【Grant-in-Aid for Scientific Research (S)】

Deciphering climate change and variation in Antarctic fast ice from icebreaker records

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Purpose and Background of the Research

●Outline of the Research

This study aims to detect signs of sea ice change in the Antarctic Ocean by examining the sea ice change in Lützow-Holm Bay, East Antarctica, where the Syowa Station is located. Fast ice thickness varies over time due to intermittent breakup by swells and runoff by wind. However, ice thickness is also affected by water temperature. Recently, ice thickness reduced due to rising water temperatures in the bay. The objectives of this study are to understand the mechanisms of fast ice breakup by swells, the long-term changes in ice thickness and water temperature, and to analyze the icebreaker navigation records. Expected outcomes are a 20-year coupled wave-ice-ocean reanalysis and an interpretation of the 20-year navigation records. The research cores are the Antarctic research expedition, physical/numerical wave-ice tank experiments, and wave-ice-ocean coupled modeling. The research combines science and engineering with application in icebreaker navigation technology on Arctic shipping routes.

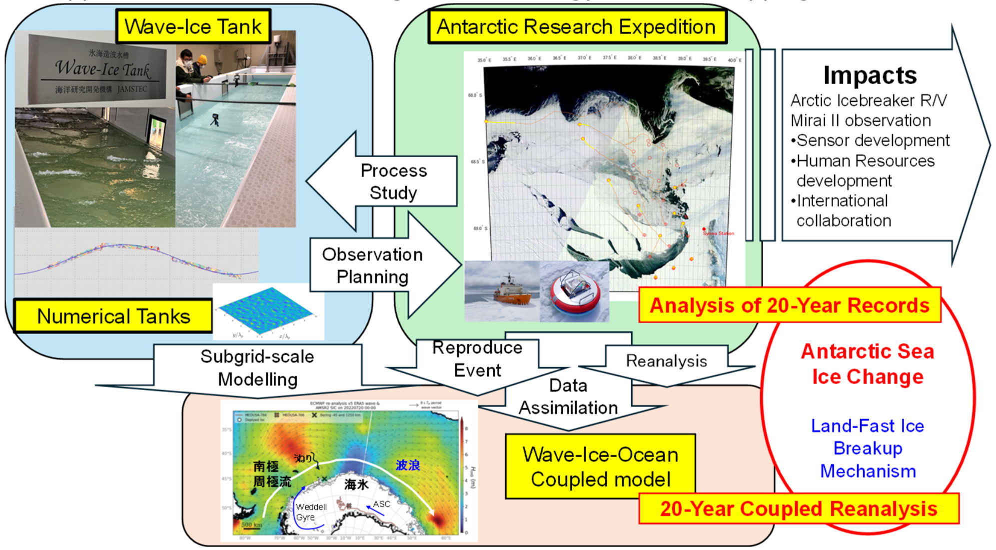

Figure 1. An overview of the research, expected outcomes, and impacts

●Background

There was no trend (1979-2020) in the Antarctic sea ice extent (IPCC AR6) until 2023 when the Antarctic sea ice extent recorded a historic low. The loss of the Antarctic ice sheet is partly due to the melting and collapse of ice shelves. In Lützow-Holm Bay, the fast ice remains even in summer, protecting the ice shelves from swells propagating from the Southern Ocean and preventing the icebreaker Shirase from sailing. The records since 1956 of Japan's Antarctic observations revealed a decadal variation of the ice thickness. In 2023, we observed for the first time the breakup and runoff of fast ice (2022-2024 Kakenhi (A)). Continuous monitoring is necessary to determine whether the fast ice will transition to a growth phase and become multi-year ice or pass a tipping point due to climate change and undergo repeated collapse due to swells.

●Outstanding questions, objectives and goal

Over the past 40 years (1983 to 2023), the number of ramming operations by Shirase (1st and 2nd generation) has increased and decreased twice (Figure 2). Studies suggest that the proportion of weak snow ice gradually increases, making it more susceptible to breakup by swells. However, ice thickness is also affected by long-term changes in water temperature. In recent years, the ice thickness decreased due to rising water temperatures in the bay, and large-scale breakup events repeated, a possible sign of climate change. The goal is to detect such a signature in the Antarctic Ocean.

Objectives; investigate the mechanisms of 1) fast ice breakup by swell; 2) the interannual variation in ice thickness and water temperature; and 3) Deciphering icebreaker navigation records

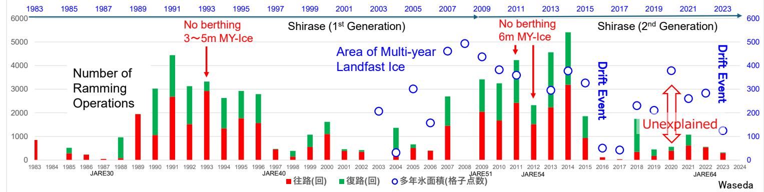

Figure 2. Number of Shirase ramming operations (red: outbound, green: inbound) and area of multi-year fast ice (blue circle)

Expected Research Achievements

●JARE– monitoring fast ice breakup, deciphering 20-year ship record

Install wave buoys (~40) each year to monitor the fast ice breakup process in Lützow-Holm Bay (started in 2023). The key is to monitor changes in sea ice's thickness and mechanical properties (Fig. 1). Correlating the Shirase's hull motion, propulsion, structural response, weather, oceanographic, and ice conditions, the ice conditions over the past 20 years will be estimated from the past ship measurement data (Fig. 3).

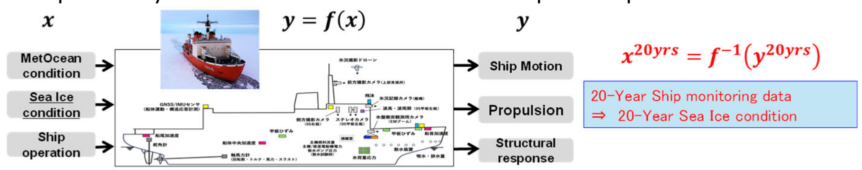

Figure 3. Inverse analysis of sea ice conditions using 20-year icebreaker records

●Wave-ice-wind-tank; numerical tank

Using a unique wave-ice-wind tunnel (8m x 1.5m x 0.6m), investigate the generation of sea ice and mechanical growth of ice under the influence of waves, the breakup and the transport of sea ice by waves. The attenuation and nonlinear interactions of waves under sea ice will be investigated (Fig. 4). These processes will be modeled (subgrid scale).

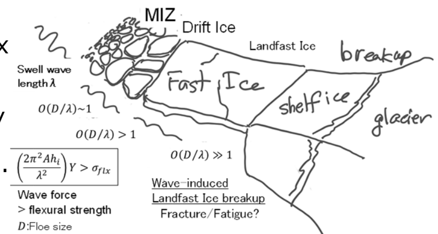

Figure 4. Waves, buffer zone (MIZ, DIZ), and Land fast ice

●20-year reanalysis of wave-ice-ocean

While weather and wave events cause sea ice breakup and runoff, snow-ice accumulation and water temperature fluctuation are slow processes changing the ice strength. A constructed coupled wave-ice-ocean model for L-H Bay will be used to reproduce breakup events and conduct a 20-year reanalysis. Ocean modeling with a considerable lack of in-situ data is a challenge (Fig. 5). We aim to improve the accuracy of the ice edge, drift ice zone, and fast ice by coupling sea ice and waves (Fig. 4).

●Expected outcomes

Sea ice reduction is pronounced in the Arctic Ocean. The technology and knowledge gained in this study will be applied in research using the Arctic R/V Mirai II. Human resources will be developed.

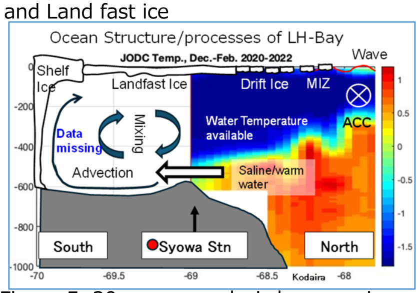

Figure 5. 20-year reanalysis by wave-ice-ocean coupled model

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