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Climate Research Data Package



SNOW
cci

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<p><u>Abstract:</u></p> <p>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 <i>snow_cci</i> 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.</p> <p>This document describes the outcome of the product generation in the second iteration of the <i>snow_cci</i> 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 and AATSR (four 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.</p>			
<p>The work described in this report was done under ESA Contract. Responsibility for the contents resides in the author or organisation that prepared it.</p>			
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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 second iteration of the *snow_cci* project. The outcome is the Climate Research Data Package – time series of products – generated for snow cover fraction (SCF) based on the sensors MODIS, AVHRR, ATSR-2 and AATSR (four 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 now available an estimate of the uncertainty of the variable per grid cell. This is included as a separate data layer.

1.2. Document Structure

The snow cover fraction datasets based on optical sensors consisting of MODIS-, AVHRR-, ATSR-2- and AATSR-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.

1.4. Acronyms

AVHRR	Advanced Very High Resolution Radiometer
CCI	Climate Change Initiative
CP	Contractual Phase
DARD	Data Access Requirement Document
DMSP	Defence Meteorological Satellite Program
ESA	European Space Agency
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
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 from MODIS covers the period 2000–2020. Global SCF products are available at daily temporal resolution with cloud cover flagged. The product is based on 1 km data from the MODIS sensor aboard the Terra satellite (launched 1999). The product version 1.0 includes two SCF variables, each with the associated per-pixel uncertainty estimation [RD-7]:

- (i) the viewable snow cover fraction (SCFV) at the surface in open areas and on top of vegetation cover that is present, such as forest canopies, and
- (ii) the snow cover fraction on the ground (SCFG) for open areas and in forested areas, derived by applying a canopy correction for snow cover in forests.

The time series characteristics of MODIS-based SCF products are summarized in Table 2.1. Gaps in the time series due to missing MODIS acquisitions are listed in Table 2.2. Specific CRDP characteristics, including the data volumes, DOI and access points for each CRDP from MODIS data are provided in Table 2.3 for CRDP v1.0, and in Table 2.5 for CRDP v2.0.

Table 2.1: Time series characteristics.

<i>Subject</i>	<i>Description MODIS CRDP v1.0</i>	<i>Description MODIS CRDP v2.0</i>
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-5]	SCAmod (Metsämäki et al. 2005, 2012, 2015) adapted and improved for snow_cci [RD-6]
Uncertainty algorithm	Error propagation approach adapted from Salminen et al. (2018) [RD-7]	Error propagation approach adapted from Salminen et al. (2018) [RD-8]
Satellite(s)	Terra (NASA)	Terra (NASA)
Sensor(s)	MODIS	MODIS
Geographical domain(s)	Global	Global
Temporal resolution	Daily	Daily
Start date time series	25.02.2000	25.02.2000
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
File format	NetCDF4, CF-v1.8	NetCDF4, CF-v1.9
Product version	Version 1.0	Version 2.0

Table 2.2: Data gaps in the TERRA MODIS time series.

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
05.12.2018	05.12.2018	Corrupted MODIS input data

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 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	10.5285/3b3fd2daf3d34c1bb4a09efef3b8ea9
Data catalogue access	https://catalogue.ceda.ac.uk/uuid/ef8eb5ff84994f2ca416dbb2df7f72c7	https://catalogue.ceda.ac.uk/uuid/3b3fd2daf3d34c1bb4a09efef3b8ea9

Table 2.4: 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

For all MODIS data, a pre-classification was applied to identify snow-free areas. The RMSE for pixels defined as snow free by the pre-classification step is assumed to be zero. In the SCF product and associated uncertainty examples shown in Figure 2.1 to Figure 2.4, the colour coding for these areas is set to transparent, i.e. showing the background map.

The applied snow retrieval algorithm is based on the SCAMod algorithm (Metsämäki et al. 2015) but replacing the constant reflectance values for snow-free forested areas and snow free ground,

suggested by Metsämäki et al. (2015), with spatially variable reflectance derived from statistical analyses of a time series of MODIS reflectance values [RD-5]. While for the 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 the CRDP v2.0 using reflectance data of the years 2000 to 2015 [RD-6]. For the CRDP v2.0, also the wet snow reflectance used in the SCAMod algorithm has been updated [RD-6] based on statistical analysis of spatially distributed MODIS reflectance data acquired at full snow cover conditions.

For all pixels used for the SCF retrieval algorithm (Figure 2.1 and Figure 2.3), the RMSE is estimated per pixel and provided as an uncertainty layer (cf. Figure 2.2 and Figure 2.4).

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-5], [RD-6]. The cloud mask per product is also overlaid on the associated 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 LandCover product for the year 2000 (ESA Land Cover CCI project team; Defourny 2016).

Further, pixels with large solar zenith angles ($> 83^\circ$) are classified as (polar) night and are masked in all 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 all layers.

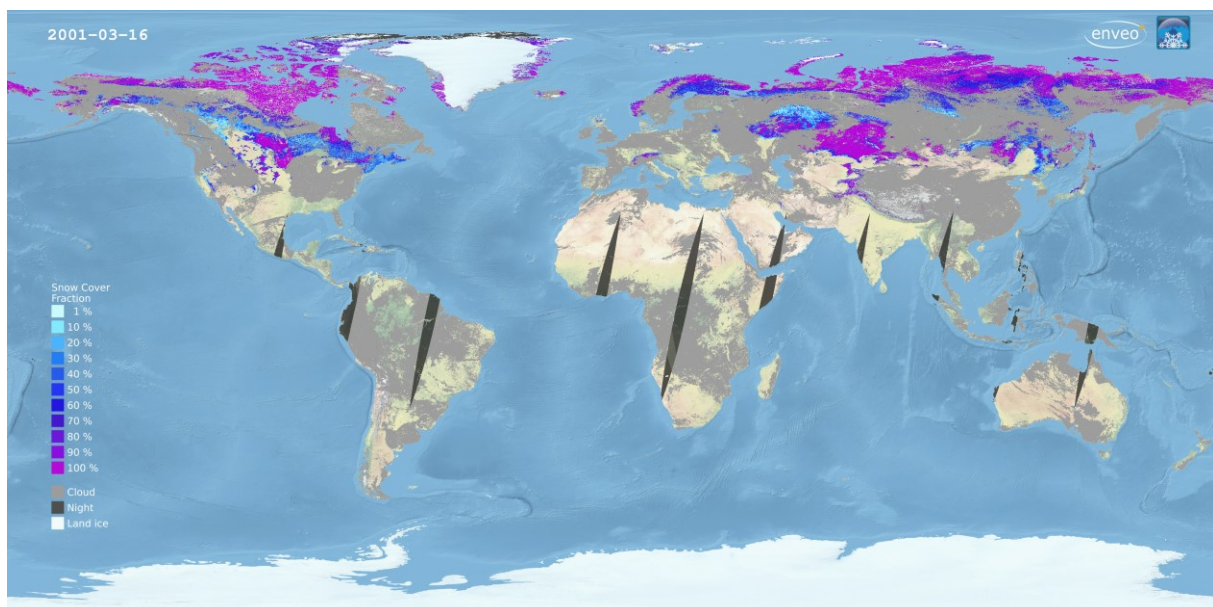


Figure 2.1: Example of SCFV product (CRDP v2.0) from Terra MODIS data of 07 March 2001.

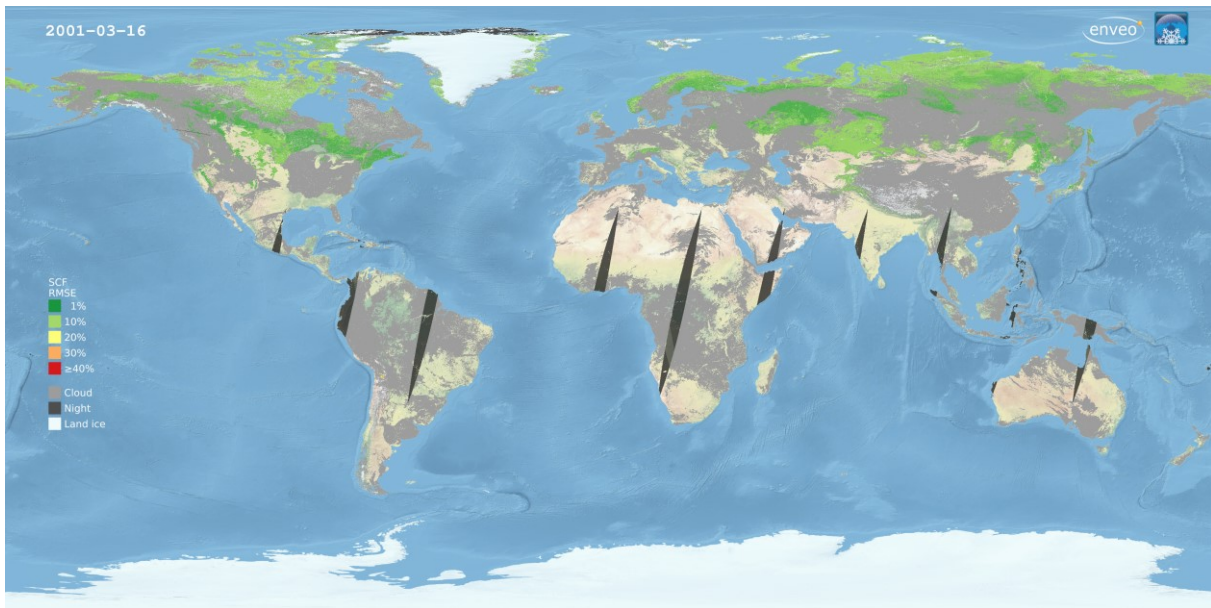


Figure 2.2: Example of corresponding SCFV uncertainty layer (CRDP v2.0) from Terra MODIS data of 07 March 2001. The RMSE for pixels defined as snow free by the pre-classification step is assumed to be zero and are set to transparent in the colour coding. For all pixels used for the SCFV retrieval algorithm, the RMSE is provided.

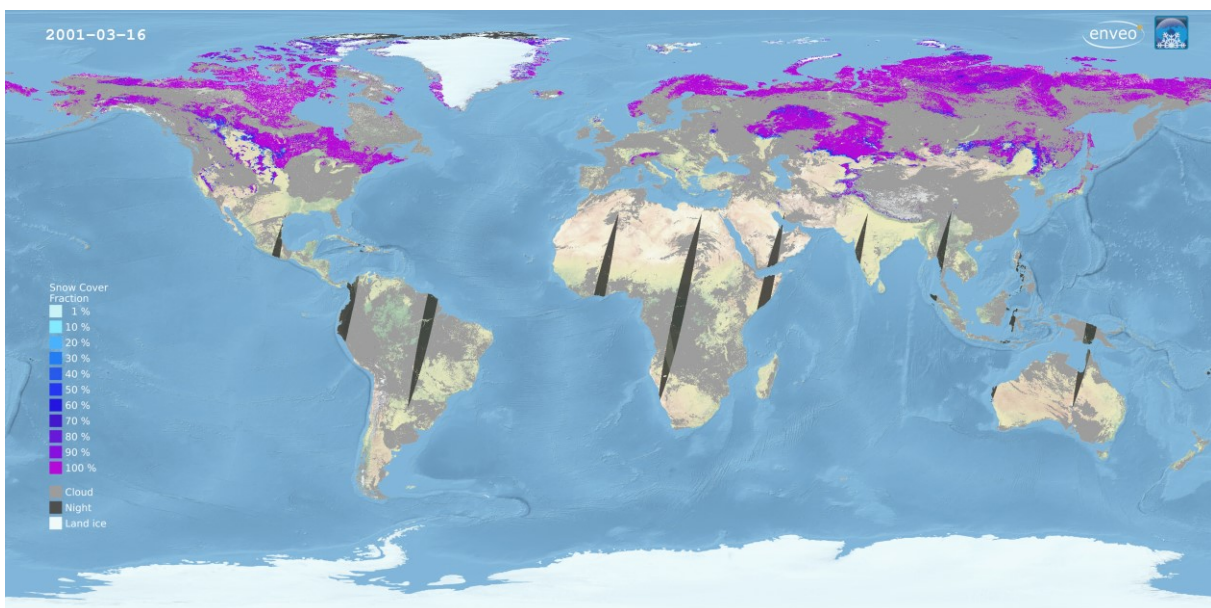


Figure 2.3: Example of SCFG product (CRDP v2.0) from Terra MODIS data of 16 March 2001.

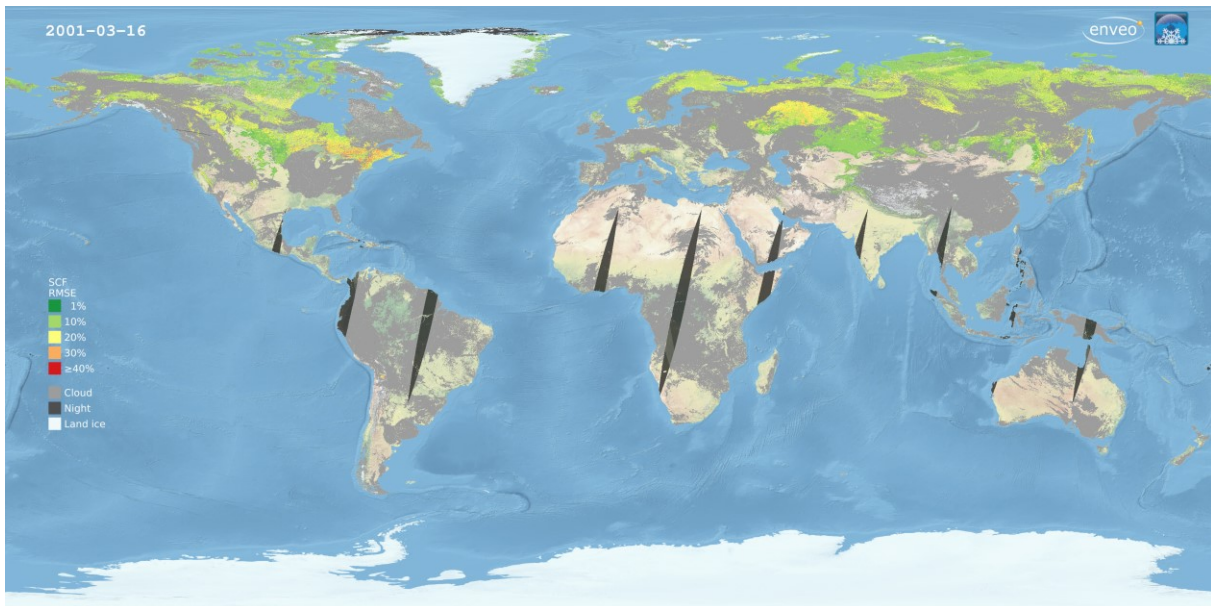


Figure 2.4: Example of corresponding SCFG uncertainty layer (CRDP v2.0) from Terra MODIS data of 31 March 2002. The RMSE for pixels defined as snow free by the pre-classification step is assumed to be zero and are set to transparent in the colour coding. For all pixels used for the SCFG retrieval algorithm, 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 pre-processed AVHRR GAC (Global Area Coverage) data from the ESA Cloud CCI project, a time series (1982–2020) was generated utilising the fractional snow retrieval algorithm of Salomonson and Appel (2006) as pre-condition (FSC (NDSI) > 5%) before utilizing the SCAMod algorithm (Metsämäki et al. 2015) for viewable snow (SCFV) and snow on ground (SCFG). The procedure is based on the normalised difference snow index (NDSI) and includes a linear scaling of the NDSI values to retrieve fractional snow (viewable snow). 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). Finally, a post-processing for latitudes ±15° and elevations below 1000 m a.s.l. was added (channel 1 < 0.30 or channel 4 > 270 K) to remove erroneous data in the tropical regions.

The time series has daily temporal resolution and includes all datasets from the NOAA prime satellites (Table 2.5) with a spatial resolution of 0.05° (GAC). The SCF time series from AVHRR has the following data gaps (no AVHRR data available): 1 November – 31 December 1994 and 1–31 January 1995. CRDP characteristics are provided in Table 2.6 and Table 2.7. Product examples in Figure 2.5– Figure 2.8.

Table 2.5: Time series characteristics.

<i>Subject</i>	<i>Description AVHRR CRDP v1.0</i>	<i>Description AVHRR CRDP v2.0</i>
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	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]
Uncertainty algorithm	Salberg et al. 2020 [RD-7]	Salberg et al. 2021 [RD-8]
Satellite(s)	NOAA-7, -9, -11, -14, -16, -18, -19	NOAA-7, -9, -11, -14, -16, -18, -19
Sensor(s)	AVHRR/2, AVHRR/3	AVHRR/2, AVHRR/3
Geographical domain(s)	Global	Global
Temporal resolution	Daily	Daily
Start date time series	1 January 1982	1 January 1982
End date time series	31 December 2019	31 December 2020
Grid size	0.05°	0.05°
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 2.0

Table 2.6: 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

Table 2.7: 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

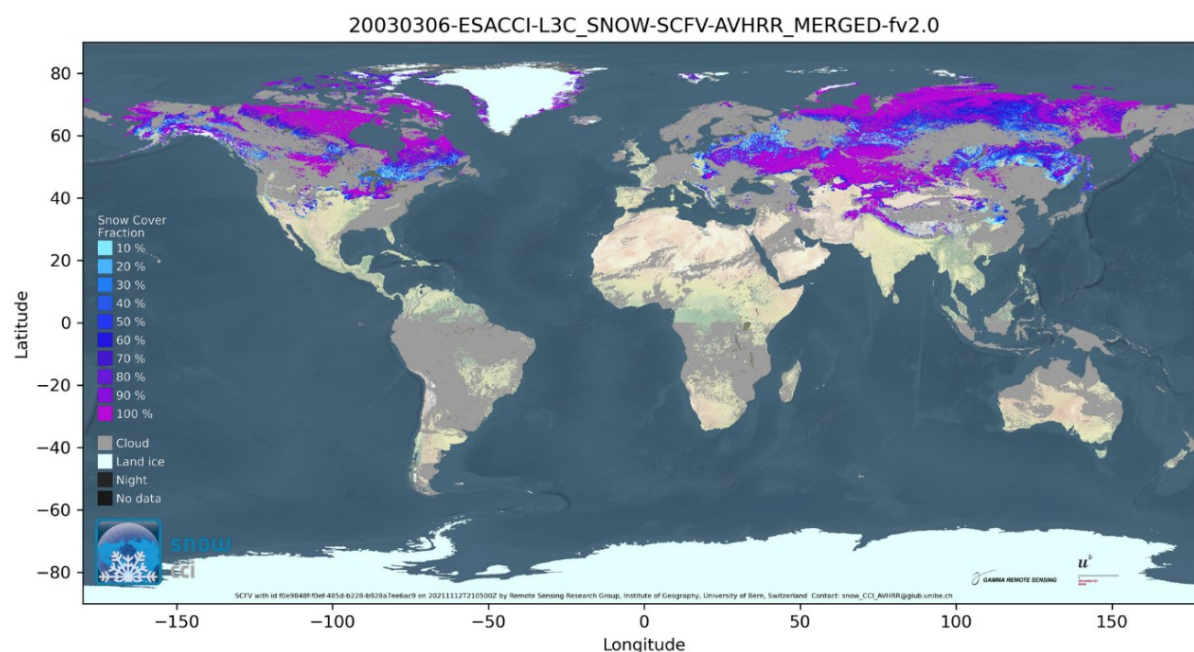


Figure 2.5: SCFV product example (CRDP v2.0) for 6 March 2003.

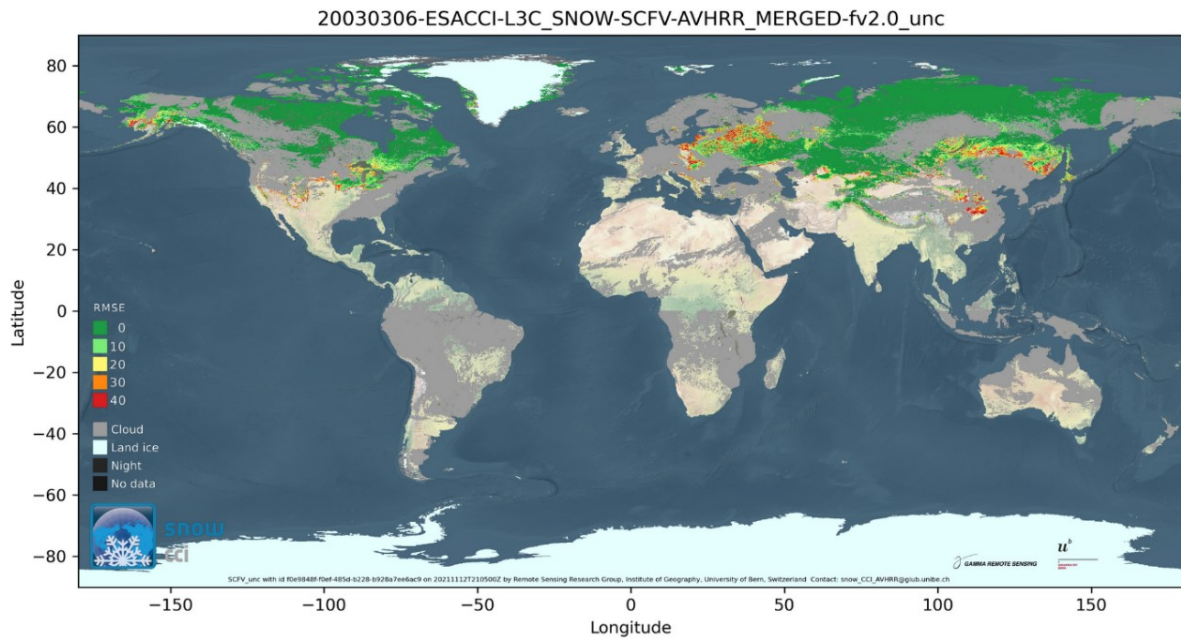


Figure 2.6: Uncertainty for SCFV product example (CRDP v2.0) on 6 March 2003.

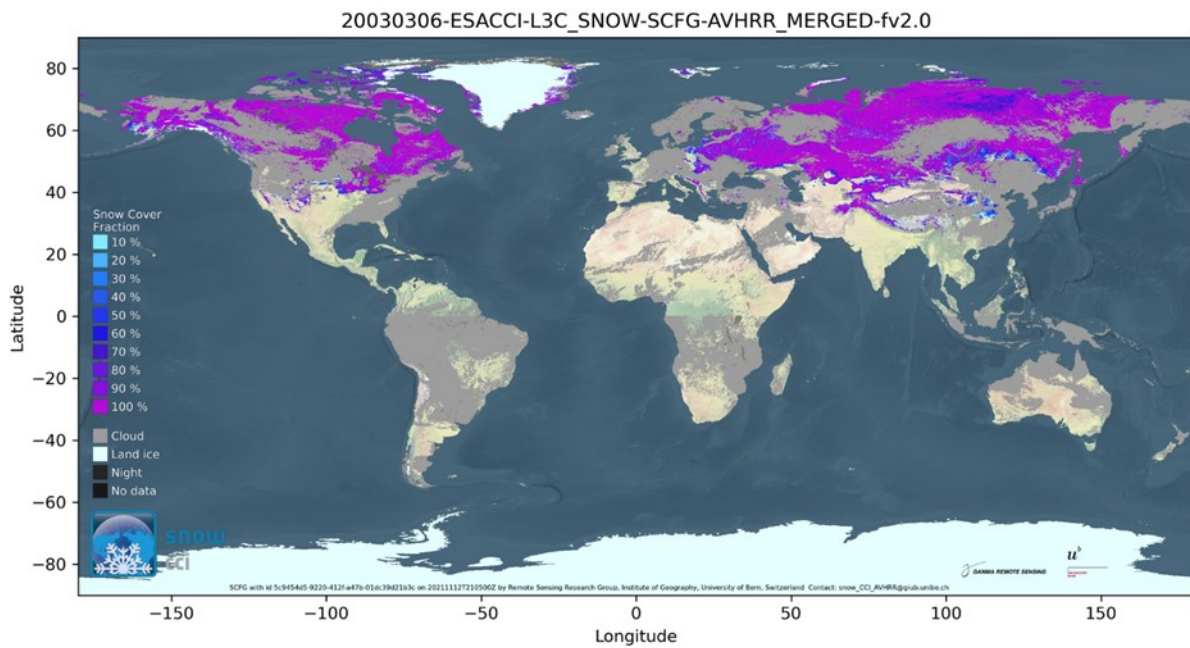


Figure 2.7: SCFG product example (CRDP v2.0) for 6 March 2003.

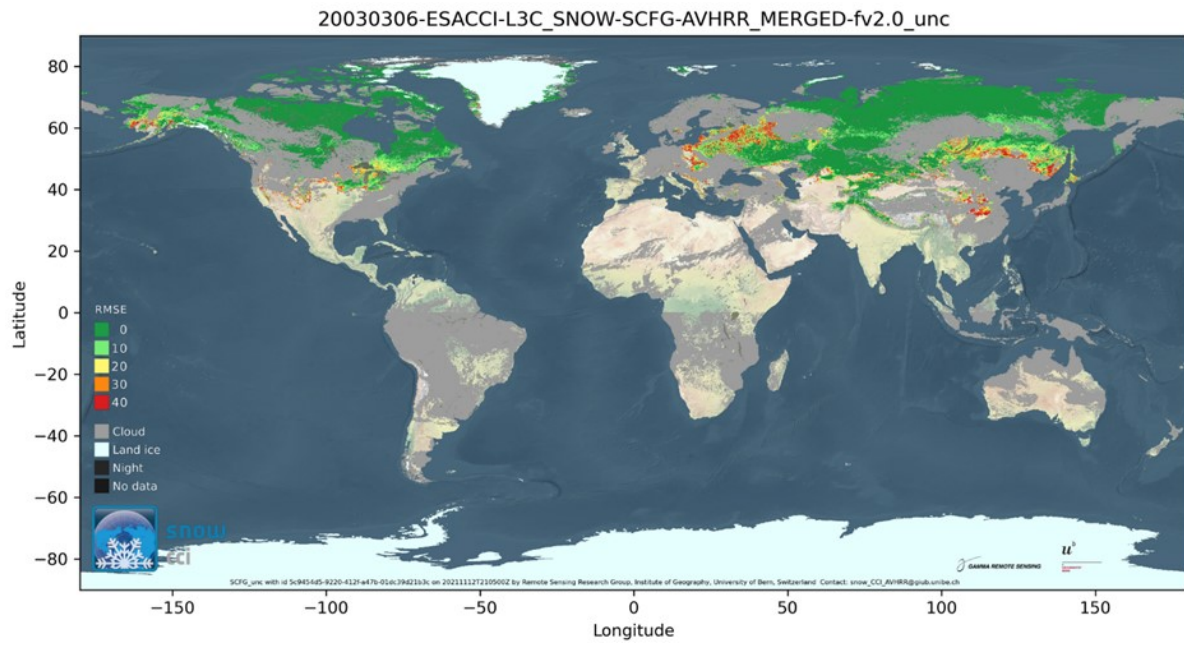


Figure 2.8: Uncertainty for SCFG product example (CRDP v2.0) on 6 March 2003.

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 2.8. Gaps in the time series due to missing acquisitions are listed in Table 2.9. Specific CRDP characteristics are provided in Table 2.10 and Table 2.11. Product examples are provided in Figure 2.9 – Figure 2.12.

Table 2.8: Time series characteristics.

<i>Subject</i>	<i>Description ATSR-2 CRDP v2.0</i>	<i>Description AATSR CRDP v2.0</i>
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 2.9: Data gaps in the ATSR-2 and AATSR time series.

<i>Start date</i>	<i>End date</i>	<i>Reason</i>
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 2.10: ATSR-2 CRDP v1.0 characteristics.

<i>Subject</i>	<i>SCFV ATSR-2 CRDP v2.0</i>	<i>SCFG ATSR-2 CRDP v2.0</i>
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 2.11: 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.

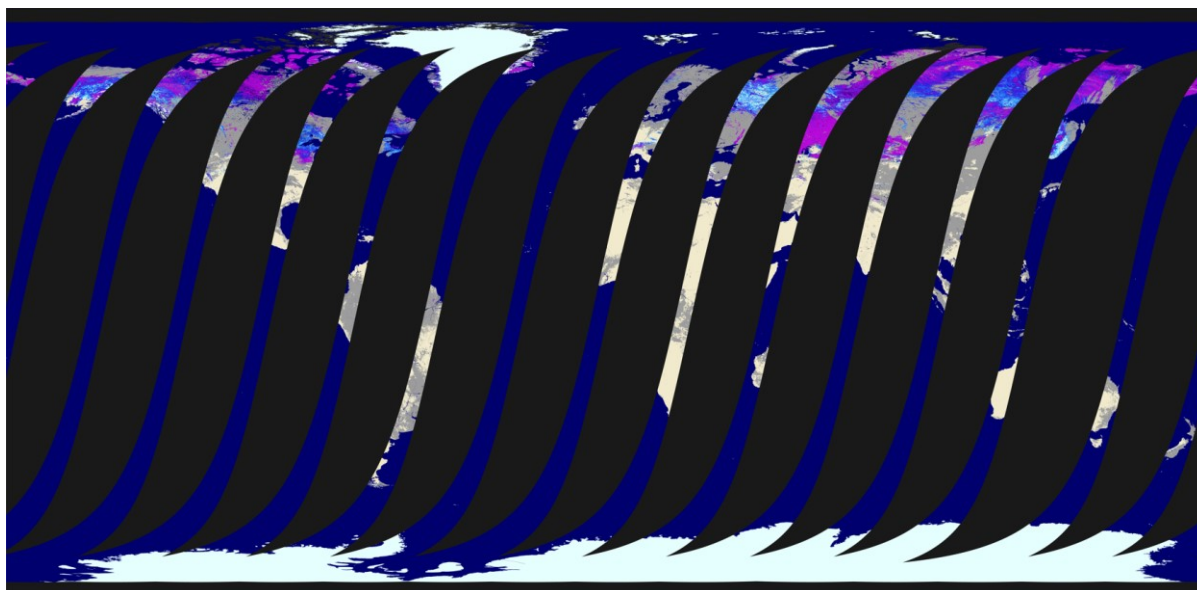


Figure 2.9: SCFV product example from ENVISAT AATSR (CRDP v1.0) on 10 March 2003.

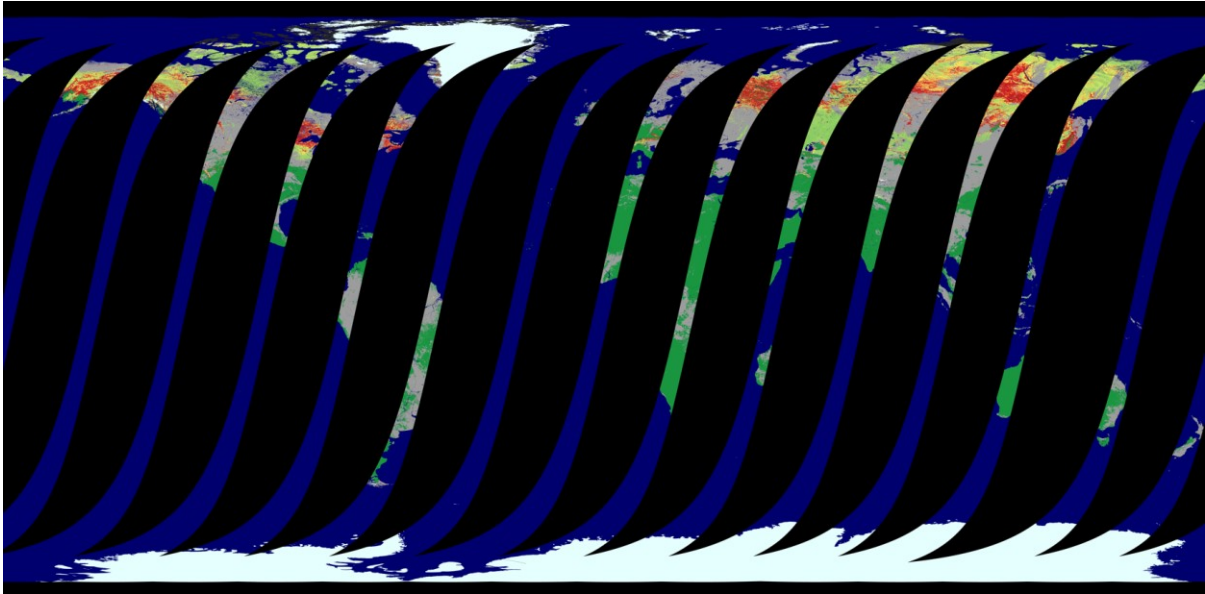


Figure 2.10: Uncertainty estimation for the SCFV product from ENVISAT AATSR (CRDP v1.0) on 10 March 2003.

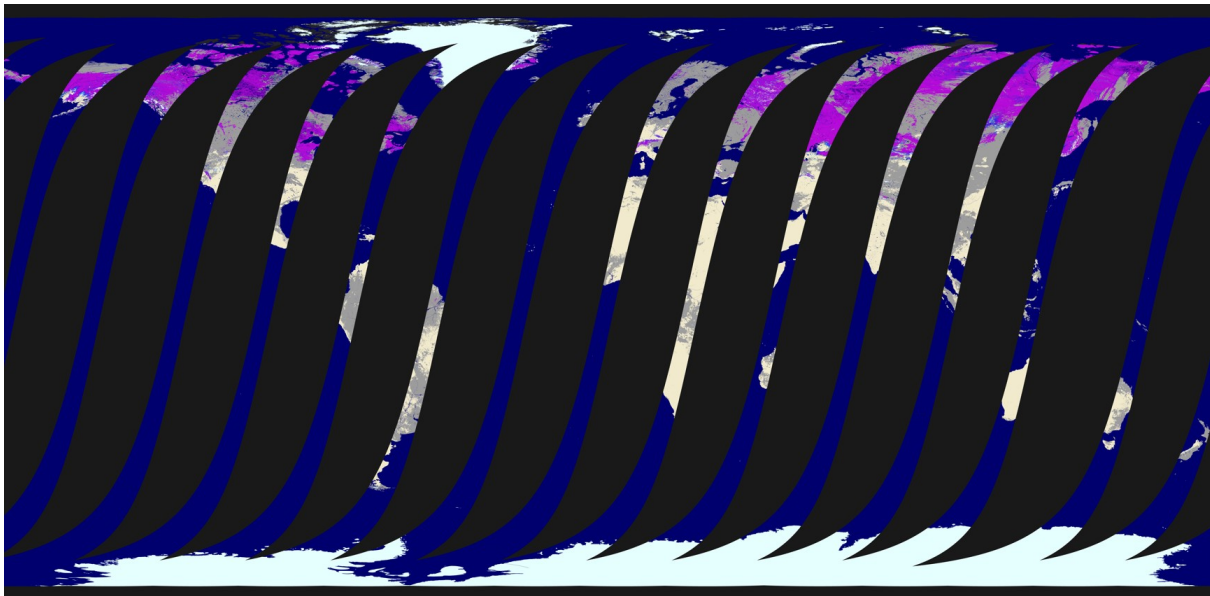


Figure 2.11: SCFG product example from ENVISAT AATSR (CRDP v1.0) on 10 March 2003.

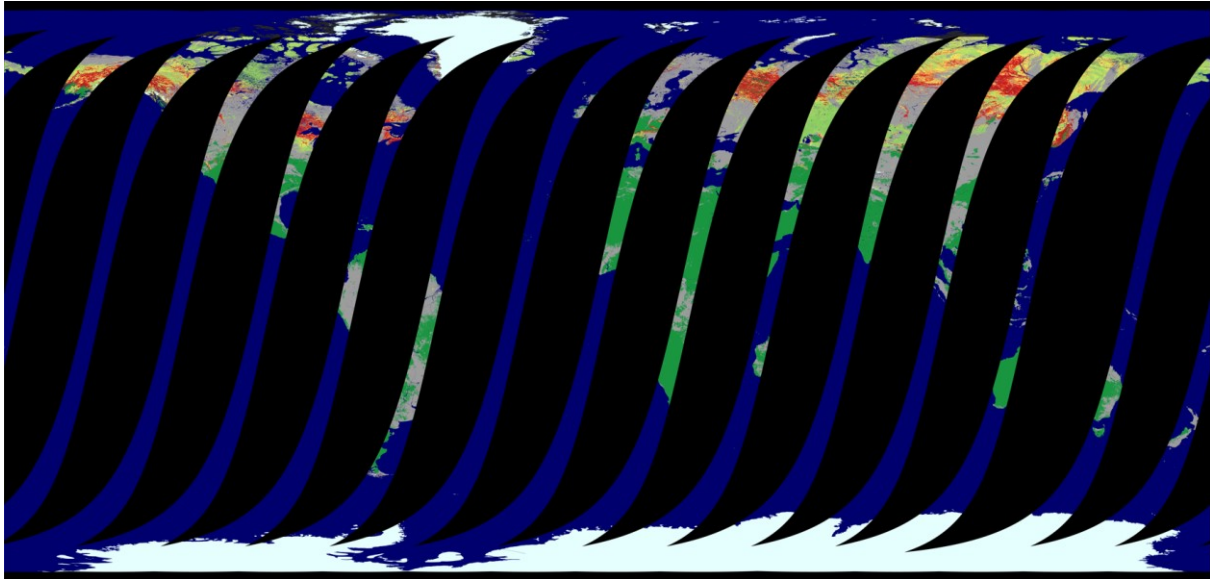


Figure 2.12: Uncertainty estimation for the SCFG product from ENVISAT AATSR (CRDP v1.0) on 10 March 2003.

3. SNOW WATER EQUIVALENT

The *snow_cci* SWE data record, based on methodology by Pulliainen (Pulliainen 2006 and Takala et al. 2011) 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 1988–2020, 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 (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.

Table 3.1: Time series characteristics.

<i>Subject</i>	<i>Description SWE v1.0</i>	<i>Description SWE v2.0</i>
Thematic variable	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)
Uncertainty algorithm	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
Sensor(s)	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)
Temporal resolution	Daily (bi-daily for 1979-1987)	Daily (bi-daily for 1979-1987)
Start date time series	6 January 1979	6 January 1979
End date time series	31 May 2018	30 May 2020
Grid size	0.25°	0.10°
Projection/datum	Geographical (lat/lon)/WGS 84	Geographical (lat/lon)/WGS 84
File format	NetCDF4, CF-v1.7	NetCDF4, CF-v1.9
Product version	Version 1.0	Version 2.0

Table 3.2: SWE CRDP characteristics.

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

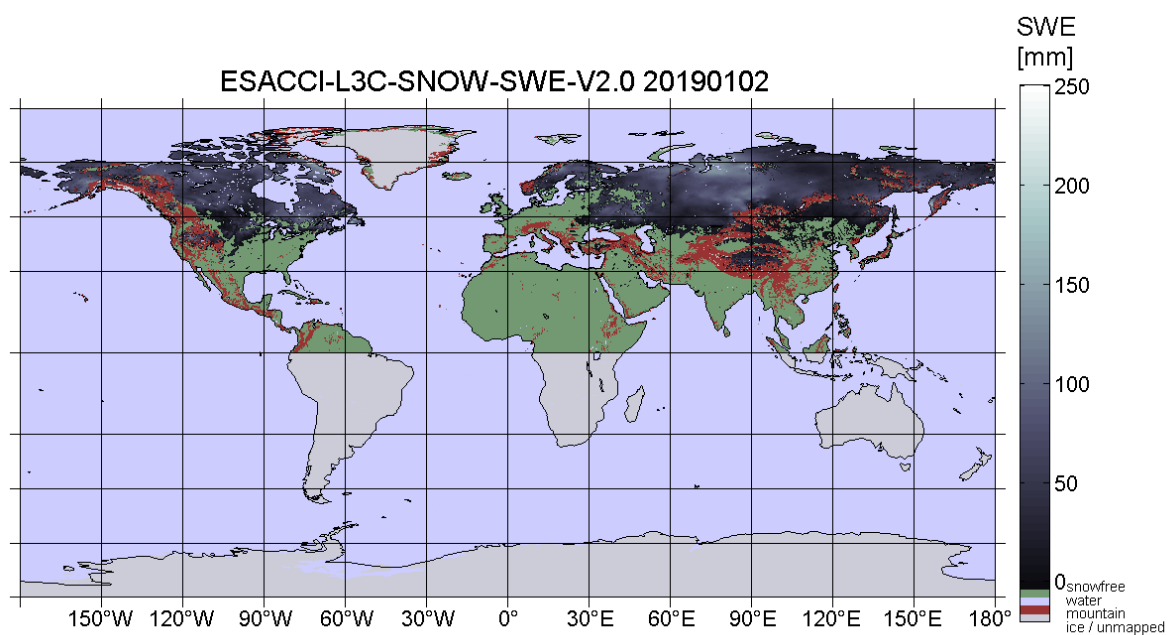


Figure 3.1: Example of SWE product (CRDP v2.0) for 2 January 2019.

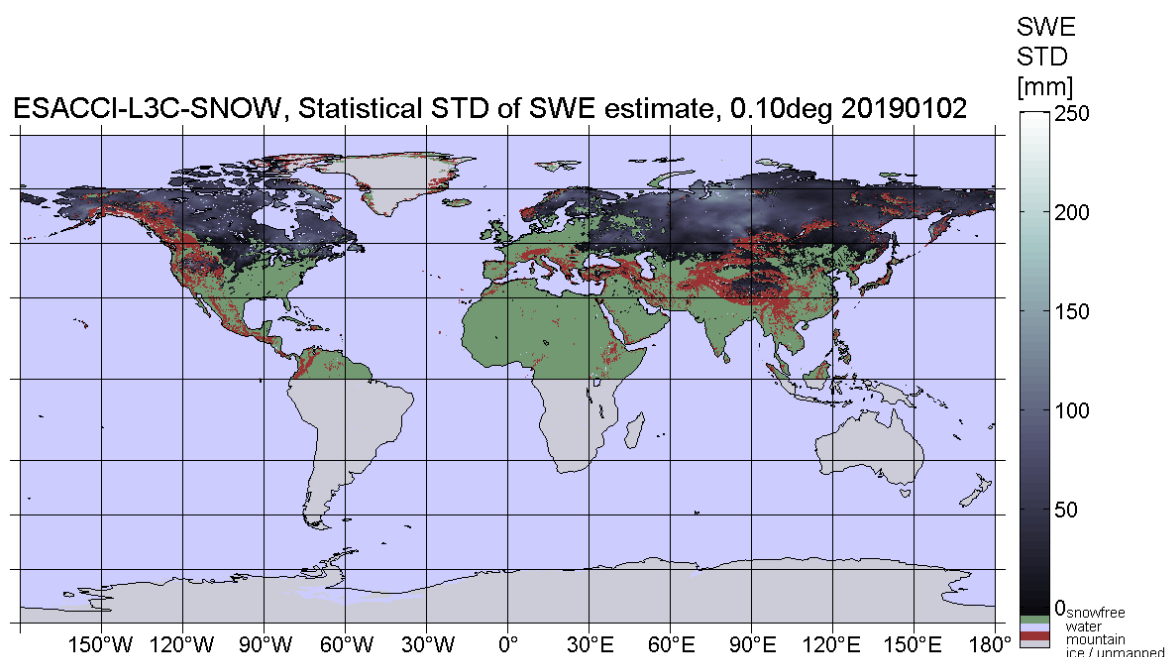


Figure 3.2: Example of corresponding SWE uncertainty layer (CRDP v2.0) for 2 January 2019.

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