A multi-sensor multi-temporal algorithm for snow cover extent retrieval from optical and passive microwave data

Rune Solberg, Øystein Rudjord, Arnt-Børre Salberg, Mari Anne Killie
Norwegian Computing Center, Norway

Changes in the snow cover over time are a sensitive indicator of climate change at the global, continental and local scale. There are rather long time series (> 30 years) of daily optical and passive microwave radiometer (PMR) data available. However, both sensor types are sensitive to weather conditions. Optical data can only be used under cloud-free conditions, and it is difficult to retrieve the snow cover accurately from PMR data when the snow is wet or for variable concentrations of water vapour in the atmosphere.

A generally more robust and accurate approach for snow cover extent (SCE) retrieval might be obtained by fusing data from the two sensor types in a multi-sensor model and analysing the result in a time series of observations. We have in the CryoClim project (www.cryoclim.net) developed such a multi-sensor multi-temporal algorithm for retrieval of SCE at global scale from AVHRR GAC plus SMMR or SSM/I data for the generation of binary SCE snow maps of 5 km resolution. The algorithm is applied for generating a 30-year time series of daily snow maps that will be updated regularly with future observations.

The basic algorithm idea is to estimate the states the snow surface goes through during the snow season with a state model. The states are not directly observable, but the remote sensing observations give data describing the snow conditions, which are related to the snow states. We have chosen a Hidden Markov Model (HMM) to model the states and their connection to the observations. HMM is building on statistical theory making it possible to establish a sound probabilistic model derived from observational data.

We model five basic state types in the model: 1) Snow, a seasonal snowpack consisting of a persisting snow layer that will only melt away over a period of time; 2) Temporary snow, a thin snow layer that easily melts away; 3) Wet snow, a state that may occur any time with a snowpack present, only observable with PMR data; 4) Cloud shadow, a moderate reduction of the snow cover as estimated from the optical data only 5) Patchy snow, one or several states with 0% < FSC < 100%, only observable with optical data; and 6) Snow free, only bare ground present.

A HMM is established for each grid cell (pixel) in the snow product. For each time step (day) the whole time sequence of states is recalculated to find the most likely sequence of HMM states (using the Viterbi algorithm) from the start (usually the summer). Single-sensor probabilities for snow based on Bayesian retrieval algorithms go into the HMM scheme as observations. The optical algorithm estimates the probabilities for snow, no-snow and cloud using the AVHRR visible and infrared channels. For SSM/I four snow classes were defined to model the snow cover: wet snow, dry snow, no-snow and no-snow with a large fraction of nearby water. For SMMR the two snow-classes snow and no-snow were considered. To improve the performance of the Bayesian algorithm for PMR data we used land cover data to stratify the retrieval.

For validation we applied SYNOP snow depth data records from the Global Historical Climatology Network Daily (GHCN-D) database for the snow-season 2004-2005. A total accuracy of 92.4% was obtained with full mapping-coverage spatially as well as temporally. When the full 30-year time series has been generated within the next few months, a more extensive validation is planned for a longer time period of the dataset.