ESA Climate Change Initiative CCI+

Climate Research Data Package

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 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.

This document describes the outcome of the product generation in the *snow_cci* project. The Climate Research Data Package – time series of products – are produced for snow cover fraction (SCF) based on the sensors MODIS, AVHRR, ATSR-2, AATSR and SLSTR (five separate time series) and for snow water equivalent (SWE) based on the sensors SMMR, SSM/I and SSMIS (one combined time series). The SCF product provides in forested areas two themes of information: snow cover fraction viewable (SCFV) on top of the forest canopy and snow cover fraction on ground (SCFG). In open land, the SCF products are identical. For all products, estimated uncertainty at the per-pixel level is available as a separate data layer in the product.

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. INTRODUCTION

The European Space Agency (ESA) Climate Change Initiative (CCI) 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 cover extent and snow mass for climate applications.

1.1. Purpose and Scope

This document describes the outcome of the product generation in the *snow_cci* project. The outcome is the Climate Research Data Package (CRDP) – time series of products – generated for snow cover fraction (SCF) based on the sensors MODIS, AVHRR, ATSR-2, AATSR, and SLSTR (five separate time series) and for snow water equivalent (SWE) based on the sensors SMMR, SSM/I and SSMIS (one combined time series). For SCF, there are two types of products available: (i) the snow cover at the surface in open areas and on top of vegetation cover that is present, such as forest canopies (snow cover fraction, viewable snow – SCFV) and (ii) snow cover on the ground for open land (same as SCFV) and corrected for the masking effect by trees in forested areas (snow cover fraction, snow on the ground – SCFG). Furthermore, for all products there is an estimate of the uncertainty of the variable per grid cell available. This is included as a separate data layer. For SCF products from MODIS and AVHRR, the sensor zenith angle and the acquisition time per day and per pixel are added layers in the CRDP version 4.0 (v4.0), and for SLSTR based products in the CRDP version 1.0 (v1.0).

This document describes the most recent versions of the CRDPs, including:

- SCFG & SCFV CRDP v4.0 from MODIS
- SCFG & SCFV CRDP v4.0 from AVHRR
- SCFG & SCFV CRDP v1.0 from SLSTR
- SCFG & SCFV CRDP v1.0 from A/ATSR-2
- SWE CRDP v4.0 from SMMR, SSM/I and SSMIS

The descriptions of previous CRDP versions are provided in the annexes.

1.2. Document Structure

The snow cover fraction datasets based on optical sensors consisting of MODIS-, AVHRR-, ATSR-2-, AATSR-, and SLSTR-based SCF are described in Chapter 2. Chapter 3 describes the snow water equivalent dataset based on three consecutive generations of passive microwave radiometers (PMR).

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 3.0, 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 (2020) ESA CCI+ Snow ECV: Climate Research Data Package, version 2.0, November 2020.

[RD-5] Schwaizer, G. S. Metsämäki, M. Moisander, K. Luojus, S. Wunderle, K. Naegeli, T. Nagler, J. Lemmetyinen, J. Pulliainen, M. Takala, R. Solberg, L. Keuris, P. Venäläinen (2020) ESA CCI+ Snow ECV: Algorithm Theoretical Basis Document, version 2.0, November 2020.

[RD-6] Schwaizer, G. S. Metsämäki, M. Moisander, K. Luojus, S. Wunderle, K. Naegeli, T. Nagler, J. Lemmetyinen, J. Pulliainen, M. Takala, R. Solberg, L. Keuris, P. Venäläinen, N. Mölg (2021) ESA CCI+ Snow ECV: Algorithm Theoretical Basis Document, version 3.0, December 2021.

[RD-7] Salberg, A.-B., K. Luojus, C. Derksen, C. Marin, R. Solberg, L. Keuris, G. Schwaizer, T. Nagler, (2020) ESA CCI+ Snow ECV: End-to-End ECV Uncertainty Budget, version 2.0, October 2020.

[RD-8] Salberg, A.-B., K. Luojus, C. Derksen, C. Marin, R. Solberg, L. Keuris, G. Schwaizer, T. Nagler, N. Mölg (2021) ESA CCI+ Snow ECV: End-to-End ECV Uncertainty Budget, version 3.0, December 2021.

[RD-9] Schwaizer, G., A.-B. Salberg, K. Luojus, M. Moisander, C. Derksen, C. Marin, R. Solberg, T. Nagler, and N. Mölg (2023) ESA CCI+ Snow ECV: End-to-End ECV Uncertainty Budget, version 4.0, July 2023.

[RD-10] Schwaizer, G., S. Metsämäki, M. Moisander, K. Luojus, S. Wunderle, T. Nagler, J. Lemmetyinen, J. Pulliainen, M. Takala, R. Solberg, P. Venäläinen, N. Mölg, L. Zschenderlein, X. Xiao (2023) ESA CCI+ Snow ECV: Algorithm Theoretical Basis Document, version 4.0, July 2023.

[RD-11] Schwaizer, G., A.-B. Salberg, K. Luojus, M. Moisander, C. Derksen, C. Marin, R. Solberg, and T. Nagler (2025) ESA CCI+ Snow ECV: End-to-End ECV Uncertainty Budget, version 5.1, November 2025.

[RD-12] Schwaizer, G., S. Metsämäki, M. Moisander, K. Luojus, M. Heinrich, S. Wunderle, T. Nagler, J. Lemmetyinen, J. Pulliainen, M. Takala, R. Solberg, P. Venäläinen, L. Zschenderlein, N. Mölg, X. Xiao (2025) ESA CCI+ Snow ECV: Algorithm Theoretical Basis Document, version 5.1, November 2025.

1.4. Acronyms

AVHRR	Advanced Very High Resolution Radiometer
CCI	Climate Change Initiative
CLARA	CLoud Albedo and RAdiation data set
CM SAF	Climate Monitoring Satellite Application Facility of EUMETSAT
CP	Contractual Phase
DARD	Data Access Requirement Document
DMSP	Defence Meteorological Satellite Program
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FDR	Fundamental Data Record
GAC	Global Area Coverage
MetOp	European Meteorological Operational Satellite
MODIS	Moderate resolution Imaging Spectroradiometer
NDSI	Normalized Difference Snow Index
NH	Northern Hemisphere
NOAA	National Oceanic and Atmospheric Administration
PMR	Passive Microwave Radiometer
PVP	Product Validation Plan
SCF	Snow Cover Fraction
SCFG	Snow Cover Fraction, snow on the Ground
SCFV	Snow Cover Fraction, Viewable snow
SMHI	Swedish Meteorological Hydrological Institute
SMMR	Scanning Multichannel Microwave Radiometer
SSM/I	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager / Sounder
SWE	Snow Water Equivalent
WGS	World Geodetic System

2. SNOW COVER FRACTION

2.1. MODIS

The *snow_cci* snow cover fraction (SCF) product time series of the CRDP v4.0 from Terra MODIS data covers the period 24 February 2000 – 31 December 2023. Global SCF products are available at daily temporal resolution. Clouds, water bodies, (polar) night, permanent snow and ice areas and salt lakes are flagged. The product is based on 0.01-degree data from the MODIS sensor aboard the Terra satellite (launched in 1999). The MODIS based CRDP v4.0 includes two SCF time series, each with the associated per-pixel uncertainty estimation [RD-9]:

(i) the snow cover fraction viewable from above (SCFV) at the surface in open areas and on top of forest canopies, and

(ii) the snow cover fraction on the ground (SCFG) for open areas and in forested areas, using a canopy correction to estimate the snow cover in forests.

Each time series is organized in daily netCDF files per year and per month. The products have the following variables:

SCFV product:

- Snow cover fraction viewable from above
- Uncertainty estimates for snow cover fraction viewable from above
- Satellite viewing zenith angle in degrees
- Satellite image acquisition time referring to the 5 minutes MODIS granule time in fractional hours of the day

SCFG product:

- Snow cover fraction on the ground
- Uncertainty estimates for snow cover fraction on the ground
- Satellite viewing zenith angle in degrees
- Satellite image acquisition time referring to the 5 minutes MODIS granule time in fractional hours of the day

The time series characteristics of the MODIS-based SCF products of CRDP v4.0 are summarized in Table 2.1. Gaps in the time series due to missing MODIS acquisitions are listed in

Table 2.2. Specific CRDP v4.0 characteristics, including the data volumes, DOI numbers and access points for each CRDP from MODIS data, are provided in Table 2.3.

It should be noted that the additional variables sensor zenith angle and satellite image acquisition time, requested by users, increase the data volume per CRDP significantly compared to the versions 1.0 and 2.0, approximately by a factor of 4.

For the SCF CRDP v1.0, CRDP v2.0, and CRDP v3.0 from MODIS the respective information is provided in Annex A.

Table 2.1: Time series characteristics of MODIS-based SCF CRDP v4.0.

Subject	*Description MODIS CRDP v3.0*
Thematic variable	Snow Cover Fraction Viewable (SCFV) and Snow Cover Fraction on Ground (SCFG)
Retrieval algorithm	SCAmod (Metsämäki et al. 2005, 2012, 2015) adapted and improved for snow_cci [RD-12][RD-10]
Uncertainty algorithm	Error propagation approach adapted from Salminen et al. (2018) [RD-11]
Satellite(s)	Terra
Sensor(s)	MODIS
Geographical domain(s)	Global
Temporal resolution	Daily
Start date time series	24.02.2000
End date time series	31.12.2023
Grid size	0.01°
Projection/datum	Geographical (lat/lon)/WGS 84
File format	netCDF4, CF-v1.12
Product version	Version 4.0

Table 2.2: Data gaps in the Terra MODIS time series in CRDP v4.0.

Start date	*End date*	*Reason*
26.04.2000	27.04.2000	No Terra MODIS acquisitions available
06.08.2000	17.08.2000	No Terra MODIS acquisitions available
16.06.2001	02.07.2001	No Terra MODIS acquisitions available
20.03.2002	27.03.2002	No Terra MODIS acquisitions available
15.04.2002	15.04.2002	No Terra MODIS acquisitions available
17.12.2003	23.12.2003	No Terra MODIS acquisitions available
21.12.2008	22.12.2008	No Terra MODIS acquisitions available
19.02.2016	27.02.2016	No Terra MODIS acquisitions available
11.10.2022	22.10.2022	No Terra MODIS acquisitions available
In every year, there are a few days with missing MODIS tiles or swaths. SCF products are generated in such cases based on the available satellite data even if the spatial coverage is small.		

Table 2.3: MODIS-based SCF CRDP v4.0 characteristics.

Subject	*SCFV MODIS CRDP v4.0*	*SCFG MODIS CRDP v4.0*
Data volume	817 GB	820 GB
Number of files	8642	8642
DOI	10.5285/bc13bb02a958449aac139853c4638f32	10.5285/375ffdb8f0a445e380b4b9548655f5f9
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/bc13bb02a958449aac139853c4638f32/	https://catalogue.ceda.ac.uk/uuid/375ffdb8f0a445e380b4b9548655f5f9/

After reading and geolocating the daily Terra MODIS data, clouds are detected using a decision-tree based algorithm (Metsämäki 2015), adapted, and extended with additional criteria for better performance on a global scale [RD-12]. The cloud mask per product is also overlaid on the associated uncertainty layer.

For all cloud-free pixels of the daily MODIS data, a pre-classification is applied. The aim of this pre-classification is to identify snow-free pixels with a negligible uncertainty based on the pixel's spectral reflectance characteristics and the brightness temperature at 11 µm. The root-mean-square error (RMSE) for pixels defined as snow-free by the pre-classification step is thus assumed to be zero.

On all remaining pixels, an adapted version of the SCAmod algorithm (Metsämäki et al. 2015) is applied to retrieve the snow cover fraction per pixel. Constant reflectance values for snow-free forested areas and snow-free ground suggested by Metsämäki et al. (2015) are replaced with spatially variable spectral reflectance maps derived from statistical analyses of a time series of MODIS data [RD-12]. While for CRDP v1.0, these reflectance maps were based on the analysis of reflectance data of one year, 2007 [RD-5], the reflectance maps were updated for CRDP v2.0 using reflectance data of the years 2000 to 2015 [RD-6] and kept unchanged for CRDP v3.0 [RD-10]. For CRDP v4.0, the method for estimating the per-pixel spectral reflectance values for snow free ground and snow free forest was updated. New reflectance maps were generated from MODIS spectral reflectance time series of the years 2000 to 2008 [RD-12]. For CRDP v3.0, the wet snow reflectance used in the SCAmod algorithm was updated based on the statistical analysis of fully snow-covered pixels, which were detected from overlapping Landsat-8 OLI-based snow maps [RD-10]. The same value for wet snow reflectance was used for the generation of the CRDP v4.0. For pixels with a solar zenith angle greater than 50°, the spectral reflectance value is adjusted in dependence on the local solar zenith angle before applying the SCAmod algorithm. Details are described in the ATBD [RD-12].

An updated version of merging the classifications from individual tiles per day into a daily global SCF composite was updated for CRDP v4.0. Details are provided in the ATBD [RD-12]. For each pixel that contains an SCF observation, the unbiased RMSE is estimated and provided in the uncertainty layer.

In all SCF products and the associated uncertainty layers, water bodies and land ice are masked using a static mask derived from the ESA CCI Land Cover product for the year 2000 (ESA Land Cover CCI

project team; Defourny 2016). Since CRDP v3.0, salt lakes causing errors in the SCF products of CRDP v1.0 and CRDP v2.0 from MODIS, are masked using maps generated by ENVEO. For CRDP v4.0, this salt lake mask was further updated. The mapping was performed manually based on MODIS reflectance data and temporal composites of the SCF products from CRDP v2.0 and v3.0, respectively. The masking of salt lakes significantly improved the SCF products in CRDP v3.0 and CRDP v4.0 by reducing the number of misclassified snow and cloud pixels caused by bright salt-lake surfaces.

Further, pixels with large solar zenith angles (> 83°) are classified as (polar) night and are masked in the SCF and SCF uncertainty layers. Also, pixels with missing or erroneous input data in at least one of the spectral bands needed in the SCF generation, are masked in the SCF and SCF uncertainty layers.

The MODIS based SCFG and SCFV CRDP v4.0 are brokered for the Copernicus Climate Change Service (C3S) for Cryosphere. The MODIS based SCFG and SCFV CRDPs v4.0 published via the CCI Open Data Portal will be disseminated via links in the Climate Data Store (https://cds.climate.copernicus.eu/, in preparation).

Examples of SCF products and their associated uncertainties are shown in Figure 2.1 to Figure 2.4. The colour coding for snow-free areas is set to transparent, i.e. showing the background map.

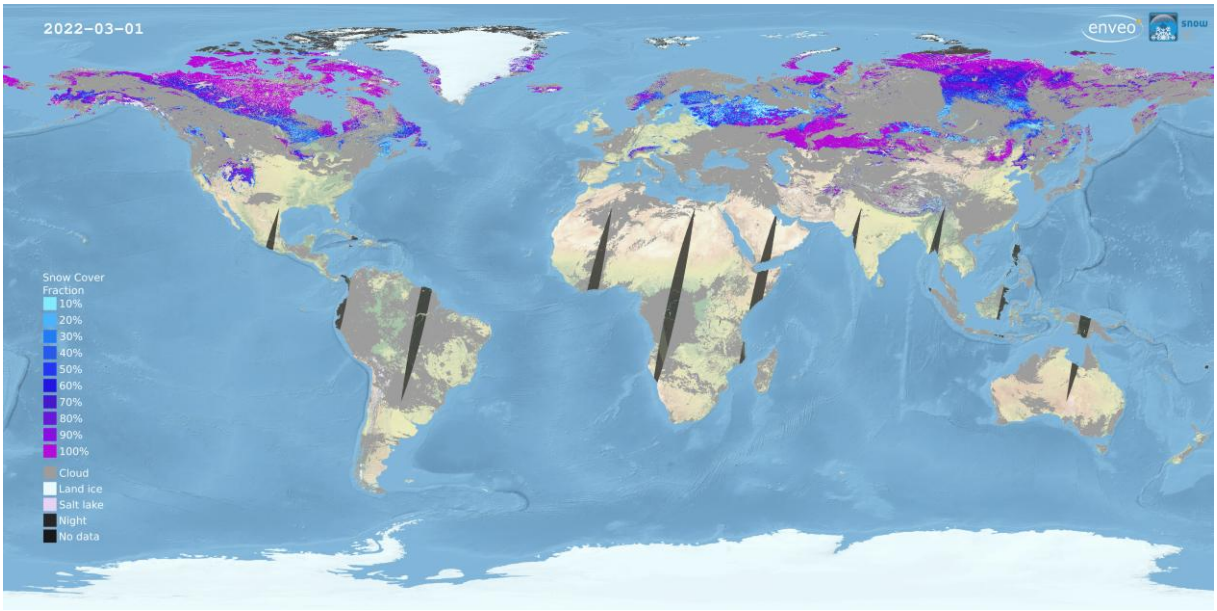

Figure 2.1: Example of SCFV product (CRDP v4.0) from Terra MODIS data of 01 March 2022.

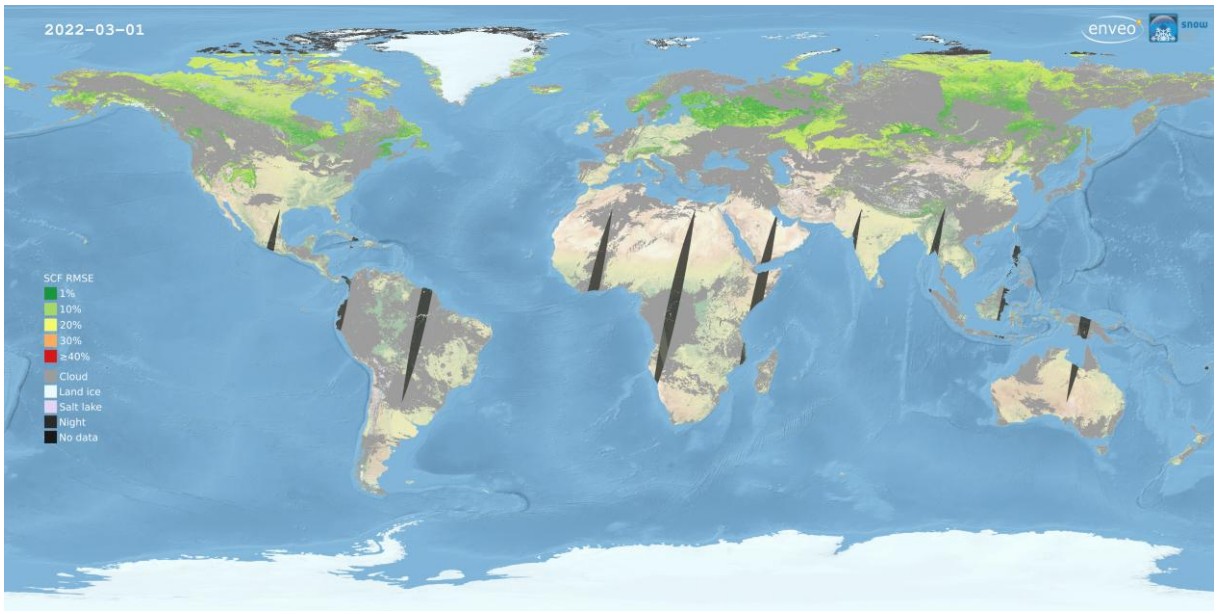

Figure 2.2: Example of associated SCFV uncertainty layer (CRDP v4.0) from Terra MODIS data of 01 March 2022. The RMSE for pixels defined as snow-free by the pre-classification step is assumed to be zero and are set to transparent in the colour coding. For all pixels used for the SCFV retrieval algorithm, the RMSE is provided.

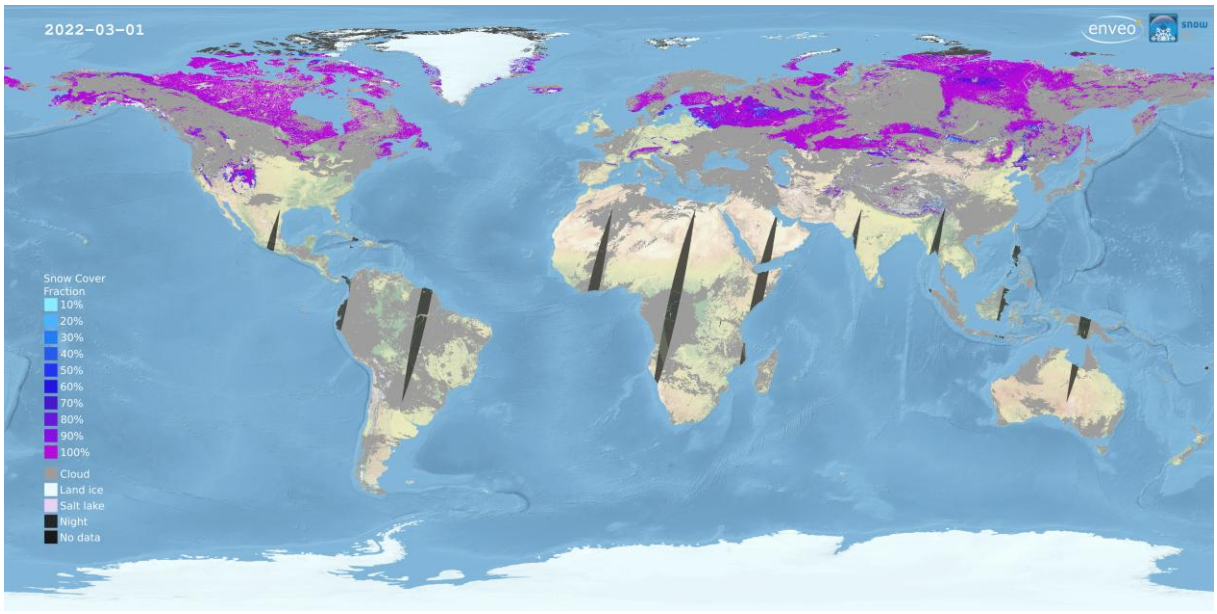

Figure 2.3: Example of SCFG product (CRDP v4.0) from Terra MODIS data of 01 March 2022.

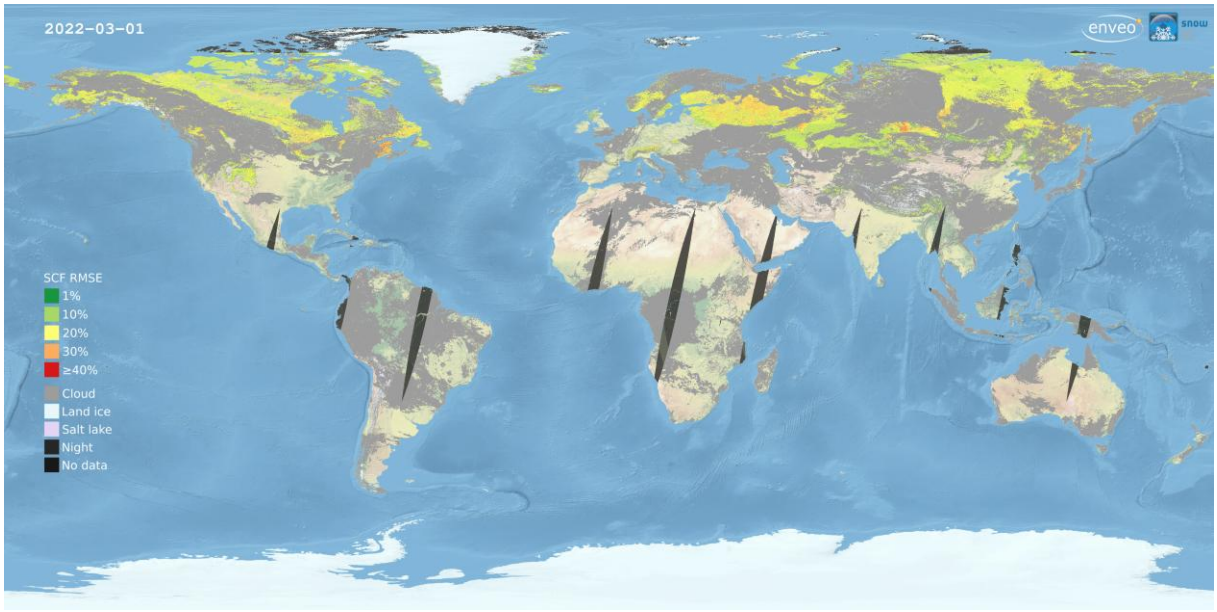

Figure 2.4: Example of associated SCFG uncertainty layer (CRDP v4.0) from Terra MODIS data of 01 March 2022. The RMSE for pixels defined as snow-free by the pre-classification step is assumed to be zero and are set to transparent in the colour coding. For all pixels used for the SCFG retrieval algorithm, the RMSE is provided.

2.2. AVHRR

The overall aim is the generation of one of the longest snow cover extent time series covering the whole globe. Based on the EUMETSAT AVHRR GAC FDR (Global Area Coverage), released in May 2023, a time series (1979–2023) was generated utilising the SCAmod algorithm of Metsämäki et al. (2015). Cloud masking relies on the probability mask of CLARA-A3, an upgrade of the existing cloud albedo and radiation (CLARA) data record developed and generated by EUMETSAT CM SAF, SMHI, which has also been produced from this FDR.

As a pre-condition, (FSC (NDSI) > 5%) was implemented based on Normalized Difference Snow Index (NDSI) calculations (Salomonson and Appel, 2006) before utilising the SCAmod algorithm (Metsämäki et al. 2015) for viewable snow (SCFV) and snow on ground (SCFG). A pre-classification was implemented to minimise erroneous results (solar zenith angle > 88°; cloud masks with retrieval uncertainty lower than 20%; water if percentage of pixel > 50; and permanent ice if percentage of pixel > 50). In addition, two thresholds were included to test whether a pixel potentially is snow free or snow covered (snow free if channel 1 < 0.12 or channel 4 > 283 K).

In addition, different post-processing steps were implemented to improve the quality of the snow products: for latitudes ±15° and elevations below 1000 m a.s.l. a test was added (channel 1 < 0.30 or channel 4 > 270 K) to remove erroneous data in the tropical regions. A second test considers channel 3b: (channel 1 – channel 3b ≥ 0.2 and channel 3b < 0.1) for the Southern Hemisphere to remove erroneous snow pixels, with an additional adaptation for the globe (channel 1 – channel 3b < 0.1 and channel 3b < 0.2). Finally, additional snow-free and cloud tests are included and described in detail in [RD-12].

The time series has daily – sub-daily temporal resolution and includes all datasets from the NOAA and MetOp satellites (Table 2.4) with a spatial resolution of 0.05° (GAC). The SCF time series from AVHRR (1979 – 2023) has 110 days without data due to missing acquisitions. The detailed periods are listed in Table 2.5. CRDP characteristics are provided in Table 2.6. Product examples are shown in Figure 2.5 to Figure 2.8. For the SCF CRDP v1.0, v2.0 and v3.0 from AVHRR, the respective information is provided in Annex B.

Table 2.4: Time series characteristics.

Subject	*Description AVHRR CRDP v4.0*
Thematic variable	Snow Cover Fraction Viewable (SCFV) and Snow Cover Fraction on Ground SCFG)
Retrieval algorithm	NDSI (Salomonson and Appel 2006) as precondition for SCAmod (Metsämäki et al. 2015), adapted and improved for snow_cci [RD-10]
Uncertainty algorithm	Schwaizer et al. [RD-9]
Satellite(s)	TIROS-N, NOAA-6, -7, -8, -9, -10, -11, -12, -14, -16, -17, -18, -19 and MetOp-A, -B, -C
Sensor(s)	AVHRR/1, AVHRR/2, AVHRR/3
Geographical domain(s)	Global
Temporal resolution	Daily – sub-daily
Start date time series	1 January 1979
End date time series	31 December 2023
Grid size	0.05°
Projection/datum	Geographical (lat/lon)/WGS 84
File format	netCDF4, CF-v1.10
Product version	Version 4.0

Table 2.5: Data gaps in the NOAA-AVHRR time series in CRDP v4.0.

Start date	*End date*	*Reason*
22.02.1979	24.02.1979	No AVHRR acquisitions available
01.10.1979	07.10.1979	No AVHRR acquisitions available
03.11.1979	04.11.1979	No AVHRR acquisitions available
07.11.1979	07.11.1979	No AVHRR acquisitions available
17.11.1979	18.11.1979	No AVHRR acquisitions available
22.02.1980	27.02.1980	No AVHRR acquisitions available
01.03.1980	01.03.1980	No AVHRR acquisitions available
03.03.1980	03.03.1980	No AVHRR acquisitions available
15.03.1980	20.03.1980	No AVHRR acquisitions available
30.03.1980	31.03.1980	No AVHRR acquisitions available
01.04.1980	02.04.1980	No AVHRR acquisitions available
26.06.1980	29.06.1980	No AVHRR acquisitions available
12.07.1980	19.07.1980	No AVHRR acquisitions available
12.12.1980	18.12.1980	No AVHRR acquisitions available
09.05.1981	11.05.1981	No AVHRR acquisitions available
01.08.1981	03.08.1981	No AVHRR acquisitions available
14.08.1981	23.08.1981	No AVHRR acquisitions available
28.05.1982	31.05.1982	No AVHRR acquisitions available

Start date	End date	Reason
25.09.1982	26.09.1982	No AVHRR acquisitions available
27.07.1983	31.07.1983	No AVHRR acquisitions available
01.08.1983	02.08.1983	No AVHRR acquisitions available
06.08.1983	06.08.1983	No AVHRR acquisitions available
14.01.1984	15.01.1984	No AVHRR acquisitions available
06.12.1984	06.12.1984	No AVHRR acquisitions available
01.02.1985	24.02.1985	No AVHRR acquisitions available
15.03.1986	15.03.1986	No AVHRR acquisitions available

Table 2.6: AVHRR based SCF CRDP v4.0 characteristics.

Subject	AVHRR SCFV CRDP v4.0	AVHRR SCFG CRDP v4.0
Data volume	555 GB	552 GB
Number of files	37,836	37,836
DOI	10.5285/3c71c04cf08a410fac2c680cbf88cfd7	10.5285/80d96e3a14854420b6f742d70877c431
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/10.5285/3c71c04cf08a410fac2c680cbf88cfd7	https://catalogue.ceda.ac.uk/uuid/10.5285/80d96e3a14854420b6f742d70877c431

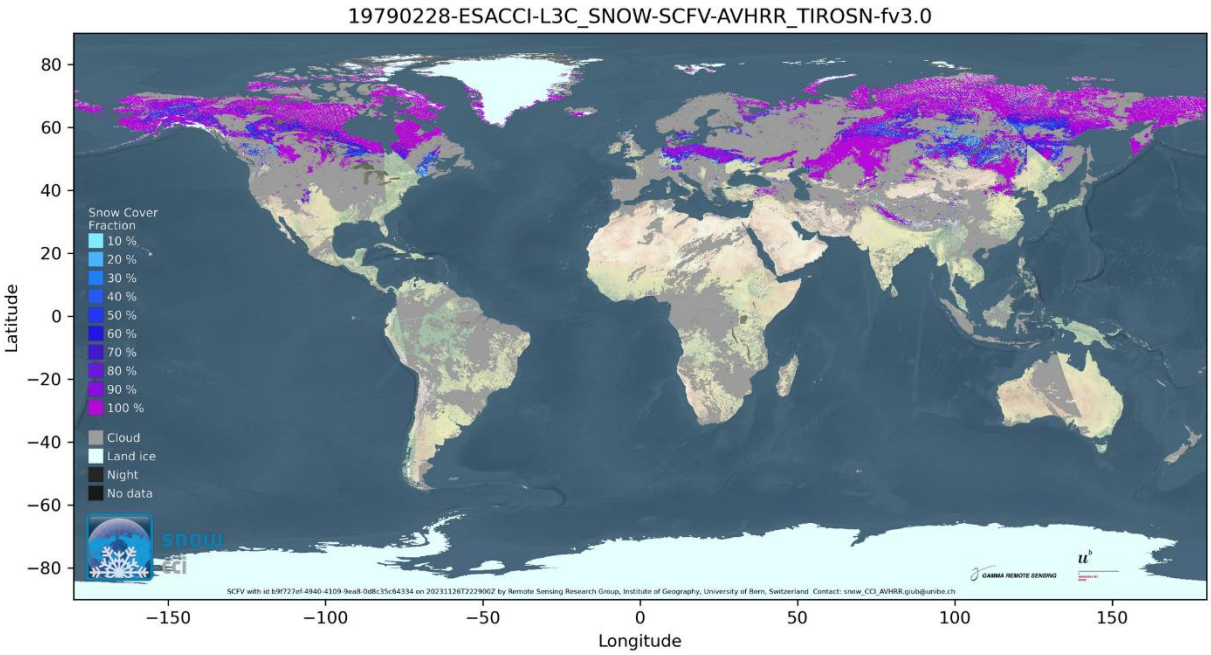

Figure 2.5: SCFV product example (CRDP v4.0) for 28 February 1979.

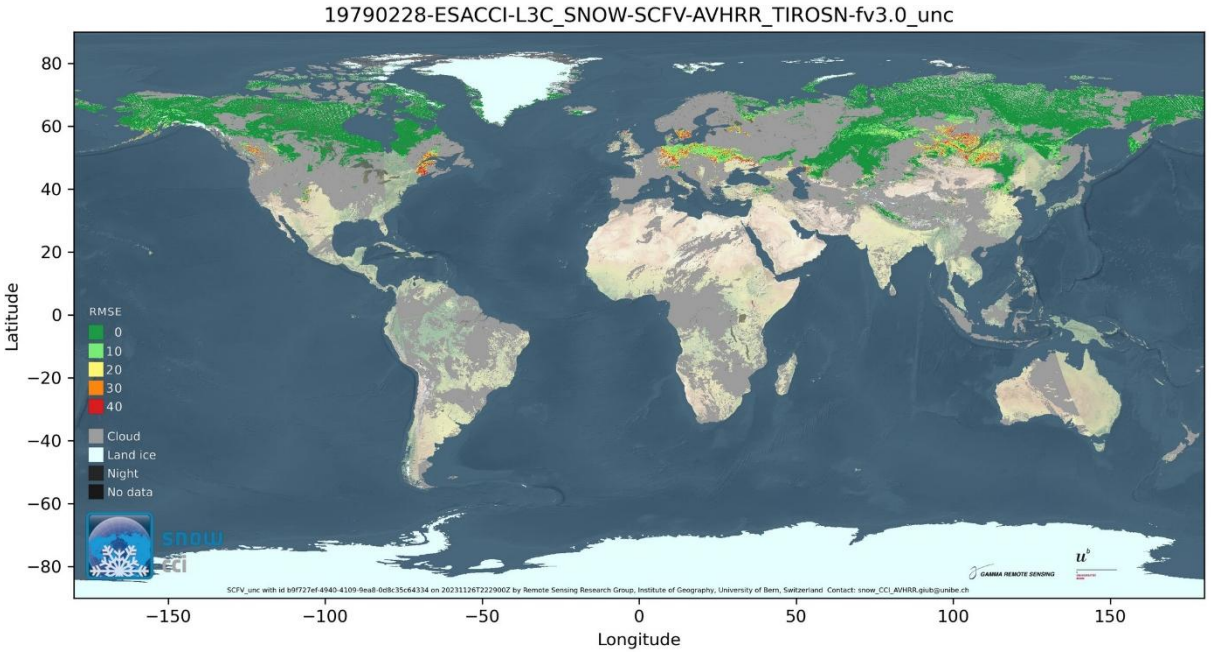

Figure 2.6: Uncertainty for SCFV product example (CRDP v4.0) on 28 February 1979.

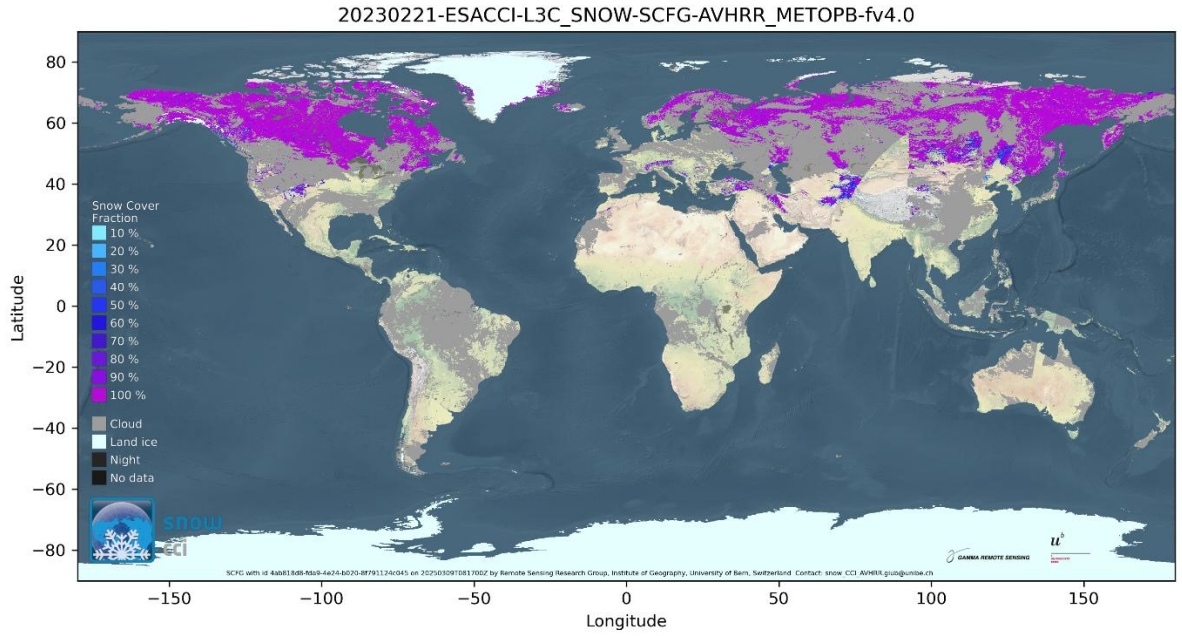

Figure 2.7: SCFG product example (CRDP v4.0) for 21 February 2023.

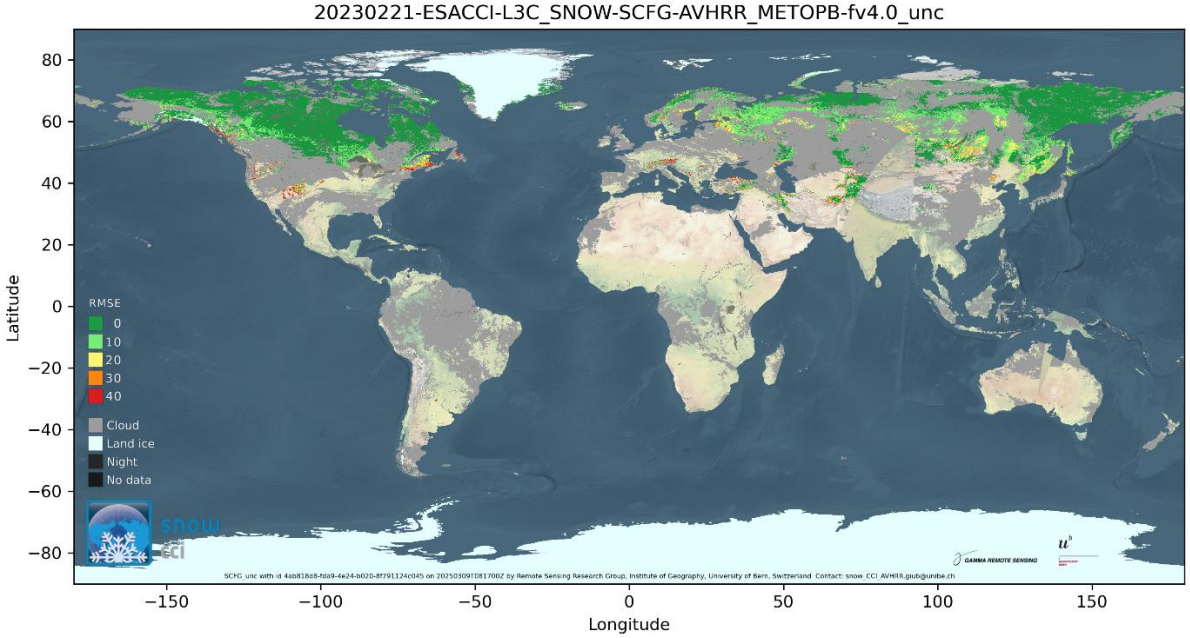

Figure 2.8: Uncertainty for SCFG product example (CRDP v4.0) on 21 February 2023.

2.3. ATSR-2/AATSR

The *snow_cci* snow cover fraction (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. The sensors have similar characteristic and provided data in 1 km resolution. Global SCF products are available at daily temporal resolution with cloud-cover flagged.

As for SCF from MODIS and AVHRR, the products are provided in two versions: (i) as the viewable snow cover fraction (SCFV) and (ii) as the snow cover fraction on the ground (SCFG) – the latter including compensation for the masking effect of the forest.

The time series characteristics of the SCF products are summarized in Table 2.7. Gaps in the time series due to missing acquisitions are listed in Table 2.8. Specific CRDP characteristics are provided in Table 2.9 and Table 2.10. Product examples are provided in Figure 2.9 to Figure 2.12.

Table 2.7: Time series characteristics.

Subject	*Description ATSR-2 CRDP v2.0*	*Description AATSR CRDP v2.0*
Thematic variable	Snow Cover Fraction Viewable (SCFV) and Snow Cover Fraction on Ground (SCFG)	Snow Cover Fraction Viewable (SCFV) and Snow Cover Fraction on Ground (SCFG)
Retrieval algorithm	SCAmod (Metsämäki et al. 2005, 2012, 2015) adapted and improved for snow_cci [RD-6]	SCAmod (Metsämäki et al. 2005, 2012, 2015) adapted and improved for snow_cci [RD-6]
Uncertainty algorithm	Salberg et al. 2020 [RD-7]	Salberg et al. 2020 [RD-7]
Satellite(s)	ERS-2 (ESA)	ENVISAT (ESA)
Sensor(s)	ATSR-2	AATSR
Geographical domain(s)	Global	Global
Temporal resolution	Daily	Daily
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
File format	NetCDF4, CF-v1.9	NetCDF4, CF-v1.9
Product version	Version 1.0	Version 1.0

Table 2.8: Data gaps in the ATSR-2 and AATSR time series.

Start date	End date	Reason
10.08.1995	13.08.1995	No ATSR-2 acquisitions available
01.01.1996	31.06.1996	No ATSR-2 acquisitions available
27.02.1999	28.02.1999	No ATSR-2 acquisitions available
29.08.1999	31.08.1999	No ATSR-2 acquisitions available
17.11.1999	18.11.1999	No ATSR-2 acquisitions available
01.01.2000	01.01.2000	No ATSR-2 acquisitions available
08.02.2000	09.02.2000	No ATSR-2 acquisitions available
01.07.2000	04.07.2000	No ATSR-2 acquisitions available
08.10.2000	10.10.2000	No ATSR-2 acquisitions available
18.01.2001	06.02.2001	No ATSR-2 acquisitions available
22.05.2001	23.05.2001	No ATSR-2 acquisitions available
12.02.2002	13.02.2002	No ATSR-2 acquisitions available
09.03.2002	19.03.2002	No ATSR-2 acquisitions available
17.05.2003	19.05.2003	No ATSR-2 acquisitions available
27.05.2002	28.05.2002	No AATSR acquisitions available
06.06.2002	10.06.2002	No AATSR acquisitions available
09.09.2002	11.09.2002	No AATSR acquisitions available
16.03.2003	18.03.2003	No AATSR acquisitions available
19.05.2003	19.05.2003	No AATSR acquisitions available
09.06.2004	09.06.2004	No AATSR acquisitions available
08.09.2006	10.09.2006	No AATSR acquisitions available
13.12.2006	15.12.2006	No AATSR acquisitions available
19.12.2008	31.12.2008	No AATSR acquisitions available
01.01.2010	31.01.2010	No AATSR acquisitions available
22.10.2010	31.10.2010	No AATSR acquisitions available
24.01.2012	25.03.2012	No AATSR acquisitions available
In every year, there are days with missing sensor swaths. SCF products are generated in such cases based on the available satellite data even if the spatial coverage is small.		

Table 2.9: ATSR-2 CRDP v1.0 characteristics.

Subject	SCFV ATSR-2 CRDP v2.0	SCFG ATSR-2 CRDP v2.0
Data volume	23 GB	23 GB
DOI	10.5285/70061acca284432ca31fd8a5cbd604d0	10.5285/0aeba0c203c2447b9553a78f99d3a276
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/70061acca284432ca31fd8a5cbd604d0	https://catalogue.ceda.ac.uk/uuid/0aeba0c203c2447b9553a78f99d3a276

Table 2.10: AATSR CRDP v1.0 characteristics.

Subject	*SCFV AATSR CRDP v2.0*	*SCFG AATSR CRDP v2.0*
Data volume	29 GB	29 GB
DOI	10.5285/d7773cb976d64b1c900a518773428df6	10.5285/e7e31b86b2644e0da69090bc37360c97
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/ d7773cb976d64b1c900a518773428df6	https://catalogue.ceda.ac.uk/uuid/ e7e31b86b2644e0da69090bc37360c97

The retrieval algorithm includes four components: cloud screening, pre-classification, fractional snow cover retrieval and post-processing. A decision-tree approach is applied for cloud screening (Metsämäki et al. 2015). The pre-classification includes tests to whether a pixel is clearly bare ground due to the reflectance level or surface temperature. It also checks whether a snow-index based method gives a very small value (Salomonson & Appel 2006). The snow cover fraction retrieval is based on the SCAmod algorithm (Metsämäki et al. 2015). The post-processing includes a latitude test to remote potential false snow in the tropics for low elevations, and temperature and radiance tests to remote potential remaining false snow.

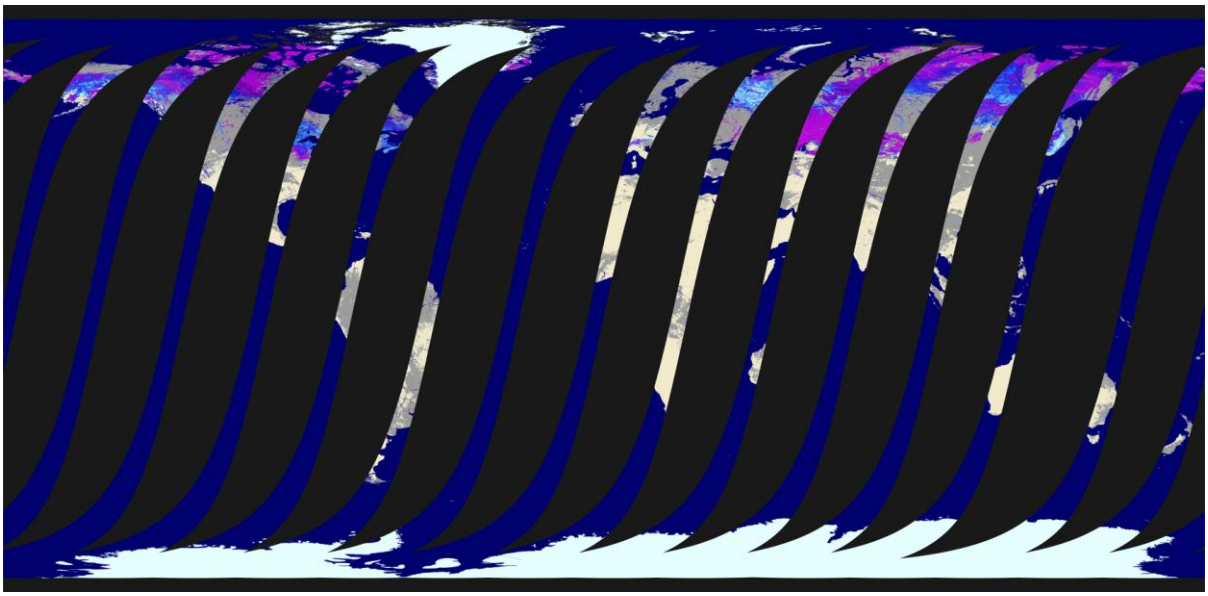

Figure 2.9: SCFV product example from ENVISAT AATSR (CRDP v1.0) on 10 March 2003.

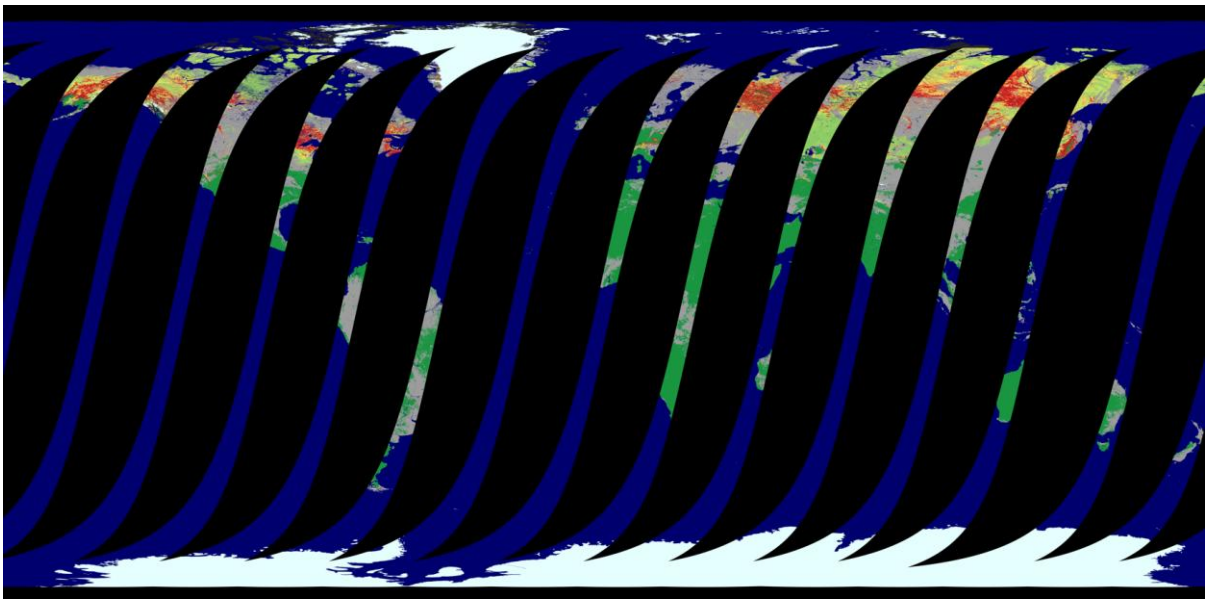

Figure 2.10: Uncertainty estimation for the SCFV product from ENVISAT AATSR (CRDP v1.0) on 10 March 2003.

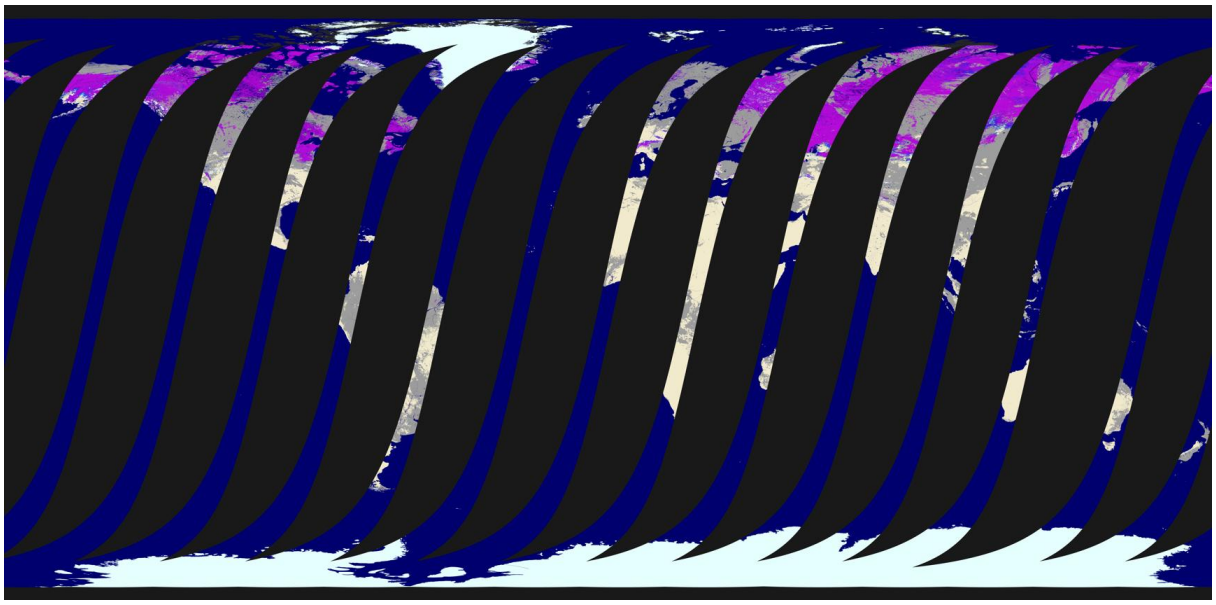

Figure 2.11: SCFG product example from ENVISAT AATSR (CRDP v1.0) on 10 March 2003.

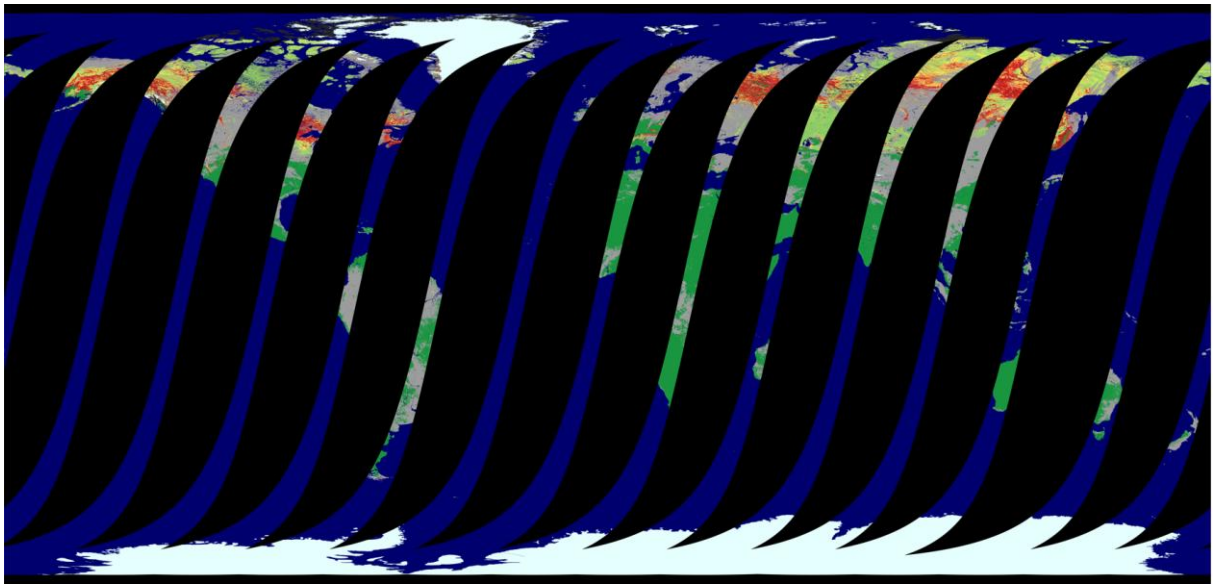

Figure 2.12: Uncertainty estimation for the SCFG product from ENVISAT AATSR (CRDP v1.0) on 10 March 2003.

2.4. SLSTR

The *snow_cci* snow cover fraction (SCF) product time series of the CRDP v1.0 from Sentinel-3 A&B SLSTR data covers the period 1 September 2020 – 31 December 2022. Products generated with the same processing chain from 1st January 2023 onwards are generated by ENVEO within the Copernicus Climate Change Service (C3S) for Cryosphere, and will be published via the Climate Data Store (https://cds.climate.copernicus.eu/, in preparation). Global SCF products are available at daily temporal resolution. Clouds, water bodies, (polar) night, permanent snow and ice areas and salt lakes are flagged. The product is based on 0.01-degree data from the SLSTR sensor aboard the Sentinel-3A and Sentinel-3B satellites (launched in 2017 and 2018, respectively). Sentinel-3A&B SLSTR data with processing baseline version 4.0 are only available since mid January 2020. The start date for the CRDP v1.0 was selected to be aligned with the hydrological year on the Northern Hemisphere. The SLSTR based CRDP v1.0 includes two SCF time series, each with the associated per-pixel uncertainty estimation [RD-9]:

(iii) the snow cover fraction viewable from above (SCFV) at the surface in open areas and on top of forest canopies, and

(iv) the snow cover fraction on the ground (SCFG) for open areas and in forested areas, using a canopy correction to estimate the snow cover in forests.

Each time series is organized in daily netCDF files per year and per month. The products have the following variables:

SCFV product:

- Snow cover fraction viewable from above
- Uncertainty estimates for snow cover fraction viewable from above
- Satellite viewing zenith angle in degrees
- Satellite image acquisition time in fractional hours of the day

SCFG product:

- Snow cover fraction on the ground
- Uncertainty estimates for snow cover fraction on the ground
- Satellite viewing zenith angle in degrees
- Satellite image acquisition time in fractional hours of the day

The time series characteristics of the SLSTR-based SCF products of CRDP v1.0 are summarized in Table 2.11. Gaps in the time series due to missing SLSTR acquisitions are listed in Table 2.12. Specific CRDP v1.0 characteristics, including the data volumes, DOI numbers and access points for each CRDP from SLSTR data, are provided in Table 2.13.

Table 2.11: Time series characteristics of SLSTR-based SCF CRDP v1.0.

Subject	*Description MODIS CRDP v3.0*
Thematic variable	Snow Cover Fraction Viewable (SCFV) and Snow Cover Fraction on Ground (SCFG)
Retrieval algorithm	SCAmod (Metsämäki et al. 2005, 2012, 2015) adapted and improved for snow_cci [RD-10]
Uncertainty algorithm	Error propagation approach adapted from Salminen et al. (2018) [RD-9]
Satellite(s)	Sentinel-3A & Sentinel-3B
Sensor(s)	SLSTR
Geographical domain(s)	Global
Temporal resolution	Daily
Start date time series	01.09.2020
End date time series	31.12.2022
Grid size	0.01°
Projection/datum	Geographical (lat/lon)/WGS 84
File format	netCDF4, CF-v1.12
Product version	Version 1.0

Table 2.12: Data gaps in the Sentinel-3A&B SLSTR time series in CRDP v1.0.

Reason
SCF products are available for every day of the time series. In every year, there are a few days with missing SLSTR tiles or tracks. SCF products are generated in such cases based on the available satellite data.

Table 2.13: SLSTR-based SCF CRDP v1.0 characteristics.

Subject	*SCFV SLSTR CRDP v1.0*	*SCFG SLSTR CRDP v1.0*
Data volume	82 GB	81 GB
Number of files	852	852
DOI	10.5285/f5dce1f7bec2447093cf460a4d3ba2c2	10.5285/38a71d034b5c4097821de29ee3bc2498
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/f5dce1f7bec2447093cf460a4d3ba2c2	https://catalogue.ceda.ac.uk/uuid/38a71d034b5c4097821de29ee3bc2498

After reading and geolocating the daily Sentinel-3A&B SLSTR data, clouds are detected using a decision-tree based algorithm (Metsämäki 2015), adapted, and extended with additional criteria for better performance on a global scale [RD-12]. The cloud mask per product is also overlaid on the associated uncertainty layer.

For all cloud-free pixels of the daily SLSTR data, a pre-classification is applied. The aim of this pre-classification is to identify snow-free pixels with a negligible uncertainty based on the pixel's spectral

reflectance characteristics and the brightness temperature at 11 µm. The root-mean-square error (RMSE) for pixels defined as snow-free by the pre-classification step is thus assumed to be zero.

On all remaining pixels, an adapted version of the SCAmod algorithm (Metsämäki et al. 2015) is applied to retrieve the snow cover fraction per pixel. Spatially variable spectral reflectance maps for snow free ground and snow free forest derived from statistical analyses of a time series of SLSTR data of 2022 to 2023 are used [RD-12]. For estimating these per-pixel spectral reflectance values, the same concept was applied to MODIS and SLSTR data [RD-12]. For the wet snow reflectance, the same value as used for MODIS CRDP v4.0 was used for the generation of the CRDP v1.0 from SLSTR [RD-12]. For pixels with a solar zenith angle greater than 50°, the spectral reflectance value is adjusted in dependence on the local solar zenith angle before applying the SCAmod algorithm. Details are described in the ATBD [RD-12].

For merging the classifications from individual tiles per day into a daily global SCF composite, the same criteria as for MODIS CRDP v4.0 were used. Details are provided in the ATBD [RD-12]. For each pixel that contains an SCF observation, the unbiased RMSE is estimated and provided in the uncertainty layer.

In all SCF products and the associated uncertainty layers, water bodies and land ice are masked using a static mask derived from the ESA CCI Land Cover product for the year 2000 (ESA Land Cover CCI project team; Defourny 2016). Salt lakes are masked using the same map as used for MODIS CRDP v4.0.

Further, pixels with large solar zenith angles (> 83°) are classified as (polar) night and are masked in the SCF and SCF uncertainty layers. Also, pixels with missing or erroneous input data in at least one of the spectral bands needed in the SCF generation, are masked in the SCF and SCF uncertainty layers.

Examples of SCF products and their associated uncertainties are shown in Figure 2.13 to Figure 2.16. The colour coding for snow-free areas is set to transparent, i.e. showing the background map.

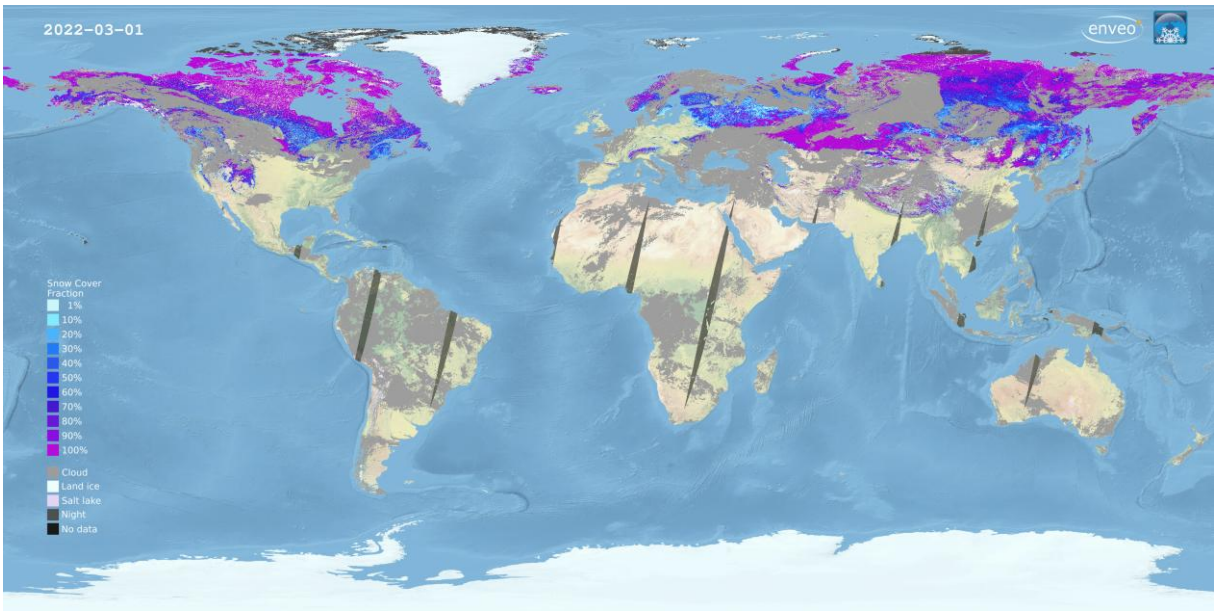

Figure 2.13: Example of SCFV product (CRDP v1.0) from Sentinel-3 SLSTR data of 01 March 2022.

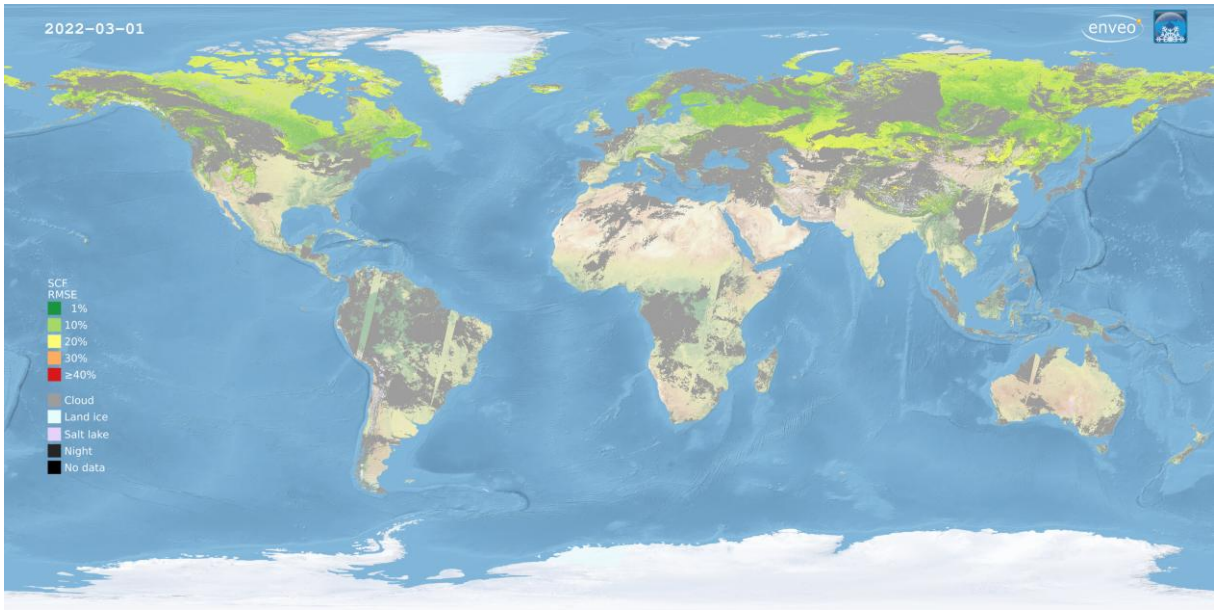

Figure 2.14: Example of associated SCFV uncertainty layer (CRDP v1.0) from Sentinel-3 SLSTR data of 01 March 2022. The RMSE for pixels defined as snow-free by the pre-classification step is assumed to be zero and are set to transparent in the colour coding. Also, pixels affected by (polar) night or no data are set to transparent in the map. For all pixels used for the SCFV retrieval algorithm, the RMSE is provided.

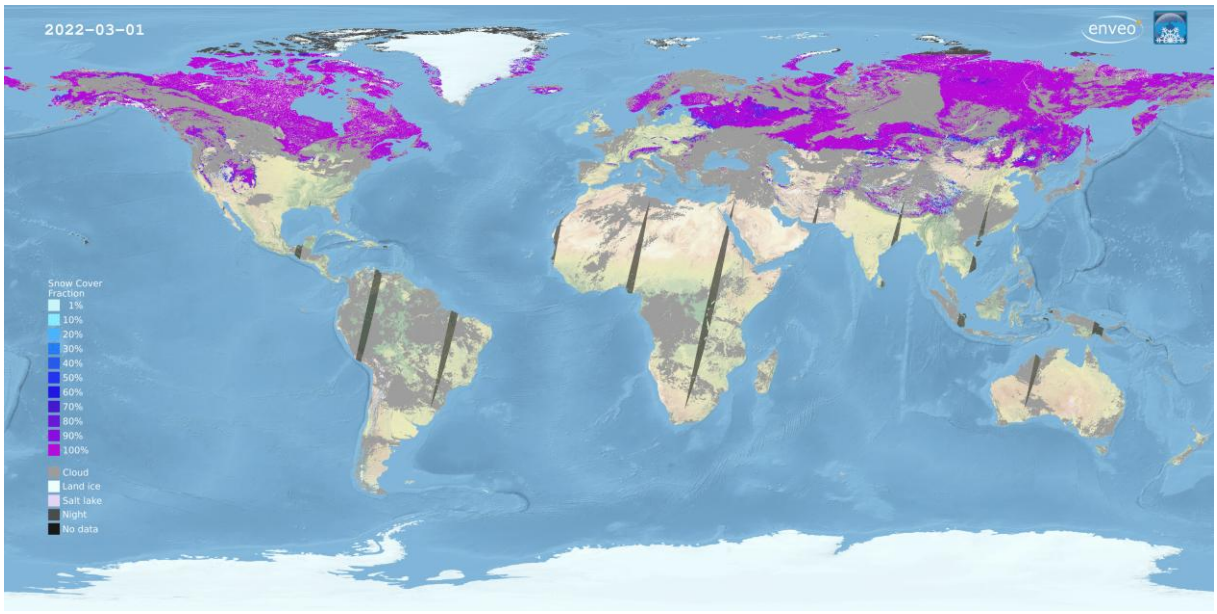

Figure 2.15: Example of SCFG product (CRDP v1.0) from Sentinel-3 SLSTR data of 01 March 2022.

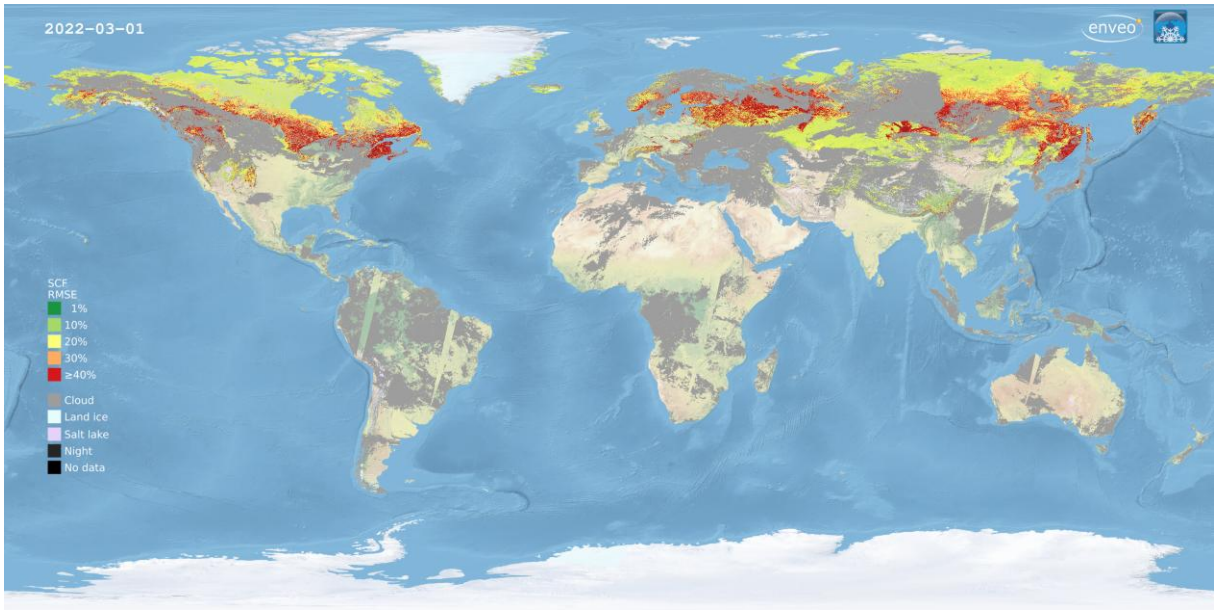

Figure 2.16: Example of associated SCFG uncertainty layer (CRDP v1.0) from Sentinel-3 SLSTR data of 01 March 2022. The RMSE for pixels defined as snow-free by the pre-classification step is assumed to be zero and are set to transparent in the colour coding. Also, pixels affected by (polar) night or no data are set to transparent in the map. For all pixels used for the SCFG retrieval algorithm, the RMSE is provided.

3. SNOW WATER EQUIVALENT

The *snow_cci* SWE data record, based on methodology by Pulliainen (2006), Takala et al. (2011) and Venäläinen et al. (2023), utilises a data-assimilation-based approach combining space-borne passive microwave radiometer data (SMMR, SSM/I and SSMIS) with data from ground-based synoptic weather stations. The satellite sensors utilised provide data at K- and Ka-bands (19 GHz and 37 GHz, respectively) at a spatial resolution of approximately 10 km. The Northern Hemisphere (NH) SWE record is produced daily for the period 1988–2023 and bi-daily for the years 1979–1987. Note that there are no SWE retrievals during the NH summer; SWE is retrieved during the NH winter season only. SWE information is provided for terrestrial, non-mountainous regions of the Northern Hemisphere, excluding glaciers and Greenland.

Specific CRDP characteristics are provided in Table 3.1 and Table 3.2. An example of a SWE product is shown in Figure 3.1 with the corresponding uncertainty product in Figure 3.2. For the SWE CRDP v1.0, CRDP v2.0 and CRDP v3.1 the respective information is provided in Annex C.

Table 3.1: Time series characteristics.

Subject	*Description SWE v4.0*
Thematic variable	Snow Water Equivalent (SWE)
Retrieval algorithm	FMI GlobSnow SWE algorithm (Takala et al. 2011)
Uncertainty algorithm	Takala et al. 2011, updated model for North America
Satellite(s)	Nimbus-7, DMSP F8, DMSP F11, DMSP F13, DMSP F17 and DMSP F18
Sensor(s)	SMMR, SSM/I and SSMIS
Geographical domain(s)	Northern Hemisphere (excluding mountains/glaciers/ice sheets/water)
Temporal resolution	Daily (bi-daily for 1979-1987)
Start date time series	6 January 1979
End date time series	31 December 2023
Grid size	0.10°
Projection/datum	Geographical (lat/lon)/WGS 84
File format	NetCDF4, CF-v1.9
Product version	Version 4.0

Table 3.2: SWE CRDP characteristics.

Subject	*SWE CRDP v4.0*
Data volume	30 GB
DOI	10.5285/edf8abd23f4a40aabd4d52e48dec06ea
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/edf8abd23f4a40aabd4d52e48dec06ea/

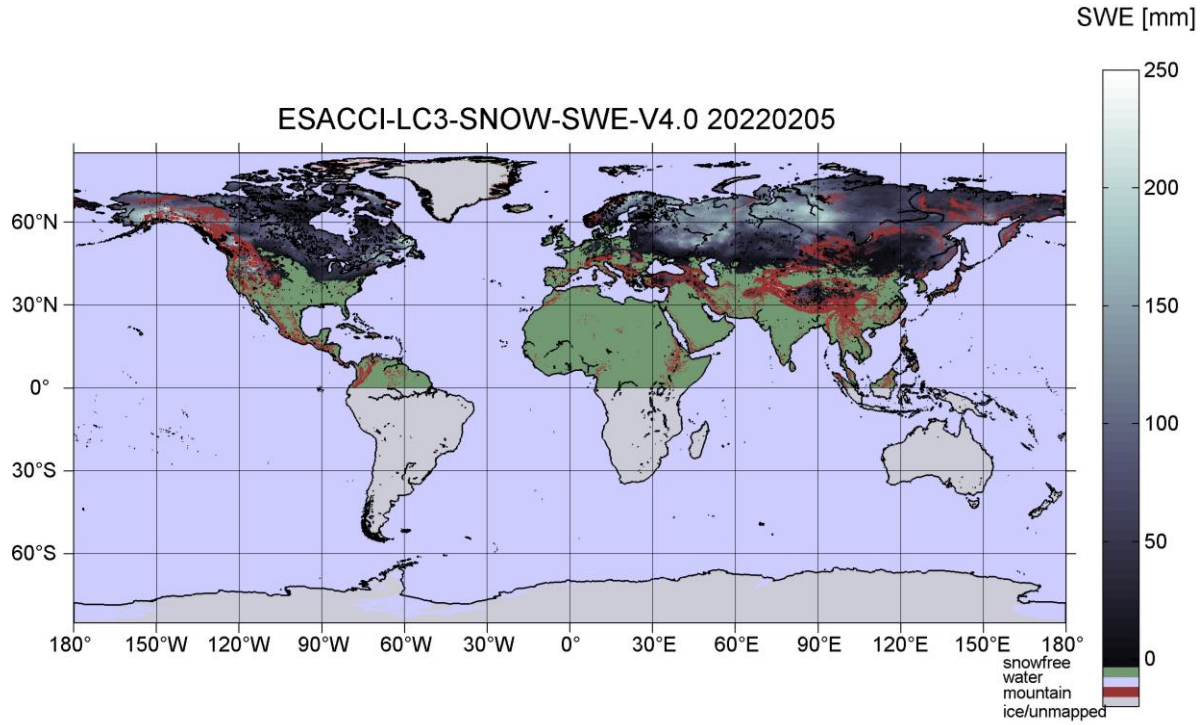

Figure 3.1: Example of SWE product (CRDP v4.0) for 5 February 2022.

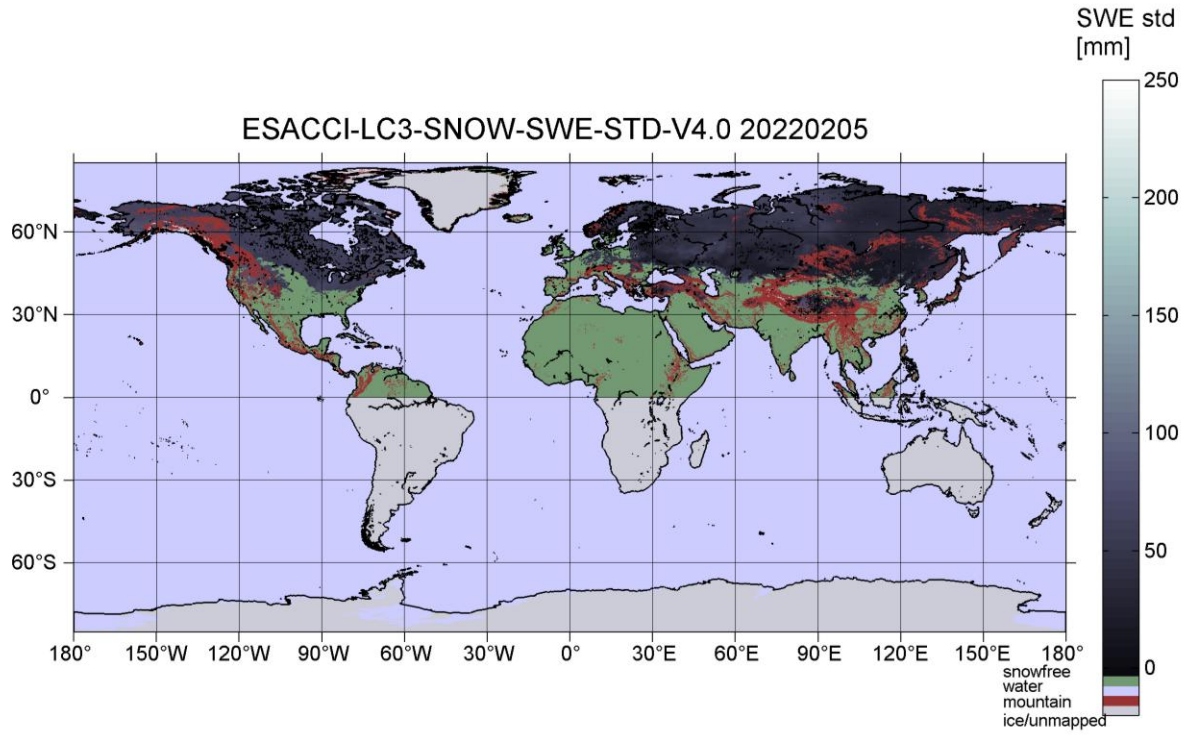

Figure 3.2: Example of corresponding SWE uncertainty layer (CRDP v4.0) for 5 February 2022.

4. RELEASE NOTE

Release of 4th *snow_cci* Climate Research Data Packages (to be published on snow cci webpage)

The 4th ***snow_cci*** **Climate Research Data Packages (CRDP)** including **Snow Cover Fraction (SCF)** time series from MODIS and AVHRR sensors and **Snow Water Equivalent (SWE)** time series from SMMR, SSM/I and SSMI/S instruments and the **1st SCF CRDP** from **SLSTR** sensor have been released in Q3/Q4 2025.

Daily SCF products are available with 0.01° (about 1 km) pixel spacing from Terra MODIS data for the period 24/02/2000 – 31/12/2023, and from Sentinel-3 SLSTR data for the period 01/09/2020 – 31/12/2022, and with 0.05° (about 5 km) pixel spacing from AVHRR data for the period 01/01/1982 – 31/12/2023. In **forested areas**, the **SCF CRDPs** provide two different thematic information: **snow viewable on top of the forest canopy (SCFV)**, and **snow on the ground (SCFG)**, i.e., a canopy correction was applied. In **non-forested areas**, the SCFV and the SCFG products are equal.

Daily SWE products are available with 0.10° (about 10 km) pixel spacing for the winter periods 1979 - 2023. SWE products provide the snow mass information for the Northern Hemispheric land areas, but the geographic extent of the products is global.

The ***snow_cci*** **products** are available via the CCI Data Portal (**http://cci.esa.int/data)**.

Further details on the dataset and direct access to the dataset are provided at the CEDA Archive:

- **Global daily Snow Cover Fraction on Ground (SCFG) products from MODIS (2000 - 2023)**, 1 km pixel spacing
- **Global daily Snow Cover Fraction Viewable (SCFV) products from MODIS (2000 - 2023)**, 1 km pixel spacing
- **Global daily Snow Cover Fraction on Ground (SCFG) products from SLSTR (2020 - 2022)**, 1 km pixel spacing
- **Global daily Snow Cover Fraction Viewable (SCFV) products from SLSTR (2020 - 2022)**, 1 km pixel spacing
- **Global daily Snow Cover Fraction on Ground (SCFG) products from AVHRR (1979 - 2023)**, 5 km pixel spacing
- **Global daily Snow Cover Fraction Viewable (SCFV) products from AVHRR (1979 - 2023)**, 5 km pixel spacing
- **Global daily Snow Water Equivalent (SWE) products (1979 - 2023)**, 10 km pixel spacing

5. REFERENCES

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A. MODIS SCF CRDP V1.0, V2.0 AND V3.0 CHARACTERISTICS

Tab. A.1: Time series characteristics for MODIS SCF CRDP v1.0, v2.0 and v3.0.

Subject	*Description MODIS CRDP v1.0*	*Description MODIS CRDP v2.0*	*Description MODIS CRDP v3.0*
Thematic variable	Snow Cover Fraction Viewable (SCFV) and Snow Cover Fraction on Ground (SCFG)	Snow Cover Fraction Viewable (SCFV) and Snow Cover Fraction on Ground (SCFG)	Snow Cover Fraction Viewable (SCFV) and Snow Cover Fraction on Ground (SCFG)
Retrieval algorithm	SCAmod (Metsämäki et al. 2005, 2012, 2015) adapted and improved for snow_cci [RD-5]	SCAmod (Metsämäki et al. 2005, 2012, 2015) adapted and improved for snow_cci [RD-6]	SCAmod (Metsämäki et al. 2005, 2012, 2015) adapted and improved for snow_cci [RD-10]
Uncertainty algorithm	Error propagation approach adapted from Salminen et al. (2018) [RD-7]	Error propagation approach adapted from Salminen et al. (2018) [RD-8]	Error propagation approach adapted from Salminen et al. (2018) [RD-9]
Satellite(s)	Terra (NASA)	Terra (NASA)	Terra
Sensor(s)	MODIS	MODIS	MODIS
Geographical domain(s)	Global	Global	Global
Temporal resolution	Daily	Daily	Daily
Start date time series	25.02.2000	25.02.2000	24.02.2000
End date time series	31.12.2019	31.12.2020	31.12.2022
Grid size	0.01°	0.01°	0.01°
Projection/datum	Geographical (lat/lon)/WGS 84	Geographical (lat/lon)/WGS 84	Geographical (lat/lon)/WGS 84
File format	NetCDF4, CF-v1.8	NetCDF4, CF-v1.9	netCDF4, CF-v1.10
Product version	Version 1.0	Version 2.0	Version 3.0

Tab. A.2: MODIS-based SCF CRDP v1.0 characteristics.

Subject	*SCFV MODIS CRDP v1.0*	*SCFG MODIS CRDP v1.0*
Data volume	190 GB	190 GB
Number of files	7190	7190
DOI	10.5285/ef8eb5ff84994f2ca416dbb2df7f72c7	10.5285/3b3fd2daf3d34c1bb4a09efeaf3b8ea9
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/ef8eb5ff84994f2ca416dbb2df7f72c7	https://catalogue.ceda.ac.uk/uuid/3b3fd2daf3d34c1bb4a09efeaf3b8ea9

Tab. A.3: MODIS-based SCF CRDP v2.0 characteristics.

Subject	*SCFV MODIS CRDP v2.0*	*SCFG MODIS CRDP v2.0*
Data volume	192 GB	194 GB
Number of files	7558	7558
DOI	10.5285/ebe625b6f77945a68bda0ab7c78dd76b	10.5285/8847a05eeda646a29da58b42bdf2a87c
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/ebe625b6f77945a68bda0ab7c78dd76b	https://catalogue.ceda.ac.uk/uuid/8847a05eeda646a29da58b42bdf2a87c

Tab. A.4: MODIS-based SCF CRDP v3.0 characteristics.

Subject	*SCFV MODIS CRDP v3.0*	*SCFG MODIS CRDP v3.0*
Data volume	806 GB	803 GB
Number of files	8277	8277
DOI	e955813b0e1a4eb7af971f923010b4a3	80567d38de3f4b038ee6e6e53ed1af8a
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/e955813b0e1a4eb7af971f923010b4a3	https://catalogue.ceda.ac.uk/uuid/80567d38de3f4b038ee6e6e53ed1af8a

B. AVHRR SCF CRDP V1.0, V2.0 AND V3.0 CHARACTERISTICS

Tab. B.1: Time series characteristics for AVHRR SCF CRDP v1.0, v2.0 and CRDP v3.0.

Subject	*Description AVHRR CRDP v1.0*	*Description AVHRR CRDP v2.0*	*Description AVHRR CRDP v3.0*
Thematic variable	Snow Cover Fraction Viewable (SCFV) and Snow Cover Fraction on Ground SCFG)	Snow Cover Fraction Viewable (SCFV) and Snow Cover Fraction on Ground SCFG)	Snow Cover Fraction Viewable (SCFV) and Snow Cover Fraction on Ground SCFG)
Retrieval algorithm	NDSI (Salomonson and Appel 2006) as precondition for SCAmod (Metsämäki et al. 2015) [RD-5]	NDSI (Salomonson and Appel 2006) as precondition for SCAmod (Metsämäki et al. 2015) [RD-6]	NDSI (Salomonson and Appel 2006) as precondition for SCAmod (Metsämäki et al. 2015), adapted and improved for snow_cci [RD-10]
Uncertainty algorithm	Salberg et al. 2020 [RD-7]	Salberg et al. 2021 [RD-8]	Schwaizer et al. [RD-9]
Satellite(s)	NOAA-7, -9, -11, -14, -16, -18, -19	NOAA-7, -9, -11, -14, -16, -18, -19	TIROS-N, NOAA-6, -7, -8, -9, -10, -11, -12, -14, -16, -17, -18, -19 and MetOp-A, -B, -C
Sensor(s)	AVHRR/2, AVHRR/3	AVHRR/2, AVHRR/3	AVHRR/1, AVHRR/2, AVHRR/3
Geographical domain(s)	Global	Global	Global
Temporal resolution	Daily	Daily	Daily – sub-daily
Start date time series	1 January 1982	1 January 1982	1 January 1979
End date time series	31 December 2019	31 December 2020	31 December 2022
Grid size	0.05°	0.05°	0.05°
Projection/datum	Geographical (lat/lon)/WGS 84	Geographical (lat/lon)/WGS 84	Geographical (lat/lon)/WGS 84
File format	NetCDF4, CF-v1.9	NetCDF4, CF-v1.9	netCDF4, CF-v1.10
Product version	Version 1.0	Version 2.0	Version 3.0

Tab. B.2: AVHRR based SCF CRDP v1.0 characteristics.

Subject	*AVHRR SCFV CRDP v1.0*	*AVHRR SCFG CRDP v1.0*
Data volume	34 GB	33 GB
DOI	10.5285/d9df331e346f4a50b18bcf41a64b98c7	10.5285/5484dc1392bc43c1ace73ba38a22ac56
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/d9df331e346f4a50b18bcf41a64b98c7	https://catalogue.ceda.ac.uk/uuid/5484dc1392bc43c1ace73ba38a22ac56

Tab. B.3: AVHRR based SCF CRDP v2.0 characteristics.

Subject	*AVHRR SCFV CRDP v2.0*	*AVHRR SCFG CRDP v2.0*
Data volume	35 GB	34 GB
DOI	10.5285/763eb87e0682446cafa8c74488dd5fb8	10.5285/3f034f4a08854eb59d58e1fa92d207b6
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/763eb87e0682446cafa8c74488dd5fb8	https://catalogue.ceda.ac.uk/uuid/3f034f4a08854eb59d58e1fa92d207b6

Tab. B.4: AVHRR based SCF CRDP v3.0 characteristics.

Subject	*AVHRR SCFV CRDP v3.0*	*AVHRR SCFG CRDP v3.0*
Data volume	617 GB	614 GB
Number of files	40,710	40,710
DOI	10.5285/7491427f8c3442ce825ba5472c224322	10.5825/56ff07acabab42888afe2d20b488ec49
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/7491427f8c3442ce825ba5472c224322	https://catalogue.ceda.ac.uk/uuid/56ff07acabab42888afe2d20b488ec49

C. SWE CRDP V1.0, V2.0 AND V3.1 CHARACTERISTICS

Tab. C.1: Time series characteristics for SWE CRDP V1.0, CRDP V2.0 and CRDP V3.1.

Subject	*Description SWE v1.0*	*Description SWE v2.0*	*Description SWE v3.1*
Thematic variable	Snow Water Equivalent (SWE)	Snow Water Equivalent (SWE)	Snow Water Equivalent (SWE)
Retrieval algorithm	FMI GlobSnow SWE algorithm, (Takala et al. 2011)	FMI GlobSnow SWE algorithm, (Takala et al. 2011)	FMI GlobSnow SWE algorithm, (Takala et al. 2011)
Uncertainty algorithm	Takala et al. 2011	Takala et al. 2011	Takala et al. 2011
Satellite(s)	Nimbus-7, DMSP F8, DMSP F11, DMSP F13 and DMSP F17	Nimbus-7, DMSP F8, DMSP F11, DMSP F13 and DMSP F17	Nimbus-7, DMSP F8, DMSP F11, DMSP F13 and DMSP F17
Sensor(s)	SMMR, SSM/I and SSMIS	SMMR, SSM/I and SSMIS	SMMR, SSM/I and SSMIS
Geographical domain(s)	Northern Hemisphere (excluding mountains/glaciers/ice sheets/water)	Northern Hemisphere (excluding mountains/glaciers/ice sheets/water)	Northern Hemisphere (excluding mountains/glaciers/ice sheets/water)
Temporal resolution	Daily (bi-daily for 1979-1987)	Daily (bi-daily for 1979-1987)	Daily (bi-daily for 1979-1987)
Start date time series	6 January 1979	6 January 1979	6 January 1979
End date time series	31 May 2018	30 May 2020	30 May 2022
Grid size	0.25°	0.10°	0.10°
Projection/datum	Geographical (lat/lon)/WGS 84	Geographical (lat/lon)/WGS 84	Geographical (lat/lon)/WGS 84
File format	NetCDF4, CF-v1.7	NetCDF4, CF-v1.9	NetCDF4, CF-v1.9
Product version	Version 1.0	Version 2.0	Version 3.1

Tab. C.2: SWE CRDP V1.0, CRDP V2.0 and CRDP V3.1 characteristics.

Subject	*SWE CRDP v1.0*	*SWE CRDP v2.0*	*SWE CRDP v3.1*
Data volume	110 GB	115 GB	30 GB
DOI	10.5285/ fa20aaa2060e40cabf5fedce7a9716d0	10.5285/4647cc9ad3c044439d6c643208d3c494	10.5285/9d9bfc488ec54b1297eca2c9662f9c81
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/ fa20aaa2060e40cabf5fedce7a9716d0	https://catalogue.ceda.ac.uk/uuid/ 4647cc9ad3c044439d6c643208d3c494	https://catalogue.ceda.ac.uk/uuid/9d9bfc488ec54b1297eca2c9662f9c81