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Winter Climate Change in the Arctic for the mid-Holocene and Last Glacial Maximum from PMIP2 Coupled Simulations

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1. Introduction

According to the IPCC 4th report, the earth has warmed by 0.74℃ for the past 20th century (IPCC, 2007) and the warming over the Korean peninsula is about 1.7℃, which is more than twice the global average temperature. Observations and modeling studies have suggested that the Arctic is one of the fastest climate changes in response to the greenhouse gas increase in recent years. Moreover, projections of future climate changes using numerical models indicate that the Arctic will undergo a large climate change in the near future. The marked Arctic warming is associated with the ice-albedo feedback due to the presence of snow and ice sheet which have high reflectivity of the short wave radiative heat fluxes. The Arctic climate variability appears to influence the climate change in northeast Asia including Korea, especially in winter by modulating the Siberian-Mongolian High (Jeong and Ho, 2005).

Even though many climate projections are available from different hierarchy of climate models, we cannot totally convince the degree of climate change predicted by numerical models. Although one model reproduces the present climate in a reasonable degree, we cannot guarantee that it will predict future climate precisely because climate background is different. One way to test the credibility of numerical models is through paleoclimate modeling by comparison with existing proxy data. Moreover, the paleoclimate information provides a clue to the future climate change because the future climate change under warm background mirrors that of the colder climate background.

The winter climate change for the mid-Holocene occurred at 6000 years before present (6k BP) and Last Glacial Maximum at 21,000 years before present (21k BP) serve a good opportunity to investigate the Arctic climate change because the climate was colder than present and the proxy evidence is relatively abundant. We aim at investigating the change in the Arctic climate change in winter for the mid-Holocene, Last Glacial Maximum (LGM) compared to preindustrial period using data from the second phase of Paleoclimate Modeling Intercomparison Project (PMIP2).

2. Numerical models and experiments

Data from PMIP2 experiments are used to analyze the climate change of the Arctic for the mid-Holocene and LGM, The numerical models participated in the PMIP2 are atmospheric general circulation model coupled with ocean general circulation model and sometimes coupled with dynamic vegetation model. Among the PMIP participants, five models (i.e., CCSM, ECHAM5-MPIOM1, IPSL, MIROC3.2, and UBRIS-HadCM3M2) are used for the mid-Holocene analysis and four models except for the ECHAM5-MPIOM1 are used for the LGM analysis.

Three sets of experiments are included. The reference (control) simulation is a preindustrial (about 1750 A.D.) type climate and this is referred to as PI, which is forced by present conditions of topography, atmospheric greenhouse gas concentrations (280 ppm), and orbital parameters of the year 1950. The mid-Holocene experiment, called MH, used the same conditions as the PI except for orbital parameters which set for 6000 years before present. The LGM experiments include the lowered atmospheric greenhouse gases (185 ppm), orbital parameters for 21,000 years before present, and LGM ice sheet topography of ICE-5G. More detailed illustrations for the coupled models and experimental setup used in the PMIP2 are available at http://www-lsce.cea.fr/pmip2.

3. Results

We examined the simulated surface air temperature (SAT) and mean sea level pressure (MSLP) for the winter months (December-January-February, DJF) in comparison to the observed values to examine the performance of models. Observation shows that during DJF the SAT is minimum over Greenland and the MSLP is higher over the Asian continent associated with the Siberian-Mongolian High pressure and over North America, while it is lower over the North Pacific and North Atlantic associated with the Aleutian and Icelandic lows, respectively. These features are well reproduced in all the coupled models, even though the locations and strengths of the high and low pressure centers vary. Overall, all models reproduce the present climate in a reasonable degree.

In the mid-Holocene, the surface temperature decreases by less than several degrees over the subarctic regions, especially over Siberia and over Canada, whereas a slight warming is simulated over the Arctic. The warming is especially pronounced over the Greenland and Labrador Seas. The mid-Holocene winter cooling ranges from about 0.1℃ to about 0.7℃. In the LGM, surface temperature reduction is much more substantial by more than 30℃ than the mid-Holocene. The surface cooling is marked over the Laurentide and Fennoscandian ice sheets over North America and northern Europe, respectively (Fig. 1). The marked cooling in these regions is presumably due to the change in elevation and surface albedo as suggested by Kim et al. (2003). Overall, in the LGM surface temperature reduction in the northern hemisphere ranges from about 5℃ to 6.5℃, which is consistent with the proxy evidence.

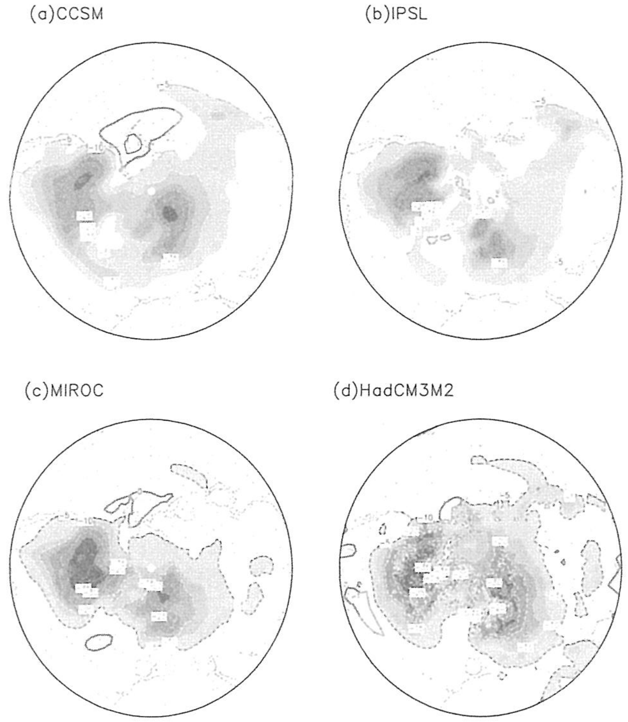

Fig. 1 The modeled changes (LGM minus PI) in mean DJF surface air temperature. Decreases are shaded, contour interval is 5 K.

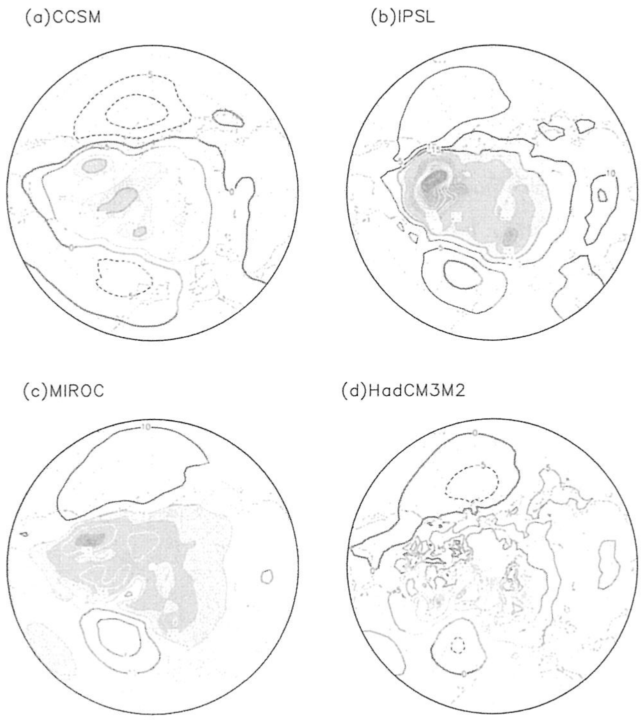

Fig. 2 The modeled changes (LGM minus PI) in mean DJF SLP. Increases are shaded, contour interval is 500 Pa.

In the mid-Holocene, the reduction in surface temperature over northern Asia and North America is reflected as the increase in MSLP in those regions. Over the Arctic, MSLP is overall reduced in consistent with the slight warming. In the LGM, the substantial reduction in SAT over North America, northern Europe, and the Arctic leads to the marked increase in MSLP, especially in the IPSL and MIROC models (Fig. 2).

3. Conclusion

In conclusion, in the mid-Holocene winter the reduced incoming solar radiation due to the change in orbital parameters results in the reduction of surface temperature over the subpolar land regions. This leads to the increase in mean sea level pressure over these regions. In the LGM, the reduced atmospheric CO_2 concentration and ice sheet topography over North America and northern Europe leads to the marked surface cooling and associated surface pressure.

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