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Operational Snow map production for whole Eurasia using microwave radiometer and ground-based observations

Juha-Petri Kärnä, Juha Lemmetyinen, and Martti Hallikainen
Laboratory of Space Technology
Helsinki University of Technology
FIN-02015 TKK
Email: Juha-Petri.Karna@tkk.fi

Panu Lahtinen
Finnish Meteorological Institute
Earth Observation
Helsinki, FINLAND

Jouni Pulliainen and Matias Takala
Finnish Meteorological Institute
Arctic Research Centre
Sodankylä, FINLAND

Abstract—An operational system for production of snow water equivalent (SWE) maps over the whole Eurasia is presented. The system uses synoptic weather station measurements and microwave radiometer data to determine the snow water equivalent over the area. The novel feature of the system is that it combines satellite observations of brightness temperature with ground-based data applying a non-linear Bayesian data assimilation technique. This yields accuracy characteristics better than those of only using either of the two data.

I. INTRODUCTION

Hydrological processes in boreal forest zone are highly affected by the seasonal snow cover. Thus, hydrological models operationally used for run-off and river discharge forecasting employ spatially distributed information on physical snow pack characteristics. In Europe, the most important period is the spring melt season and the snow parameters essential for forecasts include the snow water equivalent (SWE) and snow depth (SD). However, the spatial accuracy of SWE/SD estimates is relatively poor. Moreover, measurements on some important parameters, such as snow liquid water content, are not carried out operationally. Space-borne observations can be used to overcome these problems. Space-borne radiometers provide information that can be used for the mapping of SWE regardless of cloud cover. Radiometer measurements can also be used to retrieve information on snow wetness.

A Bayesian inversion method for deriving SWE using microwave radiometer data is employed. The applied estimation method for SWE is based on the semi-empirical modeling of microwave brightness temperature as a function of forest cover (biomass level), soil properties and snow pack characteristics. The inversion method takes into account the statistical accuracies of the two data sources, microwave radiometers and weather station data. Synoptic weather station snow depth measurements are used in the assimilation process. Investigations are carried out using primarily Advanced Microwave Scanning Radiometer - EOS (AMSR-E) data. In this investigation, the SWE estimation is performed for the whole northern Eurasia.

II. DATA

Investigations are carried out using microwave radiometer data and weather station snow depth measurements. The Advanced Microwave Scanning Radiometer for EOS (AMSR-E) data is used as microwave data. The AMSR-E instrument is a twelve channel, six frequency microwave radiometer instrument mounted on the polar-orbiting EOS-Aqua satellite [1]. Vertically polarized channels 18.7 and 36.5 GHz are used in the snow depth analysis. The horizontally polarized channels, 18.7H and 36.5H, are used in snow status determination. The AMSR-E data is available from NSIDC (National Snow and Ice Data Center) via FTP and WWW. Only descending orbits are used, since they pass over the area during night time. The level 2A data products (resolution of 21 km) [2] are rectified to 0.25 degree grid covering the area of 0° to 180° E and 55° to 85° N.

Synoptic weather station data from the WMO network is used (Fig. 1). Snow depth measurements are interpolated over the whole area under investigation using Kriging interpolation [6], see Fig. 2 for an example.

The Kriging method also produces the snow depth error distribution map, which is used in the assimilation procedure (Fig. 3).

III. METHOD

A Bayesian inversion method for deriving SWE using microwave radiometer data is used [4]. The semi-empirical Helsinki University of Technology (HUT) snow emission model [5] is used to model the snow covered forest emission. The model parameters used are shown in Table I.

Since the model is sensitive to snow grain size, which is an unknown parameter, the synoptic weather station snow depth data is used to determine snow grain size at all weather station locations.

The modeled brightness temperature difference is first fitted to the observed brightness temperature difference \( T_{d_{eff}} = T_{18.7H} - T_{36.5H} \) using the snow grain size \( d_0 \) as a fitting
Fig. 1. Synop weather stations above latitude 55° N providing snow depth data.

Fig. 2. Kriging interpolation of snow depth measurements from March 13th, 2007.

Fig. 3. Snow depth error map of March 13th, 2007. The map is a product of the Kriging interpolation. It shows how the snow depth information uncertainty increases when the distance from the weather station increases.
TABLE I
HUT SNOW EMISSION MODEL PARAMETERS USED.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow pack density</td>
<td>0.24</td>
<td>g/cm³</td>
</tr>
<tr>
<td>Effective soil surface roughness</td>
<td>3.3</td>
<td>mm</td>
</tr>
<tr>
<td>Temperature, soil/snow/vegetation</td>
<td>-5</td>
<td>°C</td>
</tr>
<tr>
<td>Soil dielectric constant</td>
<td>6-1j</td>
<td></td>
</tr>
<tr>
<td>Mean forest cover</td>
<td>77</td>
<td>%</td>
</tr>
<tr>
<td>Mean forest stem volume</td>
<td>80</td>
<td>m³/ha</td>
</tr>
</tbody>
</table>

The melting or wet snow is generally challenging for microwave instruments. To overcome wrong estimates due to melting snow, a traditional dry snow depth algorithm [3] is used to mask out wet snow areas.

The snow depth is estimated first from brightness temperatures of 18.7 and 36.5 GHz horizontally polarized channels, \( T_{18.7H} \) and \( T_{36.5H} \)

\[
D = 15.9 (T_{19H} - T_{37H})
\]

Pixel is mapped as snow if

\[
D > 80 \text{ mm and } T_{37H} < 250 \text{ K and } T_{37H} < 240 \text{ K}
\]

Fig. 4. The flow chart of the snow map assimilation method.

IV. SYSTEM

The snow map production system is automated to produce a SWE every day covering the whole Eurasia. The developed system is operated by the Finnish Meteorological Institute (FMI). The system is implemented using MathWorks MATLAB and scripts and it runs in Linux platform. The microwave and weather station data is fetched automatically and preprocessed. The snow depth measurements are interpolated over the whole area. Then the actual assimilation is performed and water areas are masked out. The method is demonstrated by SWE estimation maps produced over Eurasia for spring 2007. The spatial resolution (pixel size) of the maps is 0.25 x 0.25 degrees. Example maps are available through WWW, at http://snow.fmi.fi (Fig. 5).

Results are available in several formats, including MATLAB mat-file, PNG image and ASCII. Also a Google Earth plugin is available in the WWW-page, to visualize the latest snow map in Google Earth tool (Fig. 6).

V. VALIDATION

The algorithm and the method are already validated in a peer-reviewed paper [4].

The performance of SWE estimation is analyzed by comparing the obtained estimates with independent SWE reference data sources: (a) hydrological model predictions and snow course observations covering the area of Finland and parts of Russia, and (b) observations at weather stations throughout the Northern Eurasia.

VI. CONCLUSION

An operative snow mapping system is demonstrated. The system assimilates weather station snow depth measurements to microwave radiometer data producing snow depth maps covering the whole Eurasia at spatial resolution of 0.25 degrees.
The system will be further developed to achieve better results over Finland where more dense in situ measurements and detailed land cover information are available.

ACKNOWLEDGMENT

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REFERENCES