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Iceberg and sea ice drift tracking and analysis off north-east Greenland

Renat Yulmetov [a,b,*], Aleksey Marchenko [a,b], Sveinung Løset [a,b]

[a] The University Centre in Svalbard, Pb. 156, 9171 Longyearbyen, Norway
[b] Sustainable Arctic Marine and Coastal Technology (SAMCoT), Centre for Research-Based Innovation (CRI), Norwegian University of Science and Technology (NTNU), Trondheim, Norway

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ABSTRACT

Drifting icebergs and sea ice floes can be serious threats to offshore structures in the Arctic; however, information about their drift is limited. We performed GPS tracking of 9 icebergs and 10 ice floes in the Kanumas area of the Greenland Sea during 2012–2014. The obtained coordinates were used to analyse the drift trajectories, derived velocities, spectra and relative drift of the icebergs and sea ice. This paper presents statistical data on the drift velocities and demonstrates the differences between drifts in the shear ice zone and the central pack or marginal ice zone. The maximum drift speed reached by an iceberg was 1.66 m/s, which happened during strong southerly wind at 66°N. The relative drift of icebergs and adjacent sea ice is strongly dependent on ice conditions and wind, but also it is determined by the different types of applied drag forces. Then, spectral analysis revealed that GPS errors may prevent capturing processes faster than one cycle per hour. In addition, for the first time, we measured the rotation of four icebergs around their vertical axes. Icebergs make an average of between one and two revolutions per day under the periodic tidal current. However, the instantaneous angular velocity reached 0.001 rad/s at some moments. Finally, this paper proposes an iceberg drift model including the rotation. The modelling results are in good agreement with the measured evolution of the icebergs' yaw angles. The drift data and the rotation model can be used when planning offshore activities in the area or as an input for numerical models involving sea ice.

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1. Introduction

The main challenges for Arctic offshore operations are remoteness, low temperatures and the presence of sea ice and icebergs in surrounding waters. Knowledge about ice conditions is necessary for design and operation of Arctic structures. For more fundamental scientific reasons, these interests are linked to global warming and global ice cover dynamics and kinematics. The ice cover extent and its discharge from the Arctic may serve as climate change indicators (Stroeve et al., 2012).

Traditionally, the observation of ice and iceberg drift has been performed by drifting stations, buoys and remote sensing. The famous International Arctic Buoy Program started in 1979 and has tracked more than 650 Argos-type buoys since then (Pfirman et al., 1997). Initially, the Argos buoys gave position estimation errors in the range of a few hundred metres. Such accuracy was sufficient for the gridded global scale climate models and the Arctic mass balance calculations.

Modern Lagrangian ice drift products based on synthetic aperture radar image analysis have provided velocity estimates with a precision of a few millimetres per second. However, their time resolution ranges from several hours to several days (Weiss, 2013). Such resolution has been sufficient to validate large-scale sea ice drift models (Sumata et al., 2015) but is not sufficient for the tactical scales when hourly forecasts are needed.

Finally, the ice tracking drifters (ITDs) consisting of a GPS module and an Iridium modem have been used to obtain drift patterns and drift speed of ice and icebergs (Larsen et al., 2015) to validate forecasting models (Turnbull et al., 2015; Yulmetov et al., 2012) and to study the frequency response of the ice cover (Leppäranta et al., 2012). This type of tracker benefits from relatively high spatial and time resolutions of GPS transponders and light weight (<5 kg with battery).

Such accurate data are always needed for particular regions in the Arctic. The number of regions related to petroleum offshore development includes the Beaufort Sea, Barents Sea, the Kara Sea, the Pechora Sea, the Greenland Sea, and Sakhalin. Offshore operations in ice-infested waters are subjected to ice actions that can be reduced using ice management. Ice management is commonly defined as the sum of all activities aiming to reduce ice action on an offshore object (Eik, 2008). The success of ice management

* Corresponding author at: The University Centre in Svalbard, Pb. 156, 9171 Longyearbyen, Norway.
E-mail address: RenatY@unis.no (R. Yulmetov).

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depends on knowledge about incoming ice and icebergs, and general environmental conditions.

Usually, physical ice management consists of the separate tasks of ice breaking and iceberg management. However, icebergs might drift together with sea ice towards an offshore structure. The role of broken ice in the iceberg drift and the differences between ice and iceberg drift must be studied for the area. Drift tracks and velocities obtained by the ITDs can be used to validate state-of-the-art numerical models of ice management operations in pack ice (Scibilia et al., 2014; Yulmetov et al., 2016).

A complex survey of ocean and ice conditions over the east Greenland offshore area and in the Fram Strait was conducted during two consecutive research surveys: Oden Arctic Technology Research Cruises (OATRC) in September 2012 and August 2013 (Lubbad et al., 2013; Scibilia et al., 2014). The studies included mechanical tests of sea ice and ice ridges, ocean current measurements and CTD-profiling, mooring deployment and retrieval, ice management trials, ice and iceberg monitoring and tracking, and marine mammal observations.

In this paper we present and analyse drift data obtained from ITDs between autumn 2012 and spring 2014. The analysis includes mostly kinematic characteristics derived from coordinates and time measurements by applying different mathematical operations. We concentrate mostly on engineering applications, and large scale ice cover dynamics is beyond the scope of the study. Deformation characteristics, drift correlations between the trackers and wind/ocean currents are not presented.

The paper is organized as follows: Section 2 gives a brief overview of environmental conditions at the drift area and describes the equipment. Sections 3 and 4 present drift patterns and drift velocities for ice floes and icebergs that were free drifting, landfast or grounded. The relative drift of icebergs and adjacent ice floes is presented in Section 5. The next section analyses drift spectra and recommends that special care should be taken when measuring frequencies higher than one cycle per hour (cph) using GPS. A new approach for measuring iceberg rotation during drift is presented, and the rotation model is proposed in Section 7. The final section provides some conclusions and suggestions for future studies.

2. Setup

The East Greenland Shelf is well known for its heavy ice and iceberg conditions. First-year and multi-year ice together with ice ridges are discharged from the Arctic Basin southwards through

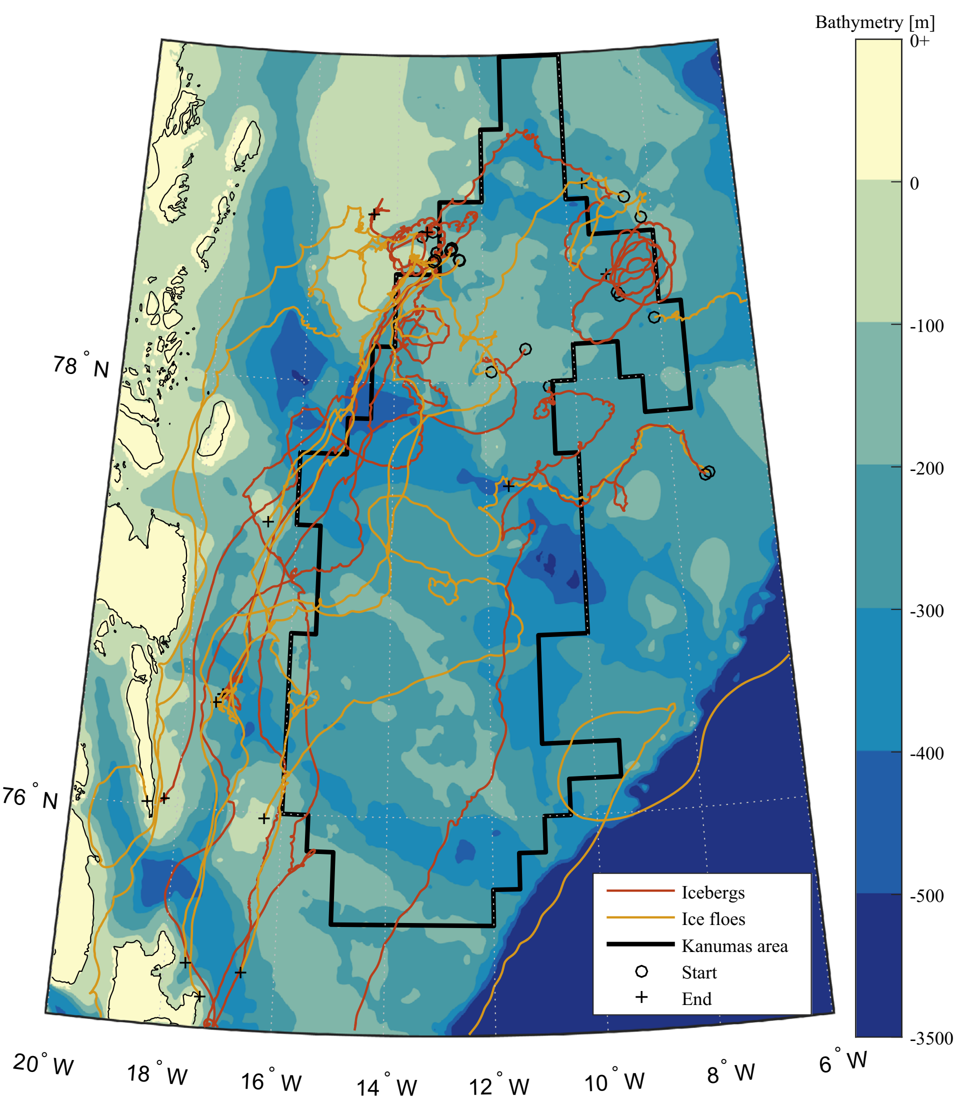

Fig. 1. Drift trajectories of 9 icebergs and 10 ice floes over the Greenland Shelf. A number of icebergs were grounded in the shallow areas of Belgica Bank and to the south-east of Store Koldewey.

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