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Author(s)	本田, 茉莉子
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博士（環境科学）　　氏　名/Applicant　本田　茉莉子

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Seasonal and interannual variabilities in temperature, salinity, sea ice-melt amount, and primary production in the southern Sea of Okhotsk
（オホーツク海南部における水温・塩分・海氷融解量・生物基礎生産の季節・経年変動）

The Sea of Okhotsk, a marginal sea of the North Pacific, represents the southernmost sea in the Northern Hemisphere with a sizable seasonal sea-ice cover. The coastal polynya of the northwestern Sea of Okhotsk is formed by the prevailing northwesterly winds bring very cold air mass over the Okhotsk Sea. The sea ice produced in the northwest region is advected to the south by the winds and the East Sakhalin Current (ESC). The ESC intensifies in winter, flows southward along the Sakhalin Island and transports negative heat and freshwater related with sea-ice and river discharge from the Amur River to southern regions. In recent decades, surface air temperature over the upstream region of the cold winds blowing into the Sea of Okhotsk has warmed more rapidly than the global average, leading to reduced sea-ice production in the northwestern coastal polynya. In contrast, the Soya Warm Current (SWC), which originates from the Japan Sea, transports heat and salt into the southern Okhotsk Sea, particularly along the Hokkaido coast. The Japan Sea has experienced remarkable surface warming in recent decades (Lee and Park, 2019; JMA, 2023; Usui and Hirose, 2025). Hence, the recent warming in the Japan Sea is likely to affect the southern Okhotsk Sea via the SWC.

In the first part of this study, the sea-ice melt amount in the Sea of Okhotsk was estimated from spring hydrographic data accumulated over nearly a century. Immediately after sea ice melts completely, a low-salinity surface layer distributes above the Winter Water layer at the freezing point. Sea ice-melt amounts are estimated by integrating the salinity deficit from Winter Water for each vertical profile. An algorithm was developed to automatically identify profiles showing a clear salinity deficit, which was then converted into the ice-melt amount for all available data. The climatological distribution revealed that the ice-melt amount decreases toward the ice edge, with large values around northern Sakhalin, consistent with spatial variations in ice thickness. In the southern region (south of 48°N), where sea ice is advected from the north, the mean meltwater thickness was estimated as ~71 cm. The ice-melt amount in this region has decreased by approximately 30% since the 1990s, likely affecting the regional climate through reduced latent heat release and influencing biological productivity via weakened stratification. Moreover, no significant long-term trend was detected during 1930–1970, implying that this method can extract sea-ice information even before the satellite era.

In the second part, interannual variations in temperature and salinity were investigated on the shelf off Hokkaido, where the SWC is distributed, using 40 years of observational data. A major challenge is to resolve the

strong temperature and salinity fronts between the SWC and offshore waters to accurately capture interannual variability. To solve this, a new mapping method (Mensah and Ohshima, 2023) was applied to construct updated climatological fields. Analysis of anomalies relative to the climatology revealed a distinct warming trend, which is confined to the SWC region, with the largest increase (1.35 °C over 40 years) occurring at depths of 30–50 m. This warming is mainly driven by inflow from the Japan Sea rather than by local atmospheric forcing, consistent with the warming trends in sea surface temperature and 2 m air temperature over the southern Japan Sea. The absence of a warming signal offshore of the SWC can be explained by annual winter cooling under sea-ice cover, which resets accumulated heat anomalies within that year. In contrast, a significant freshening trend was observed in autumn in the offshore region, likely associated with increased Amur River discharge after 2010. Time-series analyses demonstrated that temperature, salinity, and SWC transport vary synchronously, despite substantial interannual variability.

In the third part, seasonal variations in biological primary productivity in the Okhotsk Sea were analyzed using profiling float data equipped with dissolved oxygen sensors. The Okhotsk Sea typically experiences a prominent spring bloom after sea-ice melt. Satellite observations of chlorophyll a concentration show high values in spring and autumn but not in summer. However, ship-based observations (Kasai et al., 2015) indicated that summer primary production integrated over the euphotic layer is comparable to that in spring and autumn. The floats with oxygen sensors, deployed in the Okhotsk Sea, recorded vertical profiles of temperature, salinity, and dissolved oxygen at intervals of 5–10 days. I focused on oxygen supersaturation from spring to late summer and the oxygen increase in summer. Oxygen supersaturation appeared in the surface layer (0–20 m) during April–June, shifted to the subsurface layer (20–40 m) in July–August, and disappeared by October. The increase in dissolved oxygen during July–August was converted to Net Community Production (NCP) using the Redfield ratio, and its magnitude corresponded to approximately one-third to one-half of the spring NCP showed by Kishi et al. (2021). Composite analysis of NCP with vertical profiles of stratification revealed that subsurface NCP maxima occurred just below the depth of maximum stratification, consistent with mechanisms of subsurface bloom formation in other regions. These results suggest that profiling floats can capture subsurface blooms invisible to satellites in the Sea of Okhotsk.