ODEN ARCTIC TECHNOLOGY RESEARCH CRUISE 2012

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ABSTRACT
Future development of Arctic offshore fields will require knowledge of the metocean and ice conditions in the Arctic basins and it will also require an understanding of the interaction mechanisms between ice and structures. Within the last decades both academia and the petroleum industry have carried out comprehensive studies and model developments for Arctic operations. This work has so far mainly been limited to theoretical studies and physical tank model test. The next natural step towards reducing uncertainties in Arctic offshore operations will be to perform in-situ data measurements at relevant locations. In this context, the Norwegian University of Science and Technology (NTNU) made the initiative to the Oden Arctic Technology Research Cruise 2012 (OATRC2012).

OATRC2012 was an innovative and exciting research programme funded by Statoil and performed by NTNU through the research-based innovation centre: *Sustainable Arctic Marine and Coastal Technology (SAMCoT).* The programme was carried out in collaboration with the Swedish Polar Research Secretary (SPRS) and the Swedish Maritime Administration (SMA). The icebreaker *Oden* was used during the second half of September 2012 as a scientific platform to perform a research expedition to the waters Northeast of Greenland.

OATRC2012 succeeded in the overall cruise objective "*To perform a safe cruise collecting highly desired scientific data and to perform full-scale field trials for testing of key technologies*", and without any accident it provided NTNU/SAMCoT with considerable amount of valuable data. This paper presents OATRC2012, including the expedition's objectives, and gives an overview of the performed research and the main findings.

INTRODUCTION
The Norwegian University of Science and Technology (NTNU) hosts a centre for research-based innovation called "Sustainable Arctic Marine and Coastal Technology (SAMCoT)", see SAMCoT (2013). The centre works with the development of robust technology necessary for sustainable exploration and exploitation of the valuable and vulnerable Arctic region. To researchers in SAMCoT, field work in Arctic waters is extremely useful. This field work does not only provide a wealthy source of knowledge and a considerable amount of full-scale data, but also gives a real-life experience which help SAMCoT researchers, especially the young scholars, to better understand their research topics. In just 2012, SAMCoT organised and performed several field-work activities. The biggest among those was the *Oden Arctic Technology Research Cruise 2012* (OATRC2012) where 27 researchers were on-board the

Swedish icebreaker *Oden* in the waters Northeast of Greenland (NE Greenland). The cruise lasted for 10 days during the second half of September 2012. OATRC2012 was financed by Statoil and executed in collaboration with The Swedish Polar Research Secretariat (SPRS) and the Swedish Maritime Administration (SMA).

The overall objective of OATRC2012 was to *perform a safe cruise collecting highly desired scientific data and to perform full-scale field trials for testing of key technologies*. To the largest extent, the cruise achieved its targets and considerable amount of data were collected and several technologies were tested during the cruise. Safety and environment were considered seriously in the different phases of the project and OATRC2012 ended without a single accident.

OBJECTIVES AND SCOPE OF OATRC2012

The main scientific scope of OATRC2012 was to: 1) study the physical and mechanical properties of sea ice and icebergs, 2) quantify the characteristics of sea-ice and icebergs drift and the influence of the metocean conditions, 3) assess the quality of weather forecast from recognised service providers, 4) evaluate the use of modern technologies in Arctic research, e.g. satellite sensors, micro drones and laser scanner, 5) test seabed mapping using the multi-beam scanner on-board Oden, 6) study the icing phenomenon by measuring sea spray distributions and droplet sizes versus sea state and speed/heading of the ship, 7) examine the performance and manoeuvrability of Oden in different ice conditions and in open water in order to validate and calibrate the numerical models for floaters in ice, 8) study the interaction processes at the waterline between Oden and ice, 9) analyse the efficiency of different ice management scenarios, and 10) carry out several activities within the framework of Arctic environmental research, e.g. turbulence measurements, underwater noise measurements, marine mammal observations, etc.

The research activities were divided into three main work-packages as follows:

- WP0: Pre-Cruise Activities
- WP1: Metocean and Ice Data
- WP2: Ice Management and Ship Manoeuvring Data

Figure 1 illustrates the scope of OATRC2012 and the numerous activities within each work-package. The detailed description of each activity can be found in the OATRC2012 data report, Lubbad et al. (2012).

Table 1: Technical data of *Oden*.

Length	107.75 m
Beam	31.2 m
Draft	7.0-8.5 m
Total power	18 MW, 24500 hp
Speed in open water	15 knots, normal sea speed 11 kn
Crew	20 persons, up to 60 scientists
Icebreaking capability	1.9 m level ice at 3 knots
Bunker capacity	4600 m3, equal to 27000 NM in open sea at 13 knots or 100 days
Displacement	11000 – 13000 tonnes
Propulsion	4 medium speed, 8-cylinder Sulzer diesel engines. 2 propellers in nozzles
Helicopter pad	Mi-8 or equivalent
Building yard	Götaverken-Arendal AB 1988 (NB953)
Owner	Swedish Maritime Administration

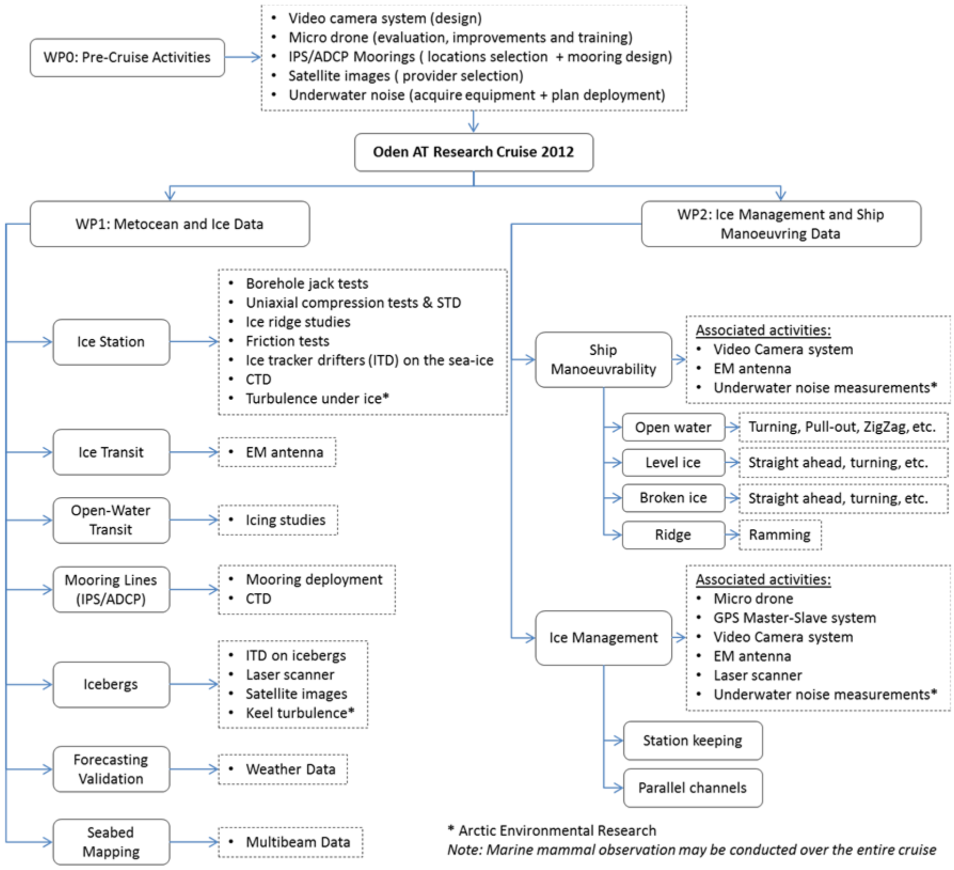


Figure 1: OATRC2012 Research activities.

RESEARCH VESSEL

The Swedish icebreaker *Oden* was used for this research cruise. Figure 2 shows a picture of *Oden* when breaking ice while Table 1 displays the technical data of the icebreaker.

Figure 2: Oden off NE Greenland.

Oden was equipped with different instruments to collect the navigation and propulsion data. Meteorological data were accessible from the weather station on-board. The icebreaker offered multi-beam sonar for seabed mapping and two Motion Response Units (MRUs) to measure the vessel motions in 6 Degrees of freedom. An innovative video system together with an electromagnetic antenna was installed in the bow area to study the interaction between sea-ice and hull of *Oden*.

CRUISE SCHEDULE AND TRACK

The cruise started from Longyearbyen on the 15th of September 2012 and it lasted for 10 days in total. Figure 3 displays the track of *Oden*.

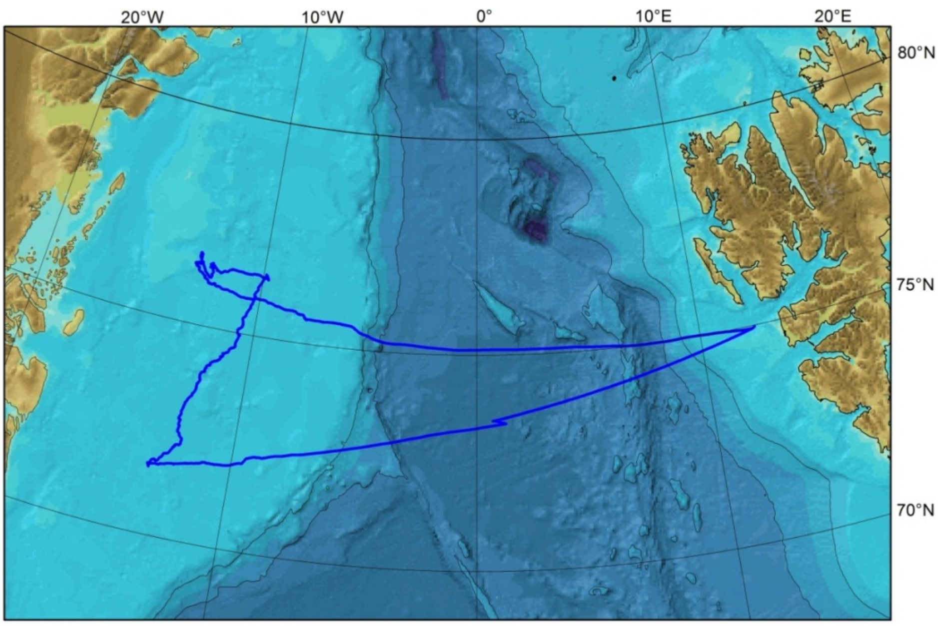


Figure 3: Track of Oden, 15.09-25.09.2012. The southern leg is the track on the way over to NE Greenland.

PERFORMED RESEARCH AND MAIN FINDINGS

The scientific scope of OATRC2012 was relatively wide and a large number of research activities was carried out. Figure 4 shows the approximate time spent on the different activities during the cruise. Due to space limitation in this paper, this section selects only some of the activities for discussion.

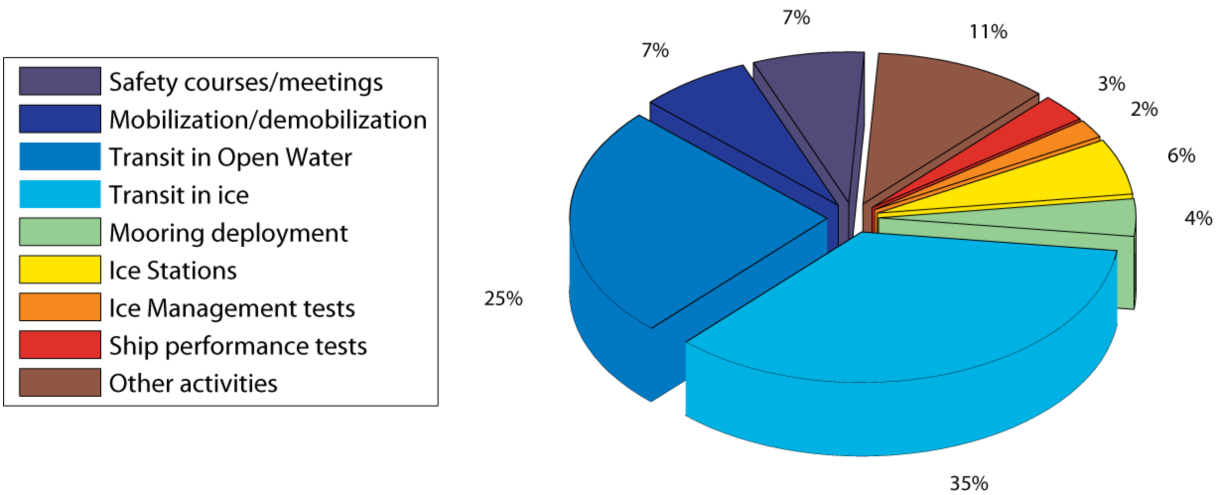
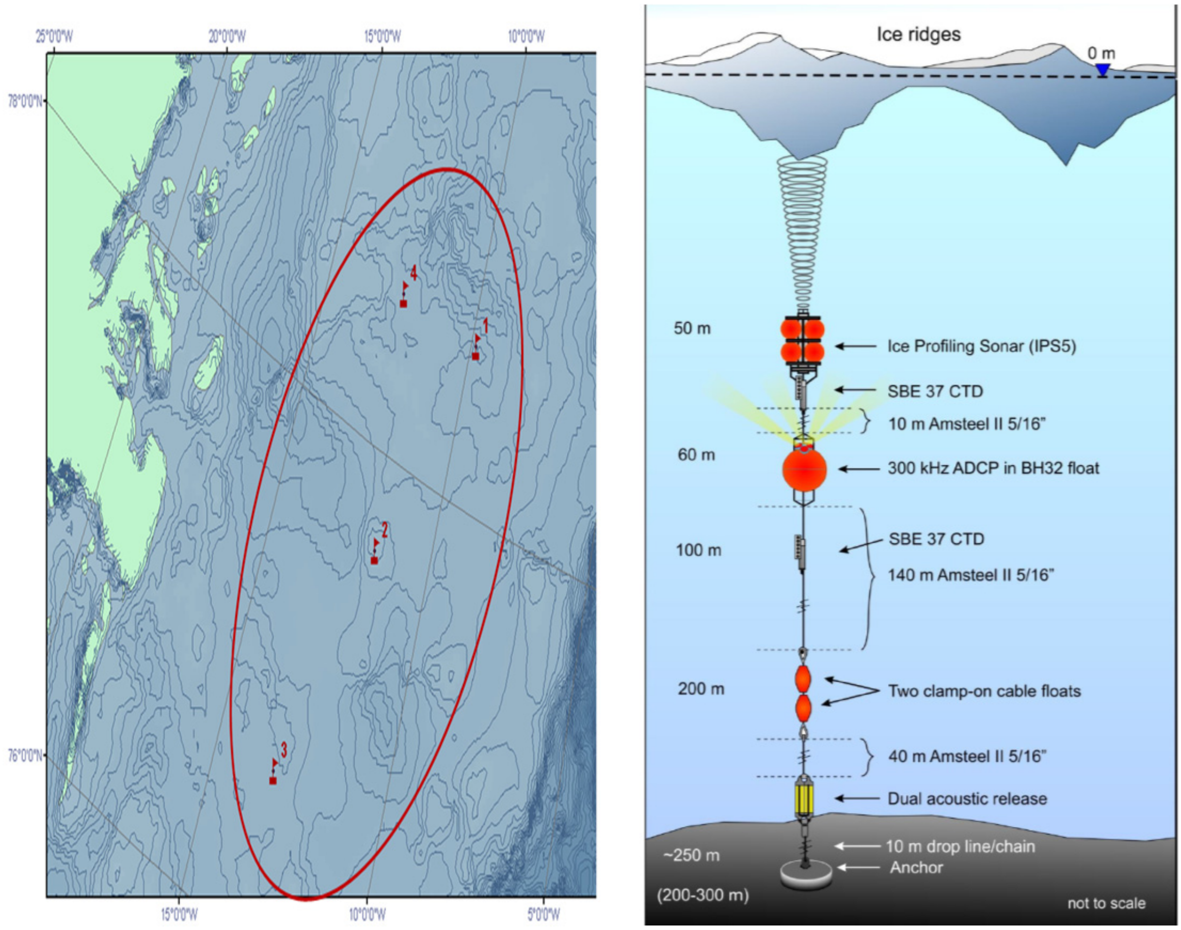


Figure 4: The approximate time spent on the different activities during OATRC2012

Deployment of IPS/ADCP moorings

The Ice Profiling Sonar (IPS) and Acoustic Doppler Current Profiler (ADCP) moorings are specially designed instruments anchored to the seabed and provide data on ice drift, ice thickness including ice ridge keels, sea currents and hydrography. During OATRC2012 four of these moorings were deployed in the positions shown in Figure 5a. The outline of such moorings is illustrated in Figure 5b.



a) b)

Figure 5: IPS/ADCP moorings: a) positions (vertically stretched figure); b) schematic layout.

The deployment was performed after the principle of anchor last. In high ice concentrations, this was done in the way that all elements of the mooring were mounted and connected on the deck of *Oden*. Then *Oden* trusted weakly against a larger floe and the propeller washing provided an opening in the ice cover of about 1.5 ship length. The top buoy was then lowered into the water and pulled the rest of the instruments gently over board in the wake of the ship. Finally the deadweight connected to the port aft-crane was positioned behind the aft and a slip hook was released when the deadweight had been lowered into the water; hence the moorings could be safely and accurately installed on the intended location. The moorings are equipped with batteries of 2-year life-time meaning that the four moorings can log data continuously for a period of two years. Nevertheless, we plan to retrieve the data and to redeploy the moorings in the same positions in the summer of 2013.

Ice Stations

The ice stations were performed by mooring *Oden* to a solid ice floe. After the ship had been moored, the floe was entered by a gangway and the equipment was brought on the ice by the port aft-crane of the ship. An ice station lasts approximately for 5 to 8 hours allowing researchers to perform a considerable number of tests on the ice. The spatial variation of the ice properties was studied by coring the ice at various locations. The profiles for temperature, salinity and density were measured for each ice core. A borehole jack and a uniaxial compression apparatus were used to measure the ice strength. A special testing setup was built to measure friction between ice and ice and also between ice and steel. A number of ice drift trackers were deployed on the ice to measure the ice drift after we had left the site. A few ridges were profiled to study their morphology and properties. Figure 6 gives an impression of the work on one of the two ice stations (Ice Station 1) during the cruise.

During the ice stations, the ice thickness across the entire floes including the ridges was recorded by an Electromagnetic antenna (EM-antenna). Before leaving the floes, Oden would run through the ridges and along the sections recorded by the EM-antenna while recording vessel parameters such as velocity, RPM, vessel motions etc.

Figure 6: Part of the activities on the sea-ice during Ice Station 1 (Location #4).

Iceberg studies

Related to planning and preparations of marine activities in Arctic waters, the encounter frequency of icebergs is one of the most important parameters. The encounter frequency is used to estimate the frequency of impacts between a structure and an iceberg or alternatively the frequency of icebergs entering an alert zone in an ice management system. In order to estimate the encounter frequency, information regarding iceberg presence together with information on size distribution and drift speed distribution need to be known. The total expected number of iceberg encounters can be expressed as (Fuglem et al., 1996):

$$\eta_e = \rho_a \cdot (w_s + \overline{w}_i) \cdot \overline{v}_i \cdot T \quad (1)$$

where ρ_a is the average areal density of icebergs per year (number of icebergs per unit area), w_s is the structure or alert zone width, $\overline{w}_i$ is the mean iceberg length, $\overline{v}_i$ is the mean iceberg drift speed and T is the number of seconds per year.

In order to estimate the average areal density, images taken from air planes or from satellites are usually applied. By collecting images continuously over a region and counting the iceberg detections in each image, it is possible to find average values for ρ_a and also seasonal variations if images are taken each month of the year through several years. Offshore NE Greenland, no systematic iceberg flight reconnaissance has yet taken place. With respect to satellite detections, the icebergs are usually surrounded by sea ice complicating the detection capabilities.

During the *Oden* cruise, iceberg detections from satellite Synthetic Aperture Radar (SAR) sensors were evaluated. Images of different resolution were ordered along the planned *Oden* sailing route. In order to provide ground truth data a combined marine mammal and iceberg watch were present on the bridge as long as there was daylight (typically 13 h per day). The marine radars were also applied for iceberg detections but appeared to be inefficient for his purpose. At a couple of occasions, a helicopter survey was also conducted for iceberg surveillance. Despite varying visibility during the cruise it was in general possible to identify icebergs with high degree of certainty up to 2 nm on each side of the vessel along the sailing route.

44 icebergs were detected visually whereof 4 were tagged with 5 Ice Tracking Drifters (ITDs). Drift data from the drifters are described in an associate paper by Yulmetov et al. (2013). The iceberg drift varied significantly both with time and space. The Westernmost icebergs showed very slow drift (less than 0.1 m/s in average) and were possibly affected by the presence of land-fast ice. One iceberg further East showed a drift velocity of 0.17 m/s and a max velocity of 0.80 m/s. Sea ice floes where also tagged with ice drift beacons. Figure 7 shows iceberg and sea ice drift trajectories from beacons deployed during the Oden cruise.

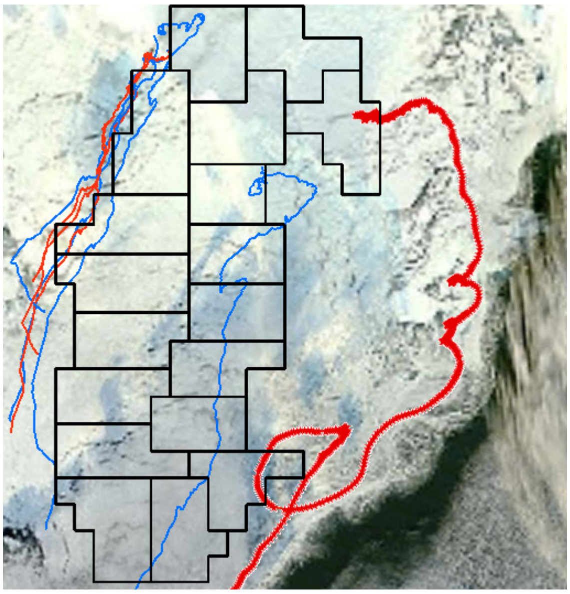


Figure 7: Iceberg and sea ice drift trajectories through the NE Greenland lease blocks. Background is a Modis image from mid October 2012 with a spatial resolution of 1 km. Blue lines are iceberg drift while red lines are sea ice drift.

Regarding satellite iceberg detection the SAR images showed far more detections than was observed visually. There were also significant variations in the number of detections from day to day. The SAR images covered various regions with various resolutions whereof crude resolution images were delivered most frequently (3 images per 2 days). It was also attempted to take images with optical satellite sensors. However, due to cloudy and foggy conditions throughout the cruise no optical images where taken during the cruise. Studies of the satellite image iceberg detections are still on-going and will be published in a separate paper. So far the general conclusion has been made that care should be made when applying SAR images for iceberg detections in ice covered waters.

Estimation of iceberg lengths and heights were generally made in comparison with vessel dimensions when closing up to icebergs and by use of Steinar binoculars for icebergs at some distance. Some of the dimensions were also estimated from helicopter observations. All observed icebergs were surrounded by sea ice with concentrations ranging from 3/10 to 9/10.

Sixteen of the 44 observed icebergs were considered to be grounded. All of these were observed to the West of mooring Location #4, see Figure 8. One ice drifter was deployed on one of the grounded icebergs. The largest observed iceberg had a waterline length of around 300 m while the majority had lengths in the range of 35 to 150 m as shown in Figure 9. Some of the grounded icebergs had sails up to above 30 m from the waterline while the floating icebergs had sail heights in the range of 4 to 17 m.

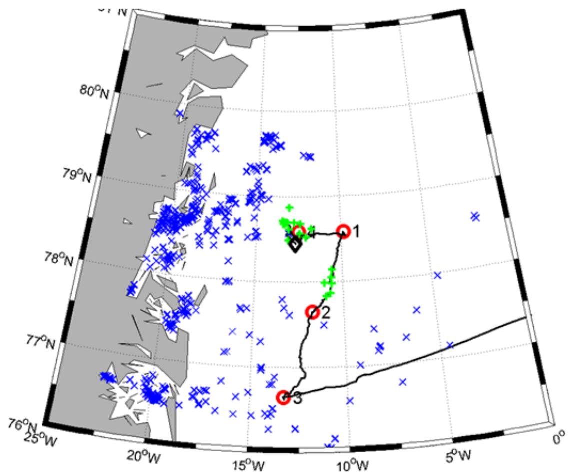


Figure 8. Map showing detected icebergs where + shows location of visually detected icebergs in the period 18.09.-23.09.2012 while x shows iceberg detections from a Radarsat image of 23.09.2012. Locations for mooring deployments are shown with red circles.

The smaller icebergs were typically irregular and weathered while the larger were tabular. Several of the grounded icebergs were apparently wedge-shaped but most probably just an effect of one side rising during a scouring process.

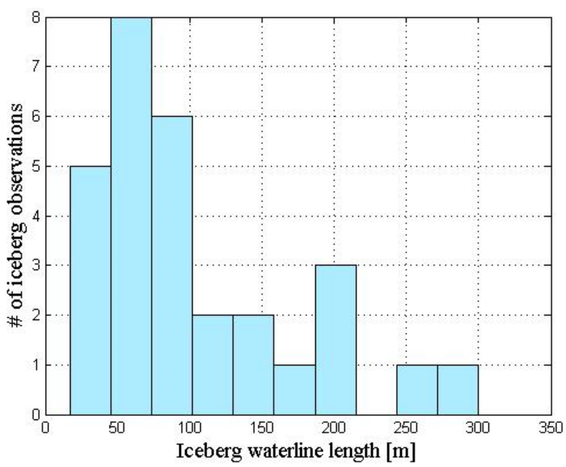


Figure 9. Histogram of the number of observed icebergs vs. waterline lengths.

Ice management tests

During OATRC2012 a 4-hour ice management test was performed to analyse the efficiency of an ice management scenario where *Oden* is used to protect a vessel on station keeping. The procedures of this test were as follows:

- The position of the Protected Vessel (PV) was fixed at (N78° 33.6', W013° 06.3').
- The captain was told to manage an area upstream as shown in Figure 10.
- The captain used the long stroke technique; namely run up- and down-stream with some criss-crosses. One leg of these long strokes took about 30 minutes; see Figure 10 for the dimensions of the planned region.
- Helicopter surveillance took off 15:12 (UTC) to survey the unmanaged area and landed 15:32.The ice management had partly started when in the air.
- Second helicopter mission took off 17:21 and landed approximately at 17:40.

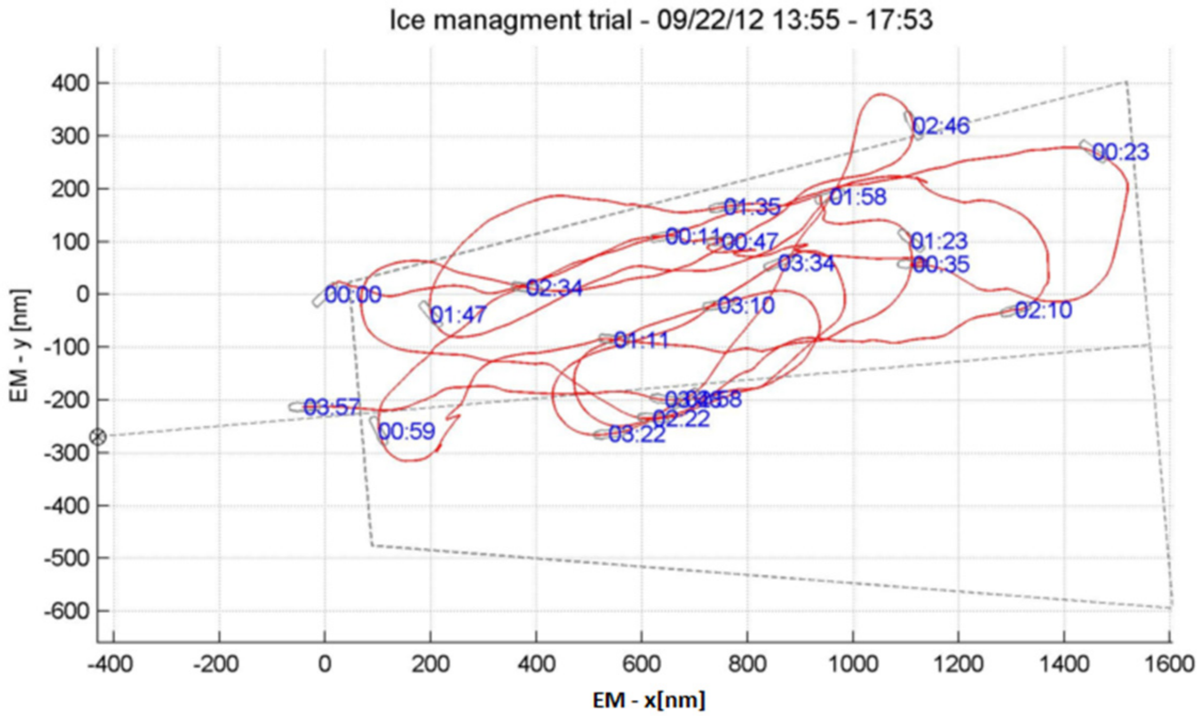


Figure 10. The trapezoid illustrates the boundaries of the area to be managed with the protected vessel shown of the second axis. The track of *Oden* is shown in red.

As shown in Figure 10, the managed ice drifted to the North and did not envelope the PV as originally intended. This is mainly due to the unforeseen change in the direction of sea currents. Consequently, one could conclude that a successful ice management scheme is hardly reachable without at least a now-cast of the ice drift.

HEALTH, SAFETY AND ENVIRONMENT FOR OATRC2012

A prerequisite to consider this research cruise being a success was that accidents should not occur during operations. Subsequently the issues of Health, Safety and Environment (HSE) were high on the agenda throughout the complete project execution. In addition an early risk assessment mapped initial high HSE risks due to the nature of this research cruise; working in a remote location, long medevac durations, working in a cold climate, operations on sea ice and icebergs, handling of weapons (polar bear guards). Hence the wording "*perform a safe cruise"* was deliberately included in the overall cruise objective. Although all partners in the project have the same ultimate zero accident HSE philosophy, HSE framework and HSE requirements differentiate due to the different backgrounds represented in the project, e.g. commercial, academic and governmental. Alignment of the HSE framework and HSE requirements for this operation and reducing HSE risks to acceptable level was imperative.

Through an open dialogue, definition of clear roles and responsibilities, acknowledgement of the different backgrounds and focusing on reaching the final HSE objective, a pragmatic approach was found. Risk assessments at different levels, understanding the specific Arctic nature of this project, played a key role herein. On the other hand the diversity in backgrounds brought different highly relevant expertise into the project, for example SPRS and SMA with long marine operational experience in Arctic waters, NTNU and The University Centre in Svalbard (UNIS) with extensive research activities on sea ice and icebergs experience, and Statoil with offshore marine operations and risk assessment competence. The open dialogue atmosphere created a fruitful collaboration, learning from each other and building on each other's strong points. From a HSE perspective the cruise succeeded without a single accident.

An HSE plan was implemented, defining the HSE framework and HSE requirements in the project. The HSE plan included many HSE activities, amongst others:

- Mandatory pre-cruise medical check of all embarking personnel
- One day Arctic safety course during mobilization for the scientific personnel and facilitated by UNIS
- Mobilization of an experience dedicated HSE officer from UNIS on-board *Oden*
- Mobilization of doctor and extended hospital capabilities on-board *Oden*
- Risk management through implementation of HAZID, HAZOP and Safe Job Analysis (SJA)
- Implementation of specific procedures when working on the sea ice or icebergs.

Marine mammal observation programme

Although not an authority requirement, it was decided to implement a marine mammal observation programme on board. Two marine mammal observers were mobilized with standard equipment (binoculars and cameras) and a marine mammals sighting protocol, an observer effort protocol and an ice observation protocol were kept. Marine mammal observations were performed continuously during the entire cruise at hours of daylight and sufficient visibility. Ice observations were made when operating in ice. Combining marine mammal observations and ice observations responsibilities were effective.

The probability to see marine mammals during the *Oden* research cruise was considered relatively low due to the short duration of the cruise. None of the activities during the *Oden* cruise are seen as dangerous to marine mammals. Nevertheless, encounter with marine mammals should be handled with caution and consequently a code of conduct was established. This code of conduct dictated operational adjustments in case of encounters of larger groups of marine mammals or encounters in the near vicinity of the vessel. During the cruise a total of 42 marine mammals were seen. This were 28 seals that could not be identified to species level, 2 bearded seals, one hooded seal, 3 polar bears and a group of 8 orcas. There was one walrus observed by a crew member, but this could not be confirmed by the marine mammal observers. The actual marine mammal encounters during operations, while adhering to the code of conduct, did not require any operational adjustments.

CONCLUSIONS

OATRC2012 is a good example for the cooperation between academia, industry and governmental research sectors. The scientific scope of the cruise was relatively wide and quite many research activities were carried out. The cruise provided a wealthy source of knowledge and a considerable amount of full-scale data to SAMCoT researchers. Safety and environment were considered seriously in the different phases of the project and OATRC2012 ended without a single accident.

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