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Skill of remote sensing snow products for distributed runoff prediction

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S U M M A R Y

With increasing availability of remote sensing snow cover products we aim to evaluate the skill of these datasets with regard to hydrological discharge simulation. In this paper ten model variants using different snow cover data (MOD10A1, IMS, AMSR-E SWE, GLOBSNOW SWE and observed in situ snow depth) and two different model structures for snow accumulation and snowmelt switching (based on snow cover data time series or temperature time series) are calibrated with a global optimisation algorithm. The simulated discharge is subjected to five criteria for validation, while the GLUE methodology is used for uncertainty analysis of the ten model variants. The skill of the datasets is tested for the Biebrza River catchment, which has a hydrological regime dominated by snowmelt. The discharge simulations are conducted with the distributed rainfall–runoff model WetSpa. MOD10A1 was the only data source which improved the validation Nash–Sutcliffe (NS) scores in reference to a standard model. However, other evaluation measures indicate that the following data sources performed better than the standard model: MOD10A1, observed snow depth and GLOBSNOW for Kling–Gupta efficiency and for high flows; IMS and MOD10A1 for bias; GLOBSNOW and MOD10A1 for coefficient of determination. MOD10A1 has the highest spatial resolution of all analysed data sources which might contribute to the high skill of this data. The use of the data-based switching model structure generally narrowed the behavioural parameter sets during the uncertainty analysis when compared to the temperature-based switching. However, no clear relation was observed between the prediction confidence interval and the two model structures. It is concluded that the skill of the remote sensing snow cover data for the model is positive, although, strongly varying with the data source used.

1. Introduction

With the increasing availability of remote sensing based snow cover products the number of studies using these data in hydrological models are growing. Certainly the most popular remote sensing snow products are derived from the Moderate Resolution Imaging Spectroradiometer (MODIS)\Terra and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) sensors, but the multi-sensor products like the Interactive Multisensor Snow and Ice Mapping System (IMS) and the relatively new Global Snow Monitoring for Climate Research (GLOBSNOW) are gaining interest. The quality of these data sources is assessed against observations in meteorological stations (Parajka and Blöschl, 2006; Chen et al., 2012; Byun and Choi, 2014). Some studies intercompare two snow products with the ground truth (Şorman et al., 2009; Gao et al., 2010; Hancock et al., 2013). However, a comparison of all available remote sensing products at the same time is methodically difficult, since they contain different variables e.g.: snow cover fraction (SCF), snow water equivalent (SWE) or snow cover extent.

Hydrological models, however, are flexible in using various quantitative snow variables, because they use different model concepts for simulating snow processes. Most relevant studies use one particular snow cover dataset as input data in a hydrological model (Yan et al., 2009; Butt and Bilal, 2011; Bavera et al., 2012). More interesting results are, however, obtained when a remote sensing snow product is compared in a hydrological model with other datasets or with measurements from meteorological stations (Udnaes et al., 2007; Şensoy and Uysal, 2012; Yatheendradas et al., 2012). These studies reveal the influence of different data sources on modelling results. Hydrological models are thus a good framework for quality assessment of remote sensing snow cover data.

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Several studies show how remote sensing snow cover data can aid in hydrological modelling. Molotch and Margulis, 2008 used SCF data from various sensors in order to simulate SWE with a spatially distributed snowmelt model. Parajka and Blöschl, 2008 used MODIS snow cover data in combination with discharge data for hydrological model calibration in a number of catchments in Austria. The models calibrated with use of the MODIS data improved the simulation of snow cover, but slightly decreased efficiency of discharge simulation when compared to models calibrated with discharge data only. These findings were in agreement with Udnaes et al., 2007 and Şorman et al., 2009. Another approach was presented by Shrestha et al. (2014) who used MODIS snow cover data in order correct snowfall in a distributed hydrological model. The model using the corrected snowfall improved discharge and snow cover simulation when compared to models using uncorrected data. However, so far a study performing a multi-data-source intercomparison with different remote sensing snow products (obtained from microwave and optical sensors at different spatial resolutions) directly using the data as input for a hydrological model is still lacking. It is important to mention that these experiments are indirect assessments, i.e. the snow cover data quality is evaluated in regard to the skill to simulate the discharge, and is not compared to the snow ground truth in meteorological stations.

Because of this indirect evaluation of the snow cover data, the comparison of different snow products should be conducted with an appropriate hydrological model. The model should allow using remote sensing input data, hence be distributed and physically based, because only in this case both the spatial distribution and the states of the snow variables may be evaluated. Of the available hydrological models fulfilling these criteria, the most popular are VIC, DHSVM, WEB-DHM-S, MIKE SHE, SWAT or WetSpa. The GIS, grid-based structure of the WetSpa model allows straightforward implementation of remote sensing input data (Chormański et al., 2008; Berezowski et al., 2012; Verbeiren et al., 2013). Moreover, WetSpa was proven to be sensitive to the spatial distribution of snow cover in particular (Berezowski et al., 2014). An open question is the comparison method for the simulation results of models using different snow products.

Verbeiren et al., 2013 compared WetSpa modelling scenarios using different distributed data. In their study each model variant was calibrated with a local method (PEST; Doherty, 2010) and the simulation results were compared in terms of several evaluation criteria. This framework could be improved by using a global optimisation algorithm e.g. Shuffled Complex Evolution (SCE; Duan et al., 1992), which should give more reliable parameter estimates. Another improvement could be to subject the different models to uncertainty analysis. For this purpose Younger et al., 2009 used the Generalized Likelihood Uncertainty Estimation (GLUE; Beven and Binley, 1992). GLUE was used in their study to show how the rainfall data perturbed by different factors influenced the uncertainty in hydrological modelling scenarios.

The aim of this paper is to assess the influence of different snow cover data on discharge simulations with a distributed hydrological model. The influence is assessed by means of global calibration and uncertainty analysis of ten hydrological model variants using different snow cover data sources and different model structures. The paper also answers the question: Can remote sensing snow cover data be used as a direct driver for snow processes in order to improve the discharge simulation in comparison to a standard model which uses only in situ data? In Section 2 we describe the study area, data and the hydrological modelling experiment. The latter gives insight into the hydrological model with its variants compared in the study and the methods of calibration and uncertainty analysis. In Section 3 a detailed description is given of the performed analyses and comparison with other studies. In Section 4 the most important findings of the study are presented.

2. Methods

2.1. Study area

The study area is the Biebrza River catchment located in the north-eastern part of Poland (Fig. 1). The catchment is of medium size (6845 km^2) dominated by agricultural land-use (54%) with a big share of forests (26%) and grasslands (17%); a minor part is

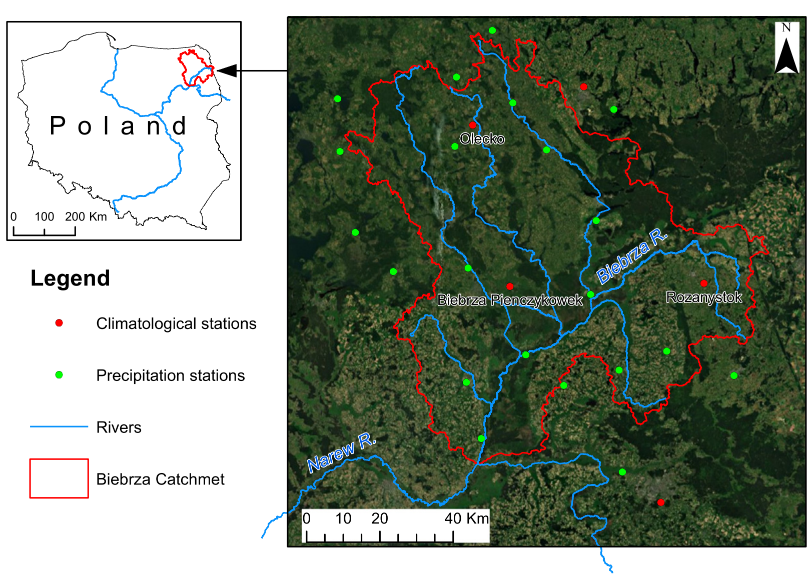

Fig. 1. Map showing the true colour satellite image of the study area. The red and green points indicate the meteorological stations from which the data was used in this study. At the climatological stations (red) the precipitation, temperature and snow depth data were measured, while the precipitation stations provide the precipitation data only. The three labelled stations were used to conduct the snow data accuracy assessment described in Section 2.3. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)