Geophysical Research Abstracts
Vol. 13, EGU2011-4130, 2011
EGU General Assembly 2011

Monitoring the Landscape Freeze/Thaw State by Fusion of K_u and C Band Scatterometer Data

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The landscape Freeze/Thaw (F/T) state is closely related to various bio- and geophysical processes, such as vegetation dynamics and the hydrologic cycle. Due to the scarcity of in-situ monitoring sites, remote sensing methods have been applied to observe the F/T state at large scales; in particular, microwave remote sensing has been shown to be an apt tool. Knowledge of the F/T state can be used for, for example, global models of the carbon cycle and vegetation phenology, as well as for other earth observation techniques, e.g. soil moisture retrieval.

Scatterometers are active radar instruments that measure the backscatter σ^0. Our aim is to infer the F/T state based on scatterometer data: SeaWinds on QuikScat in K_u band and ASCAT on MetOp in C band. The key advantage of the sensor fusion lies in the fact that σ^0 is sensitive to different factors at different frequencies, the most striking example being the backscatter of dry snow, which strongly increases with increasing frequency. We thus propose a novel algorithm for retrieving the landscape F/T state on a large scale based on the aforementioned input data. It is based on a probabilistic time series model and allows us to estimate the probability of each of three states at a given time: frozen, non-frozen and thawing.

The probabilistic model is an adaptation of the well-known Hidden Markov model (HMM) – the F/T state is assumed to be a Markov chain, whose value is not directly observable. At each epoch, however, its current state influences the measurements: σ^0 at both frequency bands. The simple structure assures that inference can be done efficiently, e.g. the calculation of the probability of the state on a given day. The algorithm does not use training data; the parameters are estimated for each time series in an unsupervised fashion. This is achieved by maximizing the marginal likelihood in the framework of the Expectation Maximization algorithm.

The algorithm is analyzed and tested in a study area in Russia and northern China, which encompasses the region of $120 - 130\,E$ and $50 - 75\,N$ and covers a variety of biomes such as Tundra, Taiga and Steppe. The time series of the probability of the state are validated with in-situ snow and temperature data as well as global climate models. In general, the accuracy exceeds 90%, but the algorithm can fail in agriculturally used land (fields, pastures) and bare rock outcrops in mountainous regions. On a more qualitative level, the study affirms the importance of using two distinct frequencies, as particularly dry snow, vegetation and the freezing of the soil water manifest themselves differently at K_u and C band.

The proposed algorithm yields satisfactory results in general, particularly in the Tundra and Taiga. The validation with external data has revealed weaknesses, such as rock outcrops in mountainous areas. The benefits associated with the systematic fusion of different data sources include the improved temporal coverage and the sensitivity to various influence factors such as snow cover. Overall, the study demonstrates that probabilistic time-series model such as the HMM are a promising tool for remote sensing data analysis in general and for determining the F/T state in particular.