ESA Climate Change Initiative (CCI+)

Essential Climate Variable (ECV)

Greenland_Ice_Sheet_CCI+ (GIS_cci+)

User Requirements Document (URD)

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Table of Contents

Change Log

Issue	Author	Affected Section	Reason	Status
1.0	NBI	All	Document Creation and write draft	2019-06-28

Acronyms

Acronym	Explanation
AD	Applicable Document
AIS	Antarctic Ice Sheet
CCI	Climate Change Initiative
CFL	Calving Front Location
CMUG	Climate Modelling User Group
CRG	Climate Research Group
ECV	Essential Climate Variable
EGU	European Geophysical Union
EO	Earth Observation
ESA	European Space Agency
GIS	Greenland Ice Sheet
GCOS	Global Climate Observing System
GCW	Global Cryosphere Watch
GMB	Gravimetric Mass Balance
GLL	Grounding Line Location
IASC	International Arctic Science Committee
IMBIE	The Ice sheet Mass Balance Inter-comparison Exercise
IS	Ice Sheets
IPCC	Intergovernmental Panel on Climate Change
IV	Ice Velocity
MFID	Mass Flow Rate and Discharge
NASA	National Aeronautics and Space Administration
NetCDF	Network Common Data Form
NSIDC	National Snow and Ice Data Center
PROMICE	Programme for Monitoring of the Greenland Ice Sheet
RD	Reference Document
SEC	Surface Elevation Change
SCAR	Scientific Committee for Antarctic Research
SoW	Statement of Work
URD	User Requirements Document
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

1 Introduction

This document is the User Requirements Document (URD) prepared for the "Greenland_Ice_Sheet_cci+" (GIS_cci+) project in accordance to the Contract [AD1] and the Statement of Work (SoW) [AD2].

The objective of the URD is to document the user requirements of climate science and climate services for the development of the ECV data products. The ECVs in the GIS_cci+ project are:

- Surface elevation change (SEC)
- Ice velocity (IV)
- Gravimetric Mass Balance (GMB)
- Mass Flow Rate and Ice Discharge (MFID)

The three first ECVs (SEC, IV, GMB) are heritage from the Greenland_Ice_Sheets_cci Phase 2 project, and the fourth (MFID) is added to the ECV parameter portfolio in the Greenland_Ice_Sheet_cci+ project according to the SoW [AD2].

In addition to the ECVs, an experimental product is developed: a lake drainage data product (LAKES) described in the Technical Proposal [RD1].

1.1 Purpose and Scope

The URD document is part of Task 1 Requirements Analysis deliverables, with deliverable id: D1.1. The URD is updated at the beginning of each review-design-produce-assess cycle as described in the SoW [AD2]. This version of the URD is the initial cycle 1 version.

The URD for the Greenland_Ice_Sheet_cci+ project is updated based upon the current ECV requirements according to the GCOS 2016 Implementation Plan [GCOS (2016)]. The documents from the previous results CCI ECV project, specifically on the URD and the CAR compiled in Phase 2 of the Ice Sheets cci ([RD2]and [RD3]) are also considered. The update is done through engagement with the user community, as well as consultation with the CRG.

In preparation of this URD, we have not performed an independent user survey within the community, but we have relied on previous extensive user surveys performed in 2012 and 2014 as part of the Phase 1 Ice_sheets_cci [RD4] and Phase 2 Antarctic_Ice_sheet_cci [RD5], respectively. These surveys provided a consistent overview of user groups and user requirements. In the Greenland_Ice_Sheet_cci+ project, the new ECV, MFID, and the research product LAKES potentially involves additional new user groups related to local meltwater and hydropower plants in Greenland. This is discussed in chapter 2 below.

We have continuously involved the user community in the previous cci projects, thereby prepared for this update of the URD. The user involvement has been done through the homepage, newsletters distributed by an updated email list, and by presentation of cci data products at scientific conferences and at other meetings. In addition, we have here surveyed the literature and on-line data archives to assess requirements within different user groups, and finally, the CRG have been consulted for feedback on the user requirements.

The user requirement analysis for the Greenland_Ice_Sheets_cci+ was performed on this basis.

1.2 Document Structure

This document is structured as follows:

- Chapter 1 describes the purpose and structure of the document
- Chapter 2 describes the background and the user groups for the Greenland_Ice_Sheets_cci+.
- Chapter 3 analyses the user requirements using various sources.
- Chapter 4 provides the download statistics of the released products.
- Chapter 6 concludes the document and provide an overview of user requirements.

1.3 Applicable and Reference Documents

Table 1.1: List of Applicable Documents

No	Doc. Id	Doc. Title	Date	Issue/ Revision/ Version
AD1	ESA/Contract No. 4000126023/19/I-NB, and its Appendix 1	CCI+ Phase 1 New R&D pm CCI ECVs for Greenland _Ice Sheet_cci		-
AD2	ESA-CCI-EOPS-PRGM-SOW-18-0118	Climate Change Initiative Extension (CCI+) Phase 1 – New R&D on CCI ECVs – SoW	2018.05.31	Issue 1 Revision 6

Table 1.2: List of Reference Documents

No	Doc. Id	Doc. Title	Date	Issue/ Revision/ Version
RD1	ST-DTU-ESA-CCI-P2-GIS-TROP	Technical Proposal (TPROP) of Greenland_Ice_Sheet_CCI+	2018.09.09	
RD2	ST-DTU-ESA-ISCCI-URD-001-v2.4	User Requirement Document (URD), for Phase 2	2018.06.28	2.4
RD3	ST-DTU-ESA-ISCCI-CAR-001	Climate Assessment Document (CAR). for Phase 2	2018.10.26	3.1
RD4	ST-DTU-ESA-ISCCI-URD-001	User Requirement Document (URD), for Phase 1	2012.08.03	1.5
RD5	ST-DTU-ESA-ISCCI-CAR-001	Climate Assessment Document (CAR). for Phase 1	2015.09.28	2.1

Note: If not provided, the reference applies to the latest released Issue/Revision/Version

Table 1.3: List of Other References

[GCOS (2016)] – GCOS-200 The Global Observing System for Climate: Implementation Needs. Available online at https://library.wmo.int/opac/doc_num.php?explnum_id=3417.

2 Background

2.1 The need for Ice Sheets ECV products

Ice sheet monitoring: There is a global focus on understanding the current mass loss of ice sheets and the processes controlling their response to climate changes. Increasing evidence of sustained mass loss from land ice worldwide has generated a need to understand the consequences of present and future climate changes on ice sheet mass and to predict their future contribution to the global and regional sea level change.

Glaciological and Cryospheric research: . In the recent years, the fast-flowing marine outlet glaciers in both Greenland and Antarctica have attracted a significant interest both from the scientific community and the general public because these glaciers experience a large mass loss. A major uncertainty in predicting future sea level is, however, that the processes controlling the dynamic mass loss from marine terminating glaciers are not fully understood. While the bedrock and fjord geometries exert a control on the retreat and stability, atmospheric and oceanic conditions have been proposed to be the driver of the observed mass loss, and the floating tongues and formation of sea ice at the front may affect upstream flow through buttressing effects. Monitoring the changes in high temporal and spatial resolution is needed to resolve the responses of these dynamic outlet glaciers to atmospheric and oceanic drivers. New IV products based on the Sentinels have higher spatial and temporal resolution than previously possible, and this has provided new opportunities for the climate modelling community which has been able to utilize these data to their full extent.

Ice sheet modelling: Although ice sheet models have recently been developed to a higher order that includes ice stream dynamics, the numerical schemes are complex. Model simulations require large computer resources and the capacity of the computing systems implies constraints on the possible space and time resolution. Continental-scale ice sheet models are still running on a lower resolution than available satellite data, e.g. surface elevation and velocity, and are thus not using the full capacity of satellite-based data in validations, but the gap has been closing in recent years. These models generally need long time series to understand the effect of large-scale changes in climate and precipitation. To understand the processes controlling changes in ice flow and outlet glaciers, it is necessary to have access to high-resolution observations. A number of studies have recently been devoted to studies of ice stream flow and seasonal behaviour of outlet glaciers using state-of-the-art higher-order models thereby increasing the demand for multi-year records of high-resolution observations in both time and space.

Climate modelling: In recent years, community ice flow models have been developed and coupled into climate models, mostly off-line, but progress is made into fully coupled climate and ice sheet model systems. The purpose of these coupled modelling efforts is to investigate the coupled response and evolution of ice sheets, in particular to understand the past evolution or future contribution to the global sea level. With increasingly higher resolution and improved parameterizations, these model investigations are now able to use remote sensing products, e.g. IV or SEC, to tune the model parameters or validate model performance.

Marine ecosystems and environment: Changes in hydrology and melt water fluxes influence the environment and infrastructure locally around the fjords of Greenland. Changes in fresh water fluxes impact marine ecosystem and fishing opportunities, and the future potential of hydropower is essential for local planning. Access to long-term products is needed in order to adapt and mitigate to changing environmental conditions.

The international research community is relatively un-organized in regards of a formalized program to long-term monitor the Greenland Ice Sheet (GrIS) changes. The CCI program therefore fills a gap in systematically provide remote sensing data products from the Greenland ice sheet.

2.2 Users of Ice Sheets ECVs

Key end users of the Greenland_Ice_Sheet_cci ECV products can generally be divided into:

1. **Ice sheet modellers** who are using the ECV parameters to validate and/or initialize their models, e.g. comparing modelled and observed SEC, IV, GMB or MFID, or using the ECV parameters to constrain model parameters, e.g. constrain basal drag and ice viscosity by tuning modelled IV to fit observations.

2. **Remote sensing scientists** who monitor ice sheet changes and derive volume and mass changes from satellite observations.
3. **Glaciologists and surface mass balance scientists**, who are interpreting satellite observed volume and mass changes, e.g. deriving mass change from observed volume changes by using firn densification models, or comparing observed mass loss with estimates from surface mass balance models based on climate models and observations.
4. **Climate and Ocean modellers**, who are interested in the ice sheet component of the climate system and its interactions with other parts of the climate system, e.g. freshwater fluxes from ice sheet on shorter timescales or orographic forcing of wind patterns on longer timescales.
5. **Authorities and organizations** with an interest in local marine ecosystem or hydrology related to industrial or infrastructure issues, e.g. fishing industry or hydropower planning, practical planning, e.g. potential oil- and gas exploration around Greenland.

The direct users of the Greenland_Ice_Sheet_cci+ data products are thus a relatively broad group working with different approaches and at different levels. Their data needs are not the same, but the cci and cci+ program is a huge improvement in accessing relevant and reliable data in standard formats.

Experience from earlier phases of the Greenland_Ice_Sheet_cci program has demonstrated a strong interest from the user communities in long-term records of ice sheet ECVs from satellite observations to be available in user friendly formats and from easily accessible platforms.

The new IV data produts resolve the seasonal variation of ice dynamics in outlet glaciers, and has opened for a new type of glacier studies on seasonal timescales as well of planning opportunities for local authorities, which were not possible before.

3 Analysis of users requirements

3.1 CGOS Requirements for the Primary ECV Parameters

The Global Climate Observing System (GCOS) represents the scientific and technical requirements of the Global Climate Observing System on behalf of United Nations Framework Convention on Climate Change (UNFCCC) and Intergovernmental Panel on Climate Change (IPCC).

According to GCOS [GCOS (2016)], efforts should be made to:

(a) understand the processes related to the increase in mass loss of both ice sheets through improved observations and in situ measurements;

(b) reduce uncertainties in estimates of mass balance by improving measurements of ice-sheet topography and velocity and ice-sheet modelling to estimate future sea-level rises.

The GCOS definition for the Ice Sheets and Ice Shelves ECV states:

"The understanding of the timescale of ice-sheet response to climate change has changed dramatically over the last decade. Rapid changes in ice-sheet mass have surely contributed to abrupt changes in climate and sea level in the past."

The GCOS product requirements for the Greenland_Ice_Sheets_cci+ parameters are [GCOS (2016)]:

Target Requirements:

Product	Frequency	Resolution	Required measurement uncertainty	Stability
Surface elevation change	30 days	Horizontal 100m	0.1m/year	0.1m/year
Ice Velocity	30 days	Horizontal 100m	0.1m/year	0.1m/year
Ice mass change	30 days	Horizontal 100m	$10km^3$/year	$10km^3$/year
Grounding line location and thickness	yearly	Horizontal 50km; Vertical 10m	1m	10m/decade

Table 3.1. GCOS requirements 2016 [GCOS (2016)].

3.2 User requirements from Greenland_Ice_Sheet_cci Phase 2.

The previous phases of the Greenland_Ice_Sheet_cci had four ECVs: SEC, IV, GMB, GLL and CFL. The user requirements from the Phase 2 of the Greenland_Ice_Sheet_cci are summarized below [RD2]:

User requirements for ECV parameters					
	SEC	IV	GMB	GLL	CFL
MINIMUM spatial resolution	1-5km	100m-1km[1]	100 km	100m-1km	100m-500m[1]
OPTIMUM spatial resolution	<500m	50m-100m	50 km	50m	50m
MINIMUM temporal resolution	annual	annual	annual	annual	annual
OPTIMUM temporal resolution	monthly	monthly[1]	monthly	monthly	monthly[1]
MINIMUM accuracy	0.1-0.5m/yr	30m/yr		-	-

OPTIMUM accuracy	<0.1 m/yr	10m/yr	20 Gt	-	-
What times are observations needed	all year	all year	all year	all year	all year

Table 3.2. User requirements from Ice_Sheets_cci Phase 1 User Survey [RD2].
[1)] User requirements may later be updated on these parameters

In the user survey in the phase 1 of the Ice_Sheets_cci [RD4], the users were asked to provide any requirements they have to error information. Most users mentioned that error per data point would be the most valuable error information, but in some cases an overall error for the dataset would be sufficient.

Users were asked to prioritize the temporal and spatial coverage of data if required, for example in the case of limited resources to process data.

Four options were given for both SEC and IV (multiple choices were possible):

A. High resolution over entire ice sheet, snapshots or short time-series (SEC: 17%, IV: 34%).
B. Low resolution over entire ice sheet, long time-series (SEC: 28%, IV: 15%).
C. Low resolution in the interior, high resolution in coastal areas (SEC: 77%, IV: 64%).
D. Low resolution, except at specific fast flowing glaciers (SEC: 13%, IV: 28%).

3.3 SoW Requirements

The SoW [AD2] states that:

"The purpose of the Ice_sheets_Greenland_cci project is to provide users with high quality, stable and consistent ECV data records for use in science and for the development of services. GCOS provides a high-level specification of the requirements for Ice Sheets and Ice Shelves ECV products in the GCOS Implementation Plan (2016, [RD-1]). However, it is recognised that there is a spectrum of different user requirements within climate and ice sheet science, depending on different specific applications of the ECV."

The SoW has technical requirements (TR) to the user requirements analysis [AD2]:

[TR-14] The analysis shall use the GCOS expressed requirements for Ice Sheet ECVs by involving the key science bodies as conduits for community consensus and establish active interaction with the ice sheet and climate research communities.

- We are in contact with the ISMIP6 consortium regarding data formats for exchange of data.
- GIS_cci+ consortium members participate in various GCW, IPCC, IMBIE, and IASC cryosphere activities.
- All members of the PROMICE consortium are also members of the *GIS_cci+*.
- The PI of the proposal is also chairman of the Danish SCAR national committee, and together with *AIS_cci* members push the enhanced use of EO data also for Antarctic research.

[TR-15] As an update from CCI Phase 1 and 2, the Contractor shall identify potential new users who represent the broad variety of applications over ice sheets and survey their requirements for satellite-based Ice Sheet ECV products.

- This will be carried out as part of the User Requirements work package in two cycles.

- In the current cycle, new user group were identified related to the new ECV, MFID. These user groups are associated with marine ecosystems and marine biochemistry science, local authorities and companies in charge of fishing industry and infrastructure.

[TR-16] User requirements for ECV product uncertainties shall be re-assessed and updated if needed. This includes how the uncertainties should be expressed in the ECV products.

- According to an earlier user survey, users stated that the most valuable error information would be error per data point. However, in some cases an overall error for the data set would be sufficient.
- The uncertainty representation developed and implemented in the former Greenland_Ice_Sheet_cci will be continued into the Greenland_Ice_Sheet_cci+ products.

3.4 Requirements from the international research community

The Climate Modelling User Group (CMUG) is ESA's climate modelling expert group in the Climate Change Initiative (CCI) project. CMUG is a consortium comprising the Met Office Hadley Centre, the Max Planck Institute for Meteorology, the European Centre for Medium-Range Weather Forecasts (ECMWF) and Météo-France.

The Climate Research Group (CRG) is the Ice_Sheets_cci expert group who are engaged in the project and involved in understanding climate dynamics specifically related to the Ice Sheets ECV.

The CMUG and the CRG were invited to participate in the user survey during the earlier phases of the project. [RD4]. In preparation of the user requirements analysis, the CRG were consulted for feedback and input.

As part of the cooperation with the international research community outlined in the technical proposal [AD], a user workshop is planned in Nuuk, 2021, in connections with a dedicated Greenland meeting on cryosphere changes. Here users of ECV data and stakeholders will present and discuss research related to the ECV products.

3.5 Overview of planned data products

The Technical Proposal presents an overview of the planned ECV production scheme (see table). The ECV production will accommodate the user requirements, however, with a yearly cycle of the SEC and of the IV in the interior due to the limited funding of the cci+ [AD3].

ECV product	Spatial resolution	Temporal resolution	Period for cci/cci+ FDCR	Satellite/other data and regions for cci+
SEC	5 km	1 year	1992-2021	CryoSat-2, Sentinel-3, IceSat-2, AltiKa All ice-sheet Experimental merged product for all missions to be developed
IV	250 m	1 year 6 days in margin zone	1992-2021 (12 or 6 day repeat data since 2014)	Sentinel-1A/B (radar) All Greenland on yearly basis Data for all margin zone through *CryoPortal* Optical IV data over ice streams from Sentinel-2 and Landsat-8 Lake drainage data IV rapid changes
GMB	25 km	Monthly	2002-2021 (break 2017-18)	GRACE-FO Greenland-wide and Zwally drainage basins
MFID	N/A (500 m internal grid spacing)	Quarterly values across basins	2014-2021 (2010- for select ice streams)	Sentinel-1 for IV (supplemented with earlier EnviSat and CosmoSkymed data) Thickness data from IceBridge/PROMICE radar sounding. DMI HIRHAM firn models. 9 major ice streams

Table 3.5. Overview of the GIS_cci+ data products 2019-2021, extending the earlier GIS_cci ECV's [AD3].

4 Download Status of Data Products

The data products are released to the users for download at the Greenland_Ice_Sheets_cci data product website and from the CCI Data Portal. The download status provides important information on the interest and usage of the products.

The release of high-temporal resolution IV data products from Sentinel-1 in 2017 clearly demonstrated how these data are in high demand. Every year, with a whole new year of data being published, the interest is increasing, showing that only are the data in demand, the knowledge of these data must also be growing.

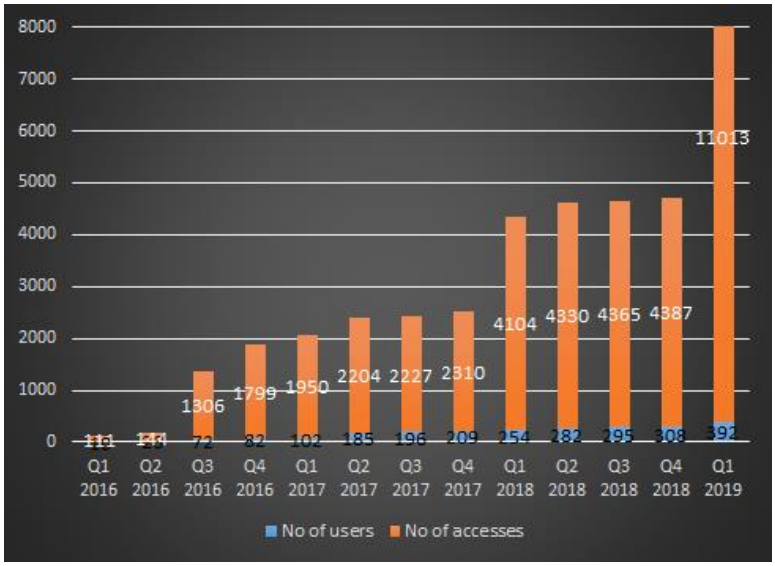

Figure 4.1. CCI Data Portal Usage (Last Update: Q1 2019, waiting for ESA's input).

Figure 4.2. Project Data Product Website Usage - Accumulated Downloads (Last Update: 20 Jun 2019).

5 Conclusions

The user requirements for the Greenland_Ice_Sheet_cci+ ECV parameters have been reviewed and updated from previous phases of the cci project.

The spatial resolution is particularly important for outlet glaciers [RD4]. The resolution is not similarly important in the central ice sheet areas. The required temporal resolution is annual, but monthly resolution would allow seasonal changes to be resolved. This is particularly important for investigations of marine outlet glaciers [RD3]. A higher temporal resolution would allow investigations of key processes that occur on seasonal timescales, and could potentially lead to ground-breaking results. The Sentinel data has a high resolution and it will be possible to provide the optimum monthly resolution in ECV products based on Sentinel data. The download statistics show that there is a significant interest from users in these new products.

Users were asked to list the priorities in case of insufficient data coverage or limited resources to process the data. All users would generally prefer lower resolution in the interior, and high resolution in coastal areas, both for the SEC and IV parameters. The ECV production will accommodate the user requirements. As explained in the section above, the ECV will be produced with a yearly cycle of the SEC and of the IV in the interior due to the limited funding of the cci+ [RD1].

ECV product	Spatial resolution	Temporal resolution	Period for cci/cci+ FDCR	Satellite/other data and regions for cci+
SEC	5 km	1 year	1992-2021	CryoSat-2, Sentinel-3, IceSat-2, AltiKa All ice-sheet Experimental merged product for all missions to be developed
IV	250 m	1 year 6 days in margin zone	1992-2021 (12 or 6 day repeat data since 2014)	Sentinel-1A/B (radar) All Greenland on yearly basis Data for all margin zone through *CryoPortal* Optical IV data over ice streams from Sentinel-2 and Landsat-8 Lake drainage data IV rapid changes
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Table 5.1. Overview of the GIS_cci+ data products 2019-2021, extending the earlier GIS_cci ECV's [RD1].

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