ESA Climate Change Initiative (CCI+)

Essential Climate Variable (ECV)

Greenland_Ice_Sheet_CCI+ (GIS_cci+)

User Requirements Document (URD)

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Change Log

Issue	Author	Affected Section	Reason	Status
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2.0	NBI, CSH	1, 2, 3.4, 3.5, 4, 5	Revision for Cycle 2 sent to project PI and team	2021-01-06
2.1	NBI, CSH	3.5	Corrected according to review	2021-01-11
3.0	NBI, CSH	All	Updated to the Phase 2 project format. A subsection 2.3 is added about new user groups. New GCOS requirements are included in chapter 3. All sections are revised and updated according to SoW	Released to ESA 2023-05-17
	L. Sørensen D. Fantin S. H. Larsen J. Wuite	Section 3.5	Updated table 3.3 according to the SoW and project contract.	
3.1	D. Fantin C. Hvidberg	front page, 1.1, 3.1, minor corrections in all sections	Updated according to review by A.M. Trofaier	

Acronyms

Acronyms	Explanation
C3S	Copernicus Climate Change Service
CCI	Climate Change Initiative
CFL	Calving Front Location
CS2	CryoSat-2
DEM	Digital Elevation Model
DMI	Danish Meteorological Institute
DTU-N	DTU Microwaves and Remote Sensing Group
DTU-S	DTU Geodynamics Group
ECV	Essential Climate Variable
ENVEO	ENVironmental Earth Observation IT GmbH
EO	Earth Observation
ESA	European Space Agency
GCOS	Global Climate Observation System
GEUS	Geological Survey of Denmark and Greenland
GFZ	Deutsche GeoForschungsZentrum
GIS	Greenland Ice Sheet
GLL	Grounding Line Location
GMB	Gravimetry Mass Balance
IMBIE	Ice Sheet Mass Balance Inter-Comparison Exercise
InSAR	Interferometric Synthetic Aperture Radar
IV	Ice Velocity

MEaSUREs	Making Earth System Data Records for Use in Research Environments (NASA)
MFID	Mass Flux and Ice Discharge
NBI	Niels Bohr Institute, University of Copenhagen
NEGIS	North East Greenland Ice Stream
OptIV	Optical IV
OT	Offset Tracking
PROMICE	Danish Program for Monitoring of the Greenland Ice Sheet
RA	Radar Altimetry
S&T	Science and Technology AS
S2	Sentinel-2
SAR	Synthetic Aperture Radar
SEC	Surface Elevation Change
SMB	Surface Mass Balance
SoW	Statement of Work
TPROP	Technical Proposal
TUDr	Technische Universität Dresden
UL	University of Leeds
URD	User Requirement Document

1 Introduction

This document is the User Requirements Document (URD) prepared for the Phase 2 of the Greenland_Ice_Sheet_cci+ (GIS_cci+) project in accordance with the Contract [AD1] and the Statement of Work (SoW) [AD2] with the Annex B.

This URD document is hence updated as described in the Technical Proposal of the Phase 2 of the GIS_cci+ [RD1]. It is based on User Requirement Document (URD) [RD2] and Climate Assessment Report (CAR) [RD3] from Phase 1 of the GIS_cci+.

The URD document is part of the Task 1 Requirements Analysis deliverables, with deliverable id: D1.1. The URD is reviewed and updated annually at the start of each reprocessing cycle, as described in the SoW Annex B [AD2]. This URD is prepared in the first iteration of Task 1 in Q1 of Year 1.

1.1 Purpose and Scope

The objective of the URD is to provide detailed specifications of the user requirements for the Greenland Ice Sheet (GIS) Essential Climate Variable (ECV) from climate science communities, stakeholders and climate services, including also specific requirements according to different applications.. GCOS provides the high-level user requirements for the Greenland Ice Sheet ECV, and these are discussed below in section 3.1.

The ECV products in the GIS_cci+ phase 2 project are:

- Surface elevation change (SEC) – gridded data from radar altimetry
- Ice velocity (IV) – gridded data from synthetic aperture radar interferometry and feature tracking
- Gravimetric Mass Balance (GMB) – gridded data from gravimetry and time series
- Mass Flow Rate and Ice Discharge (MFID) – time series from marine outlet glaciers
- SupraGlacial Lake (SGL) - lake volume products over 79N and Zachariae catchments

The portfolio of ECV products have been gradually developed during the GIC_cci projects. The three first ECV products (SEC, IV, GMB) are a heritage from the Greenland_Ice_Sheets_cci (GIS_cci) Phase 2 project. The fourth ECV product (MFID) was added to the ECV product portfolio in the GIS_cci+ Phase 1 project. The fifth ECV product, SGL, was included as an experimental ECV R&D product in the GIS_cci+ Phase 1 project, and SGL outlines were produced over the Sermeq Kujalleq (Jakobshavn) glaciological catchment in GIS_cci+. In the GIS_cci+ Phase 2 project, the focus has shifted from SGL outlines to SGL volumes, being produced by a new Machine Learning (ML) technique, and SGL remains as an experimental ECV product according to the SoW Annex B [AD2], and described in a separate CNN.

The earlier phases of the GIS_cci project included two additional ECV products, Grounding Line Location (GLL) and Calving Front Location (CLF) as an optional activity, but these ECV products are not included in the GIS_cci+ Phase 2 project (see further discussion in section 3.1 below). The need for further development on these ECV products can be assessed if additional project resources will become available.

The URD document is updated based on the current ECV requirements according to the new Global Climate Observing System (GCOS) ECV Requirements from 2022 [GCOS (2022)]. The documents from the previous phases of the GIS_cci+ project are also considered, specifically the URD and the CAR compiled in GIS_cci+ Phase 1 [RD2] [RD2] as well as the compilation of the CAR by the Climate Research Group (CRG).

In preparation for 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 Ice_sheets_cci and Antarctic_Ice_sheet_cci [RD3][RD4], respectively. These surveys provided a consistent overview of user groups and user requirements. Since these user surveys were performed, additional ECV products have been included in the GIS_cci project portfolio. In the GIS_cci+ project Phase 1, MFID was included as an ECV product, and SGL was included as an experimental ECV product. MFID and SGL potentially involve 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 and continuously reviewed the user requirements accordingly, thereby preparing for this update of the URD. The user involvement has been done through the homepage, newsletters distributed by an updated email list, and by the presentation of CCI data products at scientific conferences, workshops and other meetings, and supplemented by surveys of literature and online data archives with new products from other relevant CCI projects. A user workshop is planned and will provide further input for the Year 2 iteration of Task 1.

The update of the user requirement analysis for the GIS_cci+ Phase 2 project is thus done through engagement with the user community, consultation with the CRG, and surveys of relevant data archives. We plan to consult the CMUG and CRG following the user workshop for additional feedback on user requirements for the Year 2 iteration of Task 1.

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 GIS_cci+.
- Chapter 3 analyses the user requirements based on various sources.
- Chapter 4 provides an overview of the download statistics and use of the released products.
- Chapter 5 concludes the document and provides 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. 4000126523/19/I-NB -	CCI+ Phase 1 New R&D pm CCI ECVs for Greenland _Ice Sheet_cci (incl CCN3)	Cont: 2019.03.06 CCN3: 2022.12.05	-

	Greenland_Ice-Sheets_CCI+ and its Appendix 1 (incl CCN3)			
AD2	ESA-EOP-SC-AMT-2021-53	Climate Change Initiative Extension (CCI+) Phase 2 - New R&D on CCI Essential Climate Variables -SoW (incl Annexes)	2022.06.10	Issue 1 Revision 2

Table 1.2: List of Reference Documents

No	Doc. Id	Doc. Title	Date	Issue/ Revision / Version
RD1	ST-DTU-ESA-GISCCI+-URD-001 -v2.1	User Requirement Document (URD), for Phase 1	2021.01.11	2.1
RD2	ST-DTU-ESA-GISCCI+-CAR-001	Climate Assessment Document (CAR), for Phase 1	2022.05.06	4.0
RD3	ST-DTU-ESA-ISCCI-URD-001	User Requirement Document (URD), for Phase 1	2012.08.03	1.5
RD4	ST-DTU-ESA-ISCCI-URD-001-v 2.4	User Requirement Document (URD). for Phase 2	2018.06.28	2.4

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

2 Background

2.1 The need for Greenland Ice Sheet ECV products

Ice sheet monitoring: There is a world-wide focus on understanding the increasing mass loss of ice sheets and the processes controlling their response to climate changes [IPCC (2021)]. Evidence of sustained mass loss from the large ice sheets in Greenland and Antarctica shows the urgent need to understand the consequences of present and future climate changes on ice sheet mass loss and to predict their future contribution to global and regional sea level change.

Glaciological and Cryospheric research: In recent years, the fast-flowing marine outlet glaciers in both Greenland and Antarctica have attracted 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 control on the retreat and stability, atmospheric and oceanic conditions are the drivers of the observed mass loss. Floating tongues, ice shelves and the presence of sea ice and mélange provide buttressing effects at the grounding line. Changes in these conditions due to calving, surface melting, or subsurface melting can affect the stability of the grounding line, and lead to changes in the frontal position, ice thickness and upstream flow. Monitoring the changes in high temporal and spatial resolution is needed to resolve the response of these dynamic outlet glaciers and to disentangle effects from various atmospheric and oceanic drivers. New IV products based on the Sentinels have higher spatial and temporal resolution than previously possible, and changes on monthly and weekly timescales can now be resolved. The last decade has demonstrated how the ice sheet and climate modelling communities have been able to utilise these data for various purposes and generated a new research focus on the short-term fluctuations and how they relate to decadal trends that have emerged.

Ice sheet modelling: Although ice sheet models have been developed to include ice stream dynamics in higher order approximation of the stress balance, the numerical schemes of the ice sheet models are complex and computationally demanding. Continental-scale ice sheet models used for projections require large computer resources and the possible spatial resolution and temporal coverage are limited. The spatial resolution of these ice sheet models is still lacking behind the resolution of satellite-based data, e.g. SEC and IV, and thus not able to benefit from the full capacity of satellite-based data for validations. In recent years, the gap has been closing, with resolution down to 2-5 km in continental-scale ice sheet models, and finer when adaptive grids are used [Goelzer et al. (2020)]. Long-time series of SEC and IV can be used to initialise ice sheet models for projections by adjusting the models to match historical trends. This was not done systematically in the Ice Sheet Model Intercomparison Project (ISMIP) 6 assessment [Nowicki et al. (2020)] for the Climate Modelling Intercomparison Project CMIP 6 [Fox-Kemper et al. (2021)], as recently pointed out [Aschwanden et al. (2021)] and discussed in the CAR [RD2], but is expected to be included in upcoming assessments, such as ISMIP 7, thereby increasing the demand for long ECV records from the ice flow modelling community. In focused studies of processes controlling changes in ice flow and outlet glaciers, it is necessary to have access to high-resolution observations. A number of recent ice flow modelling studies have focused on ice stream flow and seasonal behaviour of marine outlet glaciers using state-of-the-art higher-order models and adaptive grids, thereby making full use of the high-resolution in the new ECV products, 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 [Goelzer et al. (2020)].

Glacial hydrology and freshwater fluxes: During the past decades of warming climate in Greenland, the interest in understanding changes in glacial hydrology has intensified. Glacial hydrology encompasses water storage and transport in glaciers as well as the drainage of this water to river systems and fjords. Changes in glacial hydrology are of crucial interest to the local communities due to the effects on the environment and infrastructure. Several studies have addressed the increasing amount of meltwater and the expansion of areas experiencing surface melt. Understanding percolation and refreezing is key to quantifying the runoff and the potential for ice slab formation within the firn. Supraglacial lakes form from surface melt and drain through subglacial drainage networks, and coupled ice and hydrology models are now being developed to quantify the effects of englacial water storage and transport on ice dynamics. With the high-temporal and spatial resolution products of e.g. IV and SGL, becoming available, it is now possible to identify and understand relationships between surface melt, lake drainage and ice flow speed-up, to improve the projected response of the outlet glaciers to increased surface melt.

Marine ecosystems and environment: Changes in hydrology and freshwater fluxes influence the environment and infrastructure locally around the fjords of Greenland. Changes in freshwater fluxes impact marine ecosystems and fishing opportunities, and the future potential of hydropower is essential for local planning. Increased surface melt and risk of outburst floods from englacial water reservoirs and supraglacial lakes must be considered in urban planning and infrastructure constructions. Access to long-term products is needed in order to adapt and mitigate changing environmental conditions.

The international research community is relatively unorganised in regards to a formalised program to long-term monitor the Greenland Ice Sheet (GrIS) changes. The CCI program has gradually changed this by becoming a reliable data provider of satellite-based products and therefore fills a gap in systematically providing remote sensing data products to monitor the Greenland ice sheet.

2.2 Users of Greenland Ice Sheet 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. **Hydrologists** who are interested in monitoring the freshwater from the Greenland ice sheet and in managing water resources for commercial, environmental and academic settings.

6. **Authorities and organizations** with an interest in the 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.

7. **Copernicus Climate Change Service (C3S)** and other climate services who are providing information about the state of the climate based on high-level quality-assured data products from satellite sensors for use by a range of public and private sectors.

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.

2.3 New user groups of Greenland Ice Sheet ECVs

The GIS_cci+ data products based on the Sentinel-1 missions have provided opportunities to study the evolution of seasonal cycles and short-term changes in IV down to a temporal resolution of weeks or days and with a spatial resolution of fewer than ten metres for some products on a systematic and regular basis. This is highly relevant, mainly because the ice sheet does respond on these short temporal and spatial timescales, and because there is a scientific and practical interest in monitoring these variations.

The short-term responses are mainly caused by fluctuations in surface melting during the summer melt season. Surface meltwater drains to the base and affects basal sliding and is thus reflected in IV. Supraglacial lakes are formed by surface meltwater, and the seasonal evolution of SGLs is also reflected in IV, due to their drainage to the base. The response of IV to surface meltwater affects the discharge of marine outlet glaciers on a basin-wide scale, thus reflected in the MFID.

The high-resolution data products from GIS_cci+ have opened the opportunity for new use of ECV products which was not possible before. Process studies of how short-term fluctuations in ECV parameters link to atmospheric variability and weather, and how these fluctuations link to longer-term trends in mass loss are now in high focus. An improved understanding of these processes is needed to predict the evolution of ice sheets in a future warmer climate with increasing amounts of meltwater. The overall goal is to improve the projections of ice sheet mass loss and sea level rise. In addition, direct use of the data products for planning purposes by local authorities and stakeholders has now become possible.

The high-temporal resolution IV product is used to generate the MFID ECV data products in the GIS_cci+. With the MFID ECV product, the ice discharge from key outlet glaciers is continuously monitored. In select areas, IV data products are generated to map the ice flow in higher resolution, and also in select areas, supraglacial lakes are identified and mapped in the new, *proof-of-concept* SGL ECV data product. This will provide novel opportunities for systematic studies of the ice flow response to the formation and drainage of supraglacial lakes in these specific areas, entirely based on satellite observations.

3 Analysis of users requirements

3.1 GCOS Requirements for the main 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."

In 2022, GCOS published new ECVs requirements for Ice Sheets and Ice Shelves ECVs [GCOS (2022)]:

Surface Elevation Change (SEC) -

- Definition: Measurements of the change height above a reference (geoid or ellipsoid) of the snow-air surface of uppermost firn layers
- Unit: Annual change in elevations above sea level measured in meters (m/year)

Ice Velocity (IV) -

- Definition: Surface-parallel vector of the surface ice flow
- Unit: m/year (average speed in grid cell of surface ice flow)

Ice volume change -

- Definition: Direct measurements of local volume changes or inferred volume changes from combining measurements
- Unit: km^3/year

Grounding Line Location (GLL) and Thickness -

- Definition: Location of the line (zone) where ice outflow to an ocean begins to float, and thickness of ice at that location.
- Unit: m (thickness), coordinates of location

The target Requirements are listed in Table 3.1 (covering both Greenland and Antarctica). For each of the requirements a goal (G), breakthrough (B) and threshold (T) value are presented. The definitions of these requirements are defined as:

- Goal (G): an ideal requirement above which further improvements are not necessary.
- Breakthrough (B): an intermediate level between threshold and goal which, if achieved, would result in a significant improvement for the targeted application. The breakthrough value may also indicate the level at which specified uses within climate monitoring become possible. It may be appropriate to have different breakthrough values for different uses.
- Threshold (T): the minimum requirement to be met to ensure that data are useful.

Comments to the GCOS ECV definitions:

Ice volume change: The Ice volume change can be derived directly from the SEC ECV product. The GMB ECV product is related, but cannot be directly derived due to density variations within the upper firn layers. The great advantage of GMB is, however, that it can be derived directly from gravity observation by the GRACE satellite. In Table 3.1 below, we have converted the required uncertainty into ice mass change to be used for the GMB ECV data production here.

Ice velocity: The GCOS requirements are based on the user requirements developed in the earlier phase of the GIS_CCI project [RD3].

Grounding Line Location (GLL) and Thickness: This ECV product is mainly relevant for the Antarctic Ice Sheet (AIS) as the AIS is surrounded by floating ice shelves, and because the stability of the grounding lines is subject to oceanic forcings and sensitive to climate change, which can potentially lead to large and abrupt changes in ice mass. The GLL ECV product was included in earlier phases of the GIS_cci+ project.

Table 3.1. GCOS requirements 2022 [GCOS (2022)] (covering both Greenland and Antarctica)

ECV Product	Temporal Resolution[1]	Horizontal Resolution	Required Measurement Uncertainty[2]	Stability[3]
Surface elevation change	(G) 1 month (B) - (T) 12 months	(G) - (B) - (T) 100m	(G) - (B) - (T) 0.1m/year[4]	(G) - (B) - (T) 0.1m/year
Ice Velocity	(G) 1 month (B) - (T) 12 months	(G) 50m (B) 100m (T) 1000m	(G) 10 (B) 30 (T) 100m/year[4]	(G) - (B) - (T) 10m/year[6]
Ice Volume Change	(G) 30 days (B) - (T) 365 days	(G) - (B) - (T) 50m	(G) - (B) - (T) 10 Gt/year[4,5]	(G) - (B) - (T) 1 Gt/year[5]
Grounding Line Location and Thickness	(G) - (B) - (T) 1 year	(G) 100m (B) - (T) 1000m	(G) - (B) - (T) 1m	(G) - (B) - (T) 1m

[1]Temporal resolution or frequency of measurements
[2]Measurement uncertainty includes all contributions and is expressed in units of 2 standard deviations
[3]Stability is the change in bias over time and quoted per decade
[4]Error of measured in-situ using the geodetic method and remotely sensed surface elevation.
[5]Corrected for ice mass change (1 km^3/year ~ 1 Gt/year)
[6] The unit in GCOS [(2022)] is m/s and is likely an error. Here we assume that it is m/year.

3.2 User requirements from previous phases of Greenland_Ice_Sheet_cci

The user requirements from the previous Greenland_Ice_Sheets_cci Phase 1 and Phase 2 were developed upon user surveys, as mentioned above, and summarised below in Table 3.2 [RD3][RD4]. The Greenland_Ice_Sheet_cci included the following ECV products: SEC, IV, GMB, GLL and CFL.

Table 3.2. User requirements from Ice_Sheets_cci Phase 1 User Survey in 2012 [RD4].

	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

1) User requirements may later be updated on these parameters

In the user survey in the Phase 1 of the Ice_Sheets_cci [RD3], the users were asked to provide any requirements they have for 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 prioritise 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 the entire ice sheet, snapshots or short time series (SEC: 17%, IV: 34%).

B. Low resolution over the 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 objective of the CCI (and its extension CCI+) … is to realise the full potential of the long-term global Earth Observation archives that ESA together with its Member states have established over the last thirty years, as a significant and timely contribution to the ECV databases required by United Nations Framework Convention on Climate Change (UNFCCC)."

Further, the SoW [AD2] with Annex B notes about the requirements:

"CCI+ takes, as its primary source of requirements, the GCOS Status and Implementation Needs documents…according to the GCOS product requirement for the Ice Sheets and Ice Shelves ECV." [GCOS (2020)]

Specifically for GIS_cci+, the Annex B of the SoW [AD2] states that the focus of Phase 2 project is to quantify the current mass balance of the Greenland Ice Sheet and the increasing rate of mass loss over the period covered by ESA satellite observations and from several generations of satellite sensors.

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

These technical requirements are listed here, together with a brief description of how we will address them in the GIS_cci+ Phase 2 project:

[TR-1] GIS_cci **shall** develop and deliver ECV products (SEC, IV, GMB) that strive to meet the GCOS requirements for the Greenland Ice Sheet ECV, within the limits of the available EO infrastructure and technical feasibility, and guided by the CCI programmatic priorities.

- The user requirements developed for SEC, IV and GMB during Phase 1 of the GIS_cci+ are in compliance with the GCOS requirements.
- Additional user requirements for MFID and SGL were also developed during Phase 1 of the GIS_cci+ and derived from the primary ECV products, but not specified by GCOS.

[TR-2] The Contractor **shall** identify and engage with the Ice Sheets ECV end-user community throughout the course of the project, for the following purposes:

- Update detailed user requirements for climate and glaciological research and climate services, elaborating on the high-level requirements specified by GCOS.
- Assist users to understand the advantages and limitations of satellite-based Ice Sheets ECV products in the context of their specific applications.
- Providing climate users with ECV data sets tailored to their needs.
- Obtain feedback from climate users on the performance of the Ice Sheet ECV products provided.
- Stimulate wider uptake and exploitation of Ice Sheet ECV products.
- Build confidence in the products among the user community by demonstrating their value, communicating the necessary know-how, and developing tools to allow users to fully exploit the Ice Sheet ECV data products.

This **shall** be achieved through a combination of engagement with key climate research and modelling groups, interaction with other European and national projects and international bodies, as well as individual or institutional bilateral contacts. Where appropriate, interaction with other CCI projects as users of the Ice Sheet ECV products **shall** be required.

- The coverage of the data products is planned according to the user priorities and in accordance with the project resources and priorities, see section 3.5 below.
- We are in contact with the ISMIP6/7 consortium regarding their data needs for model initialisation and validation. We collaborate closely with the CRG on data needs and how to integrate data and models.
- The team members are engaged in various research projects, collaborations and consultancy tasks with numerous groups, including European, international and national research projects, local authorities in Greenland and government agencies.

- GIS_cci+ consortium members participate in various GCW, IPCC, IMBIE, and IASC cryosphere activities.
- Several team members participate in the AIC_cci+ and Glaciers_cci+. One team member is the scientific lead of SNOW_cci+. This ensures coordination across the cryosphere cci projects.

[TR-3] The Contractor shall raise the profile of the GIS_cci project and the ECV products delivered by:
- Publishing in peer-reviewed science journals.
- Presenting work at high-profile scientific conferences.
- Organising at least one dedicated user workshop during the project (Possibly jointly with AIS_cci).

- We plan a user workshop before the Year 2 iteration of Task 1: Requirements analysis. This workshop will allow us to present the products to a wider group and get feedback from users on their needs.
- The record of publications and conference abstracts documents our efforts to publish and present the data products in various contexts.

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 GIS_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 [RD3][RD4]. In preparation for 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 (TPROP) [AD1], a user workshop is planned to be held. Initially, the plan was to hold the workshop in Nuuk, in April 2023, in connection with the DTU/Asiaq "Mapping the Arctic Conference", but the event has been rescheduled to a later dedicated science/cryosphere change meeting, selected to provide an optimal forum for users of ECV data and/or local stakeholders.

Data from the Greenland_Ice_Sheets_cci and cci+ was used in the Greenland mass balance assessment [The Imbie team (2020)]. The assessment has attracted high interest from the international scientific community, demonstrating a great interest in research related to ECV products.

3.5 Overview of planned data products

The TPROP presents an overview of the planned ECV production scheme (see table). The ECV production will accommodate the user's requirements. However, limited to a yearly cycle of the SEC and of the IV in the interior due to the limited funding of the cci+, see the TPROP [AD1].

Table 3.3. Overview of the GIS_cci+ data products 2023-2024, extending the Phase 1 GIS_cci+ ECV products and earlier GIS_cci ECV products [AD1].

ECV product	Spatial resolution	Temporal resolution	Period for cci/cci+	Satellite/other data & Regions for CCI+
SEC	5 km	1 year (Greenland-wide)	1992-2021 (*) 2022-2024 (CCI+-P2)	ERS-1/2, ENVISAT, CryoSat-2, Sentinel-3A/B.
				Greenland-wide, updated annually. 2 and 5-year means. New: sub-annual elevation changes ice sheet wide.
IV	250 m (OT) 100m (InSAR)	1 year (Greenland-wide)	2014-2017 (*) (OT) 2017-2024 (C3S) (OT) 2018-2021 (*) (InSAR) (Greenland-wide)	Sentinel-1A/B, SAOCOM-1A/B, (SAR), Sentinel-2 (optical).
		6/12-day (Margins, selected areas)	Since Oct 2014 (*) Since Oct 2014 (CCI+-P2) (Margins)	All Greenland on yearly basis. All margin zone is available through *CryoPortal.* 1992-2024 products are available through the CCI and *PROMICE* data portals.
	100m (OptIV)	Summer Season (Variable temporal resolution).	2016, 2019-2021 (*) 2022-2024 (CCI+-P2) (key ice streams)	Optical IV data over 9 key ice streams from Sentinel-2.
GMB	50 km	Monthly	2002-2021 (*) (data gap 2017-18) 2022-2024 (CCI+-P2)	GRACE-FO, GRACE.
				Greenland-wide and Zwally drainage basins.
MFID (#)	N/A (200m internal grid spacing)	Monthly (across basins)	2014-2021 (*) 2014-2024 (CCI+-P2) (Select ice streams)	IV data from Sentinel-1-A/B. Ice thickness data & ice mask from BedMachine_v5, surface elevation from PRODEM (CCI+-P2)
				Data for 9 major outlet glaciers.
SGL	10 m	Monthly (Select areas)	2019 (*) (outlines)	Sentinel-2 optical data. Landsat-8 used for validation, ArcticDEM used for sink detection. (Experimental ECV product)
	10 m	Monthly (Select areas)	2019 (CCI+-P2) (volume)	Two select regions: Nioghalvfjerds-bræ and Zachariæ Isstrøm

(*) Delivered in previous phases of the CCI/CCI+ project.

(#) Data for all discharging ice through *PROMICE.* (using data from various MEaSUREs products)

The MFID product is a satellite-derived product building on the cci+ data, and using ancillary data together with glaciological models to obtain the ice discharge for key outlet glaciers in Greenland. The product is highly relevant for mass budget assessments and is one of the contributors to the input-output-based assessment. The product was developed and assessed in GIS_cci+ Phase 1 building on the glaciological expertise present in the cci+ team.

The SGL product is a new experimental product designed to address the timely question of how increased melt will influence supraglacial lake formation and drainage, as well as the response of ice dynamics to drainage events and thereby relate to the IV product. The design of the SGL product and related IV response is building on innovative ideas and a strong observational and theoretical background within the cci+ team. Notice that a new method for SGL is developed in GIS_cci+ Phase 2.

Overall, it is clear that the combined expertise of the CCI+ team within remote sensing, and glaciology, in addition to first-hand knowledge and access to in-situ observations and validation data provides a unique basis for the development of these new products.

As noticed in the table, several of the data products are combining data from many sensors. Using several sensors makes it not only possible to extend the temporal and spatial coverage of the records, but also improve the accuracy and reliability of the data. The MFID and SGL products combined with IV show how data from several sensors can be combined with modelling to provide more advanced products and address broader user groups, thereby increasing the use of the data.

Two products in the earlier CCI projects are not continued in the current GIS_cci+ Phase 2 project, CFL and GLL. CFL will continue to be delivered by *PROMICE* by GEUS, therefore in practice expanding earlier time series of CFL from the CCI project. With declining interest among users, GLL is discontinued, as the few remaining floating outlets in Northern Greenland are presently thinning and breaking up.

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 (http://products.esa-icesheets-cci.org/) 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 not only are the data in high demand, but the knowledge of these data must also be growing and become more widespread. It seems clear that the number of downloads seems to be closely related to the amount of data available, and after reaching a new data release, the numbers increase to a higher level.

Figure 4.1 shows the download statistics from the website, distributed on the different ECV products. The greatest interest is still in IV products, but the interest is increasing in all ECV products. It should be noted that the GIS_cci ECV data products are distributed through several channels, and this data portal is only one out of several sites.

The GIS_cci data products are also available from portals hosted with the team members, e.g. DTU (https://data.dtu.dk/DTU_Space), ENVEO (https://cryoportal.enveo.at/), PROMICE (https://promice.org/). The number of downloads from these other platforms is of the same order of magnitude as from the official ESA_cci site.

As an example, here are the download status from DTU per May 12-2023:

SEC: https://doi.org/10.11583/DTU.12866000.v2 (715 downloads)

GMB: https://doi.org/10.11583/DTU.12866579.v1 (1407 downloads)

IV: https://doi.org/10.11583/DTU.12865709.v1 (401 downloads).

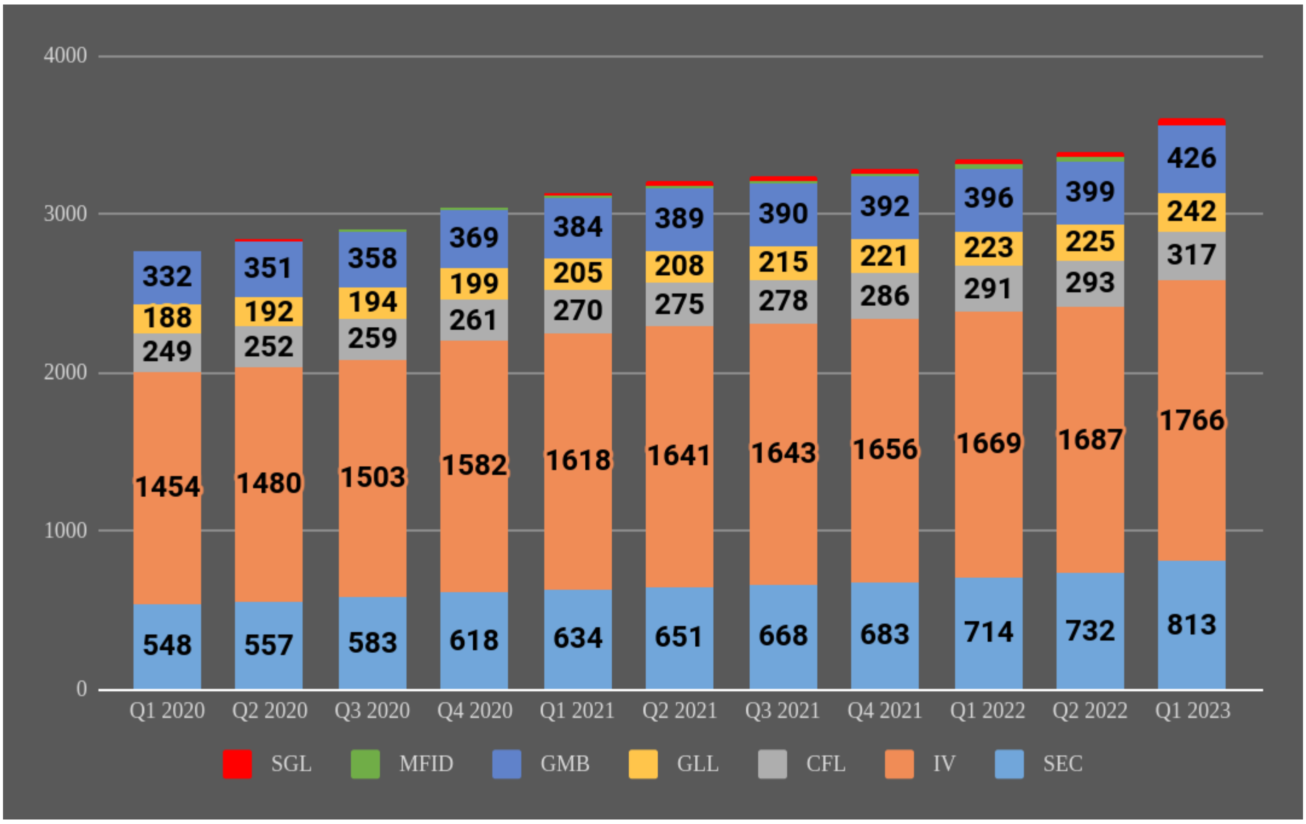

Figure 4.1. Project Data Product Website Usage showing Accumulated Downloads. Last Update: Q1 2023, extending back to Q1 2020 (Historical data available upon request).

5 Conclusions

The user requirements for Phase 2 of the Greenland_Ice_Sheet_cci+ ECV parameters have been reviewed and updated from previous phases of the CCI project, here for the Year 1 iteration of Task 1: Requirements Analysis.

According to the users, spatial resolution is particularly important for outlet glaciers [RD3]. The resolution is not similarly important in the central ice sheet areas. The required temporal resolution is annual, but the monthly resolution would allow seasonal changes to be resolved. This is particularly important for investigations of marine outlet glaciers [RD3], where a higher temporal resolution allows investigations of key processes that occur on seasonal timescales. The Sentinel data has a high resolution and has made it possible to provide the optimum monthly resolution in ECV products. Several studies building on these data are being published and demonstrating that the data are state-of-the-art and can lead to new and ground-breaking results. The download statistics show that there is significant interest from users in the CCI products. All products have generated significant and continuous interest from users, and the number of downloads is increasing after each data release.

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's requirements. As explained in the section above, the ECV products 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+ [AD1].

An overview of ECV products and their specification is seen in Table 3.3.

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