Dependence of Dansgaard-Oeschger cycle on ice sheet topography

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It is known that over the last 120,000 years, the climate, ice sheets, and atmospheric CO_2 concentration have changed along with the orbital parameters. Paleoclimate reconstructions indicate the existence of more than 25 climate change events with abrupt hemispheric temperature increases, called Dansgaard-Oeschger (DO) events and which occurred at intervals of several thousand years during the last glacial period. During each DO event, the northern hemisphere alternated between cold and warm states, with the southern hemisphere warming (cooling) slowly while the northern hemisphere was cold (warm). The DO cycles had a period of about 1,000 to 5,000 years, and did not occur frequently during the relatively cold Marine Isotope Stages (MIS) 2 and MIS4, and during the relatively warm MIS5. During MIS3, when climate conditions were moderate, DO cycles occurred frequently.
Evidence suggests that DO cycles are closely related to abrupt changes in the Atlantic meridional overturning circulation (AMOC). A strong AMOC is thought to correspond to a Northern Hemisphere warm period (DO interglacial), and a weak AMOC to a Northern Hemisphere cold period (DO glacial). Freshwater supply to the ocean due to ice sheet melt and collapse, and changes in salinity between low and high latitudes in the North Atlantic were initially thought to be important for AMOC variability, but recent studies suggest that thermal processes related to sea ice and convection in North Atlantic is important, and models are beginning to reproduce self-sustained oscillations caused by internal feedbacks of the atmosphere-ocean system. Recent studies using a coupled atmosphere-ocean general circulation model (AOGCM), MIROC4m, found three types of AMOC states: a state in which the strong mode continues for a long time, a state in which the weak mode continues for a long time, and a state in which the AMOC oscillates between these two modes over thousands of years. A study using MIROC4m clarified the relationship between the AMOC mode and background conditions such as orbital parameters and atmospheric CO_2 concentration and suggested that the presence or absence of oscillations is closely related to high latitude ocean temperature and sea ice. However, the effects of differences in ice sheet topography on AMOC modes and oscillations are not clear.
Here, we investigate the effects of ice sheet topography on AMOC variabilities. For this purpose, we run and analyze sensitivity experiments simulated with AOGCM MIROC4m. We investigate the dependence of the AMOC mode on ice sheet topography by comparing experiments with more than 20 different ice sheet configurations, including sensitivity experiments with different ice sheet elevation and extent.
A comparison between experiments with different ice sheets shows that an increase in ice sheet area has the effect of changing the AMOC from a long-term strong state to a oscillating state or from an oscillating state to a long-term weak state. On the other hand, when the ice sheet altitude is increased, the AMOC changes from a long-term weak state to a oscillating state or from an oscillating state to a long-term strong state. Experiments combining CO_2 concentration and ice sheet topography show that as ice sheet altitude increases, the CO_2 concentration at which DO oscillations are likely to occur decreases. On the other hand, as ice sheet area increases, the CO_2 concentration at which DO oscillations are likely to occur increases. Thus, the effects of ice sheet growth on the AMOC are found to be opposite for area increase and altitude increase. In terms of the actual DO cycle record, The increase in ice sheet area can be interpreted as one of the reasons why the DO glacial period was longer and oscillations did not occur as much in MIS4 and MIS2 with the growth of the ice sheet.

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