Field studies and modelling of sea state, drift ice, ice actions and methods of icebergs management on the Arctic shelf (FIMA)

1. Objectives

The exploration and exploitation of hydrocarbon deposits on the Arctic shelf increases the navigational activity and specific marine operations related to the use of offshore facilities, logistics and transport of oil/gas products in icy waters. These activities should all be done in a safe and sustainable manner related to human beings, environment and assets. Unless properly understood and designed for, the presence of ice represents an increased risk in these waters. In this light the project focuses on knowledge-building in Norway and Russia related to understanding the impact by the presence of ice on the upcoming offshore activity. The outcome of the research should contribute to a reduction of risks related to offshore activity in the High North. More specifically the project will undertake field studies and modelling of drift ice, ice actions on offshore installations and methods of iceberg management in regions of offshore development on the shelf of the Barents Sea. The project aims to describe characteristics of drift ice, ice ridges and icebergs in regions with low probability of ice occurrence and high priority of offshore development (the region around Bjørnøya and further to the Central Barents Sea). Field works will include deployment of ice trackers on drifting ice and icebergs, morphological studies of ice ridges, ice strength tests and standard oceanographic measurements of water characteristics, sea current velocities and waves. The modelling will include numerical simulations of sea state, ice and iceberg drift, thermodynamic consolidation of drifting ice ridges, and probabilistic estimates of ice and iceberg characteristics in the regions of offshore development. Mathematical models of FPU (floating production units) manoeuvring and iceberg tow in ice conditions will be elaborated and validated for operational use. The project will strengthen researcher recruitment within the area of research.

The scientific cooperation between the Norwegian and Russian research groups involved is organized as follows:. The Norwegian team focuses on field activities (e.g., deployment of ice trackers and ice strength tests) and meso-scale modelling of natural phenomena and processes related to technology (e.g., consolidation of drifting ice ridges and iceberg tow) of importance for the offshore development in the region. The main activity of the Russian group is focused on numerical simulations of hydro-thermodynamic processes in the atmosphere and ocean in the Barents Sea region with high temporal and spatial resolution to provide input data for the meso-scale modelling. A part of the research activity of the Russian group will also be focused on numerical simulations of technological processes and field activities in Svalbard in close cooperation with the Norwegian group.

2. Background and approaches

Background and status of knowledge

The Norwegian group of scientists from UNIS and NTNU has long experience of research in the field of Arctic offshore engineering, ice mechanics and applied oceanography. Each of the participants has an experience of field works in the Arctic and especially in the North-West Barents Sea and on the land fast ice in Spitsbergen fjords where field studies have been performed each year since 1996. The following field works have been performed:

- in-situ tests on ice strength (compressive, flexural, tensile, indentation, fracture toughness),

- measurements of sea ice characteristics (temperature, salinity and density),
- morphological studies of ice ridges (geometrical sizes, macro-porosity, ice content),
- CTD (water salinity, temperature and pressure) and ADCP (water velocity) profiling,
- measurements of turbulent characteristics of under ice sea currents,
- measurements of surface waves,
- deployment of ice trackers for the monitoring of drift ice,
- monitoring of ship-ice interaction,
- monitoring of ice loads on fixed and floating quays.

In laboratory conditions the following works have been performed:
- tests for ice strength (compressive, indentation) and creep,
- tests on ice and ice ridges actions on fixed structures and FPU,
- iceberg tow tests,
- tests on icebergs drift in wave conditions,
- tests on sea ice permeability and thermal expansion.
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Mathematical models and numerical simulations have been performed for the following processes:
- ice ridges build up and thermodynamic consolidation,
- ice gouging,
- ice-ship interaction,
- ice and ice ridge actions on fixed and floating structures,
- deformations of ice in specific tests,
- wave propagation below the ice,
- icebergs drift and tow,
- wave action on floating icebergs.

Analysis of ship accidents related to ice actions has been performed for the Northern Sea Route and Svalbard region.

The Norwegian research group has a history of joint cooperation with Russian scientists in the field of Arctic Technology. This cooperation was supported by four projects of the NRC (PetroArctic, POLRES) and SIU (SAFELOT, SMIDA). High and successful activity of the Norwegian research group was granted by the SFI project for the organizing of the Centre for Research-based Innovations “Sustainable Arctic Marine and Coastal Technology” (SAMCoT) (2011-2019). Federal State Budgetary Institution «N.N.Zubov Memorial State Oceanographic Institute” (SOI) is responsible for the contract “Study of the Dynamics of the Barents and Kara Seas Coastal Zone under Climate Change in the Arctic” supported by SAMCoT in 2013-2015. In 2011-2013 UNIS has fulfilled the contract from Limited Liability Company «Scientific-Research Institute of Natural Gases and Gas Technologies – Gazprom VNIIGAZ» (VNIIGAZ) “Carrying out simulation experiments under natural ice conditions. Elaboration of physical-mathematical models, performance of calculation”. At the moment, an Agreement for Scientific and Technological Cooperation between UNIS and VNIIGAZ is active. Since 1996 more than 60 Russian students have studied at UNIS, and after that more than 20 of them became PhD students at NTNU and UNIS and got job in International companies such as Statoil, DNV, Multiconsult, ExxonMobil, Shell, etc.. Particularly at the present time two students from Moscow Institute of Physics and Technology (MIPT) are PhD students at NTNU and UNIS in the field of Arctic Technology. This kind of collaboration increases the knowledge level needed for a safe and sound development and exploitation of the Barents Sea. Several Russian students studied at UNIS and NTNU have practice to work for projects of SOI and VNIIGAZ.

Gaps

The ice actions caused by ice floes, ice ridges and icebergs interacting with ships and offshore platforms are not well predicted in a number of the Barents Sea regions where offshore development is planned in the nearest future. The gaps are as follows:

- description and probability of meteorological conditions supporting ice and icebergs drift into the regions of offshore development,
- physical properties of drift ice and icebergs in the regions of offshore development,
- ice strength properties under high loading rates,
- influence of waves on iceberg drift,
- probability of ship collisions with drifting floes, ridged ice and icebergs,
- manoeuvring of FPUs in ice.

Approaches, hypotheses and choice of method

Characteristics of sea water and ice drift in the Barents and Kara Seas will be reproduced for different scenarios of atmospheric forcing and boundary conditions by numerical simulations with INMOM (Institute Numerical Mathematics Ocean Model) realised at the SOI supercomputer. This will provide data on sea currents, sea level, temperature and salinity of sea water, concentration and thickness of drift ice with anticipated horizontal resolution of around 2.5 km, vertical resolution of around 10 m and temporal resolution of around 0.5 h. Tidal currents are calculated using data from the Poseidon Global Tide model in the boundary conditions. Atmosphere forcing is reconstructed with the models WRF (Weather Research and Forecasting Model) and COSMO-RU.

The model for the Barents Sea will be validated using data of ice trackers deployed on the drifting ice since 2008, locations of marginal ice zone (MIZ) reconstructed by sea ice maps, data from CTD (conductivity, temperature, and depth) and ADCP (Acoustic Doppler Current Profiler) profiling performed in the North-West Barents Sea since 2010, reconstructed satellite data on the displacements of drift ice. Coefficients of turbulent viscosity and diffusion in under ice water layers will be adjusted using the data of sea current measurements with ADV (Acoustic Doppler Velocimeter) and CTD-data.

Drift and diffusion of rare ice floes and icebergs in the MIZ will be calculated with the data on wind velocity, sea current, wind waves and swell. Wave data will be reproduced by numerical simulations with the SWAN and Russian Atmosphere-Wave model. Based on the results of this modelling the probability of ship collision with ice floes and growlers and their speeds will be estimated depending on meteorological conditions and ship location relatively to the MIZ which is usually identified with 15% ice concentration.

Numerical simulations of thermal evolution of drifting ice ridges embedded in the drift ice with adjacent water layer will be performed with Comsol Multiphysics taking into account boundary conditions at the air-ice interface and at the water boundary of the computational domain. Water flow through the unconsolidated part of the ridge keel will be taken into account. Temporal evolution of ice ridge temperature will be measured by ice trackers with thermistor-strings deployed on ice ridges in the North-West Barents Sea. The deployment of the ice trackers will be performed according to the work plan of the Centre for Research-based Innovation SAMCoT.

Drift of icebergs will be calculated using data from numerical simulations of sea currents and waves. Atmosphere forcing will be reconstructed using data of numerical simulation of hydrodynamic meso-scale model COSMO-RU resolving dynamics of Polar lows. Forces applied to drifting icebergs will be parameterized using numerical simulations of 3D water and air flows near icebergs of representative shapes. Numerical simulations will be performed for the estimates of iceberg occurrence in the regions of offshore development in the Barents and Kara Seas.

The outcome of these physical environmental studies will be applied when developing a model of iceberg tow where we consider the tension of tow lines, realistic vertical profile of sea current velocities measured near icebergs, wind forcing, added mass effects and iceberg rotation around the vertical axis. Movements of icebergs and icebreaking tug-boats will be described by standard equations of marine hydrodynamics in water flow with acceleration. The influence of surface and internal waves and swell on the iceberg tow will be estimated by using analytical solutions of wave diffraction on floating cylinders and calculated with SESAM software for icebergs of realistic shapes. The influence of tow wire on tug-boats will be simulated for different scenarios of sea and weather conditions. The influence of broken ice on the iceberg tow will be considered using discrete element modelling of broken ice.

Manoeuvring (rotation) of FPU in conditions of broken/managed ice will be studied using standard equations of marine hydrodynamics taking into account ice loads on the hull parameterized according to known scenarios of ice-structure interaction (crushing, ridging, bending). Simulations will be performed for several types of ice and hydro-meteorological conditions around FPU and for different values of initial FPU orientation with respect to ice drift direction. Ice conditions are described by ice concentration, drift velocity and thickness. Hydro-meteorological conditions are characterized by local profiles of sea current velocities, wind velocity and waves.

Ice and icebergs action on ship/platforms will be estimated using the data of field experiments on ice strength (tests for compressive strength, indentation and flexural strength) in the Barents Sea and Spitsbergen fjords. Field works will be performed with original test rigs adjusted for the experimental studies of ice strength with high loading rate. In numerical simulations the dependence of ice strength from the loading rate will be used to estimate loads at the interface between ice and structures (ship/platforms), when the speed of ice impact is proportional to the relative speed of the ice and structure. Relative speed will be calculated using data of numerical simulations of ice and icebergs drift under drag forces induced by wind and current, and wave drag forces.

3. The project plan, project management, organization and cooperation

Research partners and tasks

Research partners from the Norway	**Research partners from Russia**
The University Centre in Svalbard (UNIS) P.O.Box 156, N-9171 Longyearbyen Phone.: +47 79023300 Fax: +47 79023301 E-mail: post@unis.no Web: www.unis.no	Federal State Budgetary Institution «N.N.Zubov Memorial State Oceanographic Institute"(SOI) Kropotkinsky Per. 6, Moscow, Russian Federation, 119034, Phone/Fax: +7 499 2467288 E-mail: adm@oceanography.ru Web: www.oceanography.ru
Norwegian University of Science and Technology (NTNU) Department of Civil and Transport Engineering.	Limited Liability Company «Scientific-Research Institute of Natural Gases and Gas Technologies – Gazprom VNIIGAZ» (VNIIGAZ)

NTNU NO-7491 Trondheim, Norway Tel.: +47 73594640 Fax: +47 73597021 E-mail: postmottak@adm.ntnu.no Web: www.ntnu.edu	P.O. Box 130, Moscow 115583, Russia Address: Razvilka, Leninsky Rayon, Moskovskaya oblast, 142717, Russia Tel.: +7 (498) 657-42-06 Fax: +7 (498) 657-96-05 Web: www.vniigaz.ru E-mail: vniigaz@vniigaz.gazprom.ru

Norwegian research group	**Russian research group**
1. Prof. Aleksey Marchenko (UNIS/NTNU) 2. Prof. Sveinung Løset (NTNU/UNIS) 3. Prof. Knut Høyland (NTNU) 4. Assoc. Prof. Raed Lubbad (NTNU) 5. Dr. Nataly Marchenko (UNIS) 6. PostDoc. Aleksey Shestov (UNIS) 7. PostDoc. Ekaterina Kim (NTNU) 8. PostDoc. Wenjun Lu (NTNU) 9. PhD st. Renat Yulmetov (NTNU/UNIS) 10. PhD st. Åse Ervik (NTNU)	1. Dr. Nikolay Diansky (SOI/ INMRAS) 2. Dr. Nikolay Yakovlev (INMARS) 3. Dr. Ilia Kabatchenko (SOI) 4. Dr. Dmitry Onishchenko (VNIIGAZ) 5. Dr. Mikhail Chumakov (VNIIGAZ) 6. Dr. Anatoly Gusev (INMRAS) 7. Dr. Marina Karulina (KSRC) 8. PhD st. Vladimir Fomin (MIPT) 9. Junior Researcher Mikhail Nikitin (HCR) 10. PhD st. Mikhail Naumov (VNIIGAZ)

INMRAS – Institute of Numerical Mathematics of the Russian Academy of Science, Moscow
MIPT – Moscow Institute of Physics and Technology, State University, Moscow
KSRC - Krylov State Research Centre, St.-Petersburg
HCR - Hydrometeorological Centre of Russia, Moscow

Research tasks/ Work Packages

Project activity will be split into four Work Packages:

- WP1. Collection of field data
- WP2. Modelling of sea state and atmosphere characteristics
- WP3. Modelling of ice and icebergs drift
- WP4. Modelling of ice loads and ice management

Specific tasks of the Work Packages are specified as follows:
WP1. Collection of field data
T1.1. Deployment of ice trackers on the drifting ice and icebergs in the Barents Sea
T1.2. Investigation of morphological properties of ice ridges and icebergs in the Barents Sea region.
T1.3. Investigation of ice strength.
T1.4. Measurements of sea state characteristics.

WP2. Modelling of sea state and atmosphere characteristics
T2.1. Numerical simulations of sea state characteristics and waves in the Barents Sea.
T2.2. Numerical simulations of atmospheric processes in the Barents Sea region including Polar lows dynamics.

WP3. Modelling of ice and icebergs drift
T3.1. Numerical simulations of ice floes and icebergs drift under the action of sea currents, surface waves and wind.
T3.2. Statistical characteristics of ice and icebergs drift in regions with low ice concentration, correlation of their extreme values with sea state and wind.
T3.3. Numerical simulations of thermodynamic consolidation of drifting ice ridges.

WP4. Modelling of ice loads and ice management
T4.1. Modelling of iceberg tow.
T4.2. Modelling of FPU manoeuvring in ice conditions.
T4.3. Modelling of iceberg collision with ship/FPU.
T4.4. Case studies and probabilistic estimates of ship damage due to the collision with ice floes in wave conditions.

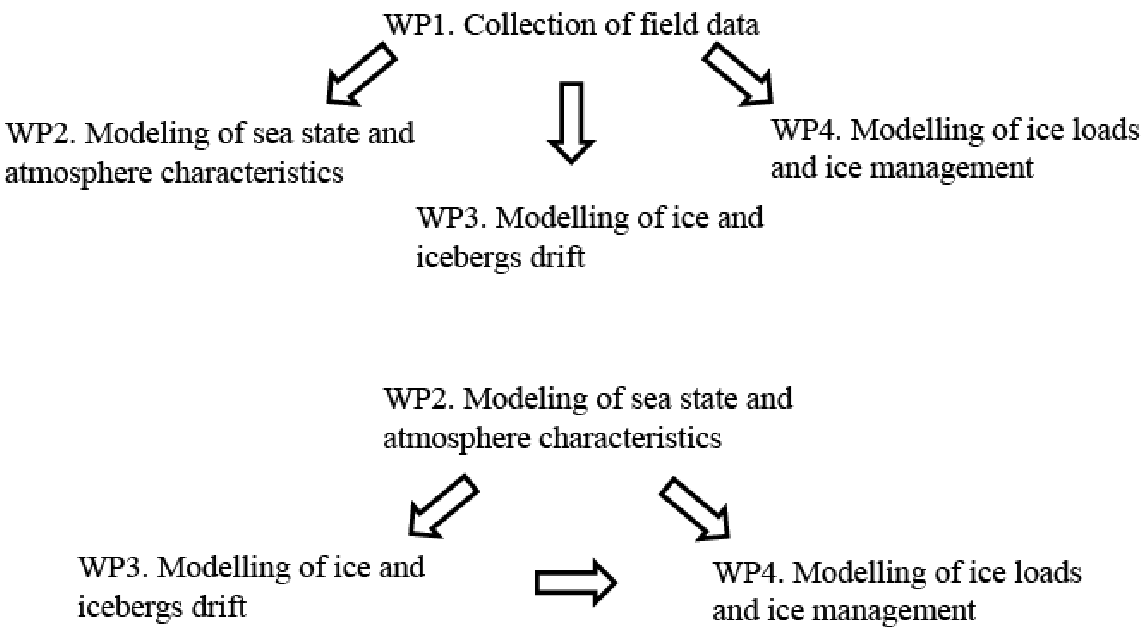

Figure 1. Scheme of information fluxes between the Work Packages.

Deliverables of the Work Packages are organized according to the Scheme of information flow between the Work Packages (Fig. 1) and include the following information:

WP1.
GPS positions of the ice trackers deployed on the drifting ice and icebergs, geometrical characteristics of ice ridges and icebergs, data on macro-porosity of ice ridges, temporal evolution of vertical temperature profiles of ice ridges, data on compression, tensile and indentation strength of sea ice depending on its temperature, salinity and loading rate, data on vertical profiles of the temperature, salinity and velocity of sea water below the drifting ice (CTD and ADCP profiling), data on turbulent characteristics of under ice boundary layer. The field work is performed in the period March-May each year by a boat rented for the UNIS course AT-211.

WP2.
Time series of sea current velocities, water temperature and salinity in specified regions of the Barents Sea up to the depth 100 m with vertical resolution 1 m, spatial resolution 2 km and temporal

resolution 1 hour, spectral characteristics of surface waves the in marginal ice zone, characteristic of sea currents, waves and wind during extreme weather events.

WP
3.
Data on characteristics of ice floes and icebergs drift under the action of regular and extreme weather events in specified regions of the Barents Sea, data on temporal evolution of ice ridges keels on the way of their drift during winter season in specified regions of the Barents Sea.

WP
4.
Formulation of mathematical model describing temporal evolution of the tag boat velocity during iceberg towing and tow line tension depending on iceberg characteristics and current data on the wind velocity and vertical profile of sea current velocity near the boat, results of numerical simulations in case studies. Formulation of mathematical model describing rotation of FPU in conditions of steady and drifting ice in different weather conditions, results of numerical simulations in case studies. Formulation of mathematical model of iceberg collision with ship/FPU, results of numerical simulations in case studies. Formulation of mathematical model describing collision of ships with floes in wave conditions, method of probabilistic estimations of the collision locations on the ship hulls.

Table 1. Involvement of partners in the research tasks.

	T11	T12	T13	T14	T21	T22	T31	T32	T33	T41	T42	T43	T44
UNIS	v	v	v	v			v	v	v	v	v	v	v
NTNU	v	v	v	v			v	v	v	v	v	v	v
SOI					v		v	v		v			v
VNIIGAZ						v	v	v		v	v	v	v

Project management

Project management will be organized with the help of the Central Management Group (CMG)
responsible to the control of the project works and financial expenses according to the work plan and the budget. CMG group will support contacts and communications with other relevant projects and research groups. Meeting of CMG group will be organized each month by telephone and/or Skype. All decision of CMG group will be formulated in electronic form with remote access from the web page of the project. CMG group include group leaders from UNIS, NTNU, SOI and VNIIGAZ.

Cooperation with Russia

The cooperation with Russian partners of the FIMA project is supported through the projects:

1. SFI project for the organizing of the Centre for Research-based Innovations “Sustainable Arctic Marine and Coastal Technology” (SAMCoT) (2011-2019).
2. CPRU-2011/10042 “Safety of Maritime Operation and Sustainable Industrial Development in the Arctic (SMIDA)”, 2012-2015
3. Project “Experiments on waves in oil and ice”, Research Council of Norway under the PETROMAKS2 scheme. Funding ID: 233901, 2014-2017.

4. Dissemination and communication of results

Stage 1. Organizing of the webpage at UNIS, workshop at UNIS, presentations on the International

Conferences POAC (Trondheim, 2015), paper in local newspaper Svalbardposten, workshop in Moscow.
Stage 2. Presentation of project goals and results on scientific seminars in Russia (SOI, VNIIGAZ), preparation of scientific papers, presentations on the International Conference RAO/CIS Offshore (St.Petersburg, September, 2015).
Stages 3. Submission of 3 papers in scientific journals, presentation of the project work on the day of open doors at UNIS, workshop at NTNU.
Stage 4. Presentations of project work for students at UNIS and NTNU, presentation of project results on IAHR Ice Symposium 2016.
Stage 5. Presentation of project goals and results on scientific seminars in Russia (SOI, VNIIGAZ), Preparation of scientific papers, writing the book.
Stage 6. Submission of 4 papers in scientific journals, presentations of project results on the VI International Conferences «Russian Offshore Oil and Gas Development: Arctic and Far East» (ROOGD2016, Moscow, VNIIGAZ, October 2016), workshop at NTNU, writing the book.
Stage 7. Workshop in Longyearbyen, presentations of project results on the International Conferences POAC 2017, workshop at UNIS, preparation of scientific papers, writing the book.
Stage 8. Presentation of project goals and results on scientific seminars in Russia (SOI, VNIIGAZ), preparation of scientific papers, writing the book.
Stage 9. Submission of the book for the printing.

Communications with users will be performed by regular meetings with industrial partners for SAMCoT project.