Retrieving snow density from passive microwave measurements at L-band

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Introduction

Snow cover and its physical parameters such as depth, density and water equivalent are important environmental parameters as they describe the stored freshwater in the snow pack, effect the energy exchange and control hydropower. The remote sensing of these parameters by space and airborne instruments have been conducted for decades. The passive microwave remote sensing has been traditionally used to retrieve the snow water equivalent, the amount of water stored in the snow pack. Typically the measurements from frequencies 19 GHz and 37 GHz have been used for this purpose. Previous studies [3] and [2] have shown that the observations from L-band $(1-2\,\mathrm{GHz})$ are sensitive to the snow density and furthermore demonstated the possibility to retrieve the snow density from the multiangular passive microwave measurements at the L-band. Retrieval method proposed in [3] employs a physical forward model simulating the emitted microwave radiation from snow covered ground. Parameters of interest are retrieved from the observations by minizing a cost function between model predictions and observations. To understand the uncertainty of the retrieval, caused by the measurement and modelling errors, we write the retrieval problem as a Bayesian inference problem. The retrieval approach is applied to measurements from Finnish Meteorological Institutes Intense Observation Area (IOA) station, located in Sodankylä, Finland, during the years 2009-2015, which were also used in [2].

Measurements

The ELBARA-II instrument shown in figure 1 measures the upwelling brightness temperature $T_\mathrm{B}(\theta,p)$ from two polarizations $p=v,h$ and from incident angles $\theta_k\in[0,\pi)$. The instument measures the total upwelling brightness temperature

$$T_\mathrm{B}(\theta,p)=T_\mathrm{B,e}(\theta,p)+T_\mathrm{B,r}(\theta,p) \qquad (1)$$

where $T_\mathrm{B,e}$ is the emitted and $T_\mathrm{B,r}$ the reflected brightness temperature from the scene. In particular, measurements from the winter 2011-2012 are considered here.

Figure 1: ELBARA-II measuring the upwelling brightness temperature at IOA site, located in Sodakylä, Finland. Photo: C. Mätzler, 2011

Methods

The L-band emission model introduced in [3] is used in this study. The model gives the measured $T_\mathrm{B}(\theta,p)$ as a function of four parameters; the snow density ρ_s, ground permittivity ϵ_g, ground temperature T_g, and empirical ground-snow surface rouchness parameter z. The model assumes a homogeneous snow layer on top of a homogeneus ground layer. Volume scattering and absorption are neglected, which is a reasonable assumption at the L-band when the ground is fully frozen and the snow is dry. The measurements $T_\mathrm{B}(\theta_k,p)$ are represented by a vector

$$T_\mathrm{B,obs}\in\mathbb{R}^{2n} \qquad (2)$$

where n is the number of incident angles. The corresponding modelled observations are denoted by

$$T_\mathrm{B}(x)\in\mathbb{R}^{2n} \qquad (3)$$

where

$$x=\left[\rho_s,\epsilon_g,T_g,z\right]^T\in\mathbb{R}^4 \qquad (4)$$

is the vector of unknowns. However, in this study we consider the ground temperature T_g and empirical rouchness parameter z fixed, and only focus on retrieving the pair (ρ_s,ϵ_g). In particular the ground temperature T_g is fixed according to in-situ measured value. When modelled as random variables, the observation and unknown are connected by

$$T_\mathrm{B,obs}=T_\mathrm{B}(x)+\xi, \qquad (5)$$

where the error ξ is assumed to be a normal distributed random variable with zero mean and covariance matrix C

$$\xi\sim\mathcal{N}(0,C). \qquad (6)$$

The covariance matrix is written as

$$C=\begin{bmatrix}\sigma_v^2\mathbf{I} & \mathbf{0}\\ \mathbf{0} & \sigma_h^2\mathbf{I}\end{bmatrix} \qquad (7)$$

where σ_v and σ_h correspond to the measurement channels $p=v,h$. Both σ_v and σ_h are unknown and also modelled as random variables. The retrieval problem is written as a Bayesian inference problem for the unknowns $x=[\rho_s,\epsilon_g]^T$ and $\sigma=[\sigma_v,\sigma_h]^T$ as

$$\begin{aligned}T_\mathrm{B,obs}\,|\,x,\sigma &\sim\mathcal{N}\left(T_\mathrm{B}(x),C\right)\\ x_k&\sim U(a_k,b_k),\quad k=1,2\\ \sigma_p^{-2}&\sim\Gamma(\alpha,\beta),\quad p=v,h\end{aligned}$$

The prior distributions of x and σ are assumed to be independent. The joint posterior distribution of x and σ given the measurement $T_\mathrm{B,obs}$ is written according to Bayes formula as

$$\pi(x,\,\sigma|\,T_\mathrm{B,obs})\propto\pi_\mathrm{likelihood}(T_\mathrm{B,obs}\,|\,x,\sigma)\pi_\mathrm{prior}(x)\pi_\mathrm{prior}(\sigma). \qquad (8)$$

This is sampled by Metropolis-Hastings algorithm.

Results

The sampled values of the pair (ρ_s,ϵ_g) are compared against in-situ measured reference values. We show two retrievals to demonstrate the performance of this setup for the retrieval problem. The figure 2 shows an example of two parameter retrieval with good match with the reference value. The figure 3 on the other hand shows an example where the match between the retrieval and the reference value is not satisfactory.

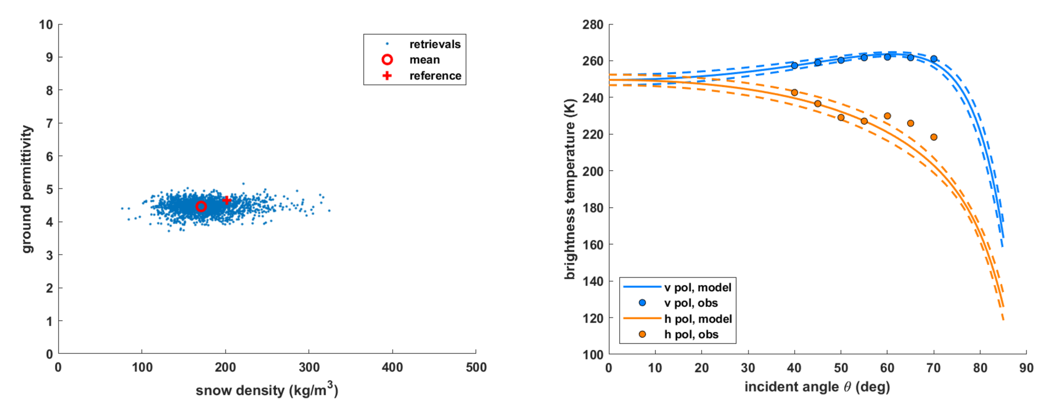

Figure 2: An example of good retrieval. Retrieval vs. reference (left) and model vs. observations (right).

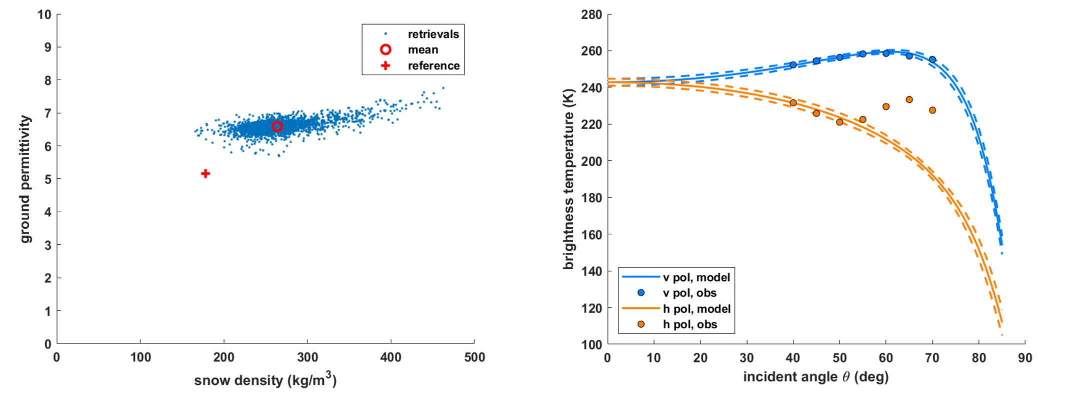

Figure 3: An example of bad retrieval. Retrieval vs. reference (left) and model vs. observations (right).

Conclusions

The failure of the retrieval is primarily connected to the modelling error. In figure 3 the model is unable to explain the measurements which causes the decrese in the retrieval quality. This type of examples lead to believe that the modelling error plays a big part in this retrieval problem. An appropriate choise for the error term ξ in equation (5) is believed to mitigate this problem. A particular choise given by (6) and (7) is applied to the retrieval problem. The appropriate choise of error term ξ or the covariance matrix C is a central problem in the on going work on this problem.

References

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Acknowledgements

I thank Juha Lemmetyinen and Johanna Tamminen for their time, helpful comments, and advice on this topic.