VARIATIONS OF ATMOSPHERIC OSCILLATION FACTORS AND 500 HPA CIRCULATION PATTERNS AND THEIR RELATIONS*

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ABSTRACT

Wavelet analysis, EOF and CCA are used to analyze the variations of atmospheric circulation factors, including the key atmospheric oscillations, W, C, E and subtropical high (SH), and their relationships. The results are shown that the variations of atmospheric circulation factors both in troposphere and lower atmosphere layer are different on different time scales. The most significant variation of atmospheric circulation factors is in the period less than 7 years. The correlation relations of atmospheric circulation factors are different on different time scales. Combination patterns of circulation factors have impact on the relationships of factors. There are lag correlations between combination patterns of circulation factors in former year and that of in next year.

Key words: atmospheric circulation, interannual variation, interdecadal variation, correlation

I. INTRODUCTION

Early in the 1960s, Wang (1964, 1965) studied the long-term oscillations of atmospheric circulations and found some significant results. From then on, many scholars began to study this problem. Mu and Li (2000) studied the interdecadal variations of atmospheric circulations and found that the principal interdecadal oscillations referred to 10—20 years. Other studies showed that the interdecadal variations had a quasi-10-year period at the Northwest Pacific and East Asia (Li 1998). Deng et al. (2001) considered that the significant variations of SO and NAO were interannual variations. Later, some scholars studied the variations of atmospheric active centers and found many significative results (Zhu et al. 1997; Zhang and Qian 2000; Mu et al. 2001). In the former studies, variations of certain atmospheric circulation factors were mostly studied, but the interrelations of atmospheric circulation factors on different time scales and the combination patterns of atmospheric circulation factors were lack of study. It is known that one part of atmospheric circulation systems has interaction to others and the

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variations of any part were not isolated. If we want to study the variations of one certain atmospheric circulation factor, we should study not only its self-variations but also the impact of one factor on another factors. That is to say, climate changes are of globality. Based on those analyses, the variations of atmospheric circulation factors and their possible relations are studied.

II. DATA

All data used in this paper range from 1901 to 2001. Data of four oscillations come from Internet and the web addresses are as follows: www. cru. uea. ac. uk; www. cgd. ucar. edu; www. atmos. colostate. edu. Circulation pattern data, including W, C, E circulations provided by NCC (National Climate Center) of China and Yunnan Meteorological Observatory. SH(subtropical high) data come from Mu et al. (2001). All data are annual mean and standardized before analyzed.

III. VARIATION CHARACTERISTICS OF ATMOSPHERIC CIRCULATION FACTORS

Climatic change can be thought as a combination of variations on different time scales, that is, climatic change = interannual variation + interdecadal variation + climatic base state. In this paper, DB16 wavelet analysis is adopted to decompose the variations of atmospheric circulation factors. As we know, there are two types of wavelet functions. One is orthogonal and the other is non-orthogonal. DB16 wavelet is compared with Mexh wavelet and the results are as follows (Yan et al. 2004). Mexh wavelet transform coefficients cannot present the whole variations of signals because it is non-orthogonal and there is repeatable or correlated information among Mexh wavelet coefficients on different time scales. In other way, because of orthogonal characters of DB16 wavelet, every time scale coefficient is orthogonal with other so that high or low frequency coefficients on different time scales can be distilled. Reconstructing those coefficients, more distinct variations of signals on different time scales can be studied. In this way, orthogonal wavelet analysis is also adopted in this paper.

1. *Variation Characteristics of Atmospheric Oscillations*

It is known that SO, NAO and NPO denote the characters of macro-scale in the lower atmosphere in the past (John and David 1981; Rogers 1981). SO (Southern Oscillation) refers to the transmeridional seesaw structure of pressure between the eastern Pacific and the Indian Oceans; NAO (North Atlantic Oscillation) refers to the pressure opposition between Icelandic low and Azores high; NPO (North Pacific oscillation) refers to the pressure opposition between Aleutian low and SH in the Pacific. In the near future, a fourth atmospheric oscillation was found and named Antarctic Oscillation (AO), which refers to a large scale alternation of atmospheric mass between the mid-latitude's and high latitude's surface pressures (Thompson and Wallace 1998). Those four oscillations denote the planetary scale changes in low-level atmospheric circulation.

The results of wavelet analysis of four oscillations are shown in Table 1 and Fig. 1. Table 1 shows the variance of four oscillations on different time scales. Figure 1 shows that every series is decomposed into six frequency-bands. In this figure, the first series is source series and the abscissa represents time, ranging from 1901 to 2001.

Table 1. Variance of Four Oscillations

Resolution Scale	2^0	2^1	2^2	2^3	2^4	2^5
Levels	d1	d2	d3	d4	d5	a5
Periods(a)	<3.5	3.5−7	7−14	14−28	28−56	>56
Variance (SO)	45.78%	31.48%	15.78%	2.74%	2.07%	2.14%
Variance(NAO)	49.09%	23.56%	15.61%	4.19%	1.81%	5.74%
Variance(NPO)	41.48%	23.62%	12.23%	8.65%	10.71%	3.31%
Variance(AO)	45.97%	26.6%	10.82%	7.03%	4.01%	5.56%

Figure 1 and Table 1 show that the most significant variation of four oscillations is in the period less than 3.5 a, with 35% to 44% of variability. Next, the 3.5−7 a period, with 23% to 32% of variability, takes second place. Those two bands form the interannual variation of four oscillations and the sum variability ranges from 65% to 77%. For interannual variation, the variation of SO is the strongest among four oscillations, with 77% of variability, meaning that SO is the strongest signal in the period less than 7 a band. Interdecadal variation is composed of the 7−28 a band of period ,with 17% to 21% of variability. Finally, the variance of climatic base state, belonging to >28 a band of period, ranges from 4% to 14%. The variation of NPO is significant in >28 a band, meaning that NPO is a strongest signal in the period of more than 28 a band. NPO has obvious climatic trend, and it dropped during 1910s to 1940s and during 1960s to 1980s, while NPO arised before 1910s and during 1940s−1960s and after 1980s.

2. *Variation Characteristics of Atmospheric Circulation Patterns and SH*

It is known that there are 3 atmospheric circulation patterns in the Atlantic and Eurasian area at 500 hPa, that is W,C and E circulation patterns. The main characters of W pattern are as follows. 1) Zonal circulation prevails and the basic flow moves along the zonal. 2) There are a series of short-wave troughs and ridges. 3) The zonality of SH is very clear. The main characters of C are as follows. 1) Large amplitude quasi-stationary waves appear. 2) Ridges are located in the east of continent and ocean and troughs are located in the west of continent and the middle part of ocean. The main characters of E are that upper ridges dominate in Europe, and surface pressure ascending appears in Kara Sea. It is clear that the abnormal development of circulation patterns has important impact on climatic changes. SH is also an important member in the Northern Hemisphere. Therefore, it is necessary to study the variations of those systems. Table 2 and Fig. 2 show the results of those systems.

Table 2. Variance of Three Circulation Patterns and SH

Resolution Scale	2^0	2^1	2^2	2^3	2^4	2^5
Levels	d1	d2	d3	d4	d5	a5
Periods (a)	<3.5	3.5−7	7−14	14−28	28−56	>56
Variance (W)	29.89%	14.68%	11.4%	14.67%	15.68%	13.68%
Variance(C)	36.86%	15.83%	5.92%	13.96%	14.79%	12.63%
Variance(E)	32.55%	12.57%	12.99%	12.47%	3.42%	26.01%
Variance(SH)	41.3%	15.23%	20.67%	11.29%	7.91%	3.61%

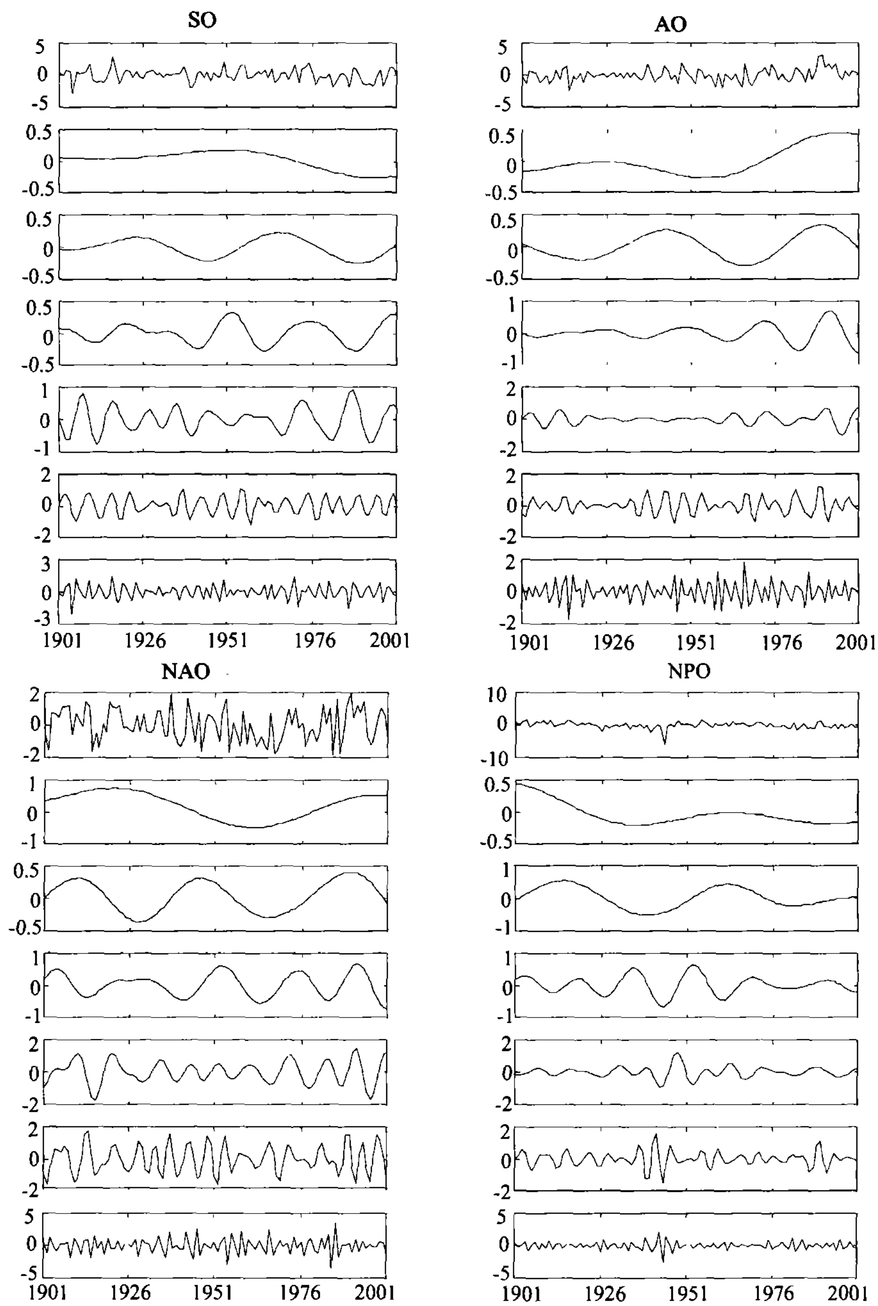

Fig. 1. Indices of SO, NAO, AO and NPO and their six frequency-band components.

Figure 2 and Table 2 show that the most significant variation of W, C, E and SH is the interannual variation, with 44% to 56% of variability. Compared the variability of atmospheric circulation factors in the troposphere with four oscillations, we can find that the variability decreases. Among all atmospheric circulations in the troposphere, the variation of SH is the strongest, which means that SH is the strongest signal in the period less than 7 a band. The variability of climatic base state, belonging to >28 a band, ranges

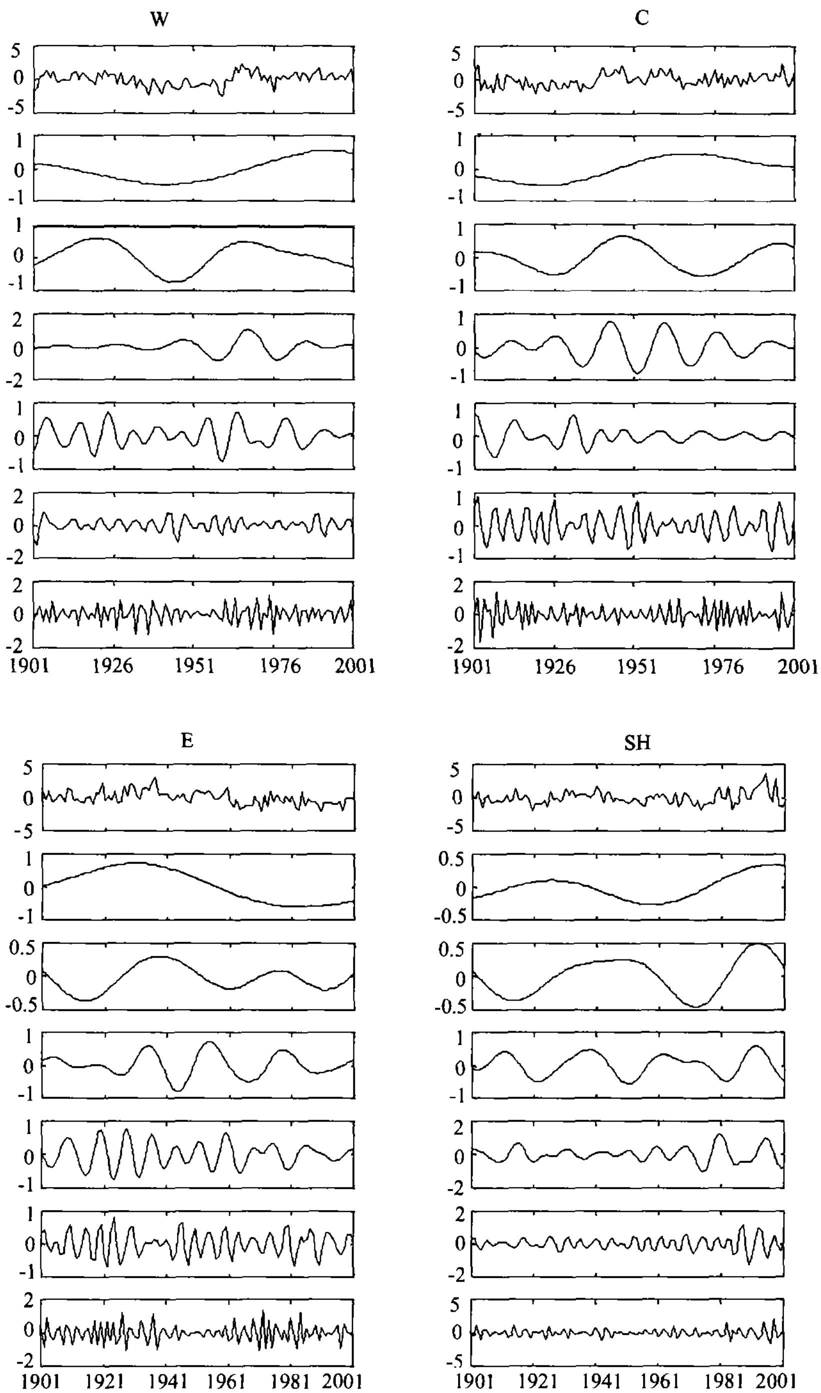

Fig. 2. Indices of W,C,E and SH and their six frequency-band components.

from 11% to 29%. Compared with four oscillations, it can be found that the variability of climatic base state increases, which means that the variation of climatic base state in the mid troposphere is more clear than that in lower atmosphere. The variation of E is significant in >28 a band, with 29.43% of variability. That is to say, E is the strongest signal in >28 a band. As a strongest signal in >28 a band, the variations of frequency of E increase during 1910s to mid-1930s but decrease during mid-1930 to 1990s.

Based on the above analysis, it is found that the variations of atmospheric circulation factors in the mid troposphere and lower atmosphere vary with different time scales. The most significant variation is in the <7 a band of period, with 44.57% to 77.13% of variability. The interannual variation (<7 a) in the lower atmosphere is clearer than that in the mid troposphere but it is reverse in the > 28 a band of period. In the lower atmosphere, SO and NPO are the strongest signal in the <7 a and >28 a band of period, respectively. In the troposphere, SH and E are the strongest signal in the <7 a and >28 a band of period, respectively. The climatic trend of NPO and E is distinct. NPO dropped during 1910s to 1940s and during 1960s to 1980s, while it arised before 1910s and during 1940s—1960s and after 1980s. The variations of E increase during 1910s to mid-1930s but decrease during mid-1930 to 1990s.

IV. CORRELATIONS OF ATMOSPHERIC CIRCULATION FACTORS

1. *Correlation Analysis*

Multi-scale variations of each atmospheric circulation are studied. Next, correlation analysis is adopted to study the relationship between one atmospheric circulation and the others.

The upper triangular part in Table 3 shows the correlation coefficients of source series. SO and AO are positively correlated with NPO and NAO in the lower atmosphere, respectively. In the mid troposphere, every circulation pattern is negatively correlated with the other circulation patterns but no correlation with SH. As a whole, there are manifestly positive correlations between W and AO; there are manifestly negative correlations between E and AO, SH and SO, NPO, NAO.

The correlations of source series can only explain the general relationship of atmospheric circulations. It is known that source series is composed of many components on different time scales, which means that the above study results are mixed. Therefore, it is necessary to analyze the correlations of atmospheric factors on different time scales. Considering the composed components in the <7 a band of period and calculating their correlation coefficients, we obtain the results shown in the lower triangular part in Table 3. Among all lower atmospheric circulation factors, the positive correlations of SO and NPO, AO and NAO are still manifest; among all mid troposphere circulation factors, every circulation pattern is positively correlated with the others but no correlation with SH. As a whole, W is manifestly positive correlated with AO, NAO; there are manifestly negative correlations between C and NAO, E and AO, as well as SH and four oscillations.

Table 3. Correlations of Atmospheric Circulations of Source Series (upper triangular part) and Interannual Variation Components (lower triangular part)

Correlation coefficients	W	C	E	SH	SO	AO	NAO	NPO
W	1	**−0.35**	**−0.67**	−0.10	0	**0.30**	0.19	0.16
C	**−0.35**	1	**−0.44**	0.16	−0.20	0	**−0.31**	−0.18
E	**−0.58**	**−0.50**	1	−0.07	0.17	**−0.28**	0.07	−0.03
SH	−0.19	0.06	0.06	1	**−0.35**	−0.14	**−0.24**	**−0.34**
SO	0.15	−0.18	0.02	**−0.24**	1	−0.00	−0.04	0.31
AO	**0.47**	−0.12	**−0.34**	**−0.36**	0.13	1	**0.72**	0.07
NAO	**0.37**	**−0.35**	−0.04	**−0.35**	0.10	**0.77**	1	0.10
NPO	0.07	−0.06	−0.03	**−0.33**	0.30	0.19	0.11	1

Boldface: 95% significance level, the same after

The same method is adopted to calculate the interdecadal variation and climatic base state and the results are shown in Table 4. For the interdecadal variation, the correlations of SO and NPO; AO and NAO, NPO are manifest in the lower atmosphere; the correlations of each pair of circulation patterns, SH and C, E are manifest in the mid troposphere. As a whole, the correlations of W and NAO;C and SO, NAO, NPO; E and SO, NAO are manifest. For climatic base state, the correlations of each pair of four oscillations are manifest except NAO and NPO in the lower atmosphere; the correlations of each pair of circulation patterns, SH and C are manifest in the mid troposphere. In the mass, the correlations of W and SO, NPO; C and SH, four oscillations; E and SO, AO, NPO are manifest.

Table 4. Correlations of Atmospheric Circulations of Interdacadal Variation Components (upper triangular part) and Climatic Base State Variation Components (lower triangular part)

Correlation coefficients	W	C	E	SH	SO	AO	NAO	NPO
W	1	**−0.33**	**−0.73**	0.06	−0.18	0.02	**−0.23**	0.10
C	**−0.32**	1	**−0.39**	**0.23**	**−0.26**	0.07	**−0.26**	**−0.43**
E	**−0.72**	**−0.42**	1	**−0.28**	**0.42**	−0.08	**0.39**	0.18
SH	−0.12	**0.34**	−0.07	1	**−0.52**	**−0.25**	**−0.37**	**−0.22**
SO	**−0.21**	**−0.41**	**0.47**	**−0.78**	1	−0.02	0.08	**0.35**
AO	0.15	**0.33**	**−0.34**	**0.89**	**−0.96**	1	**0.61**	**0.26**
NAO	0.11	**−0.27**	0.13	**0.50**	**−0.56**	**0.53**	1	**0.17**
NPO	**0.45**	**−0.28**	**−0.26**	**−0.61**	**0.43**	**−0.60**	0.00	1

In summary, the correlations of atmospheric circulations vary on different time scales but still remains certain changeless relationship. The relationship of three models, AO and NAO,SO and NPO; SH and SO, NAO, NPO; C and NAO are consistent on different time scales, but the relationships of the rest circulation factors vary with different time scales.

2. *Empirical Orthogonal Function Analysis*

The knowledge of the one-to-one corresponding relationship of factors on different time scales is obtained through the above analysis. We only consider the relationship of two factors, but not consider the impact of other factors' variation on this relationship. In this section, EOF analysis is adopted to study the correlation patterns and relationships of atmospheric circulation factors.

Table 5. Variances of the First Four Principal Components

Principal components	1	2	3	4
Variability (%)	28.32	23.38	16.50	13.25

EOF analysis is adopted to study an 8-dimensional series, combined by all atmospheric circulation factors. Table 5 shows the variability of the first four principal components, whose accumulating variability is 81.49%. In this paper, we will study the first two principal components, with 51.7% of variability, owing to the variability of the third principal component under 20%. Table 6 and Fig. 3 show the first principal component and its timeseries; Table 7 and Fig. 4 show the second principal component and its time series.

Table 6. Factor's Loading of the First Principal Component

Atmospheric circulation factors	AO	NAO	SO	NPO	W	C	E	SH
Loading	−0.46	−0.49	−0.22	−0.31	−0.41	0.31	0.14	0.36

The first principal component shows the first pattern of composite variable, with 28.32% of variability. NAO is the most important factor for its absolute value of loading is maximum. The sign of loading denotes in-phase or out-phase. NAO, AO, W, NPO and SO possess negative loading and their variations are in-phase; C, E and SH possess

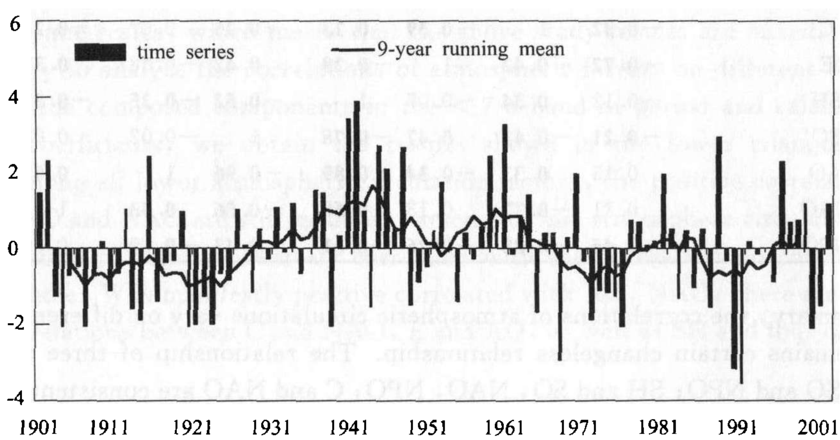

Fig. 3. Time series of the first principal component.

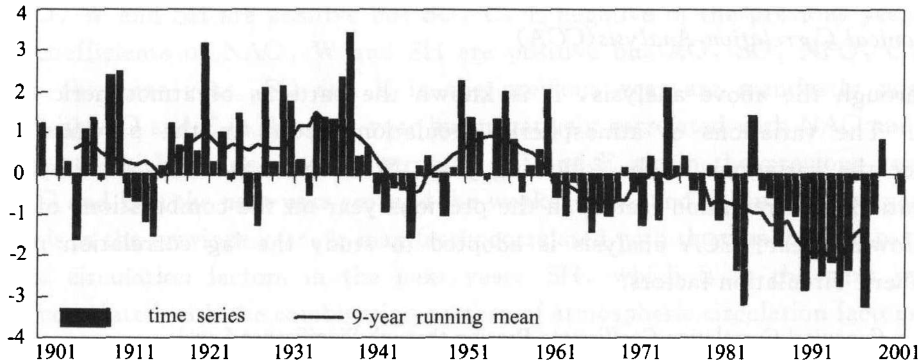

Fig. 4. Time series of the second principal component.

positive loading and their variations are also in-phase. That is to say, NAO, AO, W, NPO and SO are out-phase with C, E and SH. It can be studied that NAO is manifestly positively and negatively correlated with AO and SH, respectively, which are mentioned above. In this way, it can be concluded that the relationships of NAO and AO, SH are steady, which is the steady mode in the first principal component. Figure 3 shows the manifest interannual and interdecadal variation of the time series of the first principal component. The variations of the first principal component are in negative phase before the end of 1920s, during 1960s to the end of 1970s and during the mid-1980s to the mid-1990s. The variations of the first principal component are in positive phase during 1930s to the end of 1960s, during the end of 1970s to the mid-1980s and after mid-1990s.

Table 7. Factor's Loading of the Second Principal Components

Atmospheric circulation factors	AO	NAO	SO	NPO	W	C	E	SH
Loading	−0.27	−0.0	0.39	0.21	−0.36	−0.36	0.63	−0.27

The second principal component shows the second pattern of variable, with 23.38% of variability. E is the most important factor for its absolute value of loading is maximum. W, C, AO, SH and NAO possess negative loading and their variations are in-phase; NPO, SO and E possess positive loading and their variations are in-phase. That is to say, W, C, AO, SH and NAO are out-phase with NPO, SO and E. It can be studied that E is manifestly positively and negatively correlated with SO and W, C, respectively, which are mentioned above. In this way, it can be concluded that the relationships of E and SO, W, C are steady, which is the steady mode in the second principal component. Figure 4 shows the manifest interannual and interdecadal variation of the timeseries of the first principal component. The variations of the second principal component are in positive phase before 1940s and during the end of 1940s to 1960s. The variations of the second principal component are negative phase after 1960s.

In summary, the patterns of the composite variable of atmospheric circulation factors exist and the different pattern has explicit impact on the circulation factors. The relationships of NAO and AO, SH and of E and SO, W, C are steady. The interannual and interdecadal variations of time series of each principal component are manifest.

3. *Canonical Correlation Analysis(CCA)*

Through the above analysis, it is known the patterns of atmospheric circulation factors. The variations of atmospheric circulation factors in the previous year will influence the variations in the following year. Well then, is there any impact of the combinations of circulation factors in the previous year on the combinations of factors in the following year? CCA analysis is adopted to study the lag correlation patterns of atmospheric circulation factors.

Table 8. Canonical Correlation Coefficients Passing through Significance Level

Group	1	2	3
Canonical correlation coefficients	0.59	0.58	0.41

The first factor group ranges from 1901 to 2000 and the second ranges from 1902 to 2001 in CCA analysis. The results show that three canonical correlation coefficients, which are 0.59, 0.58, 0.41, pass through the 95% significance test. In this paper, the first and the second pairs of canonical variables are analyzed.

Table 9. Loading Factors of the First Canonical Correlation Eigenvector

Atmospheric circulation factors	AO	NAO	SO	NPO	W	C	E	SH
Loading factors (previous year)	−0.40	0.14	0.03	0.16	−0.25	−0.54	−0.65	−0.12
Loading factors(next year)	−0.49	0.22	−0.09	0.10	0.72	0.04	0.09	−0.40

For the first pair of canonical eigenvectors(Table 9), weighting coefficients of NAO, SO and NPO are positive but AO, W, C, E and SH negative in the previous year, while weighting coefficients of NAO, NPO, W, C, E are positive but AO, SO and SH negative in the next year. The combination pattern of atmospheric circulation factors in the previous year is correlated with that of in the next year. AO, W, C, E in the previous year are manifestly positively correlated with AO and SH in the next year but negatively correlated with W in the next year, which means that the stronger AO, W, C, E in the previous year are, the stronger AO and SH in the next year are, and the weaker W in the next year is. E, which is in the previous year, is manifestly correlated with the combination pattern of atmospheric circulation factors in the next year. W, which is in the next year, is manifestly correlated with the combination pattern of atmospheric circulation factors in the previous year.

Table 10. Loading Factors of the Second Canonical Correlation Eigenvector

Atmospheric circulation factors	AO	NAO	SO	NPO	W	C	E	SH
Loading factors(previous year)	0.07	0.16	−0.83	0.26	0.06	−0.01	−0.44	0.15
Loading factors(next year)	−0.41	0.47	−0.07	−0.06	0.15	−0.12	−0.42	0.62

For the second pair of canonical eigenvectors (Table 10), weighting coefficients of AO, NAO, NPO, W and SH are positive but SO, C, E negative in the previous year, while weighting coefficients of NAO, W and SH are positive but AO, SO, NPO, C and E negative in the next year. SO and E in the previous year are manifestly positively correlated with AO and E in the next year but negatively correlated with NAO and SH in the next year, which means that the stronger SO and E are in the previous year, the stronger AO and E in the next year are, and the weaker NAO and SH in the next year are. SO, which is in the previous year, is manifestly correlated with the combination pattern of atmospheric circulation factors in the next year. SH, which is in the next year, is manifestly correlated with the combination pattern of atmospheric circulation factors in the previous year.

The results of canonical correlation analysis show that the combination patterns of atmospheric circulation factors in the previous year are manifestly correlated with that of in the next year. In canonical correlation analysis, it is considered both the interaction of factors and the impacts of factors in the previous year on the factors in the next year. The stronger AO, W, C, E in the previous year are, the stronger AO and SH in the next year are, and the weaker W in the next year is. The stronger SO and E are in the previous year, the stronger AO and E in the next year are, and the weaker NAO and SH in the next year are.

V. RESULTS AND DISCUSSIONS

Based on the above analysis, the conclusions may be drawn as follows.

(1) Variations of atmospheric circulation factors in the mid troposphere and lower atmosphere are different with different time scales. The mos significant variation is in the <7 a band of period, with 44.57% to 77.13% of variability. The interannual variation (<7 a) in the lower atmosphere is clearer than that in the mid troposphere but it is reverse in the >28 a band of period. In the lower atmosphere, SO and NPO are the strongest signal in the <7 a and >28 a band of period, respectively. In the mid troposphere, SH and E are the strongest signal in the <7 a and >28 a band of period, respectively.

(2) The climatic trend of NPO and E is distinct. NPO dropped during 1910s to 1940s and during 1960s to 1980s while NPO arised before 1910s and during 1940s—1960s and after 1980s. The variations of frequency of E increase during 1910s to mid-1930s but decrease during mid-1930 to 1990s.

(3) The correlations of atmospheric circulations vary with different time scales but still remain certain changeless relationship. The relationships of three circulation patterns, AO and NAO, SO and NPO, C and NAO, SH and SO, NAO, NPO are consistent on different timescales but the relationships of the rest circulation factors vary with different timescales.

(4) The patterns of the composite variable of atmospheric circulation factors exit and the different patterns have explicit impact on circulation factors. The relationships of NAO and AO, SH and the relationships of E and SO, W, C are steady. The interannual and interdecadal variations of time series of each principal component are manifest.

(5) The combination patterns of atmospheric circulation factors in the previous year are manifestly correlated with that of in the next year. The stronger AO, W, C, E in the previous year are, the stronger AO and SH in the next year are, and the weaker W in the next year is. The stronger SO and E are in the previous year, the stronger AO and E in the next year are, and the weaker NAO and SH in the next year are.

Interannual and interdecadal variations of climatic change have become a foreland question in recent years, whereas, the study of this question is still immature. In this paper, the variations of atmospheric circulation factors and their relationships are studied and some results are found. But the study of physics mechanism is less. In the following study, the more study of physics mechanism is needed.

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