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Review on the Data Application and Climate Variability in China for Various Timescales

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Abstract: Temperature and precipitation are two main variables in climate changes. Spatial-temporal resolutions of temperature and precipitation, and recent studies on climate variability in China are summarized and discussed in this review. Recent 100-year datasets are used to reveal quasi-20-year and quasi-70-year oscillations in eastern China, as well as precipitation pattern shift in China. An oscillation with the timescale of 70−80 years is introduced in eastern China, derived from 500-year and 1000-year proxy and observation records. Finally, it is noted that more research achievements on climate change in China depend upon developing or reconstructing long-term series, studying in regularity and mechanism, as well as upon prediction and service etc.

Key words: China; climate change; data; variability

Introduction

It has become more and more acceptable that today's global and regional climate is revolutionizing as a consequence of global warming. Many analyses suggest that the Northern Hemisphere (NH) climate of the past 1000 years was characterized by an irregular but steady cooling, followed by a strong global warming (GW) during the 20th century. Temperature was relatively warm during the 11th−13th centuries and relatively cool during the 16th−19th centuries. These periods coincide with what are traditionally known as the Medieval Warm Epoch (MWE) or called the Medieval Climate Optimum and the Little Ice Age (LIA), respectively, although these anomalies appear to have been most distinct only in and around the North Atlantic region. Based on these analyses, the warmth of the late 20th century appears to have been unprecedented during the millennium.

An interesting topic of climate change from the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [1] is the last millennium temperature series over the NH, derived from Mann *et al*.[2]. An dispute based on this series came from two aspects. Firstly, the variation amplitude of the MWE, LIA and GW were largely weakened than previous studies. Secondly, the long-term steady cooling before the 20th century, followed by a strong global warming during the 20th century, will lead to a conclusion of temperature increasing rapidly in the 21st century due to the anthropogenic interference. Information for the temperature variability of this series was mainly based on tree ring chronology in the NH during the early period. A new assessment can be noted from the fourth report of IPCC [3] that attention should be paid to those long-term proxies so that study of historical temperature changes could focus on recent several hundred years. The core issue is how to get appropriate data and analyze the climate variability in a more accurate way.

More accuracy, longer time period and wider spatial coverage of temperature and precipitation records are necessary to understand the global climate change, which is also the first object of science community. However, it is hard to reach the goal due to many limitations. It is of fundamental importance to find other ways to reconstruct the climate of the past. High spatial-temporal resolution data from the mid-20th century are useful for fast-changing climate evolution, but long-term series are also important for slow-changing climate evolution. Therefore, it is helpful to improve the process of research on climate change all over the world by analyzing the characteristics of climate

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change with detail data in China.

1 Data and variability: climate in recent 100 years

The primary problem of climate change research is how to get long-term observation or proxy series of temperature and precipitation. In recent years, different kinds of temperature and precipitation data over the whole area of China can be downloaded from internet. On the other hand, Wang *et al*.[4−6] published seasonal series of recent 100 years in China, containing temperature series in 10 areas of China and precipitation series of 71 stations. Most of these data are observations, especially in East China, which can be used to analyze the decadal oscillation. Although the time lengths of these series are not enough for the research of long-period oscillations, still adequate for the study of changes in climate patterns between different areas in China. There are some relevant conclusions as showed below.

There are long- and short-period oscillations in climate changes. Similar to the temperature change of the NH and the world in recent 100 years, temperature in China has an increasing trend, as well as long-period and quasi-20-year oscillations in the precipitation change[7]. According to the observed precipitation data in Seoul and historical records in Beijing and East China (which are longer than 200 years), it can be confirmed that there is a quasi-70-year oscillation in East China [8], in which there are approximately opposite dryness/wetness changes between the Yangtze River basin and North China. Furthermore, analyses of the temperature and precipitation of recent 120 years in East China and the runoff series of the Yangtze River and the Yellow River brought a new view of abnormal climate changes in China [9]. Half of the 20-year short oscillation is the warm decadal period and the other half is the cold decadal period, so is the 70-year oscillation. When the two warm phases overlap, the climate will be abnormally warm. In the 1920s, two warm phases and two dry phases overlapped in the Great Bend of the Yellow River, and in the northernmost boundary region of East Asian summer monsoon, which caused a decadal abnormal drought in Northwest China in that decade [9].

There is a spatial shift of abnormal precipitation regime in China. Based on the precipitation data of 35 stations and those of 71 stations provided by Wang, and using different analysis methods, we found that the interdecadal abnormal precipitation signal appeared in Northwest China first [10−11], then moved slowly eastward and southward to the southern China. From the research on the precipitation data of nearly 500 stations in recent 40 years in China, we also found that four obviously turning points in 1983, 1987, 1979 and 1991 correspond to an obvious increasing trend after that time, respectively, in Northeast China, Northwest China, the lower Yangtze River and South China [12].

2 Data and variability: climate in recent 500 years

The longest observation precipitation record of East Asia is from the year of 1777 in Seoul, which lasts more than 200 years. Before the 20th century, people in Seoul used copper rain gauge to record precipitation. They used the time scale of 2 hours and the measurement unit of precipitation amount with Chi (100/3 mm) and Cun (10/3 mm). In China there were also records of rainy or sunny days in Qing Dynasty, but without rainfall amount record. With these records, the quasi-70-year oscillation can also be deduced. The long term precipitation oscillation in Seoul was synchronous with dryness-wetness oscillation in the lower Yangtze River, while reverse with that in North China [8]. Of the 70-year oscillation, the last transition of the precipitation pattern in East China occurred in 1977−1979.

The most reliable data of the climate in the past 500 years in China is the drought /flood index series of 100 stations in the East China since 1470. There are many researches on this data [13−14]. We have extended this series to the year of 1999 with modern observation precipitation data, done some researches on the time series of the spatial mode, and found that there were 3 variation centers in China, i.e. North China, the lower Yangtze River, and South China, and the biggest variation center of century time scale shifted among them [15].

Using the recent-500-year drought/flood index, Zhu *et al*. [16−17] has found out that there was the quasi-80-year oscillation in different areas of East China, most of which had a wide spectrum varying with time. By using the rotated empirical orthogonal function (REOF) expansion for the recent-500-year drought/flood index series and analyzing the time coefficient series in the lower Yangtze River through the wavelet method, we found that the oscillation periods were mostly 90 years in the former 200 years and 70 years in the latter 200 years [18], so that the average period of the oscillations in the whole 500 years was about 80 years.

3 Data and variability: climate in recent 1000 years

Some scholars in China have reconstructed temperature or dryness/wetness series in recent 1000 years, majority of which are temperature series [19−24]. These series are mostly derived from ice cores [25] and tree rings [26−27] in the west and from document records in the east [28−29] of China. Synthesizing these different kinds of proxy series, Wang *et al*. [21] reconstructed a 1000-year temperature series in China. With these data and the stalagmite deposit sequence in Beijing [30], we discussed the relationship between temperature and dryness/wetness features in North China in the last 1000 years [18] and believed that there were MWP, LIA and modern climate warming during the 1000 years. Transforming the 1000-year precipitation types in East China [28] into the dryness/wetness index series in North China, the lower Yangtze River and South China, and analyzing the relationship and pattern of the dryness/wetness changes in these three regions using mathematic methods [8], it can be inferred that there were short-period oscillations (20−30 years) and long-period oscillations (70−80 years) in the three regions of East China, and there were also phase differences between oscillations in different regions, earlier in the north than in the south.

4 Outlook

Looking back on the climate change research in China recently, especially on dryness and wetness changes, regional climate pattern shifts in recent century are confirmed and quasi-20- to 30-year and quasi-70- to 80-year oscillations in eastern monsoon region are known, as well as the dryness/wetness abnormal signals spreading to south in eastern China. Looking forward, climate change research in China is necessary in the three aspects below.

4.1 *Data development*

The chief problem for climate research is the data. Climate change includes the change of climate states and extreme climate events. At present, recent daily data are generally used in extreme climate research. Scientists in China also used the daily observation data of 700 stations all over China in recent 50 years to study extreme events. There are daily observation series for 70−80 years in East China and at Dunhuang, Zhangye, Yulin and other stations in the west. And the development of these data is of great importance for the global climate change research. But the spatial-temporal resolutions in China are not enough, and the data in the west are relatively sparse with only 30 years for some series, and the datasets in the east are not evenly distributed. There is also a conformity problem in recent 50 years, for the conformity of hydrology data and meteorology observation data will greatly contribute to environment change research in China.

The data in recent half century are mainly observation records, and in recent century both observation and proxy records. But it is expected that the century datasets mainly consist of observation records, and that proxy data are fairly and evenly distributed throughout China.

In China, because of the limitation of proxy data distribution, there is not a kind of proxy that can cover all over the country. Many researches are limited to a certain region. To offset this limitation, climate reconstruction will be one of the topics in historical climate research. The reconstruction subjects include temperature, hydrology climate (dryness/wetness) and the dryness index consisting of temperature and precipitation. The historical drought and flood records are mainly from the historical document records and tree ring chronology. The former mainly locates in eastern China, including classified dryness and wetness data in the east for 500 years [31] and regional wetness index in the east for 2000 years [32]. In recent years, historical rain and snow records in eastern China for nearly 300 years are developed [22]. The latter are mainly in the west, including precipitation [33] and runoff [34] series from tree ring chronology in Xinjiang and dryness/wetness series over the Tibetan Plateau. In all, the integration of proxy records in western China and the document records in eastern China, is the fundamental work of the regional climate research and reconstruction in China, as well as study on the mechanism and characteristics of global change events at decadal to centennial scales during the recent 500 or 1000 years. So far, 140 proxy climate series of different kinds covering the whole country for a few hundred years have been collected.

4.2 *Regularity and mechanism research*

Once long-term and high-spatial-resolution data are obtained, the climate change regularity and mechanism can be analyzed and discussed. The climate variability research includes temperature, dryness and wetness, significant abrupt change point of dryness/wetness and environment index, regularity (trend and quasi-period oscillation) and the phase relationship of climate changes among adjacent regions. The quasi-70-year oscillations can be deduced even from the last millennium temperature series over the NH derived by Mann *et al*. [35]. This oscillation existed not only in the previous 900 years but also in the recent century. It is expected that the quasi-70-year oscillation will continue to exist in the future climate change. No matter the “hockey stick” or the “noodles” trend, there is no doubt about the warming in the 20th century. Both the temperature trends before the 20th century illustrate the temperature transition from high to low. In the series from Mann *et al*. [2], abrupt temperature fall in the 15th century can also be discerned. It has been noted that differences of original proxies in time resolution and spatial coverage can deduce various evolutions, even contrary trends in the past climate change. To eliminate the differences, besides getting exact data and using proper methods, the mechanism research is necessary. So we collect 18 large-scale circulation and ocean thermodynamics factor series from hundreds to thousands of years, including Arctic Oscillation (AO), North Atlantic Oscillation (NAO), Siberian High intensity, North Pacific Oscillation (NPO), Pacific Decadal Oscillation (PDO) and others. Behind climate abrupt change, regularity and regional climate shift, there should be mechanisms, which dominate these changes. As the external forcing factors of climate system, solar activity and volcanic eruption also need to be considered carefully in the mechanism analysis from hundreds to thousands of years.

The mechanism for the climate change can be considered as the relationship among the thermal, dynamic and synoptic factors, which is used in the short-range weather forecast. The spatial heat contrast will control the general circulation and results in the rainy weather or other synoptic phenomena. The order of them can fully indicate the evolution orientation. The anomaly of thermal contrast between sea and land, middle and low latitudes or middle and high latitudes will induce the anomaly of the general circulation, and it will definitely result in the shift of climate, even influence the frequency of the synoptic waves. However, the orders of many research work are opposite, they usually get the jump point of climate change firstly and the features of change and shift, and then go to analyze the anomaly of general circulation and finally thermal contrast. The ways used to check the mechanism are statistical analysis, numerical modeling, and dynamics. It should be noted that the same spatial-temporal scale needs to be considered among the thermal, dynamic and synoptic factors.

The climate over China is influenced by thermal and dynamic effects of the Tibetan Plateau, thermal force from the seas surrounding China, and thermal effects from high latitudes. The monsoon circulation and westerly circulation round the Tibetan Plateau and then converge and cover the east part of China. The seasonal northward advance of the interaction between these two circulations and the northernmost latitude arrived change annually and inter-annually, which will affect the climate change of neighboring regions. The recent research shows that the most outstanding region of the interaction between the low and middle latitudes is located in China, produced by the two circulations mentioned above [9].

4.3 *The research about forecast and service*

The aim of the climate research is to improve the climate forecast. Some temporal characteristics might be detected, such as quasi-period oscillations. However, the time scale of such oscillation is not constant, for example, the time series of drought/flood index in the Yangtze River fluctuate with a quasi-period of 70−90 years. The precondition of climate forecast is to hold the variation characteristics and collect the latest information. There is a time range of the oscillation, namely a relatively wide spectrum. An oscillation may disappear after a spell, or even turn to another period suddenly. The difficulty of the short-range weather forecast is to catch the transition of the different weather. However, the climate forecast needs to deal with the problem how to find out the transition point alternated from different but regular oscillations on a determined time scale. In the past, the users were directly told of the transition weather and oscillations as prediction, and they could not understand, so the manner was unfair and unscientific. If the insurance agent joins into the forecast and service, then all the participators will benefit. Such a dependent relationship can be simply considered as meteorological economics.

The increasing of the global mean temperature can be predicted by climate modeling under some scenarios, such as double global CO_2 levels in the next hundred years. However, climate change includes not only the inter-decadal and other time scale oscillations, but also the long-term trend. The reason for the decreasing of temperature in the past several hundred years before the 20th century is not found yet, and the human actions are not the only reason for global warming. And the temperature increasing in recent 100 years also includes changes at multiple time scales. Based on the facts that both the trend and oscillations exist in temperature change, we can predict that the global mean temperature in 2040−2050 will approach to the average value declared by the Third Assessment Report of IPCC [35].

Based on the quasi-20- and quasi-70-year oscillations of climate change over the east of China, we predict that the temperature over North China will increase continually at the beginning of the 21st century, and it will decrease around 2020 and maintain a cold climate at interdecadal scale until 2040, overlapped with a long warming trend. In the first 10 years of the 21st century, the climate of North

China will change from dry to wet spell, and the wet era will persist to 2030 [9]. At the same time, the less-precipitation pattern over North China will move to the lower reaches of the Yangtze River, and the more-precipitation pattern over lower reaches of the Yangtze River will shift to South China. The problem whether the climate pattern will turn around 2010 or not, has been discussed for several years [36], and the main issue is that we have not recognized the diversity of the climate variability and its mechanism enough.

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