

## Estimating the Thermodynamic State of Snow Covered Sea Ice Using Time Series Synthetic Aperture Radar (SAR) Data

*D.G. Barber and J.Y. Yackel*  
University of Manitoba, Winnipeg, Canada

*R.L. Wolfe*  
Transport Canada, Ottawa, Canada

*W. Lumsden*  
Environment Canada, Ottawa, Canada

### Abstract:

Microwave remote sensing of sea ice has traditionally focused on the estimation of dynamic, kinematic, and structural characteristics of the ice surface/volume. Recent evidence shows that the thermodynamic state of sea ice can be estimated using the temporal evolution of the average relative scattering coefficient ( $\Delta\sigma^\circ$ ) measured with a Synthetic Aperture Radar (SAR). This thermodynamic/microwave scattering link has broad implications in ice related engineering (e.g., ice strength estimation) and in ocean-sea ice-atmosphere process studies (e.g., ice-albedo feedback).

In this paper we present the theoretical framework required to link the thermodynamics, brine volume and microwave scattering over snow covered sea ice. The principal coupling in this relationship shows that as the temperature of the ice/snow volume increases there is an associated increase in the brine volume. This creates an increase in the complex permittivity ( $\epsilon^*$ ) of the volume thereby causing a change in the microwave scattering coefficient ( $\sigma^\circ$ ). We show how  $\Delta\sigma^\circ$  changes as the seasonal evolution of the ice volume progresses from winter through to melt pond formation. We then show how this information can be exploited to estimate various characteristics of the thermodynamic state of the sea ice at a particular point in the seasonal evolution (e.g., winter; onset of melt; pendular and funicular snow regimes; ice decay, etc.). We conclude by reviewing how this time series information may find utility within the Arctic Ice Regime Shipping System (AIRSS).

### Introduction

Arctic sea ice is a dynamic component of the earth's cryosphere over all spatial and temporal scales. The areal extent and subsequent ablation rate of sea ice undergoes tremendous seasonal variation in response to the surface radiation receipt and the timing of the import or advection of energy. Because the average thickness of Arctic sea ice is only about three meters, small changes in the energy absorbed will significantly affect its spatial extent due to the relatively small thermal capacity of sea ice. Physical properties of the system include snow and sea ice microstructure (grain structures and inclusion morphology), mesostructure (density, bulk salinity, and thickness) and macrostructure (ice type, surface roughness, kinematics and spatial distribution). Engineering properties include the thermal,

electrical (complex permittivity ( $\epsilon^*$ )) and mechanical (ice strength, elasticity and friction) characteristics of the snow and ice. The dielectric properties define the electrical conductivity of the snow and ice relative to the wavelength and polarization of incident electromagnetic energy. Microwave scattering from a Synthetic Aperture Radar (SAR) is strongly linked to the dielectric properties of the material (Ulaby et al., 1986). Brine volume is a function of ice temperature and salinity, and strongly dictates the dielectric properties and various mechanical strength characteristics of sea ice.

Research has evolved to a point where we can now consider the development of an 'Electro-Thermophysical' model of snow covered sea ice. Development of such a model would link the physical, electrical, thermodynamic and electromagnetic (EM) scattering characteristics of the seasonally evolving sea ice cover. A significant opportunity from such a modeling framework would be the estimation of sea ice strength based on the remote measurement of EM interactions with a seasonally evolving icescape. In this paper we review our current understanding of the theory relating to the development of each of the components of this proposed 'Electro-Thermophysical' model and provide empirical evidence showing that microwave scattering is affected by the thermodynamic state and evolution of the seasonally evolving sea ice surface. We conclude with some examples of how this relationship may be exploited in sea ice climate and engineering related problems.

### Methods

Data used in this investigation were collected during the Seasonal Sea Ice Monitoring and Modeling Site (SIMMS) (LeDrew and Barber, 1994) and the Collaborative-Interdisciplinary Cryospheric Experiments (C-ICE; Drobot and Barber, 1998). These field programs operated during the seasonal transition from winter to summer, within snow covered first and multi-year sea ice types near Resolute Bay, NWT. These field experiments have been conducted annually between 1990 to 1997. A standard suite of energy balance measurements were made at sites over first year and multi-year sea ice types. All components of the surface energy balance were ascertained using a one second sampling rate integrated into 15 minute averages. In general these data were collected continuously from April to July of each season. Shortwave and longwave radiative fluxes were computed for the surface as was the conductive flux