UNIVERSITY OF TROMSØ UIT

FACULTY OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF ENGINEERING SCIENCE AND SAFETY

OPTIMIZATION OF MARITIME OPERATIONS IN ARCTIC

Rating of improvement of weather routing/decision support systems for maritime operations in the Arctic region

Kåre Johansen

TEK - 3900 Master`s thesis in Technology and Safety in the High North

May 2013

UNIVERSITY OF TROMSØ UiT

Faculty of Science and Technology
Department of Engineering and Safety
Professor Dr.ing. Egil Pedersen

Master Thesis

Academic Years 2011~2013

for

Kåre Johansen

Ship Routing in Arctic Waters

The Arctic region represents a challenging environment for maritime operations due to polar lows with fast changing winds, drifting ice, icing, and limited visibility. Safe operations of ships require proper planning and knowledge in how to handle a ship when experiencing harsh weather conditions. An important method for planning a safe voyage is ship weather routing that provides optimum track for ocean voyages based on forecast of weather, sea condition and the ship's performance in a seaway. In the high north, the effect of ice must be included in the routing programme which requires new or additional methods to be developed.

State-of-the-art of technologies and knowledge that are relevant for ship routing in Arctic waters are represented by the Norwegian Meteorological Institute in Tromsø (provider of weather forecast services in the high north), Kongsberg Satellite Services AS (processing of satellite images for ice navigation assistance), Tokyo University of Marine Science and Technology (development of an advanced navigation system research laboratory for real-time sensor monitoring and remote navigation control of research vessel) and Kongsberg Maritime AS (development of ice-bridge simulator).

This thesis shall investigate various aspects of importance for developing an operational weather routing programme/service for ships operating in the Arctic region. The work shall include, but is not limited to, the following:

- An overview of existing weather routing services of ships with emphasis on;
    - optimisation methods and limitations,
    - usefulness in Arctic waters.
- Proposal of a model structure and algorithms for ship routing and decision making in Arctic waters.

- Assessment of the quality and reliability of sensor monitoring of the Arctic environment with emphasis on estimation of ice thickness/density from processing of satellite images.
- Assessment of the advanced navigation system research laboratory at Tokyo University of Marine Science and Technology with emphasis on usefulness in decision-support on maritime operations in Arctic waters.

In the thesis the candidate shall present his/her personal contribution to the resolution of problem within the scope of the thesis work. Theories and conclusions should be based on relevant theory and different simulations.

The manuscript should be typed single-sided in Times New Roman font style. Every sheet shall be numbered and arranged according to: Title and subtitle (if desired), the text defining the scope, abstract, acknowledgements (if any), nomenclature and conventions (if any), contents, main body of thesis (suitably divided in numbered main chapters with titles, numbered sub-paragraphs for which further headings are optional), conclusions with recommendations for further work, references and appendices (if appropriate). All figures, tables and equations shall be numerated.

The thesis should be organized in a rational manner to give a clear exposition of results, assessments, and conclusions. The text should be written as concisely as possible, but not at the expense of clarity. Descriptive or explanatory passages, necessary as information but which tend to break up the flow of the text, should be put into appendices. Units and symbols should conform to the recommendations contained in the International System of Units (SI). The thesis should in general not exceed 100 pages.

The supervisor may require that the candidate, in an early stage of the work, present a written plan for the completion of the work. The plan should include a budget for the use of any computer and laboratory resources that will be required and charged to the department. Overruns shall be reported to the supervisor.

The original contribution of the candidate and material taken from other sources shall be clearly defined. Work from other sources shall be properly referenced using an acknowledged referencing system.

The thesis shall be submitted in two bound volumes, signed by the candidate, and as an electronic file.

Supervisor : Egil Pedersen, Department of Engineering and Safety, University of Tromsø.
Co-advisor(s) : Dr Kensuke Kirimoto, Department of Marine Technology, NTNU.
Start : 01st September, 2011.
Deadline : 15th May, 2013.

Tromsø, 01st September 2011

Egil Pedersen

Abstract

The decreased ice extent caused by increased air and sea temperatures has led to a growing interest in the Arctic waters. There are different maritime industries that have plans to expand northwards for various reasons. First of all there are different developments in oil and gas industry in Barents, Kara, Greenland, Arctic sea around the coast of Canada and Alaska. New ship trading routes like The Northern sea route and The North west passage. Fishing industry are moving north along with fish stocks. A growing interest from cruise and tourism industry seems also to be an increasing trend. Therefore, reliable ship routing/decision support systems need to be evaluated, developed, improved, implanted and made available to maritime industry in Arctic.

To make a reliable ship routing/decision support systems it is important to take into consideration experiences from accidents that have happened in the Arctic areas. These accidents can help us to provide a clear view on what type of information, data, communication, infrastructure and other resources that needs to be developed. The main lessons to be learned from former accident are that to be able to conduct more efficient and safer maritime operations, more and better information needs to be available. This must be in terms of supporting decision systems based on different remote sensing information. Nothing of this is possible without a maritime communication infrastructure with sufficient bandwidth and integrity.

The main approach to the task was to come up with a proposal to an ice information algorithm based on appropriate remote sensed ice information. The proposed algorithm was meant to be a contribution or an improvement to an existing ship routing/decision support system. In addition to this algorithm proposal there will be taken a comparison between the weather input from an existing ship routing/decision support system and weather information from Norwegian Meteorological Institute (NMI).

There were numerous suitable routing/decision systems, but the best suited system for this task was the Weather Information for Safety and Economy (WISE). WISE is developed and constantly evolving by Japan Marine Science Inc. (JMS).

The best suited contributors of remote sensed ice information are Kongsberg Satellite Services (KSAT), located in Tromsø. KSAT is the leader in providing ground station network services and they support satellites that cover all Arctic areas. NMI is the most suited meteorological distributor for the Arctic area with most interest for this task.

Key words: *Sea ice, remote sensing, Synthetic Aperture Radar (SAR), Weather Information for Safety and Economy (WISE).*

Preface

This thesis is intended to fulfill the Master degree program for “Safety and Technology in the High North” at the Institute of Engineering and Safety at the University of Tromsø. The work on this master thesis was carried out from August 2012 to May 2013.

In October 2011 I and my supervisor, Professor Egil Pedersen, conducted a trip to Tokyo as a preliminary study of the development of the ship routing system “Weather information for Safety and Economy” (WISE) at Japan Marine Science and the advanced navigation system “J Marine Geographical Information System” (J-Marine GIS) at Tokyo University of Marine Science and Technology. The development of WISE is done by Japan Marine Science Inc. (JMS) and J-Marine GIS is developed by Japan Radio Co., Ltd. The trip to Tokyo gave me a good basis for understanding of how ship routing and advanced navigation systems works.

First of all I will thank Dr. Hideki Hagiwara of JMS and Assoc. Professor Etsuro Shimizu of Tokyo University of Marine Science and Technology who both took us in and showed us their systems in Tokyo. Dr. Hagiwara has in addition to providing support through the assignment work also given me access and guidance to the WISE system. I will also like to tank Frode Dinessen and Sjur Wergeland at Norwegian Meteorological Institute for providing me support through different meteorological issues during my thesis work.

Finally, I want to express my gratitude to my supervisor, Professor Egil Pedersen, for good support during this thesis and for introducing me to JMS and Tokyo University of Marine Science and Technology.

Tromsø May 15th, 2013

Kåre Johansen

Table of Contents

1 Introduction

The practice of following predetermined routes for shipping originated in 1898 and was adopted, for reasons of safety, by shipping companies operating passenger ships across the North Atlantic. Related provisions were subsequently incorporated into the original International Maritime Organization (IMO) convention, Safety of Life At Sea (SOLAS). IMO's responsibility for ships' routing is enshrined in SOLAS Chapter V, which recognizes the Organization as the only international body for establishing such systems.

It has been placed greater emphasis on optimization of maritime traffic during the last years. Optimization of maritime traffic is supposed to make the business safer, more economical, time saving and to minimize polluting to the environment. Information sailors have to take into consideration when optimize a sailing route is based on weather and oceanographic parameters. The most important optimization information, related to this thesis, will be different information about sea ice. Ice thickness, ice age, covered areas, trends and movement is important information for optimization of maritime traffic in Arctic areas. Information about ice is not only important for optimization when sailing, but also as a decision support system for all maritime activity in this area.

In addition to visual observation of ice onboard, there is a multitude of data information sources available for seafarers like satellite images, different ice model data and weather forecasts. However, it is not easy for sailors to take into consideration all this type of data and parameters when planning a sailing route, and some of this data is not available or difficult to get when sailing far north. Some of the ice information is not always useful for sailors because of satellite limitations. When sailing outside coverage areas of geostationary satellites, about North for 70-75^0 North latitude, the information has to be received from polar orbit satellites.

It is important to know that ice information from this type of satellites is not continuous, and received ice images could be too old or inaccurate set in relation to reality.

There are many different weather routing services which offers all kind of weather and oceanographic information. This is information like: wind, wave, current and ice, and the basis of this information ends up with different simulated and calculated ship routes. The common characteristics of these simulated routes are to minimize fuel consumption, cost of routes related to range of arrival times and to provide the basis for a safe voyage. But there are no weather routing services which offers complete and detailed optimization information for marine activity in Arctic.

1.1 Background and motivation

The basic background and motivation for this thesis is related to:

- Increased maritime activity in Arctic and the content of the master program descript.
- The knowledge of Norwegian maritime history in Arctic, especially the history of different kind of fisheries and sealing which has been exercised in this region.
- University of Tromsø (UiT) is strongly influenced by the institute's focus on research in Arctic areas.
- The interest in how Norway as a seafaring nation shall maintain and develop new aspects of maritime Arctic expertise.

The professional background is the relation between decreased ice extend followed by increased maritime activity in the Arctic region. For a period of 3 decades, the average sea ice extend has decreased approximately 2.5 million square kilometers. Figure 1.1 shows the average Arctic sea ice extends from September to march in different graphs. The grey graph show the average sea ice extends between 1979 and 2000 with a ±2 standard deviation. The green graph shows the average sea ice extend from 2011 to 2012. And the last blue graph show the average sea ice extends from 2012 to 2013.

Maximum ice extent in the Arctic Ocean occurs normally in March while the 2007. The years since 2007 have all seen an ice extent well below the average over the period 1979-2000. The smallest average monthly Arctic sea ice extent was recorded in the winter of 2006. Figure 1.1 shows that all years since 2006, except of 2008, have seen a maximum ice extent well below the average for the period 1979-2000. More details about the global ice coverage can be found on the web pages of National Snow and Ice Data Center (NSIDC, 2013).

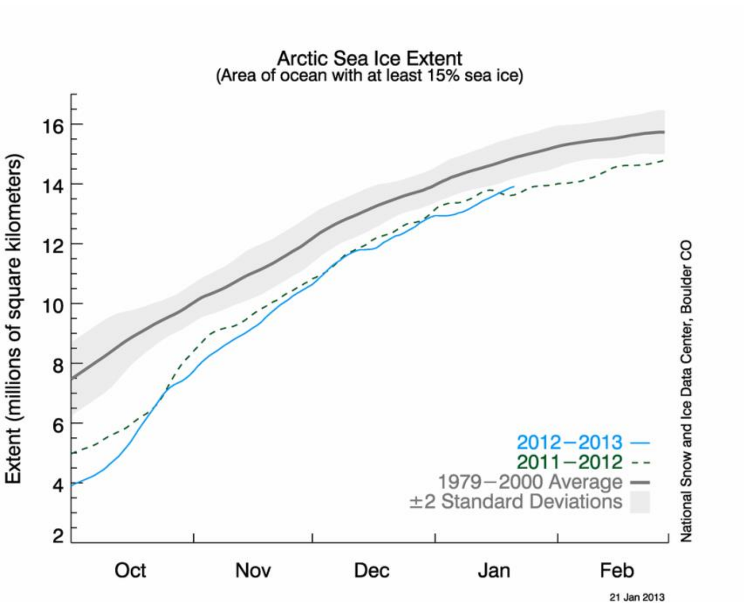


Figure 1.1 Average Arctic sea ice extents. (Source: NSIDC)

1.2 Master program description

The program focus on the technical and safety related challenges associated with industrial activities in the High North. Special attention is given to maritime and offshore operations in the harsh and vulnerable Arctic environment. The students are introduced to methods and tools for managing advanced, complex and integrated technical systems with respect to operation and maintenance, reliability and production assurance, health, safety & environmental risk as well as emergency preparedness. The program is a 2 year, full-time study with a fixed schedule. The courses will to some extent be adapted to part-time students. The first year consists of 50 ECTS of mandatory courses being common to all students and one 10 ECTS elective course. These are technical descriptive courses and method oriented courses. All courses are independent of each other. In the second year the students will achieve a specialization of their field of study through elective courses and by the choice among a number of pre-defined syllabuses. The students will also carry out a specialization project. The last semester is dedicated to a 30 ECTS master thesis (UIT, 2012).

When this course started in august 2010, the master program was a little differently. Back then the master program also was a 2 year, full-time study with a fixed schedule and the first year consisted of 50 ECTS of mandatory courses being common to all students and one 10 ECTS elective course. The differences between the programs are in the second year. The students carried out a specialization master thesis of 60 ECTS in 2010, and second year in the current program consists of a 30 ECTS specialization project and a 30 ECTS master thesis.

1.3 Previous work

There is a lot of previous and present work going on in this field. From the RMS Titanic disaster in 1912 to the present the aim has been to increase the safety of maritime operations in both Arctic and Antarctic.

The practice of following predetermined ship routes originated in 1898 and shipping companies operating passenger ships crossing the North Atlantic seas adopted use of predicted ship routes (IMO, 2012).

Figure 1.2 shows a map with different transatlantic routes from the American continent to Europa used by the passenger shipping companies "Red Star Line" and "White Star Line". Titanic was a White Star Line owned ship which followed one of the northern routes of the map.

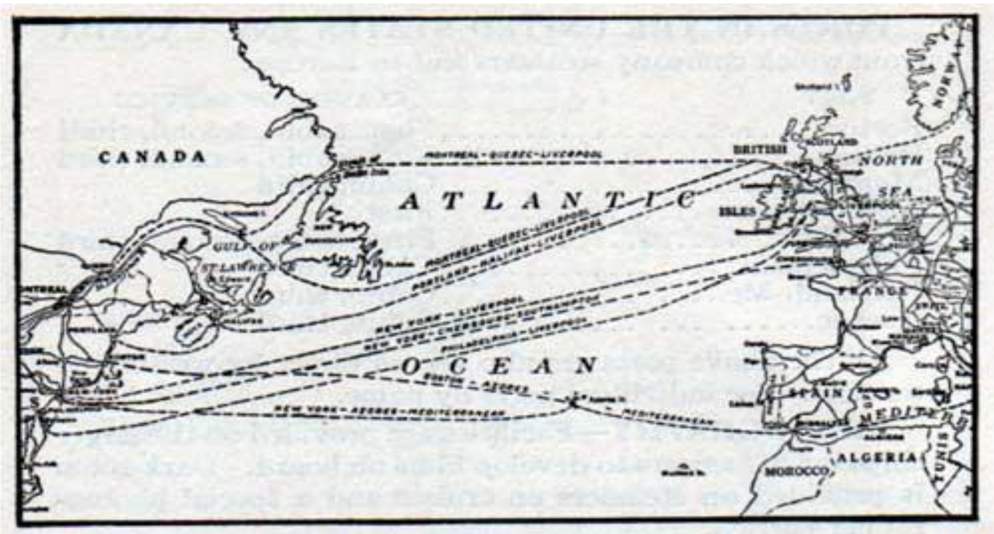


Figure 1.2 Description of transatlantic routes. (Source: The Gjenvick-Gjønvik Archives)

These transatlantic ship routes were established on the basis of experiences of how far south elements of sea ice could occur. From time to time sea ice floes could occur as far south as the northernmost routes cf. figure 1.3. In case of the Titanic disaster some ice floes had followed sea currents further south than normal and into the areas of the northernmost routes. The only way to detect ice floes, in those days, was to see them visually. If a ship detected ice floes they informed all ships in the area about the danger. In this way ship could be informed about dangers ahead and based on this information they could add the routes.

Figure 1.3 The Titanic route. (Source: Discovernorthernireland)

1.4 Present work

Today's ship routing is a broad term that includes a lot of ship traffic information, but in this task there will just be taken into consideration Arctic weather and oceanographic aspects of routing. More specific what algorithms, framework or models is available and under development for ship routing and decision making for maritime operations in Arctic. Remote sensing by SAR satellites is the most effective way to observe sea ice (bergs, thickness, age and drift trends).

The previous and present work is more or less the same in this context. This because of the fact that the most appropriate algorithm and models continues to evolve. There will just be taken into consideration three of the most appropriate models and algorithm examples in this thesis, the Polar View Consortium, the “Ice Tracking by SAR Image” (ITSARI)
and Ice Ridging Information for decision making in Shipping operations (IRIS).

Polar View consortium models provide a wide variety of earth observation sea ice products and the most appropriate products in this context is the sea ice and iceberg monitoring systems. Their algorithms are transmitting raw SAR-satellite images into these products. The sea ice monitoring and forecasting service meet the users requirements with specific technical products like:

- Global ice monitoring. *Timely information on sea ice and other met-ocean conditions is essential for all types of marine operations in Polar Regions. This service builds on existing capabilities by providing global sea ice products at improved spatial resolutions for the entire Arctic Ocean.*
- High resolution ice charts. *High-resolution ice charts covering local areas in the European Arctic provides fine scale information about sea ice concentration in fjords, straits and marginal ice zone for marine safety and habitat research.*
- Medium resolution ice charts. *The Danish Meteorological Institute (DMI) will provide medium resolution ice charts covering all Greenland waters on a weekly basis. The chart production will be executed using the current ice charting system.*

- Regional sea ice forecasting. *The regional sea ice service provides forecasts of ice motion, concentration, thickness, ridges and deformations for the Baltic Sea area using numerous multi-category sea ice models*.

- Sea ice thickness charts. *Sea ice thickness charts provide users at sea with timely ice thickness charts based on SAR data and ground truth in an appropriate resolution for ice navigation* (polar view, 2012).

The Polar View iceberg monitoring algorithm extracts both icebergs and other targets like ships and offshore structures from SAR satellite images. The algorithm processes the images to target identification, location, size and trends. Figure 1.4 shows an overview over how the polar view iceberg monitoring algorithm work from data acquisition to end users.

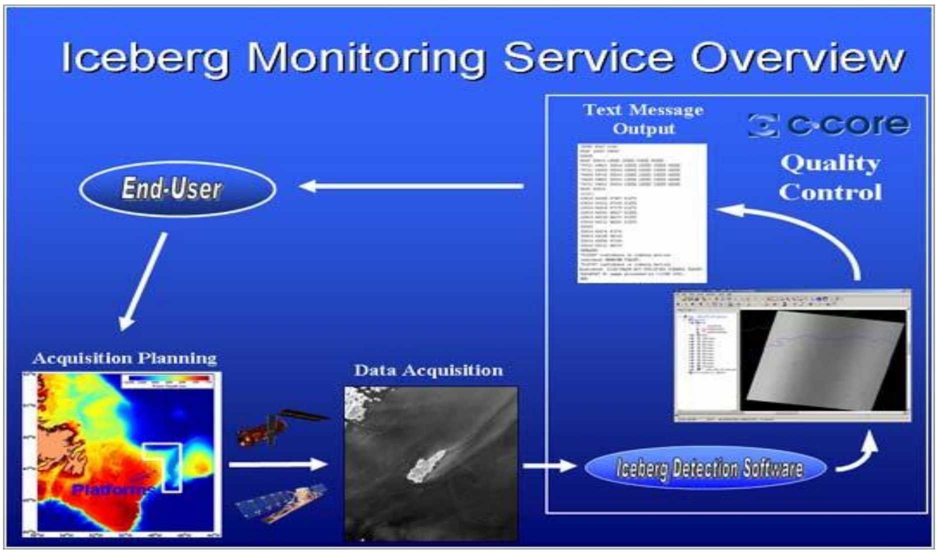


Figure 1.4 Overview from data acquisition to end user. (Source: Polar view)

The ITSARI algorithm was originally developed for tracking icebergs in the Antarctic, but it has been adapted to track individual sea ice floes and icebergs in Arctic to. Ice floes and icebergs are identified and tracked by satellite images and then processed by using brightness values and shape characteristics. The algorithm has also been adapted to detect the fast ice edge and pack ice edge. Figure 1.6 show iceberg movement observations for a period of 10 days in August 2010. The movements are affected by katabatic Winds cf. figure 1.5, and sea currents (ITSARI, 2010).

Katabatic wind is cooled high density air going downhill, forced by gravitation, from higher cool and snowy/icy elevations.

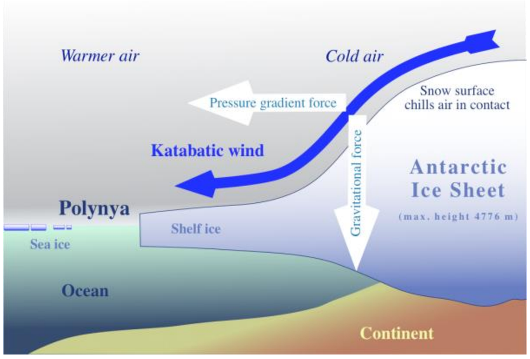


Figure 1.5 Katabatic winds. (Source: Wikipedia, 2013)

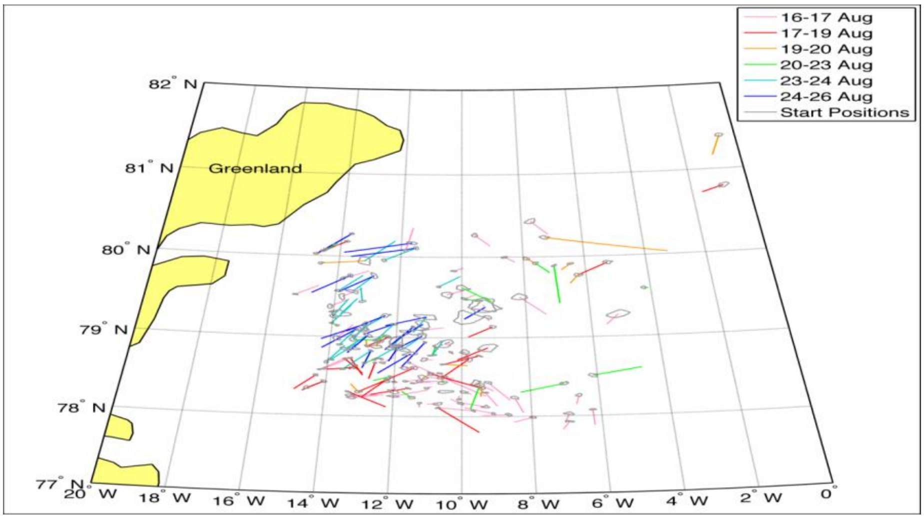


Figure 1.6 Tracking of ice features by ITSARI algorithm (Source: Ice Object Tracking. Pdf, 2010)

IRIS combines state-of-the-art ice modeling, ship transit modeling, and optimization methods as an operative on board route optimization system prototype for ice covered waters. The ice model calculates predictions of the ice conditions surrounding the ship on its route from departure to destination. The basic principles of the IRIS ice routing optimization is presented in figure 1.7.

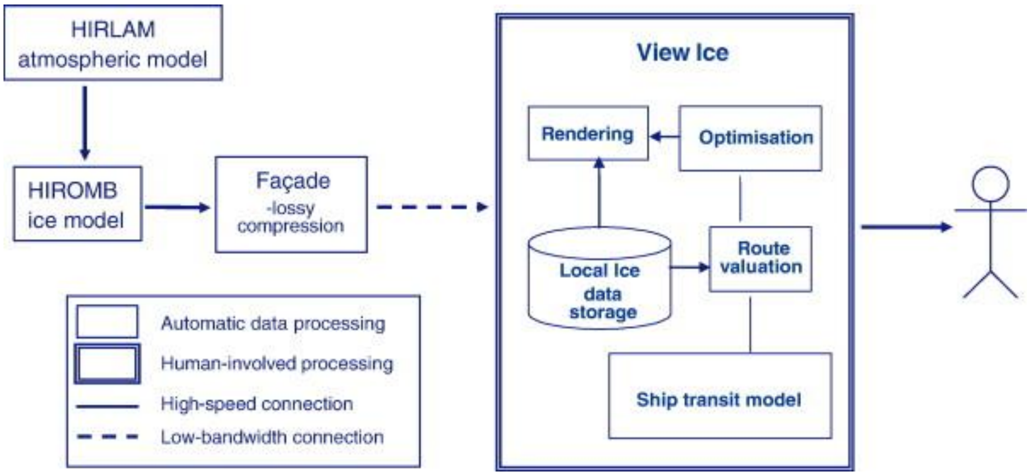


Figure 1.7 Schematic view of IRIS system. (source: IRIS, 2009)

The “HIROMB ice model” output contains of more data than appropriate to be transferred to the optimization process on a ship. It is therefore required to reduce the amount of transferred data to a minimum. The “Façade lossy compression” is reducing the amount of data by lowering the image resolution by selecting only the necessary parameters. The compression is lossy because of the amount of data is reduced to a level which is appropriate to be transferred over a mobile link, but the transferred data must be sufficient to achieve the required quality of the optimization result. The IRIS system architecture runs the ice model and lossy compression on a server onshore, and the route optimization calculation onboard.

The solution of the lossy compression process is that the ice model data are presented in a grid format in which every grid point contains parameters for describing the ice conditions change over time. A grid format related to this task consists of using the same grid framework during the entire voyage and just getting the changes in ice conditions (grid points) transferred. In this way you can reduce the amount of data required to a minimum and still maintain the quality of the optimization result. The grid ice data in the IRIS system is distributed three different parameters which describe the level ice thickness, the ridged ice thickness and the ice concentration cf. figure 1.8.

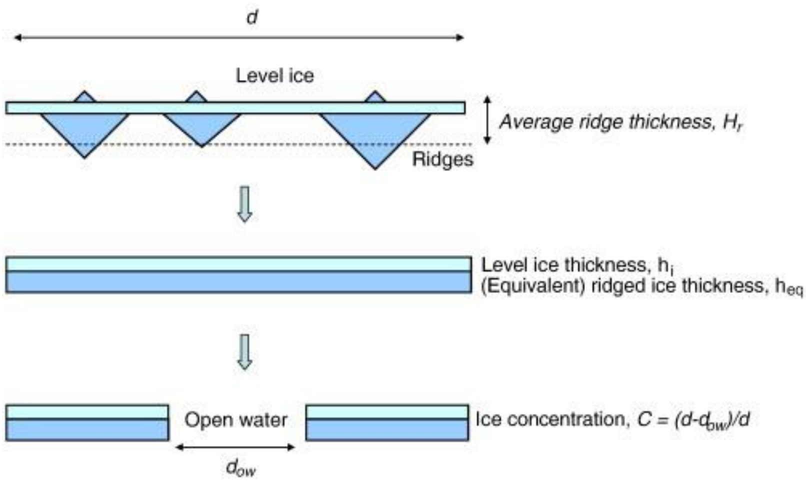


Figure 1.8 Illustration of the three parameters. (source: IRIS, 2009)

The meteorological forcing for the ice model HIROMB is supplied by the atmospheric model HIRLAM (High-Resolution Limited-area model) cf. figure 1.7. The HIRLAM model collects its data both from Swedish Metrological and Hydrological Institute (SMHI) for forecasts up to 48 h and European Centre for Medium-range Weather Forecasts (ECMWF) for forecasts up to ten days ahead. Based on this metrological data the HIROMB is able to simulate very realistic fields of ice ridging variables, but that the ice ridging is somewhat underestimated (IRIS, 2009).

The common futures for all this three systems and models are that they should show and model future ice conditions by delivering and presenting the right amount of relevant information to the users onboard. In addition, all systems have to compress all data transmitted to the ships because of limited bandwidth and reduced costs.

The bandwidth limitations and costs related to transferring data will be explained and discussed in 4.5.3 “Challenges and limitations of SAR satellite systems in Arctic”.

1.5. Limitations

This thesis main task is to investigate various aspects of importance for developing an operational weather routing program/decision support service for ships and different installations operating in the Arctic region.

Investigating every aspect of importance will be too extensive so this thesis will be limited to:

- Assessment between different model structures and algorithms that will be appropriate for a weather routing program/decision support service for Arctic conditions. Especially assess between different "state of the art" models or algorithms for processing different sea ice remote sensed images taken by polar orbit SAR-satellites.

- Assess similarities and differences between foreign and Norwegian weather distribution services. To be more specific the "requested ocean environmental forecast" by the WISE system and forecasts delivered by Norwegian Meteorological Institute (met.no). The main question related to this point is:

  Does the WISE weather imput emphasize the effect of polar lows, sea current, sea and air temperatures, sea ice aspects and other important weather information for Arctic areas?

1.6 Organization of the thesis

This thesis consists of three main parts:

- A case study of different general aspects related to ship routing
- Introducing of the WISE routing system and J-Marine GIS
- Different simulations for testing of various aspects of interest and possible challenges related to ship routing in Arctic

This thesis has concluding remarks and a recommendation or a proposal to a solution based on the reviewed theory and simulations.

The thesis consists of 8 sections:

1. *Introduction*: Presentation of background and motivation, previous and present work, limitations, research approach and strategy and algorithms.
2. *Environmental conditions in Arctic waters*: Presentation of Arctic waters, Arctic water sea ice theory, causal relationship to reduced ice extent and future ice distribution predictions.
3. *Maritime activities and operations in Arctic*: Presentation of different contributors of maritime activities in Arctic and maritime challenges in Arctic waters.
4. *Present technology for ice navigation*: Presentation of ship routing/decision making programs (WISE and J-Marine GIS), automatic identification system, technology for detecting and tracking sea ice and challenges and limitations of SAR and communication satellite systems.
5. *Simulation and results*: Simulations using the WISE routing system.
6. *Proposal of ice algorithm or model solutions*: Presentation of possible solution based on simulation and theory.
7. *Discussion*: Evaluation and discussion based on simulation and theory.
8. *Concluding remarks and recommendations for future research*: Presentation of concluding remarks and recommendations for future research based on theoretical aspects and simulation.

1.7 Contribution to the thesis

This thesis will first off all be a contribution to a better understanding in different aspects of ship routing- and decision making systems for maritime Arctic operations. These different basic theories must be examined to support this understanding:

- What areas of Arctic can we expect to encounter elements of ice, and basic sea ice theory
- What kind of maritime activities and operations is performed in Arctic, and what is the main challenges of this operations
- Presentation of present technology of different aspects of maritime operations in Arctic

Proposed solutions that can improve both ship routing and more specific decision making for various maritime operations will also be an important contribution to this thesis. This contribution part will be based on theory and different simulations.

The final contribution, based on findings in this thesis, will be some suggestion for future research. What specific field in improvement of safety of maritime operations in Arctic will have greatest impact, and what specific field of ship routing and decision making has the greatest limitations. This is the main questions related to suggestion for future research.

1.8 Research approach and strategy

1.8.1 Empirical approach

The first part of the empirical research approach for this thesis was to achieve an understanding of how a ship routing/decision making system was structured and the functioning. The preparatory part of the research was a literature survey and a study of existing appropriated systems. The supervisor of this thesis decided that the most dedicated and appropriated system for simulations was the WISE system of Japan Marine Science (JMC). To get the best basis for ideas and understanding a study of The WISE system in Tokyo/Kawasaki was needed.

A study of the WISE system in Tokyo took place in October 2011. In addition to study the WISE system, a study of the advanced navigation system, J-Marine GIS at Tokyo University of Marine Science and Technology took place.

The second part of the research approach and strategy was to come up with a proposal to a best appropriate algorithm or method for sea ice information. This proposed algorithm or method is meant to be a possible improvement for the WISE system and it will be based on "state of the art" research and possible near future predictions.

The third part of the research was to compare the ocean environmental forecast input on the WISE system with weather and oceanic forecast from the Norwegian Meteorological Institute (NMI).

In order to achieve a better understanding of how meteorological providers work, a meeting at NMI in Tromsø was arranged. This meeting included an introduction into what methods they use to collect data, make forecasts and how they distribute the forecasts.

The initial question related to this part of the research was: if the forecast from NMI is more appropriate for the WISE system is it then possible to add information from NMI as an oceanic forecast provider to the WISE system?

In this part of the research approach the WISE system was used (in real) together with parallel observation from NMI forecasts.

The main question related to the third part was: Are the weather and ice forecast input from WISE reliable due to maritime operations in Arctic or would it be more appropriate to connect weather information from NMI, if possible, to the system?

1.8.2 Approach

A case study approach was chosen as the main research strategy. Case studies are analyses of systems that are studied holistically by one or more methods. As a research strategy, the case study is used in many situations to contribute to our knowledge of related phenomena like the issues in this thesis.

In general, case studies are the preferred strategy when "How" or "why" questions are being posed, when the investigator has little control over events, and when the focus is on contemporary phenomenon within some real-life context (R K Yin, 2003).

This case study consists of several "how" and "why" questions such as, how the various issues is solved and why they have to be solved like that etc. Figure 1.9 shows the relationship between case study and focus on contemporary events.

Strategy	Form of research question	Requires control over behavioural events?	Focuses on contemporary events?
Experiment	How, why	Yes	Yes
Survey	Who, what, where, how many, how much	No	Yes
Archival analysis	How, why	No	Yes/No
History	How, why	No	No
Case study	How, why	No	Yes

Figure 1.9 Different relevant situations of research strategies. (Source: R K Yin, 2003)

Each of the strategies (figure 1.9) can be used as different ways to collect and analyze empirical evidences and logics, but the case study is the only strategy which just takes into consideration “how and why” questions with focus on contemporary events.

To be more specific, this case study is exploratory, descriptive and explanatory orientated. The exploratory part of the case study is the proposal improvement for the WISE system. The descriptive part is different descriptions of the specific parts of the theoretical aspects. The explanatory part is the different explanations through the whole task.

The essence of all case studies is that they try to illuminate a decision or a set of decisions. Why they were taken, how they were implanted and what result they are contributing (R K Yin. 2003).

1.9 Algorithm

One part of the research in this thesis is to actualize different algorithms for processing different inputs and converts it to output in the system.

A general description of an algorithm is any set of detailed instruction which results in a predicted end-state from a known beginning. There are many types of algorithm, and most of the algorithms have something to do with defining processes for the creation of "output" integers from other "input" integers.

A computer programs which consists of series of instructions listed in a specific order, designed to perform a specific task, is an algorithm. Different mathematical methods to solve equations are also defined as an algorithm.

Algorithms are only as good as the instructions given, however, and the result will be incorrect if the algorithm is not properly defined. Well-prepared algorithm with strictly formed data information, on initial stage, is therefore important for securing of the quality of any systems.

Classes of Algorithms:

•*Dynamic Programming Algorithms*: This class remembers older results and attempts to use this to speed the process of finding new results.

•*Greedy Algorithms*: Greedy algorithms attempt not only to find a solution, but to find the ideal solution to any given problem.

•*Brute Force Algorithms*: The brute force approach starts at some random point and iterates through every possibility until it finds the solution.

•*Randomized Algorithms*: This class includes any algorithm that uses a random number at any point during its process.

•*Branch and Bound Algorithms*: Branch and bound algorithms form a tree of sub problems to the primary problem, following each branch until it is either solved or lumped in with another branch.

•*Simple Recursive Algorithms*: This type goes for a direct solution immediately, and then backtracks to find a simpler solution.

•*Backtracking Algorithms*: Backtracking algorithms test for a solution; if a solution is found the algorithm has solved, if not it recurs once and tests again, continuing until a solution is found. This method could be shown in different flowcharts.

•*Divide and Conquer Algorithms*: A divides and conquers algorithm is similar to a branch and bound algorithm, except it uses the backtracking method of recurring while dividing a problem into sub problems (Wisegeek, 2013).

Flowcharts are often used to represent algorithm graphically. Figure 1.10 shows a general example of an Advanced Microwave Scanning Radiometer - Earth Observing (AMSR-E) System algorithm shown as a flowchart.

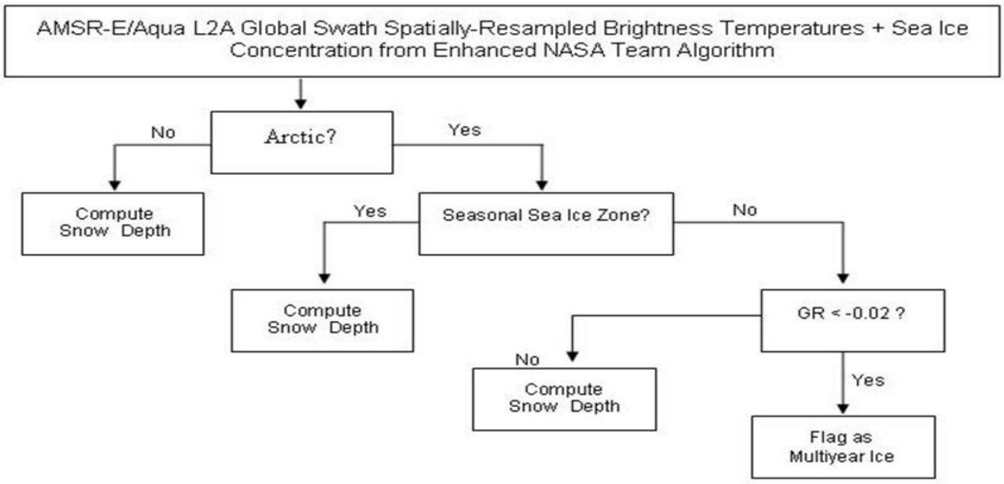


Figure 1.10 Flowchart of snow depth algorithm. (Source: NSIDC, 2013)

The algorithm in Figure 1.10 is originally a model for detecting snow depth, but in addition this algorithm could be used to compute concentrations of multiyear ice information from SAR-images over both multiyear ice and deep snow on top of first-year ice results in increasingly negative values for the "Spectral gradient ratio corrected for the sea ice concentration (GR).

To separate between multiyear ice and deep snow on top of first-year ice the algorithm only retrieves snow depth in regions where the value of GR is greater than -0.02. In the regions where the GR is less than -0.02, the algorithm flag the outcome as multiyear ice (NSIDC, 2013).

KSAT use for the ITSARI algorithm to track ice objects in Arctic. This algorithm identifies the position of the ice edge, and the tracking of distinctive ice floes within the pack allows an approximation of the direction and speed of travel of the pack.

2 Environmental conditions in Arctic waters

2.1 Arctic

Arctic is a region located at the northern-most part of the Earth. The region consists of the Arctic Ocean and parts of Canada, Russia, Greenland, the United States, Norway, Sweden, Finland, and Iceland. The Arctic region consists of a vast, Ice-covered ocean, surrounded by treeless permafrost. The region can be defined as north of the Arctic Circle (66° 33'N), the approximate limit of the sun and the polar night, but the southern limit of Arctic area is stretching south of 60°N in North America and in the Bering sea cf. figure 2.1.

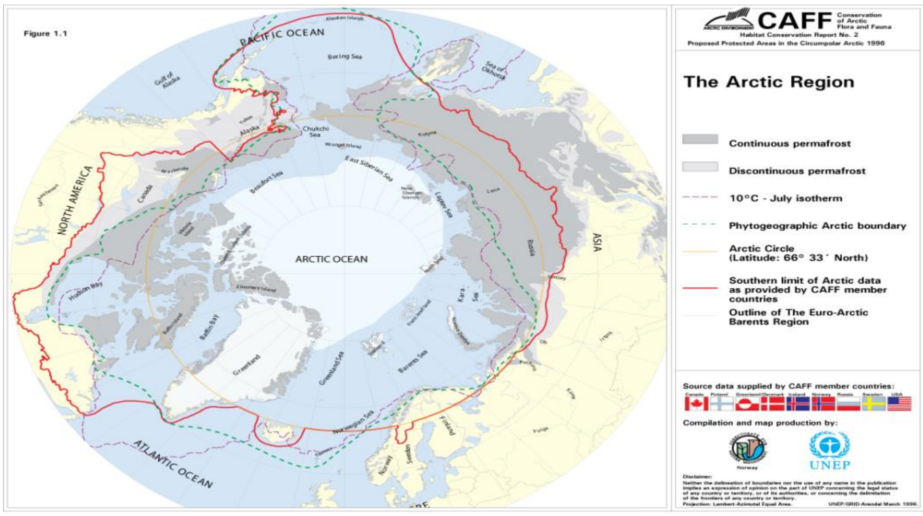


Figure 2.1 The Arctic region (Source: GRIDA, 2006)

Figure 2.1 shows different boundaries in addition to the red boundary (southern limit of Arctic area). Some of these boundaries are self-explanatory, but the boundaries for continuous- and discontinuous permafrost, phytogeography Arctic boundary and 10^{0}C-july isotherm has to be more explained.

- Continuous permafrost:

  The dark grey area consists of constant frozen soil year round. The mean air temperature is below the freezing point of water.

- Discontinuous permafrost:

  These light grey areas consist of a lot of permafrost, but that will often be interrupted by regions without. The areas with discontinuous permafrost have a typical mass temperature between -2 and -6 degrees Celsius.

- 10^0C-july isotherm:

  Meaning that the short summer (24-hr average 10 °C or more) lasts 1–3 months and always less than 4 months never occurs north of this boundary.

- Phytogeographic Arctic boundary:

  This boundary corresponds to the northern limit of tree growth and fig? shows that the boundary varies both above and below the Arctic circle.

- Arctic circle:

  The Arctic Circle is a boundary that marks the extremity of the polar day 24-hour sunlit day “midnight sun”), and polar night (24-hour sunless day).

- Southern limit of Arctic area:

  This boundary is provided by Arctic council that consist of all the eight countries associated to the Arctic region (CAFF), (GRIDA, 2006) .

2.2 Arctic water ice

2.2.1 Sea ice

Sea ice is largely formed by frozen seawater, but it could also be formed of freshwater. Fresh water freezes at 0°C, and the ice which is formed of saltwater has a freezing point below freshwater ice, at about -1.8 °C. Sea ice formed by fresh water may be contrasted with icebergs, which are chunks of ice shelves or glaciers that calve into the ocean. Some icebergs are compacted snow and hence are fresh water from the beginning. But the ocean icebergs formed by sea water loses its salinity during a process that is related to time. The process that dilutes the salt content is made by snow and melting water that forms on top of the iceberg.

2.2.2 Sea ice types

Land-fast ice, or simply fast ice, is sea ice that has frozen along coasts or to the sea floor over shallow parts of the continental shelf, and extends out from land into sea. Unlike drift ice, it does not move with currents and wind.

Drift ice consists of ice that floats on the surface of the water, as distinguished from fast ice, attached to coasts. When packed together in large masses, drift ice is called pack ice. Pack ice may be either freely floating or blocked by fast ice while drifting past.

Pancake ice is sea ice broken into small round chunks looking like pancakes.

Pack ice is polar ice packs formed from seawater in the Earth's Polar Regions. We distinguish between The Arctic ice pack of the Arctic Ocean and the Antarctic ice pack of the Southern Ocean. Polar packs significantly change their size during seasonal changes of the year.

Because of vast amounts of water added to or removed from the oceans and atmosphere, the polar ice packs experience a significant impact from global changes in climate. (ec.gc.ca, 2013).

However, in these thesis I will concentrate on distinguish between is one-year and multiyear ice. A simple two-stage approach classifies sea ice into first year and multiyear ice. First-year is ice that has not yet survived a summer melt season, while multi-year ice has survived at least one summer and can be several years old.

The age of the ice is a key descriptor of the state of the sea ice cover. Old or multiyear ice is thicker and harder than younger ice, and therefore more dangerous to shipping.

Figure 2.2 shows a bulk carrier which vas damaged by elements of multi-year ice in Hudson strait (Canada).

Figure 2.2 Bulk carrier damaged by multi-year ice (Source: Canadian Coast Guard)

2.2.3 One year ice

One year or new ice is the designation of frozen sea and it is usually very salty because it contains of concentrated droplets called brine that are trapped in pockets between the ice crystals. This type of ice has greater density than multi-year ice, but it is softer due to salinity of the brine.

2.2.4 Multiyear ice

Multiyear ice has a lot of properties that distinguish it from first-year ice, based on processes that occur during the summer melt. Multiyear ice contains of much less brine (salt) and more air pockets than first-year ice. Less brine means harder ice that makes it more difficult for ships to navigate through the ice. As ice ages, the brine in young ice drains through the ice, and by the time it becomes multiyear ice.

Figure 2.3 shows the process when ice rejects salt over time and becomes less salty resulting in a higher melting point.

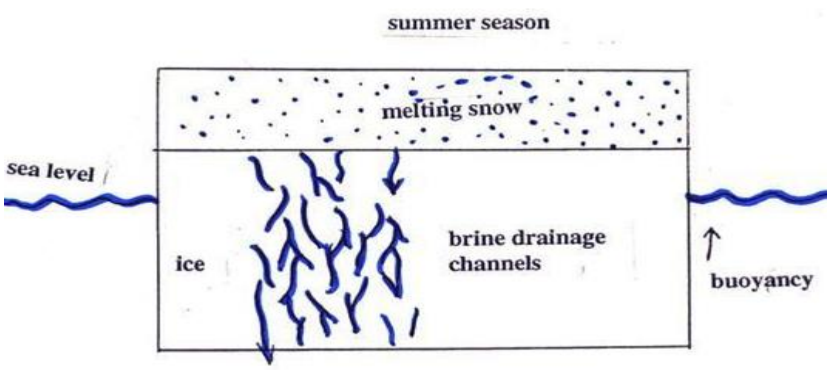


Figure 2.3 Brine drainage of sea ice (Source: Beyondpenguins)

Brine can move out of sea ice in different ways:

1. Aided by gravity, the brine migrates downward through holes and channels in the ice, eventually emptying back into the ocean.

2. The ice surrounding the brine compresses and breaks the brine pockets, allowing the brine to escape to the ocean.

3. When the sea ice begins to melt during the summer, small freshwater ponds (called melt ponds), form on the top layer of the ice, travels through the cracks and holes in the ice, washing out remaining brine.

4. When the sea ice surface cools, brine increases in salinity to the point at which it can melt ice at its underside. This leads to a downward migration of brine droplets, ultimately allowing the brine to escape into the ocean below the ice sheet.

Multiyear ice is much more common in the Arctic than in the Antarctic. This is because of ocean currents and atmospheric circulation that moves sea ice around Antarctica, causing most of the ice to melt in the summer as it moves into warmer waters. The upper ocean heats up due to absorption of solar heat by open water areas. Arctic Ocean, however, is relatively land-locked (typographic conditions prevent the ice to move with the sea current) and that makes extensive Multiyear ice to take shape. But the multiyear ice extend is decreasing in Arctic and there are almost gone in Antarctic (NSIDC, 2013). The decreased distribution of multiyear ice could lead to possible new Arctic trans-polar routes without assistance of icebreakers.

2.3 Causal relationships to reduced ice extent

The main cause of decreased ice extend is increased temperatures, both in air and sea. If we take a closer look at fig.2.4, 2.5 and fig. 1.1, for the same period, we easily see the relationship between increased temperatures and decreased Arctic sea ice extend.

The temperatures have risen steadily over most of the Arctic region in the recent decades, especially during the winter. But temperature changes vary.

Some areas have actually experienced lower temperatures, but the temperature rise in Alaska and Canada is about 3-4 ° C, during the last 50 years.

ACIA (Arctic Climate Impact Assessment) report concludes with an average warming in the Arctic at 2.1°C since 1850. This is almost two times more than global warming. Scientists expect global warming of 1.4 to 6°C over the next 100 years (ACIA, 2004).

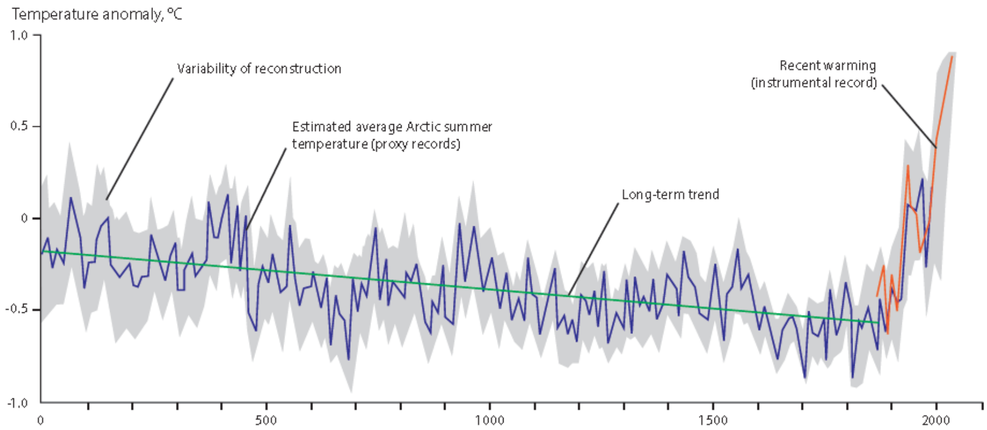


Figure 2.4 Estimated Arctic average summer air temperature anomalies (Source: SWIPA 2011)

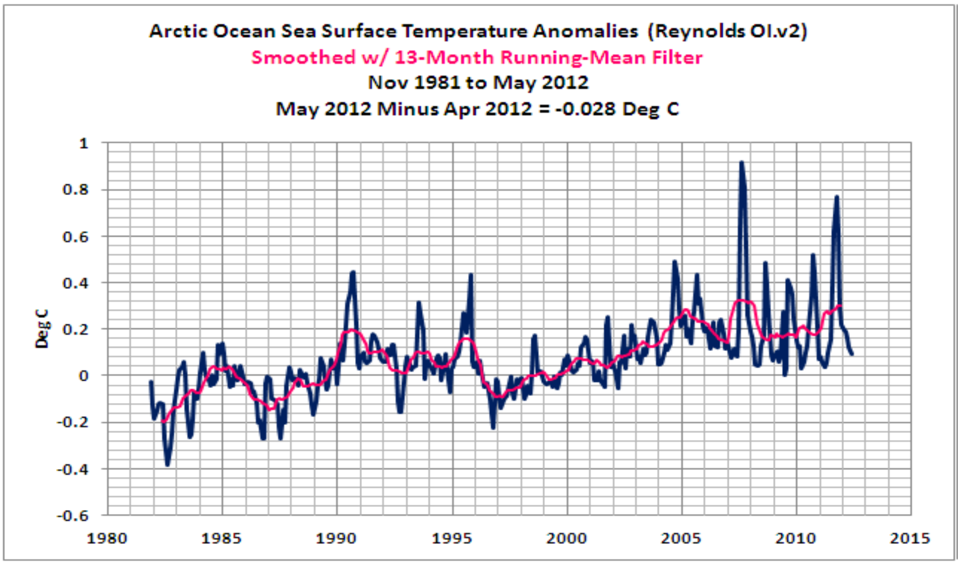


Figure 2.5 Arctic sea surface temperatures. (Source: Worldpress.com)

2.3.1 Causes for fast average warming in the Arctic compared to other regions

The main causes for faster average warming in Arctic, than other regions are:

1. As snow and ice melt, the surface of the oceans and land will absorb more solar energy.
2. Less heat used for evaporation of water in the Arctic than in areas further south.
3. It created the atmosphere that must be heated to provide heating of air near Earth's surface is thinner than in the tropics.
4. With less sea ice, more heat from the sun is absorbed by the ocean in summer and the heat will be transferred to the atmosphere during winter.
5. Heat is transported to the Arctic via the atmosphere and ocean currents. Changes in circulation can increase warming in the region (ACIA, 2004)

These five main causes are visualized in figure 2.5:

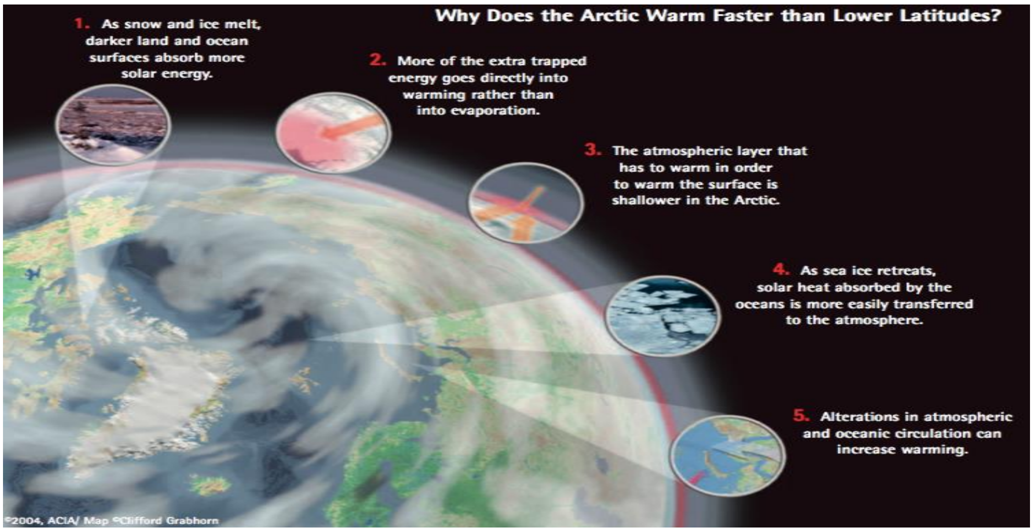


Figure 2.6 Visualization of the main causes of warming n Arctic (Source: ACIA, 2004)

2.3.2 Future predictions of ice extent in Arctic

If we take a look into future predictions of ice extent in Arctic by study different images and read research articles. We easily see that the concentration of sea ice in Arctic will decrease dramatically in just few decades. The visualized predictions in figure 2.6 are taken from the Arctic Climate Impact Assessment (ACIA) rapport (AMAP, 2012).

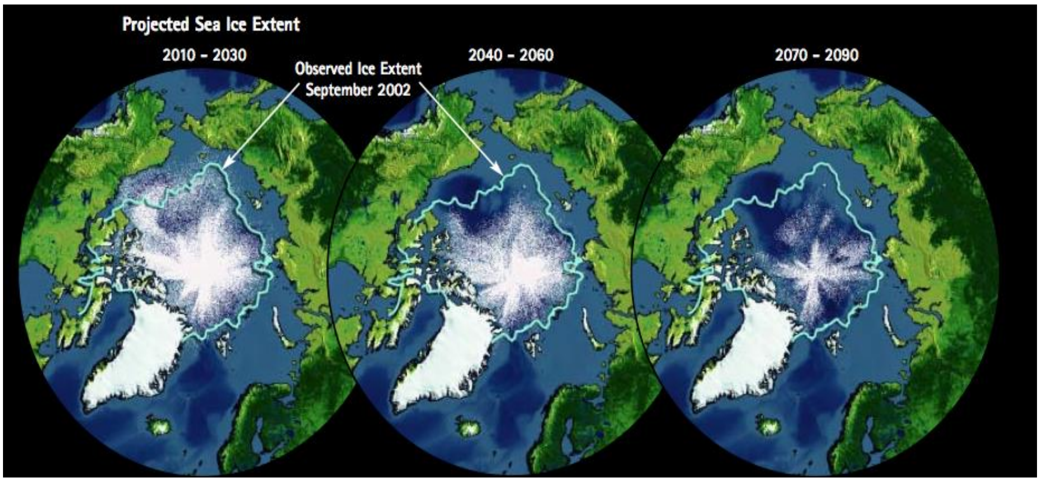


Figure 2.7 Visually prediction of ice extends in Arctic (Source: AMAP, 2012)

3 Maritime activities and operations in Arctic

Marine navigation is expected to increase as both the North-West and North-East passages from the North Atlantic to the West coast of the Americas and to Asia respectively become ice free larger parts of the year. Tourism activity is also expected to expand, with more cruise ships visiting the area as well as a growing use of the sea routes for general transportation of goods and people to and from the cities and settlements in the area. Fishing and hydrographic survey vessels will investigate the new and partly uncharted areas left open by the ice retreat.

Also, as a consequence of the withdrawing ice, the oil and gas sector has an increasing interest in the Arctic, as large and so far mostly un-explored resources are known to be present in the area (mycoordinates.org).

On the basis of the article above there are four main contributors for the growing maritime activity in Arctic:

- Oil & Gas industry
- Fishing industry
- Commercial ship trading routes
- Cruise ship traffic

3.1 Oil industry

International oil industry shows a growing interest in the Arctic region as the ice extension is decreasing. The Russians discovered the Stockman field in 1988 and Norwegian oil companies are surveying areas far north in the Arctic sea. Statoil started production of gas outside the coast of Finnmark in 2007 and ENI Norge will start oil production in the same area in 2013.

The demarcation line in Barents Sea between Russia and Norway was approved 15.09.2010. This agreement may, in the near future, lead to increased oil activity on both sides of this line. Canada and USA is developing and producing oil in the Arctic waters. Denmark and Iceland is developing oilfields and they are both preparing for oil production in Arctic waters.

There are several different categories of oil activities like:

- *Seismic surveys* – a geophysical method to investigate the subsurface
- *Drilling operations* – exploration and production well drilling
- *Completion* - creating and installation of oil production installations, different pipelines and other equipment
- *Oil production* – oil, condensates or gas production
- *Oil loading operations* – offshore loading of oil, condensates or gas
- *Supply activities* - supply of different equipment and other items
- *Ice management* - Ice management is the sum of all activities where the objective is to reduce or avoid actions from any kind of ice features. This will include, both is not limited by:
  - Detection, tracking and forecasting of sea ice, ice ridges and icebergs
  - Threat evaluation
  - Physical ice management such as ice breaking and iceberg towing
  - Procedures for disconnection of offshore structures applied in search for or production of hydrocarbons

Ice Management consists in practice of keeping sailing routes near fixed or other installations open, and sometimes it is also necessary to protect the installations themselves from dangerous ice. Figure 3.1 illustrate an ice management operation with two ice managing ships (yellow and blue) helping a drillship (red) to keep position (Eik, Ice Management. 2009).

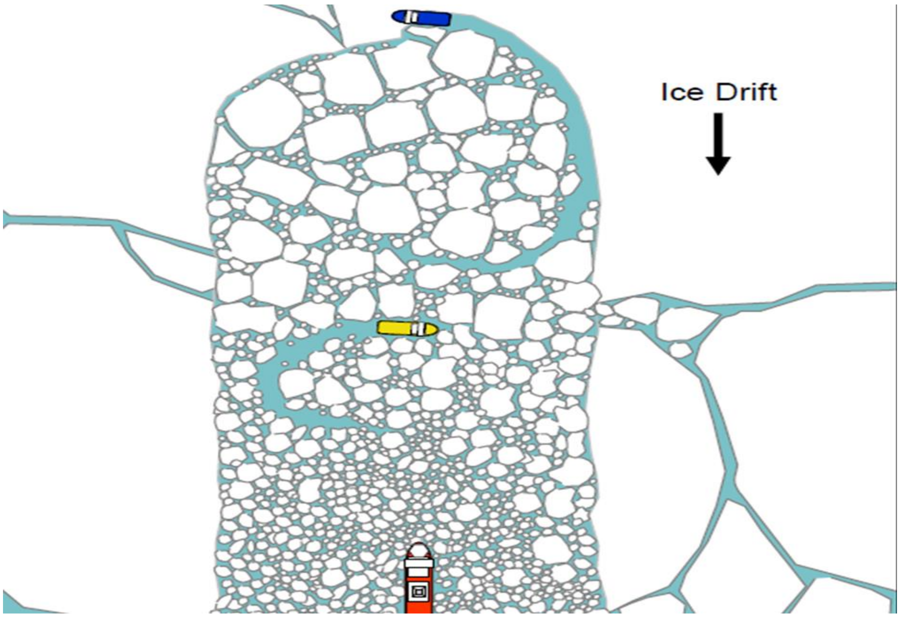


Figure 3.1 Ice management. (Source: Eik, Ice Management. 2009)

3.2 Fishing industry

Decreased ice extension is strongly related to increased temperatures, both in air and the sea, and this increased sea temperatures affect the distribution of different fish species. Figure 3.2 shows the joint distribution of the various commercial fish species moving north. As the commercial fish spices are moving north, the fishing boats follows this northerly movement.

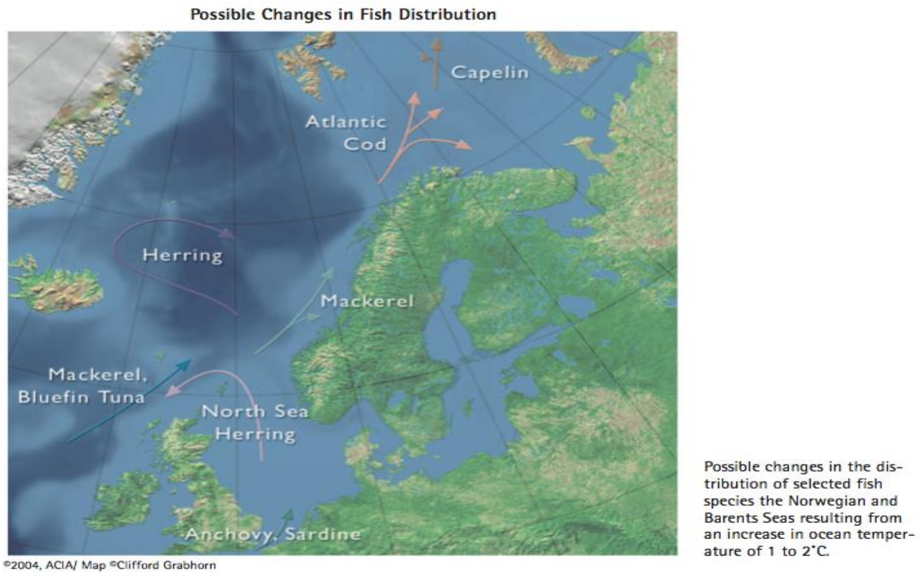


Figure 3.2 Predicted fish distribution (source: AMAP, 2012)

Norwegian shrimp trawlers are fishing as far north as 85^0 N, and they are often I contact with ice. Sometimes they fail to calculate the amount of ice and its movements, and when they need help to get loose cf. figure 3.3.

Figure 3.3 Norwegian shrimp trawler in the ice (Source: heroynytt, 2009)

3.3 Commercial ship trading routes

The Arctic Ice melting is opening the waters in the area for commercial ship trading routes. There are two main routes witch is possible to sail, The Northern Sea Route (NSR) and Northwest Passage (NWP) cf. figure 3.4. These sea routes along the Arctic waters

follows the coasts of Northern Canada and Russia, and they holds a potential of a decreasing number of days in shipping goods from the Pacific to Atlantic coasts in Europe and North America, and vice versa. In addition, this could provide a means to transport natural resources, such as oil and gas, extracted in the Arctic. Currently these routes have not been possible to use, due to the ice conditions, but with decreases in ice extension this could provide a new possibility. In addition, this would mean increased risk for the sensitive environment along these coasts, with oil spills and pollution.

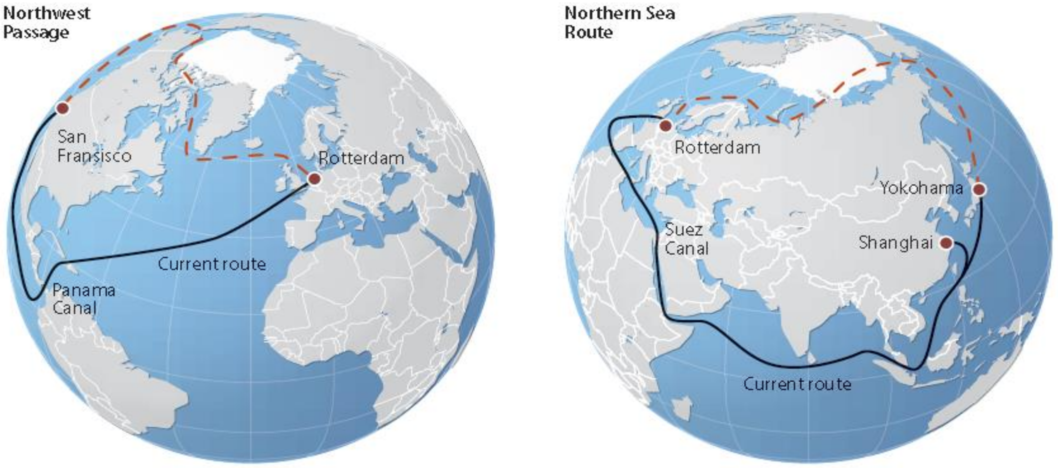


Figure 3.4 NSR and NP compared with currently used shipping routes (source: SWIPA 2011)

NSR is the shortest link between Western Europe and Eastern Asia, connecting the Pacific and Atlantic Oceans along the northern coast of Russia. This shipping route reduces the transportation costs by an average of 40% on key Asian-European routes. Such reductions could attract up to 80% of the global transportation market during ice-free periods of the year. The NSR route has additional advantages over other shipping routes including avoidance of cargo ship size restrictions imposed by the canals and also the increasing piracy problems in Indian and Eastern Pacific Oceans (SWIPA 2011)

Figure 3.5 Image of first LNG shipment through the NSR (Source: Gazprom, 2012)

3.4 Cruise ship traffic

There has been a large increase in cruise traffic in the Arctic during the last decades. Ships which has contact with ice is increasing in a time of shrinking ice and warmer climates, and the shrinking of ice creates new opportunities and longer seasons for cruise ship traffic in Arctic. At Svalbard we had in 2007 almost 50,000 passengers visited the islands with large cruise ships.

This is a doubling since 2002 and in addition, approx. 20,000 passengers carried on day trips and shorter expedition cruises. In Antarctica, Canada, Russia and Greenland, we had a similar development.

The vessels and crews which sailed into these areas, in the beginning, were not always suitable for the purpose. Ship officers showed lack of experience, and this led to a number of near accidents and also actual accidents. If we take a closer look at known accidents like the Maxim Gorkij and Explorer accidents, we see a lot of similarities. Both these accidents showed lack of experience by the officers on the ships.

November 23th 2007 the S/M Explorer (figure 3.6) hit an iceberg located near the South Shetland. In the case of the "Explorer", that had ice class 1A, the ship sailed relatively unaffected by a belt with easy (first year) ice. The speed was high and when the ship came into contact with a little bit of hard-old glacial ice (Growler), in the ice belt, it was impossible to avoid damage to the hull (Skipsrevyen, 2007)

Figure 3.6 Explorer accident (Source: Skipsrevyen, 2007)

The Maxim Gorkij accident (figure 3.7), June 19th 1989, was similar to the Explorer accident. The ship runs into an iceberg with full speed (Kjerstad 2008). The differences between those two accidents are that the officers on Explorer did see and know about the ice, but they didn’t know about the “growler” in the belt with easy ice. The officers on Maxim Gorkij didn`t know about ice in the area, and they didn’t expect to meet ice as far south. This type of misinterpreting was the same as for the Titanic disaster in 1912.

Figure 3.7 Maxim Gorkij accident (Source: Commentum, 2012)

Accidents like this could be avoided if the ship officers had the ability to detect these potential dangers before they turn to real dangers. It is also important for ship officers to take into consideration the risk of sail into ice covered waters, especially if the ships is not build for sailing in ice.

3.5 Maritime challenges in Artic waters

Increased maritime activity from oil- and fishing industry, new sea trading routes and cruise traffic, in the Arctic region, has led to a rise in the need for an improved management for ship operations and safety for this region. There are several challenges to take into consideration when sailing into these kinds of areas.

In this thesis there will be considered which different challenges maritime activity will meet in the northern part of the region.

The main challenges in Arctic waters, compared to other sea areas, are:

- *Polar lows.*These lows are small, intense low pressure formed in cold Arctic air over warmer waters in the in the winter season, and can lead to extreme wind and snow (Kjerstad 2008). Figure 3.8 shows a polar low with the center marked with a red cross.

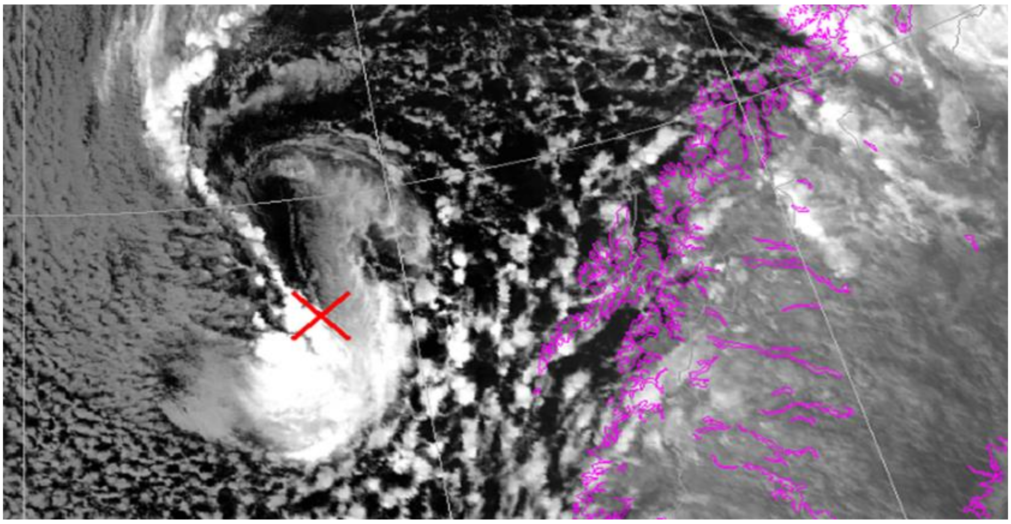


Figure 3.8 Satellite image of a polar low (Source: met.no)

- *Drifting ice.* cf. Titanic, Maxim Gorkij, and Explorer etc.
- *Limited visibility.* Arctic “havrøyk” or fog is very common in these areas and occurs when cool air flows over warmer waters. This phenomenon is most common in the summer, but in the winter there is a phenomenon which is called ice fog (frosty). Both these phenomena’s lead to poorer visibility at maritime operations.
- *Fast changing wind.* Due to large temperature differences.
- *Remote area.* Large distances cause difficulties for search and rescue (SAR) and potential oil disasters operations.

- *Satellite coverage.* Poor coverage of both weather and navigation satellites. Out or range of geostationary satellites.
- *Icing on ships and installations.* This phenomenon is related to low temperatures in combination with snowfall and/or sea spray caused by high seas.

3.5.1 Icing on ships and installations

Icing on ships and installations can cause different operational and technical problems for maritime operations in Arctic. The most serious threat followed by icing on ship and installations is the lack of seaworthiness related to accumulation of ice on the outside of the upper structure of a device. The accumulation of ice leads to decreased ship or installation stability.

Any craft that floats in water has its own center of gravity (G) and a matching center of buoyancy (B). Those two centers are equal and ensure that a device floats in the water. Figure 3.9 shows a model of a device where G (blue), B (red) and the metacenter M (green) are shown. As long as G is below M the device floats stabile in the water I.e. we have a positive GM (distance between G and M). M is almost fixed on any device, but G can be moved by moving, adding or removing weights on board. If weight like ice is added above G, then G moves up and leads to decreased GM followed by poorer stability.

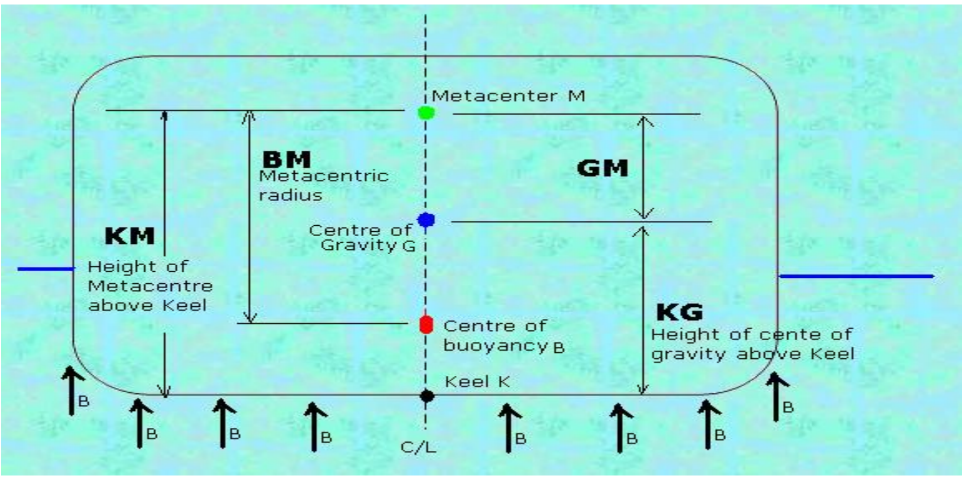


Figure 3.9 Illustration of a device with explanatory notations (Source: own)

The next figure illustrates the relationship between GM and the ship's stability. In figure 3.10, the ship to the left has a negative GM while the ship at the right has a positive GM. Negative GM is a dangerous condition that causes the vessel to the left capsizing.

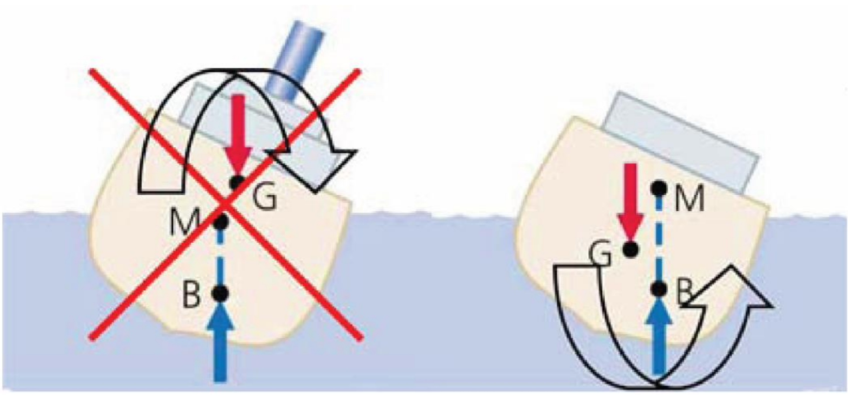


Figure 3.10 Illustration of ship`s stability (Source: npd.no)

Heavy icing, especially when it accumulates on upper structures over time, will sooner or later affect the stability of a device. In severe conditions the GM becomes indifferent (G an M on the same place) or negative (G above M). Indifferent or negative GM is very dangerous cf. figure 3.10, and can easily cause a capsizing of a device. It is therefore important to avoid or limit situations that lead to icing. Figure 3.11 show a ship affected by icing.

Figure 3.11 Photos of an icy ship (Source: Wordpress.com)

Sea spray icing occurs when wave-generated spray comes in contact with cold upper structures together with air temperature below freezing.

The prediction of degree of icing is shown in the following empirical formula which originally is built on an algorithm presented by (Overland, 1990).

$$PPR = \frac{V_a(T_f - T_a)}{1 + 0.3(T_w - T_f)}$$

PPR = Icing Predictor (m^oCs^{-1})

$\mathbf{V_a}$ = Wind Speed ($m\ s^{-1}$)

$\mathbf{T_f}$ = Freezing point of seawater (usually between -1.7 ^oC and -1.8 ^oC)

$\mathbf{T_a}$ = Air Temperature (^oC)

$\mathbf{T_w}$ = Sea Temperature (^oC)

The following table (figure 3.12) shows the expected icing rates for 20-75 meter vessels that are steaming towards the wind.

PPR	<0	0-22.4	22.4-53.3	53.3-83.0	>83.0
Icing Class	None	Light	Moderate	Heavy	Extreme
Icing Rates (cm/hour) (inches/hour)	0	<0.7 <0.3	0.7-2.0 0.3-0.8	2.0-4.0 0.8-1.6	>4.0 >1.6

Figure 3.12 Icing class and rate (Source: navy.mil)

There are two general factors to be considered when there is a risk of sea spray icing: Environmental factors and vessel or device characteristics.

The environmental factors which affect sea spray icing are:

1. Wind Speed - Usually above 18 knots (9.3 m/s) sometimes lower
2. Air Temperature - Below freezing -1.7 ^{o}C (29 ^{o}F)
3. Water Temperature - Usually below 7 ^{o}C (45 ^{o}F)
4. Freezing Temperature of Water
5. Wind Direction, Relative to the Ship
6. Swell and Wave Characteristics – size, length and direction

The vessel or device characteristics which affect sea spray icing are:

1. Ship Speed
2. Ship Heading (with respect to wind, waves and swell)
3. Ship Freeboard
4. Ship Handling
5. Ship Cold Soaking
6. Ship movements
7. Ship bow design

There must be taken into consideration these environmental factors and vessel or device characteristics in planning and executing maritime operations to avoid or reduce icing. There are factors within vessel or device characteristic witch can be effective measures to avoid or reduce icing. Speed reduction and ship heading with respect to wind, waves and swell is probably the most effective measures. It is situations like in figure 3.12 which should be avoided by changing the ships heading and reducing the ship`s speed.

Figure 3.12 Sea sprays icing from waves and swells (Source: Canadian Coast Guard)

In addition to reduction of stability icing can affect important safety and technical installations like:

- Icing on different antennas which can reduce or prevent the performance of the ships communication and navigation etc. systems.
- Icing can affect the performance of different safety equipment such as: Life raft and mob boat facilities, hatches and doors, different fire- fighting and mooring equipment etc.
- Icing can lead to increased shear forces on ships and installations if ice accumulates on just parts of a vessel or a device.

Safe operations of ships require proper planning and knowledge in how to handle a ship due to this type of challenges. A customized decision support or ship routing system, which takes into consideration this main challenges, could therefore be an important contributor to safer maritime operations in Arctic.

If an accident does happen in the Arctic the consequences can be serious. The remoteness, the large distances, and the rough weather cause difficulties for search and rescue (SAR) operations as the nearest airstrip is often very far away. Also the Arctic environment is vulnerable and very slow in regeneration after for instance an oil spill, so an accident could initiate an environmental disaster.

There is a need for improved systems for positioning and navigation in the Arctic soon. Most professionals will not wait to roam the Arctic area, and the authors of this paper therefore encourage more focus on research and development for improved navigation systems in the Arctic (mycoordinates, 2010)

4 Present technology for ice navigation

4.1 Ship routing service/decision making program for maritime activities

In general a ship routing/decision making program is a tool for helping shipping companies and ship officers to get their ships from port to port as safely, fast and economically as possible. In this thesis there will be taken into consideration aspects for securing different marine operations in addition to ship routing.

Routing service systems and decision making programs are based on different inputs like: sufficient knowledge of all different oceanic conditions in the selected area, different ship information and weather and oceanic forecasts information such as:

- Wind - direction and strength
- Sea wave - height, direction and frequencies
- Temperature - sea and air
- Sea currents - direction and strength
- Ice information - concentration, thickness, age, trends and movement

The system calculates and presents the right amount of relevant information to the ship officers onboard based on the input information.

Figure 4.1 shows an image of the WISE routing system developed by Japan Marine Science. This system shows information about wind strength and direction, wave height and direction. Information about wave height is located in the bottom right of the image. Wind and wave directions are visualized by “arrow directions” on the image. The image also shows three different estimated ship routes with route information in the “route information table” to the upper left in the image. There is information that enables the ship officers to separate the different routes in the bottom to the left in the image (different colors).

The system information enables vessels to obtain the latest weather and sea condition forecasts on board at any given time. Based on these forecasts and planned navigation routes, simulation can be performed on board.

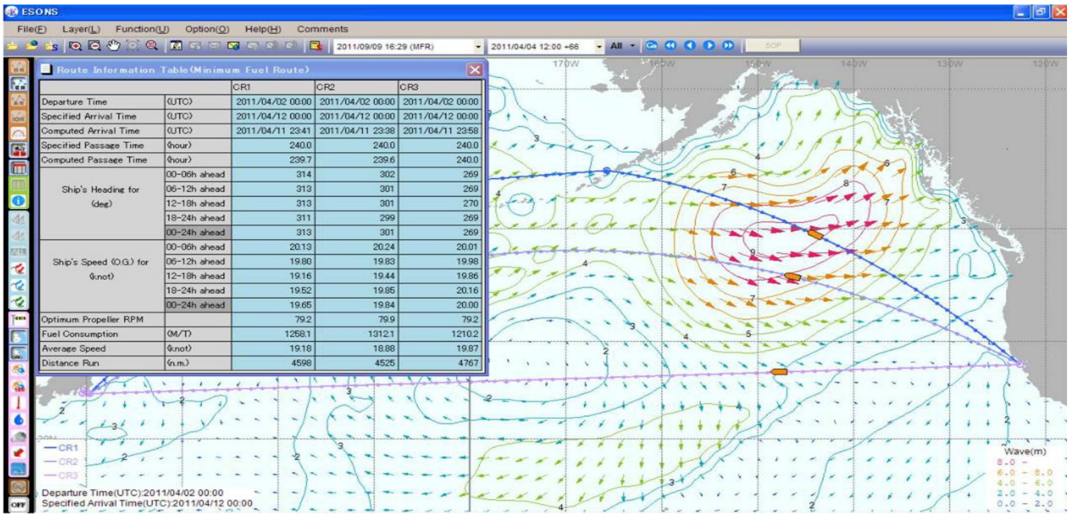


Figure 4.1 Image of WISE ship routing system (Source: jms-inc)

A routing program/service for Arctic conditions must, in addition to the information on the WISE system consist of detailed ice identification services. An algorithm that in addition to compute detailed information about sea ice, should also compute and give the users a most continuous ice picture as possible. Especially the oil industry would be interested in identification of ice movements and trends. Not only to increase their ship traffic optimization, but also for an early detection of dangerous ice for possible fixed or floating oil production or drilling installations, and different oil loading operations. Experiences of Canadian and Russian oil activities in icy areas show that the detection of ice is important for efficient ice management.

What specific ice information such a system should include must be based on information from, and cooperation between different ship officers who have experience of sailing in the Arctic. One must identify between solutions that exist and the opportunities that are possible in the near future, based on this information.

There are three main factors that must be present in order for a ship routing/decision making program to perform as expected, that is: availability, deliverability and dependability.

Availability is the ability for an item to be in a state to perform required function under given conditions at a given instant time, assuming that the required external resources are provided (Barabady, 2007).

Deliverability is the ratio of deliveries to planned deliveries over a specific period of time, when the effect of compensating elements such as substitution from other producers and downstream buffer storage is included (Barabady, 2007).

Dependability Is the collective term used to describe the availability performance and its influencing factors: reliability performance, maintainability performance and maintenance support performance (Barabady, 2007).

All these factors are related to the availability and the reliability performance of the system. The system must function under all circumstances and be independent of where you are on Earth.

4.2 Introduction of the WISE routing system

The WISE routing system consists of software which can obtain the latest weather- and ocean environmental forecasts at any time. This forecasts which is basically communicated via INMARSAT gives the system basis to calculate the optimum ship route. When the WISE software is installed on board the ship officers can request forecasts for a selected area and for specific weather information like: wind, wave, ocean current, etc.

WISE routing gives the ship officers opportunity to simulate (onboard simulation) routes and software calculation of the optimum route to a specific destination based on received forecasts.

It is possible to add IRIDIUM as communication system instead of INMARSAT. It is done by just change the ship's e-mail address to which the ocean environmental forecasts are sent. This enables the system to send forecast request high north in Arctic.

4.2.1 Features of WISE routing system

Weather forecast

- The latest forecasts are available from various centers providing the user with information like: wind, surface pressure, wave, 500hPa height, air temperature.
- Forecasts up to 8 days ahead, 12 hours intervals or every 6 hours provides the user with information like: ocean current, sea surface temperature and sea ice.
- Nowcast is updates every day provides the users with information like: extreme weather (tropical cyclone, hurricanes and storms).

Ship database

The database calculate ship`s speed, ship motions and engine power under influence of predicted ocean weather conditions.

Prompt response

When the request is send from the ship, the latest requested weather information is returned by e-mail in about 10 minutes after the request.

Function of display

All requested weather information can easily be displayed in an understandable way. The user can choose what information is shown on the display.

Onboard simulation

It is possible to calculate between different routes like the Minimum Time Route (MTR), Minimum Fuel Route (MFR) and the captains route (CRs) by carrying out onboard simulation.

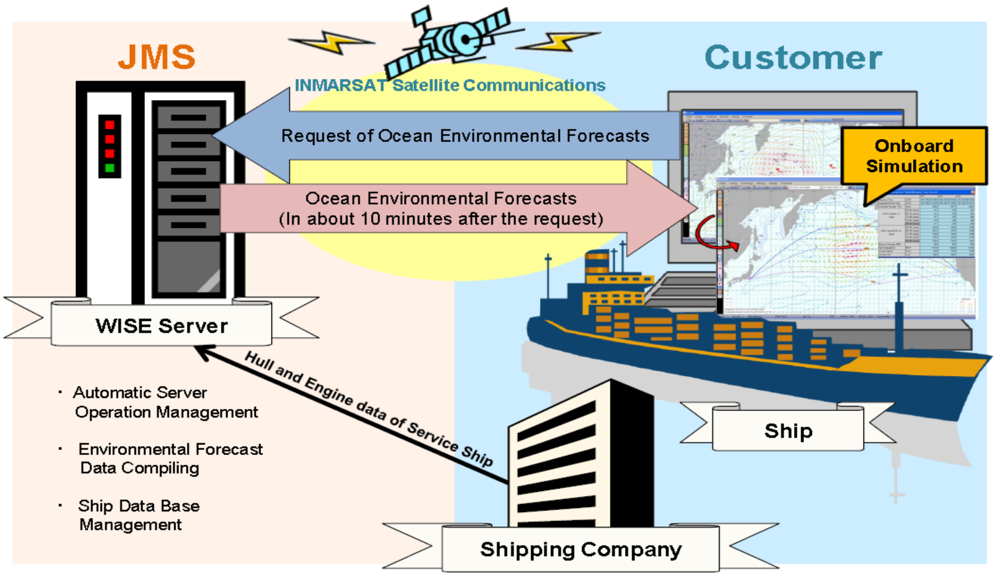


Figure 4.2 Overview over the WISE routing features (Source: WISE, 2012)

Figure 4.2 shows the displayed result of different onboard simulations of one specific voyage. The display distinguishes between three different CRs routes and one MFR route. The fuel consumption of the MFR route is: 1,060.8tonn and for CR1, CR2 and CR3: 1,151.5tonn, 1,254,6tonn and 1,112.6tonn. For all these four routes the specified passage time is 240 hours (same arrival time).

If we take a closer look at the display we can see that the CR2 has the shortest distance (4487 nautical miles) and the CR3 has the longest (4731 nautical miles), although the CR2 looks longer. The reason is that the CR2 is a “great circle route” and CR3 is a “loxodromic route”. The map on the display is Mercator projected i.e. The map section is unfolded for earth roundness.

Because the Earth is round and the map on the display is a Mercator projection the loxodromic route will be shown as a straight line, but it is a curved line in reality. CR2 is shown as a curved line on the Mercator map, but it is a straight line in reality.

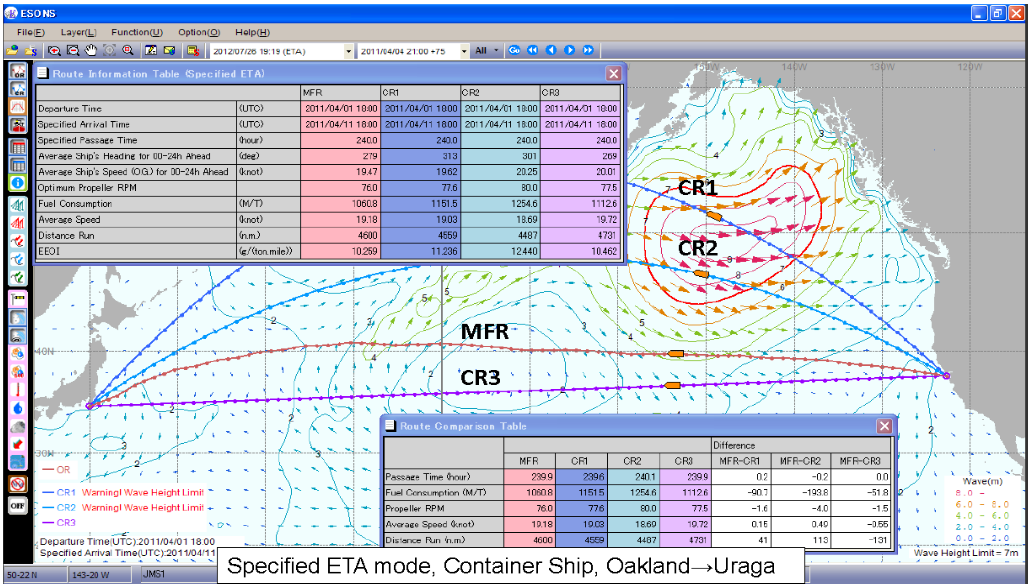


Figure 4.3 Onboard simulation display (source: WISE, 2012)

The routes simulated in figure 4.3 are based on calculations of the following specific weather information:

- Wind/surface pressure forecast chart
- Wave forecast chart
- Ocean environmental forecasts at a point on the route
- Winds on route
- Waves on route
- Ocean currents on route
- Route Information/Comparison Table
- Detailed Information on Route

The ship officers can choose what specific weather information they need to get the best possible basis for optimum route planning. Figure 4.4 shows that information about tropical cyclones is not possible to select because of the selected ocean area are distant from tropical areas.

Figure 4.4 shows a neck of the requested ocean environment information related to figure 4.3. The area and the date/time is the same as in figure 4.3.

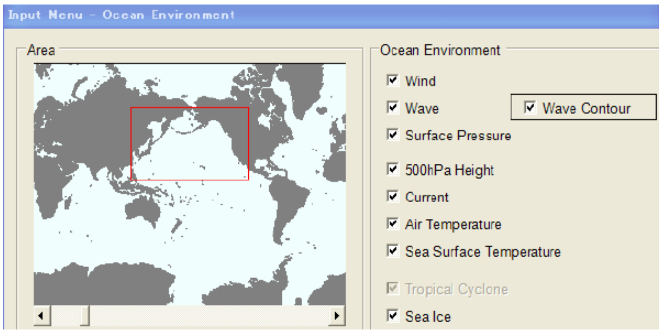


Figure 4.4 (Source: WISE, 2012)

4.2.2 Operation procedure of WISE routing

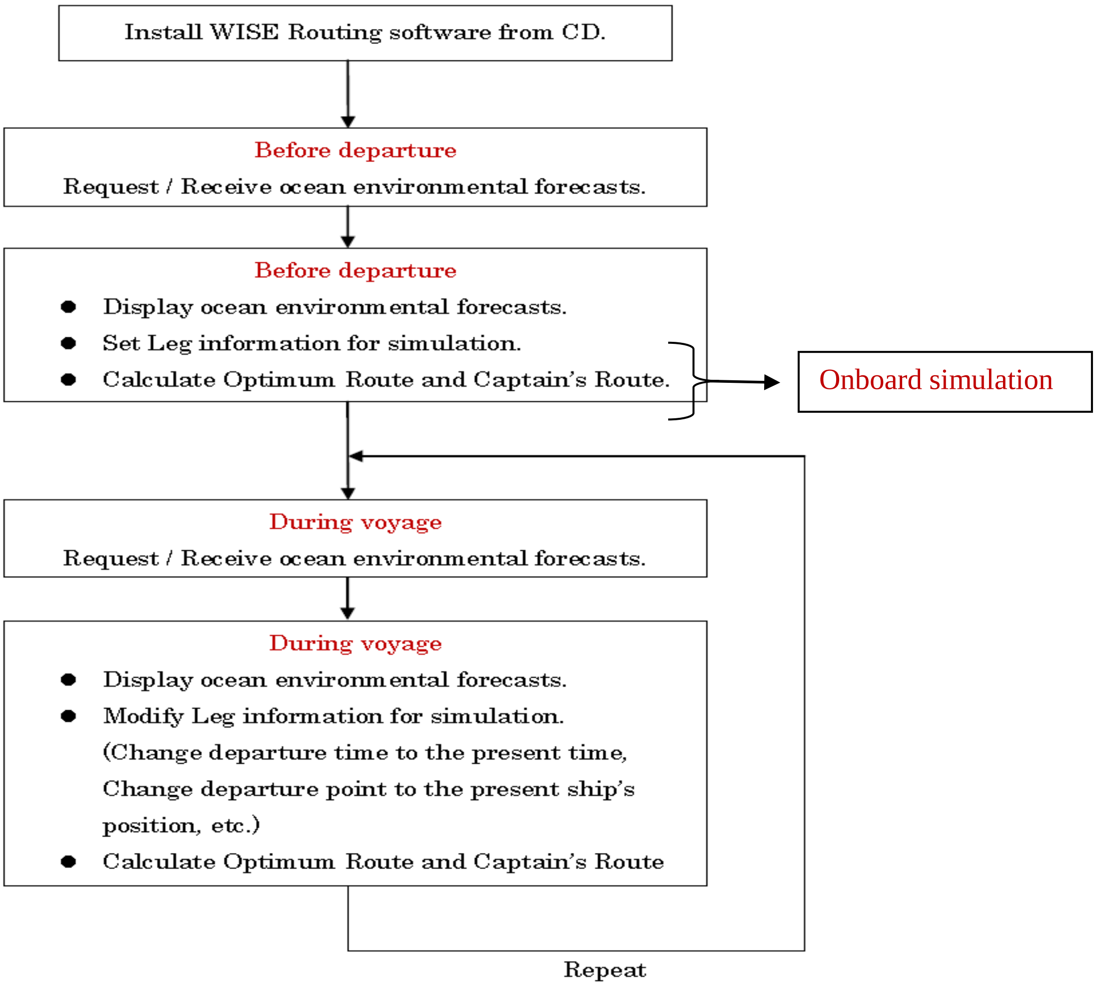


Figure 4.5 Flow diagram over operation procedures (Source: WISE, 2012)

The procedures of onboard simulation starts with setting a leg, and then starting simulation and calculating Captain`s route and Optimum route. Finally the different routes are displayed with compering calculation results (WISE, 2012).

4.2.3 WISE optimum route algorithm

The most relevant algorithm related to The WISE system is the calculation algorithm of optimum route. The term “optimum” related to routing is calculations of:

- Minimum passage time
- Minimum fuel consumption within specified passage time
- Minimum damage to ship and cargo
- Maximum comfort for passengers
- Combination of the above criteria

The optimum route is determined by simulating the navigation of a ship on various alternative routes from departure to destination based on weather forecasts and oceanic conditions. Requirements for an effective weather routing are:

- Accurate weather- and oceanic forecasts (Wind, sea, swell, currents, ice conditions, etc.).
- Good predictions of ship`s speed, engine power, drift angle and ship`s motions affected by waves and swell.
- Practical computation of an optimum route for various demands of both shipmaster and owner.

Figure 4.6 Visualised requirements. (Source: WISE)

Prediction of ship`s speed is the determination to fulfil the equilibrium equation between total resistance (still water resistance, wind resistance and added resistance due to waves) and propeller power. The ship`s speed (V) in waves is represented as the function of wave high (h), wave direction from bow (θ) and propeller power (n). The following equation (figure 4.7) is developed by investigating a ship`s log book due to the impact waves and swell.

$$V = f(h, \theta, n)$$

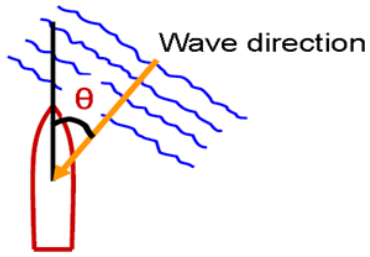


Figure 4.7 Statistical analysis of wave impact. (Source: WISE)

The wave and swell impact has in addition to resistance and a probably loss of speed, also a safety impact. Slamming, propeller racing and shipping green water at bow could easily lead to extreme stress on both ship and shipload.

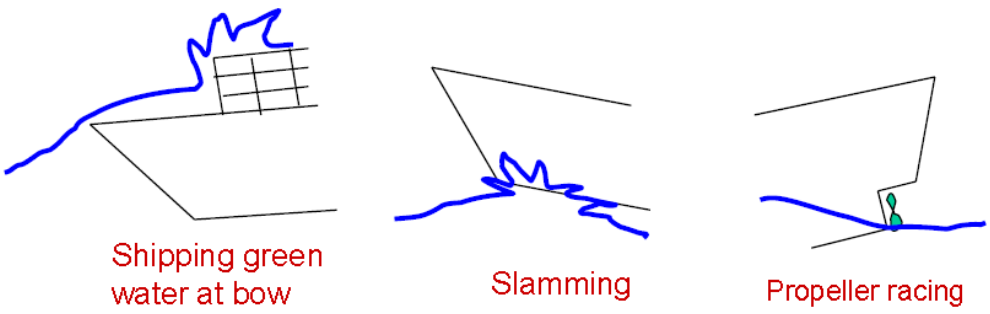


Figure 4.8 Visualization of safety impacts. (Source: WISE)

The mathematical function of WISE optimum routing is expressed by the following mathematical formula:

$$J = \int_{t_0}^{t_f} A(\vec{X}, \vec{U}, t)\,dt + B(t_f, t_s)$$

A	Ratio for optimum route calculation based on "optimum criteria"
$\vec{X} = \begin{bmatrix} \phi \\ \lambda \end{bmatrix}$	Ships position vector (Ø = latitude, λ = longitude
$\vec{U} = \begin{bmatrix} \theta \\ n \end{bmatrix}$	Ship heading = θ, number of propeller revolutions = n
$A(\vec{X}, \vec{U}, t)$	Evaluated quantity per unit time during a voyage
$B(t_f, t_s)$	Evaluated quantity at destination
t_f	Actual arrival time at destination
t_s	Scheduled arrival time at destination given by captain
t_0	Actual time of departure

The function of the mathematical model enables the route to avoid hazards and obstacles that impair the optimal route. Ratio (*A*) in the mathematical function is based on inputs of various weather, oceanic and topographical conditions. These inputs calculates ratio (*A*), and leads to the optimum route on the basis of optimum route criteria's. The quantitative value of ratio (*A*) evaluates the ships position (*X*), heading and power (*U*) at any time during a voyage, and this evaluation adapts the route based on a combination of chosen criteria's. The criteria's for calculation of ratio (A) does not consists of taking into consideration ice conditions in the calculations of optimum route.

There are different methods of calculating optimum route and the WISE system use the isochrone method. An isochrone is defined as an outer boundary of the attainable region from the departure point after a certain time. In the isochrone method, isochrones from departure point are computed one after another, and minimum time route to the destination is determined.

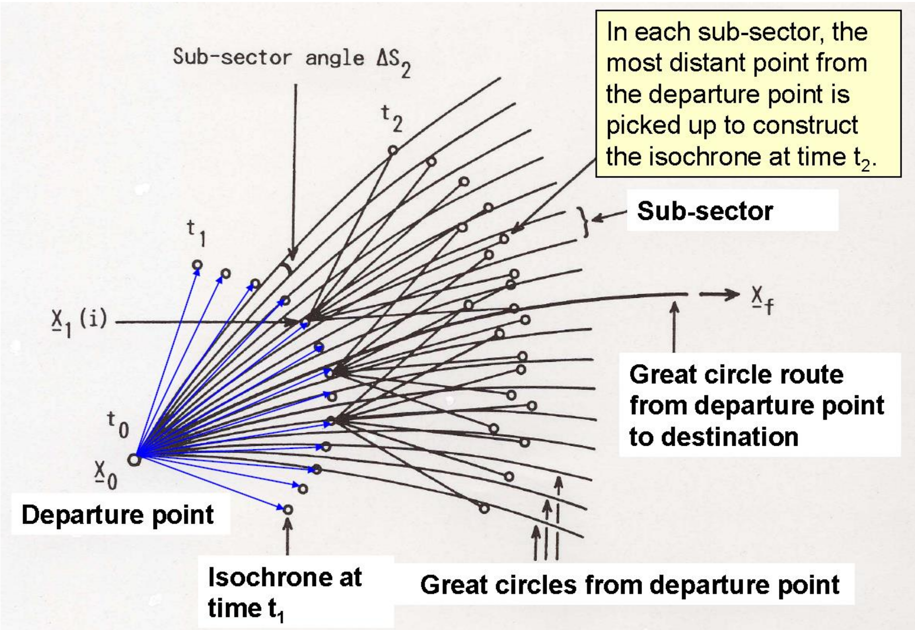


Figure 4.9 Calculation of isochrones. (Source: WISE)

The principle of the isochrone method is that the optimum route could be recalculated with changing weather and oceanic forecasts.

4.3 Introduction of J-Marine GIS

The JRC Marine Geographic Information System (J-Marine GIS) provides proper solutions to various oceanographic problems. J-Marine GIS is based on the underlying technology of the original Geological Identification System (GIS).

A GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. A GIS helps you answer questions and solve problems by looking at your data in a way that is quickly understood and easily shared. GIS technology can be integrated into any enterprise information system framework (esri.com).

Related to this thesis, a GIS based system has to incorporate various types of oceanic information layers witch can be applied upon a "base sea map". J-Marine GIS is capable to superimposing and monitor various types of geographical and oceanic information related to this thesis. Figure 4.10 shows a section of different spatial data/geographical information from J-Marine GIS.

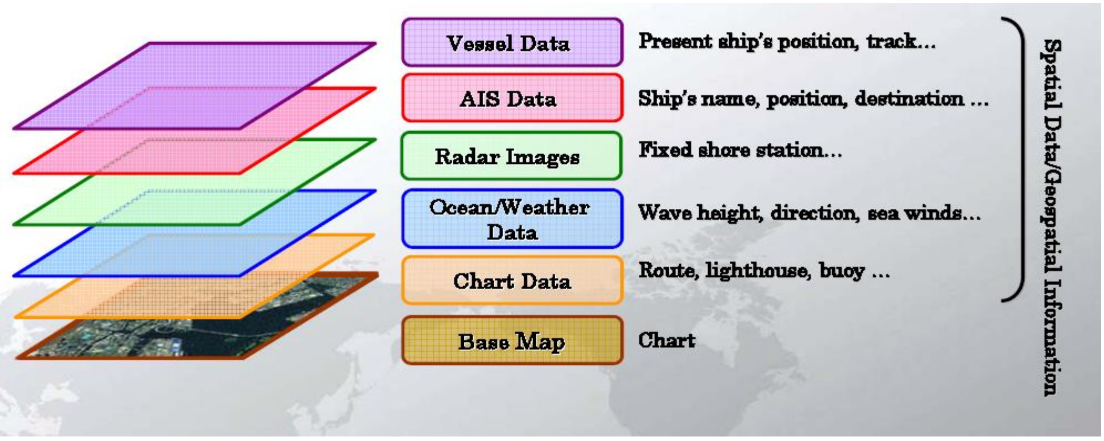


Figure 4.10 Example of marine GIS solution. (Source: J-marine GIS)

J-Marine GIS consist of functional modules witch are controlled by the GIS Data Management System. Any system as the user requires can be configured by incorporated modules to meet the user`s application. J-Marine GIS can be developed to various types of systems by handling different types of information. These systems which is adapted to different user criteria`s is:

- As ship route management as an "Optimum Route Navigation System" by adding an optional layer "Optimum Route Data" for best route calculation.
- Advanced Navigation Systems
- Fleet Management System
- Oil Rig Management System
- Fishing Ground Managing System

4.4 AIS (Automatic Identification System)

There is an important information system in addition to the different information about meteorological and oceanic condition a decision making system should have opportunity to support. This system is a satellite based AIS (Automatic Identification System). AIS are an automatic tracking system for identifying and locating ships position, course, speed and information about the crew and purpose of the voyage. This system was originally made for collision avoidance, VTS (vessel traffic services), search and rescue and different maritime security services limited by VHF (Very High Frequency) covering areas. The covering area for VHF/AIS receivers are typically only up to 74 kilometers.

In this context the AIS system could be an important contributor to increased safety, especially in search and rescue operations. Because of the remoteness, e.g. to a ship in distress relies on assistance from the nearest ship.

In such cases it will be very important for both ships in distress and rescue agencies to know what other ships which are close and able to help the ship in distress. But AIS for Arctic conditions, with long distances, has to be a satellite based monitoring service with a much larger coverage area than the VHF based system.

Studies which are now going on try to monitor AIS-ships from the Norwegian AISSat-1satellite. Experiences from this study have been good, especially in the Arctic (Kjerstad, 2011).

Figure 4.11 shows AIS plots (yellow) north of both Svalbard and Novaya Zemlya.

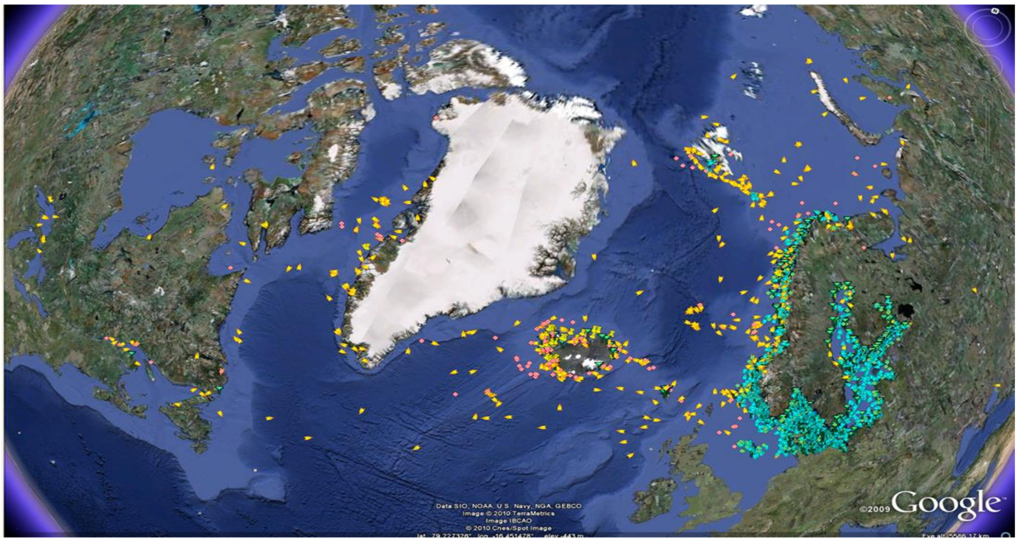


Figure 4.11 AISSat-1 registered ship positions (yellow and pink) (source: KSAT)

4.5 Technology for detection and tracking sea ice

There are several methods for detecting and tracking sea ice conditions such as:

- Satellite images
    - Synthetic Aperture Radar (SAR) - high resolution
    - Optical - low resolution
- Airplane recognizance
- Marine radars
- Sonars and different autonomous underwater vehicles (AUV)
- Visual observations

The most appropriate information to take into account for optimal decision support is remote sensing from satellite radar images. This remote sensed information gives the ship-masters and mates opportunity to view different conditions from a distance, rather than by direct contact. In modern usage, the term generally refers to the use of aerial sensor technologies to detect and classify objects on Earth both on the surface, and in the atmosphere and oceans.

For this thesis the remote sensing information will be referred to the ability of satellite radars to detect features, like sea ice, on the Earth's surface. The other detecting methods give more direct information during a sea voyage instead of in advance.

The principle behind remote sensed satellite radar images are actively emitted microwaves sent by transmit sensors, on the radar, towards the earth`s surface. These emitted microwaves reflect off the earth`s surface and return to the receive sensors on the radar. The satellite radar sensors are divided into two categories, high- and low resolution sensors. Low resolution satellite radar images are limited by poor resolution (5-50 km) and are depending of clear weather to be able to give the users usable data. High resolution satellite radar images are providing far better data images (resolution of about 30 m) and this system are also independent of clear weather. Therefore, high resolution satellite images would be the most appropriate tool for decision-making (Kjerstad 2008).

4.5.1 Synthetic Aperture Radar (SAR)

SAR is equipped with advanced sensors that sends microwaves towards the earth`s surface and receives the signals reflected from the surface. This reflected signal is called backscatter. Synthetic aperture radar systems are able to observe features and objects like ice on the sea surface both at night time through cloudy and foggy conditions. It is also possible to classify the age, thickness and movement of sea ice from SAR data information.

SAR microwave sensors can distinguish between first-year and multi-year ice by detect the different electromagnetic properties of the ice. In general, thicker multi- year ice is readily distinguishable from the younger, thinner ice because radar energy bounces back to the sensor from the bubbles in the ice left when brine drains.

Synthetic aperture radars (SAR) are very useful tools for measuring the extent of thick and thin sea ice. Figure 4.12 shows an illustration of the Cryosat–2 satellite.

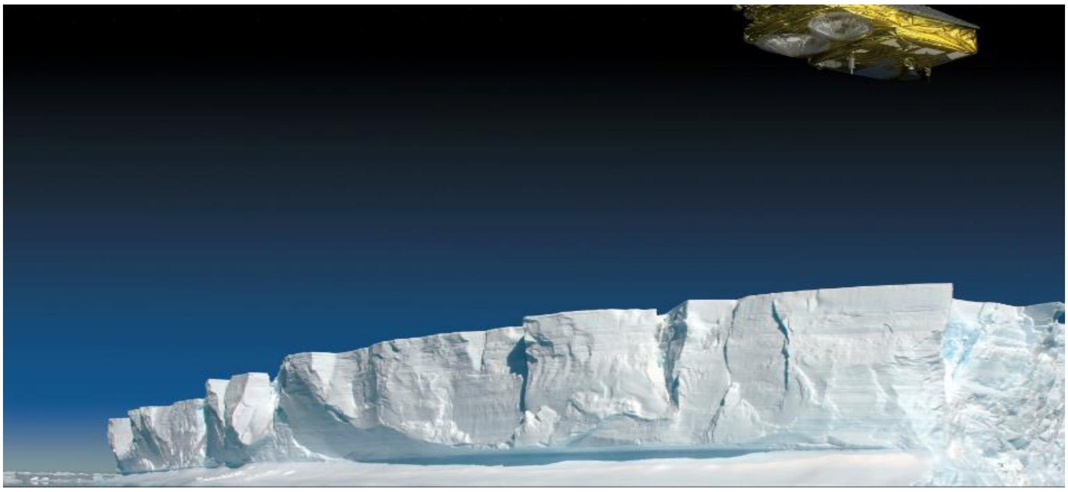


Figure 4.12 Image of Cryosat-2 satellite (Source: ASTRIUM, 2013)

In general the SAR sensor operates in three different modes depended of what image resolution which is required:

- *in the 'Spotlight' mode, an area 10 kilometres long and 10 kilometres wide is recorded at a resolution of 1 to 2 metres,*
- *the 'Stripmap' mode covers a 30-kilometre-wide strip at a resolution between 3 and 6 metres,*
- *and in the 'ScanSAR' mode, a 100-kilometre-wide strip is captured at a resolution of 16 metres* (DLR, 2011).

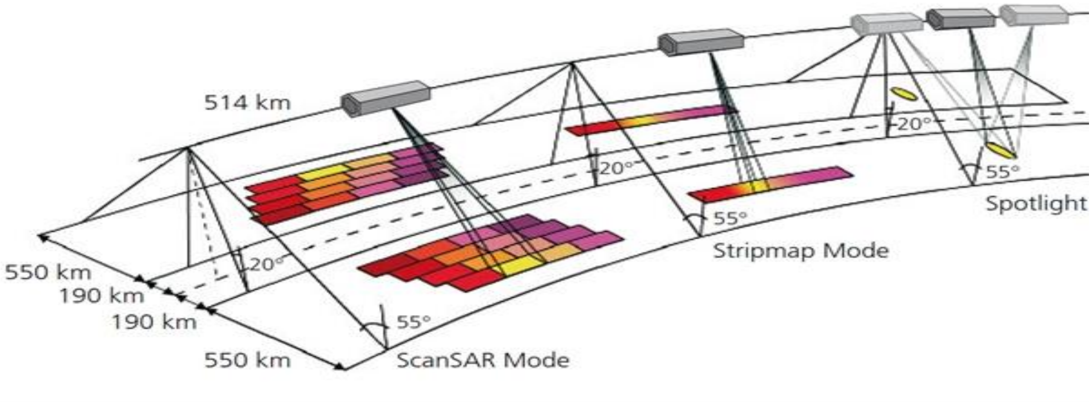


Figure 4.13 Image of different SAR modes (Source: DLR, 2011)

The principle behind measuring the thickness of the ice from a satellite is exemplified by the Cryosat satellite systems. The satellite measures the thickness of polar ice using an instrument called an altimeter, which fires pulses of microwave energy at the ice and records how long they take to return. The Cryosat-2 satellite has two antennas which makes it possible to scan the surface very precisely. The calculation of the ice thickness is done by comparing how long it takes for the echoes to return from the top of ice floes and from the water in cracks in the ice, called leads. The aim is to measure the freeboard which is the part of the ice that sits above the waterline (ASTRIUM, 2013).

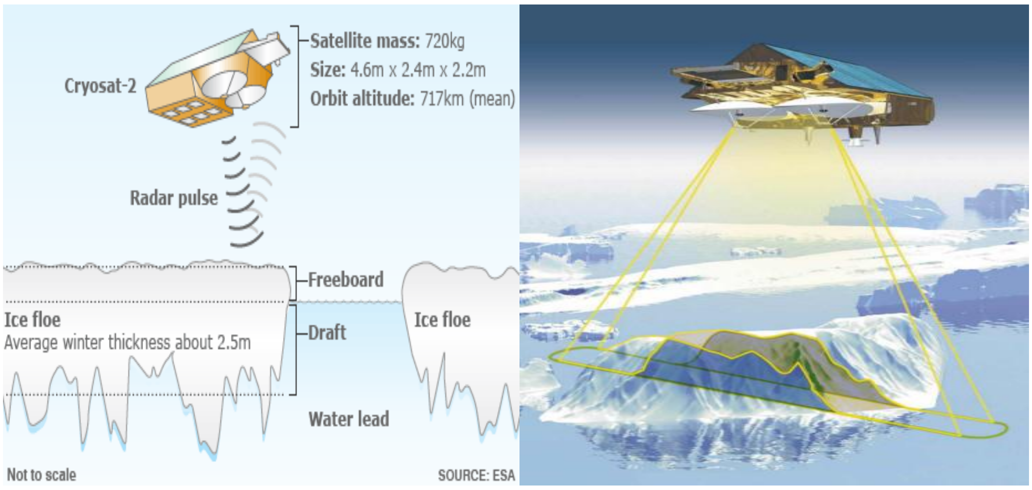


Figure 4.14 Image of cryosat-2 principle with2 antennas (Source: ASTRIUM, 2013)

4.6 Technology for transmitting and receiving data

Technology for transmitting and receiving data information related to this thesis is a complex process. The whole technology is based on transferring different data information through different Satellite systems. In general, we can distinguish between two different satellite systems, Earth observation satellites and different communication satellites. Each satellite system has to have ability to communicate with a ground station or with each other.

Active Earth observations SAR-satellite both transmits and receives radar pulses and then transmits the resulting image to an appropriate ground station. The received image is then processed or data handled and then distributed to different users through appropriated communication satellite systems. The different users (in this case) ships, have to receive the processed image through a communication satellite system which is related to the coverage area of the satellite.

It is not necessarily always possible to receive completely updated images if a ship is far north In Arctic. This will be discussed in 4.5.3 “Challenges and limitations of SAR satellite systems in Arctic”.

4.6.1 Ground station network services

Ground station network services consist of receiving and processing raw data from satellites and then distribute the processed data to different users. There are several different providers of such services, but this thesis will just take in consideration the best suited services for the task, Kongsberg Satellite Services (KSAT).

KSAT is a world leading ground station network for polar orbiting satellites. Their ground stations at Svalbard, the Arctic Svalbard Satellite Station (SvalSat) at 78^0N latitude and in Antarctic (Trollsat) at 72^0S latitude enable a coverage delivering of 26 out of totally 28 northern and southern polar passes per day.

Svalsat alone is the largest commercial ground station in the world, and it provides all- polar orbit satellite support (14 of 14 passes per day).

KSAT utilize Synthetic Aperture Radar (SAR) images from polar orbit SAR satellites to show detailed ice conditions around ships and for every specific area, independent of weather and sunlight conditions. The information is delivered in efficient data packages which can be accessed even under restricted low-bandwidths conditions, such as over satellite phones.

These images, as recent as 30 minutes, provides the ship officers with the very latest information on the sea ice condition of their surroundings and anticipate what lies ahead (KSAT, 2013).

Figure 4.15 shows different examples of SAR images processed and distributed by KSAT.

Figure 4.15 Detailed SAR image examples (Source: KSAT, 2013)

Figure 4.16 shows a flowchart overview over different systems and components which is involved in the data information flow from an image is taken to the user can receive it.

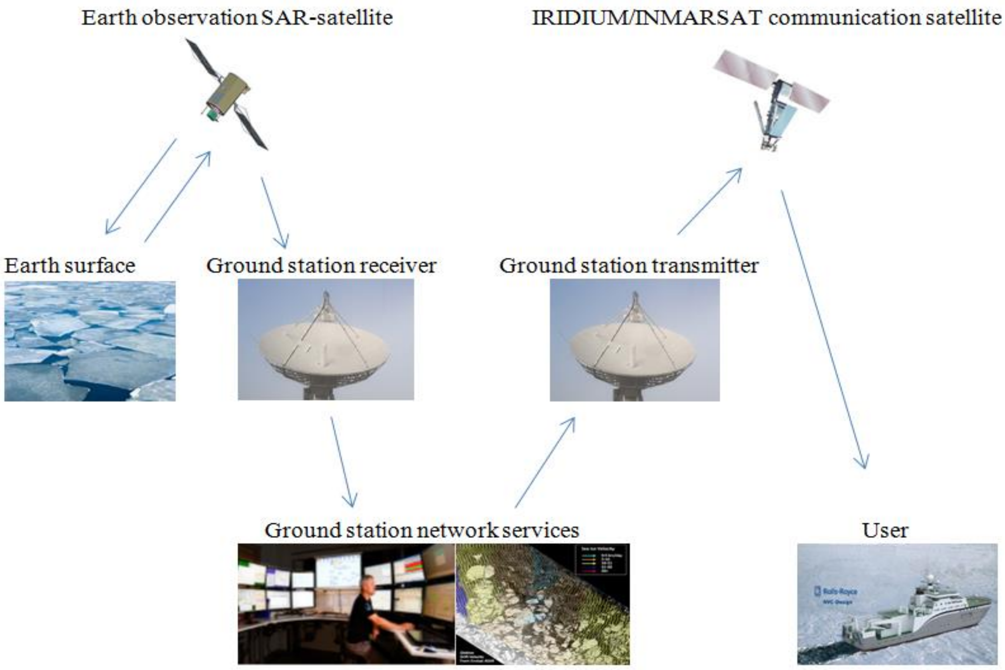


Figure 4.16 Flowchart overview of data information (own illustration)

4.6.2 Meteorological oceanographic forecasting providers

Like different ship routing- and ground station network services there are many providers of weather and meteorological oceanographic forecasts. The common features of these meteorological oceanographic forecast providers, related to this task, is that they are depending of different satellite data distributed by ground station network services. Some oceanographic meteorological providers distribute special forecasts over specific areas and some provides more general forecasts for whole regions or worldwide.

This thesis will just concentrate on The Norwegian Meteorological Institute (NMI) and the oceanic environmental forecasts for the WISE routing system.

Both these forecast providers can supply various weather services like short- and long term forecasts focusing on specific weather information in addition to more ordinary forecasts like:

- Earthquake warnings
- Tsunami warnings
- Typhon, storm, hurricane and polar lows warnings
- Different ice information and warnings
- Icing on ships warnings
- Sea current, wave high and direction information
- Specific and general forecasts

To enable such diversity in their forecasts both NMI and the oceanic environmental forecasts of WISE has established cooperation with several other weather providers and different ground station network services. MNI has for example established cooperation both on national, European and international basis and both NMI and Japan Meteorological Agency (JMA) is members of World Meteorological Organization (WMO) (met.no).

The ocean environmental predictions of WISE routing are provided with specific data by several providers like:

- Wind, wave, surface pressure, air temperature forecasts up to 192 hours ahead are provided by Japan Meteorological Agency and this forecasts is updated every 6 hours.
- Ocean current analysis data are provided by HYCOM (U.S. Hybrid Coordinate Ocean Model) and this forecast is updated once a day.
- Typhoon, hurricane, cyclone forecasts are provided by U.S. Navy Joint Typhoon Warning Center and this forecast is updated every 6 hours.
- Sea surface temperature and ice concentration analyses data is provided by U.S. NOAA NCEP (National Center for Environmental Prediction) and this forecast is updated once a day.

Despite of this cooperation with different providers, there is reason to believe that there are some differences between NMI and WISE forecasts for Arctic areas. All weather forecast providers have developed weather services focusing on areas associated to their interest.

4.6.3 Challenges and limitations of satellite systems in Arctic

Ships sailing in Arctic are depended on good and continuous connection with satellites to be able to receive and transmit voice and data information. There are two different satellite systems which provide data communication in Arctic. The geostationary- and the polar orbit satellite communication systems. The main differences between these two systems are covering areas.

The general coverage area for geostationary satellites is between south for 70-75^0 North latitude and north for 70-75^0 South latitude (figure 4.17). The figure shows that the exact coverage latitude is depending of what longitude the ship is at.

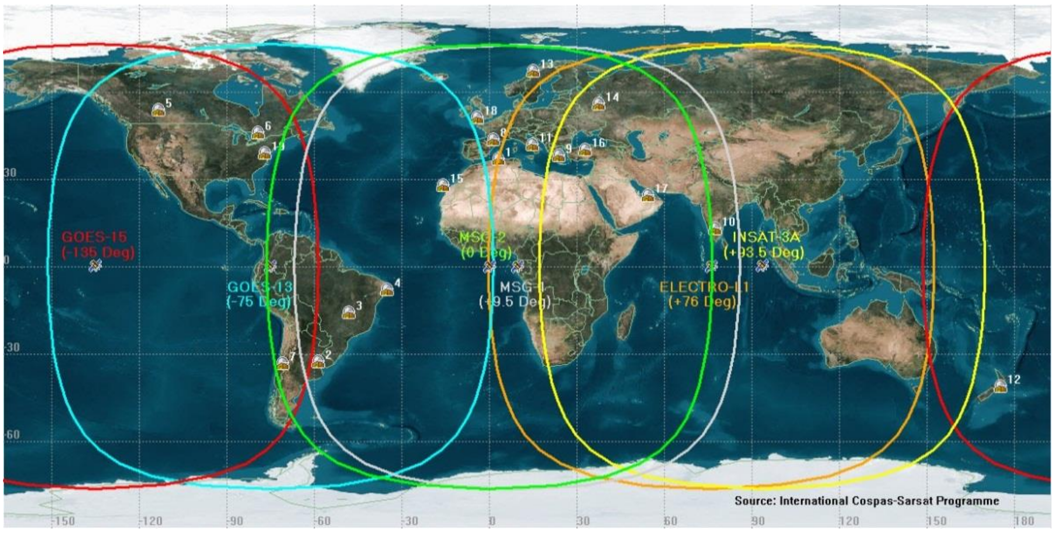


Figure 4.17 GEOSAR Satellite Coverage area (Source: International Cospas-Sarsat Programme)

The communication systems that communicate with geostationary satellites are the INMARSAT system and the communication system that is connected to polar orbit satellites is IRIDIUM. Figure 4.18 show the IRIDIUM coverage area in Arctic.

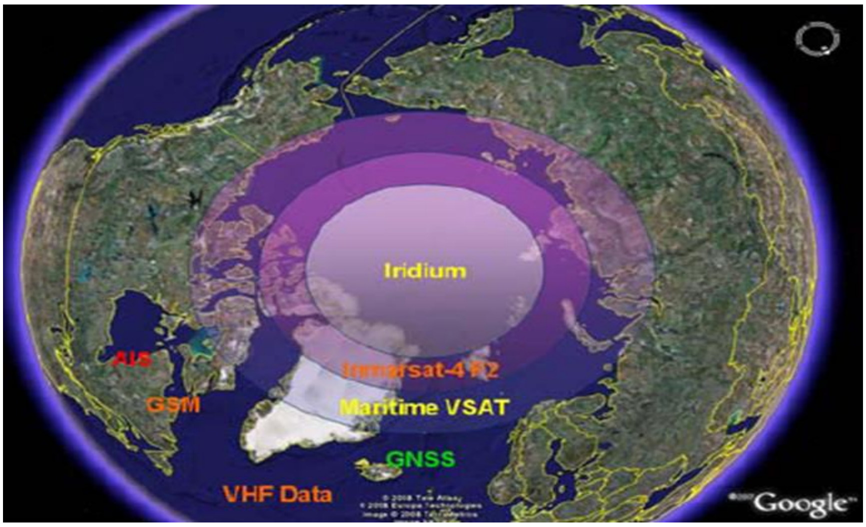


Figure 4.18 Marine communication system coverage (Source: MarSafe.Pdf/sintef)

Ships located in positions north of the geostationary covering areas are depended upon receiving data signals from polar orbit satellites. Polar orbit satellites cover the areas north and south for the geostationary satellite coverage areas in addition to worldwide coverage. The IRIDIUM satellite constellation consists of 66 active satellites in orbit, and additional spare satellites to serve in case of failure (Wikipedia). Polar-orbit satellites which on average orbit the Earth 14 times per day can today provide satellite images (earth observation), telecommunications (IRIDIUM) and ship positions based on the AIS signal.

Tele- and AIS communication is continuous worldwide covered by polar orbit satellites, but earth observation data has to be downloaded from polar orbit SAR satellites to an appropriate satellite observation service.

When the data is received by the satellite observation services it then has to be processed and sent back to selected ships trough IRIDIUM or INMARSAT communication satellites cf. flowchart at figure 4.11.

Limitations and challenges related to communication satellite systems in Arctic are limited bandwidth of the IRIDIUM communication system. IRIDIUM is the only system to transmit and receive data by far north in Arctic, and the normally bandwidth is just 2.4 Kbps, but the system also have a special service called “open port”. This special service allows the system to use several telephone lines at the same time. With adapted equipment on board a ship, it is possible to achieve a transmission speed of up to 128 Kbps (Kjerstad, 2011).

The bandwidth limitation of IRIDIUM reduces the ability of frequent transmits of images, if the resolution is to be maintained. Figure 4.14 shows an example on a high resolution image. The size of this particular image Is 2730.22 Kb (2795748 bytes). With a bandwidth of 2.4 Kbps it will take almost (2730.22Kb/2.4Kbps = 1137.5 sek) i.e. 19 minutes to download this image.

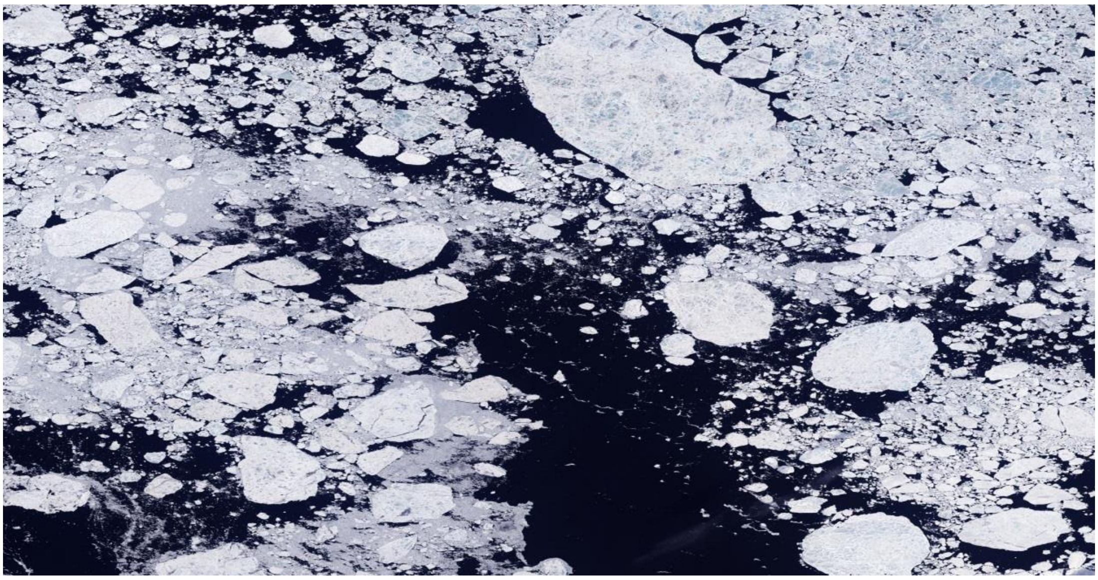


Figure 4.14 High resolution ice image (Source: AGU)

There are also possible limitations and challenges related to Earth observation SAR satellites. Each polar-orbiting SAR satellite is capable of image just small parts of the Earth's surface on each orbit.

This limitation of SAR data Polar-orbiting SAR satellites is related to their low altitude orbits (about 600-1000 km), and the low altitude affects the width of each swipe of the satellite cf. figure 4.4. An average polar orbit satellite is orbiting the Earth approximately every 100 minute I.e. 14 times per day and the line of the orbit shifts with the rotation of the Earth. For one satellite to cover the hole Earth`s surface can take up to several months, and to ensure good coverage of a specific area so the area must be covered by several satellites. Figure 4.15 show the ground paths of multiple orbital revolutions during one day for one near-polar orbiting satellite (KSAT, 2013).

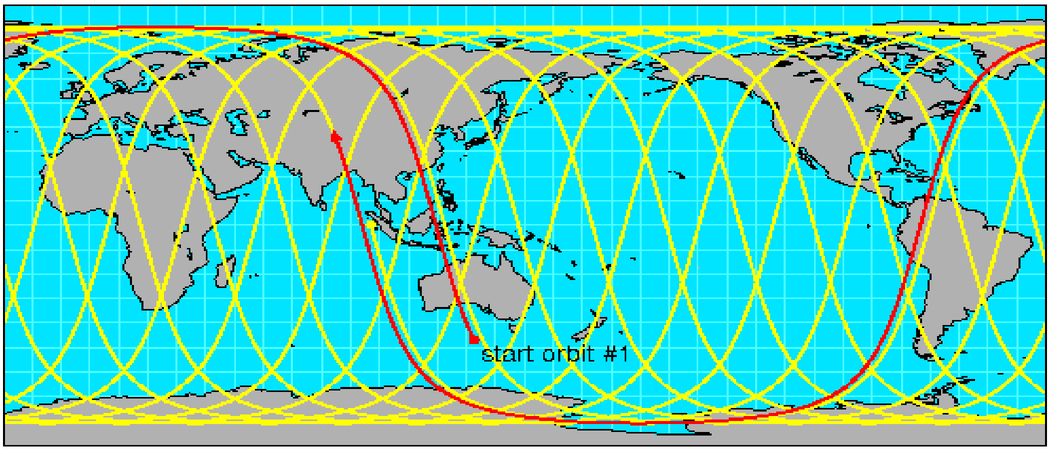


Figure 4.15 Multiple orbital revolutions during one day (source: sfsu)

KSAT`s vise-president, Fredrik Landmark claims that KSAT are able to receive data from all 14 s passages of polar orbit satellites per day, at Arctic Svalbard Satellite Station (SvalSat) ground station. He also claim that satellite owners and operators can both upload tasking commands and receive data from every orbit from one ground station (SvalSat). Despite of KSAT`s receive opportunities some areas will probably be less covered than other, as showed In figure 4.16.

Tromsø Network Operation Centre (TNOC) at KSAT supports more than 50 different SAR satellites (05.05. 2011) and the number of satellites is increasing so every area of the Earth, that probably is less covered, will be more rapidly covered in near future (KSAT, 2013).

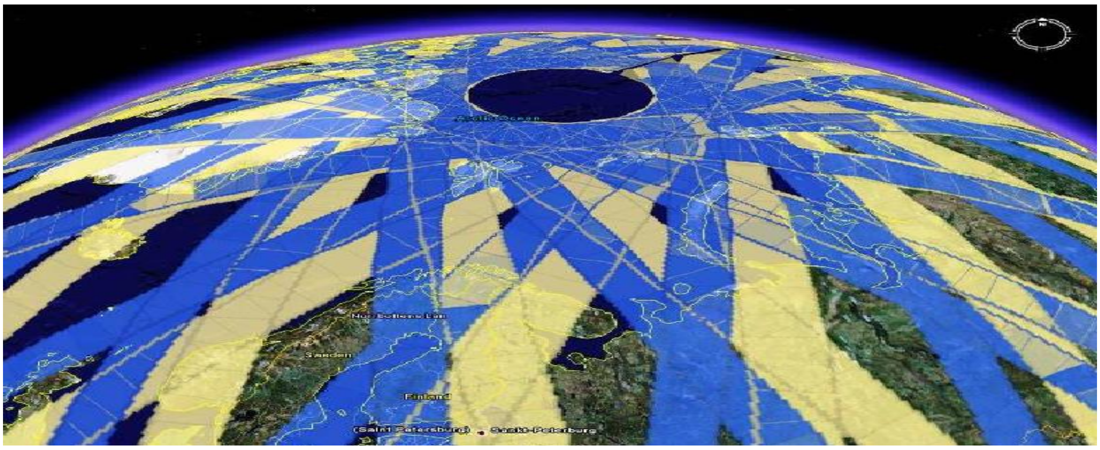


Figure 4.16 Visualization of different polar orbit satellite tracks (KSAT, 2013)

5 Simulation and results

This part of the thesis was to investigate different aspects of routing and different weather and oceanic input associated to routing systems. The survey was divided into three simulation parts. The first simulation part was to test out similarities and possible differences between weather forecasts from NMI and “ocean environmental forecast” by WISE. The second simulation part of the investigation was to test out how detailed the WISE system showed specific ice conditions on the display. The third and last simulation part of the investigation was to test how the WISE system took into account elements of ice when calculating optimum routes.

The first simulation was to test if there were similarities and possible differences between oceanic weather forecasts by NMI and “ocean environmental forecast” by WISE. The area for this oceanic forecast simulation was outside the coast of Troms and Finnmark, in Northern Norway. Both these weather distributors base their forecasts on the same satellite images, but they use different models to predict the weather.

Detection of polar lows is difficult to predict before they appear visually or on a satellite image, and there are various models used for detection and prediction of polar lows. The weather situation in areas where polar lows appears becomes unclear with changing winds, and these situations are appropriate for this part of the test. Therefore, detection of polar lows was chosen as object for this part of the test.

Figure 5.1 shows a satellite image of a polar low west of Lofoten. The center of the low is marked with a red cross.

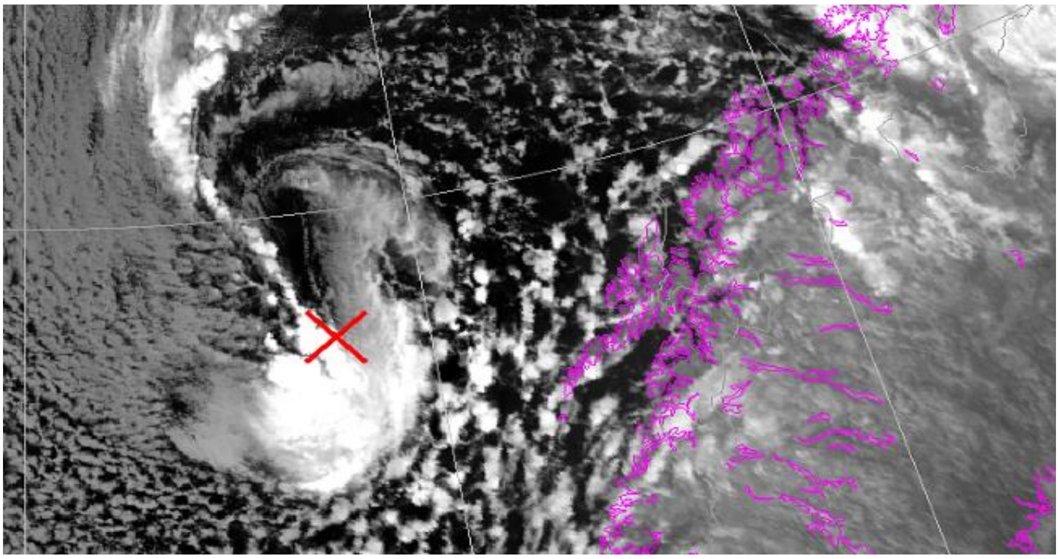


Figure 5.1 Image of a polar low 4th April 2013, 08:00 UTC (Source: met.no)

Figure 5.2 and 5.3 shows an overview over the wind situation over the same area and time as in figure 6.1. This overview is taken from requested "ocean environmental forecast" by WISE and from NMI.

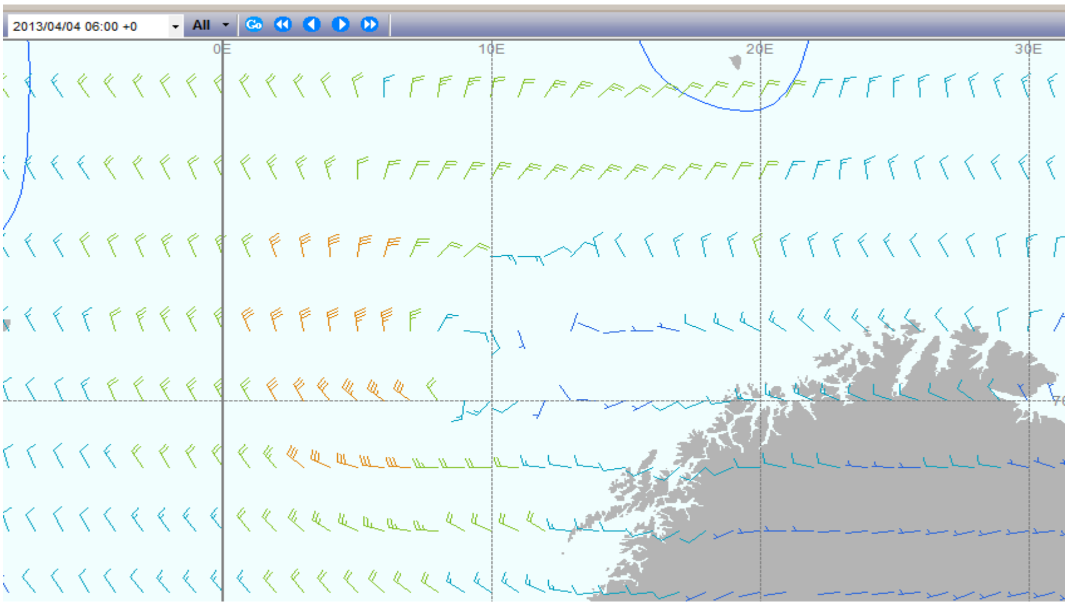


Figure 5.2 Display of wind situation 4th April.2013, 06:00 UTC (Source: WISE)

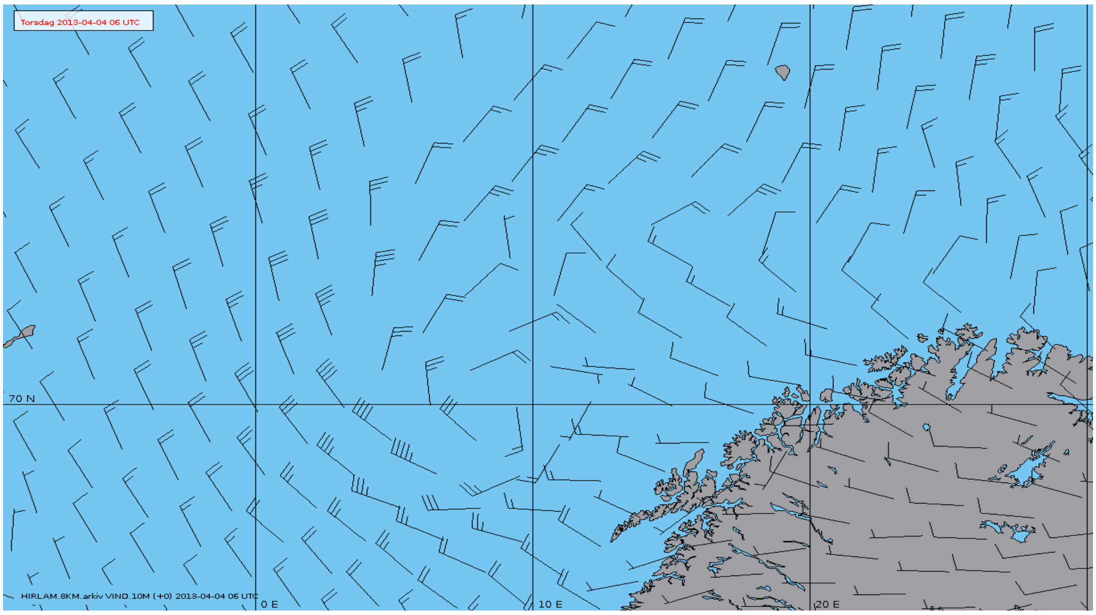


Figure 5.3 Display of wind situation 4th April.2013, 06:00 UTC (Source: met.no)

Figure 5.2 and 5.3 shows that both “ocean environmental forecast” by WISE and NMI has detected and also displays the same polar low as the satellite image in figure 5.1. Notice that the center of the low is further south on the satellite image than on the WISE and NMI display. The reason is that the low was moving in southerly direction that day, and it matched well with the time difference of two hours between WISE and NMI display and the satellite image.

The second simulation part was to test out how detailed the WISE system showed specific ice conditions on the display. The test area was a selected section around Bjørnøya at date 8th April. Figure 5.4 shows how the Wise system displays the ice condition in the selected area. The blue ring marked with 10 that stretch a little bit south of the island shows that there is 10% ice within the ring.

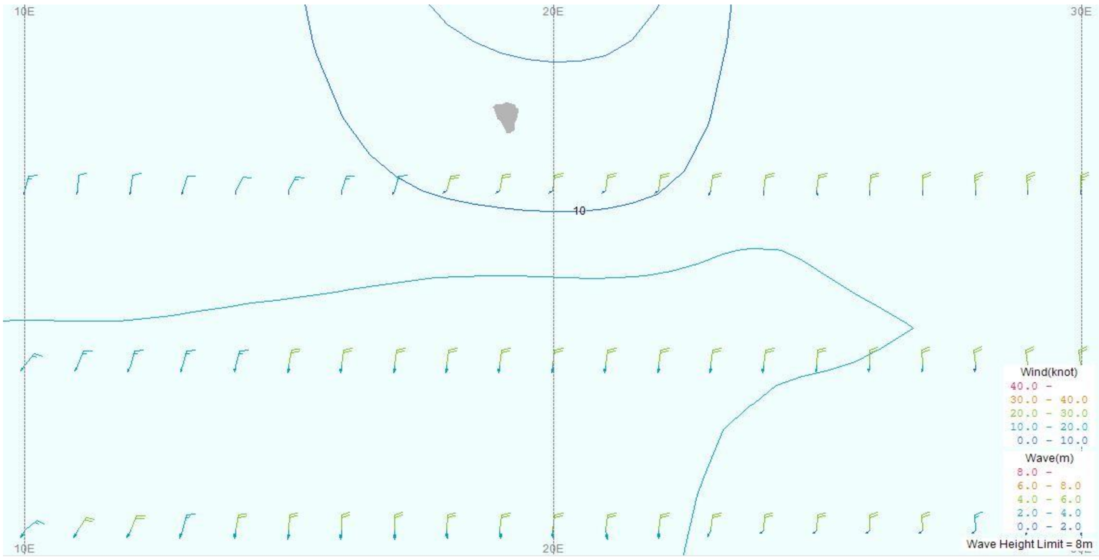


Figure 5.4 Ice condition at Bjørnøya 8th April 08:00 UTC (Source: WISE)

Figure 5.5 shows the ice conditions of the same area processed by NMI. In this display, the ice is indicated by the color combination of blue (open water) to red (very close drift ice). The green (very open drift ice) area is a little more detailed than on the WISE display.

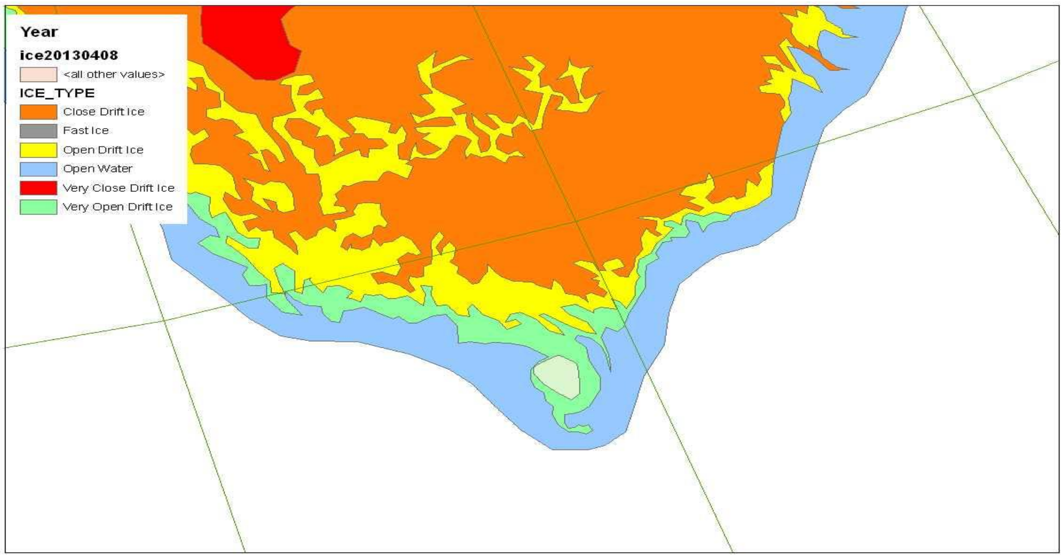


Figure 5.5 Ice condition at Bjørnøya 8th April 08:00 UTC (Source: met.no)

Figure 5.6 shows a photo taken by Sjur Wergeland at NMI 8th April 2013 (the same day) approximately 13:00 UTC. The photo shows the ice distribution, in real, and it`s almost similar with the green area from figure 5.5.

Figure 5.6 Bjørnøya 8th April (photo: Sjur Wergeland)

By analyzing figure 5.4 and 5.5, one can assume that the WISE system makes a rougher estimate of the ice conditions than dedicates ice images like figure 5.5.

The third simulation part of the investigation was to test how the WISE system took into account elements of ice when calculating optimum routes. A route from north of Jan Mayen to south of Cape Farwell, Greenland was selected. This route was selected because it would be affected by ice during the route. Figure 5.7 shows an overview of the area for the selected route and a rough estimate of the route.

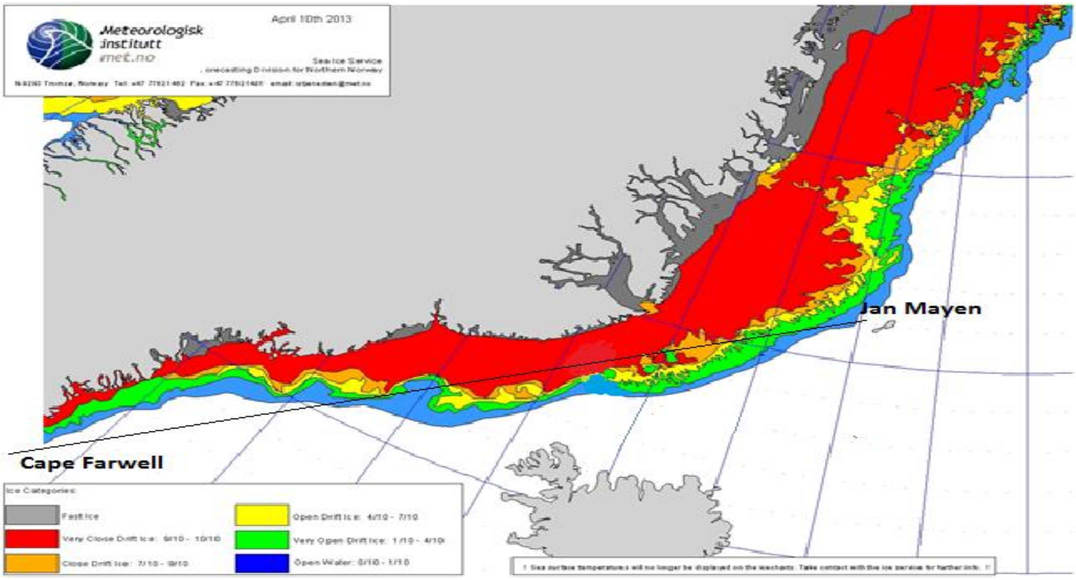


Figure 5.7 Overview of routing area 10th April 2013 (Source: met.no)

The WISE system was set up with calculating an optimum route based on requested “ocean environmental forecast” for the same area and date. The simulated voyage started 9th April 13:41 UTC and set the ship in position (67^{0}27`N 027$^0$33`W) 10th April 2013 15:00 UTC. Figure 5.8 show the ship position visually on the WISE display.

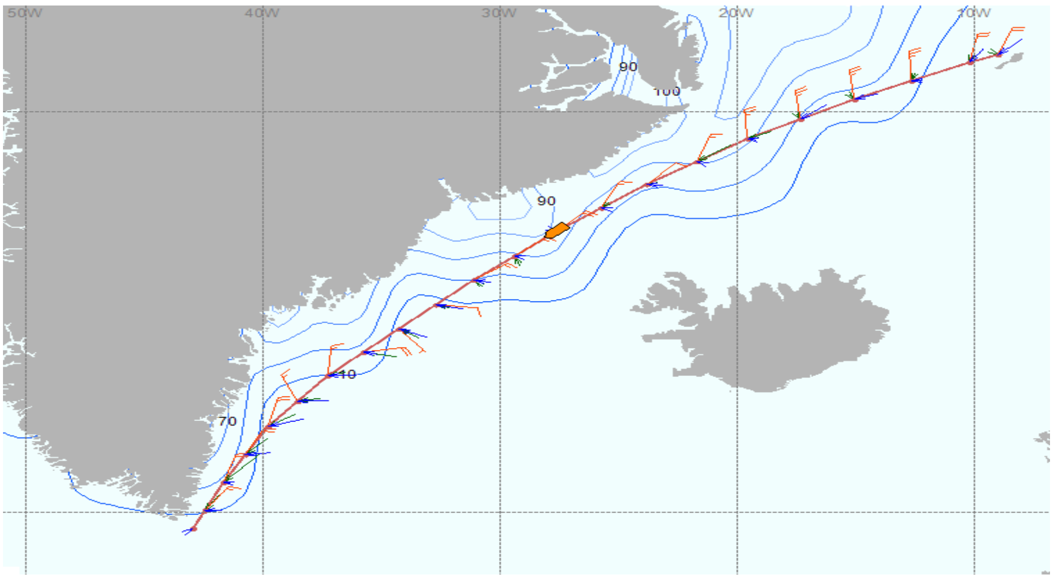


Figure 5.8 Ship position 10th April 2013 15:00 UTC (Source: WISE)

The position of the ship, 10th April 2013 15:00 UTC, is in an area where ice conditions are not suitable for sailing. Figure 5.9 shows the position visually in an area of very close drift ice. The ship position is set into the figure by NMI.

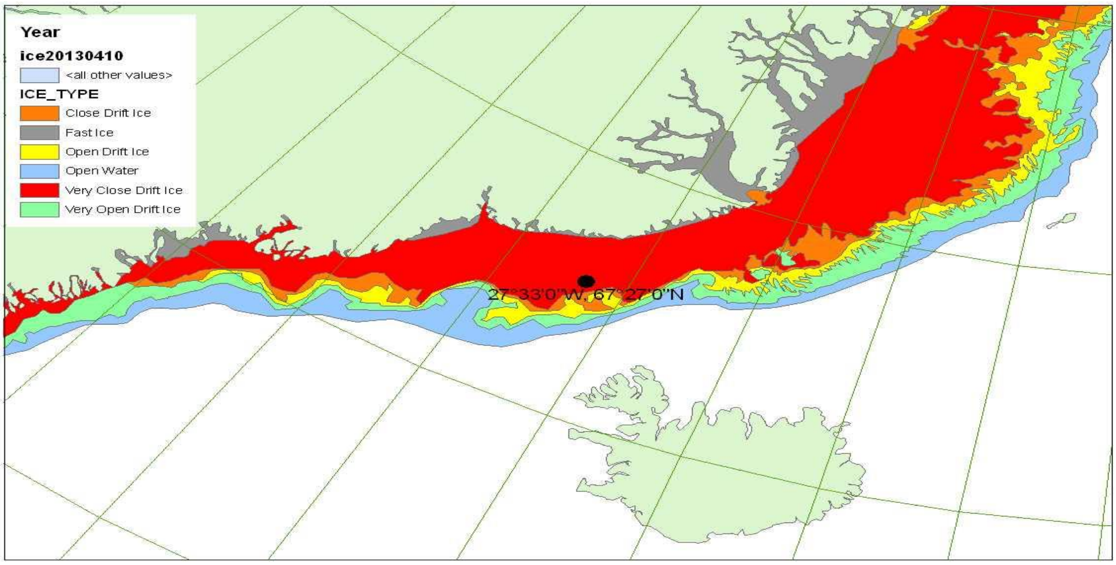


Figure 5.9 Ship position 10th April 2013 15:00 UTC (Source: NMI)

The third simulation part of the investigation showed that the WISE system was not taking into account ice conditions in their calculation of optimum routes. The optimum route was calculated and displayed straight through icy waters.

6 Proposal of Ice algorithm or model solution

The best possible knowledge of different ice situations is essential in planning and performance of marine operations in high north Arctic areas. The proposal of an ice algorithm or a model for how different ice information could lead to improved safety of maritime operations in Arctic is based on current and relevant theory. There are various criteria that must be applied to such a system, according to theory mentioned earlier in the thesis. First of all the model solution must be designed for best production performance.

Production assurance can be seen as a process of continuous optimization of the production facility production process. Such a continuous improvement process should be applied throughout the various life cycle phases (Gao, 2009).

The production performance concept related to this task is how reliable and which opportunities the system is made for continuous improvements. The reliability of the system is also related to the totality from development of a good design to the quality of all hardware, software input and output. Best production performance shall ensure that the system operates under different conditions.

Professor Norvald Kjerstad divides different ice information into three categories, based on degree of resolution and accuracy (Kjerstad 2011):

- Statistical data
- Low resolution data
- High resolution data

This part of the thesis is just limited to evaluation of different high resolution polar orbit SAR satellite data. To be more specific different relevant ice information like:

- Ice thickness
- Ice trends
- Ice movements
- Ice concentration
- Ice age

After studying different algorithms and models for calculating different specific ice information it became clear that each of these mentioned ice information is calculated with its own algorithm cf. ITSARI, HIROMB etc. To develop a model to provide users with relevant ice information related to all different maritime operations is complex.

It may be useful to differentiate between dedicated- routing and decision support systems. A routing system is basically a system that ensures a ship`s voyage from departure to arrival by dedicated criteria's, but it`s not a system that will work as a monitoring system for different maritime operations within specific ice covered areas. Routing systems like IRIS and WISE are build up in the same way with an onshore part where all collected data is processed, compressed and prepared for user's needs.

A dedicated decision support system could be based on a GIS application where the users can choose between different ice information related to the activity and the ice conditions within a specific area cf. figure 7.1. Many electronic chart systems (ECDIS) are now ready to present ice data as separate information layers which can be shown together with the chart basis (Kjerstad, 2011), but this GIS based system must be displayed on a dedicated display designed for GIS. The reason for this is that today's electronic map systems (ECDIS) are not adapted to GIS.

The presentation of different ice information, upon the base chart, could be based on a similar system as the J-Marine GIS system. This system collects various types of information from ships and meteorological support sites in different layers.

These different layers can be requested by the users according to the needs and then displayed upon an underlying GIS based electronic chart cf. figure 6.1.

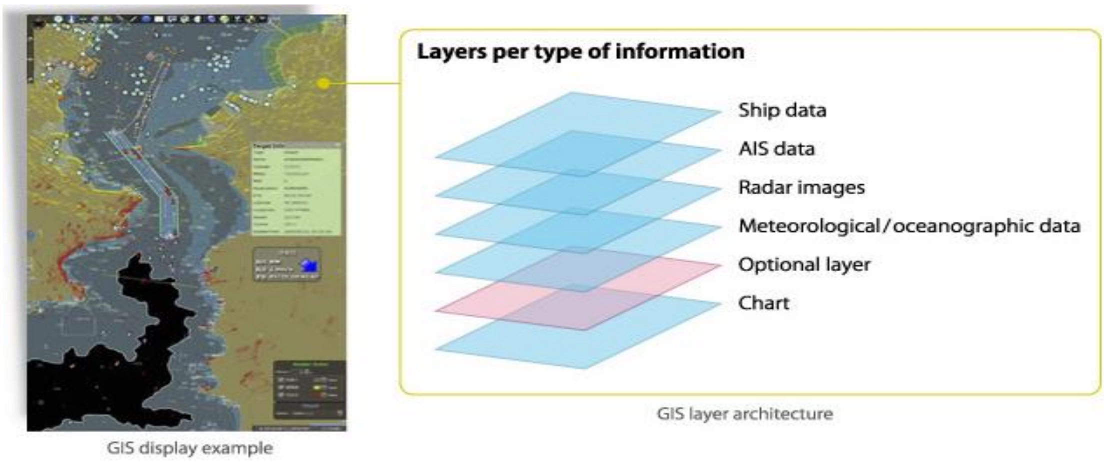


Figure 6.1 GIS display example with layers (Source: J-Marine GIS)

A system like G-Marine GIS could be an appropriate solution if the different layer, in addition to relevant existing information, consists of different relevant ice information. This solution will give the users opportunity to choose exactly what ice- and other information they need for specific operations, in Arctic. A trained user has the best possibilities to know what kind of data information needed for each operation.

All systems should have a list of optional information the users can choose to have displayed onboard or as an input for calculating different ship routes.

The investigation in this thesis gave a first impression that ice information is somewhat lacking and depended of general and too little detailed oceanic forecasts cf. figure 5.4 and 6.2.

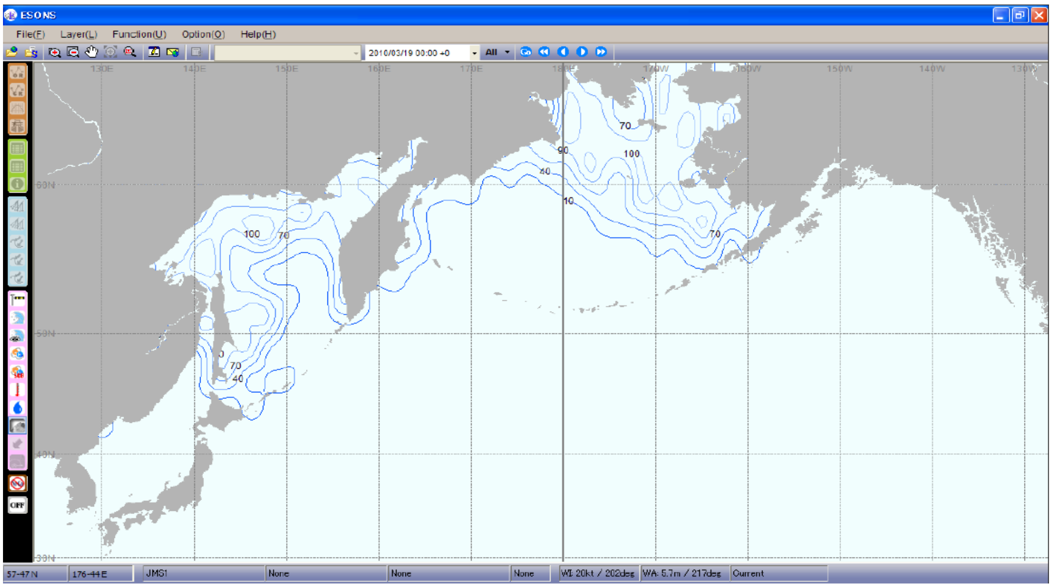


Figure 6.2 Display of sea ice concentration (Source: WISE, 2012)

The proposed models have to consist of different state of the art ice algorithms that users can choose from onboard. Unlike the presented route systems, cf. figure: 1.7 and 4.2, which sends all processed and compressed oceanic forecasts to the ship for then to be selected by the users, the proposed models must have the opportunity to select what ice or other information to be received by request, on board cf. figure 6.3. Requested ice information should just consist of the changed ice conditions (grid points) based on previous ice conditions. In this way the amount of data required will be reduced to a minimum and become more attuned to the IRIDIUM communication systems limitations.

The WISE routing system has generally good functions and shows different weather and ice conditions as purposed, but the calculation of optimum route has to consider different ice conditions In addition to general oceanic conditions. If the WISE system should be usable for routing in Arctic areas, the optimum route algorithm have to be adapted so the ice edge may be considered as land. The optimum route will be calculated to avoid contact with ice if the ice edge is considered as land.

In the presentation of the WISE optimum route algorithm, the ratios (A) was presented as the part of the function witch take into account different current “criteria’s” for optimization. Ratios (A) are the core of the WISE optimization algorithm and the key function for calculation. If WISE routing should be considered as a proposal for this thesis, the ratios (A) should be adapted so all calculated routes avoid the ice edge.

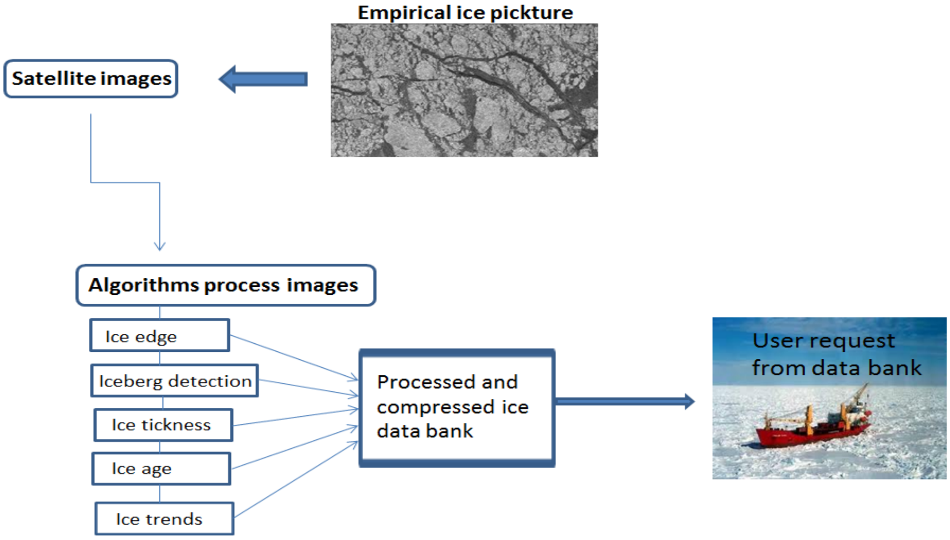


Figure 6.3 Illustration of proposed model (Source: own illustration)

One other issue of this thesis was to assess similarities and differences between forecasts provided by the WISE system and the forecasts provided by NMI. If one weather forecast provider is more suited for a system than the intended provider, the system should be constructed for switching between different providers. It is difficult to change or add other weather providers to the WISE system. This system provides requested weather information only from their own weather providers and it`s difficult to change since they already provide WISE routing to many vessels. A proposal of further improvement could be that the system made it possible to change between different weather providers adapted to the area of interest.

7 Discussion and conclusion

The further development of ship routing or decision-making systems, for high north Arctic areas, is depended upon the validity of weather- and ice forecasts, the routing agency's ability to make appropriate route recommendations based on these forecasts and appropriate communication systems.

Anticipated improvements in a routing agency's recommendations will come from advancements in meteorology, technology, and the application of different forecast models. Any improvement in the description of sea conditions by different oceanic forecast models will improve the output from ship routing and decision making systems.

Advanced planning of maritime operations combined with studies of expected weather conditions, both before and during the voyage or predictions of "open windows" for specific operations should be done by ship routing agencies in combination with on board sea keeping. This combination may provide the best opportunity to achieve the goal of optimum environmental conditions for any maritime operation.

There are different models for calculation of weather- and ice forecasts. As mentioned earlier in this thesis there are different appropriate models for ice predictions which calculates ice thickness, ice age, iceberg detection and ice trends, etc. These models predict different ice conditions with usable accuracy, and the providers of these models are still developing new technology to improve the accuracy.

Basis for all ice models are SAR images and the resolution of this images is essential for the level of detail, but the limitations in SAR data lays in the degree of transmitting capacity of communication satellites. From SAR data one will be able to classify ice conditions, but the resolution of images could be limited due to compression of data files transmitted to users.

It is important to have knowledge about probably loss of resolution due to this compression. The transmission capacity of communication satellites is probably the field of greatest potential for improvement.

One of the most important calculation models for southern Arctic, Barentshavet and coastal regions of North Norway are polar lows models. The research on polar lows, as basis for models, is to find out how these lows occur, make polar low predictions and predict their moves. Today`s knowledge and technology about polar lows preclude exact predictions before they appear. They are first detected on weather satellite images after they are formed. This unpredictability creates some uncertainties and constitutes a possible hazard to all maritime activities in Arctic. Different models have been under development for decades, but it is still difficult to give exact predictions of these lows. There will be substantial variations in forecasts if polar lows predictions fail.

Figure 8.1 show an example of significant differences between long term forecasts between two of the most trustable weather providers for Barents- and Arctic areas, Storm Weather Center and yr.no by NMI. The images in figure 7.1 are taken from the respective provider's websites 2. April. These forecast differences are related to how their polar low models predict the upcoming weather. Storm weather predictions show (upper part of the figure) much better weather than Yr (lower part of the figure), for the same period.

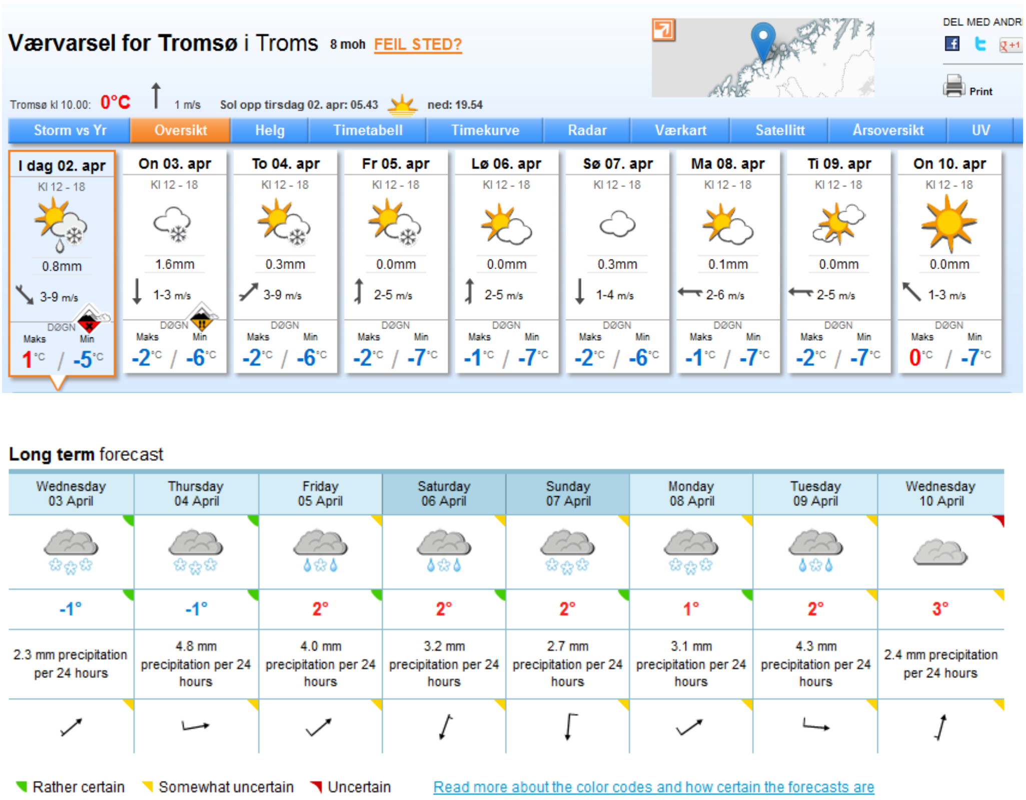


Figure 7.1 Forecast differences between Storm and Yr (Source: Storm.no and Yr.no)

These differences in forecasts show how difficult it is to predict the weather if an area is influenced by polar lows. This forecast uncertainties can therefore not form a basis for the polar low part of the evaluation between “requested ocean environmental forecast” by the WISE system and forecasts delivered by NMI. This part is limited to detection of and information (display) about polar lows.

The purpose of the simulation was to take a closer look into three different aspects related to the job description and the limitations of the thesis.

1. Testing similarities and possible differences between weather forecasts from NMI and “ocean environmental forecast” by WISE
2. Test how detailed the WISE system showed specific ice conditions on the display
3. Test how the WISE system took into account elements of ice when calculating optimum routes.

The testing of similarities and possible differences between WISE and NMI was set to provoke the systems in detection of polar lows and how they detect and displays specific ice conditions. These challenges were selected on basis of importance related to maritime operations in high north. Figure 5.2 and 5.3 shows that both WISE and NMI display the selected polar low with same accuracy, and this may confirm that they use the same source (satellite image) for their provided weather cf. Figure 5.1.

Detection of ice conditions and how detailed the WISE system displays these conditions was essential for this task. Ice conditions are dynamic and changing due to changing winds and sea current. Some areas within a specific area or a sailing route could easily change from navigable to unnavigable. The goal of any sea voyage or maritime operation is to avoid coming in contact with ice, and the importance of detailed ice predictions is therefore essential. The Area around Bjørnøya was selected for evaluating this part of the simulation.

Figure 5.4 shows that WISE displays an undetailed estimate based on a 10% line i.e. there are an estimated ice concentration of 10% within the line. Figure 5.5 shows a more detailed ice picture which turns out to match with the photo in figure 5.6. It is may not necessary for a routing system like WISE to display a more detailed ice picture due to a defined goal to not come in contact with ice within a route. A detailed ice picture is more important for specific decision making system where an operation take place within or close to ice covered areas.

Figure 5.8 shows the optimum route of WISE going straight through ice covered areas. As mentioned in chapter 4, the optimum route algorithm is not taking into consideration ice covered waters. In 10th of April at 15:00 a clock the ship is set in a position where there are elements of very close drift ice. Areas of very close drift ice are not suitable for conventional ships to sail into. It is not recommended to sail into any ice covered waters for conventional ships, even if they are classified for sailing there.

8 Concluding remarks and recommendations for future research

Ship routing and optimization of maritime operations through and within ice covered areas is challenging. Optimum route- and ice field modeling are both important subsystems witch are difficult tasks by themselves. Both subsystems should have capability to predict future ice conditions within specific areas and ship transit routes. In addition, these systems should also take care of delivering and presenting the right amount of relevant information to the users on board.

The quality of optimization depends on the quality and resolution of different ice condition data, the amount of loss in the information because of lossy compression, the accuracy of the ship transit model, the properties of the optimization method used, and the calculation time reserved for the optimization process. Optimization systems should also give results in a reasonable time in order for the results to be utilized within the time frame they apply. Satellite-based information will play an important role in ensuring safe operations near and within ice covered areas, especially in building up a comprehensive real-time ice picture.

Technological advancements in the areas of both Earth observation- and communication satellites will increase the amount and type of data information to and from ships and leads to fewer delays. These advancements will improve the ship response, performance and efficiency on basis of better and more correct weather and oceanic inputs. Being able to predict a ship's response in most weather and oceanic conditions will result in improved routing and decision procedures.

Recommendations for future research due to improving of ship routing and decision making could be related to the limitation of the communication satellite systems. The bandwidth of present communication satellite systems for Arctic areas is too limited and has to be increased in the future. The most important challenge related to present limited bandwidth is time delays of important input for different optimization systems. Compression of data files are measures for decreasing of the time delay, but it will lead to possible loss of important information.

A recommendation for future research related to simulation using WISE routing could be that the mathematical model for calculating optimum route considers the ice edge as land. By adding ice edge as criteria for ratio (A), in the mathematical model, the optimum routes will avoid ice covered areas. The meaning of calculating optimal routes should be ensuring of safe navigation in addition to efficiency for all weather and oceanic conditions.

References

Yin, R, K., (2003). *Case study research design and methods. 3th edition.* Sage publications, inc.

Kjerstad, N (2008). *Fremføring av skip med navigasjoskontroll*. Tapir Akademisk Forlag.

Kjerstad, N (2011). *Ice Navigation. 1th edition.* Tapir Akademisk Forlag.

Barabady, J (2007). *Production Assurance. Concept, Implantation and Improvement.* PhD, Luleå University of Technology.

Gustavson, E. Hancock, C. Hall, R (OTV 20117, 2011). *AUV- and Satellite Imagery- Based Ice Management around Critical Infrastructure*.

Gao, X (2009). *Design for production assurance. Reliability, Maninatinability, and Arctic conditions.* Faculty of Science and Technology, university of Stavanger.

National Snow and Ice Data Center (NSIDC, 2013). Available online: http://nsidc.org/arcticseaicenews/ (Accessed January 2013).

University of Tromsø (UIT, 2012). Available online: (http://uit.no/forstudiesokere/programside?p_document_id=270563&ar=2012&semester=H). (Accessed October 2012).

International Maritime Organisation (IMO, 2012). Available online: http://www.imo.org/ourwork/safety/navigation/pages/shipsrouteing.aspx (Accessed October 2012).

Polarview iceberg monitoring algorithm (polar view, 2012). Available online: *http://www.polarview.org/services/im.htm* (Accessed December 2012).

Ice Tracking by SAR Image (ITSARI, 2010) Available online: http://nsidc.org/noaa/iicwg/presentations/IICWG_2010/Hall_Ice_Object_Tracking_from_Satellite_Images.pdf (Accessed January 2013).

Ice Ridging Information for decision making in Shipping operations (IRIS, 2009). Kotovirta, V. Jalonen, R. Axell, L. Riska, K. Berglund, R. Cold Regions Science and Technology 55 (2009) 52-62. *A system for route optimization in ice-covered Waters.*

GRID- Arendal (GRIDA, 2006). Available online: http://maps.grida.no/go/graphic/the_arctic_region1 (Accessed January 2013).

Environment Canada (ec.gc.ca, 2013). Available online: http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=F2358C10-1 (Accessed January 2013).

Arctic Climate Impact Assessment (ACIA, 2004). Available online:
http://acia.npolar.no/litteratur/konsekvenser-av-klimaendringer-i-arktis
(Accessed January 2013).

Challenges for Positioning and Navigation in the Arctic (mycoordinates, 2010).
Available online:
http://mycoordinates.org/challenges-for-positioning-and-navigation-in-the-arctic/
(Accessed February 2013).

Ice Management (Ice Management K.J Eik)
IceManagement.K.J Eik.pdf. (2009) (Accessed February 2013).

Arctic Climate Issues 2011. (SWIPA 2011)
SWIPA overview report.pdf (2011) (Accessed February 2013).

Article from Skipsrevyen. (Skipsrevyen, 2007) Available online:
http://www.skipsrevyen.no/artikler/artikler-6-2007/tema-sikkerhet-til-sjos/1200.html.
(Accessed February 2013).

Deutsches Zentrum für Luft- und Raumfahrt (DLR) Available online:
http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10382/570_read-431/
(Accessed January 2013).

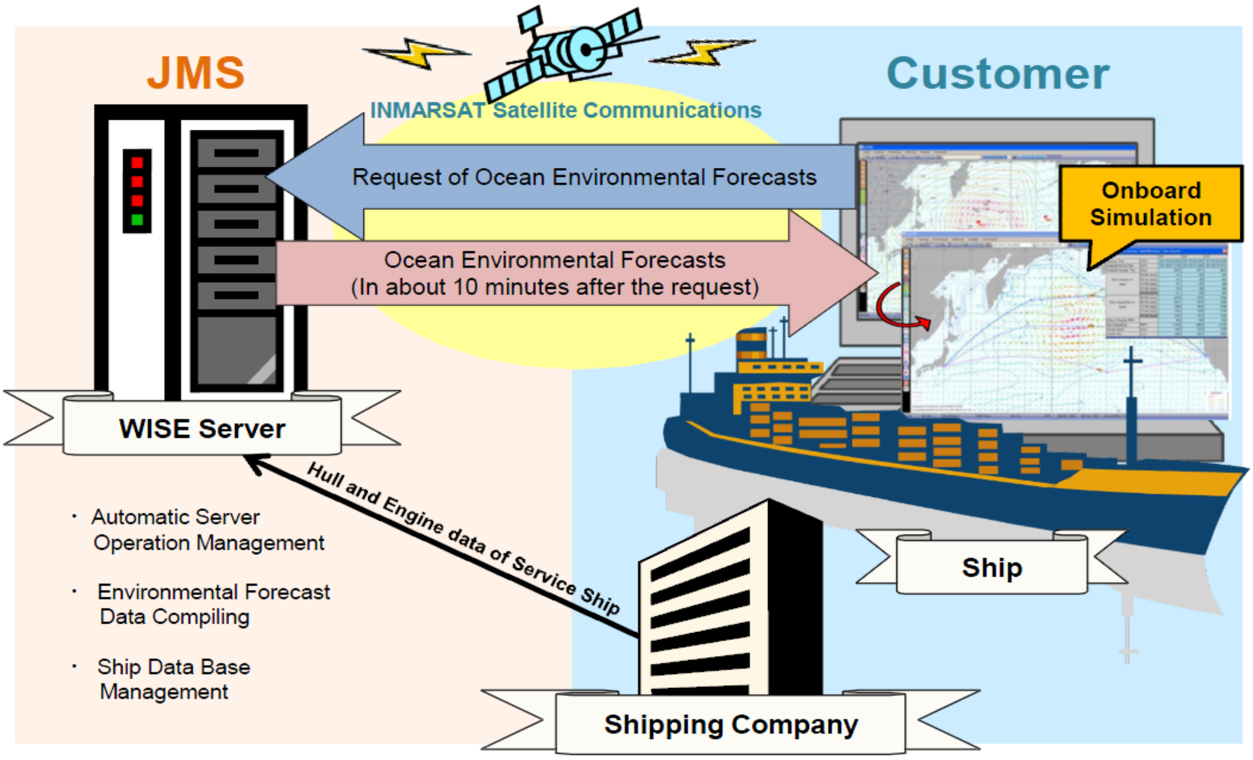
ASTRIUM (ASTRIUM, 2013). Available online:
http://www.astrium.eads.net/en/community-and-links/cryosat-2-mesuring-ice-thickness-from-orbit.html (Accessed Oktober 2012).

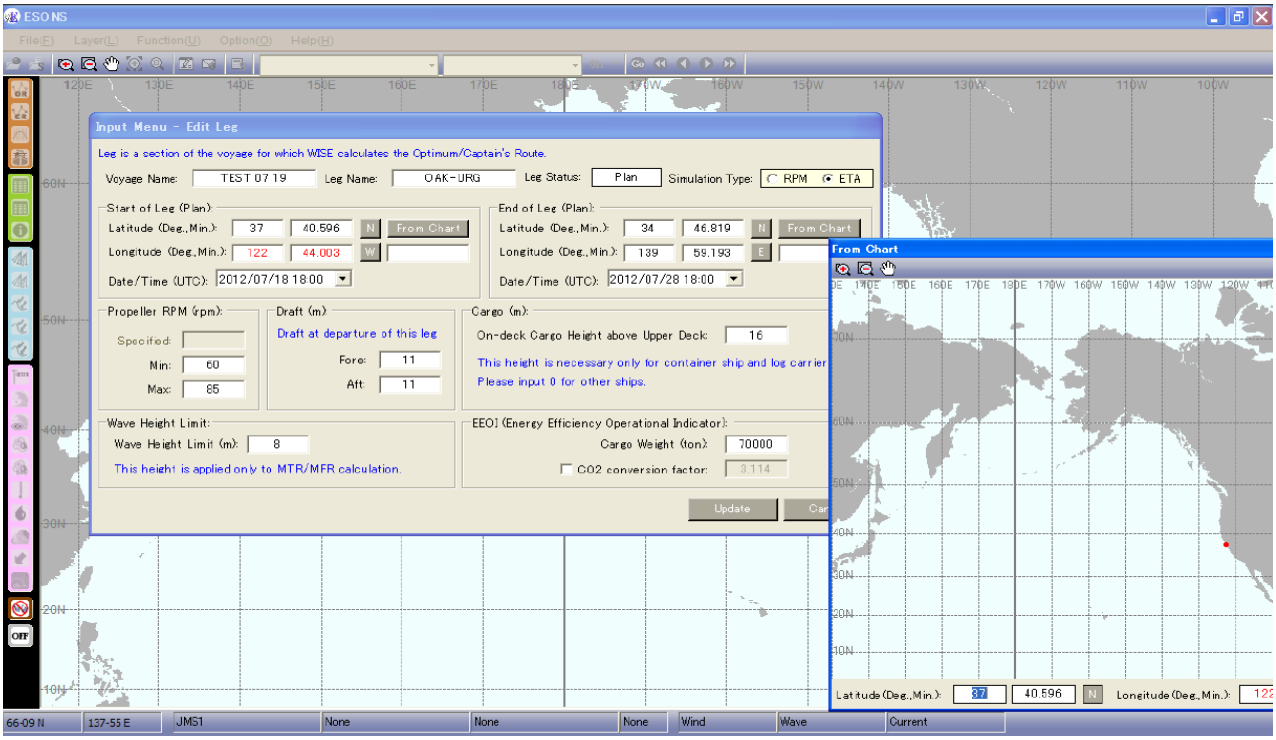
Kongsberg Satellite Services. (KSAT, 2013). Available online: http://www.ksat.no/
(Accessed January 2013).

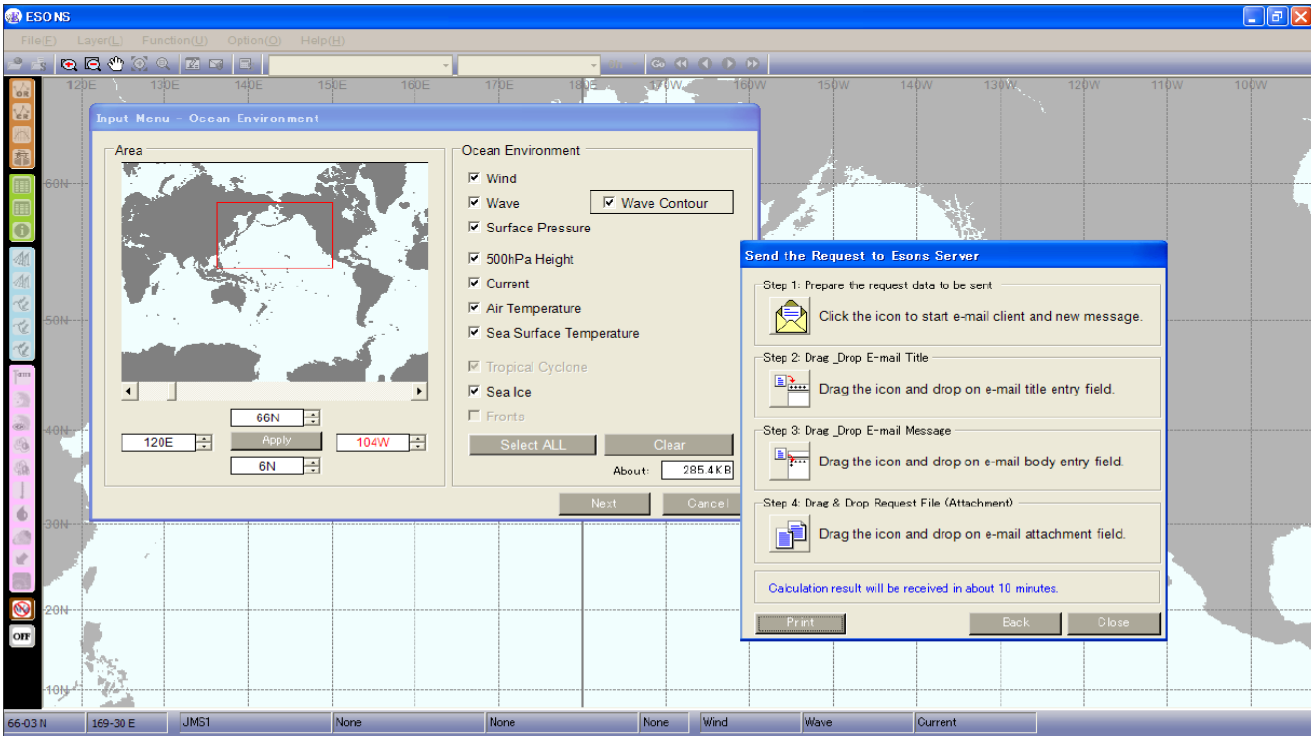
Wisegeek. (Wisegeek, 2013). Available online: http://www.wisegeek.org/what-is-an-algorithm.htm. (Accessed January 2013).

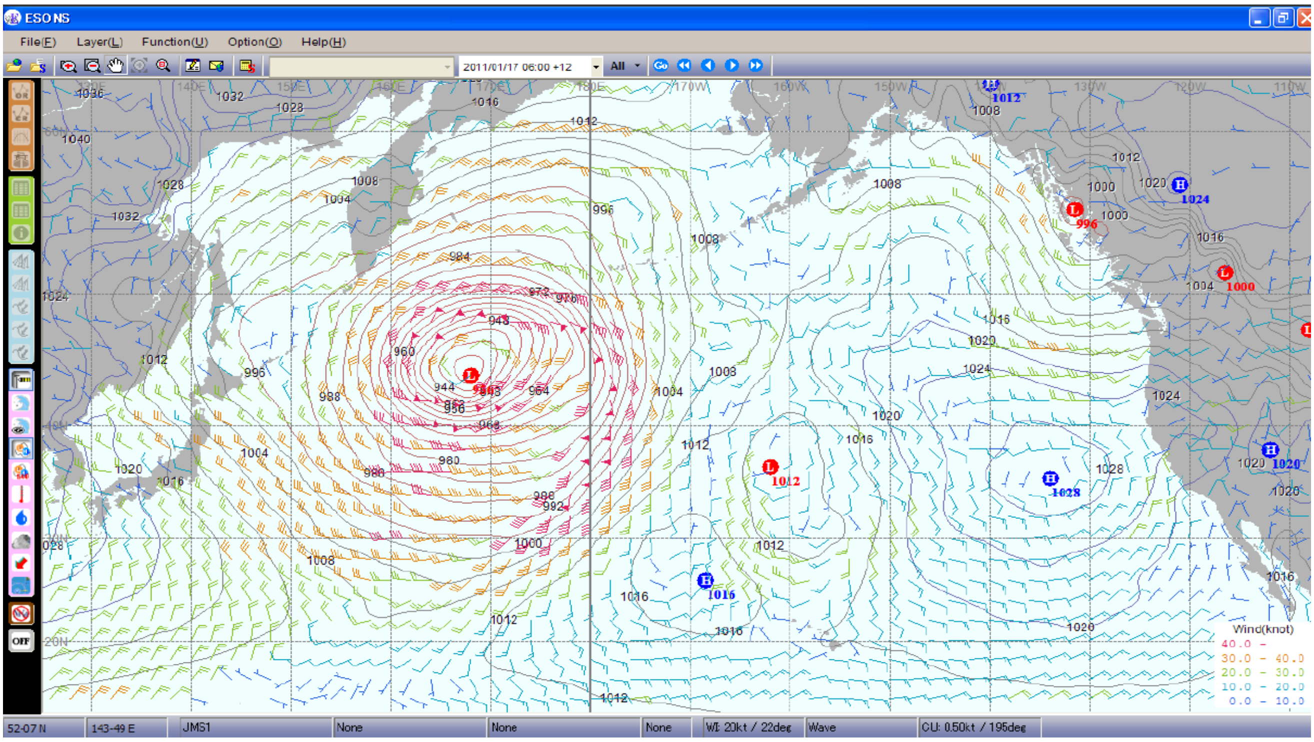
Japan Marine Science. *Weather Information for Safety and Economy, manual*. (WISE, 2012)
(Accessed January 2013).

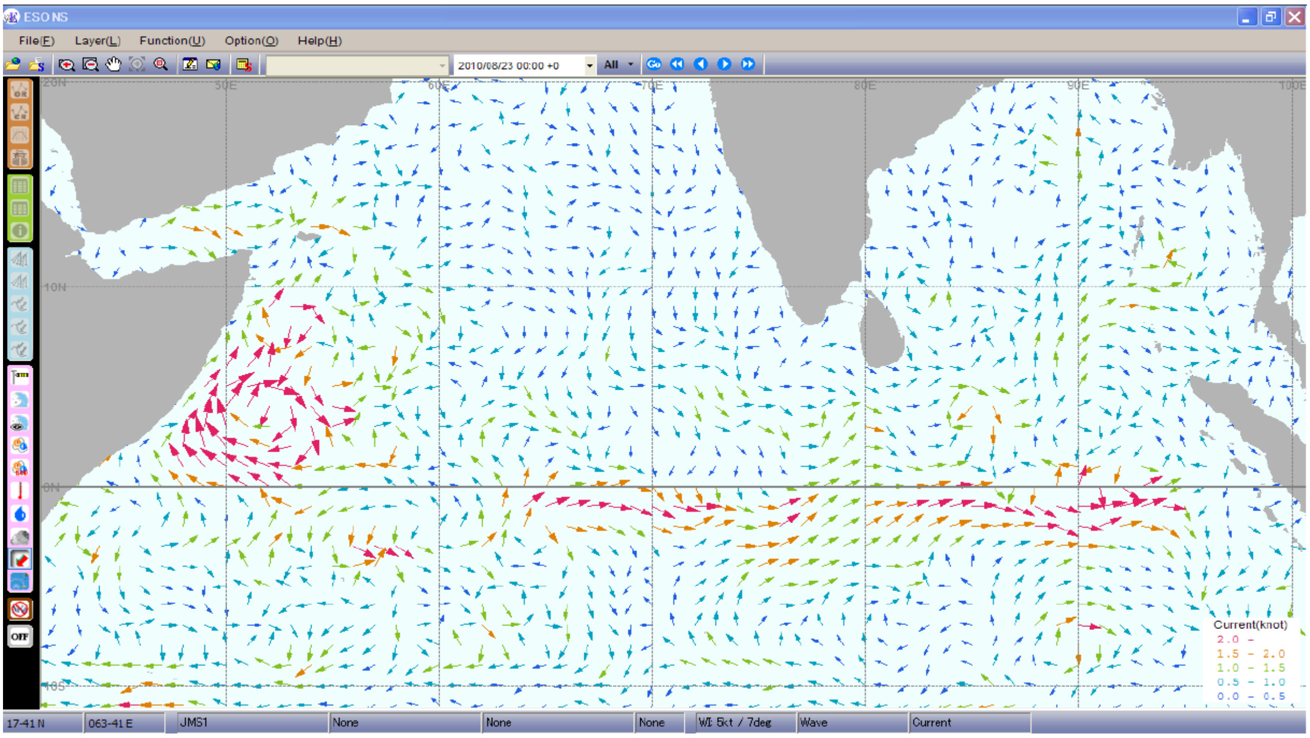
Appendix A: WISE routing

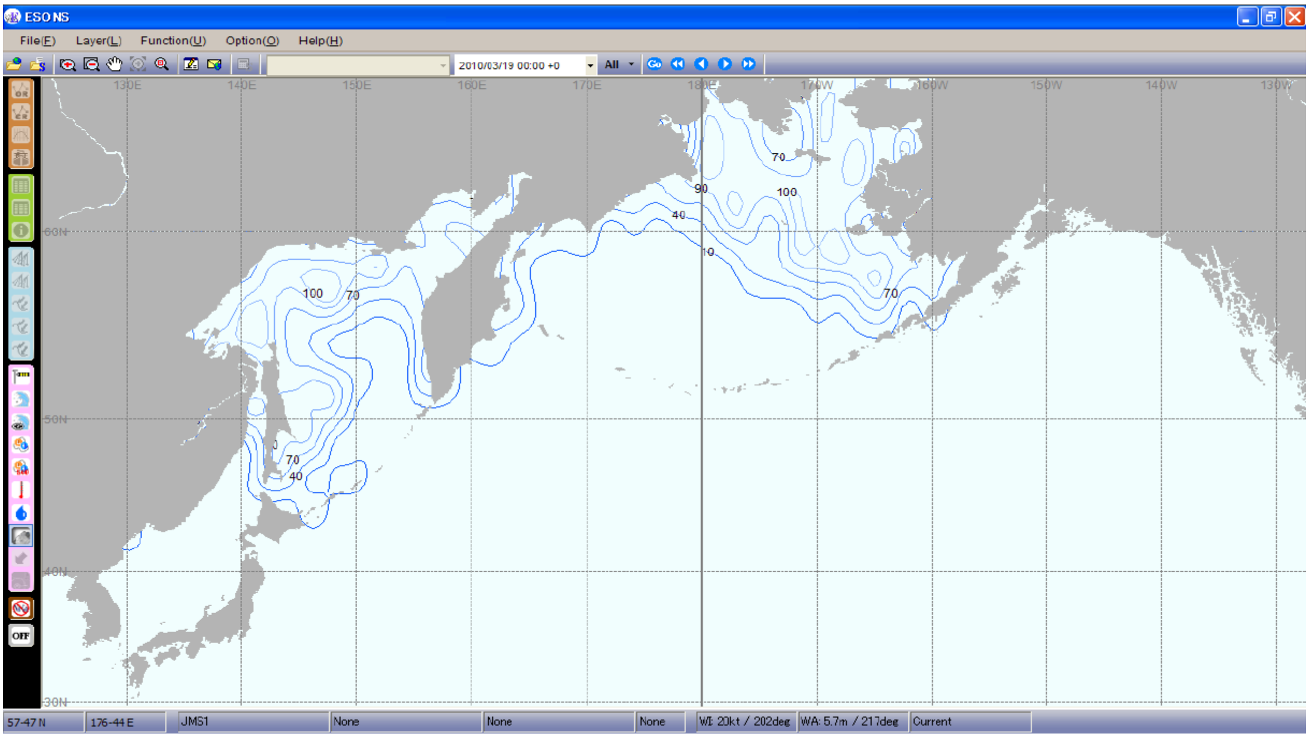

JMS
INMARSAT Satellite Communications
Customer
Request of Ocean Environmental Forecasts
Ocean Environmental Forecasts
(In about 10 minutes after the request)
Onboard Simulation
WISE Server
Hull and Engine data of Service Ship
Ship
・ Automatic Server Operation Management
・ Environmental Forecast Data Compiling
・ Ship Data Base Management
Shipping Company

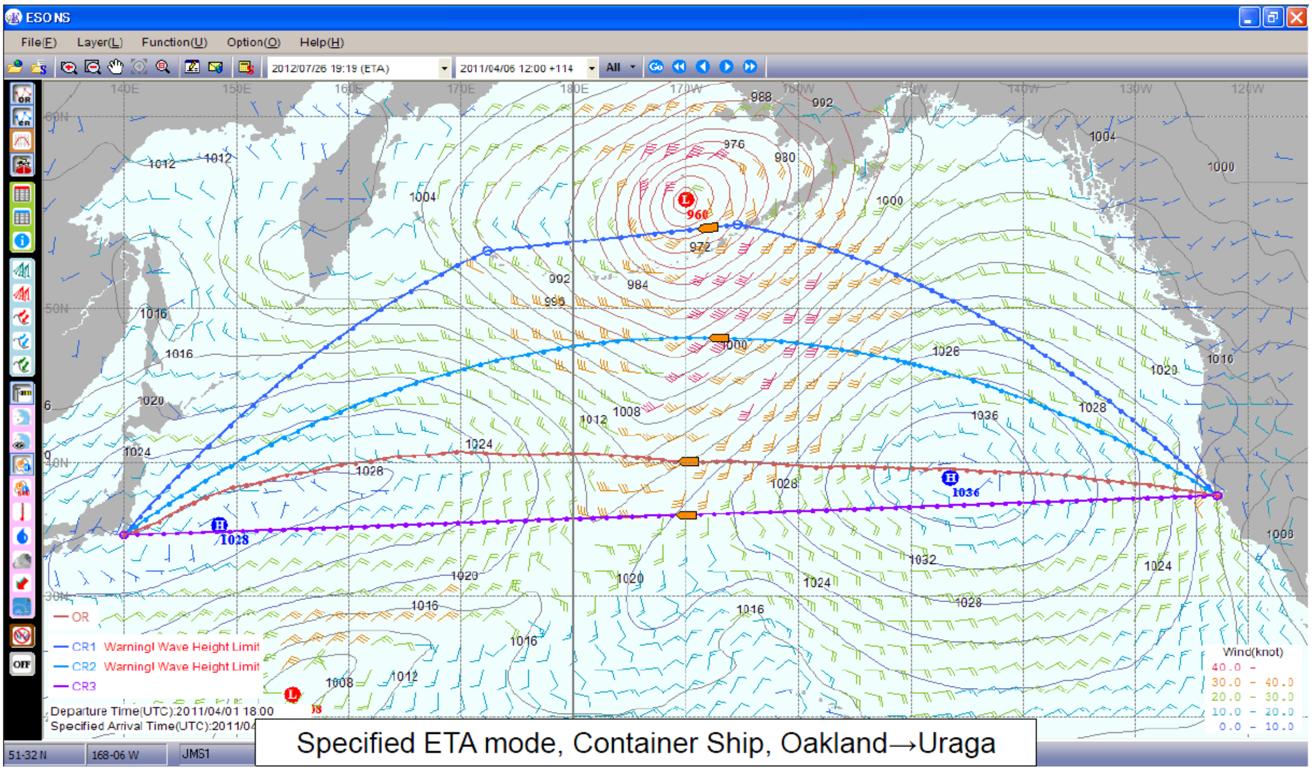

ESONS
Input Menu - Edit Leg
Leg is a section of the voyage for which WISE calculates the Optimum/Captain's Route.
Voyage Name: TEST 07 19
Leg Name: OAK-URG
Leg Status: Plan
Simulation Type: RPM ETA
Start of Leg (Plan)
Latitude (Deg.,Min.): 37 40.596 N From Chart
Longitude (Deg.,Min.): 122 44.003 W
Date/Time (UTC): 2012/07/18 18:00
End of Leg (Plan)
Latitude (Deg.,Min.): 34 46.819 N From Chart
Longitude (Deg.,Min.): 139 59.193 E
Date/Time (UTC): 2012/07/28 18:00
Propeller RPM (rpm):
Specified:
Min: 60
Max: 85
Draft (m)
Draft at departure of this leg
Fore: 11
Aft: 11
Cargo (m):
On-deck Cargo Height above Upper Deck: 16
This height is necessary only for container ship and log carrier
Please input 0 for other ships.
Wave Height Limit:
Wave Height Limit (m): 8
This height is applied only to MTR/MFR calculation.
EEOI (Energy Efficiency Operational Indicator):
Cargo Weight (ton): 70000
CO2 conversion factor: 3.114
Update
From Chart
Latitude (Deg.,Min.): 37 40.596 N
Longitude (Deg.,Min.):
66-09 N
137-55 E
JMS1
None
None
None
Wind
Wave
Current


ESONS
Input Menu - Ocean Environment
Area
66N
120E
Apply
104W
6N
Ocean Environment
Wind
Wave
Wave Contour
Surface Pressure
500hPa Height
Current
Air Temperature
Sea Surface Temperature
Tropical Cyclone
Sea Ice
Fronts
Select ALL
Clear
About:
285.4KB
Next
Cancel
Send the Request to Esons Server
Step 1: Prepare the request data to be sent
Click the icon to start e-mail client and new message.
Step 2: Drag _Drop E-mail Title
Drag the icon and drop on e-mail title entry field.
Step 3: Drag _Drop E-mail Message
Drag the icon and drop on e-mail body entry field.
Step 4: Drag & Drop Request File (Attachment)
Drag the icon and drop on e-mail attachment field.
Calculation result will be received in about 10 minutes.
Print
Back
Close
66-03 N
169-30 E
JMS1
None
None
None
Wind
Wave
Current

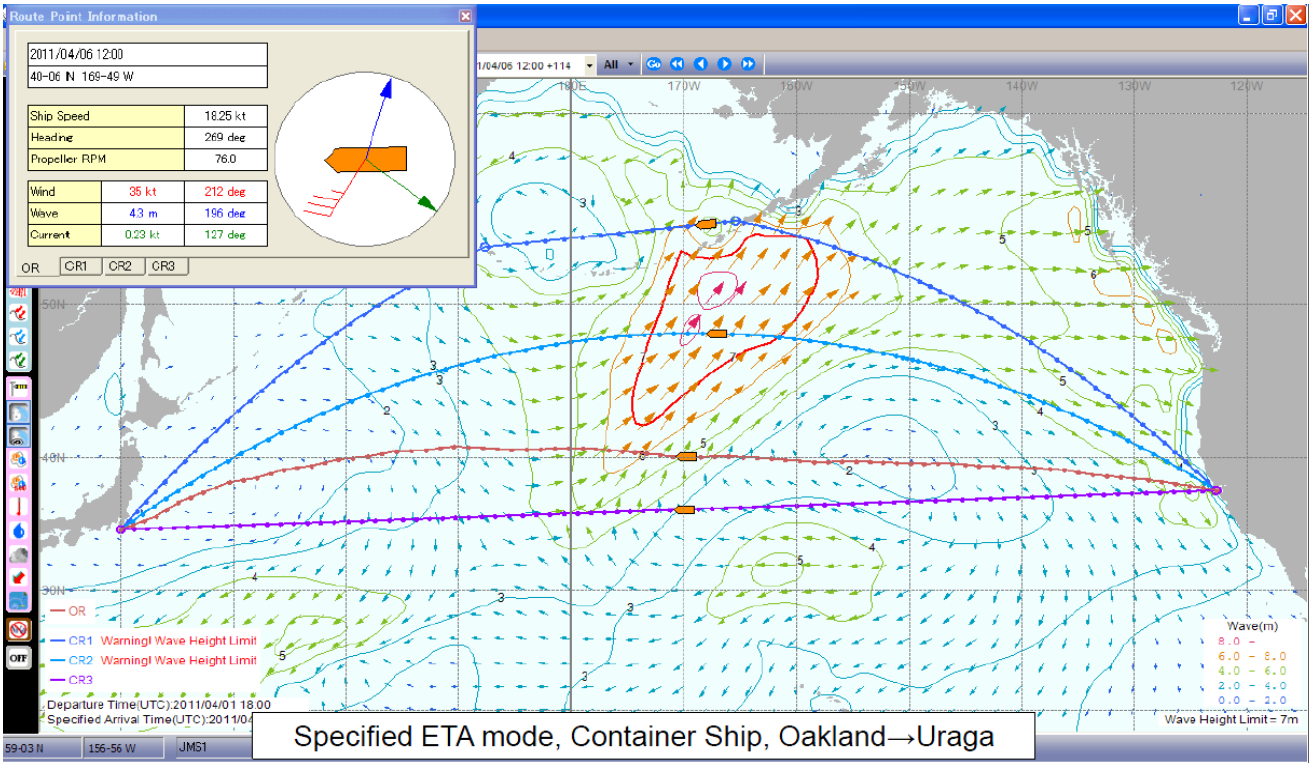

ESONS
File(F)
Layer(L)
Function(U)
Option(O)
Help(H)
2011/01/17 06:00 +12
All
Wind(knot)
40.0 -
30.0 - 40.0
20.0 - 30.0
10.0 - 20.0
0.0 - 10.0
52-07 N
143-49 E
JMS1
None
None
None
WI: 20kt / 22deg
Wave
CU: 0.50kt / 195deg


ESONS
File(F) Layer(L) Function(U) Option(O) Help(H)
2010/08/23 00:00 +0
All
Current(knot)
2.0 -
1.5 - 2.0
1.0 - 1.5
0.5 - 1.0
0.0 - 0.5
17-41 N
063-41 E
JMS1
None
None
None
WI: 5kt / 7deg
Wave
Current


ESONS
File(F) Layer(L) Function(U) Option(O) Help(H)
2010/03/19 00:00 +0
All
57-47 N
176-44 E
JMS1
None
None
None
WI: 20kt / 202deg
WA: 5.7m / 217deg
Current

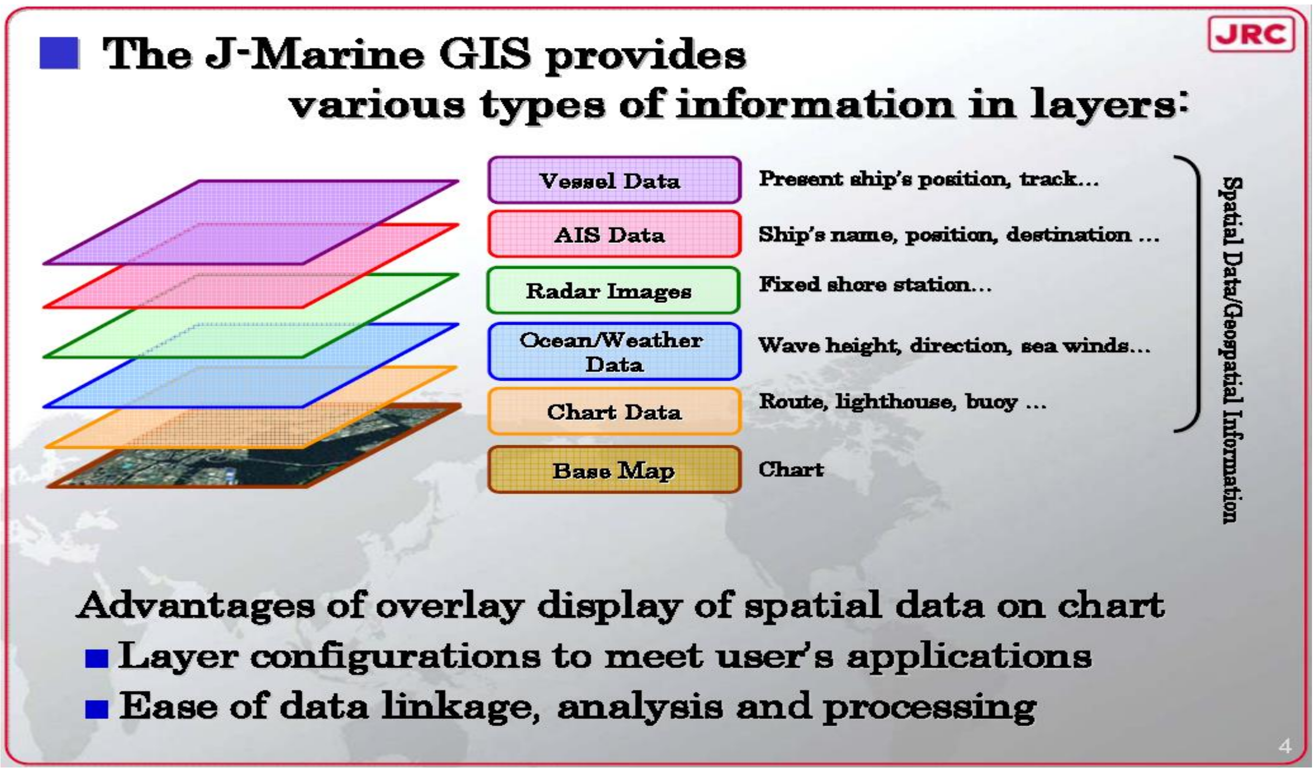


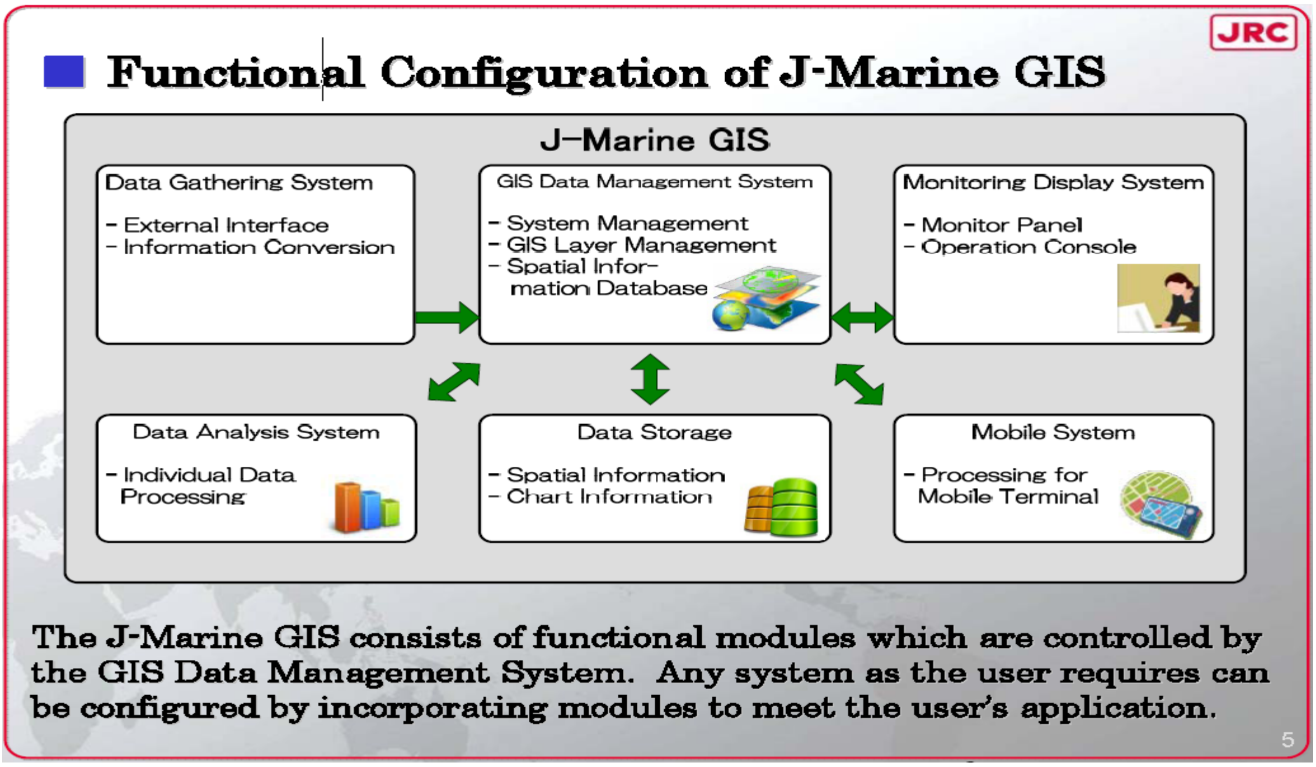
Specified ETA mode, Container Ship, Oakland→Uraga



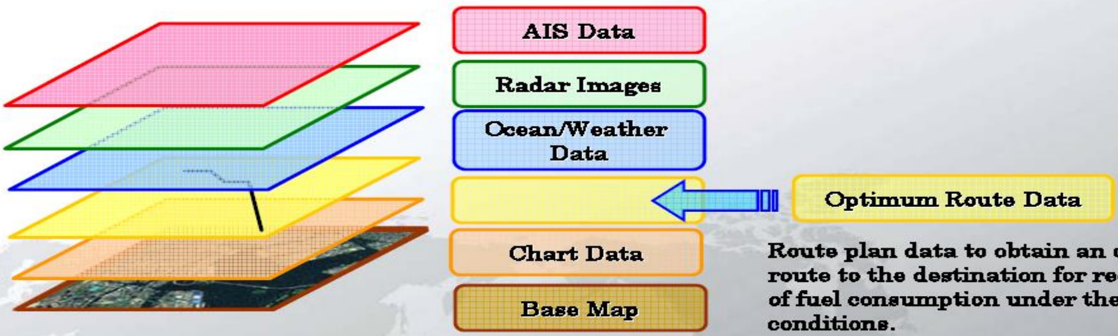
Specified ETA mode, Container Ship, Oakland→Uraga

Appendix B: J-Marine GIS


JRC
The J-Marine GIS provides various types of information in layers:
Vessel Data
AIS Data
Radar Images
Ocean/Weather Data
Chart Data
Base Map
Present ship's position, track…
Ship's name, position, destination …
Fixed shore station…
Wave height, direction, sea winds…
Route, lighthouse, buoy …
Chart
Spatial Data/Geospatial Information
Advantages of overlay display of spatial data on chart
Layer configurations to meet user's applications
Ease of data linkage, analysis and processing
4


JRC
Functional Configuration of J-Marine GIS
J–Marine GIS
Data Gathering System
- External Interface
- Information Conversion
GIS Data Management System
- System Management
- GIS Layer Management
- Spatial Infor-mation Database
Monitoring Display System
- Monitor Panel
- Operation Console
Data Analysis System
- Individual Data Processing
Data Storage
- Spatial Information
- Chart Information
Mobile System
- Processing for Mobile Terminal
The J-Marine GIS consists of functional modules which are controlled by the GIS Data Management System. Any system as the user requires can be configured by incorporating modules to meet the user's application.
5

The J-Marine GIS Solution meets the user's demand by layer expansion.



Route plan data to obtain an optimum route to the destination for reduction of fuel consumption under the weather conditions.

For instance, the J-Marine GIS can be used for ship's route management as an "Optimum Route Navigation System" by adding an optional layer "Optimum Route Data" as the result of route calculation for reduction of fuel consumption.

8

JRC-Marine Geographic Information System

Development to Various Systems

The J-Marine GIS can be developed to various types of system by handling different types of information.

15

Vessel

JRC

Advanced Navigation System

【Research & Educational Facilities for Maritime Systems】
Research facilities to support R&D and training for integrated and efficient gathering, management, analysis and indication of a variety of information on ship operation and navigation

■ Features
- Operating status of training ships
- Port vessel movement analysis
- Optimum route simulation
- Danger assessment and verification

■ Information
- AIS
- Radar
- Waves (height and direction)
- Wind direction and velocity

■ Effects
- Efficient R&D
- Quality training for research technology
- Development of new operation technology
- Joint research in different fields

■ Customers
- Universities
- Fisheries High Schools
- Navigational Training Center
- Research Institutes

J-Marine GIS Layers

- AIS Target
- Radar Echo
- Vessel Data
- Ocean Data (Wave Forecast)
- Weather Data (Wind direction/velocity)
- Optimum Route*
- Ship's Danger Assessment*
- Guard Zone
- Chart Data
- Chart Map

* : Option Layer

17

Rig

JRC

Oil Rig Management System

【Oil Rig Work Management Support Facilities】
Support of works such as equipment management, workers management, transportation management at oil rigs and oil platforms by electronic integrated means

■ Features
- Monitoring of operating status of equipment
- Remote monitoring of production volumes
- Materials management support
- Workers management support
- Trouble management

■ Information
- AIS
- Ship cameras
- Ocean/weather data (JWA))
- Production information (materials, work processes, instructions and work confirmation)

■ Effects
- Efficient transportation plan
- Safe working environment
- Quick work
- Accurate instructions
- Troubleshooting action

■ Customers
- Oil development companies
- Construction companies

J-Marine GIS Layers

- AIS Target
- Radar Echo
- Vessel Data
- Ocean/Weather Data (JWA)*
- Equipment/Production Management*
- Personal Management (Workers)*
- Maintenance/Trouble-shooting Management*
- Guard Zone
- Chart Data
- Chart Map

* : Option Layer

25

Fish Industry

JRC

Fishing Ground Surveillance System

【Fixed Net/Floating Banks Monitoring System 】

System for monitoring fishing grounds based on sensor information including water quality and temperature, set and drift, and salt concentration, or based on camera videos of fixed nets and floating fishing banks

■ Features

・Monitoring of fish school movements ・Fixed net management
・Water quality sensors ・Remote control of monitoring cameras
・Ocean/weather data analysis

■ Information

・AIS ・Monitoring cameras ・Ocean/weather data (JWA)
・Sensor information (Searchlight sonar, water quality)

■ Effects

・Energy-saving monitoring work (Personnel cost reduction)
・Ecological research into fishes

■ Customers

・Fishermen's Unions ・Fishing net companies
・Fisheries companies ・Research institutes

J-Marine GIS Layers

- Sonar Echo*
- Radar Echo
- Ocean/Weather Data (JWA)*
- Ocean/Weather Data (Buoys)*
- Guard Zone
- Chart Data
- Chart Map

*: Option Layer

31

Vessel

JRC

Fleet Management System

【Ship Operation Management Support Facilities】

Support of works such as monitoring of fleet vessels under control, schedule management and crew management;
Reduction of fuel consumption and environmental measures by precise navigation, energy-saving navigation and CO2-reduced navigation aid

■ Features

・Monitoring of vessels under control
・Optimum precise navigation aid
・Cargo handling support ・Crew management
・Maintenance and trouble management

■ Information

・AIS ・Ship camera ・Weather/ocean data (JWA)
・Ship information (Equipment, cargo handling, ship distribution, berthing schedule, etc.)

■ Effects

・Efficient ship operation plan
・Reduction of fuel consumption
・Quick action for maintenance/troubleshooting
・EEDI, EEOI, SEEMP

■ Customers

・Shipping companies
・Ship operation management

J-Marine GIS Layers

- AIS Target
- Vessel Data
- Ocean/Weather Data (JWA)*
- Optimum Precise Navigation*
- Operation/Work Management*
- Ship Distribution/ Personnel Management*
- Maintenance/Troubleshooting Management*
- Guard Zone
- Chart Data
- Chart Map

*: Option Layer

21

Terminology

■ GIS：Geographic Information System

A system incorporating a computer which stores various types of information including map and additional information in order to provide the functions of displaying, retrieving and referring to geographic information.

■ AIS：Automatic Identification System

A system provided with VHF-band digital radio communications equipment which transmits the data including ship's code, name, position, course, speed and destination and used for the purposes of avoiding collisions between ships, grasping the information on passing ships and their cargos, and supporting vessel traffic management works.

■ EEDI：Energy Efficiency Design Index

An amount of CO_2 in [g/ton mile] which is estimated in design as emitted to carry 1 ton of cargo over a distance of 1 mile under given conditions. It is equivalent to catalog fuel consumption (design value) for automobiles and the regulated value is under deliberation by International Maritime Organization (IMO).

■ EEOI：Energy Efficiency Operation Index

An amount of CO_2 in [g/ton mile] as actually emitted to carry 1 ton of cargo over a distance of 1 mile. It is equivalent to an actual fuel consumption for automobiles and the regulated value is under deliberation by IMO.

■ SEEMP：Ship Energy Efficiency Management Plan

This plan is intended for continuous management in the cycle of ① planning, ② implemen-tation, ③ monitoring and ④ assessment for improvement by monitoring EEOI to realize the most efficient ship operation for reduction of CO_2 emissions. The guidelines for this plan are under deliberation by IMO.