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snow cci

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ESA STUDY CONTRACT REPORT

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4000124098/18/I-NB	Product Specification Document		ENVEO
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Abstract:

The European Space Agency (ESA) Climate Change Initiative aims to generate high quality Essential Climate Variables (ECVs) derived from long-term satellite data records to meet the needs of climate research and monitoring activities. This document provides the product specifications for *snow_cci* ECVs (snow cover fraction – SCF; snow water equivalent – SWE). These specifications were derived from the user requirements obtained through engagement with users from across climate applications, including aspects of hydrology and meteorology. The *snow_cci* SCF product is derived from medium resolution optical data (0.05 and 0.01 degrees); the SWE product is derived from satellite passive microwave measurements (0.25 degrees) with input from weather station snow depth observations.

The work described in this report was done under ESA Contract. Responsibility for the contents resides in the author or organisation that prepared it.

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Version	Date	Changes	Originator
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2.0	16 / 12 / 2019	Updated version	Derksen, C. et al.
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3.0	07 / 12 / 2020	Third version draft	Derksen, C.
3.0	15 / 02 / 2021	Third version approved by ESA	Schwaizer, G.

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1. INTRODUCTION

The European Space Agency (ESA) Climate Change Initiative aims to generate high quality Essential Climate Variables (ECVs) derived from long-term satellite data records to meet the needs of climate research and monitoring activities, including the detection of variability and trends, climate modelling, and aspects of hydrology and meteorology. This document provides the product specifications for *snow_cci* ECVs (snow cover fraction – SCF; snow water equivalent – SWE). These specifications were derived from the user requirements obtained through engagement with users from across climate applications (see the *snow_cci* User Requirements Document for more details). These products address the GCOS parameters snow extent and snow water equivalent (from which snow depth can be inferred using different approaches to estimate snow density).

1.1. Purpose and Scope

This document provides the product specifications for satellite-derived ECVs for fractional snow cover (SCF) and snow water equivalent (SWE). These specifications represent the initial implementation as closely aligned with the climate science user requirements as possible, given the characteristics of historical and currently available satellite data and the known performance of SCF and SWE algorithms. Both the user requirements and production specification documents are updated on an annual basis.

1.2. Document Structure

A general overview of the *snow_cci* SCF and SWE products is provided in Section 2. Detailed product specifications are provided for snow cover fraction (Section 2.1) and snow water equivalent (Section 2.2). Technical specifications on product format and dissemination are provided in Section 3.

1.3. Applicable and Reference Documents

[AD-1] Derksen, C., T. Nagler and G. Schwaizer (2020) ESA CCI+ Snow ECV: User Requirements Document version 3.0, December 2020.

[AD-2] Schwaizer, G., Luojus, K., Ossowska, J., Naegeli, K., Wunderle, S., Nagler, T., Metsämäki, S., Solberg, R. (2019) ESA CCI+ Snow ECV: Product Validation and Algorithm Selection Report, version 1.0, October 2019.

[AD-3] Notarnicola, C., Premier V., C. Marin, G. Schwaizer, T. Nagler, K. Luojus, C. Derksen, C. Mortimer, S. Wunderle, K. Naegeli (2020) ESA CCI+ Snow ECV: Product Validation and Intercomparison Report, version 2.0, October 2020.

[AD-4] Derksen, C., R. Essery, D. Gustafsson, G. Krinner, and P. de Rosnay (2020) ESA CCI+ Snow ECV: Climate Applications Report, version 2.0, October 2020.

1.4. Acronyms

CCI	Climate Change Initiative
CMUG	Climate Modelling User Group
CRG	Climate Research Group
ECV	Essential Climate Variable
NDSI	Normalized Difference Snow Index
SCE	Snow Cover Extent
SCF	Snow Cover Fraction
SWE	Snow Water Equivalent

2. *SNOW_CCI* ECV PRODUCTS OVERVIEW

Overviews of the version 1 *snow_cci* products with anticipated changes for version 2 are provided in Table 2.1 (snow cover fraction) and Table 2.2 (snow water equivalent). The input data are summarized in Table 2.3. The majority of climate user requirements are met by the version 1 products; development activities planned for future versions will address some of the outstanding user requirements (see [AD-1] for more details on planned product development). The selection of the baseline algorithms was based on the results of inter-comparison and validation exercises performed as part of the ESA Satellite Snow product inter-comparison and Evaluation Exercise (SnowPEx). Additional details specific to the SCF and SWE products are provided in Sections 2.1 and 2.2.

Table 2.1: Baseline SCF product specifications for *snow_cci* versions 1 and 2.

	Snow Extent	
Parameter	Fractional snow extent [%]	
Description	Viewable Snow (SCFV); Snow on Ground (SCFG) (SCFV and SCFG are the same in non-forested areas)	
Spatial Coverage	Global (without Antarctica and Greenland ice sheet)	
EO Data	Optical imagery	
File Format	Net CDF	
	***snow_cci* Version 1**	**snow_cci Version 2**
Release Date	December 2020	Fall 2021
Algorithm Heritage	Adapted SCAmod	snow_cci Version 1, TBD
Spatial Resolution	0.05 deg (ca. 5 km) 0.01 deg (ca 1 km)	0.05 deg (ca. 5 km) 0.01 deg (ca 1 km)
Period	1982 – 2019 (5 km; AVHRR) 2000 – 2019 (1 km; MODIS)	1982 – 2020 (5 km; AVHRR) 2000 – 2020 (1 km; MODIS) 1995 - 2012 (1 km, ATSR-2/AATSR) 2016 – 2020 (1 km; SLSTR)
Frequency	Daily	Daily
Map Projection	Geographic Grid (Lat/Lon)	Geographic Grid (Lat/Lon)
Cloud Masking	Cloud CCI v3.0 (5 km) SCDAv2.0 (1 km)	TBD
Cloud Gap Filling	None	None
Temporal Aggregation	None	TBD
Spatial Aggregation	None	TBD
Uncertainty	Per-pixel unbiased RMSE	Per-pixel unbiased RMSE
Accuracy Target	10-20% unbiased RMSE	10-20% unbiased RMSE

Table 2.2 Baseline SWE product specifications for *snow_cci* versions 1 and 2.

	Snow Water Equivalent	
Parameter	Snow mass	
Description	Snow depth converted to SWE via density	
Spatial Coverage	NH non-mountain areas (without Greenland)	
EO Data	Passive microwave brightness temperatures	
File Format	Net CDF	
	***snow_cci* Version 1**	**snow_cci Version 2**
Release Date	March 2020	Fall 2021
Algorithm Heritage	GlobSnow v3	snow_cci v1
Spatial Resolution	25 km	12.5 km
Period	1979 - 2018	1979-2020
Frequency	Daily	Daily
Map Projection	Geographic Grid (Lat/Lon)	Geographic Grid (Lat/Lon)
Snow Density	Static	Dynamic
Snow Extent Mask	Passive Microwave	Passive Microwave/JAXA
Temporal Aggregation	None	None
Spatial Aggregation	None	None
Uncertainty	Per-pixel unbiased RMSE	Per-pixel unbiased RMSE
Accuracy Target	20-30% unbiased RMSE	20-30% unbiased RMSE

Table 2.3: Input data time series processing plan.

Product	*CP-1*	*CP-2*	*CP-3*
SCF	AVHRR/2 (1982-2007) AVHRR/3 (1998-2018) MODIS (Terra only; 2000-2018)	AVHRR/2 (1992-2007) AVHRR/3 (1998-2020) ATSR-2 (1995-2003) AATSR (2002-2013) MODIS (2000-2020) SLSTR (2016-2020) Merged AVHRR (1982-2020) Merged ATSR-2, AATSR & SLSTR (1995-2020) Merged Terra and Aqua MODIS (2000-2020) Merged all missions (1982-2020)	AVHRR/2 (1982-2007) AVHRR/3 (1998-2020) ATSR-2 (1995-2003) AATSR (2002-2013) MODIS (2000-2020) SLSTR (2016-2020) Merged AVHRR (1982-2020) Merged ATSR-2, AATSR & SLSTR (1995-2020) Merged Terra and Aqua MODIS (2000-2020) Merged all missions (1982-2020)
SWE	SMMR (1979-1987) SSM/I, SSMIS (1987-2018)	SMMR (1979-1987) SSM/I, SSMIS (1987-2020) Merged all missions (1979-2020)	SMMR (1979-1987) SSM/I, SSMIS (1987-2020) Merged all missions (1979-2020)

2.1. Snow Cover Fraction Product Specification

The *snow_cci* SCF product is derived from medium resolution optical data (see Table 2.3). The product contains two separate variables: (i) the snow cover at the surface in open areas and on top of vegetation cover such as forest canopies (called 'viewable snow') and (ii) snow extent on ground for open land (same as 'viewable snow') and corrected for masking by trees in forested areas (called 'snow on ground'). The fractional snow cover per resolution cell of the sensor is provided as a percentage.

Two baseline algorithms are selected for the development of SCF products version 1 [AD-2]: an NDSI based method developed for MODIS which provides viewable snow (Salomonson and Appel, 2006), and the SCAmod algorithm with heritage to the ESA GlobSnow project which provides both viewable snow and snow on ground in forested areas, described in Metsämäki et al. (2015). The algorithms were selected because they ranked highly within SnowPEx. The SCF retrieval process has 4 modules: pre-processing of satellite data, cloud screening, pre-classification of snow free areas, and SCF estimation.

Module 1: conversion to top-of-atmosphere values and the rectification of the data to the lat/lon grid

Module 2: application of sensor specific cloud screening algorithms and the use of available cloud products generated by other projects (e.g. *cloud_cci*)

Module 3: apply a multi-spectral decision tree (exploiting NDSI, thermal bands, visible bands) with spatially and temporally variable thresholds to mask areas where snow is very unlikely, including water areas.

Module 4: retrieve SCF using the two algorithms to provide viewable snow and snow on ground by correcting for the masking of canopy layer, and per-pixel uncertainty estimates for SCF estimated via the propagation of uncertainties in the various retrieval components.

2.1.1. Thematic Information

The SCF product provides the fraction of a pixel covered by snow given in percent. The products include two consistent layers providing fractional snow as it is seen from space (viewable snow) and fractional snow on ground, which applies a model to correct for the masking effect of the canopy layer (primarily forest). This correction uses auxiliary data on the density and optical transmissivity of the forest layer (note that in non-vegetated areas these two values are the same). Figure 2.1 uses tower-based photographs to illustrate the thematic difference between viewable snow and snow on ground. In the left photo, the canopy and ground surface are both snow covered. When extrapolated over a pixel, these conditions result in viewable snow close to 100%. In the right photo, there is no snow in the canopy, but snow is present on the ground. The viewable snow is therefore lower compared to the other example, but the snow on ground is similar.

Fractional snow extent is calculated only for cloud free land areas, open water areas (inland and oceans) as well as glaciers and ice sheets are masked using a common land mask.

Figure 2.1: Tower-based forest canopy photos showing viewable snow that is very similar to snow on ground (left) and viewable snow that is less than snow on ground (right). Photos courtesy of Paul Bartlett (ECCC).

2.1.2. Uncertainty Characterisation for SCF

The estimate of the pixel-level statistical accuracy for SCF considers observation noise, uncertainty in two-way forest canopy transmissivity, snow reflectance variability, forest canopy reflectance variability, and snow-free ground reflectance variability. The observation noise includes the effect of the inaccuracy of the instrument, as well as effects of other variables such as the atmospheric attenuation. The per-pixel uncertainty, expressed as unbiased RMSE, is provided for each day.

Uncertainties which cannot be specified on a pixel level will also be identified and attached to the products in the associated metadata.

Systematic error will be derived from validation of the daily SCF data set using high resolution optical imagery and reference snow measurements. Users can consult the annual Product Validation and Intercomparison Report for accuracy results.

2.1.3. Spatial Resolution and Coverage

The *snow_cci* SCF product covers global non-ice covered land areas, excluding permanent inland open water bodies (lakes, rivers; see Figure 2.2). For Greenland, coastal (non-ice sheet) areas are included. Coastal non-ice covered areas of Antarctica and islands in the southern ocean are not included in version 1, but may be considered for future versions. Permanent ice and open water areas are treated as static masks. Two time series of SCF will be processed, with the spatial resolution dependent on the input optical imagery: 0.05 deg. from 1982 (based on AVHRR) and 0.01 deg. from 2000 (based on AATSR, MODIS, and SLSTR). No spatial aggregation of the products will occur for version 1, but a strategy will be developed to meet the aggregation needs of the CMUG. Spatial aggregation of SCF is non-trivial because of the influence of variable cloud cover within aggregation windows.

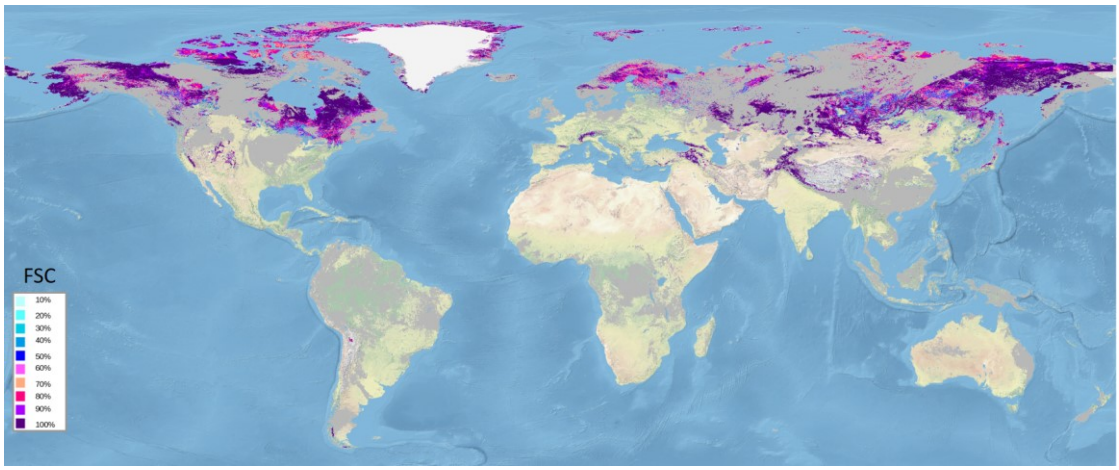

Figure 2.2: Example daily SCF map derived from SLSTR data.

2.1.4. Temporal Characteristics

Version 1 of the *snow_cci* products extends from 1982 to 2019. SCF is produced at daily temporal resolution with cloud cover flagged. Based on the results of the cloud screening round robin exercise performed in the first *snow_cci* project year with focus on clouds over snow [AD-2], it was decided to use the *cloud_cci* cloud mask for the AVHRR-2/-3 GAC based SCF products. For all other sensors, the Simple Cloud Detection Algorithm, version 2.0 (SCDA v2.0) (Metsämäki et al., 2015) was selected as the baseline cloud screening method. The approach will be adapted as needed and improved for different sensors. User demand for temporal aggregation was low, but options for weekly or monthly products will be further investigated for future product versions. The SCF product will be updated annually, following the CCI cyclical processing strategy.

2.2. Snow Water Equivalent Product Specifications

2.2.1. Thematic Information

The ESA GlobSnow SWE retrieval approach (described in Takala et al. 2011) represents the starting point for the SWE product (see Figure 2.3). The retrieval methodology combines satellite passive microwave measurements with ground based synoptic weather station observations via Bayesian non-linear iterative assimilation. A background snow depth field from re-gridded surface snow depth observations and a passive microwave emission model are required components of the retrieval scheme. Improvements to the GlobSnow algorithm implemented for *snow_cci* version 1 include the utilization of an advanced emission model with an improved forest transmissivity module and treatment of sub-grid lake ice. Because of the importance of the weather station snow depth observations on the SWE retrieval, there is improved screening for consistency through the time series.

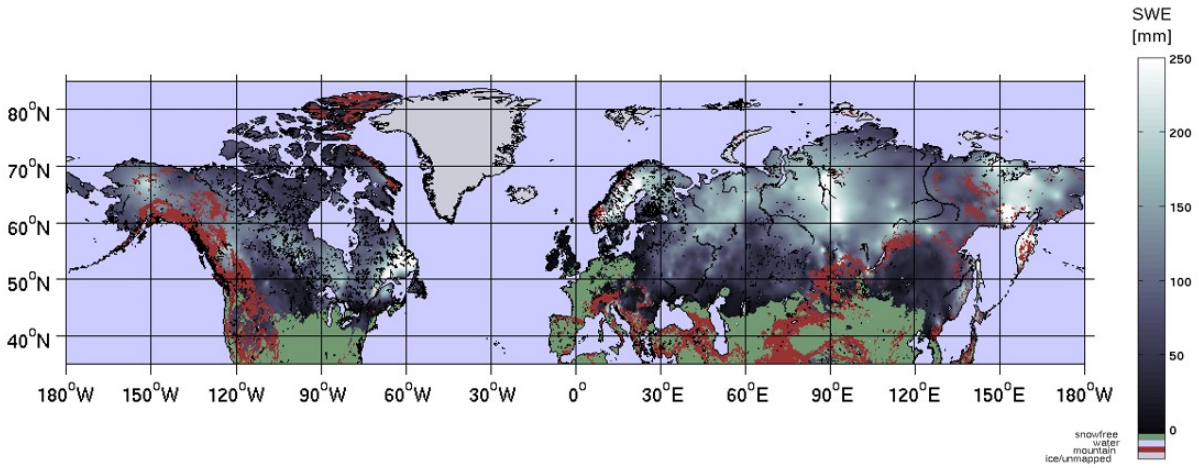

Figure 2.3: Example daily SWE map derived from SSM/I data.

2.2.2. Uncertainty Characterization for SWE

Statistical error is determined through an adaptive dynamic error propagation approach (Pulliainen, 2006; Takala et al. 2011) which considers uncertainty in the weather station observed snow depth, uncertainty of the (forward) modelling of space-borne observed brightness temperature, and the estimated sensitivity of brightness temperature to SWE. This information is provided daily as unbiased RMSE on a per-grid cell basis. Determination of systematic error (bias) is achieved through validation of the daily product using independent reference snow course measurements from Russia, Finland, and Canada. Users can consult the annual Product Validation and Intercomparison Report for accuracy results.

A key source of uncertainty with respect to the SWE ECV is the impact of variable weather station input data on time series continuity. While analysis of GlobSnow v2.1 shows there is no trend in the bias statistics over 1981-2016, this provides only an indirect metric of time series homogeneity. To this end, SWE retrievals were produced from two synoptic snow depth input data sets: stations which pass the initial consistency and QC check but may vary over time (as employed in GlobSnow v2.1 and Snow CCI v1), versus a reduced but consistent set of weather station inputs. This developmental version was evaluated within the PVIR [AD-3] and Climate Applications Report [AD-4].

2.2.3. Spatial Resolution and Coverage

For the first product version, 0.25 deg. resolution SWE time series was derived from passive microwave measurements (SMMR, SSM/I, and SSMIS) for non-alpine regions of the northern hemisphere. Because of known limitations in alpine area, a complex terrain mask is applied based on the sub-grid variability in elevation determined from a high resolution digital elevation model. A new DEM was produced for *snow_cci*, (for consistent use within SCF and SWE processing chains and validation activities) based on a new 90 m resolution TanDEM-X DEM gap-filled with SRTM V4.1 and ASTER GDEM V003 and resampled to 0.01 / 0.05 / 0.25 deg. grids. An additional SWE product with filled SWE estimates from

other sources in the masked alpine regions will be introduced in a later version. All land ice and large lakes are masked; retrievals are not produced for coastal regions of Greenland. Spatially aggregated data at the resolution required by CMUG will be derived in later product versions.

The SWE product will not be extended to the southern hemisphere because very little snow covered land occurs outside of the alpine mask.

2.2.4. Temporal Characteristics

SWE over the full northern hemisphere domain is produced at a daily time step. The product update frequency is annual, following the CCI cyclical processing strategy.

3. PRODUCT FORMAT AND DISSEMINATION

3.1. File Contents

3.1.1. Global Attributes

A full summary of global attribute fields for *snow_cci* will be developed alongside the version 1 products during the first year of the project (see Table 3.1 for a working list of global attributes with some content definitions). Definitions will be updated in subsequent versions of the PSD as required.

Table 3.1: Summary of global attribute fields.

Global Attribute	*Content*
title	ESA CCI snow product level L3C daily
institution	
source	
history	
references	http://snow-cci.enveo.at/
tracking_id	
Conventions	CF-1.8
product_version	1.0
format_version	CCI Data Standards v2.2, 2020
summary	
keywords	snow cover / snow water equivalent, sensor, platform
id	filename.nc
naming authority	
keywords_vocabulary	NASA Global Change Master Directory (GCMD) Science Keywords
cdm_data_type	Swath
comment	
date_created	
creator_name	
creator_url	
creator_email	
project	Climate Change Initiative - European Space Agency
geospatial_lat_min	-90
geospatial_lat_max	90
geospatial_lon_min	-180
geospatial_lon_max	180
geospatial_vertical_min	0

Global Attribute	*Content*
geospatial_vertical_max	0
geospatial_lon_resolution	0.01, 0.05, 0.25
geospatial_lat_resolution	0.01, 0.05, 0.25
geospatial_lat_units	degrees_north
geospatial_lon_units	degrees_east
time_coverage_start	
time_coverage_end	
time_coverage_duration	P1D
time_coverage_resolution	P1D
standard_name_vocabulary	NetCDF Climate and Forecast (CF) Metadata Convention version 1.8
license	ESA CCI Data Policy: free and open access
platform	
sensor	
spatial_resolution	0.01, 0.05, 0.25 degree
key_variables	snow_cover_fraction, snow_water_equivalent

For final products provided in netCDF format, the per-file metadata is summarized in Table 3.2. The defined grid sizes in lat/lon (WGS84 map projection) are:

- 0.25 deg. (SWE products)
- 0.05 deg. (AVHRR based SCE products)
- 0.01 deg. (MODIS based SCE products)
- 0.00025 deg. (Landsat based SCE products used for validation)

3.1.2. Variable Attributes

Per-product metadata is summarized in Table 3.2. Variable attributes for the *snow_cci* products, including uncertainty information and data quality flags were developed alongside the version 1 products. Metadata will be updated in subsequent versions of the PSD as required.

Table 3.2: Summary of product metadata.

Product	*Variable*	*Description*
SCF[G|V]	lat	Latitude at the upper left corner of each pixel [deg]
	lon	Longitude at the upper left corner of each pixel [deg]
	scf[g|v]	Snow Cover Fraction, Snow on ground / Viewable Snow
	spatial_ref	Coordinate reference system definition
	scf[g|v]_unc	Snow Cover Fraction uncertainty layer, unbiased RMSE
	time	Time information [UTC]
SWE	lat	WGS84 latitude coordinates, centre of pixel [deg]
	lon	WGS84 latitude coordinates, centre of pixel [deg]
	spatial_ref	Coordinate reference system definition
	swe	Snow water equivalent [mm]
	swe_std	Statistical standard deviation of SWE estimate [mm]
	time	Time information [UTC]

3.2. Product Characteristics and Data Access

Version 1 *snow_cci* products are provided in a latitude/longitude geographic grid. Data are 8-bit for SCF and 16-bit for SWE, with daily files in netCDF format. Individual netCDF files will be produced for each day and will include snow cover fraction or snow water equivalent, grid-cell level uncertainty estimates produced from the retrieval processing, and any relevant data flags. Data access is via the CCI data portal. Quicklook images are produced as part of each product processing line.

3.3. Filename Conventions

Filename convention is based on the CCI Data Standards document:

<Indicative Date>-ESACCI-<Processing Level>_<CCI Project>-<Data Type>-
<Product String>[-<Additional Segregator>][-v<GDS version>]-fv<File version>.nc

Definitions of the filename components are:

- Indicative Date: YYYYMMDD
- Processing Level: L3C for daily SCF and SWE version 1 products
- CCI Project: ‘SNOW’
- Data Type: SWE (snow water equivalent); Snow cover fraction data types are not yet included in the CCI Data Standards document but we propose SCFV (viewable snow), SCFG (snow on ground).

- Product String: Identifies the source satellite data for each product. For SCF, this is either AVHRR_MERGED (data spanning 1982-2019) or MODIS-TERRA (data spanning 2000-2019). For SWE, it is SMMR-NIMBUS7 (1979 through May 1987), SSMI-DMSP (October 1987-December 1991), or SSMIS-DMSP (January 1992-May 2018).
- File version: unique identifier increasing with each dataset instance

Note that the 'Additional Segregator' and 'GDS version' are not used as part of the *snow_cci* file names.

3.4. Digital Coding of SCF and SWE

Layer Name	SCFG / SCFV
Description	This layer provides the fraction of snow cover in each grid cell as a percentage
Data type	8 bit unsigned integer

Code range	Class
0-100	Mapped snow cover fraction in percent Note: 0 = snow free; 100 = fully snow covered
205	Clouds (incl. cloud shadow) Note: snow retrieval not possible due to masking of earth surface
206	(Polar) Night but satellite data available, but large solar zenith angle does not allow classification
210	Water
211	Sea (**might be added in future product version**)
212	Lake/River (**might be added in future product version**)
215	Glaciers, ice caps, ice sheets
252	ERROR Code: Retrieval / Classification failed
253	ERROR Code: Input data error (e.g. bad pixels, etc)
254	ERROR code: No satellite acquisition
255	Not Valid Pixel
All other values	Not used

Layer Name	SCFG_UNC / SCFV_UNC (uncertainty layer, unbiased RMSE per pixel)
Description	This layer provides the uncertainty of the fraction of snow cover in each grid cell (unbiased RMSE)
Data type	8 bit unsigned integer

Code range	Class
0-100	RMSE unbiased of snow cover fraction, in per cent Note: 0 = pixel identified as snow free in the pre-classification module; 1 - 100 = unbiased RMSE per pixel considered for SCF retrieval
205	Clouds (incl. cloud shadow) Note: snow retrieval not possible due masking of earth surface
206	(Polar) Night but satellite data available, but large solar zenith angle does not allow classification
210	Water
211	Sea (**might be added in future product version**)
212	Lake/River (**might be added in future product version**)
215	Glaciers, ice caps, ice sheets
252	ERROR Code: Retrieval / Classification failed
253	ERROR Code: Input data error (e.g. bad pixels, etc)
254	ERROR Code: No satellite data value
255	Not Valid Pixel
All other values	Not used

Layer Name	SWE
Description	This layer provides the SWE in mm
Data type	16-bit signed integer

Code range	Class
0	Bare ground (SWE = 0 mm)
1-500	SWE [mm]
-1	Masked: land areas on Southern Hemisphere, no SWE data available
-10	Masked: water (oceans, or water fraction > 50%)
-20	Masked: mountain
-30	Masked: Glaciers / permanent ice
All other values	Not used

Layer Name	SWE_STD (statistical standard deviation of estimate)
Description	This layer provides the uncertainty of the SWE retrieval in each grid cell (unbiased RMSE)
Data type	16-bit signed integer

Code range	Class
0	Bare ground (SWE = 0 mm)
1-250	SWE_STD [mm]
-1	Masked: land areas on Southern Hemisphere, no SWE data available
-10	Masked: water (oceans, or water fraction > 50%)
-20	Masked: mountain
-30	Masked: Glaciers / permanent ice
All other values	Not used

4. REFERENCES

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Pulliainen, J. 2006. Mapping of snow water equivalent and snow depth in boreal and sub-arctic zones by assimilating space-borne microwave radiometer data and ground-based observations. Remote Sensing of Environment, 101, 257-269, DOI: 10.1016/j.rse.2006.01.002.

Salomonson, V., and I. Appel. 2006. Development of the Aqua MODIS NDSI fractional snow cover algorithm and validation results. IEEE Transactions on Geoscience and Remote Sensing, 44, 7, 1747 – 1756, 10.1109/TGRS.2006.876029.

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