POAC '99
Espoo, Finland

Proceedings of the 15th
International Conference on
Port and Ocean Engineering
under Arctic Conditions

ICEWATCH: DEMONSTRATION OF SATELLITE SAR ICE DATA IN THE NORTHERN SEA ROUTE

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ABSTRACT

ICEWATCH is the first joint project in earth observation between Russian Space Agency (RKA) and European Space Agency (ESA). The overall objective of the project is to implement satellite monitoring by combined use of Synthetic Aperture Radar (SAR) from ESA ERS and Side-Looking Radar (SLR from RKA Okean as well as other remote sensing data to support ice navigation in the Northern Sea Route (NSR), offshore industry and environmental studies. ERS-1 SAR images have been used in ice monitoring of the NSR in several demonstration campaigns since 1991. The experience from use of SAR data onboard Russian nuclear icebreakers to assist in ice navigation is very positive and a concept for integrating ERS SAR data in the Russian ice monitoring service is demonstrated where also Okean SLR data are included. The system is currently tested in a pilot demonstration phase before it is planned to become operational. In addition to data acquisition and interpretation techniques for data integration, ice classification and data transmission techniques have been tested. A market survey has been conducted where different users and their requirements for sea ice data with focus on SAR have been identified. Results of the survey suggest that there are many new and potential users of SAR ice information in the NSR, ranging from transport, oil and gas industry to environmental institutions and local authorities of many Siberian regions. Wideswath SAR satellites such as RADARSAT (operational from 1996) and ESA ENVISAT (scheduled for launch in 2000) will improve the spatial and temporal SAR coverage of the NSR, satisfying most of the requirements for operational sea ice monitoring.

1. BACKGROUND

The rationale for the ICEWATCH project is practical as well as scientific: Ship traffic in the NSR need good knowledge of ice conditions from day to day as well as on long term basis for safe and efficient navigation. Oil exploration and production facilities in areas such as the Eastern Barents and Kara Sea areas will require both reliable design statistics and timely monitoring and forecasts of sea ice behavior. Fishing vessels need accurate ice maps updated daily in order to operate in ice edge regions throughout the year. Finally, monitoring of Arctic sea ice over many years is essential to provide an early indicator of global climate change which is predicted to be enhanced in polar regions of the northern hemisphere.

The NSR is the sailing route along the coast north of Russia between the Barents Sea and the Bering Strait (Figure 1). In ICEWATCH the studies have been concentrated to the western part of the NSR, between the Barents Sea and Yenisei river, where winter ice navigation takes place (Johannessen et al., 1997a). Sea transportation requires ice class vessels as well as icebreaker assistance in the winter season, which normally lasts from November to June. An extensive ice monitoring and forecasting service has been built up in Russia over the last 50 years to serve the sea transportation and icebreaker operations in the NSR. The service is based on data collection from ice stations, coastal stations, vessels, aircraft and satellites. But the use of spaceborne SAR has not been a part of this service.

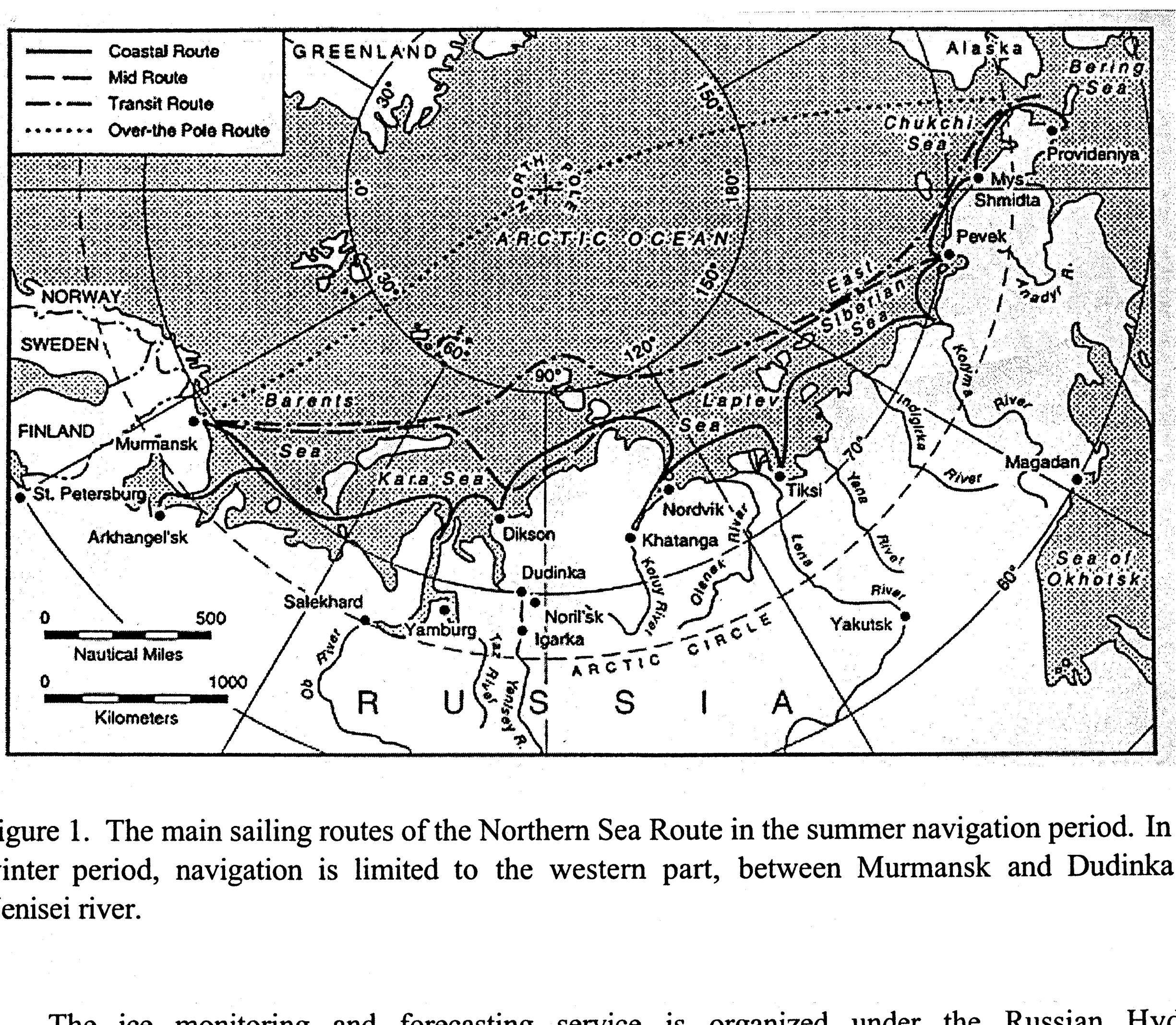

Figure 1. The main sailing routes of the Northern Sea Route in the summer navigation period. In the winter period, navigation is limited to the western part, between Murmansk and Dudinka on Yenisei river.

The ice monitoring and forecasting service is organized under the Russian Hydro-Meteorological Committee and the Ministry of Transport. The key institutions operating the ice monitoring service are the Marine Operational Headquarters (MOH) which work in cooperation with Murmansk Shipping Company and the Arctic and Antarctic Research Institute.

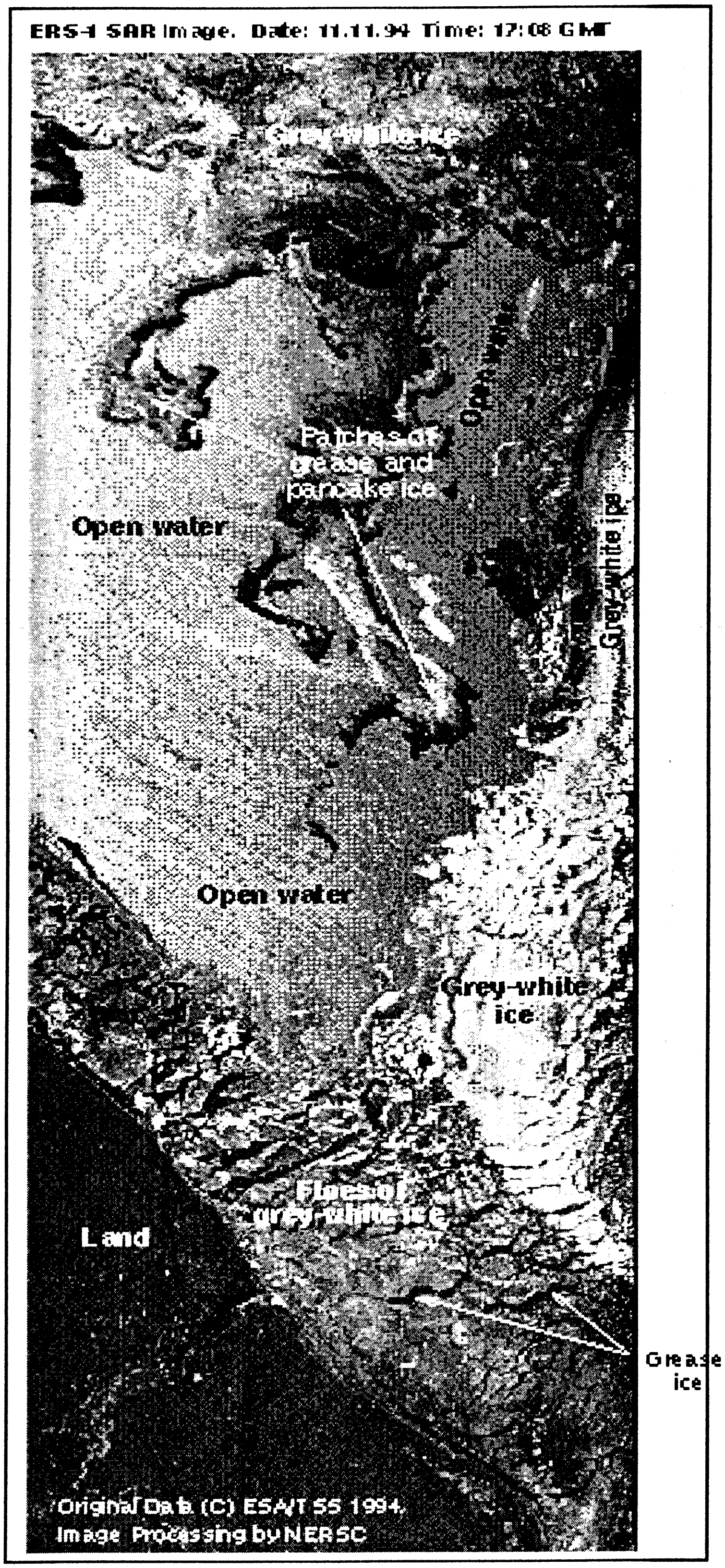

Figure 2. Example of ERS-1 SAR imageof 300 by 100 km area in the southern Kara Sea (11. Nov. 1994) in the beginning of the ice season. The annotations show the main ice types in the image.

The Nansen Environmental and Remote Sensing Center in Bergen, Norway first demonstrated use of ERS-1 SAR data for near real-time ice mapping in the NSR in August 1991, only two weeks after the launch of the ERS-1 satellite. SAR derived sea ice maps were then sent by telefax to the French polar vessel *L'Astrolabe* during her voyage through the Northeast Passage from Norway to Japan (Johannessen et al., 1992, 1996). This was the first civilian expedition through the NSR since the Russian revolution. This demonstration was evaluated as very interesting by the captains and sea ice experts onboard the Russian icebreakers which escorted *L'Astrolabe* through the ice-covered parts of the route.

Since 1993 SAR ice monitoring demonstrations have been carried out by the Nansen Centers in Bergen and St. Petersburg on several Russian icebreakers. In all these demonstration experiments, a scientist from the Nansen Center in St. Petersburg stayed onboard the icebreakers and analyzed the SAR images in cooperation with the captain and ice pilots (Johannessen et al., 1996, 1997b, c). In addition to supporting ice navigation these experiments also had scientific objectives to study various ice processes and phenomena and their SAR signature. Several hundred ERS SAR scenes have been obtained showing the different stages and conditions of ice in the NSR (Johannessen et al., 1997a). Figure 2 shows an example of an annotated SAR image of different young and new ice types from the freeze-up season in the southern Kara Sea.

3. PROJECT TASKS

The six major tasks in ICEWATCH were 1. Study of ERS SAR backscatter characteristics of different ice types in the NSR; 2. Implementation and improvement of methods and algorithms for processing, classification and interpretation of radar data; 3. Development of techniques for combined processing and use of ERS SAR and Okean SLR data; 4. Development of a scheme for polar ice radar monitoring, including study of user requirements, infrastructure and necessary equipment installation; 5. Application demonstration of radar ice monitoring for Murmansk Shipping Company icebreakers including cost benefit assessment; and 6. Recommendation for a real-time operational information system using satellite radar data.

3.1 Radar backscatter studies of sea ice types

Several hundred ERS SAR images were obtained, analyzed and interpreted for characteristic ice conditions in the NSR during the project. The ERS images demonstrated good capability to distinguish between the main ice types such as multiyear ice, firstyear ice, young ice and new-frozen ice. Different classes, forms and features of ice can also be identified such as fast ice, drifting ice, river ice, shear zones, leads, polynyas, ice topography (ridges and hummocks) and ice edge processes. However, in many cases the SAR backscatter data are ambiguous and it is difficult to classify ice the types correctly without additional data. This is particularly the problem for identification of various stages of young ice and firstyear ice, for quantification of surface roughness and to distinguish ice and open water during melt conditions. In spite of these limitations, the ERS SAR has proven to be a very useful instrument which can provide quantitative data on most of the important ice parameters except ice thickness. The ERS SAR backscatter values for various ice types were compared to simultaneous OKEAN SLR data. The OKEAN SLR system operates at a wavelength of 3.2 cm, VV-polarisation, and provides radar images with resolution of about 1.5 km in 450 km wide swaths. The main results of this task was to review state-of-art methods in radar ice classification both from ERS and OKEAN data.

3.2. Methods and algorithms for processing and analysis of SAR and SLR data

Methods for radiometric and geometric corrections of ERS SAR and OKEAN SLR images were reviewed and applied in the image processing. Derived ice parameters (ice classification and ice motion) were tested but not used in the pre-operational demonstrations. Simultaneous acquisition of SAR and SLR data were done for several cases and displayed in common map projection (polar stereographic projection). Both ERS SAR and Okean SLR data showed similar backscatter properties of multiyear, firstyear and young ice/new-frozen ice for the selected case studies.

ERS SAR and Okean SLR data will have different but complementary roles in and ice monitoring system. Okean SLR stripes obtained within one week can be merged into a mosaic which covers most of the sea ice in the NSR, as is shown by the SLR mosaic in Figure 3. The SLR mosaics show the main features of the ice pack such as ice edge location, coastal polynyas, firstyear ice and multiyear ice at a resolution of 1.5 km which is sufficient for the regional ice mapping.

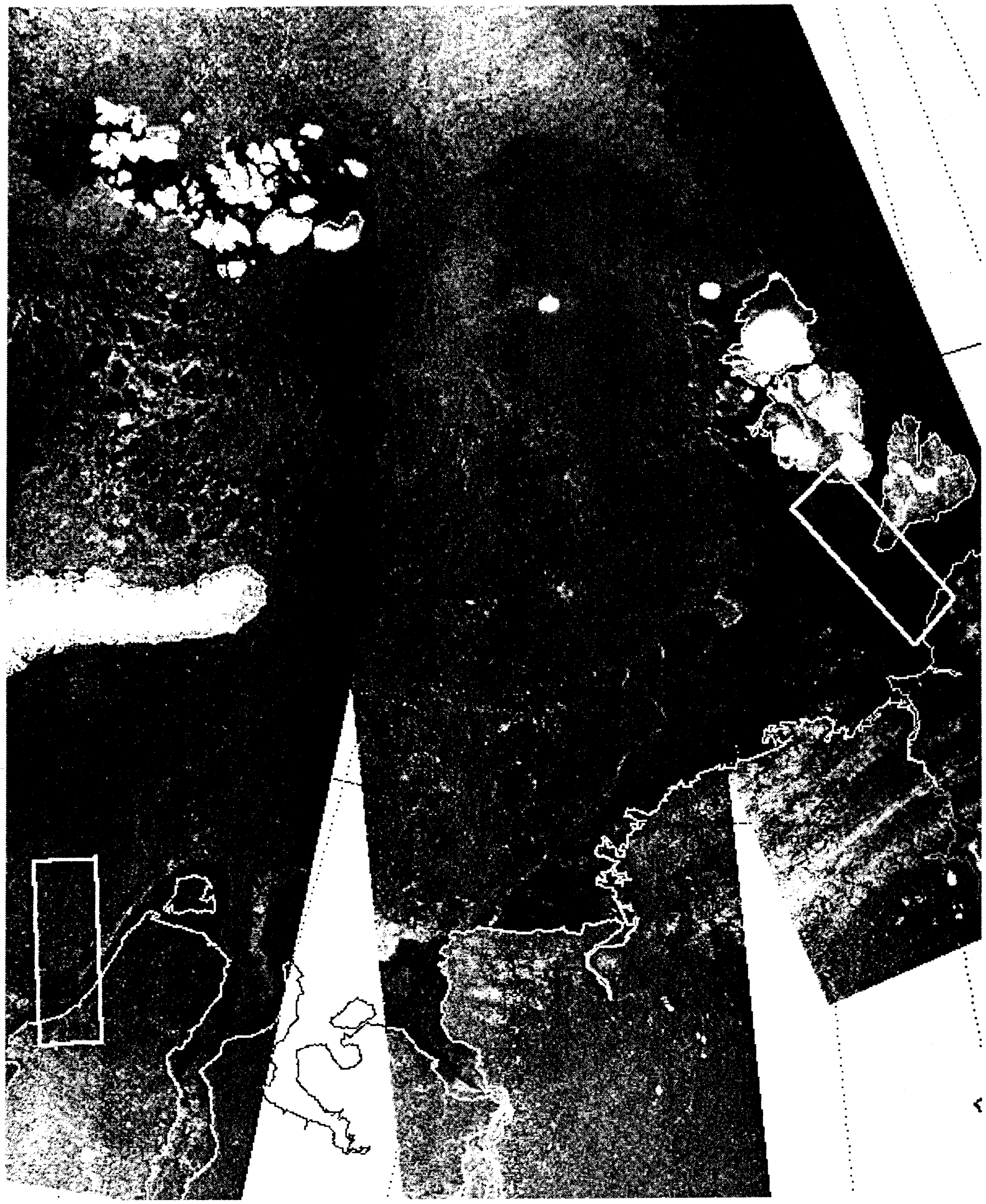

Figure 3. Okean Side Looking Radar (SLR) mosaic from 450 km wide stripes obtained between 16 and 21 May 1996. The mosaic is superimposed on a polar stereographic projection with land contours. The Okean SLR images have a resolution of about 1.5 km. The two white rectangles indicate where ERS SAR images (see Figure 4) were obtained at the same time as the SLR mosaic. Copyright: NPO Planeta.

Figure 4. ERS SAR image from Yamal coast on 19 May 1996. The image shows open water (dark signature) between the landfast ice near the coast and 90 - 100 % concentration of firstyear ice further north. The SAR image shows details of the ice cover which are not shown in the Okean SLR image in Figure 3. Copyright ESA/TSS 1996.

The main role of ERS SAR data is to cover smaller, selected areas with detailed images of the sea ice which are needed in practical applications such as ice navigation. With 100 m resolution in the ERS SAR images, most of the ice features important for navigation can be detceted. ERS SAR coverage maps can be superimposed on the SLR mosaics and the most interesting areas for SAR coverage can be selected, as shown in Figure 3. The corresponding SAR image from the Yamal coast (Figure 4) shows that there is a band of open water and lower ice concentration (7 - 9/10) outside of the landfast ice. This situation cannot be mapped with sufficient details in the Okean SLR image. The main disadvantage of ERS SAR data (lack of full coverage of the sailing route) is eliminated by use of Okean SLR data. The main disadvantage of the SLR images (lack of sufficient details) is eliminated by use of ERS SAR data in the areas where high resolution is needed.

3.4. Demonstration of real-time transmission of SAR images to icebreakers.

An important part of the ICEWATCH project is to develop methods for near real-time distribution of the high resolution, 100 m, ERS SAR images and maps to icebreakers operating in the NSR. Digital transfer of compressed images in near real-time have been successfully tested using the INMARSAT - A service. For example, on January 25 - 26 1996 the icebreaker Taymir was sailing from Dikson to Beliy Island (70° - 80° E) in 100 % ice. With a PC and modem connected to the INMARSAT station onboard, ERS-1 SAR images were received 5 hours after the satellite overpass (Figure 5). The SAR images in compressed form were transmitted with a resolution of 500 m. In the image areas of rough ice and hummocks (brighter signature) could be clearly distinguished from smooth undeformed ice (darker signatures). Based on this information the icebreaker changed its course and selected a much quicker and safer sailing route. Six to eight images were transmitted to the icebreaker in this expedition and the captain's comments to the images was that they were very useful and in difficult conditions as shown in Figure 5 many hours of sailing time can be saved. Occasional use of SAR data like this is interesting for demonstration of new technology, but there is a number of requirements which need to be satisfied before the SAR monitoring technology can become an operational tool, such as: selection of SAR coverage in strategic areas, real-time access to SAR data, data ordering procedure, interpretation of SAR

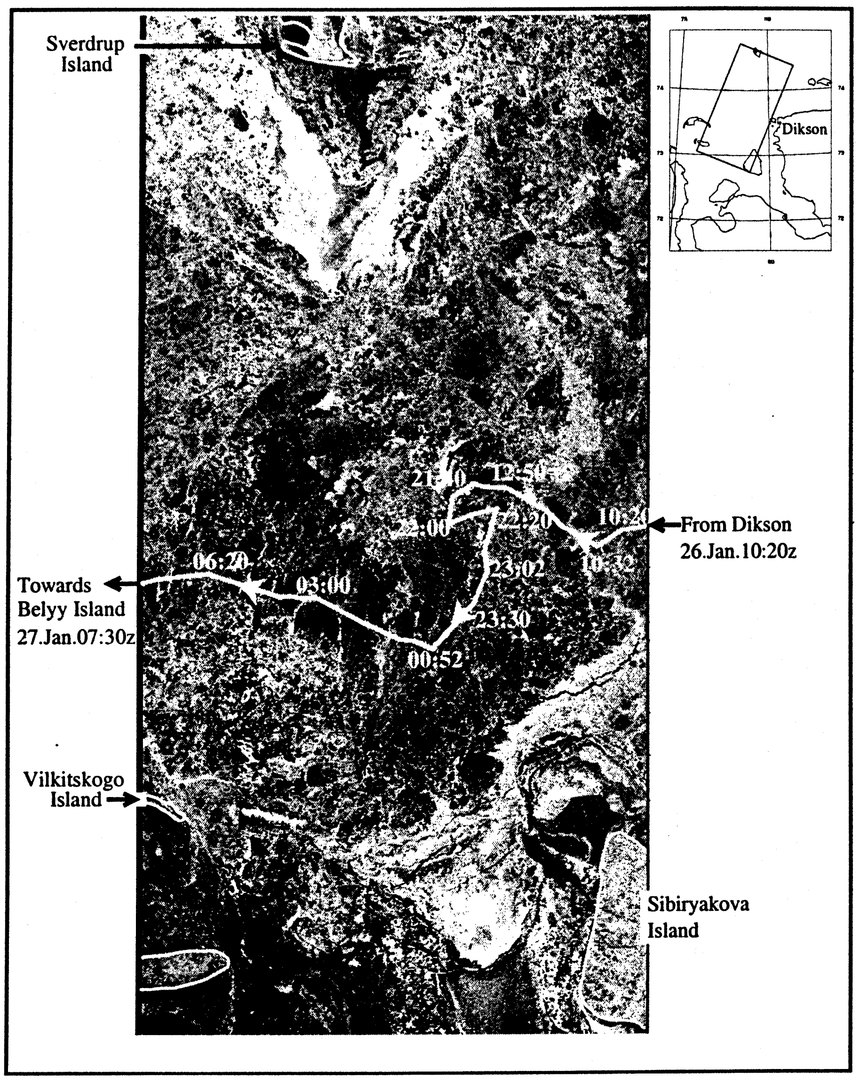

Figure 5. ERS SAR image of 26 January 1996. The image was transmitted to the icebreaker Taymyr in near real-time (within 6 hours) and was used by the captain to change the sailing route due to difficult ice conditions. The ship track with time markers are superimposed on the image. Copyright ESA/TSS 1996.

images, quantitative ice parameters from SAR, linking ERS data to the Russian ice monitoring services, transmission of ice maps and images to ships and other end users.

4. SURVEY OF SAR ICE INFORMATION REQUIREMENTS IN THE NSR

In a market investigation for satellite SAR data in Russia , which includes both Russian and non-Russian customers, representatives for more than 70 institutions have been interviewed, covering sea ice and environmental monitoring. The purpose of the market survey was to obtain estimates of current and future need for SAR data. The user categoriesfor SAR ice data are summarized in Table 1.

The users can be divided into three main groups: 1. operational users which need ice information in near real-time; 2: consulting services which mainly need archived data and statistical information on ice conditions, and 3: scientific users who need data in research and development projects. The operational users are first of all Murmansk Shipping Company's icebreaker fleet, other shipping companies operating in ice-covered seas and the Russian Hydrometeorological Service. Oil companies and offshore industry currently need consulting services, but will become operational users when they start offshore operations. Consulting services are also required from engineering companies, consulting companies and transport institutions. Scientific users include universities, marine research institutions and other environmental research institutes.

Table 2. Users of sea ice information in the Northern Sea Route

User category	User characterization	Example of users
National institutions and regional authorities	Experienced users of satellite data in ice monitoring	HydroMet Service (AARI, NPO Planeta); Russian Academy of Science; regional authorities
Shipping companies	MSC is a very experienced user while others can be new users	Murmansk Shipping Co. Far Eastern Shipping Co. White Sea/Onega Shipping Co.
Engineering companies	New users both in marine and terrestrial applications	Norilsk Nikel Arctic Marine Engineering
Oil, gas and offshore industry	Important future users with capability to pay for high quality service	GAZPROM, PeterGAZ, AMOCO, Norsk Hydro, Heerema B.V. Shell
Consulting companies	New users, some experience	Eco-Systema Ltd
Environmental research: water/ice, biosphere, climate	Several experienced users and many potential users	PINRO, Murmansk Marine Biological Research Institute,

5. RECOMMENDATION OF A NEAR-REAL TIME OPERATIONAL INFORMATION SYSTEM USING SATELLITE RADAR DATA.

It is suggested to implement an operational radar ice monitoring system which will be included in the general Russian ice monitoring service. It will use Okean SLR data for large scale surveying and SAR data for detailed observations in specific key areas, which are identified as difficult for the navigation It is recommended to obtain weekly coverage of SLR for the whole Northern Sea Route, and SAR images scenes every 1 - 2 days in key areas where ice naviation or other activities are ongoing. The priority areas and time periods for SAR coverage are shown in Table 2:

Table 2. Priority areas and periods for SAR coverage

Area	*Season of priority*	*Main users*
White Sea	December - June	Ship traffic
Pechora Sea	December - June	Oil and gas exploration
Kara Gate and Jugor strait	December - July	ship traffic
Yamal coast, Belyi island, Ob estuary	November - August	Ship traffic, oil/gas exploration, environmental monitoring
Yenisei estuary	March - July	Ship traffic
Vilkitsky and Mathiessen str.	June - November	Ship traffic
New Siberian islands	July - November	Ship traffic
Long strait	July - November	Ship traffic

With ERS-2, and from 2000 ENVISAT, it is possible to use SAR data ever day in operational ice monitoring. Up to now, SAR data have primarily been obtained in the western part of Russia because this area can be covered by European ground stations such as Tromsø Satellite Station. To provide SAR data coverage for the whole NSR and major parts of Siberia, a SAR receiving station is currently built by ESA in northern Siberia. This station will facilitate access to SAR data for the whole user community in Russia, especially near real-time data.

6. CONCLUSION

SAR derived ice information has proven to be essential in ice monitoring of the NSR, both for navigation and off-shore operations. Near real-time use of SAR data onboard Russian icebreakers can improve the ship velocity considerably if the data are obtained over the critical areas at the right time. The main limitation of ERS data is the narrow swath width which only makes it possible to cover selected parts of the NSR. With ENVISAT wideswath images, covering 450 km wide swaths, full coverage of all ice areas can be obtained every 1 - 2 days. The high cost of SAR data limits the actual use to customers who are able to finance use of such data. A realistic scenario for operational ice monitoring is synergetic use of SAR, Okean SLR, AVHRR and SSM/I data, where SAR data will be used only in difficult situations when high resolution ice information is needed. For regular monitoring the other types of satellite data will be used extensively.

7. ACKNOWLEDGMENT

The project has been supported by European Space Agency, Russian Space Agency the Norwegian Research Council and Murmansk Shipping Company.

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