Comparison of simulated and reconstructed temperature in eastern China during the last 1000 years

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Abstract: The reconstructed winter half-year temperature anomalies in eastern China was compared with the results of a 1000-year integration experiment which produced with the global atmosphere-ocean coupled climate model ECHO-G in this paper, in order to verify the simulation ability of ECHO-G on modeling regional climate of China, and understand the reasons of climate change in China over the last millennium. In the simulation, the model ECHO-G was driven by time-dependent external forcing factors including effective solar radiation and greenhouse gas concentrations in the atmosphere (CO_2 and CH_4) for the period 1000 A.D. to 1990 A.D.. The reconstructed data were the winter half-year temperature anomalies in the central region of eastern China (25°-40°N , east of 105°E) for the last 1000 years at 30-year resolution. The results show that: The correlation coefficient of the simulated and the reconstructed series is 0.37, confidence level is 97.5%. The Medieval Warm Period during 1000-1300 A.D., the Little Ice Age during 1300-1850 A.D. and the modern warming period from 1900 A.D. are all reflected from the simulated and reconstructed results. In regard to the Little Ice Age during 1300-1850 A.D. and the warming period from 1900 A.D., the positive and negative anomalies of the simulation and the reconstruction are consistent on the whole. In particular during 1,670 -1710 A.D. at Maunder sun-spot minimum, the simulated and reconstructed temperature anomalies have all reached the minimums, without any phase difference. But regarding the Medieval Warm Period during 1000-1300 A.D., certain phase differences exist between the simulation and the reconstruction. The curve pattern of the reconstructed temperature anomaly is two peaks with one valley, while that of the simulated temperature anomaly is three peaks with two valleys. The amplitude range of simulated temperature anomaly is -0.70 _ to 0.92 _, and that of reconstructed temperature anomaly is -1.1 _ to 0.9 _. The amplitude range of simulation (1.62) is slightly smaller than that of reconstruction (2.0). The mechanism analysis indicates that, in the millennium time scale, solar radiation and volcanic activity are the main controlling factors on global and regional temperature change, while in recent century, the change of greenhouse gas concentrations plays a more important role to temperature change.

Keywords_Climate_simulation_reconstruction_eastern China

Since the 1990s, under the impetus of two international research projects "Past Global Changes" (PAGES) and "Climate Variability and Predictability" (CLIVAR), massive research works have been done by scientists from all over the world on climate and environment change over past 2000 years [1-3]. But regardless of in China or in the world, majority of works concentrated in obtainment of various kinds of climatic proxy data (such as historical documents, tree ring, ice core, lake core, etc.) and reconstruction of climatic sequences [4-15]. The research on the controlling factors and dynamical mechanisms of different timescale climate change in past 2000 years was relatively deficient[16-18].

Historical climate simulation through long time modeling integration is a new thing which appears under the rapid development of both atmospheric sciences and computer sciences. It plays a vital role in understanding the reasons and dynamical mechanisms of longer timescale climate change. Because it requests super computer system, so far this kind of work is only developed in the developed countries in Europe and America, such as the US, Germany, Belgium and so on [19-21]. For the limits of computer system and the climate model, this kind of work is undeveloped till now domestically in China. The temperature of a long term integration modeling experiment over the last millennium using the global climate model ECHO-G[22] is compared with the reconstructed temperature anomalies in eastern China in this paper, in order to verify the modeling

ability of ECHO-G on regional climate of China, to find some insufficiencies in historical climate reconstruction, and to understand the reasons and mechanisms of past climate change in China. And hope it to promote relative research domestically in China, and to fulfill the objectives of comprehensively knowing the history climatic change rule, enhancing forecast ability of the tendency of future climate change, and serving for the social economy sustainable development.

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1. Model and experiment

Global atmosphere-ocean coupled climate model ECHO-G is one of the state-of-art models for long-term climate simulation at present. ECHO-G consists of the spectral atmospheric model ECHAM4 and the global ocean circulation model HOPE-G, both developed at the Max-Planck-Institute of Meteorology (MPI) in Hamburg [22]. ECHAM4 is the fourth generation of atmospheric general circulation spectral model. It is based on primitive equations with p-_ mixed coordinate system. It has a horizontal resolution of T30 in the simulations, approximately 3.75°×3.75°, and 19 vertical levels, five of them located above 200hpa, the top level is 30hPa, which is equivalent to 30km. The horizontal resolution of the ocean model HOPE-G is about 2.8°×2.8° with a grid refinement in the tropical regions, where the meridional grid point separation decreases progressively to the equator, reaching a value of 0.5° . The ocean model has 20 vertical levels. The model ECHO-G has been used in modern and palaeo-climate simulations, its simulation ability has been confirmed[23-24].

Two 1000-year integration experiments with the ECHO-G model have been carried out, one was the control simulation, in which the external forcing was kept constant in time and set to the values of the present climate. This experiment can simulate annual, interannual and decadal climate change, but cannot simulate centennial and longer timescale climate change such as the Medieval Warm Period and the Little Ice Age[25]. The other was the forced simulation, in which the model ECHO-G was forced with estimations of three external forcing factors: solar variability, greenhouse gas concentrations in the atmosphere (including CO_2 and CH_4) and an estimation of radiative effects of stratospheric volcanic aerosols[16], for the period 1000 to 1990 A.D. [26-27]. The time sequences of these forcing factors are shown in Fig.1. The result from the forced simulation is used for comparison with the reconstructed data in this paper.

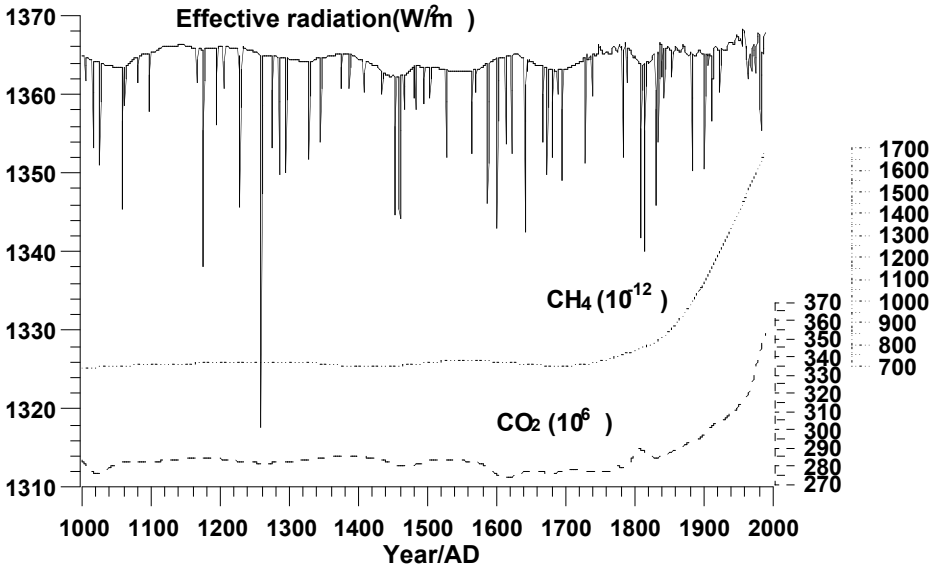

Fig. 1 Time sequence of forcing factors

2. Reconstructed data

Abundant historical document records on phonological events about cold/warm and dry/wet climate are available in China. A lot of works have been done by Chinese scientists on reconstructing historical climate change using these document records. In recent years, Ge et al. consulted and developed Zhu's method[28] of deducing climate change for the past 5000 years using phonological records in China, reconstructed winter half-year (October to April)

temperature anomalies for the past 2000 years in the central region of eastern China (25°-40°N , east of 105°E) at 10-30 years' resolution[29], in which the reconstructed temperature anomalies from 1000 A.D. at 30 years' resolution are used for comparison in this paper.

3. Comparison of simulated and reconstructed data

First the simulated temperature anomalies with ECHO-G are compared with 120 years' observed integration data [7] in eastern China (25°-40°N , east of 105°E) in order to test the simulation ability of the ECHO-G model; Then the simulated and reconstructed temperature anomalies for the last 1000 years in eastern China are analyzed.

3.1 Validation of the model capability

Fig.2 gives the comparison between the model simulation and calculated winter-half year temperature anomalies (from 1951-1980 A.D.) changes from Jones' observed integration data in the eastern China since 1870. The dash line and solid line stand for simulation and Jones' data, respectively, and dot line is zero. It can be seen that the trends of temperature change from two data sets are consistence in the eastern China since 1870. There is a correlation at 99.5% confidence level, but the simulated temperature is about 0.15 _ less than that of observation on the average, with same order corresponding to the error level of Jones' observed integration data, indicating that the modeling result and Jones' data have the same confidence.

3.2 Comparison between simulated and reconstructed temperature in eastern China

First, we select winter-half year temperature anomalies of eastern China (25°_40°N , 105°_123.75°E, 20 grid points) from 1000-year global modeling result, and then calculate 30-year average of the temperature anomalies. Finally, simulated results are compared with reconstructed winter-half year temperature anomalies (at 30-year resolution) of eastern China. Fig.3 shows the comparison of these two series, where solid line is reconstruction, dash line is simulation, and dot line is zero. The polynomial fitting curves for reconstruction and simulation are also shown in the figure.

Fig.3 indicates that reconstructed and simulated results have the same variation trends with correlation coefficient of 0.37 at 97.5% confidence level. Both simulation and reconstruction reflect the Medieval Warm Period from 1000 to 1300, the Little Ice Age from 1300 to 1850, and the warming period since 1900. The anomalies from simulation and reconstruction in the Little Ice Age (1300-1850) and warming since 1900 are fairly consistent. Especially, both simulated and reconstructed temperatures reached the minimum without phase difference in the Maunder Minimum of sunspots during 1670 to 1710. While for the Medieval Warm Period of 1000 to 1300, the simulation and reconstruction show some phase differences, reconstruction displaying two peaks with one valley while simulation appearing three peaks with two valleys. The range of simulated temperature is from -0.70_-0.92_, and that of reconstructed is -1.1_-0.9_. The amplitude of temperature anomaly is about 1.62, a little bit less than that of reconstruction (2.0). It can be seen form Fig.3 that after 1500, the reconstruction and simulation of phases and amplitudes match better than those in the period of 1000 to 1500. This may relate to the condition that the farer from present is, the more errors of external forcings will be, and less data sites can be used for climate reconstruction from documentation. In addition it is found that the difference between simulation and reconstruction becomes larger in the last 100 years. The possible cause comes from limitation of the forcing factors in the modeling experiment, because aerosol forcing is not considered in the modeling experiment. Actually, when it is closer to modern time, the regional cooling effect of aerosols is more significant, this effect is included in the reconstruction data but not in the simulation. Therefore it causes the larger difference between simulation and reconstruction in modern time, and the simulated temperature is higher than that of reconstruction.

It is worth to point out that Fig.3 shows that simulated 20th century warming is greater than that of the Medieval Warm Period while reconstructed 20th century warming is close to but not exceeds that of the Medieval Warm Period. These two different results lead to the argument on the 20^{th} century warming between modeling party and reconstruction party. The former thinks that 20^{th} century warming has exceeded the normal range of the climate change, and it will result in catastrophic impact on human beings if warming goes up. The latter believes that current climate change has not yet exceeded the range of natural climate change and it needs no panic. The argument of these two standpoints is continuing, and not fall-in a right conclusion[30]. The final

understand of this problem will depend on upgrading capacity of climate model for long term climate change simulation and more profound works on quantitative reconstruction of paleo-cliamatological data, and then reconstructing historical climate change sequences with high resolution, precision, and reliability. After then the simulation and reconstruction may give more realistic description to historical climate change and approach to the truth.

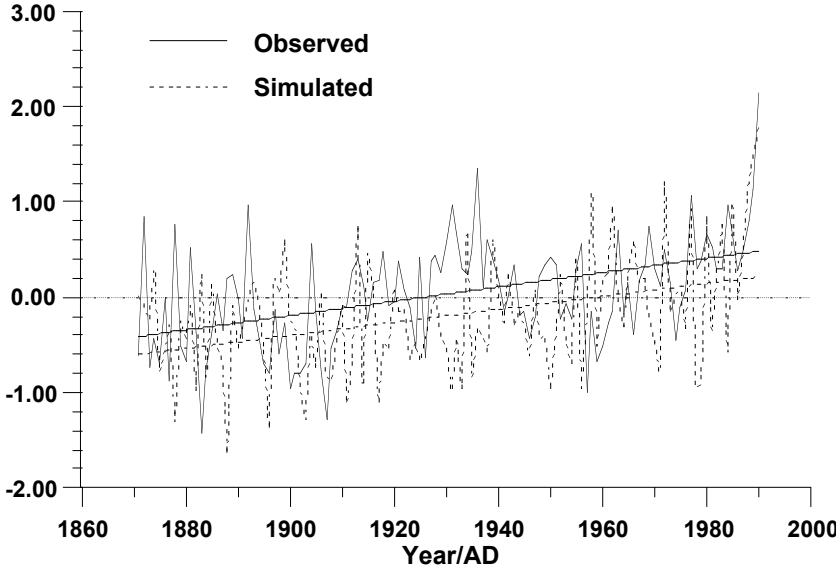

Fig.2 Comparison of simulated and observed winter half-year temperature anomalies in eastern China

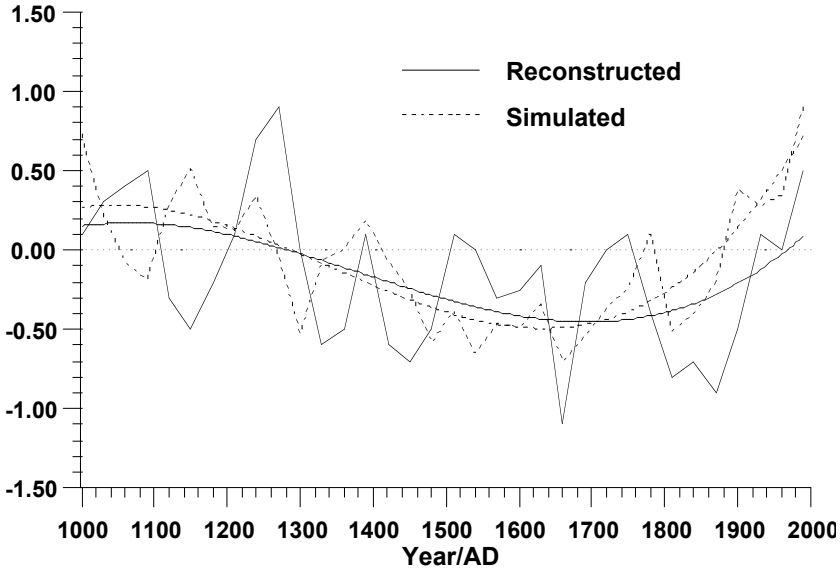

Fig.3 Comparison of simulated and reconstructed winter half-year temperature anomalies in eastern China

4 . Mechanism analysis

According to the comparison between real forced experiment (Driven by time-dependent external forcing factors such as effective solar radiation, CO_2 and CH_4 concentrations) and control experiment (Forced by the condition of solar radiation, CO_2 and CH_4 concentrations in 1990) we can find that control experiment can simulate the oscillation of the climate system around the equilibrium state, but can not reproduce the climate change scenarios at centennial time scale, such as the Medieval Warm Period and the Little Ice Age (Figure omitted). So it is affirmed that solar radiation, volcanic activity, and increase in greenhouse gases by human activities are the main forcing factors for the climate change in the past 1000 years.

In order to analyze the contribution of solar activity, volcanic activity, and greenhouse gas concentration changes in climate change in the past 1000 years, we fitted simulated 10-year average temperature anomalies in the eastern China from 1951 to 1980 in two scenarios: only effective solar radiation change is considered (affected by solar activity and volcanic activity), and both changes of effective solar radiation and greenhouse gases are considered.

The fitted curve equation in effective solar radiation change is

$$\Delta T = 0.17 + 0.13\Delta S \qquad (1)$$

here ΔT is 10-year average temperature anomaly(°C) from 1951 to 1980 in eastern China. ΔS is 10-year average solar radiation anomaly from the average (1365.75W/m^2) of 1951 to 1980 (1365.75W/m^2).

The fitted curve equation for the changes of both effective solar radiation and greenhouse gases is

$$\Delta T = 0.73 + 0.10\Delta S + 5.04\left\{\ln\left(\frac{C}{C_0}\right) + \ln\left(\frac{H}{H_0}\right)\right\} \qquad (2)$$

here ΔT and ΔS are same as above, and C is the 10-year mean CO_2 concentration of the atmosphere (10–^{6}), C_0 is the mean CO_2 concentration from 1951 to 1980 _322.65_10–^{6}_. H is 10-year mean CH_4 concentration of the atmosphere and H_0 is the mean CH_4 concentration (1510.85_10–^{12}) from 1951 to 1980.

The correlation coefficients of fitted curve (1) and curve (2) with simulated temperature anomaly series are 0.53 and 0.66 at the 99.9% confidence level, respectively. Fig. 4 gives fitted curves from above two equations and simulated curve.

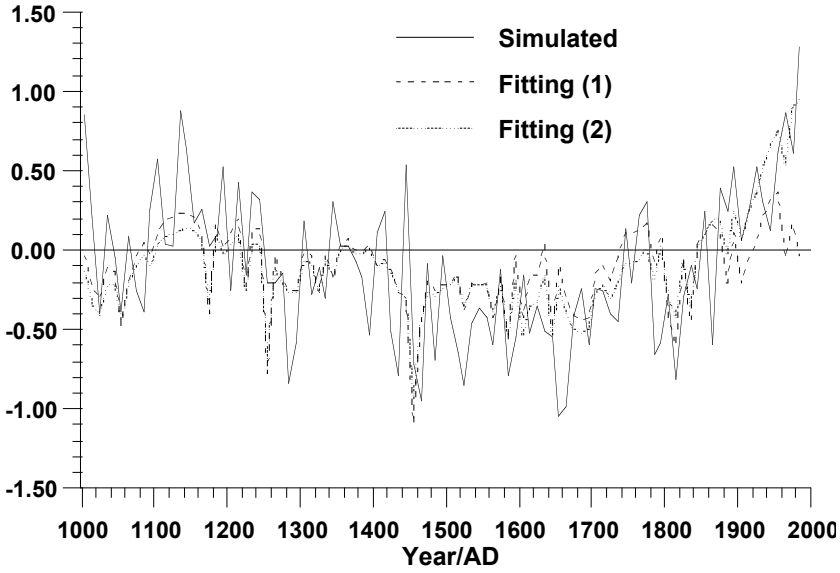

Fig.4 Time series of simulated temperature anomaly and its fittings over eastern China

From Fig.4, it can be found that effective irradiance (combined solar and volcanic effects) determined the main trend of temperature change in the last 1000 years (fitting (1), dash line). From 1000 to 1900, the curve is consistent with that of simulated temperature. While in the last hundred years since 1900, it is largely different from the simulation, and the warming trend is not significant, only oscillates around equilibrium state. When the greenhouse gases (CO_2 and CH_4) is included, the increasing of temperature in 20th century is well fitted (fitting(2), dot line). The fitted curve (2) matches with fitted curve (1) quite well in the time scales of 1000 to 1900. But in the last 100 years, curve (2) is consistent with simulated temperature much better, indicating a significant warming trend in the 20th century. It means that the increase of greenhouse gases contributes to global and regional warming more significantly in the last hundred years. Therefore, in the millennium time scale, the solar radiation and volcanic activity are main forcing factors for global

and regional temperature changes, and in the last century, greenhouse gases play a more important role in temperature change.

5. Conclusion

We can obtain following conclusions from above analysis:

(1) Reconstructed and simulated results have the similar variation trend. The correlation coefficient between reconstruction and simulation is 0.37 at 97.5% confidence level. Both simulation and reconstruction show the Medieval Warm Period from 1000 to 1300, the Little Ice Age from 1300 to 1850, and the warming period since 1900. The anomalies from simulation and reconstruction in the Little Ice Age (1300-1850) and warming period since 1900 are fairly consistent. Especially, both simulated and reconstructed temperatures reached the minimum without phase difference in the Maunder Minimum during 1670 to 1710. While for the Medieval Warm Period of 1000 to 1300, the simulation and reconstruction show some phase differences. The range of simulated temperature is from -0.70_-0.92_, and that of reconstructed is -1.1_-0.9_. The amplitude of temperature anomaly is about 1.62, a little bit less than that of reconstruction (2.0).

(2) Driven by time-dependent effective irradiance, CO_2 concentration, and CH_4 concentration, ECHO-G can catch the stage features of climate change in the eastern China in the past 1000 years. It means that the solar activity, volcanic activity, and greenhouse gases are key controling factors for historical climate change. In the millennium time scale, the solar radiation and volcanic activity are main forcing factors for global and regional temperature changes, and in the last century, greenhouse gases play a more important role in temperature change. However, simulation is not completely consistent with the realistic regional climate change in detail (every high or low value). That suggests some other factors, such as changes of aerosols and land surface, should be included in the simulation in the next step.

(3) The time resolution of reconstructed data used here is as low as 30 years. The longer the time series is, the lower the confidence is. Therefore, we have to strength work on reconstruction of climatological data, and develop and use more efficient proxy data. We need to establish higher time resolution, more accurate and reliable, and more typical historical climate data series of China, so that we can understand the rules of Chinese historical climate change more deeply.

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