Chapter 11
Social Impacts of Climate Change in Historical China

Xiuqi Fang, Yun Su, Zhudeng Wei and Jun Yin

Abstract The social impact of past climate change is one of the key areas of study relating to global climate change, particularly its ability to provide valuable lessons for dealing with ongoing challenges of global climate change. Drawing on the abundant historical literature, many recent studies have examined the social impacts of climate change in China during the past 2000 years. This paper reviews the main progress of these studies in three parts. First, a concept model based on the food security in relation to global climate change has been constructed, which can then be used to interpret impact-response processes of climate change in the history of China. Second, we derive a methodology for quantifying the impact of historical climate change, drawing on a series of 4 key social and economic sequences at a 10-year resolution. These have been reconstructed based on the semantic differential method over the past 2000 years in China. Third, using a variety of statistical analyses, we update the understanding of climate impacts throughout the history of China. The overall impacts of climate were negative in the cold periods and positive in the warm periods, at decadal to centennial scales during Chinese history. However, the impacts seemed a mixed blessing both in the cold or warm periods. The social-economic development and population growth in warm periods would intensify the natural resource shortage and disequilibria in the human-environment system, especially when encountering abrupt climate changes. Adaptation to adverse climate change could not only help people to avoid hardship whilst maximizing profits, but also expanded the capabilities for the continual development of Chinese civilization.

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L. E. Yang et al. (eds.), *Socio-Environmental Dynamics along the Historical Silk Road,*
https://doi.org/10.1007/978-3-030-00728-7_11

Keywords Historical period · Climate change · Social impact
Process mechanism · China

11.1 Introduction

As the most active element in the natural environment, climate change has had wide and profound impacts on human society at multiple temporal and spatial scales, although it might not a determinative driving force. A growing number of cases from all around the world have proved that climate change played an important role in the rise and fall of regional civilizations, especially during the period before industrial revolution (deMenocal 2001; Haug et al. 2003; Zhang et al. 2007; Büntgen et al. 2011; Butzer 2012; Buckley et al. 2014).

The lessons learned from the past are valuable for current human populations to improve our understanding of the impact of ongoing climate change, and social adaptation to the challenge of future global change appropriately (IHOPE 2010). Studies on the impacts of past climate change worldwide can be summarized as follows. First, climate change could lead to both positive or negative social changes, from production systems to social systems, such as harvest fluctuation, population variation and migration, economic fluctuation, social harmony and crisis, and dynastic transition, at multiple temporal and spatial scales (Büntgen et al. 2011; Tol et al. 2010; Pederson et al. 2014; Zhang et al. 2007; Lee et al. 2008). Second, the way of climate change impacting society could be summarized through 5 general patterns (Fang et al. 2017), including periodic changes (Zhang et al. 2005; Lee et al. 2008), pulse (Pederson et al. 2014), adaptive transition (Willcox et al. 2009; Chen et al. 2015), collapse (Weiss et al. 2001; Haug et al. 2003; Douglas et al. 2015), migration and replacement (Büntgen et al. 2011, 2016; Kuper et al. 2006; Timmermann et al. 2016). Third, there is a set of studies focusing on the impact mechanism of climate change. A few attempts have been made under an idealized theoretical framework, for example the concept of social resilience for interpreting historical collapse as summarized from case studies (Butzer 2012), or a set of causal linkages relating climate change to large-scale human crises in preindustrial Europe (1500–1800) based on statistical analysis (Zhang et al. 2011). However, most of the above conclusions have been derived from direct comparisons of historical climate change events and related social phenomena occurring during the same period. A more detailed understanding of the processes and mechanisms of climate change impacts remain to be researched quantitatively.

China is a country that has great potential for the research of impacts of past climate change. As an agriculture-oriented society under the Asia monsoon climate regime, the history of China has been strongly impacted by climate change. Although historical China varied its borders from dynasty to dynasty, its core social-economic closely aligned with the major agricultural area throughout history. This geographic and temporal overlap allows for continuous comparison across the Chinese core areas. There are abundant historical records spanning thousands of years that relate the impacts of and adaption to climate change in China. These records provide opportunity for studying the process and mechanism of the social impacts of past climate change and human adaptation. Using the information from these historical literatures, a number of studies have examined the interaction mechanisms and processes of social impacts of historical climate change in China. This paper summarizes the main findings relating to the impacts of climate change in China during the past 2000 years.

11.2 Concept Model: Impact-Response Processes of Climate Change Under the Framework of Food Security

Agriculture was the foundation for ancient China, as such food security was not only the material foundation for human survival, but also the base for maintaining the economic development and the stabilization of social system. There is a general consensus that climate change has had a strong impact on historical agricultural production in China (Ge 2011; Ge et al. 2014; Zhang et al. 2005, 2006).

To further understand the impact of climate change, recent studies use concepts of vulnerability and food security in relation to Global Changes(GECFS) (Ericksen 2008) to illustrate the impacts of, and responses to (impact-response processes) historical climate change in China. Corresponding to the concepts of food access, food availability and food utilization, the food security of historical China can be simplified to three levels of security—food production, food supply and food consumption. In this system, the impact of climate change is most pronounced upon grain harvest in the food production subsystem. These impacts are then transferred further up to the subsystems of economy, population and society (Fig. 11.1). However, due to the complexity of human society, the impact-response processes of climate and social change could not be attributed to a simple causality. The initial impact could be amplified or suppressed in feedbacks, which processed within or between subsystems of human society (such as cultivated land area, population, policy, and the surrounding neighbors, etc.) (Fang et al. 2015). Both the spontaneous behaviors of the people and the policies and operations of governments played very important roles in all steps of adjusting the responses to the impacts of climate change. But each adjustment had its limitation under the given historical condition. The impact of climate change could be positive or negative. To a certain degree, even the negative impacts could be converted into new opportunity for development if right countermeasures were taken.

(1) Food production security, is the fundamental aspect in ensuring an overall food security. The relationship between any given population and the productivity of its land-use systems is dynamic and responsive not only to demographic forcing but also to the social and economic processes regulating resource demand, land availability, technology adoption and availability, environmental variation, and

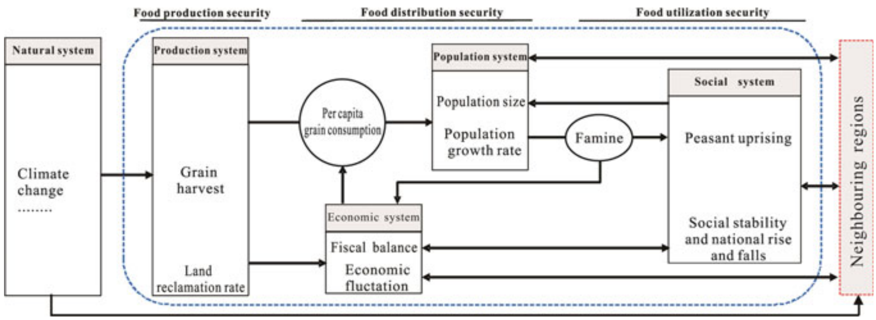


Fig. 11.1 A conceptual model of climate change impact-response in the history of China based on food security (after Fang et al. 2014a, 2015)

the potential for intensive use of land to degrade its potential productivity over time (Ellis et al. 2013). As one of the factors affecting the balance of food productivity and population, impact of climate change is more sensitive during the phases of productivity crises. Changes in per capita grain production could possibly reflect the sensitivity of the food production subsystem to climate change. The security of food production in response to climate change in the historical period was initially based on the per unit yield. Annual yields were influenced by both the sensitivity of the crops to climate conditions, and the human capacity to ensure the stability of production and to resist agricultural disasters. Both regional cultivated land area and population were important factors in food production security, shifting the balance of per capita food production.

(2) Food supply security, refers to means for either individuals or the wider society to acquire enough food to meet food security standards. Factors in this include the volume of production yield, or the capacity for regulating food supplies by the society. Climate change impacted on the food supply security by changing regional food production and supply capacity in the historical period. When individual food supply security was not satisfied, consumers would at first try to survive themselves by using their own food stocks, or in more severe cases, to draw on natural and foraged foods. The adaptive response to declining food supply in market was generally to raise the price of foods in order to attract more food into the market, as well as to restrict consumer demand. In wider society, insecure food supply could possibly lead to conflicts among different social classes, the public and the government. To avoid conflicts, the government had to use its economic capacity and administrative power to regulate the food supply and ease social contradictions. The main measures included reducing tax or delaying tax collection, controlling food prices by supplying state reserved grain to markets, dispatching food from other regions, and migrating people to other regions, etc.

(3) Food consumption security also involves both individuals and wider society. It refers to the way in which demand of food maintained security of individual

livelihood and social-economic development. If insecurity in the food supply of individuals threatened the security of individual's food consumption, it would become a threat to survival, potentially resulting in a large number of famine victims. The famines could develop into refugee flows, trigger social unrest, and even cause social instability or collapse. Under such situations, the measurements for regulating food consumption security taken by the governments generally included the following aspects: to relieve refugees in order to avoid enlarging the size of refugee populations; to encourage spontaneous or organized migration to reduce population pressure in the region affected by climate change; to maintain public security and social stability, and to avoid the feudal dynasty being endangered by enlarged unrests.

Under this framework of food security, the impact and response mechanisms of climate on society in historical China began with the direct impact of climate on the harvest, and then were transmitted in two basic routes. One was harvest—famine victims—social instability for individual food security; the other was harvest—economy—social stability for social food security (Fang et al. 2014a). Along the individual food security transmission chain, the impacts were regulated by social food security, which was mainly through the regulation of economy to population and social system.

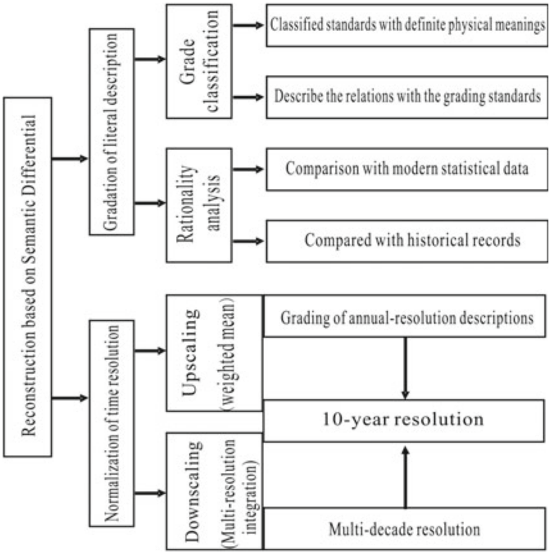
11.3 Methodology: Quantifying Historical Social and Economic Series Based on Semantic Differential Over the Past 2000 Years in China

Reconstructing social-economic series with the same temporal resolution, duration, and continuity as climate series is a precondition for studying the processes and mechanisms of the impacts of climate change in history. The key quantifiable variables should be able to represent the subsystems of agriculture, population, economy, society, etc. The most difficult issue for the quantification is a lack of standardized social-economic statistical data in historical China. Other data, such as population, farmland area, price and etc. are discontinuous throughout the past few thousand years, except for the relatively continuous data of crop harvest in the Qing Dynasty.

On the other hand, China has abundant, continuous and high-resolution historical literature over the past 2000 years to record or describe the social-economic conditions. The Chinese words are rich in meaning. The semantic differential of these words is definite, and the meaning of the word is generally stable during the history. Therefore the historical records could be used to reconstruct graded climatic series (Zheng et al. 2006) and socio-economic series based on Semantic Differential. The two key methods for the reconstruction are gradation of literal description and normalization of time resolution, respectively (Fig. 11.2) (Fang et al. 2014b).

The core of the Semantic Differential method is to convert the qualitative description of the social-economic conditions during different historical periods into quanti-

Fig. 11.2 Methodology for quantifying historical social and economic series based on Semantic Differential (Fang et al. 2014b)



tative grades. In this method, the properties of the objects are distinguished by bipolar adjectives (relativity and antonym), which are quantified by the adverbs of different degrees, such as extreme, very, somewhat, normal, etc. To construct the grading scale by Semantic Differential, it is important to pay attention to whether the meanings of the vocabularies are easily distinguished, and to consider the physical meanings of the standard vocabularies corresponding to each level as much as possible. There are generally 4 steps that the literal descriptions are quantified to grades, although the implementation for quantifying the literal descriptions to grades is varied based on individual properties of the records. These steps are as follows: (1) collecting the direct and indirect literal records on social and economic description; (2) confirming the standard of classified quantification against reconstruction indexes; (3) ranking the grades of social-economic condition reflected in the historical documents, on the basis of the classified quantification standard; (4) analyzing the rationality of classified results (Fang et al. 2014b).

Following is an example of the gradation of historical harvest (Su et al. 2014; Fang et al. 2014b). It is based on 2755 items of original descriptions regarding agricultural yields garnered from the 25 chronicles on the dynastic histories of China named *Twenty-Four Histories* and *Qing History Draft,*[1] covering the period from Western Han Dynasty (206 BC–AD 24) to the Qing Dynasty (AD 1645–1911). Detailed descriptions on the steps and the uncertainties of the reconstruction are described in Su et al. (2014) and Yin et al. (2015).

The bipolar adjectives, such as “bumper” and “poor” in the records of harvest in historical China were used to distinguish the good or bad variation on the annual grain

[1]《二十四史》和《清史稿》.

production relative to average grain yield (normal or common year). The superposition of adverbs of degree, such as “very bumper/poor”, “near bumper/poor”, were used to further distinguish the level of the harvest.

The key words describing crop harvest corresponded well to the quantified ten-point harvest system (10 points represent 100% of per capita harvest was met; with each 1 point reduction corresponding with a 10% diminishing of harvest) in historical China. This provides proof that such descriptions of harvest have clearly physical meanings to be used to identify annual crop harvest grades that could be selected as reference, and that standard words represent the different harvest grades. Referring to the standard words, the annual grain yield was divided into six levels from 1 to 6 corresponding to the key words of “Very poor harvest”, “Poor harvest”, “Slightly poor harvest”, “Normal harvest”, “Near bumper” and “Bumper”, respectively, based on the semantic differential. By matching the descriptions on bumper or poor grain yields from historical documents to the key words, the annual harvest grade series is reconstructed, which is used to reconstruct a harvest index series for unifying the time resolution later.

Several principles are given for the gradation of annual harvest records. (1) Records with their time-scale matching or higher than the resolution of the reconstructed series are used initially. (2) Records covering the whole country or the core agricultural area of the country are prioritized as the main data source; then records covering local or marginal regions are used as auxiliary records, on the condition of correcting their spatial representation to the national scale. (3) Direct evidence from the historical record are used first, following by the indirect evidence. When disagreement between records occurs, the position supported by the majority of records is adopted. (4) In periods without any record spanning only 1 or 2 years, these are regarded as average years according to the basic principle that history usually recorded unusual events rather than common events; if the no-record years are up to or more than 3 to 4 consecutive years, they are graded in reference to the major historical events of the period.

Time-scale normalization is mainly used to solve the problems that time resolutions of original grade series are unequal or the series is discontinuous, by up-scaling or down-scaling the series. 10 years have been used as the basic time unit for up-scaling the annual resolution data or down-scaling the lower than decadal resolution data (Fang et al. 2014b).

The 10-year resolution harvest grade series of China in past 2000 years is an example of time up-scaling (Fig. 11.3). The historical harvest records were recorded in annual resolution, but they were discontinued in some years. To reconstruct a grade series of harvest in 10 years resolution, an up-scaling method was needed to convert annual resolution series into decadal resolution series. In our research, the annual harvest grade series had been converted to a decadal harvest index by calculating decadal average of the annual harvest grade with unequal weights. Then a harvest grade series at 10 years resolution has been reconstructed by dividing the decadal harvest index value into 5 grades.

The 10-year resolution macroeconomy grade series of China in past 2000 years is an example of time down-scaling (Wei et al. 2015a; Fang et al. 2014b). The series was

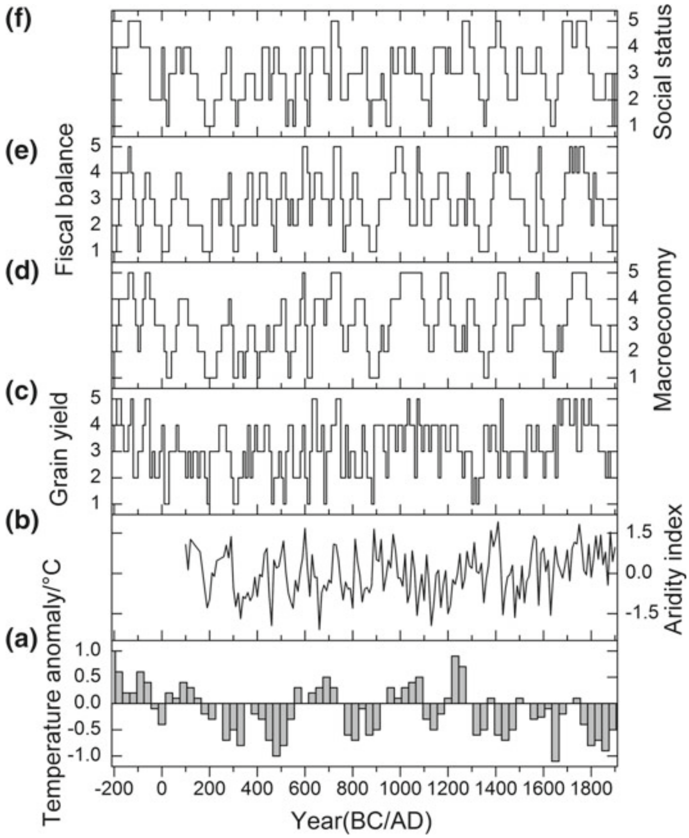


Fig. 11.3 Climate Change and socio-economic grade series during the past 2000 years in China. **a** Winter-half-year temperature anomaly with 30-year resolution during 210 BC-1910 AD in Eastern China (Ge 2011); **b** wet-dry index of Eastern China during 101-1910 AD (Zheng et al. 2006); **c**–**f** 10-year resolution grade series of the grain harvest (Yin et al. 2015), macroeconomy (Wei et al. 2015a), fiscal balance (Wei et al. 2014), social vicissitudes (Yin et al. 2016a), respectively, in the past 2000 years in China, and the grade 1–5 represents the state from bad to good, respectively

reconstructed on the basis of 1091 records regarding the economic history of China, extracted from 25 books written by leading Chinese scholars and published in the last thirty years. The time resolution of the historical records on the macroeconomy of China varied from annual scale to the empire-scale (usually 20–30 years) resolution or even dynasty-scale (centennial scale) resolution. The 10-year resolution macroeconomy grade series of China was reconstructed through the following steps. First, to identify the grade or changing trend from one grade to other one, according to each historical record; then by integrating all data in different resolutions from annual to centennial to divide relative low temporal resolution data into 10 years resolution step by step, using the differences of start/end year and temporal resolution among the records; and lastly re-sampling the grade data decade by decade.

Using the gradation methodology of semantic differential, 4 historical social-economic graded series of China in 10 years resolution over the past 2000 years, including harvest (Su et al. 2014; Yin et al. 2015), economy (Wei et al. 2015a, b), finance (Wei et al. 2014) and social vicissitudes (Yin et al. 2016a, b), have been quantitatively reconstructed (Fig. 11.3). In addition, other series of famine index, peasant uprising frequency, and frequency of wars waged between nomadic and farming groups of China in 10 years resolution over the past 2000 years were also reconstructed (Teng et al. 2014; Fang et al. 2015; Su et al. 2016). Detailed descriptions on the specific steps and the uncertainties for each reconstructed series are in the cited references.

The duration of the series mentioned above was from 210 BC to AD 1910 that covered the Western Han Dynasty (206 BC–AD 24) to the Qing Dynasty (AD 1645–1911) of China. All the series could represent the social systemic changes in China as a whole over the past 2000 years, because they have a similar spatial coverage and are mainly based on the historical records coming from the eastern part of China, which has long been the major agricultural area as well as the core social-economic area throughout the dynastic history of China. Using these series, and the winter half-year temperature series (Ge 2011) and wet-dry series (Zheng et al. 2006) in eastern China, which also covered the key farming region over the

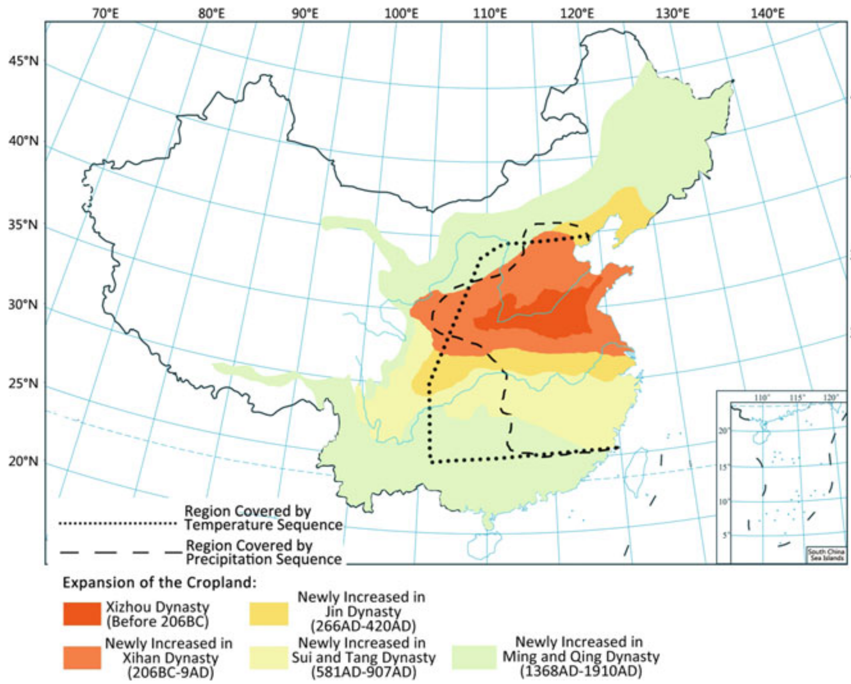


Fig. 11.4 Historical expansion of the major agricultural area in the history of China and the region covered by the temperature series and the wet-dry series over the past 2000 years (Yin et al. 2015)

past 2000 years (Fig. 11.4), the impacts of historical climate change on society of China could be quantitatively analyzed.

11.4 Scientific Understanding: The Macroscopic Rhythm of Climate and Social-Economic Changes

By analyzing the relationship between climate change and social-economic changes in China over the past 2000 years, the scientific understanding of general characteristics of the impacts of historical climate change on social-economy in China are summarized in the following.

First, as many scholars have surmised (Hsu 1998; Lee et al. 2008; Zhang et al. 2005, 2006; Ge 2011; Ge et al. 2014; Pei et al. 2014), the general characteristics of the impacts of historical climate change were negative in the cold periods and positive in the warm periods. On the centennial scale, the flourishing of economic and social health, population increase and territorial expansion generally occurred in the warm periods, with an inversion occurring during cold periods (Yin et al. 2015, 2016b; Wei et al. 2014,2015a, b). Among the 34 dynastic prosperity periods in the empirical China, 18 occurred in warm or relative warm periods, 26 of them occurred when the climate changed from cold to warm. On the other hand, 11 of the14 dynastic transitions periods occurred in cold or relative cold periods (Yin et al. 2016b). The primary driver of the above processes are regarded to be warm conditions generally benefitting agricultural development. The better harvest could provide the material foundation to accelerate social-economic development. The main impact of cold periods are to increase vulnerability of human systems, causing a capacity decrease in social-economic system, limiting ability to respond to climate change or social-economic crisis.

Second, further to simple correlation of negative conditions in the cold periods and positive in the warm periods, both the impacts of warm and cold climate seemed a mixed blessing from a view of social development. The social-economic development and population growth in warm periods increased the pressures on the natural environment via resource utilization. For the agriculture-based society of empirical China, such a high pressure could lead to natural resource shortage and disequilibria in the human-environment system, and trigger social crisis when abrupt climate change (such as cooling and precipitation decrease) occurred. Among the 9 high social risk periods indicated by the social-economic series over the past 2000 years in China, 8 were partially or wholly contemporary with the transition periods of climate from warm to cold (Ge et al. 2015; Yin et al. 2016b). During these periods, extreme climate events or disasters were likely to trigger social crises, some of which even became the trigger for social turbulence and dynastic collapse or replacement. The collapse of the Ming dynasty was a typical case. On one hand, climate change turned to cold and dry at the late 16th century to early 17th century that caused the crop yields decrease directly, resulting in a chronic food crisis in North China, destroying the military farm system, and thus exacerbated fiscal deterioration. On the other hand, peasantry uprising in Shaanxi and Shanxi provinces were triggered by the severe droughts which lasted more than 10 years (1627–1643 AD) in northern China (named “Chongzhen Drought”), the worst drought event in North China over the past 500 years. The drought had also replenished the peasantry troops, and severely disrupted the food supply for the government troops. The Ming Dynasty eventually collapsed in a peasant uprising (Zheng et al. 2014; Xiao et al. 2015).

Finally, successful adaptation could not only help populations to mitigate harms while also to expanding productivity, but also enhancing the capabilities for the continual development of Chinese civilization. The Chinese people could choose suitable countermeasures according to the temporal and regional differences in order to adapt to the impacts of climate change. For example, the warm climate of the “Medieval Warm Period” increased heat resources in most areas of China. To adapt to the warm climate, the people expanded the crop planting boundary northward in the 10th–13th century, especially in the agriculture-pasture transitional zone in northern China and the transitional area between the warm temperate zone and subtropical zone. During the Medieval Warm Period, the Song dynasty (960–1279 AD) had to adapt to the regional differentiation of precipitation regimes, with conditions dry in the south and wet in the north of eastern China. As a response, rice planting areas were expanded to the Yellow River basin of northern China, while Champa rice plantation with a shorter growing season and a rice-wheat succession cropping system was developed in the Yangtze River basin of southern China. The rice-wheat succession cropping system, which was finally established in the South Song dynasty (1127–1279 AD) and has been used to the present day, is regarded as an important revolution of cropping system in Chinese agricultural history that had a profound contribution to sustaining food security and socioeconomic development in China (Ge et al. 2015). Another example of adaptation was by the Qing Dynasty during the Little Ice Age (Fang et al. 2013; Xiao et al. 2015). With the exception of its earliest periods, the Qing Dynasty was characterized by tense human-environment relationships for the rapid population growth. Against this background, the Qing Dynasty responded and adapted to the impacts of climate change in many ways, including the introduction and expansion of some higher yield crops (such as corn, tuber crop), adjustment of the cropping system to fit the changed climate (such as adopting double cropping rice in the Yangtze river basin during a period of climate warming in the early 18th century) (Atwell 2002; Ge 2011) and some other agricultural measures. In addition, social changes such as encouraging migration to marginal regions for reclamation took place. Taking a long time scale perspective, the migration and reclamation appears to be driven by not only by population pressure and some political factors, but was also strongly impacted by climate change, especially extreme climate events. On the short time scale, migrations were often the result of flood and drought disasters. For example, in the mid to late 17th century, tens of thousands to hundreds of thousands of people migrated spontaneously or were migrated by government to the areas beyond the Great Wall, after almost every extreme drought or flood event occurred in North China (Ye et al. 2012). Up to the 19th century, the capacity of Qing Dynasty in coping with disasters was weakened significantly by fiscal crisis. The quarantine policy which isolated Hans and Manchus or Mongols with the Great Wall and the Willow Palisade was conditionally removed and eventually abolished by the Qing Dynasty. As a result, migration to Northeast China where was a vast territory with a sparse population became the main way of dealing with the impacts of adverse climate and extreme climate disasters for the people in North China. These migrations not only reduced social risk in North China, but also promoted the development of Northeast China (Fang et al. 2013; Xiao et al. 2013, 2015).

11.5 Conclusions and Prospects

Based on long-term and continuous historical literature, this paper summarizes the main impacts of climate change during the past 2000 years in China.

First, a concept model based on Food Security is given for studying the impact-response processes of climate change in the history of China. The food security-based concept model proposed in the present study is not only applicable to the ancient China, but also to traditional societies relying greatly on agriculture or food production in other areas.

Second, a methodology based on Semantic Differential has been developed for reconstructing and grading social and economic series over the past 2000 years in China, permitting the impacts of historical climate change on Chinese society to be quantitatively analyzed.

Third, it has renewed scientific understanding of the impacts of climate change in the history of China, with the impacts generally being negative in the cold periods and positive in the warm periods but also mixed blessing, and a successful adaptation to climate change should be considered according to temporal and regional differences. It is different from the traditional Malthusian population theory that positive checks (i.e. hunger, disease, and war, et al.) on population would appear since population growth rate usually exceeded production growth rate (Malthus 1826). Climate change would lead to the relative overpopulation by shrinking natural resource and thus suffered society from Malthusian trap, but on the other hand, human adaptations could help the people to survive and to create new opportunities even under the bad climate conditions. This cognition of responses to climate change in history could provide valuable lessons for dealing with ongoing challenges of climate change.

Although the summary and review in this paper is mainly based on research in recent years, the main conclusions align with the consensus of other scholars. Due to limitations of this article length, we are not able to provide a more detailed data analysis, which are available in the cited references.

Because the impacts of historical climate change were highly related to the specific situations of climate and socio-economic development, many gaps in research on climate-human relationship in Chinese history remain. For instance, it may be productive to investigate the synergetic features between climate change and socio-economic fluctuations based on those reconstructed time series; it would be helpful to track the pathways of the transmission of the impacts from climate change to ecological changes, agricultural production, population, economic fluctuation, and political or cultural development for better understanding how active elements of human agency (i.e. population, economy and policy, etc.) moderated the impact-response chain from a macro-history perspective; finally it is important to untangle the influence of climate change from other factors on historical events.

Future studies on historical climate impacts should be focus on spatial and temporal diversification, comprehensive regional analysis and comparison. Therefore it is necessary to carry out more case studies with specific spatial-temporal scales, from a micro-history perspective. As a result, multidisciplinary integration will be a great help in promoting research on the impact of historical climate change.

Acknowledgements This work was supported by the National Natural Science Foundation of China (Grant No. 41371201), the Strategic Priority Research Program of the Chinese Academy of Sciences (XDA19040101), and the Major State Basic Research Development Program of China (973 Program) (Grant No. 2010CB950103).

References

Atwell, W. S. (2002). Time, money, and the weather: Ming China and the "Great Depression" of the mid-fifteenth century. *The Journal of Asian Studies, 61,* 83–113.

Buckley, B. M., Fletcher, R., Wang, S. Y. S., Zottoli, B., & Pottier, C. (2014). Monsoon extremes and society over the past millennium on mainland Southeast Asia. *Quaternary Science Reviews, 95,* 1–19. https://doi.org/10.1016/j.quascirev.2014.04.022.

Büntgen, U., Tegel, W., Nicolussi, K., McCormick, M., Frank, D., Trouet, V., et al. (2011). 2500 years of European climate variability and human susceptibility. *Science, 331,* 578–582.

Büntgen, U., Myglan, V. S., Ljungqvist, F. C., McCormick, M., Di Cosmo, N., Sigl, M., …, Kirdyanov A.V. et al. (2016). Cooling and societal change during the Late Antique Little Ice Age from 536 to around 660 AD. *Nature Geoscience*, 9, 231–236.

Butzer, K. W. (2012). Collapse, environment, and society. *Proceedings of the National Academy of Sciences of the United States of America, 109,* 3632–3639.

Chen, F. H., & Dong, G. H. (2015). Agriculture facilitated permanent human occupation of the Tibet Plateau after 3600 B.P. *Science, 347,* 248–250.

deMenocal, P. B. (2001). Cultural responses to climate change during the late Holocene. *Science, 292,* 667–673. https://doi.org/10.1126/science.1059827.

Douglas, P. M., Pagani, M., Canuto, M. A., Brenner, M., Hodell, D. A., & Eglinton, T. I. (2015). Drought, agricultural adaptation, and sociopolitical collapse in the Maya Lowlands. *Proceedings of the National Academy of Sciences of the United States of America, 112*(5), 607–5612.

Ellis, E. C., Kaplan, J. O., Fuller, D. Q., Vavrus, S., Goldewijk, K. K., & Verburg, P. H. (2013). Used planet: A global history. *Proceedings of the National Academy of Sciences of the United States of America, 110,* 7978–7985. https://doi.org/10.1073/pnas.1217241110.

Ericksen, P. J. (2008). Conceptualizing food systems for global environmental change research. *Global Environmental Change, 18,* 234–245.

Haug, G. H., Gunther, D., Peterson, L. C., Sigman, D. M., Hughen, K. A., & Aeschlimann, B. (2003). Climate and the collapse of Maya civilization. *Science, 299,* 1731–1735.

Fang, X. Q., Xiao, L. B., & Wei, Z. D. (2013). Social impacts of the climatic shift around the turn of the 19th century on the North China Plain. *Science China Earth Sciences, 56,* 1044–1058.

Fang, X. Q., Zheng, J. Y., & Ge, Q. S. (2014a). Historical climate change impact-response processes under the framework of food security in China. *Scientia Geographica Sinica, 34,* 1291–1298.

Fang, X. Q., Su, Y., Yin, J., Wei, Z. D., Zheng, J. Y., & Luo, Y. H. (2014b). Methodology for quantifying social and economic series on the base of Semantic Differential to serve the research on impacts of climate change. *Quaternary Sciences, 34,* 1204–1214.

Fang, X. Q., Su, Y., Yin, J., & Teng, J. C. (2015). Transmission of climate change impacts from temperature change to grain harvests, famines and peasant uprisings in the historical China. *Science China: Earth Sciences, 58,* 1427–1439.

Fang, X. Q., & Zhang, D. Y. (2017). Patterns of the impacts of climate change on civilization. *Advances in Earth Science, 32,* 1218–1225.

Ge, Q. S. (2011). *Climate Change through every Chinese dynasty*. Beijing: Science Press.

Ge, Q. S., Fang, X. Q., & Zheng, J. Y. (2014). Learning from the historical impacts of climatic change in China. *Advances in Earth Science, 29,* 23–29.

Ge, Q. S., Zheng, J. Y., Fang, X. Q., Liu, J., Yang, B. (2015). Highlights of the research project on the forcing and impacts of the warm periods in the past 2000 years. *China Basic Science*, 22–26.

Hsu, K. J. (1998). Sun, climate, hunger, and mass migration. *Science in China Series D-Earth Sciences, 41,* 449–472.

IHOPE. (2010). *Developing an integrated history and future of people on earth: Research plan* (IGBP Report No. 59). Stockholm: IGBP Secretariat.

Kuper, R., & Kröpelin, S. (2006). Climate-controlled Holocene occupation in the Sahara: Motor of Africa's evolution. *Science, 313,* 803–809.

Lee, H. F., Fok, L., & Zhang, D. D. (2008). Climatic change and Chinese population growth dynamics over the last millennium. *Climatic Change, 88,* 131–156.

Malthus, T. R. (1826). *An essay on the principle of population, or a view of its past and present effects on human happiness; with an inquiry into our prospects respecting the future removal or mitigation of the evils which it occasions* (6th ed.). London: John Murray.

Pei, Q., Zhang, D. D., Lee, H. F., & Li, G. (2014). Climate change and macro-economic cycles in pre-industrial Europe. *PLoS ONE, 9,* e88155. https://doi.org/10.1371/journal.pone.0088155.

Pederson, N., Hessl, A. E., Baatarbileg, N., Anchukaitis, K. J., & Di Cosmo, N. (2014). Pluvials, droughts, the Mongol Empire, and modern Mongolia. *Proceedings of the National Academy of Sciences of the United States of America, 111,* 4375–4379.

Su, Y., Fang, X. Q., & Yin, J. (2014). Impact of climate change on fluctuations of grain harvests in China from the Western Han Dynasty to the Five Dynasties (206 BC–960 AD). *Science China: Earth Sciences, 57,* 1701–1712.

Su, Y., Liu, L., Fang, X. Q., & Ma, Y. N. (2016). The relationship between climate change and wars waged between nomadic and farming groups from the Western Han Dynasty to the Tang Dynasty period. *Climate of the Past Discussions, 12,* 137–150.

Teng, J. C., Su, Y., & Fang, X. Q. (2014). The reconstruction and analysis of famine sequence from the Western Han to the Qing Dynansty (206BC ~ 1911AD). *Journal of Chinese Historical Geography, 29,* 26–32.

Timmermann, A., & Friedrich, T. (2016). Late Pleistocene climate drivers of early human migration. *Nature, 538,* 91–95.

Tol, R. S. J., & Wagner, S. (2010). Climate change and violent conflict in Europe over the last millennium. *Climatic Change, 99,* 65–79.

Wei, Z., Fang, X., & Su, Y. (2014). Climate change and fiscal balance in China over the past two millennia. *The Holocene, 24,* 1771–1784. https://doi.org/10.1177/0959683614551224.

Wei, Z., Rosen, A. M., Fang, X., Su, Y., & Zhang, X. (2015a). Macro-economic cycles related to climate change in dynastic China. *Quaternary Research, 83,* 13–23.

Wei, Z., Fang, X., & Su, Y. (2015b). A preliminary analysis of economic fluctuations and climate changes in China from BC 220 to AD 1910. *Regional Environmental Change, 15,* 1773–1785.

Weiss, H., & Bradley, R. S. (2001). Archaeology. what drives societal collapse? *Science, 291,* 609–610. https://doi.org/10.1126/science.1058775.

Willcox, G., Buxo, R., & Herveux, L. (2009). Late Pleistocene and early Holocene climate and the beginnings of cultivation in northern Syria. *The Holocene, 19,* 151–158.

Xiao, L. B., Fang, X. Q., & Ye, Y. (2013). Reclamation and revolt: Social responses in Eastern Inner Mongolia to flood/drought-induced refugees from the North China Plain 1644-1911. *Journal of Arid Environments, 88,* 9–16.

Xiao, L. B., Fang, X. Q., Zheng, J. Y., & Zhao, W. Y. (2015). Famine, migration and war: Comparison of climate change impacts and social responses in North China between the late Ming and late Qing dynasties. *The Holocene, 25,* 900–910.
Ye, Y., Fang, X., & Khan, M. A. U. (2012). Migration and reclamation in Northeast China in response to climatic disasters in North China over the past 300 years. *Regional Environmental Change, 12,* 193–206. https://doi.org/10.1007/s10113-011-0245-6.
Yin, J., Su, Y., & Fang, X. (2015). Relationships between temperature change and grain harvest fluctuations in China from 210 BC to 1910 AD. *Quaternary International, 355,* 153–163.
Yin, J., Su, Y., & Fang, X. Q. (2016a). Climate change and social vicissitudes in China over the past two millennia. *Quaternary Research, 86,* 133–143.
Yin, J., Fang, X. Q., & Su, Y. (2016b). Correlation between climate and grain harvest fluctuations and the dynastic transitions and prosperity in China over the past two millennia. *The Holocene, 26,* 1914–1923.
Zhang, D. D., Jim, C., Lin, C. S., He, Y. Q., & Lee, H. F. (2005). Climate change, social unrest and dynastic transition in ancient China. *Chinese Science Bulletin, 50,* 137–144.
Zhang, D. D., Brecke, P., Lee, H. F., He, Y.-Q., & Zhang, J. (2007). Global climate change, war, and population decline in recent human history. *Proceedings of the National Academy of Sciences of the United States of America, 104,* 19214–19219. https://doi.org/10.1073/pnas.0703073104.
Zhang, D. D., Jim, C. Y., Lin, G. C. S., He, Y. Q., Wang, J. J., & Lee, H. F. (2006). Climatic change, wars and dynastic cycles in China over the last millennium. *Climatic Change, 76,* 459–477.
Zhang, D. D., Lee, H. F., Wang, C., Li, B. S., Pei, Q., Zhang, J., et al. (2011). The causality analysis of climate change and large-scale human crisis. *Proceedings of the National Academy of Sciences of the United States of America, 108,* 17296–17301. https://doi.org/10.1073/pnas.1104268108.
Zheng, J. Y., Wang, W. C., Ge, Q. S., Man, Z. M., & Zhang, P. Y. (2006). Precipitation variability and extreme events in eastern China during the past 1500 years. *Terrestrial, Atmospheric and Oceanic Sciences, 17,* 579–592.
Zheng, J., Xiao, L., Fang, X., Hao, Z., Ge, Q., & Li, B. (2014). How climate change impacted the collapse of the Ming dynasty. *Climatic Change, 127,* 169–182.