PROCESS OF TRANSITION BETWEEN COLD AND WARM PERIODS AND ITS PREDICTION

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Received June 12, 2001; revised December 28, 2002

ABSTRACT

The oscillation of multi-time scales and the process of transition between cold and warm periods over most parts of China and its 6 regions (the Northeast, North China, Changjiang River Valley, South China, the Southwest, the Northwest) were analyzed with wavelet transformation and by computing the variances of the wavelet components for the temperature grade series during January 1911 to February 2001. The prediction model for cold and warm periods has been developed and the trend of cold and warm change in the coming 10 years is predicted. The results show that the oscillation with periods of around 30—40 years was the strongest in the last 100 years and the 3-year oscillation in both winter and summer was also stronger, especially in winter. The transition time of cold and warm periods in terms of winter mean did not coincide with that of annual mean, but the difference between summer mean and annual mean is less. The processes of transition of 6 regions are somewhat different, their main characteristics are that the beginning year of significant warming for 1980s to 1990s was very different for the southern and the northern part of China. It is found that the stronger oscillation with 3-year period causes cooling in Northeast China in recent several winters. The experimental predictions show that the models used in the paper can project the major transition between high and low temperature periods.

Key words: trend of coldness and warmness, process of transition, inter-annual oscillations, inter-decadal oscillations

I. INTRODUCTION

Beginning from the 1980s, the global warming appeared and has been continued. Recent 20 years are the warmest period since middle of 18th century. It is similar over China. But the warming process of China is not completely synchronous with that of the globe. Besides, the decade 1990s is warmest, i. e., a sharp increase of temperature occurred. Under the climatic background, in recent one or two years the air temperature in the Northeast has changed notably. The temperature mean of 3 stations (Harbin, Changchun and Shenyang) in January 2000 shows that the former is 2°C lower than the January mean of 1951 to 2000. However, the monthly mean temperature in January 2001 dropped more significantly , i. e. 4°C lower than the January mean of 1951 to 2000, it is the lowest since 1978. The monthly mean temperature of other two months (December, February) also dropped 2°C that was the first decrease since 1985. The temperature means of winters (December 1999 to February 2000, December 2000 to February 2001) dropped 1℃ and 3℃ compared with the same period of the other years respectively. Is it a significant inter-annual or inter-decadal oscillation? Does it indicate that the warm winter lasting for more than ten years will end? Since the winter in the Northeast has been colder and colder, does it mean that the change will expand continuously to the southern and western parts of China, and it may lead to the transition to a lower temperature period over the whole China? To answer the above questions we have to know not only the external causes such as the greenhouse effect, the solar and volcanic activity but also the oscillations that play the main role in the transition between cold and warm periods over most parts of China (Houghton et al. 1994). They may be either inter-annual or inter-decadal oscillations (Berger and Labeyrie 1987; Wei and Cao 1995; Wallace et al. 1996; Wang and Zhu 1999). We should know that how the transition between cold and warm periods over most parts of China makes progress?

The oscillation of multi-time scales and the process of transition between cold and warm periods over China and several regions in the last 100 years were analyzed by means of wavelet transformation and its variance analysis for the temperature grade series from January 1911 to February 2001. The prediction model for cold and warm periods has been developed, with which change trends of cold and warm periods in the coming 10 years have been predicted.

II. DATA AND METHOD

1. *Data*

The temperature grade series (TGS) from January 1911 to February 2001 over the six regions (the Northeast, North China, Changjiang River Valley, South China, the Southwest, the Northwest), which were processed by the Institute for Weather and Climate and the Central Meteorological Observatory (1984), are used in this paper. The TGS data are composed of five grades, 1 stands for the warmest, 2 for warmer, 3 for normal, 4 for colder and 5 for the coldest. The temperature grade values of above regions were calculated by averaging grade values of representative stations of every region. The representative stations of each region are as follows:

The Northeast (NE): Hailar, Qiqihar, Jiamusi, Harbin, Changchun, Shenyang

North China (NC): Beijing, Taiyuan, Jinan, Zhengzhou, Xuzhou

Changjiang River Valley (CJ): Nanjing, Shanghai, Hankou, Yichang, Changsha, Zhijiang, Wenzhou

South China (SC): Nanning, Wuzhou, Guangzhou, Shantou, Xiamen, Zhanjiang

The Southwest (SW): Chengdu, Chongqing, Xichang, Guiyang, Kunming

The Northwest (NW): Yan'an, Xi'an, Lanzhou, Xining, Jiuquan

The monthly TGS is very useful for studying the transition between cold and warm periods over China in the last 100 years (Zhang and Li 1982). Generally speaking, the transition of cold and warm periods in both winter and summer are more significant than in both spring and autumn. Therefore we focus on the feature of transition of cold and warm periods in aspect of annual mean temperature, winter (December, January, February) and summer (June, July, August) mean temperature in the last 100 years. Moreover the prediction for the transition was also made.

2. *The Method*

The analysis method used in this paper is wavelet transformation and its variance analysis, which is based on the invariant of reflection group. A time series can be decomposed by the wavelet transformation into the time and frequency domains in order to have a more direct and distinct understanding on the change in a complicated time series and its features of multi-time scales.

Suppose that a function $g(t)$ satisfies the following conditions

$$\int_R g(t)\mathrm{d}t = 0, \tag{1}$$

$$\int_R \frac{|G(\omega)|^2}{\omega}\mathrm{d}\omega < \infty, \tag{2}$$

where $G(\omega)$ is the frequency spectrum of $g(t)$, the transformation of function $f(t)$ reads

$$W_f(a,b) = |a|^{-1/2}\int_R f(t)\bar{g}(\frac{t-b}{a})\mathrm{d}t, \tag{3}$$

where a is a frequency parameter, b a time parameter, $g(t)$ mother wavelet function. Here, taking the Mexican hat function as a mother wavelet function, its expression is

$$g(t) = (1 - t^2)\frac{1}{\sqrt{2\pi}}\mathrm{e}^{-t^2/2}, \qquad -\infty < t < \infty \tag{4}$$

wavelet variance is

$$\mathrm{Var}(a) = \sum (W_f)^2(a,b). \tag{5}$$

3. *Prediction Model*

According to the characteristics of transition of cold and warm periods over most parts in China, we have developed a new prediction model and its basic idea is that components of inter-annual and inter-decadal oscillations are implicated in the temperature series and can be extracted by means of deleting noises and unpredictable parts, thus the prediction model of transition of cold and warm periods was built. The model is capable of making multi-step predictions and making an extreme value prediction.

For the wavelet transformation of the oscillations $X(i)$ with different scales of temperature series, we define an oscillation function

$$OSC_L(i) = \frac{1}{N_L}\sum_{j=0}^{N_l} X(i + jL), \qquad i = 1,2,\cdots,L \tag{6}$$

where L is period length of oscillations function, N_L satisfying $N_L \leqslant [N/L]$, N is sample size. Making extension for OSC_L series

$$OSC_L(t) = OSC_L(t - L \cdot INT[\frac{t-1}{L}]), \qquad t = 1,2,\cdots,N. \tag{7}$$

If M oscillation functions are selected, the prediction model of transition of cold and warm periods is written as

$$X(t) = \sum_{i=1}^{M} a_i OSC_i(t) + e(t), \qquad t = 1,2,\cdots,N, \tag{8}$$

where a_i' s are coefficients for different oscillation function; when making Q step forecasts, firstly $OSC_L(t)$ is extended to $t=N+Q$ with Eq. (7), then inputted into Eq. (8), thus the prediction can be made.

III. THE VARIANCES INTER-ANNUAL AND INTER-DECADAL OSCILLATIONS

The variances of oscillations of TGS represent the energy weights for oscillations of multi-time scales. Figure 1 show the change in wavelet variances for the TGS with frequencies for annual mean, winter and summer means over most parts and 6 regions in China. It is shown that the wavelet variances of annual mean were growing with increasing frequency and the growing trend was very notable (Fig. 1). The oscillation energy focused mainly on around 30—40 year scales but that under 10-year scales was weaker. It is found that the inter-decadal oscillations with periods of around 30—40 years were the strongest in the last 100 years. It can be seen from Fig. 1a that change trends of annual mean in North China, Changjiang River Valley, South China, the Southwest and the Northwest were consistent with that over most parts and the oscillation energy with periods more

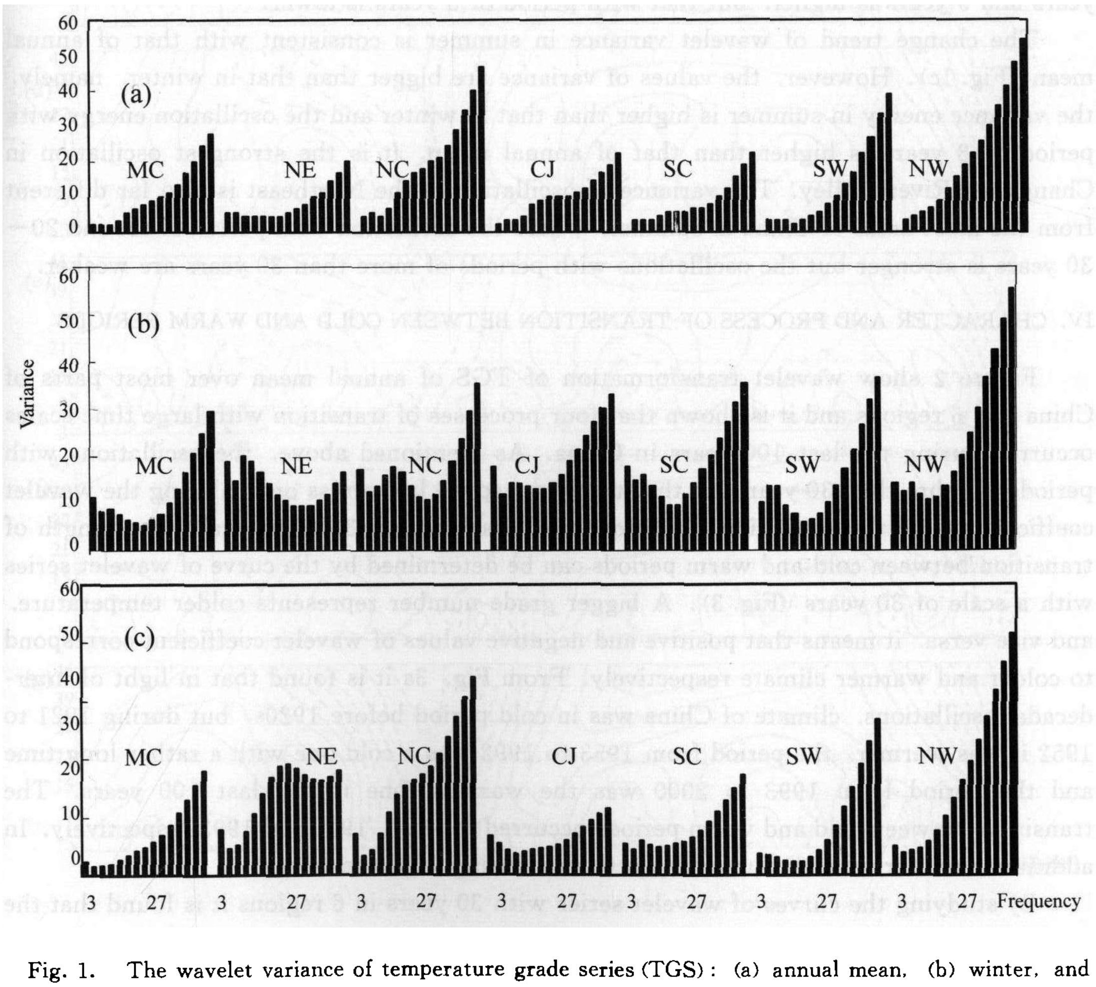

Fig. 1. The wavelet variance of temperature grade series (TGS): (a) annual mean, (b) winter, and (c) summer. Here MC stands for most parts of China, and other acnonyms see the text.

than 30 years is prevailing. Nevertheless, the variances in the Northeast were different from other regions, i.e. the oscillation energy for annual mean with periods of around 30—40 years was stronger, but the oscillation energy with periods of 3 years and 6 years was stronger than that with periods of around 10—20 years.

The variance energy in winter was different from that of annual mean (Fig. 1b). The oscillation energy with periods more than 30 years is still prevailing, but the energy with period of 3 years exceeds that of other scales within 30 years, namely, the 3-year oscillation was very obvious in winter. The change trends in North China, Changjiang River Valley, South China, the Northwest were consistent with that over most parts of China. The change trend in Northeast is quite different from that over most parts of China and the above 4 regions, where the oscillation energy with period of 3 years not only is higher than that of periods of within 30 years, but also is over than that with period of around 30—40 years. The results show that the major oscillation in the Northeast in winter is the 3-year oscillation. The wavelet variance of the Southwest is also different from that over most parts of China in winter and the oscillation energy with periods of 6 years and 9 years is higher, but that with period of 3 years is lower.

The change trend of wavelet variance in summer is consistent with that of annual mean (Fig. 1c). However, the values of variance are bigger than that in winter, namely, the variance energy in summer is higher than that in winter and the oscillation energy with period of 3 years is higher than that of annual mean, it is the strongest oscillation in Changjiang River Valley. The variance of oscillation in the Northeast is also far different from the most areas of China in summer, where the oscillation with period of around 20—30 years is stronger but the oscillations with periods of more than 30 years are weaker.

IV. CHARACTER AND PROCESS OF TRANSITION BETWEEN COLD AND WARM PERIODS

Figure 2 show wavelet transformation of TGS of annual mean over most parts of China and 6 regions and it is shown that four processes of transition with large time scales occurred during the last 100 years in China. As mentioned above, the oscillations with periods of more than 30 years are the strongest, so we laid stress on analyzing the wavelet coefficients with the scale, i.e. its frequency parameter $a=30$. The exact time length of transition between cold and warm periods can be determined by the curve of wavelet series with a scale of 30 years (Fig. 3). A bigger grade number represents colder temperature, and vice versa, it means that positive and negative values of wavelet coefficient correspond to colder and warmer climate respectively. From Fig. 3a it is found that in light of inter-decadal oscillations, climate of China was in cold period before 1920s, but during 1921 to 1952 it was warmer, the period from 1953 to 1992 was a cold one with a rather long time and the period from 1993 to 2000 was the warmest one in the last 100 years. The transition between cold and warm periods occurred in 1921, 1953 and 1993 respectively. In addition, another weaker fluctuation occurred during 1930s to 1940s.

By studying the curves of wavelet series with 30 years in 6 regions it is found that the processes of transition were different among 6 regions and their main characters as follows: (1) The weaker fluctuation during 1930s—1940s mainly appeared in 3 regions of the northern part of China (the Northeast, North China, the Northwest), especially the

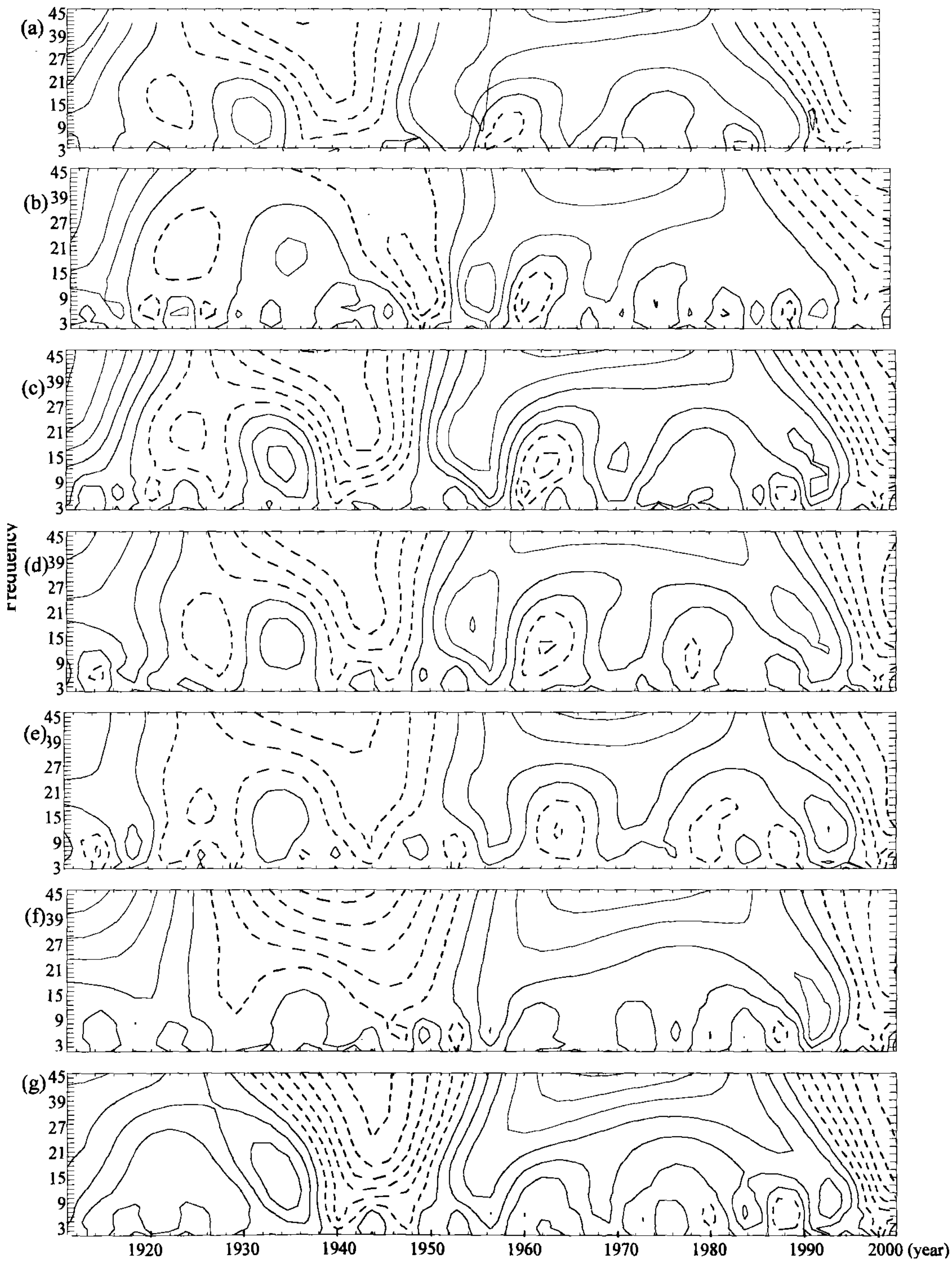

Fig. 2. The wavelet transformation for annual mean of TGS for (a) MC, (b) NE, (c) NC, (d) CJ, (e) SC, (f) SW and (g) NW.

fluctuation was prominent in the Northwest. After 1950s the change trends in the southern part of China were in agreement with those in the northern part of China. (2)

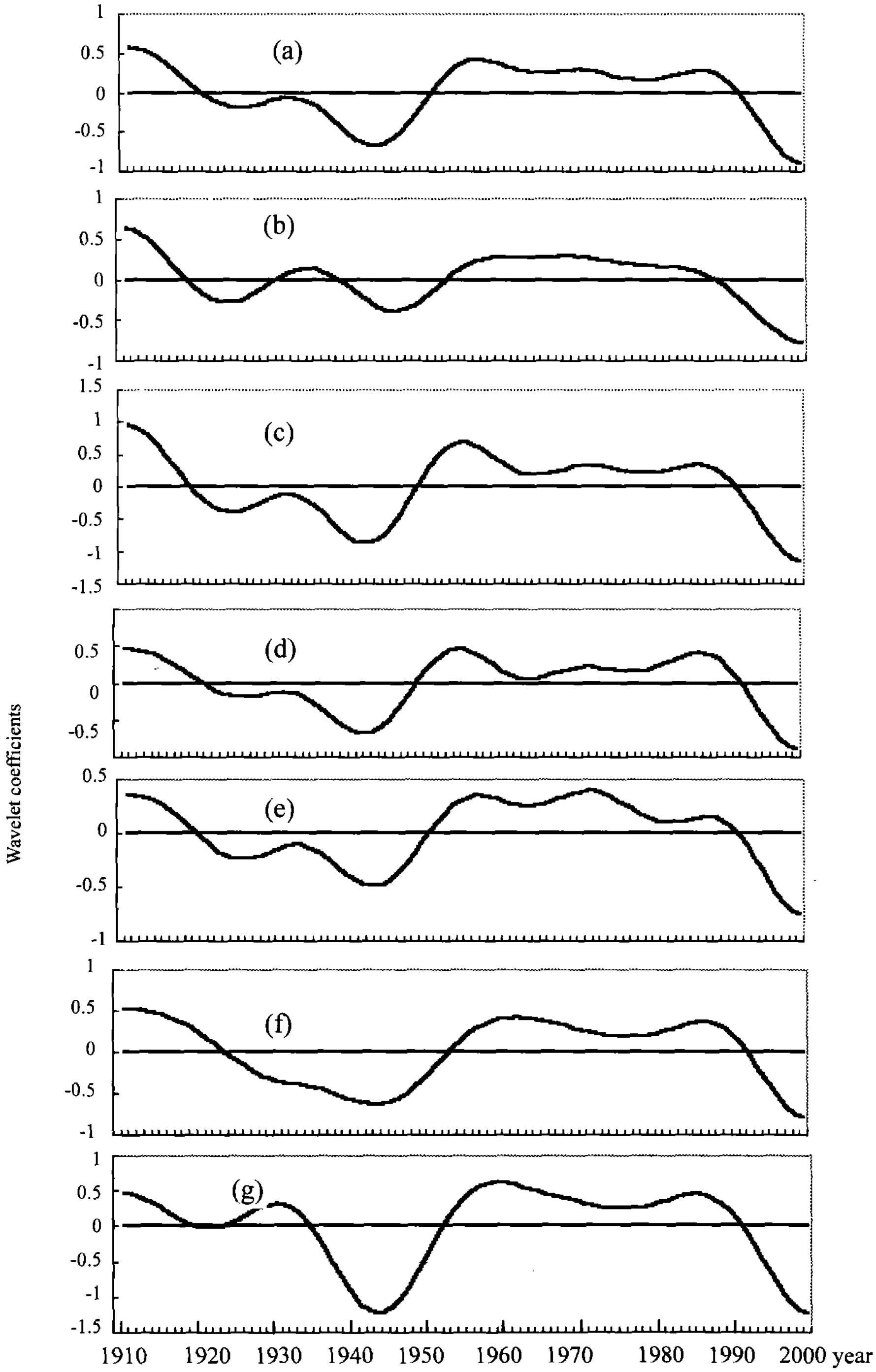

Fig. 3. The wavelet series with a scale of 30 years of annual mean of TGS for (a) MC, (b) NE, (c) NC, (d) CJ, (e) SC, (f) SW, and (g) NW.

Two processes of transitions from cold to warm period in China occurred during the beginning of 1920s and 1990s respectively, the beginning year of the transition in the Northeast was earlier than that in other areas, where the warming happened in 1921 and 1992, respectively. However, the warming in the Northeast happened in 1920 and 1989, respectively. It was 3—4 years earlier than other areas, because the beginning of warming was in 1992 in North China and the Northwest and in 1993 in Changjiang River Valley, South China and the Southwest.

From Fig. 4 that is a chart of wavelet transformation of TGS in winter over most parts of China and 6 regions, we find that the change trend in winter was different from annual mean during last 100 years and the inter-annual oscillation with small scale was also significant. Four transitions also occurred during the last 100 years in winter, but the beginning and ending years of transforming from one period to another were different from annual mean. Meanwhile, the differences among regions were more obvious. Take wavelet series with 30 year's scale to determine exact time in which the transition occurred. It is found from Fig. 5 that the beginning of the warm period started in 1934 and ended in 1950. A cold period began in 1951 up to 1986 and another warm period began in 1987 and extended up to now. It is found from above analysis that the beginning year of warming in winter during the first half of the 20th century was postponed a rather long time in comparison with that for annual mean, and the warming in winter occurring in 1980s—1990s was about 5 years earlier than that for annual mean.

By studying wavelet series with 30 year scale in winter in 6 regions, features of transition between cold and warm periods are reduced to three points: (1) The change trend of winter temperature in the Northeast was far different from that in most parts of China and other regions, especially before 1960. It can be seen from Fig. 5b that the fluctuation of temperature in the Northeast was more frequent than other regions. Even the trends for 1938—1951 and 1952—1963 in the Northeast were in opposite with that in other regions, but after 1964 the trend in the Northeast was consistent with other regions. However, the warming began in 1960s, which was the earliest and was about 4 years earlier than that over most parts of China. Especially, the temperature of 2000—2001 in winter implied an inkling of cooling in the Northeast. (2) There was difference between northern parts and southern parts of China in respect of process of transition, especially for the warming during 1980s—1990s. The Northeast was the earliest, with the beginning in 1983, then 1985 in North China and the Northwest, and 1990 in Changjiang River Valley, South China and the Southwest. (3) The warming amplitude in 1990s was bigger than in 1940s, in which the warming in 1940s was not obvious but it was outstanding in 1990s in the Northeast.

It is found from Fig. 6 that the change trends with small time scales in the Northeast, North China and the Southwest were very different from that over most parts of China, but the trends with large time scales were all similar. However, the change trends with large scales in other regions (Changjiang River Valley, South China and the Northwest) were different from that over most parts of China in which the trend of Changjiang River Valley was similar to that of South China, i.e. the warming period there was longer than cooling one, but the cooling period in the Northwest was longer than warming one.

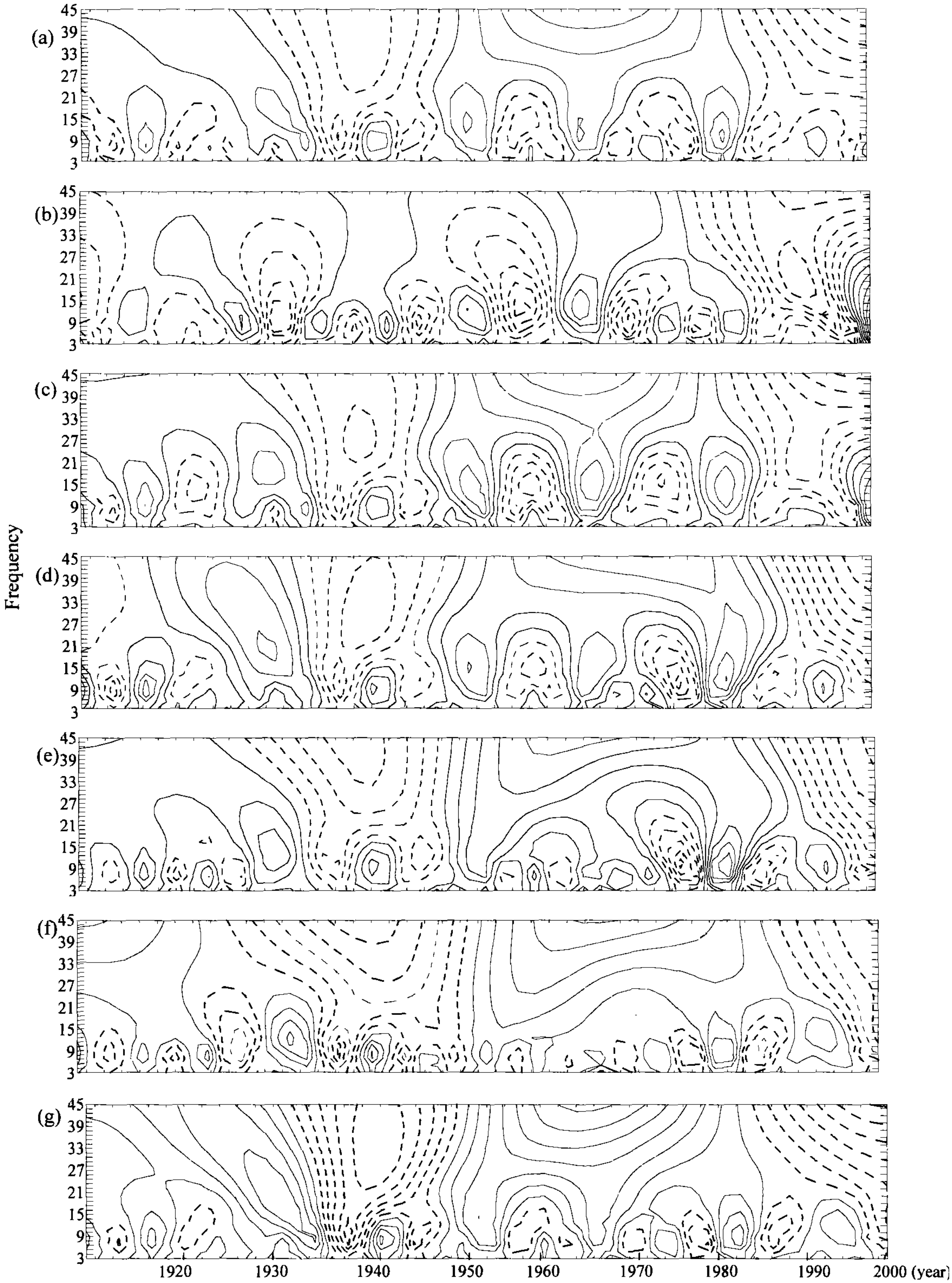

Fig. 4. As in Fig. 2. but for winter.

It is shown from the wavelet series with 30 years in summer (Fig. 7a) that the change trends and process of transition between cold and warm periods in summer over most parts

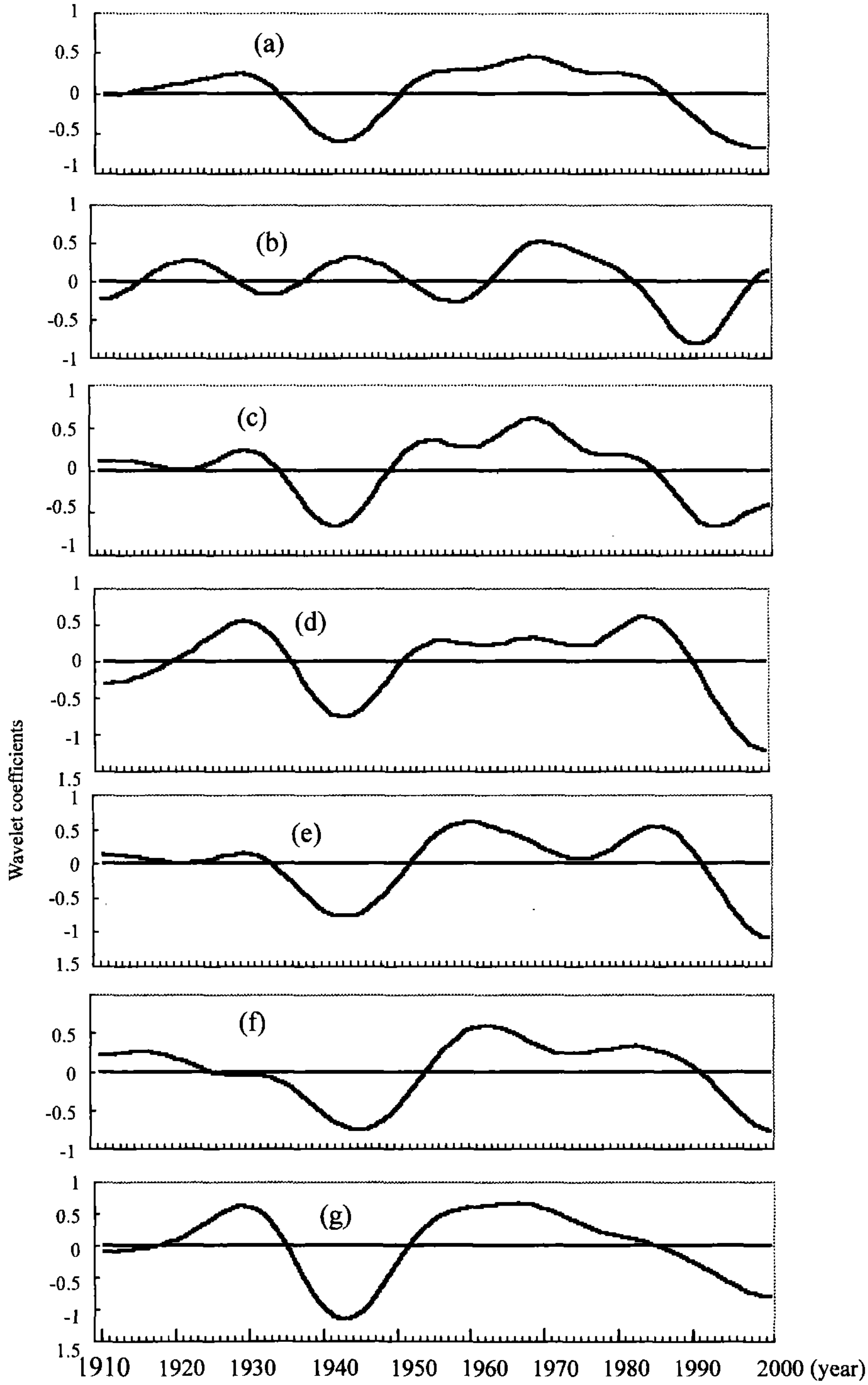

Fig. 5. As in Fig. 3, but for winter.

of China were much closer to annual mean than in winter. Comparing the curves of Fig. 7b to 7g it is found that there were two obvious differences between the process of the transition in summer and that in winter. Firstly, the process of warming of the northern part and the southern part of China was opposite to winter, i. e. the beginning year of warming in southern regions, where the occurring time was in the beginning of 1980s, was

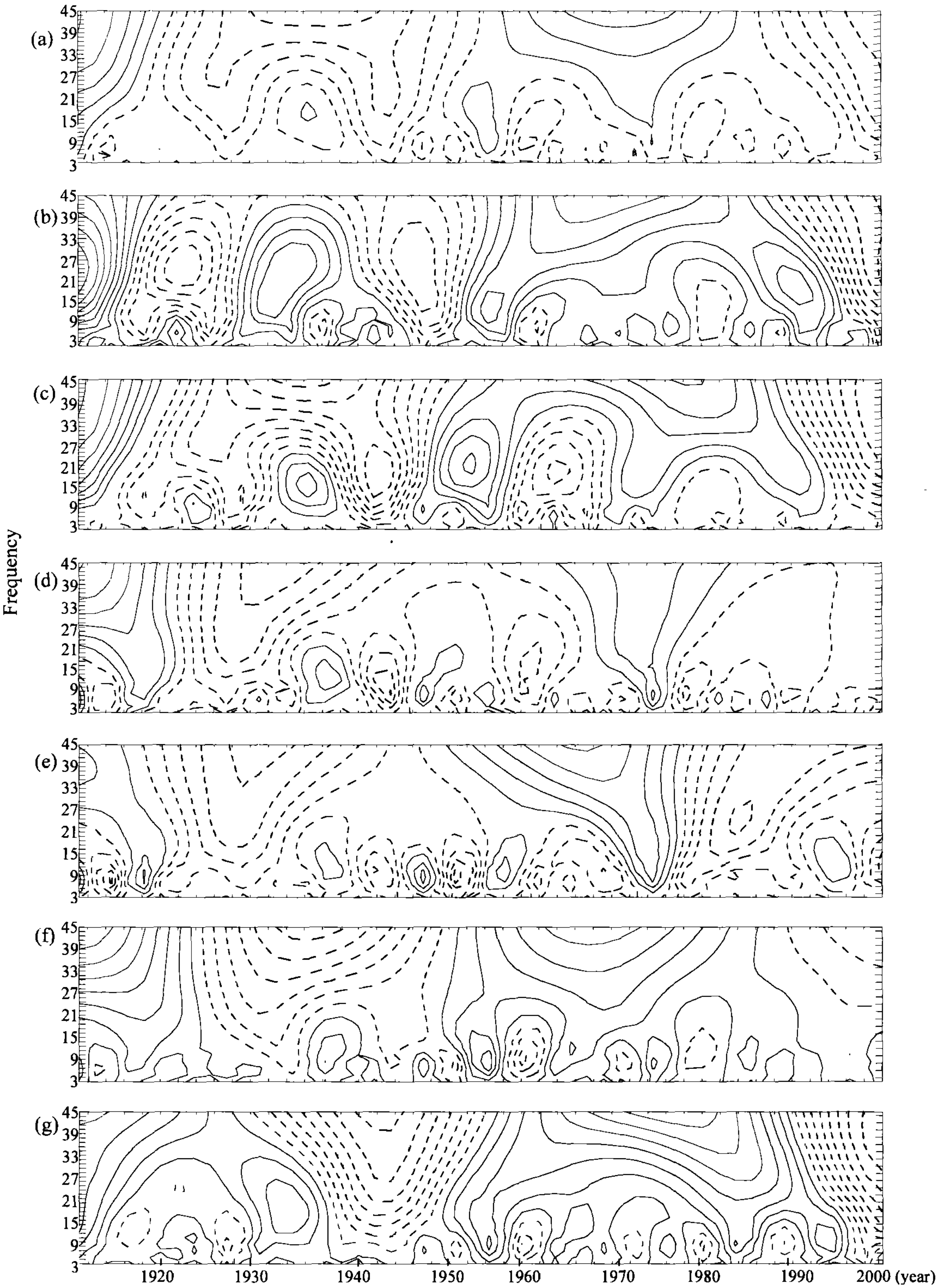

Fig. 6. As in Fig. 2 but for summer.

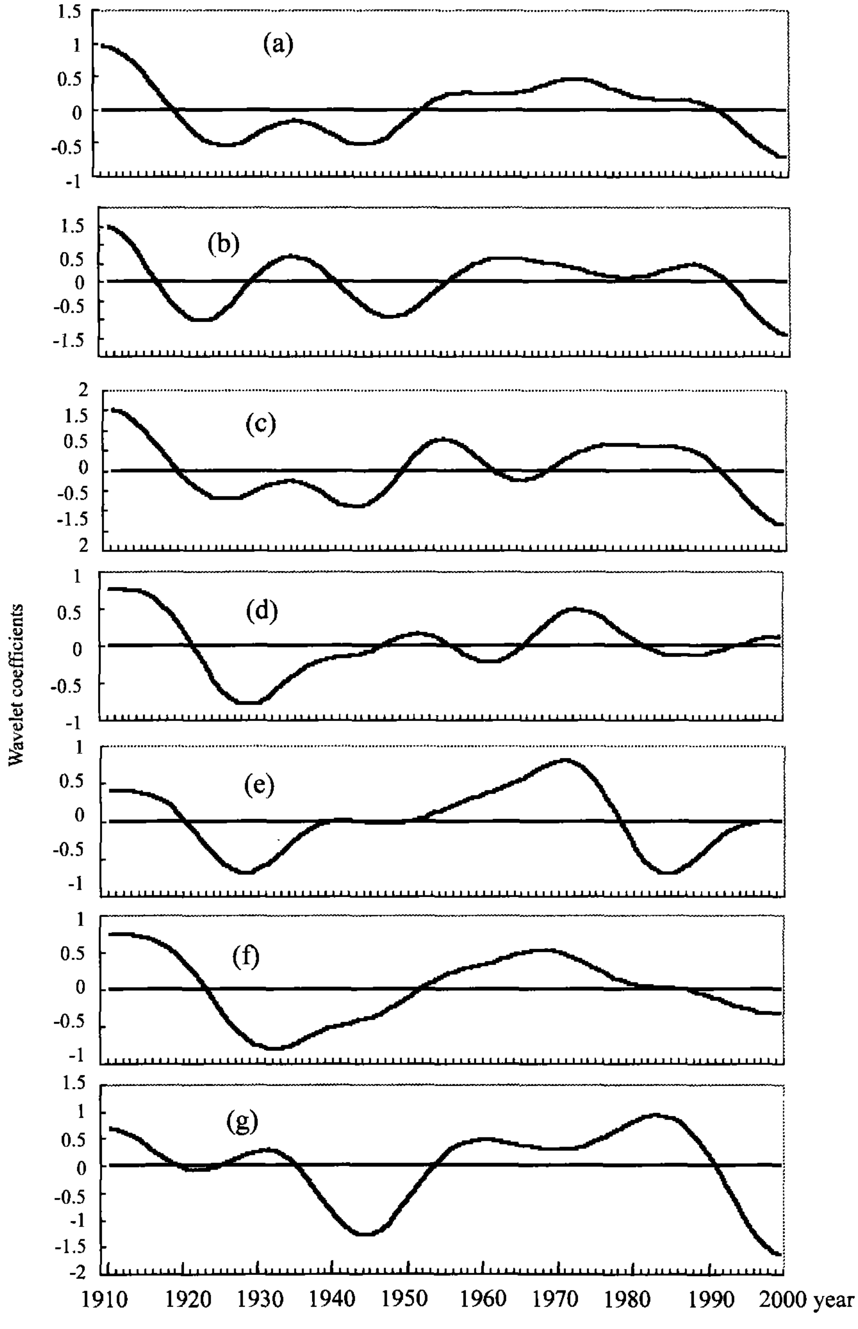

Fig. 7. As in Fig. 3 but for summer.

earlier than in northern regions (the Northeast, North China, the Northwest). The warming amplitude was not large in South China. However, the beginning year of warming occurred in 1992 in the northern part but the amplitude was very large. Secondly, an oscillation happened in 1930s—1940s in the Northeast, which was sharper than that of most parts of China and other regions in China. The change trend of North China in 1960s — 1970s was inconsistent with that of most parts of China and other regions. However, a weaker oscillation from cold to warm periods happened, and the change trend in other periods was consistent with that of most parts of China and other regions.

V. PREDICTION EXPERIMENT OF CHANGE TREND OF TEMPERATURE

As mentioned above, there were inter-decadal oscillations with periods of around 30—40 years in the change trend of the temperature in China. Meanwhile, the inter-annual oscillation with a period of 3 years was much more significant in winter and summer. Therefore, the change trend of the cooling and warming over most parts and 6 regions of China can be predicted by means of Eqs. (6) — (8).

Firstly, the TGS for 1911s—1990 is modeled. The results show that several processes of transition between cold and warm periods, such as the process occurring from 1920s, from 1950s and during 1980s—1990s, are well simulated by the prediction models. The hit ratio scores for departure sign of fitting and observation in winter, whose change amplitude was bigger than that of other seasons, are listed by Table 1. The fitting of the change trends both over most parts and 6 regions of China is in good agreement with the observed, especially the hit ratios in the Northeast, South China and the Southwest are equal to or more than 90%.

Table 1. The Hit Ratio Scores for Departure Sign of Fitting and Observation in Winter

Region	R(%)
most parts of China	81
the Northeast	91
North China	79
Changjiang River Valley	86
South China	90
the Southwest	90
the Northwest	87

The trend predictions made for independent samples during 1991—2000 are shown in Fig. 8 and from the solid lines which show observations it can be seen that change trends of the air temperature in the Northeast and North China were going up but the warming in the Southwest and the Northwest were not obvious during 1990s. The predictions of the warming trend in which significant warming occurred in 1998 and 1999 were in agreement with the observations. The cold trend in the first half of 1990s and the warm trend in the end of 1990s in the Southwest and the Northwest can be predicted by the models very well.

The predictions for 2001—2010 by means of the model show that the warming trend, which lasted for more than 10 years up to now, will decrease slightly but the temperature in the coming 10 years will not go down to the values before warming. The models infer

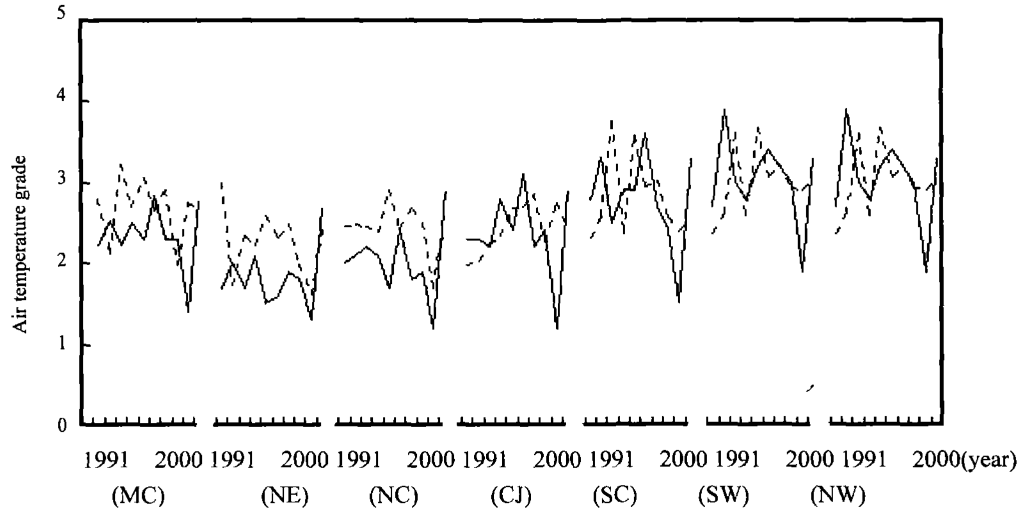

Fig. 8. The observations (solid line) and predictions (dotted line) for the TGS in winter during 1991—2000.

that the decreasing trends in the Northeast and North China will appear in a couple of past winter. It maybe contributes to the 3-year oscillation. There is no obvious evidence that the climate will turn over.

VI. CONCLUDING REMARKS

(1) It is shown from the wavelet variances that the oscillations with a period of around 30—40 years are the strongest in these of the multi-time scales in the last 100 years and the oscillations with a period of 3 years in winter and summer are stronger than that of annual mean, especially in the Northeast in winter, their variances are beyond that of inter-decadal oscillation with a period of more than 30 years. The inter-decadal oscillations with a period of around 30 — 40 years are of main climatic oscillations. However, the external forcing, such as sun and volcanic periodic activities, may play a role in the inter-decadal oscillation. The inter-annual oscillation with a period of 3 years may be dominated by air-sea interaction.

(2) Four transitions between cold and warm periods with long time scales, occurred during the last 100 years. The four periods of annual mean series, including colder period before 1920s, warmer one during 1921—1952, colder one with a longer time during 1953 — 1992 and warmer one during 1993 — 2000, are in agreement with those detected by means of other methods by other work (Wang 2001). The beginning years of transition between cold and warm periods in winter and summer did not synchronize with that of annual mean. For TGS in winter there were four cold and warm periods, i. e. colder period before 1933, warmer period during 1934—1950, colder period during 1951—1986 and warmer period during 1987—2001. In light of 30-year scale, the warming amplitude during 1987—2001 is bigger than that of 1940s in winter, especially in the Northwest, but the difference between summer and annual mean is less over most parts of China.

(3) The processes of transition over 6 regions are different. Especially for the

warming process during 1980s—1990s, their main character is that the beginning year was very different between the southern and northern parts of China. The beginning of the warming was the earliest in the Northeast in 1983, then beginning in 1985 in North China and the Northwest, and the latest beginning was till 1992 in Changjiang River Valley, South China and the Southwest. Therefore, the warming process in winter which was the sharpest in the 20th century, began from the northern part of China and extended into the southern part of China, but the summer case was opposite to the winter case, i. e. the beginning year of the southern part of China where the warming has already occurred in beginning of 1980s was earlier than that of the northern part of China, where the warming has just occurred in 1992. However, the warming amplitude of the northern part of China was bigger than that of the southern part of China.

(4) Based on the diagnosis for the inter-annual and inter-decadal oscillations, prediction models were built. The results of fitting the dependent sample and predicting experiments made for independent samples for 1991 — 2000 show that the models are available for the simulation and prediction of the temperature change trends. The warming trend will decrease slightly but the temperature in the coming 10 years in China will not go down to the values before warming of 1980s—1990s.

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