ESA Climate Change Initiative CCI+

Product User Guide

snow cci

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ESA STUDY CONTRACT REPORT

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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. The main goal of *snow_cci* project is to generate homogeneous, well-calibrated, long-term time series of the key snow cover variables snow area extent and snow mass for climate applications.

This document is a user guide for the snow products produced in the second iteration of the *snow_cci* project. The product time series are snow cover fraction (SCF, viewable and on the ground) based on the sensors MODIS, AVHRR, ATSR-2/AATSR and SLSTR (separate time series) and snow water equivalent (SWE) based on the sensors SMMR, SSM/I and SSMIS (one combined time series). The document provides a comprehensive description of the thematic content of the products, coding, metadata and file format. It also includes a description of known limitations and strengths of the products. Guidelines for product access and suggestions for software tools to handle the data, are also provided.

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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1.0	11 / 11 / 2019	First version approved by ESA	Schwaizer, G.
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3.0 draft	13 /12 / 2021	Third version	Solberg et al.
3.1	17 / 12 / 2021	Minor update of third version according to feedback from ESA (approved by ESA)	Solberg et al.

TABLE OF CONTENTS

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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. The main goal of the *snow_cci* project is to generate homogeneous, well-calibrated, long-term time series of the key snow cover variables snow area extent and snow mass for climate applications.

1.1. Scope of the Document

This document is a user guide for the snow products produced in the second iteration of the *snow_cci* project. The product time series are snow cover fraction (SCF, viewable and on the ground) based on the sensors Moderate resolution Imaging Spectroradiometer (MODIS), Advanced Very High Resolution Radiometer (AVHRR), Along-Track Scanning Radiometer (ATSR-2) and Advanced Along-Track Scanning Radiometer (AATSR) (separate time series) and snow water equivalent (SWE) based on the sensors Scanning Multichannel Microwave Radiometer (SMMR), Special Sensor Microwave/Imager (SSM/I) and Special Sensor Microwave Imager/Sounder (SSMIS) (one combined time series). The document provides a comprehensive description of the thematic content of the products, the coding, metadata and file format. It also includes a description of known limitations and strengths of the products. Guidelines for product access and suggestions for software tools to handle the data, are also provided.

1.2. Document Structure

The document introduces with a summary description of the *snow_cci* project (Chapter 2). Then follows documentation on the snow cover fraction (SCF) products (Chapter 3), including a general description of the snow variable in the context of this project (Section 3.1) followed by a specific description of the MODIS SCF product (Section 3.2), AVHRR SCF product (Section 3.3), ATSR-2/AATSR SCF product (Section 3.4) and Sea and Land Surface Temperature Radiometer (SLSTR) SCF product (Section 3.5). The snow water equivalent (SWE) product is described in Chapter 4. All product descriptions include subsections for thematic information, overall product characteristics, data representation and known strengths and limitations. Then follows a description that deals with topics common to all the products (Chapter 5). These are filename convention, file format – including global and variable attributes, and metadata – and at last software tools to handle the products and how to access the products, including our use and citing policy.

1.3. Applicable and Reference Documents

[AD-1] Phase 1 of the ESA Climate Change Initiative CCI+ New ECVS (Snow). ESRIN Contract No: 4000124098/18/I-NB.

[AD-2] Climate Change Initiative Extension (CCI+) Phase 1 – New Essential Climate Variables (Annex E: Snow ECV (Snow_cci), ESA-CCI-PRGM-EOPS-SW-17-0032.

[AD-3] Technical Proposal (Part 3) in response to ESA Climate Change Initiative Phase 1 ESA ITT AO/1-9041/17/I-NB, ENVEO Innsbruck, Austria.

[RD-1] Wunderle, S., Naegeli, K., Schwaizer, G., Nagler, T., Marin, C., Notarnicola, C., Derksen, C., Luojus, K., Metsämäki, S., Solberg, R. (2021). ESA CCI+ Snow ECV: Data Access Requirements Document, version 3.1, February 2021.

[RD-2] Notarnicola, C., Marin, C., Schwaizer, G., Nagler, T., Luojus, K., Derksen, C., Mortimer, C., Wunderle, S., Naegeli, K. (2021). ESA CCI+ Snow ECV: Product Validation Plan, version 3.0, October 2021.

[RD-3] Wiesmann A., Hetzenecker M., Schwaizer G., Nagler T., Takala M., Luojus K. (2021) ESA CCI+ Snow ECV: System Requirements Document, version 3.1, April 2021.

[RD-4] Solberg, R., G. Schwaizer, T. Nagler, M. Hetzenecker, S. Wunderle, K. Naegeli, C. Neuhaus, A. Wiesmann, K. Luojus, M. Takala, J. Pulliainen, J. Lemmetyinen, and M. Moisander (2021) ESA CCI+ Snow ECV: Climate Research Data Package, version 3.0, November 2021.

[RD-5] Salberg, A.-B., K. Luojus, C. Derksen, C. Marin, R. Solberg, L. Keuris, G. Schwaizer, T. Nagler, (2021) ESA CCI+ Snow ECV: End-to-End ECV Uncertainty Budget, version 3.0, November 2021.

1.4. Acronyms

AATSR	Advanced Along-Track Scanning Radiometer
ATSR-2	Along-Track Scanning Radiometer
AMSR	Advanced Microwave Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CCI	Climate Change Initiative
CEDA	Centre for Environmental Data Analysis
DEM	Digital Elevation Model
DMSP	Defence Meteorological Satellite Program
CP	Contractual Phase
DARD	Data Access Requirement Document
ECV	Essential Climate Variable
ESA	European Space Agency
GAC	Global Area Coverage

GCMD	Global Change Master Directory
MetOp	European Meteorological Operational Satellite
MODIS	Moderate resolution Imaging Spectroradiometer
NDSI	Normalized Difference Snow Index
NOAA	National Oceanic and Atmospheric Administration
PMR	Passive Microwave Radiometer
PVP	Product Validation Plan
QA4EO	Quality Assurance framework for Earth Observation
RMSE	Root Mean Square Error
SCF	Snow Cover Fraction
SCFG	Snow Cover Fraction, snow on the Ground
SCFV	Snow Cover Fraction, Viewable snow
SLSTR	Sea and Land Surface Temperature Radiometer
SMMR	Scanning Multichannel Microwave Radiometer
SSM/I	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager / Sounder
SWE	Snow Water Equivalent
UTC	Coordinated Universal Time
WGS	World Geodetic System

2. *SNOW_CCI* PROJECT

Seasonal snow cover is the largest single component of the cryosphere, covering about 50% of the Northern Hemisphere's land surface during mid-winter. The seasonal snow cover is an important component of Earth's hydrological and climate systems.

The seasonal snow cover is a crucial and challenging research issue in climate analysis and modelling. It influences energy, moisture and gas fluxes between the land surface and the atmosphere; its high albedo provides a significant feedback effect in a warming climate; and its sensitivity to precipitation and temperature regimes makes it widely recognised as a fundamental indicator of climate variability and change. Snow is also a major, if not dominant, freshwater source in many alpine, high- and mid-latitude regions and an important contribution to the global water cycle.

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. The main goal of the *snow_cci* project is to generate homogeneous, well-calibrated, long-term global time series of daily products of the key snow cover variables snow cover fraction (SCF) from optical sensor satellite data and snow water equivalent (SWE) from passive microwave radiometer satellite data. This includes to set up reliable, fully validated processing chains for these products and carrying out a comprehensive validation/inter-comparison study.

The *snow_cci* project focuses in its first phase on the development and implementation of methods and processing systems to generate consistent multi-sensor time series from ESA and third-party satellites. These products are contributing to the determination of the long-term trends in seasonal snow since the early 1980s, currently still a matter of debate due to various inconsistencies between different snow cover datasets, as shown in the ESA QA4EO project SnowPEx.

The SCF product has a spatial resolution ranging between 0.01° and 0.05° (about 1 km and 5 km, respectively, at mid-latitudes). The aim is to generate time series of daily global homogeneous snow cover fraction maps from different optical satellite sensors. In forested areas, information is provided for snow on the top of the forest canopy (SCFV, 'viewable snow') and for snow on the ground applying a canopy correction (SCFG, 'snow on ground'). The products are expressed as fractional snow per pixel and are derived from medium spatial resolution optical satellite data. The multi-sensor time series, starting from the beginning of the 1980s to present day, include data from AVHRR-2/3, ATSR-2, AATSR, and MODIS, and will be complemented with Sentinel-3A/B SLSTR in future (available currently as prototype products). For each product, the uncertainty is estimated for each pixel taking spectral capabilities, calibration, and geolocation accuracy into account. A key aspect of the long time series of daily products is cross-sensor consistency of the products.

The snow water equivalent production system is built on the GlobSnow SWE production system and is further developed by improving various aspects of the processing chain, including time-varying snow density, influence of land cover and implementation of techniques for enhancement of brightness temperature resolution. The daily global time series is based on SMMR, SSM/I and SSMIS data (from several DMSP F-series satellites) starting in 1979 to present day. A key aspect is the synergy between the daily time series of SCF and SWE products, with the aim to get a consistent cross-parameter data set.

The first version of the climate data record generated in the frame of the *snow_cci* project is based on MODIS and AVHRR sensors for SCF (two separate time series) and on SMMR, SSM/I and SSMIS for SWE (combined in one time series).

The second version of the *snow_cci* climate data record contains improved SCF products from MODIS and AVHRR sensors, and improved SWE products from SMMR and SSMI/I. A new SCF climate data record from ATSR-2 and AATSR is added. The prototype SCF products generated from Sentinel-3A/B SLSTR data for the year 2020 are not released to the public, but an improved version of these products is planned to be added to the SCF climate data records in *snow_cci* phase 2 (planned for the period 2022 – 2025). Table 2.1 provides an overview of the products sets from *snow_cci*.

Table 2.1: Input data time series processing plan per project year.

Product	*Project Year 1*	*Project Year 2*	*Project Year 3*
SCF	AVHRR/2 (1982-2016) AVHRR/3 (2006-2018) MODIS (Terra only; 2000-2018)	AVHRR/2 (1982-2016) AVHRR/3 (2006-2019) MODIS (2000-2019) ATSR-2 (1995-2003; samples) AATSR (2002-2013; samples) SLSTR (2016-2019; samples)	AVHRR/2 (1982-2001) AVHRR/3 (2001-2020) ATSR-2 (1995-2003) AATSR (2002-2012) MODIS (2000-2020) SLSTR (2020) Merged AVHRR (1982-2020)
SWE	SMMR (1979-1987) SSM/I, SSMIS (1987-2018)	SMMR (1979-1987) SSM/I, SSMIS (1987-2019)	SMMR (1979-1987) SSM/I, SSMIS (1987-2020) Merged all missions (1979-2020)

3. SNOW COVER FRACTION

3.1. Thematic Description

The *snow_cci* SCF products are derived from medium resolution optical data (see Table 2.1), and contains two separate variables: (i) the snow cover at the surface in open areas and on top of vegetation cover that is present, 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 grid cell in the product is provided as a percentage.

Two baseline candidate algorithms were selected for the development of SCF products: The Normalized Difference Snow Index (NDSI)-based method developed originally for MODIS, which provides in forested areas viewable snow (Salomonson and Appel, 2006), and the SCAmod algorithm with heritage to the ESA GlobSnow project, which provides in forested areas snow on ground (Metsämäki et al., 2015). The algorithms were selected because they ranked highly within SnowPEx project's studies. The SCAmod algorithm was selected and adapted for the SCF version 1.0 retrieval using auxiliary data newly developed in the *snow_cci* project for a consistent detection of viewable snow and snow on ground. The parameters used in the SCAmod algorithm were improved and refined for the SCF version 2.0 retrieval. The SCF processing chain has four main modules: pre-processing of satellite data, cloud screening, pre-classification of snow-free areas based on the NDSI and SCF retrieval using the adapted SCAmod.

The products include pairs of files providing SCF for viewable snow and snow on ground, both including a measure of retrieval uncertainty per pixel as a separate layer. The SCF 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. For Greenland, coastal areas (with no land ice) are included. Coastal ice-free areas of Antarctica and islands in the Southern Ocean are excluded in versions 1.0 and version 2.0 but might be considered for future versions if requested by users. Permanent ice and open water areas are treated as static masks. Pixels acquired at large solar zenith angles are masked as class (polar) night.

Three time series of SCF are available as climate research data package (CRDP), with the spatial resolution depending on the input optical imagery: 0.05° from 1982 to 2018 (based on AVHRR), 0.01° from 1995 to 2012 (based on ATSR-2 and AATSR) and 0.01° from 2000 to 2020 (based on MODIS). No temporal aggregation of the products is included in version 2.0.

3.2. MODIS SCF

3.2.1. Overall Description

The MODIS-based *snow_cci* SCF product time series covers the period 2000-2020. Global SCF products are available at daily temporal resolution with cloud-cover flagged. The product is based on data from the MODIS sensor aboard the Terra satellite (launched 1999). The sensor provides data in 250, 500 and 1000 m spatial resolution. 1 km data is provided from all 36 spectral bands.

The whole global Terra MODIS 1 km Level 1B dataset was downloaded and made available to the project at NR. It was decided not to fill in gaps with Aqua MODIS data in the version 1.0 and version 2.0 as potential impacts from illumination variations due to the afternoon orbit have not yet been analysed properly.

The characteristics of the MODIS SCF product version 1.0 and version 2.0 are described in Table 3.1.

Table 3.1: MODIS SCF products version 1.0 and version 2.0. These characteristics are valid for the viewable snow cover fraction (SCFV) and the snow cover fraction on ground (SCFG) products.

Subject	*Snow Cover Fraction CRDP v1.0*	*Snow Cover Fraction CRDP v2.0*
Variable	Snow cover fraction [%]	Snow cover fraction [%]
Accuracy target	10-20% unbiased RMSE	10-20% unbiased RMSE
Retrieval algorithm	SCAmod, Metsämäki et al., 2015, adapted and improved	SCAmod, Metsämäki et al., 2015, adapted and improved
Uncertainty algorithm	Error propagation, adapted from Salminen et al. (2018)	Error propagation, adapted from Salminen et al. (2018)
Cloud screening algorithm	Simple Cloud Detection Algorithm, Metsämäki et al., 2015, adapted and improved	Simple Cloud Detection Algorithm, Metsämäki et al., 2015, adapted and improved
Satellite(s)	Terra (NASA)	Terra (NASA)
Sensor(s)	MODIS	MODIS
Input product(s)	MOD02 and MOD03 Collection 6.1	MOD02 and MOD03 Collection 6.1
Geographical domain(s)	Global	Global
Start date time series	25.02.2000	24.02.2000
End date time series	31.12.2019	31.12.2020
Grid size	0.01°	0.01°
Projection/datum	Geographical (lat/lon)/WGS 84	Geographical (lat/lon)/WGS 84
Temporal resolution	Daily	Daily
Temporal aggregation	None	None
Number of layers	2	2
Metadata	Global attributes in NetCDF4 file, CF-v1.8, conformal with CCI data standards v2.2, 19/05/2020	Global attributes in NetCDF4 file, CF-v1.9, conformal with CCI data standards v2.3, 26/07/2021
Auxiliary data	Water and permanent snow and ice masks aggregated from Land Cover CCI product for the year 2000; forest canopy transmissivity map for the retrieval of snow on ground, reflectance maps for snow-free forest and snow-free ground	Water and permanent snow and ice masks aggregated from Land Cover CCI product for the year 2000; updated forest canopy transmissivity map for the retrieval of snow on ground, updated reflectance maps for snow-free forest and snow-free ground

Subject	Snow Cover Fraction CRDP v1.0	Snow Cover Fraction CRDP v2.0
Data representation	Unsigned byte (8 bits)	Unsigned byte (8 bits)
File format	NetCDF4, CF-v1.8	NetCDF4, CF-v1.9
Product access	CCI Data Portal, CEDA archive: SCFV products: https://catalogue.ceda.ac.uk/uuid/ef8eb5ff84994f2ca416dbb2df7f72c7 SCFG products: https://catalogue.ceda.ac.uk/uuid/3b3fd2daf3d34c1bb4a09efeaf3b8ea9	CCI Data Portal, CEDA archive: SCFV products: https://catalogue.ceda.ac.uk/uuid/ebe625b6f77945a68bda0ab7c78dd76b SCFG products: https://catalogue.ceda.ac.uk/uuid/8847a05eeda646a29da58b42bdf2a87c

3.2.2. Data Representation

The products are provided as two files, each containing two layers:

1. SCFV product:
    a. Snow cover fraction, viewable snow
    b. Uncertainty estimates for snow cover fraction, viewable snow
2. SCFG:
    a. Snow cover fraction, snow on the ground
    b. Uncertainty estimates for snow cover fraction, snow on the ground

The coding of the product and the associated uncertainty estimation are described in Table 3.2. Examples of the MODIS-based SCFV and SCFG products are shown in Figure 3.1 and Figure 3.3, the associated uncertainty estimations per pixel are presented in Figure 3.2 and Figure 3.4, respectively.

Table 3.2: Coding for the MODIS SCF products and associated uncertainty estimation (valid for viewable snow and snow on ground).

Code(s)	SCF product coding description	SCF uncertainty coding description
0	snow free	Uncertainty for pixels classified as definitely snow free in the NDSI-based pre-classification
1-100	SCF [%] (100 = fully snow covered)	Unbiased RMSE estimate for pixels considered in the SCF retrieval, resulting in snow cover fraction in percent (0 = snow free; 100 = fully snow covered in SCF product). For snow-free pixels resulting from the SCF retrieval approach, also the uncertainty estimation is provided.
205	Cloud	Cloud (snow retrieval not possible due to masking of earth surface, no uncertainty estimate provided.)
206	(Polar) Night (satellite data available, but large solar zenith angle (SZA > 83°) does not allow classification)	(Polar) Night (satellite data available, but large solar zenith angle (SZA > 83°) does not allow classification)
210	Water	Water
215	Glaciers, icecaps, ice sheets	Glaciers, ice caps, ice sheets
252	ERROR: Retrieval failed	ERROR Code: Retrieval / Classification failed
253	ERROR: Input data error (e.g. bad pixels)	ERROR Code: Input data error (e.g. bad pixels, etc)
254	ERROR: No satellite acquisition	ERROR Code: No satellite data value
255	Not valid data	Not Valid Pixel
All other values	Not used	Not used

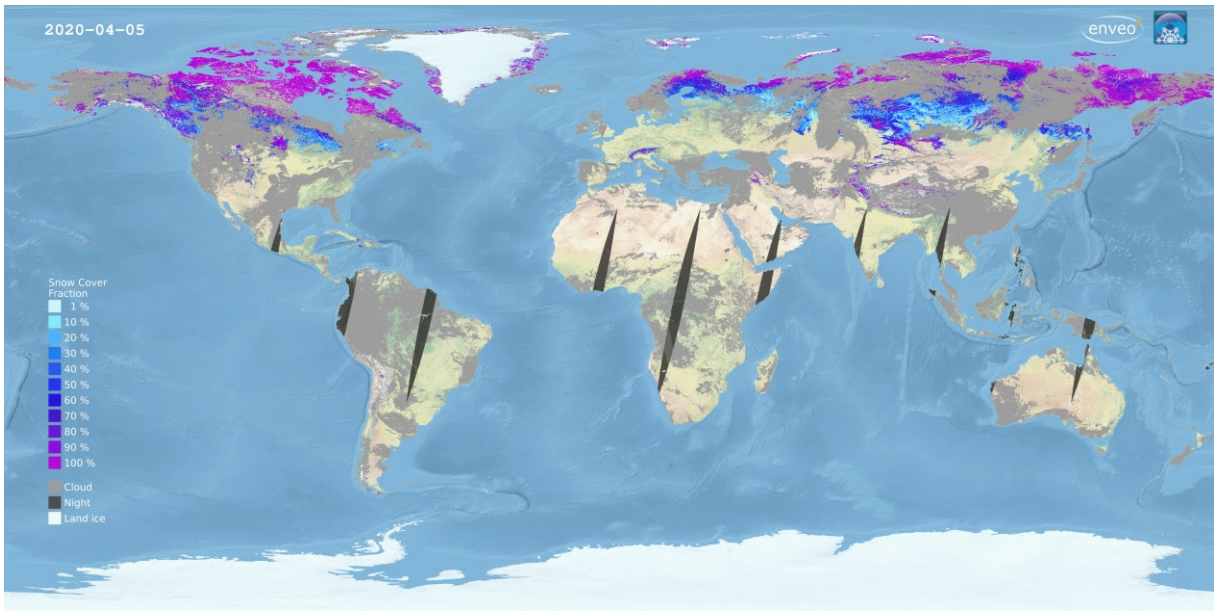

Figure 3.1: SCFV product example from Terra MODIS on 05 April 2020 (CRDP v2.0).

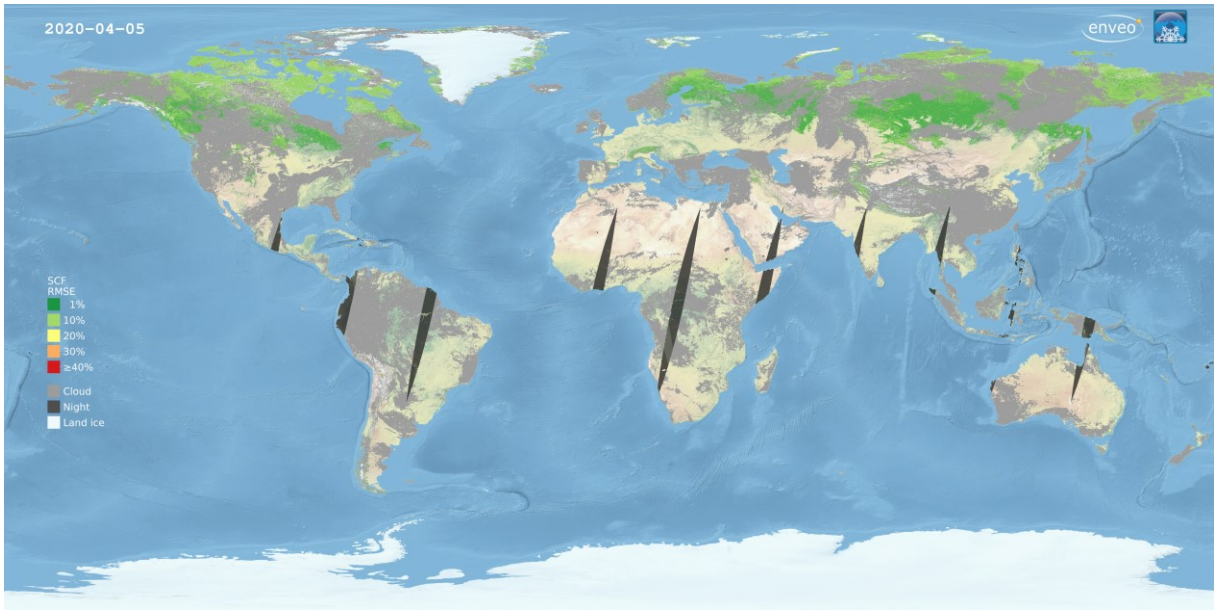

Figure 3.2: Example of the uncertainty estimation for the SCFV product from MODIS data on 05 April 2020 (CRDP v2.0) (cf. Figure 3.1).

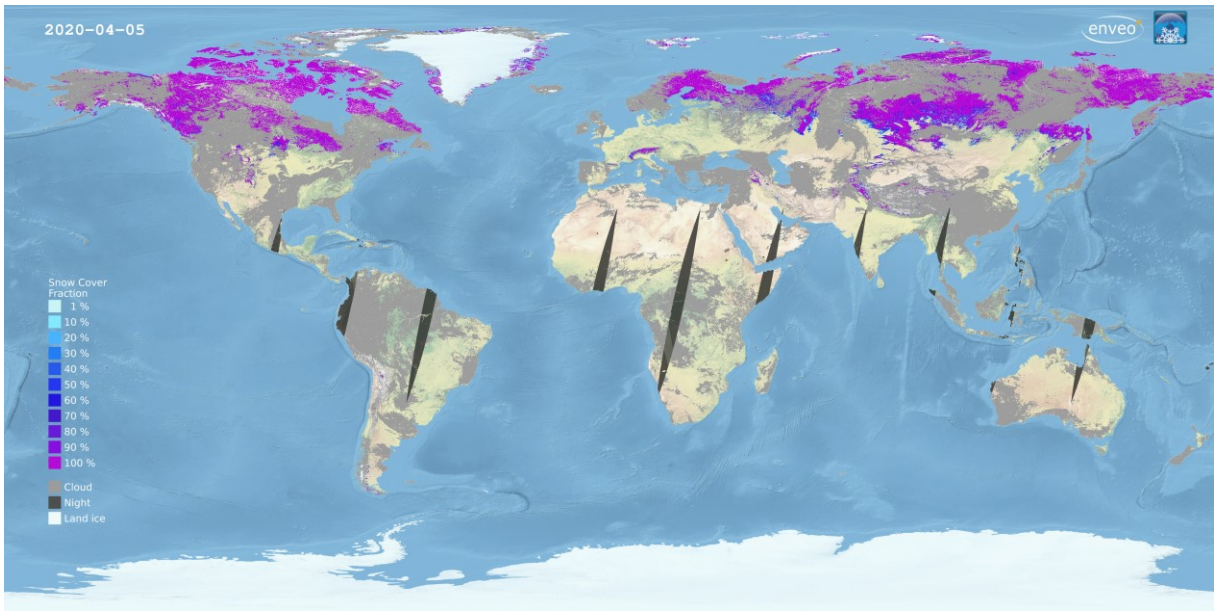

Figure 3.3: SCFG product example from Terra MODIS on 05 April 2020 (CRDP v2.0).

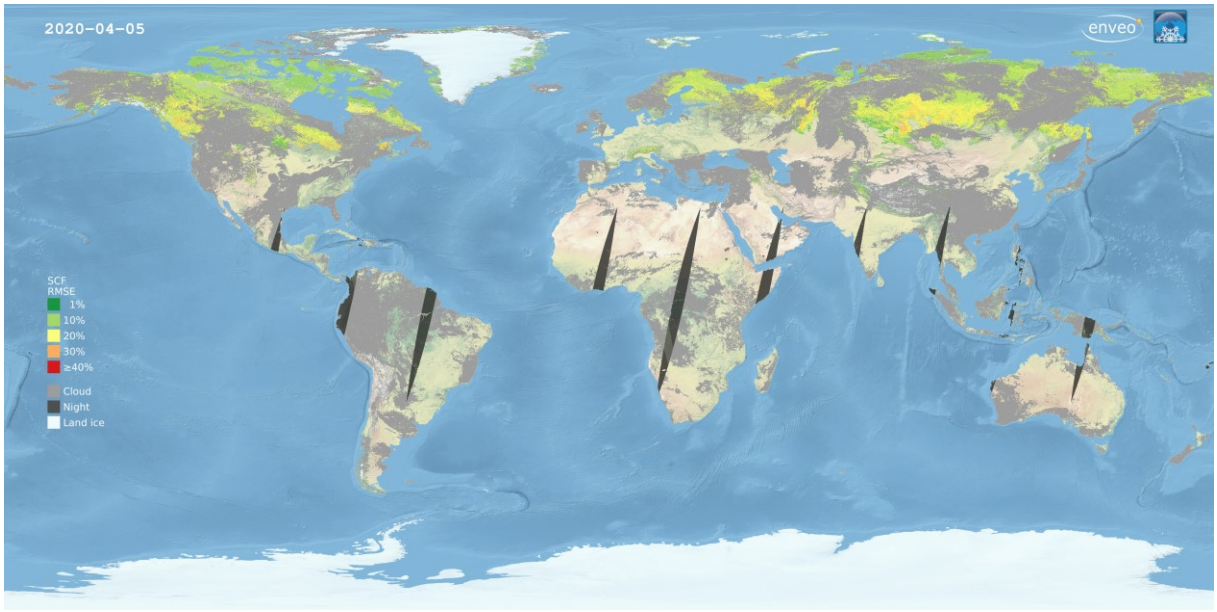

Figure 3.4: Example of the uncertainty estimation for the SCFG product from MODIS data on 05 April 2020 (CRDP v2.0) (cf. Figure 3.3).

3.2.3. Known Strengths and Limitations

Strengths: The products provide the fraction of snow cover per pixel on global land areas. The spatial resolution of the products with 0.01° pixel spacing is high compared to other available satellite-based global snow products. In forested areas, the SCFV products provide information on snow on the top of the forest canopy, while the SCFG products provide the canopy-corrected snow on ground. The snow classification in open land for SCFV and SCFG is consistent for the product generation from Terra MODIS data for the full time series, from end of February 2000 till December 2020. The applied pre-classification to identify pixels with high probability of snow-free conditions, e.g. in very warm regions,

improves the global snow extent product significantly. The cloud-screening approach is developed for clouds over snow and works in general better than other cloud masks.

Limitations: Changes in the forest due to forest clearance or reforestation are not yet considered, but a static forest mask valid for the year 2000 is used to separate between open land and forested areas. The classification accuracy of pixels affected by cloud shadow or in small cloud gaps is often lower than for large areas observed at clear-sky conditions. Further improvements of the cloud screening approach are currently in development. Pixels with a solar zenith angle greater than 83° are too dark for a reliable classification and are masked as night or polar night. Although the major water bodies are masked out, misclassification of snow can occur for changing water bodies, as a static mask from the year 2000 is used for identifying water for the full time series. Salt lakes can have similar reflectance characteristics as snow cover in the visible spectral range. Some of the salt lakes located at high elevations are not captured by the pre-classification module and are classified as snow covered. This issue is planned to be fixed in a future version of the product.

3.3. AVHRR SCF

3.3.1. Overall Description

The AVHRR SCF product time series cover the period 1982-2020. Global SCF products are available at daily temporal resolution with cloud cover flagged. The Cloud CCI project's cloud mask is used for cloud masking.

The Advanced Very High Resolution Radiometer (AVHRR) is one of the oldest systems in orbit (since 1981), born by NOAA satellite platforms and recently also on the European MetOp satellites. AVHRR is the only sensor offering an exceptional long optical data record (almost 40 years) for global applications, with a spatial resolution of 4 km (Global Area Coverage, GAC). Only local archives offer data with 1 km spatial resolution (Local Area Coverage, LAC) for shorter periods and regionally limited.

The AVHRR sensors had two major changes over the lifetime of its programme. The AVHRR-1 aboard NOAA-8 and -10 duplicated the thermal band 4. Therefore, this sensor is not used for snow monitoring because the capability for cloud detection is limited. The main difference between AVHRR-2 and -3 is splitting of channel 3 into two channels 3A and 3B in AVHRR-3.

This exceptional long data record based on AVHRR was also the driver to use this data set for the ESA Cloud CCI project. In advance of the actual cloud retrieval, the AVHRR data were calibrated and geocoded. Therefore, this processed and readily available data set of AVHRR GAC data are also used for the retrieval of the global SCF time series.

The characteristics of the AVHRR SCF product is described in Table 3.3.

Table 3.3: AVHRR SCF version 1.0 and 2.0.

Subject	*Snow Cover Fraction CRDP v1.0*	*Snow Cover Fraction CRDP v2.0*
Variable	Snow cover fraction [%]	Snow cover fraction [%]
Accuracy target	10-20% unbiased RMSE	10-20% unbiased RMSE
Retrieval algorithm	NDSI (Salomonson and Appel, 2006) as precondition for SCAmod (Metsämäki et al., 2015)	NDSI (Salomonson and Appel, 2006) as precondition for SCAmod (Metsämäki et al., 2015)
Uncertainty algorithm	Salberg et al. 2020 [RD-5]	Salberg et al. 2021 [RD-5]
Cloud screening algorithm	Cloud CCI product; Version 3	Cloud CCI product; Version 3
Satellite(s)	NOAA	NOAA
Sensor(s)	AVHRR/2, AVHRR/3	AVHRR/2, AVHRR/3
Input product(s)	GAC (PyGAC processed by ESA Cloud CCI consortium)	GAC (PyGAC processed by ESA Cloud CCI consortium)
Geographical domain(s)	Global	Global
Start date time series	01.01.1982	01.01.1982
End date time series	31.12.2019	31.12.2018
Grid size	0.05°	0.05°
Projection/datum	Geographical (lat/lon)/WGS 84	Geographical (lat/lon)/WGS 84

Subject	Snow Cover Fraction CRDP v1.0	Snow Cover Fraction CRDP v2.0
Temporal resolution	Daily	Daily
Temporal aggregation	None	None
Number of layers	2	2
Metadata	Global attributes in NetCDF4 file, CF-v1.9, conformal with CCI data standards v2.2, 19/05/2020	Global attributes in NetCDF4 file, CF-v1.9, conformal with CCI data standards v2.2, 19/05/2020
Data representation	Unsigned byte (8 bits)	Unsigned byte (8 bits)
File format	NetCDF4, CF-v1.9	NetCDF4, CF-v1.9
Product access	CCI Data Portal, CEDA archive: SCFV products: https://catalogue.ceda.ac.uk/uuid/d9df331e346f4a50b18bcf41a64b98c7 SCFG products: https://catalogue.ceda.ac.uk/uuid/5484dc1392bc43c1ace73ba38a22ac56	CCI Data Portal, CEDA archive: SCFV products: https://catalogue.ceda.ac.uk/uuid/763eb87e0682446cafa8c74488dd5fb8 SCFG products: https://catalogue.ceda.ac.uk/uuid/3f034f4a08854eb59d58e1fa92d207b6

3.3.2. Data Representation

The products are provided as two files, each containing two layers:

1. SCFV product:
    a. Snow cover fraction, viewable snow
    b. Uncertainty estimate for snow cover fraction, viewable snow
2. SCFG:
    a. Snow cover fraction, snow on the ground
    b. Uncertainty estimate for snow cover fraction, snow on the ground

The product coding is explained in Table 3.4. Examples of the AVHRR-based SCF products are shown in Figure 3.5 (SCFV) and Figure 3.7 (SCFG). Examples of corresponding uncertainty are shown in Figure 3.6 (for SCFV) and Figure 3.8 (for SCFG).

Table 3.4: Coding for the AVHRR SCF products and associated uncertainty estimation.

Code(s)	SCF product coding description	SCF uncertainty coding description
0 - 100	SCF [%]; 0 = snow free; 100 = fully snow covered	Estimate of RMSE [% SCF]
205	Cloud masked (including cloud shadow)	Cloud masked (including cloud shadow)
206	Satellite data available, but polar night	Satellite data available, but polar night
210	Water	Water
215	Glaciers, icecaps, ice sheets	Glaciers, icecaps, ice sheets
254	ERROR: No satellite acquisition	ERROR: No satellite acquisition
All other values	Not used	Not used

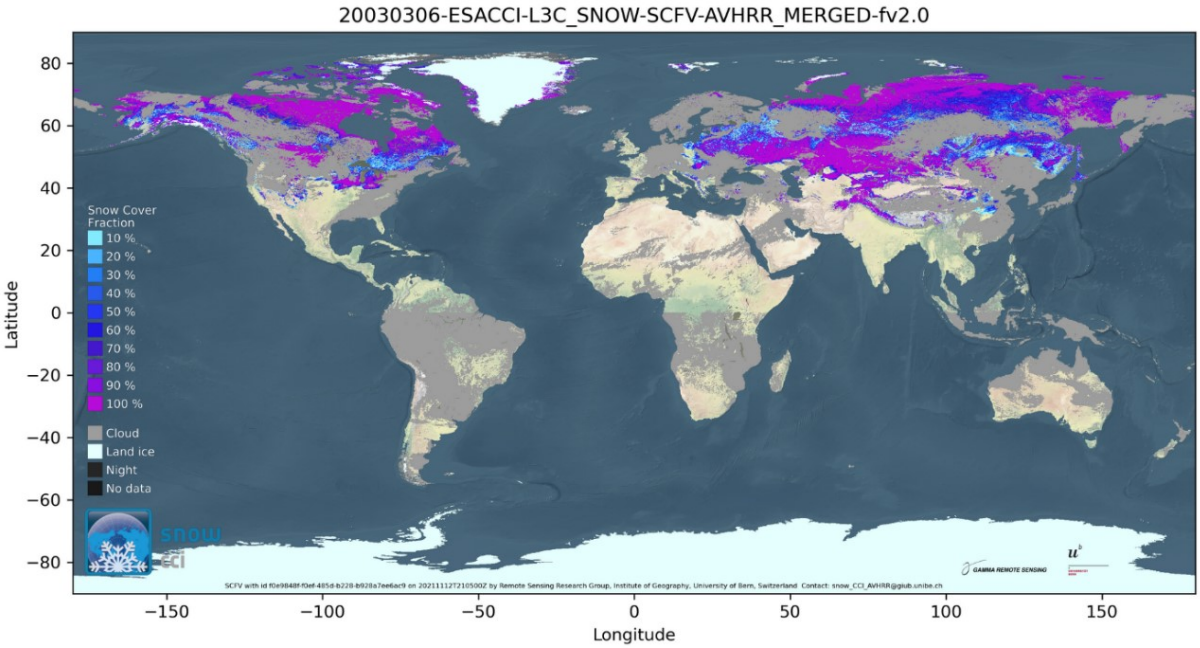

Figure 3.5: SCFV product example for 6 March 2003.

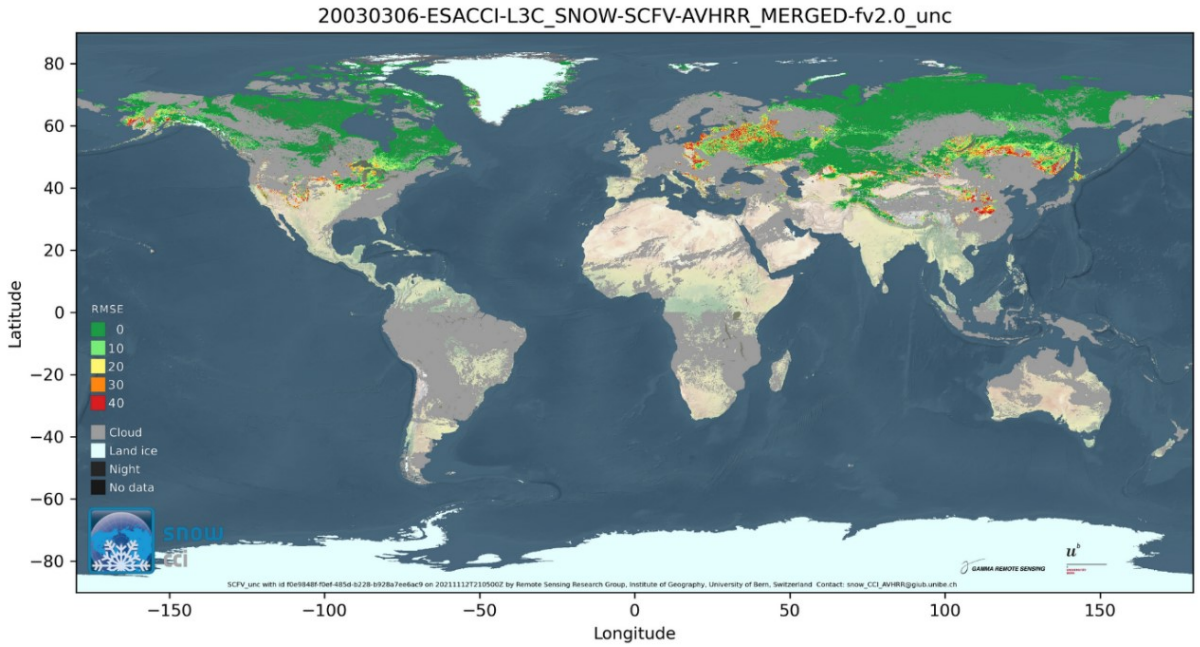

Figure 3.6: Uncertainty for SCFV product example on 6 March 2003.

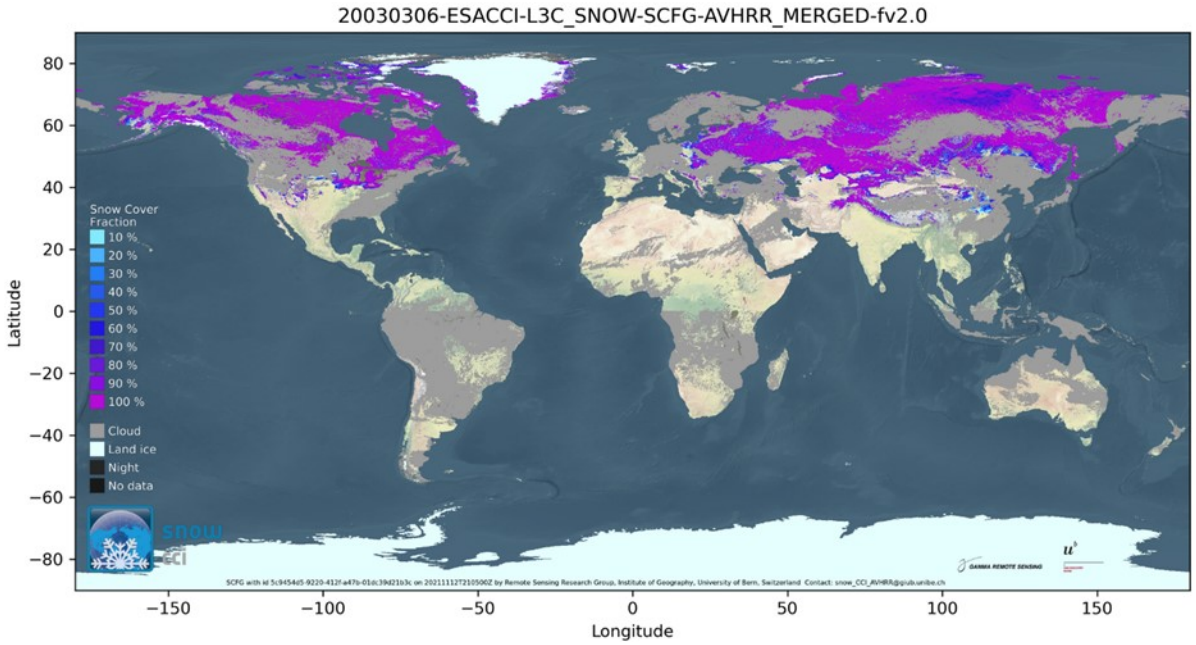

Figure 3.7: SCFG product example for 6 March 2003.

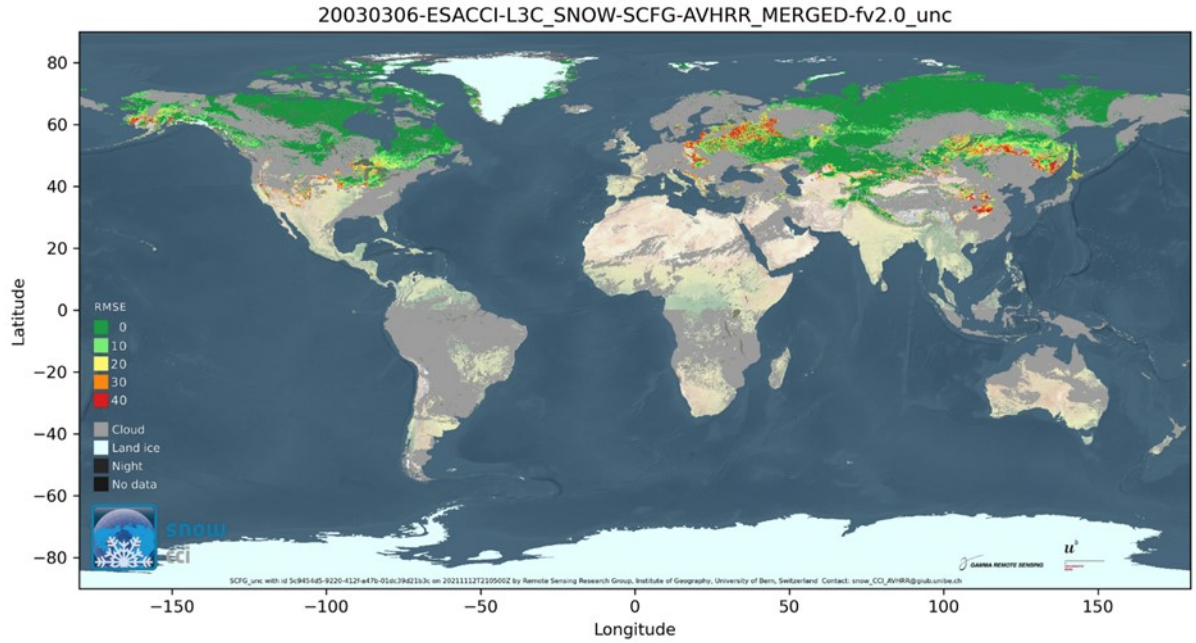

Figure 3.8: Uncertainty for SCFG product example on 6 March 2003.

3.3.3. Known Strengths and Limitations

Strengths: The only sensor in orbit with a time series of almost 40 years fulfilling the requirements of WMO for climate period; the Cloud CCI's cloud mask is reliable and consistent over time.

Limitations: Medium spatial resolution of 4 km results in reduced detectability of snow in heterogeneous terrain in comparison to 1 km data. Lack of orthorectification may cause radial positional shifts in mountains. Channel 3 of the early AVHRR/2 sensor (NOAA-7 and NOAA-9) has some noise, which affects the quality of SCF based on NDSI as precondition for SCAmod.

3.4. ATSR-2/AATSR SCF

3.4.1. Overall Description

The SCF product time series based on the ESA ATSR family of sensors consists of two sub-sets based on Along-Track Scanning Radiometer 2, ATSR-2 (1995-2003) and Advanced Along-Track Scanning Radiometer, AATSR (2002-2012), respectively. Global SCF products are available at daily temporal resolution with cloud-cover flagged.

The first ATSR sensor (ATSR-1) launched on the ESA ERS-1 satellite, did unfortunately not include any visual and near-infrared bands and is therefore not suitable for snow mapping. The ATSR-2 sensor was launched on the ESA ERS-2 satellite in 1995 and included three more bands covering visual and near-infrared wavelengths, seven bands in total. The AATSR sensor was launched on ESA ENVISAT in 2002 and included a similar set of bands as ATSR-2. The spatial resolution of the data provided by both sensors were 1 km. Both sensors included two components, one looking downward (nadir) and the other looking forward (55°). Both instruments were conical scanners keeping constant distance between the sensor and the geoid. The across-track width was 500 km.

ATSR-2 and AATSR data have generally been available in Level-1B version 3.0 format. ESA is currently reprocessing the data to the same format as used for SLSTR. The reprocessed data, version 4.0, also include some other improvements and harmonisation with SLSTR. AATSR version 4.0 was generated in spring and summer 2021 and has therefore been used as input data for SCF product generation. As the reprocessing of ATSR-2 Level-1B data did not take place with *snow_cci* Phase 1 project period, we have used the 3.0 format as input.

The whole global ATSR-2 and AATSR 1 km Level-1B datasets were downloaded from ESA and stored at NR. The product generation took place on the Uninet Sigma2 Fram supercomputer, which is part of the national HPC infrastructure in Norway, with data transfer over a high-speed connection.

The characteristics of the ATSR-2 and AATSR SCF products are described in Table 3.5.

Table 3.5: ATSR-2 and AATSR SCF products version 1.0. These characteristics are valid for the viewable snow cover fraction (SCFV) and the snow cover fraction on ground (SCFG) products.

Subject	*ATSR-2 Snow Cover Fraction CRDP v1.0*	*AATSR Snow Cover Fraction CRDP v1.0*
Variable	Snow cover fraction [%]	Snow cover fraction [%]
Accuracy target	10-20% unbiased RMSE	10-20% unbiased RMSE
Retrieval algorithm	SCAmod, Metsämäki et al., 2015, adapted and improved	SCAmod, Metsämäki et al., 2015, adapted and improved
Uncertainty algorithm	Salberg et al. 2021 [RD-5]	Salberg et al. 2021 [RD-5]
Cloud screening algorithm	Simple Cloud Detection Algorithm, Metsämäki et al., 2015, adapted and improved	Simple Cloud Detection Algorithm, Metsämäki et al., 2015, adapted and improved
Satellite(s)	ERS-2 (ESA)	ENVISAT (ESA)
Sensor(s)	ATSR-2	AATSR

Subject	*ATSR-2 Snow Cover Fraction CRDP v1.0*	*AATSR Snow Cover Fraction CRDP v1.0*
Input product(s)	Level-1B version 3.0	Level-1B version 4.0
Geographical domain(s)	Global	Global
Start date time series	01.08.1995	20.05.2002
End date time series	22.06.2003	08.04.2012
Grid size	0.01°	0.01°
Projection/datum	Geographical (lat/lon)/WGS 84	Geographical (lat/lon)/WGS 84
Temporal resolution	Daily	Daily
Temporal aggregation	None	None
Number of layers	2	2
Metadata	Global attributes in NetCDF4 file, CF-v1.9, conformal with CCI data standards v2.3, 26/07/2021	Global attributes in NetCDF4 file, CF-v1.9, conformal with CCI data standards v2.3, 26/07/2021
Auxiliary data	Water and permanent snow and ice masks aggregated from Land Cover CCI product for the year 2000; forest canopy transmissivity map for the retrieval of snow on ground, reflectance maps for snow-free forest and snow-free ground	Water and permanent snow and ice masks aggregated from Land Cover CCI product for the year 2000; updated forest canopy transmissivity map for the retrieval of snow on ground, updated reflectance maps for snow-free forest and snow-free ground
Data representation	Unsigned byte (8 bits)	Unsigned byte (8 bits)
File format	NetCDF4, CF-v1.9	NetCDF4, CF-v1.9
Product access	CCI Data Portal, CEDA archive: SCFV products: https://catalogue.ceda.ac.uk/uuid/70061acca284432ca31fd8a5cbd604d0 SCFG products: https://catalogue.ceda.ac.uk/uuid/0aeba0c203c2447b9553a78f99d3a276	CCI Data Portal, CEDA archive: SCFV products: https://catalogue.ceda.ac.uk/uuid/d7773cb976d64b1c900a518773428df6 SCFG products: https://catalogue.ceda.ac.uk/uuid/e7e31b86b2644e0da69090bc37360c97

3.4.2. Data Representation

The products are provided as two files, each containing two layers:

3. SCFV product:
    a. Snow cover fraction, viewable snow
    b. Uncertainty estimates for snow cover fraction, viewable snow
4. SCFG:
    a. Snow cover fraction, snow on the ground
    b. Uncertainty estimates for snow cover fraction, snow on the ground

The coding of the product and the associated uncertainty estimation are described in Table 3.6. Examples of AATSR-based SCFV and SCFG products are shown in Figure 3.9 and Figure 3.11. The associated uncertainty estimations per product grid cell are presented in Figure 3.10 and Figure 3.12, respectively.

Table 3.6: Coding for the ATSR-2 and AATSR SCF products and associated uncertainty estimation (valid for viewable snow and snow on ground).

Code(s)	*SCF product coding description*	*SCF uncertainty coding description*
0	Snow free	Uncertainty for pixels classified as definitely snow free in the NDSI-based pre-classification
1-100	SCF [%]; (100 = fully snow covered)	Unbiased RMSE estimate for pixels considered in the SCF retrieval, resulting in snow cover fraction in percent (0 = snow free; 100 = fully snow covered in SCF product). For snow-free pixels resulting from the SCF retrieval approach, also the uncertainty estimation is provided.
205	Cloud	Cloud (snow retrieval not possible due to masking of earth surface, no uncertainty estimate provided.)
206	(Polar) Night (satellite data available, but large solar zenith angle (SZA > 80°) does not allow classification)	(Polar) Night (satellite data available, but large solar zenith angle (SZA > 80°) does not allow classification)
210	Water	Water
215	Glaciers, icecaps, ice sheets	Glaciers, ice caps, ice sheets
252	ERROR: Retrieval failed	ERROR Code: Retrieval / Classification failed
253	ERROR: Input data error (e.g., bad pixels)	ERROR Code: Input data error (e.g., bad pixels, etc)
254	ERROR: No satellite acquisition	ERROR Code: No satellite data value
255	Not valid data	Not Valid Pixel
All other values	Not used	Not used

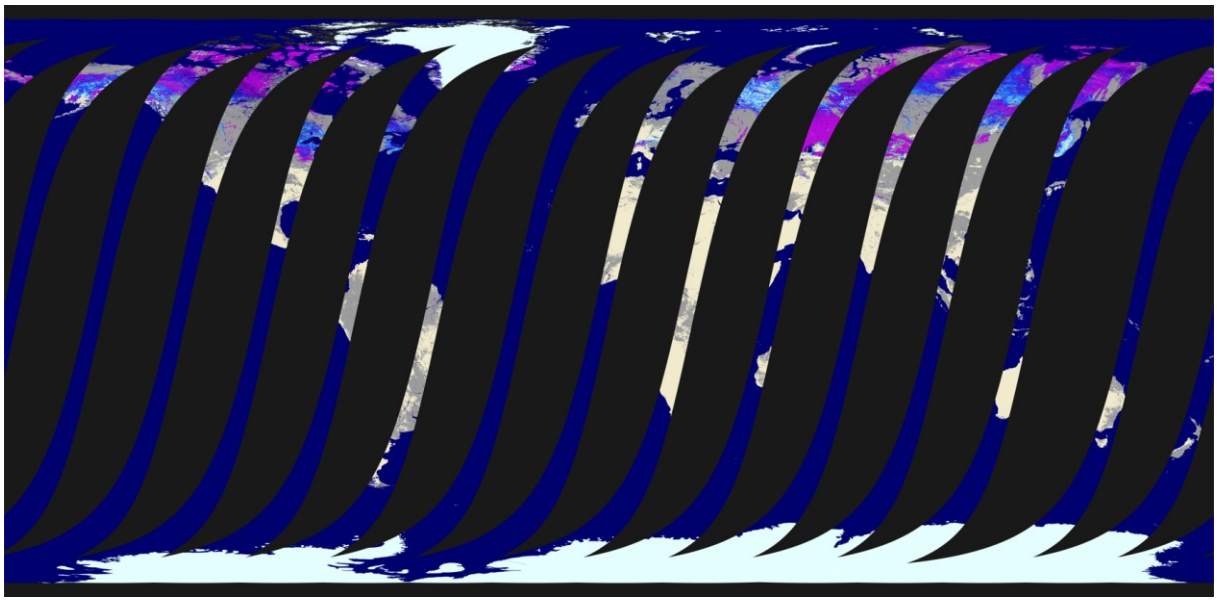

Figure 3.9: SCFV product example from ENVISAT AATSR on 10 March 2003.

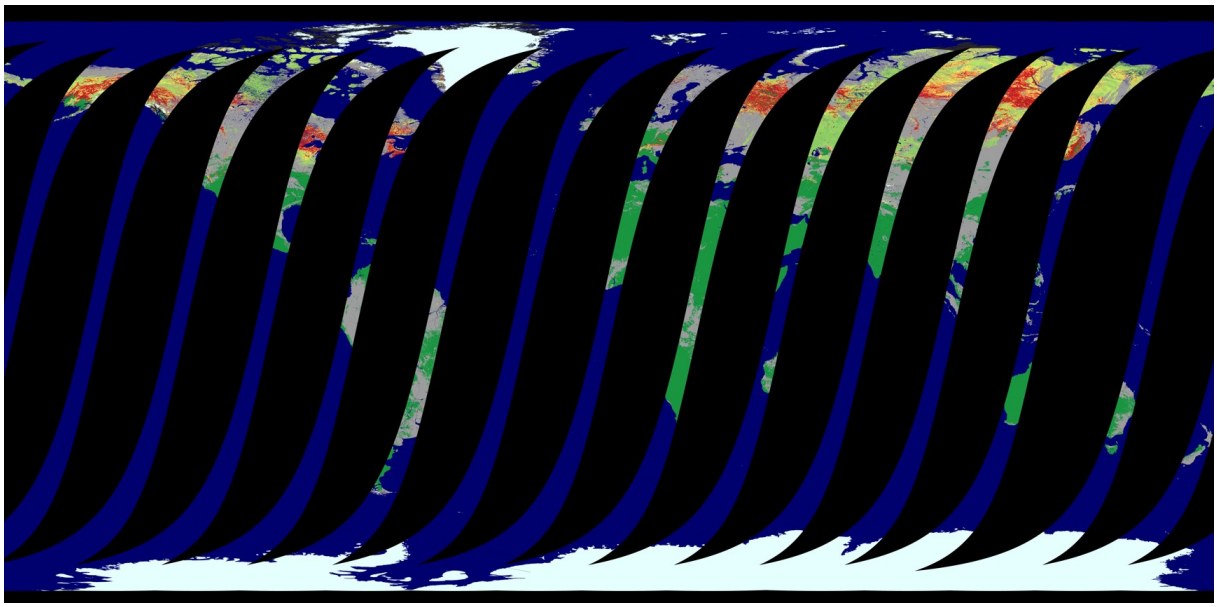

Figure 3.10: Example of the uncertainty estimation for the SCFV product from ENVISAT AATSR on 10 March 2003 (cf. Figure 3.9).

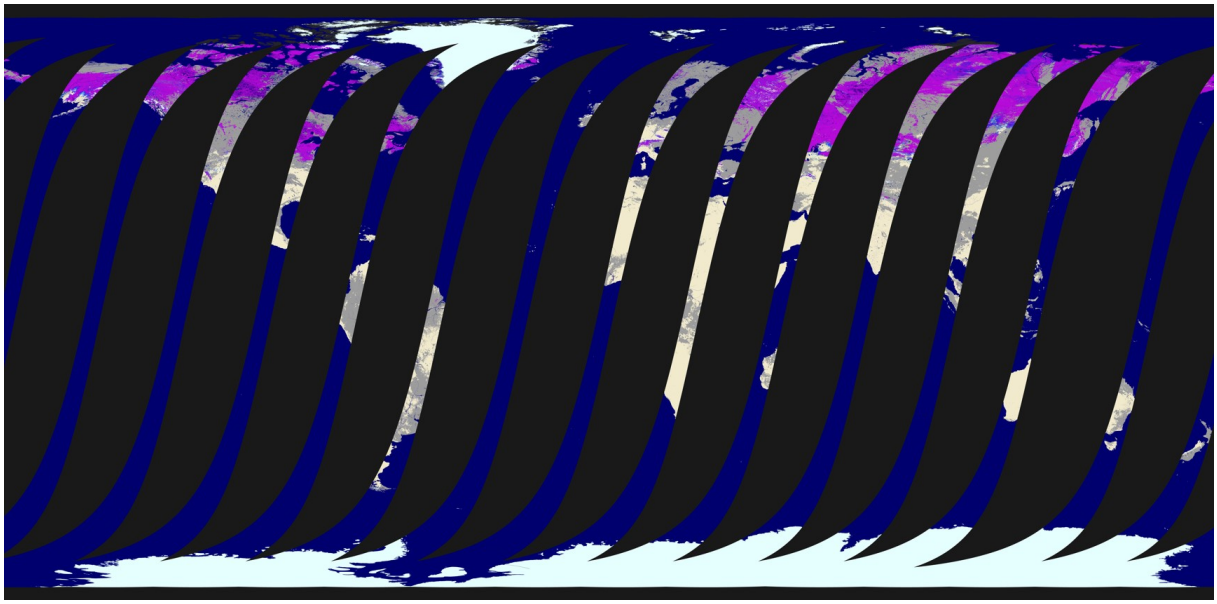

Figure 3.11: SCFG product example from ENVISAT AATSR on 10 March 2003.

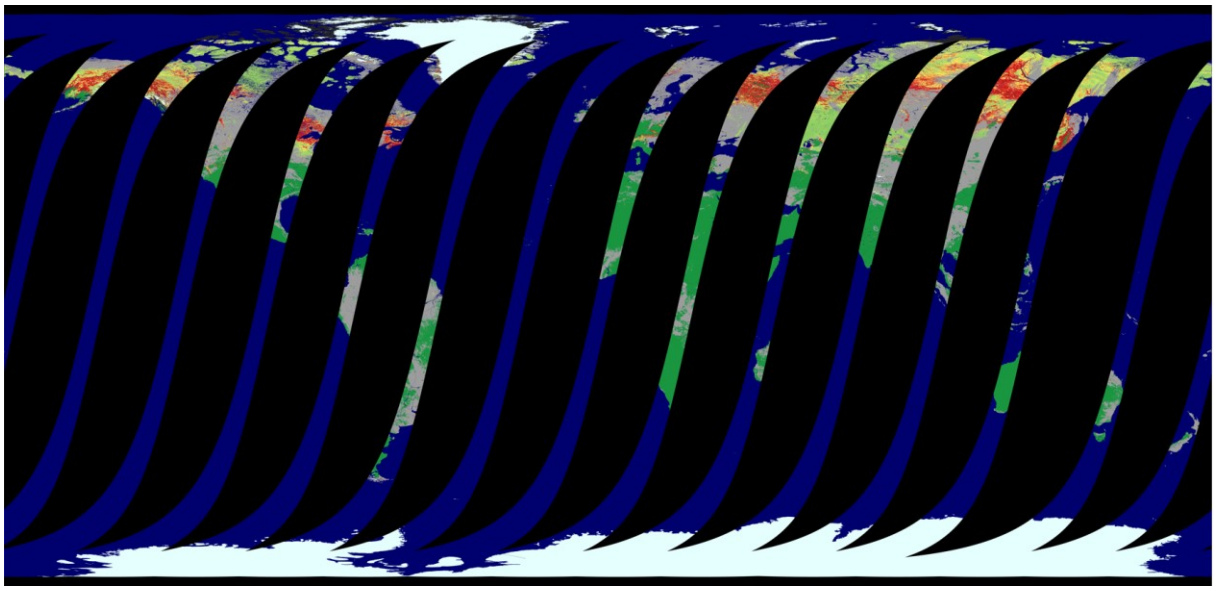

Figure 3.12: Example of the uncertainty estimation for the SCFG product from ENVISAT AATSR on 10 March 2003 (cf. Figure 3.11Figure 3.3).

3.4.3. Known Strengths and Limitations

Strengths: The length of the combined ATSR-2 and AATSR data record is rather significant covering 17 years. The sensors provide global coverage with a rather high spatial resolution of 0.01°. The products provide both snow of the ground and viewable snow, which increase their utility. The similarity of the two sensors and calibration ensures consistent retrieval quality. The cloud screening is the best available for cloud detection over snow and ice surfaces. For solar elevations above 20-25°, a situation also appearing at high latitudes in March, the cloud screening performance has proved to be very accurate.

Limitations: The daily products include larger gaps between the swaths due to the rather narrow across-track width of the sensor. This means that it takes several days to cover the whole earth's surface, and the coverage is again limited by cloud cover. As for the other SCF products, changes in the forest due to forest clearance or reforestation are not yet considered. The cloud screening is not working very well during the darkest period of the year at higher latitudes.

3.5. SLSTR SCF

SCF prototype products are generated for the year 2020 but require some sensor-specific adaptations of the algorithm and the used auxiliary layers. Final products are planned to be made available to the public in a future version of the *snow_cci* climate research data package.

4. SNOW WATER EQUIVALENT

4.1. Thematic Description

Snow water equivalent (SWE) is an important variable indicating the amount of accumulated snow on land surfaces. The retrieval is based on passive microwave radiometer (PMR) data considering the change of brightness temperature due to different snow depth, snow density, grain size and more. The retrieval algorithm handles data from the sensors SMMR, SSM/I, SSMIS, AMSR-E and AMSR-2. Between AMSR-E and AMSR-2 there is a gap between October 2011 and July 2012, but the data set has low priority for the generation of the global time series.

The *snow_cci* SWE product is based on the ESA GlobSnow SWE retrieval approach (Takala et al., 2011). The retrieval methodology combines satellite passive microwave radiometer (PMR) measurements with ground-based synoptic weather station observations by 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 2 include the utilisation 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.

Version 2 of the *snow_cci* SWE product is based on SMMR, SSM/I and SSMIS PMR data for non-alpine regions of the Northern Hemisphere. Because of known limitations in alpine terrain, a complex-terrain mask is applied based on the sub-grid variability in elevation determined from a high-resolution digital elevation model. All land ice and water bodies are also masked; retrievals are not produced for coastal regions of Greenland.

Future extension of the SWE product to the Southern Hemisphere is dependent on sufficient in situ snow-depth measurements for algorithm input, whether extensive snow-covered land occurs outside of the alpine mask and the availability of snow-course measurements for validation. These issues will be investigated for later product versions.

4.2. Overall Product Description

The *snow_cci* SWE product time series v2.0 covers the period 1979-2020. Northern Hemisphere SWE products are available at daily temporal resolution with alpine areas masked. The product is based on data from the SMMR aboard NIMBUS-7, and SSM/I and SSMIS sensors aboard DMSP 5D F-series satellites. The satellite bands provide spatial resolutions between 15 and 69 km and are re-gridded to 12.5 km grid size.

SWE products over the full Northern Hemisphere are produced daily for the period 1988–2020, and bi-daily for the period 1979–1987.

The characteristics of the SWE product versions 1.0 and 2.0 are described in Table 4.1.

Table 4.1: *snow_cci* SWE version 2.0 specifications.

Subject	*SWE CRDP v1.0*	*SWE CRDP v2.0*
Variable	Snow water equivalent [mm]	Snow water equivalent [mm]
Accuracy target	20-30% unbiased RMSE	20-30% unbiased RMSE
Retrieval algorithm	Takala et al., 2011; Pulliainen, 2006	Takala et al., 2011; Pulliainen, 2006
Masking	Mountainous areas, glaciers/permanent ice, water	Mountainous areas, glaciers/permanent ice, water
Satellite(s)	Nimbus-7; DMSP 5D F8, F11, F13, F17	Nimbus-7; DMSP 5D F8, F11, F13, F17
Sensor(s)	SMMR, SSM/I and SSMIS	SMMR, SSM/I and SSMIS
Input product(s)	Calibrated brightness temperatures for 19 & 37 GHz bands for SMMR, SSM/I, SSMIS from NSIDC	Calibrated brightness temperatures for 19 & 37 GHz bands for SMMR, SSM/I, SSMIS from NSIDC
Geographical domain(s)	Northern Hemisphere	Northern Hemisphere
Start date time series	6 January 1979	6 January 1979
End date time series	31 May 2018	30 May 2020
Grid size	0.10°	0.10°
Projection/datum	Geographical (lat/lon)/WGS 84	Geographical (lat/lon)/WGS 84
Temporal resolution	Daily	Daily
Temporal aggregation	None	None
Number of SWE data layers	2	2
Metadata	Global attributes in NetCDF4 file, CF-v1.7, conformal with CCI data standards v2.1, 2019	Global attributes in NetCDF4 file, CF-v1.9, conformal with CCI data standards v2.3, 2021
Data representation	Signed short (16 bits)	Signed short (16 bits)
File format	NetCDF4, CF-v1.7	NetCDF4, CF-v1.9
Product access	CCI data portal, CEDA archive: https://catalogue.ceda.ac.uk/uuid/fa20aaa2060e40cabf5fedce7a9716d0	CCI data portal, CEDA archive: https://catalogue.ceda.ac.uk/uuid/4647cc9ad3c044439d6c643208d3c494

4.3. Data Representation

The SWE product includes two data layers:

1. SWE: Snow water equivalent retrieval
2. SWE_STD: Uncertainty estimate (statistical standard deviation) for snow water equivalent retrieval

Layer 1 and 2 coding and legend are described in Table 4.2 and Table 4.3, respectively. An example of the SWE product is shown in Figure 4.1 with the corresponding uncertainty estimate in Figure 4.2.

Table 4.2: Coding and legend for the SWE product, layer 1.

Code(s)	*Description*
0	Bare ground, no SWE retrieved (SWE = 0 mm)
1-500	SWE [mm]
-1	Masked: land areas for which no SWE retrieval attempted
-10	Masked: water (oceans, or water fraction > 50%)
-20	Masked: mountain
-30	Masked: Glaciers / permanent ice
All other values	Not used

Table 4.3: Coding and legend for the SWE product uncertainty, layer 2.

Code(s)	*Description*
0	Zero SWE retrieved
1-250	SWE_STD (standard deviation) [mm]
-1	Masked: land areas for which no SWE retrieval attempted
-10	Masked: water (oceans, or water fraction > 50%)
-20	Masked: Mountain
-30	Masked: Glaciers/permanent ice
All other values	Not used

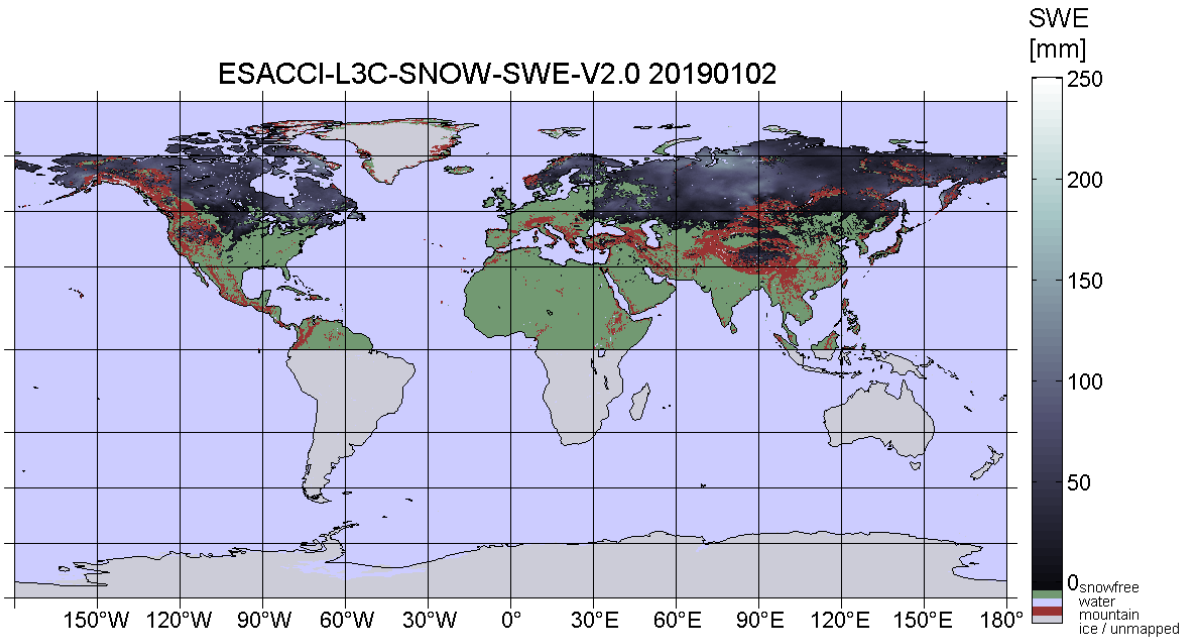

Figure 4.1: Product example, layer 1, snow water equivalent.

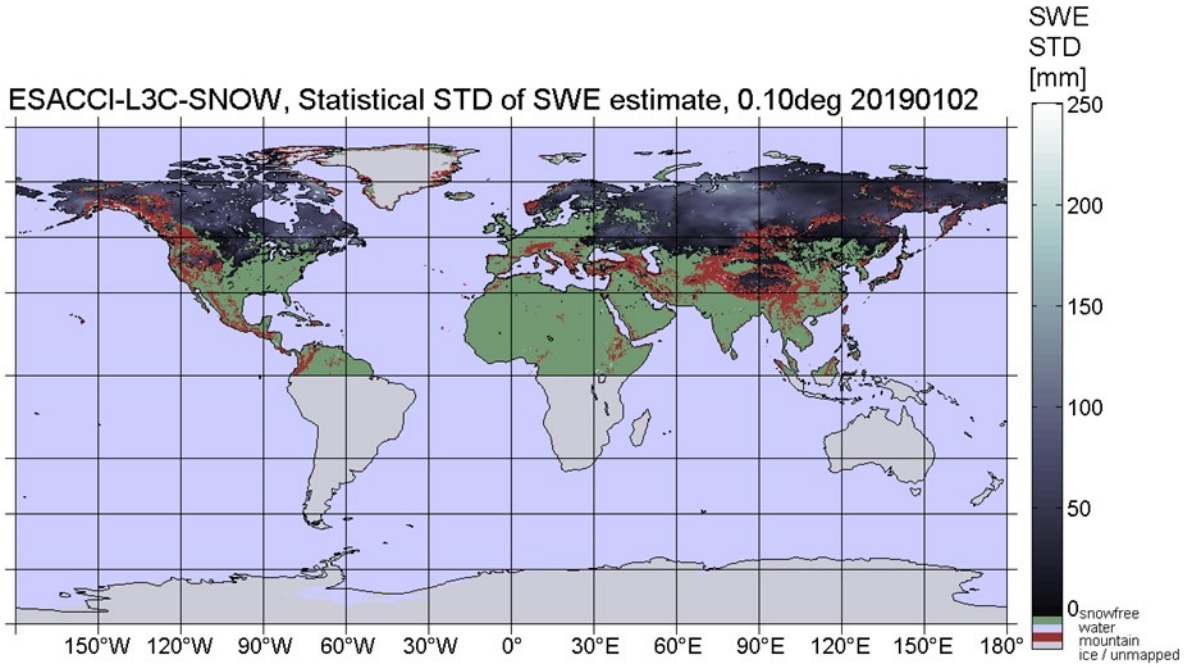

Figure 4.2: Product example, layer 2, estimate of standard deviation of SWE.

4.4. Known Strengths and Limitations

Strengths: As the method utilises passive microwave radiometer data for retrieval of the snow, it is completely unaffected by clouds or light conditions. This combined with the wide swaths of the satellite instruments allow for continuous daily observations of snow without any undue gaps in the time series. Using background snow depth, acquired from weather station observations, as an initial guess, allows for much more accurate estimates of snow mass than any method utilising only one

source of input data. The dataset is validated against independent snow transect data from Canada, Russia and Finland. These attributes make the dataset the most accurate long time series on the mass of snow in the Northern Hemisphere.

The uncertainty layer SWE_VAR gives information on how reliable the SWE retrieval has been for the given pixel in the data layer (SWE); it represents the statistical standard deviation of the SWE estimates. If a user has a known threshold for the retrieval accuracy needed to utilise the SWE data in their respective end-user applications, the SWE_VAR field can be used to select the SWE data to be utilised for the users' needs.

Limitations: The algorithm can be used to measure snow packs roughly between 0.05 m and 1.00 m in thickness and only under dry snow conditions. Depth less than 0. 05 m cannot be reliable retrieved because the brightness temperature difference between the two frequencies, falls within 2 K detection precision of the radiometer instruments used. With snow depths greater than 1 m, the brightness temperature signal starts to saturate. Even relatively small amount of liquid water will contaminate the signal making retrieval of SWE impossible. The product is also dependent on the spatial density of the weather station observations available to calculate the background snow depth and snow grain size fields that are applied in SWE retrieval. Where the network is sparse the SWE estimates will also be less accurate, especially in regions where large variations in SWE level are typical (e.g. tundra) and pointwise measurements are unable to catch the typical range of SWE conditions.

Beside limitations caused by signal saturation and availability of weather station data the product is subject to biases caused by using a static snow density value, a necessary simplification. Density of snow usually varies between 100 kg/m^3 (fresh, recently fallen snow) and 400 kg/m^3 (tightly packed mature slab). The used value of 240 kg/m^3 gives good result over continental scale and across the whole snow season but leaves detectable seasonal bias that a user should be aware of. As result SWE values tend to be somewhat overestimated during early accumulation period and underestimated during late winter and melting period. The project team intends to investigate and strives to implement a dynamic snow density consideration for SWE retrieval for the next product version. Additionally, an end user can correct for the static density, if they have actual snow density data, for a region of interest. However, for climate change studies, the static snow density is not a major issue, as a constant snow density consideration will not induce any significant temporal biases in the long-term data record.

5. COMMON FILE FORMAT AND ACCESS DESCRIPTION

5.1. Filename Convention

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), SCFV (viewable snow) and 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), ATSR_2_ERS_2 (data spanning 1995-2003), AATSR_ENVISAT (data spanning 2003-2012) and MODIS-TERRA (data spanning 2000-2020). For SWE, it is SMMR-NIMBUS7 (1979 through May 1987), SSMI-DMSP (October 1987-December 1991), or SSMIS-DMSP (January 1992-May 2019).
- 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.

5.2. File Format

The metadata are according to the netCDF-4 CF convention. For the first version of snow products, three CF versions are used (version 1.8 for SCF/MODIS; version 1.9 for SCF/AVHRR and version 1.7 for SWE). For the second version of the snow products, the CF version 1.9 is used. The conventions define metadata that provide a definitive description of what the data in each variable represents, and the spatial and temporal properties of the data. The data are included in the same file as the data, thus making the file "self-describing". Global and variable attributes are described in the following.

5.2.1. Global Attributes

The global attribute fields for the products are described in Table 5.1, with examples for the content.

Table 5.1: Example of global attribute fields for a SCFV product v2.0 from MODIS data.

Global Attribute	Content
title	ESA CCI viewable snow product level L3C daily from MODIS
institution	ENVEO IT GmbH
source	TERRA MODIS, Collection 6.1: calibrated radiances 5-min L1B swath data, 1 km (MOD021KM) and geolocation fields 5-min L1A swath data, 1 km (MOD03)
history	2021-11-08: ESA *snow_cci* processing line SCFV, version 2.0
references	http://snow-cci.enveo.at/
tracking_id	aafb5e27-5872-4000-b207-b5dd9b8f8816
Conventions	CF-1.9
product_version	2.0
format_version	CCI Data Standards v2.3, 2021
summary	The SCF product provides daily information on snow cover fraction (0 – 100 %) per pixel for global land areas except permanent snow and ice areas with about 1 km pixel size. The product is based on medium resolution optical satellite data. In forested areas, the product provides information on snow on the top of the forest canopy. Clouds are masked. The product uncertainty for observed land pixels is provided as unbiased RMSE per pixel in the ancillary variable.
keywords	snow cover, MODIS, TERRA
id	20040306-ESACCI-L3C_SNOW-SCFV-MODIS_TERRA-fv2.0.nc
naming authority	at.enveo
keywords_vocabulary	NASA Global Change Master Directory (GCMD) Science Keywords, Version 12.1
cdm_data_type	Swath
comment	The following auxiliary data set is used for product generation: ESA CCI Land Cover from 2000: water bodies and permanent snow and ice areas are masked based on this dataset. Both classes were separately aggregated to the pixel spacing of the SCF product. Water areas are masked if more than 30 percent of the pixel is classified as water, permanent snow and ice areas are masked if more than 50 percent are identified as such areas in the aggregated map.
date_created	2021-11-05 16:28:38Z
creator_name	ENVEO IT GmbH
creator_url	http://enveo.at
creator_email	snowcci@enveo.at
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
geospatial_lat_resolution	0.01
geospatial_lat_units	degrees_north
geospatial_lon_units	degrees_east
time_coverage_start	20040306T000000Z
time_coverage_end	20040306T235959Z
time_coverage_duration	P1D
time_coverage_resolution	P1D
standard_name_vocabulary	CF Standard Name Table v78
license	ESA CCI Data Policy: free and open access
platform	TERRA
sensor	MODIS
spatial_resolution	0.01 degree
key_variables	scfv
doi	https://catalogue.ceda.ac.uk/uuid/ebe625b6f77945a68bda0ab7c78dd76b

5.2.1. Variable Attributes

Variable attributes include uncertainty information. The uncertainty estimation has been developed alongside the products and is provided as additional layer for each SCF product.

5.2.2. Metadata

As required by the CCI data standards v2.3, 2021, the metadata per daily product must be compliant with CF1.9 and INSPIRE standards. For the SCF products version 1.0, two different CF versions are used (version 1.8 for SCF/MODIS; version 1.9 for SCF/AVHRR). The CCI data standards v2.1, 2019 with metadata compliant with CF1.7 and INSPIRE standards are used for the SWE products version1.0. For the *snow_cci* products version 2.0, the CF version 1.9 is used for all SCF and SWE products.

5.3. Software Tools

All products generated in the frame of the *snow_cci* project are conformal with the CCI data standards and are thus provided in netCDF-4 format. Data are readable by any software tool able to open and read netCDF file format. A list of open source and commercial software tools for reading, displaying and working with netCDF files is available online, at https://www.unidata.ucar.edu/software/netcdf/software.html.

5.4. Product Access and Policy

All official products generated in the *snow_cci* project are shared via the ESA CCI data portal, providing free and open access.

The datasets should be cited following the instructions provided per product at the Centre for Environmental Data Analysis (CEDA) archive, accessible via the project "ESA Snow Climate Change Initiative (snow_cci)" https://catalogue.ceda.ac.uk/uuid/93cf539bc3004cc8b98006e69078d86b.

6. REFERENCES

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