A Monthly Atmospheric Circulation Classification and Its Relationship with Climate in Harbin*

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ABSTRACT

In this study, the classification scheme developed by Jenkinson and Collison (1977) based on a typing scheme of Lamb (1950) is applied to obtain circulation types from the mean sea-level pressure on a monthly basis. Monthly mean sea-level pressure data from 1951 to 2002 are used to derive six circulation indices and to provide a circulation catalogue with 27 circulation types. Five major types (N, NW, C, CSW, and SW) which occurred most frequently are analyzed to reveal their relationships with the temperature of Harbin on various time scales. Stepwise multiple regression is used to reconstruct temperature anomaly. The monthly mean rainfall of all types occurring and the composite maps of three major types (C, CSW, and SW) relevant to Harbin's precipitation are studied.

The results show that the dominant types in winter are types N and NW. types C, CSW, and SW occur frequently in summer. Types N and NW favor a negative temperature anomaly and correspond to less rainfall, while types C, CSW, and SW often induce a positive temperature anomaly and correspond to more rainfall. Moreover, a successful statistical model can be established with only one of the six indices and large-scale mean temperature. Using the model, 77.3% of the total variance in the temperature anomaly between 1951 and 2002 can be reconstructed. Type C has a close relationship with total rainfall and type C precipitation plays a major role in determining the total rainfall of Harbin in recent years. This classification scheme is a statistical downscaling model and its relationships with temperature and precipitation can be used to forecast regional climate.

Key words: atmospheric circulation classification, temperature, precipitation, statistical downscaling, Harbin

1. Introduction

Global or regional climate and its change are influenced by atmospheric circulation patterns, especially extreme climate events. It is very important to know the characteristics and anomaly of the large-scale atmospheric circulation in order to analyze climate and climate change (Li, 2000). Different atmospheric circulation patterns are relevant to different regional climates. Therefore, studies of local climate change are often linked to variations in the atmospheric circulation (Yarnal, 1984). In characterizing large-scale circulation, an index which describes features of the large-scale circulation can be useful in explaining changes in surface climate (Kozuchowski, 1993). One of such indices is the "zonal index", originally developed by Rossby (1941), which has been widely used in studying European climate (Kozuchowski et al., 1992). Due to the improved understanding of the teleconnection patterns of the planetary atmosphere, more useful indices have been developed and used in regional climate research worldwide (Malmgren et al., 1998). As an example, the regional temperature variability in Sweden has been successfully associated with the North Atlantic Oscillation (NAO) by Chen and Hellström (1999). Studies of the relationship between atmospheric circulation and regional climate can reveal the reasons for regional climate change and can be used as a tool for climate prediction of different temporal scales.

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Another description of circulation is based on weather types. In Europe, the concept of "Grosswetterlage" has found many applications (e.g., Schubert and Henderson-Sellers, 1997). This approach builds on a classification scheme to group a large number of meteorological data into distinctive types of weather. The schemes are usually classified as either objective or subjective. Several objective schemes exist and the majority of them are based on multivariate techniques that can be easily performed by computer (Davis and Kalkstein, 1990). Objective schemes have the advantage of being effective and repeatable. However, mathematical constraints may limit the applicability of such techniques to real situations. Another problem is that the types defined depend on the data used, which means that the classification may vary, if data from different periods are used. This is problematic if the focus is not on condensing the information, but on studying the long-term variations. On the other hand, subjective schemes are usually based on experience and distinctively defined patterns which make them straightforward and easy to interpret. The obvious drawback is the subjectivity and inefficiency of the judgement. However, this disadvantage can be overcome by defining objective rules for such a scheme, making automatic determinations possible (Jenkinson and Collison, 1977). A successful example is the computerized classification based on Lamb scheme (Briffa, 1995). This method has been compared with an objective method. Since our aim is to obtain standardized circulation information that is independent of data examined, the automatic Lamb classification is a reasonable choice. It is computationally simple and is based on a single, widely-available, and free atmosphere variable: gridded sea-level pressure (SLP). This method has been widely used in Sweden (Chen, 2000), Spain (Goodess and Palutikof, 1998), Portugal (Zhang et al., 1997), etc. But such classification has rarely been developed in China to the authors' knowledge. Thus, it is highly necessary to develop and test its applicability in China and it is expected that the catalogue will constitute a useful tool in climate research.

Although Lamb (1950) scheme was originally developed to classify daily weather types (Jones and Kelly, 1982), many studies reveal that it can be successfully used to classify monthly weather types. Lamb (1950) scheme is adopted here to create a circulation type catalogue for Northeast China on a monthly basis and demonstrate the usefulness of the circulation climatology by studying the relationship between large-scale circulation and climate variables (temperature and rainfall).

2. Data and method

2.1 *Data*

The data used here are global 2.5°×2.5° monthly mean reanalysis gridded sea-level pressure (MSLP) and surface temperature from 1951 to 2002 downloaded from the homepage of NCEP; Monthly mean temperature, rainfall, and wind speed data of Harbin Station from 1951 to 2002 obtained from the National Meteorological Information Center of China.

2.2 *Method*

Harbin is located in Northeast China and the south of Heilongjiang Province (45°45′N, 126°46′E). Its altitude is 143 m. An area bounded by 35°-55°N, 110°-140°E, centered at 45°N, 125°E is selected to construct the circulation climatology which includes 16 gridded points (Fig.1).

In the area below, the geostrophic wind (u_g, v_g) and shear vorticity (ξ_x, ξ_y) of the center (45°N, 125°E) can be computed using MSLP of the 16 gridded points:

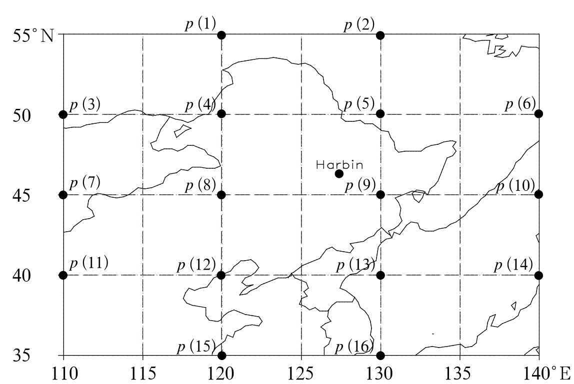

Fig.1. The grid points used in constructing the circulation climatology.

$$u_{\mathrm{g}} = -\frac{1}{f_{45}\rho}\frac{\partial p}{\partial y} \approx -\frac{1}{f_{45}\rho}\frac{\triangle p}{\triangle y} \approx \frac{1}{2f_{45}\rho}\left[\frac{p(12)-p(4)}{\triangle y} + \frac{p(13)-p(5)}{\triangle y}\right]$$
$$= \frac{1}{2\triangle y f_{45}\rho}\big[p(12)+p(13)-p(4)-p(5)\big], \tag{1}$$

$$v_{\mathrm{g}} = \frac{1}{f_{45}\rho}\frac{\partial p}{\partial x} \approx \frac{1}{f_{45}\rho}\frac{\triangle p}{\triangle x} \approx \frac{1}{4f_{45}\rho}\left[\frac{p(5)-p(4)}{\triangle x_1} + \frac{2p(9)-2p(8)}{\triangle x} + \frac{p(13)-p(12)}{\triangle x_2}\right]$$
$$\approx \frac{1}{4\triangle x f_{45}\rho}\big[p(5)+2p(9)+p(13)-p(4)-2p(8)-p(12)\big]$$
$$\approx \frac{1}{4\triangle y\cos 45^\circ f_{45}\rho}\big[p(5)+2p(9)+p(13)-p(4)-2p(8)-p(12)\big], \tag{2}$$

$$\xi_x = -\frac{\partial u}{\partial y} \approx \frac{1}{\triangle y}\left\{\frac{1}{2f_{40}\rho}\left[\frac{p(15)-p(8)}{\triangle y} + \frac{p(16)-p(9)}{\triangle y}\right] - \frac{1}{2f_{50}\rho}\left[\frac{p(8)-p(1)}{\triangle y} + \frac{p(9)-p(2)}{\triangle y}\right]\right\}$$
$$\approx \frac{1}{\triangle y^2 f_{45}\rho}\left\{\frac{\sin 45^\circ}{2\sin 40^\circ}\big[p(15)+p(16)-p(8)-p(9)\big] - \frac{\sin 45^\circ}{2\sin 50^\circ}\big[p(8)+p(9)-p(1)-p(2)\big]\right\}, \tag{3}$$

$$\xi_y = \frac{\partial v}{\partial x} \approx \frac{1}{2\triangle x}\left\{\frac{1}{4f_{45}\rho}\left[\frac{p(6)-p(5)}{\triangle x_1} + \frac{2p(10)-2p(9)}{\triangle x} + \frac{p(14)-p(13)}{\triangle x_2}\right] - \frac{1}{4f_{45}\rho}\right.$$
$$\left.\cdot\left[\frac{p(4)-p(3)}{\triangle x_1} + \frac{2p(8)-2p(7)}{\triangle x} + \frac{p(12)-p(11)}{\triangle x_2}\right]\right\} \approx \frac{1}{8\triangle x^2 f_{45}\rho}\big[p(6)$$
$$+2p(10)+p(14)-p(5)-2p(9)-p(13)+p(3)+2p(7)+p(11)-p(4)-2p(8)-p(12)\big]$$
$$\approx \frac{1}{8\triangle y^2\cos^2 45^\circ f_{45}\rho}\big[p(6)+2p(10)+p(14)-p(5)-2p(9)-p(13)+p(3)$$
$$+2p(7)+p(11)-p(4)-2p(8)-p(12)\big], \tag{4}$$

If $u = \frac{1}{2}[p(12)+p(13)-p(4)-p(5)],$ (5)

$$v = \frac{1}{4\cos 45^\circ}[p(5)+2p(9)+p(13)-p(4)-2p(8)-p(12)]$$
$$\approx 0.3536[p(5)+2p(9)+p(13)-p(4)-2p(8)-p(12)], \tag{6}$$

$$V = \sqrt{u^2+v^2}, \tag{7}$$

$$\xi_u = \frac{\sin 45^\circ}{2\sin 40^\circ}\big[p(15)+p(16)-p(8)-p(9)\big] - \frac{\sin 45^\circ}{2\sin 50^\circ}\big[p(8)+p(9)-p(1)-p(2)\big]$$
$$\approx 0.55\big[p(15)+p(16)-p(8)-p(9)\big] - 0.4615\big[p(8)+p(9)-p(1)-p(2)\big], \tag{8}$$

$$\xi_v = \frac{1}{8\cos^2 45^\circ}\big[p(6)+2p(10)+p(4)-p(5)-2p(9)-p(13)+p(3)+2p(7)$$
$$+p(11)-p(4)-2p(8)-p(12)\big]$$
$$\approx 0.25\big[p(6)+2p(10)+p(4)-p(5)-2p(9)-p(13)+p(3)+2p(7)$$
$$+p(11)-p(4)-2p(8)-p(12)\big], \tag{9}$$

and

$$\xi = \xi_u + \xi_v, \tag{10}$$

then

$$u_{\mathrm{g}} = \frac{1}{\Delta y f_{45}\rho}u, \tag{11}$$

$$v_{\mathrm{g}} = \frac{1}{\Delta y f_{45}\rho}v, \tag{12}$$

$$\xi_x = \frac{1}{\Delta y^2 f_{45}\rho}\xi_u, \tag{13}$$

$$\xi_y = \frac{1}{\Delta y^2 f_{45} \rho} \xi_v, \quad (14)$$

where $u, v, V, \ \xi, \ \xi_u$, and ξ_v can be used as six circulation indices to classify atmospheric circulation types; $f = 2\Omega\sin\varphi$ is the geostrophic parameter; f_{40}, f_{45}, and f_{50} are geostrophic parameters in 40°, 45°, and 50°N, respectively ($f_{40} = 2\Omega\sin 40°; f_{45} = 2\Omega\sin 45°; f_{50} = 2\Omega\sin 50°$); ρ is the density of air; R is the radius of the earth; $\Delta x, \Delta y$ are spacial differences, $\Delta x = R\cos 45° \frac{10\pi}{180}, \Delta x_1 = R\cos 50° \frac{10\pi}{180}, \Delta x_2 = R\cos 40° \frac{10\pi}{180}$. Because the difference between $\Delta x, \Delta x_1$, and Δx_2 is small here, to be simple, make $\Delta x = \Delta x_1 = \Delta x_2; \Delta y = R\frac{10\pi}{180}$; $p(n)(n = 1, 2, \cdots, 16)$ is the MSLP at grid point n; u and v are westerly (zonal) and southerly (meridional) components of the geostrophic wind, V stands for the combined wind speed; ξ_u (meridional gradient of u) and ξ_v (zonal gradient of v) are westerly and southerly shear vorticities, and ξ is the total shear vorticity. MSLP is used because it has the longest record of all circulation variables. All the indices have units of hPa/(10° latitudes) at 45°N. The various constants appearing in the equation are derived from the fact that the grid cells represent areas of different sizes. Once u and v are known, the wind direction can be determined. There are basically two main categories of circulation type. The so-called directional flow types (north, N; northeast, NE; east, E; southeast, SE; south, S; southwest, SW; west, W; northwest, NW) are characterized by coherent wind direction ($|\xi| < V$). The other category emphasizes rotation of the atmosphere ($|\xi| > 2V$), which can either be cyclonic (C) or anticyclonic (A). There is also a possibility of hybrid categories ($V < |\xi| < 2V$), which can be any combination of the two main categories. In the case where $V < 6$ and $|\xi| < 6$, the circulation is unclassified (UD). Altogether, 27 types are possible.

3. Results

3.1 *Frequencies of circulation types*

The method described above was used to infer circulation types for every month from 1951 to 2002. The results show that the classification performs well and the situations in different months with same circulation type are reasonably similar. The frequencies of the 27 circulation types over the period of 1951-2002 are displayed in Fig.2.

Five possible types missed, i.e., E, CNE, CE, ASE, and UD types. The occurrence of the majority of the types is below 5%, implying that a few types should be enough to describe the most frequent situations for Harbin. If 8.3% (corresponding to once a year on the average) is defined as the lower boundary of dominant types, only five types, i.e., N (24.68%), C (17.15%), NW (9.29%), SW (8.65%), and CSW (8.33%) can be considered as frequent. These five types account for 68.1% of all the months and thus

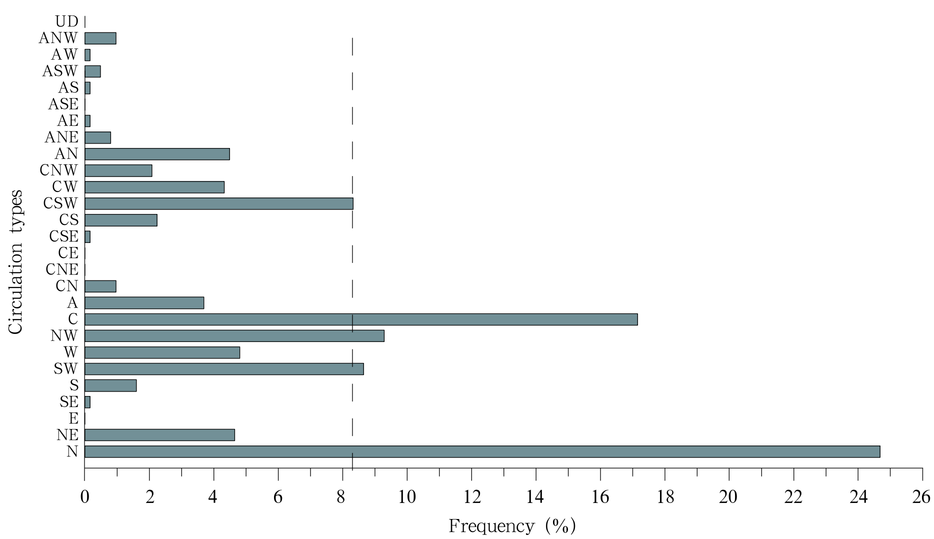

Fig.2. Frequency distribution of the circulation types during 1951-2002.

can be taken as major types.

3.2 *Monthly frequencies of the circulation types*

It is interesting to examine seasonal variations in the frequency of the circulation types. Table 1 offers the frequencies for each month. The feature is that types N, NE, AN, and NW occurred frequently from October to March, mainly in winter. While types C, SW, and CSW mainly occurred from April to September. It can be seen from the figure (omitted) of monthly mean SLP pattern in Northern Hemisphere that there is a strong cold Mongolia high located in Eurasia in wintertime. Northeast China is just to the east of the Mongolia high. Thus the wind direction of Harbin is mainly from north and northwest. On the contrary, in summertime, it is a low pressure system in Northeast China with southwest wind. Therefore, the circulation types are correspondent to the real situation.

Table 1. Monthly frequencies (%) of the circulation types from 1951 to 2002 (Bold numbers indicate frequency over 15%)

Type	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
N	**63.46**	**59.62**	**46.15**	0	0	0	0	0	1.92	9.62	**48.08**	**67.31**
NE	13.46	**15.38**	13.46	0	0	0	0	0	0	0	3.85	9.62
E	0	0	0	0	0	0	0	0	0	0	0	0
SE	0	0	0	0	0	0	0	1.92	0	0	0	0
S	0	0	0	0	0	3.85	11.54	3.85	0	0	0	0
SW	0	0	0	13.46	1.92	**23.08**	**17.31**	**30.77**	**17.31**	0	0	0
W	0	0	0	9.62	5.77	0	0	5.77	**26.92**	9.62	0	0
NW	3.85	1.92	**15.38**	1.92	0	0	0	0	9.62	**40.38**	**28.85**	9.62
C	0	0	0	**48.08**	**48.08**	**30.77**	**32.69**	**26.92**	**15.38**	3.85	0	0
A	7.69	5.77	0	0	0	0	0	5.77	13.46	7.69	3.85	0
CN	0	0	9.62	0	0	0	0	0	0	1.92	0	0
CNE	0	0	0	0	0	0	0	0	0	0	0	0
CE	0	0	0	0	0	0	0	0	0	0	0	0
CSE	0	0	0	0	0	0	0	1.92	0	0	0	0
CS	0	0	0	0	1.92	9.62	13.46	0	1.92	0	0	0
CSW	0	0	0	0	**26.92**	**30.77**	**25.00**	11.54	3.85	1.92	0	0
CW	0	0	0	**17.31**	**15.38**	1.92	0	3.85	5.77	7.69	0	0
CNW	0	0	5.77	9.62	0	0	0	0	1.92	7.69	0	0
AN	9.62	11.54	7.69	0	0	0	0	0	0	0	11.54	13.46
ANE	1.92	5.77	0	0	0	0	0	0	0	0	1.92	0
AE	0	0	0	0	0	0	0	1.92	0	0	0	0
ASE	0	0	0	0	0	0	0	0	0	0	0	0
AS	0	0	0	0	0	0	0	1.92	0	0	0	0
ASW	0	0	0	0	0	0	0	3.85	0	1.92	0	0
AW	0	0	0	0	0	0	0	0	0	1.92	0	0
ANW	0	0	1.92	0	0	0	0	0	1.92	5.77	1.92	0
UD	0	0	0	0	0	0	0	0	0	0	0	0

3.3 *Seasonal variation of frequencies of the major types*

Figure 3 reveals seasonal variation of the frequency distribution for five most frequent types. Types C and N have the strongest seasonal variation, N occurred mostly in winter but C in summer. For most of the time, frequencies of type N and types C, CSW, and SW appear to be anticorrelated. That is to say, when type N occurs, types C, CSW, and SW rarely occur. Frequencies of type NW and types C, CSW, and SW also appear to be anticorrelated, but weaker than that of type N.

3.4 *Interdecadal variation of frequencies of the major types*

In order to know the extent to which the Harbin's

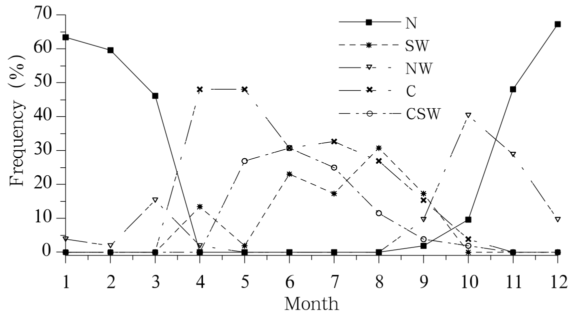

Fig.3. Seasonal variation of the frequency distribution for five major circulation types during 1951-2002.

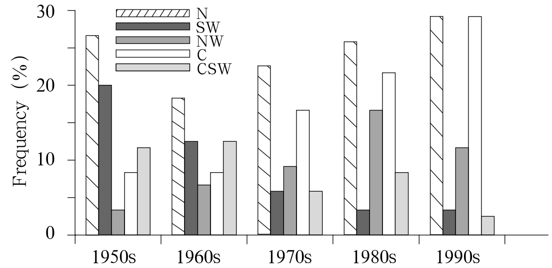

Fig.4. Frequency changes of five major circulation types during 1951-2000.

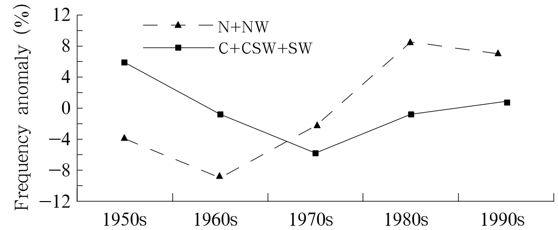

Fig.5. Interdecadal changes in frequency anomaly of types N+NW and C+CSW+SW.

climate change is related to large-scale atmospheric circulation, Fig.4 shows frequency changes over a 10-yr interval from 1951 to 2002 for the five most frequent circulation types. Type C increased with the time. Type N also increased from the 1960s, which means that the circulation types in Northeast China are dominated by type N in winter and type C in summer in recent years. Meanwhile, types CSW and SW decreased. Again, type N and types CSW, SW appear to be anticorrelated. Variation in NW is not apparent. In the recent 50 years, the frequency of N+NW increased more quickly than that of C+CSW+SW and exceeded it in the early 1970s. The frequency of C+CSW+SW decreased between the 1960s and 1970s. Then it began to increase slowly in the 1980s. On the whole, the proportion of types N+NW increased recently (Fig.5).

4. Relationship between the monthly mean temperature in Harbin and the circulation

The surface temperature anomalies in Harbin are related to the circulation types and the indices. Just as shown in Fig.6, types NW and N generally favor a cooler climate, whereas types CSW, SW, and C are biased toward the positive temperature anomalies, although variation within each group is not considerable. It is also correspondent to the feature that types NW and N usually occur in winter while types SW, CSW, and C often occur in summer. As described above, as the proportion of types N+NW increased these years, the annual mean temperature should have been decreased. But the observed temperature in Harbin has increased sharply especially since the 1980s (Fig.7). In order to find out the reason, Fig.8 shows the velocity anomaly of types N+NW and C+CSW+SW. The trend of them was almost similar to a sharp drop from the 1980s, but the mean velocity of types N+NW is weaker than that of C+CSW+SW, which indicates that wind from the north in winter is much weaker than that since the 1980s and consequently cold air from the north is much weaker. It is because the Mongolia high is weaker than before. Therefore, types N+NW increased although the cold air is weak, the surface temperature did not necessarily decrease. Other factors such as the enhanced greenhouse effect can also contribute to the increased temperature.

It is expected that the circulation types can only explain part of the variance in the temperature, because of the limited number of the types and more or less arbitrary divisions between the groups. An alternative way to study the association between atmospheric circulation and the temperature is to apply the six circulation indices. This provides a new possibility of mathematical modelling thanks to the continuous nature of the derived indices. A statistical approach, which involves regression of the temperature anomalies by the indices and large-scale temperature, will be employed to study the effect of the relationship. Since the derived indices are inter-correlated due to the atmospheric dynamics and the nature of the indices, part of the information contained by one index is also present in another. Thus, a stepwise multiple regression model is chosen to link the temperature anomalies (predictant) and the indices, large-scale temperature (predictors). The criteria used to include an index in the model is 95% confidence level. If the index is not significant at the 95% level according to F-test, it is excluded. Finally, V and large-scale temperature (region selected as Fig.1) are selected. The model takes the form as follows:

$$T_{\mathrm{a}} = -4.053 - 0.16V + 1.202t,$$

where T_{a} is the temperature anomaly (°C). The indices have the same units as mentioned before. The multiple correlation coefficient is 0.879. This statistical model means that the higher the large-sale temperature, the higher the temperature in Harbin. Due to the fact that V and T_{a} are anticorrelated, i.e., when the wind is strong, the temperature is usually low. Figure 9 displays the reconstructed temperature series based on the statistical model together with observed anomalies. As can be expected from the high correlation, the reconstruction is fairly satisfactory.

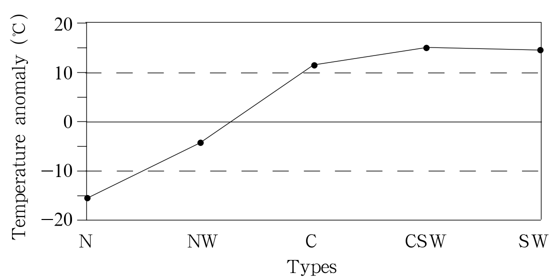

Fig.6. Temperature anomaly of five major circulation types (annual mean temperature in Harbin between 1951 and 2002 is 3.98 °C).

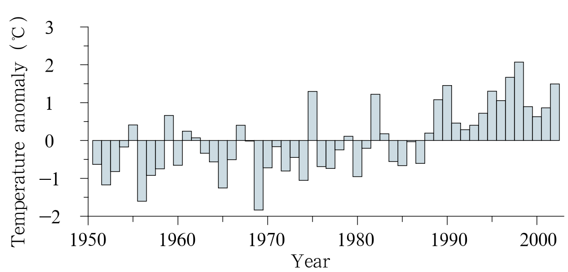

Fig.7. Temperature anomaly during 1951-2002 in Harbin.

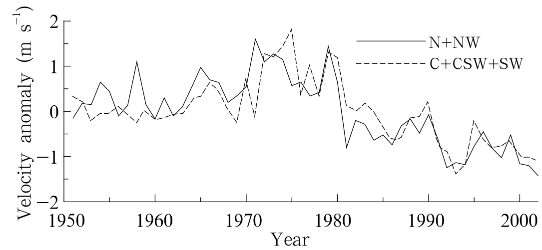

Fig.8. The observed velocity anomaly of types N+NW and C+CSW+SW in Harbin.

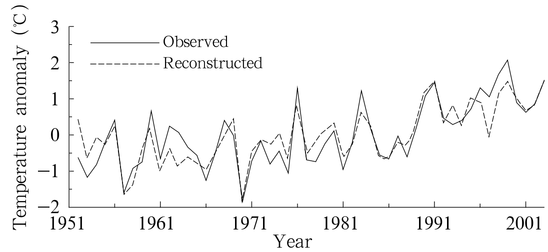

Fig.9. The observed and reconstructed temperature anomaly from 1951 to 2002 in Harbin.

5. Relationship between the precipitation in Harbin and the circulation

Table 2 lists the frequencies for all the types that are presented monthly mean precipitation, monthly maximum precipitation, and frequency times mean precipitation for each type. It shows that the most frequent type is type N, followed by cyclone type. These two types occupy 41.8% of the cases. All other types have a frequency below 10% and most of them below 5%. In terms of the monthly mean precipitation, the most important types are types S, SE, CSE, CS, and CSW which have a mean rainfall of more than 100 mm. These five types are all under the south wind condition. Different types are associated with different precipitation distributions and the means. A frequent type does not necessarily have an importance in terms of total precipitation, if it has a low mean precipitation. Similarly, though types S, SE, CSE, CS, and CSW have a large amount of precipitation, not all of them appear frequently. It is not reasonable to take all of them as major precipitation types of Harbin. Thus, we should consider the product of the frequency and the mean precipitation. The frequency times monthly mean precipitation can be taken as a threshold to determine the major precipitation types. If 8.3% (once a year on the average) times 44.52 mm (monthly mean precipitation from 1951 to 2002 in Harbin) is defined as the lower threshold of major precipitation types, then three types, i.e., types C, SW, and CSW, are selected. The precipitation happens mostly in summer, which is relevant to the fact that types C, SW, and CSW occur most frequently in summer. Based on these results, we use the three major types to discuss the relationship between weather types and the precipitation in Harbin. Composite maps of these three circulation types (1951-2002) are shown in Fig.10. When it is C weather type, there is a whole cyclone located in Heilongjiang Province. The circulation pattern of type CSW is similar to that of type SW with a low pressure system but for location of the low center. The center of type CSW is further east to the center of type SW. Harbin lies in the east of the cyclone and air flow is southeast, which brings a large amount of moisture from the ocean.

Frequency of different circulation types and their associated precipitation change with time. It is of interest to study how these changes evolve with time. Figure 11 plots the precipitation associated with the three major circulation types, together with the total precipitation. Type C has the closest relationship with the total precipitation (R=0.562). The contribution to the total precipitation of the three types varies with time. Types SW and CSW mainly influence Harbin's precipitation variation before the 1980s, especially type SW played an important role in the 1950s. After the 1980s, precipitation of type C played a major role in determining the changes of the total rainfall. The observed C+CSW+SW and annual total precipitation have a trend that they decreased from the end of the 1960s to 1970s, then increased smoothly from the 1980s (Fig.12). It has the same trend as the frequency of C+CSW+SW. In the study of interdecadal variation of summer rainfall in Northeast China (Huang et al., 1999), it came to the same conclusion. The close relationship between total types and types C+CSW+SW rainfall further indicates that it is reasonable to take these three types as major

Table 2. Frequency, monthly mean precipitation, monthly maximum precipitation, and frequency multiplied by mean precipitation of all circulation types (Bold numbers indicate major precipitation types)

Type	Frequency (%)	Mean rainfall (mm)	Maximum rainfall (mm)	Frequency×Mean rainfall
S	1.60	144.89	310.20	231.82
SE	0.16	136.20	136.20	21.79
CSE	0.16	103.20	103.20	16.51
CS	2.24	101.22	207.20	226.73
CSW	8.33	100.68	241.80	**838.66**
AE	0.16	84.90	84.90	13.58
C	17.15	83.10	352.70	**1425.17**
SW	8.65	81.81	223.60	**707.66**
AS	0.16	81.10	81.10	12.98
W	4.81	39.56	86.60	190.28
ASW	0.48	39.30	67.90	18.86
CW	4.33	39.12	143.80	169.39
CNW	2.08	26.02	68.20	54.12
AW	0.16	23.00	23.00	3.68
A	3.69	22.64	128.80	83.54
NW	9.29	16.82	67.60	156.26
ANW	0.96	15.98	31.40	15.34
CN	0.96	14.18	25.40	13.61
NE	4.65	8.77	38.10	40.78
ANE	0.80	8.14	16.00	6.51
N	24.68	7.35	57.80	181.40
AN	4.49	4.80	22.40	21.55

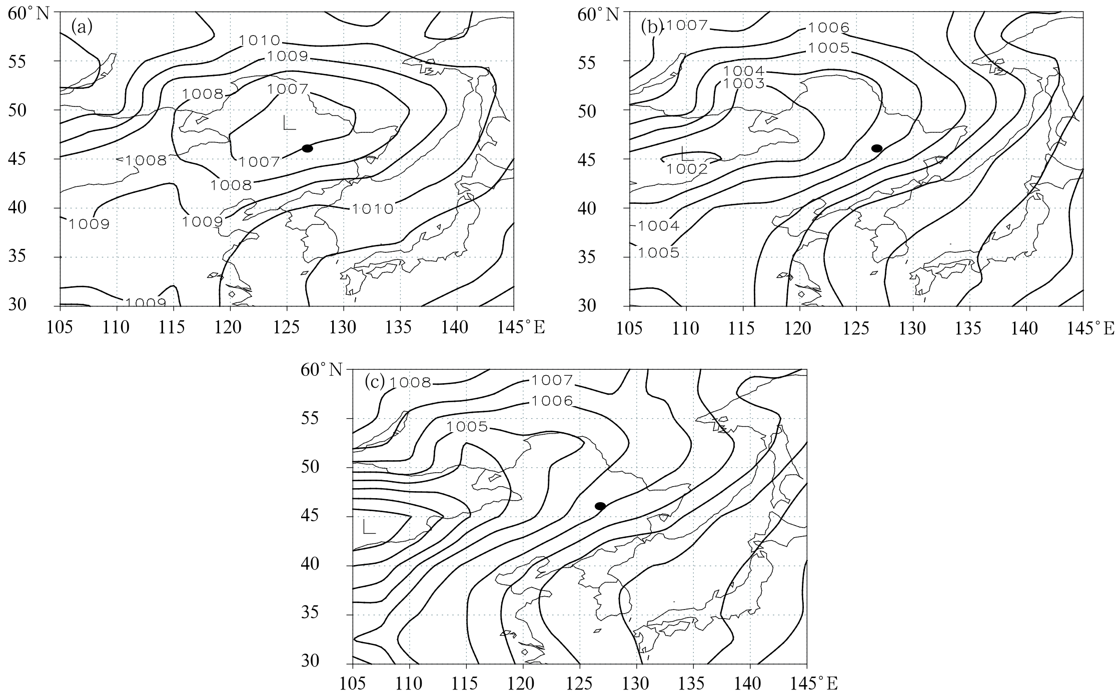

Fig.10. Mean sea level pressure composite maps of types C, CSW, and SW (the dot is the location of Harbin Station).

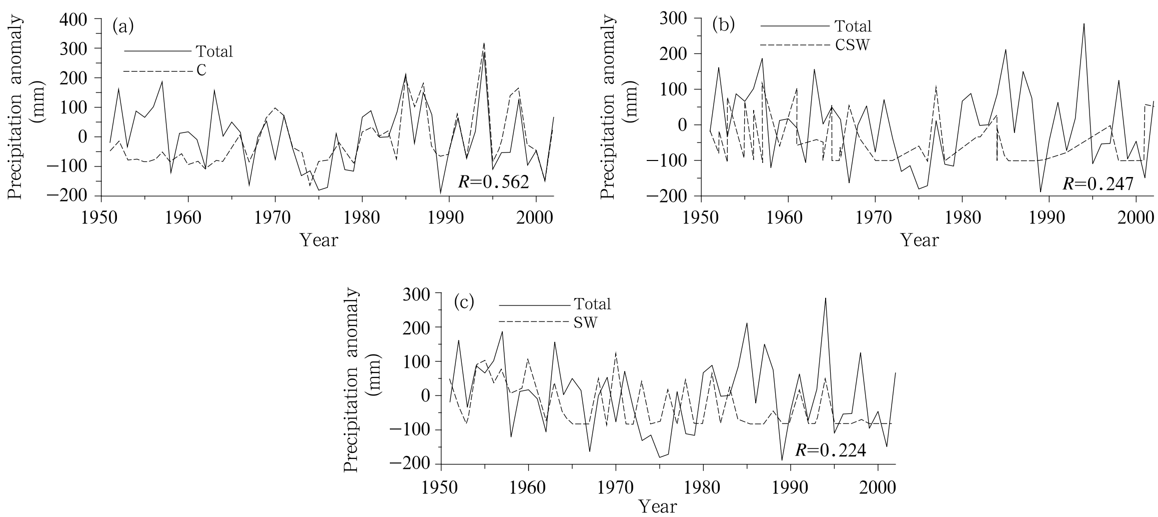

Fig.11. The observed precipitation variations of types C, CSW, SW, and total types.

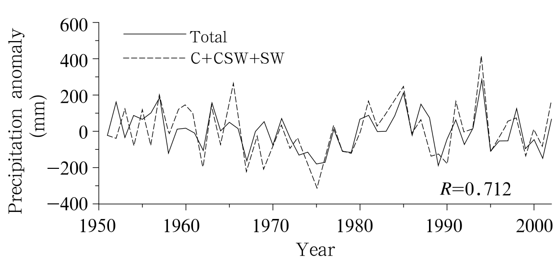

Fig.12. The observed C+CSW+SW and total precipitation anomaly.

precipitation types in Harbin.

6. Conclusions

The relationship between large-scale circulation and two climate variables (monthly mean temperature and rainfall) is discussed here. The main conclusions can be drawn as follows:

(1) The frequencies of various circulation types are presented. Although 22 out of the possible total

of 27 circulations appear, the frequency of most types is so small that only five types dominate. The most frequent types are identified as types C, CSW, SW, N, and NW. The cold season is characterized by types N and NW, whereas the warm period is dominated by types C, CSW, and SW. The period of October-March is considered to be transitional.

(2) To demonstrate the usefulness of this climatology, mean temperature in Harbin is studied with the help of the large-scale circulation types and indices. It is shown that directional flows with a northern component (N, NW) are often associated with negative temperature anomalies and the southern conditions (CSW, SW, and C) favor positive anomalies. Extremely high temperatures accompany the southwesterly flows which bring warmer air from the ocean. On the other hand, northerly flows bring cold air from the polar region leading to low temperature. It is clear that the classification is helpful in interpreting the temperature anomalies.

(3) The derived indices and large-scale temperature have been used to develop a statistical model linking temperature anomalies to circulation indices and large-scale temperature, i.e., $T_{\rm a} = -4.053 - 0.16V + 1.202t$. It is established by stepwise multiple regression. In view of the fact that 77.3% of the total variance in temperature anomalies during 1951-2002 can be reproduced only from the pressure, it is concluded that the atmospheric circulation plays an important role in determining climate in Harbin and the derived circulation climatology is a useful tool in regional climate research.

(4) As major precipitation types in Harbin, types C, CSW, and SW have different contributions to the total rainfall and vary with time. Type C dominates the total rainfall in recent 20 years.

(5) The interdecadal variations of the climate in Harbin and large-scale circulation patterns indicate that northern wind appears more frequently from the 1980s but it is weaker than before. Southern air flow has also an increased trend from the 1980s. Consequently, the interdecadal characteristics of Harbin's climate are that the temperature increased significantly from the 1980s. At the same time, the precipitation increased slowly though there is a small decrease from the late 1960s to 1970s.

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