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STUDIES OF THE RETRIEVAL OF SEA ICE THICKNESS AND SALINITY WITH WIDEBAND MICROWAVE RADIOMETRY

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ABSTRACT

Sea ice thickness and salinity are important quantities in understanding and forecasting the evolution of the cryosphere. However, the retrieval of multiple sea ice parameters through microwave remote sensing is a challenging task. In this study, the potential advantages of using a multi-channel wideband microwave radiometer are demonstrated through simulations of the retrieval of both sea ice thickness and salinity for multiple ice types and for different numbers of radiometer channels.

***Index Terms*—** Microwave radiometer, Sea ice, Retrieval

1. INTRODUCTION

Sea ice is a significant component of the cryosphere that has important implications for Earth's changing climate. Sea ice thickness affects the ice mass balance and regulates energy transfer between ocean and atmosphere. In addition, sea ice salinity impacts the salt content of oceans through the freeze/melt cycle and ice drift. Therefore, the monitoring of these parameters through remote sensing is motivated for understanding and forecasting changes in the cryosphere. In the last decade, L-band microwave radiometry has been effectively used for estimating sea ice thickness [1,2]. Furthermore, wideband radiometer observations over sea ice have shown the possibility of estimating sea ice salinity together with its thickness [3]. Given these developments, studies of the potential retrieval performance that could be achieved are of interest to understand the advantages and limitations of wideband microwave radiometers for sea ice retrieval.

In this study, we discuss the advantage of using multiple microwave radiometer channels over the frequency range 0.5-2 GHz. For this purpose, sea ice thermal radiation is modeled for a range of sea ice thicknesses and salinities. Monte Carlo simulations of a model-based retrieval algorithm for sea ice thickness and salinity are then performed by adding radiometer measurement uncertainty to the modeled brightness temperatures. The results of the simulation show the advantage of using multiple radiometer channels in improving retrieval performance.

2. SEA ICE EMISSION MODEL

Sea ice is modeled as a multilayer structure of snow, ice and ocean. Although the sea ice and snow media contain small-sized inhomogeneous particles, volume scattering from these inhomogeneities can be neglected at 0.5-2 GHz frequencies considered [4]. Surface roughness effects are also neglected in this simulation. Dielectric properties of the snow layer are estimated based on a mixing formulation [5]. Sea ice permittivity depends on the brine volume content, with ice permittivities computed from [6] for both multi-year (MYI) and first-year (FYI) ice types. The sea water permittivity is estimated from [7] with a typical Arctic salinity (31 ppt) at the freezing temperature (-1.8°C). Atmospheric loss and scattering at these frequencies are extremely small so that their contributions are also excluded from the model. The final brightness temperature of the multi-layer medium is estimated through an incoherent radiative transfer (RT) model with planar boundaries and multiple reflections.

3. RETRIEVAL ALGORITHM

Simultaneous retrievals of sea ice thickness and salinity from an airborne campaign over Greenland's Lincoln Sea were reported using the Ultra-Wideband Microwave Radiometer (UWBRAD) in [3]. In that experiment, sea ice microwave emissions calculated for numerous sea ice thickness and salinity conditions were used to create brightness temperature Look-Up-Tables (LUT) that were compared with the measured radiation. The best estimates of thickness and salinity were selected by minimizing the total Root-Mean-Square-Error (RMSE) over the 12 frequency channels measured. Although no in-situ data were available for validation, the method returned physically reasonable results for the regions observed.

The simultaneous retrieval of both ice thickness and salinity requires accurate brightness temperatures; therefore, radiometer measurement uncertainty is a key parameter. However, increasing the number of frequency channels can help to enable or improve retrievals even for higher levels of measurement uncertainty. In order to explore this trade-off, we apply a retrieval simulation with multiple radiometer channels over the frequency range 0.5 - 2 GHz. In the simulation, the forward modeled brightness temperature LUTs of each frequency channel are perturbed with independent Gaussian noise with 1°K deviation (similar to the UWBRAD sensitivity). These noisy LUTs are then used in the aforementioned retrieval algorithm in a large number of Monte Carlo realizations with varying injected noise values. Statistics of the retrieval performance can then be computed as a function of the truth ice thickness and salinity.

4. SIMULATION RESULTS

Sea ice characteristics used in the retrieval simulation are summarized in Table I. All ice types are at -7°C and covered with a snow layer of thickness 15 cm and density 0.5 g/cm^3. For each ice type, 10,000 Monte Carlo realizations were applied, and the ice parameters were determined based on the statistical outcomes. Relative errors in the thickness and salinity retrievals are plotted in Figure 1 as a function of the number of channels used for two multi-year (upper plot) and two first year (lower plot) ice types. Note that the radiometer channels were evenly distributed over 0.5-2 GHz to simulate retrieval performance. For example, if the 4-channel case is investigated, their frequencies are 0.5, 1.0, 1.5 and 2.0 GHz.

Table I: Sea ice characteristics used for simulation

Ice Type	Age	Thickness (m)	Salinity (ppt)
I	MYI	1.00	1.0
II	MYI	2.50	0.6
III	FYI	0.50	5.0
IV	FYI	0.25	10.0

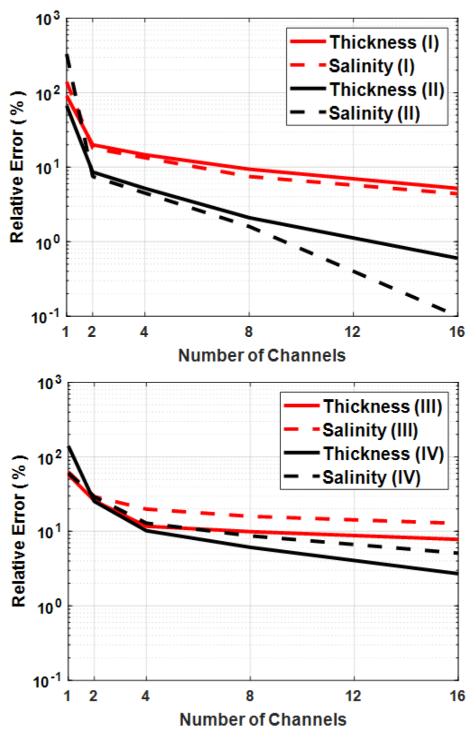

Figure 1: Relative errors of retrieved thickness and salinities for both MYI (Upper) and FYI (Lower) with the characteristics given in Table I

Typically, the thickness and salinity errors drop significantly when more than one frequency channel is used in the retrieval. As more channels are added, the errors continue to decrease, but this effect is slower in the FYI case. This can be attributed to the limited penetration depth in young ice types due to their higher salt content.

In addition, errors for the thicker and less saline MYI case II are smaller than for the thinner and more saline counterpart case I. This shows that salinity can have a stronger impact on performance for older ice types. The opposite apparently applies for the FYI case, where performance is improved for thinner ice even in the presence of a higher salinity.

In general, thickness and salinity relative error levels are near or above 100% for the case of one channel which shows that simultaneous retrieval is challenging for single channel radiometers. This is expected since there are multiple thickness-salinity combinations that can produce similar forward model predictions. The addition of a second channel addresses this problem, decreasing errors typically below 30%. For 16 frequency channels, errors are estimated to be near or below 10%.

5. CONCLUSION

The simultaneous retrieval of sea ice thickness and salinity is of interest for improving our understanding of sea ice processes. The use of multiple microwave frequency channels can enable the simultaneous retrieval of these parameters. The simulations shown demonstrate the level of improvement in precision with each introduced frequency channel to the system. These results motivate continued studies of wide-band microwave radiometers operating from 0.5-2 GHz for the remote sensing of sea ice properties.

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