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Role of sea ice on satellite-observed chlorophyll-*a* concentration variations during spring bloom in the East/Japan sea ☆

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ABSTRACT

The relationship between the spring bloom along the Primorye coast and the sea ice of the Tatarskiy Strait in the northern region of the East/Japan Sea, a semi-enclosed marginal sea in the North Pacific, was investigated using the ten-year SeaWiFS chlorophyll-*a* concentration data and DMSP/SSMI sea ice concentration data from 1998 to 2007. Year-to-year variations in the chlorophyll-*a* concentrations in the spring were positively correlated with those of the sea ice concentrations in the Tatarskiy Strait in the previous winter with a correlation coefficient of 0.77. Abrupt increases in nutrients, essential for the spring bloom in the upper ocean during spring, were supplied from sea ice-melted waters. Time series of vertical distributions of the nutrients indicated that phosphate concentrations were extremely elevated in the upper ocean (less than 100 m) without any connection to high concentrations in the deep waters below. The water mass from sea ice provided preferable conditions for the spring bloom through changes in the vertical stratification structure of the water columns. Along-coast ratios of stability parameters between two neighboring months clearly showed the rapid progression of the generation of a shallow pycnocline due to fresh water originating from sea ice. This study addressed the importance of the physical environment for biogeochemical processes in semi-enclosed marginal seas affected by local sea ice.

1. Introduction

Many studies have investigated the significance of the East/Japan Sea as a miniature global ocean and its important role in providing clues about future global climate change (Ichiye, 1984; Kim et al., 2001). One of the outstanding features is the existence of sea ice in the Tatarskiy Strait in the northern region of the East/Japan Sea (Fig. 1a), even though the spatial scales are relatively small compared with the large amount of polar ice in the Arctic and Antarctic Oceans. Sea ice in the Tatar Strait is known to be generated by strong northwesterly storms in the winter and decays periodically following an annual cycle, providing fresh and cold water into the Liman Cold Current (LCC) along the Russian coast (Martin et al., 1992, 1995; Martin and Kawase, 1998; Riser et al., 1999; Park et al., 2006).

Variation in sea ice growth, persistence, and decay and the linkage between sea ice and marine ecosystems has been recognized in several bodies of water, e.g., the Antarctic Ocean, the Okhotsk Sea, the Labrador Sea, and the Bering Sea (e.g., Eicken, 1992; Niebauer et al., 1995; Hirawake et al., 2005; Mustapha and Saitoh, 2008; Wu et al., 2007). Not a few studies have been performed using satellite ocean color data in the East/Japan Sea. Using monthly mean composite images of the Coastal Zone Color Scanner (CZCS), the temporal and spatial variability of phytoplankton pigment concentrations in the East/Japan Sea were described and the relationship between the critical depth and mixed layer depth was examined to explain the mechanisms of the spring and fall blooms (Kim et al., 2000). Seasonal and interannual variabilities of chlorophyll-*a* concentrations in the East/Japan Sea were also studied by Yamada et al. (2004). They depicted spatial differences in the starting time of the spring and fall blooms and discussed the effects of wind forcing and the thermocline on the phytoplankton bloom across the entire basin. Jo et al. (2007) showed that an early spring bloom in the East/Japan Sea can be initiated during an Asian dust event in association with precipitation using SeaWiFS (Sea-viewing Wide Field-of-View

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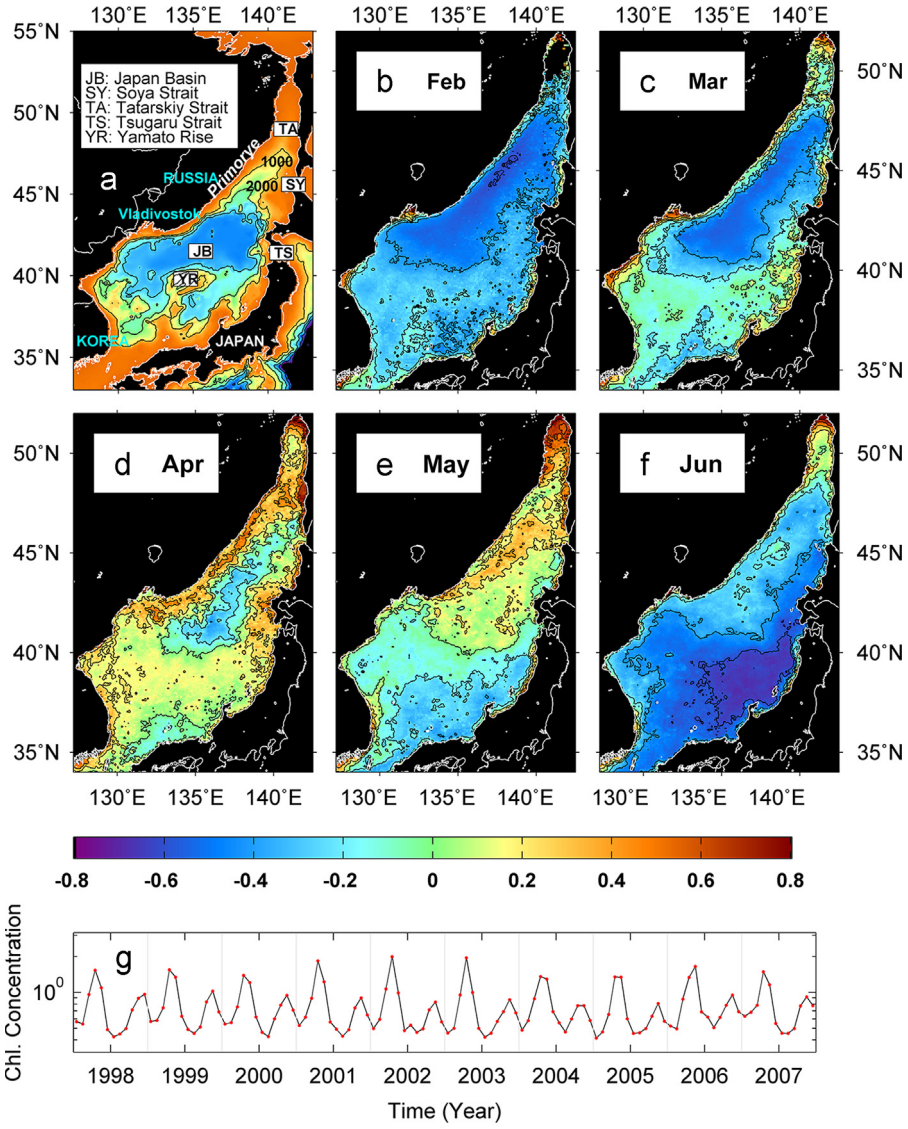

Fig. 1. (a) Bathymetry of the study area in the East/Japan Sea and ten-year averaged monthly SeaWiFS chlorophyll-*a* concentration (mg m^{-3}) distributions in (b) February, (c) March, (d) April, (e) May, and (f) June, and (g) time variations of spatially averaged chlorophyll-*a* concentrations for the period 1998–2007.

Sensor) chlorophyll-*a* concentration data. For coastal regions with dominant upwelling (e.g., Park and Kim, 2010), Yoo and Park (2009) suggested that the biological productivity of the southwestern region was primarily enhanced by wind-driven upwelling along the Korean coast using SeaWiFS data.

In the East/Japan Sea, ecological responses to variations in sea ice should be clarified because it is a globally important semi-enclosed marginal sea with fast-evolving changes in the oceanic environment. The existence of sea ice in the Tatarskiy Strait has been discussed in numerous papers (e.g., Martin et al., 1992, 1995; Martin and Kawase, 1998; Park et al., 2006). Yamada et al. (2004) presented a brief conjecture on the role of sea ice on the spring bloom along the Primorye coast by investigating year-to-year variations of sea ice area in the Tatarskiy Strait and by addressing the formation of the halocline formed by low salinity water from melting sea ice. They also showed that the fresh water off the Primorye coast was not discharged from the Amur River in spring because the northern part of the Tatarskiy Strait was covered with thick ice. However, except for Yamada et al. (2004), none of the previous research has given much attention to the role of sea ice on the ecosystem in the East/Japan Sea.

Because the spring bloom is a biological response to the physical environment, it is important to understand the physical processes involved. The primary hypothesis in this study is that the sea ice of the Tatarskiy Strait in the previous winter has a large effect on the phytoplankton bloom by providing preferable conditions with relatively cold and fresh water and a shallow pycnocline at the Primorye coast due to the southwestward advection of sea ice-melted surface water. Water columns in the continental shelf region would experience a rapid stratification because of the supply of ice-melted fresh water to the sea surface during the spring bloom. Therefore, we may expect the sea ice to have a significant role in the biogeochemical processes associated with the variations of satellite-observed chlorophyll-*a* concentrations away from the sea ice source area.

The goals of this study were to examine the year-to-year and monthly variations of sea ice concentrations in the East/Japan Sea (1) to identify the relationship between sea ice concentrations in the winter and satellite-observed chlorophyll-*a* concentration of phytoplankton during the spring bloom for rapid population growth and (2) to understand the processes and mechanisms of the spring bloom by analyzing the variations in nutrients and changes in the vertical stratification of water masses.