Summer decay of landfast sea ice on the Siberian coast

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1. Introduction

On the Siberian coast, due to the shallow water and exsiting, landfast ice is a typical ice regime feature in winter. Landfast ice is normally a stable ice sheet, congelation ice is the dominant ice type of Eurasian landfast ice (Reimnitz et al., 1995; Polyakov et al., 2003). It covers the shelf area for four to eight months each year. Because of the lack of mobility, landfast blocks the heat and momentum exchange between atmosphere and ocean. The freezing and melting of landfast ice make important contributions to salt and freshwater budgets, thereby influencing water circulation, dense water production and the location of upwelling and downwelling zones (Macdonald et al., 1999). Besides, the existence of landfast ice also influcences the coastal oceanic ecosystem, including marine mamals and phytoplankton (Tynan and DeMaster, 1997, Arrigo and Dijken, 2004)

The first documented landfast ice thickness chart in the Eurasian continental shelf (Fig.1) was based on observations and results from a calibrated analytical ice thickness model applied for ice season1938/1939 (Zubov, 1945). The seasonal landfast ice thickness was about 1.8 m in the East Siberian Sea decreasing from there to 1.2 – 1.5 m in the Kara Sea and to 1.5 m in the Chukchi Sea. Along the Taymyr Peninsula, small amount of landfast ice may survive over the summer season to become multi-year fast ice (Reimnitz et al., 1995). While the Barents, Baltic, and Bering Seas show increases in landfast ice area, the overall change for the Northern Hemisphere is negative, about −12.27 (±2.8) × 103 km2 yr^{-1}, or −7 (±1.5) % decade^{-1} relative to the long-term mean. Except in a few coastal regions, the seasonal duration of landfast ice is shorter overall, particularly in the Laptev, East Siberian, and Chukchi Seas (Johannessen, 2007). The observed changes in Arctic landfast ice could have profound impacts on the Arctic coasts.

In winter, new ice starts to form in October. landfast ice appears in different areas of the Siberian coast at different times-from the middle of September to early December. The formation of landfast ice becomes possible when young ice achieves a thickness of 10-30cm (Johannessen et al., 2007). Its outer edge further out from the coast in winter as ice grows thicker, reaching the longest offishore distance during April and May (Barber and Hanesiak, 2004, Divine et al., 2005, Volkov et al., 2002). In spring, solar, atmospheric and oceanic heat gains cause sea ice melting, and sunlight also causes internal melting of the ice and is able to penetrate the ice, landfast ice starts to breakup in May.

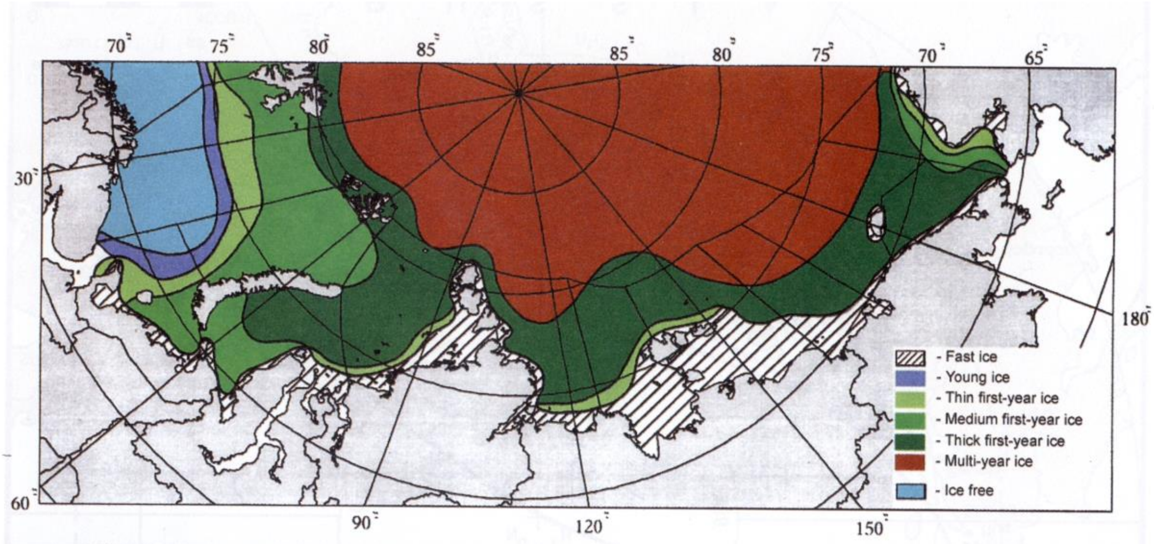

Figure 1. Average distribution of different ice types in Siberian Coast at the end of the ice cover freezing period (Johannessen, 2007).

In this study, the summer decay of landfast on the Siberian coast is examined based on satellite remote sensing and mathematical models. The summer season is a critical part of the annual cycle. Satellite images are used to monitor ice breakups, including its onset, process and final disappearance. The models were forced by the surface heat fluxes, which were derived from observations at Russian weather stations. The objectives were to investigate sequence of ice breakup, from the beginning along deterioration of ice to final disappearance, and the role of the thermal and mechanical effects. Also the question of the absence of multi-year landfast ice was examined.

2. Data and method

The formation, stability and breakage of the landfast ice follow the evolution of ice thickness and strength (Zubov, 1945; Leppäranta, 2011). We integrated modelling and remote sensing images, to understand the summer decay of landfast ice. The summer periods 2002-2015 were selected for the time dimension.

Landfast ice area is highly related with the underwater topography. The topographical data we used in this study is obtained from the International Bathymetric Chart of the Arctic Ocean (IBCAO), with a resolution of 500m. Figure 2 shows the bathymetry of Siberian coast.

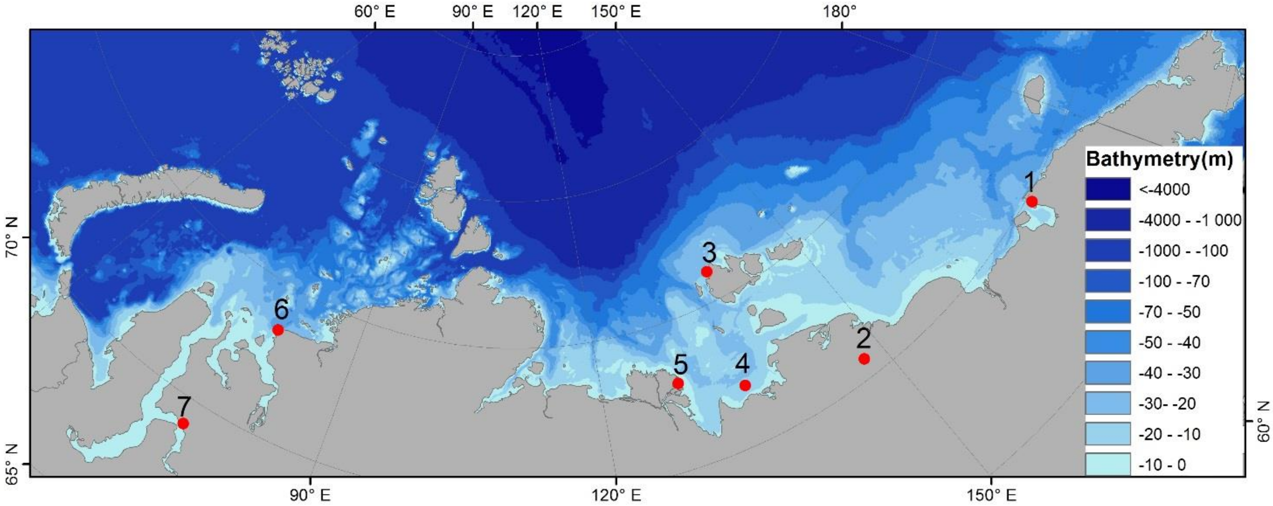

Figure 2. Bathymetry of Siberian coast. Red dots are Russian weather stations.

To get a picture about the evolution of the ice condition, High-resolution visible satellite images are used, since they reflect well the real ice conditions and provide a direct insight into the ice seasons. Both MODIS and Landsat-8 satellite images were used to map the ice conditions in the season and serve as a regional reference. MODIS images (250m resolution) are used to monitor daily changes of the landfast ice zone. Landsat images can give detailed information of ice conditions, with a resolution of 30m.

3. Results

3.1 landfast ice area

In winter, the boundary of landfast ice can achieve a stable location along the 20-30m isobath. The least developed area of landfast ice is the southwestern Chuckchi Sea, while the most significant area of landfast ice are observed near Siberian Islands, which has a mild depth difference. The width can reach 300km in the eastern Laptev Sea and 200km in the western East Siberian Sea. For areas with a sharp depth difference, Such as places near the shores of Novaya Zemlya, along the Amderma and Yamal coast, the east shores of the Severnaya Zemlya archipelago and the Taymyr coast in the Laptev Sea, as well as along the Chuckchi Sea coast, the width of landfast ice can range from 2-4 to 10-30 km.

3.2 Decay process of landfast ice

Summer decay of ice cover begins in the marginal zone. The date for the onset of decay in different region varies from mid-May to mid-June, depending mostly on latitudes. Ice decay process starts earliest in Chukchi Sea and western Kara Sea, which is located in the lowest latitude, and latest along the shores of Northern land islands. Ice breakup onset in Kara Sea varies in different years, ranging from late May to early June, which is easily influenced by first-year ice distribution.

In the process of landfast ice decay there are various stages, culminating in the melting, breakups of landfast ice and therefor its final decay. Thermal process results in thinner ice thickness and instability of ice structure, which gives way to ice breakups. In the most significant landfast ice area, small breakup begins at the side of the landfast ice edge and after several days, which usually falls on the end of June and the first 10-day of July, cracks start to appear, and extends for a short period of time (about a day) over a significant distance, spreading sometimes up to the very shore, resulting in a big breakup event. This event can last for 20 days, producing a large amount of ice floes. During this period, large floes are fractured into smaller floes, including medium floes, small floes and ice cake, due to diverging and melting. At the end of July, landfast ice is finally disappear, leaving just ice floes near shore.

The pattern mentioned above occurs to large areas of landfast ice, which is facing open water, such as western Eastern Siberian Sea and eastern Laptev Sea. Other conditions, including small areas facing open water, areas between lands, present different patterns of ice decay.Small areas facing open water is mainly distributed in Chukchi Sea, Kara Sea and the coast of islands. For such places, no significant breakup can be seen, but continuous small breakups occur, resulting the final decay of landfast ice. For areas between lands, such as straits and the entrance of half-closed bays, ice break from the outer edge. As breakups go deeper for both sides of straits, landfast ice disappear and floes drift away.

When all the ice are not away from land, landfast ice disappear, though large amounts of ice floes exist in many area. Ice in Chukchi Sea and western Kara Sea disappears in mid-June, and 10 days later in Eastern Siberian Sea and eastern Kara Sea. Still, ice disappears latest near Northern Land Islands, which occurs at the end of August.

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