NEW APPROACH FOR THE GLOBAL MAPPING OF FRACTIONAL SNOW COVERAGE IN BOREAL FOREST AND TUNDRA BELT APPLICABLE TO VARIOUS SENSORS

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1. INTRODUCTION

Spatially well-distributed and temporally frequent information on the snow cover extent is highly valuable for regional or global needs related to climate change studies, flood forecasting and weather prediction. An important snow parameter is a fraction of snow covered area (FSC), which is provided by various methods applied to different sensors, mostly optical ones. Methods for FSC-mapping are presented by e.g. Klein et al. [1], Painter et al. [2] and Vikhamar and Solberg [3]. The NDSI approach applied in NASA's SNOWMAP algorithm has recently been extended to retrieval of FSC [4]. The seasonal snow cover is practically limited to the northern hemisphere. Method *SCAmod* for FSC mapping in boreal forest and tundra belt using optical and infrared data was proposed by Metsämäki et al. [5]. The method is based on a semi-empirical reflectance model, where at-satellite reflectance is described as a function of FSC. The average reflectance values for three major reflective contributors (wet snow, snow-free ground and forest canopy) serve as constant model parameters. The forest transmissivity must be given for each calculation unit area, and is a-priori calculated for each unit-area using the *SCAmod* model itself applied to EO-data acquired over full snow cover conditions. Since no land cover data except water mask is needed, it is easily adaptable to extensive areas. This characteristics, on the other hand, limits its use to a certain vegetation/climatic zone, mainly due to the pre-set constant reflectances. These constants have been tuned to give the best performance the target area of boreal forest and tundra belt.

The data provided by optical sensors are spatially and temporally limited during the snow-melt season due to need of solar illumination and cloud-free conditions. *SCAmod* was designed to work with different sensors in order to maxmise the amount of data for FSC-calculations. This paper focuses on the accuracy assessment of SCAmod-derived FSC-estimates on boreal forests and tundra area, when applied to Terra/MODIS and Envisat/AATSR data. It is already proven that in regional scale, SCAmod provides better FSC accuracy than NDSIC MOD10_l2 product v004 [6]. In this study, *SCAmod* FSC is compared to NASA fractional product (Mod10_l2 v005). The results show clearly better performance of *SCAmod* compared to that NASA's, indicating that extending the application area of *SCAmod* is well justified. This study is made under the European Space Agency (ESA) Data User Element (DUE) funded GlobSnow.

2. STUDY AREA AND DATA SET

The methodology is demonstrated for Northern Eurasia. The validation against ground truth is carried out over Finland (~338,000 km^2) due to a good in-situ network provided by Finnish Environment Institute and the Finnish Meteorological Institute. Finland is mostly covered by boreal forests, open bogs, lakes and agricultural area, but in the north tundra is dominating the landscape. No significant altitude variations occur in the average. Finnish snow course network consists of ~150 courses which are monthly measured. At snow courses, visual observations of fraction of snow covered area are made at 80 locations along a trail of 2-4 km through various landscapes. Finnish Weather stations network consists of ~250 stations with daily measurements of snow depth and snow coverage. Snow coverage is described with a particular e-code defined by WMO, see table I.

Table I. E-codes describing fractional snow coverage.

e-code	Indication
7,9	full snow cover (wet and dry)
6	snow cover more than 50% but less than 100%
4,5	snow cover less than 50% but more than 0% /Open areas snow free, snow exists in forests
3	0% snow cover

Processing of MODIS and AATSR level1b-data included calibration to top-of-atmosphere reflectances and brightness temperatures, followed by geo-rectification to WGS-84 system with 0.01°×0.01° grid cell size. The MOD10_l2 data were rectified into the same grid. The datasets to be validated are presented in Figure 1.

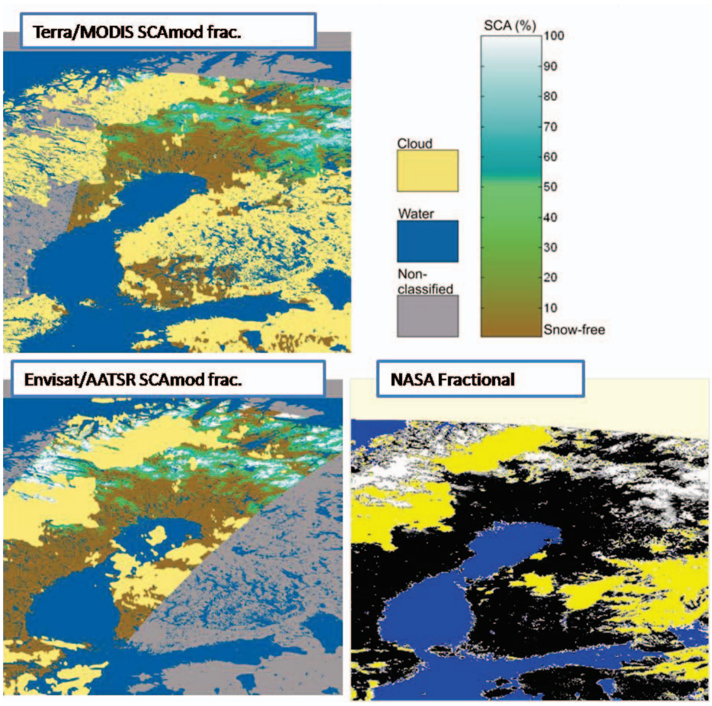

Figure 1. Three Fractional snow cover products validated in the study.

3. METHODOLOGY

SCAmod was applied to Terra/MODIS and Envisat/AATSR. The resulted FSC-estimates were compared with

NASA FSC-products and ground truth. *SCAmod* gives the FSC as follows:

$$FSC = \frac{\frac{1}{t_\lambda^2} * \rho_{\lambda,obs} + (1 - \frac{1}{t_\lambda^2}) * \rho_{\lambda,forest} - \rho_{\lambda,ground}}{\rho_{\lambda,snow} - \rho_{\lambda,ground}},$$

where $\rho_{\lambda,snow}$, $\rho_{\lambda,ground}$ and $\rho_{\lambda,forest}$ are the generally applicable reflectances for wet snow, snow-free ground and dense coniferous forest canopy at wavelength λ, respectively. $\rho_{\lambda,obs}$ stands for observed reflectance from calculation unit–area. t_λ stands for effective transmissivity for the unit-area. Band 4 (550μm) of MODIS and band 7 (550 μm) of AATSR were employed by *SCAmod*. With both sensors, we applied also 1.6 μm band in order to utilize NDSI in the recognition of snow-free areas, when the appearing green vegetation raises the reflectances and might lead to overestimation of FSC if not accounted for. Hence if NDSI<0, FSC is set to 0%.

In the validation against snow course data, the average FSC estimated for pixels covering the course is compared with average FSC observed at-ground along the course. This analysis gives RMSE describing the overall performance of each method in fractional snow cover mapping. When validating against weather station e-codes, the FSC-estimates are quantized accordingly into a 4-class system, and confusion matrices between the classifications are provided.

4. RESULTS

Validation indicates that *SCAmod* performs well in boreal forest area and tundra. Validation against snowcourse FSC shows an RMSE of 0.07 for *SCAmod* applied to AATSR-data, while with NASA FSC-product, an RMSE of 0.20 was obtained. S*CAmod* MODIS validation covers currently years 2003-2005 only, and will be extended in the full article. The results are presented in Figure 2.

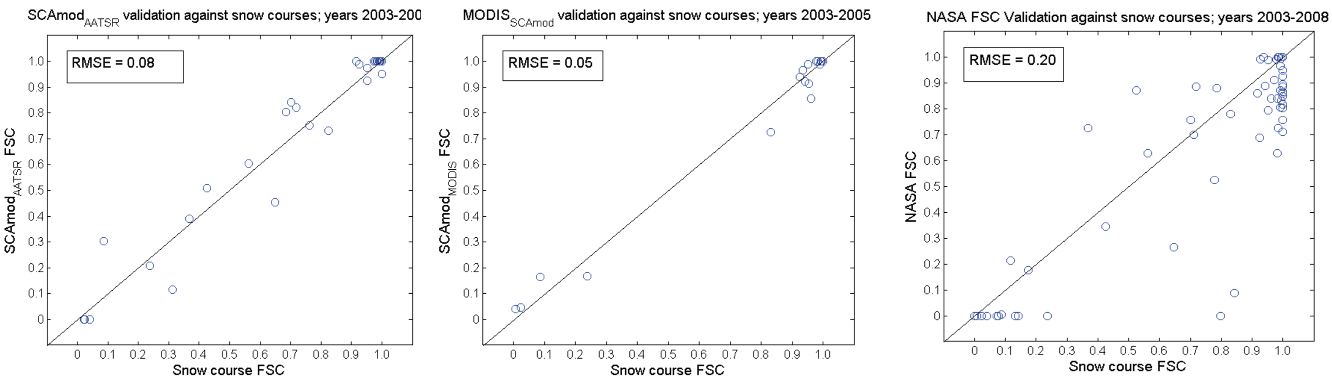

Figure 2. Snow course validation with AATSR (Left), MODIS (middle) and Mod10_l2 fractional product (Right).

Table II. *SCAmod* FSC-estimates (classified according to e-coding system) against weather station e-codes.

Data set	Reference data: e-codes											
SCAmod AATSR	Classes	0%		0%<FSC<50%		50%≤FSC<100%		FSC=100%		Total#	Commission errors	
		%	#	%	#	%	#	%	#		%	#
	FSC = 0%	**97.2**	2423	45.6	1830	0.1	2	0.0	0	4255	43.1	1832
	0%<FSC<50%	2.4	61	**28.9**	1159	10.0	238	1.9	110	1568	26.1	409
	50%≤FSC<100%	0.3	8	16.3	653	**43.6**	1038	15.8	906	2605	60.2	1567
	FSC=100%	0.0	0	9.2	369	46.3	1103	**82.3**	4734	6206	23.7	1472
Total #			2492		4011		2381		5750	14634		
Omission		2.8	69	71.1	2852	56.4	1343	17.7	1016		**36.1**	

Table II shows the confusion matrix between FSC derived with *SCAmod* applied to AATSR and weather station e-codes. Clearly, full snow coverage and snow-free ground are well recognized, while the two intervening classes remain only moderately recognized. The overall classification accuracy is 64%. This result should be carefully judged, as weather stations are point-wise measurements (although should represent the overall status in the vicinity), located in open area where the snow usually disappears a little earlier than in the surroundings with forests. Therefore in general, it is quite possible that part of FSC-estimates falling into a "wrong" category actually do reperesent the overall status quite well. NASA algorithm, on the other hand, strongly underestimates the FSC in all categories; the gained corresponding classification accuracy was 49%. The corresponding table for *SCAmod* applied to MODIS will be presented in the full article.

The fact that *SCAmod* needs the transmissivity map in order to work can be considered a weakness, since the transmissivity data in global scale are not available. Generating the transmissivity for the whole of Northern hemisphere is a time-consuming task. However, we found that transmissivity can be generated using ESA GlobCover classification. This approach evidently leads to somewhat weaker accuracy of FSC, but the preliminary studies show that it's still higher than that of NASA Fractional product. This approach allows the expansion of FSC mapping into global scale with tolerable effort.

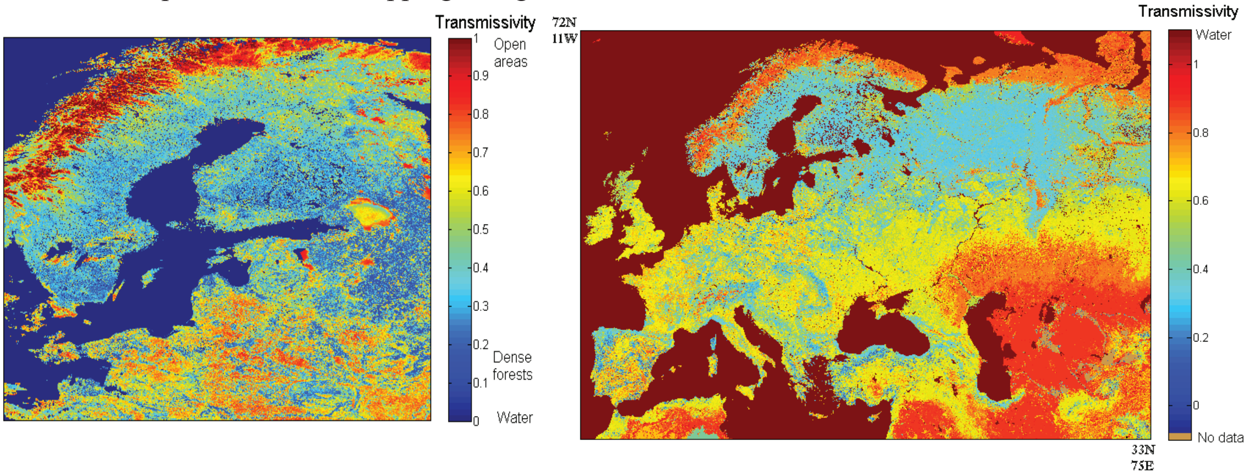

Figure 3. Transmissivity map over Baltic Sea Drainage basin derived using SCAmod-equation applied to MODIS-data at full snow cover conditions (Left) and derived from GlobCover data (Right).

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