Estimation of snow depth and water equivalent over land, from passive satellite microwave observations: forward and inverse modeling

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Requested background: Strong background in physics. Good knowledge in statistics. Proficiency in at least one programming language.

Over the past 25 years, the increase in air temperature in the Arctic has been twice as high as elsewhere on the planet, causing dramatic changes in these regions. The snow cover and its depth over the Arctic region has changed significantly. These changes in snow cover affect Earth's climate system via the surface energy budget, and influence freshwater resources across a large proportion of the Northern Hemisphere. In contrast to snow extent, reliable quantitative knowledge on seasonal snow mass and its trend is still lacking.

Since the 1970s, visible and passive microwave imagers have provided an estimate of the snow cover. Contrarily to visible observations, passive microwave data between 6 and 37 GHz are only slightly affected by clouds and are not dependent on sunlight. In addition to snow cover, they also provide information about the snow mass, expressed by a measure called snow water equivalent, defined as the depth of water that would cover the ground if the snow cover was in a liquid state.

However, the quality of the snow water equivalent estimates from passive microwave observations is still limited, mainly due to the complexity of the interaction between the satellite observations and the medium. A new mission is currently under study for the next generation of satellite missions (Copernicus Imager Microwave Radiometer, CIMR, see https://cimr.eu/team), with frequencies between 1.4 and 37 GHz. It will provide improved accuracy and/or resolution, as compared to the exiting satellite missions with similar frequencies. This is an opportunity to develop new snow algorithms using existing observations (for example from the Advanced Microwave Scanning Radiometer, AMSR), to prepare for the new Copernicus European mission. The satellite observations can be used in the Numerical Weather Prediction (NWP) models, directly by assimilation of the observations, or estimating first the geophysical parameters using the satellite observations, and assimilating the retrieved geophysical parameter in a second step. As a consequence, both forward (for direct assimilation of the satellite observations) and inverse model (for assimilation of retrieved geophysical parameters) will be tested.

We suggest here to develop:

- A forward model to simulate the AMSR observations, as a function of snow-related outputs from the NWP models of the European Center for Medium-range Weather Prediction (ECMWF), and from a large collection of in situ measurements.
- The inverse model to estimate the snow quantities as a function of the AMSR observations.

A winter-long data set of AMSR data will be collected and collocated with snow information from ECMWF analysis (e.g., temperature, snow cover, snow depth), and the sensitivity of the AMSR observations to the snow parameters will be carefully studied. A Neural Network (NN) algorithm will then be trained on the snow parameters (from ECMWF and from in situ measurements) and collocated AMSR observations, to reproduce the AMSR observations using the snow parameters, and vice-versa, to estimate the snow information from the AMSR observations. The potential of the NN methodology will be tested, as compared to other methods (e.g., linear methodologies, existing algorithms). It is expected that the available snow information, even if not perfect, produces spatial and temporal patterns of the snow properties that are realistic enough so that the NN can learn the main relationship between the snow properties and the satellite observations, and exploit these relationships.

This work will be done in relationship with the land surface group at ECMWF in Reading (UK).