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Topics:

- SWE development and validation activities of Phase 1
- GlobSnow-2 User Consultation Meeting, 4-5 December 2012, Darmstadt
- SE development and validation activities of Phase 1

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SWE development and validation activities of Phase 1

The GlobSnow snow water equivalent (SWE) product is derived through a combination of snow depth measurements from climate stations, and satellite passive microwave measurements. These two very different types of observations are connected through forward simulations with a snow emission model, from which an estimated snow depth is derived. The final SWE estimates are then produced by converting snow depth to SWE by making some assumptions about snow density. Improvements to the products can therefore be achieved by addressing the quantity and quality of the climate station snow depth measurements, improving the performance of the snow emission model, and ensuring the depth to SWE conversion is as accurate as possible. Following the release the of the baseline GlobSnow-1 v1.3 SWE data record in 2012, the GlobSnow SWE team is currently evaluating a new prototype SWE retrieval (applied over the years 2003 through 2008) with the goal of reducing, and better charactering, the uncertainty in future versions of the GlobSnow SWE product.

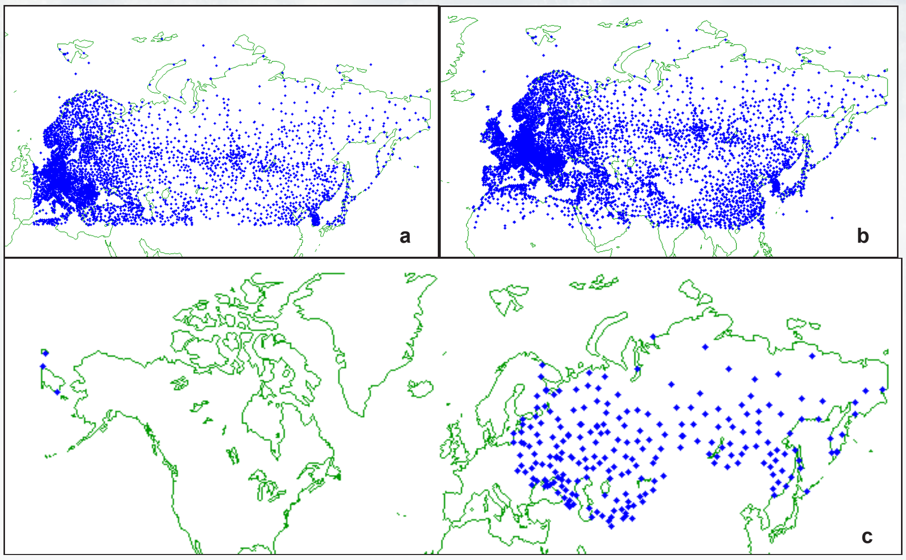

Figure 1: (a) Locations of synoptic weather stations over Eurasia used in GlobSnow SWE FPS version 1.3; (b) increased domain used in the new prototype dataset; (c) additional Russian climate station data obtained for 1978-2008.

Snow depth observations from climate stations

Measurements of snow depth made at synoptic weather stations are downloaded from the operational archive at the European Centre for Mid-range Weather Forecasting (ECMWF). The ECMWF dataset for Eurasia in the baseline GlobSnow-1 v1.3 SWE included 5638 stations, as shown in Figure 1a. The prototype GlobSnow SWE product has an extended Eurasian domain to longitude -15 in the west and to latitude 20 in the south. This increase in area now means snow depth measurements from 7248 stations (Figure 1b) are ingested into the retrieval. For the period 1978-2008, additional snow depth observations over Russia (http://meteo.ru/english/climate/descrip2.htm) were obtained, and provide much needed observations across a region where climate stations are relatively sparse (Figure 1c).

The climate station snow depth measurement network over North America available from ECMWF, and used in the baseline GlobSnow-1 v1.3 SWE dataset, is shown in Figure 2a. For the prototype dataset, this was significantly augmented by additional stations over the 1979 to 2009 time period as described in Dyer and Mote (2006; Figure 2b). The increased density of climate station observations will improve the background snow depth field produced by kriging the station data, and increase the number of grid cells for which effective snow grain size can be estimated using snow emission model simulations and satellite passive microwave measurements.

Acquring snow depth measurements near a meteorological station in Trail Valley Creek, Northwest Territories, during an Environment Canada field campaign in April 2013. Photo: Arvids Silis, Environment Canada

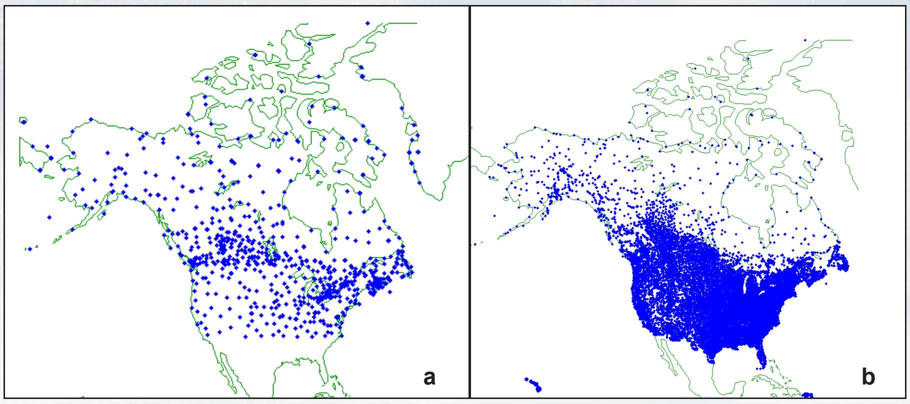

Figure 2: (a) Locations of synoptic weather stations over North America used in GlobSnow SWE FPS version 1.3; (b) increased density of stations used in the prototype SWE.

Improvements to HUT snow emission model

The forward model for microwave emission, applied in the GlobSnow SWE retrieval algorithm, is an integral part of the retrieval process. The original model (HUT snow emission model, Pulliainen et al., 1999) simulates microwave emission of terrain covered by a homogeneous layer of snow. A recent update to the model (Lemmetyinen et al., 2010) allows the simulation of stacked snow structures, resulting in an improvement of modelling accuracy. The model also includes a module for simulating microwave emission over snow-covered freshwater lakes. Applied in the retrieval algorithm, the updated model has been shown to improve retrieval results from satellite data when fractional lake cover was accounted for (Lemmetyinen et al., 2011).

The GlobSnow retrieval algorithm was updated to accommodate the improved forward model. The module for compensation of fractional lake cover still requires ancillary data on lake ice properties; several possibilities for this are being studied, including climatological data on lake ice and the application of physical lake ice models (e.g. Duguay et al., 2003) on a hemispherical scale.

Introduction of dynamic snow density

The baseline GlobSnow-1 v1.3 SWE retrieval used a static snow density of 0.24 g/cm^3 to convert snow depth to SWE. While snow depth is the primary control on SWE variability, the use of fixed snow density is physically unrealistic, because we know snow density varies through the snow season, and between different land cover types. For instance, snow in the boreal forest is largely shaped by snowfall interactions with standing vegetation, with little influence from wind, which produces deep snow with relatively low density. Conversely, tundra snow is shallow, dense, and composed of fine grained wind slabs shaped by blowing snow events.

For the prototype SWE dataset, temporally varying snow density was utilized based on an approach described in Sturm et al. (2010). A simple model, derived from analysis of over 100 000 paired snow depth and density measurements, is used to

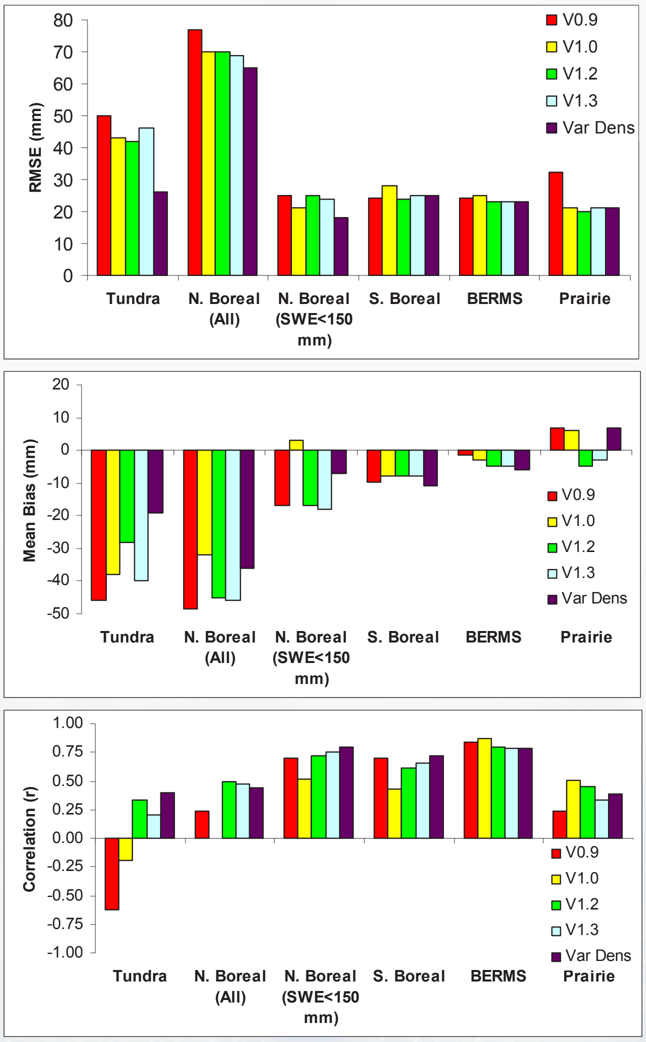

Figure 3: RMSE (top) mean bias (middle) and correlation computed for the variable density prototype with Canadian reference datasets, separate by land cover type.

convert depth to SWE based on the day of year (because density increases with time) and the magnitude of the snow depth (deeper snow tends to be more dense than shallow snow). The model applies different densification coefficients based on the type of snow (boreal, prairie, tundra).

The prototype SWE retrievals using variable density were assessed with the same Canadian reference datasets as were used in evaluations of previous GlobSnow FPS versions. While minor improvements in retrieval performance were noted for boreal and prairie environments, more notable improvement was evident at tundra sites (Figure 3). The RMSE was reduced from ~45 mm with the baseline GlobSnow-1 v1.3 SWE to 26 mm when the variable density was applied. Bias was reduced from -40 mm to -19 mm, and correlation improved from 0.20 to 0.40. The variable density approach resulted in notably higher snow density than 0.24 g/cm^3 across tundra regions, which is responsible for the improvement in retrievals, although the -19 cm bias indicates the SWE estimates are still too low.

Results of the evaluation over Eurasia and Finland indicated little improvement due to the incorporation of variable density. Figure 4 shows the SWE retrieval comparison between the baseline GlobSnow-1 v1.3 SWE and the variable density prototype using Finnish snow course data. The black points show the samples that were more accurate with the baseline v1.3 method, blue points show the samples that were more accurate with the variable density method. The baseline method produced more accurate retrievals in 684 cases and the variable density approach resulted in more accurate retrievals in 678 cases.

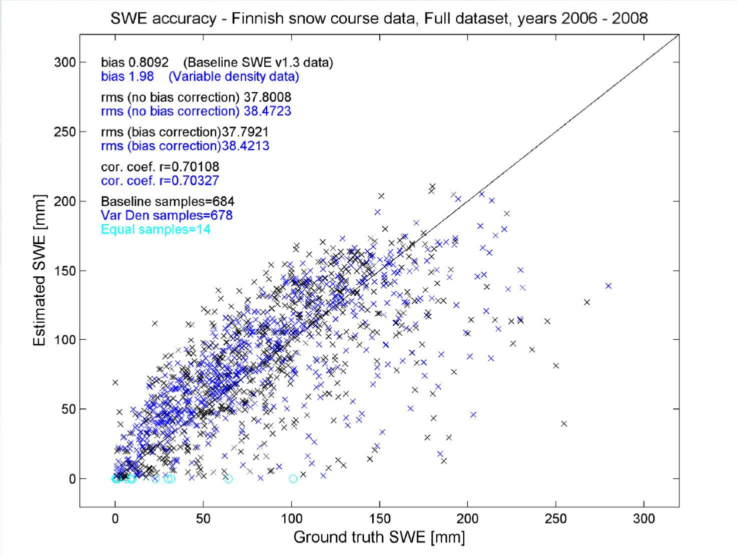

Figure 4: SWE retrieval comparison between the baseline GlobSnow-1 v1.3 SWE and the variable density datasets acquired using Finnish snow course data.

Table 1. Prototype variable SWE retrieval performance for over Russia for different seasons.

	RMS-error [mm]	Bias [mm]	Corr.coeff	Samples
All seasons	38.00 / **41.27**	3.67 / **8.94**	0.712 / **0.682**	23293
Sept.-December	25.53 / **28.13**	11.82 / **12.33**	0.710 / **0.643**	4438
January-March	35.54 / **39.84**	7.78 / **14.35**	0.738 / **0.702**	15358
April, May	56.93 / **57.98**	-24.68 / **-19.14**	0.605 / **0.578**	3496

Evaluation of the prototype variable density retrievals over Russia showed a slight increase in the retrieval uncertainty, although the bias was lower (better) for the variable density dataset during the spring period. The key difference between the two methodologies is an increase in the snow density during the snow season within the prototype method, which has the highest effect during late spring (Table 1).

While it is much more physically realistic to have variable snow density over space and time as opposed to using a static value, the evaluation results show that further developmental work is needed, particularly over boreal regions, before initiating the reprocessing of the long term (30+ years) SWE time series. An increase in the number of climate station measurements, and improvements to the snow emission model will also have an impact on future versions of the GlobSnow SWE data record. □

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Duguay, C., G. Flato, M. Jeffries, P. Menard, K. Morris, and W. Rouse, 2003. Ice-cover variability on shallow lakes at high latitudes: model simulations and observations. Hydrol. Processes, 17, 3465-3483.

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Pulliainen, J., J. Grandell, and M. T. Hallikainen, 1999. HUT snow emission model and its applicability to snow water equivalent retrieval. IEEE Trans. Geosci. Remote Sens., 37, 1378-1390.

Photo: Arvids Silis, Environment Canada

First Workshop on European Satellite Snow Monitoring Perspectives

The first Workshop on European Satellite Snow Monitoring Perspectives was held at the Eumetsat headquarters in Darmstadt, Germany, from 4-5 December 2012. It brought together the main European snow monitoring initiatives with key users, hence serving as a platform for dialogue on experiences, expectations, and perspectives regarding snow monitoring services.

The workshop addressed the current state of development of European snow monitoring capabilities, the identification of gaps and opportunities in meeting users' needs, and the definition of priorities for developments over the next decade building upon European expertise and satellite infrastructure. An important topic of discussion was how current satellite-based snow monitoring initiatives fit within Copernicus/GMES and the priorities of Eumetsat, ESA, and the European Commission (EC) over the next decade. It was decided to elaborate a White Paper for the attention of the EC, providing a perspective on the future of European satellite snow monitoring services.

A representative of the World Meteorological Organization (WMO) moderated the discussion on recommendations regarding European snow monitoring perspectives, with various users from meteorological and hydrological institutions being actively involved. The resulting recommendations address products and services, but also improvements in Europe-wide coordination and development of services to maximize benefits to users. They will serve as an input for the White Paper to be compiled within the GlobSnow-2 project.

The workshop summary and all the presentations are available through the GlobSnow website. A follow-up workshop on European Snow Monitoring perspectives and GlobSnow developments will be organized alongside the 7th EARSeL LISSIG workshop in Bern, Switzerland, preliminarily set for 3 - 7 February 2014. With one intention being the further establishment of a so-called "Group on European Satellite Snow Monitoring Perspectives".

Photo: Sini Merikallio, Finnish Meteorological Institute

SE development activities of Phase 1

The Snow Extent product in mountain regions

Determining bare-ground reflectance for mountains

The main objective of this study, carried out by the Norwegian Computing Center (NR), has been to determine top-of-atmosphere reflectance values, representative of mountain land cover types, which can be used for bare-ground reflectance parameterisation in the Snow Extent retrieval algorithm. The bare-ground reflectance values we seek are those present under fractional snow cover conditions. Since it is hard to retrieve pure bare-ground reflectance when there are still patches of snow present, we determined the reflectance values as soon as the snow had melted.

To determine the time when the snow just has completely melted on a per-pixel basis, we have used an algorithm developed by NR to analyse and interpret time series of reflectance observations. The reflectance of the observed ground surface cover is mainly determined by the local geology/mineralogy, vegetation and soil moisture. Ideally, the reflectance should have been derived for all mountain regions data and processing needed is significant, and we chose as a compromise four regions representing significant diversity with respect to the three aspects: Scandinavian Mountains, Caucasus Mountains, Tibetan Plateau and Rocky Mountains.

Terra MODIS data (band 4, which corresponds well with AATSR band 1, approx. 555 nm) was used to determine top-of atmosphere bare-ground reflectance as MODIS has more frequent coverage and therefore makes it easier to find cloud-free observations at the right time. The reflectance was further stratified into the dominating land cover classes for each region to cope for within-region variability. The land cover types were determined from the ESA GlobCover MERIS data set. The reflectance data were corrected for the effect of the incident angle to the terrain surface ('the cosine effect') by topographic radiometric normalisation (C-correction algorithm). A mountain mask was used to identify the mountain regions. An example of a mountain region studied is provided in Figure 5.

In the Caucasus Mountains, as an example, 16 of the 22 GlobCover classes are present. Since most of the region is relatively rich in precipitation, the ground is in general covered by vegetation except for steep areas where the bedrock is exposed and where the ground is covered by large rocks draining loose material away. The region is much dominated by mosaic cropland (class 20) and mosaic vegetation (class 30), both mixtures of grassland, shrubland and forest. Figure 6 shows the reflectance values determined for the GlobCover classes.

Our study concludes with a description of four alternative approaches for bare-ground parameterisation of the Snow Extent algorithm in mountains building on our findings. The easiest solution is to use a new average reflectance value for all mountain regions. The new value should be 6.6% reflectance (compared to 10% used today). A more accurate and relatively quick advancement compared to this is to use region-wise mean reflectance values where the Northern Hemisphere has

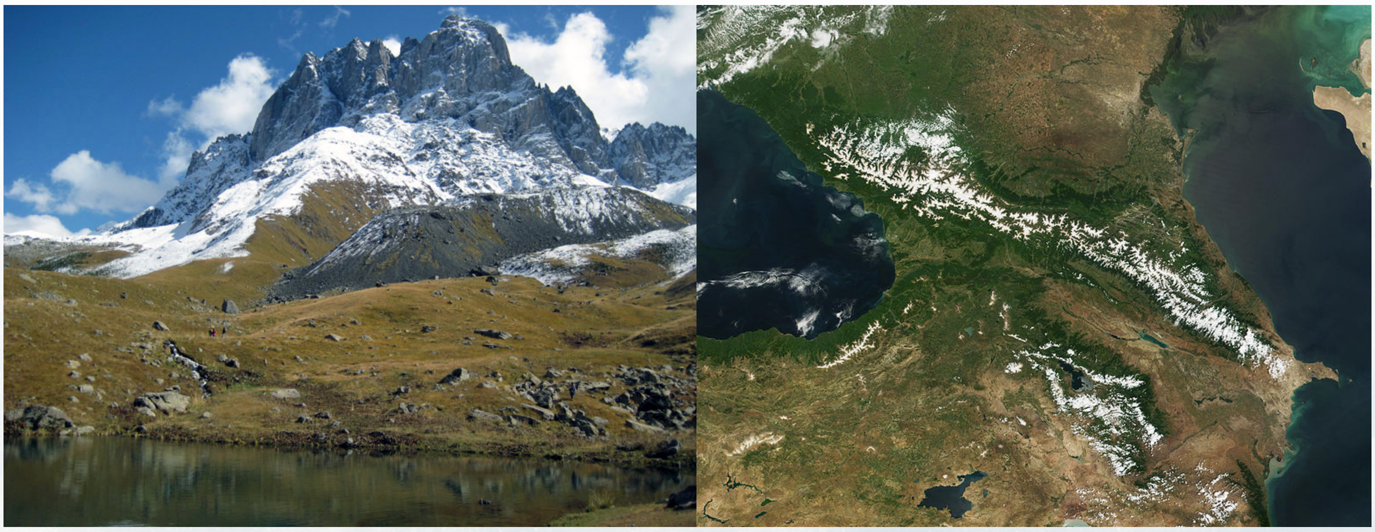


Figure 5: Caucasus Mountains seen from the ground (left) and from a satellite (right).

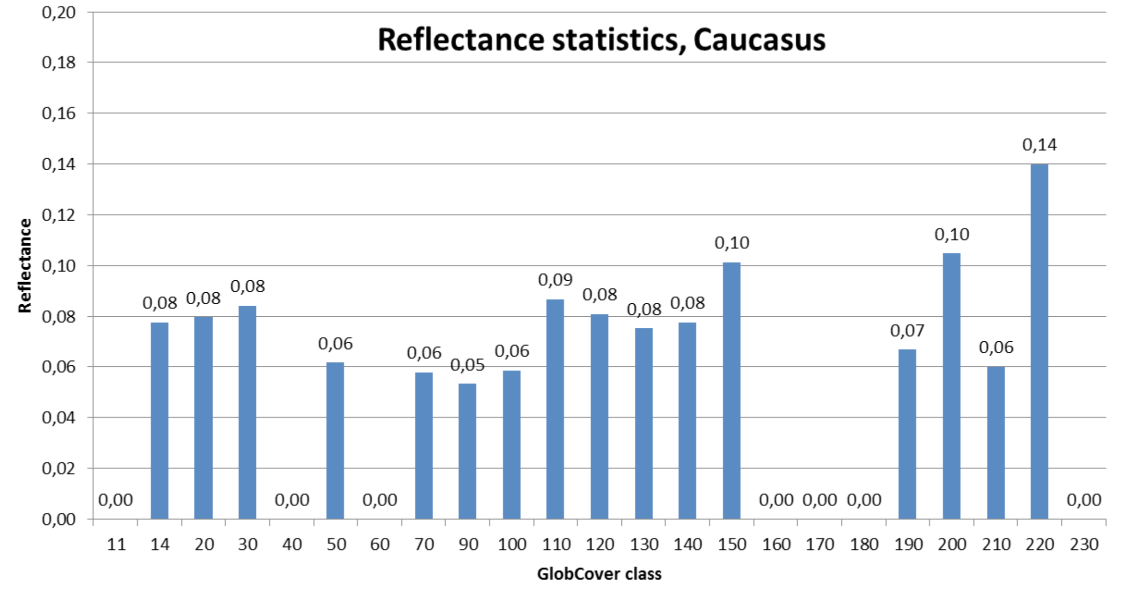


Figure 6: Mean reflectance values calculated for the GlobCover classes.

been stratified into four mountain zones. The most detailed approach would be to use a reflectance value for each land cover class present. Which approach to use operationally is still to be decided.

Computing the uncertainty of the snow extent product in the mountains

The terrain effects affecting the uncertainty of the Snow Extent product depend mainly on two factors: A reduction of measured reflectance due to cast shadows and residuals of the radiometric topographic correction. The cast shadows may be on a sub-pixel level due to small-scale terrain variations, or include several pixels (e.g. due to cast shadows from nearby peaks).

The Norwegian Computing Center (NR) has studied the effects on the uncertainty estimation due to cast shadows for two mountain regions in Norway. As a model for the cast-shadow effect from the terrain in the fractional snow cover (FSC) uncertainty estimation we consider the 'shaded relief' or 'hillshade' algorithm. The algorithm obtains the (hypothetical) illumination of a surface by determining illumination values for each pixel in the image for a given sun position. If the hillshade is estimated from a DEM with a much higher resolution than the image sensor, small-scale terrain variations may by accounted for. The output of the shaded relief algorithm is the fractional shaded area, a value between 0.0 and 1.0, where 0 corresponds to complete shadow.

The evaluation of the bias for the two regions in Norway shows that the Snow Extent product performs very well in such mountain areas for full snow cover. The bias of the products is very small even for regions with very low shaded-relief values. Based on our very preliminary study, the need for bias correction may not be needed.

However, we have so far only investigated two sites with moderate terrain relief, and only for 100% FSC. Therefore, we cannot from the study conclude whether bias correction would be needed for conditions of FSC < 100% (patchy snow cover). We recommend evaluating the bias for other sites and regions, including patchy and snow-free conditions. Other regions should include steeper (more alpine) terrain like the Alps, where there are severe terrain effects with large cast shadows.

If further investigation of the cast-shadow effect leads to the conclusion that the FSC retrieval results are unbiased with respect to the terrain effect, the same uncertainty model as plains for can be applied for mountains. This is certainly the most attractive solution as the uncertainty estimates for the Snow Extent product will be seamless and consistent between plains and mountains. However, if further analysis leads to the conclusion that bias must be taken into consideration for uncertainty estimations for mountainous regions, we suggest applying the shaded-relief approach described above. This means that a shaded-relief map needs to be constructed for each image acquisition to be used for Snow Extent product. This is feasible using the ASTER GDEM V2 global digital elevation model.

Mountains in Jotunheimen
Photo: Rune Solberg

Recent developments of the SE product

The SCAmod method behind SE-product relies on a semiempirical reflectance model based on a radiative transfer theory. It uses fixed reflectances for wet snow, forest canopy and snow-free ground as model parameters; see Metsämäki et al. (2012). Additionally, the essence of SCAmod - the two-way forest canopy transmissivity (t^2) - is applied as a spatially varying parameter. Transmissivity is related to forest density and can be estimated using multiple reflectance observations from a fully snow-covered terrain. Since the accuracy of the FSC retrievals is dependent on the applied parameters, the SE development work in GS-2 (WP2.1 led by the Finnish Environment Institute) has focused on a still better determination of those.

The Northern Hemisphere FSC mapping requires pixel-level information on forest canopy transmissivity. According to SCAmod, the transmissivity can be derived from reflectance data acquired at full snow cover conditions. In hemispherical scale this would not be feasible due to the unavailability of representative clear-sky data. Therefore, the GlobSnow approach was to first derive transmissivity data from Terra/MODIS acquisitions for several 'training areas' and then use global land cover map (GlobCover, Bicheron et al. 2008) to obtain pixel-level transmissivities on hemispherical scale, based on class-wise transmissivity statistics and the local land use classes. The resulting hemispheric transmissivity map was determined in GlobSnow-1 and was used to provide CDR for SE. It was found however, that the map could not appropriately identify the densest forests; these were assigned with too high transmissivity, which resulted to FSC underestimations clearly distinguishable e.g. in very dense boreal forest areas in Russia. The reason for this was that GlobCover data did not properly distinguish between dense and very dense forests, which hamper the statistical calculations when determining the average transmissivity for forest classes. In GlobSnow-2, the solution was to use global albedo data (GlobAlbedo) to idenfify the densest forest, otherwise using the same approach as in GlobSnow-1. In the current transmissivity map, the dense forest areas are well identified and the underestimations for forests were remarkedly diminished. The transmisivity maps for Eurasia and northern America are presented in Figure 7.

Determining bare-ground reflectance for non-mountain area

The representativeness of snow-free ground reflectance is important for the success of FSC retrieval with SCAmod. The hypothesis is that

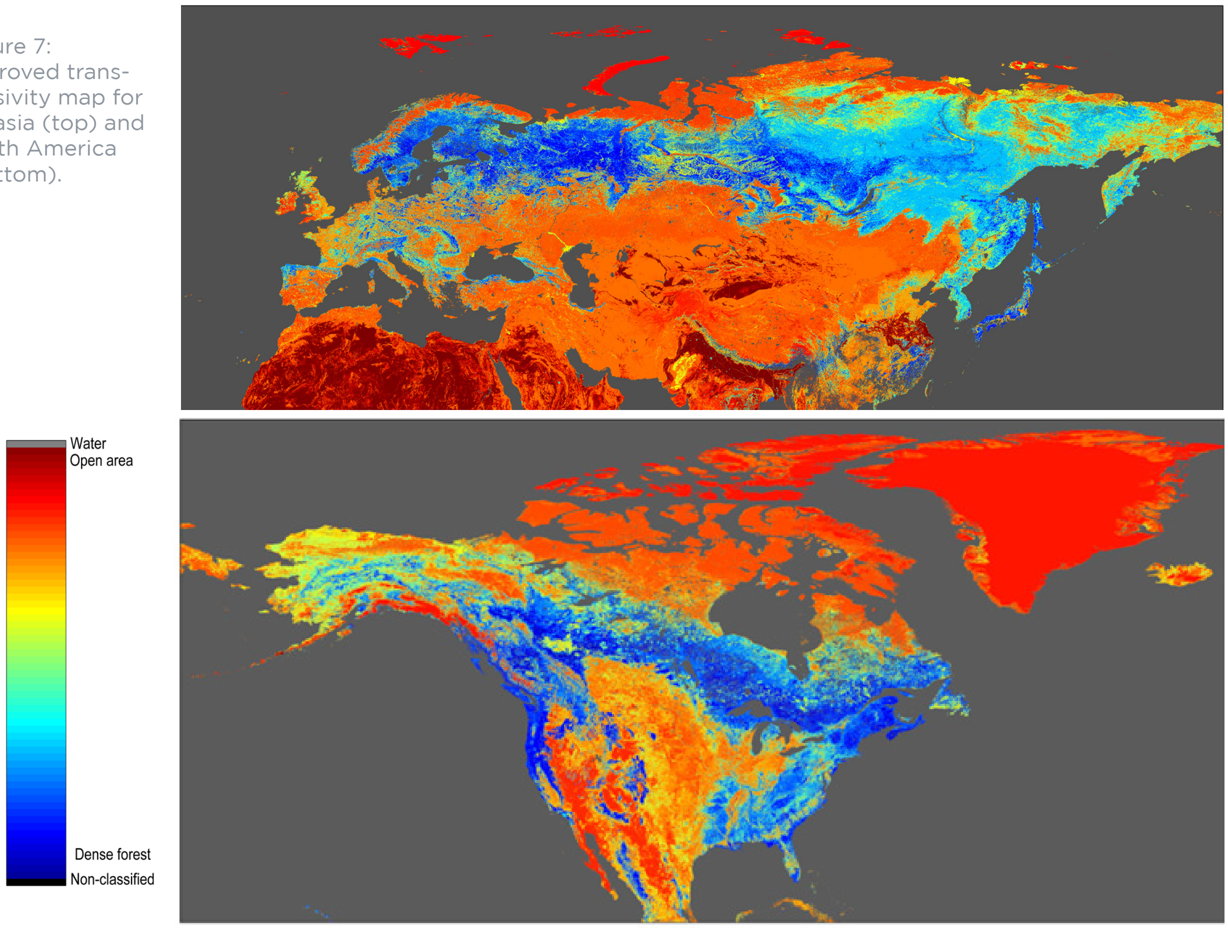
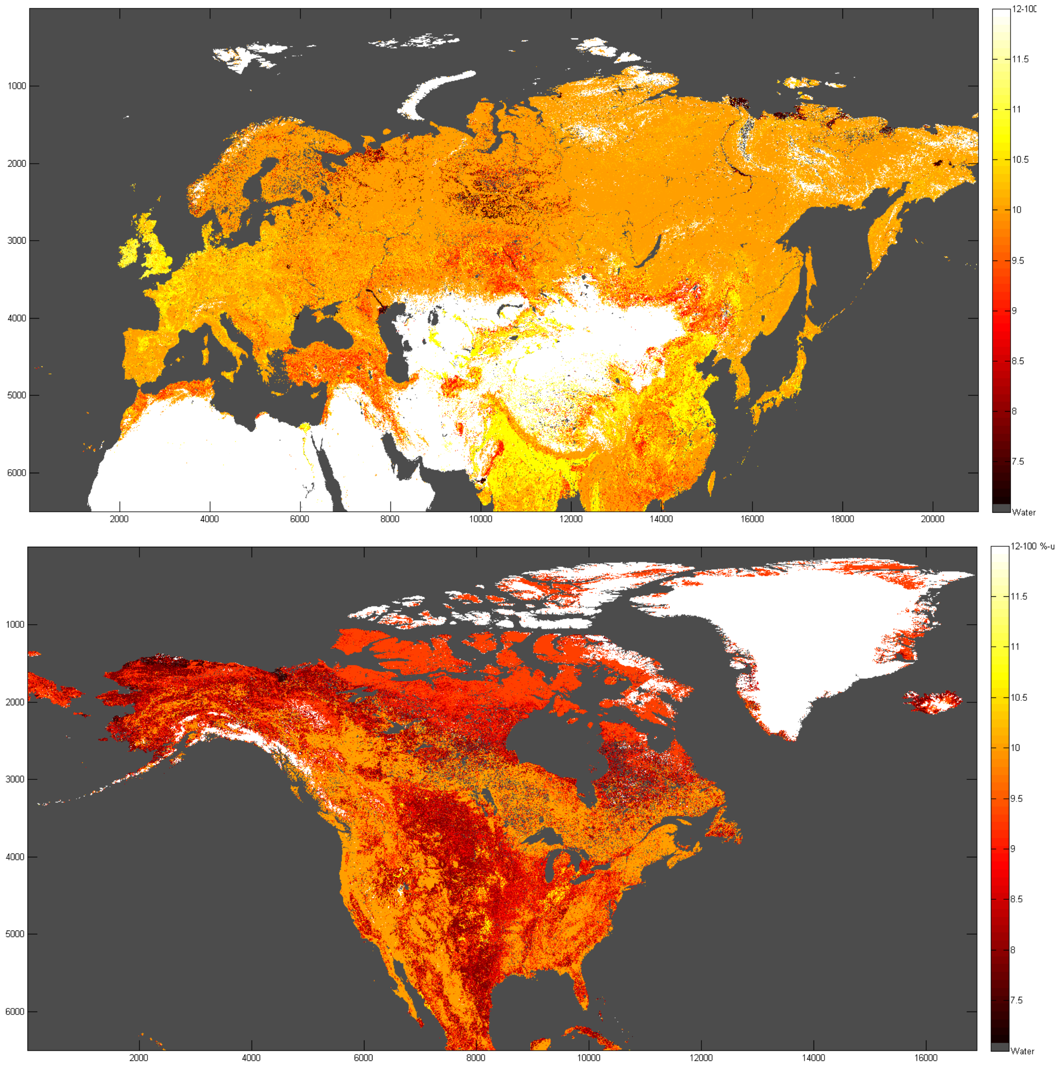


Figure 7: Improved transmissivity map for Eurasia (top) and North America (bottom).

Figure 8: Preliminary version of snow-free ground reflectance map for Eurasia (top) and North America (bottom).



snow-free ground characteristics may vary considerably depending on the local conditions i.e. climate, soil, vegetation, land use and terrain/topography.Therefore in GlobSnow-2 the aim is to investigate the spatial variability of snow-free ground reflectance in different parts of Northern Hemisphere. The final goal is to derive a map with pixel-level snow-free ground reflectance typical for the locality. The current implementation of SCAmod in GlobSnow used prefixed value of 0.10 (10%) for snow-free ground reflectance; in GlobSnow-2 investigations of the true variability has been made for several areas in different parts of Eurasia and North America. The objective is to derive information on typical average snow-free ground reflectance for predominant non-forested land cover classes in Northern Hemisphere and also to investigate the implications of their variations to the FSC-estimation accuracy. For non-mountainous areas, the snow-free ground reflectances are derived from Terra/MODIS time series, using single-band reflectances and their related indices. This approach is based on the assumption that the behavior of ground reflectance in conditions occurring directly after the snow melt adequately represents the snow-free ground reflectance during snow ablation i.e. melting snow cover including snow-free patches. The first version of Northern Hemisphere snow-free ground reflectance map (for non-mountainous areas, pre-dominantly derived from MODIS band 4 (545-565 nm) time-series for European area) is presented in Figure 8. The fixed generally applied value of 0.10 used in GlobSnow-1 was proven feasible for the non-forested and sparsely forested land cover classes in Europe. It is expected, though, that clearly different values are introduced outside Europe, mainly in arid areas with ephemeral snow. In GlobSnow-2, this will be the near-future topic of investigation.

Based on snow-free ground reflectance statistics for non-mountains and mountains, a global snow-free ground reflectance map will be developed. This includes development of methodology to combine values the non-mountainous and mountainous snow-free ground reflectances so that a smooth transition at non-mountain/mountain border is achieved. □

Reference: Metsämäki, S., Mattila, O.-P., Pulliainen, J., Niemi, K., Luojus, K., Böttcher, K. (2012): An optical reflectance model-based method for fractional snow cover mapping applicable to continental scale. Remote Sensing of Environment, Vol. 123, pp. 508-521, doi: 10.1016/j.rse.2012.04.010.

SE validation activities of Phase 1

The workpackage 2.2, led by the University of Bern, represents a substantial contribution to the validation of Globsnow snow fraction and snow extent products. Validation of snow extent products is a process to assess the product's accuracy by means of a comparison to some reference data. This procedure is considered a prerequisite to estimate the uncertainty of derived scientific results and to provide a sound basis to process a global climate data record (CDR) based on AATSR and AVHRR data. Therefore, the WP 2.2 aimed at providing a detailed description and accuracy assessment of the algorithms used for the GlobSnow SE product generation (fractional and binary).

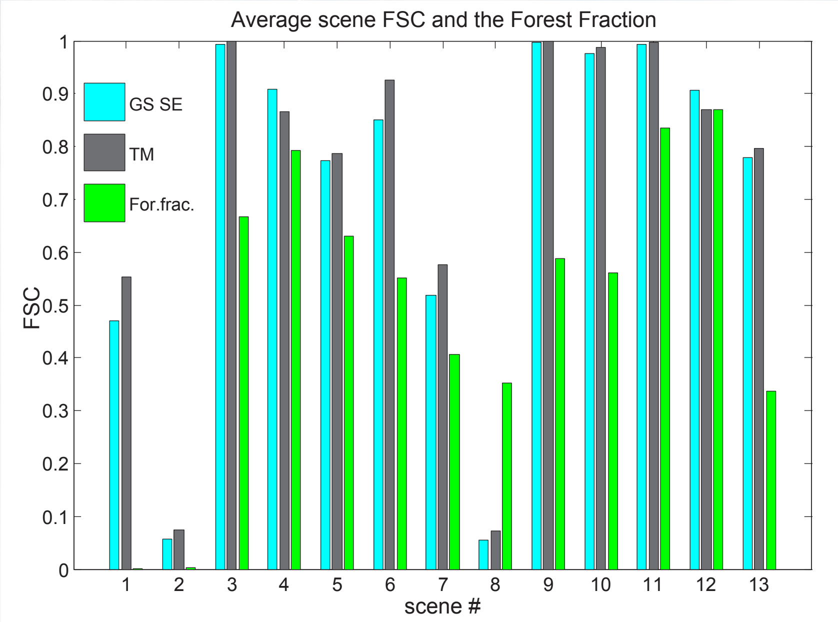


Figure 9: Landsat/ETM+ derived FSC vs. GlobSnow SE FSC for 13 TM-scenes for plains in different parts in Europe, together with the scene-level forest fraction. On average, the difference $|FSC_{GlobSnow}-FSC_{TM}|$ is 0.03 in FSC range of 0-1, i.e. 3% in FSC %-units.

In order to achieve a broad and independent indication of the products accuracy a three-level approach was used by applying different sets of reference data: Ground-based snow depth measurements (station and snow courses), high-resolution satellite data (Landsat) as well as gridded snow extent data based on either meteorological measurements or model data. Additionally, a comparison between AATSR SCAmod and AVHRR SCAmod was included to assess the cross-sensor applicability of the same retrieval algorithm. To enhance the potential to compile a CDR from blending AATSR and AVHRR SE data into one 30-year data record, a first feasibility study was performed. It consisted of a comparison of two independent snow detection schemes from both sensors for coincident overpasses. The validation period was restricted to the years 2003, 2004, 2006 and 2010 taking into account instrument characteristics, acquisition periods as well as processing time. Concerning validation areas, the selection of regions for validation not only depended on the type of reference data available but aimed at including different land use and land cover, mountainous areas, forested, and non-forested areas as the quality of the SE products is known to vary across different surface characteristics.

Overall, a high agreement between the Globsnow SE products (fractional and binary) and the different reference data sets has been found. While it is very high over flat areas (see Figure 9) it slightly decreases in complex topography (European Alps), especially in the mid-altitude levels and for SCAmod AVHRR. However, differences are expected when comparing AATSR or AVHRR to in situ point observations in complex topography

Moench and Jungfrau mountains loom above the roofs of University of Bern. Photo: Fabia Huesler, University of Bern

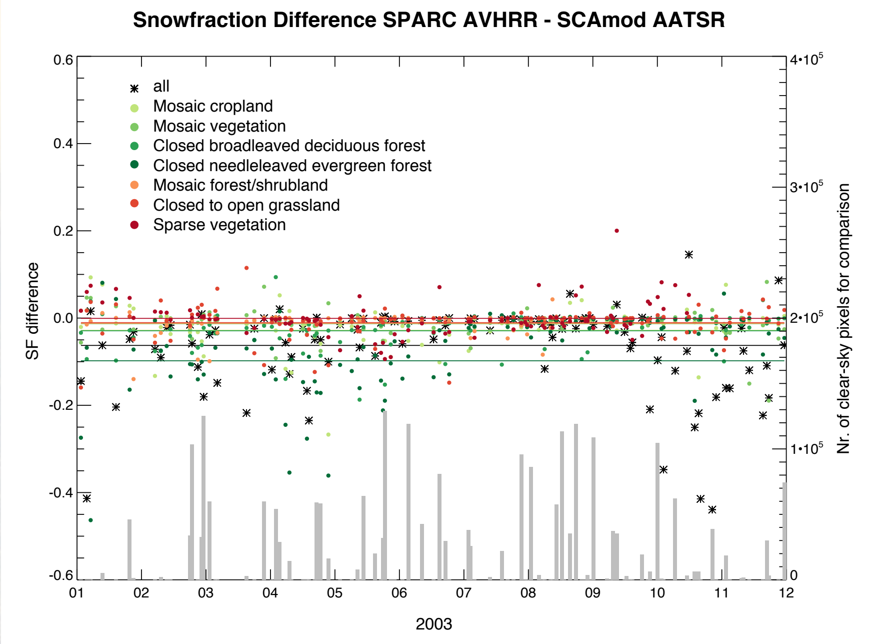


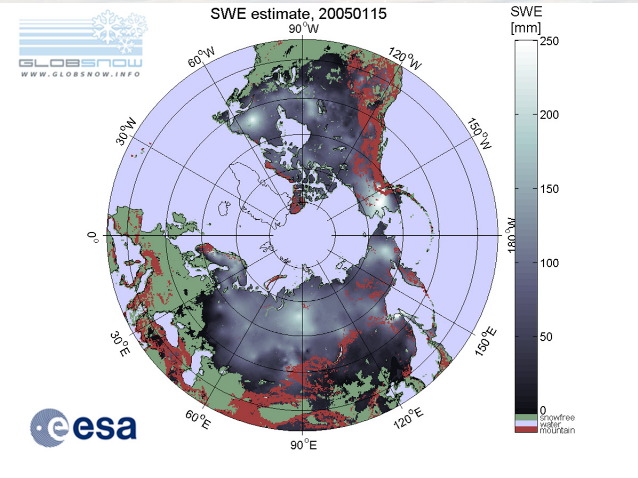
Figure 10: SCA differences between the two snow detection schemes (AATSR SCAmod and AVHRR SPARC for 2003 over the European Alps. Data points are displayed for days when a minimum of 500 coincident clear-sky pixels were available. Overall difference is given in black while the smaller colored dots refer to specific landcover classes (see legend). Lines indicate overall mean of the given landcover class and grey bars show the amount of pixels available for comparison.

due to large elevation differences within single grid cells. A slight tendency to overestimation of snow events by SCAmod, indicated by an elevated false alarm rate and a small number of missed observations at these specific sites. To further improve the snow detection accuracy, the aim is to provide additional diagnostic data, produced with varying snow-free ground reflectance information, during the early Phase-2 of GlobSnow-2.

Finally, it could be shown that there is no obvious bias between AVHRR SCAmod and AATSR SCAmod (for clear-sky cases) but differences depending on land cover/land use as shown in Figure 10. These findings might indicate that a combination of AVHRR with AATSR snow extent products might be feasible to extend the time series of AATSR to fulfill the requirement for a FCDR, but further investigations are required and will be undertaken during Phase-2. □

GlobSnow-2 Product Examples

Figure 11 (above): Weekly SE-product (Fractional Snow Cover) from VIIRS-data, April 21-27, 2013.



The processing lines for NPP SUOMI VIIRS are now operatively running for the Northern Hemipshere. The production chain utilizes both NOAA rolling archive VIIRS data and VIIRS direct broadcast data received at the FMI Sodankylä satellite receiving station.

SE-products are available from the end of March 2013 at http://www.globsnow.info/se/nrt/2013/NH_VIIRS (Fig. 11). □

Figure 12: Daily Snow Water Equivalent (SWE) product for 15 January 2005.

Photo: Arvids Silis, Environment Canada

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Project overview

The European Space Agency (ESA) Data User Element (DUE) funded GlobSnow-2 project is a direct continuation to the GlobSnow-1 project that was active from 2008 to 2012. The objective of the GlobSnow-2 project is further enhancement of the retrieval methodologies for SE and SWE products and a re-processing of the long term datasets utilizing the improved retrieval algorithms before the end of the project.

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