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RESEARCH PAPER

Modeling the East Asian Climate During the Late Cretaceous (80 Ma)

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Abstract: In this study, the East Asian climate during the Late Cretaceous (*ca* 80 Ma) is examined by using the Community Climate System Model Version 2 (CCSM2) from the National Center for Atmospheric Research (NCAR) and the reconstructed palaeogeographic data. The simulation results indicate that the large-scale prevailing wind directions and pressure systems over East Asia showed a remarkable seasonal variation during 80 Ma, so that it can be inferred that there existed a monsoon circulation over East Asia at that time. Compared to the present climate, the atmospheric circulation systems over the Eurasian continent in the Late Cretaceous showed a stronger meridional feature, which was possibly correspondent to a smaller lateral extension of the Eurasian continent at that time. Moreover, under a warmer background in the Late Cretaceous, the winter and summer monsoons over East Asia showed a synchronous variation, with a stronger winter monsoon as well as a stronger summer monsoon. The pattern of annual mean precipitation was similar to that of the present climate, with the maximum precipitation appearing in the intertropical convergence zone (ITCZ) between 10°S and 10°N. There was also more precipitation over the eastern coasts of the continent adjacent to the western Pacific, with the central value exceeding 1200 mm, and there was less precipitation in the midlatitudes of the inland areas. Although a more precipitation belt also appeared near 30°N over the western Pacific, which was similar to the present climate, there was no high precipitation belt over the land of East Asia. This feature implies that the uplift of the Tibetan Plateau plays an important role in the formation of the present baiu (plum rains). Moreover, the simulated climate over East Asia during 80 Ma was warmer relative to the present and the surface air temperature was 2 °C higher at the same latitudes compared to the present climate. This simulation result is closer to the estimation from the geological evidences.

Key Words: Late Cretaceous; greenhouse climate; paleoclimate modeling

1 Introduction

"The warming effect of greenhouse gases" has become a major scientific issue faced by the contemporary scientists. Because the Cretaceous is the most recent period with a pronounced greenhouse effect, it is the best period for understanding the climatic features under the earth's greenhouse effect and has recently attracted extensive attentions. A large number of the isotopes, paleontology, and paleoclimate and paleo-ocean evidences have shown that compared to the present "icehouse" status, the CO_2 concentration in the Cretaceous was approximately 4–10 times as large as the present concentration[1–4]. During the Cretaceous, global annual mean temperature was approximately 7–14 °C higher than that of the present climate[5–7], and the sea level reached the highest over the past 250 Ma. The latitudinal oceanic temperature gradient was only 0.15–0.3 °C per degree of longitude, which is much lower than 0.73 °C per degree of longitude of the present day[8,9]. Clearly, the Cretaceous climate and oceans were characterized by a typical "greenhouse state". Therefore, studying on the climatic features in the Cretaceous is crucial not only to

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understand the evolution of the past climate change but also to predict the future regional climate features under global warming.

Chinese scientists have done many geological studies on the Cretaceous climates over East Asia. On the basis of climatic features from different proxy indicators at the different uplifting stages of the Tibetan Plateau, Zhang[10] pointed out that the height of the Tibetan Plateau was lower than 1000 m above sea level in Cretaceous and the plateau was not high enough to obstruct the atmospheric circulation. Thus, the planetary wind systems prevailed over China. Liu et al.[11] pointed out that in Cretaceous, the prevailing of the planetary wind systems over East Asia was owing to the long-term stable Earth's crust over China, the flattened land, and the weak topographic effect on the atmospheric circulation as well as the regulation of the Paleotethian and the eastern oceans on the land climates. Using the relationship between the distribution of organism and the climate, Huang et al.[12] comprehensively studied the Cretaceous pollen and plant fossil data in the Songliao Basin. They suggested that the Cretaceous paleoclimates over the Songliao Basin showed a cyclic feature, reflecting the humid and subhumid subtropical climates. Jiang et al.[13,14] studied the paleoclimatic implication of the desert spatial pattern and temporal evolution in Cretaceous, exploring reasons for the zonal distribution of the desert and the drought climate. Their results show that there existed a subtropical high-pressure zone over East Asia in the Late Cretaceous and the planetary circulation prevailed over there. Accordingly, the southeast and southwest monsoons appeared over East Asia. Wang et al.[15] used the geological data in the central and northern parts of the Tibetan Plateau to study the time and process of an earlier uplift of the plateau and its impacts on the climate in the central Asia.

Global and regional climate models have been widely used to study the continental paleoclimates during Cretaceous. Early in the 1980s, Barron et al.[16] simulated the atmospheric circulations in the middle Cretaceous using a general circulation model (GCM). Their simulations, however, showed a much lower winter temperature in the inland areas, which is inconsistent with the geological evidence that many noncold hardiness plants appeared in the inland areas. Otto-Bliesner et al.[17] modeled the impacts of vegetation cover on the Late Cretaceous (66 Ma) climates using the GENESIS model and the reconstructed paleovegetation, in which a lower CO_2 concentration was considered and the greenhouse effect was neglected. Their results show that if considering the feedback of the high-latitude forest on local climates, the simulated climate features are closer to those interpreted by the geological evidences. Upchurch et al.[18] investigated the sensitivity of the Late Cretaceous climates to vegetation changes using the GENESIS model. They found that the existence of the Cretaceous forest played a very important role in maintaining the high-latitude local warm climate.

In the recent years, Chinese scientists have extensively carried out the paleoclimate simulations to study the features of atmospheric circulation and climate as well as mechanisms responsible for the paleoclimate changes. Liu et al.[19] simulated the impact of the changes in the greenhouse gas concentration on the rapid warming during the past millennium using a GCM model. Zhao et al.[20] simulated the last glacial maximum climate over East Asia using the CCM3 global climate model. Zheng et al.[21] simulated the East Asian climates for 6 ka BP and 21 ka BP using a regional climate model, finding out that the simulated results agree better with the geological data when effects of vegetation are considered in the simulations. Jiang et al.[22] simulated climates at 3 Ma with the IAP-AGCM model. Zhou et al.[23] and Yu et al.[24] simulated impacts of the Australian plate drift on climates at 14 Ma. Chen et al.[25] simulated an impact of the Tibetan Plateau uplift on climates in the mainland of China during the period of 40–50 Ma, pointing out that the plateau uplift made the East Asian climate cool. The foregoing studies promote the application of climate models in the East Asia paleoclimate research.

From the foregoing analysis, the previous studies on the Cretaceous paleoclimates in East Asia were done from the sedimentology while paid little attention to the simulations of the Cretaceous climate features in East Asia. It has not been known that the general features of the Cretaceous East Asian climate and its evolution. Meanwhile, because the paleoclimate reconstructions from the climate models are the basis of studying mechanisms for the paleoclimate change, it is very meaningful to reasonably reconstruct features of atmospheric circulation and climate in Cretaceous, and to further explore their impacts on the East Asian environment. In this study, a global climate system model is applied to simulate the East Asian climate during the Late Cretaceous and to analyze a general pattern of the climate at that time, in which our simulation is designated around 80 Ma, corresponding to the Campanian stage of the Late Cretaceous.

2 Climate model and data

2.1 Model

In this study, we use the Community Climate System Model Version 2 (CCSM2) developed by the National Center for Atmospheric Research (NCAR)[26]. This model is composed of 4 components: atmosphere, ocean, sea ice, and land surface. The atmosphere component is the Community Atmosphere Model Version 2.0 (CAM2.0), a successor of the Community Climate Model Version 3 (CCM3), with an approximate horizontal resolution of 3.75° × 3.75° in longitude and latitude, and 26 layers in the vertical direction[27]. The land surface component is the Community Land Model Version 2 (CLM2), including a 10-layer soil