# GlobSnow 2

# Newsletter

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**Topics:**

- Key achievements of GlobSnow-1 and GlobSnow-2 projects
- GlobSnow SWE v2.0 product
- GlobSnow SE v2.1 product
- Future data dissemination and Interaction with end-user community

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# Key achievements of GlobSnow-1 and GlobSnow-2 projects

The main objective of the European Space Agency (ESA) Data User Element (DUE) funded GlobSnow-1 and GlobSnow-2 projects was the development and implementation of methodologies for producing long-term records of snow cover information at the global scale intended primarily for climate research purposes. The efforts were focused on developing and adapting algorithms for the derivation of snow extent (SE) and snow water equivalent (SWE) from satellite data. The project has resulted in two new hemispheric records of SE and SWE extending 17 and 35 years respectively.

The GlobSnow SWE product is the first satellite-based daily SWE dataset for the non-alpine northern hemisphere that extends from 1979 to present day. The previous existing daily SWE records have spanned a shorter time period (2002-2014) or described the snow conditions on a monthly basis for a similar period (1978-2014). The GlobSnow SWE record utilizes a novel data-assimilation based approach for SWE estimation which combines weather station measurements of snow depth with satellite passive microwave measurements. This approach was shown to be superior to alternative algorithms which solely utilize satellite data through comparison with extensive ground reference datasets.

The GlobSnow SE product is the first northern hemisphere, daily, moderate resolution record on sub-pixel fractional snow cover that has been produced from ESA ATSR-2 and AATSR measurements. The GlobSnow SE dataset complements the previous records generated with greater temporal coverage but a lower spatial resolution (AVHRR 1980-2014) and records with similar resolution but a shorter time series (MODIS 2001-2014). It utilizes a unique fractional snow cover algorithm and so contributes to our understanding of historical snow conditions.

Complementary to the long-term SWE and SE time series, an operational near-real time (NRT) snow information service was implemented, which produces daily northern hemisphere maps of SE and SWE based on the methodologies developed within the project.

The GlobSnow SWE data set has been utilized by the World Meteorological Organization (WMO), Global Cryosphere Watch (GCW) initiative to provide a daily near-real time tracker of hemispherical snow conditions. The tracker presents the status and progress of total terrestrial snow mass, set in context with regard to the 35-year historical climatology for the Northern Hemisphere. The GlobSnow SWE data record was utilized in the "Climate change, impacts and vulnerability in Europe 2012" an European Environment Agency report to portray the changes in snow conditions for European domain for the years 1980 - 2011.

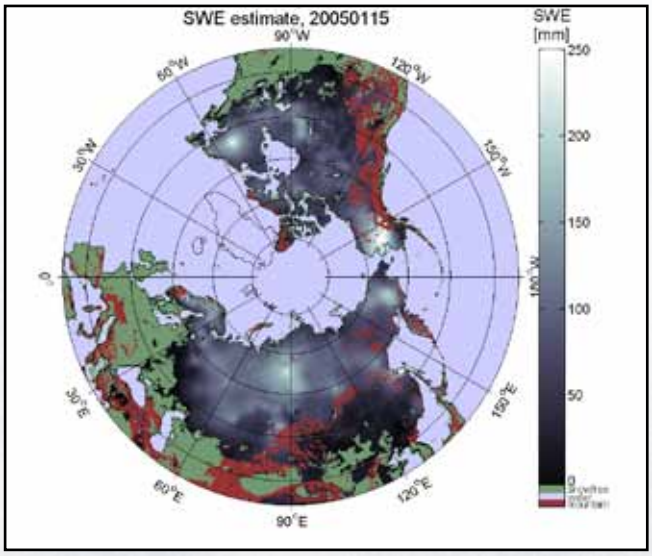


Figure 1 (above): GlobSnow v2.1 SE monthly product for April 2006.

Figure 2 (left): Globsnow SWE product for 15 Jan. 2005.

In the cover a view from Alpe di Siusi, Val Gardena, Italy. Photo by Sini Merikallio.

# GlobSnow SWE v2.0 product

The GlobSnow Snow Water Equivalent (SWE) product set version 2.0 for the Northern Hemisphere represents SWE estimates retrieved from Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave/Imager (SSM/I) sensors combined with ground-based weather station data from 1979 until 2014. The dataset provides coarse resolution (25 km) gridded daily information on SWE for Northern Hemisphere complemented with information on snow extent. The SWE product is calculated for terrestrial regions excluding mountains and glaciers. The SWE products are distributed in both NetCDF-CF and HDF-formats: a single file contains the data for a single day; each file containing two fields

1. the SWE estimate and
2. an error estimate (statistical standard deviation of the SWE estimate).

Recent enhancements to the SWE product include the improved quantification of product uncertainty characteristics and the improvement of overall product accuracy, especially in terms of consistency between different years. This is essential for the employment of the GlobSnow-2 SWE product to establish a hemispheric Climate Data Record (CDR) for the period 1979 - 2014. The main advancements include the following topics:

1. estimation of systematic error characteristics in addition to statistical error,
2. homogenization of the multiple-year synoptic weather station snow depth measurements used as input to the SWE algorithm,
3. regional treatment of statistical error characteristics of the weather station snow depth data,
4. use of an updated forward snow emission model to describe the spaceborne observed microwave brightness temperatures,
5. enhanced temporal coverage for the dataset, starting from September 1979 and extending to May 2014.

Concerning product accuracy characteristics, the new GlobSnow-2 SWE product provides a total error that includes the contribution of statistical (random) error and the systematic error, the latter being evaluated from an extensive data set of independent SWE observations available for Eurasia covering 1980-2009. The homogenization of applied weather station observations includes the filtering of outliers and selection of stations that report the snow depth consistently through the time period of the SWE product. In case of the statistical accuracy of weather station observations, different RMS errors are assigned depending on whether the site and region represents open areas or forested landscapes. As a result, the new SWE product version provides a more reliable time-series of the hemispheric behavior of snow mass than the earlier versions.

The development of the retrieval algorithm investigated the usage of dynamic, spatially varying and temporally evolving snow density as part of the SWE retrieval. Several iterations for SWE retrieval using a dynamic snow density scheme were implemented and evaluated; however in the end the constant snow density (240 kg/m3) used for previous product versions was retained for the final SWE v2.0 algorithm. While transferring to dynamic snow density is still desired, a sufficient and consistent improvement to the overall retrieval process was not found with the prototype dynamic snow density schemes evaluated to this point.

## Validation results for the v2.0 SWE product

The GlobSnow v2.0 SWE dataset was evaluated against several independent ground-based datasets collected from the Former Soviet Union, Russia, Canada and Finland. The retrieval accuracy is improved for some regions and largely unchanged for others when compared with the previous v1.0 and v1.3 SWE datasets. The full dataset evaluation is still on-going, but as an example, the Figure 3 shows the retrieval characteristics of different GlobSnow SWE

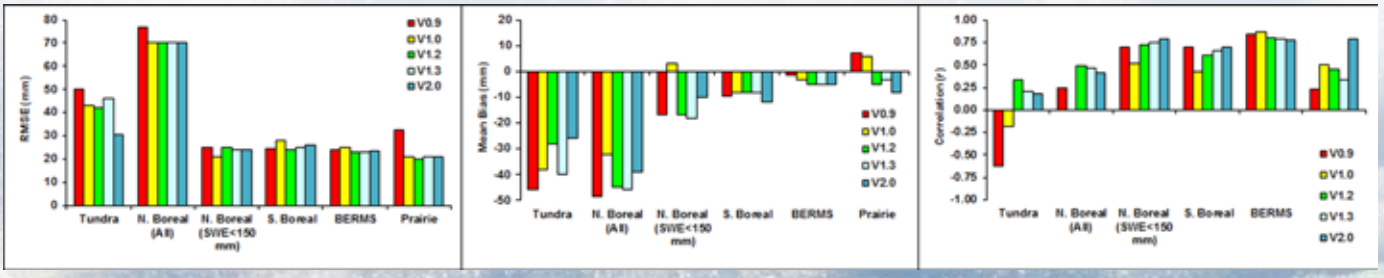


Figure 3: The evaluation of various GlobSnow SWE datasets with Canadian reference data. The left panel shows the Root-Mean-Squared-Error for different datasets, center panel shows the mean bias and right panel shows the correlation coefficients between SWE datasets and the reference data.

datasets when compared with Canadian reference data. It is evident that for tundra and northern boreal forest reference measurements the retrieval accuracy has improved, while for other regions it has remained consistent.

The long term trends, based on the GlobSnow v2.0 SWE dataset, are similar to the trends from previous GlobSnow datasets, and captures a snow mass climatology similar to other gridded SWE products. Trend analysis of the GlobSnow data record shows the hemispheric snow mass has been slowly declining for the spring months for the past 33 years, as seen in Figures 4 and 5.

The SWE products are distributed in both NetCDF-CF and HDF-formats: a single file contains the data for a single day; each file containing two fields:

1. the SWE estimate and
2. an error estimate (Statistical Standard Deviation of the SWE estimate).

The aim in the accomplished further development of the SWE product has been the improved quantification of product uncertainty characteristics and the improvement of overall product accuracy, especially in terms of consistency between different years. This is essential for the employment of GlobSnow-2 SWE product to establish a hemispheric Climate Data Record (CDR) for the period 1979 - 2013. The main advancement includes the following topics:

- estimation of systematic error characteristics in addition to statistical error,
- homogenization of the multiple-year synoptic weather station observation data sets on snow depth inputted to actual SWE estimation algorithm,
- regional treatment of statistical error characteristics of applied synoptic snow depth data,
- use of new forward model version to describe the space-borne observed microwave brightness temperature,
- enhanced temporal range for the dataset, starting from September 1979 and extending to May 2013.

Concerning product accuracy characteristic the new GlobSnow-2 SWE product provides a total error that includes the contribution of statistical (random) error and the systematic error, the latter being evaluated from an extensive data set of independent SWE observations available for Eurasia covering different years. The homogenization of applied weather station observations includes the filtering of outliers and selection of stations that report the snow depth uniformly through the time period of the SWE product. In case of the statistical accuracy of weather station observations different RMS errors are assigned depending on whether the site and region represents open areas or forested landscape. As a result, the new SWE product version provides a more reliable time-series of the hemispheric behavior of snow mass than the earlier product versions.

The development of the retrieval algorithm investigated the usage of dynamic, spatially varying and temporally evolving snow density for SWE retrieval. Several iterations for SWE retrieval using a dynamic snow density scheme were implemented and evaluated; in the end the constant snow density consideration from GlobSnow-1 project was selected for the final SWE v2.0 algorithm as a sufficient and consistent improvement to the overall retrieval process was not yet reached with the dynamic snow density scheme.

## Reference


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GlobSnow-2 Algorithm Theoretical Basis Document (ATBD) for SWE Algorithm, http://www.globsnow.info/docs/GS2_SWE_ATBD.pdf


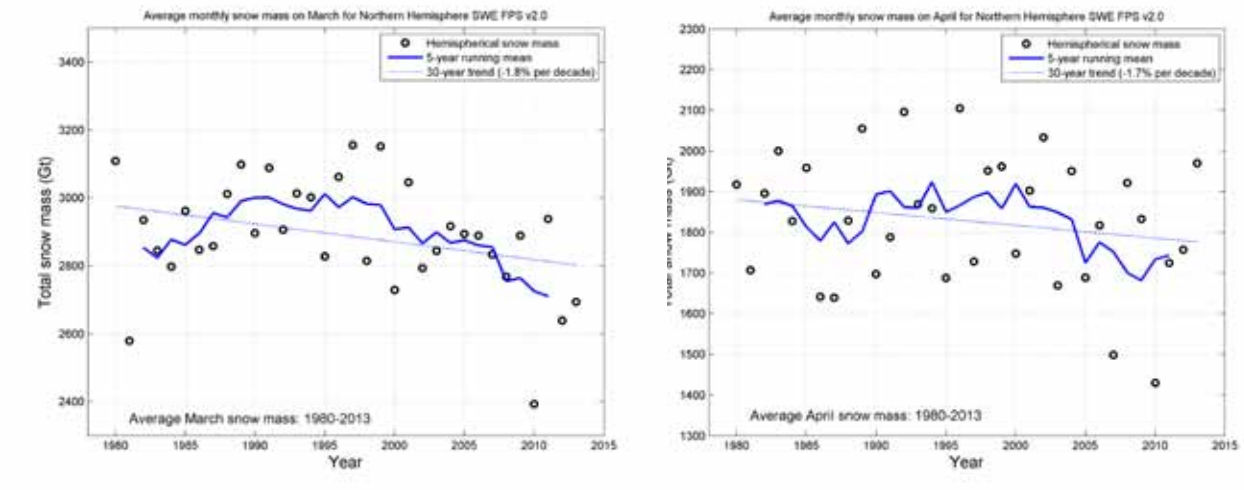


Figure 4 and 5: The long term trends, for March (left) and April (right), based on GlobSnow SWE v2.0 monthly data, for Northern Hemisphere for 1980 - 2013.

# GlobSnow v2.1 SE product

## Product description

The GlobSnow SE product portfolio includes maps of Fractional Snow Cover (FSC, range 0–100% or 0–1) on a 0.01°x0.01° 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). The Daily Fractional Snow Cover (DFSC) product provides fractional snow cover in percentage (%) per grid cell for all satellite overpasses of a given day. 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. An example of monthly SE product is presented in Fig. 1. The SE data record also includes the uncertainty associated to each FSC estimate (Metsämäki et al., 2014), relying on a statistical propagation error analysis. The uncertainty layer – featuring unbiased standard error of FSC – for April 2006 monthly product is presented in Fig. 6.

## The evolution of SE products

The Fractional Snow Cover as provided by GlobSnow SE product is based on the SCAmod method (Metsämäki et al., 2012), originally developed for Northern Europe boreal forest and sub-arctic regions. The semi-empirical reflectance model-based method 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. In the beginning of GlobSnow-1 project, SCAmod was chosen to be applied to plains while the linear spectral unmixing method NLR by the Norwegian Computing Centre was to be applied to mountain areas. Both these methods were further developed in order to achieve the hemispherical coverage; this included the calibration of the applied static values for the reflectance constituents (end-members). As to SCAmod, the major effort was the establishment of NH forest transmissivity map, essential for the method performance: a method using a combination of the reflectance observations and global land cover data (as provided by ESA GlobCover) was developed (Metsämäki et al., 2012).

During the development work, algorithms and products were evaluated using Europe as a study area. Comparison of SE prototype products with other Earth observation snow products, in situ snow observations and high-resolution data was carried out. These evaluations were used in the verification of the product quality. Finally, applying the developed methods and parameterizations within GlobSnow-1 project, the production and release of SE v1.2 data record took place in 2011.

Eventually, using two different methods produced inconsistencies at the mountain borderlines. So within GlobSnow-2, SCAmod was chosen for the application to the entire GlobSnow domain. One important focus was to still improve the FSC retrievals in dense forest areas. It was recognized that the NH tranmissivity map was not representative for the densest forests. Therefore a new approach for identification of the densest forests using global albedo (ESA GlobAlbedo) data was developed. The resulting new transmissivity map was a major achievement in GlobSnow-2 and led to a significantly improved capability of the SE product to capture snow in dense forest areas. In addition, the earlier static value for the snow-free reflectance was replaced by spatially varying field, based on MODIS reflectance time-series analysis combined with GlobCover data (Metsämäki et al. 2015).

The development of a simple, computationally low-cost cloud screening method was also one aim of the GlobSnow-project. A cloud masking algorithm SCDA dedicated to (A)ATSR-based snow mapping was developed within GlobSnow-1. This method used a set of empirically derived thresholding rules taking advantage of (A)ATSR spectral bands and their ratios. This method was further improved

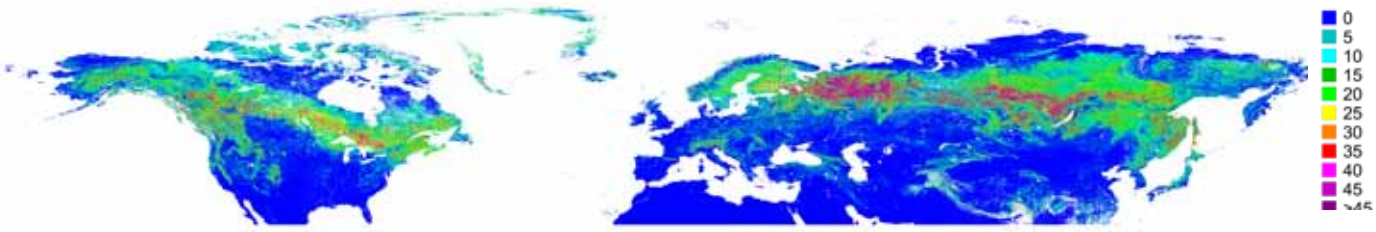


Figure 6: Mean absolute deviation of the daily FSC difference maps for the total area generated from GlobSnow-2 SE v2.1 and MOD10_L2 products for the period 1 Oct 2003-31 May 2004.

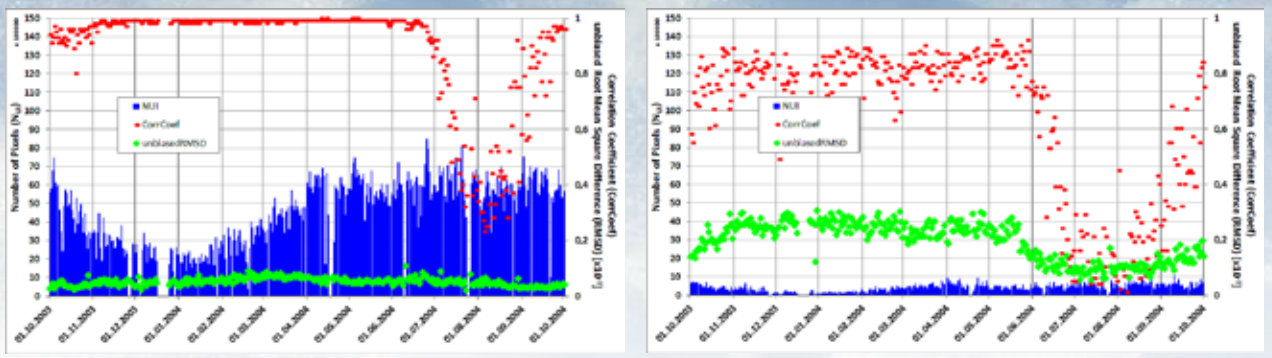

Figure 7: Daily statistical analyses for the intercomparison of the different surface classes of GlobSnow-2 SE v2.1 product and the MOD10_L2 product for the period 1 October 2003 to 1 October 2004: left: plain non-forested areas; right: mountainous forested areas.

within GlobSnow-2, particularly focusing on discrimination between clouds and patchy snow cover, however not at the expense of false cloud omissions during the snow season.

At the end of 2013, ESA released a new version #3 for (A)ATSR level 1b data, which was employed to produce the SE v2.0 data record in December 2013. This data record also included the uncertainty layer. It was found later that v2.0 SE products whenever based on AATSR suffer from inconsistencies in the geolocation, due to the update in level 1b georeferencing not accounted for by the GlobSnow SE-processor. This problem was fixed and a new v2.1 SE dataset was produced for the AATSR era.

In addition to (A)ATSR, AVHRR data was used for comparison studies and as backup for NRT-products for European area. The comparison dataset includes NOAA/AVHRR-based snow maps provided by SPARC method; NRT-production relies on SCAmod-method applied to Metop-AVHRR.

## Full evaluation and intercomparison of GlobSnow SE v2.1 products

Assessing the quality of the recently released version 2.1 of the GlobSnow-2 Snow Extent (SE v2.1) products is crucial for the usability of the products. The daily GlobSnow-2 SE v2.1 products were intercompared and evaluated with selected reference data sets on a hemispheric, continental, regional and local scale. The intercomparisons of snow extent information was performed not only for all areas covered by the GlobSnow and the reference snow extent product, but also for selected surface types in different environments and climate zones.

For reporting the results of intercomparisons, statistical parameters are used. Additionally, daily FSC difference maps were calculated based on the GlobSnow-2 SE v2.1 products and other hemispheric and continental FSC products.

An example of the mean difference map from GlobSnow-2 SE v2.1 products and the MOD10_L2 products for the period 1 October 2003 – 31 May 2004 derived from daily difference maps is shown in Figure 7. The intercomparison of the daily GlobSnow-2 SE v2.1 products with reference snow maps from other EO data and from snow course observations in Finland show mean correlation coefficients ranging between 0.65 and 0.84, with mean unbiased RMSD of 10 to 20 % and mean bias values ranging between -3.5 and 2.5. The mean derived standard deviations are in the order of 25 %. Larger differences in the products were found for forested areas in plain and mountainous terrain, and during the melting and summer seasons. During the main winter season, and especially in plain non-forested areas, the DFSC products match well with the selected reference snow products from other sources, as illustrated exemplarily in the Figure 7. It is noteworthy that the typical problems in snow cover mapping in forest areas affect the evaluation, as many of the applied algorithms for generating reference data are developed for different environments.

Further investigations on the differences of various snow products from different sensors and derived by different approaches are ongoing under the lead of ENVEO in the ESA funded project “SnowPEx - Satellite Snow Product Intercomparison and Evaluation Experiment”.

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## Reference for Metop-AVHRR SE method:


Hüsler, F. and Jonas, T. and Wunderle, S. and Albrecht, S. (2012): Validation of a modified snow cover retrievalalgorithm from historical 1-km AVHRR data over the European Alps. Remote Sensing of Environment, 121, 1, pp. 497—515

GlobSnow-2 Algorithm Theoretical Basis Document (ATBD) for SE Algorithm, http://www.globsnow.info/docs/GS2_SE_ATBD.pdf

# Future data dissemination and Interaction with end-user community

## Data access and sustainability

The long term SE and SWE datasets produced within the GlobSnow-1 and -2 projects are maintained and housed at the dedicated GlobSnow-servers operated at the Sodankylä National Satellite Data Center, which is part of the Finnish Meteorological Institute, Arctic Research Centre. The archiving systems are available for GlobSnow products on a permanent basis. The open data distribution is established through the permanent LITDB archiving system of FMI, which will also be maintained after the project timeframe. The data can be accessed via ftp and www-based front ends via **www.globsnow.info** project-website.

## White Paper on future perspectives for a European Satellite-based Snow Monitoring Strategy

The GlobSnow consortium was involved in drafting a community wide-white paper on future perspectives for a European Satellite-based Snow Monitoring Strategy. The aim of the white paper is to set out recommendations to space agencies, international and national institutions and decision makers responsible for decisions regarding strategic and financial issues. The White Paper also identifies future challenges, opportunities and needs regarding satellite-based snow services and product development within European and global frameworks over the next decade. The White Paper provides a short overview on the current status of satellite-based snow services and products, identifies gaps with respect to users' needs, and discusses requirements for future R&D and snow services.

The White Paper refers to the ongoing programmes and initiatives with the intention of improving coordination within and between communities involved in monitoring, developing, disseminating and implementing satellite-based snow products. The summary of current users' needs, and gaps in needs regarding satellite-based snow services and products are based on user consultation workshops, review processes within the snow community, and literature.

The following needs for progress towards a Satellite-based Snow Monitoring Strategy for the benefit to the users was identified during the drafting process:

- Establish a cross-continental Group on Satellite Snow Monitoring Perspectives.
- Improve the user-interaction in all product phases from the development phase to data dissemination for a better user acceptance of satellite-based snow products.
- Perform regular product intercomparison, validation and product assessment exercises (e.g. WMO GCW endorsed ESA SnowPEx project), coordinated within the community.
- Communicate and provide quantified product uncertainties following common definitions and establish rules and procedures in consultation with the end-users.
- Consider and assure in time a transfer from R&D products and services into future sustainable initiatives to guarantee a continuity for the end-users.
- Promote successful demonstration projects and pilot-products through various channels to exploit the improved capabilities of new EO sensors in the upcoming national and international space programmes.

The White Paper provides a high-level description and identifies what should be done to better meet users' needs with upcoming new satellite infrastructure and what role funding agencies, users and the entire community could play.

## Conferences and end user interaction

The GlobSnow activities were widely presented to end-user community within several conferences and workshops during the GlobSnow-1 and -2 projects. Dozens of talks were given at international conferences and a large number of peer-reviewed articles were published. Of particular interest were the Snow and Land Ice workshops of the European Association of Remote Sensing Laboratories, which took place in Bern, Switzerland in 2011 and 2014. Special half-day sessions were dedicated to GlobSnow presentations and end-user interaction during both 2011 and 2014 workshops.

## Project overview

The European Space Agency (ESA) Data User Element (DUE) funded GlobSnow-2 project continued the efforts of the GlobSnow-1 project that was active from 2008 to 2012. The key objective of the GlobSnow-2 project was 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.

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Winter morning in Helsinki, Finland. Photo and Newsletter layout by Sini Merikallio