Coincidental occurrence process of frazil ice and high biomass off Amery Ice Shelf

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Antarctic coastal regions are the most productive regions in the Southern Ocean and could dramatically influence global carbon cycle and ecosystems. During the austral spring, large phytoplankton blooms develop in polynyas with peak productivity occurring from December to January. According to the chlorophyll estimation from satellite, net primary production (NPP) in the Antarctic coastal polynyas rapidly declines from February to March (Arrigo et al., 2015).
Recent studies have found the regions with high biomass in Antarctic coastal regions during February-March (Lieser et al., 2015; DeJong et al., 2018). This high biomass is collaterally observed with frazil ice. Chlorophyll estimation algorithms using Moderate Resolution Imaging Spectroradiometer (MODIS) data mask pixels with high sea ice coverage to prevent the contamination by excess reflection of visible light. Therefore, the regions with high biomass collaterally observed with frazil ice have not been counted in NPP estimation in Antarctic coastal regions. These high biomass regions potentially have a large impact for global carbon cycle as the CO_2 sink. However, incidence processes and causes of frazil ice with high biomass have not been investigated in details. In this study, we focus on the regions of the Cape Darnley polynya and offshore of the Amery Ice Shelf in February and March during 2003-2011 to understand the processes and causes of high biomass collaterally observed with frazil ice.
First, we calculated Green Index from MODIS surface reflectance data obtained from the study area to identify green colored regions implicate high biomass. Second, we identified the region of frazil ice, using the algorithm that discriminates ice type between frazil ice and thin solid ice from AMSR-E passive microwave data (Nakata et al., 2019). These two analyses clearly show that the high biomass and frazil ice coincidentally occur both temporally and spatially in late summer. In particular, both of high biomass and frazil ice have a peak in their distributions at the same location about 50 km offshore of the Amery Ice Shelf in March. This is also suggesting an unknown frazil ice formation process distinctly different from a coastal polynya process.
We consider Ice Shelf Water (ISW) as a trigger of coincidental occurrence of frazil ice and high biomass. According to the CTD-tag data obtained from seals in the region off Amery Ice Shelf in late summer, ISW that is partly supercooled exists at depths of 250-400 m and the surface water is heated by solar radiation in the region from the ice shelf front to 68.3 deg. S. While in the region north of 68.2 deg. S, the surface water has reached the freezing point. Previous studies reported that ISW flows out to 50-100 km offshore from the ice shelf front and generates frazil ice at depths of 250-300 m (Dieckmann et al., 1986; Hughes et al., 2013).
To summarize the above analyses, coincidental occurence of frazil ice and high biomass is assumed to be caused by the following processes.
1. ISW is formed and flows out to the outside of Amery Ice Shelf cold cavity.
2. ISW becomes supercooled during the outflow, and frazil ice is generated.
3. Generated frazil ice gradually rises toward the surface. In the region south of 68.3deg. S, frazil ice is melted because of heated surface water. Frazil ice can appear at the surface in the region north of 68.2 deg. S, where the surface water reaches the freezing point.

4. Frazil ice scavenges phytoplankton existing in water column and carries it to the surface. Simultaneously, iron contained in ISW enhances the biological production and increases biomass. The process proposed in this study may also occur in regions just off other ice shelves. In the future, we should clarify the details of the process off Amery Ice Shelf with in-situ observation and explore the possibility of occurrence in regions off the other ice shelves.

Keywords: sea ice, polynya, ice shelf water, remote sensing, biological production

