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# Physical structures and interior melt of the central Arctic sea ice/snow in summer 2012

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ABSTRACT

The physical structures, solar irradiance and reflectance of snow and sea ice in high Arctic were investigated based on snow pit, ice coring, and borehole measurements from August 29 to September 2 in 2012. In all of the six short-term stations, the snow cover was stratified: fresh snow in the top (if any) with dendritic grains (1–4 mm in grain size), fine-grained snow in the middle (4–9 mm), and coarsely spherical grained snow in the bottom (8–16 mm). The incident and reflected irradiance were wavelength-dependent, whereas the albedo and its dependence on wavelength were relatively diverse and scattering. The integrated albedos were 0.47–0.92, largely depending on the snow type, grain size, thickness, and water content. Ice coring and thin sections indicated that all ice covers were first-year, and were dominated by the columnar grained ice. And all the ice cores were characterized by a large number of gas and brine pockets and tubes, the size and content of which were much greater than those of sea ice cover during the winter congelation. The vertical stratifications of ice density, temperature and salinity were quantified using linear regression. Overall, the salinity and density increased with an increasing depth, while the temperature decreased against depth except the top 10–20 cm, where the temperature was dependent on the air and snow temperatures. The estimates of inclusion volume (including gas and brine) gave insight into the sea ice composition (ice-brine/gas matrix). The comparison of the present volumetric fraction of inclusions with previous ones indicated to some degree that the sea ice inclusion volume increased in the ice interior, thus the volumetric fraction of pure ice decreased at the end of summer melt, indicating a rigorous melting within the Pacific Arctic sea ice covers. Our work suggests that the volumetric fraction of sea ice inclusions as a function of temperature, density and salinity can be considered as an alternative indicator for Arctic sea ice reduction, just like the sea ice extent, thickness, age and melting duration.



## 1. Introduction

There is considerable interest in changes in Arctic ice cover, particularly in response to global warming. A growing number of observation, remote sensing and prediction work have demonstrated that the Arctic sea ice cover is declining at the end of the summer melting during the past three decades, with respect to ice extent (Stroeve et al., 2012), ice thickness (Kwok and Intersteiner, 2011; Kwok and Rothrock, 2009), and, thus ice volume (Kwok et al., 2009; Laxon et al., 2013). Besides, the Arctic perennial ice, the year-round ice cover, has significantly reduced and perhaps underwent a faster loss during the last decade, according to the QuikSCAT/SeaWinds satellite and buoy data (Maslanik et al., 2011; Nghiem et al., 2007; Polyakov et al., 2012). Passive microwave data have also indicated that the timing trends of the melt onset and freeze-up, and therefore melt season length, ranged from −1.0 to −7.3 d per decade, 1.1 to 8.4 d per decade, and 1.2 to 12.9 d per decade, respectively, for 10 different regions over the last 30 years (Markus et al., 2009; Rodrigues, 2009). Accordingly, it is reasonable to believe that the time horizon for summer ice-free Arctic is very likely to occur in the first half of the 21st century, roughly 2030 ± 10 years (Overland and Wang, 2013).

The decrease in Arctic sea ice is of great climatic, environmental, economic, social and wildlife management interest. For instance, the diminishing sea ice has had a leading role in recent Arctic temperature amplification; it is said that the rise in Arctic near-surface air temperature has been almost twice as large as the global average in recent decades (Screen and Simmonds, 2010). One of the most visible and straightforward phenomena resulting from the low ice concentration is the appearance of NW and NE Passage in summer Arctic Ocean (Liu and Kronbak, 2010). The ice conditions, such as the concentration and thickness,

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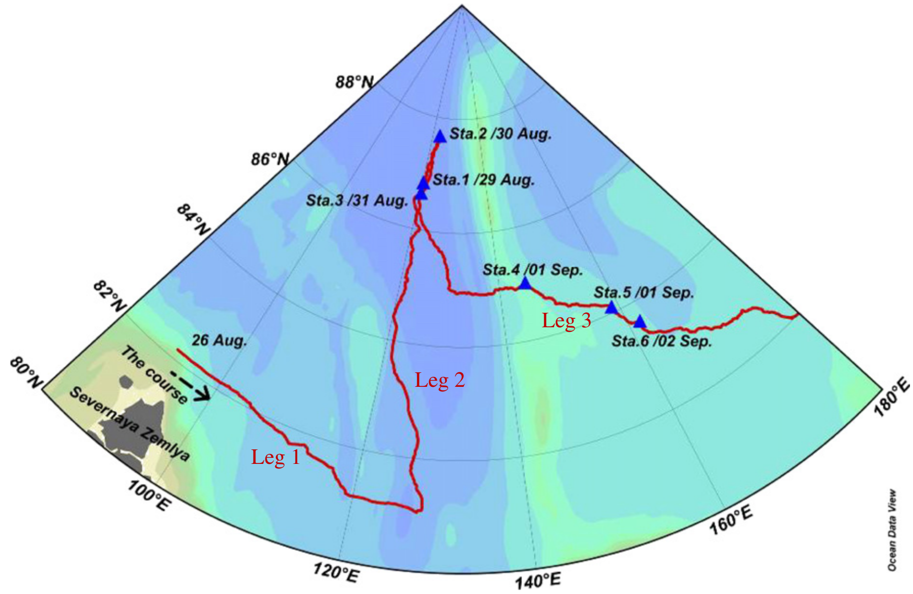


**Fig. 1.** Short term ice station positions (blue triangles) during the high-latitude cruise (red line).

dominate the way the ice cover contacts with icebreaker or commercial vessels, and the forces exerted on vessels' keels (Su et al., 2011a, 2011b and Timco and Johnston, 2004). Actually, the nature of the sea ice cover, i.e. the physical structure with respect to crystalline texture, gas and brine configuration, determines the mechanical properties that are vital to ice loads upon ships and marine and coastal infrastructures (Moslet, 2007; Schulson, 1999). Therefore, adequate knowledge of sea ice physics is of particular interest to the increases in shipping in summer, in icebreaker design, and in offshore construction.

Recently, most of published work has been conducted on the quantitative reduction of Arctic sea ice, whether due to rigorous melting (global warming) or ice drifting. Yet, changes in the physical properties of summer sea ice cover are not well known, for instance the microstructure, salinity, density and temperature. The changes in the physical structure of ice cover shed light on the changes in ice–impurity (gas and brine inclusions) matrix, i.e. the interior melting. Although the melt in the interior is also an indispensable amount to quantify the ice loss/melting together with extent and thickness decrease (Leppäranta et al., 2010), few publications have been reported on the summer Arctic sea ice.

In this paper we present the in situ investigations on the microstructure, physical and optical properties of sea ice/snow in central Arctic in summer of 2012, and discussed the implications of the present results to the fast change in Arctic sea ice. Section 2 introduces the Chinese research expedition, and the in situ methodology. Section 3 compiles the physical structures and properties of sea ice and snow, and spectral albedos at each ice station. In Section 4 we estimate the gas and brine volume within sea ice, and discuss the implications to the sea ice reduction or deterioration in terms of the interior melt. Conclusions are presented in the last section.

## 2. Materials and methods

### 2.1. The Arctic expedition

Arctic sea ice is one of the most sensitive regions to the global climate change. Arctic sea ice decline, particularly, is one of the most visible and significant changes in the climate system, which has captured the research interests all around the world. Since 1998, China has launched five summer-Arctic research expeditions (CHINARE). During the 5th CHINARE in 2012 (CHINARE-2012), the R/V Xuelong track within ice zone fell into two sections: Northeast Passage and high-latitude voyages (Fig. 1). The Northeast Passage sailing passed through the Chukchi Sea, East Siberia Sea and Laptev Sea along the Eurasian coast from July 19 to August 2. The high-latitude navigation passed through north of Svalbard islands, central Arctic Ocean, and Chukchi Sea from August 23 to September 8. During the navigation, routine visual observations were made every half an hour from the bridge by trained observers, to document ice thickness, type, concentration, and melt pond coverage. Surface temperature of water and sea ice along the tracks were measured by a downward-looking infrared thermometer.

Six short-term ice stations (~2 h) were conducted in the central Arctic during the second sailing section. Snow/ice thickness was measured by hand and EM devices. Ice cores were collected for density, salinity, temperature and structural texture observations. The surface albedo of snow/ice was also investigated for ~1–2 h during each ice station.

### 2.2. Measurements

#### 2.2.1. Snow covers

Snow covers were investigated at each ice station with respect to thickness, temperature, density, grain size, texture, and spectral albedo. All investigating approaches are described as follows.

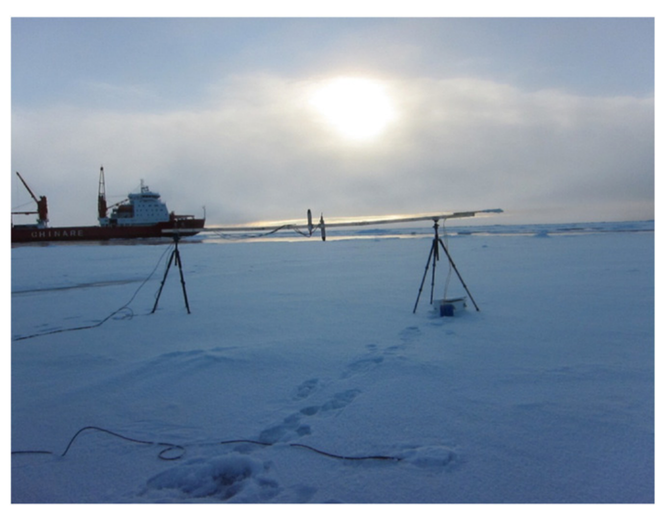

**Fig. 2.** Irradiance investigation of snow on the ice cover.