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Simulation of North-East Asia Climate Change for the Last Glacial Maximum

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1. Introduction

The global climate fluctuates from glacial to interglacial with about 100,000 year periods for the last 0.5 million years. It is believed that the climate fluctuations are due to the periodic variation of earth's orbital parameters (Hays et al., 1976). The Last Glaciation occurred at 20,000 years ago and this time is called the Last Glacial Maximum (LGM). According to CLIMAP (1981), the global mean sea surface temperature was about 5°C lower in the LGM than at present with a small temperature change in the low latitudes and a large change in the high latitudes. There was an expansion of ice sheet over North America and northern Europe with an height of 1,500-2,000 m and the sea ice expanded to 50°S in the southern hemisphere and 45°N in the North Atlantic.

Many geological and geochemical proxy data are used to depict the climate change pattern of the LGM, these have limitations in describing the climate change mechanism. Besides proxy data, numerical models have been used to investigate the climate change for the past and present. In order to understand the climate change mechanism of the LGM, many classes of numerical models have been used (Gates, 1976; Manabe and Hahn, 1977; Kutzbach and Guetter, 1986, Weaver et al., 1998; Ganopolski et al., 1998; Hewitt et al., 2001; Kim et al., 2002, 2003). However, because these models are composed of low spatial resolutions, they have limitation in simulating regional-scale climate features such as North-east Asia. In this study, we used a relatively high-resolution climate model and investigate the climate change of North-eastern part of Asia for the LGM.

2. Model and experiments

The simulations were performed with the Community Climate Model version 3 (CCM3) atmospheric general circulation model at about 75 km with 18 vertical levels. The CCM3 includes a comprehensive model of land surface processes known as the NCAR Land Surface Model (LSM). Important physical processes are represented as described in detail by Duffy et al. (2003).

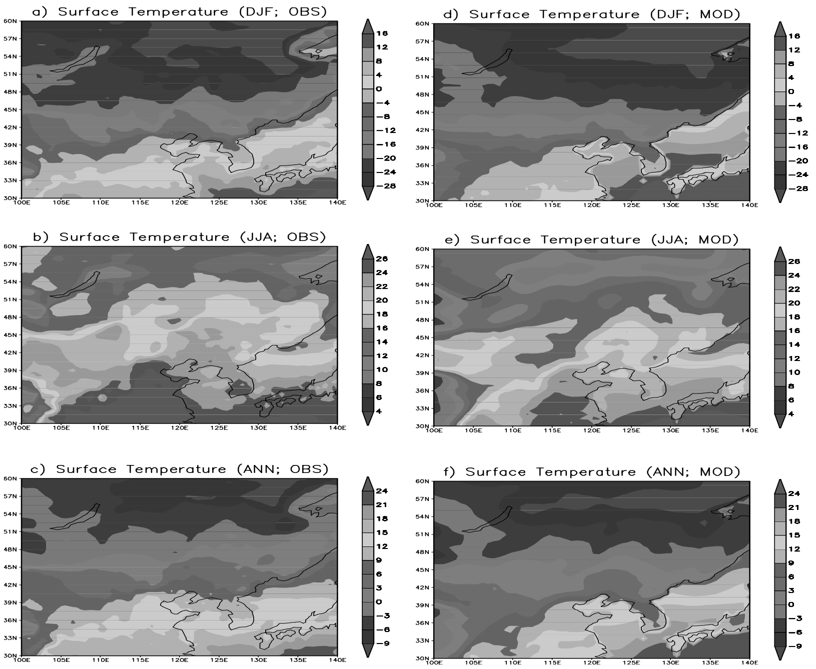
Two experiments are analyzed. The modern climate simulation, referred to as MOD, is forced by climatologically-averaged monthly sea-surface temperatures (SSTs) and sea ice distributions provided by NCAR, a specified CO_2 concentration of 355 ppm, and present land mask and topography. The second experiment features glacial boundary conditions. Over ocean the SST and sea ice are prescribed using climatologically averaged monthly data prepared with the August and February reconstructions by the CLIMAP (1981). The glacial surface topography was modified following the Ice-4G reconstructions and the land mask is modified to account for the lower sea level (~120 m). The atmospheric CO_2 concentration is reduced to 200 ppm following ice core data. Vegetation and soil types are unchanged except over glaciated surfaces. Land points arising due to sea level reduction are assigned a medium soil type. Orbital parameters set to 20k BP.

3. Results

The modern experiment reproduces the climate features reasonably well in comparison to observations (Fig. 1). For example, in winter there is a remarkable temperature reduction over land in comparison to surrounding seas due to the lower heat capacity. This feature is well represented in the modern simulation. On the other hand, in summer the land is heated faster, the temperature over land is slightly higher than surrounding seas.

Over Mongolia in winter surface temperature drops less than 20℃, while in summer temperature increases to more than 15℃. The annual mean surface temperature ranges from about -3 to about 3℃ over Mongolia. The general features of the observed is reasonably well simulated in the MOD experiments.

Under LGM boundary conditions, surface temperature is reduced in different ranges in different regions. The largest temperature reduction by more than 18℃ is found in the continental margins around the Korean peninsula in winter. The marked surface cooling in these regions are due to the exposure of ocean to land in the LGM that leads to the change in surface albedo and consequent substantial cooling. On the other hand, in summer the surface temperature slightly increases in comparison to present, because the exposure to land allows more surface heating than it was ocean. Over Mongolia, surface temperature change is relatively less than the around the Korean peninsula. In winter, surface temperature is reduced by more than 8℃ in most areas of Mongolia, while in summer surface cooling ranges from –2 to more.



a) Surface Temperature (DJF; OBS)

d) Surface Temperature (DJF; MOD)

b) Surface Temperature (JJA; OBS)

e) Surface Temperature (JJA; MOD)

c) Surface Temperature (ANN; OBS)

f) Surface Temperature (ANN; MOD)

Fig. 1 Geographic distribution of observed surface air temperature (SAT) for a) winter (December-January-February), c) summer (June-July-August), e) annual-mean, simulated in the MOD for b) winter, d) summer, f) annual-mean.

Overall, in the LGM surface is cooled by 4~6℃ in the Korean peninsula and 6~12℃ over Mongolia. An analysis of surface heat fluxes shows that the surface cooling is mainly due to the increase in outgoing longwave radiation associated with the reduced CO_2 concentration.

The reduction in surface temperature leads to a weakening of the hydrological cycle. Fig. 3 shows the change in precipitation and precipitation minus evaporation budget for the winter, summer, and annual-mean. In winter, precipitation decreases largely in the southeastern part of Asia by about 1~4 mm/day, but over Mongolia there is not much change in precipitation because there is no moisture source due to the development of high-pressure system. In summer, a larger reduction is found over China and Mongolia, while less reduction or almost no change in precipitation is found in the southern part of the Korean peninsula (Fig. 3c). Overall, annual-mean precipitation decreases by about 44% in the north-east Asia in the LGM.

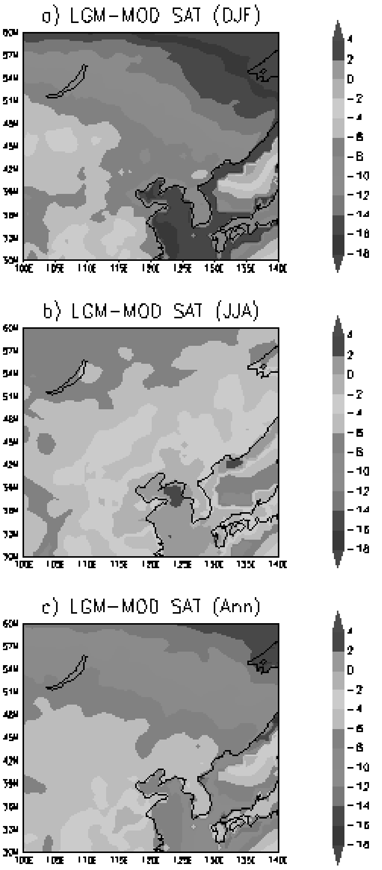


Fig.2 Geographic distribution of the change in SAT for a) winter, b) summer and c) annual-mean.

In northeast Asia, evaporation is also overall reduced in the LGM (not shown), but the reduction of precipitation is larger in most area, eventually leading to a drier climate (Fig. 3). In winter, there is little change in precipitation minus evaporation (P-E) over Mongolia due to the lack of moisture source as mentioned above, while in the Korean peninsula the net reduction in P-E is simulated. It is interesting to note that the P-E shows a substantial positive in the continental margin around the Korean peninsula. The wetter climate over these regions seems

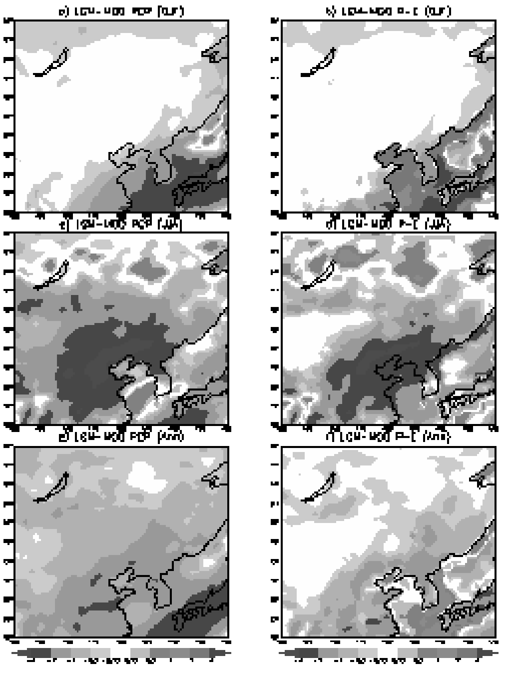


Fig.3 Geographic distribution of the change in precipitation for a) winter, c) summer, e) annual-mean and precipitation minus evaporation for b) winter, d) summer, f) annual-mean. Units are in mm day^{-1}.

to be due a much more reduction in evaporation than that of precipitation due to the marked surface cooling shown in Fig. 2a. In summer, overall drier climate is simulated in the LGM over both Korea and Mongolia, while there is the wetter climate in the north of Mongolia, which is associated the increase in precipitation.

Overall, annual mean P-E budget is negative over the continent of the north-east Asia including China, Korea, and Mongolia, but there is a net increase in P-E over the continental margin around the Korean peninsula, associated with marked reduction evaporation over precipitation due to the marked surface cooling by the exposure of ocean to land.

In conclusion, in the LGM surface temperature is reduced by 4-12℃ in the north-east Asia and the reduction of surface temperature leads to the weakening of hydrological cycle with the reduction of precipitation by 44% in the LGM. Eventually, the climate is much drier in the LGM over northeast Asia, except around the Korean peninsula where a wet climate is simulated due to the marked surface cooling.

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