論文の内容の要旨

A climate modeling study on the mechanism of Antarctic ice sheet changes in the past and future
（過去と将来の南極氷床変動メカニズムの理解に向けた気候モデリング研究）

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Understanding the nature of the Antarctic ice sheet is important for projecting future sea level change, which has a significant impact on human activities. Combined ice sheet and climate modeling studies are conducted to project future climate change associated response of the Antarctic ice sheet. Paleoclimate is used to validate numerical models used for future projections, and it is indicated the Antarctic ice sheet retreated in the past such as the Last Interglacial (LIG, about 130,000 years ago). However, there are two significant problems in understandings of the climate and Antarctic ice sheet. The first problem is the relationship between the forcing and response of Antarctic ice sheet during the LIG. Climate model simulations did not reproduce warm climate in the Antarctic region, when the boundary conditions of insolation and greenhouse gas concentrations at the LIG is used. The retreatment of Antarctic ice sheet during the LIG can be explained by warmer Antarctic climate, but the ultimate cause is unknown. The second problem is in the processes of the retreatment of Antarctic ice sheet to climate change. Basal melting of the Antarctic ice shelves, determined by heat delivered by

ocean, is an important factor in the response of the Antarctic ice sheet to climate change. However, change in basal melting rate is simply parameterized without considering ocean temperature and circulation changes in the Antarctic shelf seas. The objective of this study is to understand the mechanisms and physical processes of Antarctic climate and Antarctic ice sheet changes in the past and future.

In chapter 2, I focus on the Antarctic climate during the transition from the glacial to interglacial, especially the last two interglacials, the LIG and the present interglacial (PIG). I focus on the time series of reconstructed Atlantic Meridional Overturning Circulation (AMOC) and the speed of Northern Hemisphere ice sheet melting during deglaciation before the early LIG. A transient simulation from the glacial to the interglacial is conducted using an atmosphere-ocean coupled general circulation model (AOGCM). The different time series in the AMOC during the deglaciations were simulated, and the magnitude of simulated temperature differences in the Antarctic regions were shown to be close to reconstructions of the early LIG and the early PIG. The results suggest that the difference in Antarctic climate between the last two interglacials was caused by the speed of Northern Hemisphere ice sheet melting, through the “bipolar seesaw” mechanism derived from ocean circulations driven in the North Atlantic.

In chapter 3, the responses of basal mass balance of Antarctic ice shelves to climate changes are investigated. The climatic outputs of an atmosphere–ocean general circulation model of a doubling of CO_2 and Last Glacial Maximum conditions are used to force a circumpolar ocean model that resolves ice shelf cavity circulation. It is found that the basal melting rate change due to warming is much greater than due to cooling. This is mainly because the intrusion of warm water onto the continental shelves, linked to sea ice production and climate change, is crucial in determining the basal melt rate of many ice shelves. The results indicate the water mass formation associated with sea ice production and brine rejection in the Antarctic coast by the atmospheric processes,

combined with the subsurface ocean temperature change, are important to basal melting of Antarctic ice shelves.

In chapter 4, based on the results of the Chapter 2 and 3, I discuss how the different climates between the early LIG and the early PIG could constrain the future retreatment of Antarctic ice sheet. The climate of the LIG is compared with future projection based on CO_2 emission scenarios of RCP 4.5 and 8.5. Although the mechanisms of Antarctic warming are different, the early LIG and the future climate change exhibit warmer winter Antarctic surface air temperature and subsurface ocean temperature in the Antarctic region. The time series of future projection indicate the extent of Antarctic warming would reach the LIG within ~300 years even in a stabilized CO_2. According to the results of the climate model, it is suggested that it may reach the threshold of a several meters of sea level rise due to the retreatment of Antarctic Ice Sheet in near future, even under a reduced emission and stabilized atmospheric CO_2 concentrations.