Annual Report 2015

Sustainable Arctic Marine and Coastal Technology

SAMCoT

NTNU
Norwegian University of Science and Technology

SAMCoT KEY FIGURES	2015*	2014	2013	2012	2011	Accum.Fig.
Turnover (in 1000NOK)	74 299	33 666	59 887	45 770	13 859	227 481
PhD Defences	5	3	3	1	0	12
Published Journal Papers	29	16	5	7	7	64
Published Conference Papers	52	40	40	18	15	165
MSc Thesis	11	6	7	8	2	34
Mass & Other Popular Media	12	24	11	8	3	58
Industry Partners	13	13	11	11	9	13
Research Partners	8	8	7	7	7	8
Public Partners	2	1	1	1	1	2
PhD Candidates	26 (7 Fem.)	21 (6 Fem.)	22 (4 Fem.)	19 (4 Fem.)	10 (1 Fem.)	26
Post Docs	9 (2 Fem.)	4 (1 Fem.)	3	1	0	9

*Turnover including OATRC2015

VISION: SAMCoT is a leading national and international centre for the development of robust technology necessary for sustainable exploration and exploitation of the valuable and vulnerable Arctic region.

SAMCoT meets the challenges created by ice, permafrost and changing climate for the benefit of the energy sector and society.

SAMCoT

Aleksey Shestov, SAMCoT Work Package 1 Deputy Leader during leg six of N-ICE

Photo: Anaïs Orsi

Green Light!

Seven Centres for Research-Based Innovation (SFI) supported by the Research Council of Norway (RCN) were evaluated in 2015 in one-day site visits by teams of four experts chosen by the RCN. Two of the experts had competence to evaluate the Centre from a scientific point of view, while the other, "generalists", had experience of similar programs for university-industry research collaboration on an international level. The generalists evaluated the management, organization and funding of the Centres, and also their interactions with user partners in terms of mutual mobility of researchers, transfer of results and encouraging innovation.

THE EVALUATION PROCESS HAD TWO MAIN PURPOSES:

- To form the basis for a decision by RCN on whether to continue financing each individual Centre for the final three years of the eight-year term
- To comment on and give advice to the Centres on their activity and how it should be improved in the form of recommendations.

On March 10th 2015 the evaluation team from the Research Council of Norway met with the SAMCoT Director, the Centre Management Group, PhD students, post-docs, representatives of the host institution, representatives of the industrial and public partners of SAMCoT and the chair of the SAMCoT Board. The discussions centered on the research at SAMCoT followed by a meeting with the PhDs and post-docs as well as further discussions on the management and organizational structure of SAMCoT.

The final evaluation from the RCN is available at the
Sentre for forskningsdrevet innovasjon (SFI) website
(see Evaluation report SFI-II (PDF - 978 KB).

EVALUATION HIGHLIGHTS:

- *The centre showed an excellent and relevant internationally recognised research environment.* The research profile of the Centre in ice science and engineering is very high, and the Centre is internationally visible and well recognised. The Centre is clearly visible to its peers in the scientific community. This visibility has been secured by publishing in the key journal, Cold Regions and Science and Technology, and in particular by presentations at international ice conferences. Importantly they are also organizing and hosting two key international conferences - POAC 2015 and the IAHR Ice Symposium 2020.
- *The overall management is good and the different bodies, Board, EIAC, CMG and SAC have clear missions and roles in relation to each other. The centre has excellent support from the host institution and its partners.* The centre also demonstrates the capability to change direction when needed for example the interventions in WP1 and WP6. It was gratifying to see the good cohesion of all research environments despite the number and geographical dispersion of the partners. *The panel also observed good financial gearing, that included a combination of in kind and cash contribution from a well-managed partnership with international industrial partners.*
- Discussions with the student and post-doc community confirmed their enthusiasm for working on the challenging problems of ice and the Arctic environment. The group was extremely supportive and confident, that their work was delivering real value with good consequences for their employability.

The Research Council of Norway

SAMCoT

Photo: Øyvind Buljo

SAMCoT: The Year 2015 in Review

2015 was a crucial year for SAMCoT. The Midway evaluation performed by the Centre's main funder, the Research Council of Norway, allowed the Centre to undergo an internal review where all partners were involved. This review process resulted in an objective evaluation of the Centre's activities and aims, and provided opportunities for improvement, as well as validation for most of the Centre's main activities and direction. SAMCoT received a Green Light from the RCN that allows the Centre to continue its work, as initially planned, until 2019. SAMCoT was, in addition, rewarded with a renewed motivation to continue with its activities and to achieve its targets. Furthermore the Centre will intensify its work towards establishing the basis of the Centre's future research targets for after 2019.

SAMCoT currently counts 23 different partners after adding the Swedish Polar Research Secretariat (SPRS) as a Public Partner in 2015. SPRS's contribution will be fundamental to SAMCoT`s field activities. From the total, 13 partners are industry partners including oil and gas companies, offshore contractors, design institutes and regulatory bodies. Eight are research partners including both universities and research institutes greatly relevant both for the specific scientific knowledge of their researchers as well as for their facilities (e.g. ice laboratories, tanks and basins). The final two are public partners highlighting SAMCoT's relevance to society in general. All partners, through the thorough and committed work of their General Assembly (GA) Members, contributed to SAMCoT`s reporting efforts for the Midway evaluation.

To provide our members with updated information on activities and to strengthen collaboration among the partners, SAMCoT hosts two annual general meetings which all SAMCoT partners are encouraged to attend:

- SAMCoT Scientific/PhD/PostDoc Seminar
- SAMCoT Technical Workshop

All six SAMCoT Work Package leaders presented the current status and future plans of their research areas during the Technical Workshop held in October before an audience of approximately 65 industry and research partners. This event allowed industry and research partners to provide feedback on the activities and address their priorities and thoughts regarding the way forward. There was consensus around the strategic decisions taken that affected the Cost, Time and Resource (CTR) planning for 2016 concerning each SAMCoT Research Area.

SAMCoT has entered its harvesting period. A greater focus on innovation and value creation supports SAMCoT`s vision of providing fundamental research and other deliverables that have an impact on the development of the robust technology needed by the industry.

A clear delivery of the Centre is the twelve PhD candidates that have now received their doctoral degrees. Some are already working in the industry, while others have chosen an academic career as postdocs. Three out of the five PhD candidates linked to SAMCoT that defended their doctoral thesis in 2015, decided to continue within SAMCoT as Postdocs, ensuring continuity and progress in their areas of research.

The Exploitation and Innovation Committee (EIAC)

For the participating industry partners it is not only important that the scientific level of the research is high, but also that the research is relevant for their current and future Arctic activities. Hence, a strong EIAC is fundamental to the work and strategic direction of SAMCoT. Initially the EIAC's primary task was to steer the direction of the research topics in the different research areas. Now that this task is clearly achieved, the focus has changed to identifying innovative techniques. As per the Consortium Agreement mandate, the EIAC monitors project results with respect to the potential for commercial exploitation and proposes to the General Assembly further development of such results as separate spin-off innovation projects, EU-projects or pre-competitive projects. To this end, the EIAC met four times in 2015 to steer the research topics where needed, to closely follow up the deliverables achieved by SAMCoT researchers and to assess potential innovations that represent added value to the industry. A key element to the work done in 2015 was the planning of a gap assessment workshop that took place in February 2016.

From left to right, PhDs Torodd Nord, Andrei Tsarau and Emilie Guegan, now working within SAMCoT as Postdocs, in a photo with NTNU`s Rector Gunnar Bovim during the Doctoral Award Ceremony on March 11th 2016.

As a result of this activity, the EIAC defined a new framework for monitoring innovations and will populate this framework with current progress towards final innovation deliverables. In addition, the Work Package leaders and the EIAC have achieved alignment between the specifics of the proposed innovation deliverables. The goal is to find win-win solutions that combine: (1) specific and achievable objectives; (2) educational impact for the PhDs and Postdocs and (3) high impact results that are in a format that can be used by the whole SAMCoT community.

Contribution to Scientific Dissemination

Scientific dissemination is a key activity for SAMCoT researchers. In order to catalyze SAMCoT efforts to achieve this aim, NTNU/SAMCoT hosted The 23rd International Conference on Port and Ocean Engineering under Arctic Conditions (POAC) in 2015. The conference was held in Trondheim on June 14th-18th at Gløshaugen, NTNU. SAMCoT contributed by producing 26% of the total number of conference papers. The POAC conference is a highly specialized and well-known forum for exchange and discussion of research results, field experience and unique issues related to coastal and offshore engineering in ice-covered waters. POAC began in 1971 in Trondheim, Norway and since then, it has been held on a regular basis every two years at different international venues. Over the years this conference has been the mainstay of the Arctic engineering community.

The objective of POAC, well in line with SAMCoT's own objectives, is to improve knowledge of ice-related problems by having scientists, technologists, and design and development engineers discuss and exchange ideas on relevant topics. Hence, this conference is an important discussion arena for our researchers and partners.

Collaborations and Associated Projects

SAMCoT has established extensive collaborative links with different research programs and organizations. Some of the collaborative efforts in 2015 outside of SAMCoT`s own internal network were:

- The Norwegian Center of Excellence, Centre for Autonomous Marine Operations and Systems (AMOS). SAMCoT's collaboration with AMOS is well routed and provides advantages for both Centres. Currently four PhDs involved in research linked to ice management are benefiting from this collaboration.
- The Center for Research-based Innovation, Center for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA). This collaboration has resulted in the addition of a female researcher to SAMCoT's Floating Structures area of research.
- Two SAMCoT researchers were chosen as part of a select group of scientists who spent time on the RV Lance during the N-ICE 2015 cruise, funded by the Norwegian Polar Institute, the Fram Centre, and the Norwegian Ministry of Climate and Environment.

- The Polish-Norwegian Research Programme, aiming to reduce economic and social differences and to promote bilateral cooperation through popularization and support of scientific research. A PhD position linked to SAMCoT`s activities within Work Package 6 was funded by the project "Vulnerability of the Arctic Coasts to Climate Changes" (ARCOAST) with excellent results.
- The participation through SAMCoT's hosting institution (NTNU) in member-based organizations like Technoport aims to stimulate knowledge-driven innovation. SAMCoT PhDs and Postdocs were invited to follow Innovation workshops at Technoport 2016 to assist in the process of turning ideas into innovations.

The Hamburg Ship Model Basin (HSVA), one of SAMCoT's research partners, launched the associated project Ice-Induced Vibrations of Offshore Structures (IVOS) in 2015. This project will run for a 36 month period and includes the participation of, and additional funding from, the following SAMCoT Industry Partners: DNV GL, ENGIE, Kværner, Multiconsult, Shell and TOTAL.

Ice-induced vibrations have been the subject of extensive research for many decades. Different theories have been developed by researchers to explain the occurrence of the lock-in phenomenon, which is the most severe type of vibration. However, current theories about the rise and continuation of lock-in are highly debated. A limited number of full scale measurements are available which contain records of lock-in. Current modelling approaches are often developed based on these limited data sets. Unfortunately none of the current numerical models is able to reliably predict the occurrence of lock-in. In addition, full scale measurements often suffer from incomplete measured data on the ice-structure interaction process.

As a consequence, the solution to the problem of deficient full scale measurements for the development of numerical models and understanding of the lock-in phenomenon, are scale model tests. However, no adequate scaling law has yet been found for the transfer of model test data into the full scale regime.

IVOS aims to address these problems by focusing on two main objectives:

1. Increasing the understanding of the physical mechanisms leading to lock-in by studying the local pressure distribution at the ice-structure interface and the synchronization processes
2. Developing applicable scaling methods for dynamic ice-structure interaction problems and the transition from ductile to brittle failure, focusing on the correct scaling of lock-in.

The first phase of model tests was completed in September 2015; lock-in was established successfully for different structural configurations and in different ice drift velocities. The data obtained provides an excellent basis for the theoretical study of the lock-in process.

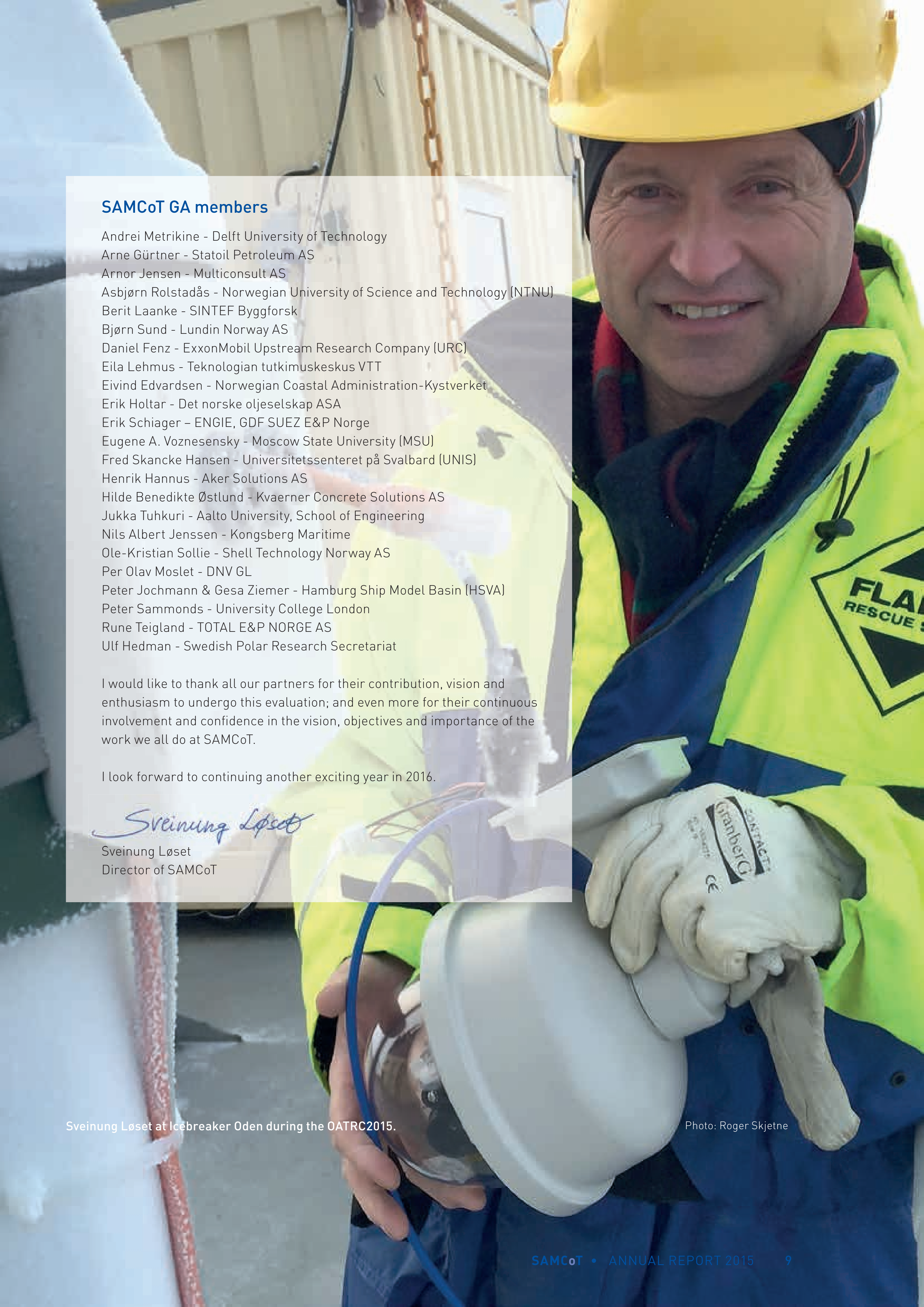
Three meetings were held in 2015, a project meeting in Trondheim (May 6th), a kick-off meeting in Hamburg (June 10th) and a follow-up meeting in Trondheim (October 21st). The project has a specific archive area in the SAMCoT eRoom to facilitate the exchange of data and to keep all partners updated on schedule and tasks. In addition, an FTP server has been set up to share video files.

Field Work

Finally, yet importantly for this summary, we have to emphasize SAMCoT's strong focus on acquiring full-scale data to understand different physical processes linked to the interaction of ice with fixed and floating structures. These full-scale data form the basis for the modelling work carried out in the different research areas.

Different field activities were carried out by Work Package 1 (WP1) researchers, often together with researchers from other WPs, in the following locations: North-West Barents Sea and Barents Sea Opening; Greenland Sea and the Svalbard Archipelago: Svea Bay, Kapp Amsterdam, Wahlenberg Fjord, Van Mijen Fjord, Paulabreen Glacier, Advent Fjord and Akselsundet. In addition, WP6 in collaboration with MSU carried out extensive fieldwork at Baydaratskaya Bay in the Kara Sea.

In addition to these efforts, SAMCoT's participation in the Oden Arctic Technology Research Cruise 2015 (OATRC2015) provided many of SAMCoT's PhD candidates and researchers with invaluable full-scale data for their research and the opportunity to adjust their scientific approach and methodology. This successful research cruise included two icebreakers from the Swedish Polar Research Secretariat. It is not often that PhD candidates get the opportunity to observe two icebreakers co-working on ice management. Such experience is of an incalculable high value. ExxonMobil Upstream Research Company funded OATRC2015.



SAMCoT GA members

Andrei Metrikine - Delft University of Technology
Arne Gürtner - Statoil Petroleum AS
Arnor Jensen - Multiconsult AS
Asbjørn Rolstadås - Norwegian University of Science and Technology (NTNU)
Berit Laanke - SINTEF Byggforsk
Bjørn Sund - Lundin Norway AS
Daniel Fenz - ExxonMobil Upstream Research Company (URC)
Eila Lehmus - Teknologian tutkimuskeskus VTT
Eivind Edvardsen - Norwegian Coastal Administration-Kystverket
Erik Holtar - Det norske oljeselskap ASA
Erik Schiager – ENGIE, GDF SUEZ E&P Norge
Eugene A. Voznesensky - Moscow State University (MSU)
Fred Skancke Hansen - Universitetssenteret på Svalbard (UNIS)
Henrik Hannus - Aker Solutions AS
Hilde Benedikte Østlund - Kvaerner Concrete Solutions AS
Jukka Tuhkuri - Aalto University, School of Engineering
Nils Albert Jenssen - Kongsberg Maritime
Ole-Kristian Sollie - Shell Technology Norway AS
Per Olav Moslet - DNV GL
Peter Jochmann & Gesa Ziemer - Hamburg Ship Model Basin (HSVA)
Peter Sammonds - University College London
Rune Teigland - TOTAL E&P NORGE AS
Ulf Hedman - Swedish Polar Research Secretariat

I would like to thank all our partners for their contribution, vision and enthusiasm to undergo this evaluation; and even more for their continuous involvement and confidence in the vision, objectives and importance of the work we all do at SAMCoT.

I look forward to continuing another exciting year in 2016.

Sveinung Løset
Sveinung Løset
Director of SAMCoT

Sveinung Løset at Icebreaker Oden during the OATRC2015.

Photo: Roger Skjetne

Data Collection and Process Modelling

Photo: Aleksey Shestov

WORK PACKAGE 1 (WP1)

The winter period from January to early May is the most active period for the collection of ice data. WP1 focuses on the collection and process modelling of data obtained from different physical locations in the Arctic. In 2015 some of the locations used for field activities within WP1 were: North-West Barents Sea and Barents Sea Opening; Greenland Sea and the Svalbard Archipelago (Svea Bay, Kapp Amsterdam, Wahlenberg Fjord, Van Mijen Fjord, Paulabreen Glacier, Advent Fjord and Akselsundet). In-field/laboratory works and theoretical investigations were performed as part of the overall planned activities of WP1. These activities could be divided into four groups:

1. Sea State and Ice Conditions in the North-West Barents Sea, Barents Sea Opening, Greenland Sea and in the Arctic Ocean to the North of Spitsbergen
2. Monitoring of Sea Ice and Iceberg Drift; Mechanical Properties of Ice and Applied Oceanography
3. Sea Ice Actions in the Coastal Zone
4. Geographical Information System (GIS)

Sea State and Ice Conditions in the North-West Barents Sea, Barents Sea Opening, Greenland Sea and in the Arctic Ocean to the North of Spitsbergen

To investigate the sea state and ice conditions in the North-West Barents Sea, Barents Sea Opening, Greenland Sea and in the Arctic Ocean to the north of Spitsbergen, WP1 researchers focused on the area of the North-West Barents Sea. They centred on the analysis of the characteristics of surface currents and drift ice and numerical modelling of the thermodynamic consolidation of drift ice ridges. For the analysis, WP1 used ice tracker data from Oceanetic Measurements, Canada and surface drifters deployed in 2008-2015 from the National Oceanic and Atmospheric Administration (NOAA) at the U.S. Department of Commerce. By using these data, WP1 researchers could construct trajectories of ice drift from the North-West Barents Sea to the region of Bjørnøya. In addition, by using the archive from National Centers for Environmental Prediction and National Centre for Atmospheric Research (NCEP/NCAR), WP1 researchers were able to reconstruct water and air temperature along the trajectories for the period February to May 2015.

The Arctic Technology Department has launched a new course AT-334 in Arctic Marine Measurements Techniques, Operations and Transport. Module I is completed. For two weeks students studied different sea ice environments and worked in the University in Svalbard UNIS ice laboratory where they modelled processes of level ice formation and growth and ice ridge thermodynamic consolidation.

Consequently, the researchers used these data to formulate the boundary conditions in a finite element model of thermodynamic consolidation of drift ice ridges. 3D simulations performed in Comsol Multiphysics 5.0 demonstrated synchronous consolidation of ice rubble filling ridge keels and melting of the ridge keels from below. A 3D Finite Element (FE) model of thermodynamic consolidation of ice ridges was constructed in Comsol Multiphysics, and numerical simulations were performed for the modelling of drift ice ridges in the North-West Barents Sea and Barents Sea Opening.

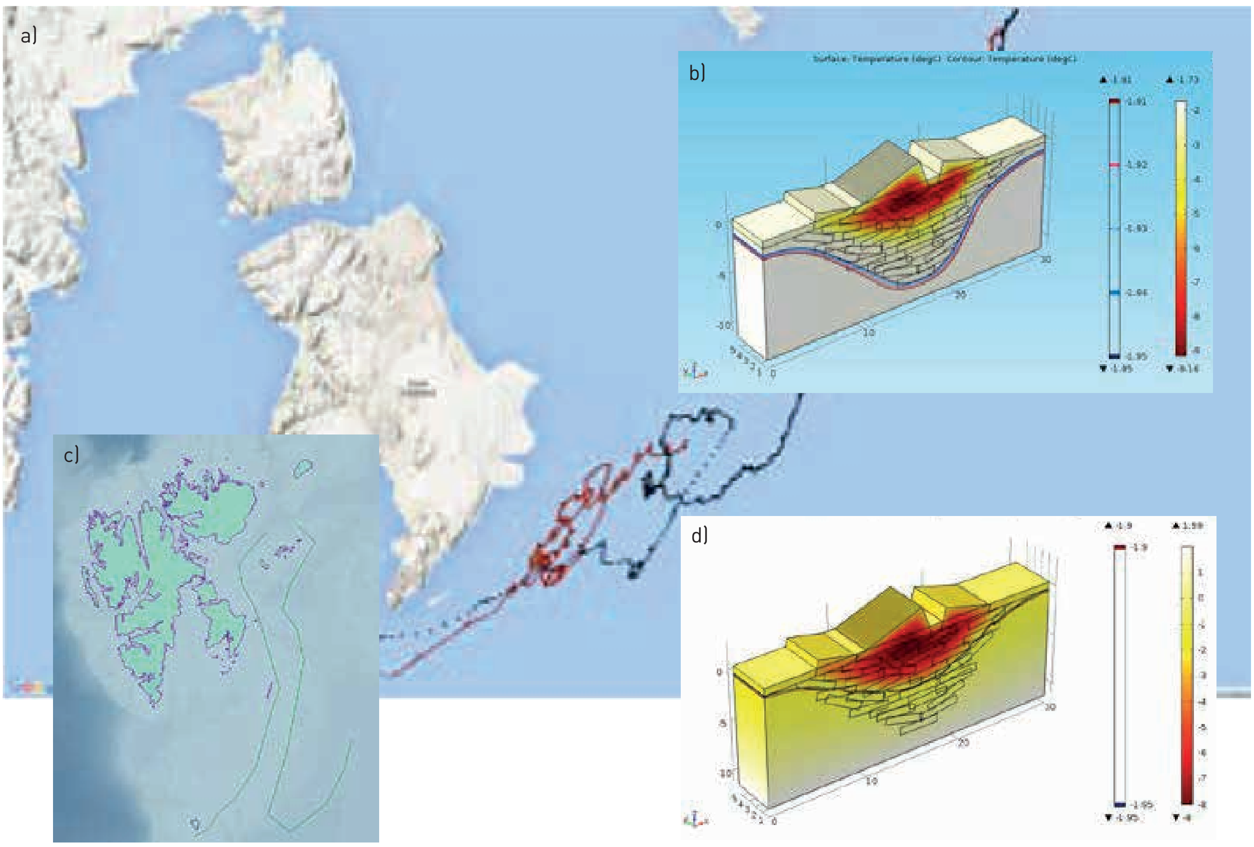


Figure WP1_1. Drift ice ridges trajectories: North-West Barents Sea a), Barents Sea opening c). Thermodynamic evolution of ice ridges, b) & d) during the two months drift along the trajectories.

Monitoring of Sea Ice and Iceberg Drift, Mechanical Properties of Ice and Applied Oceanography

To gain further knowledge in the areas of monitoring of sea ice and iceberg drift, mechanical properties of ice and applied oceanography, field works were focused on in-situ tests of ice strength, morphological studies of icebergs, standard oceanographic measurements in ice covered waters (i.e. Conductivity, Temperature, and Depth (CTD) profiling; Acoustic Doppler Current Profiler (ADCP) profiling of water velocity profiles; Acoustic Doppler velocimetry (ADV) measurements of water velocity in the ice adjacent layer), monitoring of wave damping in the marginal zone of drift ice, deployment of ice trackers on drift ice ridges and monitoring of ice load on fixed quays.

In-situ tests for the compressive, tensile and shear strength of floating sea ice were performed with an original rig creating horizontal load over the entire ice thickness. Tests for flexural strength and torsion strength were performed with an original rig creating a vertical load in the upward and downward directions. Test results will be used for the formulation of the failure envelope of floating ice for in-plane and bending deformations. Oceanographic measurements were performed in the Van Mijen Fjord (west of Spitsbergen) on shallow water covered by ice, near the front of Paulabreen Glacier, and in the Wahlenberg Fjord (west of North-East Land) below level ice and around floating icebergs frozen in fast ice. Morphological studies of two icebergs in the Wahlenberg Fjord were performed with a laser scanner (Riegl Vz-1000). The shapes of iceberg sails and iceberg masses were reconstructed using collected data. Monitoring of surface waves in the marginal zone of

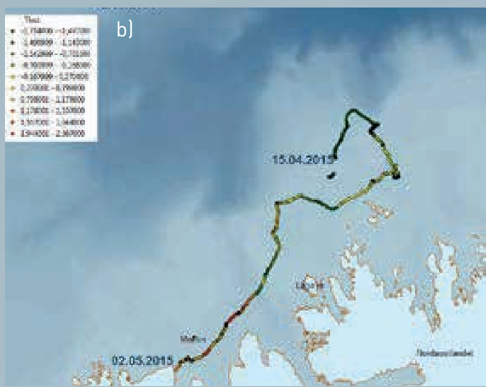


Figure WP1_2. Deployment of ice tracker with thermistor-string on drift ice ridge a).
Drift trajectory of the ice tracker b).

Figure WP1_3. PhD candidate David Wrangborg using the Laser scan to capture an Iceberg in the Wahlenberg Fjord. The result of the scan is shown here superscript to the photo.

Figure WP1_4. In-situ test for tensile strength of floating ice

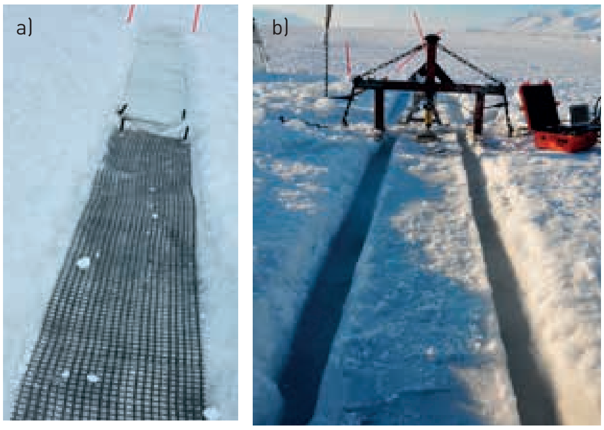


Figure WP1_5. Installation of synthetic net on the surface of cantilever beam (a). Flexural strength test with frozen synthetic net (b).

Arctic drift ice was performed to the north of Spitsbergen. During the experiment RV BjorkHoug penetrated through MIZ for 2 nm. Wave measurements were performed on several stations by two sensors (SBE 30plus) mounted on the same rope fixed on the ship board. In the same place ice trackers equipped with thermistor strings were deployed on the drift ice ridge with 8 m draft.

Other field activities performed by WP1 researhcers aimed to the collection of data and further studies were performed during a field campaign in 2015 on the level, land-fast ice in Van Mijen Fjord, Spitsbergen.

Sveabukta Bay in Van Mijen Fjord is a natural field polygon for research and educational studies of sea ice at UNIS. An extensive knowledge of ice mechanics has been developed over the last 20 years at the Arctic Technology Department. Several small- and large-scale in situ experiments on ice mechanics are conducted yearly. The aim of the present work was intended to complement existing knowledge on the physical properties of sea ice through the season, to give a better understanding for the planning and preparation of further field experiments. This work is valuable even as a standalone study. Starting on February 12th and continuing until April 29th the site was visited several times. During this period, several cores were taken to perform studies on the microstructure and the physical and mechanical properties of ice. In addition, temperature profiles through the ice and conductivity below the ice were logged over time. All results were presented in the paper `Hydrology of Braganzavågen under ice-covered conditions` in the Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions.

As a key result of the work done in monitoring sea ice and iceberg drift, WP1 researchers were able to formulate a model of the passive turn of a vessel with an internal turret in conditions of close drift ice using the method of limit stress analysis in plasticity and the theory of granular materials. Model equations consist of the kinematic and dynamic equations describing the movements of the vessel and the ice loads on the vessel hull when solid ice drifts against the vessel. It is shown that movements of the vessel before it takes final position parallel to the ice drift, consist of translational displacements, rotation without axial displacement and rotation with axial displacement. On the last stage of the turn the vessel rotates as a whole, together with the effective mooring line, around the elasticity center of the mooring system. Tension of the mooring line reaches maximum at this stage.

Sea Ice Actions in the Coastal Zone

Laboratory works included a set of original experiments on the investigation of thermo-elastic waves in saline ice. Cylindrical ice samples were insulated by foam plastic from their lateral sides and from the bottom. Their surface was under periodical cooling with a 12 minute period produced by a cooling system at the cold laboratory of UNIS. During the 12 minute period the room temperature was varied with an amplitude of about 1°C. Fibre Bragg Grating (FBG) strain sensors registered vertical displacements of the ice surface within the same period and an amplitude of about 1 m. The dependence of the amplitude on ice salinity and temperature was investigated during the experiments.

An elaborated theory, based on modified Darcy's law, describing liquid brine migration through the ice is used to explain the dependence of the amplitude of the thermo-elastic waves on the ice temperature and salinity.

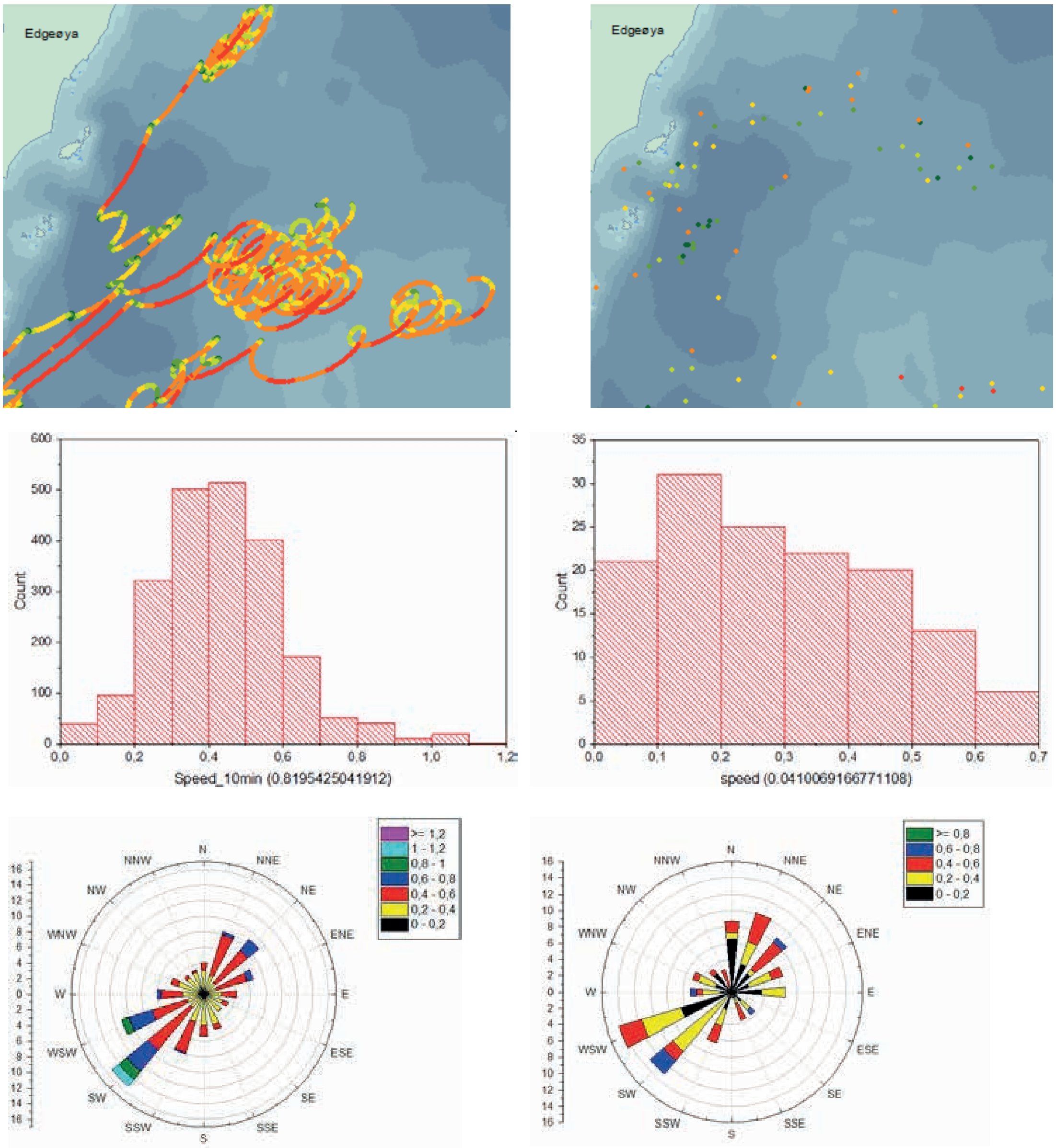


Figure WP1_6. Comparison of drift velocities calculated from ice trackers data collected with 20 min sampling interval (left columns) and NOAA buoys data collected with sampling intervals 6 hours (right columns) in the Barents Sea Opening.

Monitoring of ice loads on the cofferdam of a fixed quay in Kapp Amsterdam and the shore line in Svea Bay with load cells (Geokon) was performed synchronously with water level and ice temperature measurements. Both ice loads on the cofferdam and ice loads on the shoreline show a clear dependence on the phase of semidiurnal tide, but the character of this dependence varies with the time. The highest loads are observed during spring tides and lowest during neap tides. The formation of ice loads on the shoreline is explained by the variable shape of the ice across the fjord over the tidal cycle. Ice loads on the cofferdam of the fixed quay are created by the ice confined inside the cofferdam. The origin of these loads is related to the upward and downward migration of liquid brine through the ice under the influence of tide-induced water pressure below the ice, and brine freezing in the top layers of the ice. This process is accompanied by an increase in the ice temperature.

Focus Activities 2015

Sea State and Ice Conditions in the North-West Barents Sea, Barents Sea Opening, Greenland Sea and in the Arctic Ocean to the North of Spitsbergen

- Deployment of three Iridium ice trackers (Oceanetic Measurements) with thermistor strings on the drift ice ridges to the north of Spitsbergen in April-May 2015
- Analysis of field data on the characteristics of sea currents in under-ice boundary layers collected during four events of wave propagation below the drift ice in the Barents Sea since 2006
- Calculation of eddy viscosity and estimates of the damping of surface waves propagating below the drift ice in the Barents Sea
- Modelling of wave propagation below the drift ice in the North-West Barents Sea

Sea Ice Actions in the Coastal Zone

- Ice loads on the shoreline and a fixed quay were measured with pressure load cells (Geokon) in 2013-2015 and analyzed according to tide measurements
- Monitoring of the deformation of coastal ice and structural elements of a fixed quay were performed with Laser scanner (Riegl-VZ 1000) in 2013-2015
- The influence of shoreline icing on the semidiurnal variations of the ground water level in the shoreline zone was investigated based on air and soil temperature data and pore pressure collected around the pipeline landfall in Longyearbyen in 2012-2015
- Laboratory modelling of ice loads on a cofferdam due to thermal expansion of ice was performed in the ice tank at the UNIS cold laboratory. An original system of Fiber Bragg Grating sensors, designed for laboratory measurements of strain and temperature, was used to investigate the thermal expansion of ice induced by the migration of liquid brine through the ice in the field of a temperature gradient
- An original system of Fiber Bragg Grating sensors designed for laboratory measurements of strain and temperature was used to investigate thermo-elastic waves on the surface of saline ice
- A thermo-mechanical model of saline ice was constructed and validated using the experimental data on thermo-elastic waves

Aleksey Shestov in a field campaign for WP1 at Svea.

Monitoring of Sea Ice and Iceberg Drift, Mechanical Properties of Ice and Applied Oceanography

- CTD and ADCP profiling around iceberg in the Wahlenberg Fjord in April 2015
- Profiling of two icebergs in the Wahlenberg Fjord and one iceberg in the Advent Fjord has been performed with Laser scanner (Riegl Vz-1000) in April and May 2015
- Monitoring of iceberg drift and rotation in the Advent Fjord was performed from two cameras installed on the shoreline
- Characteristics of ice drift and surface currents in the North-West Barents Sea and Svalbard region were investigated and compared using the data from ice trackers deployed on drift ice and icebergs, and data from floating buoys provided by NOAA
- Original in-situ equipment to study tensile, compressive and shear strength of floating ice was designed and deployed on sea ice in March and on fresh ice in October 2015
- Experiments on flexural strength of sea ice strengthened by synthetic nets were performed in March 2015
- Original tests on torsion were designed and performed with floating L-shaped cantilever beams on sea ice in March and on fresh ice in October 2015
- Original tests on friction between floating sea ice blocks were designed and performed on land-fast ice in March 2015
- CTD and ADCP profiling was performed in shallow coastal zones in the Braganzavagen and near Paulabreen Glacier in the Van Mijen Fjord. The influence of shallow depth and ice on sea water salinity increase was investigated in the Braganzavagen. The influence of fresh water discharge on the seabed erosion, increase of ice thickness and freshening of the under-ice water layer was investigated near Paulabreen front
- Data on sea currents, velocities and tides were collected near the floating quay in Longyearbyen. Data are useful for the design project of a new floating quay in Longyearbyen
- Data on surface currents in Advent fjord and Akselsundet were collected with ice drifters using AstroDog antennas and MetOcean Buoys in October-November 2015
- ADCP AWAC was deployed from the tag boat in the navigational strait Akselsundet for the high frequency measurement of vertical profiles of sea currents according to a request from the port captain in Svea
- Modelling of iceberg drift and rotation in the Greenland Sea
- Modelling of passive turn-on-a-spot of a turret-moored vessel in conditions of closed drift ice

Geographical Information System (GIS)

In 2015 **NATALY MARCHENKO** continued with the development of the SAMCoT GIS for Arctic technology applications. The main focus was on sea ice movement in the Western Barents Sea. In order to find the best source of information for this marginal region, the work focused on the comparison of Sea Ice Products data on sea ice drift (speed and direction) with data from drifting buoys (ice trackers installed by the UNIS Arctic Technology department). The results have been presented in a report and in a conference paper that will be presented at the 23rd International Association of Hydro-Environment Engineering and Research (IAHR) International Symposium on Ice in 2016. The data (sea currents, water and air temperature and salinity) for modeling of ice ridge transformation during their drifts in the Western Barents Sea have been obtained by means of GIS and delivered to colleagues in WP1.

SAMCoT Industry Partners (IPs) have shown a clear interest in the use of GIS to deliver data already obtained through different activities linked to WP1. To accommodate the wishes of SAMCoT IPs, WP1 researchers are currently developing a "common format" for data transfer. In collaboration with Statoil (Kenneth Eik and Guy Maurice), Marchenko has developed a test project named ArcGIS including data obtained from ice trackers. This work will continue in 2016 with the intention to make the data obtained by WP1 available for SAMCoT partners.

A different approach to the work involving GIS relates to the inclusion of laser scan data into the SAMCoT GIS. The technique for scanning along the mechanical ice tests will be developed to give new information and performance on ice deformation under various loads.

Photo: Evgeny Salganik

Material Modelling

Photo: Sveinung Løset

WORK PACKAGE 2 (WP2)

As work continues on the modelling of freeze bonds in 3D DEM simulations, the results seem promising. Freeze-bonds can be modelled and their inclusion improves the prediction of simulations of full-scale punch-through tests.

Another effort is devoted to the prediction of ice rubble shear strength using critical state theories.

In soil mechanics a thermo-hydro-mechanical (THM) finite element model for frozen soil is completed. The numerical tool developed enables isogeometric analysis with B-splines used as a numerical solution method leading to a local mass and energy conserving simulation, unlike the standard finite element method. The developed numerical tool can e.g. be used to more precisely simulate frost heave of a buried pipeline.

Most of the activities carried out in Work Package 2 (WP2) are rounding off and researchers in WPs 3, 4 & 6 have started making use of the results provided by their colleagues from WP2. All WP2 PhD candidates are about to submit their thesis and Post-Doc Polojärvi has become Assistant Professor at Aalto University.

Frozen soil

SAMCoT PhD Candidate Yared Bekele has been working in the development and completion of a fully coupled thermo-hydro-mechanical (THM) finite element model for frozen soil is completed. The numerical tool developed has the following important features:

- Isogeometric analysis with B-splines used as a numerical solution method leading to a local mass and energy conserving simulation, unlike the standard finite element method
- Full nonlinear implementation using Newton-Raphson iterations with implicit time stepping
- Volume expansion and contraction incorporated into the governing equations

The developed numerical tool is used to simulate frost heave where a field-scale experimental data set is available; see Smith and Patterson (1989). The experiment was performed on a pipeline buried in silt with an initial temperature of +4ºC and transporting chilled gas at -5ºC. The external environment also has a subzero temperature of -0.75ºC. Freezing is thus initiated from two fronts. The frost heave simulation using the developed THM numerical tool resulted in heave displacements that are in good agreement with the experimental data. A heave displacement of about 20 cm is observed at the centerline of the pipe. See the initial and final configurations shown below (Figure WP2_1).

Bekele`s research within WP2 is continued within WP6, Post-Doc Seyed Ali Amiri will use Bekele's THM numerical Framework and implement his own material model.

Figure WP2_1 Initial and final configurations of a heave displacement observed at the centerline of the pipe.

Ice rubble

Sergey Kulyakhtin and Anna Pustogvar, about to submit their PhDs Thesis, and Post–Doc Arttu Polojärvi,, currently appointed Assistant Professor of Ice Mechanics at the Department of Applied Mechanics at the Aalto University's School of Engineering, have been working on ice rubble through experimental, analytical and numerical approaches.
Pustogvar` s research focuses on determining a standard methodology for sea ice density measurements. Although ice density is widely used for solving engineering and geophysical problems no standard methodology exists when it comes to sea ice. Based on the laboratory tests performed at UNIS in 2015 and field tests performed in 2013 during OATRC2013 WP2 researchers compared the most common mass/volume and hydrostatic weighing methods. The results showed that the hydrostatic weighing is currently the best available method for measuring sea ice density. Figure WP2_2 shows the spread is significantly lower for the hydrostatic weighing than for the traditional mass/volume approach

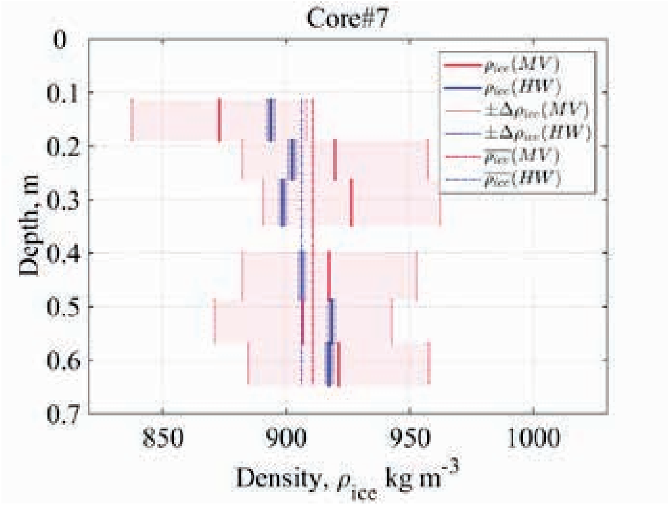
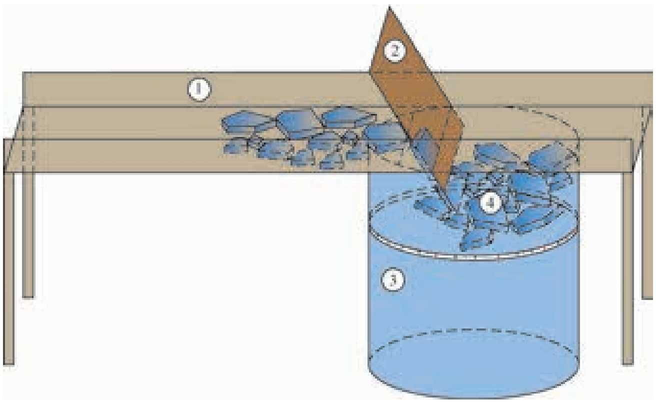
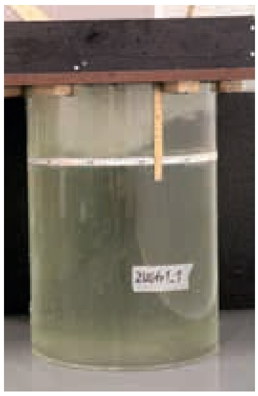


Figure WP2_2 Sea ice density profile of a core sampled, March Van Mijen Fjord, Spitsbergen; The density - mass/volume (MV) and hydrostatic weighing (HW) methods

Ice rubble macroporosity is another vital parameter, and up to date most values derive from 1D drilling. However, drilling gives insight only on linear representation of porosity. In cold laboratory of NTNU we performed ice rubble packing tests in order to understand if 3D macroporosity differs from the porosity obtained by drilling (Figures WP2_3, WP2_4 & WP2_5). With the laboratory results WP2 researchers verified an analytical model of ice rubble macroporosity. This model operates with ice fragment gradation curves as the main input which can be obtained from observational studies of ice fragments in ice ridges.





Figures WP2_3 Test set-up for the ice rubble packing experiments: 1 – packing table, 2 – guiding plank, 3 – plexiglass cylinder filled with saline water, 4 – ice rubble & Figure WP2_4 An example of ice rubble packing test performed in the cold laboratory at NTNU

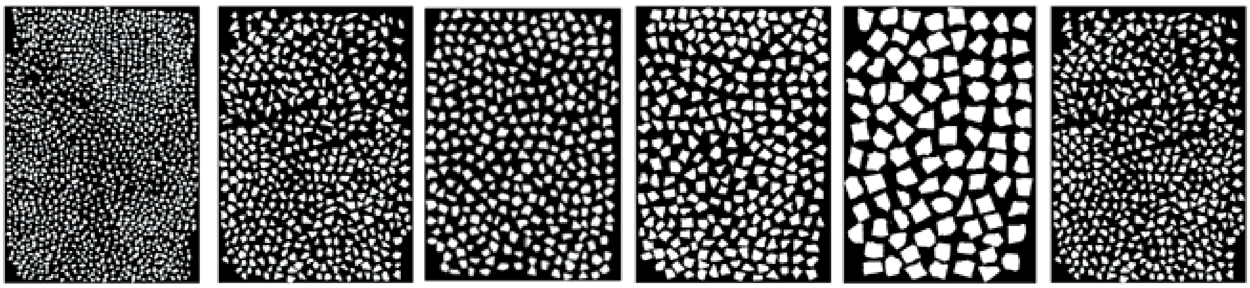


Figure WP2_5 Results of ice production for monodisperse ice fragment packings

Further more, Pustogvar and Polojärvi are working together to understand the relationship between linear and volumetric porosity. Through DEM simulations of ice rubble accumulation virtual linear porosity profiles are made and compared with the volumetric porosity. This work will constitute the final part of Pustogvar's PhD and will be completed early in 2016.

On a parallel research path, Sergey Kulyakhtin has published a journal paper in Cold Regions Science and Technology arguing that the volumetric behavior of ice rubble is important. Data from literature on bi-axial compression was re-analyzed through the concept of critical state soil mechanics, and clearly shows that by including the volumetric component the precision in prediction of properties increase substantially. Kulyakhtin has completed his numerical continuum based FEM model for ice rubble and validated it against measurements carried out in 2011 within the RITAS: EU HYDRALAB - IV Project "Rubble Ice Transport on Arctic Structures" project. Figure WP2_6 shows photograph from the RITAs experiments and Figure WP2_7 shows the numerical simulations of the same case. The forces and rubble accumulation is well simulated.

Figure WP2_6 Picture from the ice rubble-structure interaction experiments (RITAS project)

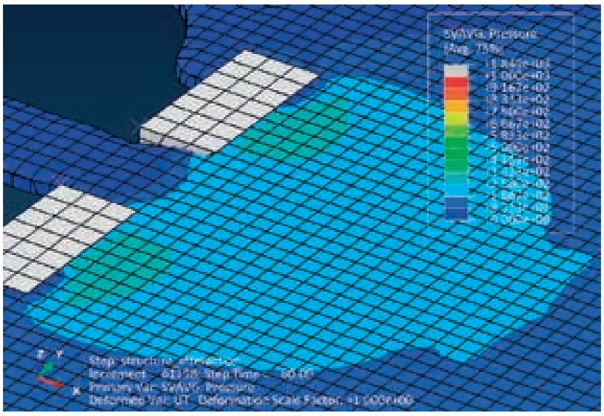


Figure WP2_7 A snapshot from FE simulations of the RITAS experiment shown in Figure WP2_6

In addition, Kulyakhtin closely collaborates with ssistant professor Polojärvi on how to determine stress-strain relation from discrete element ice rubble bi-axial compression tests. Kulyakhtin and Polojärvi used the results of ice rubble bi-axial test with the Aalto DEM model to investigate how the stresses derived from the contact forces between ice blocks converges as a function of averaging domain size. Figure WP2_8 shows how the prediction improves with increasing number of ice blocks.

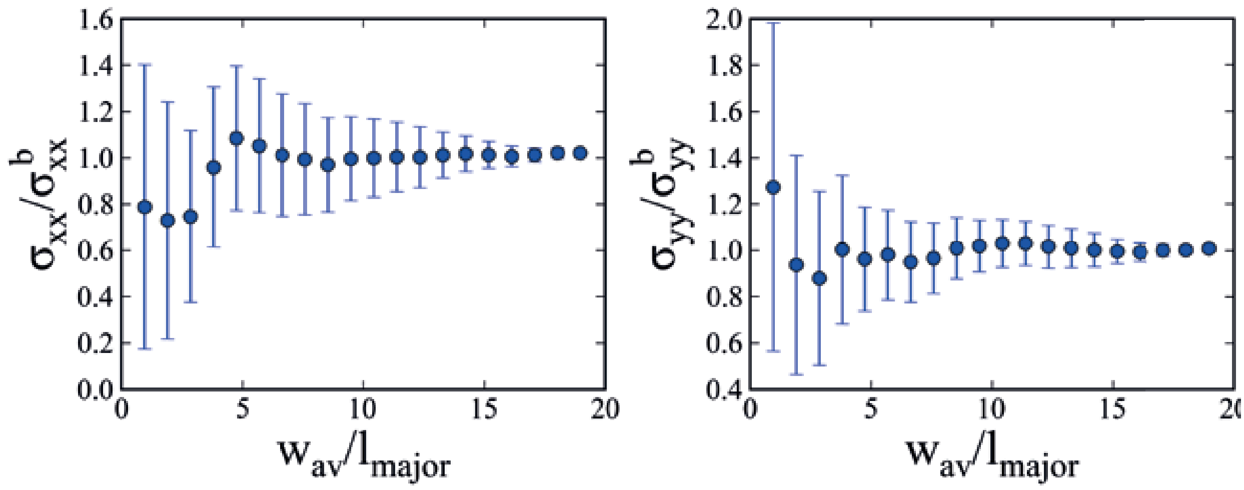
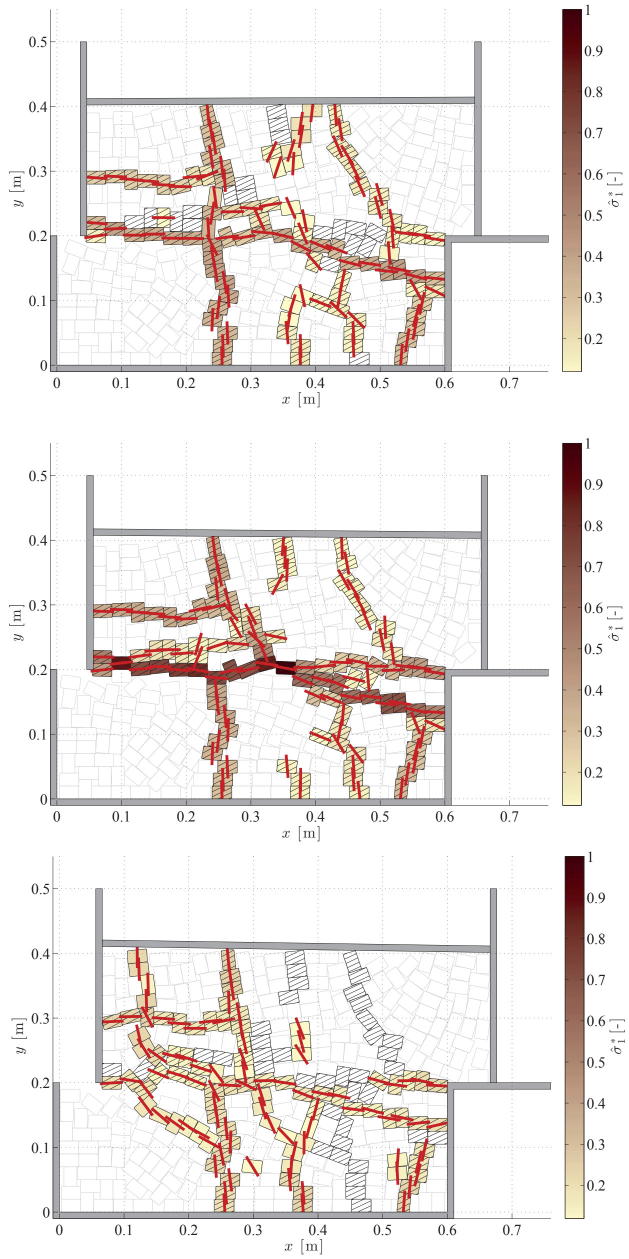


Figure WP2_8 Converges of the horizontal (σ_{xx}) and vertical (σ_{yy}) stresses as a function of averaging domain size (w_{av}) over the maximum dimension of ice blocks (l_{major})

Polojärvi has also addressed several other aspect through numerical analysis through discrete (DEM) and combined finite-discrete (FEM-DEM) simulations. Experimental work in NTNU laboratory with a shear box formed the basis for studying how to understand ice rubble behavior in shear box tests can be interpreted. The study showed that one should account for granular behavior of the ice rubble in shear box tests or otherwise one may measure something that one did not set out to measure. The simulations showed that force chains generated inside the shearing rubble causes high loads measured in an experiment. Figures WP2_9, WP2_10 & WP2_11 show how the force chains develop through simulations of a shear box test. In 2015 the journal paper was published. Polojärvi continued his work on the behavior of partly consolidated ice rubble. He implemented a numerical model for freeze bonds bonding the blocks within an ice rubble, and work towards a paper on this is on the way. Finally, Polojärvi addressed the modelling of 3D sheet for ice-structure interaction simulations and published preliminary results on POAC15.



Figures WP2_9, WP2_10 & WP2_11: Force chains development through simulations of a shear box test

ANNA PUSTOGVAR arrived in Longyearbyen on the Svalbard Archipelago in January 2011 as one of the many Russian students that choose the University Centre in Svalbard (UNIS) to study Arctic Technology. She decided to follow courses during the spring semester in the subjects of Frozen Ground Engineering and Ice Mechanics. Pustogvar so much enjoyed the atmosphere and the courses at UNIS that she decided to stay one more semester. Shortly after that, she came back to Longyearbyen to work as an assistant on the fieldwork that Anton Kulyakhtin was carrying out as part of his PhD position at NTNU.

A few months later it was time for her to return to St. Petersburg where she received a Master in Science. It was also there that she heard about her current PhD position from Sergey Kulyakhtin, whom she knew from fieldwork. The subject was very interesting, and already knowing Professors Løset, Høyland and a couple of other future colleagues from her time in Longyearbyen, made the decision to apply for the position at SAMCoT an easy one, and one she has not regretted.

Pustogvar's research focusses on experimental work and analysis of data. In 2015 she submitted her papers to the journal Cold Regions Science and Technology on an improved method to measure ice density and on experimental and analytical modelling of ice rubble porosity. She will work on virtual experiments on porosity of ice rubble as a visiting researcher in early 2016, and on the submission of her third and last journal paper in collaboration with Assistant Professor Polojärvi and Professor Tuhkuri. Pustogvar recommends all new PhDs to use the opportunity to work in different locations as "it helps to increase your productivity and gain new ideas," she said.

Back in St. Petersburg she is currently working on finishing her thesis. *"Although it is quite a stressful time, it is also very exciting to summarize the work which I have been doing for the past three years,"* she explains.

And, in the future?"Who knows, I am interested in learning more about remote sensing of ice. This field is intensively developing, however, monitoring of ice still has lots of potential to be improved and I would like to contribute."

Photo: Sergey Kulyakhtin

Fixed Structures in Ice

Photo: Aleksey Shestov

WORK PACKAGE 3 (WP3)

The work on fixed structures is sub-divided into Ice-induced vibrations and Ice ridge action.

SAMCoT WP3 researchers study how the structural vibrations of a structure affect the ice pressures. Furthermore, the Numerical modelling of Ice Induced Vibrations (IIV) considering the contact between ice and structure was applied for a detailed analysis of the forced vibration experiments from the autumn of 2011, where WP3 researchers were involved and developed novel scaling and dimensionless parameters for ice-induced vibrations. WP3 has also conducted full-scale field work to examine in-situ ice ridge properties and the development of a numerical model for ice ridge action on structures based on WP2 is well under way.

In 2015 WP3 researchers have started the modelling on ice load estimation through combined finite-discrete element simulations trying to achieve a better understanding of the nature of variability in ice loads.

Ice-Induced Vibrations

Torodd Nord defended his thesis successfully in 2015 and is now a SAMCoT Post-Doc. The research on ice-induced vibrations involved experimental work and data processing. Two papers were published and one paper submitted in the Journal of Cold Regions Science and Technology (Nord et al., 2015a; Nord et al., 2015b). In these model-scale contributions, we elaborate on two fundamental regimes of ice-induced vibrations and we demonstrate how the global behavior of the structure influences on the pressure at the ice-structure interface. At full scale, we instrumented the Hanko-1 channel marker in the Gulf of Finland with accelerometers and strain gauges that will be used to study ice-induced vibrations (Figure WP3_1). The methodology used to decide upon sensor types and locations was presented at the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions (Nord et al., 2015c).

Nord introduced a novel methodology to the ice-research community by applying a joint input-state estimation algorithm to identify ice forces and structural responses. This algorithm was successfully applied at full-scale by using data collected in the STRICE (STRuctures in ICE) project (2001-2003). Here, ice forces measured by panels were compared with ice forces identified using the joint input-state estimation algorithm (Nord, 2015 d).

During the winter season 1973-1974, professor emeritus Mauri Määttänen installed strain gauges and accelerometers to study ice-induced vibrations on the Kemi-1 lighthouse in the northern Gulf of Bothnia (Määttänen, 1975). 43 years later, he was SAMCoT's leader for the instrumentation of the Hanko-1 channel marker (Figure WP3_1). The data will be used by Nord and Määttänen to identify ice forces and to study ice-induced vibrations.

Hayo Hendrikse is about to submit his thesis on numerical simulations of ice-induced vibrations. Two papers were accepted in the Journal of Cold Region Science and Technology. He expects to defend his PhD thesis the spring of 2016.

Photo: Aki Kinnunen, VTT

Figure WP3_1 Mauri Määttänen and an VTT Engineer installing strain gauges to the Hanko-1 channel marker in the Gulf of Finland.

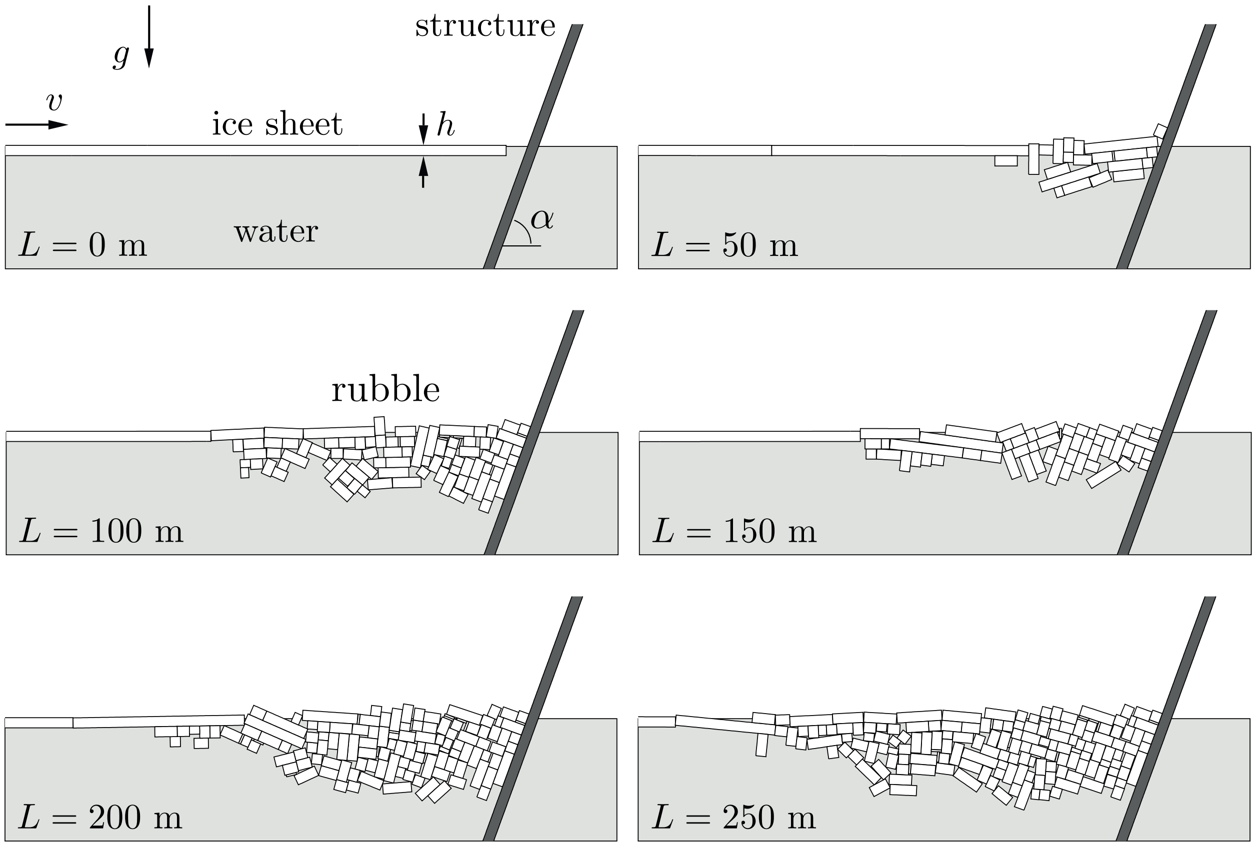


Figure WP3_2 snapshots of simulations an advancing ice sheet towards an inclined structure and visualizes how the ice rubble accumulates in front of the structure.

Ice ridge action

Janne Ranta continued with good progress in 2015. He and Assistant Professor Polojärv addresses ice rubble accumulations and ice load estimation from finite-discrete numerical simultions (FEM-DEM). They have submitted a paper at Cold Regions Science and Technology about statistics related to ice loads and how to achieve high quality information about ice-structure interaction processes and ice loads.

The results in the paper suggest that peak ice loads are clearly affected by few physical ice parameters only. The study also demonstrates a large scatter in the data. Consequences of the high scatter were tentatively discussed in the POAC'15 conference paper from which we have continued to study ice loads in more detail by focusing on ice load distributions. At the moment they are writing a second paper, which focuses on the error margins in repeated ice load measurements.

Åse Ervik was employed in the autumn 2014 and initiated the studies on ice ridge action in WP3. Her work builds on the activity in WP2 and WP1. In 2015 she published a paper in POAC`15 with initial analysis of the EU funded projects LOLEIF/STRICE where full scale ice actions on the lighthouse Nordstrømsgrund were measured the winters from 1999 through 2003. Ervik spent the spring at UNIS on Svalbard where she carried out fieldwork on the land fast ice around Svalbard and in the Arctic basin.

In the spring of 2015 SAMCoT`s WP3 and WP1 collaborated on a field work activity on properties of decaying first-year ice ridges, lead and carried out by Post-doc Aleksey Shestov and Ervik. The primary objective of the project was to understand the effects of the new thin, first year, sea ice regime in the Arctic on energy flux, ice dynamics and the ice associated ecosystem, and local and global climate. The expedition took place on the research vessel RV Lance frozen in and drifting with the young sea ice in the Arctic

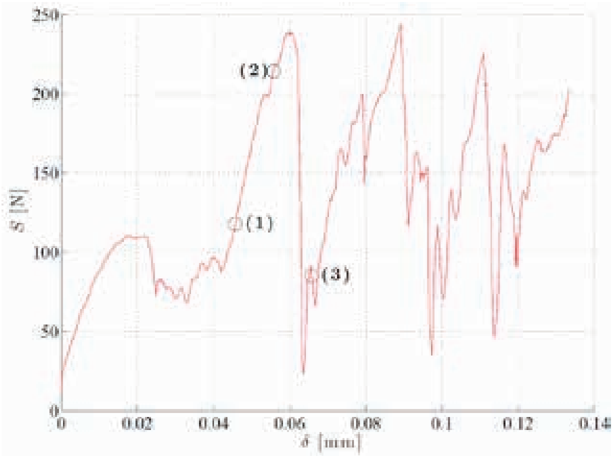


Figure WP3_3 shows force-time trace from the simulations and illustrates the need for to use statistical tools to analyse ice loads.

Ocean over six legs from 11th of January to 23rd of June 2015. Together they planned and carried out a program from May 21st to June 23rd, four ice ridges were subjected to morphology mapping and coring for mechanical and physical properties in drift ice in the Arctic basin north of Svalbard. The field campaign was part of a multidisciplinary project organized and lead by the Norwegian Polar Institute (NPI) http://www.npolar.no/en/projects/n-ice2015.html.

Ervik and Shestov investigated the consolidation, development of porosity, keel depth and geometry and mechanical properties of ridges. Thermistor-strings were deployed through several ridges and monitored the internal temperatures. The investigation showed that while the rubble in the lower part of the keel melted, the consolidated layer in the upper part of the keel grew (Figure WP3_4).

They performed drillings through the ridges to establish the macro porosity and cored ice samples that were tested mechanically in KOMPIS, a portable device to measure uni-axial compressive strength of ice (Figure WP3_5). Simultaneously the rubble porosity decreased and the strength of the consolidated layer and the sail decreased. This shows that for ridge in their decay phase the consolidated layer takes up a bigger portion of the total keel than earlier in the ridge lifetime. The results further indicate that the present ISO formulation for ice ridge action may overestimate the ridge action from decaying ridges as its mechanical strength is lower than earlier in the season, even though the consolidated layer may be thicker.

In the autumn Åse continued her work on a continuum based numerical model to simulate crushing of the consolidated layer and continued to identify events of ridge interaction with the Nordströmsgrund lighthouse (LOLEIF/STRICE data).

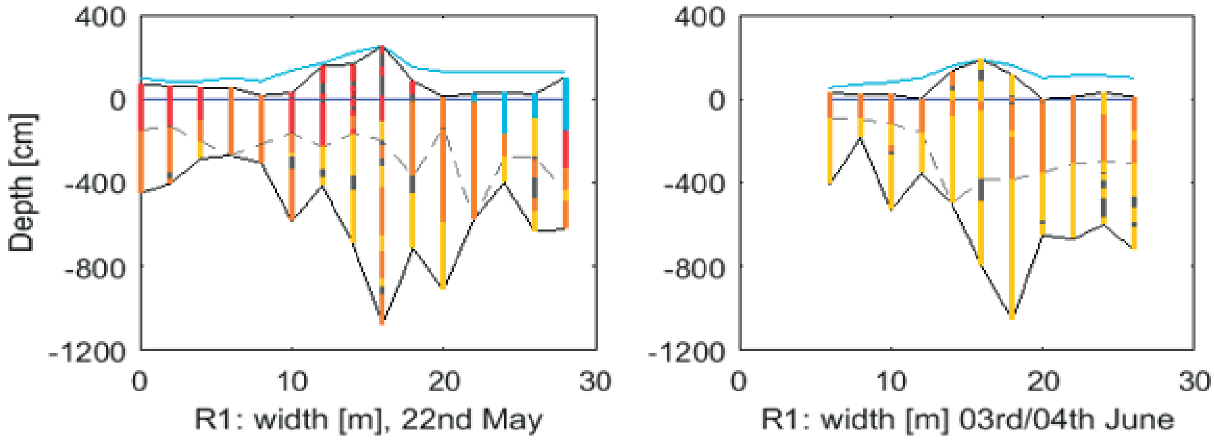


Figure WP3_4 Ridge diagram

Photo of KOMPIS, a Norwegian custom made device for field testing of Ice Strength, used in Svea by SAMCoT researchers.

Photo: Aleksey Shestov

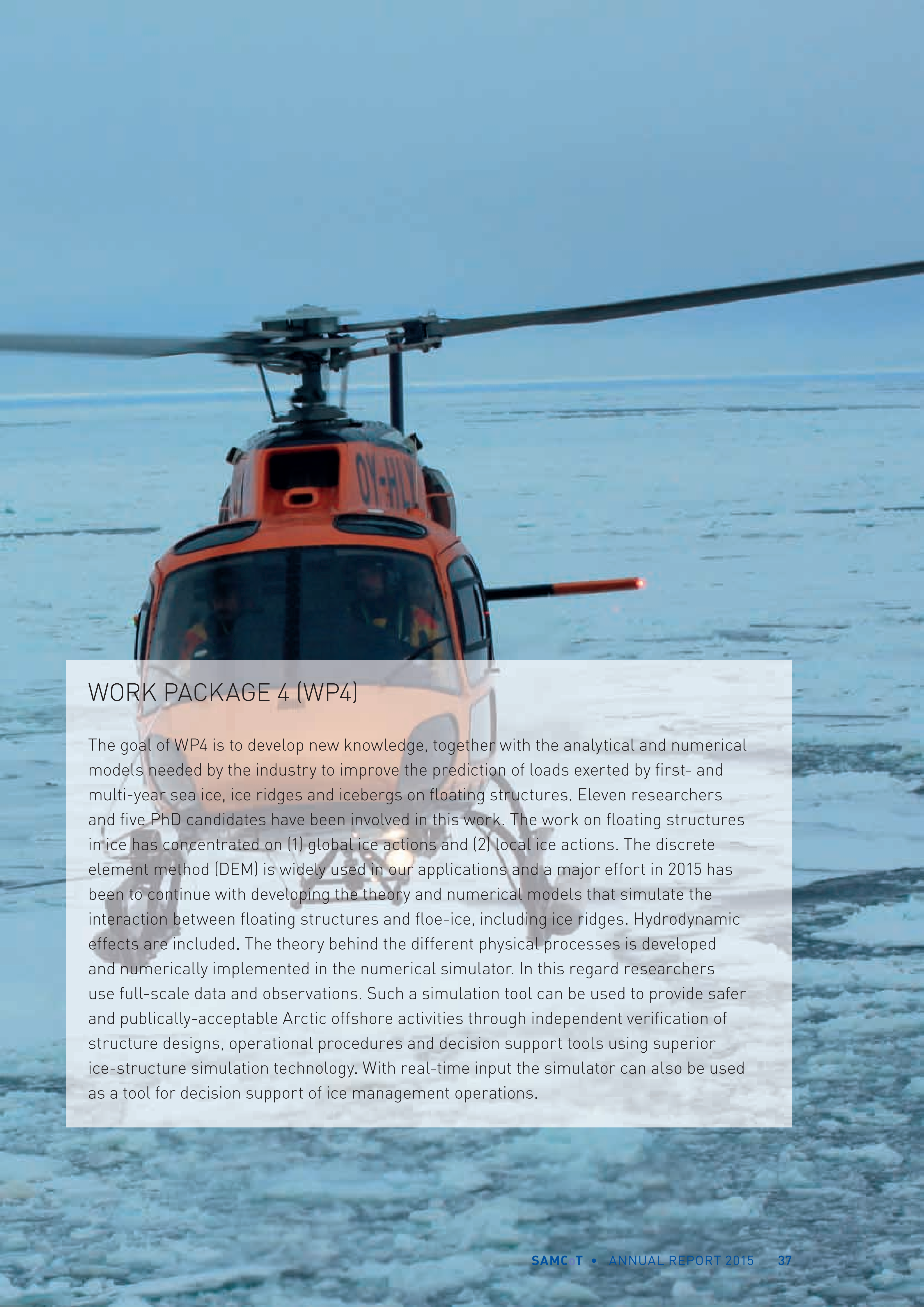
In the spring of 2015 SAMCoT`s WP3 and WP1 collaborated on a field work activity on properties of decaying first year ice ridges, lead and carried out by Post-doc Aleksey Shestov and Phd Candidate **ÅSE ERVIK**.

During the N-ICE 2015 cruise, funded by the Norwegian Polar Institute, the Fram Centre, and the Norwegian Ministry of Climate and Environment, the Lance was frozen into the Arctic ice for six months so that scientists could study ice conditions from winter's deep freeze to spring breakup – a cradle-to-grave approach. Researchers spent as long as 6 weeks on the ship, studying everything from the tiny plankton and alga in the Arctic Ocean to turbulent mixing in the waters under the winter ice.

Ervik, on the right in the photo, would spend Each day, between 12 to 15 hours out on the two ice ridges that she selected for study, drilling holes and measuring something called porosity, or the gaps between big blocks of ice at the bottom of an ice ridge. She also tested the sonar equipment to see how it would work to provide 3-D images of the ice ridge, and participated in the testing of a geomagnetic measurement device (GEM) that hopefully can produce 3-D images of the porosity of the ice ridges in the future.
An ice ridge may sound like a simple structure, but it is anything but. The top layer is called the consolidated layer, which is frozen fairly solid. Underneath is the rubble, which is what exactly it sounds like: different-sized ice chunks frozen together in a crazy mix. There can be holes between the chunks – which are measured as porosity. Ervik worked with a Finnish PhD student, Annu Oikkonen; both researchers were always watched over by a polar bear guard.

Photo: Frede Lamo

Floating Structures in Ice



WORK PACKAGE 4 (WP4)

The goal of WP4 is to develop new knowledge, together with the analytical and numerical models needed by the industry to improve the prediction of loads exerted by first- and multi-year sea ice, ice ridges and icebergs on floating structures. Eleven researchers and five PhD candidates have been involved in this work. The work on floating structures in ice has concentrated on (1) global ice actions and (2) local ice actions. The discrete element method (DEM) is widely used in our applications and a major effort in 2015 has been to continue with developing the theory and numerical models that simulate the interaction between floating structures and floe-ice, including ice ridges. Hydrodynamic effects are included. The theory behind the different physical processes is developed and numerically implemented in the numerical simulator. In this regard researchers use full-scale data and observations. Such a simulation tool can be used to provide safer and publically-acceptable Arctic offshore activities through independent verification of structure designs, operational procedures and decision support tools using superior ice-structure simulation technology. With real-time input the simulator can also be used as a tool for decision support of ice management operations.

Global ice actions

WP4 develops the theory and methods to study the overall actions that different ice features may exert on a floating structure. This is illustrated in the generalized structure shown in Figure WP4_1. The ice feature can be any continuous or fragmented ice field, where the latter is either naturally broken by gravity waves or artificially broken e.g. by icebreakers. Further, it may include ice ridges. Depending on the confinement, ice concentration and floe size distribution, the governing mechanisms during ice-offshore structure interactions can differ considerably from those that dominate when the structures interact with level ice.

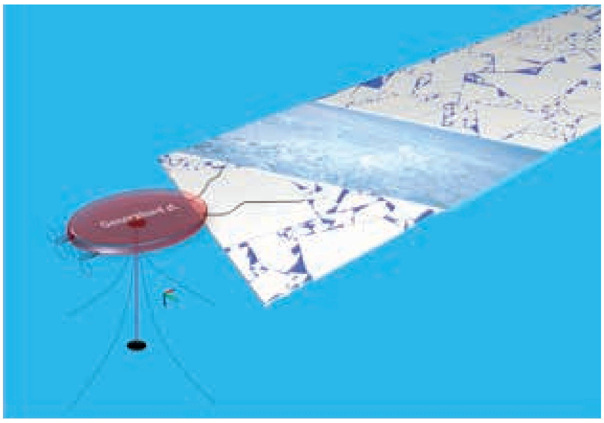


Figure WP4_1. Illustration of a generalized structure exposed to different kinds of ice features.

Numerically, time-domain modelling is inevitable due to the considerable nonlinearities in the interaction processes. The distinct nature of ice floes in a broken ice field has often promoted the use of DEM, where ice floes are treated as rigid bodies and the contact forces are modelled as spring-dashpot forces or simply estimated from Newton's laws of motion. DEM is used extensively in our global ice action modelling. Figure WP4_2 illustrates the processes and forces considered in our modelling.

Figure WP4_2. The building blocks of the DEM modelling illustrated on a photo of the Oden icebreaker during a full-scale ice management trial off Northeast Greenland.

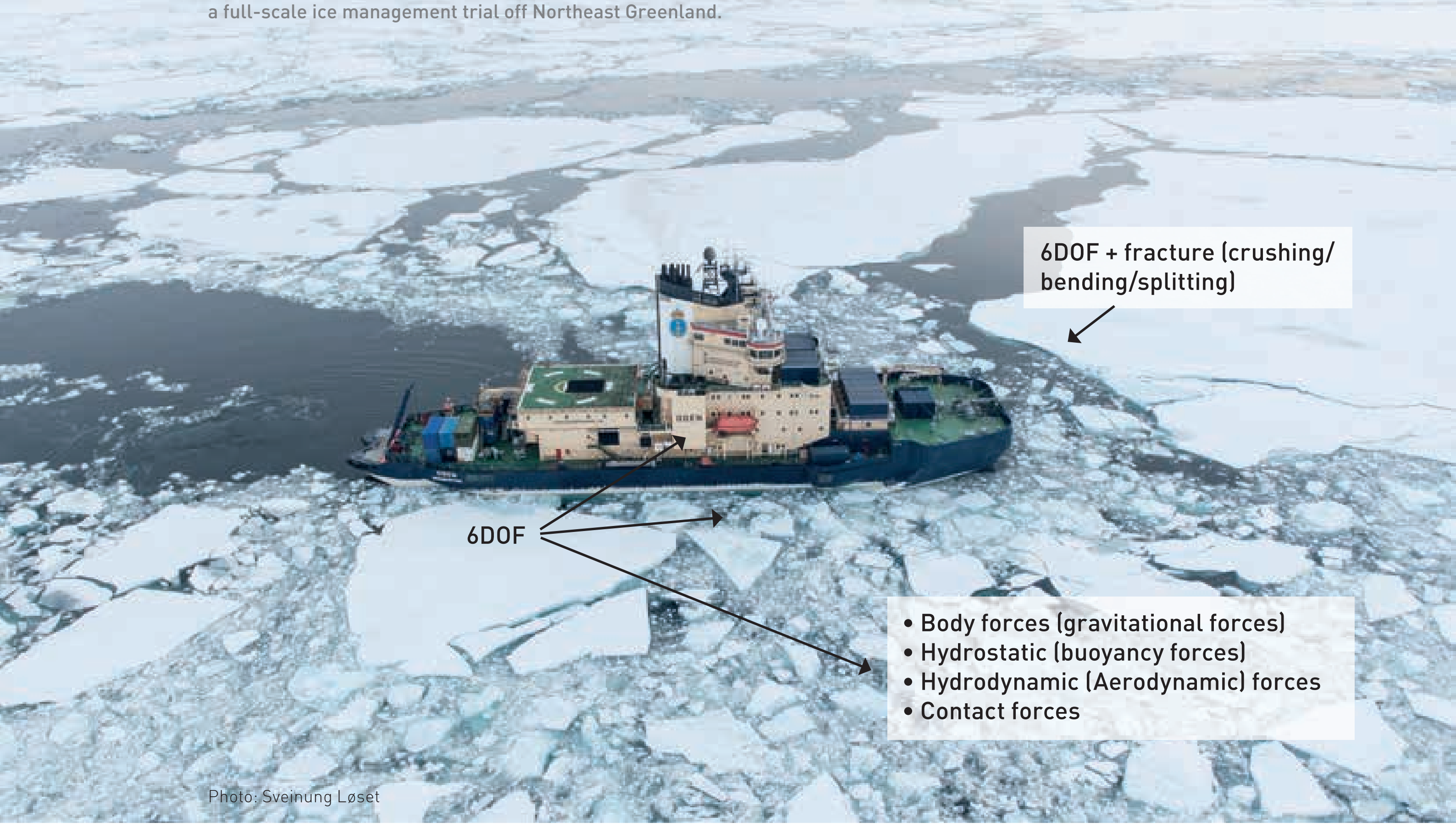


Photo: Sveinung Løset

Fracturing of ice:

In 2015, Dr Wenjun Lu continued his research work covering the fracturing of sea ice. In addition to the frequently observed splitting failure mode, some other important out-of-plane failure modes were identified and studied theoretically. Figure WP4_3 depicts the so called 'radial cracking' of an ice floe under a vertical contact load that has been studied numerically. The Figure shows how the radial crack propagates (i.e. α = 2 ,..., 80 percent of the floe size) within ice floes of different sizes (i.e., n=1, 4, 8 is an increasing size number that represents the ratio between floe size and the characteristic length of a plate on an elastic foundation). In short, this figure shows that small ice floes fail by radial cracking while large ice floes fail by circumferential crack formation.

Combining with previous studies, all these different failure modes constitute different scenarios during ice-floe ice interactions. The ability to capture these different failure modes will give a reasonable estimate of the ice fracturing load depending on floe ice's size, confinement and the interaction speeds. It is expected that the analytical solutions of these different failure modes will be implemented in the numerical simulator so as to cover a simulation over a large temporal and spatial scale.

Apart from the fracturing of a single ice floe, the practical advantage of parallel channel-induced fracturing events, which are beneficial for an ice management operation, also caught Lu's eye. Its fracture principle is similar to other fracture events. A series of theoretical and experimental efforts have been made to study the parallel channel fracturing processes. The objective is to study what parallel channel spacing would lead to an efficient ice management operation (i.e. to better control the broken ice size within neighbouring channels).

Moreover, as a preparation for the full tests in March 2016 to acquire the fracture properties of sea ice, a trial test was carried out in March 2015 together with a preliminary theoretical analysis on the fracture test design (see Figure WP4_4). The trial test was conducted at Svea, Spitsbergen. The test was theoretically designed and the equipment was tested in the field. The Ditch Witch trencher proved to be an effective tool for cutting large ice sheets. Based on the experience obtained in this trial test, a new test campaign is scheduled for March 2016. The objective of this test is to acquire the fracture properties of sea ice (e.g., fracture toughness, fracture energy and the traction-separation curve). These quantities are important in describing the fracturing process of sea ice, especially considering that the traction-separation curve is an indispensable material property in computational mechanics used to simulate the fracture initiation and propagation within most materials (e.g., concrete, metal, fibre reinforced plastics, etc.)

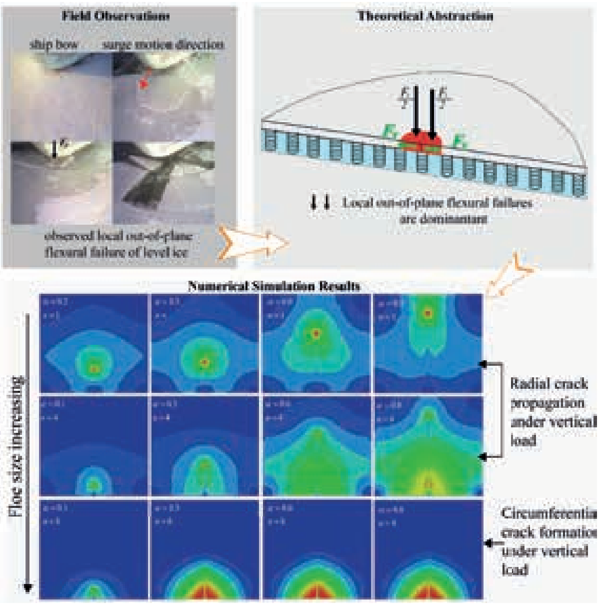


Figure WP4_3. Continuation of theoretical studies on different fracture patterns of ice floes (e.g. different out-of-plane failure scenarios are depicted depending on the floe sizes).

Figure WP4_4. A trial campaign in the field to acquire the fracture properties of sea ice.

Modelling the hydrodynamic effects on floe ice-structure interactions

Discrete element methods have been widely used by many researchers worldwide to model the dynamics of broken-ice fields and the dynamics of structures surrounded by ice. However, despite the large number of ice-related applications of DEM described in the scientific literature, prior development of the method has focused mainly on improving the modelling of contact interactions between ice floes and structures, whereas the effects associated with fluid dynamics have been largely neglected. The PhD thesis of Andrei Tsarau, which was successfully defended in December 2015, introduced several hydrodynamic models that can be incorporated into DEM to improve the simulation of marine operations in broken ice and to enable new applications of the method to ice-related problems.

Flow regimes in different areas around a structure may differ significantly from each other, i.e. the flow regime upstream of the structure is fundamentally different from that downstream and also from that in the wake of a propeller if the marine structure is equipped with propellers. Thus, three major topics and three corresponding approaches were considered in the thesis:

- Potential theory was adopted to model the hydrodynamic effect on ice floes upstream of a structure
- The Vortex Element Method (VEM) was employed to simulate the hydrodynamics in the downstream wake
- A special technique based on empirical formulas was developed to predict the dynamics of ice in the propeller wash of a ship.

The novel synthesis of DEM and a potential-flow model presented by Tsarau, enabled simulations of the hydrodynamic interactions in multi-body systems, e.g. structures in broken-ice fields. Unlike standard potential-flow codes,

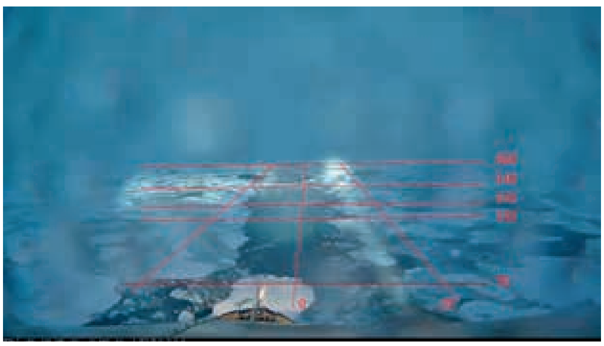


Figure WP4_5. Full-scale prop-wash test with the icebreaker Frej. An isolated ice floe was pushed along an ice-free channel with the propeller wash (units in metres).

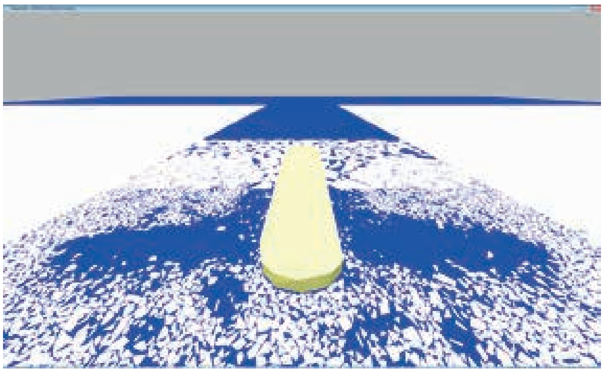


Figure WP4_6. Numerical simulation of channel clearing with the propeller wash of a ship.

this method can handle the actual motions of bodies as they arbitrarily move and rearrange themselves in the system.

For the first time, the formation of vortices in the flow downstream of an offshore structure was shown to have an effect on the spreading of broken ice in the wake of the structure. This effect was efficiently simulated by employing VEM, demonstrating a new application of the method to ice-related problems.

The propeller-wash effect has been used for decades in Arctic marine operations to remove ice locally. However, a comprehensive numerical model that can accurately simulate such operations is presented for the first time in Tsarau's thesis. This model predicts the propeller-flow velocities, calculates the hydrodynamic forces on the ice and integrates the equations of motion of the ice cover, which is represented by an ensemble of rigid bodies that may interact with each other. The computations associated with collision detection and collision responses are performed by an efficient physics engine which was integrated with a fluid-flow model to enable hydrodynamic simulations in the overall simulation environment.

In September 2015, a specially designed full-scale experiment with the Swedish icebreaker Frej was conducted to calibrate the prop-wash model (Figure WP4_5). Additionally, a validation study in which previously collected experimental data were compared with numerical predictions has proved the high accuracy of the model in simulations of an offshore operation in which the propeller flow of a vessel was employed to clear channels in multi-layered ice rubble (Figure WP4_6).

Application of multibody dynamics to model structures – floe ice and ice ridge interactions

In 2015 PhD candidate Marnix van den Berg continued with his discrete modelling work of ice ridge – floater interaction. Some simulation examples are shown in Figures WP4_7-9. Figure WP4_7 shows the simulation of a floating structure breaking through an ice ridge. We see crushing of ice (red colour) in the contact zone area between the floater and the ridge on the right hand-side and ice failing behind the ridge (on the left side). The rubble formation behind the ridge is shown in more detail in Figure WP4_8. Figure WP4_9 shows a ship moving through level ice. Both splitting failure and bending failure occur in this simulation.

Van den Berg made progress in combining a lattice model of the intact ice with a non-smooth discrete element model of broken ice blocks. The goal of the PhD of Van den Berg is to develop and apply a numerical modelling technique that will enable the ice engineering community to perform discrete simulations of ice-structure interactions within reasonable calculation times and computing power. He does this by combining two numerical modelling techniques: the non-smooth discrete element method and a lattice model. Combining these modelling techniques is challenging and is an ongoing topic of his research.

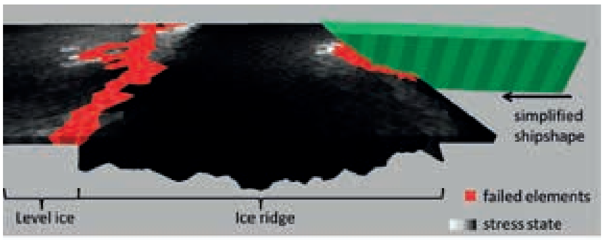


Figure WP4_7. Simulation of a floating structure (green colour) breaking through an ice ridge. The floater is moving from the right towards the left.

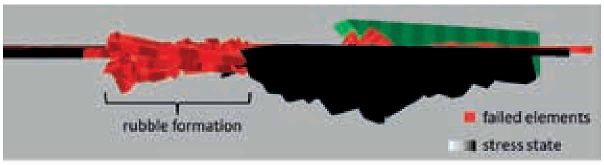


Figure WP4_8. Simulation showing more details of the rubble formation depicted behind the ridge.

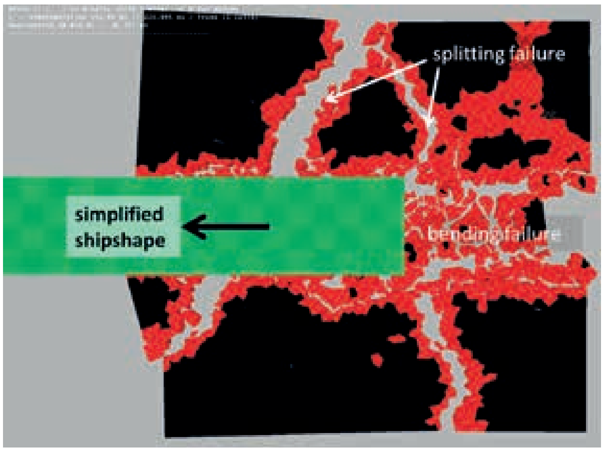


Figure WP4_9. Simulation of a ship going through level ice.

Effects of hydrodynamics on the interaction with level ice

In 2015 PhD candidate Chris Keijdener spent most of his time working on building a semi-analytical model of ice structure interaction which can capture the effects of hydrodynamics.

Although hydrodynamics is an important effect to capture (see the Figure below), not many of the current models include it due to its complexity. That is why the focus of Keijdener's PhD is to first understand all the aspects of the hydrodynamics that have a significant influence on the interaction and then find a simplified way to add these effects to existing models.

During autumn 2015 the linear interaction model was completed. The breaking lengths and interaction forces are found to behave qualitatively differently when compared to a model which only includes hydrostatics, and their behaviour is much closer to that observed in model tests.

However, there were still some discrepancies with the model test data. The reason for this turned out to be the nonlinear hydrodynamics terms. To include these, the semi-analytical model had to be upgraded. This was done by using the perturbation method to handle the nonlinearities. The upgrade of the model should be finished by early 2016. During this stage of his PhD Keijdener will focus on trying to find a simpler way to add the effects of the hydrodynamics to existing models.

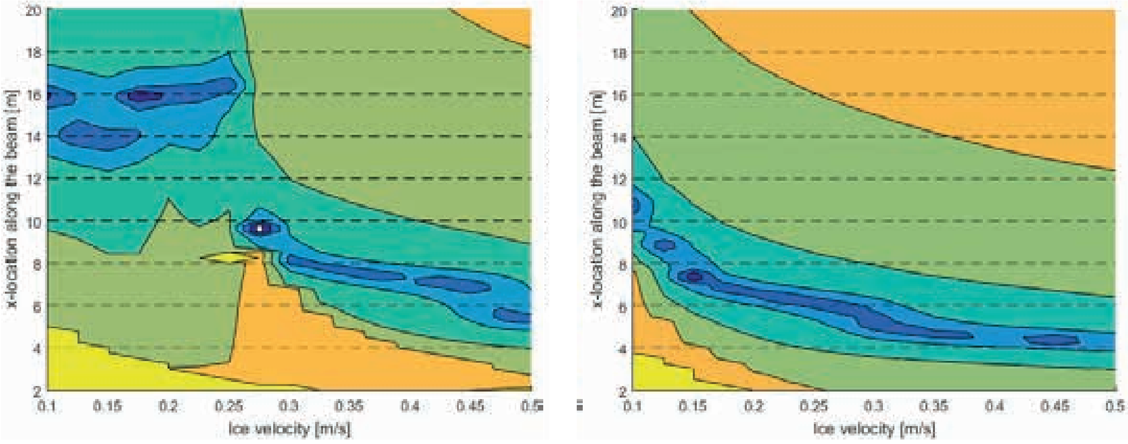


Figure WP4_10. The probability of level ice breaking at a specific length while interacting with a downward-sloping rigid structure shown at various interaction speeds. The right graph includes hydrodynamics and the left graph does not. Blue indicates a high probability.

Local ice actions

A proper understanding of local ice actions and action effects is important in the design of ships and offshore structures. Local, in this respect, means that loads on a contact area are typically of size 1 m^2, but in general are determined by the structural arrangement. Depending on the local contact conditions such as shape of the structure, ability to deform etc., the local ice action will vary. Here SAMCoT's research efforts focused on the following topics: Fluid-Structure Interaction, analysis of ice-structure collisions; Understanding of local ice actions on ships and offshore structures and Validation of SPH based approach to fracture of ice.

Application to ultimate limit state design (little or no plastic deformations)

In order to bridge the gap between local ice loads used for the design of ice-going vessels and offshore structures, analysis of the International Association of Classification Societies Ltd. Polar Class (IACS PC) and Russian Maritime Register of Shipping (RM) semi-analytical models have been performed. A summary of the analysis can be found in the 23rd International Conference POAC`15 paper "Understanding the effect of assumptions on shell plate thickness for Arctic ships". In addition, the detailed analysis, including derivations of the rule formulae and uncertainty quantifications, has been published in the International Journal of Ocean Engineering (see paper "Discussion of assumptions behind rule-based ice loads due ice crushing"). Results from this study have been used to extend the ice failure maps developed earlier by Dr Lu. Solutions for localized ice edge crushing have been added to theoretically different fracture patterns (see the POAC15 paper "Toward a holistic load model for structures in broken ice"). The updated ice failure map is shown in Figure WP4_11 and is based on observations of ice failure in contact with floating ship-shaped structures in level ice and in low ice concentrations.

Application to accidental limit state design (significant plastic deformations)

Within the context of local ice loads due to an abnormal ice event, our group has been addressing two effects: the effect of structural deformations (coupled ice-structure interaction during an impact event) and the effect of surrounding water (hydrodynamic interaction effects).

Coupled ice-structure interaction

Results of ice and structure collision experiments, where both the ice and the impacted structure undergo permanent damage, have been presented at POAC15; for detailed information refer to the paper entitled "Pilot study of ice-structure interaction in a pendulum accelerator". We highlight that further investigations of this coupled interaction are vital to improve the understanding of ice loads in a realistic impact scenario and to establish additional requirements to limit catastrophic damage to vessels with design loads with high probabilities (less than a 100 year return period).

Hydrodynamic interaction effects

In the analysis of ice-vessel collisions, hydrodynamic effects from the surrounding water may also be important because they affect the motions of the ice and the vessel before and after the collision (e.g. see Figure WP4_12).

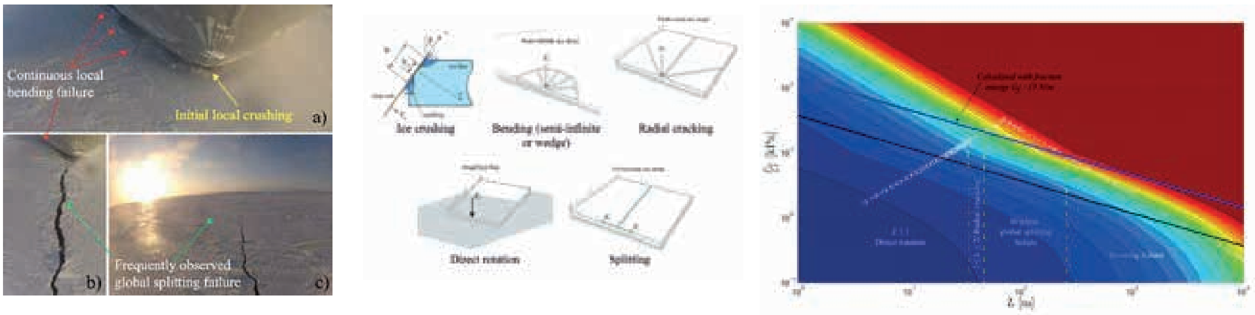


Figure WP4_11. Updated ice failure map and the corresponding fracture patterns.

To check whether or not the fluid-structure-interaction (FSI) technique of LS-DYNA (an advanced general-purpose multiphysics simulation software package) can be applied to the analysis of vessel-ice collisions, numerical simulations of collision experiments at the Aalto Ice Basin in Finland have been carried out. The input parameters for the ice model and the fluid model were set independent from the test used in order to validate the overall performance of the FSI model. To verify the fluid modelling in LS-DYNA, analyses were performed to determine the frequency-dependent added-mass coefficients for a spherical body and a rectangular block. The coefficients for different frequencies were compared to the added mass coefficients calculated in Wadam (software for marine hydrodynamics and wave structure analysis) with the same geometry. In the POAC15 paper entitled "Fluid-structure-interaction analysis of an ice block structure collision" we address verification issues arising from fluid modelling that uses an equation of state. To build credibility in the constitutive ice model and to validate ice input parameters, experimental data from indentation and impact tests were used. The FSI simulation results were compared with the laboratory experiments where a floating structure was impacted with an approximately one tonne ice block at a speed of 2.0 m/s (see Figure WP4_12). In short, the FSI method with verified ice and water models is able to predict accurately the collision response of the floater as far as sway accelerations are concerned. A comparison between the conventional constant added mass approach and the FSI analysis is currently in progress. Our preliminary results indicate that for collision problems in which the hydrodynamic interaction effects are important, the FSI method can provide more realistic and reliable predictions of the floater acceleration history than the conventional constant added mass approach.

Validation of Smooth Particle Hydrodynamics (SPH) based approach to fracture of ice

Within this topic SAMCoT's research efforts focused on understanding which experimental data sources are better suited for validation of the SPH based approach, and what are the possible size and scale effects. In collaboration with WP2, we searched for scale- and size-invariant ice parameters that can be used for the validation of SPH based numerical and analytical models of ice-structure interactions (including the SPH based model) by re-analysing available in-situ and laboratory indentation test data at different scales. Currently, we are investigating a crushing specific energy index of ice and the possibility of its implementation into numerical and/or theoretical models developed within WP4. As a part of this study and in collaboration with the National Research Council of Canada (Bob Gagnon), data from indentation experiments conducted on iceberg ice at Pond Inlet in 1984 were re-analysed for three different spherically-terminated indentor sizes. Preliminary results indicate that for any given test the crushing specific energy of the ice shows little, if any, dependency on the volume of the displaced ice and tends towards a constant value. Furthermore, there is no apparent correlation between the crushing specific energy of the ice and indentor size. Possible reasons for these observations will be discussed in the 23rd IAHR International Symposium on Ice 2016 paper ("A preliminary analysis of the crushing specific energy of iceberg ice under rapid compressive loading")

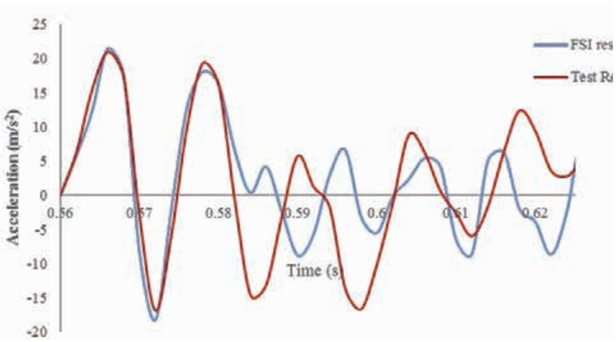


Figure WP4_12. Measured and calculated accelerations of the floater versus time.

RUNA A. SKARBØ is the lastes addition to SAMCoT's WP4 team of researchers. She started her PhD work in October 2015 as part of a collaborative project between the Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA) and SAMCoT. CIRFA is hosted by the Department of Physics and Technology at UiT – the Arctic University of Norway.

Her topic of research is ice drift prediction and the mitigation of impact from sea ice on marine operations. The goal of her research is to use observations to produce a model to predict the ice drift around a vessel operating in the Arctic. Information about ice drift is required to perform efficient and effective ice management operations. This model will eliminate the need to place physical tracking beacons on the ice, which is both expensive and has a high risk as they are often lost. The predictions are based on a combination of regional ice drift data retrieved from synthetic aperture radar (SAR) satellite images and local ice drift data obtained from radars on the vessels.

Since her arrival at NTNU, Skarbø has focused on defining her PhD project plan, including studies on a research cruise in the Arctic Ocean in 2014. In addition, she has completed different courses to gain a further understanding of ice mechanics and the fundamentals of ice drift in the Arctic Ocean. After just a couple of months, Skarbø was ready to start working on publications, hence the conference paper she will submit for the 23rd IAHR International Symposium on ICE 2016 on drift prediction of icebergs and ice floes in the Greenland Sea.

Companies performing offshore activities in ice-infested waters show great interest in iceberg drift prediction due to the severe consequences of an iceberg-structure collision and because its prediction presents a great challenge. This is due to the fact that iceberg drift prediction is mainly dependent on ocean currents which are not well known in the Arctic. Skarbø's publication looks at whether the drift of icebergs can be modelled using information about the drift of ice floes nearby. The drift of sea ice is easier to predict, as it is mainly affected by wind, which is better known in the area..

Photo: Tom Willems


RECCO

Ice Management and Design Philosophy

WORK PACKAGE 5 (WP5)

The research activity of WP5 includes a number of different activities. One of them is pursuing the next generation motion control systems for floaters. This will be more proactive in complex environments and be able to "see", predict, and better act on the surrounding environment. The research necessitates instrumentation of some of the needed surveillance tasks of ice management. Of particular interest is global load monitoring and also remote ice drift tracking and forecasting with hazard detection. The first enables more reactive motion control of the vessel and improved understanding of the ice conditions. The second reduces the number of helicopter flights and the disposal of electronic equipment and batteries into the ocean, since physically placing tracking buoys on the ice will not be needed.

Another important activity is the use of inertial measurement units (IMUs) strategically placed on a ship. A time-frequency decomposition method has been developed, and detection algorithms will be used to identify unusual ship-ice interaction events and changes in the ice drift direction.

A novel design philosophy for Arctic offshore floaters protected by ice management

PhD candidate Farzad Faridafshin presents and explores three major options for the design of marine structures under uncertainty, as stochastic, robust, and distributionally robust optimization frameworks. The first two methodologies relate to probabilistic (or reliability-based) and non-probabilistic structural design methods respectively, which are well-established and understood in structural mechanics applications. The third option, not as much explored, specifically attempts to immunize the design against the choice of (generally multivariate) probability distributions. Using this methodology, instead of requiring an inclusive joint probability density function, a more limited amount of prior information is extracted from a dataset. Such prior information can, for example, be the first- or higher-order moments of a set of data, possibly in addition to some qualitative assumption regarding the shape and tail behaviour of the underlying probability distribution. In this methodology, our incomplete knowledge of the distribution is invested in defining a distributional set, out of which the worst realization is sought, and forms the basis for design. In other words, the true distribution is unknown to us, but is believed to belong to a set, out of which we choose the worst one for design purposes.

An appropriate class of distributions for reliability applications is based on the so-called log-concavity of the probability density function (just think of it as a mathematical property). Interestingly, this class covers the majority of probability distributions that are common in structural reliability analysis. By only extracting the vector of means and the covariance matrix from a set of multivariate data, and by assuming that the underlying (yet unknown) distribution is log-concave, Faridafshin has shown how a particular level of reliability can be achieved in a design process. This works by establishing an uncertainty set (which happens to be an ellipsoidal set with the dimension of uncertainty) whose size is related to the target reliability. In this framework, even though it is possible to achieve specified reliability level, the mathematical procedure builds upon solving a robust optimization problem.

Using an empirical model for the floater response in a managed ice environment, the above methodology was applied to evaluate the required capacity for the mooring lines of a conical floating unit, given an annual exceedance probability of 10-2 (according to ISO 19906). Eight uncertain parameters were identified and the 8-dimensional uncertainty set was established. The required capacities were determined for two different ice management scenarios i.e. for no ice management and for the case with one traditional multiyear icebreaker. For illustration purposes, the Figure below shows the case where only two of the parameters involved are considered uncertain i.e. the rest of the parameters are treated deterministically. These two parameters are chosen to be the thickness of the consolidated layer (HC) and the keel draught (HK) of the ridges in the long-term environment. In the Figure, both the uncertainty set (bold black curve), as well as its projection on the response surfaces (in grey and blue) are illustrated where the points of minimum required capacity (equivalent to maximum action effect) are marked with bold (grey and blue) dots.

Other classes of distributions such as the unimodal and Chebychev families are also studied in Faridafshin's research. These represent more relaxed prior assumptions and consequently result in more conservative designs.

Faridafshin is working on a number of publications discussing the theory and applications of the method and is expected to finish his PhD during 2016.

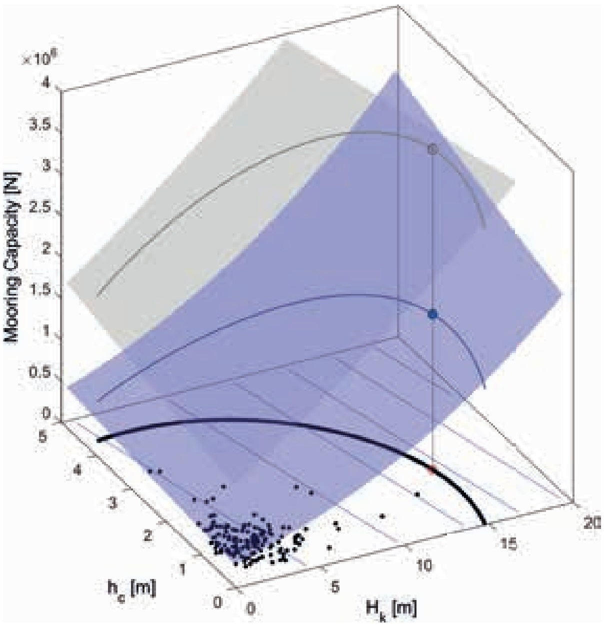


Figure WP5_1 Required mooring capacity of an offshore floater corresponding to annual exceedance probability of 10-2: with ice management (1.9 MN, blue dot) and without ice management (3.9 MN, grey dot). Black dots indicate measured environmental data forming the basis for design. The bold black curve corresponds to the ellipsoidal uncertainty set based on the first two moments as well as the assumption of log-concavity. The red dot is the so-called design point.

Iceberg drift observations and iceberg towing in broken ice

Iceberg towing in ice still has not been performed in full-scale. Model-scale experiments on iceberg towing in ice are represented by only one experiment in the Hamburg Ship Model Basin (HSVA). A validation study based on these very limited data has been run by PhD candidate Renat Yulmetov for his numerical model of iceberg towing in ice. The model was developed further to address the impulse-to-force conversion and now uses a relationship between the impact impulse and peak force measured in different experiments. In addition, the position stabilization has been improved by switching from the Baumgarte stabilization to a position projection method with pseudo velocities.

The average forces when compared between the experiment and simulation are in fairly good agreement. However, they are different from the ice resistance expressed by existing analytical estimates that has been derived for icebergs. The main source of error is the confinement in the experiment, which results in higher values for the resistance. A draft of a paper has been prepared ready for journal submission.

At the same time a deeper analysis of iceberg and ice tracking data from the OATRC 12/13 campaigns has been made. The statistical velocity distributions have been obtained. It was found that drift speed and direction distributions are very different for objects drifting in the shear zone compared to those in the central pack. Therefore, icebergs and ice show different drift characteristics in different regions.

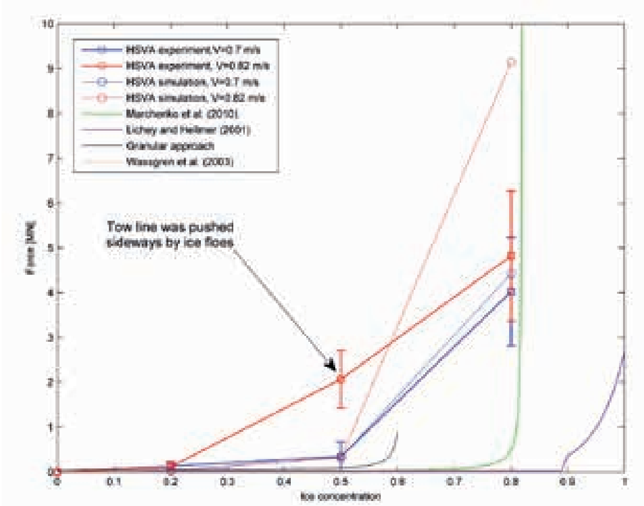


Figure WP5_2 The mean ice resistance compared for the experiment, model and existing analytical approximations.

In addition, the yawing of icebergs has been measured, analysed and modelled. The model is based on the equations of motion for a cylinder in an unbounded fluid. The modelling results demonstrated good agreement with the measured rotation. The yawing of icebergs is very important during towing operations, because large rotations may result in unbalanced tension in tow lines which can put the iceberg management operation at risk. The model in this case is directly relevant and helps to predict possible rotations. A paper about iceberg observations off North East Greenland has been submitted to the Ocean Engineering journal and is now under revision. Yulmetov will defend his thesis soon.

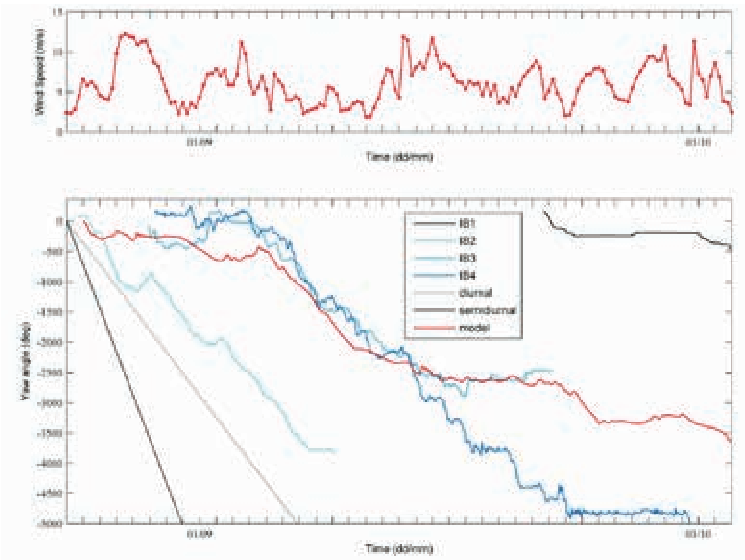


Figure WP5_3 Measured and simulated yaw of icebergs. Strong wind suspends the rotation caused by the rotating ocean currents.

Allision risk models for harsh environments

A lot of current research is looking at collisions between ships, from structural analysis of the effects of various impacts on a ship's hull to complex traffic models trying to estimate the risk of collision between ships in various situations and areas.

However, very little research is looking at more specialized cases such as allision. An allision is an impact between a ship and a stationary object. PhD candidate Martin Hassel is looking specifically at impacts between ships and offshore (petroleum) installations. There have been a few incidents worldwide, along with a few near-misses, but documentation and data are notoriously difficult to obtain.

Hassel's allision risk model aims to become the industry standard allision risk tool for the Norwegian Continental Shelf (NCS). It incorporates a wide array of risk influencing factors using a Bayesian network (BBN). The BBN is primarily made up of three components: the ship traffic patterns; the platform response to a ship on collision course and the ship's own ability to avoid an impact with a stationary petroleum installation in its path.

Work continues on developing a new allision risk model primarily designed for the offshore industry on the NCS. A workshop with subject matter experts was held in February 2016, and an article about the development and finalization of the model is in progress. The article will be a follow-up to the article describing the model architecture that was submitted to the journal Safety Science in December 2015.

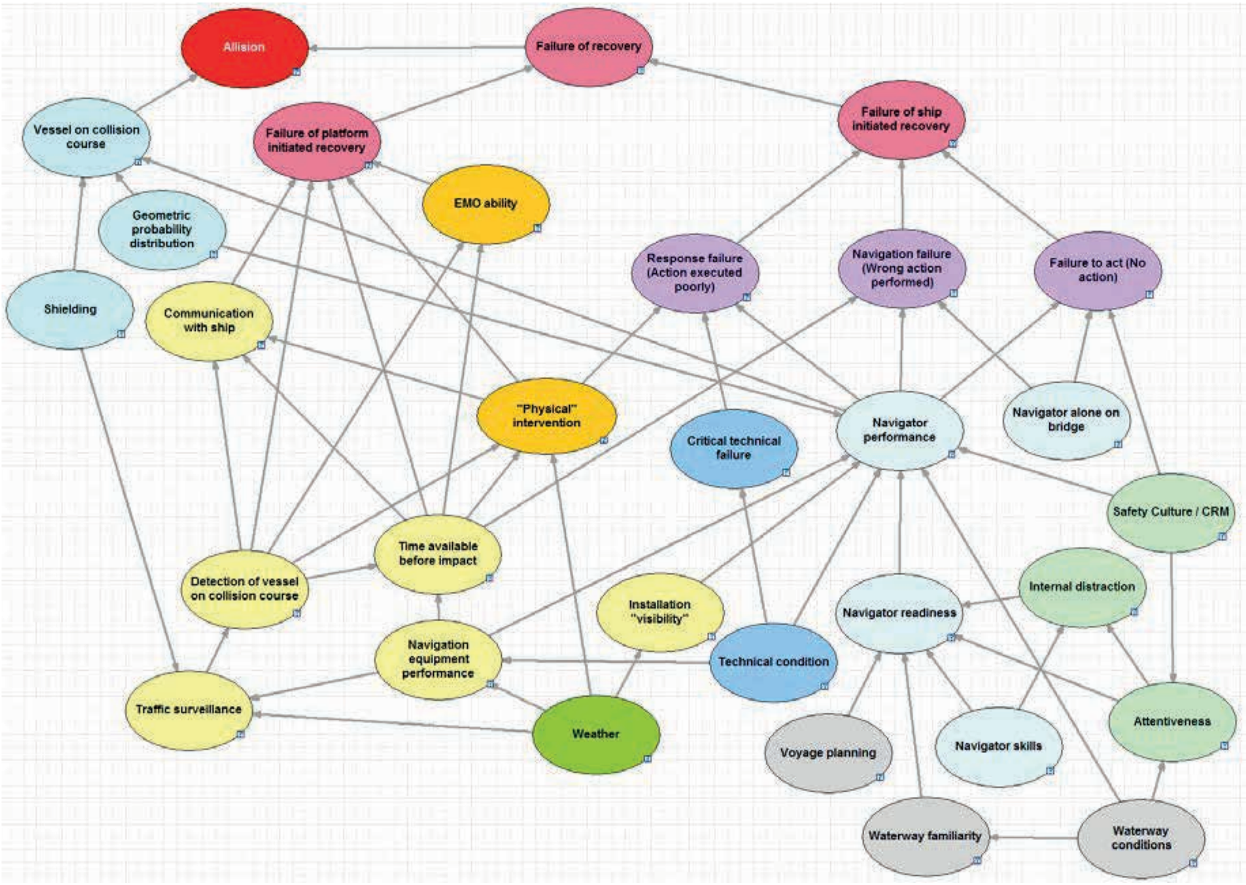


Figure WP5_4 Bayesian network of allision model.

Spectral analysis of ice-induced accelerations

PhD candidate Hans-Martin Heyn has developed a system consisting of low-cost inertial measurement units (IMUs) coupled with a method for analysing the frequency components of ice-load signals. The overall aim is to provide an additional tool for the ice observing part of an ice management system for the detection of the severity of ice loads on a ship or structure.

An array of three to four IMUs are installed throughout the ship, preferably close to the ice-interaction zone. IMUs measure the translational accelerations and the rotation rates at their mounting position. The recorded data are pre-processed in order to remove noise and to align the readings of all sensors.

Heyn applies a time-frequency distribution, based on the Wigner-Ville distribution, on the ice-induced acceleration measurements. The results are time-varying power spectral densities, which allow for a significantly improved frequency analysis of the ice-load signals.

The system has been tested during OATRC`15 in September 2015. The ice-load measurement system was installed on the Swedish icebreakers Oden and Frej. On board each icebreaker four separate IMUs were installed at various positions in the vessel. A central server collected the data from the individual IMUs on each ship, and served as a time synchronisation server for the sensor units. Furthermore, synchronised data from other ship systems such as the GPS system, the gyro-compass and wind sensors were collected. Images from a 360° camera system and individual 180° cameras were used on each ship to identify the ice conditions around the vessel.

During the expedition between the 20th September 2015 and 30th September 2015, a total of 72 hours of ship motion measurements were taken. The first analyses of ice-induced accelerations have been conducted for the data collected on the icebreaker Frej.

Figure WP5_5 shows the time-frequency distribution of the heave-motion acceleration measured by the sensor installed on the port and starboard facing hull.

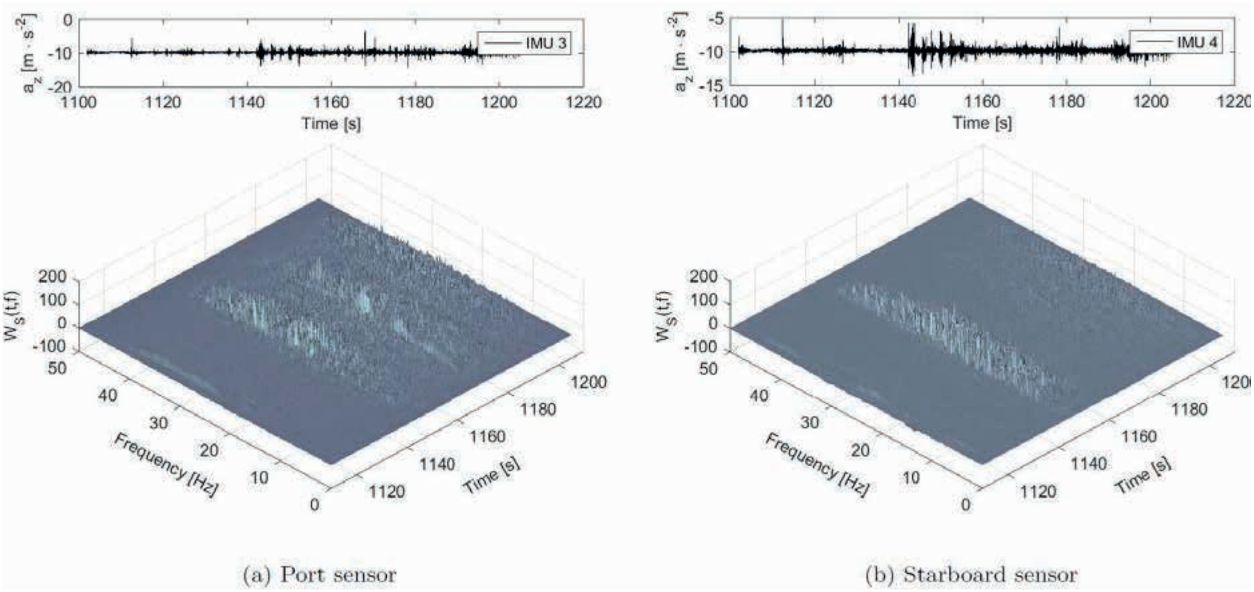


Figure WP5_5 Time-Frequency distribution of the transition from broken ice to unbroken level-ice

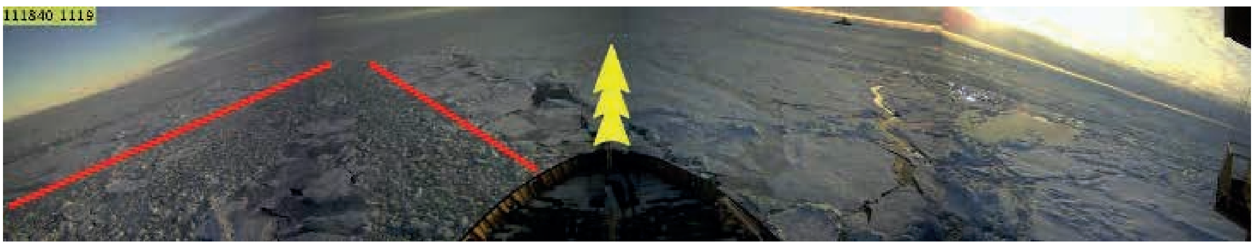


Figure WP5_6 Ice condition while moving from broken to unbroken level-ice

While moving in managed ice, the energy of the vibrations caused by the ice were hardly measurable. Upon entering the unbroken ice field, the ice around the vessel failed by crushing and bending. Due to the bending of the ice, the ice failed mostly through circumferential cracking. The transition into unbroken ice is clearly visible in the time-frequency distribution due to a significant increase in the energy of the signal over all frequencies. In particular, vibrations with frequencies between 20 Hz and 30 Hz show a significant increase in energy. After a few seconds, the excitation decreases but the energies of the heave-vibration signals are still significantly higher than in the broken ice field. The significant excitations upon exiting the ice channel can be explained by a sudden decrease in velocity of the vessel. The kinetic energy upon contact with the unbroken ice might have caused a significant amount of crushing prior to bending of the ice. As soon as the ship's speed decreased, bending failure might have been the dominant failure mode, which created significantly fewer vibrations than crushing but still more than the ice interaction with already broken ice inside the ice channel.

The distribution of the frequencies allows for the identification of the dominant ice failure mode. Figure WP5_7 and Figure WP5_8 show the power spectral densities of two situations with different dominant failure modes. In the case of ice crushing, as shown in Figure WP5_7, high frequency components become dominant. Crushing against the hull can cause high frequency, random vibrations, which can explain the significant increase in power at the higher frequencies between 25 Hz and 40 Hz. When the ice fails by bending, a repeating force pattern is measured, which is the reason for the excitation in the low frequencies, as shown in Figure WP5_8.

The technique presented allows for a significant improvement in ice observing systems on ice-going vessels or on structures in ice. Further research is ongoing to identify the direction of the ice force, so that the system can be used as feedback in ice-capable control and monitoring systems for Arctic offshore operations.

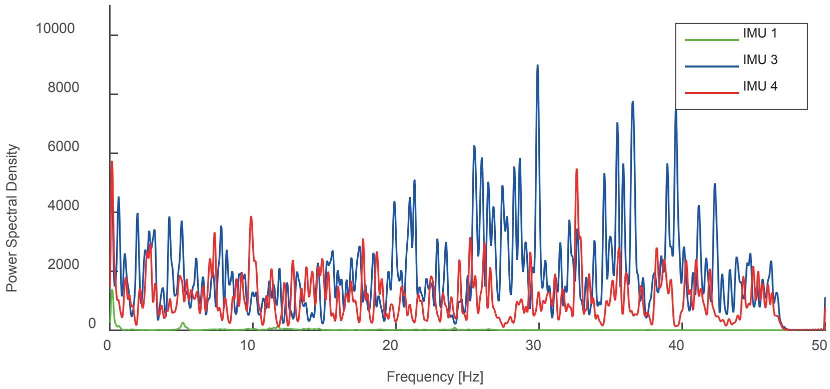


Figure WP5_7 Power spectral density of 20 seconds of measurements while crushing against the hull occured

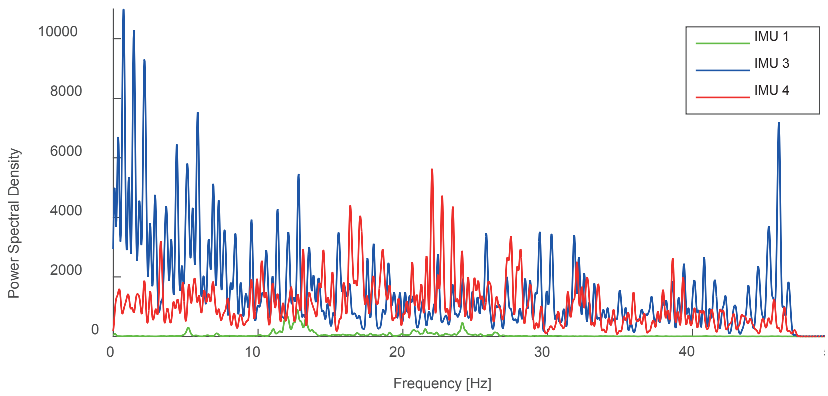


Figure WP5_8 Power spectral density of 20 seconds of measurements while failure by bending of the ice occurred

Floe size distribution from sea-ice images

Dr Qin Zhang defended her thesis successfully in the winter of 2015. In addition to her work as PhD candidate, Zhang contributed to the OATRC15 research cruise. During this field activity a helicopter was used to capture ice conditions in the marginal ice zone (MIZ). An example image is shown in Figure WP5_9. A global sea-ice floe identification method was performed on the image to identify the ice floe and brash ice, and the result is shown in Figure WP5_10 (it should be noted that the error identification in the left-bottom part of the figure was caused by the blur of the input image, but it can be improved by local processing). The coverage percentage of different sea-ice types were: 58.00% ice floe; 4.85% brash ice and 21.21% slush.

Based on the identification result, the floe size distribution (FSD) was estimated as shown in Figure WP5_8. Then, the cumulative distribution of ice floe sizes as a function of floe size was calculated (see WP5_Fig. 11), and a power law was fit to the curves to determine the statistical distribution of ice floe size (it should be noted that our floe database produces a complete database of all floes in the image, where each floe is represented by pixels other than the geometric parameters. Hence, FSD can be easily updated by using the "representative diameter" calculated from the database).

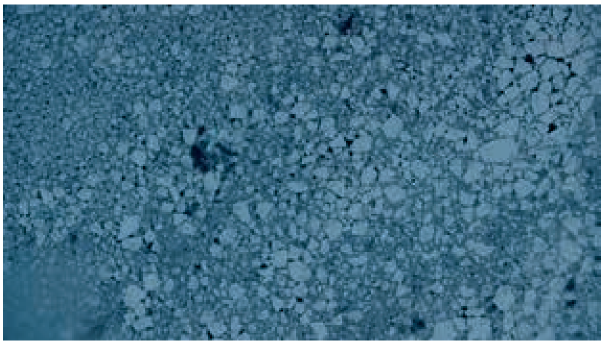


Figure WP5_9 Input helicopter MIZ ice image.

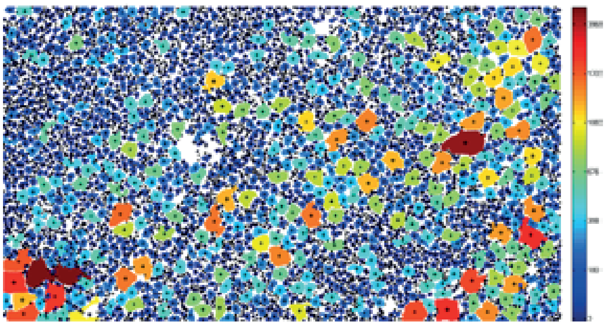


Figure WP5_10 Sea-ice floe and brash ice identification result (global processing).

To modify the sea-ice floes and brash ice for the numerical simulation of the ice-structure interaction, the sea-ice floes were simplified by assigning a minimum-area-polygon to each floe, and the brash ice was reshaped by assigning a same-area-circle to each brash ice piece. As a result of the simplification the polygonized floes will not be smaller than the actual identified floes. The individual floe data, such as its original pixels, the polygon fit, its position, area, perimeter, image and camera data, etc. are all stored in a database for further processing.

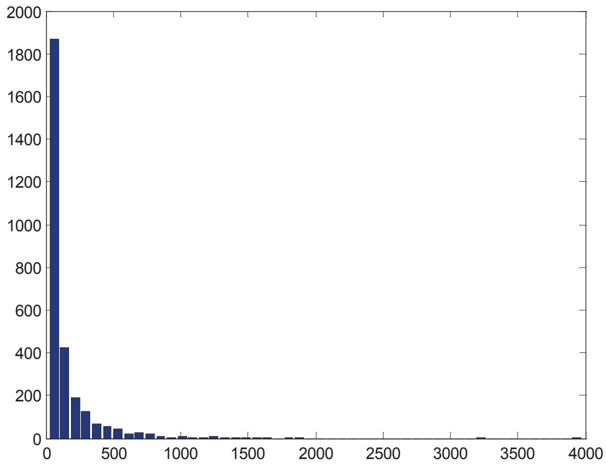


Figure WP5_11 Floe size (pixel number) distribution.

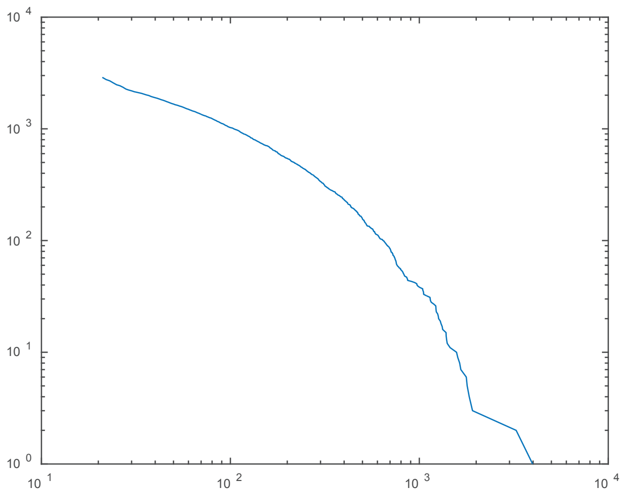


Figure WP5_12 The cumulative distribution of ice floe sizes (pixel number) as a function of floe size. Both axes are logarithmically scaled.

Dynamic positioning in drifting sea-ice

PhD candidate Øivind Kjerstad started his work as researcher in SAMCoT in 2015. Located in Svalbard, Kjerstad studies technology for marine operations in drifting sea-ice. Not only is his research exciting, it also allows SAMCoT to pursue the next generation of dynamic positioning (DP) motion control systems. WP5's objective is to keep the development as general as possible so that the results apply not only to the limited number of operations in polar environments, but also the vast fleet of DP vessels around the world.

In a long-term perspective, following the trend in other autonomous applications such as self-driving cars, planes, and drones, the marine vessels should gain the ability to autonomously observe, predict, plan, and act on their surrounding environment more independently. This will complement the operator so that both computers and humans can do what they do best. In a short-term perspective, Kjerstad`s research is focused on improving precision and reactivity of the DP control system and automating some of the required surveillance tasks on ice management. Currently Kjerstad is working with sensor technology to measure the global load on the ship and apply these signals in monitoring- and closed-loop control systems. The control designs are also extended by new advances in control theory. In order to plan and act according to the environment we are incorporating radar and camera technology, as part of the online ice observation system.

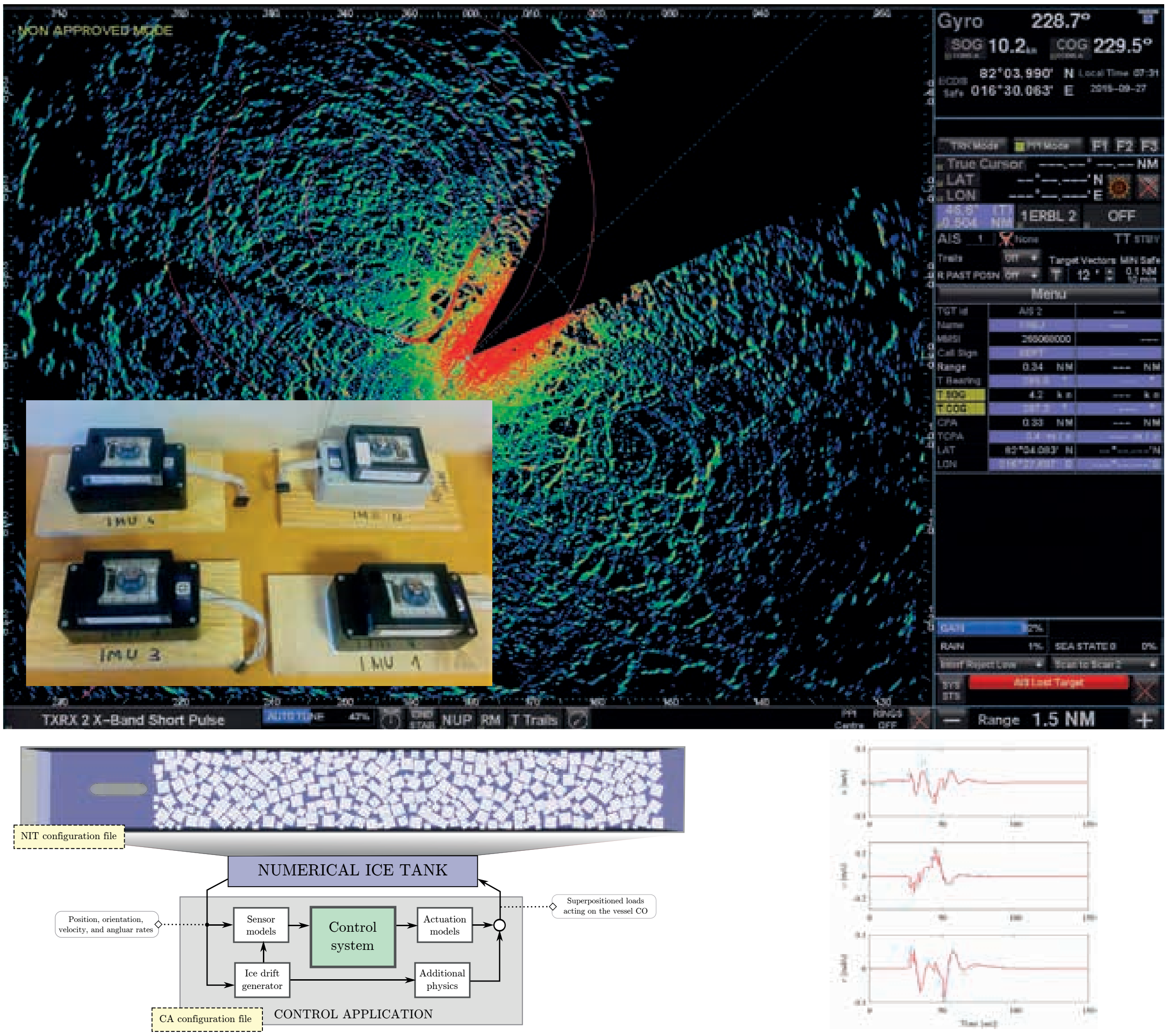


Figure WP5_13 For the next generation DP control systems inertial sensors, radar technology, high fidelity numerical simulations, and hybrid designs are all integral parts.

Iceberg detection and monitoring using an AUV equipped with multibeam sonar

PhD candidate Petter Norgren's research on iceberg detection and monitoring using an AUV equipped with multibeam sonar aims at developing methods for autonomously detecting and mapping an iceberg under the influence of wind and ocean currents. One of the main challenges when mapping icebergs from the underside is the unknown rotation. While it is possible to measure the linear translation of the iceberg using an upward-looking Acoustic Doppler Current Profiler (ADCP), it is not possible to measure the rotation of the iceberg. Therefore, the algorithm developed detects and follows the edge of the iceberg, eliminating the need to know the rotation of the iceberg in the mapping phase. This research was presented at the POAC conference in Trondheim in June 2015.

Due to warping of the collected data as a result of translation and rotation, an estimate of the rotational speed of the iceberg would be desirable if the data are to be processed on board the AUV. Therefore, one of the research objectives for 2016 will be to develop a method for estimating the rotation of the iceberg in real-time.

Field campaign: Northernmost shipwreck mapped with AUV and remotely-operated underwater vehicle (ROV)

In the period between August 31st and September 6th, Norgren participated as a field assistant on the UNIS course AT334 that, in addition to teaching students about marine Arctic operations, also included underwater robotics and underwater archaeological surveys. During the course, a survey was conducted in Tryghamna, close to the inlet of Isfjorden, where a previous multibeam survey indicated a high probability of an unmapped shipwreck. The NTNU REMUS 100 AUV was first used to verify the position and presence of a shipwreck by mapping the area with sidescan sonar, before a small-size ROV was used to capture video images of the shipwreck. Further information about the finding can be found at: **http://www.nrk.no/troms/har-funne-det-nordlegaste-skipsvrak-i-verda_-_-dette-er-berre-starten-1.12560855**. A side scan image of the shipwreck can be seen in the Figure WP5_14.

In addition to the survey in Tryghamna, several surveys were conducted in Adventsfjorden in an attempt to uncover more objects of interest. None was found, but the mapping of Adventsfjorden will continue next time AT334 is held. A picture of the REMUS 100 AUV in Adventsfjorden can be seen below, with KNM Thor Heyerdahl seen in the background.

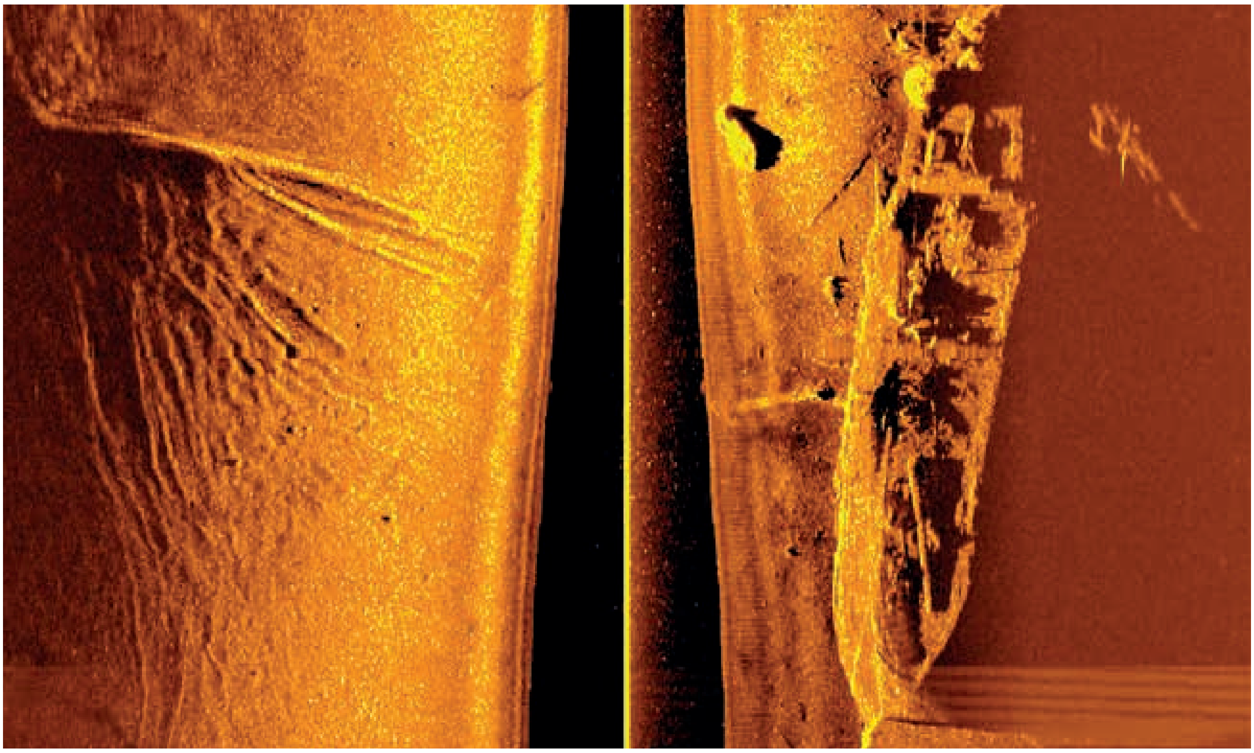


Figure WP5_14 Sidescan sonar image of the shipwreck.

Coastal Technology

WORK PACKAGE 6 (WP6)

The goal of WP6 is to develop new knowledge and the analytical and numerical models needed by the industry to improve the prediction of Arctic coastal erosion and the influence of climate change. These are essential for the design of environmentally friendly and sustainable coastal structures and technologies.

In 2015 researchers in WP6 continued to analyse full-scale data from different sites in the Arctic including Baydaratskaya Bay in the Kara Sea and Varandey in the Pechora Sea, Russia. Progress was made on developing Thermo-Hydro-Mechanical (THM) constitutive models for simulating the behaviour of frozen soils as well as research on numerical modelling of sediment transport using a computational fluid dynamics model.

This research leads to a better understanding of the mechanisms behind Arctic coastal erosion. In parallel with the field studies, major efforts have been focussed towards developing numerical models that attempt to predict the effects of climate change and the presence of man-made structures on the erosion rates in the Arctic.

Coastal zone development in the Arctic is quite demanding. The construction of roads, harbours and other facilities in the Arctic faces several challenges, e.g. exposure to combined actions from waves, currents and ice, high coastal erosion rates, building on permafrost soils and the remoteness and lack of local material suitable for construction purposes. Moreover, climate change may result in a warmer Arctic with less sea-ice cover leading to higher wave forces on structures, more unstable permafrost soils and increasing rates of coastal erosion during the service lifetime of structures.

In order to address these general challenges according to the industry partners' needs for innovation, several research projects have been carried out.

Simulating the behaviour of frozen soils

Postdoc Seyed Ali G. Amiri and PhD student Mehdi Kadivar are working to develop THM constitutive models for simulating the behaviour of frozen soils. Amiri has developed an elastoplastic model to describe the mechanical behaviour as well as the behaviour due to variation of temperature. The proposed model is able to represent many of the fundamental features of the behaviour of frozen soils such as ice segregation phenomena and strength-weakening due to pressure melting. Currently, this model is being implemented in the commercial software package PLAXIS and will soon be ready to use in geotechnical engineering practice.

Amiri submitted a paper describing his model to the Canadian Geotechnical Journal. The reviewers suggested minor revisions and we expect this paper to be published quite soon in 2016. Amiri's second step is to extend his model to consider the effect of strain rate on the stress-strain behaviour of the soil. Good progress has been made in this direction and reasonable results are already being achieved.

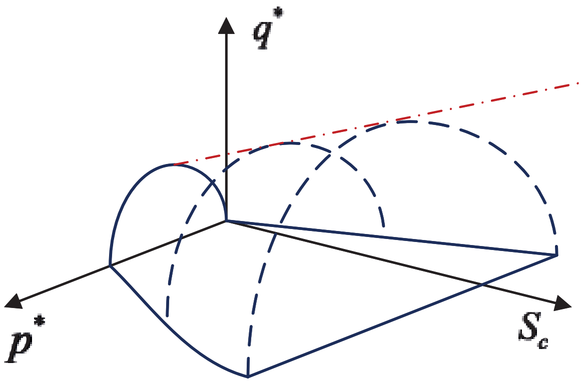


Figure WP6_1 Three-dimensional view of the yield surfaces in p*- q*- S space


Figure WP6_2 Norwegian Geotechnical Institute`s (NGI) frost heave cell device.

Since August 2015, Kadivar has been a visiting researcher at the laboratories of the NGI working with NGI's frost heave cell device to understand the behaviour of soil during freezing and to measure the amount of frost heave. By using NGI's device, it is possible to monitor the temporal freezing behaviour of soil at different temperatures. The soil sample, either intact or reconstructed, is placed into the cell and adjustable temperature is applied from the top, bottom and side of the sample. The freezing characteristics of soil that can be studied by this device are the location of freezing front, expansion of soil sample and amount of water intake from an external source during the test. The location of the freezing front is obtained by checking the temperature at the sides of the sample in different time steps. The main purpose of Kadivar's work at NGI is to study the frost susceptibility of normally-consolidated clay at different temperatures. Mehdi will sum up his work at NGI and come back to NTNU by the end of January 2016.

CFD model REEF3D

PhD candidate Nadeem Ahmad is working on the three-dimensional numerical modeling of local scour in cold climates. Ahmad's position, although strongly linked to SAMCoT is funded through the affi liated Norwegian-Polish research project "Vulnerability of the Arctic coasts to climate changes" (ARCOAST). He uses the open-source computational fluid dynamics (CFD) model REEF3D, developed by the CFD group at the Department of Civil and Transport Engineering at NTNU, Trondheim. REEF3D has a wide range of applicability within the fi eld of coastal and ocean engineering, simulating wave hydrodynamics, wave-structure interaction, fl oating body dynamics, sloshing or sediment transport. The sediment transport is coupled with the high-resolution wave and fl ow field. In the first part of the PhD study, the numerical model has been validated for local scour laboratory cases under current and wave conditions. His dissemination contribution to WP6 is of great importance, adding three conference papers and one journal paper to the total number of papers for this WP in 2015 (see list of publications).

Measurements and Modelling of Arctic Coastal Erosion

Postdoc Emilie Guegan dedicated 2015 to completing her doctoral thesis and writing and submitting journal papers in collaboration with researchers at NTNU, UNIS, SINTEF and Moscow State University (MSU).

Guegan had two journal papers accepted with minor revision in 2015 and we expect these papers to be published in 2016. The highlight of 2015 for Guegan was definitely the public defence of her doctoral thesis on December 10th, 2015. The defence was successful and concluded with positive comments from her opponents, Prof. S.Knutson (Luleå University, Sweden) and Prof. P. Overduin (Alfred Wegner Institute, Germany).

During her Postdoc, Guegan plans to continue and extend the scope of her fieldwork to include jet erosion tests, which she believes are highly applicable to Arctic coasts. Guegan intends to focus on erosion of cohesive sediment under turbulent flow, which can provide valuable full-scale data for modelling of Arctic coastal erosion. For example, measuring field erodibility in terms of critical shear stress and erodibility coefficient provides important inputs to hydrodynamic models and can be used to validate geotechnical THM models.

Dr. Anatoly Sinitsyn has been the co-supervisor for Emilie Guegan in 2015 and together they have submitted two journal papers of which one has already been accepted. During 2015 Sinitsyn visited Vestpynten field site several times and downloaded data from thermistor strings and piezometers. In collaboration with PhD candidate David Wrangborg (working in WP1 in 2015), Sinitsyn scanned the coastal bluff at Vestpynten with a laser scanner. Two data reports describing the overall data collection and laser scanning in Vestpynten were prepared by Sinitsyn and Guegan in 2015.

Figure WP6_3 Sinitsyn readind data from thermistor string at Vestpynten.

Russian Field Sites: Baydaratskaya Bay in the Kara Sea & Varandaey

Sinitsyn presented a paper at The XVI European Conference on Soil Mechanics and Geotechnical Engineering (ECSMGE) about the geotechnical investigation of permafrost in Svalbard. Sinitsyn reviewed the final report from The State Oceanographic Institute (SOI), Moscow on the Varandey fieldwork from 2012 to 2015, and he is taking part in the discussion between SOI and the leaders of WPs 1 and 6 about the continuation of the fieldwork in Varandey.

In 2015, Sinitsyn and Guegan took the first step towards translating the knowledge gained in WP6 into guidelines required by the industry for the design of environmentally friendly and sustainable coastal structures and technologies. This work resulted in two reports which will be communicated, discussed further and followed up in 2016.

With support from SAMCoT/WP6, MSU performed extensive fieldwork at Baydaratskaya Bay in the Kara Sea in 2015. Valuable full-scale data were gathered and made available to SAMCoT researchers. This included mapping, measuring coastline retreat rate, observing the underlying physical processes, time-lapse photography of slope degradation processes, continuous temperature measurements of the soil at two typical sites of the coast, etc.

Daria Aleksyutina during her stay in Trondheim as visiting researcher at NTNU

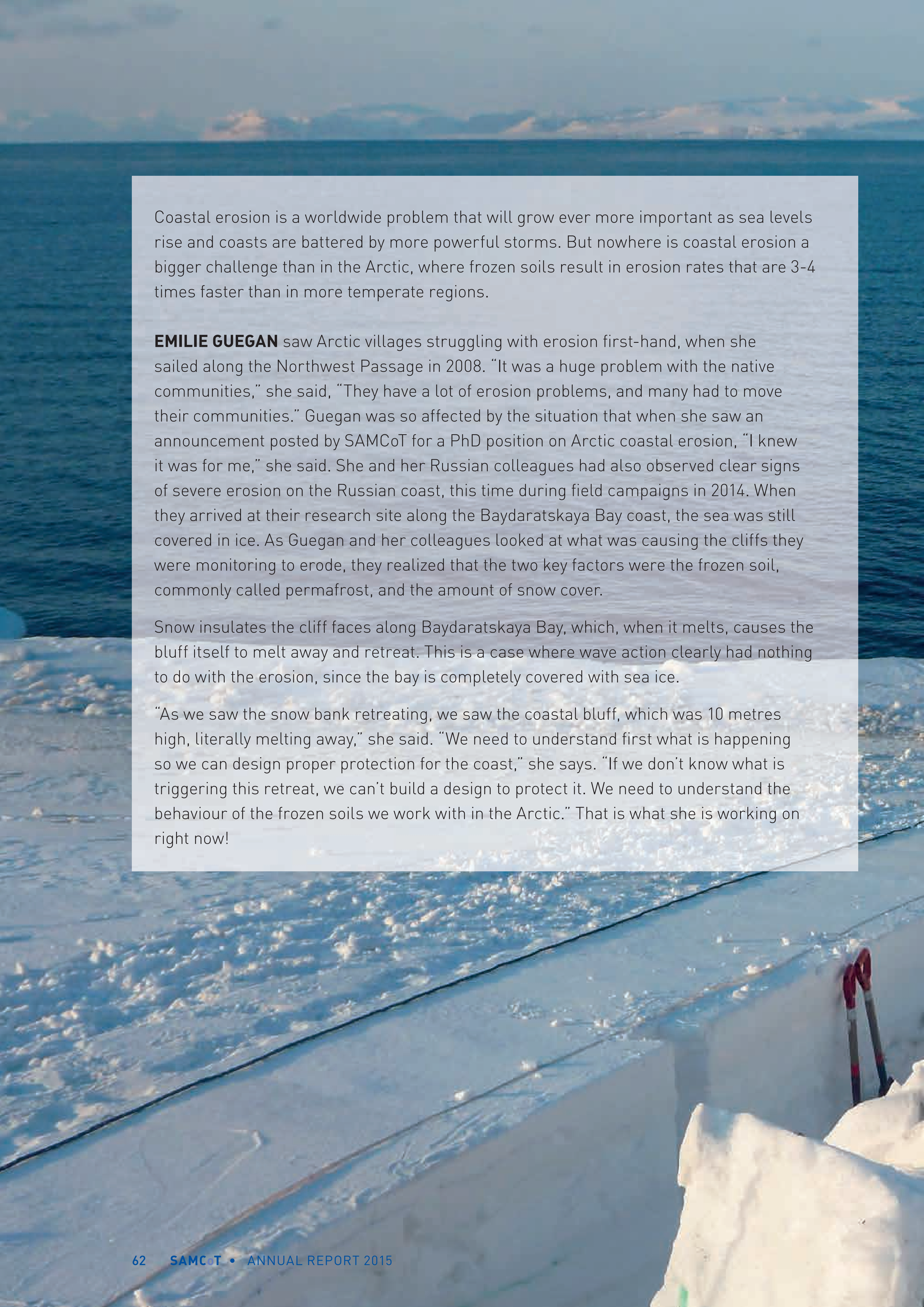
PhD candidate Daria Aleksyutina at MSU studies the features of coastal erosion for coasts composed of frozen soils (typical for Baydaratskaya Bay). In 2015 she concluded her laboratory work on frozen soil and performed numerical simulations of costal retreat based on her laboratory data, enabling her to calculate the interval of coastal erosion rates for different soils. Daria Aleksyutina stayed at NTNU as a visiting PhD student for three months from the start of August to the end of November 2015. In this period, she collaborated with researchers at NTNU and was able to submit the scientific paper `Baydaratskaya Bay: A recessing Arctic coast, heavily affected by complex cryogenic processes` to the international Journal of Permafrost and Periglacial Processes. In addition, she completed the first draft of her doctoral thesis.

Coastal Erosion in a Changing Climate

SINTEF researchers made noticeable contributions to WP6 in 2015. Dr Thi Le has developed a numerical method for estimating the size of the failure mass which is an important factor governing the rate of coastal erosion. The method is described in a journal paper published in 2015. While this method is developed for research software (CODE_BRIGHT) and can be used for unsaturated soils, it still needs to be tested further for frozen soils. An additional contribution from SINTEF is a journal paper published in 2015 describing the terrestrial processes affecting unconsolidated coastal erosion disparities in the central fjords of Svalbard. Finally, Dr Arne Instanes submitted a paper to the journal Cold Regions Science and Technology in 2015 discussing how to incorporate climate-warming scenarios in coastal permafrost engineering design, incorporating case studies from Svalbard.

Figure WP6_4 Sampling from different parts of the coastal sediments at Baydaratskaya Bay for later laboratory work.

Figure WP6_5 Time-laps photo shooting of thermal abrasion process at Baydaratskaya Bay.



Coastal erosion is a worldwide problem that will grow ever more important as sea levels rise and coasts are battered by more powerful storms. But nowhere is coastal erosion a bigger challenge than in the Arctic, where frozen soils result in erosion rates that are 3-4 times faster than in more temperate regions.

EMILIE GUEGAN saw Arctic villages struggling with erosion first-hand, when she sailed along the Northwest Passage in 2008. "It was a huge problem with the native communities," she said, "They have a lot of erosion problems, and many had to move their communities." Guegan was so affected by the situation that when she saw an announcement posted by SAMCoT for a PhD position on Arctic coastal erosion, "I knew it was for me," she said. She and her Russian colleagues had also observed clear signs of severe erosion on the Russian coast, this time during field campaigns in 2014. When they arrived at their research site along the Baydaratskaya Bay coast, the sea was still covered in ice. As Guegan and her colleagues looked at what was causing the cliffs they were monitoring to erode, they realized that the two key factors were the frozen soil, commonly called permafrost, and the amount of snow cover.

Snow insulates the cliff faces along Baydaratskaya Bay, which, when it melts, causes the bluff itself to melt away and retreat. This is a case where wave action clearly had nothing to do with the erosion, since the bay is completely covered with sea ice.

"As we saw the snow bank retreating, we saw the coastal bluff, which was 10 metres high, literally melting away," she said. "We need to understand first what is happening so we can design proper protection for the coast," she says. "If we don't know what is triggering this retreat, we can't build a design to protect it. We need to understand the behaviour of the frozen soils we work with in the Arctic." That is what she is working on right now!

SAMCoT RESEARCH STRUCTURE

The organizational structure of each Work Package supports the intercollaboration among SAMCoT Research and Industry Partners as well as the international strategy of the Centre.

The research strategy of the Centre as well as the implementation of the activities are closely monitored by the Centre Management Group, which reports to the EIAC, SAC and Board.

In this section, we have furnished information on the main researchers in each WP, as well as the SAMCoT PhD candidates, Postdocs and Master candidates.

KEY & VISITING* RESEARCHERS

ALEKSEY MARCHENKO
UNIS (M)
Data Collection and Process Modelling
WP1 Leader

ALEXANDER SAKHAROV*
MSU (M)
Ice Mechanics
WP1

ANATOLY BROUSHKOV
MSU (M)
Cold Regions Geology
WP6

ANATOLY SINITSYN
SINTEF (M)
Physical-mechanical Properties & extent of Coastal Permafrost
WP6 Deputy Leader

ANDREI METRIKINE
TUDelft (M)
Dynamic Ice Action
WP3 Deputy Leader, WP4

ARNE INSTANES
SINTEF (M)
Geotechnical Engineering
WP6

ARVID NÆSS
NTNU (M)
Mathematical Statistics
WP5

BEN LISHMAN*
UCL (M)
Ice Friction
WP1

ELIZ-MARI LOURENS
TUDelft (F)
Dynamic Ice Action
WP3

ERLAND SCHULSON*
TSED (M)
Ice Mechanics
WP1 - SAC Chair

EUGENE MOROZOV*
P.P.SIO (M)
Applied Oceanography
WP1

EVGENY KARULIN*
KSRC (M)
Ice-structure Interaction
WP1

INGRID UTNE
NTNU (F)
Ice Management/Safety
WP5

JUKKA TUHKURI
Aalto (M)
Discrete Element Modelling of Ice Rubble and Ice Ridges
WP2 & 3

JØRGEN AMDAHL
NTNU (M)
Iceberg Impact on Floaters
WP4 Deputy Leader

KNUT V. HØYLAND
NTNU (M)
Ice Rubble and Ice Ridge Action
WP2 & 3 Leader

ØIVIND K. KJERSTAD
UNIS/NTNU (M)
Arctic Marine Cybernetics
WP5 Deputy Leader

MARINA KARULINA*
KSRC (F)
Ice-structure Interaction
WP1

MARK JOHNSON*
UAF (M)
Applied Oceanography
WP1

NATALY MARCHENKO
UNIS (F)
GIS - Geographic Information System
WP1

PETER SAMMONDS
UCL (M)
Ice Friction
WP1 & 2

ROGER SKJETNE
NTNU (M)
Ice Management
WP5 Leader

STEINAR NORDAL
NTNU (M)
Coastal Technology
WP6

SVEINUNG LØSET
NTNU (M)
Ice actions on Floaters
Director & WP4 Leader

THI MINH HUE LE
SINTEF (F)
Coastal Technology
WP6

MAURI MÄÄTTÄNEN
NTNU (M)
Dynamic Ice Action
WP3

PETER CHISTYAKOV*
MSU (M)
Ice Mechanics
WP1

RAED LUBBAD
NTNU (M)
Ice Management and Coastal Technology
WP6 Leader

SALLY SCOURFIELD*
UCL (F)
Ice Friction
WP1 & 2

STIAN RUUD
DNV GL (M)
Verification & Examination Mngmt Arctic Offshore Operations
WP5

VLADIMIR GORBATSKY*
P.P.SIO (M)
Applied Oceanography
WP1

ROLF H. LANDE
DNV GL (M)
Non-probabilistic Methods for Assessing Reliability
WP5

TUDelft	Delft University of Technology
KSRC	Krylov State Research Centre
TSED	Thayer School of Engineering at Dartmouth
UCL	University College London
MSU	Moscow State University
P.P.SIO	P.P. Shirshov Institute of Oceanology
UAF	University of Alaska Fairbanks
NTNU	Norwegian University of Science and Technology
Aalto	Aalto University, School of Engineering
UNIS	University Centre in Svalbard
SINTEF	Stiftelsen SINTEF

PhD CANDIDATES

ANDREI TSARAU
2012–2015 (M)
Floater-intact level ice interaction (processes in the waterline)

ANNA PUSTOGVAR
2012 (F)
Const. Models for Ice Rubble, experimental

CHRIS KEIJDENER
2013 (M)
Stationary Dynamic Regimes of Ice-floater Interaction

DARIA ALEKSUTINA
2011 (F)
Composition, structure and properties of sediment cores and frozen soil

DAVID WRANGBORG
2012 (M)
Ice-water actions on coastal structures

EMILIE GUEGAN
2012–2015 (F)
Modeling of erosion rates and erosion mechanisms in coastal permafrost

FARZAD FARIDAFSHIN
2012 (M)
Alternative methods for quantifying safety

NADEEM AHMAD
2014 (M)
CFD: Waves + Sediment transport (Ccohesive soil + permafrost)

HAYO HENDRIKSE
2011 (M)
Ice-induced vibrations – numerical modelling

JANNE RANTA
2014 (M)
Ice rubble pile-up, statistical analysis of DEM simulations

MARAT KASHAFUTDINOV
2010 (M)
Multi-scale modelling of iceberg drift and its application to IM

MARNIX VAN DEN BERG
2014 (M)
AUV for under ice operations, subsurface monitoring sea ice & icebergs

MARTIN HASSEL
2014 (M)
Risk and Safety of Marine Operations under Arctic Conditions

MARTIN STORHEIM
2011 (M)
Structural Resistance of Ships and Offshore Structures to Extreme Ice Loads

MEHDI KADIVAR
2015 (M)
THM Engineering model (Elastic-Plastic-Creep)

TAYA SINITSYNA
2014 (F)
Ice field heterogeneity and ice loads

PETTER NORGREN
2012 (M)

Autonomous Underwater Vehicles for operations under ice

QIN ZHANG
2012–2015 (F)

Image Processing for Ice Parameter Identification in Ice Management

RENAT YULMETOV
2012 (M)

Observations and Numerical Simulation of Iceberg Free Drift and Towing In Broken Ice

RUNA SKARBØ
2015 (F)

Ice drift prediction and mitigation of impact from ice on marine operations

SERGEY KULYAKHTIN
2011 (M)

Constitutive modelling of ice rubble, FEM

OLE-CHRISTIAN EKEBERG
2011-2015 (M)

Studies of ice ridge shape and geometry from upward looking sonar data

TORODD NORD
2011–2015 (M)

Ice-induced vibrations – analysis of measurements

YARED BEKELE
2012 (M)

THM coupled finite element modelling of frozen soil

ÅSE ERVIK
2014 (F)

Ice ridge action, numerical modelling Sep

MASTERS

HEGE LINDBJØR NILSEN	2015 (F)	Finite Element Simulations of Punch Tests on Ice Rubble with the Modified Cam Clay Model
SJUR MOE GREVSGÅRD	2015 (M)	Finite Element Simulations of Unconsolidated Keel Actions from First-Year ice ridges
IVAR GJESSING	2015 (M)	Control and simulation of a thruster-assisted moored offshore vessel in sea-ice
DARJA KSENOFONTOVA	2015 (F)	Thermodynamic Consolidation of broken ice and ice ridges
GURO LARSEN	2015 (F)	Ice Detection and Tracking based on satelite and radar images
ANTON AGAFONOV	2015 (M)	Deformation of sheet pile wall by thermal expansion of ice and soil backfilling
ZHENGRU REN	2015 (M)	Fault Tolerant Control of Thruster-Assisted Position Mooring System
BÅRD BLASTERDALEN	2015 (M)	Permeability, growth and morphology of coastal ice
THOR BILLINGTON	2015 (M)	Online shape estimation of icebergs at sea
DMITRII MURASHKIN	2015 (M)	Influence of brine migration on thermal expansion of sea ice
SYEDA WAHIDA RAFIQ	2015 (F)	Numerical Modelling of Sediment Transport in the Arctic

POSTDOCTORAL RESEARCHERS

EKATERINA KIM 2014 (F)	Integrated Finite Element method in Ice – Structure
WENJUN LU 2015 (M)	Numerical Modelling of Ice-structure Interaction
ALEKSEY SHESTOV 2013 (M)	Ice ridges properties WP1 Deputy Leader
ARTTU POLOJÄRVI 2013 (M)	Discrete element modelling of ice rubble (DEM-FEM, own code)
SEYED ALI G. AMIRI 2014 (M)	THM Engineering model (Elastic-Plastic-Creep)


ODEN

OATRC2015

The Norwegian University of Science and Technology (NTNU) and The Swedish Polar Research Secretariat (SPRS) established in 2012 a collaboration in polar research under the umbrella of the memorandum of understanding "Nordic Cooperation in Polar Research" signed on January 29, 2010. NTNU works with the development of robust technology necessary for sustainable exploration and exploitation of the valuable and vulnerable Arctic region. SPRS is a government agency that promotes and co-ordinates Swedish polar research including following and planning research and development, as well as organizing and leading research expeditions to the Arctic and Antarctic regions.

A manifestation of the collaboration between NTNU and SPRS is the two research cruises which were performed with the Swedish icebreaker Oden in the autumn of 2012 and 2013 to the waters northeast of Greenland. These cruises named "Oden Arctic Technology Research Cruise 2012/2013 (OATRC2012/2013)" were organised as SAMCoT associated projects with financial support from Statoil.

In the autumn of 2015, NTNU and SPRS performed their third research cruise, this time involving the Swedish icebreakers Oden and Frej in the international waters north of Svalbard. The cruise was called "Oden Arctic Technology Research Cruise 2015 (OATRC2015)". OATRC2015 was fully financed by the ExxonMobil Upstream Research Company (URC). The participants in the research cruise were 62 persons. The cruise started on the 18th of September of 2015 from Longyearbyen and the icebreakers (Oden and Frej) returned to Longyearbyen 13 days later on the 2nd of October. The track of the research cruise is depicted in Figure to the right.

The overall objective of OATRC2015 was to perform a safe cruise collecting highly valuable scientific data and to perform full-scale field trials for testing of key technologies in the realm of improving Arctic HSE practice. The scientific scope of OATRC2015 is summarised as follows:

- Collection of full-scale data necessary to build, calibrate and validate numerical models for floaters in ice
- Collection of full-scale data necessary to build, calibrate and validate numerical models for Ice Management (IM) operations
- Collection of data relevant for health, safety and environmental research.

OATRC2015 was a very successful research cruise. It gave many of the PhD students in SAMCoT valuable full-scale data for their research. In particular, the opportunity given by two icebreakers co-working on ice management was of high value.

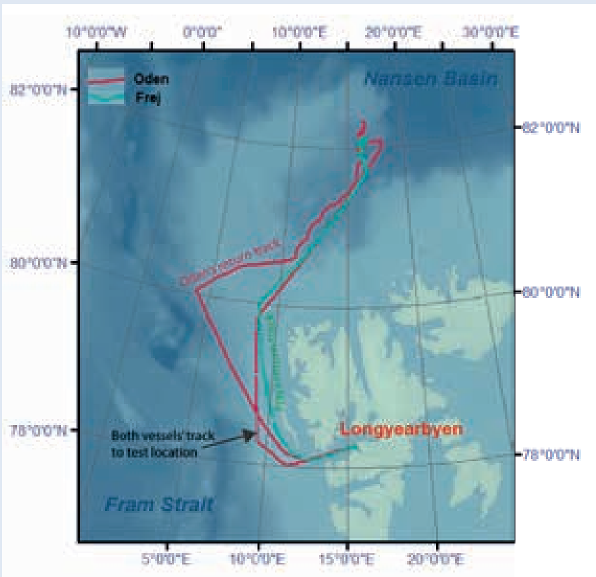


Figure: Tracks of Oden and Frej, 18.09.2015-02.10.2015.

PhD Defences

OLE-CHRISTIAN EKEBERG • JUNE 3RD

Studies of ice ridge shape and geometry from upward looking sonar data

Ekeberg is currently Senior Engineer in DNV GL and works with challenges related to Arctic oil and gas exploration. He is currently the project manager of the RigSpray project working with the development of knowledge, models and a tool to estimate marine icing loads required for design.

Main supervisor: Knut V. Høyland, SAMCoT WP3 Leader and Professor at the Department of Civil and Transport Engineering.

TORODD NORD • NOVEMBER 20TH

Force and state estimation on bottom-founded structures prone to ice-induced vibrations

During his postdoc, Nord is working with the estimation of ice forces and responses of structures that suffer from dynamic ice actions. Currently enrolled in different courses at the Department of Cybernetics, Nord aims to acquire further knowledge on estimation methods. And in doing so, assess their applicability on estimation problems related to dynamic ice-structure interactions.

Main Supervisor: Knut V. Høyland, SAMCoT WP3 Leader and Professor at the Department of Civil and Transport Engineering

EMILIE GUEGAN • DECEMBER 10TH

Erosion of Permafrost Affected Coasts: Rates, Mechanisms and Modelling

Guegan's postdoc builds on the research she did for her PhD, where she will continue her studies of frozen soils and erodibility, as well as build a computer model that allows her to combine what she has learned about cliff stability and erosion with information on wave action. Guegan also plans to continue and extend the scope of her fieldwork to include jet erosion tests, which she believes very applicable for Arctic coasts.

Main supervisor: Professor Steinar Nordal at the Department of Civil and Transport Engineering.

ANDREI TSARAU • DECEMBER 15TH

Numerical Modelling of the Hydrodynamic Effects of Marine Operations in Broken Ice

Andrei Tsarau plans to do experimental and numerical work linked to research subjects such as waves in ice and wave/ice actions on structures. In the light of the observed climate change in the Arctic, there is a need for in-depth research in the field of wave/ice interaction. This research will focus on marginal ice zones (MIZ), transitional areas between the open ocean and the pack ice cover. Here ice actions contribute to the formation of ice floes as ocean waves penetrate into the ice field. Hence an important research both for winter navigation as well as for offshore structures.

Main supervisor: Sveinung Løset SAMCoT WP4 Leader and Professor at the Department of Civil and Transport Engineering

QIN ZHANG • DECEMBER 17TH

Image Processing for Ice Parameter Identification in Ice Management

In addition to her work as PhD candidate, Zhang collaborated in the OATRC15 research cruise. During this field activity, a helicopter was used to capture ice conditions in the marginal ice zone (MIZ). Zhang developed the algorithms that facilitated the online imaging processing.

Main Supervisor: Roger Skjetne SAMCoT WP5 Leader & Professor at the Department of Marine Technology

DISSEMINATION

One criterium for a successful SFI is high scientific quality of research. To ensure such quality, SAMCoT's Scientific Advisory Committee (SAC), comprising leading international academics, provides the Centre with the necessary research quality assurance to support the Board in scientific matters. SAMCoT's SAC meets annually and produces a written report evaluating the scientific quality of the work carried out by SAMCoT researchers, and in particular of the PhD candidates linked to the Centre. Professor Erland M. Schulson, Dartmouth College's first George Austin Colligan Distinguished Professor of Engineering and Fulbright Arctic Chair 2013-2014, is the Chair of SAMCoT's SAC.

SAMCoT has many international collaborators that provide a firm basis for the Centre's research results. SAMCoT's internal communication efforts are remarkable, with the organization of a total of three workshops in 2015: a PhD - Scientific Seminar; a Technical Workshop and a course on Health, Safety and the Environment (HSE) specific to the Arctic. SAMCoT researchers carry out annual site visits to their international industrial and research partners. Long-term collaborations with mutual visits are performed with several key ice laboratories including VTT Technical Research Centre of Finland, Aalto University (Finland), Hamburgische Schiffbau-Versuchsanstalt (Germany), University College London (UK), Technical University of Delft (The Netherlands), Moscow State University (Russia), and Krylov Ship Building Research Institute (Russia). The collaborations are ongoing, with great benefit in productivity. In addition, there has been joint working with several other groups, which are not formal members of the Centre, as reflected in the list of publications.

In 2015, SAMCoT researchers published five doctoral theses, 11 master theses, 29 journal papers and 52 conference papers. As a validation of the high level of research produced by SAMCoT, it is worth mentioning the École Polytechnique Fédérale de Lausanne (EPFL) Dimitris N. Chorafas Foundation award received by Wenjun Lu in 2015. The purpose of this award is to distinguish innovative and high level research. Lu is currently employed as a Postdoc within SAMCoT's WP4. SAMCoT researchers are also committed to present their findings in the popular media, showing their enthusiasm to make science more understandable and accessible. Hence the 63 oral presentations and 17 publications in mass media and other popular media.

PhD defences (5):

Ekeberg, O.C. Studies of ice ridge shape and geometry from upward looking sonar data. *Doctoral theses at NTNU, 2015:119.*

Nord, T. Force and response estimation on bottom-founded structures prone to ice-induced vibrations. *Doctoral theses at NTNU, 2015:217.*

Tsarau, A. Numerical Modelling of the Hydrodynamic Effects of Marine Operations in Broken Ice. *Doctoral theses at NTNU, 2015:281.*

Guegan, E. Erosion of permafrost affected coasts: rates, mechanisms and modelling. Erosion of permafrost affected coasts: rates, mechanisms and modelling. *Doctoral theses at NTNU, 2015:328.*

Zhang, Q. Image Processing for Ice Parameter Identification in Ice Management. *Doctoral theses at NTNU, 2015:340.*

Published International Refeered Journal Papers (29):

Ahmad, N., Bihs, H., Saud Afzal, M. and Arntsen, Ø. Three-dimensional CFD Modeling of Wave Scour Around Side-by-Side and Triangular Arrangement of Piles with REEF3D. *Journal Procedia Engineering.*

Bekele, Y., Kvamsdal, T., Kvarving, A.M. and Nordal, S. Adaptive isogeometric finite element analysis of steady-state groundwater flow. *Journal for Numerical and Analytical Methods in Geomechanics.*

Bogorodskiy, P. and Marchenko, A. Thermodynamic Effects Accompanying Freezing of Two Water. *Journal of Marine Physics.*

Collins, C.O., Rogers, E. and Marchenko, A. In Situ Measurements of an Energetic Wave Event in the Arctic Marginal Ice Zone. *Journal of Geophysical Research Letters (GRL).*

Collins, C.O., Rogers, E., Marchenko, A., and Babanin, A.V. A Moored Arctic Floater in First-Year Sea Ice Ridges. *Journal of Offshore Mechanics and Arctic Engineering.*

Ekeberg, O.-C., Høyland, K.V. and Hansen, E. Ice ridge keel geometry and shape derived from one year of upward looking sonar data in the Fram Strait. *Journal of Cold Regions Science and Technology.*

Hansen, E., Gerland, S. and Høyland, K.V., Pavlova, O. and Gunnar Spreen, G. Time variability in the annual cycle of sea ice thickness in the Transpolar Drift. *Journal of Geophysical Research.*

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Hendrikse, H. and Metrikine, A. Interpretation and prediction of ice induced vibrations based on contact area variation. *Journal of Solids and Structures.*

Jørgensen, U. and Skjetne, R. Online Reconstruction of Drifting Underwater Ice Topography: The 2D Case. *Asian Journal of Control.*

Karulin, E., Marchenko, A., Karulina, M., Sakharov, A.N., Chistyakov, P.V., Verbitskaya, M.Yu. and Ignatieva, E.D. Compression testing of sea ice by penetrating the ice sheet with a semi-cylindrical indenter. Process numerical simulation. *Journal of Transactions of the Krylov Shipbuilding Research Institute (TKSRI).*

Kim, E. and Schulson, E.M. A phenomenological explanation of the pressure–area relationship for the indentation of ice: Two size effects in spherical indentation experiment. *Journal of Cold Regions Science and Technology.*

Kim, E. and Amdahl, J. Discussion of assumptions behind rule-based ice loads due to crushing. *Journal Ocean Engineering Conference.*

Kjerstad, Ø.K., Metrikin, I., Løset, S. and Skjetne, R. A Phenomenological Investigation of the Managed Ice Loads on a Stationkeeping Vessel. *Journal of Cold Regions Science and Technology.*

Kowalik, Z., Marchenko, A., Brazhnikov, D. and Marchenko, N. Tidal currents in the western Svalbard Fjords. *Journal Science Direct Oceanologia.*

Kulyakhtin, S. and Høyland, K.V. Ice rubble frictional resistance by critical state theories. Journal of Cold Regions Science and Technology.

Le, T.M.H., Gallipoli, D. and Sanchez, M. Stability and failure mass of unsaturated heterogeneous slopes. *Journal Canadian Geotechnical Journal.*

Lu, W., Lubbad, R. and Løset, S. Out-of-plane failure of an ice floe: Radial-crack-initiation-controlled fracture. *Journal of Cold Regions Science and Technology.*

Marchenko, A.The influence of added masses on rotation and towing of drifting icebergs. *Journal of Transactions of the Krylov Shipbuilding Research Institute (TKSRI).*

Møen, E., Høiseth, K.V., Leira, B. and Høyland K.V. Experimental study of concrete abrasion due to ice friction — Part I: Set-up, ice abrasion vs. material properties and exposure conditions. *Journal of Cold Regions Science and Technology.*

Møen, E., Høiseth, K.V., Leira, B. and Høyland K.V. Experimental study of concrete abrasion due to ice friction — Part II: Statistical representation of abrasion rates and simple, linear models for estimation. *Journal of Cold Regions Science and Technology.*

Morozov, E., Marchenko, A. and Fomin, Y.V. Supercooled Water near the Glacier Front in Spitsbergen. *Journal of Atmospheric and Oceanic Physics (AOP).*

Nord, T., Lourens, E-M. and Øiseth, O., Määttänen, M., Høyland, K.V. Laboratory experiments to study ice-induced vibrations of scaled model structures during their interaction with level ice at different ice velocities. *Journal of Cold Regions Science and Technology.*

Nord, T., Lourens, E-M., Øiseth, O. and Metrikine, A. Model-based force and state estimation in experimental ice-induced vibrations by means of Kalman filtering. *Journal of Cold Regions Science and Technology.*

Polojärvi, A., Tuhkuri, J. and Pustogvar, A. DEM simulations of direct shear box experiments of ice rubble: Force chains and peak loads. *Journal of Cold Regions Science and Technology.*

Sessford, E., Bæverfjord, M.G. and Hormes, A. Terrestrial processes affecting unconsolidated coastal erosion disparities in central fjords of Svalbard. *Journal Polar Research.*

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Zhang, Q., Skjetne, R., Metrikin, I. and Løset, S. Image Processing for Ice Floe Analyses in Broken-ice Model Testing. *Journal of Cold Regions Science and Technology.*

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Arntsen, Ø. CFD modeling of local scour around a pair of tandem cylinders under wave conditions. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Ahmad, N., Bihs, H., Kamath, A. and Arntsen, Ø. Numerical simulation of waves and local scour around vertical cylinders in a triangular arrangement using reef3d. *Proceedings of the National Conference on Computational Mechanics (MekIT).*

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Amiri, A.G., Kadivar, M. and Grimstad, G. A new concept in developing a constitutive model for saturated frozen soils. *Proceedings of the ICCDCG.*

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Bæverfjord, M.G., Gylland, A., Sinitsyn, A. and Wold, M. Soil Investigations for Sustainable Foundations in Arctic coastal areas. *Proceedings of the Geotechnical Engineering for Infrastructure and Development (ECSMGE).*

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Bueide, I.M. and Høyland, K.V. Confined compression tests on saline and fresh freeze-bonds. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Ervik, Å. Full scale actions from first year ridge interactions with fixed structures. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

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Heyn, H-M. and Skjetne, R. Estimation of Forces caused by Ship-Ice Interaction using on-board Sensor Measurements. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Keijdener, C. and Metrikine, A. An efficient method for computing the time domain response of a floating ice block including hydrodynamics. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Kim, E., Amdahl, J., Storheim, M. and Løset, S. Understanding the effect of assumptions on shell plate thickness for arctic ships. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Kim, E., Lu, W., Lubbad, R., Løset, S. and Amdahl, J. Toward a holistic load model for structures in broken ice. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

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Kulyakhtin, A. A system to measure ice accretion mass. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Lishman, B. and Polojärvi, A. 2D DEM of ice rubble: the effect of rate-dependent friction. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

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Marchenko, A. and Brandvik, P.J. Surface heating of oil spills in ice conditions. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

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Marchenko, A. and Lishman, B. Properties of thermo-elastic waves in saline ice. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Marchenko, A. and Onishchenko, D. Analytical modeling of passive turn of turret moored vessel in close ice. *Proceedings of the International Conference and Exhibition for Oil and Gas Resources Development of the Russian Arctic and Continental Shelf (RAO/CIS Offshore).*

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Polojärvi, A., Tuhkuri, J. and Pustogvar, A. Why simulate ice rubble shear box tests? *Proceedings of the Numerical Methods in Geotechnical Engineering (NUMGE).*

Pustogvar, A. and Høyland, K.V. Density measurements of saline ice by hydrostatic weighing in paraffin. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Ranta, J., Polojärvi, A. and Tuhkuri, J. Ice load estimation through combined finite-discrete element simulations. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Ren, Z., Skjetne, R. and Hassani, V. Supervisory Control of Line Breakage for Thruster-Assisted Position Mooring System. *Proceedings of the IFAC Conference on Manoeuvring and Control of Marine Craft (MCMC).*

Ren, Z., Skjetne, R. and Kjerstad, Ø.K. A Tension-based Position Estimation Approach for Moored Marine Vessels. *Proceedings of the IFAC Conference on Manoeuvring and Control of Marine Craft (MCMC).*

Sakharov, A., Karulin, E., Marchenko, A., Karulina, M., Sodhi, D., and Chistyakov, P. Failure envelope of the brittle strength of ice in the fixed-end beam test (two scenarios). *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Samuelsen, E.M., Løset, S. and Edvardsen, K. Marine icing observed on KV Nordkapp during a cold air outbreak with a developing polar low in the Barents Sea. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Scourfield, S., Sammonds, P., Lishman, B. and Marchenko, A. The effect of ice rubble on ice-ice sliding. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Shestov, A., Wrangborg, D. and Marchenko, A. Hydrology of braganzavågen under ice-covered conditions. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Storheim, M., Nord, T., Kim, E., Høyland, K.V., Langseth, M., Amdahl, J. and Løset, S. Pilot study of ice-structure interaction in a pendulum accelerator. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Tsarau, A., Lubbad, R. and Løset, S. Recent advances in modelling the hydrodynamic effects on ice motion and ice- structure interactions offshore. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Wold, M., Instanes, A. and Watn, A. Thermal modelling of erosion protection with Geosynthetic containers in combination with Light Clay Aggregate. *Proceedings of GEOQuébec, 2015.*

Wrangborg, D., Marchenko, A. and Murashkin, D. Measurement of loads exerted by sea ice on the quay at kapp amsterdam on Svalbard. *Proceedings of the International Conference on Port and Ocean Engineering under Arctic Conditions (POAC`15).*

MSc theses (11):

Billington, T. Online shape estimation of icebergs at sea. *NTNU.*

Gjessing, I. A. Control and simulation of a thruster-assisted moored offshore vessel in sea-ice. *NTNU.*

Larssen, G. Ice Detection and Tracking Based on Satellite and Radar Images. *NTNU.*

Lindbjør Nilsen, H. Finite Element Simulations of Punch Tests on Ice Rubble with the Modified Cam Clay Model. *NTNU.*

Ren, Z. Fault Tolerant Control of Thruster-Assisted Position Mooring System. *NTNU.*

Syeda Wahida, R. Numerical Modelling of Sediment Transport in the Arctic. *NTNU.*

Grevsgård, S.M. Finite Element Simulations of Unconsolidated Keel Actions from First-Year ice ridges. *NTNU.*

Ksenofontova, D. Thermodynamic consolidation of broken ice and ice ridges. *St'Petersburg Politechnical University.*

Agafonov, A. Deformation of cofferdams due thermal expansion of ice and gravelling. *St'Petersburg Politechnical University.*

Blasterdalen, B. Deformation of sheet pile wall by thermal expansion of ice and soil backfilling. *NTNU.*

Murashkin, D. Influence of brine migration on thermal expansion of sea ice. *Moscow Institute of Physics and Technology.*

Key Notes and Oral Presentations (63):

Aleksyutina, D. Composition, Structure and Properties of Sediment Cores and Frozen Soils. *SAMCoT Scientific Seminar.*

Amiri, A.G. A new concept in developing a constitutive model for frozen soils. *SAMCoT Scientific Seminar.*

Bekele, Y. and Kyokawa, H. THM Coupled Finite Element Modeling of Ground Freezing and Thawing. *SAMCoT Scientific Seminar.*

Berg, vd M. Loads from ridges on floaters - discrete numerical modelling. *SAMCoT Scientific Seminar.*

Ervik, Å. Ice ridge loads on fixed structures. *SAMCoT Scientific Seminar.*

Farid-Afshin, F. The common basis for Probabilistic and Non-Probabalistic Design of Structures. *SAMCoT Scientific Seminar.*

Farid-Afshin, F., Lande, R.H. and Næss, A. The Common Basis for Probabilistic and Non-Probabilistic Design of Structures Under Different Degrees of Data Availability. *Presentation International Conference on Uncertainty Quantification in Computational Science and Engineering (UNCECOMP).*

Guegan, E. Coastal Erosion. *SAMCoT Scientific Seminar.*

Hassel, M. Challenges with bringing Collision Risk Models used in the North Sea and Norwegian Sea to the Barents Sea. *SAMCoT Scientific Seminar.*

Hassel, M., Utne, I.B. and Vinnem, J.E. Challenges With Bringing Collision Risk Models Used In The North Sea and Norwegian Sea To The Barents Sea. *Presentation, the Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Heyn, H-M. Ideas on Ice Force Estimation in Position Mooring. *AMOS Conference.*

Heyn, H-M. and Skjetne, R. Estimation of Forces caused by Ship-Ice Interaction using on-board Sensor Measurements. *Presentation, the Port and Ocean Engineering under Arctic Conditions (POAC`15).*

Høyland, K.V. Arctic Technology at NTNU (UNIS). *Workshop DTU.*

Høyland, K.V. Material modelling. *SAMCoT Technical Workshop.*

Høyland, K.V. and Metrikine, A. WP3 Fixed Structures in Ice. *SAMCoT Scientific Seminar.*

Høyland, K.V. and Metrikine, A. Fixed structures in ice. *SAMCoT Technical Workshop.*

Kadivar, M., Amiri, A.G. and Grimstad, G. Elasic-Viscoplastic Constitutive Model for Frozen Soil. *SAMCoT Scientific Seminar.*

Keijdener, C. Improving 1D ice-floater interaction models. *SAMCoT Scientific Seminar.*

Kim, E. Discussion of Assumptions behind Rule-based Ice Loads due to Crushing. *SAMCoT Scientific Seminar.*

Kjerstad, Ø.K. Dynamic positioning in ice: Modeling, simulation, and control. *AMOS Conference.*

Kjerstad, Ø.K. DP in Managed Ice. *SAMCoT Scientific Seminar.*

Løset, S. WP4 Overview. *SAMCoT Scientific Seminar.*

Løset, S. Floating structures in ice. *SAMCoT Technical Workshop.*

Løset, S. Challenges and innovations related to offshore operations in the Arctic. *DTU Match Points Seminars, Aarhus.*

Løset, S. The Impact of SAMCoT on future Operations in the Arctic. *Ocean Week, NTNU.*

Lu, W. The Fracture Mechanism of Parallel Channel Effect during Ice Management. *SAMCoT Scientific Seminar.*

Lubbad, R., Løset, S. and Tsarau, A. Time Domain Analysis of Floe Ice Interactions with Floating Structures. *SAMCoT Scientific Seminar.*

Lubbad, R. Coastal technology. *SAMCoT Technical Workshop.*

Marchenko, A. WP1 – Data collection and process modelling. *SAMCoT Scientific Seminar.*

Marchenko, A. Data collection and process modelling. *SAMCoT Technical Workshop.*

Nord, T. Force and response estimation on bottom-founded structures prone to ice-induced vibrations. *Presentation, Thesis for the degree of Philosophia Doctor, NTNU.*

Nord, T. Structural Health Monitoring of Large Civil Engineering. *Trial Lecture, Thesis for the degree of Philosophia Doctor, NTNU.*

Nord, T., Lourens, E-M. and Øiseth, O. Case study on the Nordströmsgrund lighthouse. *SAMCoT Scientific Seminar.*

Norgren, P. AUVs for subsurface monitoring of sea- ice and icebergs. *AMOS Conference.*

Norgren, P. AUVs for under ice surveys. *Kværner Workshop.*

Norgren, P. Iceberg detection and Edge-following using AUV with Multi-beam Sonar. *SAMCoT Scientific Seminar.*

Norgren, P. REMUS under ice - Svea 2016: Plans and preparations. *AMOS Conference.*

Norgren, P., Ludvigsen, M. and Ingebretsen, T. Tracking and remote monitoring of an autonomous underwater vehicle using an unmanned surface vehicle in the Trondheim fjord. *Presentation OCEANS MTS/IEEE.*

Norgren, P., Skjetne, R. Iceberg Detection and Edge-Following using AUV with Multibeam Sonar. *Presentation, the Port and Ocean Engineering under Arctic Conditions (POAC`15).*

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Polojärvi, A., Tuhkuri, J. and Pustogvar, A. Why simulate ice rubble shear box tests? *Workshops Other.*

Polojärvi, A. Discrete element method (DEM) simulations on ice rubble. *SAMCoT Scientific Seminar.*

Pustogvar, A. Constitutive Modelling of Ice Rubble. Experimental Part. *SAMCoT Scientific Seminar.*

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Shen, H. Ocean Waves under Ice Covers. *C – ICCDCG.*

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Skjetne, R. Highlights of the Skjetne Research Group. *AMOS Conference.*

Skjetne, R. Ice survey and surveillance for Arctic offshore operations: Development of the AUV technology for use for ice survey. *Kværner Workshop.*

Skjetne, R. Determining ice loads for OSVs. *Presentation at Lloyd's Maritime Academy Seminar on OSVs for Ice and Cold Climates.*

Skjetne, R. Overview WP5 – Ice Management and Design Philosophy. *SAMCoT Scientific Seminar.*

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Tsarau, A. Scale-model testing of moored vessels, combined effect of ice and hydrodynamics *Presentation, Thesis for the degree of Philosophia Doctor, NTNU.*

Wrangborg, D. Stresses and Deformations in Coastal Sea Ice. *SAMCoT Scientific Seminar.*

Yulmetov, R. Validating the Model of Iceberg Motion through Broken Ice. *SAMCoT Scientific Seminar.*

Zhang, Q. Ice boundary detection and ice floe identification. *SAMCoT Scientific Seminar.*

Zhang, Q. Image Processing for Ice Parameter Identification in Ice Management. *Presentation, Thesis for the degree of Philosophia Doctor, NTNU.*

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Mass Media & Other Popular Media (17):

Bazilchuk, N. Sommersafari i iskalde farvann. *GEMINI & Petro.no*

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Bazilchuk, N. Utforsker dyrelivet i iskalde farvann i Arktis. *Forskning.no*

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Ervik, Å. Forskerpraten: Åse Ervik forsker på skruis i Arktis. *NRK Distriktsprogram - Trøndelag God ettermiddag Trøndelag 09.11.2015 15.*

Field, J. Norway continues to trust in knowledge. *Research Europe.*

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Gutierrez Gonzalez, M.A. and Bazilchuk, N. Drilling down to understand sea ice. *IVT Techzone & GEMINI.*

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STATEMENTS OF ACCOUNTS 2015

In December 2015 the Annual Work Plans for both 2015 and 2016 were presented and approved by the Research Council of Norway (RCN). The RCN has the task to monitor the activities planned, ensuring their compliance with the European Free Trade Association (EFTA) Surveillance Authority (ESA) requirements.

In addition the Cost, Time and Resource (CTR) plans for each Work Package for 2016 were presented to SAMCoT's Board and approved. The CTRs provide a detailed description of each Work Package by defining: objectives; knowledge gaps; activities planned for the current year; dependencies; critical factors; assumptions; milestones and resource requirements. The tables below show, following the ESA reporting format, the figures related to the funding and costs accounted for in 2015 and reported by the Centre on January 20th 2016 to the RCN.

CRI ANNUAL WORK PLAN 2015 – COSTS (All figures in 1000 NOK)

Item	Host***** NTNU	Stiftelsen SINTEF	UNIS	Statoil	Shell	DNV GL	TOTAL	Multiconsult	Kongsberg Maritime	Aker Solutions	ExxonMobil URC	GDF SUEZ	Det Norske	Kværner	UCL	HSVA	TUDelft	Aalto University	MSU	VTT	Total
WP1			3 369	37	50	33	55	117	43	19				22							3 744
WP2	3 207			38	50	33	55	117	43	19				22	196			850			4 630
WP3 & IVOS	3 480			38	50	33	55	117	43	19				22		1 421	145	850		488	6 760
WP4	4 394			38	50	33	55	117	43	19				22			851			400	6 022
WP5	4 538		281	33	50	33	54	117	43	19				22							5 189
WP6	1 337	2 496		33	50	33	54	117	43	19				22					89		4 292
SFI Equip.	614		595												9						1 218
SFI Adm.	1 952	125	978	50	38	59	51	20	50	19	24	250	35	22	50	44	36	35		104	30943
Total budget	**19 524**	**2 061**	**5 223**	**267**	**338**	**259**	**379**	**720**	**306**	**130**	**24**	**250**	**35**	**156**	**255**	**1 465**	**1 032**	**1 735**	**89**	**992**	**35 799**

CRI ANNUAL WORK PLAN 2015 – FUNDING (All figures in 1000 NOK)

Item	Host***** NTNU	Stiftelsen SINTEF	UNIS	Statoil	Shell	DNV GL	TOTAL	Multiconsult	Kongsberg Maritime	Aker Solutions	ExxonMobil URC	GDF SUEZ	Det Norske	Lundin	Kværner	Norwegian Coastal Admin	UCL	HSVA	TUDelft	Aalto University	VVT	RCN Grant	Total funding
Type of partner**	R	R	R	L	L	L	L	L	L	L	L	L	L	L	L	P	R	R	R	R	R		
WP1			486	278	217	144	221	217	93	100	167	167	167	167	106							1 334	3 860
WP2	1 219			187	217	117	221	217	93	100	167	167	167	167	106		205			292	400	1 334	5 372
WP3 & IVOS	1 365			213	307	207	311	307	93	100	167	145	167	167	196			442	145	292	400	1 334	6 466
WP4	2 349			187	217	117	221	217	93	100	167	167	167	167	106							1 334	5 605
WP5	2 584			173	217	117	221	217	93	100	167	167	167	167	106							1 334	5 826
WP6	180	459		179	217	117	221	217	93	98	167	167	167	167	106	330						1 334	4 217
SFI Equip.																							0
SFI Adm.	1 122	125	978	50	38	59	51	20	50	30	24	250	35		22		50	44	36	35	104	1 330	4 454
Total budget	**8 819**	**585**	**1 464**	**1 267**	**1 428**	**876**	**1 469**	**1 410**	**606**	**630**	**1 024**	**1 340**	**1 035**	**1 000**	**746**	**330**	**255**	**486**	**181**	**619**	**904**	**9 326**	**35 799**

Photo: Aleksey Shestov

Annual Report 2015

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Produksjon: www.fagtrykk.no Miljømerket trykkeri, lisensnr. 241 811