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OSIMS - OPERATIONAL SEA ICE MONITORING BY SATELLITES IN EUROPE

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ABSTRACT

The overall objective the OSIMS project was to study the feasibility and benefits of using satellite data in operational ice monitoring and propose concepts for optimal use of satellite data in future sea ice monitoring and forecasting. The project has studied the requirements for ice information from practical users such as ship traffic, icebreakers and offshore industry with focus on the Baltic Sea, the Greenland area and the Northern Sea Route. The main user groups include national ice centres, weather services, sea transport authorities, shipping companies, oil companies, and offshore industry. The implications of rapidly changing computer and communication technology on today's ice services, and the role of the private sector versus the public sector, have been discussed. The study has concluded with a number of recommendations for satellite systems to be used in future operational ice monitoring (Sandven et al., 1998).

1. INTRODUCTION

Sea ice monitoring is a well-established and organized activity in countries where sea ice occur, because sea ice has important impact on sea transportation, climate, the biosphere and settlements. Data are obtained by several methods: aircraft/helicopter surveys, ship observations, reports from coastal and meteorological stations, data from drifting buoys and satellite data. Sea ice lends itself readily to remote sensing because it occurs at the surface of the oceans at high latitudes and is observable by several remote sensing techniques. The importance of satellite data has therefore increased steadily over the last 10-20 years because satellite data suitable for sea ice monitoring has improved both in quantity and quality.

The most important ice areas in Europe are the Baltic Sea region, the Barents Sea and Svalbard area, the Russian Arctic, and the waters surrounding Greenland and Iceland. Outside of Europe there are extensive regional ice monitoring activities in Canada and USA. The National Ice Center in USA performs global ice monitoring, including the whole Arctic and Antarctic regions, based in satellites data. Ice monitoring is also important in northeast Asia, in Russia, Japan and China.

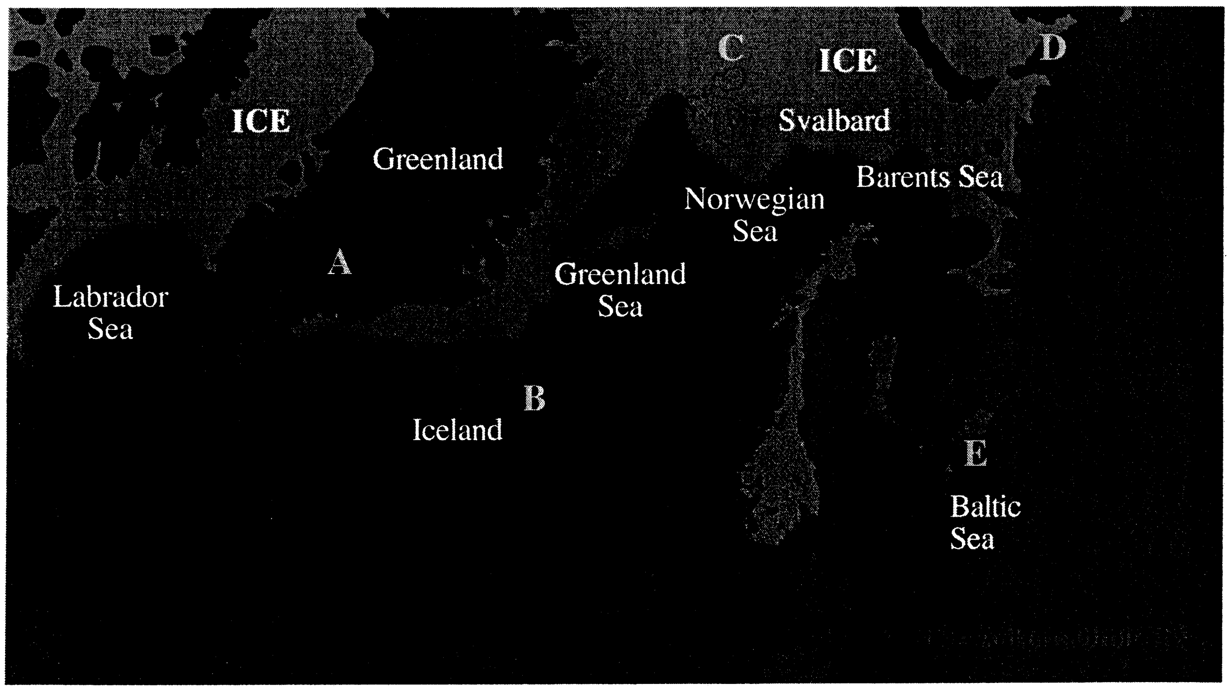

Figure 1. Sea ice areas in Europe and national ice services responsible for ice monitoring of these areas; A: Danish meteorological Institute in Greenland waters, B: Icelandic Meteorological Office in Icelandic waters; C: Norwegian Meteorological Institute in areas around Svalbard and the Barents Sea/Greenland Sea/Norwegian Sea; D: Russian Ice Service in the Northern Sea Route, and E: Finnish and Swedish ice services in the Baltic Sea in cooperation with the other countries in the region. The ice extent in this figure is derived from passive microwave satellite data (SSM/I data) from December 1997.

Global ice monitoring, which is one of the main elements in climate change detection, is only possible with use of satellite data. Starting with NASA's Nimbus-7 in 1978, passive microwave observations of the global ice areas have been regularly available for two decades, providing a unique data set to study seasonal, inter-annual and long-term variability of sea ice (Bjørgo et al., 1997). On the other hand activities like the marine traffic and off-shore industry over the ice covered areas have increased and there is a growing needs for better ice monitoring data. Sea ice monitoring is therefore one of the most important applications of several types of satellite data (passive microwave, optical/infrared, active microwave systems), since satellites have clear advantages compared to other methods (aircraft, ships, etc.) which are expensive and not practical for observation of large areas. Use of satellite data have demonstrated promising capability to improve quality of the ice charts which are necessary for safe and cost-effective operations in ice areas. Systematic use of satellite data in operational ice monitoring, especially SAR data, will bring the quality of local and regional ice charts to a higher level than today and reduce the risks of damage and accidents caused by sea ice.

2. USER CATEGORIES AND THEIR REQUIREMENTS FOR ICE INFORMATION

The background and justification for operational ice monitoring services, mainly financed by national governments, are the presence of important users who cannot work efficiently and carry out their duties without up-to-date and reliable ice information. A number of users have been interviewed about their requirements for sea ice data (Table 1). The main public sector users include national maritime administrations, local administrations, navies and coast guards, weather services, icebreaker services and other governmental agencies responsible for marine, polar and environmental activities. The private sector users include first of all shipping companies and fishing vessels operating in ice-covered seas, offshore industry and other industries depending on sea transportation such as timber, paper, mining and many others. The ice information needed by the different users include both real-time, daily monitoring and forecasting as well as statistical information based on historical data. The user requirements can be divided into the following categories:

- *Mission requirements.* To have satellite systems in continuous operation which can provide sea ice data on daily basis.
- *Product requirements.* The data products from satellites must have adequate coverage and provide necessary ice information in sufficient resolution, including near real-time data delivery.
- *Infrastructure and communication requirements.* It is of primary importance that satellite data can be readily transferred from the receiving stations to the ice centres, and from the ice centres to the end users.
- *Information and education requirements.* With increasing amount of satellite data, many data and service providers, and a variety of different products and processing algorithms, there is a strong need to organize and facilitate access to all relevant information. It is also necessary to strengthen education and training of personnel involved in ice monitoring in use of satellite data.

The user investigations suggest that the ice services will be a public responsibility also in the future, but it will be supplemented by more private financing. Specialized needs from different customers, the availability of better space-borne data, the improvements in global communication, and last but not least the importance of computer technology to produce new ice products will stimulate a market where several companies and institutes will offer data and services related to ice monitoring.

Table 1. Categories of users investigated in the study

User category	Example of organization	Type of organization
National Ice Services and Weather Services	FIMR, DMI, Ice central in Greenland, German Ice Service	Public
Sea transport authorities	Finish Maritime Administration	Public
Shipping Companies	Murmansk Shipping Company (Russia), Royal Arctic Line (Greenland),	Commercial
Oil Companies	Nunaoil (Greenland/Denmark), Statoil (Norway)	Commercial
Coast guards and navies	Danish Coast Guard, Greenland US Coast Guard	Public
Other	Fishing vessels	Commercial

3. CURRENT SATELLITE SYSTEMS USED IN ICE MONITORING

A number of polar orbiting satellites, which provide relatively good coverage at high latitudes, are used in ice monitoring (Table 2). The two most frequently used satellite data in ice monitoring are passive microwave radiometer data from SSM/I (Special Sensor Microwave Imager) and optical and infrared data from AVHRR (Advanced Very High Resolution Radiometer). These data are available every day free-of-charge and are easy to obtain. The Russian satellite data are almost exclusively used by Russian institutions which have long experience in using optical and Side-Looking Radar data. European and Canadian Synthetic Aperture Radar (SAR) data are used more and more in ice monitoring, because they provide high resolution images (100 m or better) in all weather and light conditions. SAR data are more challenging to use in operational ice monitoring because: 1) raw SAR data delivered from the satellite needs to be processed into SAR images, 2) delivery of SAR imagery in near real-time requires rapid processing and efficient computer links, and 3) the large size of the image files requires a clever compression with minimum loss of information before they can be transferred to the users. Other factors which limits use of SAR data in operational ice monitoring are high data costs and cumbersome ordering procedure.

However, pre-operational use of ERS SAR data have been successfully demonstrated in the Northern Sea Route through the ICEWATCH project, where SAR images where used to map ice in strategic areas such as straits and along sailing routes (Johannessen et al., 1997). ERS SAR data have also been used extensively in development of operational SAR ice monitoring in the Baltic Sea (Gronvall et al., 1996) and in Greenland (Sandven et al., 1998)

The different systems complement each other in terms of scale of observation, resolution, and frequency of observation. The AVHHR images have good spatial coverage, but are limited by clouds. SSM/I data have too coarse resolution (10 - 30 km) to be useful in regional ice mapping, but are important for global scale monitoring. ERS SAR images give very good and detailed information, but coverage and repeatability is insufficient for monitoring. RADARSAT wideswath SAR combines good coverage, frequent repetition and rich information, but the data cost is high.

Table 2 . The most frequently used satellites in ice monitoring.

Country/ Agency	Satellite programme	No** of satellites	Instrument	Channels	Resolution (m)*	Swath (km)*
USA	DMSP	2	SSM/I	19, 22, 37 and 85 GHz	30000	1400
USA	NOAA	2	AVHRR Visual / IR	5 (0.58-12.4 microns)	1000	2600
Russia	Okean	1	SLR, RM-08, MSU	1 for SLR (3.0 cm)	1300 x 2500 (SLR)	450
Russia	Resurs	1	MSU-SK Visual / IR	5 (0.5-12.6 microns)	170: vis/NIR 600: TIR	600
Russia	Meteor	2	Scanning TV, Visual	1 (0.5-0.7 microns)	1500	2100-2600
ESA	ERS	1	SAR	1 5.3 GHz, VVpol.	100	100
Canada	RADARSAT	1	SAR	1 5.3 GHz, HH pol.	50-100	45 - 500

* Common resolution and swath used in ice monitoring
** Currently in operation

RADARSAT ScanSAR images are used extensively in Canadian and US Ice services since the satellite was launched in 1995 (Ramsey et al., 1997). In Europe, the Finnish and Swedish ice services introduced RADARSAT in operational monitoring in 1997. An example of such scene is presented in Fig. 2, showing that the whole Bothnian Bay is covered by one such image. Also Danish Meteorological Institute is introducing RADARSATdata in operational ice monitoring in Greenland.

4. COST-BENEFIT CONSIDERATIONS

The benefits of improved sea ice monitoring by satellite data are two-fold: First, there are economical benefits due to the fact that sea transportation, offshore oil/gas exploitation and other industries is possible and profitable in ice covered areas. Secondary, there are environmental and safety issues which require operators to use sea ice information to meet the safety standards and regulations which exist today. The project has not conducted a full cost-benefit analysis of using satellite data in ice monitoring because it has been difficult to quantify the benefits, and to find figures which are representative for cost and values of the different elements of ice monitoring. Much of costs are integral parts of other activities, such as coast guard operations, public weather forecast and pollution monitoring.

Figure 2. Example of RADARSAT ScanSAR image of 19 March 1997, covering all sea ice in the Bothnian Bay. ©RSI/FIMR

There are many factors which are important for cost-benefit and safety aspects concerning winter navigation:

- Ice class requirements for vessel sailing in different ice areas is the main cost factor for ship owners and operators. Requirements are usually defined by authorities, but if better ice information can show that a lower ice class vessel can sail a given route, it represents a considerable savings for the operator.

- Environmental regulations with impact on technical standards on vessels operating in ice areas. The same argument applies for environmental regulations. However, the safety aspect can be dominant, making it difficult for the operator to use lower technical standard on the vessels.
- The fairway due in for example Finland is very high which means that the ship owners expect all costs associated with bringing ships to Finnish harbours to be included here. Normally, ship owners consider better ice service to be a part of the service financed by the fairway due.
- In the Northern Sea Route icebreaker support is mandatory and this support has a price range per ton of cargo to be transported. Currently, Murmansk Shipping Company uses a price of 6-15 USD per ton. The cost savings of better ice information are not reflected in this price.
- Use of larger cargo vessels can reduce the need for icebreaker support, but the need for accurate ice information will increase. But reduced icebreaker costs do no necessarily mean that more money can be spent on satellite data.
- Public and private ice services will have different cost-benefit estimates. The public services will have a responsibility for the overall safety at sea, which is difficult to cost-estimate. The private services are commercially oriented and the products must reflect a value which customers are willing to pay for.
- The mixture of public and private responsibilities makes it difficult to visualize who will save costs and how much if the quality of ice information improves.
- From a national perspective, improved ice service (including icebreaker service and ice charting) is cost-beneficial if a large number of ships can sail more efficiently. For example, the number of port calls to Finland during the winter season has increased from 14000 to 23000 during the last ten years. The number of icebreakers have been unchanged, which shows that it has been possible to handle a much larger ship traffic with an ice service at the same cost level as ten years ago. This can be explained by improved quality of the ice charts, and better ice management attributed to more use of satellite data, better communication of satellite data transport system from ice services to the ships and traffic control system, which makes it possible for the icebreakers and the merchant vessels to operate more efficiently.
- In Canada, cost-benefit studies have been used to assess if satellite data should replace aircraft surveys in ice monitoring as background for the RADARSAT programme (Sandven et al., 1998). Economic benefits were assessed for many applications of SAR of which ice monitoring was one of the most important. The full costs of the RADARSAT programme, however, could not be recovered from data users. But with heavy governmental support RADARSAT was launched in 1995 and is now the backbone of the Canadian Ice Service.
- Estimates made by Murmansk Shipping Company indicates that use of RADARSAT in the whole Northern Sea Route can increase the productivity of the icebreaker fleet by a factor of two. This would have significant impact on the costs of operating the icebreaker fleet. But it does not mean that the icebreaker fleet could be reduced by the same factor and the savings

could be used to purchase SAR data. The icebreaker fleet is financed by the government and it would be kept operational because of national interests.

- Winter navigation in the Baltic Sea has improved as a results of several other factors where sea ice has an indirect role such as better weather forecasting, more powerful icebreakers, more ice-strengthened merchant vessels, and last but not least; the winters in the Baltic Sea have been generally mild over the last 10 years.

5. FUTURE CONCEPTS IN SATELLITE ICE MONITORING

There is a number of factors which associated with new technologies and new demands from users which will have severe impact on how satellite ice monitoring is organized and carried out in the future (Table 3). First of all, organization and implementation of ice monitoring need be optimized for each region where ice occurs. Because the infrastructures, especially data transmission and communication, are different from one region to another, it is foreseen that the Baltic region, the Greenland area and the Northern Sea Route will not follow the same concept in development of future operational ice monitoring.

Table 3. New technologies and user demand with impact on ice monitoring

	Changes in technology and user demands
Satellites and ground stations	• satellite SAR-systems: wide swath covering most ice areas • several satellites in operation • near real-time delivery of data • SAR receiving stations which cover most sea ice areas • low-cost mobile SAR receiving stations
Access to data and processing of data.	• improved data communication on land and at sea • fully digitized data • analysis tools on computers are improved • direct downlink of SAR data to users • wide range of products • use of electronic charts onboard ships • use of Internet for distribution
Users	• budget cuts in the public sector • increased role of private sector: shipping, oil industry, fisheries • requirement to cost effective information • the user community is growing • training and education is needed to enable new users to use data

It is also expected that new concepts will allow several data and service providers to deliver ice information. The role of computer network will become more important serving as the information "highway" where all providers and users of ice information can deliver and retrieve data and data products as can be seen in the close co-operation between Finnish and Swedish icebreakers and ice services. Computer networks and fully digitized data will make exchange of sea ice data much easier. The private sector will play a more important role than before, but operational ice monitoring will still be funded mainly by governmental budgets.

An ideal ice monitoring system will use a combination of different satellite data, which are available in near real-time every day, and will be integrated with meteorological and oceanographic data and other ice data in a state-of-the-art GIS system. Access to data from different satellites and satellite receiving stations must be facilitated. Users should only need to contact one address/agency to get sea ice data and environmental data, e.g. weather and sea state, from a given area. On-line ordering and purchase of ice information products should be further developed.

The ice services should have access to all relevant satellite data in a streamlined manner which is not the case today. The products from the ice services should be improved to include forecast data and indicate drift of sea ice and icebergs. Products should include pictorial information (imagettes), optionally with drift vectors and/or weather information included. All data should in the widest possible extend be freely interchangeable between national ice services.

As a conclusion of the OSIMS study, the following recommendations are made concerning operational sea ice monitoring by satellites:

- Access to a combination of SAR, optical and passive microwave data from satellites is needed on daily basis because these instruments complement each other in a useful manner for ice monitoring.
- Long-term access to satellite data is necessary in order for ice centres to invest in infrastructure and human expertise necessary for exploitation of these data.
- The number of satellites in orbit must be sufficient to ensure coverage of the most important ice areas 2 - 4 times per day.
- Receiving stations must exist to ensure real-time SAR data from all ice areas.
- High speed computer link from SAR receiving stations and ice centres and other main users is needed for transmission of the high data volumes of SAR data.
- Streamlining of SAR processing at receiving stations and image analysis at ice centres is necessary for rapid delivery of interpreted and classified SAR images.
- Communication to ships must be improved for transmission of SAR image products to users at sea

- The capability of onboard processing and direct downlink of SAR data from satellites to users should be developed to have a similar access system for SAR data as for AVHRR, Okean SLR and SSM/I data.
- The possibility to include ice information in ECDIS and/or other computer based systems on board ships should be further investigated. In near future it is envisaged that there will be integrated information systems on ships.
- Standardization of digital ice products is necessary for efficient exchange and distribution of products. New and faster communication systems should be utilized for distribution of digital ice products.
- Increased co-operation between ice centres to ensure optimal data acquisition, processing and distribution should be encouraged. This is particular important as more satellite data will be used.
- Training and education in sea ice remote sensing is necessary for all users who are not familiar with satellite data.

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