C-band Microwave Backscatter of Sea Ice in the Weddell Sea during the Winter of 1992

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Abstract - A C-band radar was used to record the backscatter of Antarctic Weddell Sea ice in the winter of 1992. These shipborne microwave signatures are the first of their kind. Calibrated and vv-pol signatures were recorded for several ice types as the icebreaker crossed the Weddell Sea. At each site, measurements were made of snow and sea ice characteristics, meteorological information, radiation budget and oceanographic data were also collected. One-year ice reflectivity presented with relation to surface physical properties. In-situ data are used in predictions from a theoretical model and the results compared with model values. The primary scattering contributions under cold winter conditions come from the air-snow and snow-ice interfaces. Time-series data indicate C-band is sensitive to snow and ice physical changes as a result of climatic and oceanographic forcing.

1. INTRODUCTION

Spaceborne microwave remote sensing is required to monitor the extent and characteristics of winter Antarctic sea ice. In this paper we begin to develop techniques to use microwave radar signature data. During a 1992 austral winter experiment, sea ice backscatter measurements were made together with surface and dielectric properties of the sea ice and the surface flux regime could be determined. As a part of the Winter Weddell Gyre Study (WWGS '92), a C-band scatterometer was operated from the port side of the German research vessel Polarstern to obtain the first shipborne scans of the microwave backscatter properties of Antarctic sea ice. The dual-polarization radar collected like- (v) and cross-polarized (h) data at incidence angles from 15-65°. When stationary in pack ice, the radar was scanned to obtain independent samples of sea-ice backscatter (σ0) as a function of incidence angle (θ) and polarization. Field sampling provided validation data for simultaneous satellite measurements. In support, detailed surface measurements were made within the radar footprint each time a radar scan was completed.

Short 3-4 hour ice stations shown in Fig. 1 enabled radar and snow and ice measurements of a number of ice types characteristic of the winter Weddell Sea ice cover [1]. A 3-day long ice station from 21-24 July, 1992 also enabled time-sampled σ0 measurements. In addition to periodic scans of data over the entire range of incidence angles, the radar was operated at fixed in situ and cross-polarized (hv) data at incidence angles from 15-65°. At this angle σ0 is sensitive to surface physical properties and also to volume scattering within the snow and ice surface. These data provide a chance to quantify changes in σ0 as the heat flux and vapour flux regime varied over the period, and as the physical properties of the snow and ice changed.

2. SENSOR DESCRIPTION

The field sensor was a frequency-modulated, continuous-wave (FM-CW) radar, modified from a King airborne radar altimeter. (see Table 1). The antenna cluster consisted of a parabola for transmitting; a horn antenna for receiving like-polarized signals; and an alternate receiving antenna for cross-polarized signals. A steerable mount was secured to the port rail of the upper deck. The antenna was fixed in azimuth, but hinged in the elevation plane and driven using an actuator. A thin metal wire gave a simple digital readout from which θ was set.

3. CALIBRATION AND SYSTEM CORRECTIONS

Here we briefly describe the procedures used to convert measured power data into absolute backscatter. These approaches are described in further detail in [2],[3], and [4].

Fig. 1. WWGS 92 Polarstern track and surface sample sites (+). The ice margin was entered on 2 June '92, and finally exited on 31 July '92.
Internal and External Calibration

The system is internally calibrated using the PC, by storing the power and transmitter power alternately for each range. The characteristics of the transmitted signal are thus taken into account in power calculations. Independent records of internal calibration readings for each measurement were not made using the HP signal analyzer, due to time constraints in the field. However, a frequency (0-1 kHz) was applied to each sample to adjust for possible changes in the system throughout the experiment. The daily observed gated power was within 1.5 dB of the mean value between June 23rd and July 28th, thus indicating the radar to be sufficiently stable; the assumption of using the 0-1 kHz gated power as an internal reference is reasonable.

External calibration was performed periodically using a Lunenberg lens placed on the ice at a fixed distance from the ship. The theoretical maximum cross-section of a 12” diameter lens is 11.38 dB [5]. The lens had a measured value of 7 dB (after [2]) and some performance degradation over its lifetime.

Beamshape and Antenna Separation Correction

Power measurements are simplified by assuming that scattering is independent of azimuth angle and that received power is mainly from the elliptical illuminated area [5] centered at known range and defined by the effective half-power beamwidth given in Table 1. In estimating the effective beamwidth from the power, we used a narrow-beam approximation [6]. Since this method has deficiencies, Wang and Gogineni [4] describe how it is calculated accurately by integrating the power over the antenna pattern from the full measured spectrum.

Though mounted together, the antennas do not all point to exactly the same spot on the surface. With a separation of 50 cm and with slightly different beamwidths, the antenna patterns overlap imperfectly, and a correction is made to account for the error in the estimation of A, and the 'effective' gain pattern. This correction is made using formulae for parallel Gaussian beams discussed in [7]. Together, this accounts for a correction of 1.5 dB at nadir-falling to less than 1 dB at the higher incidence angles.

The target response of a typical FM-CW radar falls off at 12 dB/octave (i.e. each time range doubles). The system hardware (i.e., STC) compensates for 6 dB/octave while the post-processing of data eliminates the remaining range dependence.

4. ICE STATION IN-SITU DATA

At each site in Fig. 1 detailed radar measurements were made. Estimates of come from a number of independent samples, each of which is a statistical average of several thousand measurements of scattered power. Power is converted to $\sigma^0$ with the calibration information and corrections described in Section 3. A backscattered signature is then built up from the samples of $\sigma^0$. Data were collected for a range of ice types including pancake, dark nilas, grey, first-year and second-year ice. In-situ data included physical and chemical analyses of ice cores and snow samples, together with snow crystal macro-photography. Typical data were collected within the swath of the radar after each scan was completed. An example from a site on 2 July is shown in Fig. 2. The corresponding signature is shown in Fig. 3 as circles and crosses.

Throughout the 3 month experiment, meteorological data were acquired onboard Polarmak. Together with radiation budget calculations and oceanographic measurements, these provide a complete picture of the top and bottom boundary conditions for the sea ice. During periods when the thermal conditions were monitored within the ice, this allowed the main components of the energy budget to be estimated. Those components critical to the physical and scattering properties of the sea ice are the sensible and latent heat, and vapor fluxes.

5. MODEL SIMULATIONS

A physical and theoretical scattering model is developed to understand the scattering shown in Fig. 3, and to provide insight into the geophysical properties of the microwave scattering and emission off ice. Initial tests using in-situ snow and ice properties suggest penetration depths into the ice shown in Fig. 2a are not as high as those predicted by the model. A physical scattering model is constructed consisting of three primary layers: (i) an uppermost layer of ice snow-crust; (ii) salt-free snow with spherical crystals of varying size; and (iii) a layer of saiy snow-ice with a mean density of 0.35 g/cm$^3$. The snow particle size distribution is simulated for dry snow using a Rayleigh distribution with limits at a minimum grain diameter of 0.045 mm and maximum diameter of 0.885 mm. Layer (iii) in contrast was saiy, with a salinity of 8%.
It is assigned a complex permittivity of $\varepsilon = 2.8 + j 0.02$, assuming spherical brine inclusions with an ice density of 0.75 g/cm$^3$ at a temperature of -18°C. Beneath the snow-ice layer is assumed a continuous ice sheet with the characteristics noted in the upper layer of Fig. 2.

Measurements were made using a variety of profiling schemes to quantify the small-scale mounds of the air/snow and snow/ice interfaces. In the model it is assumed that the crust is slightly rough, but that it has an equal thickness everywhere with parallel upper and lower surfaces. This allows the second-order effects of a coherent field within the crust to be included in the computations. The roughness was large enough that Physical Optics scattering theory is valid at C-band.

Simulations incorporating surface and volume scattering take into account the snow grain-size distribution and salinity of each layer together with the measured roughness and thickness of the crust. The effective extinction of each layer is computed by summing the extinction in each of 10 discretized Rayleigh-grain radius bins within the overall size distribution. Layer volume scattering contributions are then added incoherently. Model simulated curves are shown in Fig. 3 in comparison with measured vv-polar data. Both curves each use the measured mean snow grain diameter of 0.3 mm. The upper simulated curve indicates the scattering signature for a slightly rougher surface with crust thickness 0.9 cm. In contrast, the lower curve shows the situation when the crust thickness is reduced and the roughness decreased. Results, indicate that the model response to the snow characteristics is significant. Other properties which have a large impact are the wind speed and temperature of the snow-ice interface.

The model simulations in Fig. 3 are for a situation which represents initial conditions at 19:00 hrs at the beginning of a 3-day ice station. They indicate that scattering is extremely sensitive to properties which are directly influenced by the surface energy balance. A subsequent time-set of radar data indicates how the scattering signatures change as a function of the varying surface flux environment. Exchanges of heat and water vapour caused by local gain sensible heat and evaporative cooling appear to have a significant impact upon the physical properties of the layers with time.

6. TIME-SERIES DATA

Another result from WWGS '92 field experiment is Fig. 4 shows simultaneous seismometer and scatterometer time-series data lasting from 21 to 24 July, 1992. The signature shown in Fig. 4 represents the start point in this time-series of data at Julian Day 203. The upper panel of Fig. 4 shows the scatterometer data, illustrating net outgoing heat fluxes of (and ice versa for *+*). The lowermost panel shows the C-band, scatterometer data in response to the heat fluxes together with surface temperature traces.

The period of observations is marked by a 23°C change in air temperatures caused by the passing of a low pressure front. The situation led to a swing from net negative heat flux and upward vapour flux, to net positive heat flux and initiation of surface melting. Several day variability in vv-polarized backscatter indicate several orders of magnitude change in scattering. The overall change in heat flux regime indicates a reduction in vv and hh backscatter which lags the onset of net heat gain to the snow by a few hours. High winds and a brief period of cloud-free night at Julian Day 206.2 encourage evaporative cooling and a local maximum in the values of vv and hh backscatter.

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9. REFERENCES


