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A Bayesian approach to infer ice sheet temperature in Antarctica from satellite observations

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The actual temperature profile is a determinant of ice rheology, which controls ice deformation and flow, and sliding over the underlying bedrock. Importantly, the ice flow in turn affects its temperature profile through strain heating, which makes observed temperature profiles a powerful input for ice sheet model validation.

Up to now temperature profile was available in few boreholes or from glaciological models. Recently, Macelloni et al. (2016) opened up new opportunities for probing ice temperature from space with the low-frequency passive sensors. Indeed, at L-band frequency, the very low absorption of ice and the low scattering by particles (grain size, bubbles in ice) allow a large penetration in the dry snow and ice (several hundreds of meters). Macelloni et al. (2019) performed the first retrieval of the ice sheet temperature in Antarctica by using the European Space Agency (ESA)'s Soil Moisture and Ocean Salinity (SMOS) L-band observations. They used the minimization of the difference between SMOS brightness temperature and microwave emission model simulations that includes a glaciological model.

Here, in the framework of the ESA 4D-Antarctica project, we propose a new method based on a Bayesian approach in order to improve the accuracy of the retrieved ice temperature and to provide an uncertainty estimation along the profiles. As a first step, a one-dimensional ice temperature profile model (Robin 1955) is used, which limits the retrieval to the Antarctic Plateau. Then, the new temperature emulator based on the three-dimensional glaciological GRISLI (Quiquet et al., 2018) will be used to enable retrievals over the entire continent (cf. Ritz's presentation in this session for the GRISLI emulator description).

The Bayesian inference takes as free parameters: ice thickness, surface ice temperature, snow accumulation and geothermal heat flux (GHF). Their prior probability distribution is defined as normal, centered around a priori values taken from literature, and truncated to stay in a realistic range. The observed brightness temperature distribution is normal and a normal likelihood function is used to quantify the matching between the observed and simulated brightness temperature. The parameter space investigation is achieved through a Markov Chain Monte Carlo (MCMC) method. Here, the differential evolution adaptive Metropolis (DREAM) algorithm is used, which runs multiple different Markov chains in parallel and uses a discrete proposal distribution to evolve the sampler to the posterior distribution (Laloy and Vrugt, 2012).

For each SMOS brightness temperature observation, 1000 iterations are run on 5 parallel chains. The 2500 first iterations are discarded (aka. burn-in) and only the last 2500 are used for the final ice temperature profile estimation. The posterior probability distribution captures the most likely parameter set (i.e. a surface temperature, snow accumulation and GHF combination), and so, the most likely ice temperature profiles associated to this SMOS observation. It also provides the standard deviation which is an accurate estimate of the temperature uncertainty along the depth obtained with the method.