A Bayesian retrieval of Greenland ice sheet internal temperature from ultra-wideband software-defined microwave radiometer (UWBRAD) measurements

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ABSTRACT

Ice sheet internal temperature is important for studying the glacier dynamics yet the existing remote sensing study on it limited. The ultra-wideband software-defined microwave radiometer (UWBRAD) is designed to provide ice sheet internal temperature by measuring low frequency microwave emission ranging from 0.5 GHz to 2 GHz. A Bayesian framework is designed to retrieve the ice sheet internal temperature from UWBRAD measurements with poor prior information of the ice sheet properties. In this paper, synthetic UWBRAD measurements is simulated with coherent radiation transfer model over Greenland ice divide in dry snow zone. Three parameters, the surface temperature, the geothermal heat flux, and the standard deviation of density fluctuation, are estimated via the Markov chain Monte Carlo process. The 10m ice sheet temperature can be retrieved with an accuracy of 1K. The depth-average temperature can be estimated within 2.5K. The RMS errors for vertical temperature profile are within 3.3K. The prior information of surface temperature and standard deviation of density fluctuation shows improvements towards the truth while the geothermal heat flux is partially corrected. The Bayesian framework shows feasibility to estimate ice sheet internal temperature.

Keywords: Microwave radiometry, Ice temperature, Markov chain Monte Carlo

INTRODUCTION

Ice sheet internal temperature is an important factor in understanding glacier dynamics. The ultra-wideband software-defined microwave radiometer (UWBRAD) is designed to provide ice sheet internal temperature by measuring low frequency microwave emission. Twelve channels ranging from 0.5 to 2.0 GHz are covered by the instrument. A four channel (540, 900, 1380, and 1740 MHz center frequencies) prototype of UWBRAD was completed and operated in Antarctic ice sheet at Dome-C from a tower. A Bayesian framework is designed to retrieve the ice sheet internal temperature from simulated UWBRAD brightness temperature (Tb) measurements for the Greenland air-borne demonstration scheduled for September 2016. Experiment results are examined for science goals on three levels: estimation of the 10-m firn temperature, the average temperature integrated with depth, and the entire temperature profile.

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A 1-D heat-flow model, the Robin Model, is used to generate the ice sheet internal temperature profile. It requires ice sheet surface temperature (Ts), ice sheet thickness (H), snow accumulation rate (M) and geothermal heat flux (G) as input and calculates steady state temperatures as a function of depth. The radiation transfer (RT) model utilizes the Robin model temperature profile and vertical density profile as input and calculates Tb. At lower frequencies, deeper and warmer ice contribute to the emission and higher brightness temperature can be measured; While at higher frequency bands, the resulting brightness temperature is lower, thus provides the basis of retrieval.

The effective surface temperature, geothermal heat flux and the variance of upper layer ice density are least-well known and are treated as unknown random variables within the retrieval framework. The RACMO monthly reanalysis provide surface temperature and snow accumulation rates. The Operational Ice Bridge (OIB) measurement of ice sheet thickness and the Community Ice Sheet Model (CISM) Greenland geothermal heat flux are used. The borehole measurement of smooth density at Greenland summit ice core is fitted to an exponential model as a function of depth and used for the entire simulated flight path. The high resolution neutron probe measurement of snow density at summit is used to mimic the upper layer density fluctuation. It is fitted to an exponentially decreasing Gaussian model as random density noise.

Tan et al. (2015) state that the ice particle grain size will be relatively small compared with the wavelength of microwave radiation. Thus, volume scattering will be less important than coherent effects. Thus, a coherent radiation transfer model that neglects scattering is used to simulate UWBRAD measurements.

In order to simulate UWBRAD observations, a suit of true parameters is chosen and used to describe the Robin temperature profile and coherent model to produce a Tb profile for 47 locations along the flight line. The simulated Tb is corrupted with white noise. We assume a poor knowledge of priors, which are:

1. RACMO surface temperature: error could be incorrect by as much as 3K, dTs= [-3, 3] K.

2. Geothermal heat flux G: could range range between 30 mw/m2 and the maximum value that keeps the ice sheet basal temperature under the melting point.

3. (Vertical) density variation σ_ρ: varies between 20 and 60 kg/m3.

We also assume all three unknowns are uniformly distributed in sample space. The Markov Chain Monte Carlo (MCMC) method is used to explore the sample space determined by those three parameters. We conduct a random walk between the sampling space defined by the priors. At each step, we evaluate each new iteration of the three unknown parameters based on how well it explains UWBRAD data. Our goals are to investigate whether the priors can be improved and the temperature can be estimated.

RESULTS

The estimation errors are checked on four levels: the 10 m temperature estimation error, the depth averaged temperature estimation error, the RMS error of estimation and the RMS error of 100 m averaged temperature estimation (Fig. 1). The 10 m temperatures are all estimated within ± 1 K, and mostly within ± 0.5 K despite the prior estimate being precise to ± 1.0 K. The RMS error of the UWBRAD estimates are all within 3.3 K; 28/47 points show improvement over the prior. For the 100 m averaged temperature estimation, the estimation uncertainty increases with depth and stays below 1 K up to about 1500 m.

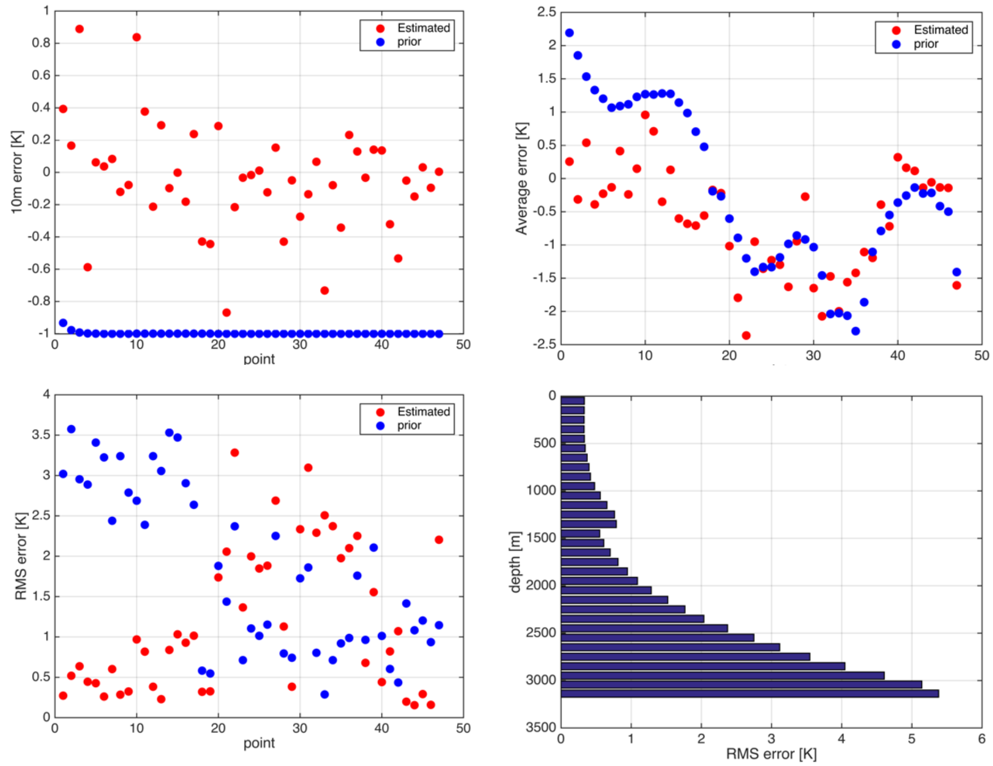

Figure 1. The 10m temperature estimation error, average temperature estimation error, the root mean square error of the temperature estimation and the RMS error of 100m depth averaged temperature estimation error

Along the flight line, a consistent high correlation, over 0.75, between surface temperature and density variation is observed, which means that multiple combinations of density variations and surface temperatures in the sample space would produce the exact same Tb. Yet the 10m temperature can still be well estimated. The Bayesian framework is capable of constrain the parameters within reasonable region by trading off among the parameters.

The MCMC estimation shows a promising capability to estimate ice sheet internal temperatures from UWBARD measurements. The 10m temperature has been shown to be retrievable. The use of prior information is important in the retrieval process.

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