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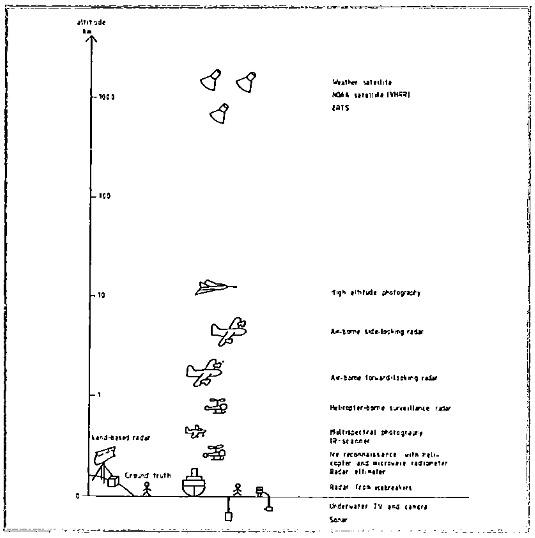


# STAICE 75

# Programme

by Åke Blomquist, Claës Pilo and
Thomas Thompson

Stockholm 1975

WINTER NAVIGATION RESEARCH BOARD
Swedish Administration of Shipping and Navigation, Finnish Board of Navigation
Research Report No 16:1

*Cover picture:*
*The icebreaker TOR in the middle of the test area for SEA ICE —75 and sensors, carriers and platforms planned for the experiment.*

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# Programme

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# Foreword

The Winter Navigation Research Board presents report no. 16:1. This report is the first in a series of reports evolving from the remote sensing experiment SEA ICE -75, that was carried out in the Bay of Bothnia in March 1975. SEA ICE -75 was an international experiment in which a number of institutions and services from Sweden, Finland and the Netherlands participated.

The first draft programme was prepared at the maritime section of the Swedish Meteorological and Hydrological Institute (SMHI). During the planning period of the project, the programme was discussed at several meetings with participating experts. The first draft was extensively revised taking into account the technical peculiarities of the various sensors and platforms that would be used during the experiment.

The great effort laid down in the preparation of this operational programme, in particular by the project managing group, is much appreciated. The Winter Navigation Research Board wish to warmly thank all those that contributed to the development of this programme and the Swedish Space Corporation for coordinating it.

Norrköping and Helsingfors, July 1976.

**Lennart Johansson** **Helge Jääsalo**

# 1. Introduction

Remote sensing techniques seem to offer interesting possibilities for mapping sea ice, particularly under unfavorable weather and light conditions that prevail in the Bay and Sea of Bothnia in winter. In order to gain experience of the capability and possible limitations of modern remote sensing techniques, a field experiment will be organized in the Bay of Bothnia (Sea of Bothnia) in March 1975. The experiment will be performed within a general cooperation between Sweden and Finland on winter navigation research.

Substantial support is given by all the participants. Of special interest is that the Rijkswaterstaat Meetkundige Dienst in the Netherlands provides a SLAR and aircraft and that the Helsinki Universtiy of Technology in Finland contributes a passive microwave radiometer and helicopter. The National Land Survey of Sweden participates with a multispectral camera package and aircraft. The National Defence Research Institute in cooperation with the Air Force and Navy takes part with a FLAR and aircraft, an ODAR and helicopter, a land-based radar station as well as an IR-scanner and aircraft. The Swedish Administration of Shipping and Navigation participates with a modern icebreaker equipped with helicopter, hydrocopter etc. The Swedish Meteorological and Hydrological Institute (SMHI) provides the staff for the extensive ground truth programme.

The Swedish Board for Space Activities finances the participation of the Swedish Space Corporation, which is responsible for the coordination of the remote sensing programme. The Swedish Space Corporation has charged Saab-Scania to participate in the experiment with a radar altimeter.

The present programme has been prepared by the project managing group which consists of Åke Blomquist, National Defence Research Institute, Claës Pilo, Swedish Space Corporation and Thomas Thompson, Swedish Meteorological and Hydrological Institute. The head of the icebreaking Service of the Swedish Administration of Shipping and Navigation Mr Agne Christenson has closely followed the preparations of the programme.

# 2. General Background

## 2.1 Needs of sea ice mapping

Huge industrial investments are planned in Norrland during the next ten years. An example is the new steel factory "Stålverk 80" in Luleå which will be operational in 1980. The outgoing cargo from this factory alone is expected to increase from today 4 million tons/year to 12 million tons/year in 1980. This is 33 000 tons/day which implies that two ships will be required to call at Luleå every day. It is quite obvious that under these conditions it will be highly desirable to keep the shipping lanes open all the year round.

Closing the port of Luleå for instance would cause the industry in Norrland great losses. A prerequisite for around-the-year shipping is the ability to provide the Ice-breaking Service and the navigation with the ice information necessary for immediate operational purposes and also to provide SMHI with input data for the ice forecasts necessary for shipping in choosing the most economic routes.

## 2.2 Present ice observations system

Today sea ice information is received from

- ☐ Weather satellites
- ☐ Helicopters and aeroplanes (visual observations)
- ☐ Icebreakers, merchant ships and shore based observers (visual observations).

All information is received in the visual or infrared part of the electromagnetic spectrum and is highly affected by water droplets and ice crystals in the atmosphere. The present ice mapping system is thus very dependent on the weather.

During winter, long periods of cloudy weather with precipitation and poor visibility normally occur. As visual sensors also are dependent on daylight and the light hours in northern Sweden are very limited (Luleå has daylight only between 0930 and 1400 at 15th January) it is usual that neither the navigation nor the ice forecasters receive sufficient information on the ice situation.

The weather satellites give information with good coverage but the resolution of the pictures will permit only very large scale features to be mapped. It is for instance impossible to evaluate pressure ridges from such pictures. The visual observations on the contrary give high resolution but poor coverage.

The sea ice mapping methods of today thus gives only a qualitative information on the ice whereas quantitative information is necessary for long term and short term ice forecasting.

## 2.3 Future sea ice mapping system

During the last years a number of different remote sensing techniques have been developed. Some of them seem to be highly suitable for sea ice mapping. Furthermore, a combination of sensors working in different parts of the electromagnetic spectrum might give valuable information for both navigation and forecasting such as

- ☐ weather and darkness independent ice information
- ☐ information with high resolution and sufficient coverage for real time distribution to navigation
- ☐ information with good coverage and sufficient resolution as input data to the ice forecasts
- ☐ quantitative sea ice information (concentration, thickness, mass etc).

## 2.4 Proposed field experiment

To obtain experience of the capability and possible limitations of modern remote sensing techniques in mapping sea ice, a field experiment is planned to take place in the Bay of Bothnia (Sea of Bothnia) during the period 13-22 March 1975.

The experiment will comprise two parts

- ☐ In specially chosen relatively small ground truth areas data will be gathered from different sensors and compared with ground truth data
- ☐ Large areas will be mapped by remote sensors and the results will, if possible, be distributed to icebreakers in real time.

The first part will be realized during three selected days during the experimental period. The days will be chosen by the project managing group (see chapter 7.5). Detailed ground truth data will be available (see chapter 4).

The second part will be realized during two or three days in the period. The flight routes will cover the western part of the Bay of Bothnia from Norra Kvarken to Luleå. In this case ground truth will mainly consist of high altitude photography.

The experiment will most probably be carried out in the Bay of Bothnia (see Figure 1). If, however, sufficient ice will be available, the Sea of Bothnia will be chosen.

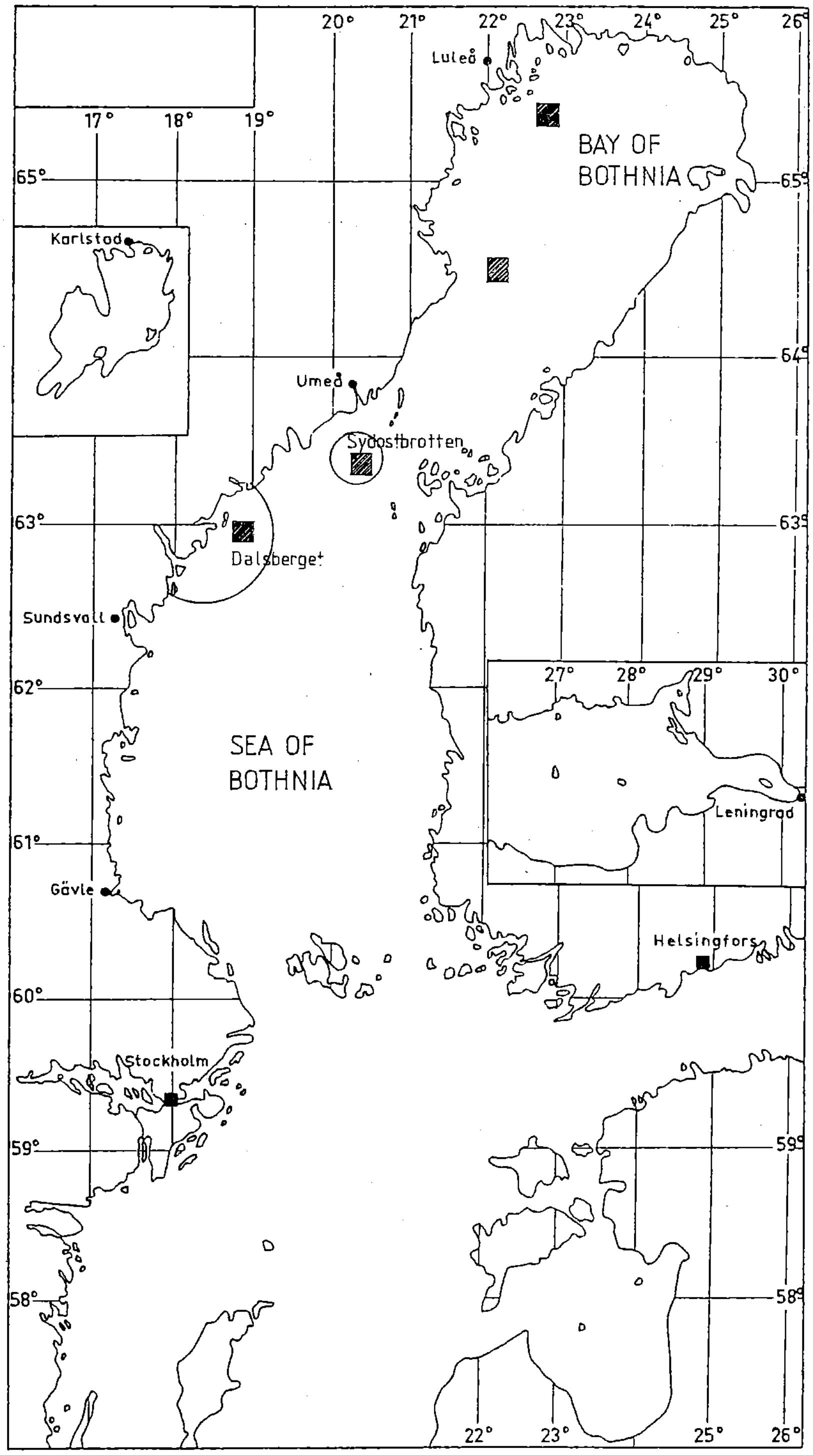



**Figure 1.** *The Gulf of Bothnia with possible positions of the GT-areas.*

# 3. Parameters to be Studied

## 3.1 General

Several parameters affect the ice signatures. The primary parameters to be evaluated from the remote sensing recordings of sea ice are

- ☐ ice or non-ice
- ☐ ice concentration (to which extent is the area covered by ice and to which extent by open water)
- ☐ roughness of the ice (to which degree is the ice deformed)
- ☐ ice thickness
- ☐ state of ice surface (melting ice, snow covered ice etc)
- ☐ type of ice.

Detailed information on these ice parameters within limited areas will give the ice-breakers and navigation possibilities to choose the most economic route during the next 6—10 hours. Large scale information on the parameters above for the whole sea area will make it possible to forecast the ice movement and development during the next 1—10 days.

The remote sensing recordings will also be affected by environmental parameters such as

- ☐ temperature and temperature variations
- ☐ cloudiness
- ☐ wind speed
- ☐ sea state including water temperature
- ☐ time of day.

The way in which these parameters effect the remote sensing recordings will be studied.

## 3.2 Ice parameters

**Ice or non-ice.** It might be difficult to distinguish new ice and level ice from open water with some sensors. The capability of different sensors in this respect should be studied and taken in consideration when making recommendations on sensor combinations suitable for sea ice mapping. Of great importance is also to be able to map ice boundaries e. g. larger leads.

**Ice concentration.** The ice concentration will be registered by several sensors, with different resolution. It will be of great importance to receive quantitative information on the concentration (e.g. 70 % of the area is ice covered). It is also of importance to study if the microwave sensors give a resolution which makes it possible to guide the winter navigation in the ice. A detail of interest is to get information whether a pack ice area is consolidated (with new ice between the thicker floes) or not (open water between the floes).

**Ice roughness.** The roughness of the ice is a very important parameter. The roughness will probably be well reproduced in the radar recordings. It is of great importance to study how accurately one can estimate the degree of roughness from these recordings (e.g. level, rafted, ridged and heavily ridged surface). From the above water recordings it may also be possible to map the roughness of the subsurface. The degree of roughness is decisive when considering the dimensions of ice ridges for ship routing in ice. The roughness is also of importance when calculating the wind stress on the ice for forecasting of ice movements.

It should be studied whether IR-sensors give additional information on ice ridges and heavy deformations. The radiation temperature may for example differ for level ice and ice ridges.

**Ice thickness.** A quantitative information on the thickness of the ice is essential for ship routing and for ice forecasting. The microwave radiometer may give information on the thickness when the ice temperature is below 0°C and the thickness less than 40 cm. Also the radar altimeter may give similar information.

It should also be studied whether other sensors give at least qualitative information on thickness. The IR-sensors, for instance, may indicate thick or thin ice, and there might be a difference in this respect also between the 3 cm and 10 cm radar recordings.

**State of ice surface.** A melting ice surface indicates that the ice resistance is somewhat smaller and the ice therefore easier for ships to penetrate. Some sensors might give different signatures for melting and frozen surfaces respectively.

If the ice surface is covered with snow, the ice has a heat isolation causing the ice to grow slower. With some sensors it might be possible to distinguish snow covered ice from snowless ice.

**Type of ice.** Different types of ice are characterized by different thickness, roughness, flow size, concentration etc. A combination of the parameters above would give a good information on the type of ice.

**Drift speed and direction.** Knowledge of the ice movement, small scale as well as large scale, is essential. Especially landbased sensors and platforms in the ice, e.g. an ice-breaker equipped with radar and Decca, are suitable for these studies.

## 3.3 Other parameters

**External parameters.** The influence of the following external parameters on the capability of the sensors should be studied

- ☐ cloud (clear sky — half cloudy — cloudy)
- ☐ wind (calm — hard wind)
- ☐ sea state (smooth sea — waves at ice edge)
- ☐ rain and snow clouds, falling precipitation
- ☐ fog
- ☐ darkness.

**Influence of altitude.** The mapping capacity will increase with increasing altitude. Simultaneously the resolution will decrease. The altitude should therefore be varied in order to optimize the relation mapping capacity-resolution.

## 3.4 Summary of experimental conditions

- ☐ Several ice types with different concentration, degree of roughness etc should be studied. The ground truth (GT) area should be shifted during the experiment in order to achieve the best results possible.
- ☐ The same GT-area should be mapped under different weather, cloud and light conditions.
- ☐ The tests should be performed during both day and night.
- ☐ The flying altitude should be varied in order to study the effect on 1) the resolution 2) the cost for covering a given area.
- ☐ Tests with IR-sensors should be performed during periods of rapid air temperature changes.
- ☐ Ice movements should be studied from the ice-breaker TOR and, if ice conditions permit, from Dalsberget and Sydostbrotten.
- ☐ The experiment should also comprise an operational phase. Recordings from SLAR, FLAR, ODAR etc should be forwarded as soon as possible to an ice-breaker for evaluation of their usefulness for immediate operational purposes.

# 4. Ground Truth Programme

## 4.1 Configuration of the ground truth area

The ground truth work will be performed at three different scales. In Figure 2 the principal layout of a ground truth (GT) area is shown. Within the GT-area ice parameters and other parameters will be mapped with various degrees of accuracy.

**The 1x1 km area.** The shaded area in Figure 2 (1x1 km) will be marked with flags and tarpaulins as shown in Figure 3. The outer edges and one line (dotted), along which the ice thickness measurements will be made very detailed, will be marked with flags. One racon will be placed in the mid-point of the area. Two of the corners will be marked with large orange-coloured tarpaulins (3,4x5,4 m).

The flags and tarpaulins will aid the carriers of the microwave radiometer and the multispectral camera in finding the area.

The area will be mapped with high precision, ice thickness will be measured at several points (Figure 3). In addition to measurements at every 200 meters, supplementary measurements will be made at all points where one might expect deviations. The ice thickness will also be measured along the dotted line at every 10 meters. Snow thickness will be measured. Ice ridges and ice roughness will be mapped. All the information will be presented on maps.

The ice-breaker TOR will be stationed close to the 1x1 km area. Temperature, wind, humidity, ice- and water-temperature will be measured in the vicinity of the ice-breaker as well as meteorological parameters, such as cloudiness, cloud base, visibility, etc. which will be regularly observed from the ice-breaker. Waves on the open water among ice floes will also be observed, as they might be identified on the radar A-display. The wind velocity and direction are of special importance when studying the drift of the ice with radar methods.

The subsurface profile of the ice will be mapped across some of the ice ridges by means of underwater sensors such as underwater camera, underwater TV and sonar. Ridge depth, -appearance, -width etc. will be studied. The subsurface profile might be of interest also in connection with the radar frequency comparison. The 10 cm waves might penetrate the ice mass, whereby the radar signature is influenced by the subsurface of the ice. Information on layers in the ice and on snow cover is therefore important. Information on the depth of the ice ridges is also of value.

**The 5x5 km area.** The area will be marked with flags, tarpaulines and radar reflectors as shown in Figure 2. The icebreaker or a racon or a caisson light house which give easily identifiable radar echoes should be within or close to the area.

Within the 5x5 km area the ice will be mapped with high accuracy. Based on visual observations and photos, the ice concentration and roughness will be estimated, leads and ridges will be mapped and ice thickness measurements made in significant points together with snow depth measurements.

To study the ice dynamics, the radar reflectors within the area will be followed from the radar on the ice-breaker and if possible from the radar stations on Dalsberget and Sydostbrotten. The radar reflectors should be located so as to facilitate detection by the participating radars. This means that they should be placed on even ice and not near ridges etc, which usually have a jamming effect. A symmetrical location of the reflectors will make radar identification of the ground truth area easier.

During the test period it is possible that the 5x5 km area has to be shifted to be able to cover different kinds of ice. The 1x1 km area and the ice-breaker will then probably have to be moved too.

**The 15x15 km area.** The area will be marked with flags and radar reflectors as shown in Figure 2.

The ice will be mapped within the area. Concentration and roughness will be estimated and ice thickness at significant points will be measured.

The mapping will not be as accurate as for the smaller areas, but special ice charts will be drawn. The radar reflectors within this area will if possible be followed from Dalsberget and Sydostbrotten as well as from the ice-breaker.

**Figure 2.** *Principle layout of the ground truth areas.*

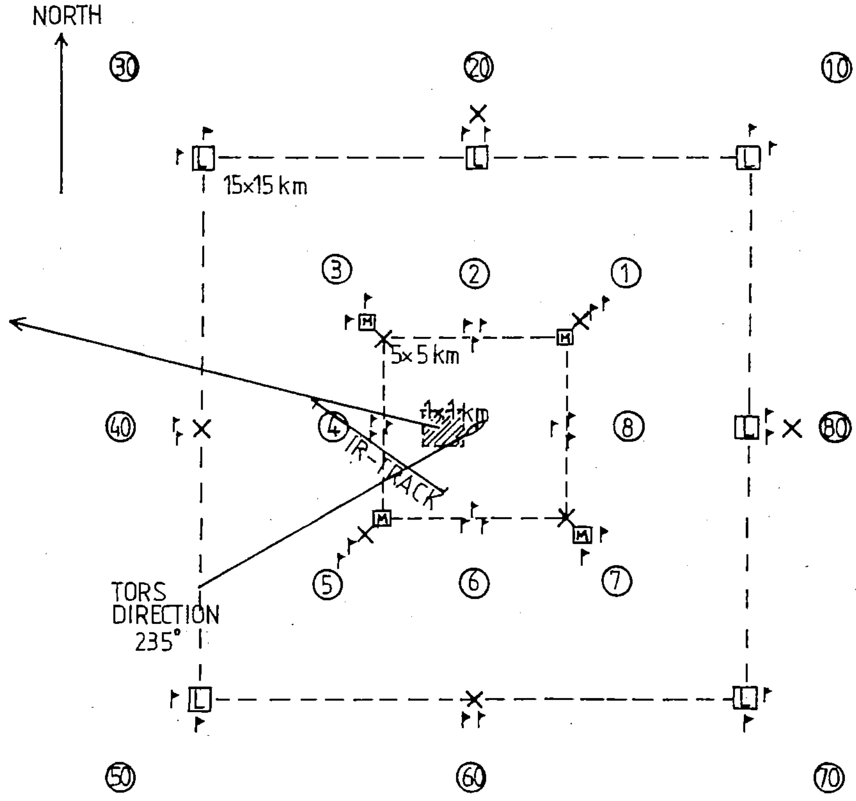
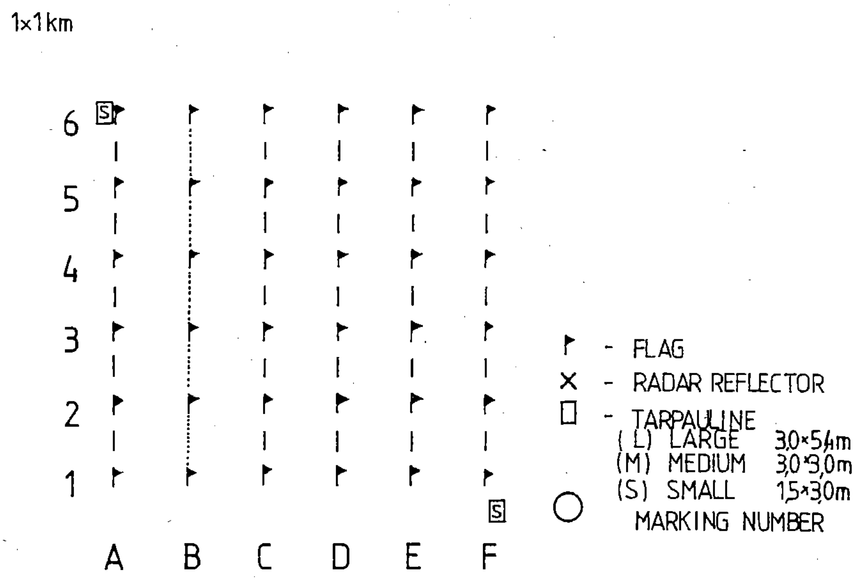



**Figure 3.** *Layout of the 1×1 km area.*




## 4.2 Ground truth methods

The following methods will be used for measuring ice parameters and other parameters.

- Ice thickness is measured with ice drill and measuring stick.
- Snow depth is measured with measuring stick.
- Ice ridges are observed visually. Their width, their height from sea level to the ridge tops are measured with measuring stick and levelling instrument.
- The direction of the ice ridges is determined by use of compasses.
- Ice surface temperatures are measured with resistance thermometers.
- Meteorological and oceanographic parameters are measured with standardinstruments.
- Slant photography will be used for ice mapping.

## 4.3 Location of the ground truth area(s)

The location of the ground truth area(s) will depend on the actual ice and weather conditions and can therefore only be chosen immediately prior to the experiment. Most probably two areas have to be selected in order to cover different types of ice. Possible locations in the Bay of Bothnia

**Figure 4.** *Location and shape of possible ground truth areas in the Bay of Bothnia.*

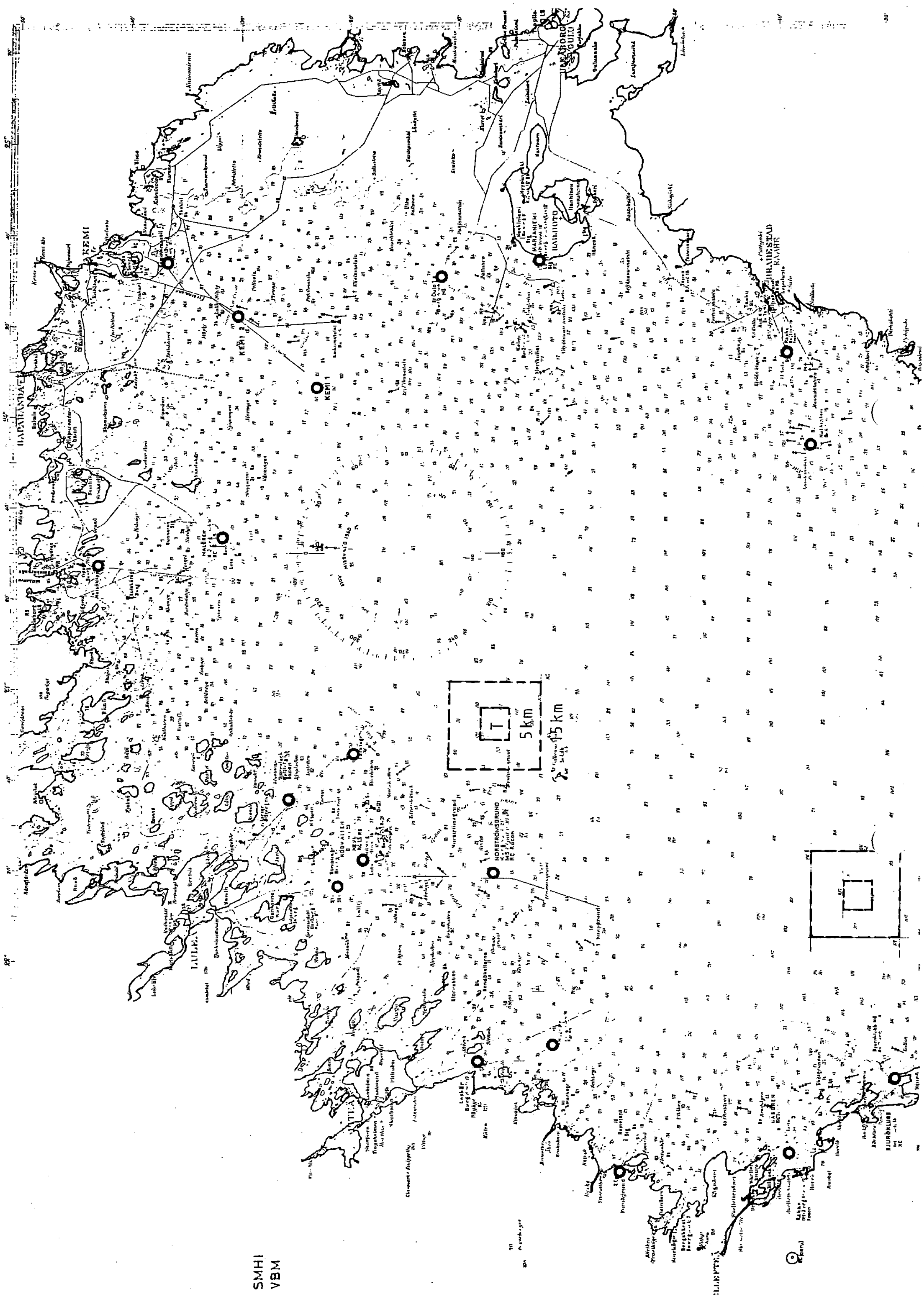
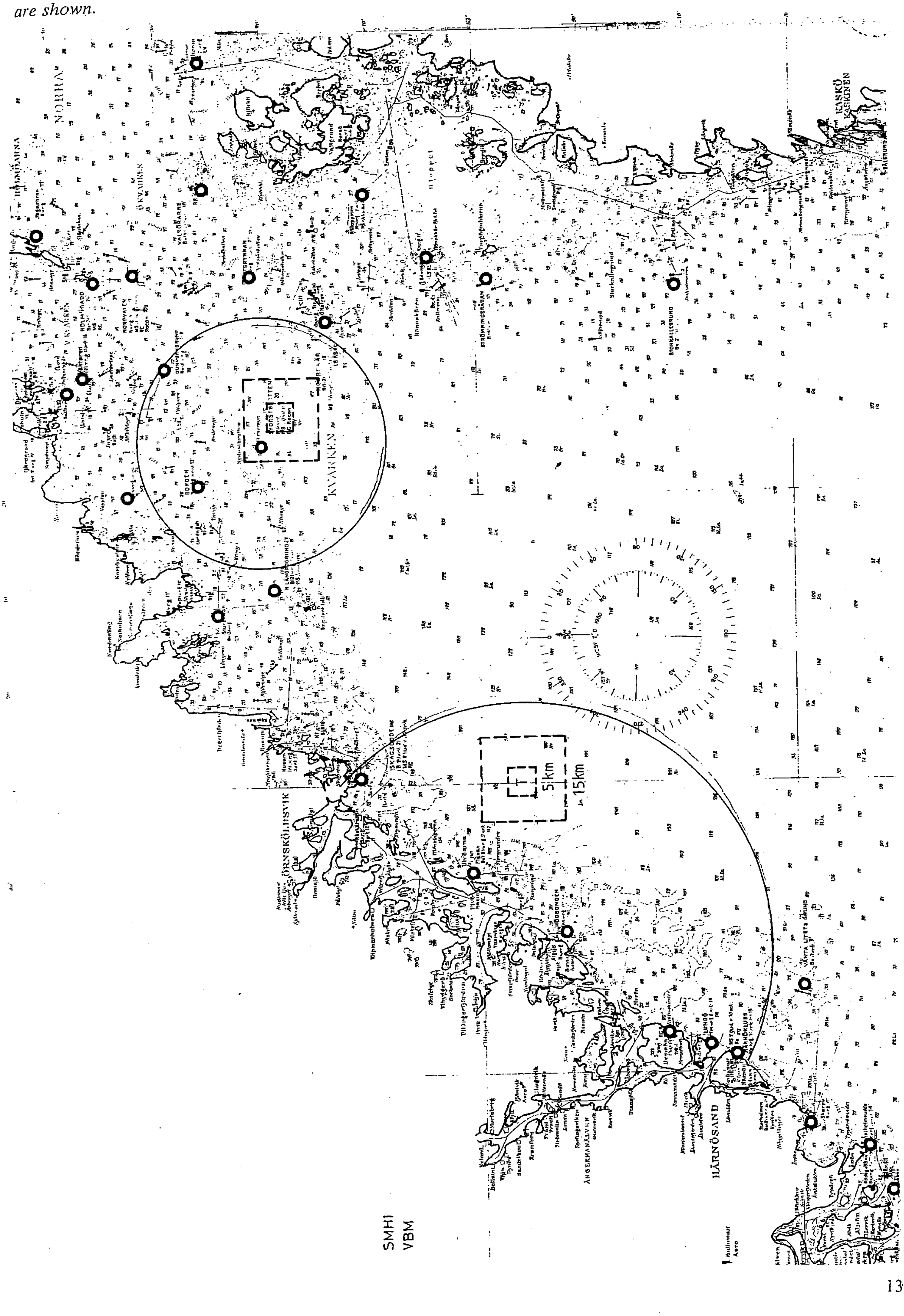


**Figure 5.** *Location and shape of possible ground truth areas in the Sea of Bothnia. The radar range from the lighthouse Sydostbrotten and the radar station at Dalsberget are shown.*

are indicated in Figure 4 and in the Sea of Bothnia in Figure 5.

If two areas are chosen SMHI will be responsible for the ground truth work in one of them and the Finnish Institute for Marine Research for the other one.

SMHI will co-ordinate the ground truth programme.



# 5. Sensors

A number of different sensors will be tested during the experiment with emphasis on microwave instruments and IR-scanner. Photography will be used primarily as ground truth together with other data gathered on the ice. Satellite pictures will be utilized for comparison. Below a short description is given of the participating sensors, carriers and scientific groups.

## 5.1 Microwave sensors

**SLAR** (Side Looking Airborne Radar). Carrier: Beechcraft Queen Air 80 laboratory aircraft belonging to the National Aerospace Laboratory (NLR) in the Netherlands. Air speed 240 km/h. Maximum altitude 6 000 m. The SLAR is an EMI X-band (3 cm), real aperture SLAR developed originally as a navigation radar for the British military aircraft TSR-2. Digital data are recorded on magnetic tape. Data are also reproduced on film. There is no experience in Sweden of using SLAR for mapping sea ice. Responsible organization: Rijkswaterstaat Meetkundige Dienst, Netherlands.

**FLAR** (Forward Looking Airborne Radar). Carrier: Pembroke aircraft belonging to the Swedish Air Force. Air speed 240 km/h. Maximum altitude 3 500 m. The FLAR is a military reconnaissance radar working in the X-band (3 cm). The antenna can be changed from horizontal to vertical polarisation. Data are recorded on magnetic tape and by photographic technique on PPI. There is no experience in Sweden of using a FLAR for mapping sea ice. Responsible organization: National Defence Research Institute (FOA).

**ODAR** (Omni Directional Airborne Radar). Carrier: Vertol helicopter belonging to the Swedish Navy. Maximum air speed with ODAR 190 km/h. Maximum altitude 3 000 m. The ODAR is working in the X-band (3 cm). There is no experience in Sweden of using an ODAR for mapping se aice. Responsible organization: National Defence Research Institute (FOA).

**Land-based radar.** Two land-based radar stations (3 cm and 10 cm) are placed 210 meters above the sea level at Dalsberget between Härnösand and Örnsköldsvik. The radars can be used with both horizontal and vertical polarization. They can be used only in the case that the experiment takes place in the Sea of Bothnia. Another X-band (3 cm) radar is placed 30 meters above the sea level at Sydostbrotten in the northern part of the Sea of Bothnia. These radar stations have been used to some extent for mapping sea ice during the winter 1972/73. Responsible organization: National Defence Research Institute (FOA).

**Radar altimeter.** Carrier: Lama helicopter belonging to Kasselflyg in Örnsköldsvik and rented by the Ice-breaking Service. The radar altimeter working at 5 GHz (6 cm) has been developed by Saab-Scania. Saab-Scania has proposed to utilize the instrument for mapping sea ice and especially for studying ice thickness and to some extent ice concentration, and ice surface structure. There is no experience in Sweden of using a radar altimeter for mapping sea ice. Responsible organization: Saab-Scania under contract to the Swedish Space Corporation.

**Microwave radiometer.** Carrier: Agusta Bell 206B Jet Ranger helicopter belonging to Helicopter Service at Helsinki and rented by the Finnish Board of Navigation. The microwave radiometer working at 5 GHz (6 cm) has been developed by the Radio Laboratory at the Helsinki University of Technology. The microwave radiometer has been tested to some extent for mapping sea ice in Finland last winter. Responsible organization: Helsinki University of Technology.

## 5.2 Optical and IR-sensors

**SR** (Scanning Radiometer). Carrier: NOAA-4 satellite. The satellite passes twice a day over the Bay of Bothnia. Altitude: 1 400 km. Pictures (visual and IR) are received in real time by SMHI. Such pictures have been used for ice mapping in Sweden for several years.

**VHRR** (Very High Resolution Radiometer). Carrier: NOAA-4 satellite. The VHRR information will be reseived at Tromsö in Norway and stored on magnetic tape for later processing. As a back-up, VHRR pictures will also be requested from Bochum in Western Germany.

**MSS** (Multi Spectral Scanner). Carrier: Landsat-2 satellite (=ERTS-2). The satellite passes every 18th day over the Bay of Bothnia. Altitude: 900 km.

**High altitude camera.** Carrier: Draken belonging to the Swedish Air Force. Altitude: 8 000 m. Pictures will be in scale: 1:200 000, size 115x115 mm covering 23x23 km. Simultaneously pictures in scale 1:14 660 can be taken covering 1,69x1,69 km. Attempts will be made to take such photos over the test area 5x5 km. High altitude photography has been used to some extent for mapping sea ice in the Gulf of Bothnia. Responsible organization: Swedish Air Force.

**Multispectral camera.** Carrier: Aero Commander 680 SL aircraft belonging to Crown Air AB in Stockholm and rented by the National Land Survey of Sweden. Maximum altitude 4 600 m. The multispectral camera package consists of four Hasselblad cameras. There is some experience in Sweden of using multispectral photos from ERTS-1 for mapping sea ice. Responsible organization: Land Survey of Sweden.

**IR-scanner.** Carrier: DC-3 aircraft belonging to the Swedish Air Force. Air speed 250 km/h. Maximum altitude 3 500 m. The IR-scanner "Tekla" has been developed by the National Defence Research Institute. Data are recorded on magnetic tape and film. There is no experience in Sweden of using IR-scanners for mapping sea ice. Responsible organisation: National Defence Research Institute (FOA).

## 5.3 Undwater sensors

Underwater camera, underwater-TV and sonar will be tested in connection with the programme for collecting ground truth data and mapping the subsurface of ice.

## 5.4 Resolution of the imaging sensors

| | Angular resolution (mrad) | Range resolution (m) |
|---|---|---|
| SLAR | 15 | 30 |
| FLAR | 68 | 45 alt 150 |
| ODAR | 50 | 52 alt 120 |
| Land-based radar, 10 cm | 14 | 37 |
| Land-based radar, 3 cm | 14 | 45 alt 150 |
| SR (NOAA-4) | | 4000 (0,5—0,7 μm) |
| VHRR (NOAA-4) | | 7500 (10,5—12,5 μm) |
| MSS (Landsat-2) | | 900 |
| High altitude camera | 0.01 | 80 |
| Multispectral camera | 0.2 | |
| IR-scanner | 20 alt 2 | |

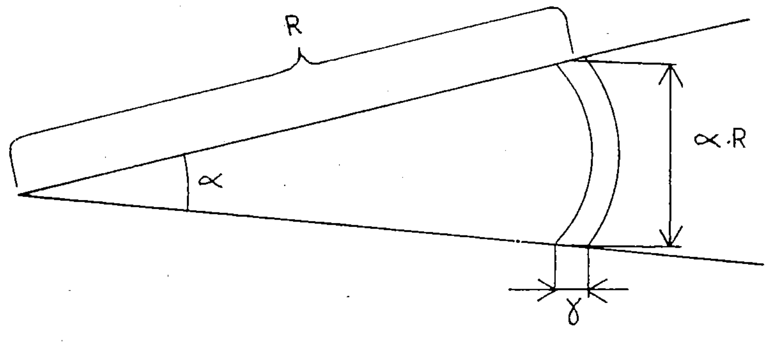
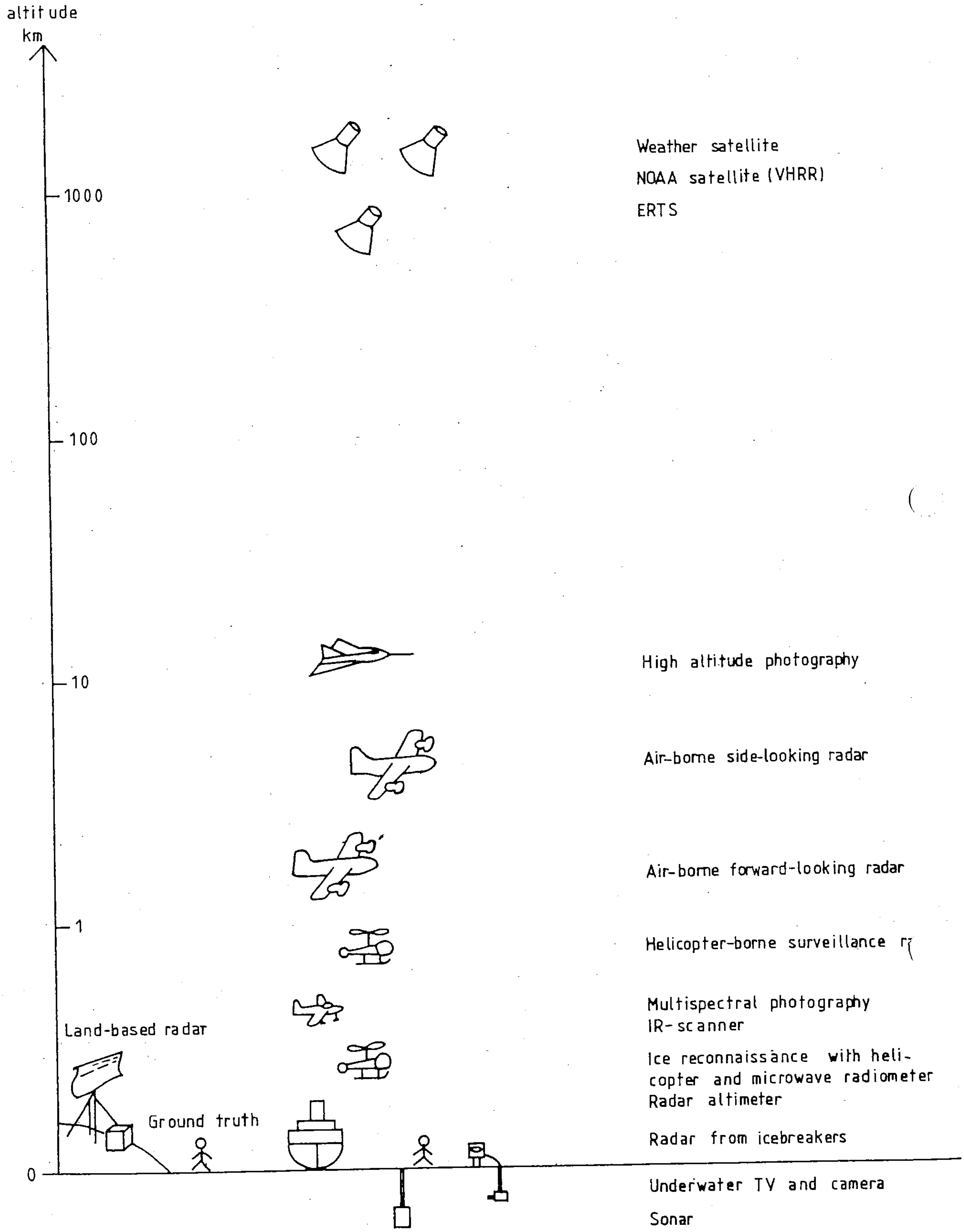



**Figure 6.** *Illustration showing a) the angular resolution, α, which is determined by the antenna lobe width b) the range resolution, γ, which depends on the pulse length.*

**Figure 7.** *Sensors, carriers and platforms planned for SEA ICE —75.*



# 6. Flight Programme

## 6.1 Radar and IR-sensors

Simultaneous, detailed studies should be performed of the ground truth area with all the available radar and IR-sensors. Simultaneous does here mean that no observable changes have occurred in the ice situation. Measurements should also be carried out by the SLAR, FLAR and IR-scanner over paths of the length of 200 km, preferably along the route Luleå-Härnön. The high altitude photography should be concentrated to the same paths.

It is desirable to present the final results on the same scales, which have to be defined. The scale 1:200 000 is recommended for the 200 km paths.

**FLAR**. This is a forward looking X-band radar with four alternative ranges: 20, 80, 160 and 240 km. Only the two shortest of these ranges are of intererst here. The radar thus covers a swath of either 28 or 112

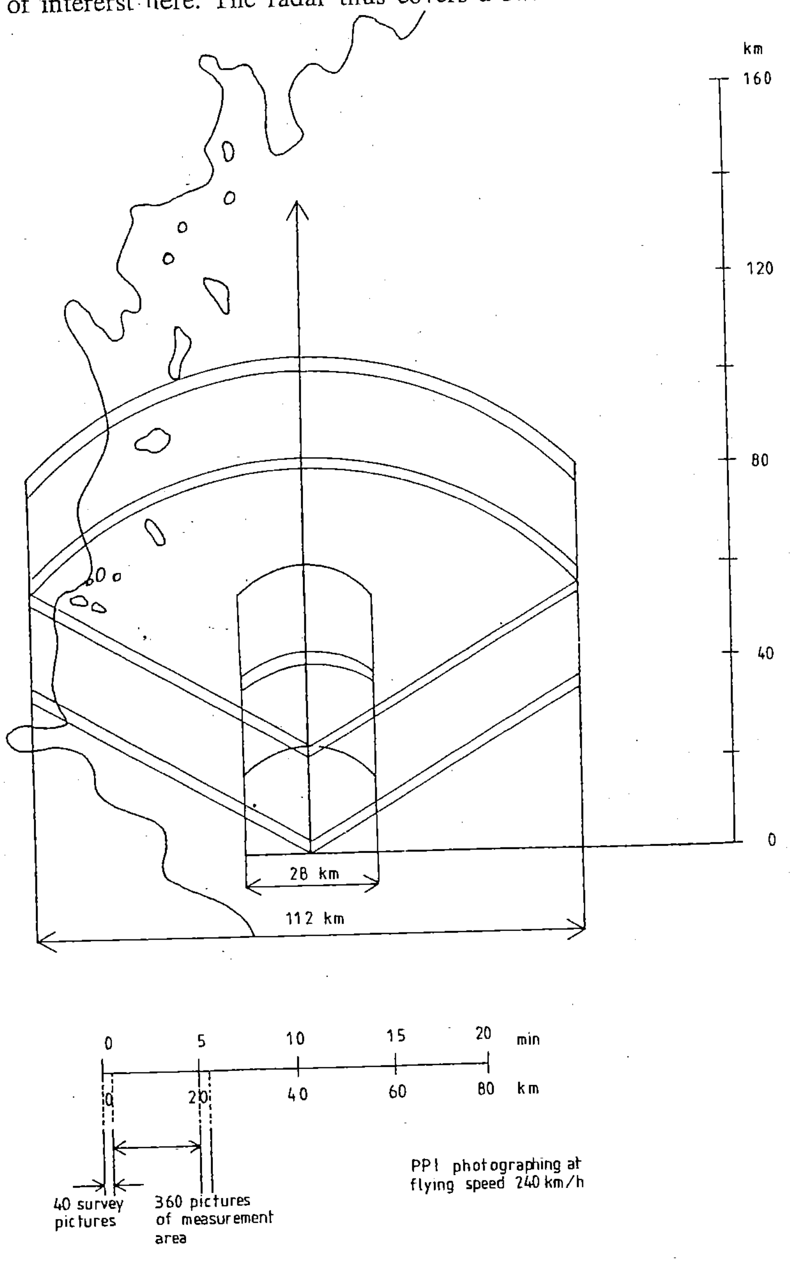



**Figure 8.** *FLAR registrations*
*a) areal coverage of survey and measurements pictures*
*b) number of exposures made during flight.*

km (see Figure 8). On the PPI this corresponds to the scales 1:250 000 and 1:1 million. In copying the film, the required scale can be obtained by enlargement, for example.

The following altitudes are recommended: 225, 450, 900 and 1800 m. It is also possible to go up to 3000 m but then there is risk of losing coverage in the near-zone.

The radar has a double PPI, one of the indicators being used for visual information and the other for photo-recording.

A two hours run will permit both a 200 km measurement and a study in detail of the ground truth area. The range 28 km should be used in the latter case and the range 112 km for survey pictures and navigational purposes.

One picture is taken every 0.75 s with the 28 km range. At a flying speed of 240 km/h this means that there is 50 m between each picture. Every five minutes, i.e. every 20 km, survey pictures are taken with a width of 112 km (see Figure 8).

The aircraft flies over the ground truth area along the path shown in Figure 9. At each chosen altitude the plane makes a figure-of-eight-run in two perpendicular directions, enabling measurements to be made along as well as across ice ridges.

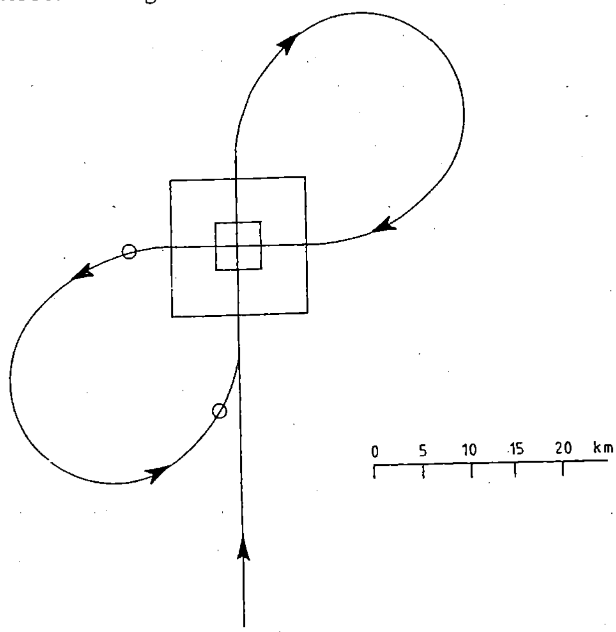



**Figure 9.** *Principle test flight program for FLAR.*

Afterwards the aircraft continues along the 200 km path or returns to the base. If the ground truth area is situated far from the aircraft base recordings should also be made during the flight from the base to the ground truth area.

During the first day of the experiment, or even before, suitable altitudes should be tested.

Both vertical (VP) and horizontal (HP) polarization should be used, if possible, under the same ice conditions. The polarization can be changed only when the aircraft is one the ground.

**SLAR.** The side looking radar enables measurements of two swaths of equal width on both sides of the aircraft or, but not at the same time, one swath on one side of the plane. The following two alternatives seem to be possible:

a) Two swaths of 6.3 km on both of the aircraft. A zone under the aircraft corresponding to twice the altitude is, however, not covered by the radar (see Figure 10a). The range 2x6.3 km corresponds to the scale 1:100 000.

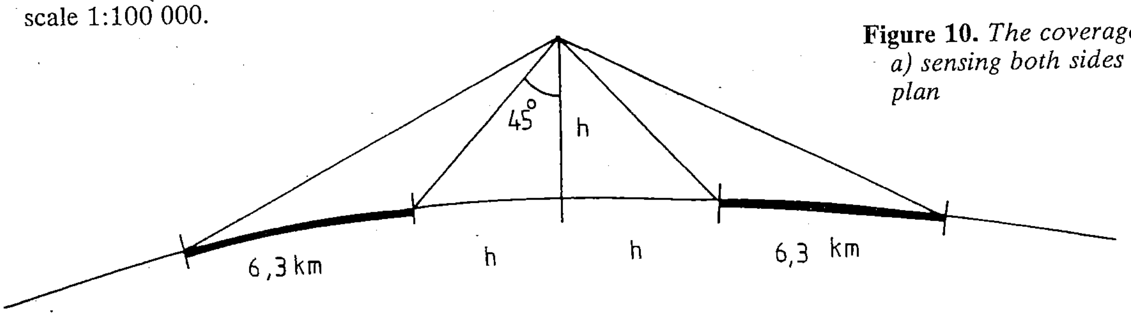
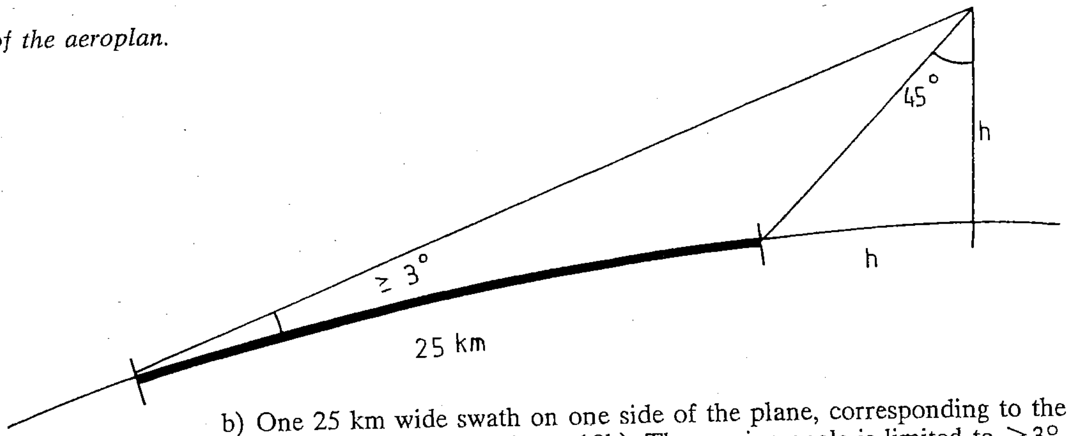



**Figure 10.** *The coverage of SLA. a) sensing both sides of the ae plan*

*b) only one side of the aeroplan.*

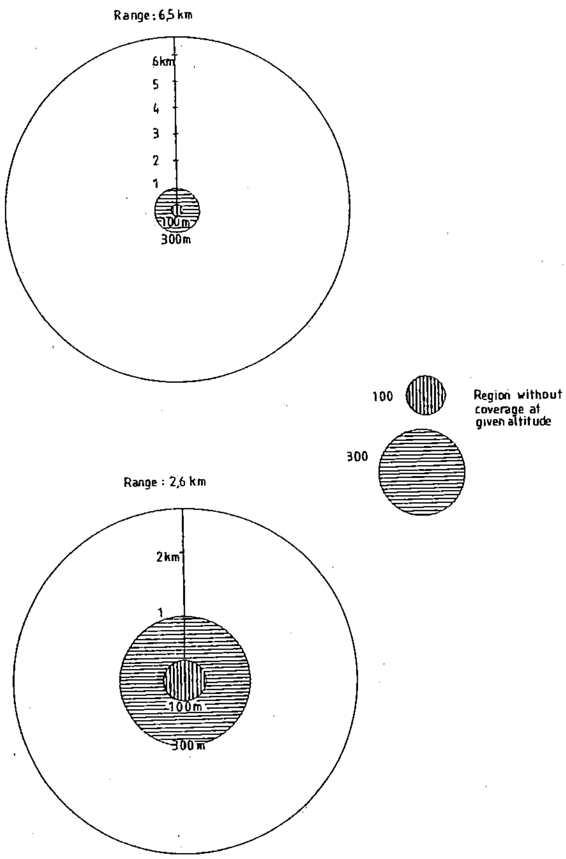



b) One 25 km wide swath on one side of the plane, corresponding to the scale 1:200 000 (see Figure 10b). The grazing angle is limited to ≥3°. This means that the range 25 km cannot be used at low altitudes, hardly below 3000 m.

The SLAR and FLAR measurements should be coordinated. The flying speeds of the SLAR and FLAR planes are identical.

As the SLAR does not give information in real time, and the aircraft has no proper equipment for navigation, it should be advantageous to have the SLAR following the FLAR. Then the SLAR should fly the same routes as the FLAR, bearing in mind that the SLAR covers a swath on the side of the plane. To achieve the best possible comparison the two sensors, suitable altitudes have to be agreed upon.

**Figure 11.** *The coverage of ODAR, with different distance settings and heigths.*




**ODAR.** The omni-directional radar has seven ranges with the following corresponding scales on the PPI.

| Distance radius (km) | Scale |
|---|---|
| 2.6 | 1:20 000 |
| 6.5 | 1:50 000 |
| 13 | 1:100 000 |
| 26 | 1:200 000 |
| 65 | 1:500 000 |
| 130 | 1:1 million |
| 260 | 1:2 million |

For studying the ground truth area, the ranges 2.6, 6.5 and possibly 13 km seem to be suitable. 26, 65 and possibly 130 km might be used to get survey pictures.

The ODAR will be used both for getting survey information intended for the project management group for its daily planning purposes (mainly runs in the morning) and for particular studies of the ground truth area.

A 1. 5 hours run might look like this: On its way from the base to the ground truth area the ODAR makes measurements on a large scale by video-filming. At a fixed site within the ground truth area, given by Decca co-ordinate, the altitudes 30 (or 50), 300 and 1000 m and suitable ranges are tested in order to find out the best possible altitude and range for the state of ice in question. Afterwards video filming on the way to another site where the same procedure is repeated. Again a new site or return to the base (or the ice-breaker).

The ODAR antenna has a vertical lobe width of 5° or 18° and the antenna can be elevated between +10° and —20°. Thus some information is lost below the helicopter, especially at higher altitudes (see Figure 11). It should be observed that at an altitude of 400 m, the distance to the radio horizon is already larger than 82 km.

**IR-scanner.** The scanning angle in the vertical plane is 90° which gives a coverage of about twice the altitude. At the altitude of 500 m the 1x1 km square of the ground truth area is thus covered. The same applies to the 5x5 km area at 2500 m.

Measurements within the ground truth area should be carried out both along and across ice ridges and other linear structures.

Recordings are made on photographic film and on magnetic tape. The information recorded on tape can be evaluated and presented to any scale (a suitable signal processing can be made).

Measurements should be made over the same ground truth area and at the same ice conditions as those studied by the SLAR, FLAR and ODAR. Weather permitting, flights should also be made over the same 200 km paths as for the SLAR and FLAR.

It seems important to investigate the information obtained by the IR-scanner on the state of ice at various ice temperatures. Runs should thus if possible be made both in the morning and in the daytime.

## 6.2 Microwave radiometer and radar altimeter

These two instruments will mainly be used for ice thickness measurements. It is important that they are tested over the same area at the same occasion. Most of the flights should be concentrated to the 1x1 km area as the most detailed ground truth measurements will be made there. The instruments are installed in helicopters (see chapter 5.1) and can therefore be flown at very low altitudes. The radar altimeter will be tested at altitudes between 4 and 10 m at a flying speed of 30 knots. Runs should be made along the line of drilled holes 10 m apart as well as across and along well defined ridges. Tests should be made over water/ice boundaries, ice of varying thickness and over snowcovered as well as bare ice. Also the effect of water on the ice should be tested. This is valid for the microwave radiometer as well.

## 6.3 High and low level photography

**High level photography.** The Swedish Air Force will be responsible for the high level photography. It may be difficult to carry through this part of the programme as it requires good weather conditions. Probably the occasions will be limited to one or two. As far as possible the high level photography should be carried out simultanously with the SLAR, FLAR and IR-runs. But if this is not possible photography from other periods will also be of value. Examples of possible flight routes are given in Figure 12. The exact routes will be settled only after that the positions of the ground truth area(s) have been determined, as it is desirable that the routes pass directly above the ground truth area(s). The films will be developed and marked for identification by the Air Force. If possible the films will be brought to TOR with the ice-breaker's helicopter immediately after having been developed.

**Low level photography.** The National Land Survey of Sweden will participate with low level photography of the ground truth area. The equipment will be a Wild RC 8 measuring camera, 23x23 cm with an UAg 152 mm objective. A Hasselblad camera package 6x6 cm will be used in parallel. For recordings in UV and IR a 100 mm objective is used and for colourfilm a 50 mm objective. The flights will be performed as shown in Figure 13.

**Figure 12.** *Examples of possible flight routes for the high altitude air photography.*

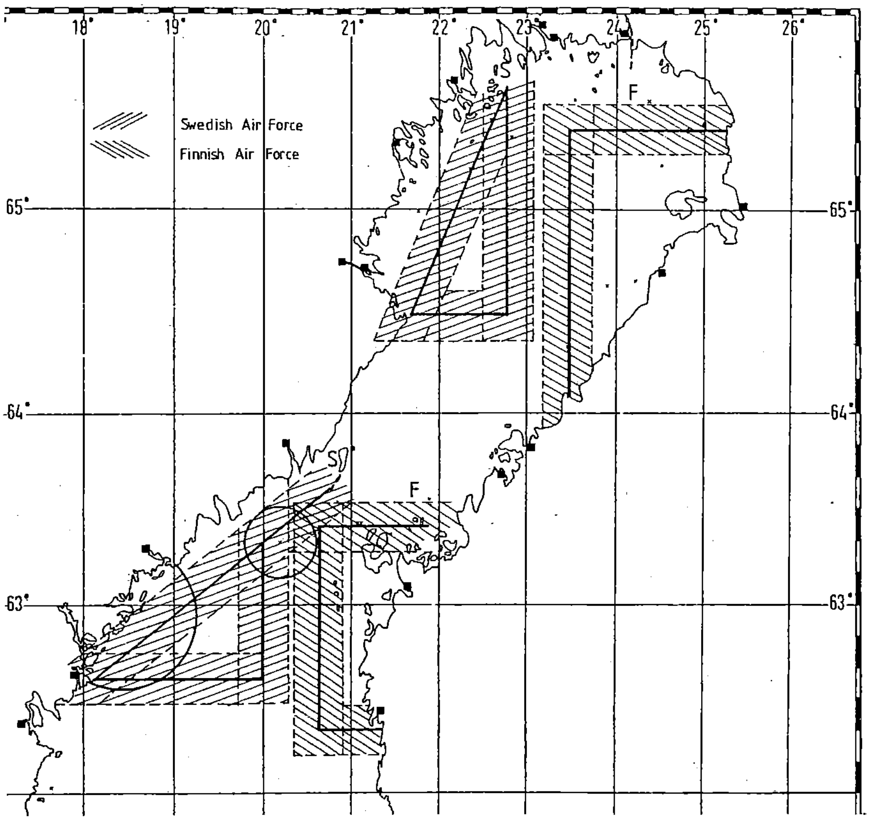
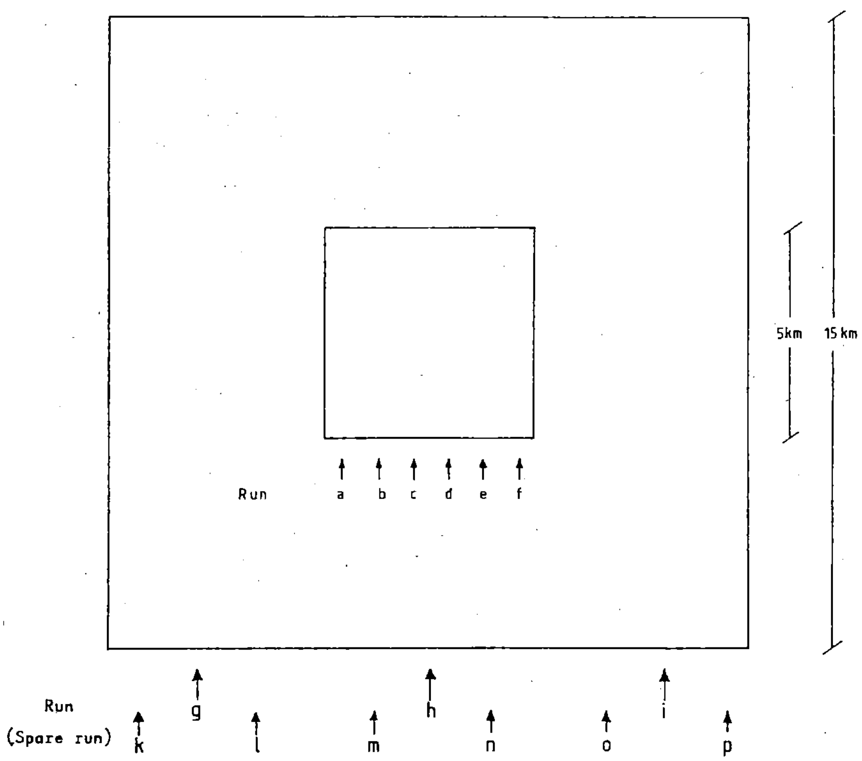



**Figure 13.** *Planned flight program for the low and medium altitude air photography.*




| Run | Film + Camera + obj | Alti-tude (m) | Scale on negative | Cover-ed area ($m^2$) | Excess covering in runs % | Excess covering between runs | No of pictures Per run | No of pictures Total |
|---|---|---|---|---|---|---|---|---|
| a – f | UV resp IR 2 Hasselblad 100 mm Colour film | 1500 | 1:15000 | 825 x825 | 20 | 0 | 2 x 9 | 2 x 54 |
| a – f | Hasselblad 50 mm Colour film | 1500 | 1:30000 | 1650 x1650 | 60 | 50 | 9 | 54 |
| g – i | Wild RC8 152 mm | 4600 | 1:30000 | 6900 x6900 | 60 | 20 | 7 | 21 |
| k – p | – " – | 2300 | 1:15000 | 3400 x3400 | 60 | 20 | 12 | 72 |

# 7. Coordination of the Experiment

## 7.1 Project managing group

The field experiment is managed by a project managing group with the following composition

| | |
|---|---|
| Project leader: | Claës Pilo, Swedish Space Corporation |
| Scientific leader: | Thomas Thompson, Swedish Meteorological and Hydrological Institute (SMHI) |
| Technical leader: | Åke Blomquist, National Defence Research Institute (FOA). |

The project managing group will be located on the ice-breaker TOR during the experiment. The group will work in close contact with the captain of the ice-breaker.

## 7.2 Safety

The captain on the ice-breaker is responsible for the safety on the sea during the experiment.

The air traffic control and the participating aeroplane and helicopter pilots are responsible for the safety in the air during the experiment.

If possible, the officer on duty on the ice-breaker will follow the participating aeroplanes and helicopters on radar.

It must be strongly emphasized that there are restricted areas along the Swedish coast where foreign aeroplanes are not allowed.

In the permission for the Duth aircraft to participate in the experiment the responsible Swedish authority has stipulated that the flights shall be performed in accordance with existing regulations for civil aviation.

The participants have to follow the safety regulations of their own organizations.

## 7.3 Communications

The officer on duty on the ice-breaker is responsible for the communications between the project managing group and the participating units.

A separate list of radio frequencies, call signals and telephone numbers will be distributed to the participants in time before the experiment.

## 7.4 Preparations before take-off

Ice reconnaissance will be performed from the helicopter on board the ice- breaker every morning during the experiment between 07.00 and 08.00 hrs.

The project managing group will obtain weather and ice forecasts from SMHI every day during the experiment at 08.15 hrs, 16.00 hrs and 20.00 hrs.

Each participating group should contact the project managing group every day during the experiment between 08.30 and 09.00 hrs to get information whether the flights will take place that day and to have the latest information on changes in the flight programme, the exact position of ground truth area(s) etc.

The project managing group shall be immediately informed of any difficulty which might hazard the participation in the experiment.

## 7.5 After take-off

After take-off radio contact should be established with the project managing group.

A tentative time schedule for the flight programme is shown in Annex 3. Depending on the weather and ice conditions the project managing group is free to make changes in the programme.

## 7.6 Record keeping

It is fundamental that all participating units keep detailed records of flight data, recordings made, etc. The importance of accurate position and time data is stressed.

# 8. Evaluation and Reporting

All primary data, results and reports from the field experiment will be available to all participating organizations.

A catalogue covering all registrations and measurements made during the field experiment will be prepared immediately after the experiment.

A "Following up" meeting with all participants in the experiment will be organized by the end of May 1975.

The following institutions will be responsible for treatment of primary data and evaluation.

| | |
|---|---|
| SLAR | Rijkswaterstaat Meetkundige Dienst together with Physics Laboratory TNO-RVO, Netherlands |
| FLAR | FOA |
| ODAR | FOA |
| Land-based radar | FOA |
| Radar altimeter | Saab-Scania |
| Microwave radiometer | Radio Laboratory, Helsinki University of Technology, Finland |
| SR (NOAA-4) | SMHI |
| VHRR (NOAA-4) | SMHI |
| MSS (Landsat-2) | SMHI |
| High altitude camera | SMHI |
| Multispectral camera | National Land Survey of Sweden/SMHI |
| IR-scanner | FOA |
| Underwater sensors | SMHI and Finnish Inst for Marine Research |
| Ground truth | SMHI and Finnish Inst for Marine Research |

Each participating institution is expected to prepare a report in English on its results before 3th June 1975. The individual reports should in particular deal with the following questions

- ☐ The sensors' capacity to map large areas of sea ice
- ☐ The sensors' ability to map ice ridges
- ☐ The sensors' ability to map the concentration of ice/open water
- ☐ The sensors' ability to measure ice thickness
- ☐ The sensors' ability to measure movements of the sea ice
- ☐ The influence of weather on the sensors
- ☐ The influence of darkness on the sensors.

A summary report in English on the experiment will be prepared by the project managing group in the autumn of 1975 and published in the series of reports from the Swedish-Finnish Board for Winter Navigation Research. The final report will result in recommendations concerning the development of weather and darkness independent remotesensing systems for surveillance of sea ice. In case some sensors are not tested this winter, e.g. the land-based radar stations, recommendations will also be made regarding additional field tests.

Time schedule for the preparation work

| **Date** | **Responsible** | **Task** |
|---|---|---|
| Febr 21 | Project man. group | Decisions whether to realize the experiment or not. |
| Febr 27 | Project man. group | Examination of the programme with the participants. |
| March 4—6 | SMHI | Airborne ice reconnaissance. |
| March 6 | Project man. group | Decision whether to locate the ground truth area to the Bay of Bothnia or the Sea of Bothnia. |
| March 7—10 | SMHI | Airborne ice reconnaissance. |
| March 9 | SMHI | Decision on in which part of the Bay of Bothnia (Sea of Bothnia) the ground truth area should be located. |
| March 11 | SMHI | Final choice of location of the ground truth area. Ice reconnaissance. Field work. Markings on the ice. |
| March 11 | Ice-breaking Service | Ice-breaker in position in the ground truth area. |
| March 12 | Project man. group | Control that the participating groups have arrived to their bases. |
| March 12 | SMHI | Field work. Further markings on the ice. |
| March 13—21 | Project man. group | Remote sensing experiment. |
| March 21—23 | SMHI | Water drag experiment. |

Annex 2

SMHI
VBM

# REMOTE SENSING of SEA ICE THE WINTER 1974/75

## PLANNING DIAGRAM

1975-02-10

| SENSOR | CARRIER | RESPONSIBLE | JANUARY 8 | FEBRUARY 4 27 | MARCH 10 21 | APRIL | MAY | JUNE | JULY | AUGUST | SEPTEMBER |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *OPTICAL AND IR-SENSORS* | | | *PREPARATIONS* | *CONTROL* | | *DATA EVALUATION* | *SUMMARY* | *PRELIMINARY REPORT* | *FINAL REPORT* | | |
| S R 1) | N O A A 2 | Thompson | | | | | | | | | |
| V H R R 2) | N O A A 2 | Thompson | | | | | | | | | |
| M S S | LANDSAT-2 | Pilo Palosuo | | | | | | | | | |
| High Altitude Camera | Draken | Thompson Grönwall | | | | | | | | | |
| Multispectral Camera | Aero Commander | Pilo Palosuo | | | | | | | | | |
| IR-Scanner | DC-3 | Fagerlund | | | | | | | | | |
| | | | | | | | | | | | |
| *MICRO-WAVE SENSORS* | | | | | | | | | | | |
| S L A R 4) | Queen Air | Pilo | | | | | | | | | |
| F L A R 5) * | Pembroke | Blomquist | | | | | | | | | |
| O D A R 6) * | Vertol | Blomquist | | | | | | | | | |
| Landbased radar | Dalsberget Sydostbrot | Blomquist | | | | | | | | | |
| Ships radar | Icebreaker | Christenson | | | | | | | | | |
| Radar altimeter | Lama | Axelsson | | | | | | | | | |
| Micro-wave radiometer | Jet Ranger | Palosuo | | | | | | | | | |
| | | | | | | | | | | | |
| *UNDER WATER SENSORS* | | | | | | | | | | | |
| S O N A R | —— | Palosuo | | | | | | | | | |
| Under water TV | Diver | Christenson Palosuo | | | | | | | | | |
| | | | | | | | | | | | |
| *GROUND TRUTH* | | | | | | | | | | | |
| Visual ice mapping incl. low light TV | Jet Ranger Lama | Thompson | | | | | | | | | |
| Visual ice mapping with ice drilling | —— | Udin | | | | | | | | | |
| Met. & ocenagr parameters | —— | Thompson | | | | | | | | | |

1) Scanning radiometer
2) Very high resolution radiometer
3) Multi-spectral scanner

4) Side-looking airborne radar
5) Forward-looking airborne radar
6) Omni-directional airborne radar
* Horisontal and vertical polarisation

| = Meeting of Remote-Sensing group

= Gathering in field

= Test period

= Breaking-up

im

SMHI
VBM

1975-02-11

# REMOTE SENSING of SEA ICE THE WINTER 1974/75
## DETAILED TIME SCHEDULE

kl 09 10 11 12 13 14 15 16

| SENSOR | SENSOR ALTITUDE | DAY 0 | NIGHT 0 | DAY 1 | NIGHT 1 | DAY 2 | NIGHT 2 | DAY 3 | NIGHT 3 | SPARE DAY |
|---|---|---|---|---|---|---|---|---|---|---|
| *OPTICAL AND IR-SENSORS* | | | | | | | | | | |
| SATELLITES | | | | | | | | | | |
| NOAA-2 (SR och VHRR) | 1.400 km | 09-11 | 21-23 | | | | | | | |
| LANDSAT-2 | 900 km | | | | | | | | | |
| AEROPLANES | | | | | | | | | | |
| High altitude camera | 10.000 m | | | | | | | | | |
| Multispectral camera | 500 - 3.000 m | | | | | | | | | |
| IR-Scanner | 500 - 3.000 m | | | | | | 05-06 | | | |
| | | | | | | | | | | |
| *MICRO-WAVE SENSORS* | | | | | | | | | | |
| SLAR (3 cm) | 1.000 - 6.000 m | | | | | | 05-06 | | | |
| FLAR (3 cm) hor.pol. vert.pol. | 500 - 3.000 m | | | | | | 05-06 | | | |
| ODAR (3 cm) | 500 - 3.000 m | | | | | | | | | |
| Ships radar (3 - 10 cm) | 25 m | | | | | | | | | |
| Landbased radar, hor.pol. (3 - 10 cm) vert.pol. | 30 och 210 m **) | | | | | | | | | |
| Radar altimeter (6 cm) | 6 - 200 m | | | | | | | | | |
| Micro-wave radiometer (6 cm) | 20 - 200 m | | | | | | | | | |
| | | | | | | | | | | |
| *UNDER WATER SENSORS* | | | | | | | | | | |
| SONAR | | | | | | | | | | |
| Under water TV | | | | | | | | | | |
| | | | | | | | | | | |
| *GROUND TRUTH* | | | | | | | | | | |
| Visual ice mapping from helikopter *) | 20 - 100 m | | | | | | | | | |
| Visual mapping from the ice | | | | | | | | | | |
| Meteorological and oceanographic measurements | | | | | | | | | | |

*) Including test with transportabel low light TV

**) Sydostbrotten 30 m, Dalsberget 210 m

Annex 3

# Annex 4

List of participants

The following persons and organizations will take part in the experiment.

| Organization | Name | Function | Placing |
|---|---|---|---|
| FINLAND | | | |
| Institute for Marine Research | H Grönwall | Responsible, ground truth (second area) | Ice-breaker Varma |
| University of Helsinki | E Palosuo | Responsible, sonar | " |
| Helsinki University of Technology | M Tiuri | Responsible, microwave radiometer | Jet Ranger |
| " | K Jokela | Assistant, microwave radiometer | " |
| " | A Laperi | " | |
| NETHERLANDS | | | |
| Rijkswaterstaat | R H J Morra | - | - |
| Physics Laboratory | G P de Loor | - | - |
| " | J F C Baesjou | Assistant, SLAR | Luleå |
| " | (or M G Disselen | " ) | " |
| National Aerospace Lab | G L Lamers | Responsible, SLAR | Queen Air |
| | J Beeke | Assistant, SLAR | " |
| | G Kolstein | " | " |
| SWEDEN | | | |
| Swedish Administration of Shipping | A Christenson | - | - |
| " | H Leopold | - | - |
| " | Y Nilsson | Captain of TOR | Ice-breaker TOR |
| SMHI | T Thompson | Scientific leader of the project | " |
| " | I Udin | Responsible, ground truth | " |
| " | A Omstedt | Assistant, ground truth | " |
| " | A Berg | " | " |
| " | J E Lundqvist | Responsible, ice forecasts | Stockholm |
| " | L Rannaleet | Responsible, weather forecasts | " |
| FOA | F Eklund | - | - |
| " | Å Blomquist | Technical leader of the project | Ice-breaker TOR |
| " | J Nilsson | Responsible, FLAR | Pembroke |
| " | G Hermansson | Assistant, FLAR | " |
| " | T Hagman | Responsible, ODAR | HKP 4C |
| " | G Knutsson | Assistant, ODAR | " |
| " | (K R Larsson | Responsible, land-based radar | Dalsberget) |
| " | (O Nyström | Assistant, land-based radar | " ) |
| " | E Fagerlund | - | - |
| " | G Lundholm | Responsible, IR-scanner | DC3 |
| " | B Sehlberg | Responsible, Air Force contacts | Stockholm |
| Land Survey | B Sandström | Responsible, MS-camera | Aero Commandor |
| Saab-Scania | H Lövsén | Responsible, radar altimeter | Lama |
| Swedish Space Corporation | C Pilo | Project leader | Ice-breaker TOR |

## Comments on the utilization of radar data

The aim of the field test is regarding the radar sensors to

- ☐ study the connection between ice properties and radar signatures
- ☐ investigate the possibilities of observing ice drift
- ☐ evaluate the capability of the various radar sensors for ice surveillance.

In the first two of these respects the Dalsberget radar has a very important function. It makes it possible to compare 10 and 3 cm as well as vertical (VP) and horizontal polarization (HP), and it has both PPI and A-display.

On the A-display the radar echo level is given as a function of the distance in a certain direction. If chosen within the coverage of the radar, the ground truth area can be studied in detail by means of the Dalsberget equipment. Each of the three squares within the ground truth area can thus be confined by proper choise of sector and range gate. The level and the character of the back-scattered signal will be studied and compared for different states of ice, ice concentration etc. Of special interest is to investigate the difference in radar signal between open sea, melting ice and frozen surface with and without snow cover.

An analysis will be made of the A-display recordings concerning the variability in time and space in order to find possible differences between various types of ice. The idea is the following. An A-display sweep of an area consisting of fast-ice, open water and ice ridges shows different radar echoes for all the three cases as regards both intensity and character. Only the open water gives variation in time, while on the other hand the two types of ice exhibit space variations of different kind. These might be useful distinctive characteristics.

As the penetration in the ice of 10 and 3 cm is different, these two wavelengths might also give different representation of the depth of the ice.

To study the ice drift, particularly small changes, a fixed reference is useful. Also from this point of view the Dalsberget measurements are suitable.

The air-borne radar sensors give a large surface coverage, and by flights along as well across ice ridges, shore leads etc, the structure of the ice can be properly investigated. The analysis of the PPI-recordings is intended to lead to the smallest resolution necessary for separating different ice parameters.

When analysing the PPI film recordings a film projector with variable picture frequency will be used. This makes it easier to find interesting ice situations for further study. Concerning the FLAR the difference between VP and HP will be particularly studied.

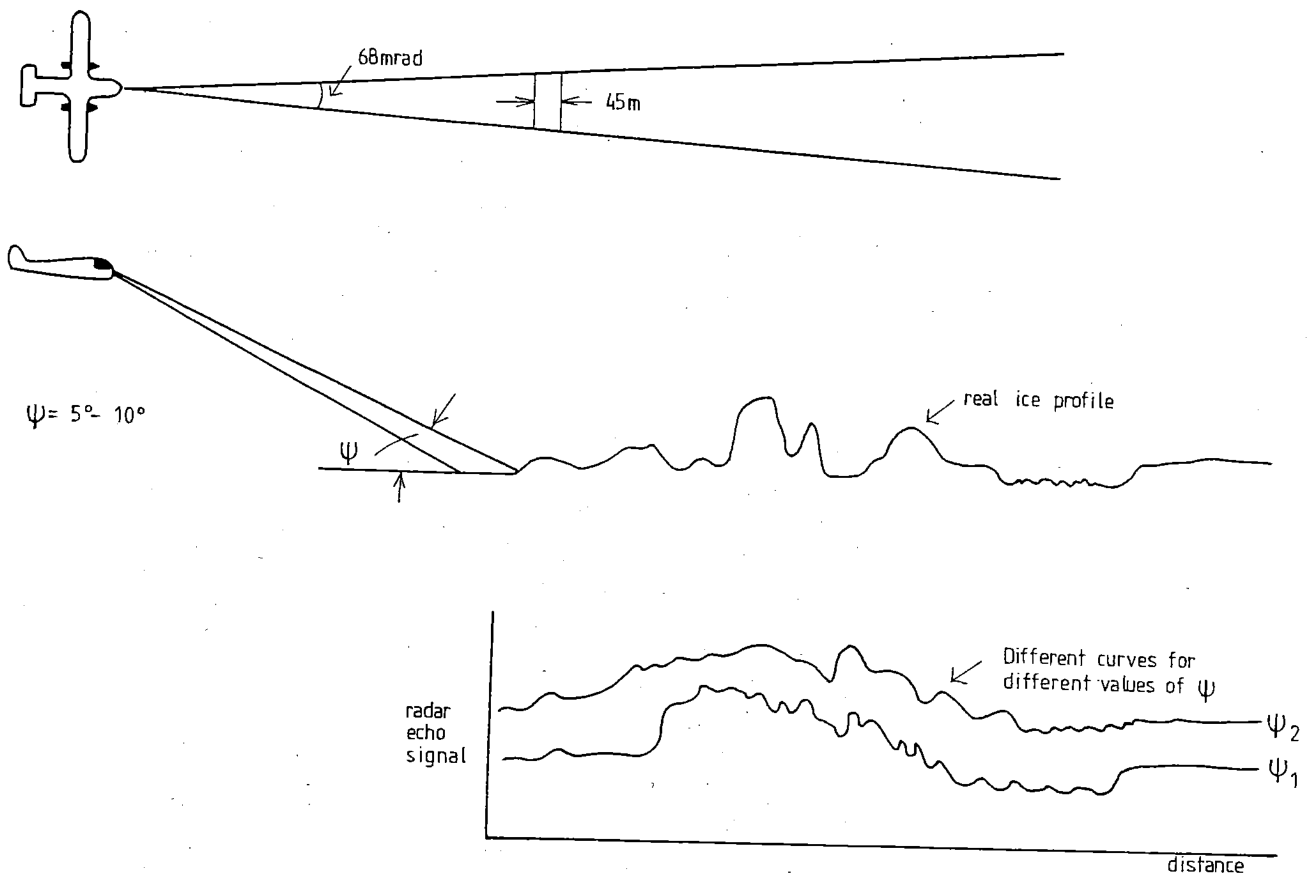
In the FLAR case there is also a possibility to use a videotape recorder. The video information can be evaluated and presented in many different ways, e.g. in the same way as the A-display recording of the Dalsberget radar. This is illustrated in Figure A 1.

When the FLAR flies along a path, radar information is obtained from the various types of ice encountered. This information can be presented as the back-scattered signal versus distance along of the path which is shown at the bottom of Figure A 1. By varying the angle of elevation different curves will be obtained indicating the influence of the grazing angle. The behaviour of the measured curves will depend on the ice situation in question.

It is important to make clear to what extent the PPI real time information is directly useful and what picture processing is necessary to make the radar information suitable for practical use in ice forecasting.

When analysing the measurements it has to be considered that all the sensors have different resolution (see chapter 5.4).

**Figure A1.** *Schematic of FLAR registration.*



# SWEDISH/FINNISH WINTER NAVIGATION RESEARCH BOARD
# REPORTS

| No. | Titel | |
|---|---|---|
| 1. | HAVSISKONFERENS. Protokoll (1972). | |
| 2. | VINTERSJÖFART I BOTTENHAVET — Erfarenheter av SCA:s distributionssystem — L. Sjöstedt och S. Hammarsten (1972). | |
| 3. | ISSKADOR PÅ FARTYG I ÖSTERSJÖN, BOTTENHAVET OCH BOTTENVIKEN. — Statistisk analys av skadefrekvenser — L. Sjöstedt och S. Hammarsten (1973). | |
| 4. | PROPELLERPROBLEM. Propellerverkningsgradens beroende av bladutformningen. H.P. Loid (1973). | |
| 5. | FARTYGS FRAMDRIVNINGSMOTSTÅND I IS. E. Enkvist (1974). | |
| 6. | VINTERSJÖFART MED STORA FARTYG I BOTTENVIKEN. (1974). | |
| 7. | VINTERSJÖFART I BOTTENVIKEN. Symposium Luleå (1974). | |
| 8. | HAVSISUNDERSÖKNINGEN I BOTTENVIKEN VINTERN 1974. A. Omstedt, T. Thompson och I. Udin (1974). | |
| 9. | KARTERING AV YTVATTENTEMPERATUREN I VATTNEN RUNT SVERIGE. J-E. Lundqvist, A. Omstedt och I. Udin (1974). | |
| 10. | EXPERIMENTS ON REMOTE SENSING OF SEA ICE USING A MICROWAVE RADIOMETER. M. Tiuri, M. Hallikainen and K. Kaski (1974). | |
| 11. | BOTTENVIKENS STÅLFYRAR — HÅLLFASTHETSANALYS OCH FÖRBÄTTRINGSFÖRSLAG. M. Määttänen (1974). | |
| 12. | FORMATION AND STRUCTURE OF ICE RIDGES IN THE BALTIC. E. Palosuo (1975). | |
| 13. | CALCULATION OF ICE DRIFT IN THE BOTHNIAN BAY AND THE QUARK. A. Valli and M. Leppäranta (1975). | |
| 14. | A NARROW BEAM SONAR TO MEASURE THE SUBMARINE PROFILE OF AN ICE RIDGE. E. Palosuo, T. Pousi and M. Luukkala (1976). | |
| 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). H. Grönvall and E. Palosuo (1976). | |
| 16:1 | SEA ICE -75. | Programme. Å. Blomquist, C. Pilo and T. Thompson (1975). |
| 16:2 | SEA ICE -75. | Ground truth report. I. Udin (1976). |
| 16:3 | SEA ICE -75. | Ice detection by SLAR. R.H.J. Morra and G.P. de Loor (1976). |
| 16:4 | SEA ICE -75. | Analysis of SLAR data. S. Parashar (1976). |
| 16:5 | SEA ICE -75. | FLAR, ODAR, ship's radar. J. Nilsson, T. Hagman and Y. Nilsson (1976). |
| 16:6 | SEA ICE -75. | IR-scanner results. E. Fagerlund and G. Lundholm (1976). |
| 16:7 | SEA ICE -75. | Radaraltimeter results. S. Axelsson (1976). |
| 16:8 | SEA ICE -75. | Dynamical report. I. Udin and A. Omstedt (1976). |
| 16:9 | SEA ICE -75. | Summary report. Å. Blomquist, C. Pilo and T. Thompson (1976). |