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GAMMA REMOTE SENSING



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1. Introduction

1.1 ESA Glaciers_cci

Long term and reliable records are required by the scientific user community to address important questions about the current state and future evolution of Earth's climate system. Earth Observation datasets from Space provide a unique and spatially extensive multi-decadal dataset from which such products can be created. However, a coordinated effort is required in order to process these complex datasets and to ultimately make such products freely available to the user community.

To address this need, the European Space Agency (ESA) initiated the Climate Change Initiative (CCI) to improve data products related to climate from long-term monitoring from space and to make these products freely available for all. The overall goal of the programme 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 Essential Climate Variable (ECV) databases required by United Nations Framework Convention on Climate Change (UNFCCC)" (www.esa-cci.org).

The Global Climate Observation System (GCOS) has established a list of ECVs which are identified as essential components of the climate system. Phase 1 of the ESA CCI program initiated projects to address 13 individual ECV's of which 'Glaciers and Ice Caps' are one. The goal of the Glaciers_cci project, which has been running since 2011, is to set up a long term and reliable production of a set of key parameters for glaciers and ice caps that are derived from available and future satellite observations. The selected key parameters produced by the Glaciers_cci are listed below:

- Glacier area
- Elevation Change
- Velocity

The Glaciers_cci project is to be completed in several phases. The first phase, completed in June 2014, had the aim of defining and validating approaches for continuously generating and updating the key parameters listed above. This included developing the processing, retrieval and validation methods over a number of key regions identified by the user community. There were many key scientific achievements from Phase 1; these included a substantial contribution to the Randolph Glacier Inventory (RGI) of glacier outlines, insights into the highly variable behaviour of glaciers in High Mountain Asia, and the first determination of the contribution to sea level changes from the glaciers and ice caps peripheral to the Greenland Ice Sheet.

The second and current (at the time of writing) phase commenced in June 2014 and will run for three years. This phase focuses on extending in time and space the products developed during Phase 1, improving the quality of the products, the inclusion of new datasets such as Landsat-8 and CryoSat-2, evolving from a prototype to a sustainable system, and maximising the scientific impact of the project. As such, the project will make substantial further progress towards meeting the GCOS and user requirements.

1.2 Document purpose and scope

This User Requirement Document (URD) represents an update to that written during years 1 and 2 of Phase 2 of the project (Glaciers_cci, 2015). It fulfils part of the requirements of Task 1 given in the Statement of Work (SoW) which specifies that "the Glaciers_cci products shall be designed to match the users requirement's within the limits of technical and algorithmic feasibility" and that "the URD [from Phase 1] ... shall be revisited...". The URD assesses the requirements of relevant organisations from the Climate Research Community and the International Glaciological Community; the requirements will be used to guide the product specifications of the Glaciers_cci project.

In this document, where specific user requirements are identified they are concisely stated and assigned a requirement ID reference code named 'URq_XX'. This will allow cross-referencing and traceability between multiple CCI documents to be achieved.

1.3 User requirements document structure

This document is structured as follows:

- Chapter 2 outlines the users of the glaciers products and potential synergy with related initiatives.
- Chapter 3 describes the user requirements of organisations, the findings of the Phase 1 user survey, and any feedback from the user community on Phase 1 products.
- Chapter 4 assesses the scientific feasibility of meeting the identified user requirements.
- Chapter 5 provides a summary of the feasible user requirements to be developed during Phase 2.

2. Users of glacier data and related initiatives

This section includes information on the types of groups who use data for glaciers and any initiatives that may be related to Glaciers_cci.

2.1 Users of glacier data

There are a number of groups who use data from glaciers, these can generally be divided into:

- Glacier and Ice Cap modellers who are using the ECV parameters to validate, constrain and/or initialise their models, e.g. using observed velocity to validate modelled velocity.
- Remote Sensing Scientists who are deriving mass budgets, volume and/or mass changes from satellite observations
- Surface mass balance modellers who are interpreting satellite observed volume and mass changes, e.g. partitioning of mass change signals into surface mass balance or dynamical changes.
- Climate modellers who are interested in the interactions of glaciers and ice caps with the climate system.
- Authorities, organisations and projects/initiatives who are interested in the monitoring of glaciers and ice caps for political or practical decisions, e.g. for water availability in regions where glaciers are the main water source, or glacier-related hazards.

The users of the Glaciers_cci data products cover a relatively broad use of topics and will therefore have a relatively broad range of requirements.

2.2 Related initiatives

The following section on Related Initiatives documents current and on-going science projects that are most related to the Glaciers_cci project. Some projects use similar techniques and datasets that will be useful to the Glaciers_cci data processing chain, whereas other projects produce datasets that may be incorporated into, or contrasted with, the Glaciers_cci products. It may also be possible to generate cross project collaborations to avoid duplication of efforts. A list of the initiatives related to Glaciers_cci is given in Table 2.1, along with a concise overview of the activities of each and the potential cross project synergies. By coordinating our activities with these groups (e.g. by selecting different key regions), overlap of work will be avoided.

Initiative	Web address	Description	Potential Synergy
Greenland_IceSheets_cci	http://www.esa-icesheets-cci.org	An ESA CCI project that aims to establish long term and reliable generation of SEC, IV, Grounding Line Location (GLL), and Calving Front Location (CFL) products for the Greenland Ice Sheet from satellite data.	Common consortium members allows for communal development of algorithms for SEC and velocity products.
Antarctica_IceSheets_cci	http://www.esa-icesheets-antarctica-cci.org/	An ESA CCI project that aims to establish long term and reliable generation of SEC, IV, GLL, and Mass Balance products for the Antarctic Ice Sheet from satellite data.	Common consortium members allows for communal development of algorithms for SEC and velocity products.
IMBIE	http://imbie.org/	A joint ESA and NASA exercise aiming to reconcile geodetic estimates of ice sheet mass balance. Phase 2 began in 2016, with a first assessment expected by the end of the year.	Change estimates of Greenland and Antarctica peripheral glaciers and ice caps will be useful for accounting for the impact of leakage in the GRACE estimates.
Landcover_cci	http://www.esa-landcover-cci.org	An ESA CCI project that aims to establish long term and reliable generation of a global land cover product from satellite data.	Glaciers_cci GO product could be used as a mask for glacier land cover type in the Landcover_cci.
GLIMS	http://glims.org	The GLIMS (Global Land Ice Monitoring from Space) initiative, hosted by the NSIDC, maintains a global inventory of the world's glaciers using, primarily, optical satellite data.	Glaciers_cci outline and velocity product to be integrated into GLIMS. Provision of guidance on data standardisation.
RGI working group	http://glims.org/RGI	The RGI (Randolph Glacier Inventory) working group is supplemental to GLIMS and works to improve the GLIMS glacier inventory.	Provision of GO from Glaciers_cci for key regions identified by the RGI.
WGMS	http://wgms.ch	The WGMS (World Glacier Monitoring Service) maintains a global database of information on fluctuations in glacier mass, volume, area and length.	Provision of SEC data from Glaciers_cci.
NSIDC	http://nsidc.org	NSIDC hosts the tabular data from the world glacier inventory, as well as the GLIMS database and the RGI.	The director of GLIMS is in the GLIMS Executive Board, the CRG and the RGI working group for coordination.
CryoLand	http://www.cryoland.eu	A project for the development of an operational service for monitoring snow and land ice, including mapping of glacier outlines, facies, lakes and velocity.	Glacier products are generated on user request (downstream services): GO, velocity maps, glacier lakes, ice / snow extent on glaciers.
CryoClim	http://www.cryoclim.net	Initiative to develop an operational service for long-term systematic climate monitoring of the cryosphere, including glacier change in Norway, and Greenland (planned).	CryoClim can provide Glaciers_cci with accurate validation data for Norwegian Glaciers.
CliC	http://www.climate-cryosphere.org	Project aimed at promoting research to understand the links between the Cryosphere and climate change.	CliC could help promote and endorse Glaciers_cci, and use the data as part of global glacier assessments.

Table 2.1: Initiatives related to Glaciers_cci and outline of the potential synergy.

3. User requirements

In this section we review the requirements of the users of glacier data. These requirements are grouped into those expressed by community groups and by scientists surveyed by the project through a user survey in Phase 1, and as ongoing feedback on our products.

3.1 Requirements from community groups

A key requirement of Phase 2 is that the project "meets the specific needs of a well identified, specialised climate research community by addressing the corresponding GCOS requirements" [R-3] (ESA Climate Change Initiative Phase 2, Statement of Work). For Glaciers_cci these user organisations include GCOS, the Intergovernmental Panel for Climate Change (IPCC), the Climate Research Group (CRG) and the Climate Modelling User Group (CMUG), the Global Terrestrial Network for Glaciers (GTN-G), the RGI Working Group and other CCI projects. We outline the requirements of these groups and of those identified in the Scientific Literature that are specific to the Glaciers_cci in the following sections.

3.1.1 GCOS

The Global Climate Observing System (GCOS) is a joint undertaking of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). GCOS is intended to be a long-term, user-driven operational system capable of providing information on the total climate system, involving a multidisciplinary range of physical, chemical and biological properties, and atmospheric, oceanic, hydrological, cryospheric and terrestrial processes. GCOS represents the scientific and technical requirements of the Global Climate Observing System on behalf of the UNFCCC and the Intergovernmental Panel on Climate Change (IPCC).

GCOS maintains a list of user requirements. The GCOS requirements for the ECV Glacier and Ice Caps, which remain relevant to Phase 2, are to produce:

- 2D vector outlines of glaciers and ice caps (delineating glacier area), supplemented by digital elevation models for drainage divides and topographic parameters [Product T.3.1, GCOS 2011]
- Elevation Change of glaciers and ice caps, from geodetic methods, in regions where outlines are available [Product T.3.2, GCOS 2011]

These products have the following technical details as requirements (Table 3.1):

ID*	Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability
URq_01	Area	15-30 m	N/A	Annual (at the end of the ablation season)	Better 5%	15 m
URq_02	Elevation change	30-100 m	1 m	Decadal	Better 5 m	1 m

Table 3.1: GCOS target requirements for glaciers.

3.1.2 IGOS and GTOS requirements for secondary ECV parameters

The Integrated Global Observing Strategy (IGOS) is a strategic planning process initiated by a partnership of international organizations that are concerned with the observational component of global environmental change issues. The IGOS partners are comprised of the Global Terrestrial Observing System (GTOS), the international organizations that sponsor GTOS, the Committee on Earth Observation Satellites (CEOS), and International global change science and research programmes.

IGOS/GTOS have formulated a set of recommendations for development of GICs observations. In addition to the GCOS requirements for GIC outlines and SEC outlined in the previous section, IGOS/GTOS list ice velocity as a requirement. The IGOS requirements for the secondary GICs ECV parameters are shown in Table 3.2 (IGOS, 2006).

ID*	Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability
URq_03	Velocity	Point – 200 m	N/A	Monthly to annually	Better 5%	-

Table 3.2: IGOS / GTOS target recommendations for GICs observations.

3.1.3 IPCC

The IPCC was established in 1988 by the UNEP and the WMO to provide a clear scientific view on the current state of knowledge in climate change and its potential impacts. In 2013/2014 The IPCC released its 5th assessment report compiled by 1000s of researchers worldwide and consisting of three main working groups which focus on the physical science of climate change, the impacts, adaptation and vulnerability to climate change, and the mitigation of climate change.

As part of the report on ‘The Physical Science Basis’ (Vaughan et al., 2013), a number of issues relating to the current state of observations of Glaciers and Ice Caps were raised. The key issues relevant to this project are as follows:

- One of the ‘Key Uncertainties’ raised in the technical summary of Stocker et al. (2013) was that “The largest uncertainty in estimates of mass loss from glaciers comes from Antarctica”. Section 4.3.3 of the main report indicates that this is because there is not currently a comprehensive inventory for the peripheral glaciers and ice caps of Antarctica, only those on the Antarctic and the Sub-Antarctic Islands.
- The certainty of global glacier area estimates is limited by regional variability in the accuracy of GOs, the minimum size of glaciers included and the subdivision of contiguous ice masses.
- Differing time spans covered by different area change measurement studies leads to uncertainty in generating regional or global scale estimates of area change.

Based on the issues outlined above the requirements are summarized in Table 3.3:

ID	Parameter	Requirements
URq_04	SEC	Prioritise SEC production for the peripheral GICs of Antarctica in particular.
URq_05	GO	Greater consistency is required in GO products, in particular in the minimum size of glaciers included, the methods for subdivision of contiguous ice masses, the provision of time stamps and the inclusion of seasonal snow and debris cover.
URq_06	GO	Globally more consistent epochs for area change measurements are required.

Table 3.3: Requirements highlighted by the IPCC AR5 Physical Science Basis report.

3.1.4 CRG and CMUG

The Climate Research Group (CRG) is the Glaciers_cci expert group who are engaged in the project and involved in understanding climate dynamics specifically related to the Glaciers ECV. In addition to using the products, a key role of the CRG in Glaciers_cci is to provide feedback on the products generated. For Phase 2 this group consists of five international scientists with expertise in climate modelling, glacier mapping and monitoring, and the GLIMS and RGI communities. The CRG has one key requirement, which is to increase the consistency on the time stamp of the GO product; as this is similar to URq_06 we do not repeat it here.

The Climate Modelling User Group (CMUG) is ESA's climate modelling expert group in the 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. CMUG has expressed the requirement listed in Table 3.4:

ID	Parameter	Requirements	Group
URq_07	GO	Data should be provided in netCDF format	CMUG

Table 3.4: CMUG Requirements.

3.1.5 GTN-G

The Global Terrestrial Network for Glaciers is the framework for the internationally coordinated monitoring of glaciers and ice caps in support of the UNFCCC. The network is authorised under GCOS and GTOS and is jointly run by the WGMS, the U.S. National Snow and Ice Data Center (NSIDC) and GLIMS. GTN-G aims to combine a) in situ observations with remote sensing data, b) process understanding with global coverage and c) traditional methods with new techniques using an integrated and multi-level approach. Requirements for the Glaciers_cci arising from the GTN-G are listed in Table 3.5.

ID	Parameter	Requirements
URq_08	SEC	Provide SEC data to the WGMS database
URq_09	GO	Provide GO data to the GLIMS and RGI database in the format specified by the RGI working group
URq_10	IV	Provide velocity data to the GLIMS database

Table 3.5: GTN-G requirements.

3.1.6 IACS Working Group on the Randolph Glacier Inventory (RGI)

The Randolph Glacier Inventory (RGI) is a collection of digital outlines of the World’s glaciers and ice caps that was developed to meet the needs of the IPCC AR5 estimate of recent and future glacier mass balance. The inventory was a cooperative effort of a community of glaciologists (including Glaciers_cci) and the results are summarized in Pfeffer et al. (2014). Although a substantial improvement on previous inventories in terms of its coverage and detail, the RGI remains a work in progress with a number of outstanding tasks to which Glaciers_cci can contribute. The list of tasks was expanded after a meeting of the IACS working group in June 2015 at the IUGG General Assembly in Prague. The lists of requirements of the RGI working group (Table 3.6) has been updated accordingly for year 2 of Phase 2.

ID	Parameter	Requirements
URq_11	GO	Improve the quality of the outlines in the RGI
URq_12	GO	Include outlines of the debris-covered parts of glaciers
URq_17	GO	Write report for IACS on ‘Differences between Large-scale Inventories’
URq_18	GO	Contribute to report for IACS on ‘Regions of Concern’

Table 3.6: RGI requirements.

Among others, the key task related to URq_17 is to determine the “magnitude of and reasons for disagreement between independently-obtained outlines” and assess “impact on estimates of glacier extent” in a written report. This sub-working group is led by F. Paul. The key tasks for URq_18 (sub-group led by J.G. Cogley) is to “Review of all Randolph regions and listing of those where improved outlines are desirable”. Submission deadline for the related reports to IACS is Dec. 2015. The RGI working group has also identified that the time span covered by GOs should be shortened (i.e. generate post 1999 outlines for those glaciers where the only outlines pre-date 1999), However, because this is similar to URq_06, we do not repeat it here.

3.1.7 Cross ECV requirements

GCOS identified 50 ECVs which fall into three domains: Atmospheric, Oceanic and Terrestrial. Glaciers and Ice Caps fall into the Terrestrial domain as well as, for example, river discharge, albedo, land cover and ice sheets. There is potential for synergy (see Section 2.2) and collaboration between the projects, in particular with the LandCover_cci to share glacier outlines, SeaLevel_cci to improve sea level budget calculations and the IceSheets_Antarctica_cci and IceSheets_Greenland_cci to ensure full regional coverage of the products. LandCover_cci have already been provided with Glacier Outline masks from Glaciers_cci. In terms of the Greenland and Antarctic_cci projects we should be sure to align the regional definitions, to ensure consistency and synergy between projects. For Greenland, the definition used has been defined within the project, and made available to the Glaciers_cci project. For Antarctica, a combination of the Zwally *et al.*, (2012) and Rignot *et al.*, (2011) basin and outline definitions will be used; both of these include the northern area of the Antarctic Peninsula in the ice sheet area. Potential synergy between the projects exists in the provision of volume change estimates for the peripheral ice bodies to enable compensation for them in gravimetry leakage effects.

The cross ECV requirements for Glaciers_cci are listed in Table 3.7.

ID	Parameter	Requirements	ECV
URq_13	GO, SEC	GO and SEC of the Antarctic and Greenland peripheral glaciers and ice caps.	IceSheets_Antarctica_cci and Ice-Sheets_Greenland_cci
URq_14	SEC	Mass change estimates of global GICs	SeaLevel_cci
URq_19	GO	Provide most recent glacier extents to Land_cover CCI for classification consistency	Land_cover

Table 3.7: Cross-ECV requirements.

3.2 Review of Phase 1 user requirements survey

In addition to the requirements listed above, as part of Phase 1 of Glaciers_cci the requirements of the international glaciological community were surveyed by way of a questionnaire. Three surveys were conducted, each with relevance to each of the three parameters (GO, SEC and IV). The questionnaires were designed to poll for information on key regions for study, the spatial and temporal coverage and sampling desired, required product formats, current community work (to avoid duplication of effort) and the availability of validation datasets. More detailed descriptions of the survey and the responses are given in the URD from Phase 1 (Glaciers_cci, 2011) and as such are not repeated here. Instead we provide an overview of the requirements which arose from the survey and are relevant to Phase 2 of the project.

The principal focus of the glacier outlines questionnaire was to identify the key regions for study. However, the survey results have since been superseded by the RGI and so the outcomes of the GO questionnaire are not relevant to Phase 2. The focus of both the SEC and velocity questionnaires was to determine the desired regions, product spatial resolution, accuracy and temporal sampling, and data projections and formats. In hindsight, the options given for a number of the questions were unclear, unrealistic or prone to biased responses and so these responses are discounted for Phase 2. For velocity there are no user requirements that are outstanding for Phase 2. The responses remaining relevant for SEC in Phase 2 are listed in Table 3.8.

ID	Parameter	Requirements
URq_15	SEC	Produce seasonal and annual SEC product
URq_16	SEC	Deliver SEC product in UTM coordinate system

Table 3.8: SEC Phase 1 user survey requirements relevant to Phase 2.

3.3 Feedback from the user community on Phase 1 products

During Phase 1 very little feedback was received from the user community on the products generated as part of Glaciers_cci. As part of the Climate Assessment Report (CAR) (Glaciers_cci, 2014), feedback on the RGI, which GOs from this project were contributed, was outlined. The feedback reported was, on the whole, a collection of the positive impacts that the updated RGI had had for e.g. sea-level change assessments and model projections of future glacier volume changes. However, one comment was received regarding user requirements for future improvements to the dataset. This related to the need for increased consistency in the time stamp of the GO product and is similar to that reported as URq_05 in Table 3.3, as such it is not repeated here.

To further improve and refine our products for Phase 2 we intend asking the users for feedback on the quality of our products. To achieve this we have modified the data download facility hosted by ENVEO to log the names and email addresses of the users and the datasets that they downloaded. When sufficient users are registered, we intend sending a targeted requests for feedback in the form of questionnaires specific to each product. The obtained feedback might be considered for future product improvement.

A first analysis of the users who have downloaded Glaciers_cci datasets revealed that these are mostly well known colleagues we already working together with. We have thus decided to delay circulation of a dedicated user feedback questionnaire. Some key users of the dataset we provided (outlines, velocity) have given a direct feedback in the last CAR. Apart from that, we have constant feedback on our products from the members of the IACS working group on the RGI and our CRG (GLIMS, WGMS, GTN-G Advisory board). They all appreciate the quality of our products and the support of their overarching goals (e.g. in terms of data production).

4. User Requirements Feasibility

Prior to devising/updating the Product Specifications, it is first of all important to assess the feasibility of being able to meet the User Requirements. The following subsections highlight and revise the user requirements, if any, that are judged to be unfeasible in light of, for example, data or time constraints. We divide SEC into DEM differencing and Altimetry, as the two techniques have different capabilities.

4.1 Glacier outlines

For GO measurements we identify one modification to the user requirements listed in the previous sections. This is:

- **URq_07:** data will be provided in netCDF format on request only.

In addition and in general, we would like to stress that, depending on the quality of the available data and time constraints, it may not be possible to derive glacier outlines for all required regions and all required time periods.

4.2 Elevation change – DEM differencing

For SEC measurements from DEM differencing we identify three User Requirements that are not fully feasible; these are as follows:

- **URq_02:** Whereas the GCOS target requirement for horizontal resolution of 30-100 m can be met in most cases, the vertical accuracy of ‘better than 5 m’ will not be met in all cases as some DEMs available, notably those from ASTER and SRTM, have reduced accuracy under difficult conditions such as steep slopes and low visual contrast for ASTER, or radar shadows and penetration for SRTM. Rather, for ASTER-derived DEMs or the SRTM DEM, DEM difference vertical accuracies of 5-10 m might be expected on average. The accuracy of the TanDEM-X DEM over glaciers has started.
- **URq_14:** Producing estimates of mass balance is beyond the scope of the baseline project. However, the SEC measurements will be converted to estimates of mass balance within Glaciers_cci option 2).
- **URq_15:** DEM differences can in general not be provided as seasonal or annual products as (i) suitable DEMs are typically only available at decadal time scales, and as (ii) the typical vertical accuracy of such DEMs is too low to estimate SEC at seasonal and annual time scales to a statistically significant level. Exceptions where seasonal to annual elevation changes exceed the DEM difference accuracy will be glacier surges or similar instabilities. Further, interpolation of elevation change at a temporal resolution of few years has been demonstrated for dense time series of ASTER DEMs (> 1-2 DEMs/year) (Wang and Kääb, 2015). However, such dense ASTER time series are only available for a few glaciers/glacier groups worldwide. Else, there are no glacier DEMs available with seasonal or annual repeat rates except a hand-full repeat airphoto or LiDAR flights used for national glacier monitoring programs for instance in Switzer-

land, Austria, Norway or Iceland. The latter data have access restrictions and their exploitation is beyond the scope of Glaciers_cci.

The requirements as outlined in the summary table in Section 5, and in all subsequent documents are altered accordingly for the above points.

4.3 Elevation change – Altimetry

For SEC measurements from altimetry we identify two User Requirements that are not fully feasible; these are as follows:

- **URq_02:** GCOS target requirement for horizontal resolution of SEC measurements of 30-100 m. This resolution is not achievable with altimetry due to the constraints of the sensors and the methods necessary for deriving elevation change measurements. The typical SEC resolution that can be reliably achieved from altimetry is 1– 5 km depending on the data and the region. By design, space-borne altimetric data are along profiles following orbit tracks, and are thus not evenly distributed.
- **URq_14:** Producing estimates of mass balance from SEC-alt are beyond the scope of this project. However, mass balance estimates will be produced as part of Option 2 from alt-dem.

The requirements as outlined in the summary table in Section 5, and in all subsequent documents are altered accordingly for the above points.

4.4 Velocity

For the Climate Research Data Package (CRDP) for ice velocity products we see the main limitations in the type and size of the glaciers for which velocity products will be generated, and the availability of suitable repeat pass SAR and optical satellite data.

The generation of the velocity CRDP will focus on large glaciers and ice caps (size > ~500 m) using SAR and optical images from available sensors. The operational generation of velocity products for slow moving small alpine glaciers would require a systematic acquisition of very high resolution repeat pass data over these areas, which is currently not available.

5. Summary

Table 5.1 provides a summary of the identified user requirements that is organised by EO data product. For each user requirement, the source and the type of work it will address are identified. Background (BG) means that this is a continuous activity, selection (S), production (P), and dissemination (D) means that the related requirement has to be considered during data selection, production, and dissemination, respectively. We aim to meet as many of these requirements as possible in the course of the annual cycle, taking into account data availability and workload constraints.

ID	Parameter	Requirements	Source	Type
URq_01	GO	For GO, EO products aim to achieve 15-30 m horizontal resolution, annual temporal resolution, better than 5% accuracy and 15 m stability.	GCOS	BG
URq_04	GO	Prioritise GO production for the peripheral GICs of Antarctica.	IPCC	S
URq_05	GO	Greater consistency is required in GO inventories, in particular in the minimum size of glaciers included, the methods for subdivision of contiguous ice masses, the provision of time stamps and the inclusion of seasonal snow and debris cover.	IPCC	P
URq_06	GO	A globally consistent epoch(s) for area change measurements is required.	IPCC, CRG, RGI	P
URq_07	GO	Data should be provided in netCDF format * on request	CMUG	D
URq_09	GO	Provide GO data to the GLIMS and RGI database in the format specified by the RGI working group	GTN-G	D
URq_11	GO	Improve the quality of the outlines in the RGI	RGI WG	P
URq_12	GO	Include outlines of the debris-covered parts of glaciers	RGI WG	P
URq_13	GO	GO of the Antarctic and Greenland peripheral glaciers and ice caps.	IceSheets_Antarctica_and Greenland_cci	S
URq_17	GO	Write report for IACS on 'Differences between Large-scale Inventories'	RGI-WG	BG
URq_18	GO	Contribute to report for IACS on 'Regions of Concern'	RGI-WG	S
URq_19	GO	Provide most recent glacier extents to Land_cover CCI for classification consistency	Land_cover	D
URq_02	SEC – alt	For SEC -alt, EO products aim to have 1 m vertical resolution, decadal temporal resolution, better than 5 m accuracy and 1 m stability	GCOS	BG
URq_04	SEC- alt	Prioritise SEC production for the peripheral GICs of Antarctica.	IPCC	S
URq_08	SEC-alt	Provide SEC data to the WGMS database	GTN-G	D
URq_13	SEC-alt	SEC of the Antarctic peripheral glaciers and ice caps.	IceSheets_Antarctica_cci	P
URq_14	SEC-alt	Mass change estimates of global GICs [**beyond the scope of this project; optional for glaciers]	SeaLevel_cci	-
URq_15	SEC-alt	Produce seasonal and annual SEC product [*** al-	Phase 1 Survey	P

ID	Parameter	Requirements	Source	Type
		timetry only]		
URq_16	SEC-alt	Deliver SEC product in UTM coordinate system	Phase 1 Survey	D
URq_02	SEC – dd	For SEC from DEM Differencing, EO products aim to achieve 30-100 m horizontal resolution, decadal temporal resolution, better than 5-10 m accuracy	GCOS	BG
URq_04	SEC- dd	Prioritise GO and SEC production for the peripheral GICs of Antarctica.	IPCC	S
URq_08	SEC- dd	Provide SEC data to the WGMS database	GTN-G	D
URq_14	SEC –dd	Mass change estimates of global GICs [**beyond the scope of this project; optional for glaciers]	SeaLevel_cci	P
URq_16	SEC-dd	Deliver SEC product in UTM coordinate system	Phase 1 Survey	D
URq_03	IV	For IV, EO products aim to achieve point to 200 m horizontal resolution, monthly to annual resolution, and better than 5% accuracy.	IGOS/GTOS	BG
URq_10	IV	Provide velocity data to the GLIMS database	GTN-G	D

Table 5.1: Summary of the Glaciers_cci user requirements organised by product, with source of requirement, and the type of requirement (BG: background; S: selection, P: data production, D: dissemination).

References

- GCOS (2011): Systematic observation requirements for satellite-based data products for climate 2011 update, GCOS-154, WMO, 128 pp.
- Glaciers_cci (2014): Climate Assessment Report (CAR). Prepared by the Glaciers_cci consortium, 19 pp.
- Glaciers_cci (2015): User Requirements Document (URD) Phase 2 year 2: Prepared by the Glaciers_cci consortium, 19 pp.
- IGOS (2006). IGOS Cryosphere Theme for the Monitoring of our Environment from Space and from Earth. Version 0.9.5.1, November 2006. 118p.
- Pfeffer, W.T. and 19 others (2014): The Randolph Glacier Inventory: a globally complete inventory of glaciers. *Journal of Glaciology*, 60, 221, 537-552.
- Stocker, T.F., and 33 others (2013): Technical Summary. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 33–115
- Vaughan, D.G., J.C. Comiso, I. Allison, J. Carrasco, G. Kaser, R. Kwok, P. Mote, T. Murray, F. Paul, J. Ren, E. Rignot, O. Solomina, K. Steffen and T. Zhang, 2013: Observations: Cryosphere. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 317–382

Abbreviations

CAR	Climate Calculation Report
CCI	Climate Change Initiative
CEOS	Committee on Earth Observation Satellites
CFL	Calving Front Location
CLiC	Climate and Cryosphere
CMUG	Climate Modelling User Group
CRDP	Climate Research Data Package
CRG	Climate Research Group
DEM	Digital Elevation Model
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
GCOS	Global Climate Observation System
GICs	Glaciers and Ice Caps
GLIMS	Global Land Ice Monitoring from Space
GLL	Grounding Line Location
GO	Glacier Outlines
GTN-G	Global Terrestrial Network for Glaciers
GTOS	Global Terrestrial Observing System
ICSU	International Council for Science
IGOS	International Council for Science
IOC	Intergovernmental Oceanographic Commission (IOC)
IPCC	Intergovernmental Panel for Climate Change
IV	Ice Velocity
PSD	Product Specification Document
NSIDC	National Snow and Ice Data Center
RGI	Randolph Glacier Inventory
SAR	Synthetic Aperture Radar
SEC	Surface Elevation Change
SoW	Statement of Work
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate
URD	User Requirements Document
URq	User Requirement
WGMS	World Glacier Monitoring Service
WMO	World Meteorological Organization