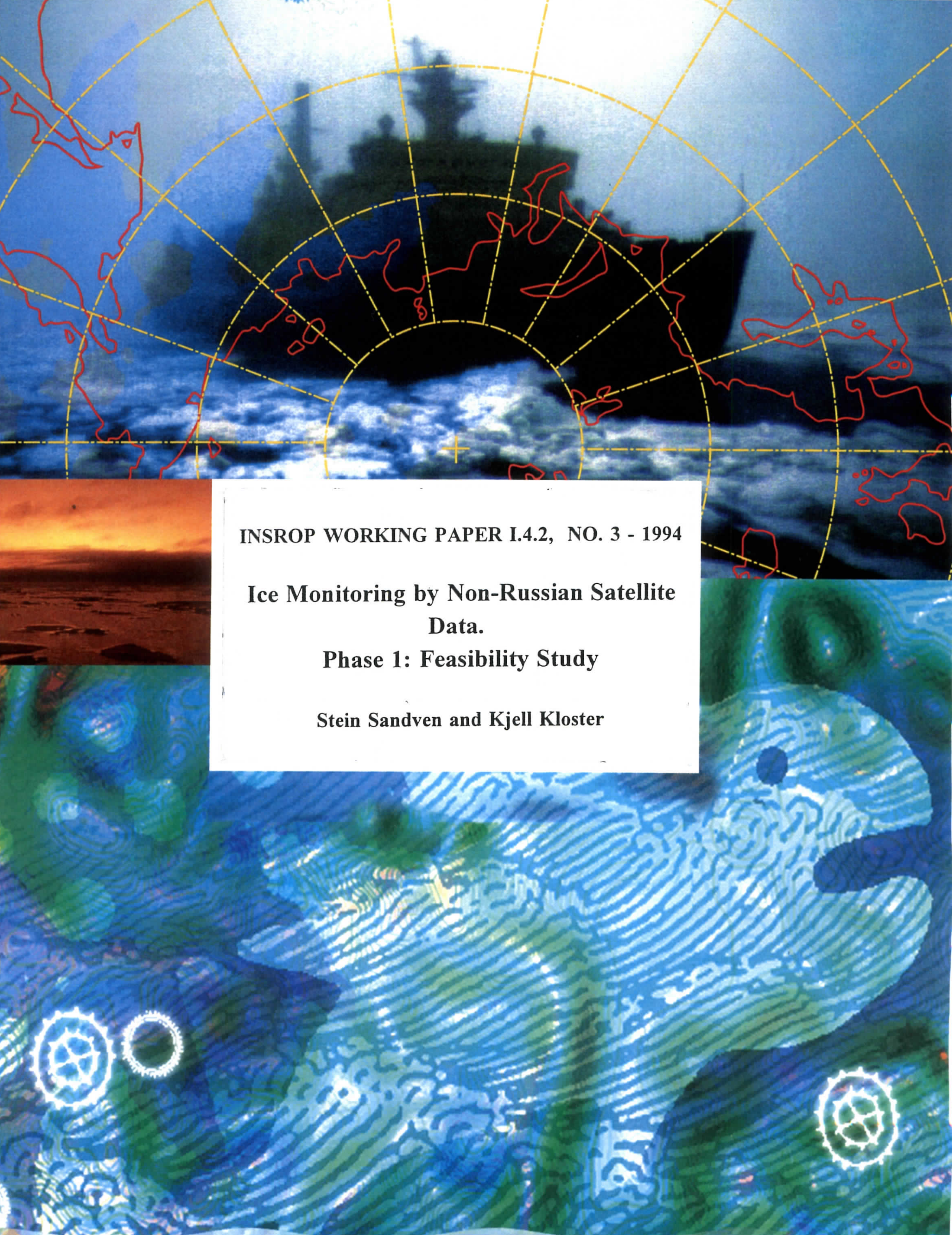


INSROP WORKING PAPER I.4.2, NO. 3 - 1994

Ice Monitoring by Non-Russian Satellite Data. Phase 1: Feasibility Study

Stein Sandven and Kjell Kloster

INSROP International Northern Sea Route Programme

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

Ship and Ocean Foundation, Japan

International Northern Sea Route Programme (INSROP)

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

Ship & Ocean Foundation, Japan

INSROP - WORKING PAPER

Sub-programme I: Natural Conditions and Ice Navigation

Project I.4.2: Ice Monitoring by Non-Russian Satellite Data. Phase 1: Feasibility Study.

By: Research Director Stein Sandven (supervisor) and Senior Researcher Kjell Kloster, Nansen Environmental and Remote Sensing Center

Address: Edvard Griegsvei 3A
5037 Solheimsvik
NORWAY

Date: 12 July

Reviewed by: Professor William M. Sackinger, Geophysical Institute, University of Alaska, Fairbanks

What is an INSROP Working Paper and how to handle it:

This publication forms part of a Working Paper series from the **International Northern Sea Route Programme - INSROP**. This Working Paper has been evaluated by a reviewer and can be circulated for comments both within and outside the INSROP team, as well as be published in parallel by the researching institution. A Working Paper will in some cases be the final documentation of a technical part of a project, and it can also sometimes be published as part of a more comprehensive INSROP Report. For any comments, please contact the author of this Working Paper.

FOREWORD - INSROP WORKING PAPER

INSROP is a five-year multidisciplinary and multilateral research programme, the main phase of which commenced in June 1993. The three principal cooperating partners are **Central Marine Research & Design Institute (CNIIMF)**, St. Petersburg, Russia; **Ship and Ocean Foundation (SOF)**, Tokyo, Japan; and **Fridtjof Nansen Institute (FNI)**, Lysaker, Norway. The INSROP Secretariat is shared between CNIIMF and FNI and is located at FNI.

INSROP is split into four main projects: 1) Natural Conditions and Ice Navigation; 2) Environmental Factors; 3) Trade and Commercial Shipping Aspects of the NSR; and 4) Political, Legal and Strategic Factors. The aim of INSROP is to build up a knowledge base adequate to provide a foundation for long-term planning and decision-making by state agencies as well as private companies etc., for purposes of promoting rational decisionmaking concerning the use of the Northern Sea Route for transit and regional development.

INSROP is a direct result of the normalization of the international situation and the Murmansk initiatives of the former Soviet Union in 1987, when the readiness of the USSR to open the NSR for international shipping was officially declared. The Murmansk Initiatives enabled the continuation, expansion and intensification of traditional collaboration between the states in the Arctic, including safety and efficiency of shipping. Russia, being the successor state to the USSR, supports the Murmansk Initiatives. The initiatives stimulated contact and cooperation between CNIIMF and FNI in 1988 and resulted in a pilot study of the NSR in 1991. In 1992 SOF entered INSROP as a third partner on an equal basis with CNIIMF and FNI.

The complete series of publications may be obtained from the Fridtjof Nansen Institute.

SPONSORS FOR INSROP

- Sasakawa Foundation/Ship & Ocean Foundation, Japan
- The government of the Russian Federation
- The Norwegian Research Council
- The Norwegian Ministry of Foreign Affairs
- The Norwegian Ministry of Industry and Energy
- The Norwegian Ministry of the Environment
- State Industry and Regional Development Fund, Norway
- Norsk Hydro
- Norwegian Federation of Shipowners
- Fridtjof Nansen Institute
- Kværner a.s.

PROFESSIONAL ORGANISATIONS PERMANENTLY ATTACHED TO INSROP

- Ship & Ocean Foundation, Japan
- Central Marine Research & Design Institute, Russia
- Fridtjof Nansen Institute, Norway
- National Institute of Polar Research, Japan
- Ship Research Institute, Japan
- Murmansk Shipping Company, Russia
- Northern Sea Route Administration, Russia
- Arctic & Antarctic Research Institute, Russia
- ARTEC, Norway
- Norwegian Polar Research Institute
- Norwegian School of Economics and Business Administration
- SINTEF NHL (Foundation for Scientific and Industrial Research - Norwegian Hydrotechnical Laboratory), Norway.

PROGRAMME COORDINATORS

- **Yuri Ivanov, CNIIMF**
  Krasnoy Konnitsy Str.6
  St. Petersburg 193015, Russia
  Tel: 7 812 271 5633
  Fax: 7 812 274 3864
  Telex: 12 14 58 CNIMF SU
- **Willy Østreng, FNI**
  P.O. Box 326
  N-1324 Lysaker, Norway
  Tel: 47 67 53 89 12
  Fax: 47 67 12 50 47
  Telex: 79 965 nanse n
  E-mail: Elin.Dragland @fni.wpoffice.telemax.no
- **Masaru Sakuma, SOF**
  Senpaku Shinko Building
  15-16 Toranomon 1-chome
  Minato-ku, Tokyo 105, Japan
  Tel: 81 3 3502 2371
  Fax: 81 3 3502 2033
  Telex: J 23704

Nansen Environmental and Remote Sensing Center Report

SUMMARY

This feasibility study gives a description of the ice monitoring of the Northern Sea Route by non-Russian satellites. The varying spatial and temporal scales of the satellite data are discussed as well as the data availability. The increased use of microwave remote sensing techniques, by passive as well as active instruments which are independent of cloud and light conditions, is a general trend in ice monitoring. Demonstration projects are implemented where the microwave instruments SSM/I and SAR are used in near-real time to assist Russian icebreakers in ice navigation. The passive sensor SSM/I provides coarse-resolution large scale ice concentration maps of the whole Arctic daily, while the active sensor SAR gives high-resolution images of the ice in selected areas where ice navigation is difficult. Both SSM/I and SAR data are available in near-real time or as offline products. The experiences from current demonstrations, technical aspects and future plans are discussed.

CONTENTS

1. Objective ....page 1
2. Background ....page 1
3. Description of satellite instruments for ice monitoring...page 4
3.1 AVHRR ....page 4
3.2 SSM/I....................page 4
3.3 ERS-1 SAR ....page 5
3.4 Radarsat SAR ....page 7
4. Satellite ice information for navigation ....page 8
4.1 Large-scale and regional monitoring ....page 8
4.2 Detailed monitoring in selected areas....................page 11
5. Demonstrations of SAR ice monitoring ....page 12
5.1 The L'Astrolabe demonstration....................page 12
5.2 The Sovetsky Soyuz demonstration....................page 12
5.3 Experience from the demonstrations....................page 12
5.4 The use of full-resolution SAR images....................page 14
5.5 The detection limit of drifting ice by SAR ....page 14
6. Data communication ....page 14
7. Conclusion and future prospects....................page 15
8. Acknowledgement....................page 15
9. References....................page 15

Technical Report

Bergen, 12. July 1994

O.M. Johannessen
Director

This report is made as part of sub-programme I. Natural Conditions and Ice Navigation of the International Northern Sea Route Programme by:

Nansen Environmental and Remote Sensing Center,
Edvard Griegsvei 3A,
N-5037 SOLHEIMSVIK,
NORWAY.
Telephone: +47 55 29 72 88
Telefax: +47 55 20 00 50
e-mail: omj@nanvax.nrsc.no

1. Objective

A main objective of this project is to demonstrate the usefulness of ice monitoring by satellites for ice navigation in the Northern Sea Route (NSR).

The objective of Phase 1 is to study the feasibilty of using microwave, visual and infrared satellite data from non-Russian satellites. The study will include present and future satellite data, technical requirements for transmission of data to ships and discussion of the ice information important for navigation.

2. Background.

The operations along the northern Russian coast are governed by Russian authorities. Until the last few years only a limited number of non-Russian ships have had access to this area. The general access to the region is governed by the Russian Ministry of Defense. The responsibility for civilian ship traffic in the region is managed under the Ministry of transport, which has its own Department of the North East Passage. The environmental monitoring, which is essential for safe operations in this polar region, is organized by the Russian Hydrometeorological Committee. The operations and monitoring of the northern sea route region are divided in the western and eastern regions, with respectively Murmansk and Vladivostok as the main ports.

The navigation along the NSR is controlled by the Marine Operational Headquarter (MOH), which is in Dikson for the western part and in Pevek for the eastern part. Both of these centers have distributed operative groups along the coast. Before entering the region, ships must inform the MOH about their departure from port and then send daily reports at 00:00 and 12:00 MMT (Moscow Mean Time).

The Murmansk Shipping Company (MSC) and the Far-East Shipping Company (FESCO) in Vladivostok, operate a large fleet of ice-classified cargo vessels. These vessels are supported by the MSC (and FESCO) Nuclear Icebreaker Fleet Service (NIFS), with several large nuclear icebreakers such as Arctica and Sovetsky Soyuz. At the Dikson MOH the Science Operational Group (SOG) of the Russian Hydrometeorological Committee and MSC provides a real-time sea ice monitoring and forecasting service to the vessels operating in the region. Figure 1 shows the main organizational scheme leading to the SOG, which is responsible for the production of the integrated sea ice maps for the western part of the region.

The sea ice information service is based on field observations from the icebreakers as well as from visual and thermal infrared (IR) satellite imagery (NOAA AVHRR; Russian Meteor and Okean satellites). On a temporal basis an airborne multi-frequency side-looking radar system is operated in the region by the Polar Institute of Fishery and Oceanography (PINRO) in Murmansk.

After the Almaz-1 radar satellite ended its operations in 1992, the Russian ice service has not had access to any satellite SAR data. Existing airborne radar systems are expensive to operate and have limited temporal and spatial coverage.

The next scheduled Russian microwave radar sensor to be launched on the Okean satellite series is a Side-Looking Radar (SLR) which is active in the 3 cm wavelength region (X-band), has a spatial ground resolution of 2 km and covers a 2000 km wide swath. The Okean is operated and data will be distributed by Planeta in Moscow.

The next Russian SAR sensor will be

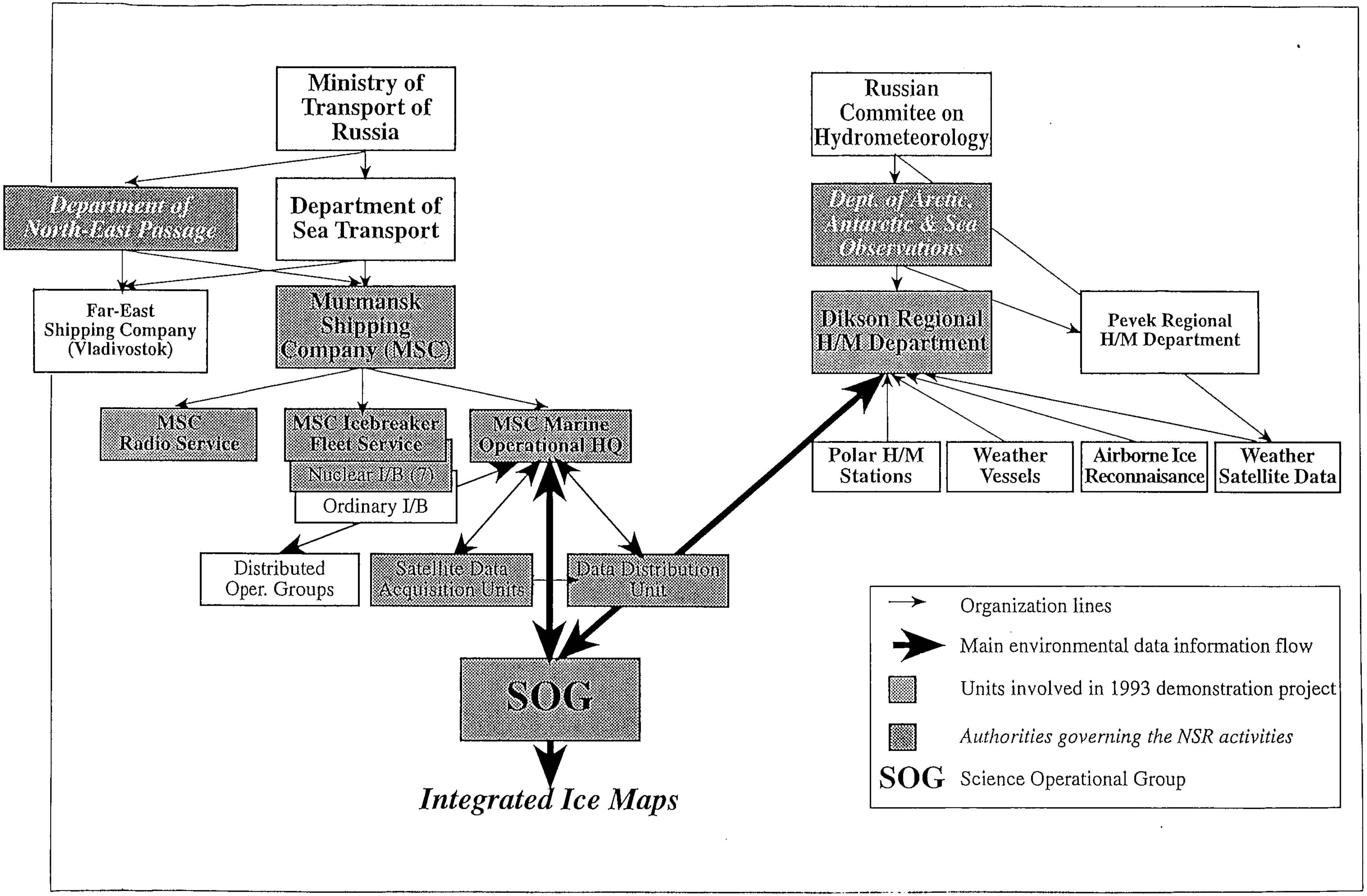


Figure 1 The Russian organization scheme and responsibilities for the civilian traffic and sea ice monitoring of the Northern Sea Route

on the Almaz-1B satellite, due to be launched after 1995. Major parts of the sensor and satellite hardware have already been built, but major parts of the integration and launch are still not realized. To complete the Almaz-1B satellite mission, international funding will be essential, and for this a Russian/US joint venture has been set up to undertake the financing of the mission.

The two major satellite orbits are:

i) the polar orbit (the satellite is circling the Earth 13 -15 times per day up to high latitudes),

ii) the geostationary orbit (the satellite is permanently positioned at a given longitude over the equator

The polar orbit is almost exclusively used for ice mapping at high latitudes, as a geostationary satellite has too large foreshortening of areas at latitudes above 65°. Some Russian satellites also use intermediate orbits (e.g. the Molynia elliptic orbit), but this orbit type is little used by other nations.

A number of Russian satellites in the Cosmos, Meteor and Okean series have had instruments more or less dedicatdt to ice mapping, using a variety of optical and microwave

Table 1. Summary of past and present satellites providing sea ice imagery of the Northern Sea Route.

Satellite	Instrument type	Instrument acronym	Image resolution	Swath width	Start year	End year	Data delivery
TIROS series (USA)	Visual and thermal IR radiometer	VHRR	1.5 km	2500 km	1970	1979	Real-time
NOAA N-series (USA)	Visual and thermal IR radiometer	AVHRR	1 km	2500 km	1978	in operation	Real-time
NIMBUS-5 (USA)	passive microwave radiometer	ESMR	30 km	2000 km	1973	1976	Real-time
NIMBUS-7 (USA)	passive microwave radiometer	SMMR	30 km	780 km	1978	1987	Real-time
DMSP (USA)	passive microwave radiometer	SSM/I	20 - 60 km	1400 km	1987	in operation	Real-time
Landsat 1 - 5 (USA)	Visual and near IR radiometer	MSS, TM	80 m 30 m	180 km	1972	in operation	Offline
SPOT 1, 2, 3 (France)	Visual radiometer	HRV	10 m / 20 m	60 km	1986	in operation	Offline
ERS-1 (ESA)	Synthetic Aperture Radar	SAR	30 m	100 km	1991	in operation	Real-time
JERS-1 (Japan)	Synthetic Aperture Radar	SAR	20 m	80 km	1991	in operation	

sensors. Ice maps in NSR also make regular use of the image data available from the optical instrument AVHRR in the American NOAA-satellites.

Past and present satellite instruments have acquired a large amount of imagery that has been archived in various data formats. Many images have also been interpreted and archived as ice maps. For the study of historical ice conditions, these data can be extracted from various archives.

Archived data can be used for many purposes, e.g. for statistical ice analysis, scientific research. The quality and diversity of ice information that can be provided by archived maps is variable and will be discussed in chapter 4.

3. Description of satellite instruments for ice monitoring.

3.1 AVHRR (Advanced Very High Resolution Radiometer).

Satellites:

NOAA polar orbit weather satellite series (no. 6 - 12) and TIROS-N.

Period:

From October 1978. NOAA-11 and NOAA-12 are now active.

Instrument characteristics:

Four or five channels in the spectral band from 0.55 μ to 12 μ. Some instruments have the thermal IR channel no.4 "split" into two channels: 4 and 5 for improved atmospheric correction. Imagery is transmitted in real-time as APT (Automatic Picture Transmisssion) and HRPT (High-resolution Picture Transmission). The use of HRPT requires steerable antennas and gives the most accurate data. Channel 1 and 2 (albedo) are uncalibrated but approximately linear to reflected sunlight. Channel 4 (and sometimes 5) are calibrated to relative accuracy of 0.2°K. Resolution is 1.1 km at nadir and swath width is 2500 km.

Ice mapping:

Limited by cloud cover (all channels), and by darkness (albedo channels 1 and 2). Successful mapping of total ice concentration although the concentration is usually estimated manually from the image. It is not possible to distinguish ice types. Features larger than a few km can be identified such as large leads, polynyas and large ice floes. In periods with prolonged cloudiness, the time between repeated images can be days or weeks. Several images can be combined to cover larger areas. The ice concentration accuracy is weather-dependent and poorly known. Image resolution is the same as for raw data.

Data sources:

1. Digital raw data of albedo and radiant power. Tromsø Satellite Station covers the western part of NSR and provides some archived images on CEOS-format magnetic medium and by file-transfer. Selected images are also available from other ground stations and centrally from Eurimage/ESA. Selected data are also available from various data-users such as NERSC.

2. Hardcopy of images.

3. Hardcopy of ice maps.

4. Digitized ice concentration maps.

3.2 SSMI (Special Sensor Microwave Imager).

Satellites:

Defence Meteorological Satellite Program (DMSP-series).

Period:

From July 1978. Satellites F10 and F11 are now active.

Instrument characteristics:

7 channels (from 19.3 to 85 GHz), dual polarization (H and V) The accuracy of measured brightness temperature is about 1 K. The spatial resolution is maximum 20 km and the instrument scans at a conical 50° incidence angle, with a swath width of 1400 km.

Data transmission:

The swath data are available at Civilian NOAA Oceanographic Data Distribution System (CNODDS) in Monterey in USA for file transfer 6 - 8 hours after the satellite overpass.

Ice mapping:

Daily coverage of the whole Arctic is available except near land. Resolution of total ice concentration is close to 20 km with the use of the 85 GHz channel. Ice edge position can be estimated at an accuracy of about 10 km. No good data within 50 km from land.

Data sources:

1. Offline data are available on CD-ROM with daily polar brightness (radiance) data from National Snow and Ice Data Center (NSIDC), CIRES, Campus Box 449, Univ.of Colorado, Boulder, Colorado 80309 USA. From 1978 18 volumes have been issued. The data are available also at NERSC.

2. Offline data on CD-ROM are also available from NSIDC with daily files of ice concentration estimated by the NASA algorithm.

3. On-line data-files of swath-data for the last two days are available at CNODDS.

4. Ice concentration maps for selected orbits estimated with the NORSEX algorithm are available from NERSC in near real-time.

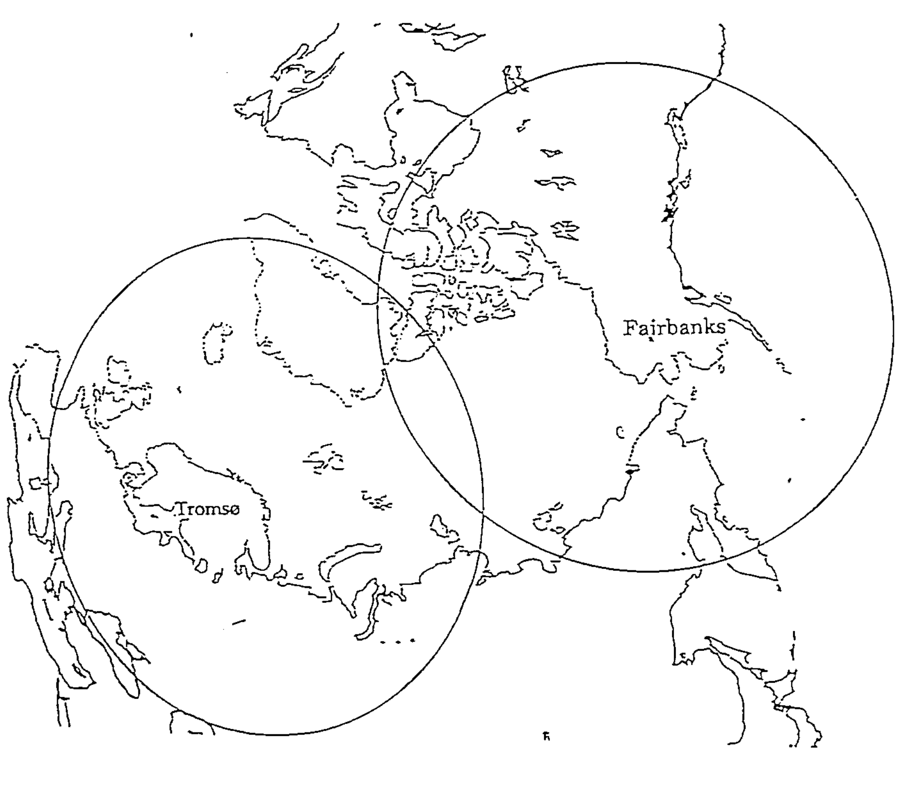


Figure 2. ERS-1 SAR coverage for the Tromsø Satellite Station and Alaska SAR Facility in Fairbanks.

3.3 ERS-1 SAR (Synthetic Aperture Radar).

Satellite:

European Remote sensing Satellite (ERS-1).

Period:

From July 1991. Still in operation. ERS-2 will replace ERS-1 in January 1995.

Instrument characteristics:

The SAR is an active microwave C-band radar (5.3 GHz) with VV polarization. The pixel size of the full-resolution SAR image is 16 by 20 m using 3 looks and a signal/noise ratio of 3, the incidence angle is 20 - 26 °and the swath width is 100 km. The repeat cycle for ERS-1 varies between 3, 35 and 168 days, while ERS-2 will be operated with only the 35 day cycle. The SAR coverage for ERS-1 and -2 is illustrated in Fig. 2.

Data transmission:

TSS processes and distributes SAR scenes in real-time in the area west of approximately 110° E which includes the whole Kara Sea and the Vilkitskogo Strait. Alaska SAR Facility (ASF) in Fairbanks covers the eastern part of NSR (east of about 140° E) The Laptev Sea is not covered by ERS-1 SAR data. A ground station for reception of SAR data in central Russia is planned and will cover also the Laptev Sea.

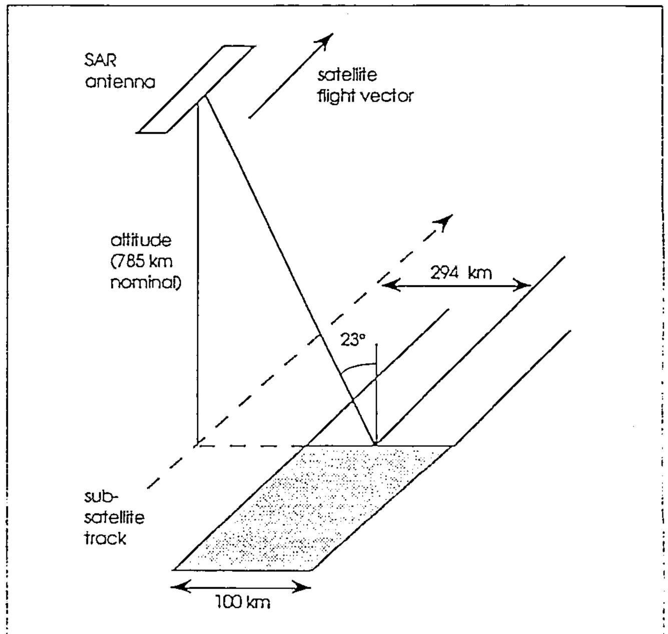


Figure 3. Principle of ERS-1 SAR imaging of the earth's surface.

Ice mapping:

Many applications of SAR ice monitoring have been demonstrated, including ice navigation in the NRS (Johannessen et al., 1992). This will be further discussed in section 5.

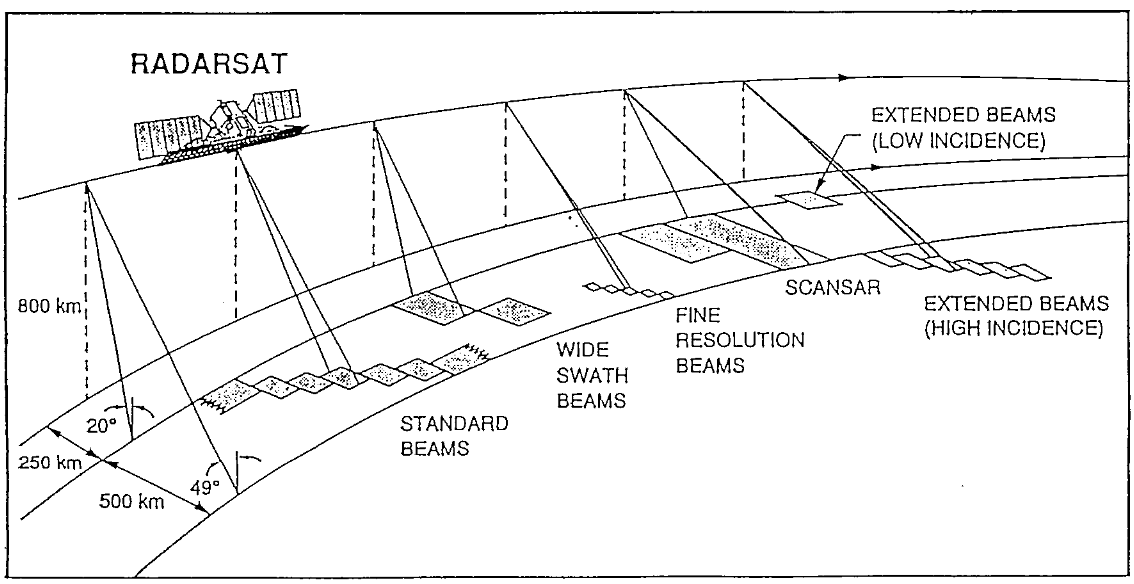


Figure 4. SAR operation modes for Radarsat.

Data sources:

1. Overview of available SAR scenes can be found at ESA's Help and Order Desk at ESRIN in Frascati, Italy, or by using an updated version of the PC-program "DESC".

2. Scenes can be ordered from ESRIN in several data formats, e.g. PRI-format for data on 12.5 m grid. Some scenes are available in FDC-format on 16 m x 20 m grid.

3. Recent scenes are available from TSS on 16 m x 20 m grid in FRI-format ("full-resolution" images).

4. Recent scenes are available from TSS as images averaged to 100 m pixel size in LRI-format ("low resolution").

5. Examples of SAR data from the eastern part of the NRS are available from ASF.

3.4 Radarsat SAR.

Satellite:

Radarsat (Canada).

Period: From spring 1995.

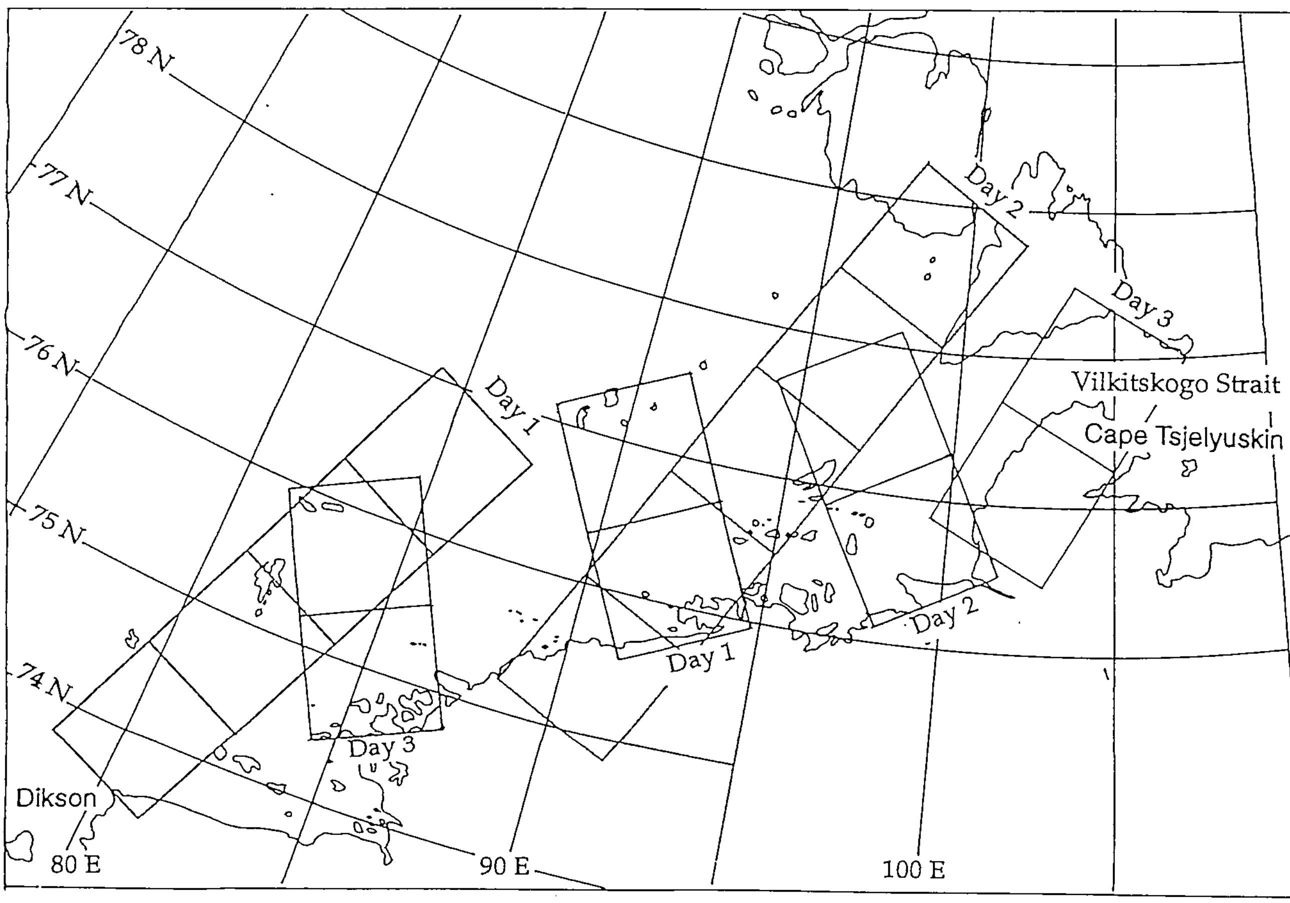


Figure 5. The boxes indicate the ERS-1 SAR coverage of the sea ice in the Kara Sea between Dikson and Cape Tsjelyuskin during a three day period. The pattern is repeated for every three day period. Each box is 100 by 100 km. Radarsat SAR will from 1995 provide SAR stripes which are up to 500 km wide.

Instrument characteristics:

Active microwaves in C-band channel (5.3 GHz) and HH polarization. Several "modes" with variable swath width, up to 500 km are planned with 20 - 50° incidence angle (Fig. 4). The image resolution varies from 10 - 100 m depending on operating mode and noise suppression. The repeat cycle is 24 days.

Ice mapping:

The wide swath mode covering 500 km wide stripes with 100 m resolution is expected to be very useful for regular ice mapping, especially at high latitudes such as the NSR. This means that most of the NSR, except for the Laptev Sea, will be covered within 3 days.

4. Satellite ice information and the importance for navigation.

4.1 Large-scale and regional monitoring

Monitoring of the whole NSR from the Barents Sea to the Bering Strait is done every day by SSM/I data. These data provide maps of total ice concentration as well as fraction of multiyear and firstyear ice. An example of an ice concentration map from SSM/I data is shown in Figure 6.

Regional monitoring can also be done using AVHRR images in cloudfree areas.Although the NOAA satellites fly over the NSR area several times per day, good ice images can only be obtained at irregular times. AVHRR data are used in the ice maps produced by Norwegian Meteorological Institute, National Ice Center in USA, and the Ice Center in Dikson. The ice maps produced by the Norwegian Meteorological Institute also contain sea surface temperature (Figure. 7). The maps are issued once per week and extend to about 75° E. The National Ice Center's maps are produced globally, but are divided into regions. The example in Figure 8 shows the NSR west of Vilkitskogo Strait.

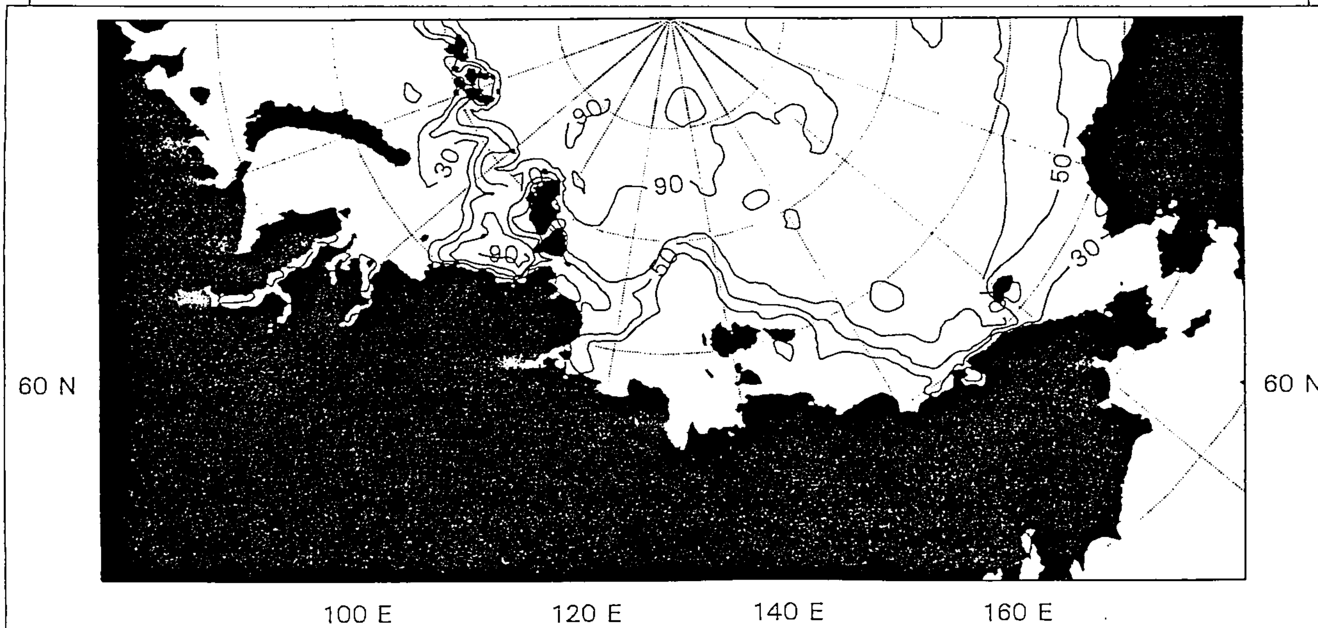


Figure 6. Ice concentration map based on SSM/I data from a summer situation with minimum ice extent. This map is from August 15 1988 and shows isolines for 30, 50, 70 and 90 % total ice concentration.

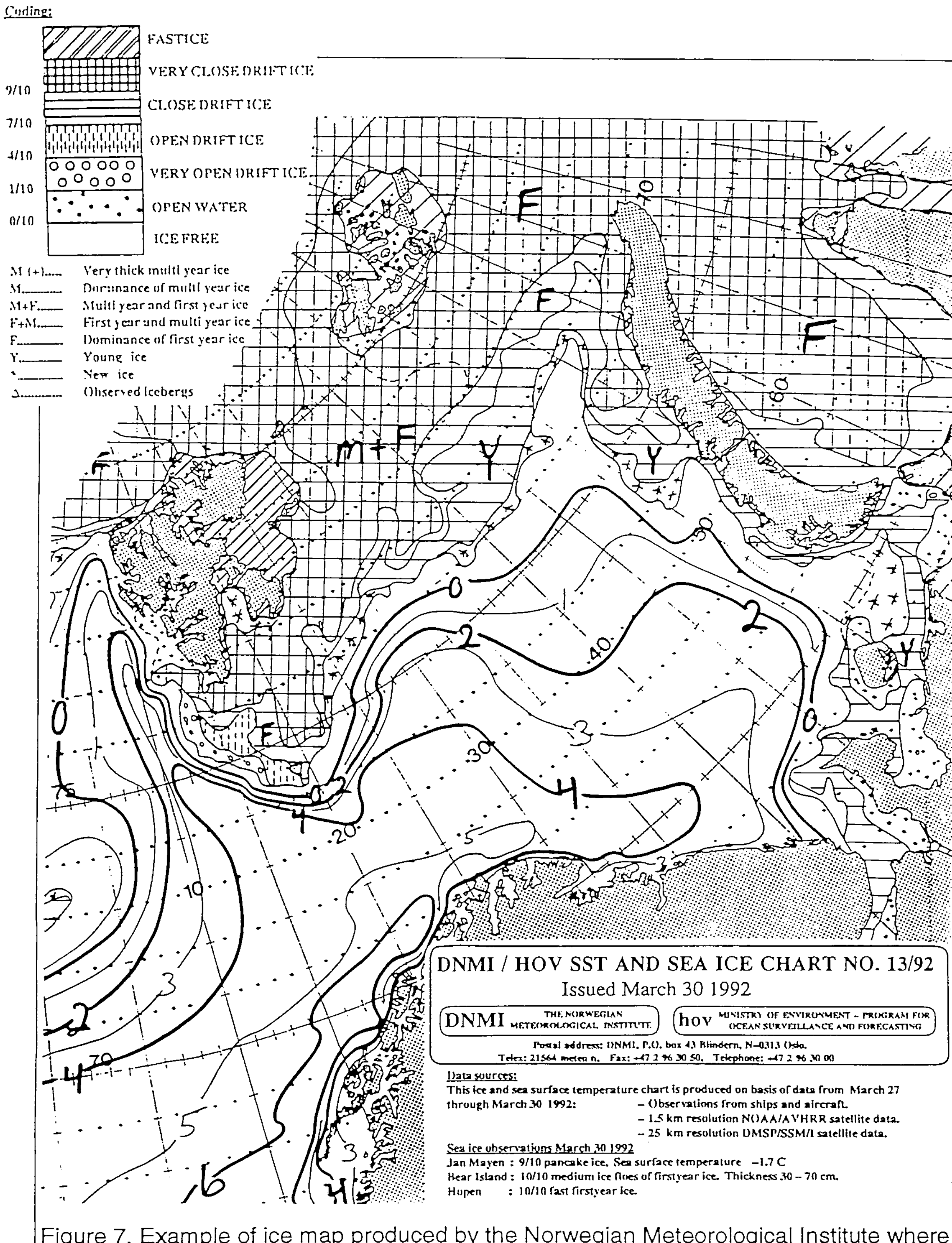
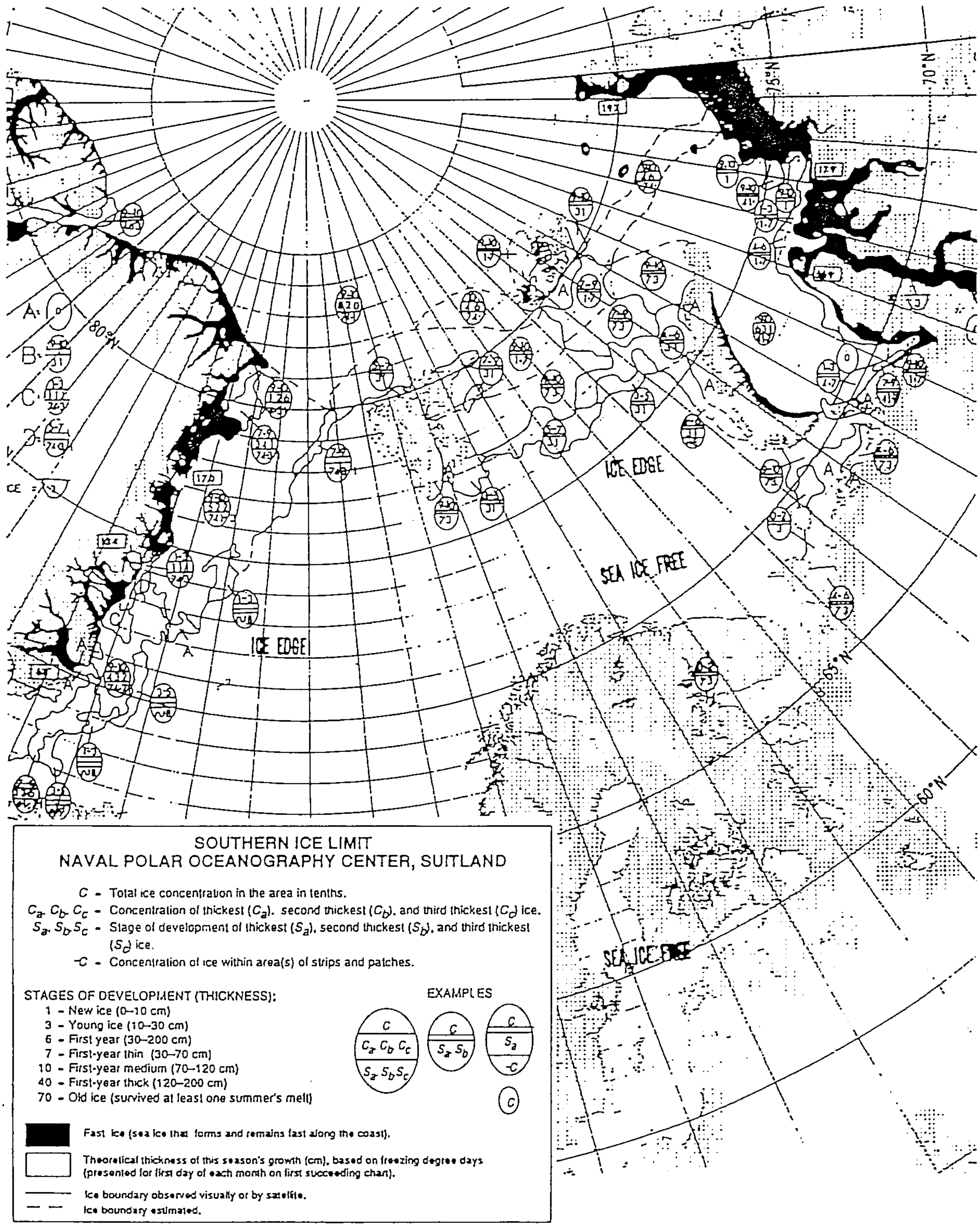


Figure 7. Example of ice map produced by the Norwegian Meteorological Institute where data from AVHRR data are used. Ice types (F and M) are derived from SSM/I data.



4.2

Figure 8. Example of ice map of the eastern Arctic for June 5, 1991, produced by the National Ice Center (formerly Navy-NOAA Joint Ice Center and Naval Polar Oceanography Center) in USA using AVHRR and SSM/I data.

4.2 Detailed monitoring in selected areas.

Detailed ice maps of smaller areas can be made from high-resolution optical sensors, such as Landsat TM and SPOT HRV. However, these data are limited by clouds and are not available in real-time. Therefore, they cannot be used for regular monitoring. AVHRR data with a resolution of 1 km are available in real-time and can also be useful for ice mapping when the requirement for detailed information is less.

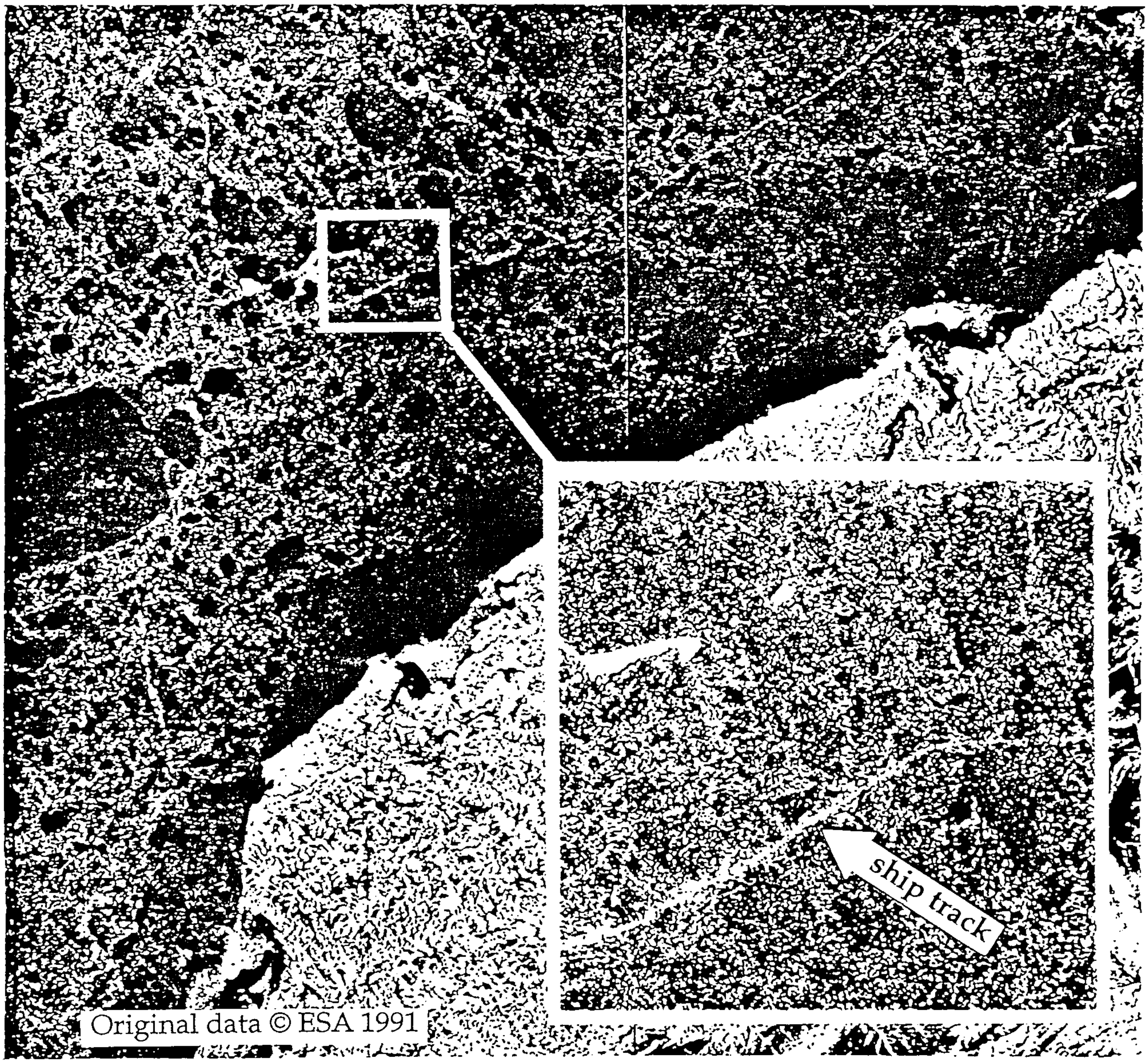


Figure 9. SAR image from ERS-1 obtained on August 16 1991 showing dense packice along the Siberian coast and the track from a Russian icebreaker. SAR images show detailed ice information such as leads of thin ice along the coast and large individual first-year floes. A series of such images were transmitted by telefax to the French polar vessel L'Astrolabe which sailed through the NSR from Europe to Japan in August 1991. The enlarged area is a full-resolution image which shows some more details, but is blurred due to the high-frequency speckle noise.

The most important data for detailed monitoring of smaller areas are the ERS-1 SAR images (Fig. 9). These images are independent of cloud and light conditions. They can be obtained along 100 km wide stripes at three day interval as shown in Fig. 5. At full resolution (pixel size of 16 x 20 m) the image is blurred due to radar speckle noise.Therefore these images are usually averaged to 100 m pixel size. They provide information about ice types, ice concentration, ice edge position, ice motion shear zones, floe size and leads.

5. Demonstration of SAR ice monitoring.

5.1 The L'Astrolabe demonstration.

In August 1991 shortly after the launch of ERS-1, the French polar vessel l'Astrolabe sailed through the NSR escorted by icebreakers. The pattern of the SAR coverage is shown in Fig. 5, but only the ascending passes were used. The images were downlinked at the ESA Groundstation in Kiruna and analysed by an ice specialist from NERSC. Both the image hardcopies and the interpreted ice maps were telefaxed to the ship using the Inmarsat communication link.

It is important for the navigation that the time period between the SAR imaging and the ship entering the imaged ice (the SAR "lead time") is as short as possible. In this experiment it varied between 4 days and 18 hours. In later experiments this time has been reduced to 2 - 3 hours.

The segmentation of SAR images into areas of water and ice, and the interpretation of the backscatter signal to different ice types and ice forms was done for the first time with ERS-1 SAR images. SSM/I ice concentration maps were used to plan acquisition of the SAR images.

5.2 The Sovetsky Soyuz demonstration.

In November 1993, the icebreaker Sovetsky Soyuz received SAR images during an expedition in the Kara Sea. The images were ordered in near-real time from TSS and analyzed at NERSC. The ice edge position and some of the prominent ice features and ice types were marked on the image. The images were telefaxed to the ship and to the MOH in Dikson.

The response from the captain onboard the icebreaker was generally positive. The quality of the images was reduced by the telefax transmission. But the information in the images was still useful because different ice types such as landfast ice, leads and thin firstyear ice could be identified. In one case, the sailing route was changed based on the information in the SAR image. An example of a SAR image sent to Sovetsky Soyuz is shown in Fig. 10.

5.3 Experience from the demonstrations

The experience from the SAR ice monitoring demonstrations so far can be summarized as follows:

1) The use of Inmarsat communication for transmission by telefax functioned better than anticipated. Most of the Northern Sea Route is within range of Inmarsat. Only an area in the Laptev Sea was out of range. This area is also out of range of ERS-1 for both the Tromsø and the Alaska ground station.

2) The quality of the SAR images sent on telefax was in some cases rather poor and in other cases very good. Especially the images near Cape Tsjelyuskin, with clear ice features including the ship track, were well reproduced onboard the ship. However, the images from the eastern part of the route, obtained during the L'Astrolabe

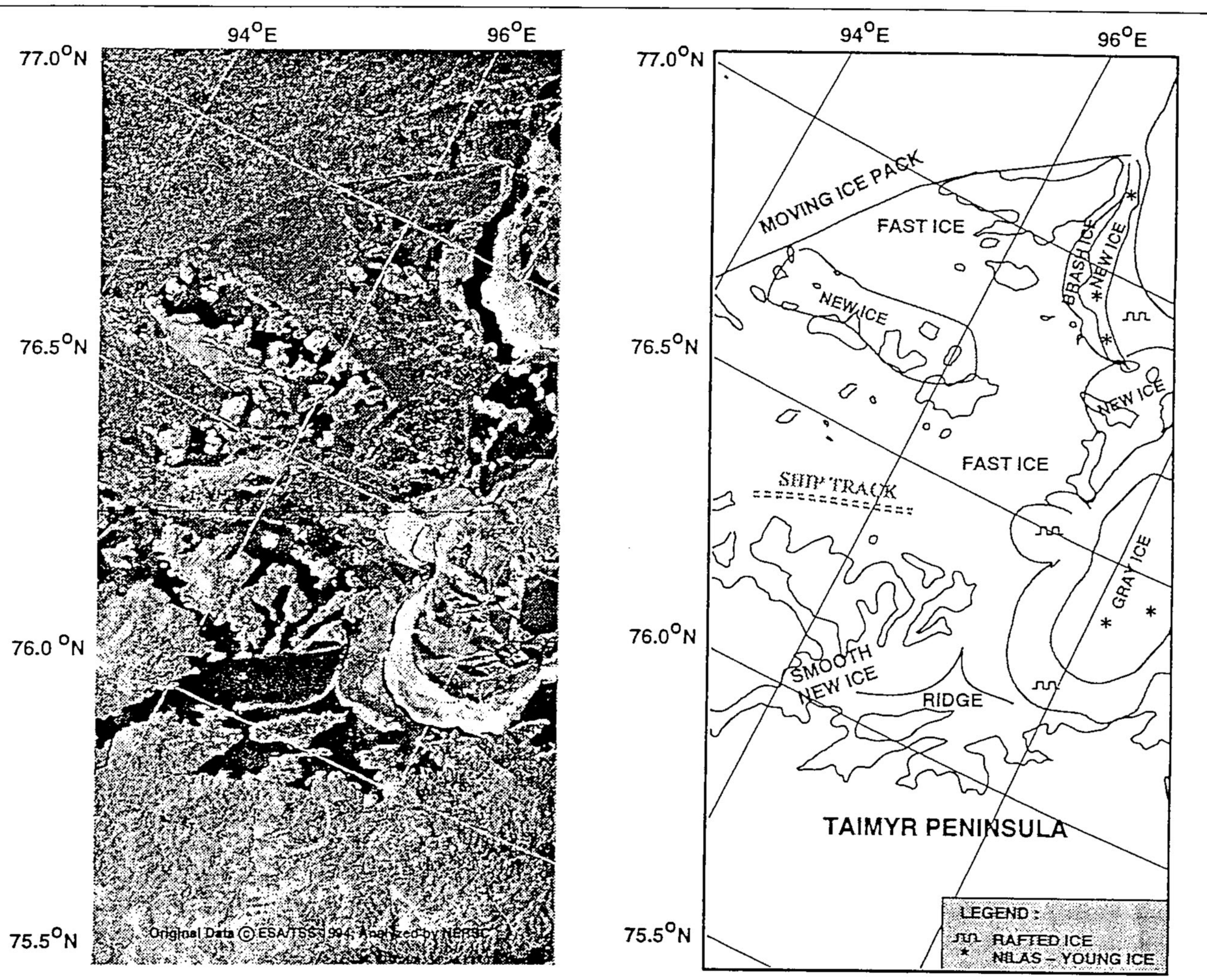


Figure 10. Example of SAR image off the coast of Taimyr peninsula from November 28 1993 (left). This was one of the SAR images sent to the icebreaker Sovetsky Soyuz to assist in ice navigation. The interpreted ice map is shown to the right.

expedition, had a more diffuse ice signature and were difficult to interpret.

3) In the presentation of an interpreted SAR image a common format should be agreed upon. The Russian ice terminology, which is well developed for describing the ice along the Siberian coast could be adopted. Also the WMO ice nomenclature is a possibility.

4) The time delay between observation and presentation onboard the ship varied from 6 hours to two days. With better ground facilities the time needed for processing and distribution of SAR images can be reduced to 1 - 2 hours. The Tromsø Satellite Station, which was not in operation during L'Astrolabe's voyage, has demonstrated that it can process and distribute a full-resolution SAR scene in less than 30 minutes.

5) Aquisition of SAR data requires that the instrument is turned on by ESA. Normal requests are required 4 -5 weeks in advance, while special requests may be made a few days in advance. During the demonstrations SAR data were not acquired in some of the important satellite passes although requests had been submitted several weeks in advance. From the user's point of view it is very important that SAR images can be ordered from 1 to 2 weeks and up to, say 1 - 2 days prior to

data acquisition. It is also important for the ship to receive the updated SAR schedule for the next 1 - 7 days so the captain knows where SAR-data will be available and can use this to plan the ship track.

5.4 The use of full-resolution SAR images.

Due to the speckle - noise which is an inherent property of full-resolution SAR imagery, the effective spatial resolution is less than the nominal pixel size of 16 by 20 m. The signal-to-noise ratio for these images is low, only about 3. In contrast, averaged images with 100 m pixels have a signal-to-noise ratio of about 12, which makes these images much more suitable for the general ice imaging. In order to benefit from the full resolution image an object to be mapped by SAR must have a high contrast compared to its surroundings. Such objects can be a large ship, a ship track in the ice, leads and well-defined ice/water boundaries. This means that full-resolution images only in special cases provide ice information which is not also included in the low-resolution images. A comparison of full-resolution with 100 m resolution image can be made from Fig. 9. The use of full-resolution images is also more computer demanding and not practical for file transmission to ships.

5.5 The detection limit of drifting ice by SAR.

Based on satellite data drifting sea ice can be quantified as concentration of ice within a unit area or as floe statistics. Both quantifications have limits of detectability. One limitation is the high variability of the contrast between the ice and the water. Backscatter from water can be both lower, nearly equal, or higher than backscatter from the drifting ice, depending heavily on wind conditions. The ice itself also has varying backscatter levels depending on ice type and surface composition.

Ice concentration of 30% and more is readily detectable in most cases. Individual floes of more than about 300 m in horizontal dimension can be observed in SAR images when the concentration is moderate or low. At high concentration (90 - 100 %) individual floes can be difficult to identify even if they are more than 1 km large. The most useful observation in the SAR images is the identification of multiyear floes in contrast to firstyear ice, and the identification of thin ice or newfrozen ice. Unfavorable conditions for ice classification often occur in the summer and fall seasons when there is wet snow and melt ponds on top of the ice.

6. Data communication

A critical part of a near-real-time ice monitoring service is the transmission of the images or maps to the users onboard ships. Inmarsat-A stations with separate telephone and telefax lines onboard the receiving ships have been used in the demonstration projects. The transmission of a one-page SAR image normally takes 3 - 6 minutes. The relatively poor quality of the SAR images after telefax transmission reduced the possibility for interpretation onboard the icebreaker. Therefore, interpreted ice maps were also transmitted by telefax, but the fine image details were not included in these maps.

File transmission using modem with the Inmarsat telephone line was tested as an alternative method. The user onboard the ship calls the computer at NERSC, logs in and transfers the image file using "ftp". The transferred image file is already reduced by compression techniques, so the size of one file is typically 100 - 200 kbyte. It is expected that marine communication, including data transmission, will improve and become less expensive in the next few years. Thus, the transmission of SAR images, preferably in compressed format, will become a routine operation.

7. Conclusion and future prospects.

The results of the feasibility study show that there are several non-Russian satellite systems which can provide useful information on the sea ice conditions in the NSR. The satellite systems are complementary to each other. The passive microwave data (SSM/I data) cover the large-scale and long-time aspects of the sea ice concentration and extent, while the SAR data are useful for detailed mapping of ice types and rapid changes in ice conditions, which is essential for ice navigation. Visual and infrared satellite data can be a useful supplement on cloudfree days.

The demonstrations have shown that there are both advantages and disadvantages of the present ERS-1 SAR system. The main advantages are: (1) SAR images can be used for detailed mapping of the ice edge and localize leads, thin ice types, landfast ice and thick multi-year ice, (2) SAR images are independent of cloud and light conditions, and (3) SAR images are available in near real-time. The disadvantages are: (1) the interpretation of the ice types can be difficult in some cases, (2) detection of ridges is generally not feasible, (3) the quality of the images is reduced by telefax transmission, and (4) the coverage is not sufficient for regular monitoring. However, the SAR coverage will be improved when RADARSAT is in operation in 1995. Up to 500 km wide swaths will be available, which means that most of the NSR will be covered every third day.

The launch of both RADARSAT and ERS-2 in 1995 will ensure continuous SAR availability for the next 3 - 4 years. After that several more SAR satellites are planned. The Tromsø Satellite Station will operate acquisition and processing facilities for real-time distribution of the data from RADARSAT in addition to ERS-2. In the eastern part of the NSR ASF will provide similar services for the future SAR satellites. Depending on available funding, Russia is scheduled to launch the Almaz-1B radar satellite in 1996 and thereafter the Almaz-2, both of which will be equipped with SAR.

European, Candian and American technology and experience in utilizing satelliteSAR data for real-time ice monitoring should be included and implemented as a part of the operational Russian sea ice monitoring and forecasting service in the NSR.

8. Acknowledgement

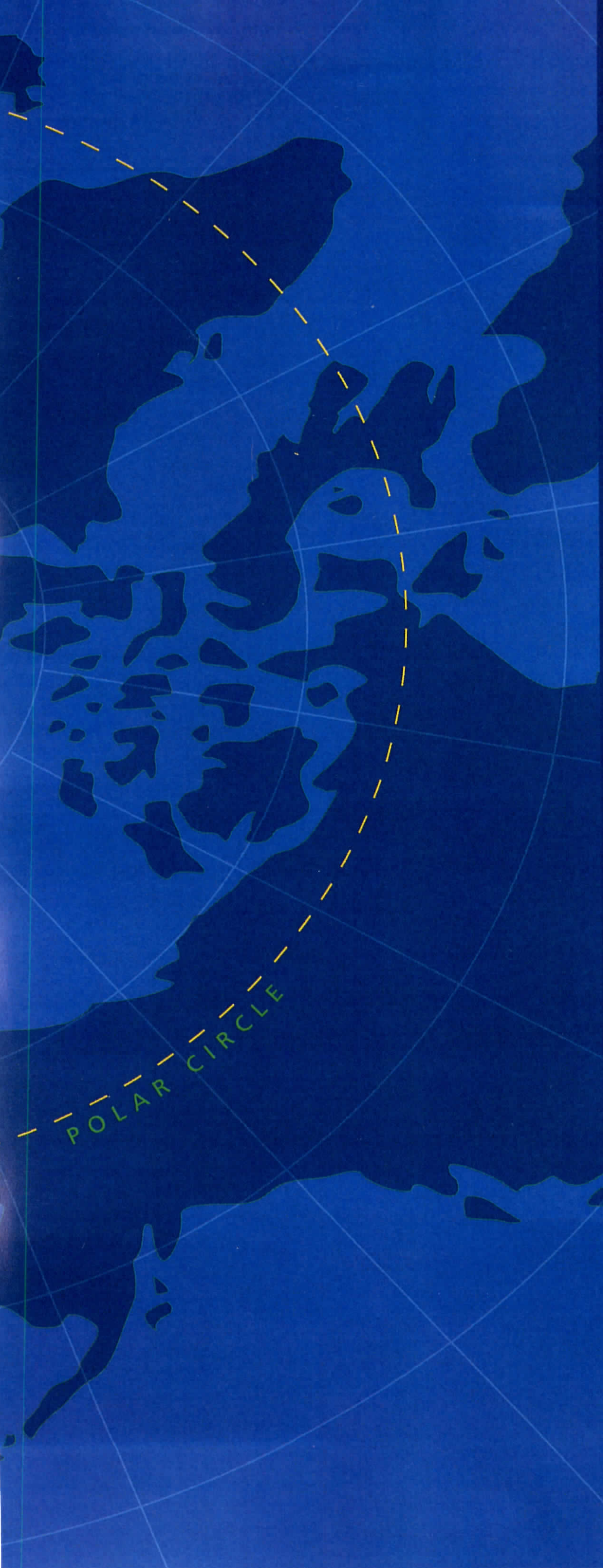
The SAR ice monitoring demonstration project has been supported by European Space Agency, Norwegian Space Agency and INSROP.

9. References.

Johannessen, O.M. et al., 1992: "ERS-1 SAR ice routing of l'Astrolabe through the Northeast Passage." Arctic News-Record, Polar Bulletin, Vol.8, No.2, 1992, pp.26 -31.

Johannessen, O.M. and S.Sandven, 1992: "ERS-1 SAR ice routing of l'Astrolabe through the Northeast Passage." NERSC technical report no. 56, February 1992.

Johannessen, O.M. et al., 1992: "ERS-1 SAR ice routing of l'Astrolabe through the Northeast Passage." In the ESA Proceedings of the European International Space Year Conference in Munchen, April 1992.



The three main cooperating institutions of INSROP

Ship & Ocean Foundation (SOF), Tokyo, Japan.

SOF was established in 1975 as a non-profit organization to advance modernization and rationalization of Japan's shipbuilding and related industries, and to give assistance to non-profit organizations associated with these industries. SOF is provided with operation funds by the Nippon Foundation, the world's largest foundation operated with revenue from motorboat racing. An integral part of SOF, the Tsukuba Institute, carries out experimental research into ocean environment protection and ocean development.

Central Marine Research & Design Institute (CNIIMF), St. Petersburg, Russia.

CNIIMF was founded in 1929. The institute's research focus is applied and technological with four main goals: the improvment of merchant fleet efficiency; shipping safety; technical development of the merchant fleet; and design support for future fleet development. CNIIMF was a Russian state institution up to 1993, when it was converted into a stock-holding company.

The Fridtjof Nansen Institute (FNI), Lysaker, Norway.

FNI was founded in 1958 and is based at Polhøgda, the home of Fridtjof Nansen, famous Norwegian polar explorer, scientist, humanist and statesman. The institute spesializes in applied social science research, with special focus on international resource and environmental management. In addition to INSROP, the research is organized in six integrated programmes. Typical of FNI research is a multi-disciplinary approach, entailing extensive cooperation with other research institutions both at home and abroad. The INSROP Secretariat is located at FNI.