A Sensitivity Study of IAP AGCM to Radiation Changes: Climate Simulation of 125kyr and 115kyr before Present

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ABSTRACT

The IAP AGCM was used to simulate the climate of 125kyr and 115kyr before present. We analysed the results and then studied the sensitivity of the model to the changes of radiation distribution induced by orbital parameter changes. The reasonability of the results was also discussed.

I. INTRODUCTION

The validation of climate models which is the goal of the atmospheric model intercomparison project (AMIP) and the paleoclimate modelling intercomparison project (PMIP)has been one of the most important problems in research of climatic change and its simulation studies. Paleoclimate simulation is one approach for the validation, because if the model agrees with the physical principles of the real climate system the climate in the past could be and must be satisfactorilly simulated by the model. It is easily understood that the correct simulation of paleoclimate which is different from the present climate and different from, as most scientists believe, the future climate is the essential condition of the correct prediction of future climate by the model.

In the previous works of Wang and Zeng(1992), the perpetual and seasonal cycle experiments were made to simulate the climate of 9000 years before and of present which is a verification of IAP AGCM to the radiation changes induced by the variations of orbital parameters of the earth. In that paper we gave the detailed description and discussion of the results and agreements were found between the results of perpetual experiments and of seasonal cycle experiments.

However, because a) 125 kyr and 115 kyr before present (125kBP and 115 kBP in brief) are the periods when the largest positive and negative deviation (from present conditions) of July insolation in the Northern Hemisphere during the last 200,000 years are found and b) 125 kBP and 115 kBP mark approximately the beginning and the ending of the climate "optimum" of the last interglacial stage, we choose these two periods to do further studies to verify the sensitivity of the model to the insolation change caused by orbital variations. During the period the North Atlantic polar front maintained a position far to the North-West like that of today (Ruddiman and McIntyre, 1977). Schnitker (1974) has concluded that deep sea circulation in the last interglacial stage, 120,000 years ago was similar to present condition and Ruddiman and McIntyre (1979) showed that the sea surface temperature in the North Atlantic did not differ more than a few degrees from present SST. Hence one can infer that SST differed even less in other regions of the world ocean.

Because of the above reasons, we specified identical surface boundary conditions (SST, sea ice, orography, etc.) as present in the two runs. The advantage to do so is that the sensitivity of the model to the orbital changes themselves could be studied by analysing the results and that the climate of the two periods can be simulated as well.

II. RESULTS

The orbital difference between 125 kBP and 115 kBP is that perihelion appeared in July (125 kBP) and January (115 kBP) respectively. The eccentricity in this period is 0.04 (present value is less than 0.02). Fig. 1 shows the monthly mean insolation anomalies relative to present for 125 kBP and 115 kBP as a function of latitude and month (from Royer et al, 1984). At 125kBP we clearly see that there exist a large positive anomaly reaching more than 50 W / M^2 in July in mid-and-high latitudes of the Northern Hemisphere, extending in the Southern Hemisphere in September-October and a large negative anomaly in the Southern Hemisphere. At 115kBP the situation is opposite with a negative anomaly in July and a positive one in January having about half the intensity of the 125kBP anomaly. Such large anomaly results directly from large eccentricity values and passing at perihelion in July and January respectively. If we compare the 125kBP insolation conditions with the 115kBP we find an excess reaching 16 percent in July and a similar deficit in January.

The IAP AGCM was integrated for four years in each experiment and we compare the results of the last year of each experiment.

1. *Global Means and Zonal Means*

The annual cycle of the global mean surface temperature and total cloudiness are presented in Fig. 2. The temperature is greater in 125 kBP than in 115 kBP in the Northern Hemisphere in summer, while in winter the temperature is lower. We find that the amplitude of temperature anomaly in summer is greater than that in winter and the annual mean temperature over land in the Northern Hemisphere is 1.13 K higher in 125 kBP than in 115 kBP while

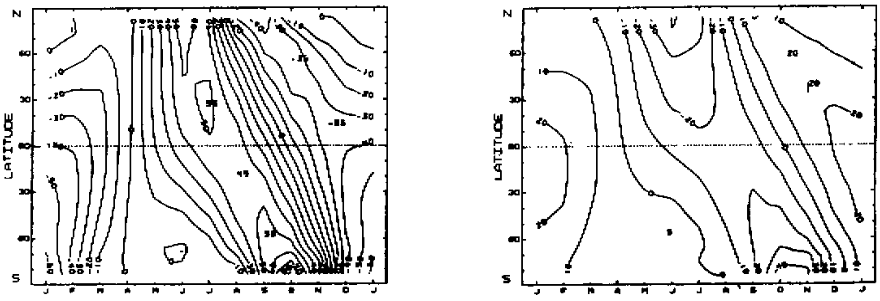

Fig. 1. Distribution by month and latitude of the monthly mean deviation from the present state (in W / M^2). A) 125000 BP minus present; B) 115000 BP minus present.

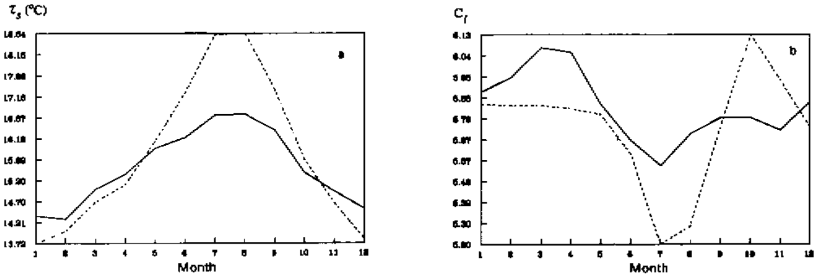

Fig. 2. The annual cycle of global mean a) surface temperature and b) total cloud amount for 125 kyr BP(dotted line) and 115 kyr BP(solid line).

such number is just 0.01 K in the Southern Hemisphere. For global mean over land, The temperature anomaly in July is 4.47 K but just −1.13 K in January (125 kBP−115 kBP). This is mainly the reflection of such feature in the Northern Hemisphere, which could be found in Table 1. However the question is why the difference between the anomalies in July and January is so large, as such phenomenon does not exist in the results of Royer et al (1984). Such situation also exists in comparison of the results of ours and of Kutzbach et al (1984) when simulating the climate of 9000 years before present.

Table 1. The Global and Hemispheric Anomalies for Mean Surface Temperature, Sea-level Pressure and Cloudiness for July, January and Annual Mean over the Land

		125 KBP-115kBPP		
		Northern Hemisphere	Southern Hemisphere	Global
Annual Mean	Ts(K)	1.13	0.01	0.77
	Slp (hPa)	0.41	0.23	0.35
	Cl (%)	-5	-5	-5
July	Ts (K)	6.22	0.84	4.47
	Slp (hPa)	-3.82	0.13	-2.53
	Cl (%)	-3	-16	-6
January	Ts (K)	-1.6	-0.67	1.3
	Slp (hPa)	1.29	-1.32	0.43
	Cl (%)	0	6	2

We noticed that in July or January or annual mean there exists asymmetry between the temperature anomalies in the NH and in the SH (greater in the NH than in the SH). For global mean surface temperature anomalies over land in the NH and in the SH are respectively 1.13K and 0.01K. One reason for this is that the area of the ocean (which has large thermal inertia) occupies a smaller part in the NH than in the SH and so the climate in the NH is more sensitive than that in the SH. While the theory of Milankovitch (Royer et al, 1984), which says "the cold summers in high latitudes of the NH resulting from an insolation deficit when the earth is at aphelion in July are not compensated by warmer winter", just points out such fact that if aphelion is in July (115kBP), the global and annual mean temperature will be lower than that when aphelion is in January(125kBP).

This feature was pointed out in Wang (1992) when he simulated the seasonal cycle of the climate of 9000 years before present. However, the question is that if the external forcing change is not from the orbital parameter variation but from the increase of CO_2 in the atmosphere, what would happen? This deserves further research.

It should be noticed that for annual mean the temperature is higher in 125kBP than in 115kBP both in the NH and in the SH, which demonstrates that the insolation change in the NH summer is the "indicator" of global temperature variation.

The global cloud amount decreased in 125kBP compared to 115kBP. The anomaly of cloud is opposite to that of temperature.

Fig.3 shows the annual cycle of zonally averaged surface temperature. We find the anomaly in middle latitude of the NH in summer is the largest compared to the anomaly in any latitude in any season. It is a little strange that although the insolation anomaly in the SH's high latitude in September and October is quite large, the temperature anomaly is small.

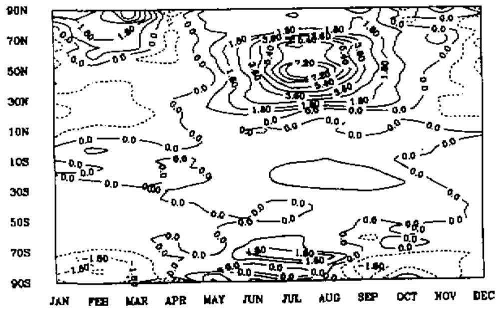

Fig. 3. The time–latitude distribution of zonal mean surface temperature anomaly(°C)(125kyr BP–115kyr BP).

We are not sure at present that whether it is the real fact or the model error. Royer et al (1984) did not publish the results in the SH's high latitudes.

2. *Global Distribution*

The distribution of temperature difference (125kBP–115kBP) for July and January is presented in Fig.4. The NH's anomaly is greater than the SH's anomaly in both months. In the NH's mid–and–high latitudes the temperature is higher in 125kBP than in 115kBP, which has the same direction with the insolation anomaly, while in January there exists regions in middle latitude of Eurasia where the temperature anomaly is opposite to the insolation anomaly, that is, the temperature is higher in 125kBP than in 115kBP. The later fact can also be found in Greenland and in the north–east coastal areas of the Pacific. It can be found that the contrast of temperature anomaly over the land and over the ocean is more obvious in July than in January. Again we can not give the explanations for this.

One may notice that in Greenland and to the north–east coast of the Pacific the temperature in 115kBP is lower than in 125kBP but with more precipitation both in July and January. This fact can also be found in Fig.5, which shows the global distribution of annual mean temperature anomaly. These facts demonstrate that the glacier in the regions could be developed. This agrees with the theory of Ruddiman and McIntyre that the major initial conditions of glaciation is the warm ocean and the summer deficit of insolation.

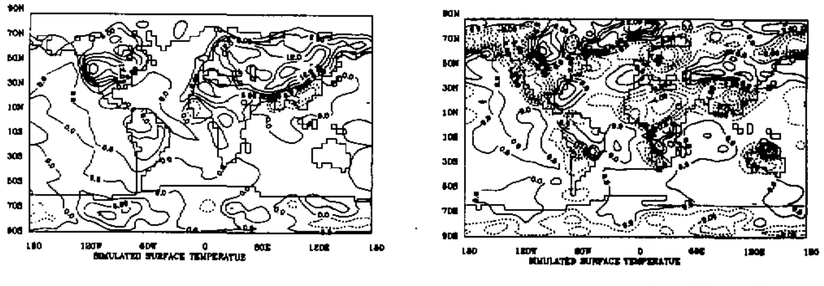

Fig. 4. The global distribution of surface temperature anomaly (125 kyr BP minus 115 kyr BP) for a) July and b) January (℃).

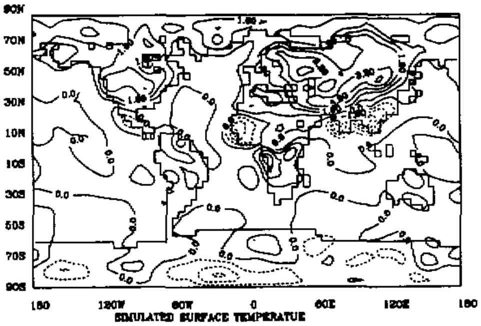

Fig. 5. The global distribution of annual mean surface temperature(℃) anomaly (125 kyr BP minus 115 kyr BP).

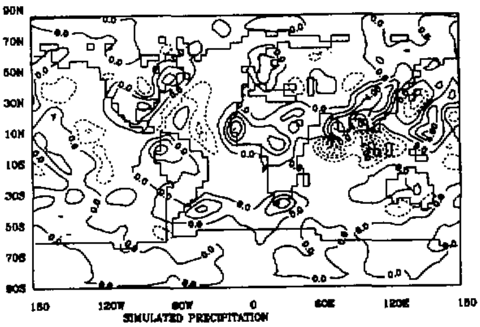

Fig. 6. The global distribution of precipitation(mm / day) anomaly for July(125 kyr BP minus 115 kyr BP).

Another change for the climate of the two periods is the summer monsoon variation. We find more precipitation in East Asia and North Africa in 125kBP than in 115kBP (Fig. 6). It can be seen from Fig. 7 that the pressure decreases over land but increases over ocean mostly.

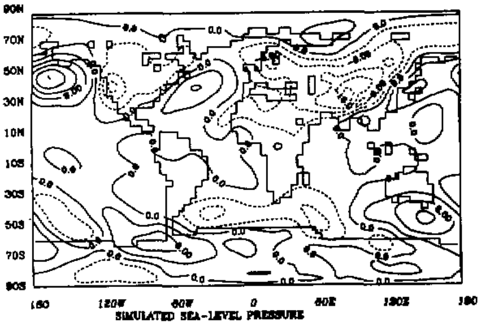

Fig. 7. The global distribution of sea-level pressure(hPa) anomaly(125 kyr BP minus 115 kyr BP).

This means that the wind and hence the water vapour transport from the ocean to the land increases and so the monsoon is stronger in 125kBP. Such case appears in Australia as well.

For the global and annual mean precipitation anomaly, the increase exists in the regions mentioned above and the decrease(125kBP−115kBP < 0) is found in Eurasia and the mid-latitude of North America. In the NH's high latitude area precipitation increases mostly. This means that in the NH drier conditions exist in mid-latitudes and wetter conditions exist in low and high latitudes.

III. DISCUSSION

This work further verified the astronomical theory of glaciation−interglaciation changes. The change of orbital parameters which can induce the variation of geographical and the seasonal distribution of insolation could cause the climatic change from glaciation to interglaciation and the reverse. In such processes the summer insolation change in the NH is the determinant factor.

The reasons for this are complicate, but at least it is one reason that the land area in the NH is much larger and the geographical and seasonal features of insolation change make another.

The asymmetries of temperature anomaly between the NH and the SH and between summer and winter are in good agreement with that obtained from 9000 yBP simulation(Wang,1992). The only difference is that the insolation anomaly here is greater and so is the temperature anomaly.

Another difference of the climate of the two periods is the monsoon variation. In East Asia, Australia and Africa the monsoon in 125kBP was stronger than that in 115kBP. Again this agrees with the earlier results (Wang and Zeng, 1992; Wang, 1992; Kutzbach et al., 1984).

We noticed that 125kBP was warmer and drier in mid−latitudes and wetter in low and high latitudes in the NH compared to 115kBP. This resembles the situation of the simulated CO_2−induced climatic change. Does it mean that similar(but different) forcing change cause similar climatic change? The author believes that further researches on this would be valuable to climatic change studies.

REFERENCES

Kutzbach et al. (1984), in *Milankovitch and Climate* (Part 2), Berger A. L. et al.(eds.), D. Reidel Publishing Comp., 801−820.

Royer J. F. et al. (1984), in *Milankovitch and Climate* (Part 2), Berger A. L. et al.(eds.), D. Reidel Publishing Comp., 733−763.

Ruddiman W. F. and McIntyre A. (1977), *J. ofGeophys. Res.*, **82:** 3877−3887.

Ruddiman W. F. and McIntyre A. (1979), *Science*, **204:** 173−175.

Schnitker D. (1974), *Nature*, **248:** 385−387.

Wang Huijun and Zeng Qingcun (1992), The numerical simulation of the climate of 9000 years before present, *Chinese Journal ofAtmos. Sci.*, **16:** 313−321.

Wang Huijun, Zeng Qingcun and Zhang Xuehong (1992), *Science In China* (Series B), No.6, 663−672.

Wang huijun (1992), *Advances in Atmos. Sci.*, **9:** 451−457.