【Grant-in-Aid for Specially Promoted Research】

Roles of sea ice in climate change: long-term by Antarctic and short-term by Arctic

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Project Information	Project Number : 25H00002　Project Period (FY) : 2025-2029 Keywords : sea ice, deep water circulation, ice-ocean albedo feedback, Arctic research icebreaker, satellite microwave radiometer

Purpose and Background of the Research

●Outline of the Research

Over the past 40 years, the Arctic summer sea ice extent has decreased by half (Figs. 1 & 2), Antarctic sea ice began to decline eight years ago and reached a record low in 2023 (Fig. 1). Sea ice formation releases high-salinity, dense water that sinks and drives deep water circulation (Figs. 3 & 4). This circulation has timescales of decades to millennia and plays a crucial role in long-term climate change due to the ocean's large heat capacity. Around Antarctica, extensive sea ice production generates Antarctic Bottom Water, driving global deep circulation (Fig. 3). Similarly, sea ice formation in the Okhotsk Sea produces dense intermediate water in the North Pacific. Reports from the IPCC suggest weakening of intermediate/deep water circulations, though the causes remain unknown. If the circulations weaken, heat and CO_2 transport could slow down, leading to more extreme climate and accelerated global warming. The dramatic loss of Arctic sea ice has already affected the global climate, but the exact mechanisms driving this decline are still unclear. This research will examine the cause and effects of on-going global sea ice decline

Q1: Does sea ice variability influence ocean circulation and climate change? We focus on changes in sea ice production in Antarctica and the Okhotsk Sea.

Q2: What is the mechanism of on-going sea ice decline? We focus on the albedo (reflectance to solar radiation) feedback effect between sea ice and open water?

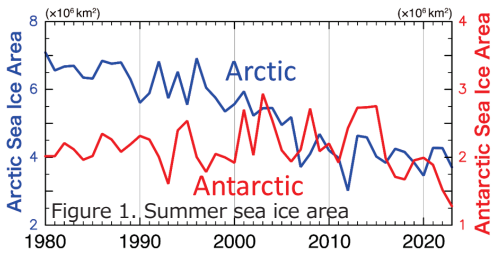


Figure 1. Summer sea ice area

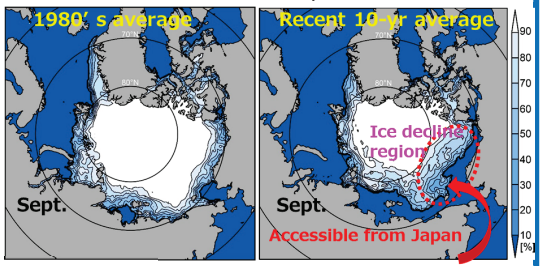


Figure 2. Change in summer Arctic sea ice

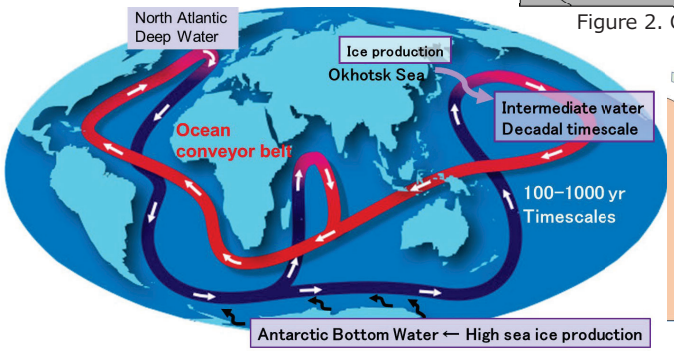


Figure 3. Deep water circulation by high sea ice production

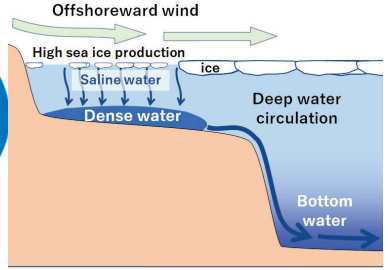


Figure 4. Bottom water formation by coastal high sea ice production

●Originality & International Superiority

Method to estimate sea ice production

Our research group has developed a method to estimate sea ice production using satellite microwave data and heat calculations. We were the first in the world to reveal a clear relationship between high sea ice production areas and intermediate/deep water formation regions (Fig. 5).

Launch of the Arctic Icebreaker *"Mirai II"*

The Arctic research vessel *Mirai II* will be launched in fiscal year 2026. The region of extreme sea ice decline in the Arctic Ocean is relatively accessible from Japan (Fig. 2), making *Mirai II* one of the world's most powerful observation platforms for this area.

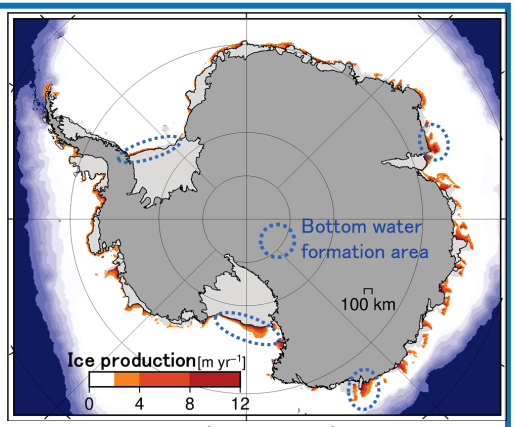


Figure 5. Annual sea ice production

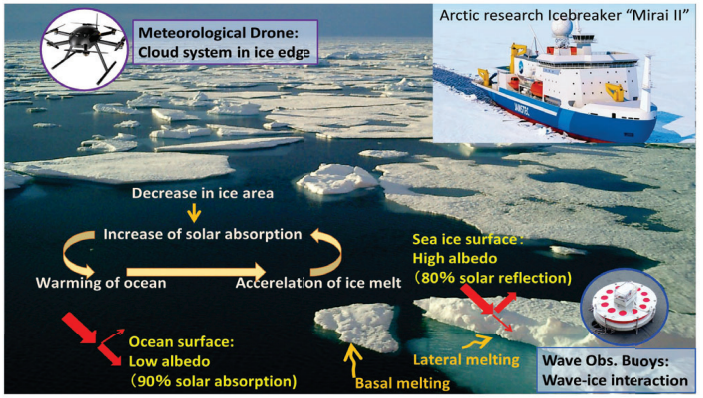
Expected Research Achievements

●Research Plan

For Q1: ① By developing algorithms for past satellite microwave data, we will create a global dataset of sea ice production spanning 50 years and clarify its long-term relationship with intermediate/deep water variability. ② High sea ice production in the Okhotsk Sea drives the intermediate overturning of the North Pacific. By resuming ocean monitoring with float observations, we aim to clarify the relationship between the Okhotsk sea ice production and overturning of the North Pacific.

For Q2: ③ As a key mechanism for the rapid decline of Arctic sea ice, ice-ocean albedo feedback, explained in Fig.6, has been proposed based on satellite data. We will verify this mechanism through direct observations from the icebreaker *Mirai II*. ④ To investigate two potential factors for Arctic sea ice variability—"wave-ice interactions" and "cloud-aerosol system at the ice edge"—, we will conduct field observations using ice-mounted wave observation buoys and a meteorological drone. ⑤ Regarding Antarctic sea ice variability, we will collaborate with the Japanese Antarctic Research Expedition and conduct observations from the icebreaker *Shirase*.

Expected Impact: By incorporating our findings into climate models used in the IPCC, the research will contribute to understanding and prediction of climate change.



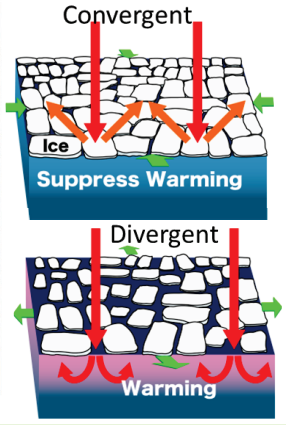


Figure 6. Acceleration of sea-ice melt by ice-ocean albedo feedback

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