# Integrated Arctic Observation System

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Project coordinator:
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## Deliverable 6.15

## Risk Assessment System
**(V2)**

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| PU | Public, fully open | X |
| CO | Confidential, restricted under conditions set out in Model Grant Agreement | |
| CI | Classified, information as referred to in Commission Decision 2001/844/EC | |

## *EXECUTIVE SUMMARY*

The motivation for developing an integrated risk assessment system is to provide insights and to simplify the process of integration, analysis and use of INTAROS data within Arctic marine risk assessments. This will support business planning and development in the Arctic region.

The risk assessment system has been built upon "The Arctic Risk Map" (https://maps.dnvgl.com/arcticriskmap/), a system designed to present data from the Arctic marine environment in an easily accessible way with focus on clear and transparent communication. The selected use case is focused on sea ice extent and concentration with some supplemental parameters. Main data sources for the current version of the system are a 30-year climatology on sea ice from the National Snow and Ice data Centre (NSIDC) and the Arctic ocean–sea ice reanalysis for the period 2007–2016 from University of Hamburg (UHAM).

The report describes a first implementation of the Risk Assessment system. It addresses the data sources and system functionality to visualise and analyse the data. The system will be further improved and enhanced until the end of the INTAROS project period and will be made available at DNV ArcGIS server. As an end user product, access to and use of the Risk Assessment system will further support the implementation of the INTAROS roadmap (D1.10) towards a future Sustainable Arctic Observing System (SAOS) based on the synthesis of results from INTAROS.

# Table of Contents

# 1. Introduction

The world's need for energy is driving interest in further industrial activity in the Arctic, yet the region's conditions are highly variable depending on the type of activity, location, and time of year. This creates a complex risk picture, and stakeholders therefore need a sound decision basis for understanding the risks associated with Arctic development and transportation.

The motivation for developing an integrated risk assessment system is to provide insights and to simplify the process of integration, analysis and use of INTAROS data within Arctic marine risk assessments. This will support business planning and development in the Arctic region. An overview of information, products and services requested by users representing primarily the private commercial sector has been collected via INTAROS user survey (Buch et. al, 2019), and among the most important products identified is risk assessments associated with safe navigation and hydrocarbon extraction. In addition, operational services with real time observations and/or short-term forecasts and ship routing services are among the most relevant products (Buch et. al, 2019).

DNV GL has built the risk assessment system upon "The Arctic Risk Map" (https://maps.dnvgl.com/arcticriskmap/), a system designed to present data from the Arctic marine environment in an easily accessible way with focus on clear and transparent communication (Figure 1).

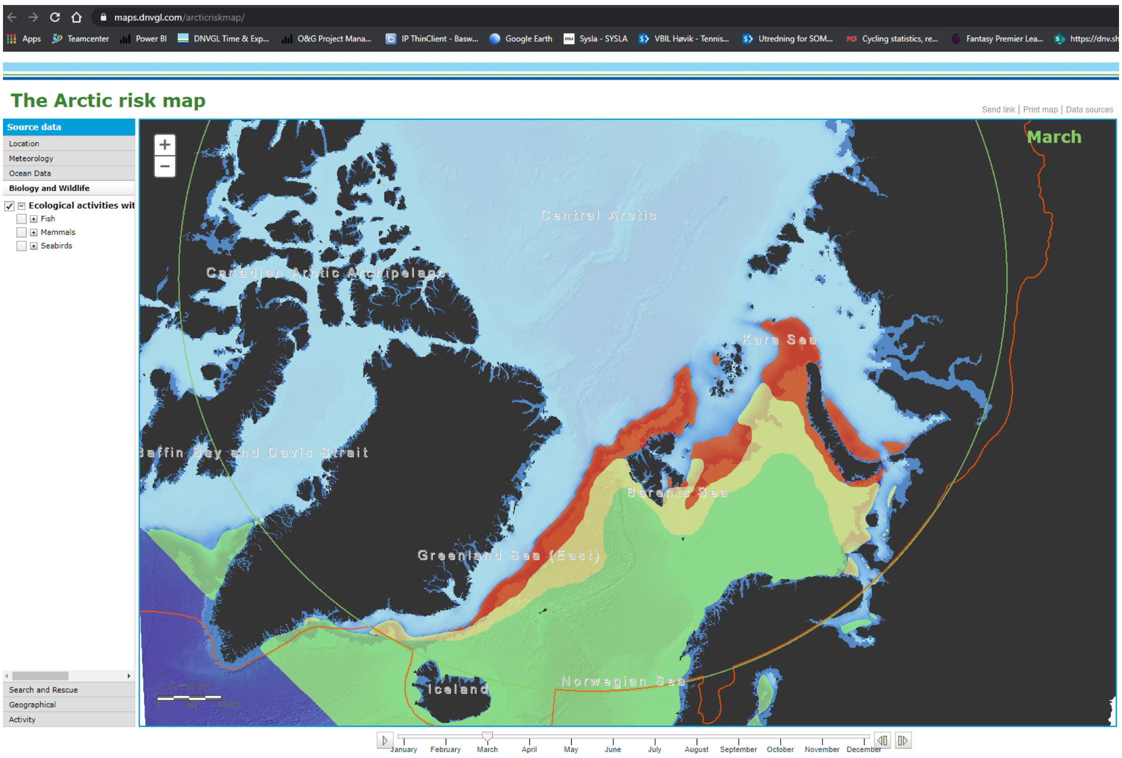



**Figure 1. Screenshot from the Arctic Risk map from DNV GL (https://maps.dnvgl.com/arcticriskmap) showing marine icing predictions (high in red, medium in yellow and low in green) in March.**

In addition to data visualization, the risk assessment system has been extended with some analytical capabilities for specific analysis on relevant data like sea ice and ocean temperature/salinity. Sea-ice represents a key risk influencing factor and presenting sea-ice data from a coherent study of past and foreseen future sea-ice conditions allows operators and authorities, and other key stakeholders, to assess current and emerging risks. Such assessments form a basis for operational and strategic planning. The risk assessment system as such is not about implementing a specific risk analysis methodology, but rather to give access to quantitative data and information concerning important risk shaping factors in the Arctic. Such access enables transparent risk-based discussions targeting various types of marine risk assessments. The current report builds upon the deliverable D6.5 from May 2020 (Aarnes et al. 2020) and describes the first implementation of the Risk Assessment system.

A premise for a successful system implementation is coordination, collaborative effort, and sharing of results from activities undertaken in INTAROS Task 6.3 *Ice-Ocean statistics*. The task includes the following five sub-tasks covered by different parties of INTAROS:

1. Integrative analysis: ice-ocean statistics using remote sensing and in situ measurements.
2. Baseline description of Arctic Acoustic environments.
3. Ice-ocean modelling and assimilation experiments.
4. Risk management system for maritime activities.
5. Formulation of user applications in maritime sector in collaboration with stakeholders.

As an end user product, access to and use of the Risk Assessment system will further support the implementation of the INTAROS roadmap (D1.10) towards a future Sustainable Arctic Observing System (SAOS) based on the synthesis of results from INTAROS.

# 2. The Risk Assessment system

### Selection of Use Case

To support design and scoping of viable use cases, a series of interviews with DNVs industry partners have been conducted. In addition, the INTAROS user survey (Buch et. al, 2019) has provided input on stakeholder needs. Some apparent use cases were identified. The first, was a use case targeting improved application of sea ice data in general. Sea ice data is used extensively in artic marine risk assessments, such as in:

- Navigation, vessel route planning (ice frequency, icing likelihood and level of icing)
- Vessel design, winterization criteria, ice class, IMO polar code requirements (ice load)
- Field development (downtime due to ice, design of ice management systems)
- Operational support (tactical ice management)

- Ship-to-ship loading operations (operability, weather windows)
- Lifeboat evacuation
- Oil spill contingency (ice conditions, operability)
- Oil trajectory modelling
- Biological resources

A high-resolution historical ice met-ocean archive will contribute to more accurate planning and design basis, as we better resolve eddies and local bathymetric conditions. This will again make planning more precise, shorten waiting times for a suitable weather window, and allow for a design which is optimized with respect to relevant environmental loads. The benefits are reduced capital expenditures related to losses from environmental loads, and cuts in operational expenses due to improved efficiency and resource utilization.

A previous planning tool for visualization and analytics on sea ice data has been made by DNV, namely the Ice Mapper tool. The Ice Mapper allowed for analysis of historical ice conditions in all regions of the Arctic (Figure 3). Depending on the end-user, sea ice conditions could be visualized by different metrics such as the mean ice concentration (fraction of cell covered by ice) over a period, or the sea ice persistence metric which is a key figure adopted in the Barents Sea management plan (Meld. St. 20 2019-2020) and relevant to describe ice edge dynamics. The analytical capabilities in the INTAROS Risk Assessment System have been based on the Ice Mapper and are further developed and enhanced.

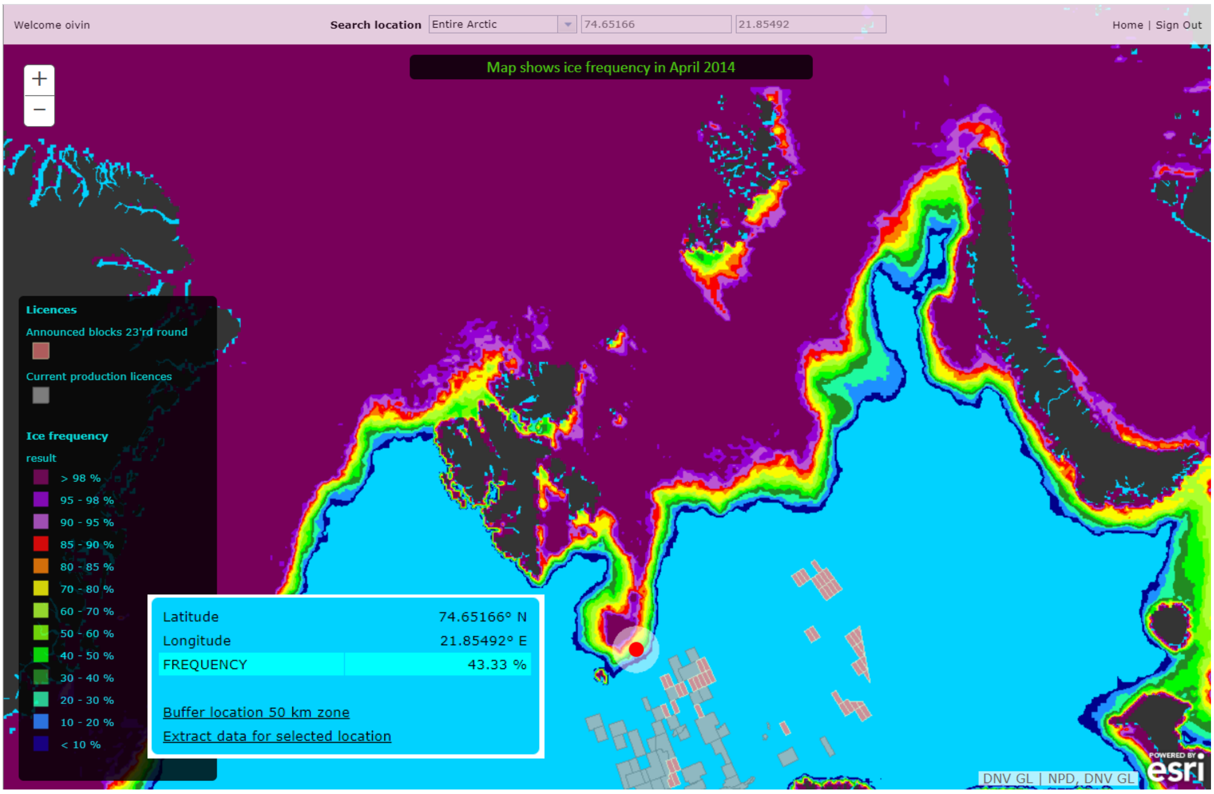
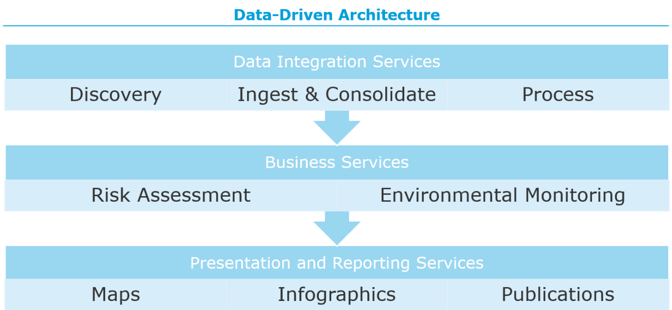


**Figure 3. Screenshot from the Ice Mapper tool from DNV GL showing probability for ice frequency >15% for April 2014**

For direct applicability to risk assessments, both towards environmental risk and towards shipping risk, the system was developed to deliver a service focused on sea ice frequency and concentration with some supplemental data layers.

## System architecture

A prerequisite to the system is to enable ready integration of sea ice data from disparate sources. Sea ice data are not all coherent in terms of resolution, spatial and temporal coverage, quality, means of acquisition, reliability, and physical properties modelled, so there is a need for harmonization and consolidation of modelled- and in-situ data. The risk assessment system adopts a data-driven architecture to facilitate this (Figure 2). Core to the platform are data ingestion and curation services, a high-resolution met-ocean data archive, and the modelling tier. The modelling tier will comprise algorithms for calculation of sea ice metrics and GIS capacity for spatial analysis and visualization. The system will use a cloud-based infrastructure to serve different components of the service.




*Approach to data integration and analysis*

1. Determine relevant data sources to the analysis (i.e., the use cases)
2. Qualify data with respect to quality, consistency, and reliability
3. Assemble and integrate data in ArcGIS
4. Spatial analysis to derive statistics on phenomena and their co-variation
    a. Capture spatial and temporal variation
    b. Location specific risk analysis

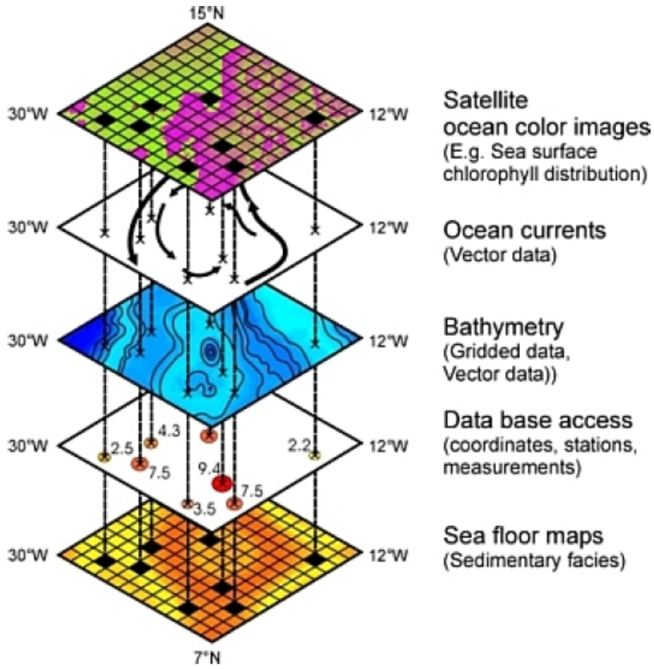



**Figure 2. Schematic view of data integration workflow.**

## Data sources and use

Main data sources for the current version of the system are a 30-year climatology on sea ice from the National Snow and Ice data Centre (NSIDC) and the Arctic ocean–sea ice reanalysis for the period 2007–2016 from University of Hamburg (UHAM). These sources are described in the following sub chapters.

### *NOAA / National Snow and Ice data Center (NSIDC)*

Data from the National Snow and Ice Data Center (NSIDC) includes a 30-year (1990-2020) climatology on sea ice concentrations satellite data from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data, Version 1 (https://nsidc.org/data/NSIDC-0051/versions/1). This data set is generated from brightness temperature data and is designed to provide a consistent time series of sea ice concentrations spanning the coverage of several passive microwave instruments. The data are provided as daily data in the polar stereographic projection at a grid cell size of 25 x 25 km. Sea ice concentration represents an area fraction coverage of sea ice. For a given grid cell, the parameter provides an estimate of the fractional amount of sea ice covering that cell, with the remainder of the area consisting of open ocean. Land areas are coded with a land mask value.

This product is designed to provide a consistent time series of sea ice concentrations (the fraction, or percentage, of ocean area covered by sea ice) spanning the coverage of several passive microwave instruments. To aid in this goal, sea ice algorithm coefficients are changed to reduce differences in sea ice extent and area as estimated using the SMMR and SSM/I sensors. The data are generated using the NASA Team algorithm developed by the Oceans and Ice Branch, Laboratory for Hydrospheric Processes at NASA Goddard Space Flight Center (GSFC). These data include gridded daily (every other day for SMMR data) and monthly averaged sea ice concentrations for both the north and south polar regions. The data are produced at GSFC about once per year, with roughly a one-year latency, and include data since 26 October 1978. Data are produced from SMMR brightness temperature data processed at NASA GSFC and from SSM/I and SSMIS brightness temperature data processed at the National Snow and Ice Data Center (NSIDC).

Potential applications for these sea ice concentration data include:

- Monitoring the distribution, extent, and area of the Arctic sea ice cover
- Identifying and monitoring large, persistent open water areas surrounded by sea ice (polynyas)
- Analyses of regional and global trends in sea ice cover
- Validation of sea ice models and climate models
- Analysis of sea ice/ocean and sea ice/atmosphere interactions

It is also important to know that SMMR and SSM/I-SSMIS have different data gaps at the North Pole due to orbital differences. Therefore, any time series of parameters, such as ice extent and ice-covered area, need to take these differences into account. A pole mask is provided for this purpose.

Particular care is needed to interpret the sea ice concentrations during summer when melt is present, and in regions where new sea ice makes up a substantial part of the sea ice cover. Some residual errors remain due to weather effects and mixing of ocean and land area within the sensor field of view, or FOV, and due to sensor differences.

It is recommended that sea ice extent and area be computed from daily maps of ice concentrations that are then used to compute monthly averages of those parameters. Computations of sea ice extents and sea ice areas should not be made from the monthly-averaged ice concentration maps because that may result in a biased time series.

**Data confidence level**

Estimates of the accuracy of the NASA Team algorithm vary depending on sea ice conditions, methods, and locations used in individual studies. Cavalieri et al. (1992) summarizes several of these studies. In general, accuracy of total sea ice concentration is within +/- 5 percent of the actual sea ice concentration in winter, and +/- 15 percent in the Arctic during summer when melt ponds are present on the sea ice. Accuracy tends to be best within the consolidated ice pack when the sea ice is relatively thick (greater than 20 cm) and ice concentration is high. Accuracy decreases as the proportion of thin ice increases

### *UHAM 10-year reanalysis synthesis*

As part of Activity 3, INTAROS Task 6.3, UHAM (University of Hamburg) has provided a 10-year high-resolution re-analysis / synthesis of sea ice data for the circumpolar Arctic (Lyu et. al, 2020) https://catalog-intaros.nersc.no/dataset/ocean-sea-ice-synthesis-from-2007-2016.

The product includes Ocean potential temperature, salinity, zonal and meridional velocity, Sea surface height, Sea ice thickness, Sea ice concentration, Sea ice drift, Momentum, freshwater, and heat fluxes at the sea surface. The product assimilates real observations of sea ice conditions obtained from ships and other platforms and is a valuable contribution to communicating expected sea ice conditions in the area. It should be noted that the synthesis covers past conditions on a daily means basis, and that it would be desirable to extend the synthesis to cover later years post 2016.

The assimilated sea ice observations rely on satellite observations. Sea Ice concentration (SIC) observations are derived from Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E, 2007–2010), Special Sensor Microwave Imager (SSMI, 2011–2012), and Advanced Microwave Scanning Radiometer 2 (AMSR2, 2013–2016). Sea Ice Thickness (SIT) observations and their uncertainties are from the optimal-interpolated CryoSat-2/Soil Moisture and Ocean Salinity (SMOS) SIT product, which takes advantage of the high accuracy of SMOS-observed thin ice (<1 m) and CryoSat2-observed thick ice. Sea surface temperature (SST) is based on optimal interpolated microwave and infrared data from the Remote Sensing System (RSS-SST). SST data are not available over the sea ice-covered region, but assumptions are made that SST is at freezing temperature (−1.96 °C) where sea ice is observed but not simulated.

Sea ice thickness representations (Figure 4) are valuable to shipping risk assessment as they are used in ship routing schemes. Class requirements, the IMO Polar Code (IMO, 2017), POLARIS (IMO, 2016) and Marine Safety Canada enforces regulation on access to waters under different ice regimes. Under the AIRSS system (Transport Canada, 2018), a decision to enter a given ice regime is based on the quantity of dangerous ice present, and the ability of a vessel to avoid dangerous ice along the route. The inclusion of sea ice thickness, along with other sea ice characteristics, thus helps to classify dangerous ice and tailor a more accurate representation with respect to end-use. For future representations, it is also desirable to consult climate- and sea ice predictions to further refine this view.

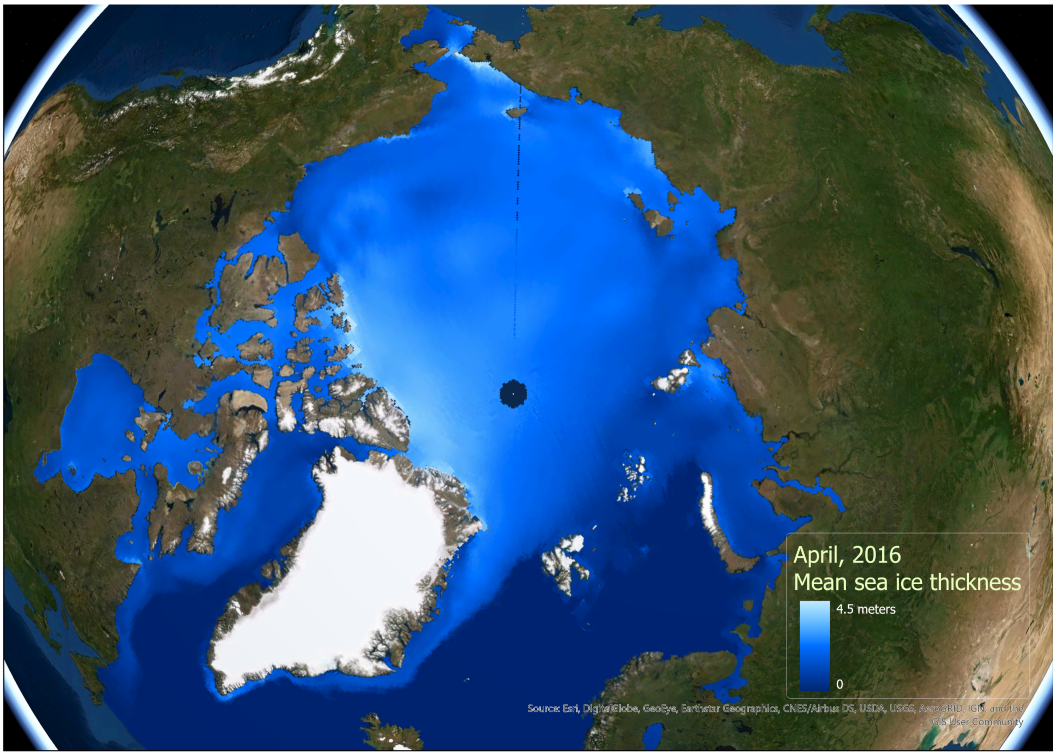



**Figure 4. Coherent representations of ice parameters such as sea ice thickness (shown above) and ice type are relevant to shipping risk assessments. Generated from UHAM data for April 2016.**

# 3. Risk Assessment System functionality

Incorporating a comprehensive spatial-temporal archive of historical sea ice records, the risk assessment tool lets the user derive fact-based knowledge on past ice conditions by visualizing the data. In addition, analysis provided enables statistical inference on Arctic climatology.

## Data visualization

The core functionality in the Risk Assessment System is the visualization of historical sea ice data. This includes showing time series of sea ice extent, concentration, and thickness. The user can select year and month and the system will plot the select parameter with a satellite image backdrop. In addition, the system is currently set up with additional data like sea water temperature and ocean salinity.

For additional useability, the user can import their own data in shapefile format (zipped in folder with all shapefiles) and apply the data as an overlap on the existing map presentation. In future versions, the system may expand to include predefined selectable layers on management relevant information like political borders, fishery zones, management areas, nature conservation areas etc.

### *Sea ice extent (1978-2021)*

The extent of sea ice is presented as a monthly Arctic Sea Ice Index (https://nsidc.org/data/G02135/versions/3). The Sea Ice Index provides a quick look at Arctic-wide changes in sea ice. It is a source for consistent, up-to-date sea ice extent and concentration images from November 1978 to the present (see Figure 1). Sea Ice Index maps also depict trends and anomalies in ice cover. The images and data are produced in a consistent way that makes the Index time-series appropriate for use when looking at long-term trends in sea ice cover. Both monthly and daily products are available, however, monthly products are better to use for long-term trend analysis because errors in the daily product tend to be averaged out in the monthly product and because day-to-day variations are often the result of short-term weather.

Figure 1 Arctic sea ice index plotted for September 2020

### *Sea ice concentration (1990-2020)*

The underlaying data for the Sea Ice Index is the NSIDC daily sea ice concentration data. Data can be visualized for selected year and months and animate the daily sea ice concentration maps (Figure 2). Maps are presented with 10 % concentration intervals.

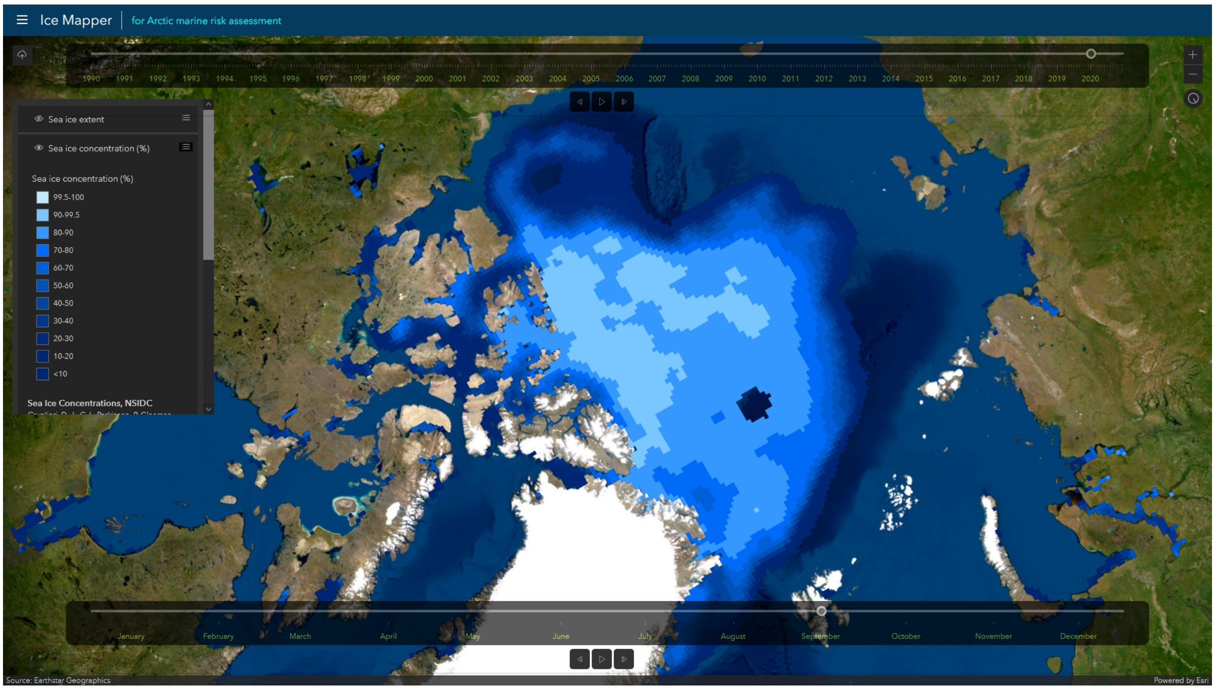


Figure 2 Arctic sea ice concentration plotted for September 2020

### *Sea ice thickness (2007-2016)*

The sea ice thickness data comes from the UHAM re-analysis dataset and are visualised with 50 cm thickness intervals (Figure 3). The thickness categories are chosen to reflect requirements of polar ice class notations for ships operating in cold climate. Many factors determine the ice-breaking capacity of a vessel incl. structural design and power and propulsion. The purpose is to provide a visualisation which translates to a "go" or "no-go" for purpose built vessels. Hence, the categories may be revised and tailored to fit the needs of the industry.

Further implementation would be to add user specified intervals according to specific needs and applications like offshore structures design basis, ship ice class notations etc.

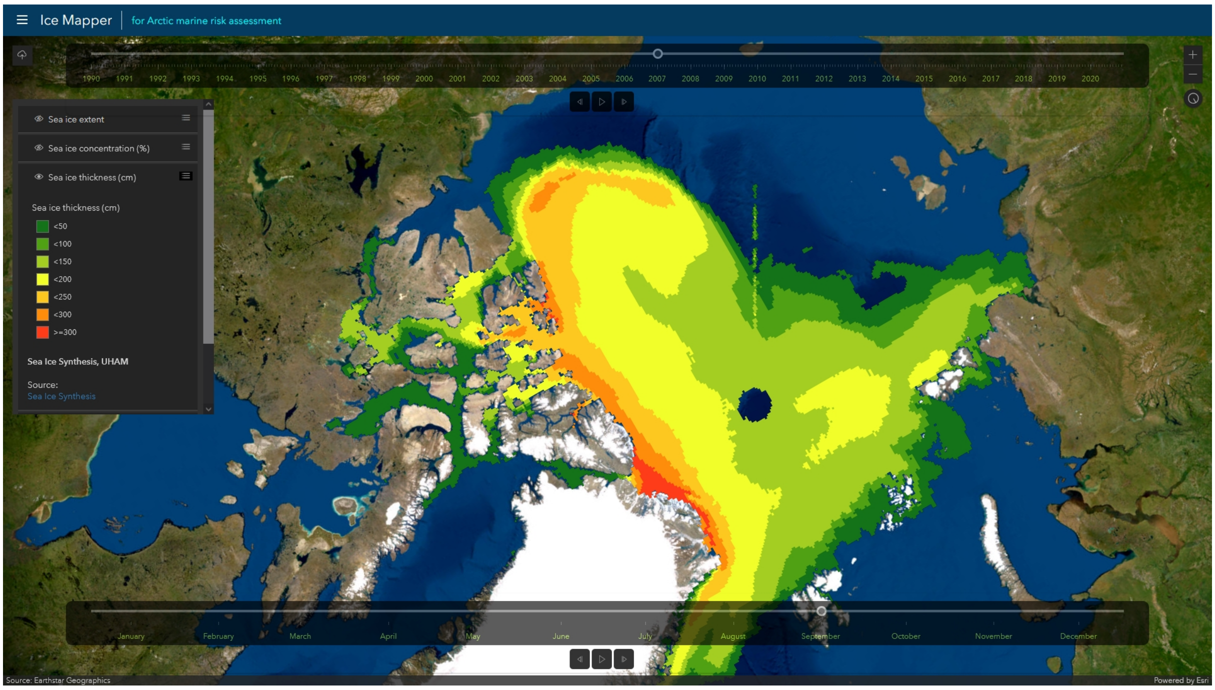


Figure 3 Sea ice thickness plotted for September 2007

### *Potential water temperature (2007-2016)*

Potential water temperature is available from the UHAM reanalysis data. In the vertical, the profiles cover mainly the top 800 m and more observations are available in the summer season than in the winter season. In the current version of the Risk Assessment System, the 5 meter and 100-meter depth layers are included but additional layers could be included in future versions. The color scale is currently fixed but also be enhanced to include thresholds to visualize temperature ranges of interest. Example plot is given in Figure 4.

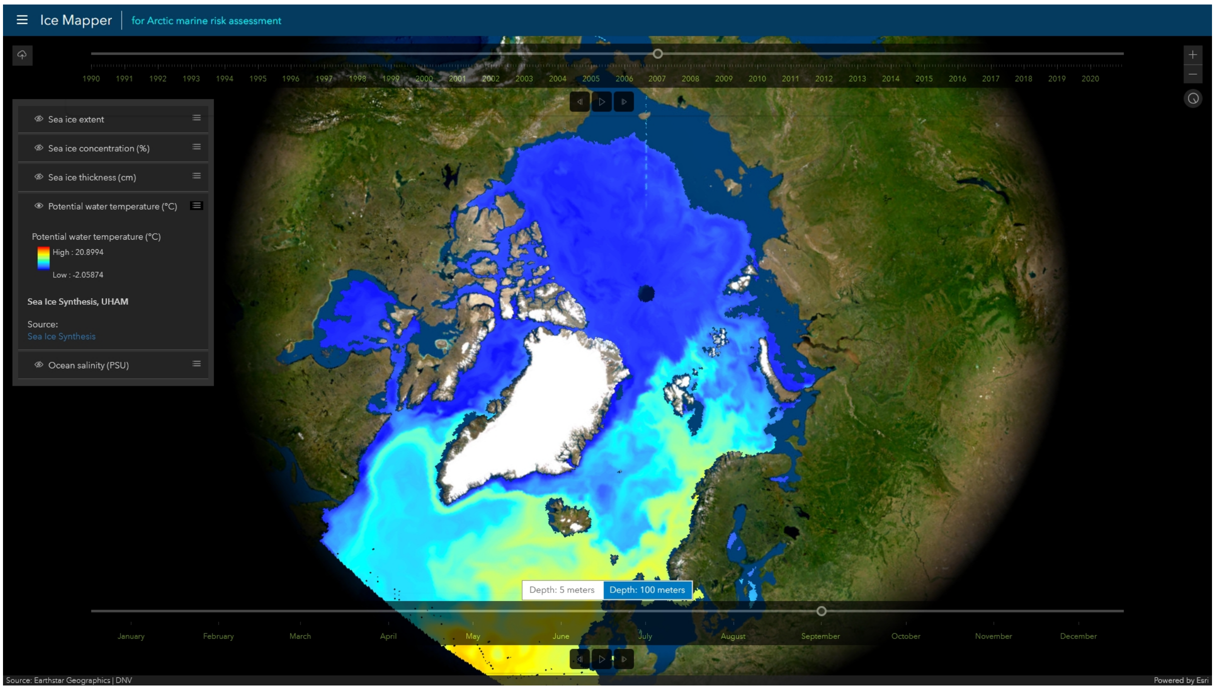



**Figure 4 Potential water temperature at 100 meters depth plotted for September 2007.**

### *Ocean salinity (2007-2016)*

From the UHAM reanalysis data, ocean state data on salinity has been extracted and prepared in the Risk Assessment System. As for the potential water temperature, ocean salinity is currently set up for two depth layers (5 and 100 meters) and can be visualized in the same manner (Figure 5). Note that the current color scale in the figure is to be reversed and improved.

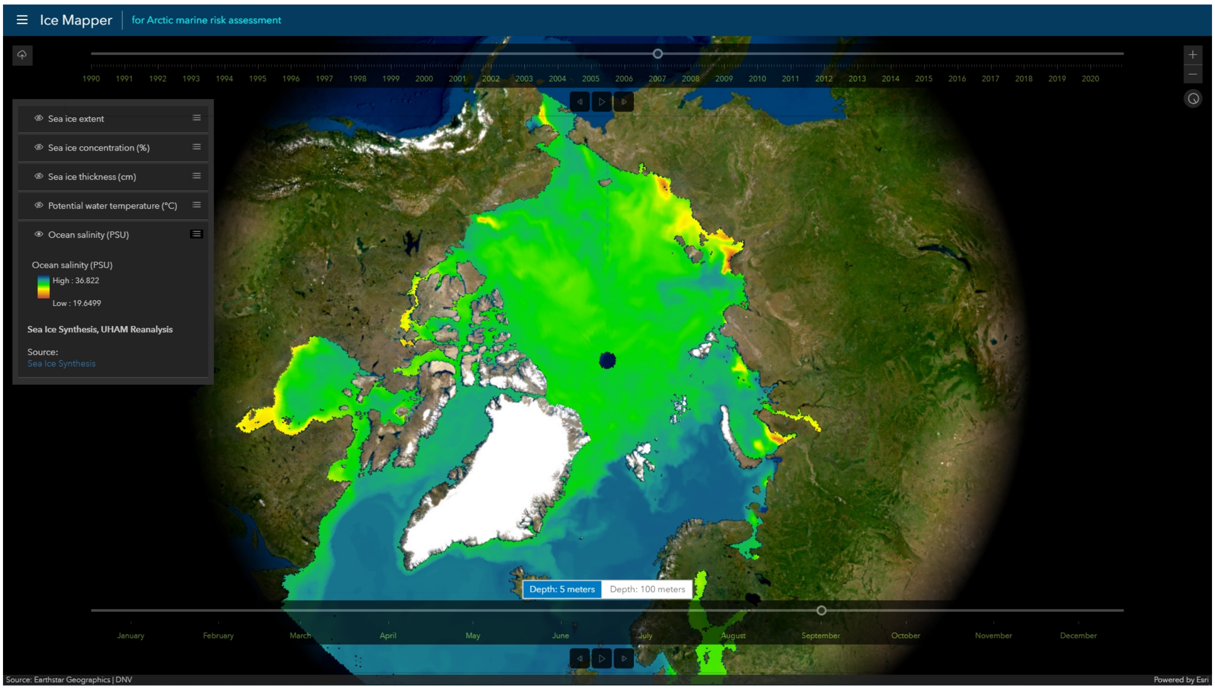


**Figure 5 Ocean salinity at 100 meters depth plotted for September 2007.**

## Sea ice statistics

The risk assessment tool also includes some analytical capabilities. This includes features like

- Infer parametric statistics on sea ice cover and persistence
- Compare and assess change in sea ice cover and variables over time
- Delineate ice edge over a given period by applying custom thresholds
- Extract variable time series for any given location (*to be implemented*).

In general sea ice statistics can be processes for a year range or for a single year. Current implemented features in the risk assessment system are presented in Figure 6 are further detailed in separate sub-sections below.

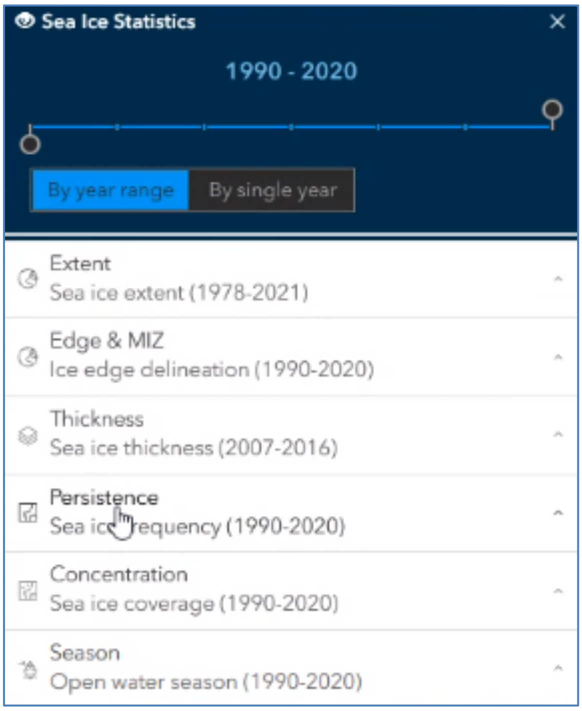


**Figure 6 Overview of sea ice statistics capabilities in the Risk Assessment System.**

### *Sea ice extent (1978-2021)*

The Risk assessment system will also include statistics as minimum, mean, and maximum (over given sea ice concentration) sea ice extent over the specified period of time and is of relevance of both climatological and operational analysis.
*The implementation of this feature is ongoing in the Risk Assessment System.*

### *Ice edge and marginal ice zone (MIZ) (1990-2020)*

Accurate representation and delineation of the ice edge (and the Marginal Ice Zone) is a critical feature for Arctic environmental management and regulation. A key objective of the risk assessment system is therefore to give a concurrent and realistic view of risk influencing factors, incl. ice metrics. Visualizations are being adapted to fit with the risk assessment process.

Upper and lower ice concentration limit can be linked with biological productivity parameters like salinity, temperature, and bathymetry to define relevant areas for ecosystem-based management or for conservation purposes. For instance, the Arctic Council has defined their large Marine Ecosystems (LME) in the Arctic based on such criteria (PAME, 2013).
*The implementation of these features is ongoing in the Risk Assessment System.*

### *Sea Ice Thickness (2007 -2016)*

As sea ice thickness data are available in the Risk Assessment System, statistics line minimum, mean and maximum ice thickness are relevant for many users and applications.
In addition, frequency for ice above a certain thickness is used in design basis both in shipping and offshore petroleum activity in the arctic.
*The implementation of these features is ongoing in the Risk Assessment System.*

## *Sea ice persistence (1990-2020)*

For visualization of sea ice persistence, the user can choose time of year (month) and thresholds for percentage ice concentration. The tool will then calculate the required statistics on the fly (*grab a coffee and wait some seconds*) and present the frequency for having sea ice above the specified threshold for the given period. A contour line delineating the chosen threshold can also be selected and plotted (Figure 7).

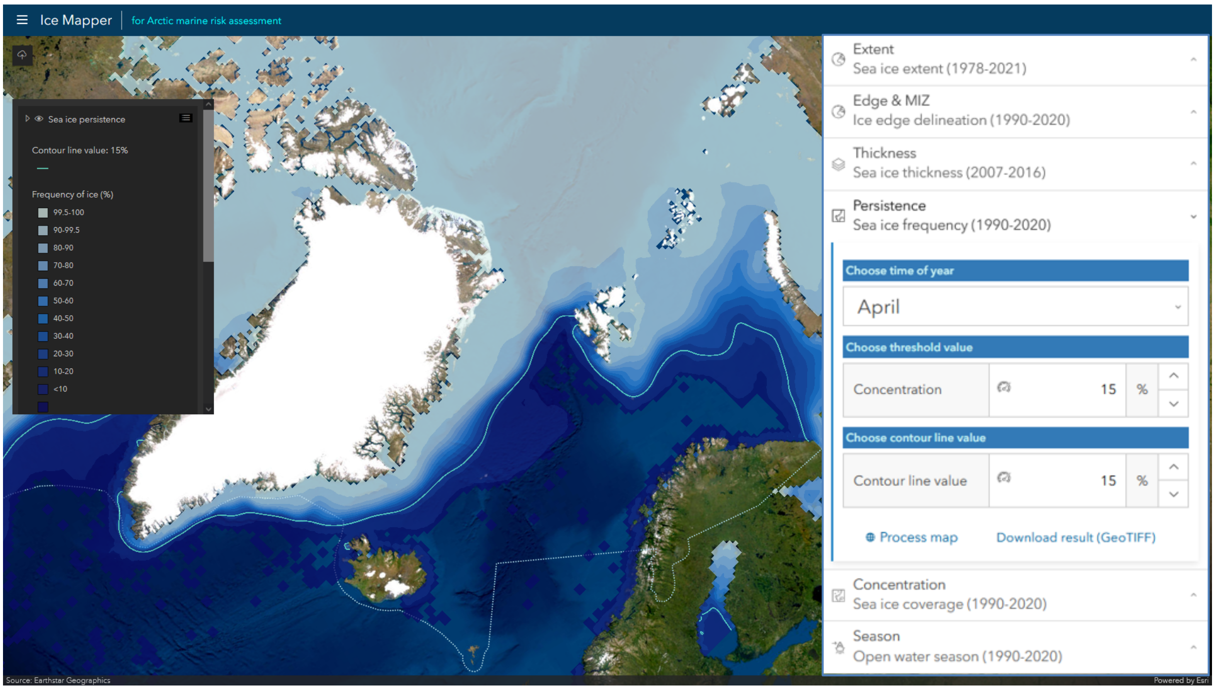



**Figure 7 Sea ice persistence plotted with frequency of ice above given threshold (here 15 %) in April (1990-2020). Contour line represents 15 % probability.**

The application is very relevant for frequency assessments of historical ice concentrations and are to a large extent debated in the Norwegian management plan for the Barents Sea where the definition of the ice edge previously was a 30 % probability for a 15 % ice concentration and is now recommended to be set to 15 % probability.

## *Sea ice concentration (1990-2020)*

As for ice thickness, statistics on minimum, mean and maximum ice concentration can be analyzed for the user selected time range. The user can select from the total time series from 1990 to 2020 and provide statistics for the selected month with an additional limiting contour line (Figure 8).

**Figure 8 Mean sea ice concentration (%) in April (1990-2020). Contour line represents 15 % probability.**

### *Open water season (1990-2020)*

The shrinking of Arctic-wide September sea ice extent is often cited as an indicator of climate change; however, the timing of seasonal sea ice retreat/advance and the length of the open-water period are often more relevant to stakeholders working at regional and local scales. The number of days with ice concentration (and/or thickness) above a certain threshold are used to define open water sailing season. In addition, the length of the seasonal open-water period has major implications for phytoplankton productivity, coastal erosion, hunting and fishing, marine shipping, and tourism (Crawford et. al. 2021). The timing of sea ice retreat and advance, more particularly, also have important implications.

The Risk Assessment System will implement a possibility to examine the open water season (number of days with ice concentration below given threshold i.e., 15 %). In addition, sea ice retreat day (the last time sea ice concentration (SIC) falls below 15% before reaching its minimum annual value) and sea ice advance day (the first time after the minimum that SIC rises above 15%) is of relevance.
*The implementation of these features is ongoing in the Risk Assessment System.*

### *Extract time variables (all data)*

In addition to on-screen visualization and analysis, a feature to extract time variables for a user specified point location is being implemented. The feature can be applied to all data that are available for visualization (now NSIDC and UHAM data) and will deliver the time series of the selected data in a comma-separated file (.csv) with a timestamp and the actual parameter value for further processing in Excel etc. Previous user selected time periods will still be valid for the extraction data.

The functionality could be further enhanced to extract combined parameters for different data layers for the same point location.

# 4. Future implementation and capabilities

In addition to ongoing implementation in the Risk Assessment System, stakeholder meetings have revealed several wishes for additional functionality and capabilities. Some of the recommendations for future implementations are cited below:

- User selectable color scales. It is important with different ways to select ranges and color palette. Advanced users can have full control or options to select among some preset scales and ranges, or both based on the oceanographic interests.
- Tailored thresholds and scales for different users within sectors in fisheries (e.g., sea temperatures never <2 or >5 degrees) or actors in governmental management. Conventional color scales, e.g., from deep blue (low) to red (high) for salinity/temperature/currents/sound speed.
- Implement possibilities for users to combine different information to compose the map of interest. E.g., ability to choose overlays like standard themes as economic zones, fishery zones, protected areas, accessible land areas for cruise ships etc.
- Further enhancement and layout/overlay possibilities when importing shape files to present in the maps.
- A menu of preset depths to produce horizontal plots of temperature, salinity, or currents. Make it possible for user to choose the depths.
- Produce timeseries of available parameters (point and profiles) at selected geographical position (*in progress*)
- Overlay or display of in situ measurements in the maps (e.g., sampled ice thickness by electro-magnetic measurement techniques from ships sent to Uni Bremen or buoy data from international Arctic buoy program).
- In future versions it would be interesting to preprocess sound speed (several formulas C= f (S, T, P)) and make this part of the assessment system. This will increase the usability of the system towards other stakeholders e.g., navy and instrument manufacturers.

### Access and availability

The Risk Assessment System application will be published on the DNV GIS platform allowing for public access over a trial period of 12 months starting January 1st, 2022.
DNV will host the service under agreement with the INTAROS project. Upon trial period end, DNV will evaluate feedback, and reassess needs for further development and improvement.

The service, software, and science are proprietary of DNV, and DNV retains all IPR rights to the service.

# 5. References

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