Journal of Ocean University of China (Oceanic and Coastal Sea Research)
ISSN 1672-5182, April 30, 2005, Vol.4, No.2, pp.99-107
http://www.ouc.edu.cn/xbywb/
E-mail: xbywb@mail.ouc.edu.cn

An Analysis of the Causes of Decadal Variations of Rainfall in Shandong in Summer

GAO Anchun[1), 2)], ZHANG Suping[2), *], SHEN Peilu[1)], and WU Jiejing[3)]

1) *Linyi Meteorological Bureau, Linyi, Shandong* 276004, *P. R. China*
2) *Physical Oceanography Laboratory, Ocean University of China, Qingdao* 266003, *P. R. China*
3) *Qingdao Meteorological Bureau, Qingdao* 266003, *P. R. China*

(Received May 11, 2004; accepted November 22, 2004)

Abstract The precipitation in Shandong in July, August as well as the whole summer (JJA) and the corresponding 500 hPa geopotential height fields are analyzed by means of the SVD (singular value decomposition) methodology. It is found that the general circulations in East Asia and the Western Pacific underwent decadal changes around 1979. The geopotential height, in particular over key areas like the South China Sea and the Philippines, increased after 1979. Corresponding to the changes in the geopotential height, the rainfall in Shandong started to decrease around 1979. The synthesized analysis shows that when the geopotential height at 500 hPa level decreases in the key areas, the Western Pacific subtropical high shifts northward and an anticyclonic anomalous cell enforces the southerly flow over Shandong-Korea-Japan, Shandong could experience a wet period. A dry period is likely to occur when the geopotential height increases in these key areas, the subtropical high moves southward or expands westward to a great distance, and a cyclonic anomalous cell controls Shandong. Respective conceptual models for the causative mechanism are obtained for the cases of July, August and the whole summer (JJA).

Key Words summer rainfall; Shandong Province; 500 hPa geopotential height; decadal variations; SVD analysis

Number ISSN 1672-5182(2005)02-99-09

1 Introduction

General circulation anomalies, especially prolonged ones, are the principal cause of large-scale climate changes. The Western Pacific subtropical high and the East Asia trough are important members in the general circulation systems. The influences of subtropical high on the annual changes of weather and climate have been studied in the past (Wang and Wu, 1997; Sun and Ma, 2001; Li *et al.*, 1997; Li *et al.*, 2003), and the subtropical high's decadal changes as well as the corresponding impact on the precipitation variations around the Yangtze valley have drawn researchers' attention recently (Gong *et al.*, 2000; Zhang and Wu, 2001; Gong and He, 2002). Yet the influences of the decadal variations of the subtropical high and other general circulation members in the Asia-West Pacific region on the rainfall in Shandong in summer have not been investigated so far.

We shall discuss the influences of the 500 hPa height field on the rainfall in Shandong in summer in terms of its decadal variations in order to obtain the causative mechanism of the climate changes and to deepen our understanding of the abnormal decline in precipitation beginning at the end of the 1970's and continuing for more than 10 years.

* Corresponding author. Tel: 0086-532-2032411
E-mail: zsping@ouc.edu.cn

2 Data Set and Methodology

2.1 Data Set

Monthly precipitation data were collected from 40 sites in Shandong Province from 1961–1997. Part of the sites are situated in the coastal areas (see Fig.1).

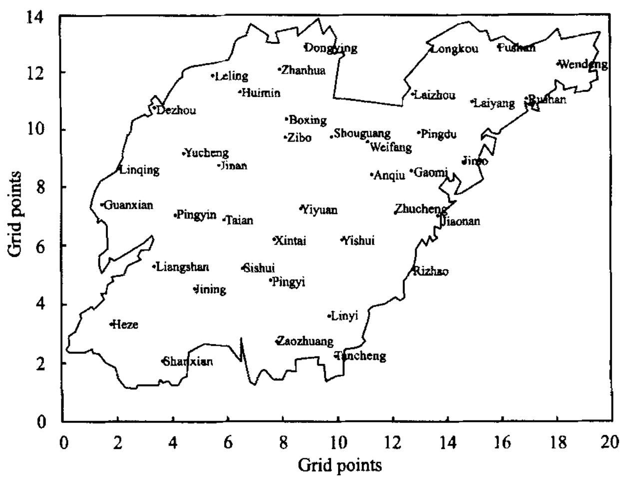


Fig.1 The distribution of the 40 weather sites in Shandong.

The monthly 500 hPa geopotential height and wind field data, reanalyzed by the NCAR/NCEP (National Center for Atmospheric Research/National Centers for Environmental Prediction) with a spatial resolution of 2.5°×2.5°, are used in the regions 10°–60°N, 110°–180°E for SVD (singular value decomposition) analysis and 10°–60°N, 80°–180°E for synthesized analysis.

2.2 A Brief Description of SVD

Since it was first introduced into meteorological study (Prokaska, 1976), the SVD technique has been found widely used in the discussions of temporal and spatial variations of two interrelated meteorological fields, and meaningful results have been obtained (Long *et al.*, 2003; Li and Li, 2001; Su *et al.*, 1999). In the present paper, the relation between the geopotential height and the precipitation in Shandong in summer are investigated by means of SVD.

Supposing there are two meteorological fields, $\boldsymbol{F}(t) = [F_1(t), F_2(t), \cdots, Fp_1(t)]$ (the left field, referred to as L hereafter) and $\boldsymbol{G}(t) = [G_1(t), G_2(t), \cdots, G_{p2}(t)]$ (the right field, referred to as $\boldsymbol{R}$ hereafter), in which $t = 1, 2, \cdots, n$ is the length of the time series, and p_1 and p_2 are the numbers of grid points or observational sites. The covariance matrix, $\boldsymbol{C}_{FG} = \boldsymbol{F}\cdot\boldsymbol{G}^T$, can be decomposed as follows:

$$\boldsymbol{C}_{\mathrm{FG}} = \boldsymbol{L}\begin{vmatrix} \sum & 0 \\ 0 & 0 \end{vmatrix}\boldsymbol{R}^{\mathrm{T}},$$

where $\Sigma = \mathrm{diag}(\delta_1, \delta_2, \cdots, \delta_p)$ is the diagonal matrix, $p \leqslant \min(p_1, p_2)$, $\delta_i > 0$, and $\delta_1 \geqslant \delta_2 \geqslant \cdots \geqslant \delta_p > 0$, $i = 1, 2, \cdots, p$; $\delta_1^2, \delta_1^2, \cdots, \delta_p^2$ are the nonzero eigenroots of $\boldsymbol{C}_{FG}^T\boldsymbol{C}_{FG}$, δ_i are the eigenvalues of the matrix $\boldsymbol{C}_{FG}$, $\boldsymbol{L}$ is the left orthogonal matrix, and $\boldsymbol{R}$ is the right orthogonal matrix of $\boldsymbol{C}_{FG}$. δ_i^2 is the variance of the i-th spatial pattern of SVD, and the variance contribution or the precision of the first k patterns can be expressed as

$$CSCF_k = \sum_{i=1}^{k}\delta_i^2 / \sum_{i=1}^{p}\delta_i^2.$$

For the details of the approach, please refer to the reference (Shi, 1995). Two new variables can be composed with the left and the right orthogonal matrixes:

$$\boldsymbol{A} = \boldsymbol{L}^{\mathrm{T}}\boldsymbol{F}$$
$$\boldsymbol{B} = \boldsymbol{R}^{\mathrm{T}}\boldsymbol{G}.$$

Given that $\boldsymbol{L}$ and $\boldsymbol{R}$ are orthogonal variables and that $\boldsymbol{A}$ and $\boldsymbol{B}$ share the maximum covariance, $\boldsymbol{A}$ and $\boldsymbol{B}$ should be the temporal coefficient matrixes of the left and the right fields and can reveal the variations of $\boldsymbol{L}$ and $\boldsymbol{R}$ with time. (L_i, R_i) is called the i-th pattern-pair or variable pattern, and each pair, along with the corresponding temporal coefficients, determines the coupled signals of the two fields. The correlation coefficients between the temporal coefficients of each pair, $r_k(\boldsymbol{A}, \boldsymbol{B})$, are called the singular correlation coefficients of the pattern-pair, which show the extent or degree of the teleconnection the k-th pair can represent. The heterogeneous correlation coefficients are defined as the extent to which the left/right temporal coefficients link with that of the right/left fields in each pair, and this means that the temporal variations of one field correlate with another field's spatial distributions (Li and Li, 2001; Su *et al.*, 1999; Shi, 1995) and the significant correlation regions represent the key areas of interaction between the two fields.

3 General Situations of Decadal Variations of Rainfall in Shandong

The monthly precipitation selected from the 40 sites can represent the precipitation in the whole province quite well. From the linear trend lines of the precipitation anomalies in both the whole summer (JJA, June, July, August) and the mid-summer months (JA, July and August) we can see all the time series trends turn rather sharply from positive to negative at around 1979 (the relevant figures are not shown here). In Table 1 more information about the turning is given. The T-test for the averages of the two time series, 1961–1978 and 1979–1997, shows that the significant levels are over 0.01 for July and 0.05 for summer. As for August, a significant level over 0.01 is found in the periods 1961–1978 and 1979–1993. Therefore, the turning points in 1979 show up clearly both in July and August as well as in the whole summer. We proceed to discuss the main causes of the decadal variations in precipitation with the help of the SVD technique in the following sections.

Table 1 T-test of the decadal variations in July, August and summer

Month (s)	Rainfall anomalies/mm		Significant level of T-test
	1961–1978	1979–1997 (1979–1993 for Aug.)	
July	25.88	–24.52	0.01
August	17.37	–32.81	0.01
Summer months	12.70	–11.43	0.05

4 Relation Between Precipitation and 500 hPa Geopotential Height

In the SVD analysis, the data are normalized in order to eliminate the influence caused by different magnitudes of elements. Then the precipitation data are taken as the left field and the 500 hPa geopotential data the right field. The correlations between the two fields are shown in Table 2. Notice that under the three circumstances (July, August, and summer) the contributions made by the first pattern-pair's square covariance are over 70% and that by the first two pattern-pairs' are over 80%, which indicates that the SVD method is effective in the decomposition. The correlation coefficients between the decomposed pattern-pairs are over the significant level of 99% ($\gamma_{\alpha=0.01}=0.43$), which indicates an obvious influence of the 500 hPa height on the precipitation. Because of the greater significance of the first pattern compared with the second, the first is the main target of this investigation.

Table 2 The covariance contribution percentages and correlation coefficients $\gamma_k(\boldsymbol{A}, \boldsymbol{B})$ of the first two pattern-pairs from the SVD

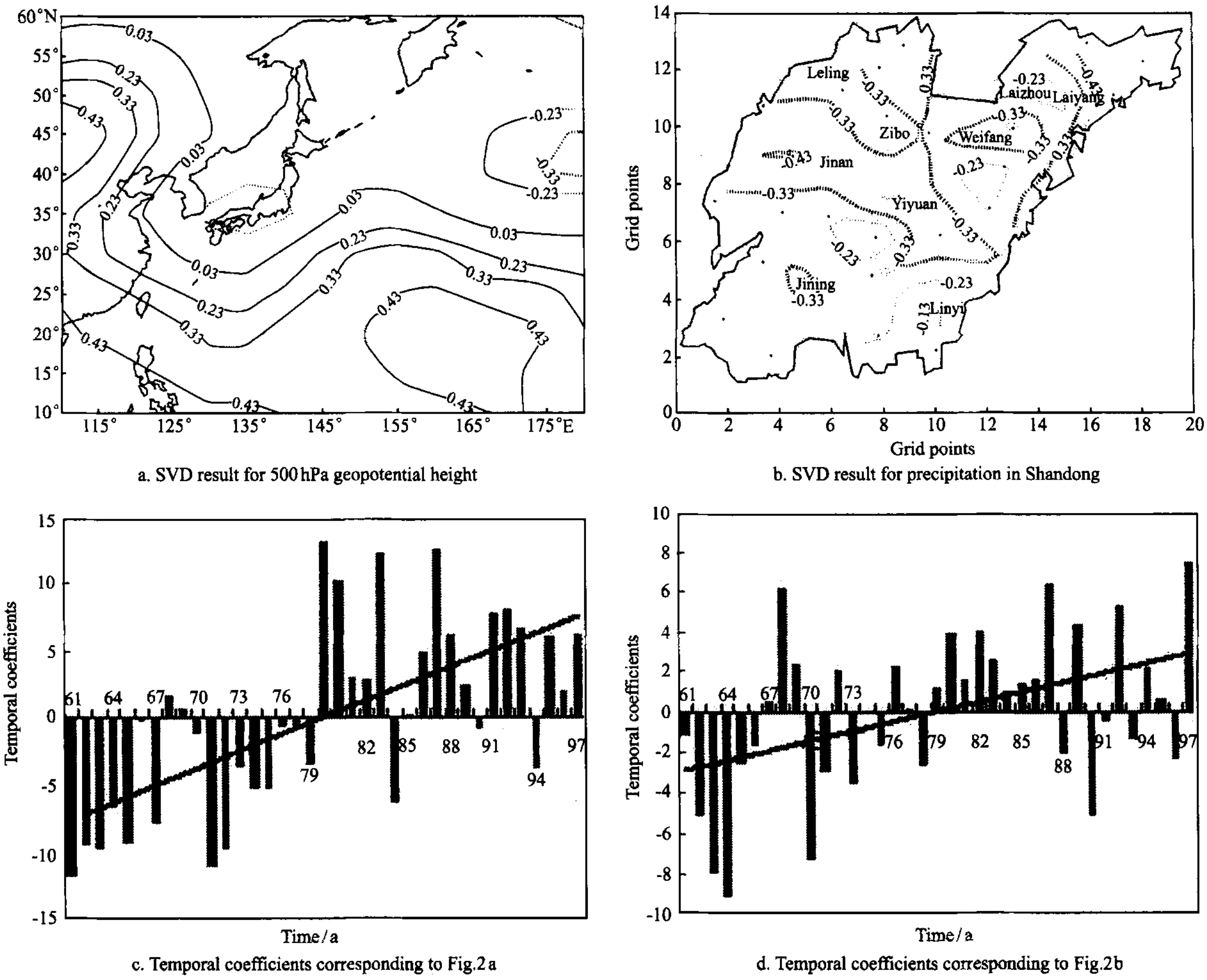
Month (s)	The square of the covariance contribution percentage / %		$\gamma_k(\boldsymbol{A}, \boldsymbol{B})$ ($\gamma_{\alpha=0.01}=0.43$)	
	1	2	1	2
July	73.56	7.60	0.5363	0.6251
August	76.26	11.39	0.6473	0.6260
Summer months	85.73	5.26	0.5063	0.5714

4.1 The SVD Analysis for July

In the first spatial pattern-pair of rainfall and 500 hPa field, the contribution to the square covariance is 73.6%, and the correlation coefficient is 0.536 3, which is greater than the confidence level of 99.9% ($\gamma_{\alpha=0.001}=0.52$). The heterogeneous correlation coefficients and the corresponding temporal coefficients are shown in Figs.2 a–d. In Fig.2 a the positive correlations are significant (above 0.05 level) in the regions of the South China Sea (SCS), the Philippines and southeast of the Philippines. The negative correlations are remarkable (above 0.05 level) in a rather small area near the dateline around 40°–45°N. All of these areas are the key regions (with a confidence level over 0.05) influencing the precipitation in Shandong in summer to a great extent.

The heterogeneous correlations in the precipitation fields (Fig.2 b) are negative all over the province and the significant areas (above 0.05 level) are located in the northwestern part, the central mountain regions of the province as well as the southern section of the Shandong Peninsula.

It can be seen from Fig.2 c that the temporal coefficients of the height field are mainly negative before 1979 and positive after 1979 (including 1979), and this means that the height field has a basically negative anomaly before 1979 and a positive anomaly after 1979 in the positive correlation areas (Fig.2 a). On the other hand, the turning point in the precipitation field is



a. SVD result for 500 hPa geopotential height

b. SVD result for precipitation in Shandong

c. Temporal coefficients corresponding to Fig.2 a

d. Temporal coefficients corresponding to Fig.2 b

Fig.2 The heterogeneous correlation coefficient distributions of the first pattern-pair (the isolines marked by 0.33, 0.43 and 0.52 represent the significant levels of 0.05, 0.01 and 0.001 respectively) and the corresponding temporal coefficients (the solid lines show the linear trends) in July.

also in about 1979 with negative coefficients before and positive ones after that year (Fig.2d), which demonstrates the wet phase before 1979 and the dry phase after 1979. The differences in the temporal coefficients of the precipitation between the two sub-sections of 1961 – 1978 and 1979 – 1997 are significant with the T-test levels of over 0.01, which is compatible with the results based on the original precipitation data. In other words, the decadal variations in the geopotential height field occur in about 1979, and the precipitation changes accordingly from the wet phase from 1961 to 1978 to the dry phase from 1979 to 1997.

4.2 The Synthesized Analysis for July

The synthesized 500 hPa geopotential height in the wet period of 1961 – 1978 (Fig.3a) depicts a wide trough over Lake Baikal, and a high ridge anchors along the coast of the Northeast Asia. The western section of the subtropical high, located in southern Japan, overlaps the ridge, and the ridge line of the subtropical high is situated between 27°N and 28°N. This condition is beneficial to the interaction between the cold air from the northwest along the rear of the trough and the warm and moist flow from the south in the west high over Shandong Province. The negative anomalies of the height field appear west of 125°E and south of Baikal with the lowest value of −20 gpm southwest of Baikal (not shown in the figures). Therefore, the cold air flows influencing Shandong are mainly along the northwest-southeast or the west-east paths, and the positive center near Japan, with the value of 5 gpm, indicates that the northern edge of the subtropical high expands northward, which is in favor of the thermal and humid air moving farther north, and this is consistent with our forecast experience. Fig.3 c shows the wind field anomalies during the wet period. There is an anticyclonic anomalous cell (ACA for short hereafter) over Japan, which is corresponding to the positive height anomalies. This ACA overlaps the western portion of the subtropical high, leading to the northward shift of the high with an accompanying warm moist transportation. The southerly air west of the subtropical high along with the ACA intensifies the southwest warm moist flow, thus, leading to the farther northward shift of the moisture.

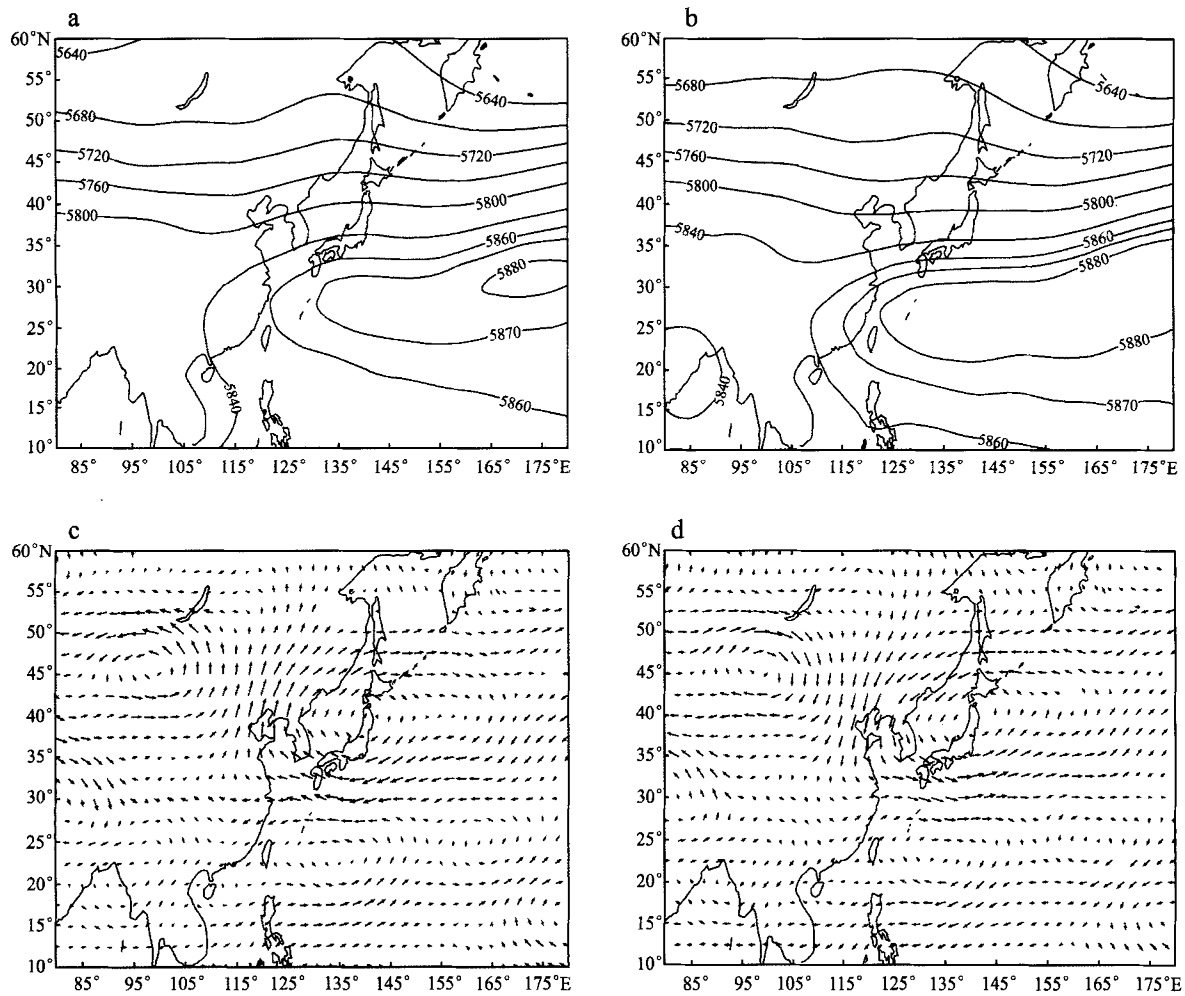


Fig.3 The composed 500 hPa geopotential height (in gpm) and wind field anomalies at 500 hPa (in ms^{-1}) in July. a and c. Wet period; b and d. Dry period.

During the dry period (1979–1997), a weak high ridge is located south of Lake Baikal and a low trough north of 35°N at about 120°E. Shandong Province is under the control of a west-northwest flow at 500 hPa height (Fig.3b). A negative height anomaly center, marked with −5 gpm, exits around Japan (not shown in the figures), which means that the lower geopotential height is near Japan, and that the subtropical high shifts southward and so does the corresponding planetary front (the belt of the maximum winds). An abnormal anticyclone and a cyclone exist southwest of Lake Baikal and over Korea-Japan, respectively (Fig.3d). The abnormal northerly winds between the two abnormal cells diminish the southerly flow from the western part of the subtropical high, resulting in less precipitation.

Combining the results abtained from the SVD and from the synthesized analysis, a conceptual model concerning the decadal variations in precipitation in July can be presented, in which Shandong would have a wet phase if the geopotential height decreases over the key regions such as the SCS and the oceans adjacent to the Philippines, an anticyclone anchors onto Korea-Japan, a cyclonic cell controls the large area southwest of Baikal, and the subtropical high shifts northward overlapped by a ridge along the westerlies near the Northeast Asia. On the other hand, Shandong would suffer a dry phase under the conditions of a rise in geopotential height in the low latitude region from South China Sea to the Philippines, an ACA cell south of Lake Baikal, a cyclonic anomaly cell over Shandong Peninsula-Korea-Japan, and a southward displacement of the subtropical high.

4.3 The SVD Analysis for August

The first pattern-pair obtained from the SVD, with the 500 hPa height and the precipitation in August involved in it, can account for 76.3% of the total covariance contribution. The heterogeneous correlation coefficients and the corresponding temporal coefficients are shown in Figs.4 a–d. The key area with obvious positive correlations are from Southern China to the SCS, an area expanding further north compared with its counterpart in July. Another key area with positive correlations is located at the Kamchatka Peninsula. The negative correlations appear mainly over Korea-Japan, as well as further east (Fig.4a). The corresponding correlation coefficients to the precipitation are negative all over the province (Fig.4b). When the geopotential height rises in the positive correlation areas, the rainfall decreases; when the geopotential height rises in the negative correlation areas, the rainfall increases.

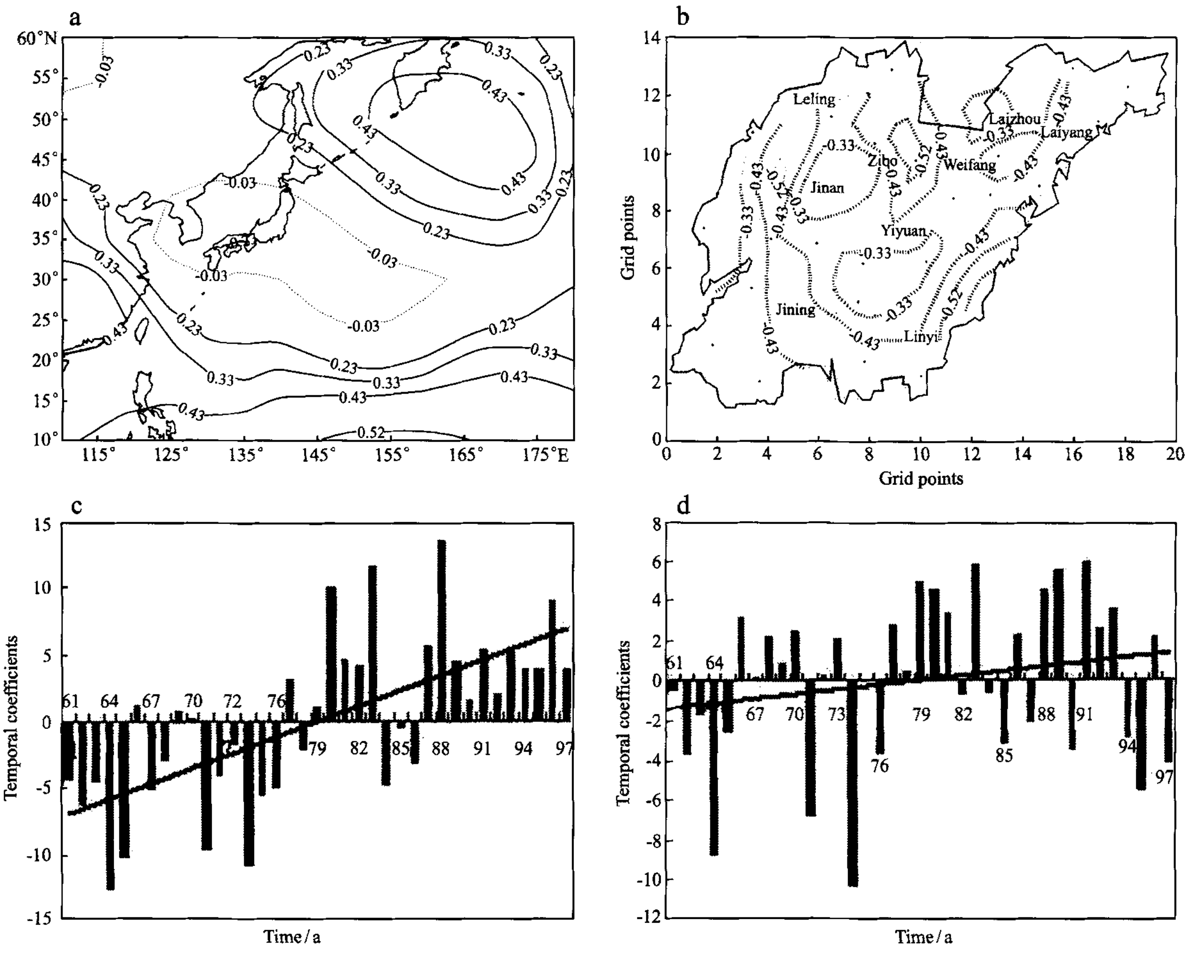


Fig.4 Same as Fig.2, but for August.

The temporal coefficients of the height are basically negative before 1979 and positive after 1979 (Fig.4c). The T-test shows that the difference between the averages of the two time series (1961–1978, 1979–1997) is not obvious, but it becomes significant if we take up the cases of 1961–1978 and 1979–1993 instead. Thus, the turning point in 1979 is also remarkable in terms of the decadal variations in rainfall (Fig.4d).

4.4 The Synthesized Analysis for August

The composed geopotential height from 1961–1978 shows that the ridgeline of the subtropical high adjacent to 30°N in August (Fig.5a) is about 2–3 degrees of latitudes to the north compared with its counterpart in July. A positive anomalous area stretches from the Shandong Peninsula to Korea. Another weak positive anomalous area appears in the Western Pacific (not shown in the Figures). The negative anomalies mainly emerge in the middle part of Russia.

The wind field anomalies of the wet period illustrate that there are two obvious ACA cells in Eastern China and the Western Pacific (Fig.5c). Shandong, located west of the anticyclone, is easily and constantly influenced by the southerly flow from the eastern part of the Bay of Bengal, the SCS and the oceanic areas east of the Philippines. The ACA and positive geopotential anomalies indicate the northward shift of the subtropical high, thus the intensified southerly winds west of the high readily reach Shandong. Furthermore, the anomalous cyclonic cell southwest of Baikal makes the westerlies robust, causing the cold air to move eastward to affect the weather and climate in eastern China.

As for the dry period of 1977–1993, the synthesized 500 hPa height (Fig.5b) demonstrates that there is a shallow ridge southwest of Lake Baikal, and Shandong is within the northwesterly flow, coming down from the ridge front. The ridgeline of the subtropical high exits at about 29°N and the western part of the high expands westward to the west of 95°E. The area encircled by the isoline of 5870 is much larger than that in the wet period. Along with the changes in geopotential height, an abnormal cyclone occupies Shandong (Fig.5d). The abnormal northerly wind pushes down southward over Shandong, which intensifies the northeast winds and blocks the warm moist air moving northward. The corresponding geopotential anomalies indicate (Fig.6). that almost all of the areas considered here are covered with positive anomalies, except the limited weak negative regions over the Shandong Peninsula, South Korea and Southern Japan.

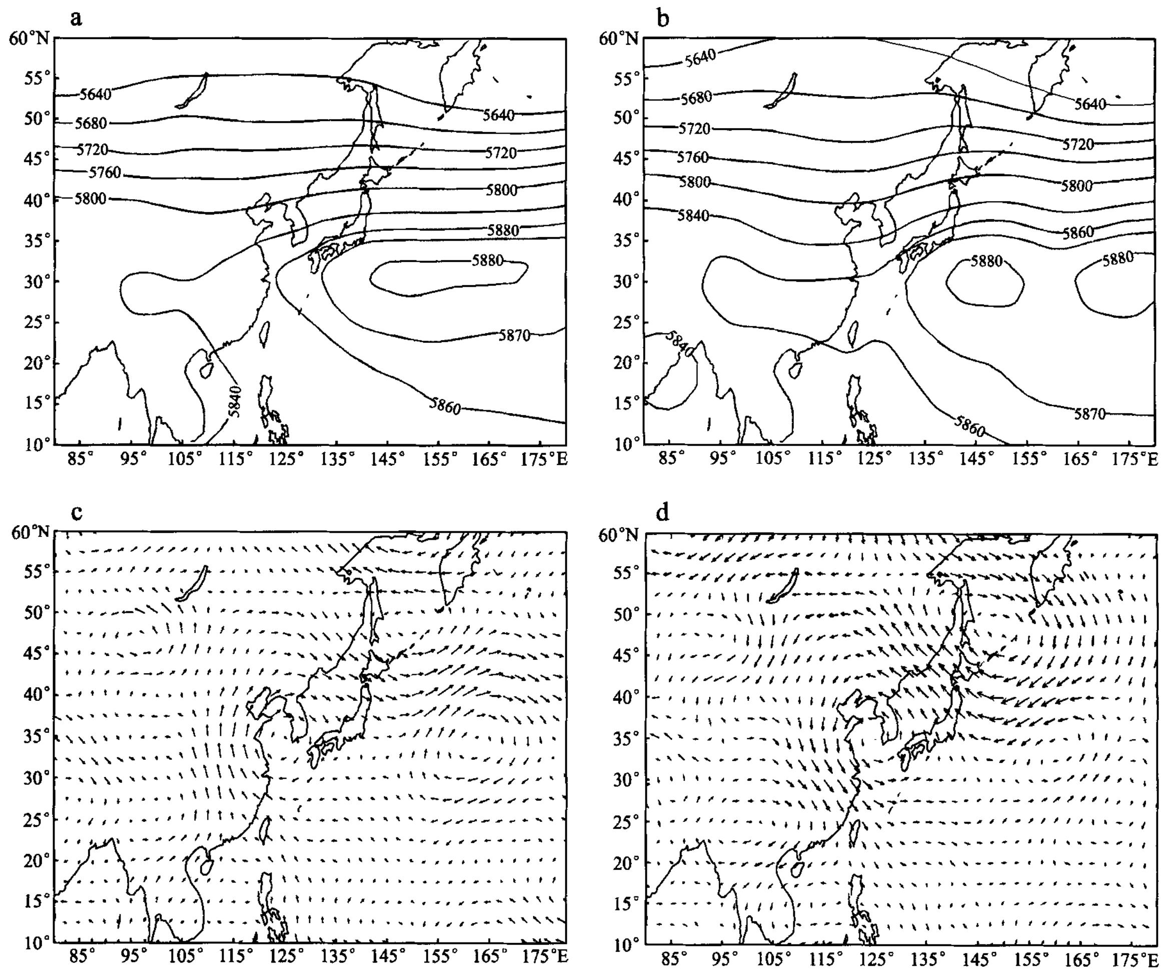


Fig.5 Same as Fig.3, but for August.

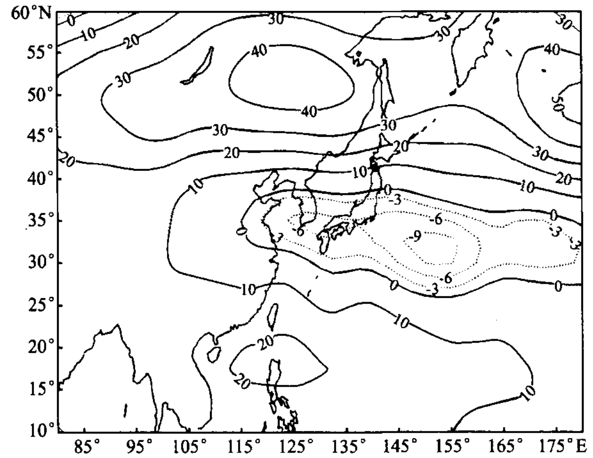


Fig.6 Composed 500 hPa geopotential height anomalies in August for the dry period (in gpm).

As is opposite to the wet phase, during the dry period Shandong is controlled by an anomalous cyclonic cell and is influenced by a northerly flow, which pushes its way southward to as far as the SCS and the Philippines (Fig.5d). This anomalous flow undermines the southerly moist air that usually moves northward to Northern China together with the development of the summer monsoon and blocks the moisture supply for precipitation in Shandong Province.

A conceptual model for the precipitation in August is now obtained based on the above discussion. A wet phase would occur if the geopotential height declines in Southern China and the SCS, the East Asia trough deepens near the Kamchatka Peninsula, an ACA exists over Shandong, and the subtropical high extends northward. A dry period would happen if an opposite situation in the height field appears across Southern China to the SCS, the East Asia trough is weaker than normal, the ridge of the subtropical high extends far westward, and an anomalous cyclonic cell controls Shandong.

4.5 The SVD Analysis for Summer

The results of SVD and synthesized analysis for summer are similar to a certain extent to those obtained for July. The first pattern-pair for summer can account for 85.73% of the total covariance contribution, and this means that the first pair can reflect the principal characteristics of the two fields to the most significant degree among the three targets discussed in this paper. The first pair's heterogeneous correlation coefficients and the corresponding temporal coefficients are shown in Figs.7a–d. A '+ − +' type wave

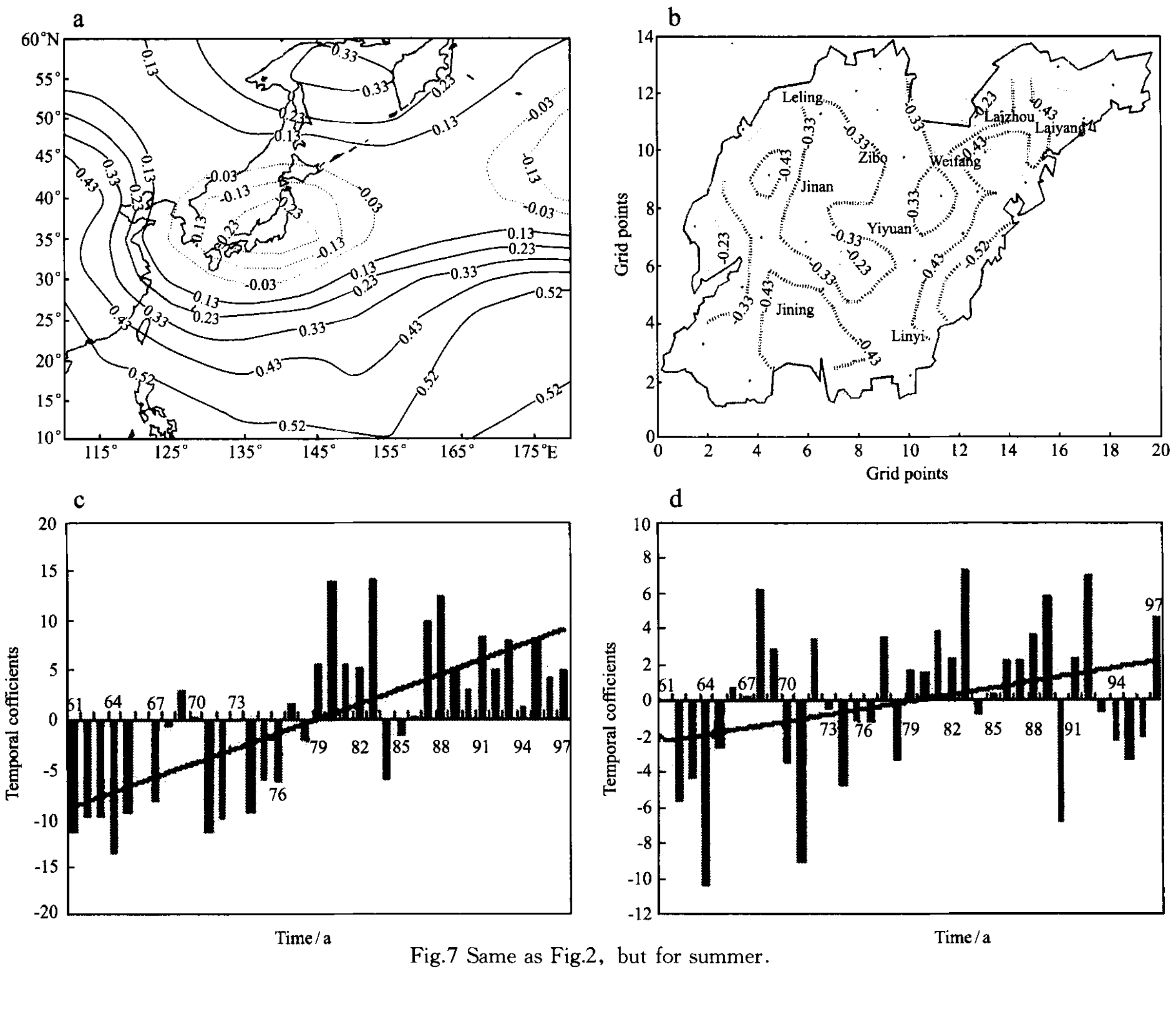


Fig.7 Same as Fig.2, but for summer.

train stretches from the Sea of Okhotsk across Japan to the SCS (Fig.7a). The confidence level over 0.001 emerges over the SCS and the oceans adjacent to the Philippines. The most significant negative correlation region is around Japan. The corresponding heterogeneous correlation coefficients, related to precipitation, show negative correlation all over Shandong (Fig.7b). If the geopotential height rises in the positive key areas, such as the SCS and the oceans around the Philippines, and at the same time the height declines in the negative key area, for example above Japan, then warm and moist air can hardly approach the middle latitudes, causing less rainfall in Shandong. On the contrary, when the height decreases over the positive key areas and increases over the negative area, Shandong would experience a wet period, particularly in areas with higher confidence levels, like southern Shandong and the eastern section along the coasts of the Bohai Sea and Huanghai Sea.

Huang and Li (1988) pointed out that if convective activities intensify over the SCS and the Philippines, an EAP (East Asia - Pacific) teleconnection pattern could occur in the 500 hPa height field: negative height anomalies would appear in the SCS and the Sea of Okhotsk, and positive anomalies would be over Japan-Korea. When compared with Fig.7a, it can be seen that the SVD's first pattern just matches the EAP pattern. Considering Fig.7b, it can be found that Shandong could have more rainfall if '- + -' type geopotential anomalies (EAP pattern wave train) appear in the region stretching over the SCS, Japan-Korea and the Sea of Okhotsk. While if a converse phase of EAP pattern occurs, Shandong could suffer a dry summer. Note that Zhang *et al.* (2004) investigated the relations between the convective activities in the SCS and summer rainfall in Shandong, using OLR (outgoing long wave radiation) data, and found the positive relations between the two, *e.g.*, more rainfall corresponding to stronger onset (convection) of the SCS monsoon. The result of this study confirms this connection. This means that the EAP pattern, the Rossby wave energy transportation along a spherical path (Hoskins and Karoly, 1981), is associated with the convective activities in the SCS and influences the summer precipitation in Shandong.

The temporal coefficients and the trends for summer are also similar to those for July (Fig.7c, 7d). The turning point is in 1979 and the difference between the two time series is significant and passes the T-test with a level of 0.05. There exist similarities in the synthesized geopotential height and wind field in summer for both the dry phase and the wet period. Discussion about them is therefore omitted.

5 Discussion and Conclusions

Based on the first pattern-pair's temporal coefficients obtained from the SVD, the whole period under discussion in this paper is divided into two stages in terms of the geopotential height, *i.e.*, a weaker period before 1979 and a stronger one after 1979. Corresponding to the height field, the wet phase is at 1961-1978 and the dry one at 1979-1997. The differences between the two time series are significant. The key areas influencing the precipitation in Shandong are identified based on the geopotential height field. Generally speaking, the key areas are from the SCS to the oceans around the Philippines in the south and from Northeast Asia to the Kamchatka Peninsula and the region south of Baikal in the north. The former is connected with the summer monsoon and the transportation of moisture, and the latter represents the activities of the cold air. This is compatible with previous studies and experiences. The synthesized analysis shows that the 500 hPa geopotential height and the wind field during the wet phase differ dramatically from those during the dry phase. Therefore, the turning point in precipitation, which occurred around 1979, is closely related to the decadal variations in the 500 hPa height and the wind field. It should be pointed out that among the members of the general circulations involved in this study, the geopotential height over the SCS and the Philippines might be the leading factor. The variations of the height in these key areas may influence the geopotential height in other regions in East Asia and the Western Pacific regions through the teleconnection pattern of EPA. The geopotential height will decline over Japan and ascend over the Sea of Okhotsk with increased height over the SCS and the Philippines. A converse height phase will occur over Japan and the Sea of Okhotsk with decreased height in the SCS and the Philippines. The variation in geopotential height over Japan is essential, because it represents the variation of the position of the Western Pacific subtropical high, which is important for the summer precipitation in Shandong.

In July, if the geopotential height declines in the key areas in the south, Shandong is likely to experience a wet phase. The mechanism could be as follows: along with an anomalous cyclonic cell, a trough expands in the region southwest of Baikal, and a high ridge superposes the western portion of the Western Pacific subtropical high near Japan, inducing the high to shift northward. As a result, an ACA enhances the southerly flow over Shandong and the cold and warm air masses readily encounter each other over Shandong, thus, bringing a wet period. The dry phase might occur if a high ridge southwest of Baikal is enhanced by an ACA and the subtropical high moves southward when enforced by an anomalous cyclone over Shandong-Korea-Japan, thus depressing the northward transport of moisture from the south to Shandong.

In August, the wet period could occur if the height decreases in the key areas in the south and increases over Japan. Positive geopotential height anomalies appear in Korea-Japan, and this means that the subtropical high might shift northward. The ACA, being centered over Japan in July, anchors exactly from southern Shandong across the Huanghai Sea to South Korea. When compared with the situations in July, it seems that the northward shift of the subtropical high should be due to the superposition of the westerly ridge in July and the movement of the high itself in August (The two obvious ACA cells between 30°N and 35°N, shown in Fig.5 c, support this viewpoint further). The causes for the dry period in August differ from those in July. Instead of its southward displacement, forced by the westerly trough in July, the subtropical high stretches westward too far to allow a humid flow to reach Shandong in August. Compared with its pattern in July (Fig.2 a), the geopotential height pattern in August (Fig.4 a) is more like that in summer (Fig.6 a). This similarity might disclose the closer relation between the midsummer month, August, and the summer season as a whole. In this case, it should be more reasonable to use the geopotential heights in August rather than those in July to represent the whole summer's height situation.

The heterogeneous correlation coefficients between precipitation in Shandong and the 500 hPa height are more remarkable in summer than they are in July and August. There is a clear '+ − +' pattern from the Sea of Okhotsk, across Japan, to the SCS, in which both the July pattern and the August pattern are included. On the other hand, the composed geopotential height and the wind anomalies are similar to what we have discussed for July. Therefore it is more sensible and practicable to investigate the situations separately for different purposes.

It is also found in this study, based on the results of the SVD analysis, that the most significant correlation coefficients between the precipitation in Shandong and the 500 hPa geopotential height appear in the areas covering the SCS, the oceans adjacent to the Philippines, the south of Baikal and Northeast Asia. But the height field in the subtropical area, for instance, an area prevailed by the Western Pacific subtropical high, does not show obvious correlations with the precipitation in Shandong. This result is somewhat inconsistent with our common knowledge. On the other hand, there exist clear differences in the synthesized analyses of the height field and the wind vector between the dry and wet periods. This problem also needs further study both physically and mathematically.

Acknowledgements

This paper is sponsored by the Personnel Introducing Program initiated by the Ocean University of China.

References

Gong, D.Y., S.W. Wang, and J.H. Zhu, 2000. Mechanism analysis of the summer rainfall along the middle to lower reaches of Changjiang River in the 1990s. *Acta Geographica Sinica*, **55**(5): 567-575.

Gong, D.Y., and X.Z. He, 2002. Interdecadal change in Western Pacific subtropical high and climatic effects. *Acta Geographica Sinica*, **57**(2): 185-187.

Hoskins, B.J., and D.K. Karoly, 1981. The steady linear response of a spherical atmosphere to thermal and orographic forcing. *J. Atmos. Sci.*, **38**: 1179-1196.

Huang, R.H., and W.J. Li, 1988. The influence of heat source anomalies over the tropical West Pacific in summer on the subtropical high above East Asia and the physical mechanisms. *Scientia Atmospherica Sinica*, (Special issue), 107-116.

Li, H.Z., P.D. Liang, and Y.L. Liang, 1977. The long range prediction of the drought and flood in the middle and lower reaches of the Yangtze in rainy season and the 500 hPa general circulation patterns as well as the variations. *Scientia Atmospherica Sinica*, **1**: 180-187.

Li, Q.C., S.F. Zhou, and S.L. Zhang, 2003. Study on the criteria for the starting of the rainy season in Shandong. *Shandong Meteorology*, **23**(91): 17-19.

Li, Y.Q., and C.Y. Li, 2001. Singular value decomposition analysis of air temperature in spring in Sichuan Province and Chongqing City and 500 hPa geopotential height. *Plateau Meteorology*, **20**(2): 165-172.

Long, F.C., Y.G. Ding, and Y. Zhou, 2003. Applicability of singular value decomposition and singular cross-spectrum to diagnose of rainfall in North China. *Journal of Applied Meteorological Science*, **14**(2): 176-187.

Prokaska, J.A., 1976. Technique for analyzing the linear relationships between two meteorological fields. *Mon. Wea. Rev.*, **104**: 1345-1353.

Shi, N., 1995. *Multivariate Analysis Methodology in Meteorological Research and Forecast*. Press of Meteorology, Beijing, 344 pp.

Su, S.J., W.G. Wang, and Q.Y. Yang, 1999. Singular value decomposition analysis between the precipitation in Yunnan and SSTA. *Journal of Yunnan University*, **21**(5): 353-356.

Sun, S.Q., and S.J. Ma, 2001. A study on relationship between the anomaly of subtropical high over the Western Pacific and the heavy flooding in Yangtze River valley in 1998. *Acta Meteorologica Sinica*, **59**(6): 719-729.

Wang, X.C., and G.X. Wu, 1997. The analysis of relationship between the spatial modes of summer precipitation anomalies over China and the general circulation. *Scientia Atmospherica Sinica*, **21**(2): 161-169.

Zhang, Q., and G.X. Wu, 2001. The large area flood and drought over Yangtze River valley and its relation to the South Asia high. *Acta Meteorologica Sinica*, **59**(5): 569-577.

Zhang, S.P., Q.Y. Liu, S.J. Liu, and D.L. Gong, 2004. Influence of the convection over the South China Sea on the summer precipitation of Shandong Province. *Journal of Ocean University of China*, **3**(1): 23-32.