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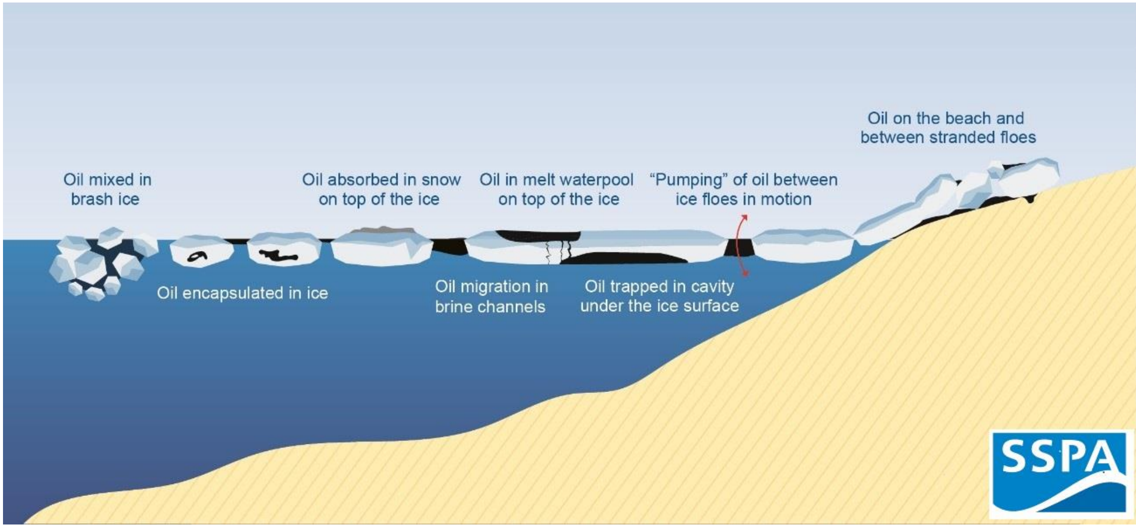
GRACE grant no
679266

Oil in ice code

D4.5

WP4: Combat of oil spill in coastal arctic water - effectiveness and environmental effects



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Executive Summary

The oil in ice code as developed and described in this report is a part of the "Integrated oil spill response actions and environmental effects – GRACE" project. The full project focuses on developing, comparing and evaluating the effectiveness and environmental effects of different oil spill response methods in a cold climate. In addition to this, a system for the real-time observation of underwater oil spills and a strategic tool for choosing oil spill response methods is developed. As of now, knowledge and practice for characterisation of various types of sea ice is primarily relevant for navigators, ship designers, meteorologists, and oceanographers. For oil responders and environmentalists engaged in impact and benefit assessments, it is however, sometimes too complex and is mainly addressing aspects related to possibilities for ship operation and manoeuvrability. This specific work task covers the development of a code that will facilitate communication and provide a rational and conclusive structure for presentation and dissemination of experimental data, and for identification of response gaps. It may also form a basis for guidance on optimal options and alternative response techniques (ART) for the response to oil spill in ice and for shoreline clean-up operations in winter conditions.

Several parameters have an impact on oil in ice and the subsequent handling of a spill. Based on the extent of impact the following five characteristic ice and oil parameters and classes are selected to be included in the oil in ice code: Ice type, Sea ice concentration, Temperature, Ice dynamic and Oil classification. These parameters, and their interrelation, affect the choice of oil recovery method. By using the oil in ice Code a uniform communication and description of the oil spill situation is enabled, upon which an appropriate response strategy could be chosen.

If the code is incorporated in national contingency plans, the code can be established as the standard for describing oil in ice, filling a gap where existing ice codes and nomenclatures are not sufficient. Further value is created if the oil in ice code should be applied as a complementary tool in sNEBA (strategic Net Environmental Benefit Analysis) processes and for documentation of sNEBA output and information of available resources for combating. The code may as well be integrated in interactive guidance tool for selection of response technique etc. Other applications where the oil in ice code may be useful include risk assessment methodologies as well as input data for drift and spreading simulations of oil in ice

Abbreviations

ECDIS – Electronic Chart Display and Information System

ENC – Electronic Navigation Charts

ETSI - Expert Team on Sea Ice

HELCOM – Baltic Marine Environment Protection Commission – Helsinki Commission

IACS – The International Association of Classification Societies

IHO – The International Hydrographic Organization

IMO – The International Maritime Organization

JCOMM – The Joint Technical Commission for Oceanography and Marine Meteorology

MARPOL – The International Convention for the Prevention of Pollution from Ships

PC – Polar Class

PWOM - Polar Water Operational Manual

SIGRID – Sea Ice Grid

sNEBA – strategic Net Environmental Benefit Analysis

SOLAS – The International Convention for the Safety of Life at Sea

STA – The Swedish Transport Agency

TRAFI – The Finnish Transport Safety Agency

WMO – The World Meteorological Organization

1 Introduction

The oil in ice code outlined in this report constitutes deliverable D4.5 and is a part of work package 4 of the GRACE project; Combat of oil spill coastal Artic water - effectiveness and environmental effects.

1.1 GRACE

The project focuses on developing, comparing and evaluating the effectiveness and environmental effects of different oil spill response methods in a cold climate. In addition to this, a system for the real-time observation of underwater oil spills and a strategic tool for choosing oil spill response methods is developed.

The results of the project will be made available for use to international organizations that plan and carry out cross-border oil spill response cooperation in Arctic sea areas. The full name of the project is ”Integrated oil spill response actions and environmental effects – GRACE"

1.2 Background to oil in ice code

There are numerous of different descriptive terms for various types and characteristics of sea ice. Different languages have different terminologies and multiple terms for equal types and phenomena may often be found. The reason for the diversity is related to the people who created the terms and the way the ice influenced the activities of these people and their occupations.

Seafarers need to describe ice conditions from a navigability point of view to prevent delays and damage risks. Ship designers need to describe ice in quantitative terms in order to define performance capacity and compliance with classification notations. Island habitants and fishermen may need to characterise the ice by its bearing capacity. Meteorological and oceanographic institutions provide services to various operators and stakeholders and need modelling tools for predictions and statistical analyses of sea ice.

Different user categories have agreed upon various standardised terminologies or codes and have also associated these with specific graphic symbols and colour schemes to facilitate communication by the use of maps and GIS technique.

For the category of oil spill responders and spill preparedness planners, there is however so far, no established clear-cut terminology or code for characterisation of ice conditions and its interaction with oil spills. It is well known, by experience, that oil spills in ice-covered waters often are difficult to handle and that the characteristics of the ice and its interaction with the oil are essentially determinant for the possibilities to cope with the response efforts and to find applicable methods. The category of responders and planners preferably include a wide range of different expertise and professions, covering mariners, scientists, technicians, planners, rescuers etc. who have no common ice and oil terminology. Therefore, a need for a designated oil in ice code is identified, in order to facilitate communication, planning and efficient operations.

1.3 Aim

The oil in ice code shall provide a tool for facilitation and streamlining of efficient communication between all professionals and stakeholders involved in oil spill issues related to sea ice. This group includes planners and responders as well as researchers and environmental scientists evaluating potential consequences of oil spills and environmental risks associated with exploration of oil and gas in Arctic areas and increased shipping activities in ice-covered waters.

The oil in ice code shall be simple and be based on established terminology and categorisation structures of relevance for various oil in ice scenarios.

1.4 Value

The access to and use of an oil in ice code may e.g. be valuable and expedient in the following cases:

- Provide a rational and conclusive structure for presentation and dissemination of experimental data
- Facilitate identification of response gaps
- Being compatible with established ice codes and registered statistics, it may provide guidance on adequate response design in preparedness planning processes
- Provide guidance on optimal options and alternative response techniques (ART) for oil spills in ice
- Facilitate operational decisions on adequate response methods
- Provide guidance on optimal options for shoreline clean-up operations in winter conditions
- Facilitate evaluation of response efforts and performance indicators after actual spills
- Consistent terminology facilitate cooperation in cross-border operations and international tier iii operations
- Facilitate airborne observation, mapping and remote sensing interpretations
- Facilitate input taxonomy in spill drift and spreading modelling
- Provide guidance for logistics planning and mobilisation of resources

1.5 Methodology

The basic of ice mechanics is reviewed in order to provide an understanding for ice development and its interaction with oil.

Several codes and nomenclature currently exists to describe ice conditions . Those are reviewed and mapped in the report in order to identify established praxis for ice codes, which may be applicable to adapt in the development of an oil in ice code.

A gap analysis identifies potential gaps in existing codes and standards, which are needed to be bridged by the new dedicated oil in ice code. Based on the outcome, a number of parameters to be included in the new code is selected. For each parameter, a sufficient classification is determined which is described and defined.

2 Sea ice

Sea ice appears in many different ways depending on area, temperature, salinity etc. Some important characteristics are briefly described below.

2.1 Ice formation

The freezing point is dependent on the salinity. Fresh water freezes at 0°C while saline sea water (3.2%) freezes at typically -1.7°C.

The freezing process starts by formation of *frazil ice*, needle-like ice crystals in the water column. When they are floating to the surface forming *grease ice* and bond together, an ice sheet is formed on the surface. The sheet formation includes different phases and in calm conditions the ice is called *nilas* before it thickens into ice floes and *level ice*. In rough conditions the first stage is *pancake ice* that consolidate to sheet ice or generate *rafting* when floes are pushed on top of each other or pile up in *ice ridges* when exposed to pressure by wind and current. Continued heat transfer from the ice to cold ambient air above, leads to thickening of the sheet underside by *congelation* of long vertical ice crystal forming *columnar ice*. Under influence of wind, current, and waves, sea ice is continuously crushed, broken and compressed forming a most irregular surface structure, described as *pack ice*.

During the freezing process, the salt in sea water is concentrated in vertical brine channels or pockets and gradually leached from the ageing ice. Newly frozen sea ice may have a salinity of 1.4% while typical first-year polar ice of 1-2 m thickness may contain 0.4 % of salt. In the summer season most of the first year ice melts, forming surface melt ponds with water and rotten ice beneath.

In polar areas where some of the first-year-ice do not melt, it continues to grow next winter season with gradually decreasing salt content. Multi-year ice may have as low as 0.1% salt content and typical thickness of 2-4 m.

When the salt content is drained from the sea ice, its mechanical properties changes and it becomes significantly harder. Though there is no multi-year ice in the Baltic Sea, Baltic Sea ice may also be very hard. Typical surface water salinity in the Bothnian Bay varies from 0.1 – 0.4%.

2.2 Ice drift

The wind creates a drag force on the ice surface and causes the ice to drift. The drag force depends on the wind speed and the characteristics of the ice surface. A rough ice surface is affected more by the wind than a smooth surface. As a general guideline, sea ice drifts with about 2-3 % of the wind speed and the Coriolis effect will generate a right offset from the wind direction on the northern hemisphere and a corresponding left offset in southern hemisphere.

2.3 Ice cover extent

2.3.1 Arctic Ocean

In the winter season, the ice cover is approximately twice as large as in the summer season in the Arctic Ocean. The minimum extent is normally around mid-September. Figure 1 shows the September ice extent from 2017.

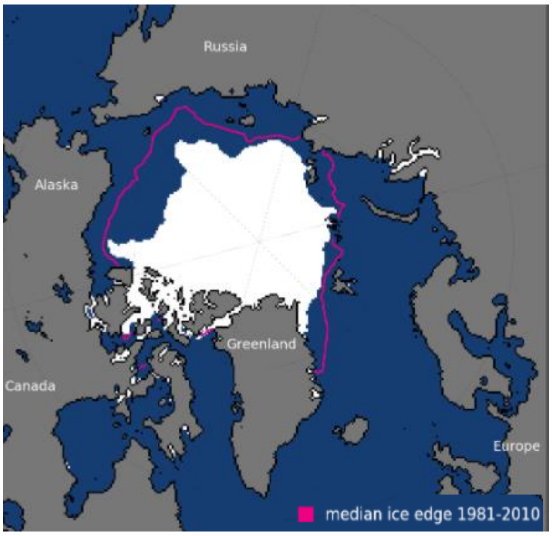


Figure 1. Arctic sea ice extent 17 September 2017, (NSIDC, 2017).

It is a well-documented fact that climate change effects contribute to reduced ice coverage and Figure 2 below clearly illustrates the trend of decreasing polar ice coverage over the past 37 years.

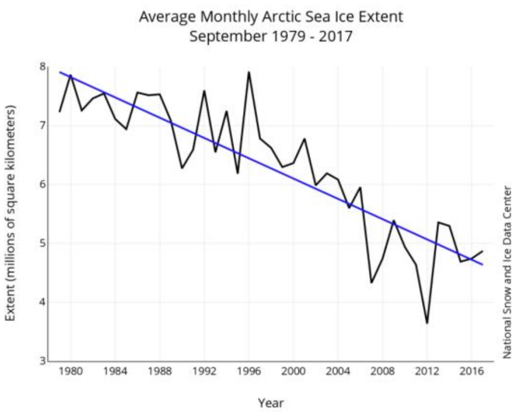


Figure 2. Decreasing trend of Arctic sea ice extent, (NSIDC, 2017)

2.3.2 The Baltic Sea

In the Baltic Sea, the ice season is normally from December to April, but with large inter-annual variations, and during extreme conditions the season can last from November to June. The latest severe season was in 1987 when sea ice-covered parts of Kattegat and Skagerrak. During extreme mild winters, ice is only formed in the Bothnian Bay, which occurred in 1989 and 2008.

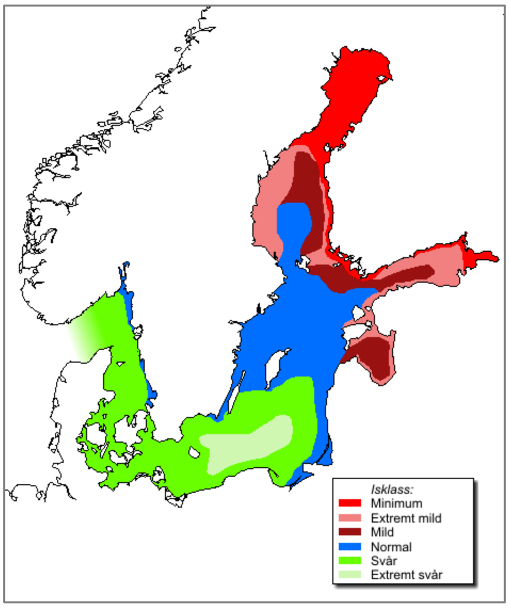


Figure 3. Approximate ice cover extent of different ice conditions in the Baltic Sea, (Havsmiljöinstitutet, 2016).

Climate change effects will also influence the future extent of the Baltic Sea ice. The ice seasons will become shorter and the ice will be thinner but the ice is also anticipated to become more mobile and pack ice and ridging generated by strong winds will continue to constitute navigational obstacles. Completely ice-free winters are, however, considered unlikely during the present century (SMHI, 2017c).

3 Existing ice codes and nomenclatures

A number of different ice classification codes, nomenclatures, and chart symbols have been developed and presented for various purposes and applications. Some examples are described in this section.

Most systems for notification/classification of ice is developed with regard to manoeuvrability of ships. This applies especially to classification in ice class rules as well as for the Egg code and Baltic Sea code which are developed to serve as basis for the need of ice breaker assistance and to classifications of ice in arctic climate and environments.

3.1 WMO Sea Ice Nomenclature

The World Meteorological Organization (WMO) publication No. 259 “Sea Ice Nomenclature” is an international sea-ice standard. The publication was originally published in 1970 and has undergone several revisions, latest amendments performed in 2014. The publication consists of three volumes (JCOMM, 2014a):

- Volume I – Terminology, contains of 220 terms and definitions, divided into 13 sections.
- Volume II – Illustrated Glossary, consists of 179 photos. The photos are mostly black and white with low quality.
- Volume III – International System of Sea-Ice Symbols, International System of Sea-Ice Symbols, is intended for use on synoptic and prognostic ice charts.

All three volumes can be found via link in List of References.

The latest revisions of the WMO Sea Ice Nomenclature were made in 1989. Since new ice charting and ice coding standards are now available, including “SIGRID-3”, “Colour Standard for Ice Charts” and “Ice Objects Catalogue”, the document are in need of a thorough revision (JCOMM, 2014a).

3.2 Baltic Sea Ice Code

The Baltic Sea Ice Code was developed by the countries around the Baltic Sea in order to provide a common terminology. It is used to describe ice conditions in ports, fairways, coastal areas and certain ship routes and consists of a four-digit code; Amount and arrangement of sea ice (AB), Stage of development (SB), Topography or form of ice (TB) and Navigation conditions in ice (KB). (SMHI, 2017b) The code is presented in Appendix 1, chapter 1.

3.3 Ice charts

Ice charts are issued by many Arctic and Baltic nations whom maintain Ice Services. The ice charts are used on ships as an aid to navigation in ice infested waters (JCOMM, 2014c).

The ice charts normally describes ice types, stage of development, ice concentration in tenths and the form of ice. The ice information is normally colour-coded using the

World Meteorological Organization Standard and/or presented in the Egg Code format. Other relevant information could include position of icebreaker assistance and traffic assistance.

Color-coding according to WMO and Egg Code format presentation is briefly described below. For more extensive information, please refer to appendix 1, chapter 2 to this report.

3.3.1 Colour code standard (The World Meteorological Organization (WMO))

The World Meteorological Organization (WMO) has developed a Colour Code Standard for use on ice charts. The standard includes two separate colour codes:

- One based on total concentration (CT) intended for use when the stage of development is relatively uniform but concentration is highly variable (e.g. Arctic summer navigation), see Appendix 1, chapter 2.1 for reference.
- One based on stage of development (SoD) intended for use when the concentration is relatively uniform (high) but the stage of development is variable (e.g. Arctic winter navigation), see Appendix 1, chapter 2.1 for reference.

The two separate colour codes are mutually exclusive – only one should be used on a single chart. The chart should include a legend describing the colour code used. The colour code does not exclude the use of black and white hatching patterns or egg codes; egg codes and/or black and white hatching may be used along with colours. The WMO Colour Code Standard is an integral part and extension of the WMO publication No. 259 “Sea Ice Nomenclature” (JCOMM, 2014d).

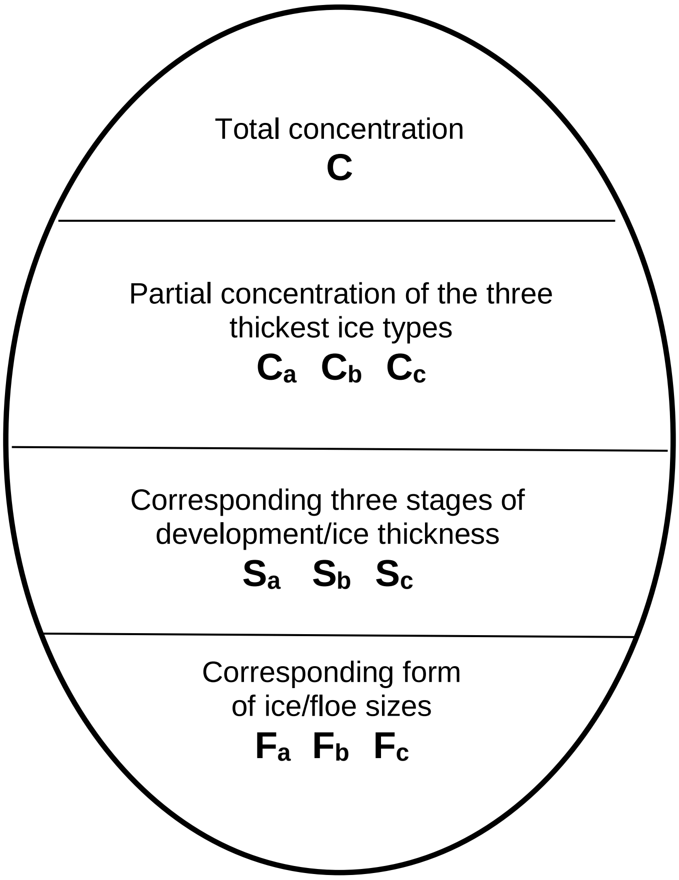
3.3.2 The Egg Code

The basic data concerning concentration, stage of development and form of ice are contained in a simple oval form, normally referred to as the “Egg Code” (JCOOM, 2014a).

The egg is divided into four sections as per below:

1. Total concentration
2. Partial concentration
3. Stage of development (age and thickness)
4. Form of ice (floe size)

A maximum of up to three classes are described within each section of the oval.



The upper section of the egg describes the total concentration **(C)** of ice in the area, expressed in tenths.

The second section of the egg describes the partial concentration of the three thickest ice types in the area; $\mathbf{C_a}$ – thickest, $\mathbf{C_b}$ – second thickest and $\mathbf{C_c}$ - third thickest, expressed in tenths.

The third section of the egg describes the stage of development (age and thickness) of each concentration of ice indicated in the second section; $\mathbf{S_a}$ – thickest, $\mathbf{S_b}$ - second thickest and $\mathbf{S_c}$ – third thickest.

The bottom section of the egg describes the corresponding form of the ice, including the floe size (**F_a, F_b, F_c**).

Detailed information on Egg Code symbols and corresponding ice concentration, development and form is found in Appendix 1, chapter 2.2.

3.4 Digital Ice Charts

As per SOLAS Chapter V regulation 19.2, ships engaged on international voyages are required to be fitted with Electronic Chart Display and Information Systems (ECDIS) according to below timetable:

Table 1 ECDIS implementation schedule (July 2012 to July 2018)
(Source: http://solasv.mcga.gov.uk/regulations/regulation19.htm)

Ship type	**ECDIS implementation schedule**
New passenger ships of 500 GT and upwards	1st of July 2012
New tankers of 3,000 GT and upwards	1st of July 2012
New cargo ships, other than tankers, of 10,000 GT and upwards	1st of July 2013
New cargo ships, other than tankers, of 3,000 GT and upwards but less than 10,000 GT	1st of July 2014
Existing passenger ships of 500 GT and upwards	1st of July 2014
Existing tankers of 3,000 GT and upwards	1st of July 2015
Existing cargo ships other than tankers, of 50,000 GT and upwards	1st of July 2016
Existing cargo ships other than tankers, of 20,000 GT but less than 50,000 GT	1st of July 2017
Existing cargo ships other than tankers, of 10,000 GT and upwards but less than 20,000 GT	1st of July 2018

As per the above timetable, there are no mandatory carriage requirements for existing cargo ships of less than 10,000 GT. However, most ships trading in ice infested waters will be equipped with Electronic Navigation Charts (ENC) and ECDIS in the near future.

It would therefore be useful if ice data could be provided in a form that can be integrated and presented in these systems.

SIGRID-3 (Sea Ice GeoReferenced Information and Data) is part of the SIGRID (Sea Ice Grid) series of standards for coding, exchange and archiving of digital ice charts. It contains the features, attributes and encoding of the Ice Objects Catalogue for Electronic Navigation Charts (ENCs) with the purpose to facilitate the automatic translation of digital ice charts into S-57 and S-10x ENC formats (JCOMM, 2014b).

The JCOMM Expert Team on Sea Ice (ETSI) approved version 3.0 of SIGRID-3 at its fifth meeting in March 2014. ETSI is recognized by the International Hydrographic Organization (IHO) as the responsible authority for the Electronic Navigation Chart (ENC) Ice Objects Catalogue (JCOMM, 2014b).

The IHO has established an on-line registry of Electronic Navigation Charts (ENC) features, whereof ice objects is included. The information is gathered from the ENC Ice Objects Catalogue and is compatible with SIGRID (JCOMM, 2014c).

3.5 The Polar Code and Vessel Ice Class System

As well as having codes and nomenclatures describing the ice itself there are ice class systems for ships, related to the construction of the vessel and how well they can manage in ice with and without icebreakers. Vessel ice class systems are not having a direct impact on the Oil in Ice Code and are therefore not described in full in this report. However, to enable a wider understanding for the type of ships trading in ice-infested waters it is worth mentioning that there are class rules for construction of ships trading in ice. Most of the members of the International Association of Classification Societies (IACS) have adopted what is called The Finnish-Swedish Ice Class Rules (FSICR) and embodied their own regulations on the classification of ships (TRAFI, 2011). FSICR are outlined based on the conditions found in the Baltic Sea and Gulf of Bothnia. The Russian and IACS class rules are thus designed do deal with significant thicker ice than FSICR.

Table 2 below presents an overview of the Finnish-Swedish Ice Class Rules and different Class Societies equivalent. Also worth mentioning related to the Vessel class rules area is that as of 1 January 2017 the Polar Code came into force. Just like vessel ice class rules the Polar Code is not directly affecting the Oil in Ice Code, but serves as valid general information related to ships trading in ice. The Polar Code consists of one safety part, that applies to ships certified under SOLAS (cargo ships of 500GT or more and all passenger ships) and one environmental part that applies to all ships certified under MARPOL Annexes I, II, IV and V respectively. Fishing vessels, although not carrying any SOLAS certificate, should also comply with the code. The safety part of the code includes design, construction, equipment, operational, training, search and rescue requirements related to the potential hazards of operating in polar regions, including ice, remoteness and severe and rapidly changing weather conditions. It is written in a goal based manner and provides both functional requirements and detailed requirements. The environmental requirements in the Polar Code are operational and the responsibility of the Master and includes amendments of the Procedures and Arrangements (P&A) manual (where required). MARPOL Annex II requires that each ship which is certified for the carriage of Noxious Liquid Substances in bulk shall be provided with a P&A Manual. The scope of this plan is to provide the arrangements and equipment required to enable compliance with MARPOL Annex II. Furthermore the environmental part includes operational requirements related to discharge of oil (prohibited) and sewage and garbage discharge.

Further details on the Finnish-Swedish Ice Class Rules Vessel Ice Classes and the Polar code is found in Appendix 1, chapter 3.

Table 2. Estimated equivalence of ice classes of different Classification Societies with the Finnish-Swedish Ice Class Rules (HELCOM, 2016).

Classification Society	**Ice Class**				
Finnish-Swedish Ice Class Rules	**1A Super**	**1A**	**1B**	**1C**	**Category II**
Russian Maritime Register of Shipping (Rules 1995)	UL	L1	L2	L3	L4
Russian Maritime Register of Shipping (Rules 1999)	LU5	LU4	LU3	LU2	LU1
Russian Maritime Register of Shipping (Rules 2008)	Arc 5	Arc 4	Ice 3	Ice 2	Ice 1
American Bureau of Shipping	Ice Class I AA	Ice Class I A	Ice Class I B	Ice Class I C	D0
Bureau Veritas	ICE CLASS 1A SUPER	ICE CLASS 1A	ICE CLASS 1B	ICE CLASS 1C	1D
CASPR, 1972	A	B	C	D	E
China Classification Society	Ice Class B1*	Ice Class B1	Ice Class B2	Ice Class B3	Ice Class B
Det Norske Veritas	ICE-1A*	ICE-1A	ICE-1B	ICE-1C	ICE-C
DNV GL	Ice(1A*)	Ice(1A)	Ice(1B)	Ice(1C)	-
Germanischer Lloyd	E4	E3	E2	E1	E

IACS Polar Rules	PC6	PC7	-	-	-
Korean Register of Shipping	1A Super	1A	1B	1C	1D
Lloyd´s Register of Shipping	Ice Class 1AS FS (+) Ice Class 1AS FS	Ice Class 1A FS (+) Ice Class 1A FS	Ice Class 1B FS (+) Ice Class 1C FS	Ice Class 1C FS (+) Ice Class 1C FS	Ice Class 1D Ice Class 1E
Nippon Kaiji Kyokai	NS* (Class 1A Super Ice Strengthening) NS (Class 1A Super Ice Strengthening)	NS* (Class 1A Ice Strengthening) NS (Class 1A Ice Strengthening)	NS* (Class 1B Ice Strengthening) NS (Class 1B Ice Strengthening)	NS* (Class 1C Ice Strengthening) NS (Class 1C Ice Strengthening)	NS* (Class 1D Ice Strengthening) NS (Class 1D Ice Strengthening)
Polski Rejestr Statków	L1A	L1	L2	L3	L4
Registro Italiano Navale	ICE CLASS 1A SUPER	ICE CLASS 1A	ICE CLASS 1B	ICE CLASS 1C	1D

4 Drift and spreading

A number of different modelling tools have been developed in order to predict the movement, areal spreading and fate and behaviour of oil spills in water. Meteorological data on predicted/observed wind velocity and surface currents are primary input data for estimations on available time windows for response efforts at sea and for identification of coastal areas at risk and shorelines threatened by oil contamination. Type of oil and its physical properties also provide important input data, and 3D-models are also incorporated to separate and quantify the fraction of oil dispersed in the water column from the prediction of the surface oil slick.

The presence of sea ice, however, makes the possibilities for prediction of drift and spreading of oil spills much more complex. In addition to factors governing the surface slick spreading, the sub surface dispersion and weathering processes introduces a variety of complex interaction phenomena significantly changing the mechanisms for drift and spreading of the spilt oil and its predictability.

A lot of efforts and empirical research have been directed to modelling and prediction of ice formation and drift (often described as coupled ice-ocean models), and some trials are presented on combined modelling of oil in ice drift prediction.

The basic mechanisms of oil spill drift and spreading are often referred to two primary regimes; transport and weathering. For these two, a total of ten physic-chemical processes are normally identified as factors governing the fate and behaviour of spilt oil:

Transport (movement and distribution)	**Weathering (change of oil properties)**
Advection (drift by wind and current)	Evaporation
Spreading (gravity, viscous, surface tension)	Emulsification
Dispersion (droplet formation, turbulent mixing)	Dissolution
Sedimentation (sinking of oiled particles)	Biodegradation
Encapsulation (oil encapsulated in ice)	Photo-oxidation

The encapsulation is the only one that exclusively occurs in ice or winter conditions, while the others are relevant also in open water conditions. Encapsulation normally occurs during ice growth processes but the porous character of fresh saline ice may also contribute to oil percolation and encapsulation. All processes are, however, highly influenced and generally reduced by the presence of ice.

These processes represents completely different physical-chemical processes and in order to design accurate prediction tools or theoretical models, a number of different models and empirical data need to be combined. There are a number of such modelling tools for open water conditions but only a few that are applicable also for oil spills in ice-covered waters and winter conditions. It is well known that the transport of oil spills in ice is highly influenced by the ice concentration/coverage ratio, and an often referred, established rule of thumb, gives the following relation between ice concentration (Conc) and oil spill transport, (Venkatesh, 1990):
Conc < 3/10; oil and ice drift independently,

Conc ≥ 3/10, ≤ 7/10; oil drifts proportionally to ice,
Conc > 7/10; the oil drift is fully govern by the ice drift and follows the ice.

In a state-of-the-art review of oil in ice modelling, the following knowledge gaps and need for development of ice-specific algorithms, was identified and ranked in order of priority (Mawuli, 2016):

1) evaporation, 2) emulsification, 3) spreading, 4) encapsulation, 5) photo-oxidation, and 6) dispersion.

The referred state-of-the-art review further identifies the need for a comprehensive database for oil spills in ice-covered waters, in order to facilitate further research and validation of developed models.

Within the GRACE project, there is no Specific Objective (Work Package) or task specifically dedicated for development of drift and spreading models for oil in ice, but in WP 5, examples of oil spill dispersion simulations are reported, (GRACE_D5.2). The simulated drift and spreading of 1 000 tones oil spills are calculated by use of a high resolution ocean circulation model at ten different locations. Dissolution of passive and transient tracers are modelled to represent the mixing process of the oil spill, and the model is not intended to give accurate description of all identified transport and weathering processes identified in the table above. Additional simulation studies of oil spills including winter season condition are planned for 2018 for the Baffin Bay area, (GRACE_D5.3, 2017).

Three established models that are regularly applied for drift and spreading prediction of oil spill in open water, are briefly described below. Other models include OILMAP and SIMAP (ASA).

4.1 Seatrack web - Helcom

Seatrack Web is an internet based tool which is used to animate how currents and winds change hour by hour, and how pollutants such as e.g. oil, evaporates and drifts. Seatrack Web simulates the drift and spreading based on weather and circulation forecasts, up to five days ahead. It is also possible to make scenarios with optional winds and currents.

Seatrack Web is used throughout the entire Baltic Sea area, including the eastern part of the North Sea. The system is developed by SMHI in cooperation with DCOO in Denmark and BSH in Germany. The project was originally financed by the Swedish Coastguard and SMHI. It is the official HELCOM drift model/forecasting and hindcasting system which is used for calculating the fate of oil spills and it is available online for national authorities and certain research organisations.

The output results can be presented as; animated maps in GIS format showing the movement and concentration of the pollutant, time series, and tables containing wind directions/speeds, currents and how the pollutant is changing. The result can also be animated. The maps also display optional geographic information, for example, sensitive areas.

The system is designed with a simple user interface and allow fast calculations with reliable forecast models for winds and currents.

The meteorological ice forecasting models for sea ice in the Baltic Sea available within SMHI, have been combined with the Seatrack Web tool, but accurate modelling of oil in ice require empirical validation and extensive testing. One example of such testing has been reported from the Runner 4 oil spill accident in the Gulf of Finland in March 2006, (Arneborg, 2017). The model applied was able to describe the drift trajectory and spreading of the oil reasonably well but the spreading behaviour was found to be highly dependent of the relative current velocity water/ice and of the ice floe size. The study suggests that the modelling of these parameters are important for further refinement of the model and also underlines the problem of lacking validation data from actual oil spill incidents in ice.

4.2 GNOME – NOAA

NOAA (US National Oceanographic and Atmospheric Administration) has developed a modelling tool, offered as an open freeware, called GNOME. GNOME (General NOAA Operational Modeling Environment). The modelling tool is used to predict the trajectory of a pollutant e.g. an oil spill in a water body. Oil spill planners and responders use the model to predict how wind, currents, and other processes might move and spread pollutants spilled on or in the water. The latest version is GNOME 1.3.10, posted November 30, 2017.

The NOAA Office of Response and Restoration (OR&R)'s Emergency Response Division (ERD) is actively developing their software suite and has released a beta version of a suite of oil spill modelling tools, comprising the next generation of GNOME. The suite will replace the desktop version of GNOME and the ADIOS oil weathering program with a new Web interface and updated weathering and transport algorithms. As part of the development process, a new model that will more accurately predict the weathering and transport of oil in cold-water environments and in ice, has been announced by NOAA (NOAA, 2017), but it is not clear if this feature is available in the beta version of the GNOME Suite per January 2018.

An additional feature announced is the integration of the Response Options Calculator (ROC) into GNOME. ROC is a multi-faceted tool that assesses the general performance of oil spill response systems, such as the mechanical recovery of oil from the water, the application of dispersant, and the burning of spilled oil, (Genwest, 2011).

4.3 OSCAR – SINTEF

SINTEF in Norway has developed the software model and simulation tool OSCAR (Oil Spill Contingency and Response) for prediction of transport and weathering of oil spills in various conditions. The model has been extensively tested and validated by physical laboratory tests and field experiments.

OSCAR has also been used together with output from coupled ice-ocean models by NERSC (Nansen Environmental and Remote Sensing Center). As part of the SINTEF Oil in Ice JIP 2006-2009, experiments with ice drifter buoys and field experiments with oil spill (7 m^3 crude oil) in the marginal ice zone in the Barents Sea was conducted. Observations from these studies have been used to test the accuracy of oil spill trajectory predictions by using two different coupled ice-ocean models as input for the OSCAR simulations. The results display how the predicted oil drift is affected by the changing ice concentration and that the combined tools improve the predictability of oil drift in ice conditions. For ice concentrations from 3/10 up to 7/10, there is however, still a need for refinement of the assumed linear dependency of oil transport and ice concentration, (Beegle-Krause, 2017).

5 Development of oil in ice code

5.1 Gap analysis existing codes

The current state of knowledge and practice for characterisation of various types of sea ice is relevant for navigators, ship designers, meteorologists, and oceanographers. For oil responders and environmentalists engaged in impact and benefit assessments, it is however, sometimes too complex and is primarily addressing aspects related to possibilities for ship operation and manoeuvrability.

Oil spill responders and environmental experts today are generally well informed on how to best respond to oil spills in various coastal environments and open water conditions. In order to make quick and informed decisions on the most feasible response option in case of oil spills in extreme winter conditions with sea ice, spill responders need to consider a number of additional parameters describing the ice conditions, the oil properties and actual oil-ice interaction phenomena. Today such considerations require good knowledge in navigational ice terminology and may be difficult to communicate in a clear-cut way to other responders, planners, or environmentalists.

The desired state is a situation where oil spill responders, planners, and environmental impact and benefit assessment experts can communicate and consider specific winter and ice aspects in an efficient and stringent manner. Communication between different disciplines like navigators and oil responders as well as among oil spill expertise and researchers, need to be facilitated and become more synergetic.

The identified gap may be bridged by a new dedicated oil in ice classification code. Such a code will facilitate the communication and provide a rational and conclusive structure for presentation and dissemination of experimental data, for identification of response gaps. It may also form a basis for guidance on optimal options and alternative response techniques (ART) for the response to oil spill in ice and for shoreline clean-up operations in winter conditions.

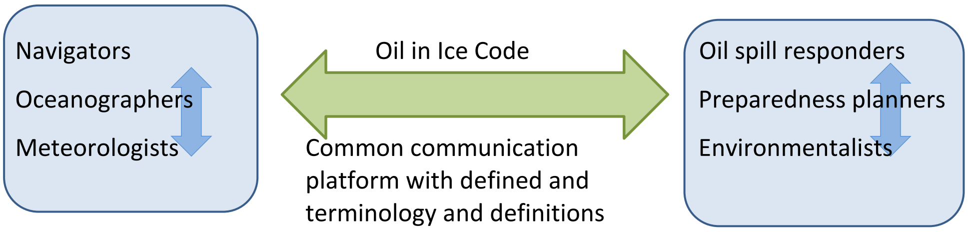


Figure 4. Oil in Ice Code as a common communication platform between scientific disciplines.

5.2 Oil and ice interaction

Most of the ice classification systems and codes listed in previous section are primarily designed in order to reflect navigability performance, but do not reflect various modes of interaction between the ice conditions and the oil properties in case of an oil spill. It is well known that there are many different modes of possible interaction phenomena when oil is spilt in ice-covered waters, and that these phenomena are determinant factors for applicable recovery methods and successful response efforts. The box scheme in Figure 5 below illustrates some basic ice and oil properties and their influence on oil spilt in icy waters. Figure 6. below exemplifies known varieties of appearance of spilled oil in ice conditions.

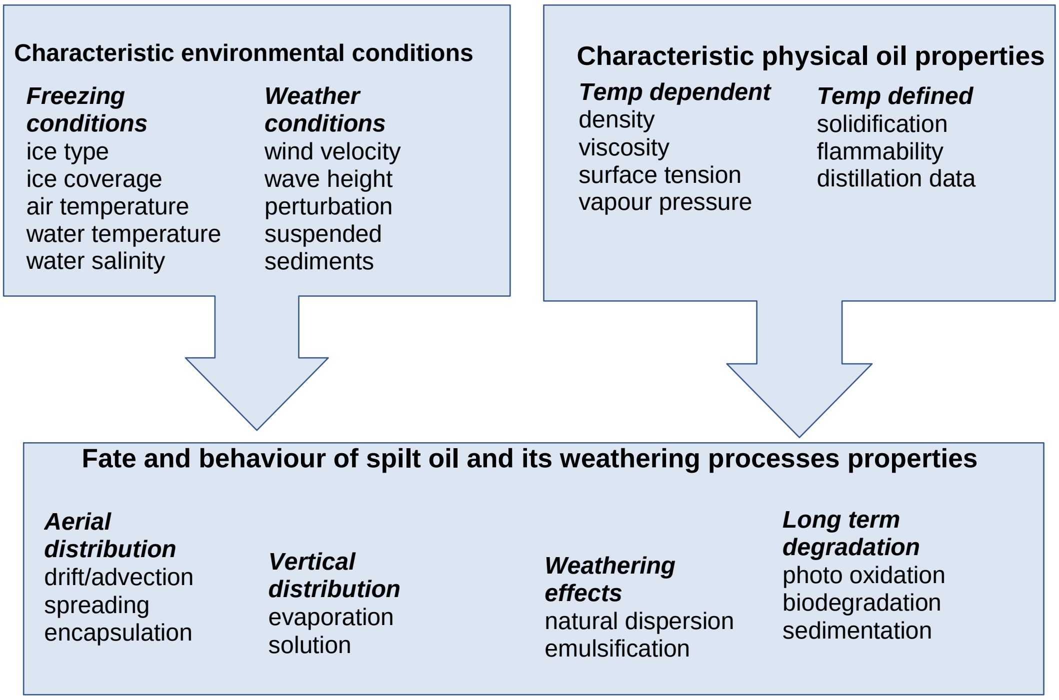


Figure 5. Box scheme: Schematic rationale on influencing factors/parameters governing the fate and behaviour on oil spills in water and ice.

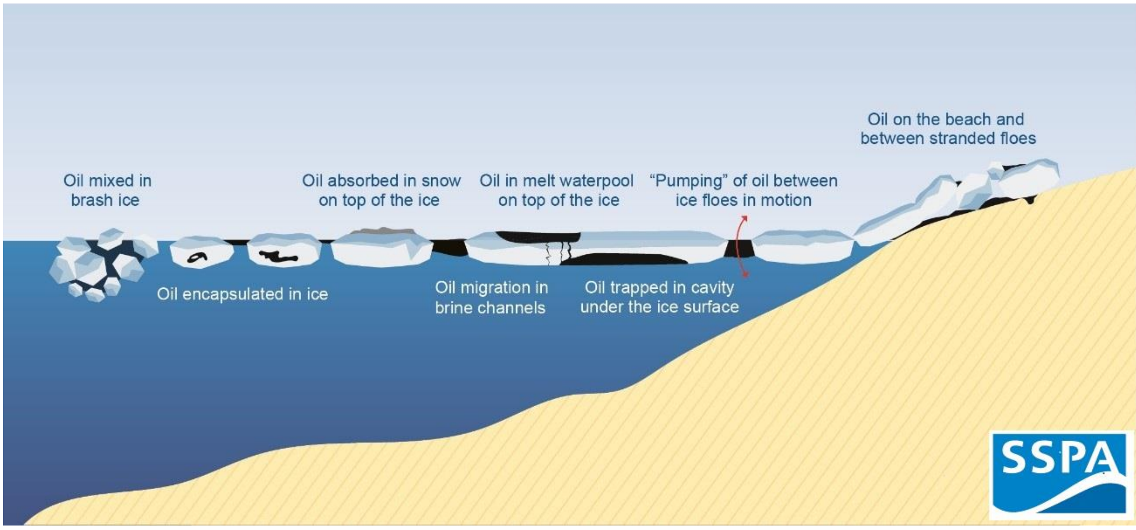


Figure 6. Known varieties of appearance of spilled oil in ice condition (Illustration: SSPA Sweden AB).

5.3 Selected parameters

Several parameters have an impact on oil in ice and the subsequent handling of a spill. Based on the extent of impact the following characteristic ice and oil parameters and classes are selected to be included in the oil in ice code:

- Ice type
- Sea ice concentration
- Temperature
- Ice dynamic
- Oil classification

These parameters are described and characterised in separate sections below.

5.3.1 Ice type

The type of ice affects both how the oil interacts with the ice and what type of vessel and oil spill recovery equipment that is needed.

Table 3 Ice type classes and associated description

Ice type class	Definition	Size	Description
0	Ice free		The term ice-free pertains to ice free water under prevailing winter conditions, i.e. ice can exist in the area or the water temperature is so close to its freezing point that ice could be expected to be developed during a cold night.
1	Slush	< 2 cm	The term slush includes all types of non-consolidated ice or snow that appears on the water, often in conjunction with freezing. There are a number of terms that are included here; snow slush, ice slush, mush, frazil. The class includes the type of ice that can mix with oil under the affection of wind and waves.
2	Small brash	< 40 cm	Pieces of ice that can be handled manually. Swell from passing ships turns small brash up side down. Safe to use booms and small workboats in the area.
3	Brash	< 2 m	This class includes bigger pieces and floes that could be found in a fairway where an icebreaker has broken the ice. The size of the ice makes it possible for workboats to operate in the area. Ice of this size is easily moved for oil spill handling.
4	Floes	< 6 m	Pieces possibly big enough to walk on, but not to work from. Oil can be accumulated underneath. Larger workboats are needed for moving the ice to enable oil spill recovery. Oil that is spread will splash up on top of the floes and mix with snow and slush, if any.
5	Large floes/pack ice	> 6 m	Possibly to work from. Larger quantities of oil can be accumulated underneath, particularly in cracks and cavities
6	Fast ice		

5.3.2 Sea ice concentration

Sea ice concentration is the amount of sea ice covering an area. It is defined as the ratio of sea ice to water, here expressed in tenths (0/10 to 10/10). The sea ice concentration has a direct impact on drift and weathering characteristics and thus the choice of oil recovery method.

0 = ice free

1 ≤ 1/10 concentration (areal coverage)

2 ≤ 2/10

3 ≤ 3/10

4 ≤ 4/10

5 ≤ 5/10

6 ≤ 6/10

7 ≤ 7/10

8 ≤ 8/10

9 ≤ 9/10

10 > 9/10

5.3.3 Temperature

Temperature is one of the most essential external factors which influences all the processes that changes the oil properties and behaviour in water and in ice.

Temperature is also important with respect to ice formation and development. Ice formation and development varies depending on air temperature, but also due to radiation loss/gain. The freezing point of the water is dependent of the salinity. Fresh water freezes at 0 °C while seawater freezes below zero degree Celsius, at about -2 °C.

In the code, temperature is referenced to air temperature and is divided into three classes as given below:

-	Freezing, temperatures below the freezing point of the water
0	Temperatures around the freezing point of the water
+	Melting, no risk of ice formation, above freezing point

5.3.4 Ice dynamic

Ice dynamic and drift and spreading of spilled oil are affected by wind, current and waves. In addition, localisation and surrounding geographic affects the movements.

In the code, ice dynamic is divided into three classes based on the respective conditions for oil in ice interaction and corresponding choice of response technique.

0 – Calm
No noticeable ice movement caused by wind, current or waves which affect spilled oil in ice.

1 – Moderate ice movements
The effect of waves and the ice concentration is able to concentrate ice and mix oil into emulsifications and slush mixtures. The ice is not ridging and is not deformed. It can be problematic for workboats and environmental protection ships to operate in the area. The possibilities for mechanical oil recovery are reduced.

2 – Severe ice movements
Strong wind in combination with heavy sea will deform the ice, break bigger ice floes and form ridges when the ice is pushed together. The prevailing forces are determined by the ice mechanics. Oil is spread in shearing- and brash zones. Oil is splashed up on top of the broken ice and is pushed into ridges. Large mixing takes place which gives emulsification and slush mixtures.

5.3.5 Oil classification

One of the most important stages in choosing an appropriate response strategy for an oil spill is to predict the behaviour of the substance spilt at sea, i.e. the way in which it is weathered and its physical properties are altered during the first hours after coming into contact with water.

The Standard European Behaviour Classification (SEBC) determines the dominant theoretical behaviour in water of a substance according to its physical and chemical properties (density, vapour pressure, solubility), and classifies it into five main categories (HNS-MS, 2017):

- Sinkers (S)
- Dissolvers (D)
- Floaters (F)
- Evaporators (E)
- Gases (G)

A substance often have several behaviours due to its nature and weathering processes (wind, waves, current). The five main categories are therefore further divided into 12 subgroups;

- Sinker (S)
- Sinker/dissolver (SD)
- Dissolver (D)
- Dissolver/evaporator (DE)
- Floater/dissolver (FD)
- Floater (F)
- Floater/evaporator/dissolver (FED)
- Floater/evaporator (FE)
- Evaporator/dissolver (ED)
- Evaporator (E)
- Gas/dissolver (GD)

- Gas (G)

The categories are further specified according to Figure 6.

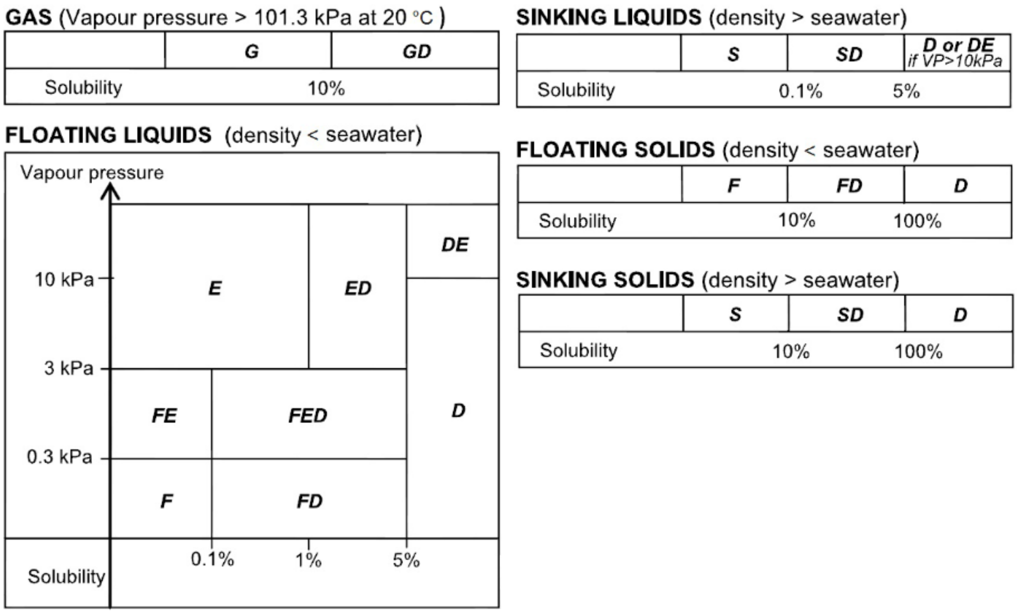


Figure 6. Specification of SEBC code for describing the behaviour in water of a substance according to its physical and chemical properties (HNS-MS, 2017).

Relevant categories for the purpose of the oil in ice code includes floaters and combined subgroups including the letter F, i.e.;

- Floater/evaporator (FE)
- Floater/evaporator/dissolver (FED)
- Floater (F)
- Floater/dissolver (FD)

Figure 7 below illustrates the 12 different sub categories of possible oil and chemical behaviours. The four mid ones represent those of relevance for the oil in ice code. Other categories are not covered by the code since these cannot be handled and no actions will therefore be requested.

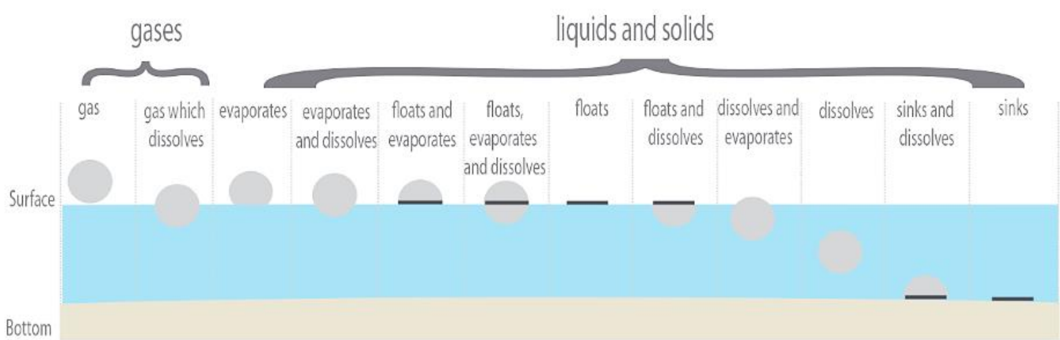


Figure 7 Oil and chemical behaviour (HNS-MS, 2017).

The characteristics of oil in terms of physical properties and the categorization outlined above are dependent on water temperature and thus water temperature and salinity. The diagram in Figure 8 shows how water density is dependent on salinity and water temperature. The figure also includes an example of oil and its density dependent on temperature.

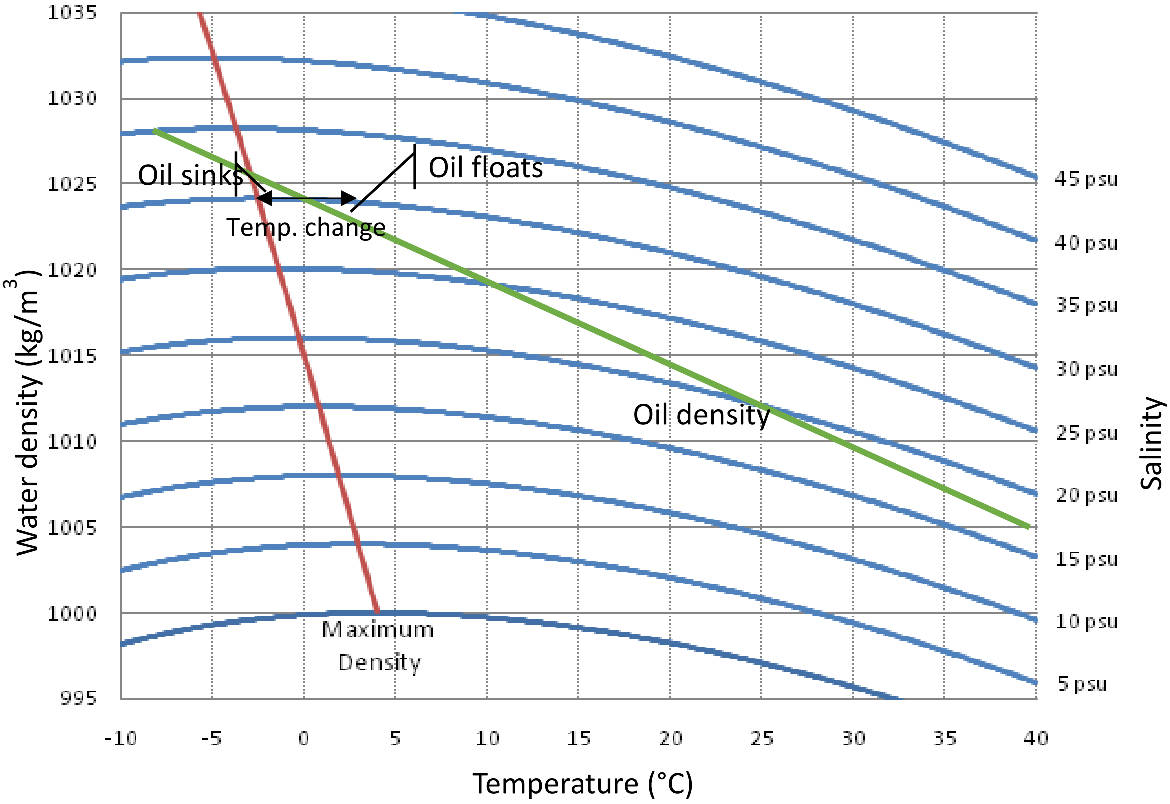


Figure 8 Water density as a function of temperature and salinity. Oil density as a function of temperature.

The figure indicates that a minor change of water temperature may cause a change of the oil characteristic, going from floating to sinking or vice versa. In areas with ice, this interaction between water temperature and oil characteristics is vital. Diesel will most likely occur as Floater/Evaporator (F/E) in case of a spill. Heavy fuel oil can occur as a Floater (F) or a Floater/Sinker (F/S). The quality of crude oil may vary but is likely to occur as a Floater/Evaporator/Dissolver (F/E/D).

Other oil characteristics of the oil of high importance is the viscosity, which is also dependent on the temperature. The viscosity will affect the appearance of the oil and whether it is solid, sticky or fluid. The viscosity varies highly between different oil types and is dependent on temperature. For instance, diesel has a low viscosity and occurs as a fluid when discharged in cold water. Heavy fuel oil generally has a high viscosity and becomes highly viscous when released in cold water. The viscosity of fresh crude oil varies considerably.

5.4 Example of usage of the code

Figure 9 shows the container ship Godafoss which grounded in the Hvaler-Fredrikstad archipelago, Norway in February 2011. The grounding accident caused an oil spill of 120 tonnes of intermediate fuel oil (IFO 380).

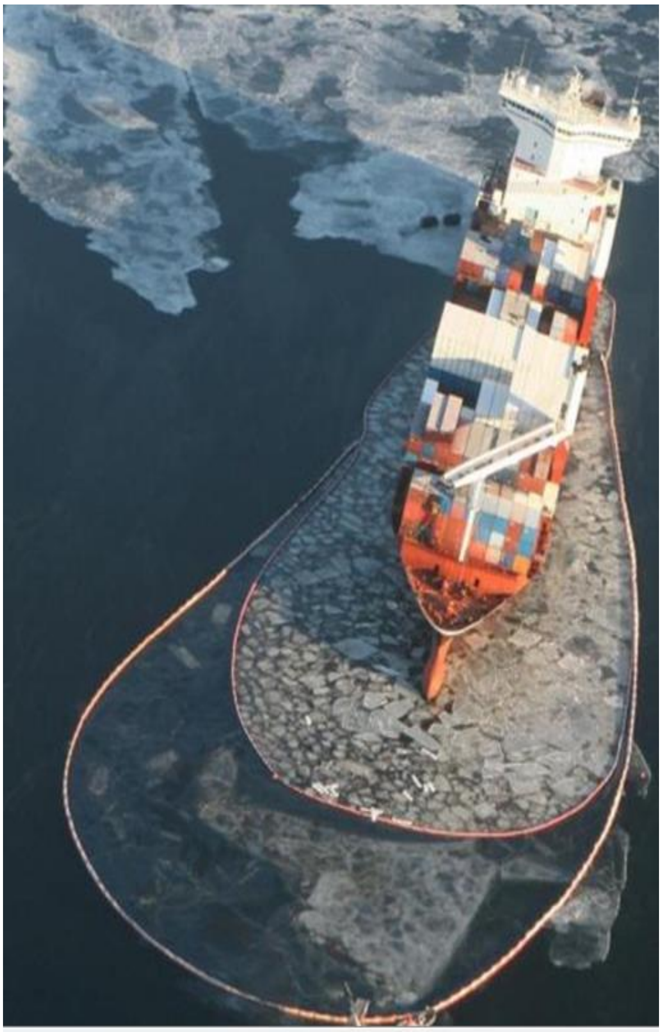


Figure 9 Containment booms around the grounded Godafoss in February 2011.

The developed code can be applied to describe the situation and the oil spill. From the picture, the ice is determined to be floes in the size of 2- 6 m in diameter. This implies *ice type 4*. In the area where the oil is present, the ice coverage is estimated to be 8/10, hence *ice concentration 8*. At the time of the spill, the *temperature was below freezing point, (-)*, and ice growths. The ice floes have moved after the spill occurred which indicates ice movements. The ice dynamics can therefore be classified as *moderate ice movements, 1.* As seen in the picture the oil propagation was limited by use of containment booms. This was possible since the oil was floating, hence is classified as a *Floater (F).* Table 4 summarizes the description of the oil in ice.

Table 4. Oil in ice code for the oil spill from Godafoss in Norway in 2011.

Parameter	Classification
Ice type	4
Ice concentration	8
Temperature	-
Ice dynamics	1
Oil classification	F

6 Discussion and conclusions

The code aims at improving the conditions for effective oil spill response in conditions where sea ice is present. The code shall provide a tool for an efficient communication between all professionals and stakeholders involved in oil spill issues related to sea ice. The information contained in the code is determined to cover the most relevant parameters in order to define relevant conditions for communication and decision making regarding oil spill in ice-covered waters. The conditions at the spill locations may change quickly and the time for the observation shall therefore be given along with the code information.

The code itself is limited to description of the situation and it does not cover recommendations on specific response or oil recovery techniques. The code shall therefore preferably by used in combination with a Strategic Net Enivronmental Benefit Analysis (sNEBA) to determine on the most adequate response strategy. The sNEBA is a planning tool and includes environmental information on biodiversity, biology and ecotoxicology of oil. The sNEBA may also contain information of available equipment and strategies for efficient operation of available resources. The description of the situation, given by the code may thus be used to determine the most appropriate response strategy.

In case of an actual oil spill, the code can be used by the person detecting the spill on site, or from remote sensing information and images, to provide the initial most vital information to responsible authorities. If the code is incorporated in national contingency plans, the code can be established as the standard for describing oil in ice. Existing ice codes are not considered sufficient for practical characterisation and description of oil in ice interaction and the presented code may be developed into an established praxis.

The usability of code is also expected to increase when it is applied as a complementary tool in sNEBA processes and for documentation of sNEBA output and information of available resources for combating. The code may as well be integrated in interactive guidance tool for selection of response technique etc. Other applications where the oil in ice code may be useful include risk assessment methodologies as well as input data for drift and spreading simulations of oil in ice.

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GRACE grant no 679266

Oil in ice code

D4.5

WP4: Combat of oil spill in coastal arctic water - effectiveness and environmental effects

APPENDIX

Table of Contents

1 Baltic Sea Ice Code

The Baltic Sea Ice Code is developed by the countries around the Baltic Sea in order to provide a common terminology. It is used to describe ice conditions in ports, fairways, coastal areas and certain ship routes and consist of a four-digit code; Amount and arrangement of sea ice (**AB**), Stage of development (**SB**), Topography or form of ice (**TB**) and Navigation conditions in ice (**KB**). The code is presented below (SMHI, 2017b):

AB – Amount and arrangement of sea ice

0 – Ice free.

1 – Open water – concentration less than 1/10.

2 – Very open pack ice – concentration 1/10 to less than 4/10.

3 – Open pack ice – concentration 4/10 to 6/10.

4 – Close pack ice – concentration 7/10 to 8/10.

5 – Very close pack ice – concentration 9/10 to 9+/10. *

6 – Compact pack ice, including consolidated pack ice – concentration 10/10.

7 – Fast ice with pack ice outside.

8 – Fast ice.

9 – Lead in very close or compact ice or along the fast ice edge / Unable to report.

*9+/10 means ice concentration 10/10 with minor leads.

SB – Stage of development

0 – New ice or dark nilas (less than 5 cm thick).

1 – Light nilas (5-10 cm thick).

2 – Grey ice (10-15 cm thick).

3 – Grey-white ice (15-30 cm thick).

4 – White ice, first stage (30-50 cm thick).

5 – White ice, second stage (50-70 cm thick).

6 – Medium first year ice (70-120 cm thick).

7 – Ice predominately thinner than 15 cm with some thicker ice.

8 – Ice predominately grey-white (15-30 cm) with some ice thicker than 30 cm.

9 – Ice predominately thicker than 30 cm with some thinner ice / No information

TB – Topography or form of ice

0 - Pancake ice, ice cakes, brash ice – less than 20 m across.

1 – Small ice floes – 20-100 m across.

2 – Medium ice floes – 100-500 m across.

3 – Big ice floes – 500-2000 m across.

4 – Vast or giant ice floes – more than 2000 m across – or level ice.

5 – Rafted ice.

6 – Compacted slush or shuga, or compacted brash ice.

7 – Hummocked or ridged ice.

8 – Thaw holes or many puddles on ice.

9 – Rotten ice / No information or unable to report.

KB – Navigation conditions in ice

0 – Navigation unobstructed.

1 – Navigation difficult or dangerous for wooden vessels without ice sheating.

2 – Navigation difficult for unstrengthened or low-powered vessels built of iron or steel. Navigation for wooden vessels even with ice sheating not advisable.

3 – Navigation without icebreaker assistance possible only for high-powered vessels of strong construction and suitable for navigation in ice.

4 – Navigation proceeds in lead or broken ice-channel without assistance of an icebreaker.

5 – Icebreaker assistance can only be given to vessels suitable for navigation in ice and of special size.

6 – Icebreaker assistance can only be given to vessels of special ice class and of special size.

7 – Icebreaker assistance can only be given to vessels after special permission.

8 – Navigation temporarily closed.

9 – Navigation has ceased / Unknown.

2 Ice charts

An ice chart produces by SMHI for the Baltic region is presented in Figure 1.

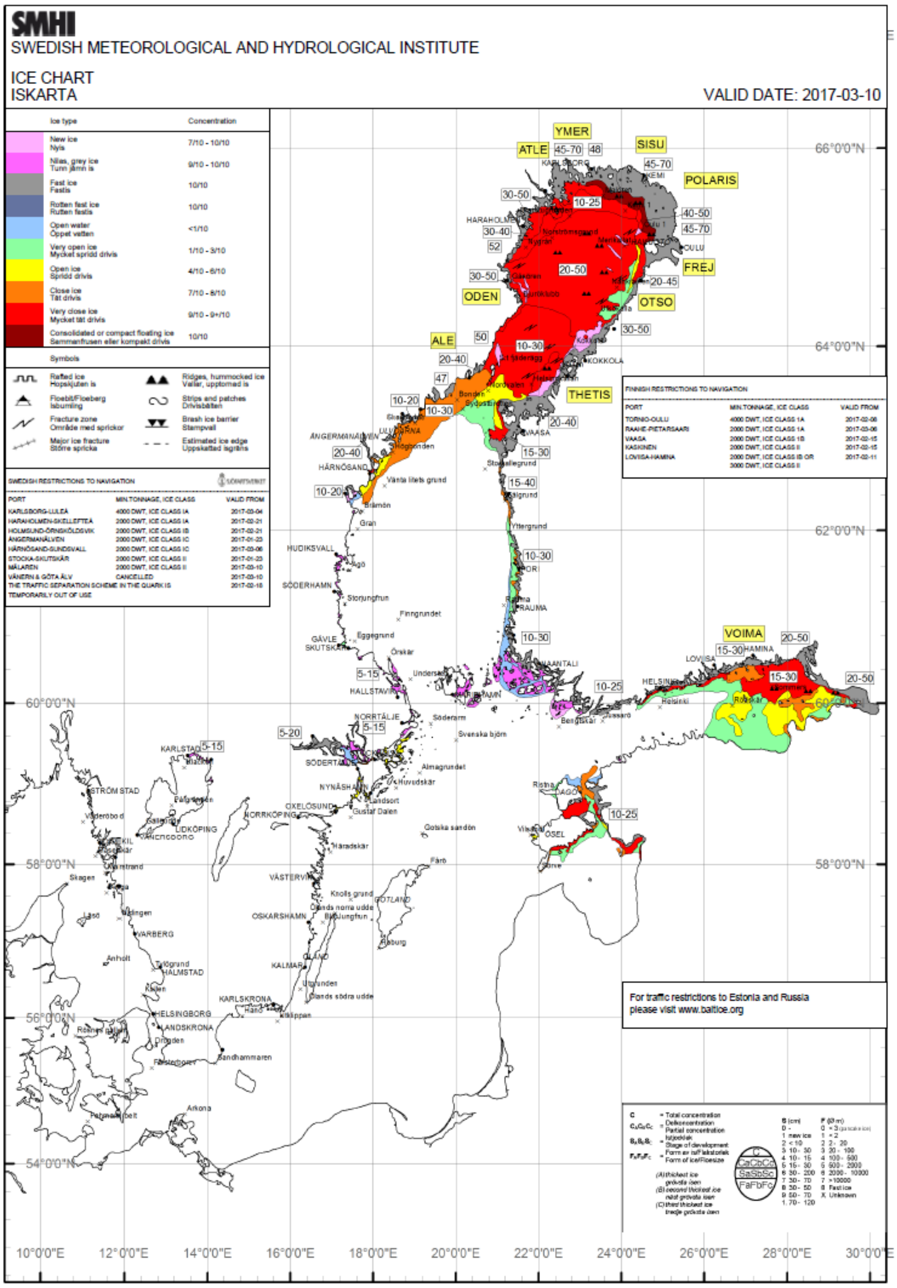


Figure 1 Example of ice chart issued by the Swedish Meteorological Hydrological Institute (SMHI) (Source: http://www.smhi.se/oceanografi/istjanst/produkter/arkiv/sstcolor/sstcolor_20170310.pdf)

2.1 Colour code standard (The world Meteorological Organization (WMO)

The World Meteorological Organization (WMO) has developed a Colour Code Standard for use on ice charts. The standard includes two separate colour codes:

One based on total concentration (CT) intended for use when the stage of development is relatively uniform but concentration is highly variable (e.g. arctic summer navigation), see Table 1 below for reference.

One based on stage of development (SoD) intended for use when the concentration is relatively uniform (high) but the stage of development is variable (e.g. arctic winter navigation), see Table 2 below for reference.

The two separate colour codes are mutually exclusive – only one should be used on a single chart. The chart should include a legend describing the colour code used. The colour code do not exclude the use of black and white hatching patterns or egg codes; egg codes and/or black and white hatching may be used along with colours. The WMO Colour Code Standard is an integral part and extension of the WMO publication No. 259 "Sea Ice Nomenclature" (JCOMM, 2014d).

Table 1 Total concentration colour code standard

Colour		**Total concentration (definition from WMO Nomenclature)**	**Number from WMO Sea Ice Nomenclature**
Alternative	Prime		
		Ice free	4.2.8
		Less than one tenth (open water)	4.2.6
		Bergy water	4.2.7
		1/10 – 3/10 (very open ice)	4.2.5
		4/10 – 6/10 (open ice)	4.2.4
		7/10 – 8/10 (close ice)	4.2.3
		9/10 – 10/10 (very close ice)	4.2.2
		10/10 (compact floating ice)	4.2.1
		Fast ice	1.1.1
		Ice shelf	10.3
	? ? ?	Undefined ice	-
Optional		7/10 – 10/10 new ice	2.1
		9/10 – 10/10 nilas, grey ice (mainly on leads)	2.2, 2.4
Areas of No Information are annotated accordingly			

Table 2 Stage of development colour code standard

Colour		**Stage of development (SoD)**	**Number from WMO Sea Ice Nomenclature**
Alternative	Prime		
		Ice free	4.2.8
		<1/10 ice of unspecified SoD (open water)	4.2.6
		New Ice	2.1
		Dark nilas	2.2.1
		Light nilas	2.2.2
		Young ice	2.4
		Grey ice	2.4.1
		Grey-white ice	2.4.2
		First-year ice (FY)	2.5
		FY thin ice (white ice)	2.5.1
		FY thin ice (white ice) first stage	2.5.1.1
		FY thin ice (white ice) second stage	2.5.1.2
		FY medium ice	2.5.2
		FY thick ice	2.5.3
		Old ice	2.6
		Residual ice	2.6.1
		Second-year ice	2.6.2
		Multi-year ice	2.6.3
		Fast ice of unspecified SoD	2.6
		Ice shelf	10.3
	? ? ?	Ice of undefined SoD	-
		Drifting ice of land origin (icebergs)	10.4.2
Areas of No Information are annotated accordingly			

2.2 The Egg Code

The World Meteorological Organization (WMO) has developed an international system for sea ice symbols to be used on ice charts (JCOMM, 2014a).

The international system encompasses ice elements and features which are grouped under the following headings:

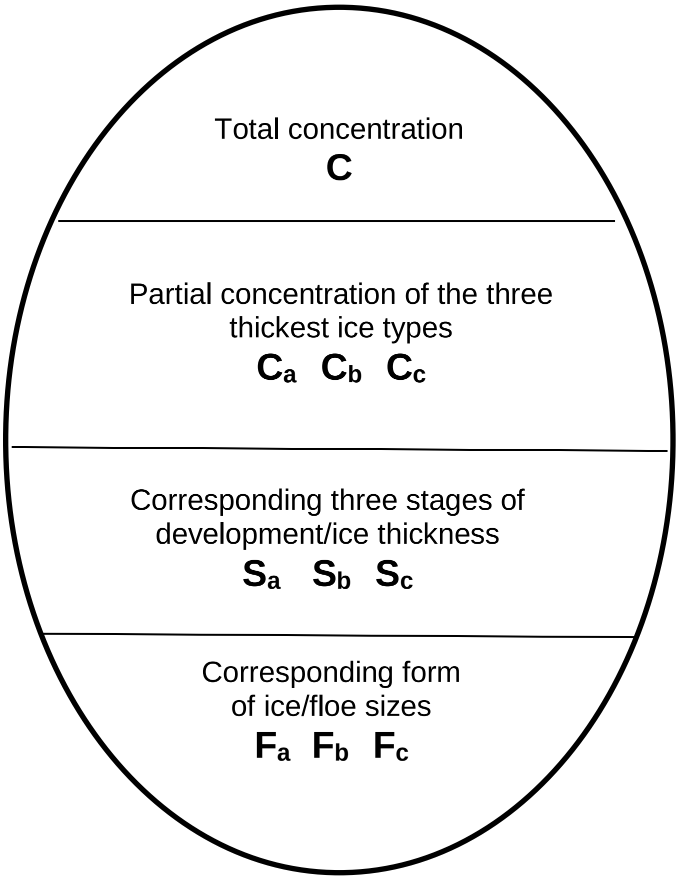
- Concentration (C)
- Stage of development (S)
- Form of ice (F)
- Dynamic processes
- Water openings
- Topography
- Ice thickness
- Stage of melting
- Surface features
- Ice of land origin
- Limits
- Strips and patches

The basic data concerning concentration, stage of development and form of ice are contained in a simple oval form, normally referred to as the “Egg Code” (JCOOM, 2014a).

The egg is divided into four sections as per below:

1. Total concentration
2. Partial concentration
3. Stage of development (age and thickness)
4. Form of ice (floe size)

A maximum of up to three classes are described within each section of the oval.



The upper section of the egg describes the total concentration **(C)** of ice in the area, expressed in tenths.

The second section of the egg describes the partial concentration of the three thickest ice types in the area; $\mathbf{C_a}$ – thickest, $\mathbf{C_b}$ **–** second thickest and $\mathbf{C_c}$ - third thickest, expressed in tenths.

Ice concentration in tenths	
Symbol	Concentration
	Ice free
0	Less than one tenth
1	1/10
2	2/10
3	3/10
4	4/10
5	5/10
6	6/10
7	7/10
8	8/10
9	9/10

9+	More than 9/10 less than 10/10
10	10/10
x	Underdetermined or unknown

The third section of the egg describes the stage of development (age and thickness) of each concentration of ice indicated in the second section; **S_a –** thickest, **S_b** - second thickest and **S_c –** third thickest.

Stage of development (age and thickness)		
Symbol	Element	Thickness
0	No stage of development	-
1	New ice	-
2	Nilas; ice rind	<10 cm
3	Young ice	10-30 cm
4	Grey ice	10-15 cm
5	Grey-white ice	15-30 cm
6	First-year ice	30-200 cm
7	Thin first-year ice	30-70 cm
8	Thin first year ice, first stage	30-50 cm
9	Thin first year ice, second stage	50-70 cm
1 ·	Medium first-year ice	70-120 cm
4 ·	Thick first-year ice	>120 cm
7 ·	Old ice	
8 ·	Second-year ice	
9 ·	Multi-year ice	
▲	Ice of land origin	
X	Undetermined or unknown	

The bottom section of the egg describes the corresponding form of the ice, including the floe size (**F_a, F_b, F_c**).

Form of ice		
Symbol	Form	Size of Floe
0	Pancake ice	30 cm – 3 m
1	Small ice cake; brash ice	Less than 2 m
2	Ice cake	3 m – 20 m

3	Small floe	20 m – 100 m
4	Medium floe	100 m – 500 m
5	Big floe	500 m – 2 km
6	Vast floe	2 km – 10 km
7	Giant floe	More than 10 km
8	Fast ice, growlers or floebergs	
9	Icebergs	
X	Undetermined or unknown	

3 The Polar Code and The Finnish-Swedish Ice class

3.1 The Finnish-Swedish Ice class

The ice classes are divided into six categories as shown in Table 3 below (TRAFI, 2010):

Table 3 General description of the Finnish-Swedish Ice Classes

Ice class	General description, operation of the ship
1A Super	Ships with such structure, engine output and other properties that they are normally capable of navigating in difficult ice conditions without the assistance of icebreakers.
1A	Ships with such structure, engine output and other properties that they are capable of navigating in difficult ice conditions, with the assistance of icebreakers when necessary.
1B	Ships with such structure, engine output and other properties that they are capable of navigating in moderate ice conditions, with the assistance of icebreakers when necessary.
1C	Ships with such structure, engine output and other properties that they are capable of navigating in light ice conditions, with the assistance of icebreakers when necessary.
II	Ships that have a steel hull and that are structurally fit for navigation in the open sea and that, despite not being strengthened for navigation in ice, are capable of navigating in very light ice conditions with their own propulsion machinery.
III	Ships that do not belong to ice class 1A Super, 1A, 1B, 1C or II.

There is a design requirement for ice classes of a minimum speed of 5 knots in a specified brash ice channel (the thickness of which varies with ice class) as per below (TRAFI, 2010):

H_M = thickness of the brash ice in mid-channel [m]

H_M = 1.0 and a 0.1 m thick consolidated layer of ice for ice class IA Super

H_M = 1.0 for ice class IA

H_M = 0.8 for ice class IB

H_M = 0.6 for ice class IC

Table 4 below shows the different ice classes and the corresponding ice thickness (h_0) values which the ship is assumed able to operate in open sea conditions. However, the design ice load height (h) of the area of the ship actually under ice pressure is assumed to be considerable less than the ice thickness (TRAFI, 2010).

Table 4 Ice thickness (h0) vs ice load height (h)

Ice Class	h_0 [m]	h [m]
IA Super	1.0	0.35
IA	0.8	0.30
IB	0.6	0.25
IC	0.4	0.22

The Finnish-Swedish Ice Class Rules have been developed by the Finnish Transport Safety Agency (TRAFI) and the Swedish Transport Agency (STA) in co-operation with classification societies. Most of the members of the International Association of Classification Societies (IACS) have adopted the Finnish-Swedish Ice Class Rules and embodied them in their own regulations on the classification of ships (TRAFI, 2011).

In order to ensure safe navigation in ice and efficient icebreaker assistance during the winter season, the Finnish and Swedish Administrations sets up winter traffic restrictions for ships bound for Finnish and Swedish ports. Traffic restrictions with regard to size and ice class of ships entitled to icebreaker assistance varies during the winter season depending on the ice conditions (TRAFI, 2011).

Ships with ice class IA or IA Super are intended for year round operation in the Baltic Sea area. This means that the Administrations do not set traffic restrictions for these ice classes. However, size restrictions may apply for ice class IA. Ships having an ice class IB or IC may have limited access to Finnish and Swedish ports for part of the year, pending on ice conditions. Ships belonging to ice classes II and III are not strengthened for navigation in ice. In Finland the fairway dues depend on the ice class of the vessel and for this reason “ice classes” II and III are used.

The Finnish-Swedish Ice Class Rules are primarily intended for merchant ships designed to trade in the Baltic Sea area. As per the Guidelines for the application of the Finnish-Swedish Ice Class Rules, (TRAFI, 2011), following issues should be taken into consideration if the Finnish-Swedish Ice Class Rules are applied to the design of ships for other sea areas than the Baltic Sea:

The Finnish-Swedish Ice Class Rules have been developed for first year ice conditions with a maximum level ice thickness of 1.0 m, ice bending strength (cantilever beam test) of about 500 kPa and maximum compressive strength of sea ice about 5 MPa.

Ice compression in the sea area should be taken in consideration.

There is no swell in the Baltic Sea like in the oceans. The vertical extension of the ice belt in the bow area may not be adequate, if the vessel is operated in an area with high swell and floating ice.

3.2 IMO Polar Code

The International Maritime Organization (IMO) has adopted the International Code for Ships Operating in Polar Waters (Polar Code) which entered into force on 1 January 2017. Related amendments have been adopted to both the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL) (IMO, 2017).

The Polar Code applies to the waters surrounding the two poles; Antarctic and Arctic, see Figure 2 and Figure 3 below for reference.

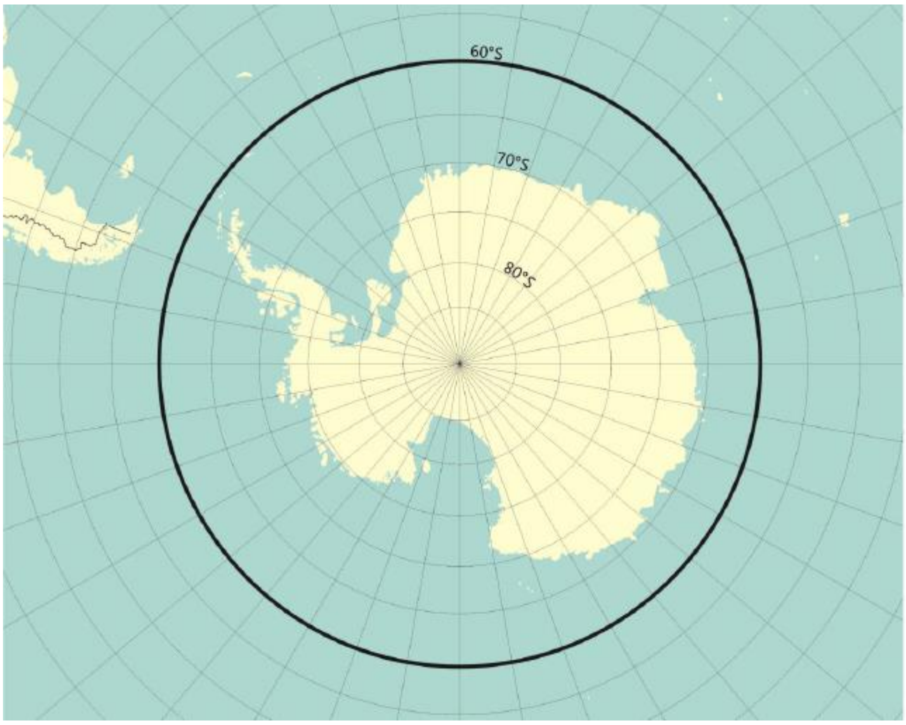


Figure 2 Antarctic area application (IMO, 2014)

Figure 3 Arctic waters application (IMO, 2014)

The goal of the Polar Code is to provide for safe ship operation and the protection of the polar environment by addressing risks present in polar waters and not adequately mitigated by other instruments of the IMO (IMO, 2014).

The Polar Code is divided into mandatory safety measures (part I-A) and mandatory pollution prevention measures (part II-A) and includes recommendatory provisions for both (parts I-B and II-B). The Code sets out goals and functional requirements covering the following (IMO, 2017):

- ship structure,
- stability and subdivision,

- watertight and weathertight integrity,
- machinery installations,
- operational safety,
- fire safety/protection,
- life-saving appliances and arrangements,
- safety of navigation,
- communications,
- voyage planning,
- manning and training,
- prevention of oil pollution,
- prevention of pollution from noxious liquid substances from ships,
- prevention of pollution by sewage from ships and
- prevention of pollution by discharge of garbage from ships.

Every ship to which the Polar Code applies shall have on board a valid Polar Ship Certificate, which classifies the vessels as either *Category A ship*, *Category B ship* or *Category C ship* as described below (IMO, 2014):

Category A; means a ship designed for operation in polar waters in at least medium first-year ice, which may include old ice inclusions.

Category B; means a ship not included in category A, designed for operation in polar waters in at least thin first-year ice, which may include old ice inclusions.

Category C; means a ship designed to operate in open water or in ice conditions less severe than those included in categories A and B.

Furthermore, every ship shall have Polar Water Operational Manual (PWOM), to provide the owner, operator, master and crew with sufficient information regarding the ship´s operational capabilities and limitations in order to support their decision-making process (IMO, 2014).

3.3 HELCOM Guidelines for the Safety of Winter Navigation in the Baltic Sea Area

HELCOM (Baltic Marine Environment Protection Commission – Helsinki Commission) is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area, known as the Helsinki Convention. The Helsinki Convention has ten Contracting Parties which are also the members of HELCOM; Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden (HELCOM, 2017).

HELCOM has published “Guidelines for the safety of winter navigation in the Baltic Sea Area”, which are intended to give instructions for Contracting Parties to the Helsinki Convention for matters related to winter navigation in the Baltic Sea area. The guidelines includes ice surveillance systems, equivalence of ice classification rules, safety requirements for ships sailing in ice conditions and operational matters related to winter navigation (HELCOM, 2016).

Table 5 below illustrates the equivalence of ice classification rules as given by HELCOM (2016). The equivalence table is based on the comparison of hull structural requirements and is estimated on the premises that the hull structural strength requirements given by the different Classification Societies is comparable with the hull structural strength required by the Finnish-Swedish Ice Class Rules for the different ice class categories.

In addition, the requirements regarding the power of the main engine as given by the Finnish-Swedish Ice Class Rules should be fulfilled (HELCOM, 2016). (Alternatively, the ship should have sufficient power for possible independent movement at a minimum steady speed of 1-2 knots through a level of ice thickness which is depending on the ice class of the ship.)

Table 5 Estimated equivalence of ice classes of different Classification Societies with the Finnish-Swedish Ice Class Rules (HELCOM, 2016).

Classification Society	**Ice Class**				
Finnish-Swedish Ice Class Rules	**1A Super**	**1A**	**1B**	**1C**	**Category II**
Russian Maritime Register of Shipping (Rules 1995)	UL	L1	L2	L3	L4
Russian Maritime Register of Shipping (Rules 1999)	LU5	LU4	LU3	LU2	LU1
Russian Maritime Register of Shipping (Rules 2008)	Arc 5	Arc 4	Ice 3	Ice 2	Ice 1
American Bureau of Shipping	Ice Class I AA	Ice Class I A	Ice Class I B	Ice Class I C	D0
Bureau Veritas	ICE CLASS 1A SUPER	ICE CLASS 1A	ICE CLASS 1B	ICE CLASS 1C	1D
CASPR, 1972	A	B	C	D	E
China Classification Society	Ice Class B1*	Ice Class B1	Ice Class B2	Ice Class B3	Ice Class B
Det Norske Veritas	ICE-1A*	ICE-1A	ICE-1B	ICE-1C	ICE-C
DNV GL	Ice(1A*)	Ice(1A)	Ice(1B)	Ice(1C)	-
Germanischer Lloyd	E4	E3	E2	E1	E
IACS Polar Rules	PC6	PC7	-	-	-
Korean Register of Shipping	1A Super	1A	1B	1C	1D
Lloyd´s Register of Shipping	Ice Class 1AS FS (+)	Ice Class 1A FS (+)	Ice Class 1B FS (+)	Ice Class 1C FS (+)	Ice Class 1D

	Ice Class 1AS FS	Ice Class 1A FS	Ice Class 1C FS	Ice Class 1C FS	Ice Class 1E
Nippon Kaiji Kyokai	NS* (Class 1A Super Ice Strengthening) NS (Class 1A Super Ice Strengthening)	NS* (Class 1A Ice Strengthening) NS (Class 1A Ice Strengthening)	NS* (Class 1B Ice Strengthening) NS (Class 1B Ice Strengthening)	NS* (Class 1C Ice Strengthening) NS (Class 1C Ice Strengthening)	NS* (Class 1D Ice Strengthening) NS (Class 1D Ice Strengthening)
Polski Rejestr Statków	L1A	L1	L2	L3	L4
Registro Italiano Navale	ICE CLASS 1A SUPER	ICE CLASS 1A	ICE CLASS 1B	ICE CLASS 1C	1D

4 List of references

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JCOMM (2014d). *Ice Chart Colour Code Standard.* Available at http://www.jcomm.info/index.php?option=com_oe&task=viewDocumentRecord&docID=4914 (Last retrieved 2017-03-15)

SMHI (2017b). *Baltic Sea Ice Code*. Available at http://www.smhi.se/en/services/professional-services/shipping/baltic-sea-ice-code-1.8965 (Last retrieved 2017-03-14)

TRAFI (2010). *Finnish-Swedish Ice Class Rules 2010*. Available at https://www.trafi.fi/filebank/a/1328276403/5e67a19cb56529f0fbd531539e08438f/9131-36441-Jaaluokkamaaraykset_TRAFI_31298_03_04_01_00_2010_EN_corr_20_Dec_2010.pdf (Last retrieved 2017-02-28)

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