Global Snow Monitoring for Climate Research

GlobSnow-2 Product User Guide
Version 1.0

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1 INTRODUCTION

This "User Guide" describes the two hemispherical records of snow parameters produced within the European Space Agency (ESA) Data User Element (DUE) funded GlobSnow project.

Section 2 presents an overview of the GlobSnow snow extent (SE) and snow water equivalent (SWE) products. Section 3 presents the snow extent product in detail. Section 4 presents the snow water equivalent product in detail. Section 5 gives the contact information regarding the products and GlobSnow project. Section 6 lists the references.

2 OVERVIEW OF THE PRODUCTS

The efforts of the European Space Agency (ESA) Data User Element (DUE) funded GlobSnow project has resulted in two new hemispherical records of snow parameters intended for climate research purposes. The datasets contain satellite-retrieved information on snow extent (SE) and snow water equivalent (SWE) extending 17 and 34 years respectively. The dataset on snow extent is based on optical data of Envisat AATSR and ERS-2 ATSR-2 sensors covering Northern Hemisphere between years 1995 to 2012. The record on snow water equivalent is produced using a combination of passive microwave radiometer and ground-based weather station data, spanning years 1979 to 2013.

The GlobSnow SWE record, based on methodology by Pulliainen (Pulliainen 2006, Takala et al. 2011) utilizes a data-assimilation based approach combining space-borne passive radiometer data (SMMR, SSM/I and SSMIS) with data from ground-based synoptic weather stations. The satellite sensors utilized provide data at K- and Ka-bands (19 GHz and 37 GHz respectively) at a spatial resolution of approximately 25 km. The SWE record is produced on a daily, weekly and monthly basis. SWE information is provided for terrestrial non-mountainous regions of Northern Hemisphere, excluding glaciers and Greenland.

The GlobSnow SE processing system applies optical measurements in the visual-to-thermal part of the electromagnetic spectrum acquired by the ERS-2 sensor ATSR-2 and the Envisat sensor AATSR. The snow cover information is retrieved by a semi-empirical SCAmod-algorithm (Metsämäki et al. 2012). Clouds are detected by a cloud-cover retrieval algorithm (SCDA, developed for GlobSnow purposes) and masked out. Large water bodies (ocean and lakes) are also masked out. The resulting product is provided in a latitude-longitude grid with a 0.01 degree spatial resolution (approximately 1 km) covering the Northern Hemisphere from 25°N to 84°N, which corresponds to the seasonally snow covered land areas of the Northern Hemisphere.

3 DESCRIPTION OF THE SE PRODUCTS

The European Space Agency (ESA) Data User Element (DUE) GlobSnow Snow Extent (SE) product set version 1.2 for the Northern Hemisphere represents information on snow coverage retrieved from ERS-2 ATSR-2 and Envisat AATSR from 1995 until 2012. There are four product types:

- **Daily Fractional Snow Cover** (DFSC), snow fraction (%) per grid cell for all satellite overpasses of a given day
- **Daily 4-classes Snow Cover** (D4SC), snow cover classified into four categories per grid cell for all satellite overpasses of a given day
- **Weekly Aggregated Fractional Snow Cover** (WFSC) for all satellite overpasses within a 7-day period based on aggregation of daily products. Available for each day based on a 7-day sliding time window giving most recent observations highest priority
- **Monthly Aggregated Fractional Snow Cover** (MFSC) for all satellite overpasses within a calendar month period providing the average, standard deviation, minimum and maximum FSC for the period

The goal of the ESA GlobSnow project is to produce SE products for the whole seasonally snow covered Earth from 1995 until 2012, i.e. the sensor record spanning Envisat AATSR and ERS-2 ATSR-2 sensors. The data set is freely available and can be downloaded via a web or FTP interface.

SE version 2.0 is the second official update of versions 1.2 and 1.0, which products were made available in November 2013. This new version includes a few algorithm updates to make the products more accurate and consistent, and additionally improved testing of fault and missing input data and better indication of such input data in the products. Improvements and known remaining issues with SE version 2.0 are described in Section 3.8.

The SE products are available in a geographical (latitude/longitude) coordinate system based on the reference ellipsoid and datum WGS84 and with a grid resolution of 0.01 degrees × 0.01 degrees. The product covers the Northern Hemisphere from 25°N to 84°N, which corresponds to the seasonally snow covered part of the Northern Hemisphere. The sensors applied are ERS-2 ATSR-2 for the period from 1 August 1995 until 31 July 2002 and Envisat AATSR for the period from 1 August 2002 until April 2012. The product set is produced and made available as an archived time series.

Each product type includes a set of layers, depending on the type of the product. For all SE products the first layer contains thematic information on the snow extent. For visualisation a common colour legend is defined, which is shown Figure 2.1. The next layers depend on the product and contain for each pixel SE retrieval uncertainty estimates and metadata information. The encoding schemes applied in each layer are described in Section 3.5 .

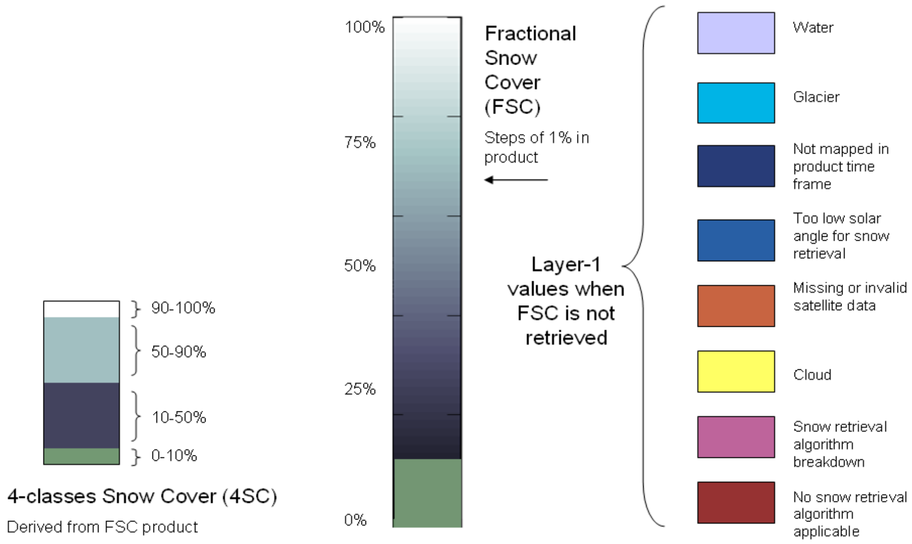

Figure 3.1: Colour legend for Layer 1 (thematic layer) of the SE product

3.1 Daily Fractional Snow Cover (DFSC)

The Daily Fractional Snow Cover (DFSC) product provides the fractional snow cover (FSC) in percentage (%) per grid cell for all satellite overpasses of a given day. The product represents the best estimate of today's snow cover, given the sensor capabilities (ATSR-2 or AATSR). If there are multiple snow observations (only far north within a day), the satellite observations applied are those giving best solar illumination (highest solar elevation). The product is generated for each day based on a 24 hours' time window limited by sunlight. The product is produced and made available for each day in near real-time.

Layers:

- Layer 1: FSC if any cloud-free observation (flagged as *cloud* if cloudy observations only; *not mapped in product time frame* if none)
- Layer 2: Uncertainty estimate of FSC retrieval
- Layer 3: Bit flags (see explanation in Section 3.3)

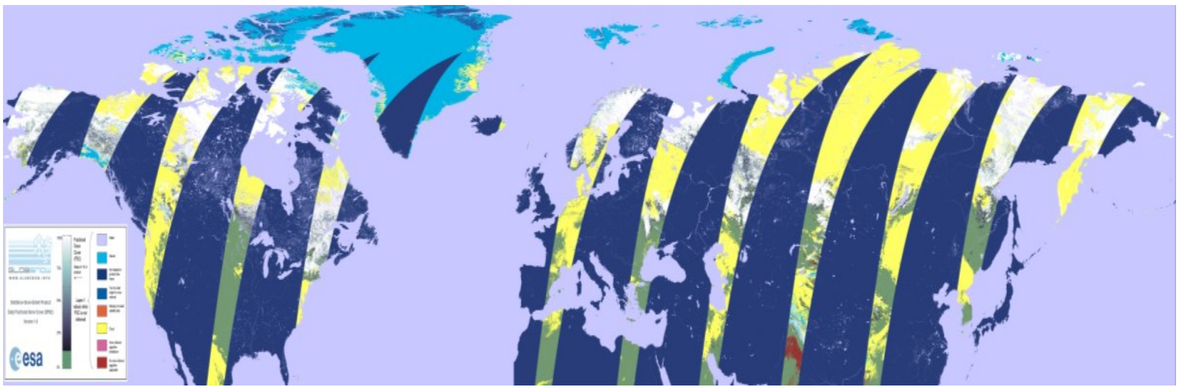

Figure 3.2: Example of Daily Fractional Snow Cover product for 10 April 2003

3.2 Daily 4-classes Snow Cover (D4SC)

The Daily 4-classes Snow Cover (D4SC) 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%

The product is derived from the DFSC product and has, therefore, the same general characteristics.

Layers:

- Layer 1: SE class if any cloud-free observation (flagged as *cloud* if cloudy observations only; *not mapped in product time frame* if none)
- Layer 2: Uncertainty estimate of FSC retrieval (not implemented yet; the layer is empty)
- Layer 3: Bit flags (see explanation in Section 3.5.3)

3.3 Weekly Aggregated Fractional Snow Cover (WFSC)

The Weekly Aggregated Fractional Snow Cover (WFSC) product is based on all satellite overpasses within a seven-day period. The product represents the best estimate of the current snow cover. It is generated daily based on DFSC products within a sliding 7-days' time window including the past seven days. The product is made available each day in near real-time.

If a calendar week product is needed, use the last product in each calendar week (each 7th product). Bit flags (see below) refer to day of snow observation (n). If there are no snow observations in period, but clouds are observed, bit flags and n represents the most recent cloud observation.

Layers:

- Layer 1: FSC for most recent cloud-free observation (flagged as *cloud* if cloudy observations only; *not mapped in product time frame* if none)
- Layer 2: Uncertainty estimate of FSC retrieval (not implemented yet; the layer is empty)
- Layer 3: Bit flags (see explanation in Section 3.5.3)
- Layer 4: Relative day number for observation (n in $t - n$, where t is the product date)

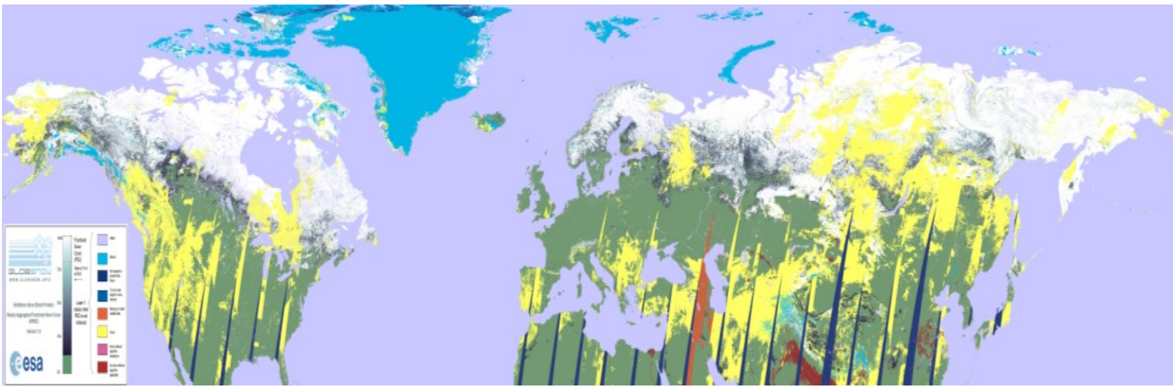

Figure 3.3: Example of Weekly Aggregated Fractional Snow Cover product for 19 April 2003

3.4 Monthly Aggregated Fractional Snow Cover (MFSC)

The Monthly Aggregated Fractional Snow Cover (MFSC) product is based on all satellite overpasses within a calendar month period. The product provides statistics for cloud-free observations of FSC within the period. It is based on DFSC products for the given calendar month. The bit flags are based on the flags of the corresponding day products. The product is generated and made available at the end of each month.

Layers:

- Layer 1: Average FSC of days with cloud-free observations) (flagged as *cloud* if cloudy observations only; *not mapped in product time frame* if none)
- Layer 2: Combined uncertainty estimate of FSC retrieval
- Layer 3: Bit flags (see explanation in Section 3.5.3)
- Layer 4: Number of days with snow observations
- Layer 5: Standard deviation of FSC retrieved
- Layer 6: Minimum FSC retrieved
- Layer 7: Maximum FSC retrieved

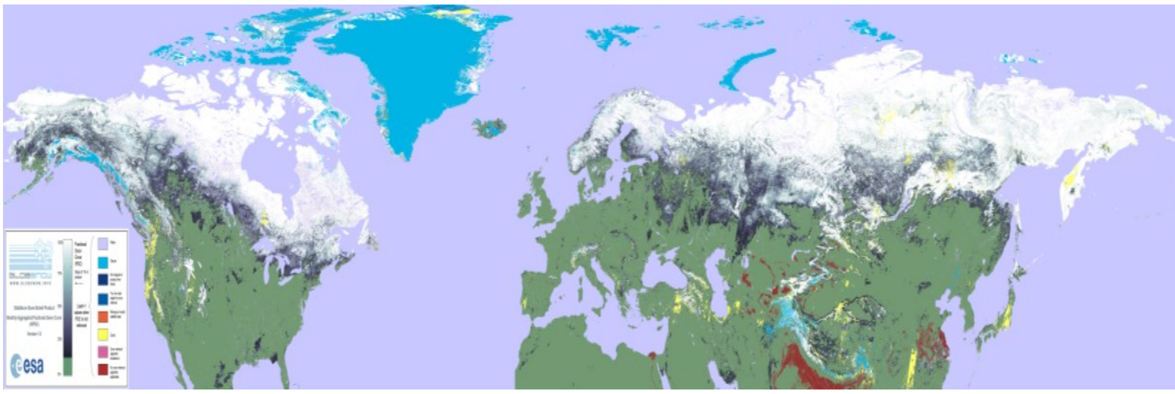

Figure 3.4: Example of Monthly Aggregated Fractional Snow Cover product for April 2003

3.5 Product encoding schemes and metadata

The encoding scheme applied in each layer and the metadata are described in the following sections.

3.5.1 Thematic information (Layer 1)

The encoding scheme applied to the thematic layer (Layer 1) is explained in Table 3.1. There are two encoding schemes for snow cover, one for FSC and one for the 4-class representation. Additionally, there are codes for other thematic classes and exceptions.

Table 3.1: The encoding scheme for Layer 1

Code	**Description**
	Snow information in the all three FSC products (DFSC, WFSC and MFSC):
100	100: FSC = 0%
101	101: FSC = 1%
…	…
200	200: FSC = 100%
	Snow information in 4-classes daily product (D4SC):
6	0% ≤ FSC ≤ 10%
7	10% < FSC ≤ 50%
8	50% < FSC ≤ 90%
9	90% < FSC ≤ 100%
	General thematic class codes applied in all products:
0	No data
20	Cloud
30	Glacier
40	Water body
	Exception codes applied in all products:
51	Outside mapping area
53	Not mapped in product time frame
54	Too low solar angle for snow retrieval (< 17°)
55	Missing or invalid satellite data
57	Snow retrieval algorithm breakdown
58	No snow retrieval algorithm applicable

3.5.2 Uncertainty (Layer 2)

Uncertainty estimate of the retrieved snow cover provides important information for many applications using snow products as input. In GlobSnow SE Product Version 2.0 the uncertainty estimation is implemented as described in the SE Algorithm Theoretical Basis Document (ATBD).

3.5.3 Bit flags (Layer 3)

The bit flags provide supplemental information to the thematic layer (Layer 1). The flags are explained in Table 3.2.

Weekly product (WFSC): Bit flags correspond to day of snow observation (n in $t - n$, where t is the product day number). If there are no snow observations in period, but clouds are observed, bit flags and n represents the most recent cloud observation.

Monthly product (MFSC): The bit flags are based on the flags of the corresponding day products.

Table 3.2: Explanation of bit flags

Bit #	Explanation, if bit set (= 1)	Specific explanation for the monthly aggregated product
1	Snow cover retrieved by SCAmod	Same
2	Snow cover retrieved by NLR	Same
3	Too low solar elevation for snow retrieval (< 17°)	Set if sustained too low solar elevation (for the whole period)
4	Low solar elevation, warning for snow retrieval (≥ 17°; < 30°)	Set if there is a snow observation in the period with low solar elevation
5	Forest density near crown closure (t^2 < 0.33, where t is the forest transmissivity applied in the SCAmod algorithm), warning for snow retrieval (for coniferous forest only)	Same
6	Saturation in thermal band (B), max value applied ($B_{3.7\ \mu m}$ → 311.78 K; $B_{11.0\ \mu m}$ → 321.0 K; $B_{12.0\ \mu m}$ → 318.0 K)	Set if there is any occurrence of saturated thermal band in the period for snow or cloud observations

3.5.4 Metadata

Table 3.3 explains specific metadata for SE products. Most of the attributes are self-describing. Note that day products are defined as Level 3A, while the aggregated products are defined as Level 3B. The average uncertainty attribute is the average of all per-pixel uncertainties in the product (not implemented in the current version). For the aggregated products, the data date attribute is the last day of the 7-days period for the weekly product. For the monthly product, the day (dd) is skipped.

Table 3.3: Specific SE product metadata. Other attributes are self-describing and according to the netCDF CF conventions (see Section 3.6.1). The column *Product* refers to which products each attribute is valid for

Attribute	**Contents**	**Product**
title	'GLOBSNOW PS SE/AATSR'	all
data_content_field_1	'Level 3A Fractional Snow Cover (%)'	DFSC
data_content_field_1	'Level 3A 4-class Snow Extent (CATEGORY)'	D4SC
data_content_field_1	'Level 3B Fractional Snow Cover (%) Aggregated Weekly '	WFSC
data_content_field_1	'Level 3B Fractional Snow Cover (%) Aggregated Monthly '	MFSC
data_content_field_2	'Uncertainty of FSC retrieval (%)'	all
data_content_field_3	'Bit Flags'	all
data_content_field_4	'Relative day number of observation'	WFSC
data_content_field_4	'Number of days with snow observations'	WFSC
data_content_field_5	'Standard deviation of FSC retrieved'	MFSC
data_content_field_6	'Minimum FSC value retrieved'	MFSC
data_content_field_7	'Minimum FSC value retrieved'	MFSC
processing_date	<yyyy-mm-dd hh:mm:ss>	all
data_date	<yyyy-mm-[dd]>	all
coordinate_system	'Lat/Lon WGS 84'	all
latitude_range	'25N-84N'	all
longitude_range	'168E-192W'	all
spatial_resolution	'0.01 × 0.01 degrees'	all
average_uncertainty	<dd.dd>	all
processing_software_name	'GLOBSNOW PS SE/AATSR PROCESSOR'	all
processing_software_version	'2.0'	all
processing_organisation	'FINNISH METEOROLOGICAL INSTITUTE'	all
retrieval_algorithm_forests_name	'SCAmod FSC ATSR'	all
retrieval_algorithm_forests_version	'3.1'	all
cloud_detection_algorithm_name	'SCDA'	all
cloud_detection_algorithm_version	'1.4.2'	all
auxiliary_data_open_water_mask_name	'GLOBCOVER ENVEO water mask'	all
auxiliary_data_open_water_mask_version	'2.0'	all
auxiliary_data_unforested_mountain_mask_name	'GLOBCOVER ENVEO unforested mountain mask'	all
auxiliary_data_unforested_mountain_mask_version	'2.0'	all
auxiliary_data_glacier_mask_name	'GLOBCOVER ENVEO glacier mask'	all
auxiliary_data_glacier_mask_version	'2.0'	all
auxiliary_data_digital_elevation_model_name	'GETASSE30'	all
auxiliary_data_digital_elevation_model_version	'3.0'	all
auxiliary_data_transmissivity_map_name	'GLOBCOVER SYKE transmissivity map'	all
auxiliary_data_transmissivity_map_version	'5.0'	all

3.6 Product format, storage and access

The file format of the products, the data types of the product layers, the file name convention and the storage catalogue structure are explained in the following.

3.6.1 File format

The GlobSnow SE products are stored in the netCDF CF format. NetCDF (Network Common Data Form) is a self-describing, machine-independent data format that supports the creation, access, and sharing of array-oriented scientific data. That the data format is "self-describing" means that there is a header which describes the layout of the rest of the file, in particular the data arrays, as well as arbitrary file metadata in the form of name/value attributes. The CF conventions define metadata that provide a definitive description of what the data in each variable represents, and of the spatial and temporal properties of the data. This enables users of data from different sources to decide which quantities are comparable, and facilitates building applications with extraction, re-gridding and display capabilities. Software libraries providing read/write access to netCDF files, encoding and decoding the necessary arrays and metadata are supplied by University Corporation for Atmospheric Research (UCAR) and others (http://www.unidata.ucar.edu/software/netcdf/). A convenient viewer is Panople (http://www.giss.nasa.gov/tools/panoply/). Users preferring the Hierarchical Data Format (HDF) might use conversion tools available at http://www.hdfgroup.org/HDF-FAQ.html#convnetcdf.

Each layer in the SE products is represented as a short integer (Table 3.4). The endianness (byte order) is little-endian (the least-significant byte is stored first).

Table 3.4: Data types for the SE product layers. SHORT is signed short integer (two bytes).

Layer #	**DFSC**	**D4SC**	**WFSC**	**MFSC**
1	SHORT	SHORT	SHORT	SHORT
2	SHORT	SHORT	SHORT	SHORT
3	SHORT	SHORT	SHORT	SHORT
4			SHORT	SHORT
5				SHORT
6				SHORT
7				SHORT

3.6.2 File name convention

The SE product files are named according to the following convention:

GlobSnow_SE_<type>_<level>_<region>_<date>_<version>.<extension>

where

<type> is 'FSC' for Fractional Snow Cover and '4CL' for 4-snow-classes system
<level> is:
'L3A' for the daily products
'L3B-W' for sliding-window weekly (7-days) aggregated product
'L3B-M' for fixed-window monthly aggregated products
<region> is 'NH' for Northern Hemisphere
<date> is the observation date in the format yyyymm[dd] (year, month and day)
<version> is the product version
<extension> is 'nc'

Example: 'GlobSnow_SE_FSC_L3A_NH_20030131_v2.0.nc'
is the daily SE FSC product for 31 January 2003, product version 2.0 in netCDF CF format

3.6.3 Repository

The products are stored at the Finnish Meteorological Institute and made freely available through both web and FTP interfaces:

- The web pages can be accessed at http://www.globsnow.info/se/
- For login access to the FTP server, contact kari.luojus@fmi.fi

There is one catalogue for each product version (e.g., archive_v.2.0/). There is one sub-catalogue for each year, each with the following sub-catalogues:

- DFSC: Daily Fractional Snow Cover products
- D4SC: Daily 4-classes Snow Cover products
- WFSC: Weekly Aggregated Fractional Snow Cover products
- MFSC: Monthly Aggregated Fractional Snow Cover products
- DFSC_ql: Quick-look pictures for DFSC products
- D4SC_ql: Quick-look pictures for D4SC products
- WFSC_ql: Quick-look pictures for WFSC products
- MFSC_ql: Quick-look pictures for MFSC products

The quick-look pictures are provided for quick and easy browsing in Portable Network Graphics (PNG) format. They come in two versions, one in full spatial resolution and the other sub-sampled to 8% spatial resolution. They are stored in separate sub-catalogues for easy handling of multiple files. One might download a whole year of the 8% quick looks and browse the time series conveniently by stepping ('clicking') through them all using a standard photo viewer.

3.7 Product processing and algorithms

The GlobSnow SE processing system applies optical measurements in the visual-to-thermal part of the electromagnetic spectrum acquired by the ERS-2 sensor ATSR-2 and the Envisat sensor AATSR. Clouds are detected by a cloud-cover retrieval algorithm (SCDA) and masked out. Large water bodies (oceans, lakes and rivers) and glaciers are also masked out. The snow cover information is retrieved by a SCAmod algorithm. The resulting snow cover map is the basis of the generation of the four product types.

The algorithms, processing chains and products have been developed jointly by the Norwegian Computing Center (NR), the Finnish Environment Institute (SYKE), ENVEO IT GmbH (ENVEO), the Finnish Meteorological Institute (FMI) and GAMMA Remote Sensing AG (GAMMA). NR has had the coordinating role of the SE development and developed the laboratory processing chain. SYKE has developed the SCDA and SCAmod algorithms, while ENVEO has evaluated the performance of the algorithms and collaborated in improvements of the SCDA. GAMMA has implemented the general operational processing system. FMI is the prime contractor of GlobSnow; FMI has been supporting the development of SCAmod and SCDA algorithms and the uncertainty estimate of the SE product, has developed the software for processing and handling of the long term data record and is responsible for operating the processing system and production of the long term climate data record.

3.7.1 Processing chain

All orbits within the product domain (geographic area) available within a day are processed at a time and combined into a orthorectified one day mosaic. 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 in the classifier.

FSC retrieval for terrain above the tree line in the mountainous is carried out by the NLR algorithm. FSC retrieval in all other areas is carried out by the SCAmod algorithm. The output is a FSC day mosaic with uncertainty grid and bit flags.

From these daily mosaics aggregated products are generated. Aggregation is based either on a sliding window approach (weekly product) or a static window (monthly product). The product file assembly includes exporting of the generated information to appropriate layers in the netcdf file format (layers and metadata).

3.7.2 Geocorrection and drift calibration

The data are transformed from the original ESA Level 1B files to the GlobSnow SE latitude-longitude grid based on the provided geolocation grid tie points. Bi-linear resampling is applied.

Long-term radiometric drift analysis has been performed by the Rutherford Appleton Laboratory (RAL). Results from Smith and Poulsen (2008) show that ATSR-2 has excellent long term stability, while for AATSR the drift measurements suggest that thin-film interference explain the observed effects. RAL has implemented a drift-correction table that is based on the observations themselves. As new satellite data are acquired, updated correction tables are published by RAL (http://www.aatsrops.rl.ac.uk/performance.html). The latest published drift-correction table is applied by the GlobSnow production system. For near real-time products, they are re-processed when a new drift-correction table becomes available. For shorter periods, the deviation between NRT and re-processed products are ignorable.

3.7.3 Cloud detection

Clouds are detected by a cloud-cover retrieval algorithm, Simple Cloud Detection Algorithm (SCDA), developed in the GlobSnow project by SYKE. Other available cloud-detection algorithms and products were tested in the project but found insufficient to discriminate well between snow and clouds. The algorithm applies bands 1, 3, 4, 5 and 6. The first order cloud detection is based on the brightness-temperature (BT) difference between 11 µm and 3.7 µm, which shows large negative values for clouds (strong reflection of solar energy at 3.7 µm). A set of additional rules are applied to remove clouds under certain conditions. The SCDA-based cloud mask has been evaluated visually against colour composite AATSR images for various test sites worldwide by ENVEO.

3.7.4 SCAmod snow retrieval algorithm

The SCAmod algorithm is based on a semi-empirical reflectance model, where reflectance from a target is expressed as a function of the snow fraction. The average generally applicable reflectance values for wet snow, forest canopy and snow-free-ground serve as model parameters. A transmissivity map provides the amount of reflected sunlight that could be observed from a satellite in forest areas. The transmissivity is an expression of the effect of forest on local reflectance observations. FSC can then be derived from observed reflectance based on the given reflectance constants and the transmissivity values. The method is described in detail in (Metsämäki et al. 2005, Metsämäki et al. 2012). The algorithm has been originally developed for forested regions and has been further evolved into a hemispherical-wide algorithm handling all terrain. Currently, band 1 (555 nm) and 4 (1.6 µm) is used by the algorithm.

The SCAmod algorithm requires generation of *a priori* forest canopy transmissivity map for the whole target area, which has previously been based on the use of clear-sky optical imagery acquired under full (dry) snow cover conditions. The generation of the transmissivity map thus limits the applicability of SCAmod to the regions which have at least few weeks of seasonal snow cover. The model parameters are adjustable and are currently based on image sampling and in situ spectrometer measurements (Salminen et al. 2009). To mitigate the limitation given by observing the actual transmissivity, an approach using land cover data from the ESA GlobCover project to estimate the transmissivity has been developed in GlobSnow. Comparison between transmissivity based on optical imagery and GlobCover-based transmissivity for selected test areas shows good correspondence.

3.7.5 Auxiliary data

Static thematic masks are used in the processing system as input to the retrieval algorithm and to label areas where SE processing is not applied, such as seas and glaciers. The following masks were generated for the SE domain:

- Open water mask
- Glacier mask

- Mask of mountainous areas (> 2° local slope)

The primary data sources for generating the masks are

- Land-cover maps from the ESA GlobCover project (about 300 m pixel size; Bicheron et al., 2008).
- Digital elevation model GETASSE30 DEM (made by ESA and made available by Brockmann Consult: http://www.brockmann-consult.de/beam/doc/help/visat/GETASSE30ElevationModel.html)

The data sets were resampled to the resolution and projection of the SE product.

3.8 Known issues with the products

The following issues with the current product are known:

- A few deviations and errors with the land mask, probably originating from the GlobCover data that were used as a basis. Most prominent is a line, one or two pixels wide, at the location of the dateline. Furthermore, the southern shore of Nunivak Island (west of mainland Alaska) is too straight.

- Parts of opposite swaths may be seen in the far north. This is just a cosmetic issue not affecting the usability of the product. There might also be an additional swath included close to the dateline originating (partly) from the day before due to data handling at the dateline.

- Sometimes one or several swaths are flagged as “missing or invalid data”, which might be one or more sensor bands lacking or showing invalid data. This is due to errors in the input data such that snow (and clouds) could not be retrieved. Sometimes this situation may last over a longer period. These swaths are flagged accordingly in the product.

- There are cases where one or more swaths are totally missing in the product. This is due to lack of data to the GlobSnow SE processor. The reason might be problems with data reception at a ground station or other problems in the satellite or ground segment.

- Clouds may in certain cases partly not be detected. These will then usually show up as snow in the product. There are two main cases of undetected clouds: a) A rim of snow around a cloudy area, shown as a lower snow fraction; and b) a cloudy area shown as high snow fraction (at or close to 100% FSC). The first case is probably related to mixed reflectance where clouds (cloud rims) are transparent and observations therefore also include a signal contribution from the ground beneath. The other case is probably related to very cold clouds with ice present.

- Scattered snow patches (of low fraction) might occur over snow-free areas in monthly products, in particular visible in the summer. The origin of the patches is undetected clouds, mostly cloud rims. As such rims might occur frequently in the summer with scattered clouds (like cumulus) they might also occur in the averaged values in the monthly products.

- Land-cover dependent errors in the retrieved FSC. Both FSC retrieval algorithms have been developed for application in the boreal zone. Using the algorithms down to 25°N means that also other types of land cover will be present than what the algorithms were developed for.

- In a similar way, a constant reference value is used for the reflectance of snow by both retrieval algorithms. In practice, snow reflectance varies somewhat with grain size, illumination angle and the presence of liquid water in the snow. Deviation between true and applied snow reflectance will result in a corresponding and proportional deviation of the FSC value in the retrieval result.

- The forest transmissivity map (a measure of how transparent the forest is seen from above) used by the SCAmod algorithm has been derived from the GlobCover land cover map. Analysis shows that the FSC will likely be underestimated for very dense forests. The effect is, e.g., visible in regions of Russia and North America.

4 DESCRIPTION OF THE GLOBSNOW SWE PRODUCT

Disclaimer:
The GlobSnow SWE product is derived using a combination of ground based data and satellite microwave radiometer-based measurements. Due to the nature of the radiometer observations, the SWE product is reliably shown on areas with seasonal dry snow cover. Areas with sporadic wet snow or a thin snow layer are not reliably detected and typically not present on the SWE product. The areas marked as snow free may thus include areas with occasional wet snow cover.

The European Space Agency (ESA) Data User Element (DUE) GlobSnow Snow Water Equivalent (SWE) product set version 2.0 for the Northern Hemisphere represents information on snow water equivalent retrieved from SMMR, SSM/I, and SSMIS sensors combined with ground-based weather station data from 1979 until present. In addition to the satellite data ECMWF collected weather station observations are employed. The SWE products are saved in both NetCDF CF and HDF4-formats: a single file contains the data for a single day; and a single file contains two fields 1) the SWE estimate and 2) an error estimate. *The snow water equivalent describes the amount of liquid water in the snow pack that would be formed if the snow pack was completely melted.*

The SWE product is produced by the GlobSnow consortium. The main responsibility for the production of SWE data lay with Finnish Meteorological Institute (FMI) and Environment Canada (EC). Additional assistance for the production of the data has been given by ENVEO IT GmbH (ENVEO), Finnish Environment Institute (SYKE), GAMMA Remote Sensing AG (GAMMA), Norwegian Computing Center (NR) and Northern Research Institute (Norut).

The SWE production system v2.0 utilizes SWE retrieval methodology (Pulliainen 2006) complemented with a time-series melt-detection algorithm (Takala et al. 2009), full methodology described in detail in (Takala et al. 2011). The SWE retrieval and melt detection algorithms are combined to produce snow water equivalent maps incorporated with information on the extent of snow cover on coarse resolution (25 x 25km grid cells). The SWE estimates are complemented with uncertainty information on a grid cell level.

The GlobSnow SWE processing system applies passive microwave observations and weather station observations collected by ECMWF in an assimilation scheme to produce maps of SWE estimates (in EASE-Grid format) over the northern hemisphere, covering all land surface areas with the exception of mountainous regions and Greenland. A semi-empirical snow emission model is used for interpreting the passive microwave (radiometer) observations through model inversion to the corresponding SWE estimates.

The basis of the SWE processing system is presented in an article by Pulliainen (2006). As applied for GlobSnow, estimates of SD (snow depth) based on emission model inversion of two frequencies, 18.7 and 36.5 GHz, are first calibrated over EASE grid cells with weather station measurements of SD available. Snow grain size is used in the model as a scalable model input parameter (being determined from the input radiometer and weather station data). These values of grain size are used to construct a Kriging interpolated background map of the effective grain size, including an estimate of the effective grain size error. The map is then used as an input in model inversion over the span of available radiometer observations, providing an estimate of SD. In the inversion process, the effective grain size in each grid cell is weighed with its respective error estimate. A snow density value is applied to each grid cell to connect depth to SWE. Areas of wet snow are masked according to observed brightness temperature values using an empirical equation, as model inversion of SD/SWE over areas of wet snow is not feasible due to the saturated brightness temperature response. The weather station observations of SD are further interpolated to provide a crude estimate of the SD (or SWE) background. The SWE estimate map and SD map from weather station observations are combined using a Bayesian spatial assimilation approach to provide the final SWE estimates.

The snow emission model applied is the semi-empirical HUT snow emission model (Pulliainen et al., 1999). The model calculates the brightness temperature from a single layer homogenous snowpack covering frozen ground in the frequency range of 11 to 94 GHz. Input parameters of the model include snowpack depth, density, effective grain size, snow volumetric moisture and temperature. Separate modules account for ground emission and the effect of vegetation and atmosphere. The model has been validated against tower-based and airborne reference radiometer observations (see e.g. Pulliainen et al., 1999, Lemmetyinen et al., 2009).

The detection of snow extent is based on a time-series melt detection approach described in (Takala et al. 2009). The algorithm can be used to determine the onset of snow-melt season using the available radiometer observations on a hemispherical scale covering the GlobSnow SWE time-series up to present day. The methodology has been calibrated against a vast Pan-Arctic dataset covering most of the land-areas of Northern Eurasia between the years 1979 to 2001. The areas that are identified as snow covered within the melt detection algorithm but for which a SWE estimate is not produced are given a marginal SWE value (0.001 mm) in the final SWE product. This information can be used to determine the extent of snow cover. The areas with a SWE value of 0mm are bare ground and areas with SWE of 0.001 mm or above are snow covered.

The SWE data is provided NetCDF CF-format and HDF-format. In addition to the raw SWE data, quicklook images are generated in png-format.

4.1 Description of the product

The SWE product is projected to Equal-Area Scalable Earth Grid (EASE-Grid) and provides the whole Northern Hemisphere (lambert's equal-area azimuthal – projection) in a single data field. The nominal resolution of single pixel is 25 km x 25 km and the geometry of the pixels varies. The data field has the size of 721 x 721 (rows x columns). Although the EASE-Grid can represent data almost to the equator the product is limited between latitudes 35° and 85° for physical reasons.

There are three products (all in the EASE-Grid) derived for SWE:

- **Daily Snow Water Equivalent** (Daily L3A SWE), snow water equivalent (mm) for each grid cell for all evaluated land areas of the Northern Hemisphere.
- **Weekly Aggregated Snow Water Equivalent** (Weekly L3B SWE), calculated for each day based on a 7-day sliding time window aggregation of the daily SWE product.
- **Monthly Aggregated Snow Water Equivalent** (Monthly L3B SWE) a single product for each calendar month providing the average and maximum SWE, calculated from the weekly aggregated SWE product.

In addition to the information on snow water equivalent, the SWE product includes information on the overall extent of snow cover. The information on snow extent is included in the product by utilizing the following coding for the SWE product, SWE values of:

- 0 mm denote snow-free areas (Snow Extent 0%)
- 0.001 mm denote areas with melting snow (Snow Extent between 0% - 100%)
- >0.001 mm denote areas with full snow cover (Snow Extent 100%)

The areas that have been flagged as snow-free or melted are identified using a time-series melt detection approach described in Takala et al. (2009). The areas that are identified as wet snow or have no SWE retrieval, but are identified as snow covered with the time-series melt detection approach are denoted with a SWE value of 0.001mm. The areas that are determined as snow-free or melted by the melt detection approach are denoted with a SWE value of 0mm. All the other areas show a retrieved SWE value (that is in all cases greater than 0.001mm).

The weekly (7-days) aggregated product is calculated using sliding window averaging: the SWE estimate for the current day is calculated as a mean of the samples from the previous 6 days and the current day SWE (for each grid cell). The monthly aggregate, a single product for each month, is calculated by determining the mean and the maximum of the weekly SWE samples.

The input data for the SWE products are SMMR for 1979-1987, SSM/I for 1987-2009 and SSMIS for 2010-2013 all acquired from NSIDC in EASE-Grid projection with a nominal spatial resolution of 25 km.

The weather station synoptic data is acquired from The European Centre for Medium-Range Weather Forecasts (ECMWF). The weather station data applied for the production of the SWE data contain the measured snow depth at the station locations.

The SWE product file includes two data fields:

- The SWE estimate [mm]
- The statistical standard deviation of the SWE estimates [mm] (i.e. the accuracy information for each SWE sample).

The data type of both data fields is a 32 bit floating point ‘float 32’. Positive values and zero are reserved for SWE and negative values for flags. The physical values of SWE are in millimeters. Negative values mean that the pixel is masked out due to water, mountains or no data (value of -1 is used for water bodies and -2 for mountains).

The mountainous areas of Northern Hemisphere are masked out from the SWE product. The mountain mask applied is derived from 4 minute averaged ETOPO2 data set which includes the Global elevation and bathymetry on 2x2 minute grid from the National Geophysical Data Center (NGDC). The dataset was original published in September 2001 and was revised to include correction to Caspian Sea area in April 2006. It contains improvements that include the blending of satellite altimetry with ocean soundings and new land elevation data from the Global Land One-km Base Elevations (GLOBE) project.

SWE estimates for wet snow areas (where retrieval using the radiometer data is not feasible) are determined from the weather station data using kriging interpolation. The methodology used to derive the snow line is described in (Takala et al. 2009).

The land-mask and the forest masks utilized are derived from the European Commission, Joint Research Centre, Global Land Cover 2000 database (GLC 2000) -data. The GLC2000 data were regridded and resampled for the EASE-Grid 25 km resolution by FMI.

4.1.1 Naming convention

The SWE products are named according to the following convention:
Globsnow_SWE_<type>_<datestring>_<versionstring>.<extension>
Where:
<type> is “L3A“ for the daily data; “L3B“ for aggregated products (weekly/monthly)
<datestring> is the date in “yyyymmdd“ -notation
<versionstring> is the product version (2.0 is the current data version)
<extension> is either “nc” or “hdf” – referring to NetCDF CF or HDF4

For example: "GlobSnow_SWE_L3A_20030131_v2.0.nc" is the daily SWE data for January 31st 2003, product version 2.0 in NetCDF CF format.

The metadata fields included within the HDF4 and NetCDF CF-files contain general information on the products.

4.2 Known issues with the SWE product

Availability of the early SWE data is limited due to two reasons: 1) Availability of ground-based weather station data prior the fall of 1979 2) operation of the SMMR sensor during 1978 to 1987.

Although the SMMR data set begins from late October 1978, the ECMWF collected ground-based weather station data record does not contain measurements before fall 1979. Therefore the SWE data set begins in November 1979 (as both microwave radiometer and ground-based weather station data are required to derive accurate SWE estimates).

The passive microwave data for 1979 to 1987 are acquired from the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) sensor which was operating every other day and thus can be used to derive the daily SWE time-series for every second day. The weekly aggregated SWE dataset however can be (and is) calculated for every day. The Special Sensor Microwave/Imager (SSM/I) family of sensors have been flown aboard several DMSP-satellites, covering an impressive data record starting from 1987. The SSM/I data are available for every day and the daily SWE products are generated for every day starting from fall 1987.

5 CONTACT INFORMATION

- For additional information and data access, contact: kari.luojus@fmi.fi

General information on the ESA DUE GlobSnow project and the products can be found at the web-site http://www.globsnow.info.

5.1 Data access

The products are stored at a file server with the Finnish Meteorological Institute.
The data can be accessed through www-based service or via ftp:

- http://www.globsnow.info/se/ (direct link to SE data)
- http://www.globsnow.info/swe/ (direct link to SWE data)
- http://www.globsnow.info/data/ (general data access-page)
- ftp://litdb.fmi.fi (for FTP-access details, please contact: kari.luojus@fmi.fi)

There is one catalogue for each product version (e.g., archive_v.2.0). There is one sub-catalogue for each year, each with the following sub-catalogues:

- L3A_daily_SWE: Daily SWE products (in NetCDF CF -format)
- L3A_daily_SWE_HDF: Daily SWE products (in HDF -format)
- L3A_daily_quicklooks: Quicklook images for the Daily SWE products

- L3B_weekly_SWE: Weekly SWE products (in NetCDF CF -format)
- L3B_weekly_SWE_HDF: Weekly SWE products (in HDF -format)
- L3B_weekly_quicklooks: Quicklook images for the weekly SWE products

- L3B_monthly_SWE: Monthly SWE products (in NetCDF CF -format)
- L3B_monthly_SWE_HDF: Monthly SWE products (in HDF -format)
- L3B_monthly_quicklooks: Quicklook images for the monthly SWE products

The quick-look pictures are provided for quick and easy browsing in Portable Network Graphics (PNG) format. They are stored in separate sub-catalogues for easy handling of multiple files. One might download a whole year of images and browse the time series conveniently by stepping (‘clicking’) through them all using a standard photo viewer.

6 REFERENCES

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