Bio-related material cycle in a coastal polynya observed with moored acoustic and optical instruments in the northeastern Chukchi Sea

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A coastal polynya is a region of high biological production as well as high ice production. During the sea ice melting season (spring), a massive phytoplankton bloom occurs there. This is caused by a favorable light environment for phytoplankton growth due to seasonal sea ice retreat and surface stratification formed by melt water (e.g. Arrigo et al., 2004). According to recent studies based on field measurements, a large phytoplankton bloom beneath fully consolidated pack ice can occur before the sea ice breakup in spring (e.g. Arrigo et al., 2014). This under-ice phytoplankton bloom likely contributes to the spring bloom. In addition, particulate materials released from melting sea ice such as iron are potential triggers of phytoplankton bloom in spring (e.g. Kanna et al., 2014). The major source of materials inside sea ice is considered to be ocean bottom sediment (e.g. Eicken et al., 2005). Some laboratory experiments indicated that ocean bottom sediment is incorporated into sea ice through an interaction with newly formed frazil ice in the water column (e.g. Kempema et al., 1983). This process is called suspension freezing. In a coastal polynya, underwater frazil ice formation associated with supercooling under turbulent conditions (the most effective ice production process) and re-suspension of ocean bottom sediment by wind-induced vertical mixing and convection can result in an occurrence of suspension freezing (e.g. Dethleff and Kuhlmann, 2010). These processes above suggest a significant relationship between high biological and ice production in a polynya. However, observational data for these phenomena are limited due to logistical and technical difficulties in sea ice regions. This study investigates the series of bio-related processes caused by sea ice formation in a coastal polynya using the mooring data obtained in the region off Utqiaġvik (formerly known as Barrow) in the northeastern Chukchi Sea along with the sea ice radar and meteorological data.

A series of coastal polynya often appears in the Chukchi Sea along the Alaskan coast (e.g. Martin et al., 2004). In the region off Utqiaġvik locating in the northernmost Alaska, mooring observations have been conducted since 2009 through a collaboration between Hokkaido University and the University of Alaska Fairbanks. For the observation in 2014 – 15, a mooring was deployed ~5 km offshore at 71.333ºN, 156.866ºW in 45.05 m of water, and year-long data were obtained with an Ice-Profiling Sonar, an Acoustic Doppler Current Profiler (ADCP), a conductivity-temperature recorder, a temperature-pressure recorder and a turbidity-chlorophyll sensor. The meteorological data were derived from the ERA-Interim data.

During November – February, continuous thin ice periods over 5 days to 2 weeks were identified by the ADCP data. These periods were associated with westward (offshore) winds, indicating the formation of a coastal polynya around the mooring site. As a typical example, Fig. 1 shows time series of the mooring and meteorological data during the period of 20 December – 3 January. For periods denoted by black bars above Fig. 1a, the ADCP detected the acoustic signals with large volume backscatter strength (SV) of > -70 dB intensified near the surface (Fig. 1a). At these times, potential supercooling of ~30 mK was recorded at 34 m and the in-situ water temperature dropped down to the freezing temperature at the depth (Fig. 1b). These facts indicate that the major scatterer is frazil ice formed in the water column associated with supercooling. On the other hand, for the periods denoted by gray bars above Fig. 1a, the ADCP detected different kind of strong acoustic signals with SV of ~-75 dB intensified in deeper depths (Fig. 1a). The bottom-intensified signature implies that the source originates from the bottom. In addition, signals were associated with strong currents with speeds of up to 1.2 m/s (Fig. 1d). Thus, the scatterers are likely sedimentary particles dispersed and transported upward from the bottom. At same times, turbidity at 35 m increased due to re-suspended sediment clearly (Fig. 1c). During the period from ~12:00 on 30 December to ~12:00 on the next day, although the acoustic signals of re-suspension of ocean bottom sediment were not detected by the ADCP, turbidity was higher than that before the re-suspension (before 29 December). This indicates that sedimentary particles remained to be suspended at the depth. On 31 December, frazil ice was detected in the water column shallower than 30 m (Fig. 1a). In contrast, on 31 December – 1 January, the bottom-intensified signals of re-suspended sediment were detected in the entire water column, and the surface-intensified frazil ice signals were detected simultaneously (Fig. 1a). These facts strongly indicate an occurrence of suspension freezing.

During the sea ice melting season (May – June), we identify signals of phytoplankton bloom. Figure 2 is similar to Fig. 1

expect for the period of 20 May – 2 June. Chlorophyll-a concentration at 35 m began to increase from 22 May and maintained relatively high value of 5 – 8 μg/L for 25 May – 1 June (Fig. 2c). According to the sea ice radar installed in Utqiaġvik, a breakup of fast ice occurred on late 23 May. Thus, this increase in chlorophyll-a concentration is likely due to a spring phytoplankton bloom. For this period, turbidity was kept at low values (Fig. 2c). After 24 May, acoustic signals with SV of -80 – -75 dB were detected (Fig. 2a). The local maximum of SV of these signals was located at the middle of the water column, and thus, these signals are different from those of frazil ice and re-suspended sediment. These signals likely originated from some biological activities related to the phytoplankton bloom such as zooplanktons. On the other hand, on 21 – 23 May, during the period denoted by a black bar above Fig. 2a, surface-intensified acoustic signals were detected by the ADCP (Fig.2a). The sea ice radar data show that fast ice covered the region around the mooring site during this period. The water temperature was 1 – 1.5 K higher than the freezing point (Fig. 2b). The values of SV of these signals (~-75 dB) were lower than those of frazil ice signals. Thus, the signals are not due to frazil ice. The air temperature was mostly above 0 ºC (Fig. 2e). Because of such high air and water temperatures, ice probably melted on the both of upper and lower sides. Considering all of these facts above, we infer that the scatterers of those signals are particulate matters released from melting sea ice such as ice algae and sedimentary particles. Chlorophyll-a concentration increased after those acoustic signals were detected (Figs. 2a and 2c). This potentially indicates an impact of such particulate matters on the phytoplankton bloom.

As described above, based on year-long mooring data, we identified potential evidences of sediment incorporation into sea ice through suspension freezing and phytoplankton blooms. This study infer the processes of high biological production in a coastal polynya and the role of sea ice in bio-related material cycle.

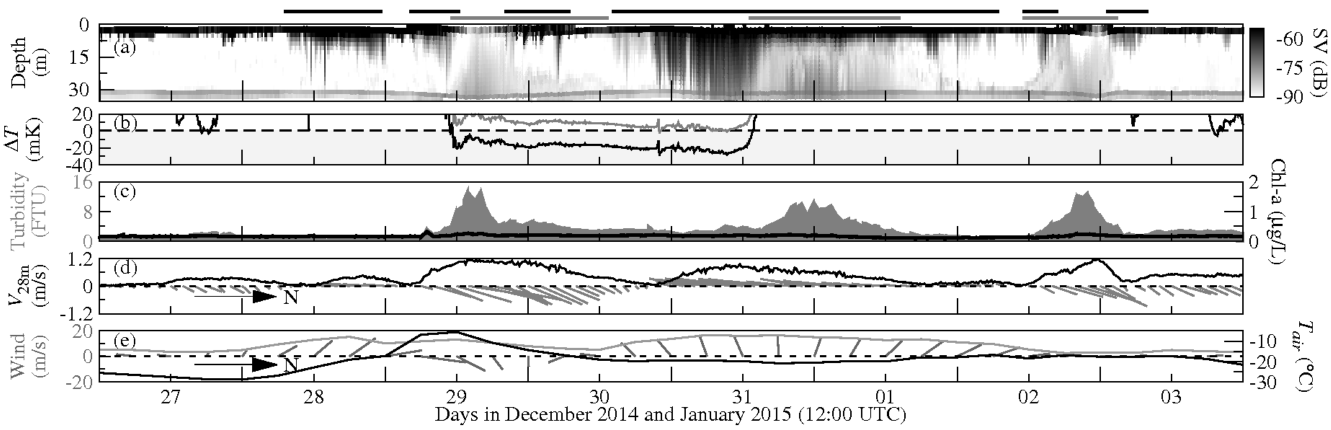

Figure 1. Time series of mooring and meteorological data during the period from 27 December to 3 January. (a) The vertical profile of the volume backscatter strength (SV) derived from ADCP data. (b) The water temperature at 34 m relative to the freezing point at the depth (gray) and the potential temperature relative to the freezing point at the surface (black). (c) Turbidity (gray shade) and chlorophyll-a concentration (black) at 35 m. (d) The current vector (gray) and speed (black) at 27 – 29 m. (e) The wind vector (gray) and speed (light-gray) and the air temperature (black) derived from the ERA-Interim data. Upward vectors denote westward (offshore).

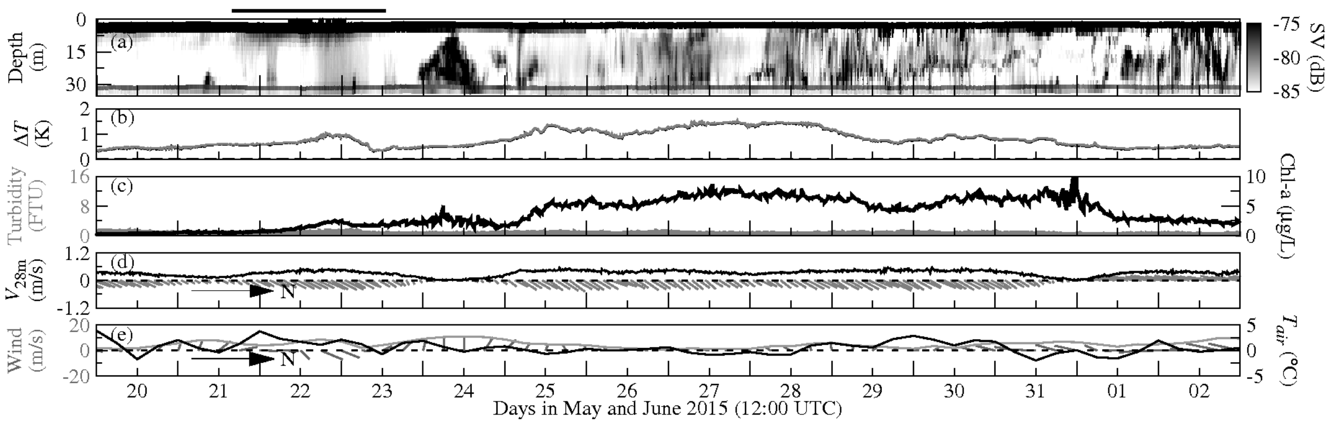

Figure 2. Similar to Fig. 1, except for the period of 20 May – 2 June.