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Introduction to GlobSnow Snow Extent products with considerations for accuracy assessment

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ABSTRACT

The European Space Agency's Data User Element (DUE) project GlobSnow was established to create a global database of Snow Extent and Snow Water Equivalent. The Snow Extent (SE) product portfolio provided within ESA DUE GlobSnow (2008–2014) is introduced and described, with a special focus on the Daily Fractional Snow Cover (DFSC) of the SE version 2.0 and its successor 2.1 released in 2013–2014. The fractional snow retrieval uses the SCAmod method designed ecpecially to enable accurate snow mapping including forests. The basics of the methodology are presented, as well as the cloud screening method applied in SE production. Considerations for future validations together with discussion on some current issues and potential inaccuracies are presented. One focus of the investigation is on the representativeness of reference FSC generated from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) data, with a particular interest in forested areas. Two methods for reference data generation are investigated. When comparing the GlobSnow Daily Fractional Snow Cover to these reference data, we try to identify how the comparison reflects the possible inaccuracies of the DFSC and to define the conditions where the reference data are not representative. It is obvious that the evaluation result strongly depends on the quality of the reference data, and that the two methods investigated cannot provide representative reference data for dense forests. For fully snow-covered dense conifer forest area in Finland, a Root Mean Squared Error of 20–30% was obtained from comparisons although DFSC indicated full snow cover correctly. These first evaluations would indicate a good performance of GlobSnow SE products in forests; however, this does not necessarily show up in validations due to the non-representativeness of the reference data. It is also concluded that GlobSnow SE products are sensitive to the representativeness of the applied SCAmod parameters and that FSC overestimations may occur in dense forests. GlobSnow SE products are available at www.globsnow.info/se/.

1. Introduction

Reliable information on seasonal, inter-annual and long-term changes in snow extent and snow mass is important for climate change studies and water management (e.g. Choi, Robinson, & Kang, 2010; Gong, Cohen, Entekhabi, & Ge, 2007; Kite & Pietroniro, 1996; Schmugge, Kustas, Ritchie, Jackson, & Rango, 2002). The two commonest snow variables detected by means of Earth observation are Snow Extent (SE) – featuring binary 'snow/non-snow' information or sub-pixel Fractional Snow Cover, FSC – and Snow Water Equivalent (SWE). Snow extent is typically derived from optical remote sensing data using single or multi-band reflectance data in the visible and near-infrared region, while snow water equivalent can be retrieved with passive microwave techniques.

The European Space Agency's Data User Element (DUE) project GlobSnow was established to create a global database of Snow Extent and Snow Water Equivalent. GlobSnow-1 was launched in 2008 and candidates for the Climate Data Record (CDR) on SE and SWE were introduced in 2011. These prototype versions were further developed in the sequel project GlobSnow-2 (2012–2014). This paper introduces the current GlobSnow SE products (versions 2.0 and 2.1) with a specific focus on daily product featuring fractional snow cover, and describes the methodology for FSC retrieval.

A very commonly used snow database is the suite of NASA MODIS (Moderate-Resolution Imaging Spectroradiometer) snow products (Hall, Riggs, Salomonson, DiGirolamo, & Bayr, 2002; Riggs, Hall, & Salomonson, 2006), archived and distributed by NSIDC (National

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Snow and Ice Data Center, US). The MODIS snow products have been extensively validated by the research community (e.g. Ault et al., 2006; Hall & Riggs, 2007; Huang, Liang, Zhang, & Guo, 2011; Rittger, Painter, & Dozier, 2013; Wang, Xie, & Lian, 2008); e.g. Rittger et al. (2013) report a Root Mean Squared Error (RMSE) ~23% (FSC %-units) for Collection 5 MOD10A1 fractional snow. This agrees with the results by Metsämäki et al. (2012) where a comparison between Collection 5 MOD10_L2 fractional snow and *in situ* FSC observations in Finland resulted in an RMSE of 20%. As for all currently available methods, the presence of forest canopy poses a problem for MODIS snow retrievals, since the canopy obscures the sensor's view of the ground. Several methodologies have been developed to better adjust to the presence of forest, but the problem remains unsolved (Dietz, Kuenzer, Gessner, & Dech, 2012; Hall & Riggs, 2007; Klein, Hall, & Riggs, 1998; Rittger et al., 2013; Vikhamar & Solberg, 2003). As forests comprise vast portions of seasonally snow-covered regions of the Northern Hemisphere, this is a serious issue.

The GlobSnow SE method development has been particularly focused on fractional snow retrievals in forested areas using ESA ERS-2/ATSR-2 (Along Track Scanning Radiometer) and Envisat/AATSR (Advanced Along Track Scanning Radiometer) data. Based on the evaluation of three different candidate methods, the semi-empirical reflectance model-based method *SCAmod* by Metsämäki, Anttila, Huttunen, and Vepsäläinen (2005) was chosen to be applied to plains while the linear spectral unmixing method *NLR* by the Norwegian Computing Center NR (Solberg, Amlien, & Koren, 2006; Solberg & Andersen, 1994) was to be applied to mountain areas (the borderline as indicated by a mountain mask). Using two different methods, however, produced inconsistencies at the mountain borderlines (Solberg et al., 2011). Therefore it was decided that only one method would be applied, instead of two. The SCAmod method was found to provide approximately similar accuracy as NLR for mountains and non-forested plains while providing a superior performance for forests, so it was chosen for application to the entire geographical domain of GlobSnow. Indeed, the challenge with GlobSnow has been the expansion of an (originally) regionally applied method to a hemispheric scale.

In the present paper we present first comparisons between GlobSnow daily fractional snow cover products and snow maps generated using high resolution Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) data. The aim is not to present an actual validation; instead, we provide considerations for the accuracy of GlobSnow products in different land covers and how this reflects on the comparison results. Particularly, the feasibility of two different methods for generating reference FSC from TM/ETM+ data is evaluated. These evaluations aim at a better understanding of how the validation results depend on the methodology chosen for reference data generation. The findings will support future validation and intercomparison work.

2. GlobSnow SE product overview

The GlobSnow SE product portfolio includes maps of Fractional Snow Cover (FSC, range 0–100% or 0–1) on a 0.01° × 0.01° geographical grid and they cover the Northern Hemisphere in latitudes 25°N–84°N and longitudes 168W–192E. GlobSnow SE products are based on data provided by ERS-2/ATSR-2 (1995–2003) and Envisat/AATSR (2002–2012), so that a continuous dataset spanning 17 years is obtained.

The ATSR-2 is a seven channel instrument providing visible and near-infrared measurements at 1 km spatial resolution. The ATSR-2 was successfully launched on board ESA's ERS-2 spacecraft in 1995 and provided data until 2008. Its successor, the AATSR started operations in March 2002 and provided data until 2012. Swath width for both these sensors is only ~500 km so complete spatial coverage at mid-latitudes cannot be achieved daily. The relevant bands for GlobSnow SE are Band 1 (0.545–0.565 μm) and Band 4 (1.58–1.64 μm) used for FSC retrievals; thermal bands 5, 6 and 7 centered at 3.7 μm, 10.85 μm and 12 μm, respectively, are used for cloud screening. The input ATSR-2/AATSR data used for SE v2.0 production are from the ESA 3rd full reprocessing exercise, which had the new datasets released during late 2013. It was found later that v2.0 SE products whenever based on AATSR suffer from poor geolocation accuracy; after SE reprocessing, this problem is not present in SE v2.1.

The GlobSnow processing system reads ESA provided Level 1B data and transfers them to the GlobSnow SE latitude–longitude grid based on the geolocation grid tie points provided within the data using bilinear resampling. All orbits within the product geographical domain available within a day are processed and combined into orthorectified one day mosaics. The local solar illumination geometry and a digital elevation model (DEM) are applied to compute a terrain illumination model which is applied for radiometric topography correction. After cloud screening, the FSC retrieval method *SCAmod* is applied to the terrain and illumination corrected reflectances for the pixels interpreted as cloud-free. Statistical uncertainty for all cloud-free pixels is also determined. Finally, some thematic masks (e.g. permanent snow and ice/glacier, water, missing/invalid data) are used for final product generation. These procedures are described in more detail in Metsämäki et al. (2014).

The processing software, running on a Linux OS-based Bright Beowulf cluster has been written in ANSI C and is operated at the FMI Sodankylä satellite data center, which also houses the data for the user community at (www.globsnow.info).

The *Daily Fractional Snow Cover* (DFSC) product provides fractional snow cover in percentage (%) per grid cell for all satellite overpasses of a given day. If there are multiple snow observations (only far north within a day), the satellite observations applied are those acquired under the highest solar elevation. The FSC is provided only for observations at sun zenith angle < 73°. The *Weekly Aggregated Fractional Snow Cover* (WFSC) product provides per-pixel FSC from the last available cloud-free observation within the past seven days. The *Monthly Aggregated Fractional Snow Cover* (MFSC) product is based on DFSC products for the given calendar month. Fractional Snow Cover is provided as an average of all available cloud-free estimates within the period. The *Daily 4-classes Snow Cover* (D4FSC) product provides snow cover classified into four categories per grid cell for all satellite overpasses of a given day. In terms of FSC, the four classes represent:

- 0% ≤ FSC ≤ 10%
- 10% < FSC ≤ 50%
- 50% < FSC ≤ 90%
- 90% < FSC ≤ 100%

Weekly and monthly products based on D4FSC are also provided, with same specifications as for daily products. The dataset is available at http://www.globsnow.info/se/. Fig. 1 presents an example of daily, weekly and monthly SE products for April 2006.

The GlobSnow SE daily product DFSC is characterized by data gaps due to the narrow swath width of the ATSR-2 and AATSR sensors. This, together with the 3 days revisit time, implies that number of observations used in the development of weekly and monthly composites is limited. This weakens the ability of these products to capture high temporal changes (snow deposited and melted in a period of a few days). This has implications for the feasibility of the products, for instance in climate change studies. However, these issues are not covered by the present paper as the focus is on the daily product.

3. Description of the FSC retrieval method

3.1. SCAmod and additional rules

The semi-empirical reflectance model-based method *SCAmod* originates from the radiative transfer theory and describes the scene reflectance as a mixture of three major constituents — opaque forest canopy, snow and snow-free ground, which are interconnected through the *apparent forest transmissivity* and the snow fraction. Transmissivity, in