is most robust in summer. ISO has distinctly important impacts on precipitation[15, 16]. In order to predict drought or flood in the wet season, more research on low-frequency oscillation has been done to reveal the rules of monsoon variation. The ISO in East Asian monsoon area have great influence on drought/flood in the basin of Yangtze River and Huaihe River[17, 18], and the propagation rules of low-frequency oscillation of summer monsoon are very important in medium- and long-term precipitation prediction. Studies on low-frequency oscillation of precipitation in the wet season in China[19, 20] indicate that seasonal cycles are significant in precipitation variations, and CISO plays an important role in modulation of the maintenance and spatial movement of rain-bands in East China. For example, in the basin of Yangtze River and area to the south of it, precipitation variations have periods of 30-60 days. Shandong lies in the mid-latitude monsoon climate region. Whether its precipitation has CISO is a question.

3.3.1 FREQUENCY STRUCTURE

After removal of the decisive contributions of annual mode and seasonal mode by filtering out the 1st to 4th harmonics, spectrum analysis was implemented on the daily series of precipitation and EAWJI. The 40-50 day oscillation of precipitation satisfied the 0.05 confidence test (Figure 6a). Oscillation of EAWJI in such bands is even more significant (Figure 6b). The frequency structure demonstrates the existence of CISO and quasi-biweekly oscillation in precipitation and EAWJI.

3.3.2 TEMPORAL VARIATION

The fitting ratios of 30-70 day period for precipitation and EAWJI are 1.4% and 0.3% respectively, and the variance contribution rate of precipitation is much greater than that of EAWJI. As shown in Figure 7, precipitation and EAWJI have the same phase in summer. There are three CISOs from late April to late October, and the strongest CISO occurs between late June and early August, which is the flood season of Shandong. It is demonstrated that heavy precipitation in the flood season is the result of modulation from the CISO to the seasonal mode. However, during the period of winter monsoon, the peak value of precipitation is weakened by CISO. During the period of spring drought and autumn drought, the peak values of CISO in May and October bring precipitation to Shandong. The above facts show that the modulation from the CISO to seasonal mode alleviates the intensive droughts and floods in Shandong.

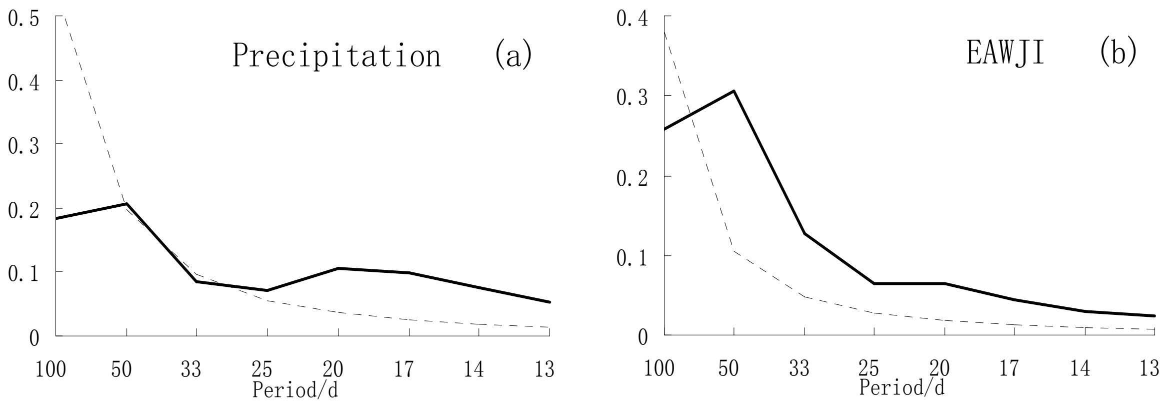

Figure 6. Spectrum analysis of the precipitation in Shandong (a) and EAWJI (b) with the 1st to 4th harmonics filtered out (Solid curve for the values of power spectrum and dashed curve for the 95% test).

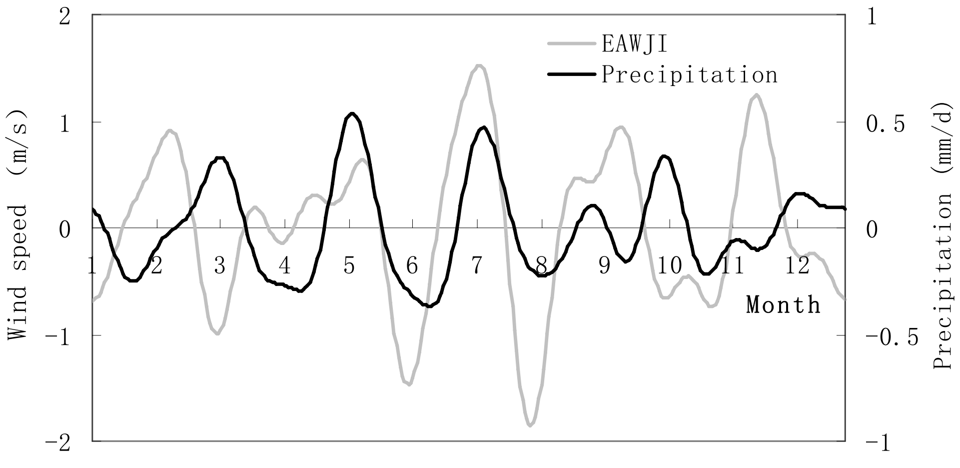

Figure 7. Temporal series of the CISO mode for the precipitation in Shandong and westerly jet index.

For the CISO mode, precipitation and EAWJI have similar phase in the summer half-year, while EAWJI proceeds a little. At the beginning of the flood season, while monsoon circulation adjusts itself, the low-frequency oscillation is robust and weather systems are intensified or weakened under this background. Wang et al.[4] studied the structure of East Asian summer monsoon system and pointed out that in the low-level troposphere, there is a convergence zone caused by southerly from the tropical region and weak northerly from the mid-latitude region, and the upper-level troposphere is predominated by the westerly north of the ridge of Northwest Pacific subtropical high. As the low-level convergence is intensified, precipitation is enhanced and the high-level subtropical jet is also intensified, and vice verse. This can explain the coincidence of variations of East Asian westerly jet with the precipitation in summer.

3.3.3 CIRCULATION PATTERN OF TYPICAL DRY, WET PHASE

The typical wet phase (7–11 July) and dry phase (5–9 August) of the CISO mode are studied for comparison. It is found that the period of 5–9 August is within the wet phase of the seasonal mode, but it is a typical dry phase of the CISO mode, indicating the interaction between variations of different scales. The circulation structures of strong (wet) and weak (dry) phases of CISO mode during the prevailing period of summer monsoon are studied in this section. It is shown that the circulation field and diversity field have reverse distribution for the two different phases (Figure 8). At the time of strong EAWJI phase, which is in accordance with wet precipitation phase, there exist cyclonic shear and upper-level convergence to the north of the jet, and anti-cyclonic shear and upper-level divergence to the south of the jet. Shandong is located under the high-level convergence center (Figure 8a) and low-level convergence (figure omitted), which leads to great opportunity of rainfall. During the weak phase of EAWJI, Shandong is located under a high-level convergence center (Figure 8b) with divergence in low-level troposphere (figure omitted), which leads to little chance of rainfall. This is the way that atmospheric circulations strongly affect the precipitation in the CISO mode. In fact, at the two sides of East Asian jet, there are still secondary circulations in the CISO mode. The structure of secondary circulation is reverse for strong and weak phase, and this is the circulation background for precipitation variations. Furthermore, it should be noted that CISO is much more robust during summer monsoon than during winter monsoon.

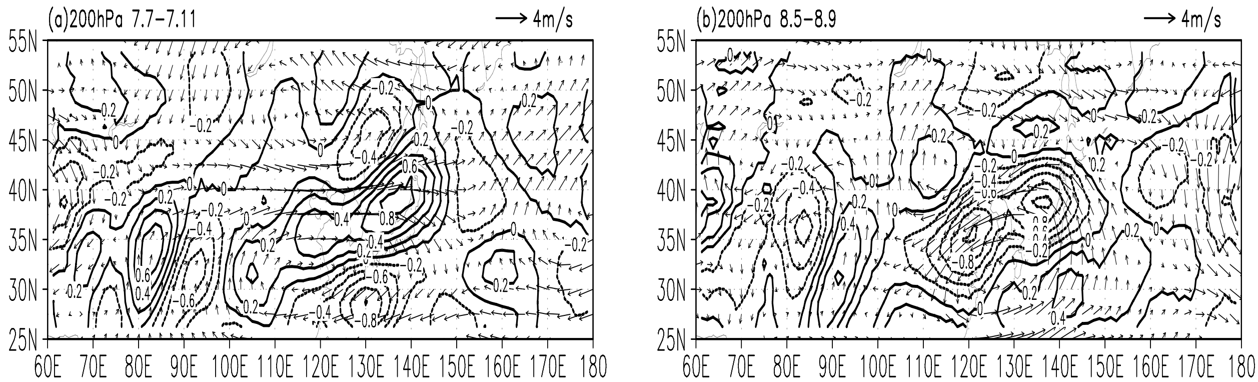

Figure 8. 200 hPa wind vectors and divergence for typical wet (a) and dry (b) phases of the precipitation in Shandong with the CISO mode (divergence in the unit of 10^{-5} s^{-1}; wind speed in the unit of m s^{-1}).

4 SUMMARY AND DISCUSSIONS

The climatic variations of precipitation are complicated. Most of the previous research focuses on precipitation series and the variations of its mean and deviation. In this paper, the climatic precipitation series of Shandong is decomposed into independent climatic components with different temporal scales, which provide a new method to the study of climatic variations of precipitation. For Shandong, precipitation is concentrated in summer, and summer precipitation is locally coherent and independent from adjacent regions. The climatic annual series of precipitation in Shandong is decomposed with the harmonics method into the annual mode, seasonal mode and CISO mode. The superposition of the three modes can fit the variation of precipitation very well. The climatic significance of each mode and its relationship with atmospheric circulation are discussed. Each mode has corresponding specific atmospheric circulation background.

Annual cycle is the dominant and basic mode for precipitation series. It is the result of annual cycle of Earth-Atmosphere thermal system and is characterized by more precipitation in the warm half-year (May to October) and less precipitation in the cold half-year (November to April of the subsequent year). The phases of annual precipitation mode are opposite to those of EAWJI. The seasonal mode reflects the basic characteristic of East Asian monsoon precipitation, clearly indicating the intense precipitation in the flood season and relatively dry period in spring and autumn. The seasonal mode also has reverse phase to EAWJI, and its modulation effect on the annual mode is significant. The modulation from the CISO to seasonal mode results in complicated variations of summer precipitation. During summer monsoon period, precipitation has the same phase with EAWJI. CISO acts as an important factor in climatic prediction. The dry and wet phases of all the modes are corresponding to specific atmospheric circulation patterns. During wet phases of both seasonal mode and CISO mode, the circulation in the region of Shandong is characterized by upper-level divergence and lower-level convergence, while dry phases are corresponding to a reverse circulation pattern. These circulation patterns are related to the stationary secondary circulation at the two sides of the jet.

Besides CISO, quasi-biweekly oscillation can also be found in climatic precipitation series. It is also an important signal due to its close relationship to abrupt precipitation changes in the flood season. This problem will be studied in another paper. It should be pointed out that the amplitudes and phases of different modes may change in different years. So does their variance contributions. These can explain the great variability of inter-annual precipitation. It is obvious that the analysis of inter-annual changes of the components, i.e. annual mode, seasonal mode and ISO, is helpful to reveal the mechanism of precipitation anomaly and may provide a new means for annual and seasonal precipitation prediction.

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