STYRELSEN FÖR
VINTERSJÖFARTSFORSKNING

WINTER NAVIGATION RESEARCH BOARD

Research Report No 10

EXPERIMENTS ON REMOTE SENSING OF
SEA ICE USING A MICROWAVE RADIOMETER

HELSINKI UNIVERSITY OF TECHNOLOGY

RADIO LABORATORY

EXPERIMENTS ON REMOTE SENSING OF SEA ICE
USING A MICROWAVE RADIOMETER

Martti Tiuri

Martti Hallikainen

Kimmo Kaski

OTANIEMI FINLAND

Preface

The Winter Navigation Research Board presents its report
No 10. This report gives an account of the experiments
and investigations carried out so far for the purpose of
developing a microwave radiometer suitable for sea ice
reconnaissance in the Baltic. The work has been carried
out by a team from the Helsinki University of Technology
led by Professor Martti Tiuri.

The Winter Navigation Research Board expresses its
appreciation of the work and its thanks to professor
Tiuri and his assistants.

Helsinki and Stockholm,   October   1974

Helge Jääsalo   Lennart Johansson

Experiments on remote sensing of sea ice
using a microwave radiometer

Martti Tiuri

Martti Hallikainen

Kimmo Kaski

Helsinki University of Technology

Summary

Investigations have been started in Finland to find out
if microwave radiometers can be used in surveying sea ice for
controlling ice breakers in the Baltic Sea. Based on theoretical
calculations of the brightness temperature of sea ice the
frequency of the radiometer was selected to be 4.7 GHz. The radio-
meter uses a novel traveling wave antenna with a beam direction
dependent on the frequency. A three-channel radiometer carried
by a helicopter measures the brightness temperatures of three
adjacent ice strips. An auxiliary radiometer at 605 MHz is used
for checking purposes. During the winter of 1974 several meas-
urements of different ice types were made, the results of which
are described and discussed.

1. Introduction

Microwave radiometer studies made in the Arctic Ocean close
to Alaska have shown that the noise temperature (brightness
temperature) of the ice surface is dependent on the age of the
ice /1/. The measured brightness temperature of the multiyear-ice
at 19.35 GHz has been 20 to 40 degrees colder than that of the
first-year ice and hence it has been possible to distinguish
multi-year ice from the first-year ice. The open water has been

found to have a brightness temperature at least 100 K less
than thick first-year ice.

On these grounds the Radio Laboratory of the Helsinki University
of Technology and the Finnish Board of Navigation agreed to a
research project to investigate if the passive microwave method
is useful in determining the ice characteristics of Bothnian Bay.
The project was started in 1972.

2. Theoretical calculations of the brightness temperature of sea ice

During the first phase of the study theoretical calculations
of the brightness temperature were made using different models for
the sea ice /2/. The brightness temperature T_e of sea ice is
dependent on the transmission coefficients at the water-ice (τ_w)
and ice-air (τ_a) surfaces, on the absolute temperatures of water
(T_w) and ice (T_z), and on the attenuation coefficient of the ice α_z:

$$T_e = \tau_a^2 \left\{ \tau_w^2 \frac{T_w}{L} + \int_0^1 T_z \frac{(1 - e^{-2\alpha_z dz})}{L_z} \right\} \qquad (1)$$

In the equation L is the total attenuation of the ice and L_z
is the attenuation of the ice layer between the point z and
the upper surface of ice (z = 0 at the water-ice interface
and 1 is the thickness of ice).

Sea ice has a very complicated structure with small pockets
of brine or salt water entrapped in it. These pockets diffuse
downwards with time and hence the salinity profile and the
attenuation of sea ice are dependent on its age and history.
Using typical salinity values and profiles occurring on Bothnian
Bay /3/ the results of theoretical calculations showed that the
brightness temperature increases with the ice thickness at fre-
quencies lower than 10 GHz, Fig. 1. At higher frequencies the
attenuation in sea ice is so high that the brighness temperature
is determined by the uppermost layer of ice. The decrease of the
brightness temperature after Feb 21 is due to the relatively
large change in the salinity profile of ice.

3. Radiometers used in the experiments

On the basis of theoretical results a frequency of 4.7 GHz was selected for the radiometer. It is also a frequency where interference level is expected to be low. The disadvantage is that the resolution of the radiometer antenna is not as good as at frequencies over 10 GHz. For purposes of comparison it was decided to use a 605 MHz radiometer at the same time.

A novel traveling wave antenna developed at the Radio Laboratory of the Helsinki University of Technology was selected as the antenna of the 4.7 GHz radiometer, Fig. 2/4/. This antenna (a grid antenna) has a beam direction which is dependent on the frequency and hence it is possible, by employing a multichannel radiometer, to measure the brightness temperature of several adjacent ice strips simultaneously (three channels in this case). The size of the 4.7 GHz antenna was about 1 x 1 m^2 with the individual beam widths of about four degrees, Fig. 3, and the 600 MHz antenna was a four element dipole array above the grid antenna. The antennas with preamplifiers were attached under the helicopter carrying the radiometer system.

Fig. 4 shows the block diagram of the radiometer system. A tunnel diode amplifier is used as a first stage of the 4.7 GHz radiometer giving a receiver system noise temperature of about 1000 K. The bandwidth of each channel is about 30 MHz. The first stage of the 605 MHz radiometer is a transistor amplifier and the system noise temperature of the receiver is about 800 K. The bandwidth is 8 MHz.

The theoretical sensitivity of a Dicke-type radiometer is

$$T = 2T_S/\sqrt{\tau B} \tag{2}$$

where T_S is the system noise temperature, B the predetection bandwidth and τ the postdetection integration time /5/. The post detection integration time is determined by the velocity of the helicopter (or airplane) and by the antenna beam width. A suitable value is 0.3 s which corresponds to a theoretical sensitivity of 0.7 K for the 4.7 GHz radiometer and 1 K for the 605 MHz radiometer.

The outputs from the three channels of the 4.7 GHz radio-
meter and from the one channel of the 605 MHz radiometer were
recorded by a four-channel tape recorder.

4. Experimental results

Preliminary experiments with the multichannel radiometer
were made during one week in March this year on Bothnian Bay.
Test sites were selected with different ice types and thicknesses.
The altitudes of helicopter flights varied from 20 m to 200 m.
The speed of the helicopter was 150...200 km/h. Several ground
truth-measurements of ice thickness and ice characteristics were
also made. The thickness of ice varied from 0 to 90 cm. In many
areas there were small and large ridges. Figures 5-7 show typical
brightness temperature recordings of the sea ice.

From the measurements the following conclusions can be made:

- Open water has a very low brightness temperature of about
  120 K which is over 100 K smaller than the temperature of
  thick ice, hence rifts and open leads are easily detected
  using the microwave radiometer.
- Already a relatively thin ice layer increases the brightness
  temperature of the sea surface considerably (8 cm ice has
  a brightness temperature which is only about 25 K lower than
  that of thick ice.
- The effect of ice thickness on the brightness temperature
  seems to be relatively small for thicknesses over about 40 cm.
  Hence accurate ice thickness measurements are not possible
  in the case of thick ice.
- Pressure ridges have brightness temperatures about 10 K less
  than those of surrounding areas with normal ice. This indicates
  that it should be possible to detect ice ridges which is
  important in guiding the ice breakers.
- 605 MHz and 4.7 GHz brightness temperatures do not differ
  very much and show similar characteristics.

5. Discussion

Preliminary results indicate that the microwave radiometer
will be a useful device in ice surveying. Independently of weather
or light conditions it can be used to find open rifts and leads
and to distinguish thick ice from thin ice. It seems possible that
ice ridges can be detected too. However it must be remembered that
the brightness temperature measurements have been made during one
week in March only and more extensive experiments during the whole
winter are necessary for confirming the results.

Latest results from sea ice investigation in Alaska /7/
indicate that the difference in the brightness temperature of
multi-year ice and first-year ice is due to the porosity difference.
The brightness temperature decreases with increasing porosity and
the surface layer of the multi-year ice can contain 30 percent
air bubbles by volume. Perhaps similar effects are involved in
ridges whose upper surfaces are older ice and elevated above the
normal ice surface.

When seeking suitable ice breaker routes thick large ice
ridges /6/, Fig. 8, must be avoided because they can be very
difficult to cross. Normal ice, even if relatively thick will
not cause trouble for modern ice breakers. Hence if a microwave
radiometer can be used to locate large difficult ridges, as the
experimental results indicate, it will speed up the ice breakers
and facilitate winter navigation. Carried by the helicopter at
an altitude of 100 to 200 meters the radiometer can see open water
areas, distinguish thin ice from thick ice and possibly detect the
size of the ice ridges.

Bad weather conditions can prevent visual ice surveys for
many weeks at a time during the winter. In these situations the
microwave radiometer on board an airplane flying at an altitude
of 1...10 km can be used to obtain a general picture of the ice
situation, find open rifts and locate thick ice areas.

Because of complicated ice situation on Bothnian Bay an imaging
microwave radiometer seems to guarantee the best results. The
radiometer system used in the experiments can be expanded to give
a rough microwave image by adding channels and, using a suitable
device, to display the results in a map form. (A mechanically or
electronically sweeping radiometer cannot be used due to sensitivity

reduction caused by a shortened integration time). The display
device can be at the ice breaker where the measurement results
are sent via a radio connection (voice channel). A 2 x 10 channel
radiometer will produce an ice map with a width about the same
as the flying altitude and with a resolution one twentieth of
the altitude.

References

/1/ T. Wilheit, J. Blinn, W. Campbell, A. Egerton, W. Nordberg:
Aircraft Measurements of Microwave Emission from Arctic
Sea Ice; Goddard Space Flight Center Preprint X-651-71-1117,
Sept 1971.

/2/ M. Hallikainen: Analysis of dielectric properties and noise
temperature of sea ice for microwave remote sensing applications;
Proceedings 1973 European Microwave Conference, Brussels
University, Vol 2 C.15.3.

/3/ E. Palosuo: The Gulf of Bothnia in Winter; Institute of
Marine Research Publications No 209, Helsinki 1963.

/4/ M. Tiuri, S. Tallqvist, S. Urpo: Chain antenna; IEEE
AP-symposium, Atlanta Georgia, June 1974.

/5/ M. Tiuri: Radio telescope receivers; VII Chapter in
Kraus: Radio Astronomy, McGraw-Hill 1966.

/6/ E. Palosuo: Formation and structure of ice ridges in the
Baltic; Styrelsen för vintersjöfartsforskning Sverige-Finland,
Forskningsrapport (to be published).

/7/ D.C. Meeks, R.O. Ramseier, W.J. Campbell: A study of
microwave properties of sea ice - AIDJEX 1972; 9th Inter-
national symposium on Remote Sensing of Environment,
Ann Arbor Michigan, April 15-19 1974.
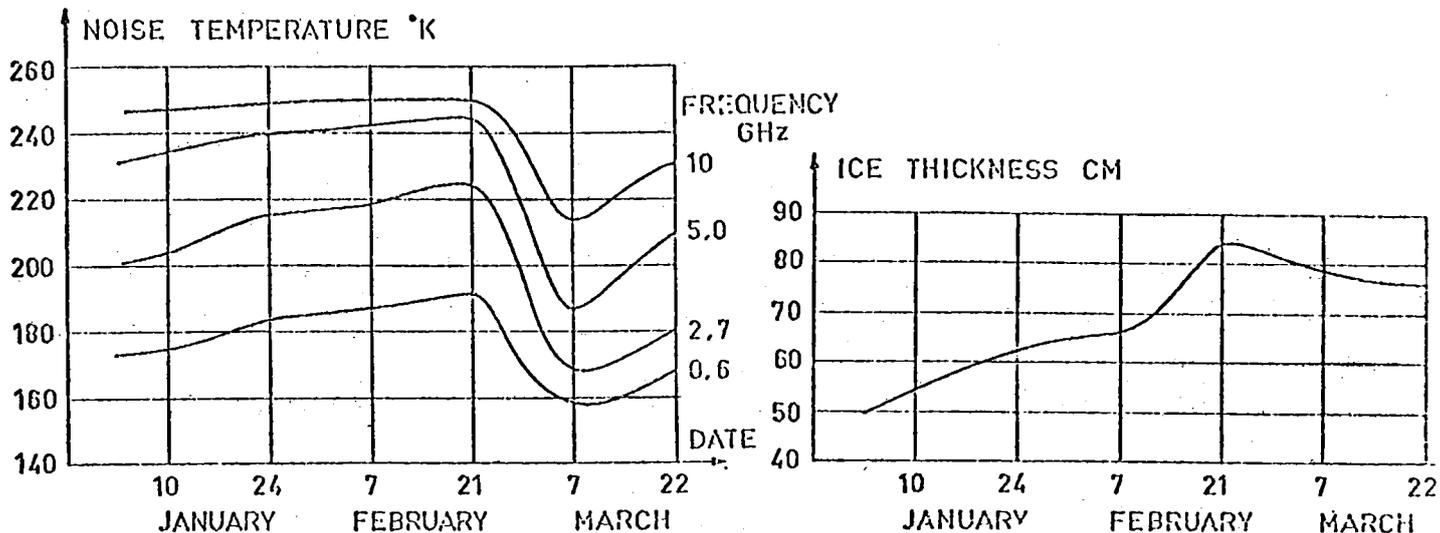
Figure 1. Calculated noise temperature of sea ice at different frequencies as a function of time (based on experimental salinity, temperature and thickness values of sea ice on Bothnian Bay)
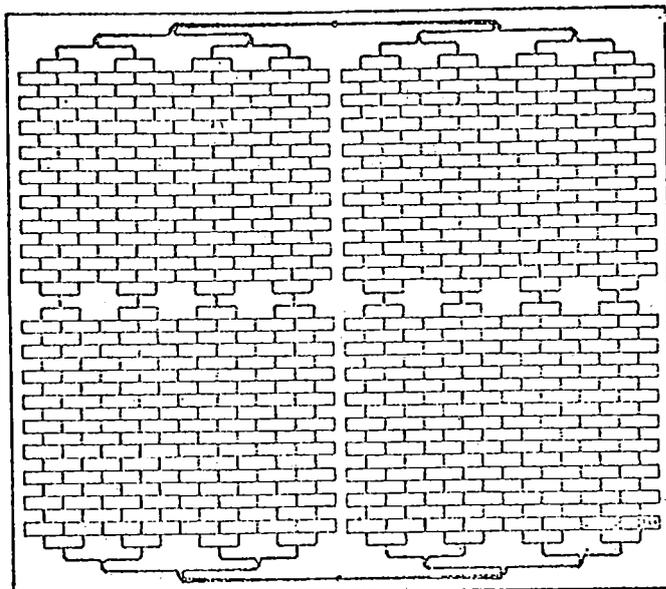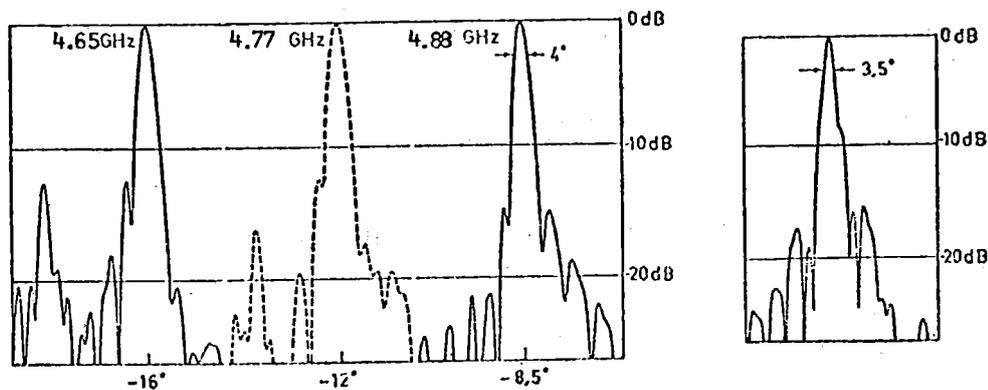

Figure 2a. 4,7 GHz grid antenna

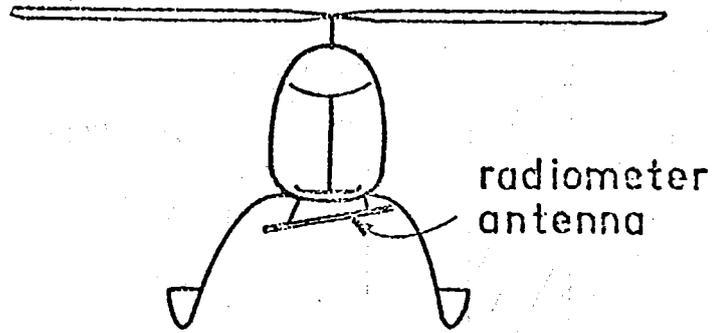Figure 2b. Radiation patterns of the grid antenna at different frequencies in two planes

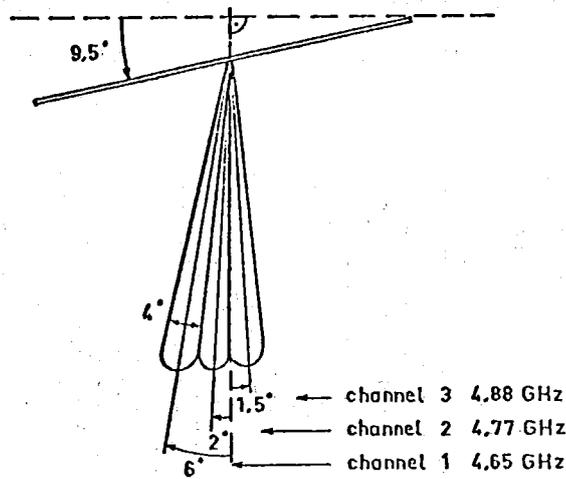Figure 3a. A helicopter with the 4.7 GHz antenna

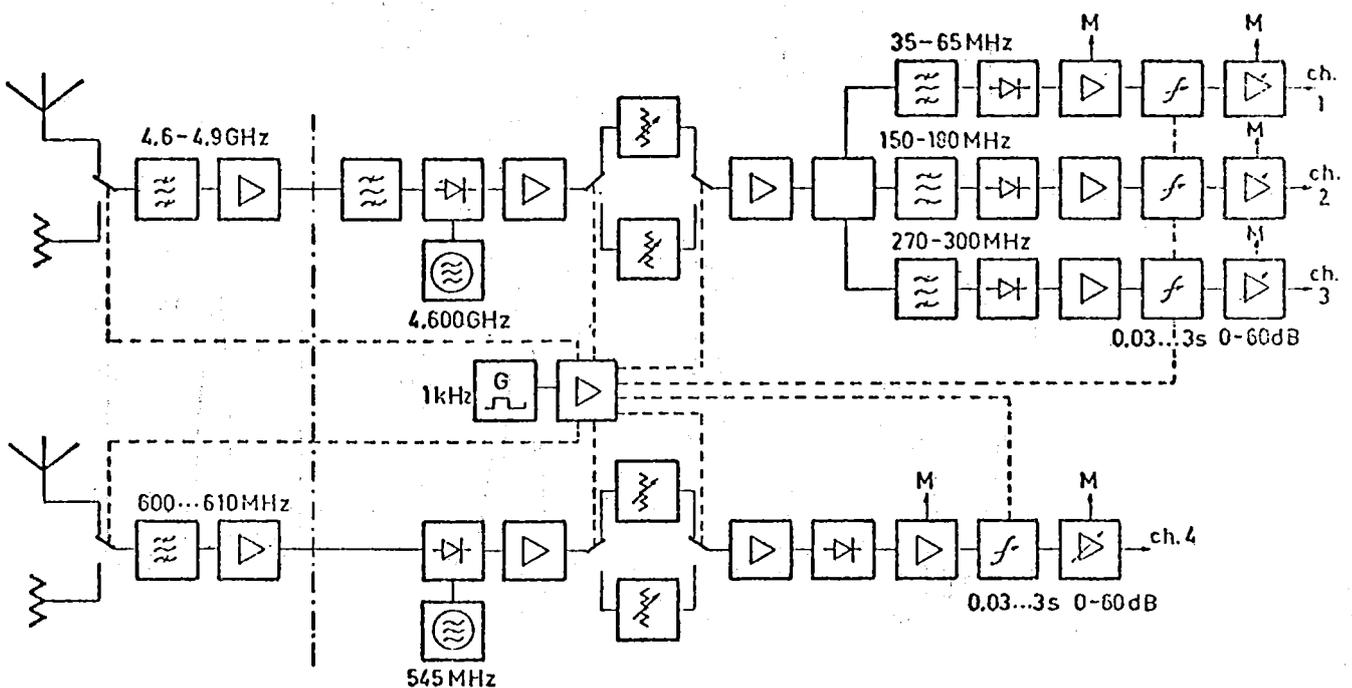

Figure3b. Beam directions of the three-channel radiometer

Figure 4. Block diagram of the radiometer system
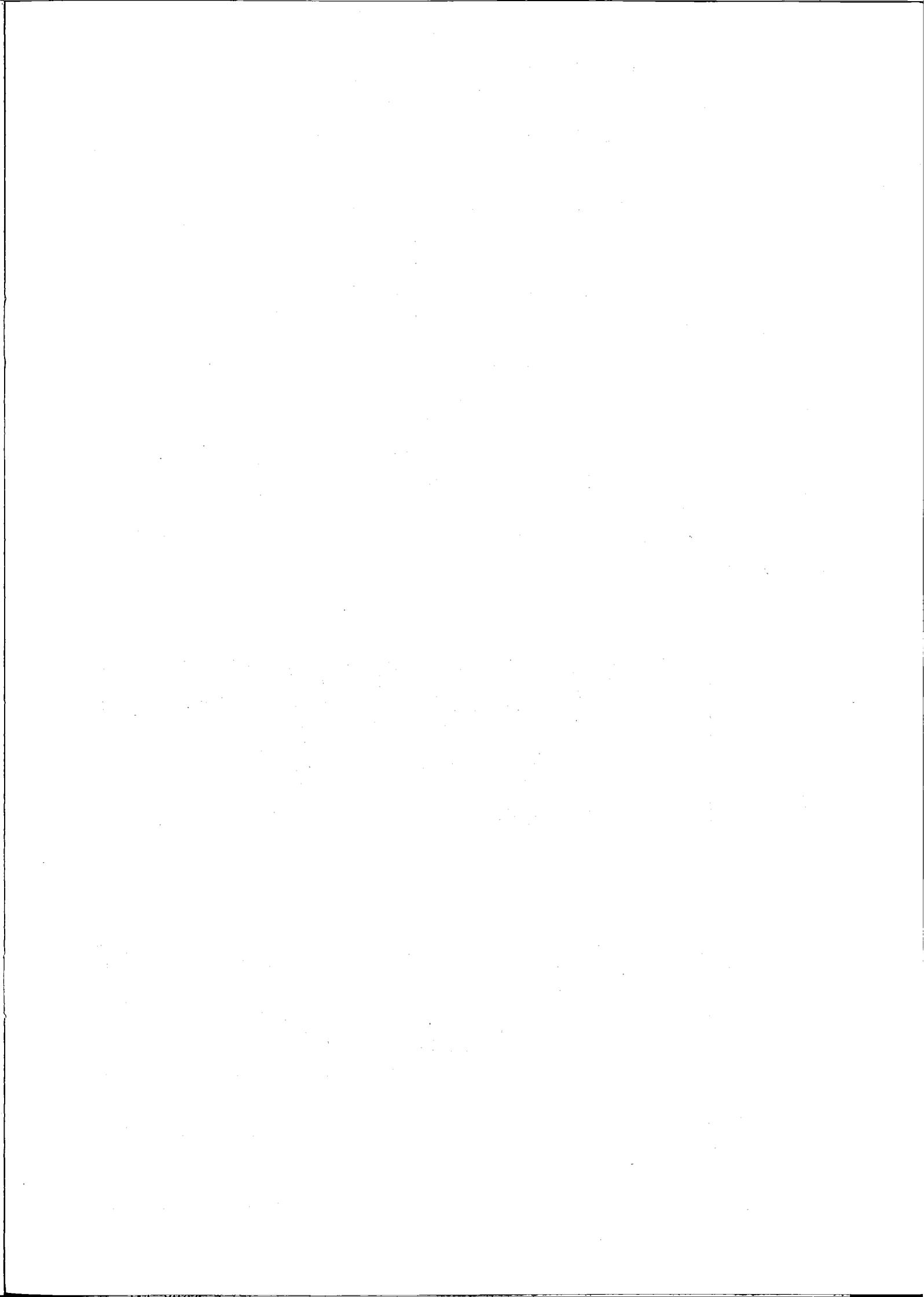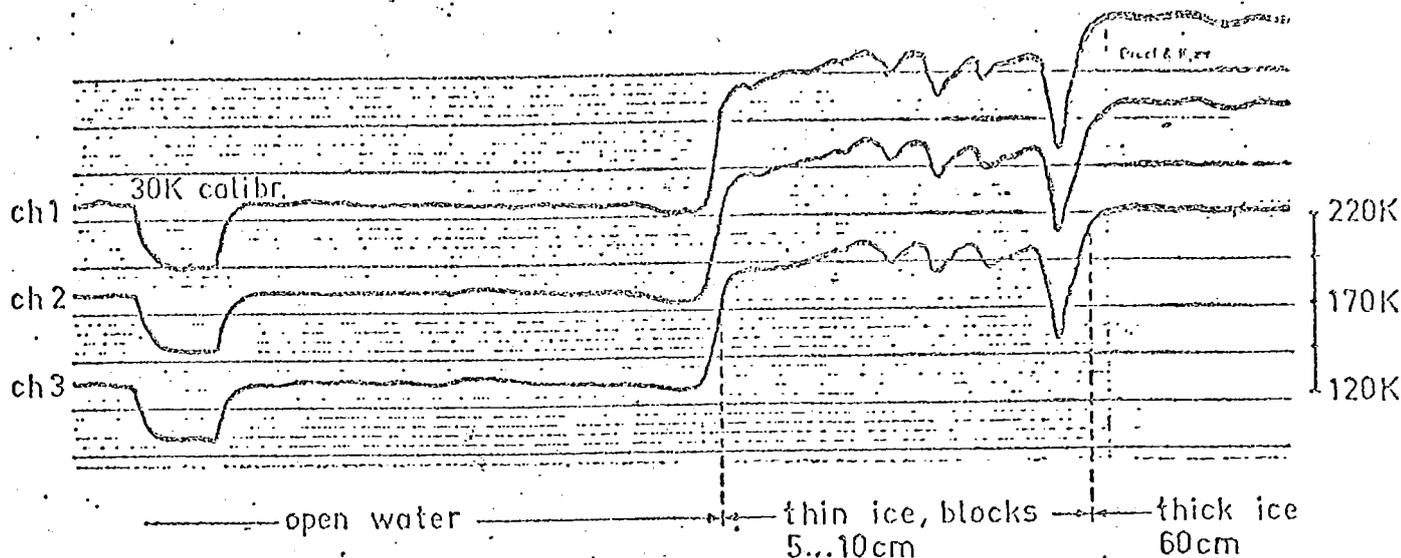
Figure 5. Measured noise temperature of open sea water and different types of ice on Bothnian Bay (4.7 GHz three channel radiometer outputs).
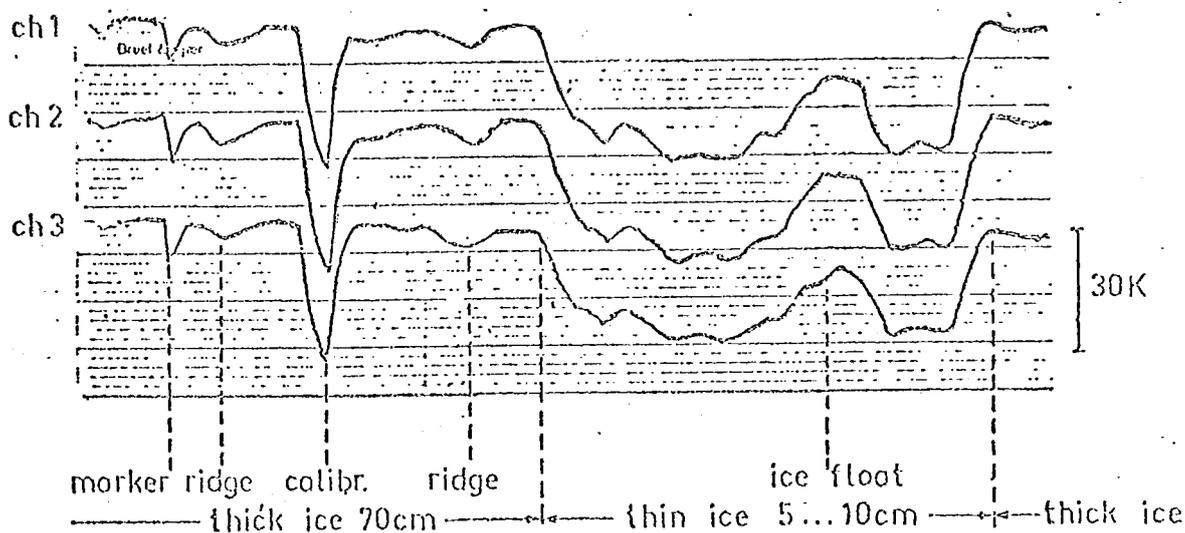
Figure 6. Measured noise temperatures of different sea ice types at 4.7 GHz on Bothnian Bay. The length of the measured area is about 2 km.
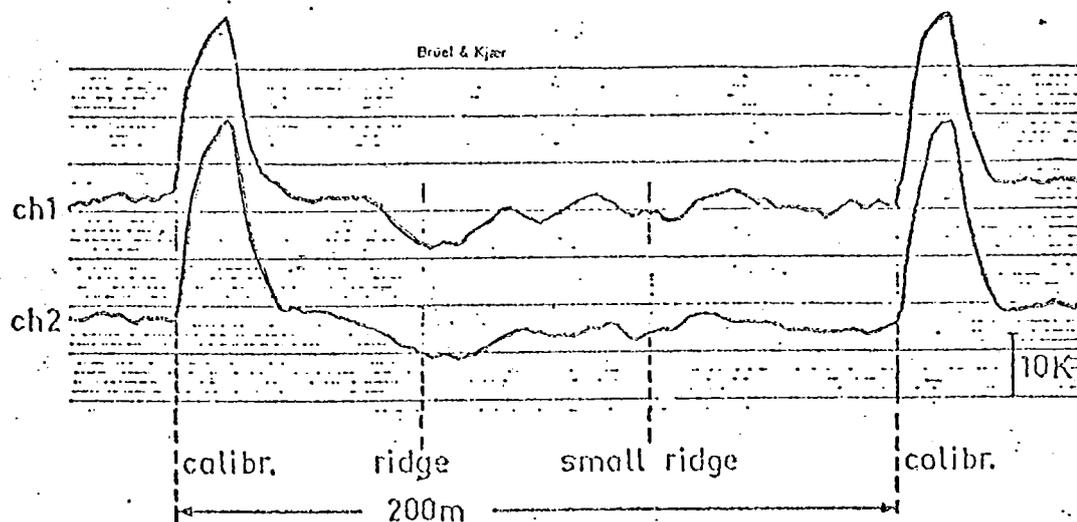

Figure 7. Measured noise temperatures of an ice ridge area (outputs of two channels at 4.7 GHz)
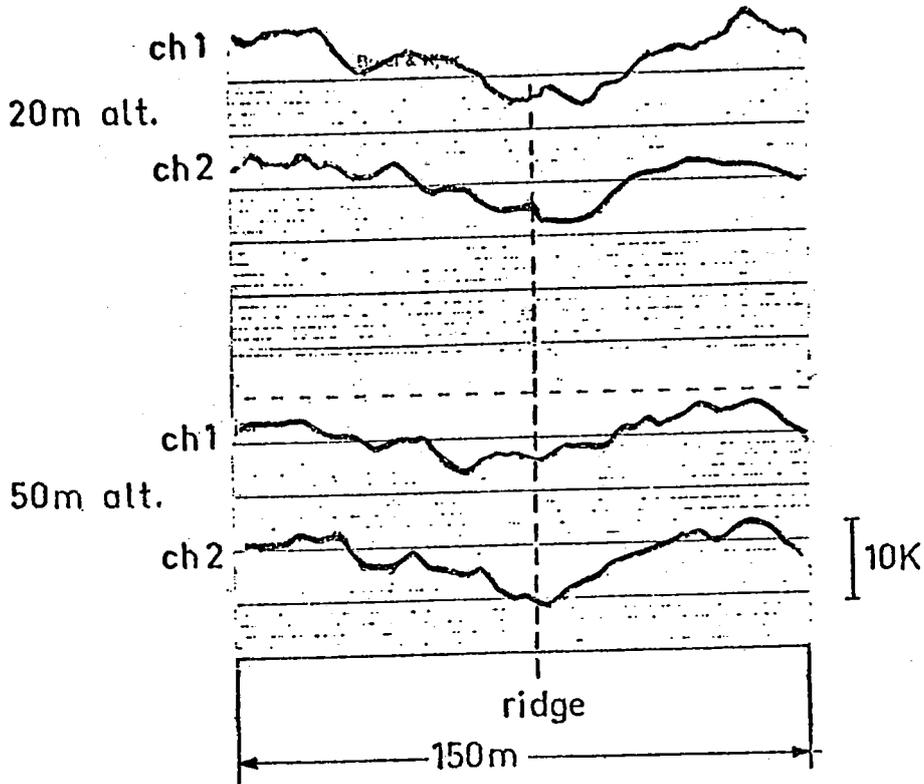
Figure 8. Measured noise temperature of an isolated ice ridge (outputs of two channels at 4.7 GHz)
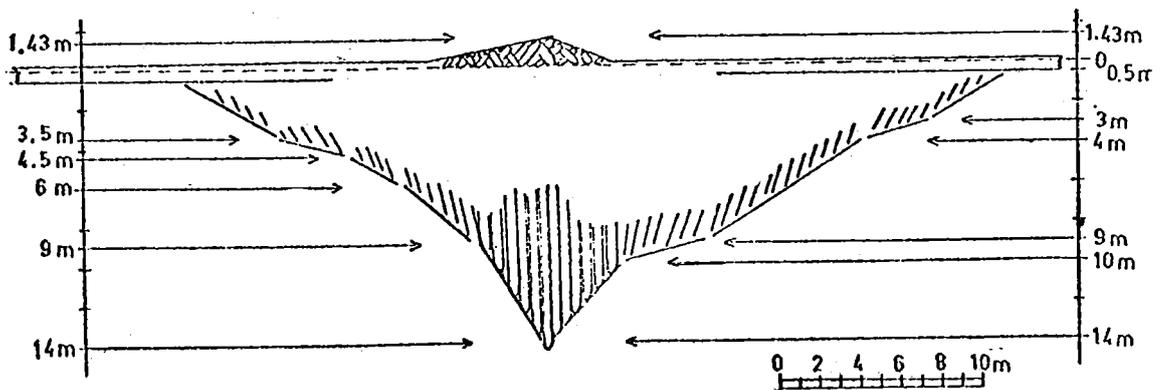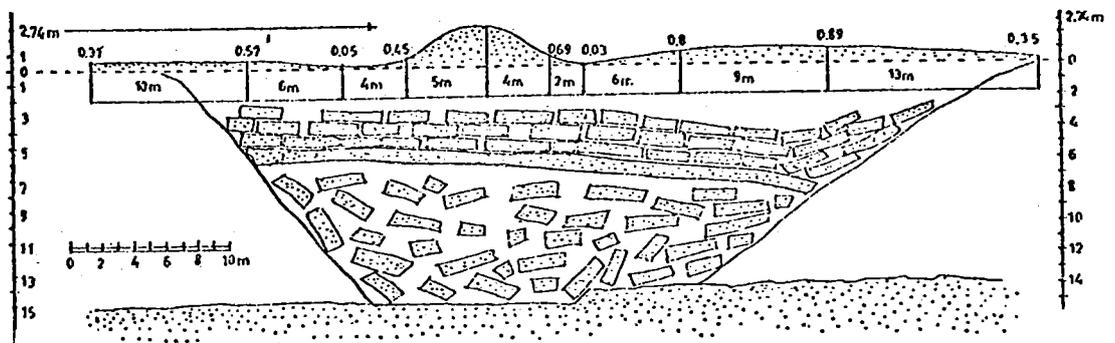

Figure 9. Cross sections of two typical ice ridges on Bothnian Bay. The first ridge extends to the sea bed.