Brightness temperature measurements, at 611 megahertz, of sea ice in the Weddell Sea

KAREN ST. GERMAIN *and* CALVIN T. SWIFT

Microwave Remote Sensing Laboratory
University of Massachusetts
Amherst, Massachusetts 01002

As part of the Winter Weddell Gyre Experiment (WWGE) 1989, we investigated the feasibility of measuring antarctic sea-ice thickness remotely by using passive microwave techniques. This required the installation of a 611-megahertz radiometer on board the West German research vessel *Polarstern*. Data were collected in transit as well as during ice stations. These data are currently being correlated with *in situ* thickness measurements as well as video recordings and other passive microwave data.

Concept. A microwave radiometer measures the power level of incoming radiation. This power level is commonly expressed as a "brightness temperature" via the following relationship:

$$P = k \times T_b \times B \Rightarrow T_b = P/(k \times B)$$

Where P = power of received radiation
T_b = brightness temperature
k = Boltzman's constant
B = bandwidth of the instrument

For a flat surface, the brightness temperature is proportional to physical temperature of the surface as:

$$T_b = e \times T = (1 - r) \times T$$

Where e = emissivity
r = Fresnal reflection coefficient

For layered media such as sea ice, the brightness temperature measured is a composite. In this case, the layers are the ice and the underlying water. Experience with C-band (4–8 gigahertz) passive sea-ice measurements suggests that under usual growth conditions the apparent brightness temperature of an ice layer increases monotonically from the low open-water value to the relatively high thick-ice value. This behavior suggests that it should be possible to measure ice thickness via brightness temperature. Swift et al. (1986) developed a theoretical model based on work done by Apinis and Peake (1976) which describes the emissivity. The theoretical curve of brightness temperature as a function of ice thickness for ultra-high frequencies is plotted in figure 1. It is clear from this curve that the ultra-high-frequency radiometer has the potential of measuring ice thickness in excess of 60 centimeters.

Figure 2 shows the estimated percentage of error in the measurement as a function of sea-ice thickness, based on an assumed brightness temperature error of ±3 Kelvin. This curve demonstrates that it is theoretically possible to derive ice thickness for sea ice up to 1 meter thick. The measurement should, therefore, provide very useful surveys of antarctic ice thickness, since the mean thickness is in the 40–60 centimeter range as reported by Wadhams, Lange, and Ackley (1987).

Field operations. The measurements were made using an ultra-high-frequency (611-megahertz) radiometer which was

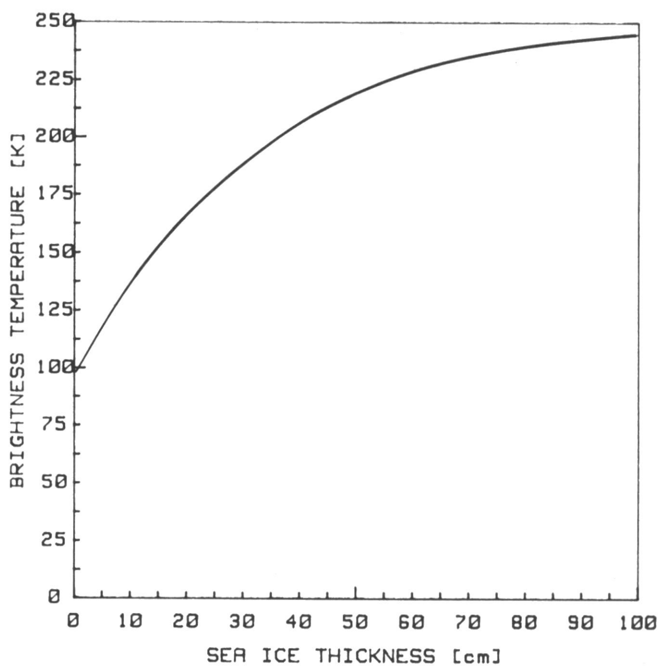

Figure 1. theoretical brightness temperatures as a function of sea-ice thickness. (cm denotes centimeter. K denotes degrees Kelvin.)

mounted on the port side of the *Polarstern*, looking downward to the ice at an oblique incidence angle. Several other passive instruments were mounted on the deck rail next to the ultra-high-frequency radiometer, in an effort to take concurrent measurements. These were 10-gigahertz, 35-gigahertz, and 85-gigahertz radiometers as well as a PRT5 infrared sensor. By adjusting the incidence angle, the radiometers were aligned to observe only ice that was undisturbed by the ship, usually 50 degrees off nadir. In addition to gathering the remote-sensing data, several groups on board did extensive *in situ* work

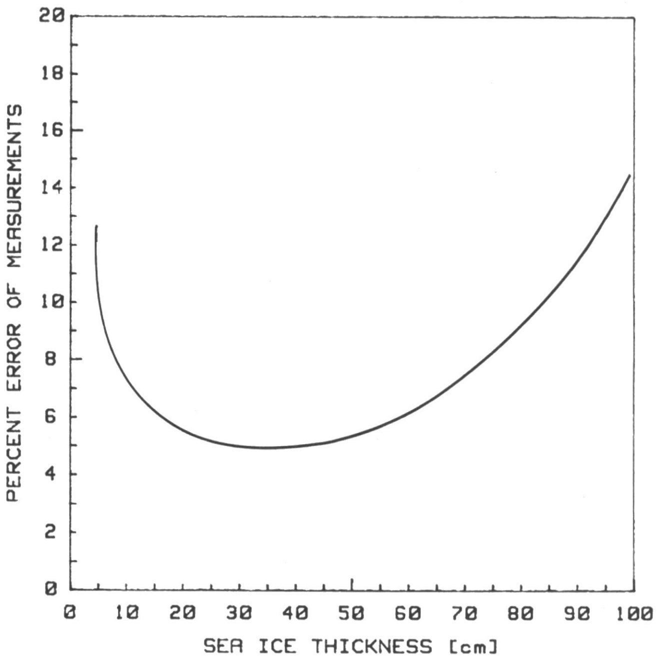

Figure 2. Estimated measurement error as a function of sea-ice thickness. (cm denotes centimeter.)

such as thickness measurements and distributions, snow-cover analysis, and ice coring for identification of ice type.

Unfortunately, we encountered problems with the PRT5, and the 35 gigahertz failed entirely midway through the expedition; therefore, the data sets are not complete. Also, due to several radio frequency interference problems and difficulties maintaining thermal stability, the quantity of ultra-high-frequency data collected is somewhat limited. Nevertheless, the results are quite promising. While passing through thin ice, the ultra-high-frequency values were proportional to the 10-gigahertz values. While passing through thicker ice, however, the 10-gigahertz data stabilized at a saturation value but the ultra-high-frequency values continued to vary, presumably with ice thickness. This is expected because the radiometric saturation thickness is roughly equivalent to the radiometric wavelength through the ice. This implies that the 10-gigahertz measurements should reach a maximum for ice roughly 3–5 centimeters thick, while the ultra-high-frequency measurements should not reach a maximum until the ice is much thicker. A quantitative analysis is still in progress.

Other polar regions work. In addition to the National Science Foundation funded ultra-high-frequency work, the University of Massachusetts is involved with several other polar regions projects. We are currently developing an improved sea-ice concentration algorithm which operates on data from the spaceborne Special Sensor Microwave/Imager. The purpose of this algorithm is to calculate ice-type concentrations (first-year ice, multi-year ice, open water) within a footprint while correcting for second-order parameters such as open-water wind speed, atmospheric vapor and liquid, and surface temperature. In addition, we recently received on indefinite loan from the National Aeronautics and Space Administration the Advanced Application Flight Experiment altimeter which, after some reconditioning, will be tested over Greenland. It is possible that the altimeter will be used in future antarctic work as well. Finally, we participate in the annual CRRELEX experiments (experiments conducted at the Cold Regions Research and Engineering Laboratory) funded by the Office of Naval Research. During these experiments, we attempt to simulate polar phenomena in a controlled environment. For example, we recently simulated the formulation and growth of pancake ice, focusing on the radiometric changes which accompanied the growth. It was the CRRELEX '88 Experiment which inspired the ultra-high-frequency antarctic work.

References

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