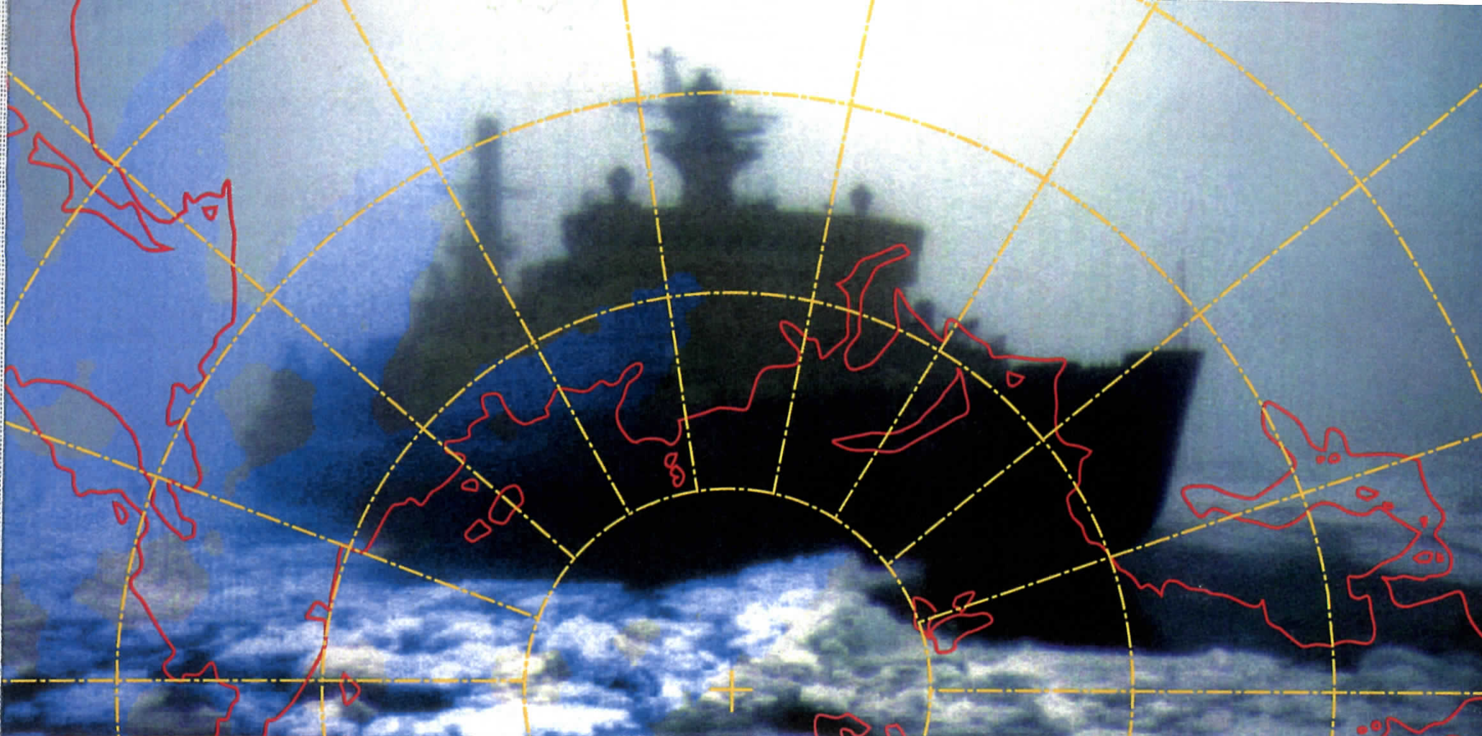

INSROP WORKING PAPER
NO. 109 - 1998, I.2.3

# An Overview of Russian Satellite Data for the Northern Sea Route

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**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

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# INSROP WORKING PAPER NO. 109-1998

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|---|---|
| Sub-programme I: | Natural Conditions and Ice Navigation |
| Project I.2.3: | Review of Russian Satellite Data for the Northern Sea Route |
| Supervisor: | Vladimir Smirnov, AARI |
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| Date: | 24 August 1998 |
| Reviewed by: | Professor Wilford F. Weeks, Portland, Oregon, USA |

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## 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.

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# ABSTRACT

This report provides an overview of a modern system for navigation support in the Northern Sea Route (NSR) based on satellite information. It summarises the main requirements for ice information necessary in planning and support of marine operations. The instrumentation onboard operational Russian satellites is described, and the composition and quality of data obtained for sea ice monitoring is discussed. The technology for processing satellite data at the Russian Ice and Hydrometeorological Information Center (the "Sever" Center) is described showing examples of how the data are used. Some examples of combined use of information from Russian and non-Russian satellites are presented, with a discussion of the benefits of synergetic use of different types of satellite data. The Russian space communication system "Kurs", which is used for distribution of sea ice data to users, is described. Finally, some future perspectives on satellite ice monitoring in the Northern Sea Route are presented.

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# 1 PROJECT GOAL

The main goal of the project is to review the use of data from currently operating Russian satellites in sea ice monitoring, and to show the advantages of ice chart production at the ice centre of the Arctic and Antarctic Research Institute (AARI) for ice navigation in the Northern Sea Route (NSR).

# 2 THE HYDROMETEOROLOGICAL SUPPORT SYSTEM FOR ICE NAVIGATION IN THE NSR

## 2.1 BRIEF HISTORY OF ICE OBSERVATIONS BY REMOTE SENSING

Regular airborne sea ice observations in the NSR began in 1941/1942 and were first carried out only during the summer navigation period. In subsequent years the methods of visual observations were improved and the frequency of observations as well as the duration of the observation season increased. Until the mid-1960s ice charts were based only on data from visual airborne ice reconnaissance. The sea ice characteristics were quite accurately described along the flight lines. The description in-between the flight lines was less accurate because of spatial interpolation. From 1968 ice reconnaissance aircraft were equipped with side-looking radar (SLR) which improved the spatial coverage considerably, and regular ice observations were performed throughout the year.

Use of data from the Russian meteorological satellites started in 1969 with the "Meteor-1" series which observed ice by TV cameras operating at visible frequencies. The "Meteor-1" series was operational until 1975. Satellite data enabled sea ice monitoring in the whole Arctic and the Antarctic sea ice areas. In the following years several new satellite instruments were taken into use in the new series of satellites: "Meteor-2" (1975-1994), "Meteor-3" (from 1987), and the oceanographic satellite "Okean-01" (from 1983). These satellites were launched in polar orbits and provided sea ice imagery in the visible, IR and microwave channels. A summary of the various Russian satellite systems is shown in Table 1 (Garbuk and Gershenzon, 1997).

Use of data from polar orbiting satellites has significantly increased the quality of ice charts in the NSR and extended the regions for ice chart production. The quality of ice charts was improved because data from satellite as well as aircraft observations were used.

| Satellite | Instrument type | Instrument Acronym | Image resolution | Swath width | Start year | End year | Data delivery |
|---|---|---|---|---|---|---|---|
| Meteor-1 | Visual radiometer | TV-camera | 1.5 km | 1000 km | 1969 | 1975 | Off-line |
| Meteor-2 series | Visual radiometer | MR-900V | 2.0 km | 2100 km | 1975 | 1994 | Real-time |
| | Visual radiometer | MR-2000M | 1.4 km | 2600 km | | | Off-line |
| | IR-radiometer | B4-100 | 8 km | 2800 km | | | Real-time |
| Meteor-3 series | Visual radiometer | MR-900B | 3.0 km | 2600 km | 1987 | in operation | Real-time |
| | Visual radiometer | MR-2000M | 1.4 km | 3100 km | | | Off-line |
| | IR-radiometer | "CLIMATE" | 3.0 km | 3100 km | | | Real-time |
| Okean-01 series | Side-Looking Radar (SLR) | SLR at 3 cm wavelength | 1.3x2.5 km | 450 km | 1983 | in operation | Real-time/ Off-line |
| | Passive microwave radiometer | RM-08 at 0.8 cm wavelength | 15 km | 550 km | | | Real-time/ Off-line |
| | Visual radiometer | MSU-M | 1x 1.7 km | 949 km/ 1875 km | | | Real-time/ Off-line |
| | Visual medium resolution radiometer | MSU-S | 345 m | 1380 km | | | Off-line |
| Resourse-01 series | Visual high resolution radiometer | MSU-E (3 channels) | 45 x 33 m | 45 km | 1988 | in operation | Off-line |
| | Visual and thermal IR-radiometer (5 channels) | MSU-SK | 170 m/ 600 m | 600 km | | | Off-line |
| Almaz-1 | Synthetic Aperture Radar | SAR (0305) | 15 m | 40 km/ ± 30-60° | 1991 | 1993 | Off-line |
| | Passive microwave radiometer (2 channels) | "Omega-SK" | 2-5 km | 540 km | | | Off-line |

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

## 2.2 Structure of the Ice Monitoring System

The observation and communication elements of the Russian ice information acquisition and dissemination in the Arctic have been built up in a hierarchic structure. Aircraft and satellite data were received, processed and analysed at the regional centres in Dikson, Tiksi, Pevek and at some other centres. These centres also analysed meteorological and oceanographic information reported by coastal hydrometeorological stations, and issued short-range ice forecasts, weather forecasts, sea level forecasts, and specially dangerous phenomena. The centres also provided navigation recommendations and advises for ship masters. The ice charts issued by these centres were produced for each of the centres responsibility area. The ice charts, together with all other relevant information were transmitted to the regional marine operational headquarters, to icebreakers, transport ships and to AARI, the "Sever" Center in St. Petersburg. The "Sever" Center prepared composite ice charts for the entire Arctic Ocean, as well as medium- and long-range meteorological and sea ice forecasts, and other specialised forecasts and recommendations. All information was reported to the regional marine operational headquarters, shipping companies and the Department of Marine Fleet where it was used for planning and management of marine transportation operations in the Arctic.

In the last few years the role of satellite data, especially new satellite sensors, have become more important in ice monitoring, whereas the use of aircraft surveys is decreasing. As a result of this change in observation technique there is no need for ice data acquisition, processing and dissemination at the regional centres anymore. The regional centres continue to have a role in acquisition and transfer of hydrometeorological information over a land meteorological network and for supporting different economic activities in their zones of responsibility.

Methods to receive Russian satellite data and for use of remote satellite communication in near real-time have been established for the "Sever" Center in St. Petersburg. Data from the entire Arctic are received in the APT mode as far east as 130°E. In the East Siberian Sea and Chuckhi Sea data are stored onboard and relayed to the "Sever" Center via NPO "Planeta" in Moscow. Unlike the regional centres, the "Sever" Center can receive data of medium and high resolution from "Resource-01", as well as NOAA AVHRR data in HRPT mode.

Processing and interpretation of satellite ice data, and mapping and production of composite ice charts are done by highly qualified experts at the "Sever" center using standardised techniques. The ice charts and all other information reports including images of local areas are transmitted to icebreakers and other users along the NSR, using the INMARSAT Communication system. The Marine Operational Headquarters at Murmansk Shipping Company is one of the main users of this information, and is currently the only entity with responsibility for planning and management of marine operations along the NSR. Also, stretching over a time period from 1933 to 1996, the Center has a Data Bank on Sea Ice of the Earth's Polar Regions stored in the SIGRID format. These archives are very valuable for studies of the sea ice situation in Polar regions. The structure of satellite sea ice monitoring for supporting shipping along the NSR is illustrated in Figure 1.

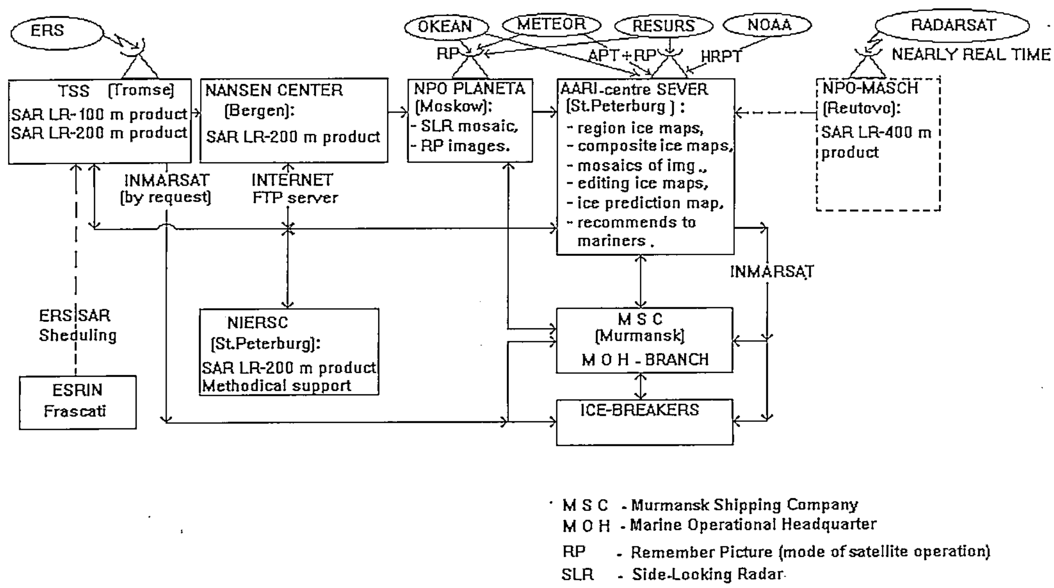


Figure 1. Scheme available for the traffic and sea ice monitoring by satellite data of the Northern Sea Route.

With RADARSAT wide swath SAR data it is possible to cover large parts of the Northern Sea Route with data every day. Tromsø Satellite Station can deliver near real-time data for the western part (i.e. west of 120°, in the Laptev Sea). This has been demonstrated in two expeditions, with 'Sovetsky Soyuz' in September 1997, (discussed in INSROP I.2.4) and in the ARCDEV expedition to Ob Gulf in April-May 1998. For the east Siberian Sea and Chuckhi Sea similar SAR coverage can be provided by Alaska SAR Facility. The main part of the Laptev Sea is outside of these two receiving stations, but a new SAR station is planned to be built in Russia, which will make it possible to have full SAR coverage of the whole NSR. The main limitations in use of RADARSAT data are financial constrains, not technical capabilities.

# 3 Ice Information Requirements for Marine Operations

The Marine Transport Operational Headquarters (MOH) is the main centre for organisation and co-ordination of ship traffic, icebreaker escort and navigation support in the NSR. The requirements to ice information differ, depending on the transport operation stage, season, ice conditions and ice class of ships (Bushuyev, 1995). The following stages of ship navigation in the NSR are usually identified with different requirements to information support:

- long term planning of marine operations for a whole year or a season;
- planning of specific sea operations when the dates of arrival of ships to the route are known;
- Management of marine operations in the process of operation.

For long term planning a general assessment of the expected (forecasted) ice conditions is made in order to make optimal decisions regarding dates and required icebreaking support for transport operations during the year. For this purpose, the results of ice regime studies, review ice charts and long-term ice forecasts developed at AARI, are used and analysed.

Planning of specific marine operations takes into account the ice situation at the beginning of the planned operation and expected changes during the period of operation in order to select the optimal routes, zones of unescorted navigation, zones of icebreaking support, optimal dates of loading-unloading activities, etc. The work includes studies of local ice charts and other relevant problems in the planning phase, and using meteorological and ice forecasts during the operation phase. Satellite images of fast ice zones are analysed for example to support loading/unloading in areas of no harbour structure.

Management of sea operation in real-time is the most complicated stage, requiring the latest operational and detailed information. At this stage, the MOH is responsible for developing recommendations for unescorted routes along segments with easy/light ice conditions, determination of a meeting place for icebreaker and ships to form a convoy, icebreaker routing of a convoy or individual ships in heavy ice conditions, and for support to loading-unloading at requested coastal points. To address these tasks icebreakers need detailed ice charts updated at least every 3rd day, as well as short-range weather and ice forecasts for 1-3 and 7-8 days.

There are not enough details in the ice charts for selection of the most optimal route in very close and heavy ice. For this purpose high-resolution satellite images can be used, if transformed to a cartographic projection and received onboard the icebreaker in real or near real-time. The time delay should not exceed 3-5 hours. However, high-resolution satellite images usually have a small swath width which makes it difficult to cover the required area at the right time. Therefore, use of ERS SAR and optical "Resource-01" high-resolution imagery at the required time and place have only been successful in a few occasions (Johannessen O.M., 1996). It has therefore been realistic for icebreakers or ships to make self-contained voyages to receive "Okean-01", "Meteor-3" and NOAA imagery in the direct transmission mode. From 1996, RADARSAT SAR data with 500 km swath width and 100 m resolution are available, which significantly increase the probability of receiving SAR imagery onboard icebreakers at required time and place. Before RADARSAT SAR data can be used operational in sea ice monitoring in the NSR, it is necessary to solve financial and data distribution problems (Smirnov, 1997).

Use of satellite images for selecting optimal routes in the ice would become more efficient if based on combined analysis of composite ice charts based on satellite images, data from coastal stations, ships and icebreakers in the given region.

In addition to ice charts and satellite imagery, the hydrometeorological support of marine operations includes provision of ice and meteorological forecasts to users 1-3 and 7-8 days in advance and navigation recommendations.

# 4 DESCRIPTION OF SATELLITE INSTRUMENTS USED FOR SEA ICE MONITORING

## 4.1 THE METEOROLOGICAL SATELLITE SERIES "METEOR-3"

The first satellite of this series was launched in 1988. At present, satellite No. 7 is active. The satellites in this series have an altitude of 1200 - 1250 km, an orbit inclination of 82.5°, and an orbital period of 109 minutes. Each satellite weights 2100 kg, and the instrumentation weights 700 kg. Table 2 presents the instruments onboard "Meteor-3" used for sea ice monitoring.

| Instrument type | Spectral waveband | Scanning frequency | Scan width from nadir (°) | Swath width (km) | Resolution Range x azimuth (km) |
|---|---|---|---|---|---|
| Visual Scanning Radiometer (MR-900B) | 0.5 - 0.8 μ | (APT 2 Hz) linear spherical scanning | | 2600 | 3 x 3 (APT/storage mode) |
| Scanning Infrared Radiometer "Climate" | 10.5 - 12.5 μ | (APT 2 Hz) linear spherical scanning | | 3100 | 3 x 3 (APT/storage mode) |
| Visual Scanning Radiometer (MR-2000M) | 0.5 - 0.8 μ | (APT 4 Hz) linear spherical scanning | 96 | 3100 | 0.7 x 1.4 (APT/storage mode) |

Table 2. Main characteristics of instruments onboard "Meteor-3" used for sea ice monitoring.

### 4.1.1 "METEOR-3" OPERATION AND DATA TRANSMISSION MODES

The scanning law of all three satellite instruments is linear by spherical Earth. The MR-900B and IR-radiometer "Climate" data are transmitted constantly in the direct transmission mode (APT analogue) using a meter range radio-link (at a frequency of 137.4 MHz) and can be received by any receiving station within the satellite radio-visibility zone.

The MR-2000M and IR-radiometer "Climate" data can be stored onboard satellite and retransmitted at a prescribed time using an analogue decimetre range radio-link (at a frequency of 466.5 MHz) to the main ground receiving stations of Roshydromet (Moscow, Novosibirsk and Khabarovsk). At the "Sever" Center the satellite data are received in the direct transmission mode, i.e. in real-time on the western NSR. Data of two orbits covering the eastern part of the route can be received in the mode of data stored and played back to the Center via Moscow with a delay of not more than 3 to 5 hours.

### 4.1.2 Information Contents of "Meteor-3" Images

The images received from the MR900B and MR2000M scanning radiometers can be used to derive the following characteristics of the ice cover:

- close and open ice edge with a location error of not more than 5-6 km
- total concentration (visually), and boundaries of solid and very close, close, open and very open ice
- land fast ice and boundaries of its extent
- flaw polynyas
- position and concentration of vast and giant ice floes
- fresh leads and extensive fractures more than 0.5 km wide
- ice drift vectors in the area of overlapping of successive images

The IR images from the "Climate" scanning radiometer have a sufficient brightness contrast for analysis and interpretation only if the air temperature is below zero, preferably below -10°C, as in the cold season from October to May. The ice cover is predominantly continuous during this period and the main purpose of monitoring is to determine the ice edge, and boundaries between areas of prevailing young, first-year and old ice. At very low air temperatures (-25°C to -35°C) the brightness contrast makes it possible to delineate zones of young ice within the first-year ice, such as open leads, and zones of thick first-year and old ice (Loschilov and Paramonov, 1997).

In cloud-free conditions, or with presence of transparent and discontinuous clouds, the following sea ice characteristics can be determined from IR-images:

- Position of the edge of young and first-year ice. It is impossible to discriminate between open water and new ice and nilas if there are no shuga strips or nilas rafted by wind and wave action on the ice.
- Determination of main stages of ice development according to the WMO Sea-Ice Nomenclature, and zones of ice with uniform thickness for thicknesses up to 70-120 cm (depending on air temperature).
- Boundaries of land fast ice, location of leads and large fractures, ice drift vectors in areas covered by successive images.

During daylight in the cold season, March-May, IR and visible range images are used jointly for determining the sea ice characteristics, which significantly increases the reliability and accuracy of the interpretation. Figure 2 shows an example of a "Meteor-3" visible image of sea ice, and an ice chart composed from the image.

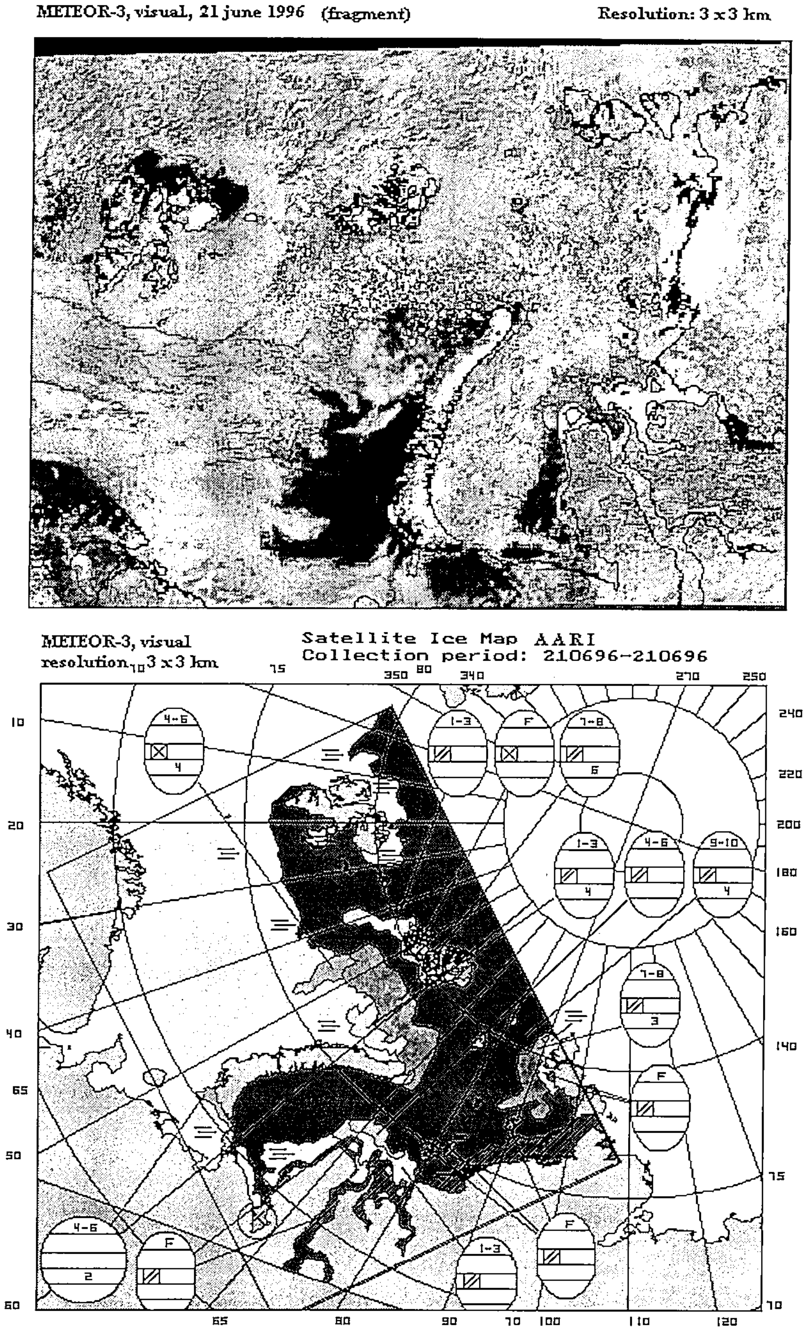


Figure 2. The lower figure displays an ice chart derived from the visible "Meteor-3" image shown in the upper figure.

## 4.2 THE "RESOURCE-01" SERIES

The first satellite of this series was launched in 1988. At present, satellite N3 launched in 1994 is active. The satellites in this series have an altitude 620 - 660 km, an orbit inclination of 98°, and an orbital period of 97 minutes. Each satellite weights 1900 kg, and the instrumentation weights 500 kg.

The next satellite of this series is to be launched in 1998. Table 3 presents the main characteristics of instruments onboard "Resource-01" used for sea ice monitoring.

| Instrument type | Spectral waveband | Scanning frequency | Scan width from nadir (°) | Swath width (km) | Resolution range azimuth (m) |
|---|---|---|---|---|---|
| Visual multi-channel high resolution scanning radiometer (MSU-E) 2 cameras | 1: 0.5 - 0.6 μ<br>2: 0.6 - 0.7 μ<br>3: 0.8 - 0.9 μ | 200 Hz | 4° programmable deviation to the left and right from nadir ± 30° | 45 km/ 80 km | 34 x 45 m/ 68 x 45 m |
| Visual and thermal multi-channel medium resolution scanning radiometer (MSU-SK) | 1: 0.5 - 0.6 μ<br>2: 0.6 - 0.7 μ<br>3: 0.7 - 0.8 μ<br>4: 0.8 - 1.1 μ<br>5: 10.4 - 12.6 μ | 12.5 Hz scanning by a cone | 74° in the horizontal plane, permanent scanning angle forward from nadir 38° | 600 km/ 600 km | 140 x 140 m/ 550 x 550 m |

Table 3. Main characteristics of the instruments onboard "Resource-01" used for sea ice monitoring.

### 4.2.1 "RESOURCE-01" OPERATION AND DATA TRANSMISSION MODES

The MSU-E radiometer can operate in two modes: high-resolution data transmission within a swath width of 45 km (one camera is activated) or every second line data transmission within a swath width of 80 km (two cameras are activated). The optical axes of cameras can deviate from nadir within ±30° to the right and left with a spacing of 2°, which provides a possible variation of the survey width within a total swath width of 800 km.

The MSU-SK radiometer provides optical-mechanical scanning of the Earth's surface in 5 spectral channels (4 visible range and 1 IR-channels). The scanning principle is by a cone, i.e. the scanning beam moves over the cone surface with an axis directed to nadir. The Earth's surface is scanned with a constant viewing angle of 38° from nadir in the front horizontal sector of 74°, i.e. within a swath width of 600 km.

The memory onboard the satellite provides recording of all information for 6.5 minutes. The information from MSU-E and MSU-SK radiometers can be relayed in the direct transmission mode or in a mode where data are stored and later transmitted via a radio-link at 8.0 - 8.5 GHz.

For sea ice monitoring, the medium resolution MSU-SK data are most relevant. Hence it is planned in the near future to set up a ground station "SCAN-ER" at the "Sever" Center in St. Petersburg, which will receive MSU-SK data in both direct transmission mode and in playback mode along the entire NSR, with a delay of not more than 3 hours (Figure 3). Receiving MSU-SK images will be free of charge for Russian users.

### 4.2.2 ICE INFORMATION FROM "RESOURCE-01" DATA

Under cloud-free conditions, medium resolution images (140 m) contain a large number of details, providing important information for ice navigation. However, it is difficult to discriminate ice types (age) in visible range images. Zones of young and thin first-year ice can be identified in the IR-images, but the resolution is coarser, about 550 m. When ice charts are produced with basis on this data, many details of the ice cover can be omitted. Due that for navigation support under heavy ice conditions it is more efficient to transmit fragments of images and the interpreted ice charts to the icebreakers. An example of the full image and a sub-image of a "Resource-01" MSU-SK scene are presented in Figure 4.

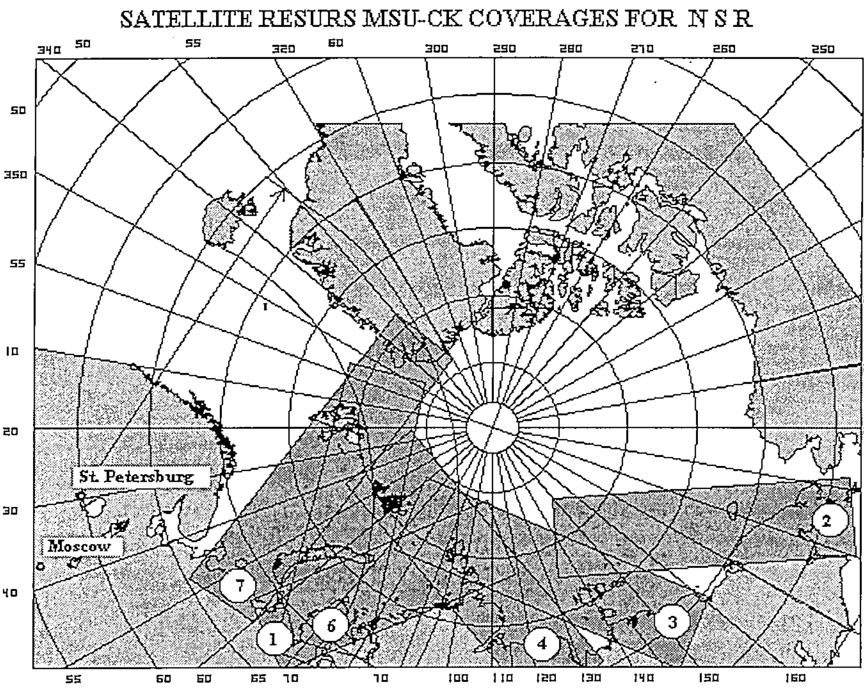


Figure 3. The medium resolution scanner (MSU-SK) on "Resource-01" covers the NSR by 7 successive orbits. Also shown, is the receiving range for real-time data by the satellite station in St. Petersburg.

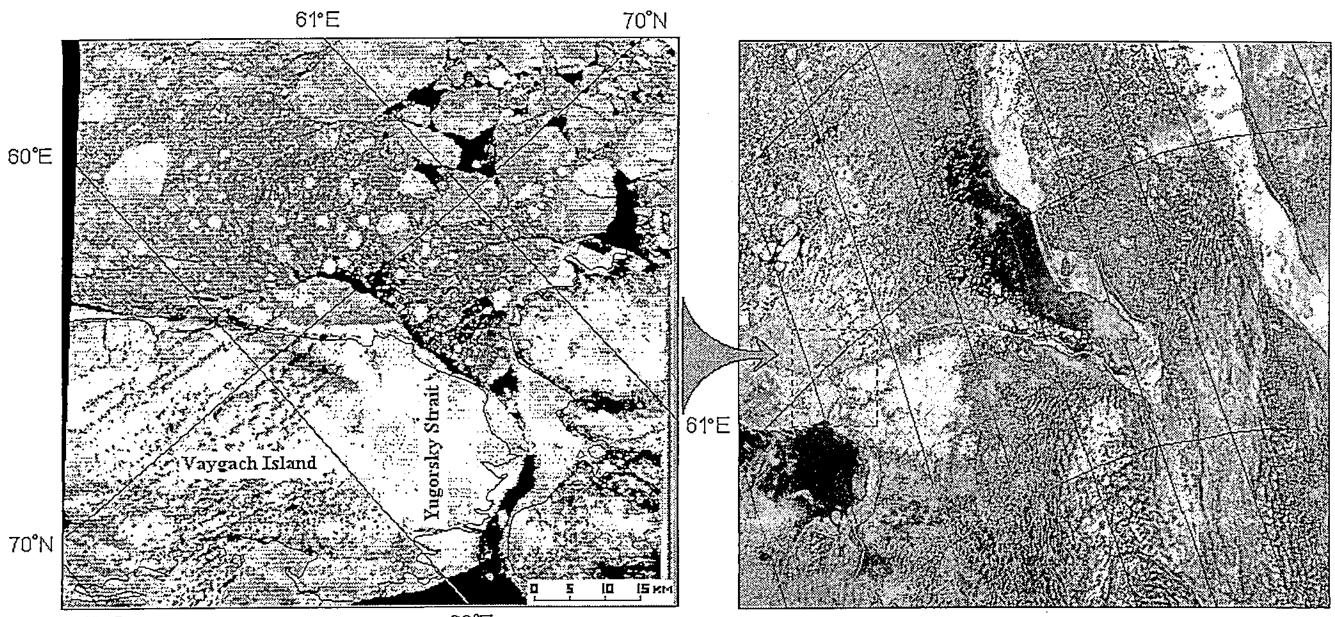


Figure 4. The full image and a sub-image of a "Resource-01" MSU-SK scene.

## 4.3 THE OCEANOGRAPHIC SATELLITE SERIES "OKEAN-01"

The first satellite of this series was launched on September 28, 1983. At present, satellite No 7 is active. The satellites of this series have an altitude 650 km, an orbit inclination of 82.5°, and an orbital period of 98 minutes. The satellite orbit has a 3-day repeat cycle, with 44 revolutions pr. cycle. Table 4 presents the main characteristics of the instruments onboard " Okean-01" used for sea ice monitoring. A geometric scheme of the coverage for the instruments onboard the "Okean-01" satellite is presented in Figure 5.

| Instrument type | Spectral waveband | Scanning frequency | Scan width from nadir (°) | Swath width (km) | Resolution Range azimuth (km) |
|---|---|---|---|---|---|
| Side-Looking Radar (SLR) | 9519 MHz (X-band, VV) | (APT 4 Hz) | 20 - 45.3 left | 460 left only | 0.85-1.3 x 2.4/ 2.8 x 2.4 (APT) |
| Passive Microwave Radiometer (RM-0.8) | 36.62 GHz (Ka - band, H) | (APT 4 Hz) | 20 - 49.7 left | 587 left only | 25 x 25 (APT) |
| Visual Multi-channel Scanning Radiometer (MSU-M) | 1: 0.5 - 0.6 μ<br>2: 0.6 - 0.7 μ<br>3: 0.7 - 0.8 μ<br>4: 0.8 - 1.1 μ | (APT 4 Hz) linear spherical scanning | 104.9 full/ 0 - 52.44 left only | 1875 full/ 937.5 left only | 1.0 x 1.7/ 1.5 x 1.7 (APT) |
| Visual multi-channel medium resolution scanning radiometer (MSU-S) | 2: 0.57 - 0.72μ<br>4: 0.70 - 1.00μ | 50 Hz linear angular scanning | 90 full | 1380 | 0.345 x 0.345 at nadir |
| Instrument for data retrieval and transmission from drifting buoys ("Kondor-2") | Instrument operating in the coded buoy query mode | | | 1600 | 3.5 x 2.5 error in location of buoys |

Table 4. Main characteristics of the instruments onboard " Okean-01" used for sea ice monitoring.

### 4.3.1 "OKEAN-01" OPERATION AND DATA TRANSMISSION MODES

The Okean instruments can operate in different modes, and have more than 20 combinations. The operation mode is determined by commands from the ground control station. The instrumentation provides overlapping images from the SLR, the scanning RM-08 radiometer and one of the MSU-M channels. During the dark season in the Arctic it is common to use a combination of SLR and RM-08. In the summertime a combination of SLR, RM-08 and the 4th channel of MSU-M is used. Each instrument onboard the satellite can operate in a self-contained mode with data transmission to the receiving station at a decimetre or meter wavelength. The MSU-S instrument can operate only on a self-contained basis in the direct transmission mode at a decimetre wavelength. Image data is transmitted from the satellite in one of the following modes:

a) In direct transmission mode at a meter wavelength (APT analogue with a frequency of 137.4 MHz). Data is transmitted in the international standard and can be received at simple ground stations by any user within the radio-visibility zone.
b) In direct transmission mode via an analogue radio-link at a decimetre wavelength (at a frequency of 466.5 MHz). Information can be received only by the ground stations of Roshydromet in Moscow, Novosibirsk and Khabarovsk.

c) In a mode where data are stored and relayed in any successive orbit passing in the radio-visibility zone of the ground receiving station, within a decimetre or a meter wavelength range. This mode allows acquisition of data at one receiving station, for example, at the "Sever" Center (St. Petersburg), for the entire NSR, and any other regions of the Earth's surface (except for latitudes south of 80°S). The time delay is determined by the time it takes for the satellite to reach the radio-visibility zone of the receiving station (Figure 6.).

For sea ice monitoring in the NSR, all operation modes of the instruments onboard the satellite are used. The command software activating the instruments is designed for obtaining the maximum coverage of the Arctic Seas by image strips and reporting the information in the direct transmission mode and the recording and playback mode to the selected ground receiving stations. The SLR is permitted to continuously operate in the direct transmission mode for not more than 12 minutes and in the data recording and playback mode for 6 minutes. However, these limitations do not influence the quality of sea ice monitoring along the NSR.

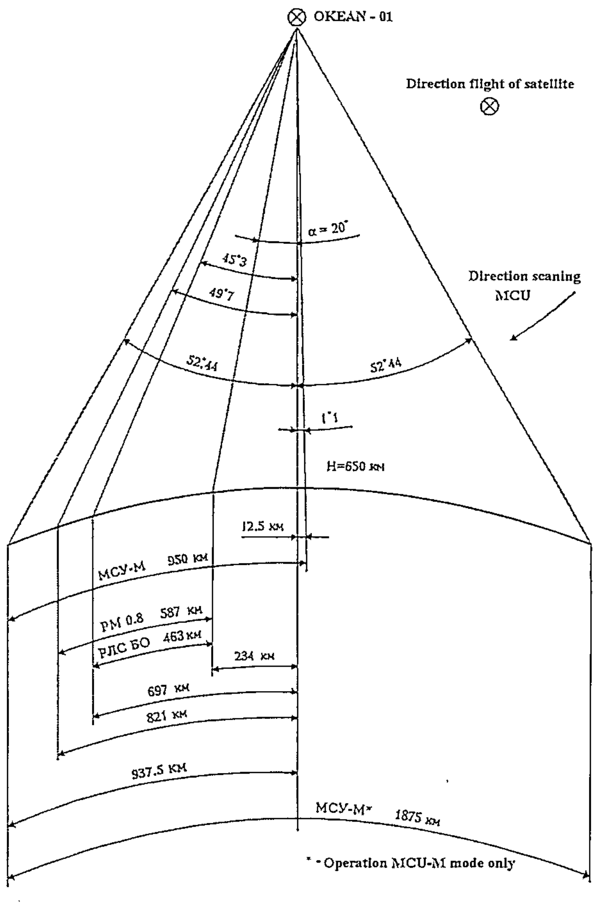


Figure 5. A principal scheme of the coverage of the earth's surface by different "Okean-01" instruments (SLR – Side-Looking Radar, RM-08 – Passive Microwave Radiometer, 0.8 cm, MSU-M – Multi-channel Low Resolution Scanning Radiometer).

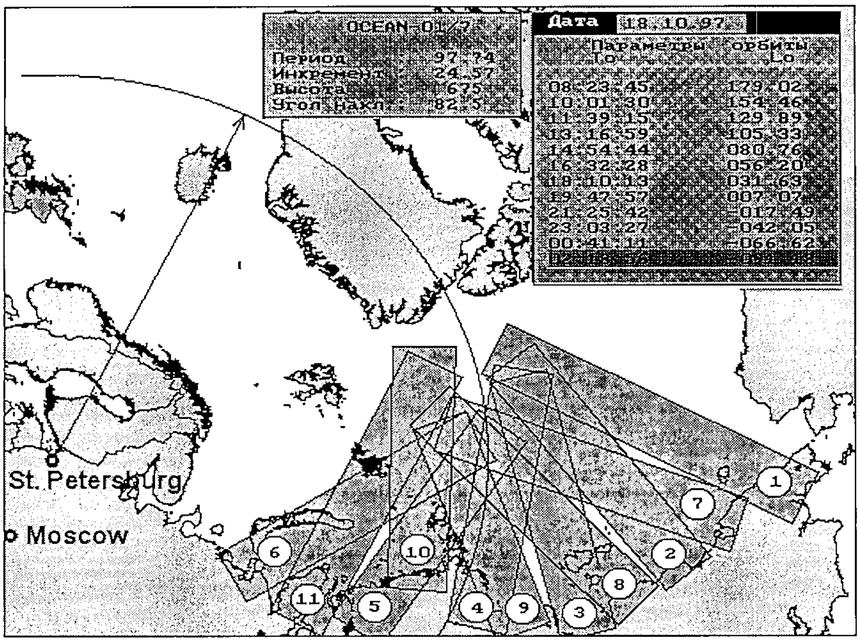


Figure 6. Coverage of the NSR by "Okean-01" SLR in successive orbits. Also shown, is the receiving range for real-time data by the satellite station in St. Petersburg.

### 4.3.2 Ice Information from SLR and RM-08 Images

The minimum detectable SLR signal in the swath width (at a signal/noise ratio > 1) corresponds to a backscatter coefficient of $\sigma^\circ$ = - 20 dB. For levelling the medium image brightness onboard the satellite, the signal amplification along the line (normally to the orbit trajectory) linearly increases and compensates the attenuation of the signal with distance from the orbital trajectory. This is caused both by the increased distance to the Earth's surface and by the angular dependence of the backscatter coefficients. The radiometric correction of SLR images is not usually applied for their operational processing and interpretation. The examination of the SLR images has shown that due to a spatial correlation of the signal changes, there are revealed narrow (with a width less than a pixel) but extensive fractures and leads in the ice if their backscatter contrast is sufficiently large. In winter images, the minimum detectable lead width in old ice is 500 m (with a contrast of 3 dB). Individual old ice floes are detected in images with a contrast of 3 dB at a minimum size of 250 m. Zones of close old ice at the background of young and first-year ice in winter images are delineated with a contrast within 3 to 9 dB. The contrast depends to a great extent on the surface roughness, the hummock and ridge concentration of first-year ice, and on the concentration of old ice. A high backscatter signal from old ice is due to strong volumetric scattering in the upper layer, consisting mainly of freshwater ice.

First-year and old ice in SLR images can be distinguished in most cases as they have typical texture differences at close backscatter coefficients. The structure and texture of images typical of these ice gradations, connected with surface topography, can be used as a key for discrimination. The density of pressure ridges, strips and patches of rafted and deformed ice increases with time and increasing ice thickness. In SLR images these features of ice surface topography create a typical tone structure allowing separation of young and first-year ice.

In SLR images of sea ice one often observes fresh fractures, flaw polynyas and leads covered by young ice with a very high backscatter coefficient. A similar effect is also observed in ERS-1/2 SAR images. This ice is sometimes erroneously interpreted as open water with a rough surface (as caused by strong winds). By analysing such images it has been shown that young ice with such extremely high backscatter signal is formed with air temperatures below –20°C, and a wind speed of more than 5 m/s. With time, the backscatter intensity of this ice decreases, and after approximately 2-3 weeks, the contrast with ambient young and first-year ice has completely disappeared.

The spatial resolution of the microwave radiometer RM-08 is by an order of magnitude lower than for SLR. However, passive microwave data provides important information in addition to the radar data. This is related to a negative correlation of emission and scatter from ice of the same age. Old ice has a strong scattered signal and a weak own emission, whereas young and first-year ice has a weak scattered signal and a strong own emission. The characteristic of combined images permits to use RM-08 data for distinguishing first-year and multiyear ice, as well as open water in large fractures and polynyas.

During summer melting the backscatter of old ice decreases. However, in the RM-08 radio-thermal images one can in most cases determine the position of the boundary between multiyear and first-year ice, as well as the position of the ice edge at rough and quiet water surface (Figure 7). SLR coverage of the whole NSR from successive Okean orbits can be acquired in near real-time by the receiving station in St. Petersburg.

## 5 Use of Data From Non-Russian Satellites at the "Sever" Center

For sea ice monitoring in the Arctic the "Sever" Center uses data from both Russian and non-Russian satellites. The main condition for combined use of data from several different satellites is the possibility for retrieving maximum information on the sea ice cover. The spectral channels, spatial resolution, information properties, quality, operational basis as well as the cost are assessed and taken into account when selecting the priority satellite data.

The ground station at the "Sever" Center continuously receives data from all accessible orbits of the meteorological satellites "Meteor-3" and NOAA. Access to a large number of images increases the probability of obtaining useful information in case of discontinuous cloud-cover and rapidly changes during a day. However, the NOAA AVHRR data can only be obtained directly to “Sever” for the western part of the NSR due to lack of antenna vision. The data for the eastern part can be obtained from the Alaska SAR Facility Station or planned Russian stations. For the eastern part of the route, only playback mode data of "Meteor-3" can be received, having a resolution of 3 km.

The "Resource-01" data have almost an order of magnitude higher resolution than the NOAA data (at close spectral channels) but the swath width is 5 times smaller. Hence, "Resource-01" MSU-SK and MSU-E data are most useful for sea ice monitoring in local regions.

Sea ice monitoring supporting navigation in the NSR is most reliable if satellite microwave data are used, as these instruments are independent of natural illumination conditions and cloud cover. Hence, the "Sever" Center widely uses the SLR data from the "Okean-01" satellite, and improves the technology for processing and interpretation of ERS and RADARSAT SAR data. There are not any principal technical obstacles for receiving these data on an operational basis. Figure 8 presents an example of a processed RADARSAT SAR image, and the mapping results using AARI technology.

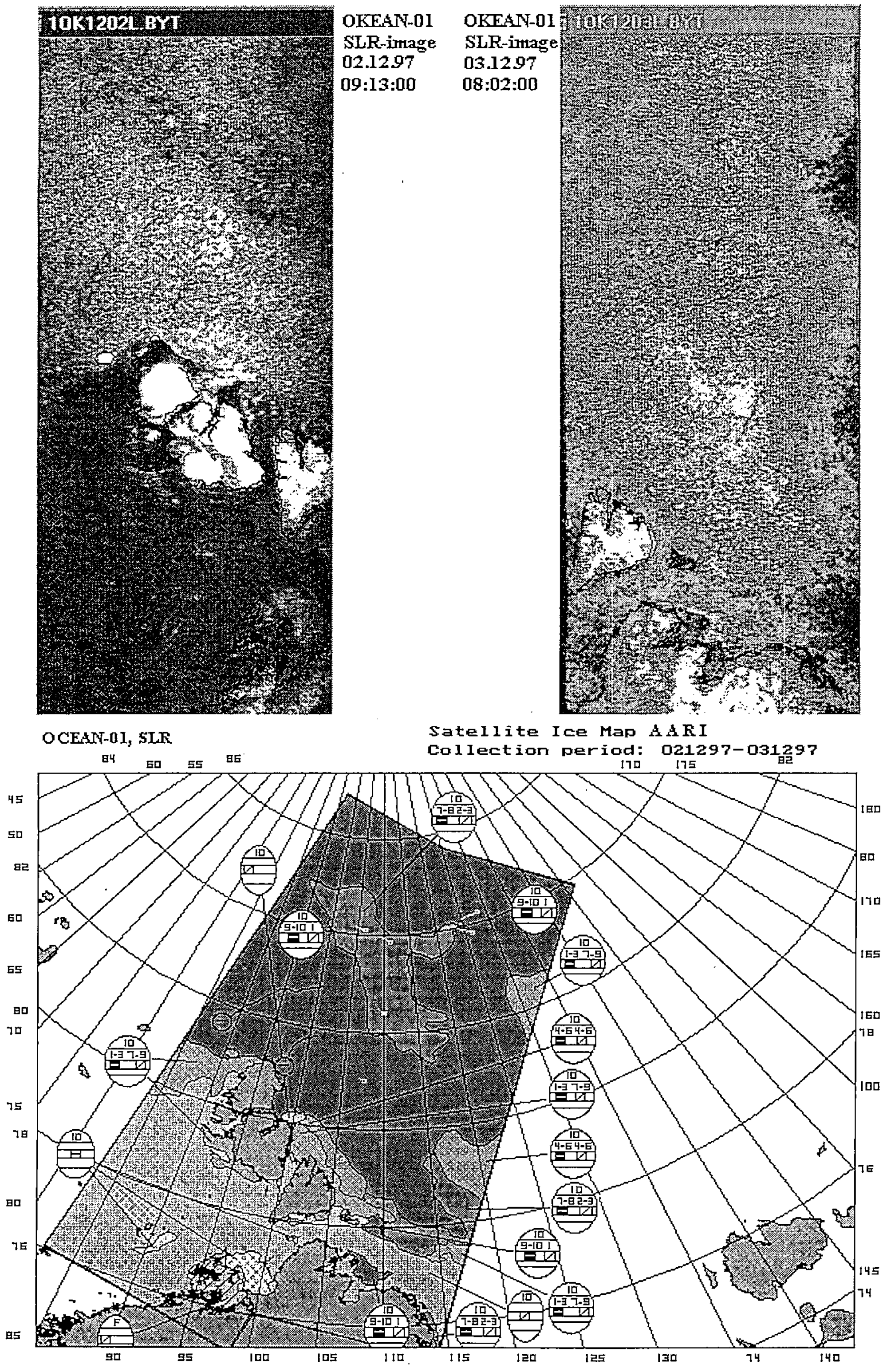


Figure 7. Sub-images of “Okean-01” radar scenes from the 2 and 3 December 1997, and an ice chart composed on the basis of these images. White lines are ice drift vectors (map scale) for 25.2 hours, displaying ice motion from 12 to 28 cm/s.

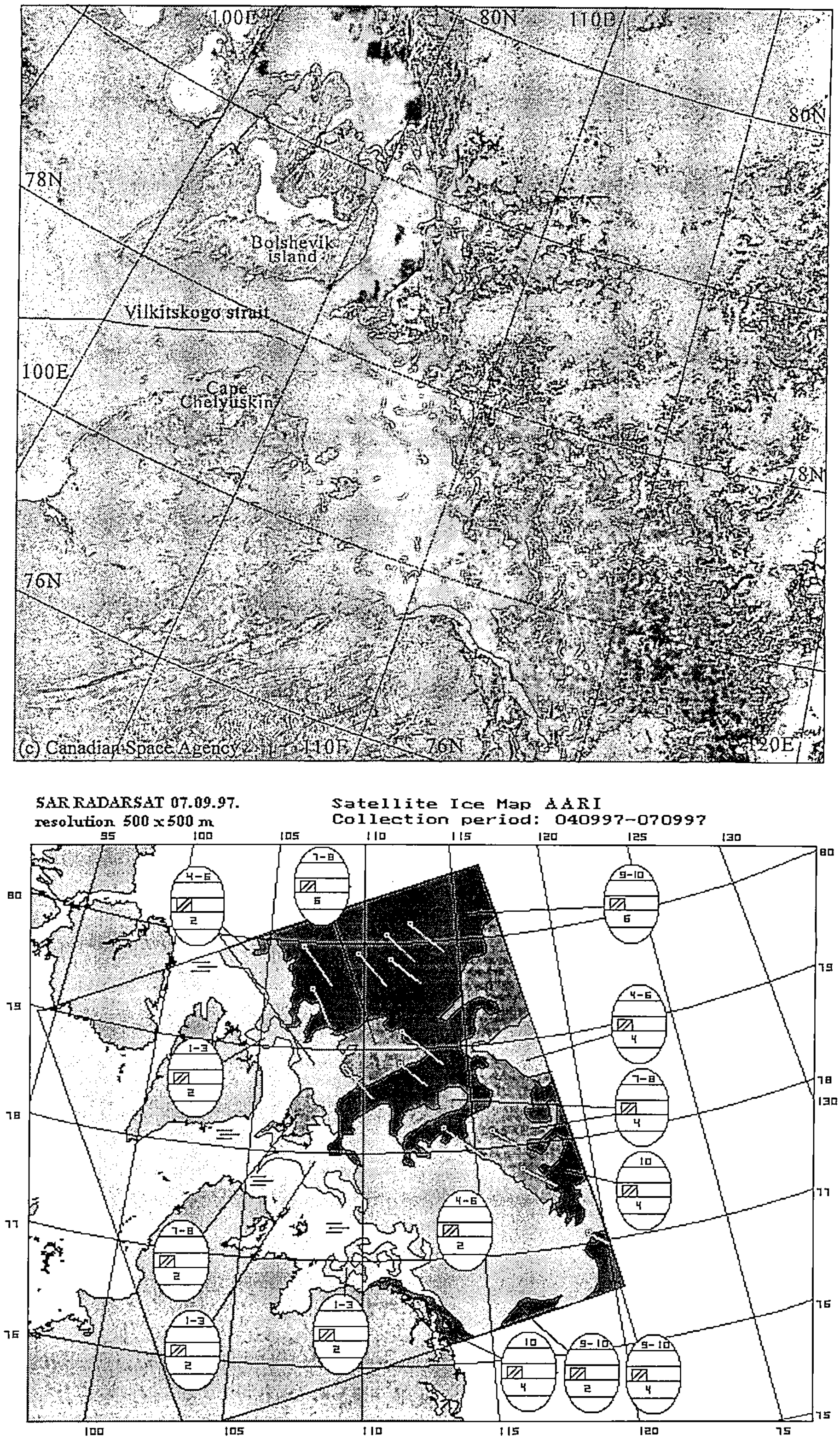


Figure 8. Upper figure: A RADARSAT ScanSAR scene of 7 September 1997 processed and geolocated by NERSC. Lower figure: Ice chart derived from RADARSAT ScanSAR scenes of 4 and 7 September 1997, using the image analysis and ice charting system at AARI. White lines are drift vectors for 3 days (map scale), displaying ice motion speed from 9 to 19 cm/s.

# 6 COMPUTER TOOLS FOR SATELLITE DATA PROCESSING

## 6.1 THE VIDEOBOX SYSTEM

Operational and qualitative ice information require continuous developments and improvements of methods for geo-positioning, interpretation, validation and other analyses of new remote sensing data. It is also necessary to determine the relations between satellite observations and sea ice characteristics, and furthermore to automate as much as possible of the data processing. When AARI began to use satellite date for sea ice observations, the corresponding methodological handbooks were developed. From 1976, hardware and software systems have been developed at the institute for satellite data processing. A software system called VIDEOBOX, which was developed and included in operational analysis in 1995, provides automated and interactive processing of "Meteor-3" and "Okean-01" images, as well as NOAA low and medium resolution. The most important functions are image rectification, image analysis, and tools for ice chart production.

A satellite image, or a corresponding sub-image is transformed from orbital data to a resampled ortophoto-chart (an image in a given cartographic projection, and a homogenous scale) of a square cross-cylindrical projection most close to the projection of the initial image. The geographical location is specified interactively by coastline contours. Cloud-free regions are identified in the optical images. These regions are then automatically transformed to a fragment of one current ortophoto-chart (composite pictures) of the entire Arctic Ocean or a sub-area. The ortophoto-chart is produced in a polar stereo-graphic projection, with a scale of 1:1,000,000, i.e. in the files of squares of 501 x 501 resolution elements, restricted by co-ordinate lines multiple to 500. The readout of co-ordinates begins at the Pole point.

The ortophoto-chart is displayed on a computer for analysis and interactive compiling of an individual ice chart. The preparation of an individual ice chart includes the following steps:

- decoding using direct, indirect and logical decoding indications;
- interpretation and delineation of the boundaries of uniform ice zones (predominantly interactive and some characteristics automatically);
- compiling of an ice chart in the CONTOUR format.

One of the layers of an ice chart presents ice drift data. This data is obtained by automated or interactive determination of co-ordinates for identical ice cover points from two subsequent ortophoto-charts. A random field of drift vectors is interpolated to the regular grid points or boundaries of zones whose position is thus traced. The CONTOUR format allows reproducing a graphic ice chart on display, obtaining a hard copy and its transmission via any communication lines. The composition and accuracy of the ice cover characteristics on the ice charts when applying different remote sensing means are described in detail in Bushuyev (1997).

AARI has developed a modified CONTOUR-2 format which was considered and in principle approved as an international format for exchanging operational and regime ice data (the 6th session of the Steering Group of the Global Sea-Ice Data Bank and the informal session of WMO CMM Sea Ice Sub-Group in Copenhagen, September 22-26, 1997). The format was published on Internet: *http://www.aari.nw.ru/formats/contour2.htm*

Based on the individual ice charts in the CONTOUR format, composite and calculated analytical ice charts are compiled and short- and medium-range ice forecasts are issued. Thus the "Sever" Center issues all types of information necessary for navigation support along the NSR.

### 6.2 DATA DISSEMINATION TO USERS

The "Sever" Center transfers review, regional and individual (local) ice charts in the CONTOUR format to different users. An ice chart in the CONTOUR format is recorded automatically during the process of interpretation and interactive mapping of satellite images when using the VIDEOBOX software and presents a vector letter-digital file. The CONTOUR formats uses the WMO International symbols for sea ice charts and conventional colouring. The "Sever" Center has experience of transmitting the ice charts in the CONTOUR format to the expedition ships in the Arctic as well as receiving ice charts from the Antarctic via INMARSAT. To icebreakers and ships without computer capacities to receive digital ice charts and information, the ice charts are sent by facsimile or in the CONTOUR format allowing manual reproduction of an ice chart to a cartographic blank form.

Today, high or medium resolution satellite images are not transmitted to icebreakers or ships from the "Sever" Center, but if necessary, there are no technical problems for transmitting satellite images.

## 7 JOINT USE OF RUSSIAN AND NON-RUSSIAN SATELLITE DATA IN SEA ICE MONITORING

### 7.1 INTRODUCTION

This chapter presents some examples of how Russian and non-Russian satellite data can be used together in ice monitoring and describes how the data complement each other. The work is a continuation of project I.4.2 in INSROP 1: Ice monitoring by non-Russian Satellite Data. Phase 1: Feasibility Study (INSROP Working Paper no. 3 - 1994) and Phase 2: Pilot Demonstration (INSROP Working Paper no. 38 - 1996). Use of RADARSAT data is discussed in more detail in a separate report from Project I.2.4: Practical demonstration of real-time RADARSAT SAR data for navigation in the Northern Sea Route.

### 7.2 COMBINATION OF OKEAN SLR AND ERS SAR

Real aperture Side-Looking Radar data (SLR) from Okean satellites have been available for ice monitoring since 1983. The Okean SLR operates at a wavelength of 3.2 cm (X-band) with VV-polarisation. With swath width of 450 km and resolution of about 1.5 km, the SLR data provide good coverage of Arctic sea ice on weekly basis, discriminating between multiyear, first-year and new/young ice and open water. With ERS SAR images, available since 1991, it is possible to observe sea ice in much more detail because the SAR images have a pixel size of about 30 by 30 m. The ERS SAR, which is C-band (5.7 cm wavelength) and VV-polarised, can provide detailed information about ice types, ice concentration, ice roughness, floe size, ice motion and other ice parameters. With a swath width of only 100 km, the area covered is fairly small and only selected areas can be monitored by the ERS SAR system. A more optimal monitoring system would require joint use of Okean SLR data and ERS SAR data.

In a joint project with NPO Planeta and AARI several examples of coincident Okean SLR and ERS SAR images have been analysed and compared (Johannessen et al., 1997). The following ice parameters have been studied:

- Delineation of open water
  Brightness of open water on ERS SAR images varies strongly due to water roughness. Calm water is characterised by darker signatures. Wind roughened water are represented by areas of higher signatures brightness, which in almost all cases exceeded the brightness of sea ice. Areas of wind roughened water also have a specific texture which can help in distinguishing it from sea ice.
- Ice type determination
  When systematic monitoring of studied areas is carried out, sea ice in delineated areas sea ice can be classified to the following ice types:
  1. grease ice,
  2. nilas,
  3. young ice (grey and grey-white),
  4. level first-year ice,
  5. ridged first-year ice, and
  6. multi-year ice.

  In delineated areas different ice types can present. In such case a partial concentration of these ice types is determined for each area. Detection of different ice types is carried out with the use of image brightness and texture.
- Fast ice forms
  Fast ice boundary can be distinguished from drifting ice, but not in all cases. Ridged ice areas in fast ice can be detected.
- Ice concentration, ice forms and ice edge position
  Ice concentration is determined in areas, delineated in ERS SAR images. Giant, vast, big and biggest among medium ice floes can be identified. Ice edge position is determined due to sharp change of brightness.
- Channels and fractures in compact sea ice
  Elongated fractures in ice cover are evident, if their width exceeds 20-30 meters. Fractures, covered with new ice, nilas and young ice are evident among first-year and multi-year ice.
- Ice surface features
  Areas of level ice, ridged ice areas and ridges among level ice can be identified from ERS SAR images.

Combining ERS SAR images with SLR data from the Russian Okean satellites may give additional information about the sea ice situation. The combined analysis can be carried out in several ways, including: (1) by comparing features in the two data sets, (2) by conducting a pixelwise comparison, and (3) by comparing derived parameters from the two types of radar images.

Figure 9 shows an ERS-1 SAR image from the Bayadaskhara Bay area and an Okean SLR image covering a part of the Kara Sea (Yamal peninsula, Ob river estuary, the area north of Dikson). The SAR image was taken on December 27 and the SLR image on December 29, 1994. In the SAR image, there is a clear variation in backscatter signature within the bay. This may reflect that young ice in different areas has variable surface roughness. A number of leads can also be seen as dark linear features in the SAR image. In the SLR image, taken two days later, there are also differences in backscatter signatures in the bay, but the details of the ice signatures cannot be identified in the SLR image.

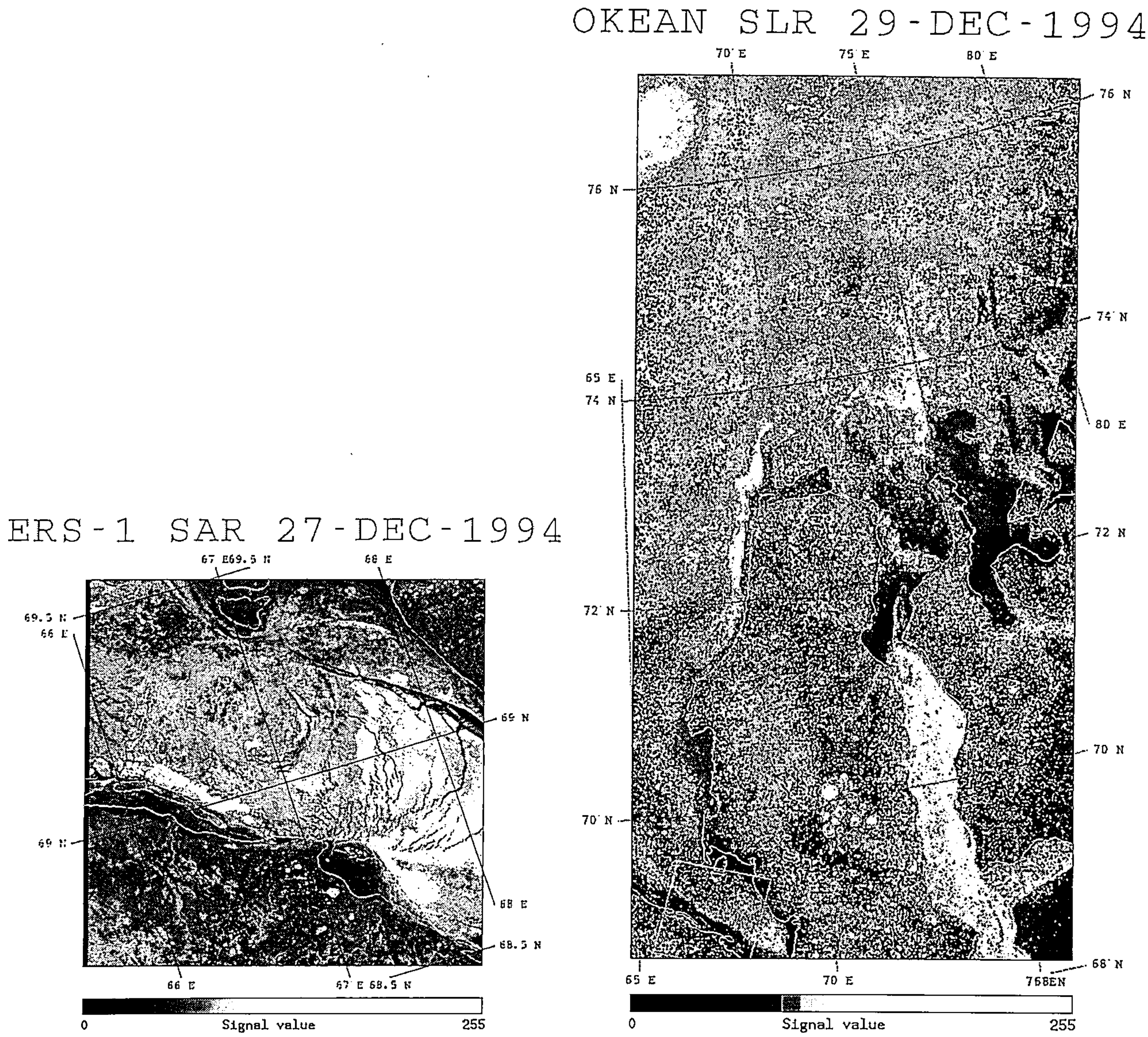


Figure 9. ERS SAR and Okean SLR image from the Bayadaskhara Bay area on December 27 and 29, 1994, at 07:01 GMT and 01:50 GMT ( Ω time). The SAR image is located in the lower, left corner of the SLR image. The location is marked with a rectangle in the SLR image. ERS Data © ESA/TSS 1994.

Another example of joint SAR and SLR ice observations is shown in Figure 10. A mosaic of several SLR swaths has been produced using data from the period from 16 to 21 May 1996, covering the central and northern Kara Sea. The Yamal peninsula, the northern part of Novaya Zemlya, Franz Josef Land, Severnaya Zemlya and the Taimyr coast are shown in the image. A digital land contour line is superimposed on the image. Two areas were covered with ERS SAR data, indicated by the rectangles on the Yamal coast and near Vikitsky Strait.

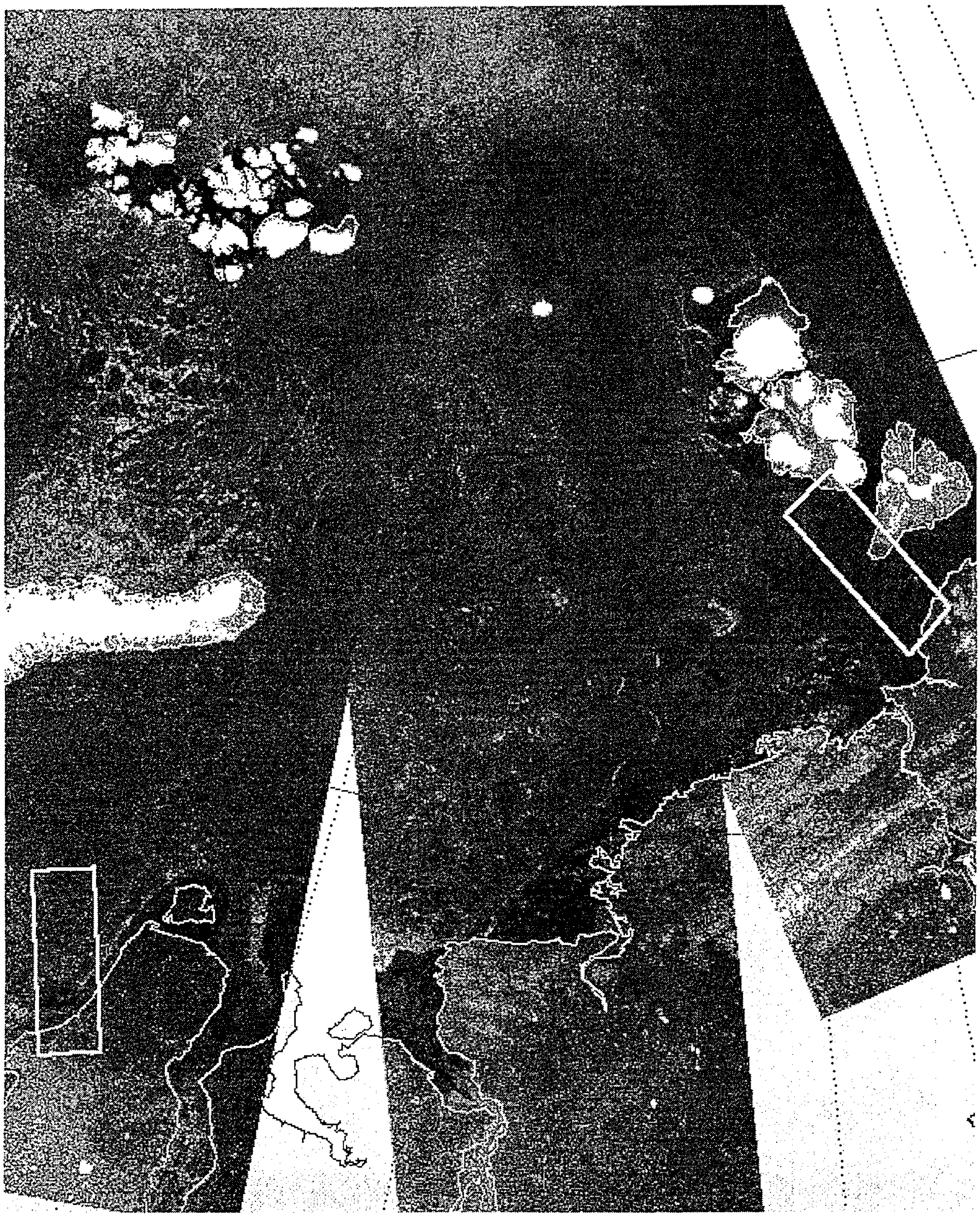

Figure 10. Digital mosaic of SLR images in the Kara Sea presented in a polar stereographic projection, obtained from Okean N7 in May 16 - 21 1996. The white rectangles mark the locations of two ERS SAR images obtained at the same time. Image courtesy: NPO Planeta, Department of thematic Processing.

Most of the ice is first-year ice, with some areas of young ice characterised by brighter signatures in the coastal polynyas west of Novaya Zemlya, off the Yenisei Gulf and along the Yamal coast. The border between landfast ice and drifting ice east of Dikson can be identified. North of Franz Josef Land the uniform area of multiyear ice is characterised by brighter signature than the first-year ice. Floe structures and leads can be observed in the multiyear ice and in the first-year ice between Novaya Zemlya and Franz Josef Land.

The SLR mosaic covers large areas at a coarser resolution than the ERS SAR data. The SLR images are therefore useful as a "background", for the SAR data which can be obtained in smaller areas where more detailed information is needed. The SAR image from the Yamal coast, presented in Figure 11, shows that most of the ice area consists of densely packed first-year ice. There is some open water/new ice and a band of lower ice concentration at a distance of 20 - 50 km from the Yamal coast. The open water and new ice area is characterised by low backscatter. Along the coast there is 10 - 20 km wide zone of landfast ice. The open water and the landfast ice can also be seen in the SLR image.

The second ERS SAR image, presented in Figure 12, is taken in the eastern Kara Sea near Vikitsky Strait where the SLR image shows just a uniform signature of first-year ice. The SAR image, however, shows a detailed mixture of consolidated first-year ice, leads, polynyas with young and new ice, landfast ice, and ice with variable surface roughness.

Digital analysis of SAR and SLR data on a pixel-by-pixel basis have been tested, but this requires both accurate radiometric calibration and that the images are geometrically transformed to the same map projection. The calibration procedure for ESA SAR provides a radiometric accuracy of ±0.5dB. A corresponding procedure for Okean SLR data is outlined in Johannessen et al (1997), but the detailed procedure is not known. Likewise, the orbits of the ERS SAR satellites are sun-synchronous and corner and centre co-ordinates accompany the image data. The different pixel size and shape between the two types of date must also be taken into the account. When the data have been prepared for pixel-by-pixel analysis, it is possible to compare backscatter values of different ice types and assess quantitatively the capability of the two instruments to classify ice types.

Figure 11. ERS-1 SAR image from the Yamal coast on May 19 1996. ©ESA/TSS 1996.

Figure 12. ERS-1 image from the Vilkitsky Strait area on May 18, 1996. ©ESA/TSS 1996.

In general, it cannot be expected to find the same ice features in the SLR and SAR images due to the different resolution. The examples above show, however, that the gross features in the SLR images are in agreement with the SAR observations. Both sensors can identify multiyear ice (higher backscatter), first-year ice (medium backscatter), young ice/rough first-year ice (higher backscatter), new ice/nilas (lower backscatter) and open water (low backscatter at low wind speeds). The difference in resolution and coverage makes the two data types complementary to each other where the SLR is suitable for strategic and operative ice mapping, while the SAR is most useful for tactical ice mapping.

### 7.3 Preliminary Results

The examples of joint use of ERS SAR and Okean SLR described in this report show that it can be very beneficial in ice monitoring to combine wide swath, medium resolution radar images with high resolution narrow swath SAR images. The SLR images are most useful for operative ice charting, while high resolution SAR is most important for tactical ice charting, especially in areas of 9 - 10/10 ice concentration. SAR data are currently available from ERS-2 and RADARSAT and from 1999 ESA's ENVISAT ASAR will be operational. Use of SAR data in ice monitoring will therefore increase in the next few years.

## 8 Russian Satellite Tracking System for Mobile Objects and Data Collection "KURS"

The satellite system "KURS" has been developed, and was in 1995 put into experimental use in Russia. Main functions of the system:

- determine the location of different types of mobile objects and its data collection
- transmission of remote object's condition parameters
- transmission of non-operated measuring systems for indication of its sensors

Technical objects, which can use "KURS" for hydrometeorological data supply in Arctic Shipping, are:

- drifting automated ice stations (determination of location, and transmission of measured hydrometeorological data)
- tracking of a wide range of mobile objects, such as ships and migrate birds and animals, and determination of their current position
- non-operated automatic meteorological units located in remote and inaccessible regions (transmission of data by unit)
- ships (transmission of meteorological data)
- radio beacons (monitoring of operating conditions)

The system consists of three parts:

a) Space segment, including 4 satellites operating in full deployment. The satellites have a circular polar orbit with 83° inclination, an altitude of 1000 km, and a period of 105 minutes. The working frequency is 405.975 MHz.
b) Earth segment, including Local User's Terminals (LUT) in Moscow, Arkhangelsk, Nakhodka and the System Center (SC) in Moscow.
c) Radio beacons, installed on mobile or stationary objects. Radio beacon can be connected with sensors of different purpose, installed on the controlled object.

Radio beacon radiates a modulated radio signal, which is received by the satellite in the area of visibility of radio beacon. Signal is processed and stored by the on-board equipment of the satellite and is then sent to LUT, while passing in the area of mutual visibility. LUT determines the radio beacon location, its identification number and decodes parameters of the object under control. The processed data are sent to the SC and thereafter to the user via terrestrial communication channels.

The first satellite of the system was launched the 5th of July, 1995. At present, an experimental evaluation of technical and operating characteristics of the system and its efficiency is carried out. It was executed a wide range of tests with different objects. The most interesting and extensive experimental test was carried out aboard the m/v "Academik Fiedorov", during a voyage from St. Petersburg to Antarctica and back in 1996 and 1997.

The main parameters of the system quality are the accuracy and the efficiency. The following results of trials have been obtained:

- The accuracy of the location of stationary objects was evaluated by data collected during anchorage in the ports. A total of 463 determinations of location was carried out. The Radial Mean Square (RMS) error of the location determination is equal 0.58 miles (1.0 km), with a probability of 0.9 the error does not exceed 1.5 km.
- For moving objects, the location error increased proportional to the velocity. For drifting objects at a velocity of 2-3 knots, the error did practically not increase. At velocities of 15-20 knots the error reaches 3-5 km.

Efficiency is determined by two factors - discreteness and delay.

Discreteness is a number of location determinations. It depends on the numbers of operating satellites, and the geographical latitude of the measured object. For circular polar orbits, this parameter increases with increased latitude position. For instance, for latitudes of 65-75 degrees and one satellite per day, 8-10 co-ordinate determinations and corresponding number of information messages can be obtained. Increasing the satellite number increases the discreteness.

Delay is the time it takes from the measuring session begins, to the user (traffic operator) receives the data. It mainly depends on mutual locations of the object and LUT. For the Arctic region, thanks to sufficient locations of the LUTs (Arkhangelsk and Nakhodka), in half of the cases the delay is a few minutes, and for the other half, about an hour. These values do not take into account the quality of the terrestrial communication channels between the SC, and the station where the users receive and process the data. This is a private problem of the users, and depends on technical matters, and how they have chosen to organise their interaction with the SC.

Already, in the stage of system demonstration, even one satellite can solve many scientific and practical problems concerned with the utilisation of the Arctic region.

## 9 Conclusion and Perspectives

The study is showing how Russian satellites which are currently in operation provide sea ice information for navigation support in the NSR. Data from different satellites also non-Russians, complement each other and are used in preparation of ice charts with update period from 1-3 to 7 days. The system of hydrometeorological support for navigation at AARI (the "Sever" Center) is described. The Center collects and analyses hydrometeorological and sea ice data which are used to prepare ice, meteorological and specialised forecasts needed by customers in the NSR. It has been shown that regular shipping in this region is impossible without a planning and management system located at the Marine Operation Headquarters, Murmansk combined with comprehensive information support from "Sever" Center.

In near future it is planned to use data of the Russian satellite "Meteor-3M-N1" which is at the final construction stage. It will be equipped with a scanning radiometer in the visible and IR-ranges ("Climate-2") with a resolution of 1 km and with a scanning passive microwave radiometer with a high frequency channel resolution of 9 km at a swath width of 1500 km. This satellite is scheduled for operation over 3 years. It will be followed by "Meteor-SM-NR" which will have similar instrumentation.

A new Russian SAR satellite, "Resource-Arktika", which will be very useful for ice monitoring, is under construction. In addition to visible scanning radiometers it will have a multi mode SAR operating at 3.49 cm, with resolution from 100 to 300 m, and swath width up to 450 km with signal processing onboard. The instrument will also operate in SLAR - mode.

It is planned to establish a Russian satellite station NPOMASH (Reutovo) which will receive, process and disseminate the RADARSAT SAR data on a commercial basis. Data of this satellite will be available to the "Sever" Center in near real-time and can be efficiently used for navigation support along the NSR. Also ENVISAT ASAR data, combined with AATSR and MERIS, will become useful in ice monitoring when this satellite is launched in 2000.

## 10 ACRONYMS

| | |
|---|---|
| "Climate" | - Scanning Infrared Radiometer |
| "Kondor-2" | - Instrument for data retrieval and transmission from drifting buoys |
| AARI | - Arctic and Antarctic Research Institute, State Research Center of the Russian Federation |
| AATSR | - Advanced Along Track Scanning Radiometer |
| APT | - Analog Picture Transmission |
| AVHRR | - Advanced Very High Resolution Radiometer |
| CONTOUR | - Russian national format for exchanging operational and archived data on sea ice |
| ENVISAT ASAR | - European Remote - Sensing Satellite sensor |
| ERS | - European Remote - Sensing Satellite |
| ESA | - European Space Agency |
| HRPT | - High Resolution Picture Transmission |
| INMARSAT | - International Mobile Satellite Organization |
| KURS | - Russian Satellite Tracking System for Mobile Objects and Data Collection |
| LUT | - Local User's Terminals |
| MERIS | - Medium Resolution Imaging Spectrometer |
| Meteor - N | - Russian Remote - Sensing Satellites |
| MOH | - Marine Transport Operational Headquarters |
| MR-2000M | - Visual Scanning Radiometer |
| MR-900B | - Visual Scanning Radiometer |
| MSU-E | - Visual multi-channel high resolution scanning radiometer |
| MSU-M | - Visual Multi-channel Scanning Radiometer |
| MSU-S | - Visual Multi-channel medium resolution scanning radiometer |
| MSU-SK | - Visual and thermal multi-channel medium resolution scanning radiometer |
| NOAA | - National Oceanic and Atmosphere Administration, USA |
| NPO "Planeta" | - Russian Scientific- Industrial Corporation, Moscow |
| Okean - 01 | - Russian Remote - Sensing Satellite |
| RADARSAT | - Canadian Radar Satellite |
| Resours - 01 | - Russian Remote - Sensing Satellite |

| | |
|---|---|
| RM-0.8 | - Passive Microwave Radiometer |
| Roshydromet | - Federal Service of Russia for Hydrometeorology and Environmental Protection |
| SAR | - Synthetic Aperture Radar |
| SC | - System Center |
| Sever | - Russian Center for Hydrometeorological and Ice Information (AARI, St. Petersburg) |
| SLR | - Side-Looking Radar |
| VIDEOBOX | - AARI Software Package for Remote Sensing |
| WMO | - World Meteorological Organization |

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Portland, Oregon, 25 May 1998

**Reviews of "An Overview of Russian Satellite Data for the Northern Sea Route" by Bushuev et al. and of "Joint Use of Russian and Non-Russian Satellite Data in Ice Monitoring" by Sandven**

**Prepared for INSROP by W. F. Weeks**

**"An Overview of Russian Satellite Data for the Northern Sea Route"**
Although the English in the this report needs a bit of polishing I find the report to be both well done and quite informative. I was particularly interested in the discussion by these very experienced ice experts relative to what useful sea ice data could be extracted from the output of a specific satellite system. I note that on p.26 that they state that it is currently not possible to obtain NOAA AVHRR data for the eastern portion of the NSR. They need to elaborate why this is so. As I recall we were easily able to aquire AVHRR data for the eastern Siberian Sea at the Alaskan SAR Facility. Is this only a problem of not having an antenna at the right location or is something else the difficulty?

**"Joint Use of Russian and Non-Russian Satellite Data in Ice Monitoring"**
This short paper is very well written and informative. It is publishable as is.

**Concluding discussion**
I feel quite strongly that these two papers would benefit greatly by combining them into one paper. I would suggest that Sandven take the two papers and attempt to combine them. While he is doing this he can also polish up the Russian version of English a bit. This should not be all that difficult as the Bushuev et al. report is quite clear and Sandven writes excellent English. If this rewriting is attempted, a bit of rearranging of the text would be in order. After the descriptions of what the different satellite systems have to offer relative to sea ice observations, then Fig. 1 in Bushuev et al. should be used in a expanded discussion of how it is proposed to get the appropriate imagery to the right place at the right time. I would particularly like to see how they propose to acquire the wide swath RADARSAT imagery which I personally think is the most valuable sensor system currently operational as far as sea ice remote sensing is concerned. For the eastern section of the NSR, I presume that the data could be downlinked and processed in Alaska and then sent to either Tromso or the Nansen Center and on to AARI. There also may be other better paths. Incidentally in Fig. 1 there are some typos: “Cever” should be “Sever” and under RADARSAT “Nearly Time” should possibly be “Nearly Real Time”. Incidentally a listing of acronyms would be helpful for many readers.

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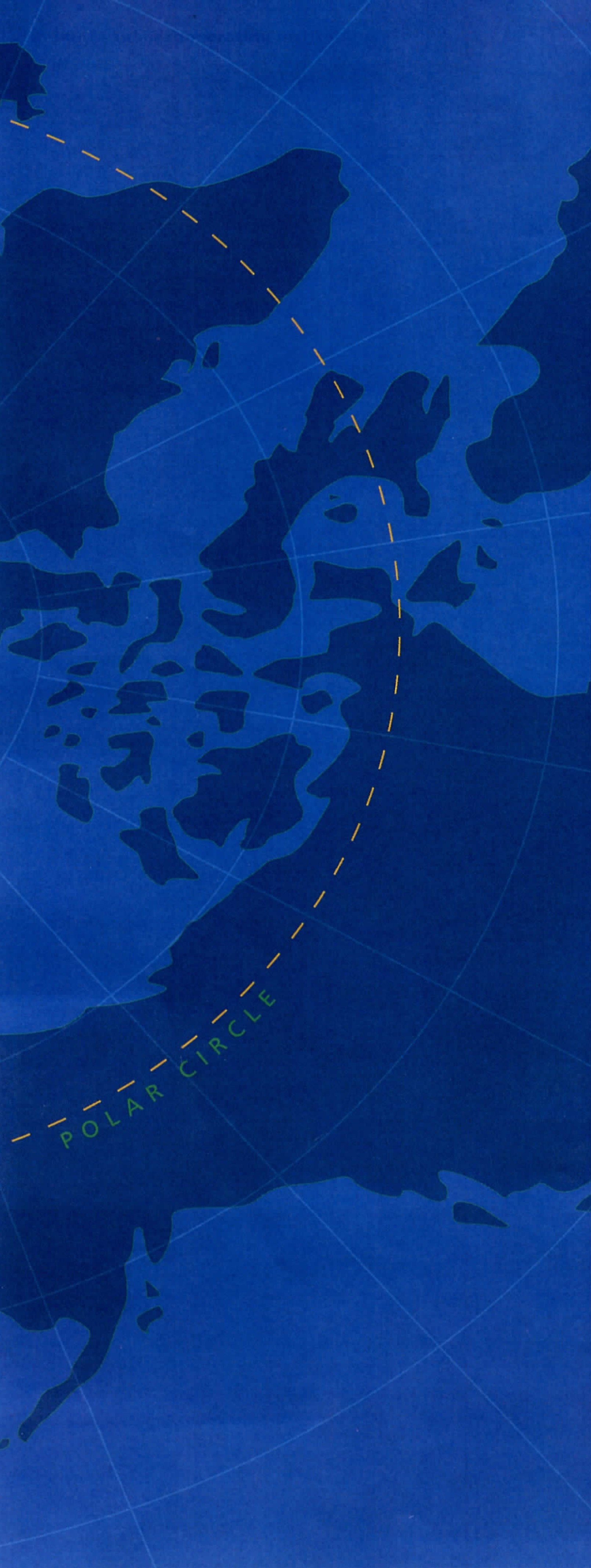


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**Ship & Ocean Foundation (SOF), Tokyo, Japan.**

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 Sasakawa 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 stockholding 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 multidisciplinary approach, entailing extensive cooperation with other research institutions both at home and abroad. The INSROP Secretariat is located at FNI.