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The accuracy of snow melt-off day derived from optical and microwave radiometer data — A study for Europe

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ABSTRACT

This paper describes the methodology for deriving yearly pixel-wise snow melt-off day maps from optical data-based FSC (Fractional Snow Cover) without conducting any interpolation for cloud-obscured pixels or otherwise missing data. The Copernicus CryoLand Pan-European FSC time series for 2001–2016 re-gridded to 0.1° serves as input for the production of 16 years of melt-off day maps for Europe. These maps are compared with passive microwave radiometer (MWR) melt retrievals, to compare the performance of these two independent datasets, particularly concerning the effect of physiographic and snow conditions on the accuracy of the melt-off day estimates. Both these datasets are evaluated against melt-off day derived from in situ snow depth (SD) time series observed at European weather stations. We also present the relationship of these snow melt-off day products to a passive microwave radiometer-derived landscape freeze/thaw product.

Our results show that the melt-off day derived from optical springtime FSC time series provides the strongest correlation with the snow melt-off day with respect to the in situ data. Overall the deviation of CryoLand FSC data derived melt-off day to that indicated by in situ observations is quite small, with positive bias of 0.9 days, and RMSE of 13.1 days. For 85% of the analyzed cases the differences are between ± 10 days. Across Europe the MWR-based detection of melt-off day is less accurate; the investigated method performs the best for areas with sustained seasonal snow cover. Based on the time series for MWR-based melt-off day (1980–2016) and FT-ESDR (1980–2014), separately for boreal forests and tundra, we also found a clear trend towards earlier snow clearance: a decrease of melt-off day by as much as ~5 days per decade in boreal forest region was observed.

1. Introduction

The mid- and high-latitude areas of Europe are characterized by seasonal snow cover. Snow cover melt influences freshwater runoff, nutrient cycles and animal and plant phenology and productivity (Vaganov et al. 1999; Aurela et al. 2004; Grippa et al. 2005; Cooper et al. 2011). In addition, snow melt timing can serve as a predictor for the onset of photosynthetic (Thum et al. 2009; Böttcher et al. 2014) and animal activity (Pöyry et al. 2017) in boreal areas. Snow cover has a strong impact on the surface albedo; therefore timing of both the melt onset and the final melt-off (snow disappearance) are of great interest. Surface albedo determines the energy budget at the surface, and one of the most immediate and dynamic modifications to surface albedo is snow cover (Barlage et al. 2005). The response of snow albedo to temperature changes over seasonally snow-covered areas is described as the snow albedo feedback. This essential mechanism is a topic of many observational and climate modelling studies (e.g. Thackeray et al. 2014; Qu and Hall 2007) for which observational estimates of snow cover are required.

Statistics of European snow cover duration, snow onset and melt-off dates have been derived from MODIS snow products by Dietz et al. (2012). We investigate the snow melt-off dates for years 2001–2016 using two different Earth observation-based snow products: i) Pan-European Fractional Snow Cover (FSC) product based on the *SCAmod* method described in Metsämäki et al. (2005, 2012), provided through the Copernicus CryoLand service funded by the European Commission (Nagler et al., 2015), and ii) Melt-off day product derived from passive microwave data produced by an algorithm developed at the Finnish Meteorological Institute (Takala et al. 2009). The latter served as input also for Snow Water Equivalent (SWE) products as provided within ESA

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DUE GlobSnow project (Takala et al. 2011). Additionally, the Freeze/Thaw Earth System Data Record (FT-ESDR) (Kim et al. 2011, 2014) which provides estimates of landscape freeze/thaw state is compared to the passive microwave melt-off day product. The goal of the investigation is to assess the accuracy of the above listed melt-off day products as well as the possible differences between them. The applied products used in our study are all fully independent.

There are different definitions for melt-off day: it may be interpreted as the first day with snow water equivalent (SWE) = 0 mm after winter seasons' maximum SWE or, alternatively, the first day with SWE = 0 mm with no subsequent snow until new snow accumulation season takes place in the following autumn. The latter condition may be met substantially later than the former, since short periods of snow cover may occur after the primary melt event (Räisänen et al. 2014). In this paper we use the latter definition, with the exception that less than three days duration late season snow periods are allowed without an effect on the identified melt-off. There are also other terms for melt-off day found in the literature, see e.g. Lindsay et al. (2015) who use LSD (Last Snow Day), related to Melt-off Day (MoD) as MoD = LSD + 1; and Dietz et al. (2012) who use SCM (Snow Cover Melt). In this paper we use a notation MoD for Melt-off Day (snow clearance), indicating the first day of snow-free period after seasonal snow period.

We are interested in the spring time snow depletion as according to e.g. Déry and Brown (2007) and Derksen and Brown (2012), spring-time trends are more evident and have the greatest potential to affect the surface radiation budget, compared to weaker trends in snow cover in fall.

2. Data sets

This section describes the datasets used in this study. Table 1 shows a summary with more detailed descriptions for each dataset in the following sub-sections.

2.1. CryoLand fractional snow cover products

The CryoLand Pan-European snow cover service (Nagler et al. 2015), currently available under the umbrella of the Copernicus Global Land service — Cryosphere theme), provides a homogeneous set of fractional snow cover products from November 2000 till present for the area extending from 72°N/11°W to 35°N/45°E with a spatial resolution of 0.005° × 0.005°. The product uses NASA Terra/MODIS (Moderate Imaging Spectroradiometer) data as input. Since February 2016, the cloud screening is based on a simple cloud detection algorithm *SCDA*, (Metsämäki et al., 2015). Prior to this, the cloud mask product of Terra/MODIS (Ackerman et al., 2010) was used. The sub-pixel FSC retrieval relies on the *SCAmod* method (Metsämäki et al. 2005, 2012), which is designed to perform well particularly in forest areas by utilizing a predetermined forest transmissivity map and a reflectance model. The transmissivity map, available for Europe and the Northern Hemisphere quantifies the transparency of the forest canopy at a pixel level and is related to crown coverage (see further details in Metsämäki et al., 2015). Since SCAmod is very sensitive to the reflectance fluctuations at the reflectance values close to those of a snow-free ground, an additional snow test is applied to the at-satellite brightness temperature as provided by the thermal infrared band 32 (*BT12*, centered at 12 μm) and on the Normalized Difference Snow Index NDSI (= [Band4 − Band6] / [Band4 + Band6]; Hall and Riggs, 1995) to discriminate between snow-free and snow cases. For the FSC production (see example in Fig. 1), only those observations that pass the snow test (BT12 < 283 K and NDSI > threshold (which is latitude, elevation and surface class dependent; Schwaizer et al. 2017) are ingested by SCAmod.

2.2. Melt-off day based on Takala et al. (2009) algorithm

The algorithm to map snow melt in Eurasia by Takala et al. (2009) is based on time series of channel differences of frequencies 18/19 GHz and 36/37 GHz, measured by several microwave radiometers. Takala et al. (2009) produced a time series of snow melt-off in Eurasia for years 1979–2007, validated using point-wise ground truth data from the extensive quality controlled INTAS-SCCONE (International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union — Snow Cover Changes Over Northern Eurasia set derived from weather station observations; Kitaev et al. 2002). Comparison of melt-off days with INTASS SCCONE observations showed a bias of 0.6 days for Scanning Multi-channel Microwave Radiometer (SMMR) and bias of 1.1 days for Special Sensor Microwave/imager (SSM/I), and RMSE of 22.5 and 22.2 days respectively (Takala et al. 2009). This indicates that the passive microwave melt retrievals generally correspond well with the ground-observed values of SCD over continental Eurasia. Moreover, as the algorithm is based on the pixel-wise time series analysis of space-borne observed difference between brightness temperatures observed at 37 GHz and 19 GHz vertically polarized channels (T37v–T19v), it compensates for the disturbing effect of spatially varying vegetation (forest) cover. In particular, the flag for snow status was used in the comparison. The snow melt reference value was obtained by identifying the day when the flag changed from the value "snow depth is correct" to either "temporary melting" or to "continuous melting". If there were more than one such change only the last one was taken into account. In addition, Takala et al. (2009) compared the results to optically derived SCA (Snow Covered Area) data to show that, in case of boreal regions, point-wise observations on snow conditions can provide information concerning larger landscapes (spatial resolution of about 25 km) in validation processes. The dataset applied here is further extended to

Table 1
Datasets used in the study.

Abbreviation	FSC	MoD_{Opt}	MoD_{MWR}	$TD_{FT\text{-}ESDR}$
EO data source	Terra/MODIS	Terra/MODIS	SMMR, SSM/I, SSM/S, AMSR-E	SMMR,SSM/I, SSM/S, AMSR-E
Product	CryoLand Fractional Snow Cover (FSC)	Melt-off day for Europe based on CryoLand FSC	Snow melt-off day for Eurasia	daily Landscape Freeze/Thaw status
Time period	2001–2016	2001–2016	1980–2016	1980–2014
Information	Fractional Snow Cover (% of the grid cell area)	Snow melt-off day	Snow melt-off day	Landscape Freeze-to-thaw day
Original coordinate grid of the product	0.005° WGS-84	0.005° WGS-84	25 km EASE-Grid	25 km EASE-Grid
Resolution used in the study	0.1° WGS-84 (re-gridded)	0.1° WGS-84 (re-gridded)	0.1° WGS-84 (re-gridded); 25 km EASE-Grid	0.1° WGS-84 (re-gridded); 25 km EASE-Grid
Reference to the product/algorithm	Nagler et al. 2015; Schwaizer et al. 2017; Metsämäki et al. 2005, 2012	Nagler et al. 2015; Schwaizer et al. 2017; Metsämäki et al. 2005, 2012	Takala et al. 2009	Kim et al. 2011, 2014

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