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Regional productivity of phytoplankton in the Western Arctic Ocean during summer in 2010

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ABSTRACT

Phytoplankton production measurements were conducted in the northeast Chukchi Sea and western Canada Basin in the summer season, from 20 July to 10 August 2010, using a ^{13}C–^{15}N dual tracer technique. The daily carbon uptake rate in the northeast Chukchi Sea in 2010 was extremely low, with a mean of 29.8 mg C m^{-2} d^{-1} (SD = 17.6 mg C m^{-2} d^{-1}). Regional and temporal differences caused the low production rate compared to previous studies in the northeast Chukchi Sea. In the western Canada Basin, the mean daily carbon uptake rate from this study was 20.6 mg C m^{-2} d^{-1}, which was influenced by the dominance of small phytoplankton resulting in a low carbon uptake rate in the region. The regionally high nitrate uptake rates compared to ammonium uptake rates in the western Canada Basin can be caused by warm-core eddies, which supply high levels of nitrate to the euphotic zone. Warm-core eddies in the Canada Basin substantially enhanced local phytoplankton production and the contribution of large phytoplankton. Therefore, the effects of physical forcing events (such as "an" eddy) on the primary production need to be examined further to better understand changes of primary production under ongoing environmental changes in the Arctic Ocean.

1. Introduction

Over the last decade, the Arctic Ocean has experienced anomalous sea ice loss during summer (Stroeve et al., 2007; Comiso et al., 2008). The sea ice loss creates longer ice-free periods and thus might allow more heating of the upper ocean during summer (Steele et al., 2008). The largest sea ice loss has been observed in the Pacific sector of the Arctic Ocean (Western Arctic Ocean), which is a region that is well matched in both the spatial pattern of sea ice loss and the distribution of warm Pacific Summer Water (PSW) (Shimada et al., 2006). In addition, Steele et al. (2010) found that about 80% of the upper ocean warming in the Pacific sector of the Arctic Ocean during summer originated in local atmospheric heating.

The continuing loss of sea ice could result in changes to various physical environmental factors in the Arctic Ocean. Changes in surface water properties, such as the near-surface temperature maximum (Jackson et al., 2010) and surface ocean acidification (Yamamoto-Kawai et al., 2009), have been observed in the Canada Basin. In addition, a strong Beaufort Gyre (Shimada et al., 2006; Yang, 2009) and thereby the accumulation of surface fresh water within the Beaufort Gyre (Proshutinsky et al., 2009) resulted in the nutricline deepening (McLaughlin and Carmack, 2010) in the Canada Basin. Under the deepened nutricline condition, eddies could have an important role in nutrient transport and phytoplankton distribution (Nishino et al., 2011a, 2013). According to Kawaguchi et al. (2012), eddies may appear more frequently because they are likely to be formed by baroclinic instability of the enhanced westward flow of the Beaufort Gyre associated with the recent loss of sea ice.

These recent environmental changes, caused mainly by the loss of sea ice, have greatly affected the physiological status, community structure, and primary production of phytoplankton (Li et al., 2009; Lasternas and Agustı´, 2010; Lee et al., 2010). Li et al. (2009) found the average phytoplankton size to be decreasing in the freshening and warming surface layer in the Canada Basin. Lasternas and Agustı´ (2010) also reported exceptional dominance of the colonial form of *Phaeocystis pouchetii* following the massive ice losses in summer 2007. In addition, Lee et al. (2010) observed higher carbon and nitrogen uptake rates in phytoplankton with the increased quantity of light passing through thinner sea ice.

Because sea ice loss is strongly related to the increase in underwater irradiance, primary production might be expected to increase in the Arctic Ocean. Based on satellite ocean color data, Arrigo et al.

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(2008) found that large increases in annual net primary production by phytoplankton on the continental shelves of the Siberian, Laptev, and Chukchi Seas, which can be explained by the increased open water area and a longer growing season. In addition, the increased wind forcing caused by the ice edge retreats can supply deep nutrient-rich waters to the phytoplankton and thus increased primary production on the shelves can be expected (Carmack and Chapman, 2003; Carmack et al., 2004). However, the upper ocean warming and freshening caused by sea ice melting may increase stratification and prevent the nutrient inputs from deep waters to the euphotic zone (Hill et al., 2013). Thus, it is important to monitor how recent phytoplankton production has changed under the rapidly changing environmental conditions in the region of the Arctic Ocean because phytoplankton production could be an important trigger of ecosystem change.

Our first Arctic cruise was conducted onboard the Korean research icebreaker *ARAON* in the Western Arctic Ocean (e.g., Northeast Chukchi Sea and Western Canada Basin) during summer in 2010. Here we describe the general characteristics of phytoplankton production in the region and compare our findings with those of previous studies to improve understanding of changes in primary production under the ongoing environmental changes in the western Arctic Ocean. In addition, the potential effects of an anticyclonic warm-core eddy found in the western Canada Basin on the phytoplankton biomass and production rate are discussed.

2. Materials and methods

2.1. Study area

Oceanographic sampling was undertaken at a total of 38 stations in the northeast Chukchi Sea and the western Canada Basin (mostly in the Chukchi Cap and the west of the Northwind Ridge; Fig. 1) from 20 July to 10 August 2010, onboard the Korean research icebreaker *ARAON*. For deck incubation, primary productivity was measured at 19 selected morning stations (Fig. 1). The study area was comprised of a shallow shelf (<100 m) and a deep basin (>3000 m). To understand the regional characteristics of primary productivity, the study area was separated into the northeast Chukchi Sea and the western Canada Basin using 165°W longitude as a boundary. The northeast Chukchi Sea is relatively shallow with a depth of <100–350 m and contained five productivity stations (Stns. 1, 3, 4, 35, and 38). The productivity stations around the Chukchi Cap and the Northwind Ridge including the western boundary of the Canada Basin were categorized as the western Canada Basin stations (Stns. 6, 8, 10, 13, 14, 16, 18, 21, 23, 27, 28, 29, 31, and 32) (Fig. 1).

2.2. Hydrographic and water sampling

Water column profiles of water temperature, salinity, and density were obtained from downcast measurements using a Seabird SBE-911+ CTD profiler mounted on a rosette. Water samples were collected with the rosette sampler equipped with 20 l Niskin bottles.

The depth of the euphotic zone (Z_{eu}) in this study was defined as the depth receiving 1% of the near-surface PAR value (photosynthetically active radiation) determined using an underwater PAR sensor (LI-COR underwater 4π light sensor), lowered with CTD/rosette sampler. The mixed-layer depth (Z_m) was defined here as the shallowest depth where seawater density first exceeded the value recorded at 5 m depth by 0.03 kg m^{-3} (Gardner et al., 1995).

2.3. Nutrient and chlorophyll a concentration measurements

The discrete water samples used for measurement of dissolved inorganic nutrient concentrations (nitrate, ammonium, phosphate, and silicate) were analyzed onboard immediately after collection, using an automated nutrient analyzer (SEAL, QuAAtro) following

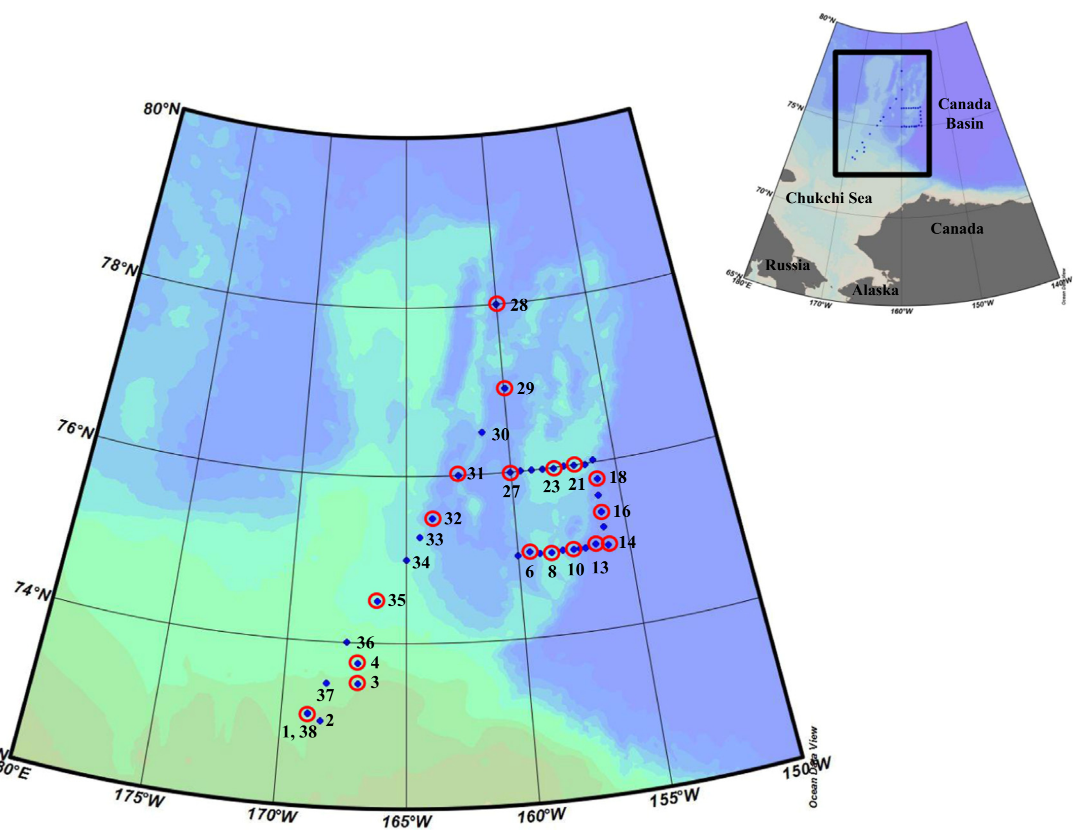

Fig. 1. Locations of the primary productivity stations during the 2010 *ARAON* cruise in the northeast Chukchi Sea and western Canada Basin. Location of st. 38 represents a revisit of st. 1.