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MICROWAVE SIGNATURES OF YOUNG SEA ICE AND ITS INFLUENCE ON ICE CONCENTRATION ALGORITHMS

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ABSTRACT

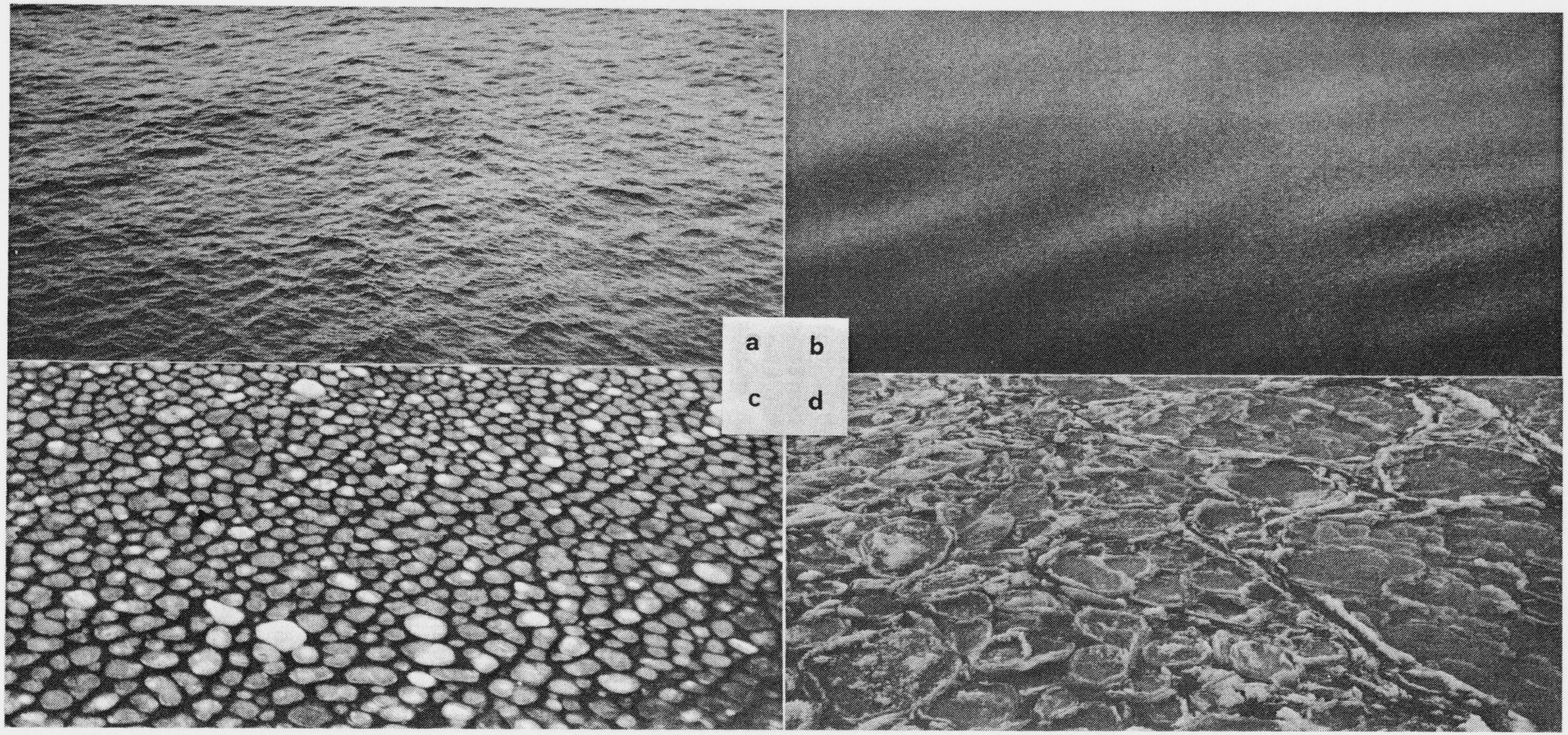
Passive and active microwave signatures show large variations when new sea ice is formed in the marginal ice zone. Whereas the emissivities increase monotonically with increasing ice thickness as a result of decreasing surface wetness, no monotonic change is found for backscattering coefficients due to the strong influence of the surface roughness. Therefore, passive sensors are preferable for ice concentration algorithms. The changes in signatures from open water to the typical first-year ice signature take place within the first few cm of ice thickness. These results are based on measurements of microwave signatures made from icebreaker based instruments during the Norwegian Remote Sensing Experiment in 1979.

1. INTRODUCTION

The microwave signatures are emissivities and backscattering coefficients as defined by Peake (1959). Both, passive and active microwave remote sensing show high contrast between open and ice-covered ocean surfaces. Together with the all weather and day and night capability of microwaves, this contrast makes the microwaves the most promising spectral band for remote sensing of sea ice. In order to assess the accuracy with which ice concentrations can be retrieved, it is necessary to study the signatures of all types of ice present, and to select those sensors which show a monotonic transition of the signature when ice is growing in thickness from open water to thick first year ice.

In addition, the critical ice thickness at which a signature is half way between open water and thick ice should correspond to the critical thickness of the remote sensing application discipline. For instance, in climatology sea ice is important for reducing the energy exchange between ocean and atmosphere; the thickness at which the energy exchange rate is reduced to one half is between 5 and 10 cm (Maykut 1978). Therefore, an optimum heat exchange sensor should have a critical thickness in the cm range.

Microwave signatures were measured mostly from aircraft, and also from sea ice platforms. In the first case, the investigation suffered from the lack of in situ observations, and in the latter case the investigation was limited to thick ice. During the Norwegian Marginal Ice Zone Experiment (NORSEX), Sept.-Oct. 1979, north of Svalbard, a multi-frequency (4.9, 10.4, 21, 36, 94 GHz) radiometer and a 10.4 GHz scatterometer installed on the Norwegian icebreaker "Polarsirkel" was used to obtain surface-based microwave signatures together with in situ observations of the objects. In addition to thick multi year ice, the experiment allowed to make measurements on open water and on freshly formed sea ice near the marginal ice zone. (NORSEX arctic working group, 1981).



<u>Figure 1</u>: The typical transition from open water to young ice in the marginal ice zone: a) calm open water with surface waves, b) microice particles damping the capillary waves, c) small pancakes, 10 - 20 cm diameter, between open water, and d) densely packed pancake ice, 0.3 - 1 m diameter (Situation B).

Figure 1 shows the transition from open water to pancakes of frazil ice. The pancake ice is the young ice of the marginal ice zone. The shape results from the motion of the gravity waves.

2. PASSIVE MICROWAVE SIGNATURES

Figure 2 shows measured spectra of emissivities, e_v and e_h, at vertical (v) and horizontal (h) polarization 50° nadir angle of calm water, micro ice particles and small pancakes.

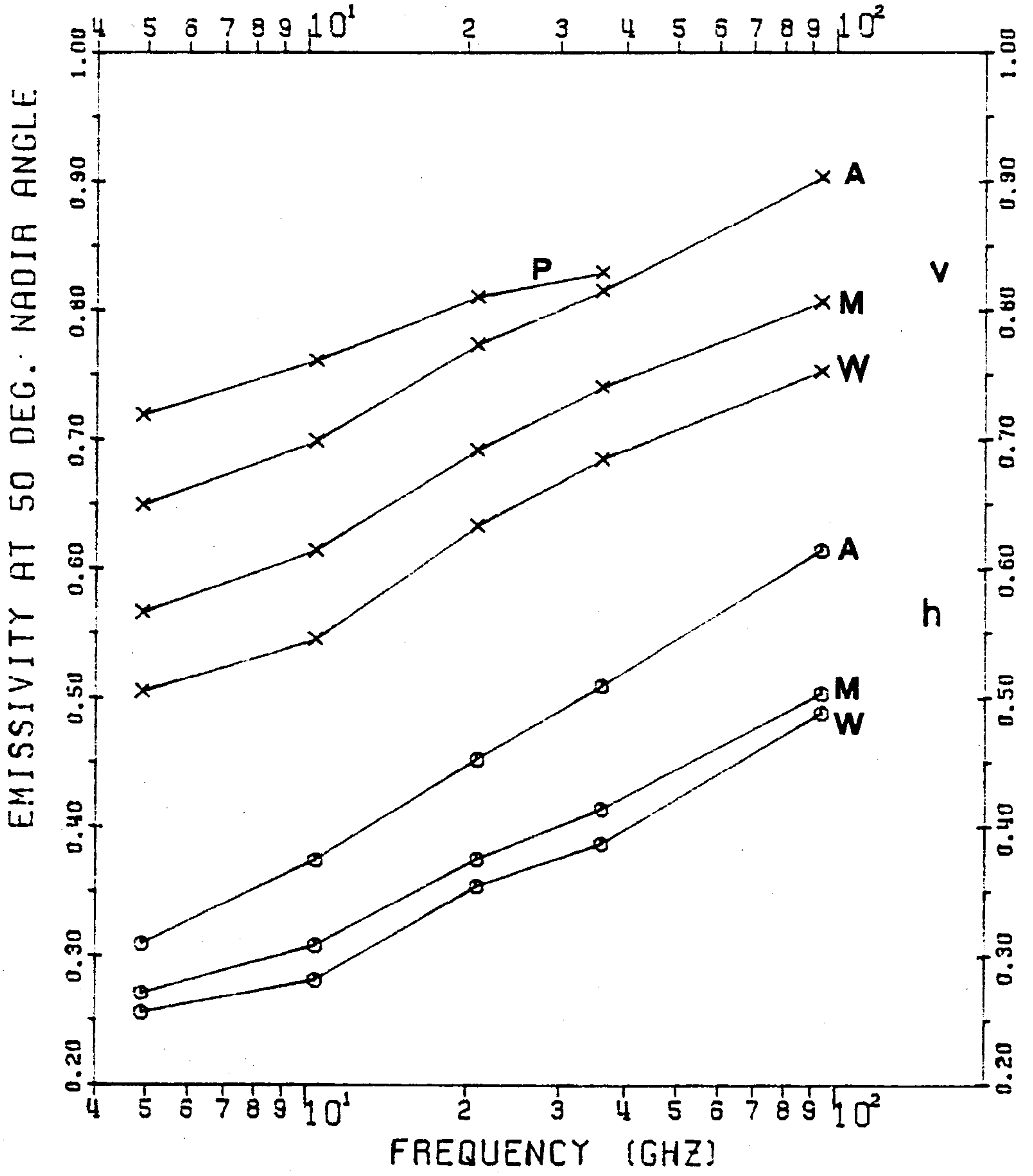


Figure 2: Spectra of emissivities from 5-100 GHz, horizontal (h) and vertical (v) polarization 50° off nadir, measured during NORSEX of calm water (W), microice particles (M), small pancakes with diameter 10-20 cm (A), and similar pancakes of Figure 1 c (P, vertical polarization only).

The accuracy of these data is better than 1% at 4.9, 10.4 and 36 GHz, a non-linearity at 21 GHz shifts the 21 GHz data to values too high at low emissivities up to 3%, and the 94 GHz data are accurate to 10%. With these uncertainties in mind, the figure shows the increase of emissivities with increasing frequency and ice thickness. The increase starts faster at vertical than at horizontal polarization. There is no indication of interference effects from superpositions of reflections at the surface and at the ice-water interface, in agreement with the high dielectric loss found for young frazil ice (Vant et al. 1974).
For thicker pancake ice the spectra converge to emissivities near 0.95 independent of frequency and very similar at both polarizations.

Figure 3 shows emissivities, vertical versus horizontal polarization at 4.9 and 36 GHz of wet ice and wet snow. In addition, the theoretical range of emissivities for Fresnel reflecting surfaces is shown.

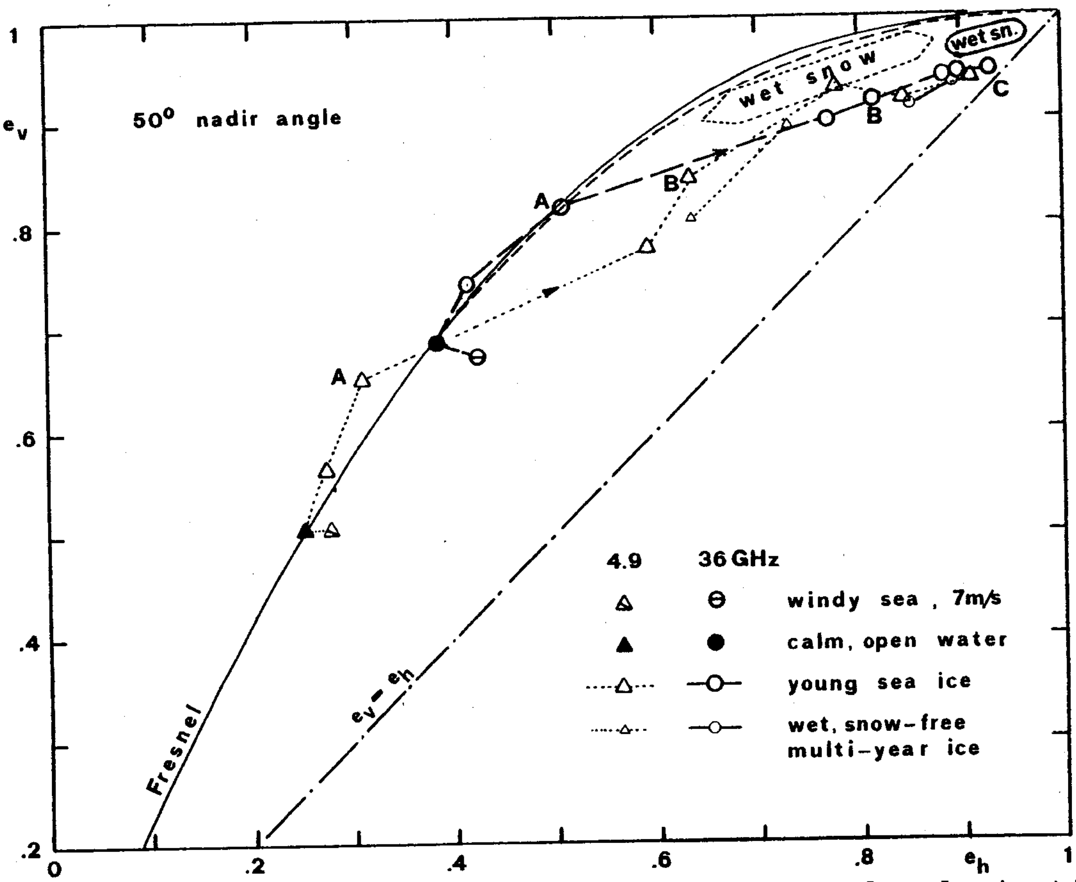


Figure 3: Emissivities, vertical versus horizontal polarization at 50° nadir angle. The solid line "Fresnel" shows values for which the Fresnel formulae are valid with real dielectric constant ($\varepsilon > 1$). The dashed line approaching this solid line is the Fresnel curve for complex $\varepsilon = \varepsilon' - i\,\varepsilon''$ with $\varepsilon' = 1$ and $\varepsilon'' > 0$.
All intermediate dielectric constants have Fresnel emissivities in the narrow range between the two lines. Measured data points of calm and slightly rough sea, young sea ice, wetted snow-free multi year ice, and wet snow at 4.9 and 36 GHz are shown.
The letters A (small pancakes in between water), B (densely packed pancakes), and C (thick pancake ice) refer to the other Figures.

Calm water clearly lies on the Fresnel line at both frequencies. Whereas the windy sea points depart from this line due to polarization mixing on the tilted surfaces, new ice goes more or less along the Fresnel line toward higher emissivities. A slight increase in polarization. e_v-e_h, Point A) results from an anisotropic effective dielectric constant: The frazil ice consists of mostly horizontally extended platelets with diameters of about 1 cm and a thickness of a fraction of 1 mm. Multiple layers of these platelets form the soft and wet pancake-like clusters with a similar ratio of diameter to thickness as the single ice crystals. This anisotropy results in larger dielectric constant in horizontal than vertical direction, which explains the observed departure from the Fresnel line toward high polarization.
When the ice becomes densely packed, the surface roughens, thus reducing the polarization (Points B to C). It is interesting to note that snow-free, wetted multi year ice shows the same emissivity as thick pancake ice.Thus the emissivity is a unique function of wetness. For the very young ice the thickness dependence appears indirectly via the change of wetness with increasing ice thickness. Very close to the black body point are the emissivities of wet snow also shown in Figure 3. The wetness range of these snow data is between less than 1% and 10% by volume. The emissivities decrease with decreasing frequency and increasing wetness, respectively.

When plotted against thickness of the young ice, the emissivity curve at 10.4.GHz appears as shown in Figure 4 (50° nadir angle, horizontal and vertical polarization). A similar behaviour is found at all frequencies. The emissivities show the monotonic increase with thickness, the critical thickness being smaller at vertical than at horizontal polarization.Both critical thicknesses are slightly smaller than the critical heat exchange thickness. The Points A, B, C on the thickness axis refer to data also shown in other figures.

3. ACTIVE MICROWAVE SIGNATURES (at 10.4 GHz)

Figure 5 shows 3 angular scans of like-polarized backscattering coefficients of small pancakes in water (A), densely packed pancake ice (B) and thick pancake ice (C). The situation A shows a pronounced difference between γ_{hh} and γ_{vv} supported again by the anisotropy of the dielectric constant. Backscattering in this case can be described by diffraction from the randomly absorbing surface with a variance higher at vertical than at horizontal polarization (Schanda, 1982). The large backscatter from the rough surface of situation B is similar to the backscattering from multi year ice. This ambiguity is a potential for confusion in radar data. Thick pancake ice (C) shows smaller backscattering because of the smaller roughness and wetness than in situation B. When the ice is covered by wet snow, the backscattering decreases further and approaches values near $\gamma = 0.01$ (-20 dB).

Figure 4 shows the variation of the backscattering at 50° nadir angle with increasing ice thickness. The vertical "error" bar at zero thickness shows the range of γ_{hh} for calm and windy (7m/s) sea. The corresponding values for γ_{vv} are slightly higher. When ice forms, the sea roughness first decreases due to the damping of the capillary waves. Therefore, Figure 4 shows first a decrease of γ. Then the inhomogeneity (Figure 1c, Situation A) and much

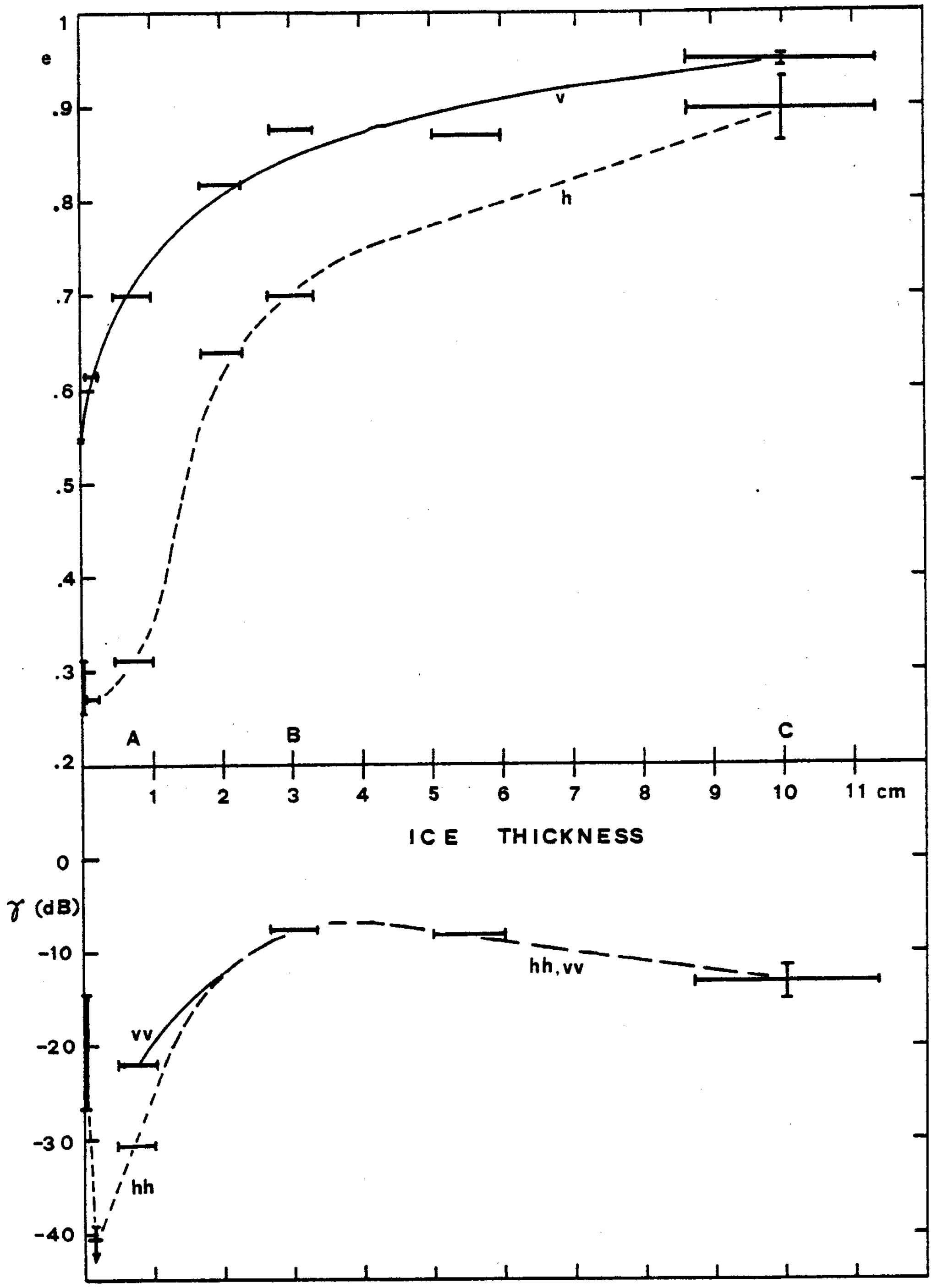


Figure 4: Emissivities, e (top), horizontal (h) and vertical (v) polarization and backscattering coefficients, γ (bottom, in dB), horizontal (hh) and vertical (vv) polarization at 10.4 GHz versus ice thickness.

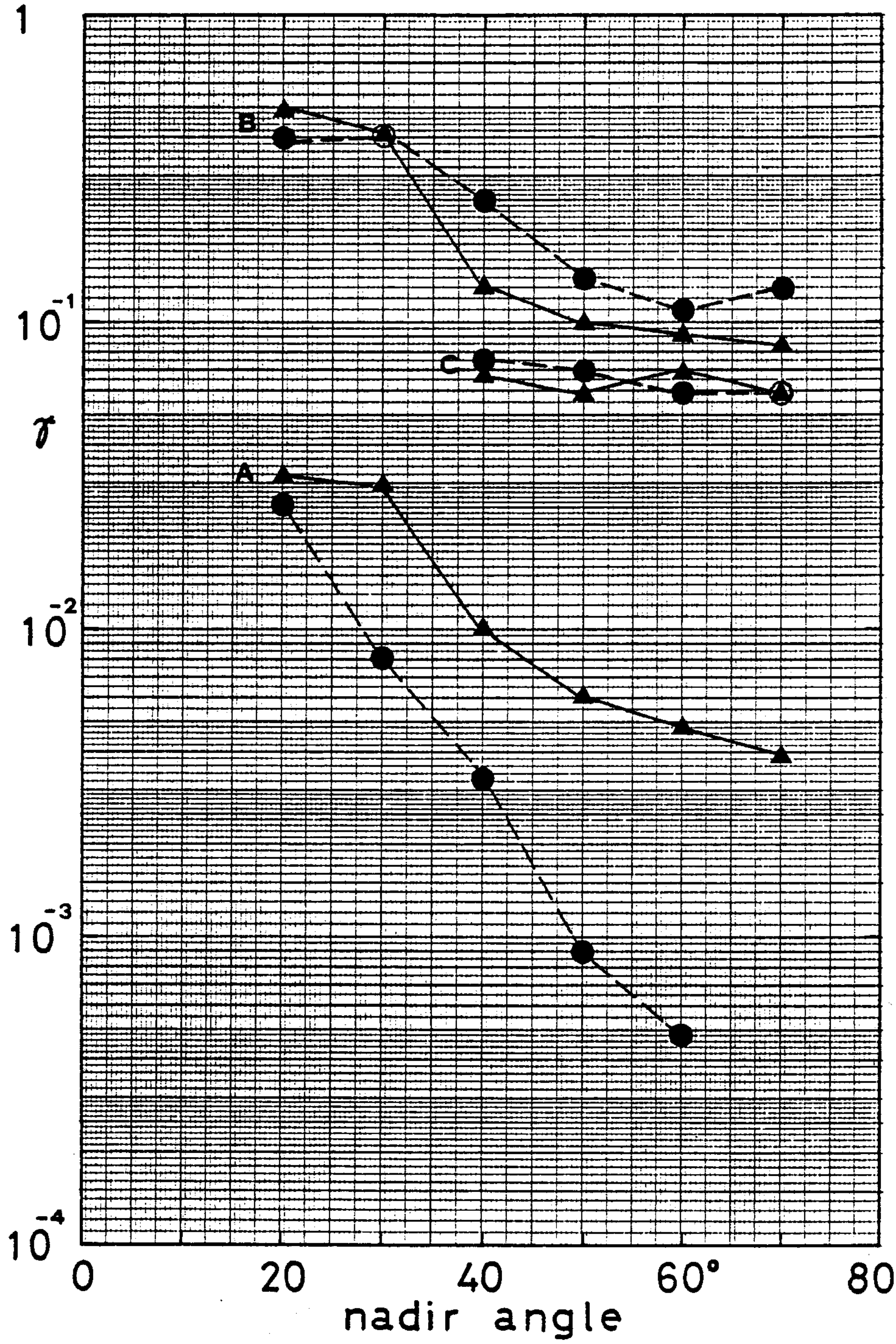


Figure 5: Backscattering coefficients horizontal ●(hh) and vertical ▲(vv) polarization versus nadir angle of the three young ice situations A, B, C.

more the roughness of the densely packed pancake ice (Figure 1d, Situation B) are responsible for a large increase in backscattering, followed by a decline as discussed above.

At smaller nadir angles, the backscattering of the thick and rough pancake ice does not change noticeably. However, the backscattering of open water, and of the very thin ice increases strongly, thus reducing the contrast between ice and water, and leading to an inversion of contrast at nadir.

CONCLUSION

Both passive and active microwave signatures show very strong changes when new ice is forming on the open ocean surface. Whereas the passive signatures show a monotonic variation with increasing ice thickness, active signatures undergo non monotonic changes; indeed, the most extreme backscattering coefficients among all ice types can be found within the young sea ice. This variation is helpful in increasing contrast at the ice edge and in other regions of young ice as long as individual ice floes can be geometrically resolved with high resolution radar imagery. Ice concentration and classification may then be deriveable from the geometrical structure, more than from the tone, of the imagery. The comptutional effort for obtaining this information will be very large.

On the other hand, the monotonic variation of emissivities allows the application of mixed signature algorithms to passive microwave data. Quantities like ice concentration, multiyear ice fraction and perhaps even energy exchange rate may be derived from imagery with large footprints such as the Nimbus-7 Scanning Multichannel Microwave Radiometer. A simple algorithm for retrieving ice concentrations from such data is being prepared on the basis of NORSEX emissivity measurements by the NORSEX arctic working group, (see also Kloster and Svendsen, 1982).

Further experiments in other arctic regions and during other seasons have to be added. The signatures of other ice types (e.g. nilas) have to be added before algorithms can be generalized in space and time.

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