IMPROVING HYDROLOGICAL FORECASTING USING MULTI-SOURCE REMOTE SENSING DATA TOGETHER WITH IN SITU MEASUREMENTS

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1. INTRODUCTION

This paper describes development of information systems and techniques for improving hydrological forecasting by applying (a) satellite observations, (b) weather radars and (c) *in situ* measurements from automatic monitoring stations. In the methodology developed and demonstrated, the observation data are accompanied with detailed soil and land cover information. The information system is concerned with the following physical characteristics relevant to river discharges and flooding: snow water equivalent (SWE), cumulative amount of precipitation, fraction of snow covered area during the melting period (FSC), soil moisture, and soil frost. The feasibility of a multi-source information system is demonstrated in a pilot experiment for Finnish Lapland, using the hydrological forecasting system of Finnish Environment Institute (SYKE) as an example of a typical operational distributed model (Watershed Simulation and Forecasting System, WSFS [1]). The developed integrated system provides information applicable to be used as input to similar hydrological forecasting systems. Using the new system, an improved performance of hydrological model forecasts is likely be to be gained, especially in case of rapid changes in e.g. snow melt, which may cause flooding and are not adequately considered in present models. The information system also provides data that may have potential for other applications as well, such as forestry and transportation.

2. STUDY AREA AND DATA SETS

For the purposes of this study, Northern Finland (Finnish Lapland) was chosen as a test area (Figure 1). However, the developed methods are applicable for all areas having seasonal snow cover, with the exception of mountainous areas.

The space-borne Earth Observation (EO) data applied include novel advanced microwave radars (such SAR systems as Envisat ASAR, RADARSAT-2, TerraSAR-X, COSMO-SkyMed and ALOS PALSAR), optical monitoring instruments (MODIS and MERIS), microwave radiometers (AMSR-E and SMOS), and scatterometers (QuikSCAT).

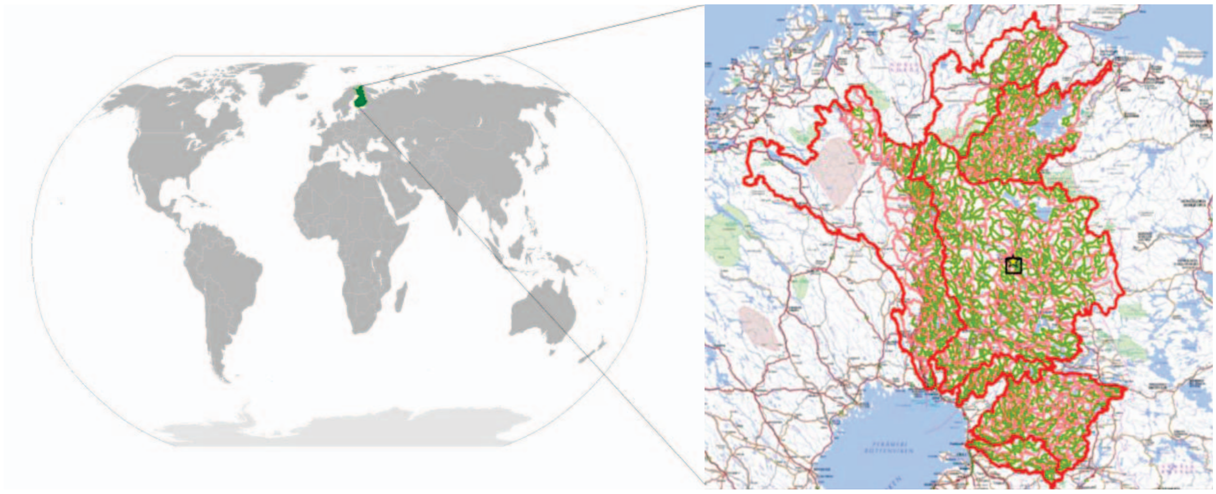

Figure 1. Study area on Northern Finland showing also the drainage areas of the hydrological model used.

Information on all physical variables mentioned above can be retrieved when the EO data sources are used together with observations from weather stations and weather radars (Luosto weather radar of FMI). This is especially the case when *in situ* observations are combined with remote sensing data.

3. METHODS

The products derived from the remote sensing data by the system are: SWE maps from microwave radiometer data [2], FSC maps from optical [3] and radar data [4], soil frost status from scatterometer data [5], and soil moisture from passive microwave data (SMOS). Figure 2 depicts three of the snow cover products. In addition, weather station measurements and weather radar products are combined to produce a cumulative precipitation over a 24 h period. The products are generated primarily using advanced Bayesian data assimilation techniques and by taking into account the effects of soil and land cover. In the following, the SWE algorithm is explained as an example.

The gridded maps of SWE estimates are produced by applying passive microwave observations and weather station observations in an assimilation scheme. A semi-empirical snow emission model is used for interpreting the passive microwave (radiometer) observations through model inversion. As a novel approach, *a priori* information of snow depth is used to calibrate the model where data is available. The basis of the processing system is presented in [2]. Here, estimates of SD (snow depth) based on emission model inversion of two frequencies, 18.7 and 36.5 GHz, are first calibrated over grid cells with weather station data of SD available. Snow grain size is used in the model as a scalable model input parameter. These values of grain size are used to construct a Kriging interpolated background map of the effective grain size, including an estimate of the effective grain size error. The map is then used as an input in model inversion over the span of available radiometer observations, providing an estimate of SD. In the inversion process, the effective grain size in each grid cell is applied in a cost function together with an estimate of the grain size variance. The difference between observed and forward modeled brightness temperature, the latter being also a function of the grain size, are also included in the cost function. The minimum of the function is found using SWE as a scaling parameter, thus giving an estimate of SWE for the respective grid cell. Areas of wet snow are masked out according to observed brightness temperature values using an empirical equation, as model inversion of SD/SWE over areas of wet snow is not feasible due to the saturated brightness temperature response.

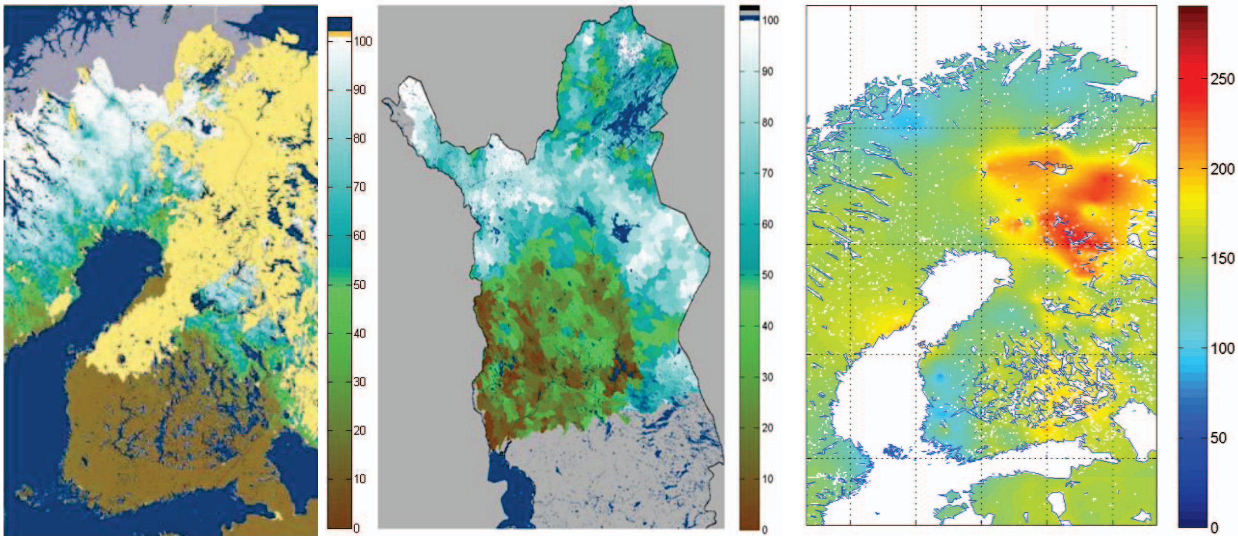

Figure 2. Left: FSC derived from MODIS data (yellow represents clouds). Center: FSC derived from RADARSAT-1 ScanSAR data. Right: SWE in millimetres derived from AMSR-E and weather station data.

The weather station observations of SD are interpolated to provide a crude estimate of the SD (or SWE) background. The SWE estimate map and SD map from weather station observations are combined using a Bayesian spatial assimilation approach to provide the final product.

The snow emission model applied is the semi-empirical HUT snow emission model [6]. The model can calculate the brightness temperature from a single homogenous snowpack covering frozen ground in the frequency range of 11 to 94 GHz. Input parameters of the model include snowpack depth, density, effective grain size, snow volumetric moisture and temperature. Separate modules account for ground emission and the effect of vegetation and atmosphere.

A time-series of high resolution RADARSAT-2 polarimetric scenes were acquired between February 25th and Sep 9th, 2009. These data were ortho-rectified using techniques described in [7]. In Pauli-decomposed images, flooded areas along rivers could be identified in the peak of snow-melting season based on double-bounce scattering.

4. SYSTEM

Remote sensing data products together with ground observations are assimilated into the SYKE's WSFS hydrological forecasting system in order to find out the effect into the accuracy of the hydrological forecasts. The assimilation method assimilates simultaneously different kinds of observation data: SWE and SCA satellite data, SWE ground observations, and discharge and water level observations. The accuracy of each observation and input data type is defined, which defines how much that data has weight in the assimilation.

The aim of the assimilation is to improve the accuracy of the estimate of the state of the hydrological system in the beginning of the forecast and that way improve the accuracy of the hydrological forecast. The improvement in the accuracy of the forecast from each different kind of new data source is derived by making spring flood forecasts over one spring with and without each type of data. Results of these will be presented.

A prototype of the demonstration system has been designed based on Google Earth, which provides easy to use viewing functions like panning and zooming and is able to show different layers of data over base map. User requirements for the demonstration system were gathered from users during a workshop.

5. CONCLUSIONS

The developed and demonstrated technology is a novel, unique approach to combine multiple data sources aiming at the improvement of flood forecast, and thereby reducing threats and damages caused by flooding. The system has been demonstrated on a test area in Finnish Lapland. Moreover, the fundamental idea is that the operational feasibility of multi-source information system is tested and validated in a demonstration case relevant to all regions of world that experience seasonal snow cover (except high mountain regions). The effect of the different types of remote sensing data to accuracy of the hydrological forecasts is presented.

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