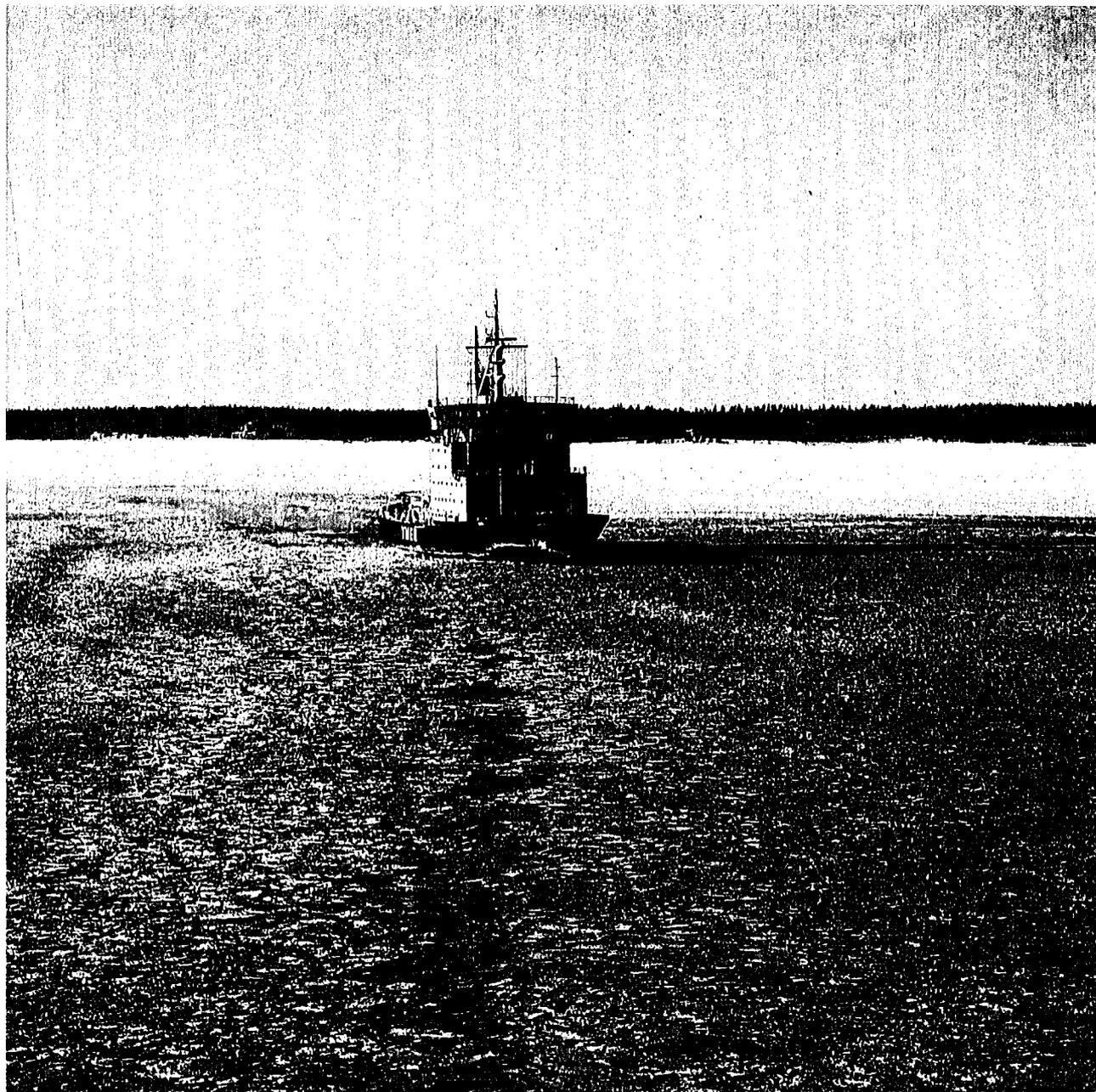


WINTER NAVIGATION RESEARCH BOARD
Swedish Administration of Shipping and Navigation, Finnish Board of Navigation
Research Report No 46



BEPERS —88

Experiment plan

Final edition, 1987

Editors: Thomas Thomppson and Matti Leppäranta

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FOREWORD

The Winter Navigation Research Board presents its report No. 46. The report presents the second and final edition of the experiment plan for BEPERS-88 (Bothnian Experiment in Preparation for ERS-1). The report has been prepared by Thomas Thompson at the Swedish Meteorological and Hydrological Institute and Matti Leppäranta at the Finnish Institute of Marine Research, based on contributions received from many scientists in Sweden and Finland. In particular the following individuals should be mentioned:

Jan Askne,	Chalmers University of Technology
Bertil Brusmark,	National Defence Research Institute
Olov Fäst,	Swedish Space Corporation
Martti Hallikainen,	Helsinki University of Technology
Bertil Håkansson,	Swedish Meteorological and Hydro logical Institute
Roland Johansson,	Chalmers University of Technology
Risto Kuittinen,	Technical Research Centre of Finland
Hans Ottersten,	National Defence Research Institute
Lars Ulander,	Chalmers University of Technology
Peter Ulrikssen,	Technical University of Lund

BEPERS-88 is a major experiment in the Swedish and Finnish preparations for the first European microwave satellite, ERS-1, which is to be launched in 1990. The general importance of BEPERS-88 is demonstrated by the international interest and participation.

The Winter Navigation Research Board expresses its thanks to all those, who have contributed and assisted in preparing the experimental plan.

Kaj Janérus

Jan-Erik Jansson

BEPERS-88 plan. Final edition.

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1 INTRODUCTION

1.1 Background

The Baltic Sea is a shallow semi-enclosed, brackish water basin. It is situated between latitudes 54° and 66° N and connected with the North Sea through the Belts and the Sound (figure 1). It is partly ice covered every winter with a maximum annual ice extent varying from 12 to 100 %. Once in a decade the ice coverage is more than 75 % during a period of one to two months. The very intensive ship traffic in the Baltic Sea is assisted by 20–30 powerful icebreakers. Sea ice information is provided several times per day by ice services in all countries in the area. The sources of ice information are conventional in-situ observations from ships and shore, air reconnaissance and satellite data, mostly NOAA AVHRR. Most data are highly weather dependent and as the average cloud cover in the Baltic Sea is 60 – 70 % during winter there is often a lack of reliable sea ice information.

The SEASAT satellite demonstrated already in 1978 the potentials of the spaceborne active microwave technique in sea ice mapping. The launch of the European Space Agency (ESA) satellite ERS-1 now opens the possibilities of testing the value and demonstrating the operational capabilities of this technique in the Baltic Sea.

It should be emphasized that the Baltic Sea is a part of the world ocean seasonal ice zone with all ice types and forms except multi-year ice and ice of land origin. The salinity of the first-year ice is however lower than in the Arctic. This may be considered as an advantage for research purposes. The systematic northward decrease in water salinity provides an excellent opportunity for studying the effects of ice salinity in the active microwave remote sensing of first-year ice.

1.2 Preparations for ERS-1

Sea ice remote sensing is one of the main research fields in the preparation for ERS-1 in Finland and Sweden. It is expected that Synthetic Aperture Radar (SAR) will provide a major improvement in operational sea ice mapping and forecasting in the Baltic Sea. Among other countries in the southern parts of the Baltic Sea also the Federal Republic of Germany and Denmark have ice information services and major interest in SAR data.

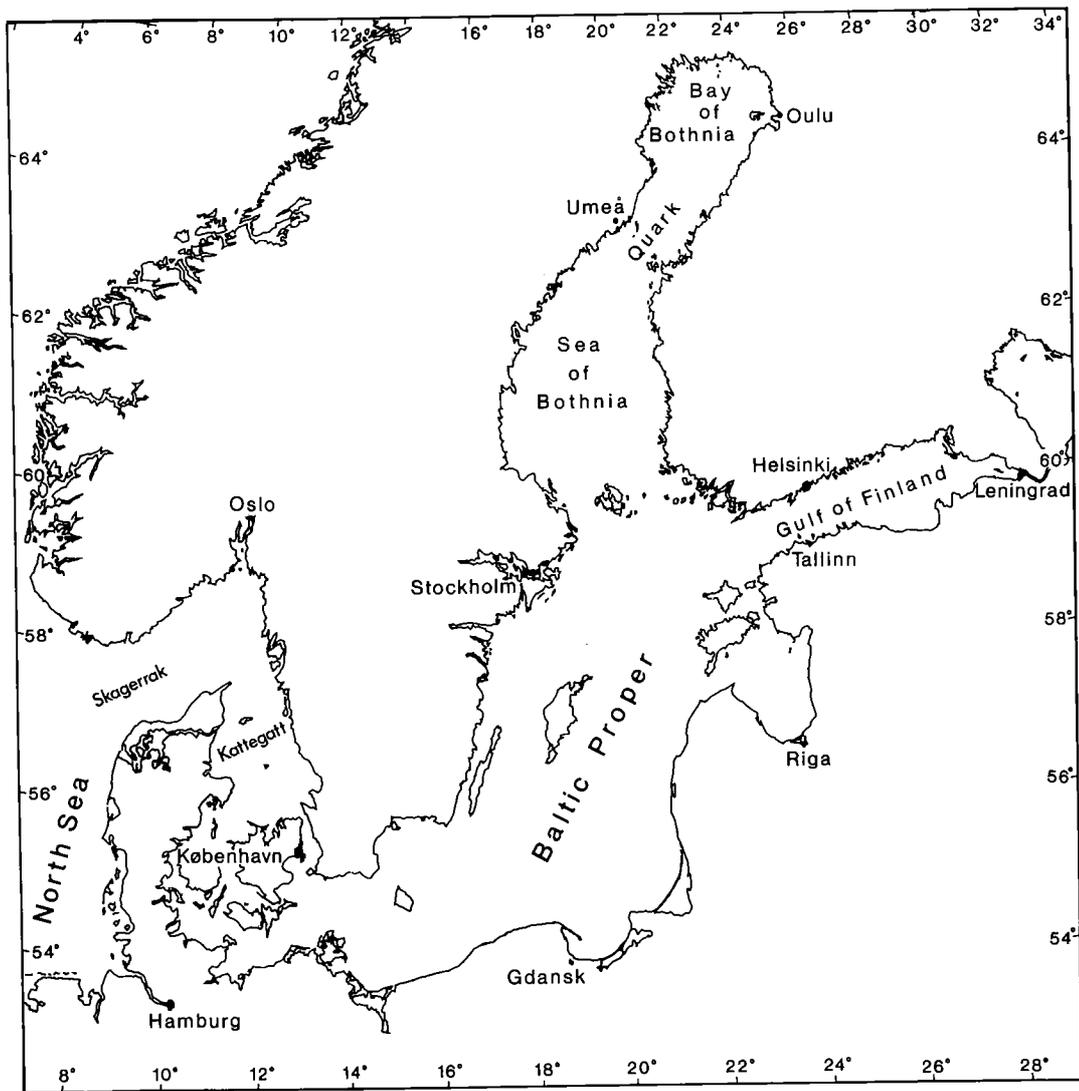


Figure 1. Index map of the Baltic Sea region.

In response to the ESA Announcement of Opportunity (AO) for ERS-1 the PIPOR (a Programme for International Polar Oceans Research) group has submitted a joint proposal in which many projects and 30 – 40 well-known and experienced sea ice and remote sensing scientists are involved. The general PIPOR programme is documented in PIPOR (1985). The PIPOR proposal also includes projects in the Baltic Sea concerned with the use of SAR in sea ice remote sensing. These start with a calibration/validation experiment followed by an application/demonstration experiment. These will be carried through basically by Finland, Sweden and the Federal Republic of Germany. The BEPERS-88 experiment can be regarded as a pilot study for the PIPOR Baltic Sea calibration/validation experiment.

1.2.1 Sweden

In 1985 the Swedish Board for Space Activities initiated programme for improving the knowledge of the ERS-1 instrumentation and their applications and to familiarize potential users with the new type of data that will become available from 1990. A steering group, called LeadERS, consisting of Jan Askne (chairman) from the Chalmers University of Technology (CUT), Olof Fäst from the Swedish Space Corporation (SSC), Hans Ottersten from the National Defense Research Institute (NDRI) and Thomas Thompson from Swedish Meteorological and Hydrological Institute (SMHI) was established. This group, to which also Peter Ulriksen from the Technical University of Lund and Folke Eklund, former research director of NDRI are adjuncted, is responsible for the initiation of BEPERS-88.

In the programme, ERS-1 data are expected to find their applications in many activities within meteorology and oceanography both operationally and in research.

The work at SMHI is mainly concentrated on:

- a. interpretation and analysis of remote sensing of sea ice, waves and winds,
- b. mathematical modeling in sea and ice geophysics,
- c. operational sea ice information services.

The research of the CUT:

- a. the use of the altimeter and synthetic aperture radar data in connection to sea ice,
- b. modelling of microwave scattering from level ice and ice ridges.

The research at the NDRI is concentrated on the processing and analysis of SAR data and they have established know-how and facilities in the field. Existing hardware includes a 30 Mflop 6 Mword array processor system for SAR raw data processing and advanced systems for post-processing of SAR images. A long experience exists within the NDRI from measurement programmes with high resolution radars.

1.2.2 Finland

The Finnish Space Committee has prepared a medium term plan for space activities in Finland. On the basis of this plan resources are allocated also for studies concerning the usefulness of ERS-1 for winter navigation purposes. In particular, as an extensive technical scientific project Finnish Institute of Marine Research, Finnish Meteorological Institute, Helsinki University of Technology and the Technical Research Centre of Finland are developing systems to disseminate remotely sensed data together with ice charts to icebreakers. In this connection studies are carried out in remote sensing of sea ice.

The work of the Finnish Institute of Marine Research deals with:

- a. geophysical interpretation in sea ice remote sensing,
- b. modelling dielectric properties of ice,
- c. basic research and mathematical modelling in sea ice geophysics,
- d. operational ice information services.

The research at the Helsinki University of Technology/ Radio Laboratory is concentrated on:

- a. developing radars and radiometers for remote sensing,
- b. conducting remote sensing measurements of sea ice,
- c. measurements and modelling of the dielectric properties of sea ice and snow,
- d. developing ground truth instruments.

The work at the Technical Research Centre of Finland deals with:

- a. various remote sensing applications,
- b. image processing systems,
- c. telecommunication techniques.

1.3 BEPERS-88

The objective of BEPERS-88 is to

- * produce sea ice remote sensing data similar to ERS-1 data together with high quality ground truth and supporting remote sensing observations.

These data will be used for

- * development of algorithms for determination of geophysical sea ice parameters and processing of SAR sea ice images,
- * evaluating the potentials of SAR in operational sea ice mapping and forecasting using numerical models,
- * planning of the PIPOR Baltic Sea calibration/ validation experiment.

In addition to SAR the following tasks are considered important for the project

- * evaluation of the altimeter for provision of sea ice and ocean parameters,
- * scatterometer measurements of sea ice.

1.4 Pilot study 1987

BEPERS Pilot Study was carried out during 30 March – 3 April 1987. The study was organized by the Technical Research Centre of Finland and Finnish Institute of Marine Research with eight research laboratories from Finland and Sweden taking part in the field programme. The SAR data was provided by the French VARAN-S, chartered from GDTA (Groupement pour le Développement de la Télédétection Aérospatiale) which carried it through together with IGN (Institut Géographique National) and CNES (Centre National d'Etudes Spatiales). The French VARAN-S SAR is an X-band SAR (frequency 9.37 GHz, resolution 3 or 9 m, horizontal polarisation). It is installed in a Boeing B-17, the "Flying Fortress". Quick-look images were available right after the flight. Raw data processing was made in France, and the processed data were then sent to Finland. The processing time was about six weeks.

The experiment included four study areas in the northern part of the Baltic Sea (Fig. 2). Three of the study areas had field groups with bases, and Helsinki airport was an additional base for coordination of the remote sensing flights in Finland. The coordination centre of the whole experiment was R/V Aranda in area II.

The experiment was very successful and no major drawbacks occurred. Even the weather was very good providing the possibility to carry out the whole ground truth programme and aerial photography and to acquire good quality satellite data to verify the SAR images. Presently, the data are under investigation. A data report will be published early 1988 including recommendations for BEPERS-88. This document will be valuable for the planning of the actual field work in BEPERS-88.

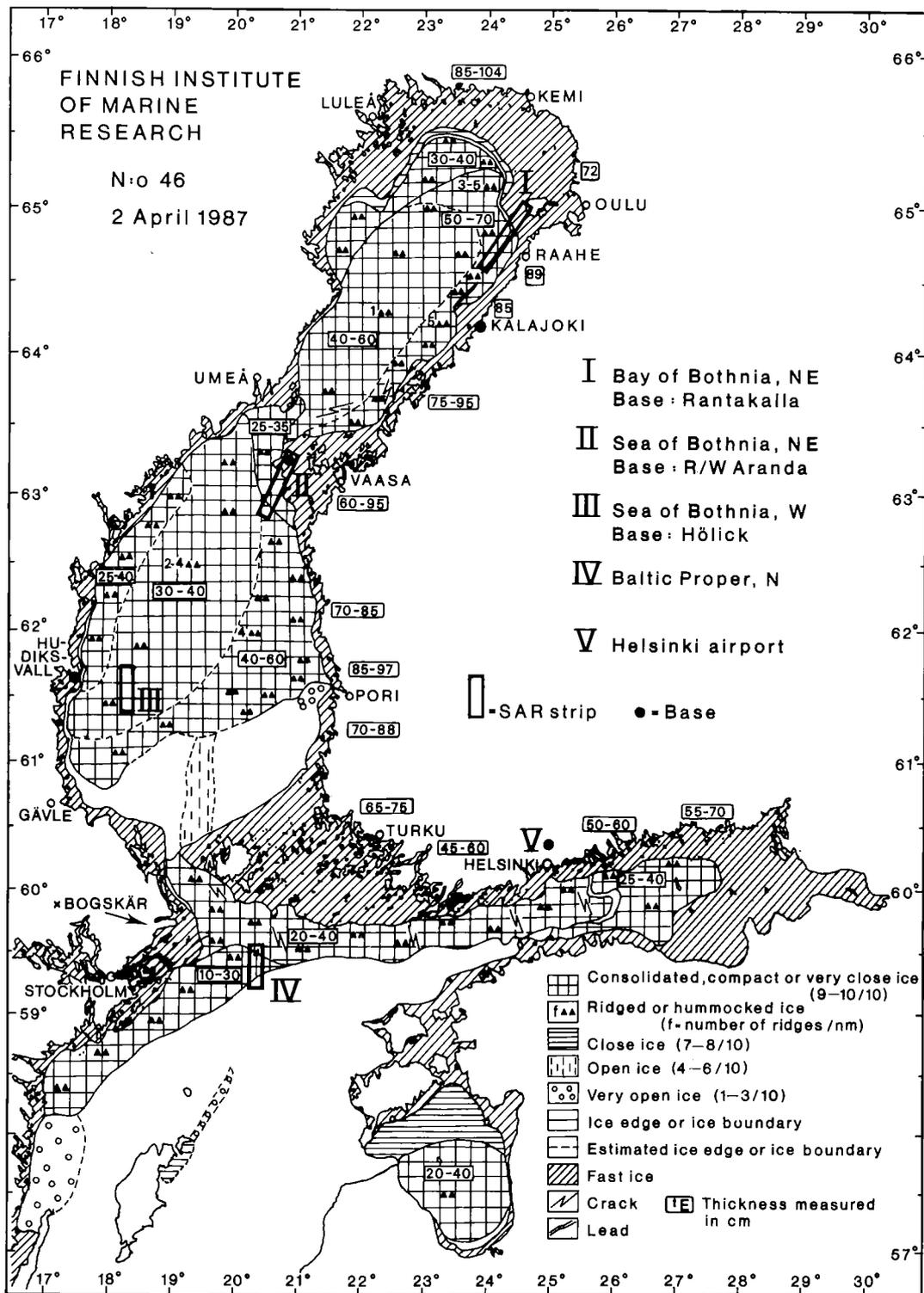


Figure 2. Baltic sea ice chart, 2 April 1987 (FIMR, 1987). Shown are also the locations of the bases and study areas in the BEPERS Pilot Study.

2 ICE IN THE BALTIC SEA

2.1 General

2.1.1 Hydrography

The Baltic Sea is situated at latitudes where the interannual variations in solar radiation, wind and air temperature are rather high. The proximity to the warm Atlantic Ocean on one side and the Eurasian continent on the other also give rise to large variations in wind and temperature, both seasonally and from day to day.

The topography of the Baltic Sea is characterized by the narrow and shallow connection with the North Sea through the Belts and the Sound (sill depth 18 m) and the division into different basins and bays. The mean depth is only 55 and the maximum depth 450 metres. The Gulf of Finland is a direct continuation of the Baltic Proper without any notable sill. In the northern part of the Baltic Proper, shoals with a depth of 30–40 metres isolate the Åland Sea, Archipelago Sea and Gulf of Bothnia from the southern basins. The Gulf of Bothnia is divided into the Sea and the Bay of Bothnia by the Northern Quark where there is a sill of 25 m.

The Baltic Sea is a brackish water basin where the salinity is determined by the inflows of saline water from the North Sea and the supply of fresh water from rivers. The salinity decreases gradually with the distance from the Belts and Sound. The surface salinity varies from 2 to 4 ‰ in the the Bay of Bothnia and in the eastern Gulf of Finland to some 9 ‰ in the southwest Baltic Proper. In the rest of the Baltic Proper, between the southern boundary of the Finnish archipelago and Bornholm, the surface layer salinity is 6.5 to 7.5 ‰. A summary of the salinity distribution in the Baltic Sea has been presented by Bock (1971). Fig. 3 shows the surface salinity in November.

At salinities of the Baltic Sea the density maximum occurs between 1° C and 3° C, so that winter deepening of the mixed layer through convective heat transfer occurs only down to these temperatures. However, further deepening may be caused by mechanical mixing due to strong winds.

In the Baltic Proper, the homogeneous winter layer usually extends down to the depth of a strong halocline at 50–70 metres. In the Gulf of Bothnia the halocline is much weaker and the winter mixing may extend more deeply. In regions with low salinity but considerable depth there is an inverse thermocline during the winter season.

The permanent circulation in the Baltic Proper is very weak. The long-term average circulation is cyclonic. There is one large gyre covering the Sea of Bothnia and another covering the Bay of Bothnia. The mean circulation contains a weak vertical shear and appears to be mainly estuarine and thermohaline. It is, however, typically well hidden behind frequent storms over the Baltic Sea. For

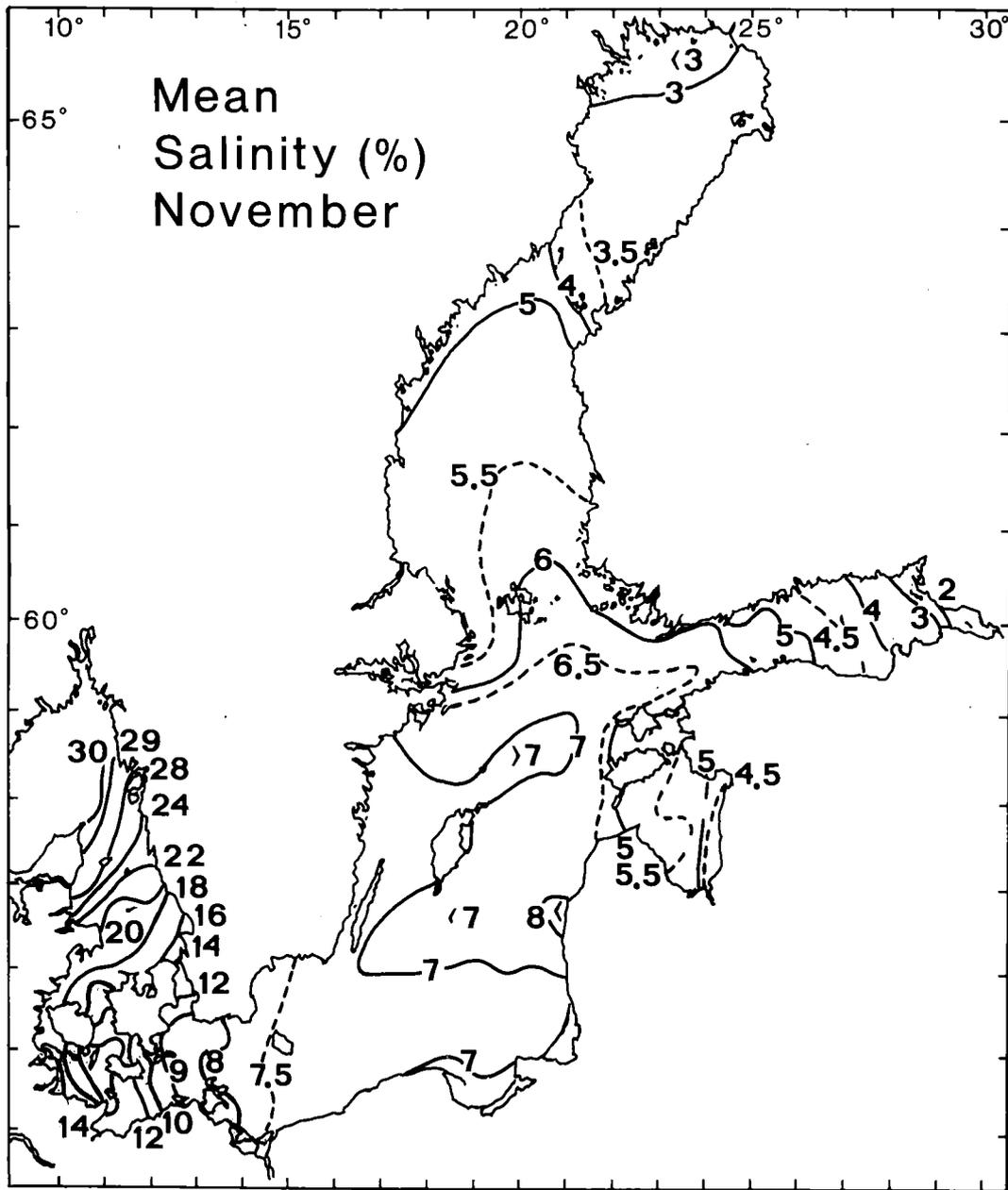


Figure 3. Mean sea surface salinity in November (bock, 1971).

further general background information reference is made to Defant (1972), Kullenberg (1980) and Mälkki and Tamsala (1985).

2.1.2 The ice season

The variations in the ice cover from year to year are considerable. The maximum annual ice coverage has been estimated for every year since 1830 and shows a variation between 12 and 100 % (Leppäranta and Seinä, 1985). In the Bay of Bothnia, eastern part of the Gulf of Finland and some archipelago areas the probability for ice occurrence is 100 %. The 50 % probability curve lies in the northern part of the Baltic Proper while the probability for annual ice occurrence is less than 10 % in the central southern part of the Baltic Proper.

The maximum ice extent generally occurs in February or early March. Examples of operational ice charts from early March during a mild and a severe winter are shown in fig. 4.

Ice formation begins in the northernmost parts of the Bay of Bothnia in late October and the ice cover extends southward during winter. On an average ice covers the Bay of Bothnia by mid-January and the Sea of Bothnia by mid-February. The dates of freezing vary however considerably from year to year. The earliest dates of freezing in the central parts of the Bay and Sea of Bothnia are early December and mid-January, respectively, and the latest date of freezing of the Bay of Bothnia is late February. It is very difficult at the beginning of the ice season to predict whether the winter will be mild, normal or severe. It is possible to give a reasonable forecast only at the end of January.

The ice occurs as fast ice and drift ice. Fast ice occurs along the coasts and in archipelago areas, mainly where the depth is less than 5 – 15 meters. Fast ice develops rapidly during the early ice season and remains stationary for the rest of the season (Leppäranta, 1981 b). The drift ice is of a dynamic nature. Winds and currents cause it to move and deform with numerous ridges and openings as result. The ridges are the most significant obstructions to navigation in the Baltic Sea. Powerful, ice strengthened ships can without great difficulties break through 50 – 80 cm thick ice but they cannot go through ice ridges and icebreaker assistance is therefore often required. The navigation conditions are also largely effected by ice motion and ice pressure.

The movement of the ice can be considerable. During storms an ice field can drift as much as 20 – 30 km in one day. The relative movement on a length scale of 1 – 30 km within the ice field is one order of magnitude less. The movement and deformation processes result in uneven and broken ice fields with distinct floes up to several kilometers in diameter, leads and cracks, slush belts, rafted ice and ice ridges. From the point of view of ice transport the Bay and Sea of Bothnia each form a rather closed system. The Baltic Proper and the Gulf of Finland form a joint system with the latter feeding ice, in the long term sense, to the northern Baltic Proper (SMHI and Inst. Mar. Res., 1982).

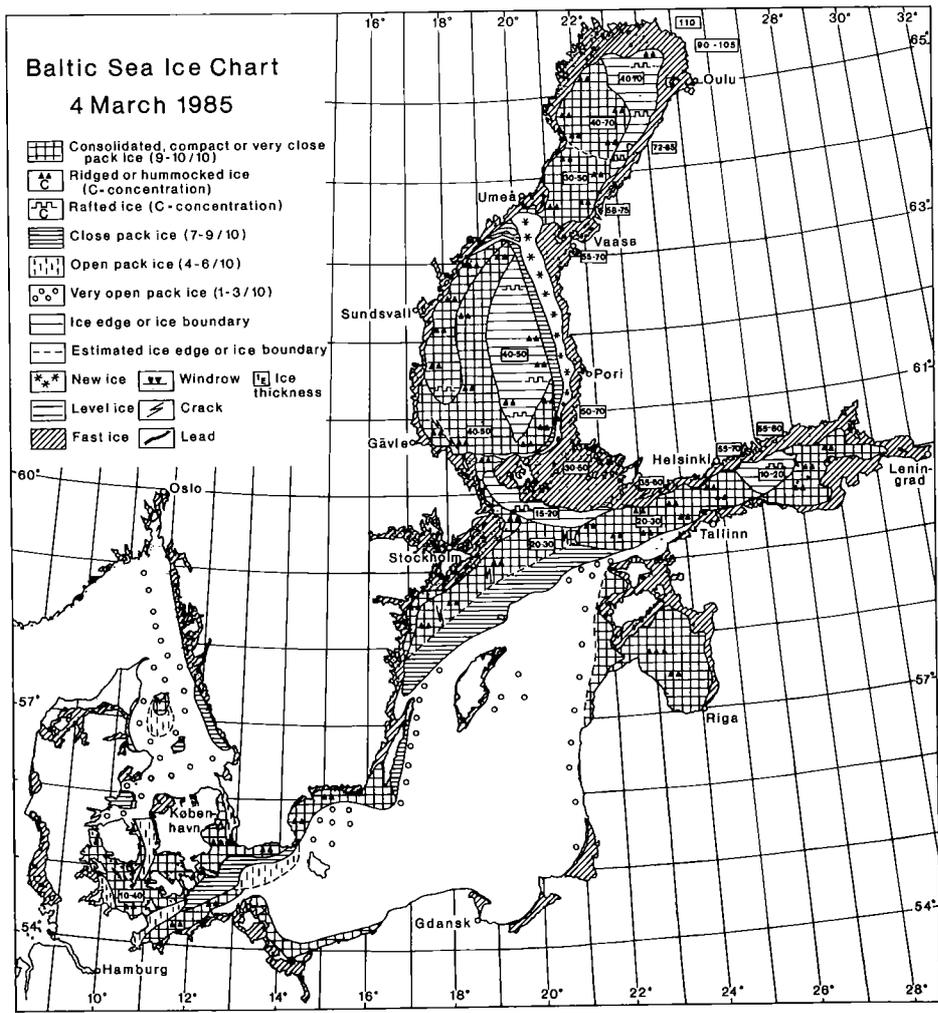
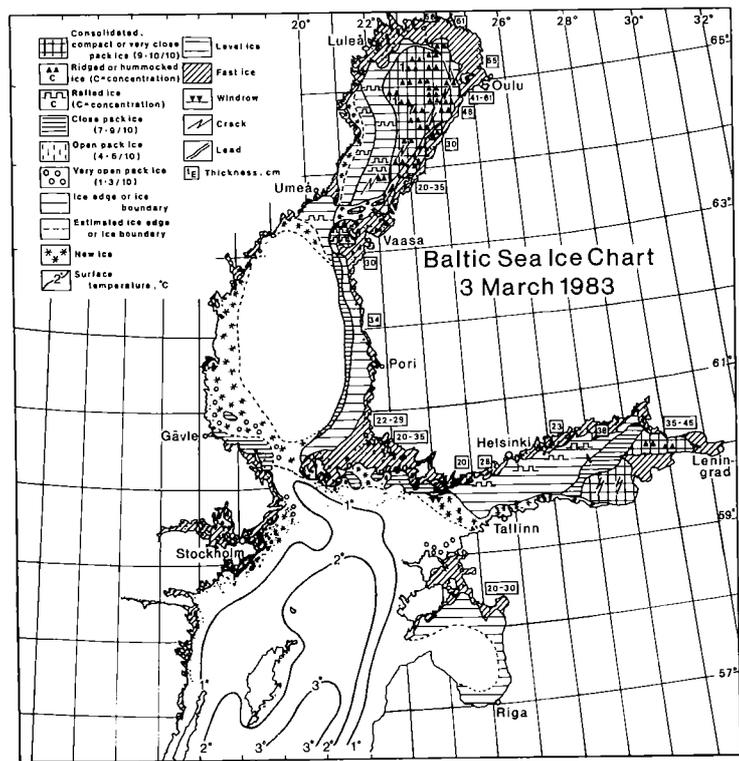


Figure 4. The operational ice charts shows the ice extent during a mild (3 March 1983) and severe (4 March 1985) winter.

2.2 Ice conditions in March

2.2.1 Ice frequency

On 1 March the probability for sea ice occurrence is 90 – 100 % in the Bay of Bothnia and in the Northern Quark. In the Sea of Bothnia the probability is 75 – 90 % along the coasts and between 50 and 75 % in the central part of the basin (see Fig. 5).

2.2.2 Crystal structure

The crystal structure of the sea ice in the Baltic Sea is similar to that of ordinary sea ice (Palosuo 1961). Three basic layer types are distinguished: snow-ice, columnar grained ice and fine-grained normal sea ice.

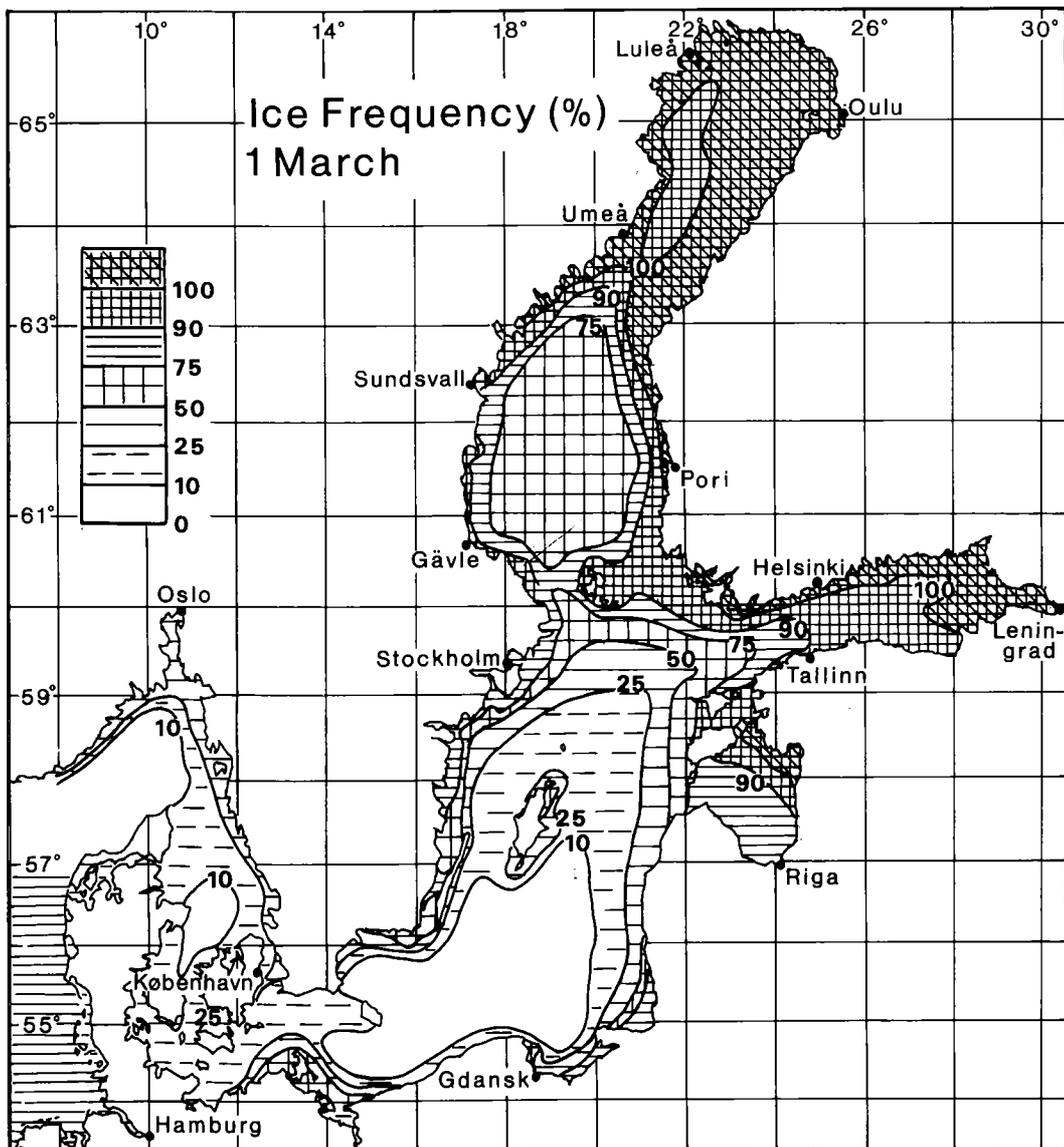


Figure 5. Mean ice frequency on 1 March.

Fine grained layers between columnar layers have been found in the Bay of Bothnia by Omstedt (1985). Snow-ice is generally opaque and may have high salinity. In winters with much snow, the snow-icethickness may amount to more than half the total thickness of the ice. The direction of the c-axis is vertical or random in the upper part of the normal sea ice sheet and turns horizontal at 10 to 20 cm depth.

2.2.3 Salinity

The newly formed ice has a salinity of one-quarter to one-half of that of the sea water in the same area. By March the salinity of the ice is reduced to approximately 50 % of its original level. A detailed study of the salinity of the ice formed in different locations has been made by Palosuo (1963). He took time series samples at six locations along the Finnish coast located according to increasing water salinity. An example of a time series for Saggö, Archipelago Sea, is presented in Fig. 6.

2.2.4 Thickness

The annual maximum level ice thickness is found in March. The maximum measured value is 122 cm (FIMR, 1987). This was found in the winter of 1985 in the northern fast ice zone in the Bay of Bothnia.

In the drift ice field the ice thickness varies very much both in space and in time due to the coupling of thermal and dynamic processes. The maximum annual level ice thickness is on average 70 – 80 cm in the north, close to 30 cm at the latitude 60 and 10 to 20 cm in the southern Baltic Sea.

2.2.5 Topography

When the ice has grown to a thickness of 10 to 15 cm or more, dynamic deformation processes may result in ridges. The structure of ice ridges in the Baltic Sea has been studied by Palosuo (1975). These studies mainly included large ridges of 100 to 300 cm sail height. Keel depths down to 28 m were reported. Spatial distribution and height of ridge sails have been studied with a laser profilometer by Leppäranta (1981 a). With a cutoff height of 30 cm, the average sail height was generally 50 to 60 cm and the height distribution fitted well into the exponential distribution. The number of ridges was typically 5 to 10 per km. It was further estimated that the mass of ridged ice was usually 25 to 75 per cent of the mass of level ice.

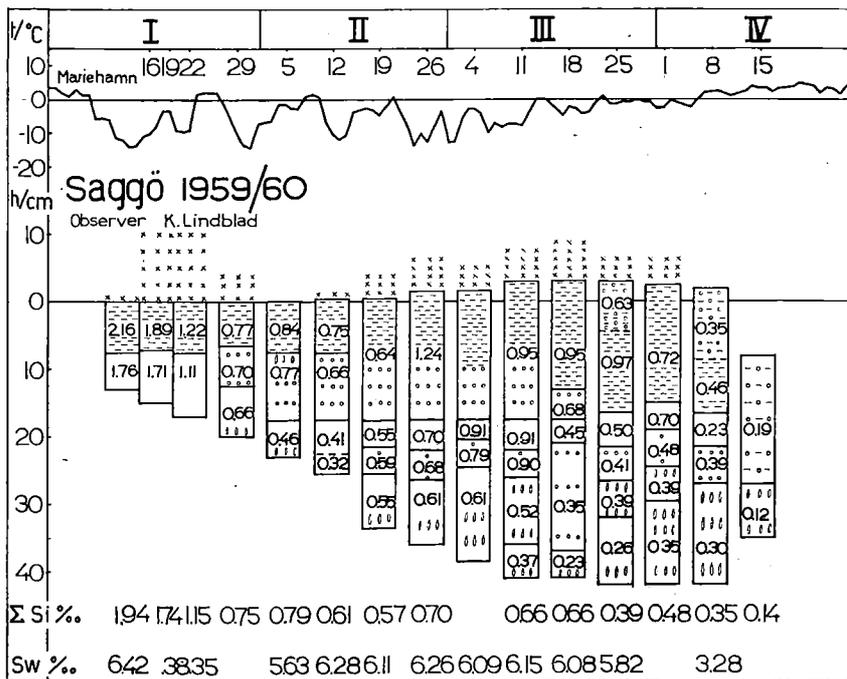
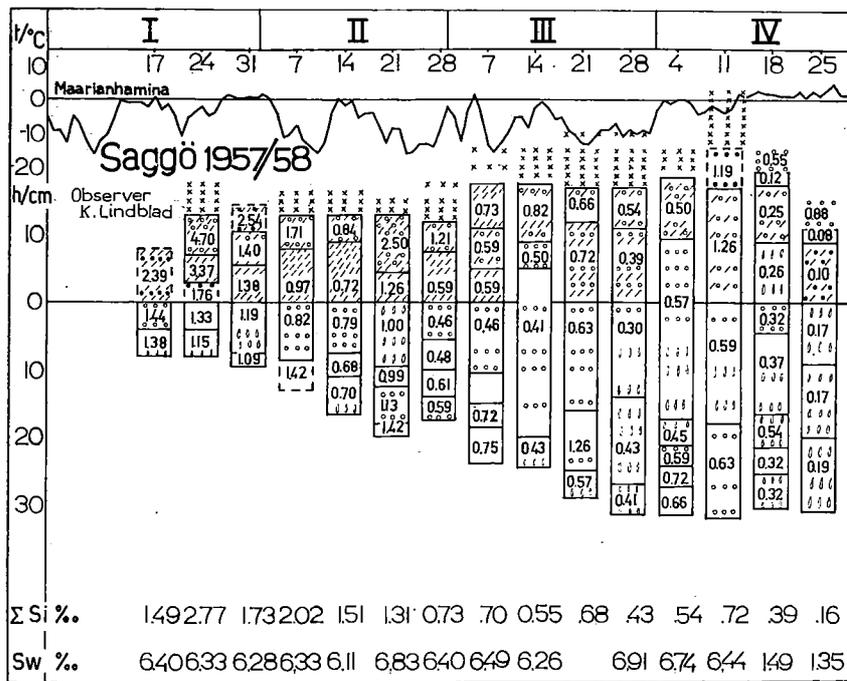


Figure 6. Time series of ice samples in the Archipelago Sea, Saggö; ice salinities, brine pockets and air bubble layers are shown. The zero-line refers to the normal sea ice-snow ice inter face (Palosuo, 1963).

3 BEPERS-88

3.1 Motivation

3.1.1 ERS-1

The C-band SAR that is to be flown on ERS-1 is an instrument of which there is very little experience in the Baltic Sea. Airborne SAR systems have been flown over arctic sea ice and even fresh water ice. BEPERS Pilot Study in 1987 is the first ground truth documented SAR experiment over brackish water sea ice, of the type that occurs in the Baltic Sea. It is now of great interest, both scientifically and as a test of its operational potential, to have an experiment including a C-band SAR carried out in the Baltic.

The Programme for International Polar Ocean Research (PIPOR) calls for international coordination in ERS-1 data taking, in-situ experiments and pilot demonstrations (PIPOR, 1985). In this proposal the Baltic Sea area has been identified as an interesting and important part of the overall programme. This is mainly due to the particular features of the area with water of varying salinity, easy access to ground truth data and heavy ship traffic. Denmark, the Federal Republic of Germany, Finland and Sweden have expressed interest in participating in the PIPOR Baltic experiments. The ERS-1 programme calls for extensive calibration and application demonstration exercises after the launch of the satellite in 1990. These exercises must be well prepared in order to give the desired results, and BEPERS-88 is therefore an important and logical undertaking also in the preparations for ERS-1, as defined in the PIPOR programme.

3.1.2 Basic research

Due to the unique ice conditions in the Baltic Sea it is necessary to develop and test algorithms for various applications of remotely sensed microwave sea ice data. In particular understanding of the interaction mechanisms between microwave backscattering and emission and low salinity, first-year ice will be furthered by BEPERS-88. Another aim is to investigate the radar backscattering from ice ridges.

The experiment will be of great value also for basic sea ice research other than remote sensing. Information about the surface topography, ice concentration, ice types, distribution and size of floes, velocities etc, obtained from the combined use of remote sensing instruments and in-situ measurements will increase our knowledge of geophysical properties and behaviour of sea ice.

3.1.3 Numerical modeling

With improved fine-mesh numerical analyses and forecast models there is also a demand for observations with a better resolution and geographical coverage. Improved data are also needed for verification of numerical models, and in this respect spatial velocity data are particularly valuable.

3.1.4 Operational Sea Ice Services

An important reason for carrying out BEPERS-88 is the requirement posed by operational sea ice and marine meteorological services on daylight and weather independent observations. The high frequency of fog and clouds in the region severely limits the possibility of observing the sea surface from today's weather satellites.

3.2 Basic outlines

3.2.1 Geographical location and area configuration

The experimental area will take the form of a long narrow swath extending from the northern part of the Sea of Bothnia through the northern Quark into the Bay of Bothnia. This area is the most interesting since it usually covers different ice types and the ice movements may be considerable. Along the swath the surface water salinity varies from 2 in the northern part to 6 ‰ in the southern. Hence, it is expected that the microscale ice structure also differs along the swath. In addition, the swath configuration facilitates the ground work and the underflight programme. Note, however, that the final decision on the exact location of the experiment area can only be taken shortly before the start of the experiment.

The swath length is planned to be 100 to 200 km depending on the ice situation and include three areas of intensive ground observations. These will be selected from the following criteria:

- a. one in thick and ridged ice, Northern Quark (Aranda),
- b. one in medium thick ice including ice movements, Sea of Bothnia (Icebreaker),
- c. one in the ice edge zone (Valdivia).

An outline of the experiment area configuration is given in fig. 7. If open water is not present in the northern part of the Sea of Bothnia, the area c. will have to be shifted to the nearest location with open water. This will in the case of a severe winter be the northern Baltic Proper.

3.2.2 Date and duration

The experiment will take place between 3 and 15 March 1988. The SAR flights are scheduled for the period 6 to 11 March. The exact schedule of BEPERS-88 will be given in the operational plan.

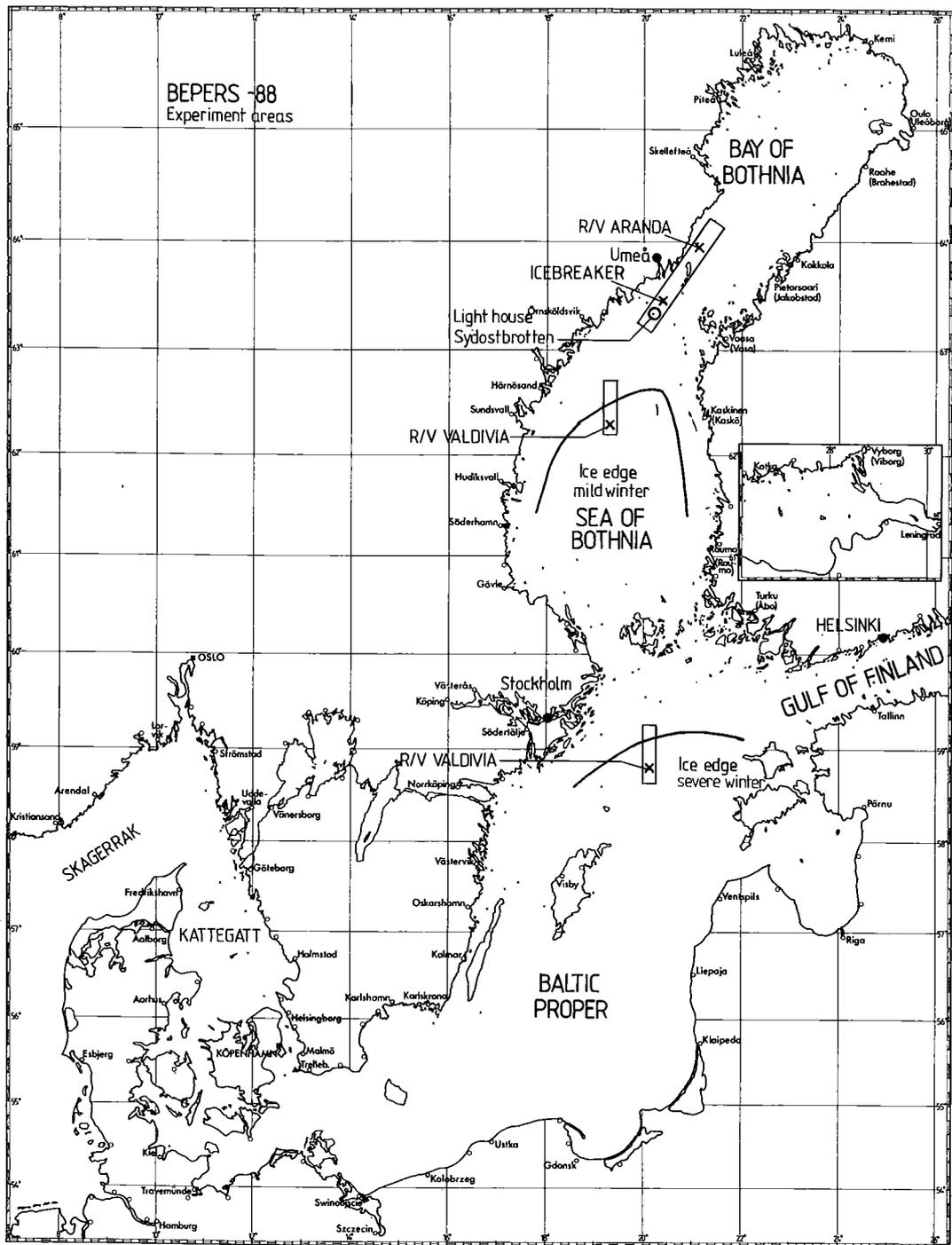


Figure 7. Configuration of the experimental area.

3.2.3 Marking and identification of experiment area

The areas of ground observations will be marked with radar reflectors as well as visual markers for identification of check points in the SAR and SLAR images and in aerial photographs, respectively. It is likely that the areas of intensive study will change shape and position during the experiment. Therefore, satellite ice buoys transmitting data via the ARGOS system will be used to follow the position of these areas. In addition, the Decca navigation system onboard the helicopters will be used for positioning purposes.

Corner reflectors will also be used for calibration and geometric rectification of the SAR images. The position of these reflectors is planned to be determined with an accuracy of ± 10 m.

3.2.4 Platforms

There will be three major activities in the experiment:

- 1 flight programme,
- 2 ground truth programme,
- 3 satellite observations.

The ground truth programme will operate from two research vessels and one ice-breaker. (Due to operational needs of the ice-breaker, it is possible that one ground truth programme has to be conducted from a shore-based station.)

The aircraft will be able to operate from airports located along the Swedish coast. The distance from the airport to the experiment area will be less than 100 km. A schedule cross-section of the experimental area is shown in fig. 8. In sections 4, 5, 6 and 7 the three major activities are described in detail.

3.2.5 Plan of organization logistics

The organization of the responsibilities of scientific planning and research is:

- * Principal Investigators (PI)
- * Co-Investigators (Co-I)
- * Investigators

The two PI's have the overall responsibility of the BEPERS-88 planning, realization and outcome. Beneath these, the four Co-I's have the scientific responsibility for the key problems. Co-ordination of the analysis and publications between different participating groups will here be important tasks. The PI's and Co-I's along with key problems are defined in section 8 and 9, respectively.

Each key problem includes a number of research groups in which a responsible Investigator is in charge. These are marked by bold letters in the various research groups defined in sections 4, 5, 6 and 7. The underlined investigator

shall take the responsibility of the planning and research of the specific measurements which different groups have in common, independently of where the measurements will be made.

During the experiment another organization will take place consisting of one Experiment Co-ordinator, taking the overall responsibility for the conduct of the experiment, and four Station Co-ordinators. A detailed description will be given in BEPERS-88 Operational plan.

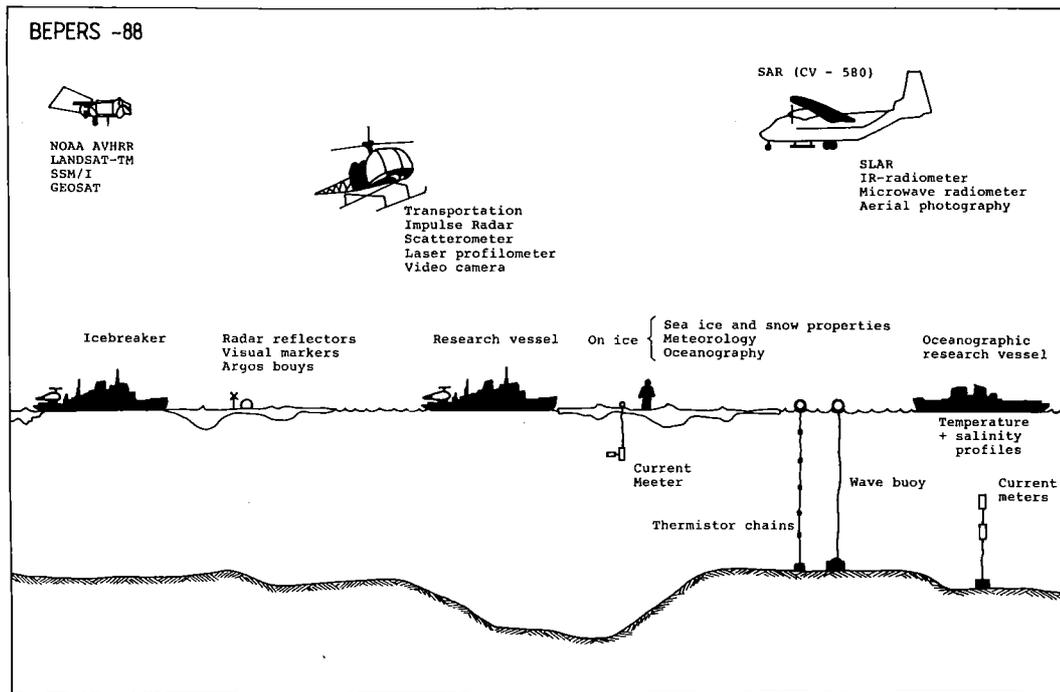


Figure 8. Facilities and observations planned for in the BEPERS-88 experiment.

4 SAR

4.1 SAR in sea ice remote sensing

The great advantage of imaging radar derives not only from its ability to observe through clouds and darkness, but also from its fine surface resolution. With this technique it may for example be possible to distinguish between leads, thick ice, and most important, ice ridges. Information of these features is of great utility for operational marine activities. However, there is a need for comprehensive research of the SAR technique applied to sea ice. In this respect the BEPERS-88 will offer a unique opportunity to obtain two-frequency, multipolarization SAR imagery at different angles of incidence with an extensive ground truth and underflight programme.

The ways in which microwaves interact with ice masses can be rather complex. For instance, sea ice is not pure ice, in that it contains entrapped sea salt in the form of both included brine and solid salt crystals. The exact amount of salt depends on the rate at which the ice grew, its age, and particularly its thermal history. If the surface is flat, as in the case of undeformed first-year ice, the radar return will be low. If the surface is rough, as in the case of new pressure ridges, a strong return will occur.

In the Baltic the ice salinity is low, therefore the electromagnetic energy penetrates into the ice where it undergoes volume scattering, that is, it is scattered by the inhomogeneities (air bubbles, cracks, brine drainage tubes) within the ice layer. In the Gulf of Bothnia the ice salinity is so low that the radiation penetrates deeply into the ice. The strength of the return maybe a complex function of the roughness of both the upper and the lower surfaces of the ice, as well as of the volume scattering within the ice.

Snow layers on the ice which are thin, chemically pure, and of a low density, usually give a very low return and, as a result, are nearly invisible at longer wavelengths (e.g. at L-band). However, if the snow-cover is thick or wet or has densified as the result of freezethaw processes and, particularly if the included air bubbles are of appropriate size to serve as effective volume scatters, moderate returns can result. Therefore, the radar return from snow may vary from strongt very weak. One result of the BEPERS-88 experiment should be a better understanding of these variations.

A prime application of multifrequency data is to determine the relative size of the volume scatterers. If the subsurface scatterers are small compared to the wavelength, Rayleigh scattering occurs and the absolute return varies as the wavelength to the fourth power.

An important application of SAR imagery is to detect ice ridges. These show up on radar images, but little has been done to develop, either comprehensive experimental data or theories for ridge scattering. This will be one of the main subjects of BEPERS-88.

4.2 BEPERS-88 SAR

The Canada Centre for Remote Sensing (CCRS) has developed a high resolution C-band synthetic aperture radar. The instrument is carried by CCRS's Con-
vair-580 aircraft.

The C-band system is a digitally controlled, two-channel radar, transmitting either horizontal or vertical polarizations and receiving both (only in half swath mode). The radar covers three swath widths, of which the nadir mode and the narrow swath range from 0° to 82° and 45° to 82°, respectively. Both swaths have a resolution of 6 x 6 m². The wide swath with a resolution of (20 x 10 m²) range from 45° to 87° of incidence.

The characteristics of the C-band SAR is given by Livingstone et al. (1987). Here follows a short summary of these:

*	Frequency	5.30 GHz
*	Wavelength	5.6 cm

REAL-TIME PROCESSING

- * 1-7 looks processed for one channel,
- * slant or ground range presentation,
- * 8-bit detected signal per pixel.

	Narrow swath	Wide swath
Azimuth resolution	6 m	10 m
Range resolution	6 m	20 m

At C-band the display and recording systems in the CV 580 aircraft are as follows:

DISPLAY SYSTEMS

HARDCOPY

dry silver
2048 pixels/line
full header annotation

time & position blocks
16 grey levels
full or half narrow swath

full, 1/2, or 1/4 wide swath

several display LUT's

Edo Western

VIDEO DISPLAY

CRT monitor
512 pixels/line
full header annotation

time & position blocks
255 grey levels
zoom to 2/1, 1/1, 1/2,
1/4 or 1/8
histogram display of
full and/or zoom
linear stretch or
histogram equalization
Knudsen Engineering

RECORDING SYSTEMS

SIGNAL	IMAGE	VIDEO
14-track HDDT all tracks used variable speed	14-track HDDT 5 tracks 30 ips	video cassette
PCM coding 4096 range cells time and Nav tagged	PCM coding time tagged time tagged	NTSC format 512 range cells time tagged
range compressed 8-bits I and Q Bell and Howell	fully compressed 8-bits amplitude Bell and Howell	fully compressed

In-flight outputs of SAR images can be obtained on dry silver paper as well as on a video cassette. The ground outputs include reproduction of the real-time SAR processor data on a high quality photographic media or transcription to computer compatible tape (CCT). Also more densely sampled data including sensor parameters on CCT can be made available for further analysis and track recovery. Beside these items there is also the image HDDT (high density digital tape) at both full and half resolution.

References about format specifications and further details of the image outputs are given in Livingstone et.al. (1987).

The CCRS radar system meets the requirements of BEPERS-88 to produce C-band SAR image data similar to ERS-1. This includes the possibility to obtain the ERS-1 incidence angle of 23. It should also be mentioned that an X-band SAR (9.25 GHz, 3.1 cm) has been completed for installation into the aircraft during the summer of 1987. This makes it possible to obtain simultaneous image data at C- and X- band.

The SAR flight programme must meet the scientific requirements as well as be coordinated with other data measurements. This co-ordination will be one of the main objectives of the BEPERS-88 Operational Plan. The SAR data will be of interest for almost all participants in the experiment.

Research group: Askne, Livingstone, Ottersten.

4.3 Electromagnetic scattering from level ice and ice ridges

In order to interpret radar images it is important to understand and model the backscattering from the ice ridges as well as from the level ice. The latter is fairly well-known (Ulaby et al. 1982) though the application to the Baltic Sea with its rather low salinity has not been done until recently (Johansson and Askne 1987). It is stated that the penetration depth might be large, meaning that the underlying water surface will contribute to the scattering. The scattering from

ice ridges is not that well understood but an attempt to model the backscattering from ice ridges was also included in the paper by Johansson and Askne (1987).

The model includes two different scattering components, one being a specular component due to ice blocks with zero incidence angle and the other being an integrated mean value obtained from the distributed ice blocks. The model does not include either snow, multiple scattering or shadowing.

In order to evaluate the backscatter models against measurements it is of vital importance that the radar is calibrated. We also need an extensive ground truth program to measure all the parameters needed in the models. Since snow, presently not included in the models, might affect the scattering significantly it is important to measure the snow parameters as well.

Parameters for level ice and ice ridges:

- * surface height standard deviation
- * correlation length
- * ice salinity
- * ice density
- * ice thickness
- * ice temperature
- * dielectric constant of the ice
- * size of air bubbles and brine inclusions

Additional parameters for ice ridges:

- * slope angle of the triangular geometry
- * standard deviation of the normally distributed ice blocks
- * area of the ice ridge
- * area of specularly oriented ice blocks

Parameters for snow:

- * surface height standard deviation
- * correlation length
- * snow density
- * liquid water content
- * snow thickness
- * snow temperature
- * dielectric constant of snow
- * distribution and size of snow grains

Research group: Askne, Johansson, Manninen

4.4 **Marking and calibration of SAR images**

A set of corner reflectors will be deployed during the field experiment at the test sites. The objectives are:

- * to provide marking in the SAR images to enable rectification,
- * to perform absolute calibration of the SAR images relating the image pixel intensity to the back-scattering coefficient.

For these purposes two types of reflectors will be used. Large trihedral reflectors with a square base (1 m base side, see fig. 9 a) will be used as markers in the SAR image, while trihedral reflectors (fig. 9 b) of 5 different sizes (in steps of 5 dB) will be used for calibration. The sizes of the latter will be chosen to span the range from the low-level signal to system saturation. A likely configuration during the field experiment is shown in fig. 9 c. Note, that the reflectors should be deployed so that reflection contributions from the reflector or the ice will be avoided. The RCS (Radar Cross Section) of the reflectors used for calibration will be measured in the laboratory and a mechanism to adjust the pointing angle in the field will be available. The possibility of acquiring an ARC (Active Radar Calibrator) with adjustable gain as a complement to the reflectors is also being investigated.

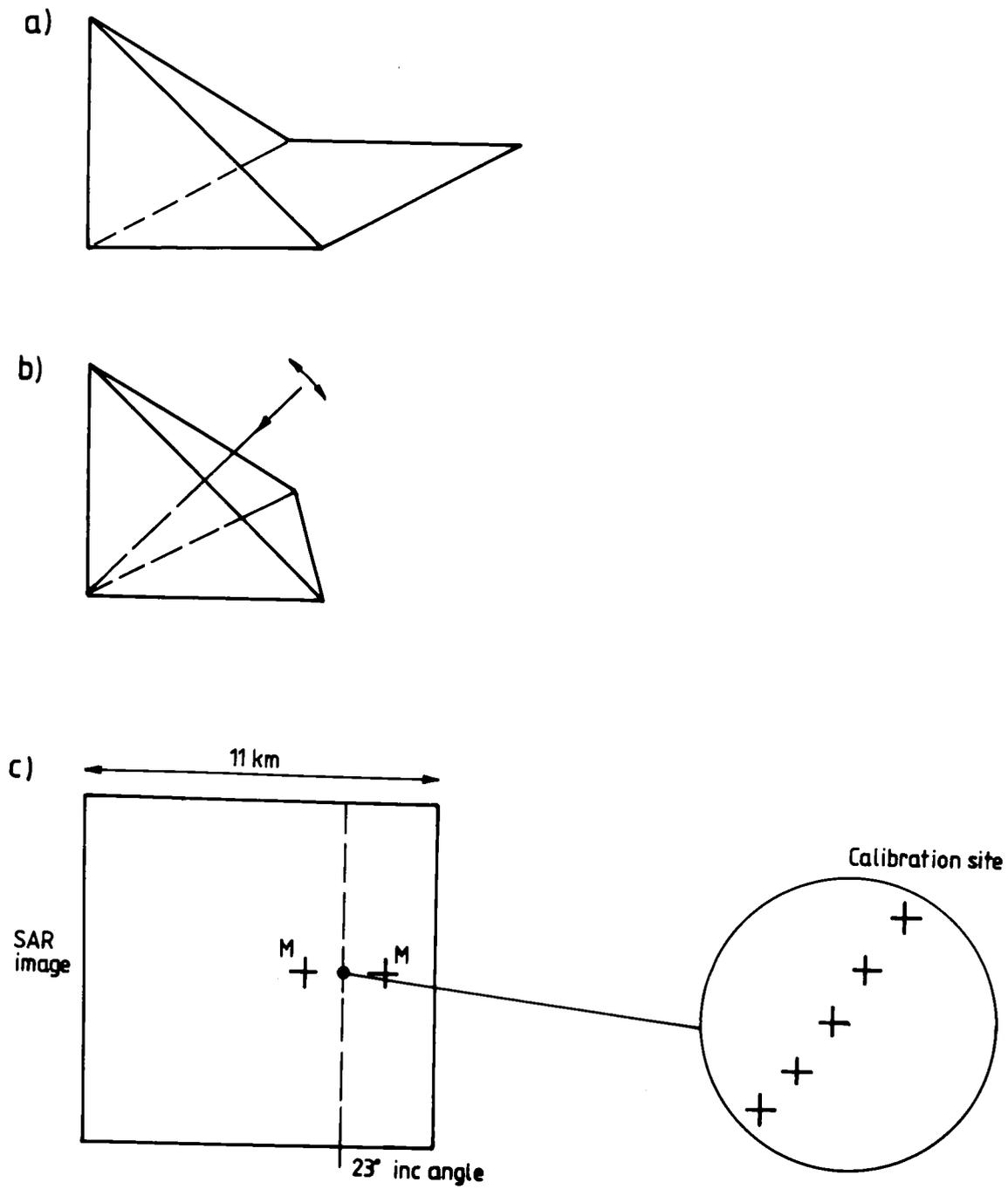


Figure 9. a) Trihedral reflector with square base.

b) Trihedral reflector with adjustable pointing.

c) Configuration of the calibration experiment. Reflectors are depicted by plus signs. An M indicates that the reflector will be used for marking.

The calibration experiment will take place at a location corresponding to an incidence angle around 23° – the same as for the ERS-1 Active Microwave Instrument in the image mode. When selecting a suitable configuration for the calibration experiment several considerations should be made:

- * The site should be selected to maximize the signal to-background ratio, S/C. This implies choosing an area of **low** σ^0 , i.e. of smooth, level ice.
- * The site should be selected in order to avoid multiple reflection into the reflectors. This will normally not be a problem on the ice except in the neighbourhood of ridges.
- * The reflectors used for calibration should be placed to minimize the influence from nearby reflectors saturating the SAR receiver. This implies that adequate spacing in azimuth and range should be provided corresponding to more than the real aperture extent in azimuth and more than the transmitted chirp pulse length in range. Alternatively, they may be placed with an **offset in range and azimuth** relative to each other as depicted in figure 9 c.

We may calculate the backscatter coefficient of an unknown area-distributed target, by assuming that the SAR system is in its linear region. To enable calibration according to the outlined strategy several parameters have to be measured before or during the experiment. These parameters are summarized in table 1.

Table 1. Parameters to be measured for the calibration experiment

	Before experiment	During experiment
Reflectors	Radar Cross Section	Location Pointing angles
SAR system	Antenna gain pattern Receiver transfer function SAR Processor parameters	Calibration signals Radiated power Antenna depression angle Aircraft roll angle Navigational parameters

Research group: Brusmark, Kuittinen, Ulander

5 SUPPORTING AIRBORNE OBSERVATIONS

5.1 Photography

Aerial photography is important as a basis for localization and comparison of in-situ and image sensor data. Furthermore, it is a complement to the ground truth programme in general. Information on snow-cover and the frequency of ridges and openings are obtained. The positions of the radar reflectors and the ground measurements will be identified from visual markers on the ice. Direct comparison with SAR data for identification and verification of various ice features will thus be possible.

Stereo photography covering a limited area of intensive studies will give quantitative information on the sea ice roughness. The vertical resolution is 0.15 to 0.20 m during good weather conditions. These data will be of value when SAR images are analyzed, since the ice ridge profile as well as the ridge orientation with respect to the flight direction may influence the SAR backscatter response. The Land Survey of Sweden will be responsible for the aerial photography and the production of stereo products. High quality (Zeiss) mapping cameras will be used.

Research group: Håkansson, Thompson

5.2 Laser profilometer

Laser profilometer is the best available instrument to measure the roughness of the ice surface on the scale of ice ridges. These have heights of the order of 0.3 to 3.0 meters a width of several meters and a spatial separation of the order of ten to hundreds of meters. The laser profilometer is used from a helicopter providing a continuous profile along the flight path. At the same time the profiled ice surface is mapped with a high speed video camera.

Prof. John Lewis will be responsible for the laser profilometer measurements. He will be based aboard Aranda, but will also be profiling the test area organized from the icebreaker. The estimated flying time is 10–15 hours.

Research group: Leppäranta, Lewis

5.3 Scatterometer and Polarimeter

The scatterometer is an important sensor for the experiment as it can support the SAR information with calibrated data. The scatterometer measures the backscattering coefficient of sea ice at different polarizations (HH, HV, VH and VV). Helsinki University of Technology will fly a helicopterborne scatterometer that operates at 5.3 and 10 GHz. The incidence angle is 23. The University of Bremen will operate a C-band scatterometer from a helicopter.

The polarimeter is a new type of radar instrument that measures the scattering matrix of the target. Using the scattering matrix, the backscattering properties of the target can be synthesized for any other polarization. The Helsinki University of Technology is constructing an airborne 35-GHz polarimeter that will be used in the experiment. The scatterometers and the polarimeter will be operated from Aranda and the Swedish icebreaker, and the flying time is approximately 15 hours.

Research group: Askne, Hallikainen, Hyyppä, Toikka, Wismann

5.4 Airborne microwave radiometer

The radiometer measures the brightness temperature (emission coefficient) of sea ice. The Swedish Coast Guard will carry a 35 GHz scanning radiometer which covers a relatively narrow swath with an angle of incidence of 25°. This radiometer is used for determining various ice types with in-situ data for calibration. The Helsinki University of Technology will use a helicopterborne multi-frequency radiometer. The estimated flying time is 2 + 5 hours (from airport and Aranda).

Research group: Askne, Hallikainen, Hyyppä, Toikka

5.5 SLAR (Side Looking Airborne Radar)

The SLAR will provide the only airborne image-data which are weather independent. From this point of view it is considered to be a complement to aerial photography, airborne scatterometer measurements and satellite images in SAR image verification. It will further be used for planning and logistics. The Swedish Coast Guard will fly its SLAR working in the X-band.

Research group: Håkansson, Johansson, Kuittinen, Ulander

5.6 IR-scanner

The IR-scanner measures the surface brightness temperature field. Knowing the emissivity of snow and ice it will be possible to get information about the variability of surface temperature. This remote sensing technique will be used together with ground truth point measurements of temperature to obtain an areal mapping of the surface temperature. In the areas of intensive study IR-scanner data can also be related to surface features and ice thickness. The Swedish Coast Guard will use their IR-scanner.

Research group: Håkansson, Kuittinen, Leppäranta

5.7 Impulse radar

The impulse radar is an instrument transmitting 2 ns long bursts of electromagnetic energy with a center frequency of 500 MHz and a 60 % bandwidth. The antenna has a wide beam pattern, with the boresight direction pointing straight down from the helicopter. This guarantees that there is always a good return from the ice surface irrespective of the helicopter attitude.

The E-field polarization of the transmitted impulse is perpendicular to the direction of flight. The reflected energy is received with a parallel and a perpendicular polarization relative to the transmitted E-field.

A CCD video camera is pointed in the boresight direction. The camera is connected to a UMATIC VCR with dual audio channels, in which the radar signals are stored.

The radar provides high resolution profiles indicating the aircraft altitude, snow thickness if any, ice thickness and the σ^0 -value of the snow/ice surface. One point per frame of the video signal is digitized, which makes it possible to separate open water, bare ice and snow covered ice. The spatial properties of the ice cover can be determined from the video ground track. The analysis is computerized and fully automatic. The obtained electromagnetic and optical information is used to evaluate the simultaneous SAR data.

The capability of the radar signal to penetrate the snow and ice layers depends on their liquid water content.

Meltwater standing on the ice will block the electromagnetic energy.

The impulse radar belongs to the Technical University of Lund and will be flown on an helicopter based on the nearest land base.

Research group: Ulriksen

6 GROUND OBSERVATIONS

6.1 General

Ground data are necessary for the correct interpretation of the remote sensing data and products. In designing and performing the ground programme the following three factors must be considered thoroughly:

- * Ground measurements are necessarily point measurements whereas remote sensing instruments see a spatial average over the pixel size. Even in the scale of a SAR pixel size (eg. 6×6 m) there may be considerable variations in the properties of ice and snow. Therefore two kinds of ground observation will be made.
 - a) Conventional point measurements at a large number of selected (relatively) homogeneous patches (areas smaller than 1 square km).
 - b) Spatial series to provide the variance structure of various ice and snow properties. These spatial series will in most cases be one-dimensional.
- * The locations of ground data points must be identifiable in the remote sensing registrations. For aerial photography these markers will be large (3×5 m) orange-colored plastic tar paulins. When possible, geometrical traces will be made in the snow as markers. Reflectors will be used for identification in SAR and SLAR images. For the thermal infrared remote sensing no special markers have been planned. It should, however, be possible to overlay thermal images with aerial photographs since the surface temperature appear to follow many features of surface topography.
- * The timing of the point observations versus the remote sensing measurements will necessarily deviate somewhat. The main reason is the fact that ground observations take a lot of time and must go on through the whole period of the experiment. Hence time-series measurements at some fixed locations will also be needed. The most sensitive parameters are here the temperature and snow properties.

Ground observations will be made at three bases: R/V Aranda (A), an icebreaker (IB) and R/V Valdivia (V). Aranda will be the main ground data base where as many different types of ground observations as possible will be made. With due consideration to the need of covering as many different types of ice as possible attempts will be made to locate A and IB close enough to each other so that exchange of research groups and equipment can take place. For this, helicopters on both ships will be used. It will not be possible to land a helicopter on Valdivia but as she will be operating in the neighbourhood of the ice edge during the experiment it may be possible to exchange people by landing on the ice.

6.2 Marking

For the evaluation of remote sensing products careful marking on the ice is necessary in order to

- a) transform images to correct geometry and
- b) locate ground data points.

The markers will consist of a radar reflector and visual markers.

For the purpose of correcting the remote sensing images to an earth coordinate system it is intended to place 5 – 8 radar reflectors on geographically fixed locations on islands and fast ice. The geographic coordinates of these markers are obtained from the Land Survey of Sweden or the GPS.

To identify the ground data spots in the radar images and in the aerial photographs these will be marked with radar reflectors as well as tarpaulins and other visual markings. Most of these points will be located in the drift ice area, and their coordinates are determined by the Decca system of the helicopters. The accuracy of the Decca system is of the order of tens of meters when calibrated with a nearby light-house.

Marking of the ice edge study area is difficult. This region may rapidly change its location and form and at the present stage of planning we can only say that the location could be anywhere from Gotland to the central Sea of Bothnia.

The radar reflectors will be corner reflectors of the trihedral type. They will be designed by CUT and produced by NDRI in Sweden and VTT in Finland. It is estimated that 25 – 30 reflectors will be required. Of these, 7 will be used at (A) and the (IB) each for marking ground truth areas and 2 will be used by (V) for marking at the ice edge. 5 to 8 reflectors will be placed at fixed geographical locations for geometric corrections of SAR images and 2 will be used for marking at the calibration site.

Research group: Brusmark, Rauste, Ulander

6.3 Microscale ice and snow observations

Microscale observations are made in the vicinity of the bases and in the drift ice field at selected homogeneous patches using helicopters. The statistical properties study, which is a part of the microscale programme, is intended to be carried through in the vicinity of the bases using a snow mobile for transportation or if necessary the helicopter.

- a) Ice structure

Ice samples will be taken of various types of ice with core drills and saws. These samples will be used for crystal structure analyses, studies of the geometry of air bubbles and brine pockets, and measurements of salinity.

Aranda Equipment for the studies in the field and freezer room for storing.

Research group: Gow, Kosloff, **Leppäranta**, Manninen, Palosuo, Weeks

Icebreaker Equipment for the above mentioned studies as well as ice mechanics. Freezer room is available for storing.

Research group: Fransson, Håkansson, Omstedt, Sahlberg, Åström

Valdivia Crystal structure samples are stored in a freezer and salinity samples are bottled.

Research group: Hillgren, Söderman, Vainio

b) Snow structure

The relevant structural properties of snow are in this experiment, density, grain size and free water content. The density is measured with a simple mass and volume measurement system and the grain size is studied in field photographs. The density can also be calculated from electric conductivity measurements. The most critical snow cover property to microwave remote sensing is the free water content. It can be measured directly with a calorimetric method or indirectly from electric conductivity.

Aranda Equipment for the field work.

Research group: Manninen, **Palosuo**, Toikka

Icebreaker Equipment for the field work. Including a dielectric probe for measurements of the free water content in the snow.

Research group: Asmus, Burnes, Garrity

Valdivia Equipment for the field work.

Research group: Pihkala

c) Ice and snow temperature

Ice and snow temperature measurements are needed for the thermal remote sensing studies and for estimating the brine volume within the ice. Field measurements are made instantaneously when sampling, and temperature time series are also measured at fixed locations.

Aranda Contact thermometer. Temperature series at one location.

Research group: Manninen, Rapo

Icebreaker Probe thermometer.

Research group: Burnes, Håkansson, Omstedt, Sahlberg

Valdivia Contact thermometer.

Research group: Vainio

d) Small scale roughness of ice surface

Roughness features of the scale from a few millimeters to several centimeters are studied with simple visual and photographic methods. Bare ice is easy to work with. For snow-covered ice, if there is notable adhesion at the snow-ice interface, sections must be sawn out. Work is also in progress to obtain a digital profiling equipment for roughness measurements.

Aranda **Research group:** Johansson, Kemppainen, Manninen, Ulander

Icebreaker **Research group:** Burns, Thompson

Valdivia None

e) Ice ridges

Ice ridges give a strong backscatter to SAR. The strength depends on the size, geometrical profile, orientation and the detailed structure of the sail of the ridge. The geometry is studied with a leveling instrument. The internal structure, the size and orientation of the ice blocks, porosity and snow cover will also be investigated. Sections are sawn through sails to make these observations. The area where these measurements take place will be stereo photographed. Work is also in progress for the construction of a digital profiling equipment which should give a detailed profile of a ridge.

Aranda **Research group:** Johansson, Kankaanpää, Kemppainen, Leppäranta, Rapo, Ulander

Icebreaker **Research group:** Brusmark, Håkansson, Larsson, Moberg

Valdivia Visual observation and profiling

Research group: Hillgren, Vainio

f) Dielectric properties of ice and snow

Dielectric systems are available to measure the complex dielectric constant of sea ice at 10 GHz, 6 GHz and 100 MHz. In case of warm weather (above -5 C) a freezer is needed at the base. Other physical parameters will also be used to estimate the dielectric properties.

Aranda Equipment for the measurements.

Research group: Ahola, Johansson, Tares

Icebreaker Dielectric constant measurement.

Research group: Asmus, Burnes, Garrity

Valdivia No work.

g) Radar backscattering

A 5.3 GHz scatterometer will be used by the Helsinki University of Technology research group to measure the backscattering behavior of sea ice near R/V Aranda. The scatterometer will be installed on a non-moving platform, 10 to 15 meters above the sea ice. Measurements will be made as a function of incidence angle at four polarizations (HH, VV, HV, VH). The ground truth includes the physical and dielectric properties of snow and ice.

Research group: Hallikainen, Hyyppä, Toikka

h) Radiometric measurements

The Helsinki University of Technology research group will complement the ground-based scatterometer measurements with microwave radiometer measurements using the same platform (see above).

Research group: Hallikainen, Hyyppä, Toikka

i) Ice thickness soundings

An FM-CW radar (frequency 1–2 GHz) is used to measure the ice thickness profile. The radar is moved on a sledge with a snow-mobile during the measurements.

Aranda **Research group:** Hallikainen, Hyyppä, Toikka

6.4 Mesoscale ice and snow observations

The purpose of the mesoscale programme is to produce detailed ice charts over the SAR imaging areas. Observations are made visually from ships and helicopters completed with a few simple ground measurements on the ice. Additional data to the mesoscale programme is provided by the routine ice information services of Finland and Sweden. Furthermore, mesoscale sea ice kinematics are measured.

a) Ice mapping

Ice mapping products describe ice type, ice and snow thickness and the amount of ridged ice. The observations are basically made visually during helicopter reconnaissance flights or, at Valdivia, from the moving ship. Ice and snow thickness will be measured occasionally. The size of ice ridges can also be estimated when landing, whereas the frequency of ridges is best seen from the air.

Aranda **Research group:** Kemppainen, Leppäranta, Stringer

Icebreaker **Research group:** Andersson, Moberg, Thompson

Valdivia **Research group:** Lensu, Stössel, Vainio, Finnish Ice Service
(aerial reconnaissance)

b) Ice kinematics

Aranda will be moored to fast ice, while the icebreaker will be moored to a floe in the drift ice and will thus be moving with the ice. The position of the icebreaker will be registered by the Decca system every quarter of an hour. Radar reflectors will be placed on the ice around the ship at distances of 2 – 5 nautical miles. Direction and distance to the reflectors will be registered by the ship's radar every half hour. In the Northern Quark the large-scale motion of the ice will be measured with 3–5 Argos buoys which provide data at about every 1 1/2 hours. In addition, movement of the markers in the ice is followed with the Decca system of the helicopters. Valdivia will register the location of the ice edge.

Aranda **Research group:** Leppäranta.

Icebreaker **Research group:** Andersson, Moberg, Thompson

Valdivia **Research group:** Stössel

6.5 Oceanographic observations

The oceanographic programme is mainly concentrated to the ice edge region and carried through by the Valdivia group. The temperature and salinity of water, current velocity and wave spectrum are measured.

a) Temperature and salinity of water

A CTD sonde and a (Batfish) Dolphin will be used for basic cross-sectional profiling. A thermistor chain will be anchored approximately 10 km from the ice edge. In addition a shipborne thermistor chain will be used to measure the very surface temperature profile (0–3 m).

Icebreaker A limited number of salinity and temperature soundings will be made.

Research group: Håkansson, Moberg

Valdivia **Research group:** Becker, Hillgren, Strübing

b) Current measurements

Current velocity is measured at 1–2 locations 20 to 30 km outside the ice edge.

Valdivia **Research group:** Becker, Hillgren, Lensu

c) Waves

One wave buoy will be used from the ship to measure the spatial variability of the wave spectrum. A second buoy will either be moored close to the ice edge, or deployed on an ice flow inside the ice edge.

Valdivia **Research group:** Hillgren, Söderman, Vainio

6.6 Meteorological observations

Each base has a standard meteorological station which is used for observations at synoptic hours (UTC 00, 03 etc.). Additional measurements are made of temperature, humidity and wind velocity in the surface boundary layer and of the radiation balance at the surface.

Aranda Three-level mast and radiation sensors for continuous measurements. One meteorologist for cloud observations.

Research group: Holmlund, Rapo

Icebreaker Onboard equipment.

Research group: Andersson, Thompson

Valdivia **Research group:** Becker.

Coastal stations Equipment for standard meteorological measurements.
(S + SF)

Research group: Andersson, Holm lund, Thompson

7 SATELLITE OBSERVATIONS

7.1 NOAA AVHRR

Receiving stations of AVHRR (Advanced Very High Resolution Radiometer) with adequate facilities for real time processing exist both at the Meteorological Institute in Helsinki, Finland and at SMHI in Norrköping, Sweden. The resolution of AVHRR is 1.1 km with 5 spectral channels. Multispectral images may be used for the large scale ice synoptics and the mapping of cloud cover over the BEPERS-88 experimental areas. The two IR-channels of AVHRR can be used for surface temperature mapping. Those measurements may, during cold weather conditions, give relative information about ice thickness. Several satellite passages per day will be received, real-time processed and stored for post processing.

Research group: Moberg, Stringer, Strübing, Thompson

7.2 LANDSAT-TM/SPOT

LANDSAT-TM and SPOT data are received operationally in Kiruna and available in delayed time. SPOT is equipped with a flexible viewing angle of its two imaging instruments. The satellite can be programmed to cover the experiment area nearly every day if required. The resolution of SPOT is 20 m in the multispectral mode (3 visible spectral channels) and 10 m in the panchromatic mode. LANDSAT-TM has 6 visible and near infra-red spectral channels and one thermal infrared. The resolution is 30 m in the visible and near infra-red channels, and 120 m in the thermal infra-red.

Both LANDSAT-TM and SPOT are considered to be an important complement to aerial photography for SAR verification, but due to the greater number of spectral channels and the relatively small difference in spatial resolution (30 versus 20 m) LANDSAT-TM will be given highest priority.

Research group: Cronström, Holmlund, Håkansson, Kemppanien, Kuttinen, Moberg, Stringer, Strübing

7.3 Special Sensor Microwave Imager (SSM/I)

These data will be available from the Canadian Atmospheric Environment Service, Centre for Research in Experimental Space Science, York University. SSM/I data in processed form will be provided in near real time (less than 4 hours) delivered directly to DHI and further to SMHI on a daily basis during BEPERS-88. SSM/I data will be used in the large scale mapping and for the validation of sea ice algorithms for brackish water areas.

Research group: Asmus, Askne, Griffith, Hallikainen, Håkansson, Ramseier, Rubenstein, Strübing.

7.4 GEOSAT Altimeter

The GEOSAT altimeter delivers data (see Fig. 10) very similar to ERS-1. Therefore GEOSAT data sets simultaneous with the airborne SAR flights will be obtained. SAR, underflight and ground truth data will be used for evaluating the capability of the altimeter to map sea ice features, especially ice type, concentration and roughness.

Research group: McIntyre, Rapley, Ulander

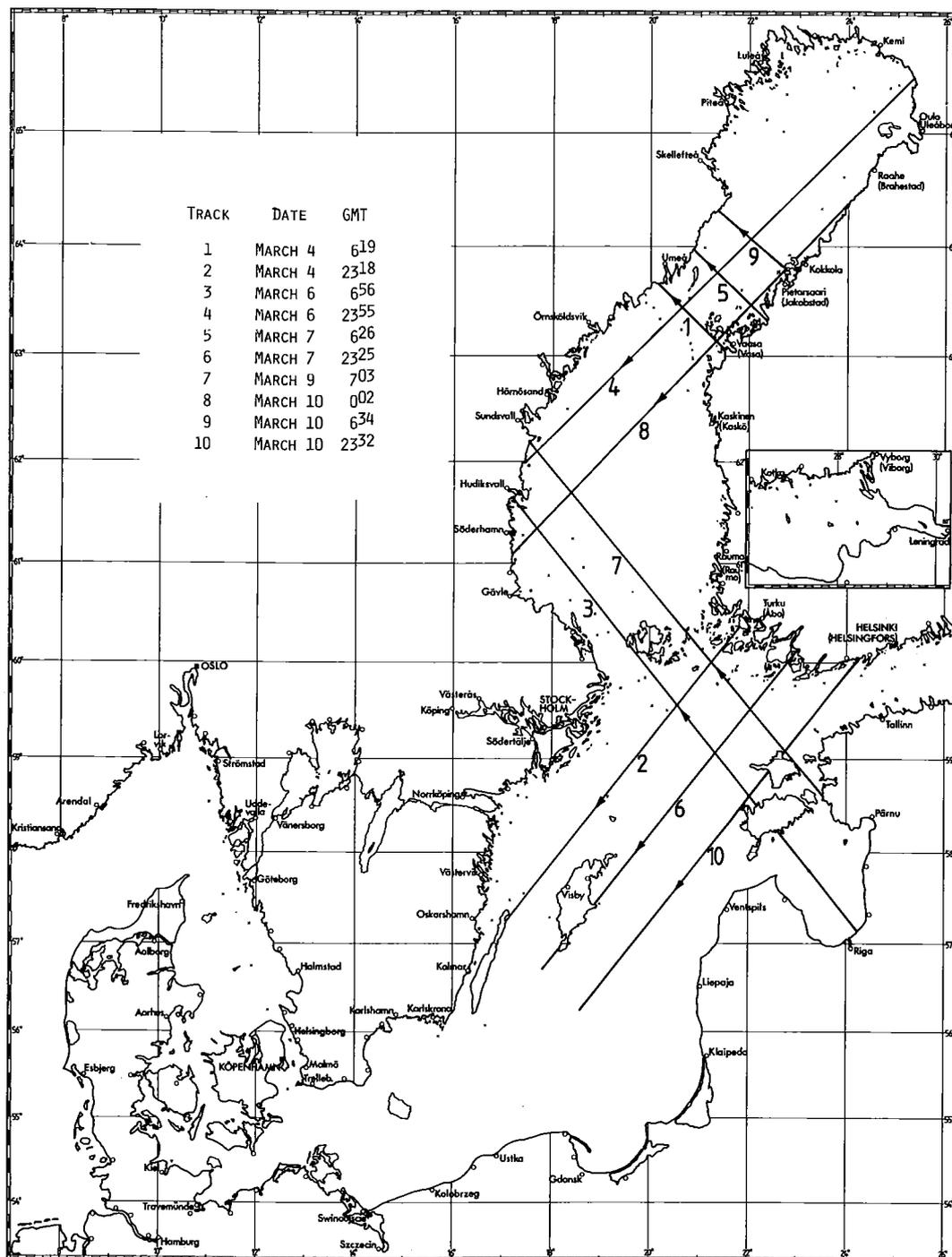


Figure 10. Extrapolated GEOSAT altimeter ground tracks during BEPERS-88

8 STRATEGY

8.1 Experiment management and coordination

LeadERS which is the group responsible for the ERS-1 preparations in Sweden has together with the corresponding body in Finland established a small group of 3 persons to be responsible for the planning and coordination of the experiment. The major tasks of the group are:

- a. preparation of the experiment plan,
- b. contacts and negotiations with participants on a national/international as well as an individual level,
- c. preparation of the final operational plan and logistics,
- d. coordination of the execution of the experiment from field bases,
- e. reporting of the success of the experiment.

The planning and coordination group is composed as follows:

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8.2 Time schedule

- | | | |
|----|-------------------|--|
| a. | 15 September 1986 | First edition of the BEPERS-88 experimental plan distributed to potential participants and to ESA, |
| b. | 15 December 1987 | Final edition of the BEPERS-88 experimental plan and, First edition of operational plan, |
| c. | 15 January 1988 | Final decision on experiment dates, |
| d. | 3-4 February | General meeting on the BEPERS 1988 field programme in Stockholm, |
| e. | 15 February 1988 | Final decision on exact geographical location, |
| f. | | 3-15 |
| | March 1988 | Duration of the experiment, |
| g. | 6-11 March 1988 | SAR flights. |

8.3 Choice of area

The experiment area will be located in the Northern Quark. It will reach north into the Bay of Bothnia and south into the Sea of Bothnia. The more exact position will be decided upon two to three weeks prior the start of the experiment. The areas of intensive ground measurements will be selected one to two weeks before the start. The final adjustment of the area will be made immediately before the start of the experiment.

8.4 Field coordination

One week prior to the start of the experiment, field bases will be established, most likely onboard the Finnish R/V Aranda, a Swedish icebreaker (caisson lighthouse base as a back-up) the R/V Valdivia from Federal Republic of Germany and at the operational center of the Swedish Coast Guard in Umeå. It will be possible to postpone the start of the experiment for a few days, in case of bad weather. The main part of the experiment will, however, have to be carried through while the SAR aircraft is available.

8.5 Operational plan

A separate BEPERS-88 operational plan will be issued in December 1987. It will include:

- * detailed experiment schedule,
- * experiment area coordinates,
- * flight plans,
- * ground activity plans,
- * aircraft, vessels, bases – field addresses etc,
- * list of participants,
- * accomodation; vessels and other bases,
- * communications.

Updates of the operational plan will be issued as required and mailed to all participants.

8.6 Communications

From 1 January a bulletin board will be opened on Telemail (OMNET). The name, will be "BEPERS. NEWS". The bulletin board will be used for posting general information on BEPERS-88 planning of interest for most participants. For those not having access to Telemail, information will be sent by telex. During the experiment the ships and aircraft normal communication facilities will be used.

9 DATA POLICY AND SCIENTIFIC WORK

The principle is that all data collected throughout the experiment will be available to the participants as required, and at the nominal cost of the data media. However, priority is given to those groups who have planned and made the measurements. In cases when the analysis involves SAR data the work should be coordinated by the respective Co-Investigator.

The release of SAR-data to third party will have to wait until BEPERS-88 participating groups have performed their own analysis. The release of SAR-data should further be based on scientific cooperation.

Each participant should analyze his or her data and is free to publish the results. This should however be made in consultation with the Co-Investigator of the object, and the report should reflect the fact that it is a result of the BEPERS-88 experiment. If other BEPERS-88 data are used, reference ought to be made to the appropriate research group(s).

A list of data holdings shall be prepared by each participant and sent to the Swedish Space Corporation right after the experiment. A complete data catalogue will then be edited by Olov Fäst and Eva Cronström and distributed by SSC.

There are three steps in the publication of the results from the BEPERS-88 experiment:

1. A short and fast presentation of the aim and outcome of the experiment. This presentation should be given the PI's (Thomas Thompson and Matti Leppäranta) and published in newsletter form in an international publication.
2. A preliminary research report published in the series of the Winter Navigation Research Board. This should give an overview of BEPERS-88 experiment and include results from various research fields prepared by the research groups.
3. A summary report should be published by the Principal- and Co-Investigators before the end of 1989. The report should be published in a well-known international journal and include an analysis of the usefulness of SAR for mapping brackish water sea ice of the type that occurs in the Baltic Sea.
4. Publications in international journals. As far as they are concerned, the four key problems should be coordinated by the appropriate Coordinating Investigator.

Some major joint reports covering the key research problems will be published when the analyses are finished. Considering the time table of ERS-1 (launch in 1990) it is strongly recommended that these major reports should be published before mid 1990. The key problems will be:

- * development of algorithms for determination of geophysical sea ice parameters and processing of SAR sea ice images (Co-I: Jan Askne and Risto Kuittinen),
- * potentials of SAR in operational sea ice mapping and forecasting using numerical models (Co-I: Matti Leppäranta and Thomas Thompson).

In addition to the SAR, two further key problems are identified:

- * evaluation of the GEOSAT radar altimeter for provision of sea ice and ocean parameters (Co-I: Lars Ulander),
- * scatterometer measurements of sea ice (Co-I: Matti Hallikainen).

In addition to these a number of problems will be considered. After the experiment appropriate groups will be established together with the Co-I's. Examples of such subjects are:

- * modelling of dielectric properties of sea ice,
- * structure of brackish water ice,
- * ice edge phenomena,
- * microwave radiometer measurements.

The research work after the experiment is planned to advance according to the following time table:

1 June	1988	First basic sets of ground truth and sensor data available. In connection to this a meeting will be considered.
30 June	1988	Data catalogue is distributed by SSC.
November/December	1988	First BEPERS-88 workshop in Sweden.
31 December	1988	Data report published.
31 March	1989	First results ready for publication.
September/October	1989	Second BEPERS-88 workshop in Finland.
31 December	1989	Summary report published.

Participants:

Paula Kankaanpää	Aranda
Hanna Kemppainen	Aranda
Pekka Kosloff	Aranda
Mikko Lensu	Valdivia
Matti Leppäranta	Aranda
Terhikki Manninen	Aranda
Juhani Rapo	Aranda
Henry Söderman	Valdivia
Jouni Vainio	Valdivia

10.2.2 Finnish Meteorological Institute (FMI)

Equipment: Meteorological programme.

Participants:

Kenneth Holmlund	Aranda
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10.2.3 Helsinki University of Technology (HUT)

Equipment: Airborne scatterometer and polarimeter, air borne radiometer, ice thickness radar, dielectric measurement system.

Participants:

Pekka Ahola	Aranda
Martti Hallikainen	Aranda
Juha Hyyppä	Aranda
Jouni Pullianen	Aranda
Teemu Tares	Aranda
Martti Toikka	Aranda

10.2.4 Technical Research Centre of Finland (VTT)

Equipment: High speed video camera.

Participants:

Risto Kuittinen
Markku Rautasuo

10.2.5 University of Helsinki (UH)

Equipment: Snow geophysics work equipment.

Participants:

Erkki Palosuo	Aranda
Pekka Pihkala	Aranda

10.3 Federal Republic of Germany

10.3.1 German Hydrographic Institute (DHI)

Equipment: R/V Valdivia, with equipment for oceanographic measurements remote sensing data.

Participants:

Gerd Becker	Valdivia
Achim Stössel	Valdivia
Klaus Strübing	DHI

10.3.2 German Remote Sensing Data Center (DFVLR)

Equipment: NOAA/AVHRR reception and processing SAR processing.

Participants:

Gredel
König

10.4 Other countries

10.4.1 Canada

10.4.1.1 Atmospheric Environment Service/Center for Research in Experimental Space Science (AES/CRESS)

Equipment: Resometer, SSM/I data

Participants:

Ken Asmus	Icebreaker
Caren Garrity	Icebreaker
Rene Ramseier	AES/CRESS
Irene Rubenstein	AES/CRESS

10.4.1.2 Canada Centre of Remote Sensing (CCRS)

Equipment: CV 580

Participants:

Lawrence Gray	CV 580/AIRFIELD
Chuck Livingstone	CV 580

10.4.1.3 Mc Gill University, Montreal

Equipment: Laser profilometer.

Participants:

John Lewis	Aranda
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10.4.2 United States of America

10.4.2.1 Environmental Research Institute of Michigan (ERIM)

Equipment: Snow and ice parameters ground truth instruments.

Participants:

Barbra Burns	Icebreaker
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10.4.2.2 U.S.Army Cold Regions Research and Engineering Laboratory
(CRREL), Hanover, N.H.

Equipment:

Participants:

Anthony Gow	Aranda
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10.4.2.3 University of Alaska, Fairbanks

Equipment:

Participants:

William J. Stringer	Aranda
Wilford F. Weeks	Aranda

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Forskningsrapporter

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- Nr 1. Havsiskonferens – Stockholm 3–4 oktober 1972.
- Nr 2. Vintersjöfart i Bottenhavet – erfarenheter av SCA:s distributions-system.
- Nr 3. Isskador på fartyg i Östersjön, Bottenhavet och Bottenviken, statistisk analys av skadefrekvenser.
- Nr 4. Propellerproblem – propellerverkningsgradens beroende av bladutformningen.
- Nr 5. Fartygs framdrivningsmotstånd i is.
- Nr 6. Vintersjöfart med stora fartyg i Bottenviken.
- Nr 7. Vintersjöfart i Bottenviken – symposium Luleå. 1974-04-18/19.
- Nr 8. Havsundersökning i Bottenviken vintern 1974.
- Nr 9. Kartering av ytvattentemperaturen i vattnen runt Sverige.
- Nr 10. Experiments on remote sensing of sea ice microwave radiometer.
- Nr 11. Bottenvikens stålfyrar – hållfasthetsanalys och förbättringsförslag.
- Nr 12. Formation and structure of ice ridges in the Baltic.
- Nr 13. Calculation of ice drift in the Bothnian Bay and Quark.
- Nr 14. A narrow beam sonar to measure the submarin profile of an ice ridge.
- Nr 15. The average surface temperature in the autumn and the early winter on the Gulf of Bothnia, the northern Baltic Sea and the Gulf of Finland (1966 – 1974).
- Nr 16:1 SEA ICE-75. Programme.
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- Nr 16:3 SEA ICE-75. Ice detection by SLAR.
- Nr 16:4 SEA ICE-75. Analysis of SLAR data.
- Nr 16:5 SEA ICE-75. FLAR, ODAR, ship's radar.
- Nr 16:6 SEA ICE-75. IR-scanner results.
- Nr 16:7 SEA ICE-75. Radar altimeter results.
- Nr 16:8 SEA ICE-75. Dynamical report
- Nr 16:9 SEA ICE-75. Summary report.
- Nr 17. The shape and size of ice ridges in the Baltic according to measurements and calculation.
- Nr 18. A numerical model for forecasting the ice motion in the Bay and Sea of Bothnia.
- Nr 19. Creep of fresh water ice at high homologous temperatures.

- Nr 20. Economics of winter navigation in the northern part of the Gulf of Bothnia.
- Nr 21. Measurement and analysis of ice-induced stresses in the shell of an icebreaker.
- Nr 22. Measurements of physical, characteristics of ridges on april 14 and 15, 1977.
- Nr 23. Ice accretion on ships with special emphasis on Baltic conditions.
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- Nr 28. Long term measurements of ice pressure and ice-induced stresses on the icebreaker Sisu in winter 1978.
- Nr 29. On the drift and deformation of sea ice fields in the Bothnian Bay.
- Nr 30. A sensitivity analysis of steady, free floating ice.
- Nr 31. A study of the large scale cooling in the Bay of Bothnia.
- Nr 32. Statistical features of sea ice ridging in the Gulf of Bothnia.
- Nr 33. Performance of marine propellers in ice-clogged channels.
- Nr 34. BASIS. A data bank for Baltic sea ice and sea surface temperatures.
- Nr 35. Vertical mixing and restratification in the Bay of Bothnia during cooling.
- Nr 36. Formation, thickness and stability of fast ice along the Finnish coast.
- Nr 37. Dynamic loads and response of icebreaker Sisu during continuous icebreaking.
- Nr 38. Undersökning av skrovformens inverkan på propellerns isbelastning samt rännans renhetsgrad genom modellförsök i is.
- Nr 39. A forecast model for water cooling in the Gulf of Bothnia and Lake Vänern.
- Nr 40. The Atmospheric boundary layer over the Botnian Bay; A review of work on momentum transfer and wind structure.
- Nr 41. An investigation of the crystal structure of sea ice in the Bothnian Bay.
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- Nr 43. Results and statistical analysis of ice load measurements on board icebreaker sisu in winters 1979 to 1985.
- Nr 44. Isförhållandena i Sveriges södra och västra farvatten.
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