User Requirements Document (URD)

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Contents

Overview

This is the User Requirements Document (URD) of the Glaciers_cci project. It is the first deliverable of Task 1 of the CCI and should provide (according to the statement of Work) 'a complete, definitive, structured set of individual requirements and constraints to meet the needs of the Climate Research Community for FCDRs and ECV data products.' This document first introduces the different user communities for the products generated by the project and then describes the basic accuracy requirements for each product. These depend on the sensor used for product generation and also address different user groups. As improved product accuracy is a major demand of the user community, we cover this topic already here. Section 2 describes the user requirements as given in various documents (e.g. by GCOS and in the IGOS Cryosphere Theme Report), as provided by the key science bodies (WGMS and GLIMS), CMUG, the CRG. the scientific literature, and from a user survey addressed to the members of the Cryolist and the GLIMS Mailing list. This survey also includes a statistical analyses of the feedback. The next Section 3 provides an updated overview on the key regions for product generation and introduces the varying levels of completeness. The final requirements analysis in Section 4 reviews the feedback from all sources and describes a potential glacier monitoring approach. After the list of references and abbreviations, the Appendix gives a summary of the product specifications for each of the three products (App. 1), the list of suggested key regions from the original proposal (App. 2), the invitation to participate in the user survey (App. 3), and the response to the questionnaire from the user community (App. 4).

1. Introduction

1.1 User communities

In the following, we provide some background information to better understand the specific set-up of the Glaciers_cci project. Glaciers and icecaps (glaciers in the following) were selected as an Essential Climate Variable (ECV) in the second adequacy report of the Global Climate Observing System (GCOS, 2003), as they provide key indicators of climate change on a global scale that rank at the same top level of confidence as direct temperature measurements (IPCC, 2001). This indicator function is related to their sensitive and strongly enhanced reaction to small changes in climate (i.e. advance or retreat of the glacier tongue after some delay). The accurate assessment of these changes requires to have a detailed glacier inventory in a digital 2-dimensional form (vector outlines). Such a data set is not yet available at a global scale with the required accuracy. The first aim of the Glaciers_cci is thus to contribute to the completion of the global glacier inventory using satellite data. This is in line with product T.2.1 in GCOS-107 (2006): 'Maps of the areas covered by glaciers' and Tier 5 of the Global Terrestrial Network for Glaciers (GTN-G). The project will also derive elevation changes and velocity fields for selected glaciers as these provide additional important information of glacier response to climate change, in particular for calculating their mass balance. The key regions and time periods to be considered for these products are based on the feedback from the CRG and the wider glaciological community (GLIMS, Cryolist).

Besides their climate indicator function, glaciers and icecaps do also contribute substantially to global sea-level rise (e.g. Meier et al., 2007; Hock et al. 2009), they have regionally an important influence on hydrology (hydro power, run-off regime) and constitute a locally important economic factor (tourism, natural hazards). These additional applications of a global glacier inventory are also listed in GCOS-107 (2006). On the other hand, they do not yet play a role in Global or Regional Climate Models (GCMs / RCMs), either as a boundary condition or a factor that can change with time. With the exception of some individual studies (e.g. Kotlarski et al., 2010a), the climate modelling community as represented by CMUG is not yet ready to assimilate the data products created by the Glaciers_cci. Rather, the hydrologic and glaciologic communities work with these data and the product requirements in regard to accuracy and spatial coverage will follow their needs. The key science bodies WGMS and GLIMS are engaged in the CRG of the project to guarantee product standards and seamless integration into the existing services.

Questionnaires with the members of the Climate Research Group (CRG) and through mailing lists (GLIMS and Cryolist) were performed to determine the status of ongoing work and to shape the details of the products. Recent results from projects like GlobGlacier, ice2sea, WC^2N are considered as well (see section 4). In this regard it is important to note that the glacier inventory data created by Glaciers_cci will include full topographic information for each individual glacier according to the guidelines prepared by Paul et al. (2009). The Glaciers_cci project will also derive elevation changes and velocity fields for selected glaciers. The key regions and time periods to be considered for these products are based on the feedback from the CRG and the wider glaciological community (GLIMS, Cryolist).

1.2 Product accuracy

Below we provide some general information on product accuracy and the different measures to determine them for each of the products and the various data sources. This specification is required here to better understand the accuracy-related user requirements for each of the products. More details will be provided in the Product Specification Document (PSD).

1.2.1 Glacier area

The quality of the derived products is a major issue for the project, as well as for the further use and application of the data by the users. When a global glacier inventory should be derived from satellite data (Tier 5 requirement of GTN-G) an appropriate sensor has to be found. Considering the required global coverage, size of the target (down to 0.01 km^2), free data availability, and processing workload, the only sensors fulfilling these requirements are the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper+ (ETM+). The ASTER sensor onboard Terra is also compliant with some of the requirements, but processing workload is much higher (orthorectification is required and spatial coverage is only 1/9 of a Landsat scene). For this reason, the glacier inventory product is based on 30 m resolution Landsat data combined with digital terrain information obtained from freely available DEMs (e.g. the 30 m ASTER GDEM, the 90 m SRTM DEM, or national DEMs). This implies that the requirements for the geometric accuracy of the satellite imagery used are in the same order of magnitude, about +/-30 m. As glaciers are generally located in high and steep mountain terrain, only orthorectified satellite scenes can be used for processing. The accuracy of the glacier outline itself (either derived from automated or manual delineation) is under good conditions seldom better than +/-1 satellite pixel (e.g. Paul et al., 2003; Andreassen et al., 2008) and less than this under more difficult conditions (e.g. Hall et al., 2003).

A much higher uncertainty results from methodological constraints, like the exact location of drainage divides in flat accumulation regions, seasonal snow cover that hides the glacier perimeter, identification of debris-covered glacier parts under difficult illumination conditions, or the ’correct’ consideration of tributaries. Whereas general remarks on these topics were published as an outcome of a GLIMS workshop in Boulder (Racoviteanu et al., 2009), there are currently no standardized procedures or guidelines in place that are applied consistently. This results in a wide variability of glacier entity assignment and related difficulties in comparison of results from different analysts or for change assessment. A major aim of the Glaciers_cci project is thus to improve data consistency by establishing the required guidelines under community consensus (e.g. via the round-robin experiments).

1.2.2 Elevation changes

Elevation changes over glaciers and icecaps can be determined by at least two different and complementary methodologies: (1) repeat altimetry and (2) DEM differencing. Whereas (1) provides the information at selected points over large and flat ice masses with a high temporal density (months) and accuracy (dm), method (2) gives the overall changes for much smaller entities with a reduced temporal resolution (decades) and a lower accuracy (m). This implies that the results from the two methods give different products (both have their dedicated user communities) and also that product accuracy has to be calculated differently. In the end it is important that the changes exceed the accuracy of the respective products, i.e. that the changes are significant. This can be achieved by extending the repeat interval of the measurements. Major factors influencing product quality are surface slope and roughness for the altimetry product, the source of the DEM (e.g. optical vs. microwave, aerial vs. satellite), and the region of the glacier (accumulation vs. ablation region, terrain steepness) for the DEM differencing product. For both products also the geometric accuracy (i.e. co-registration) is an important factor for product accuracy (e.g. Moholdt et al., 2010; Nuth and Kääb, 2011).

A final point to be considered for appropriate product accuracy is the downstream application of the data by the users. For example, the point measurements from altimetry do provide accurate information for trend analysis, but have a limited potential for spatial extrapolation to the entire glacier (e.g. Kääb, 2008). On the other hand, DEM differencing provides this information, but can fail in regions with data voids so that overall volume changes cannot be calculated for some glaciers. From a user perspective, one important requirement is the determination of the representativeness of the measured mass balance glaciers for an entire mountain range. When these mass balance glaciers are properly covered, some poorly covered glaciers in the entire region do not matter (Paul and Haeberli, 2008).

1.2.3 Velocity fields

Velocity information over glaciers provide important information on mass flux (the horizontal component of mass balance) and is thus complementary to the elevation change product. The approaches to determine velocity fields over glaciers from repeat satellite data provide information over different time periods (optical: 1 year, microwave: a few days to weeks). The products resulting from both methods thus have relevance for different user communities and also different specifications of the error terms. Assessment studies using a number of optical sensors suggest an accuracy (RMSE) of individual displacement vectors on the order of 0.5-1 pixels of the optical sensor used, i.e. about 15-30 m for Landsat, ASTER and SPOT images, and about 1 m for very high resolution sensors used for local studies. Our precision analysis, investigations and experience suggest that for SAR data errors are in the order of 5 m/year applying dual-azimuth ERS-1/2 InSAR and 10 m/year for 24 days RADARSAT-1/2, 46 days ALOS PALSAR and 11 days stripmap TerraSAR-X data using offset-tracking.

However, in order to be suitable for displacement matching on glaciers, the total displacement in the time interval between the two optical satellite images should significantly exceed the spatial resolution of the images, the investigated glacier has to show pronounced features of optical contrast such as crevasses and debris features, which implies that image matching does usually not work over snow-covered or firn-covered accumulation areas, and during the time interval between the two image acquisitions the surface changes have to be small enough to allow identification of corresponding contrast features over the interval. Although it may be possible to measure summer/winter velocities, annual velocities and/or pluri-annual velocities, the measurement of all three types is often not possible. Product generation in certain regions is thus dependent on data availability and glacier characteristics.

ERS SAR data with 1 or 3 days acquisition time interval for InSAR studies shall be taken during mid winter - to avoid temporal decorrelation - and with short (e.g. < 100 m) baselines - to avoid spatial decorrelation. Some uncertainties, related in particular to strain rates and meteorological conditions, can only be resolved once the interferogram has been formed. For SAR offset-tracking at regional scale with high resolution satellite data (e.g. ALOS PALSAR or Radarsat-1/2) scenes might be taken during all year, although best spatial coverage is achieved in winter, and preferably along successive cycles at fixed viewing geometry (incidence angle, polarization, resolution). Time series of very high resolution sensors SAR (e.g. TerraSAR-X) might be employed for complementary local studies.

2. User Requirements

2.1 GCOS documents

2.1.1 GCOS-82 (2nd Adequacy Report) and GCOS-92 (GCOS Implementation Plan)

In these two GCOS documents (GCOS, 2003 and 2004), glaciers and icecaps are somewhat mixed-up with the ice sheets. Although the latter have not been an ECV at that time, improved monitoring of their mass changes was mentioned. For glaciers and icecaps an improvement of the in-situ measurement network was recommended, in particular the re-initiation of time series in Patagonia, New Zealand and Africa. In regard to EO data it was recommended to analyze them for the determination of trends over the past two decades. The GTN-G was assigned as the coordinating body for all activities. GCOS-82 also described the role of satellite observations for the monitoring of ECVs, the implementation of the observations (with more details in GCOS-92) and the GCOS climate monitoring principles. In GCOS-92, ’parties are urged to support the operational continuation of the satellite-based products, with a ’full glacier inventory from current spaceborne cryosphere mission’ as a priority product in the terrestrial domain.

2.1.2 GCOS-107 (Satellite Supplement to GCOS-92)

In GCOS-107 (2006), ’Maps of the areas covered by glaciers’ were identified as product T.2.1 for the ECV glaciers and icecaps. This demand is still active and consequently the prime-focus of the Glaciers_cci project is in the further completion of the global glacier inventory. The listed target requirements in regard to accuracy/stability (better than 5%) and spatial/temporal resolution (30 m / 1 year cycle) are also still valid. The requirements for the satellite instruments list the importance of multispectral sensors (with a band in the SWIR) and the historic Landsat archive (starting in 1984) as a source for creating FCDRs. Both issues do still apply. On the other hand, the GCOS-107 document is now somewhat outdated in regard to the points data archiving needs and inadequacy of current data holdings: With the opening of the Landsat archive by USGS and the related free provision of already orthorectified Landsat scenes through an easily accessible web portal (glovis.usgs.gov), major requirements from the user community were fulfilled in the mean time. The now applied orthorectification (L1T product) does in nearly all cases fulfil the spatial accuracy requirements of GCOS-107 (exceptions exist where the SRTM DEM is erroneous).

A further important requirement is also fulfilled: The continuity of the existing archive and service from WGMS is secured for the coming decades by the Swiss government (GCOS, 2008). In some regions the re-evaluation of historical map and field data started, to make them available for validation purposes. Testing the suitability of these data for this purpose is a subject of current research as methodological issues often prevent a direct comparison (e.g. high-resolution satellite imagery must be acquired at the same date, length changes need to be assessed along the same lines of sights). As an immediate action GCOS-107 recognizes that ’The generation of a consistent historical data record spanning the Landsat 4/5 TM data record would provide major advancement in global monitoring of glaciers’. This requirement already received attention in some regions (e.g. Bolch et al., 2010), but is still a major issue on a global scale. The second phase of the CCI programme will help to bring this issue back on the agenda as a next step.

2.1.3 The response of CEOS to the GCOS Implemtation Plan (GIP)

With actions T.1 and T.2, CEOS recognizes the forthcoming gap in the current Landsat data record and promises to assess the feasibility of using the historic archive for generating FCDRs of this ECV. With the upcoming Sentinel 2 (ESA) and LDCM (NASA) missions, action T.1 might be resolved in the near future, but Landsat 5 has to be kept in operation til that time (late 2012) to avoid data gaps. After being in operation for more than 26 years, there is no guarantee that this can be accomplished. Action T.2 is in part already fulfilled with the opening of the Landsat archive at USGS. It is hoped (though not mandatory for the success of the Glaciers_cci project) that further data distributors (e.g. CCRS, Eurimage) will follow the example of the glovis.usgs.gov portal or join the existing archives in the years to come. Currently at least the Eurimage archive can be seen with the EOLISA browser (pers. Comm. S. Plummer), but the quality of the quicklooks is too poor to use them for a clear decision.

2.2 The IGOS Cryosphere theme report

The IGOS Cryosphere theme report (IGOS, 2007) gives a comprehensive overview of the ECV, the status of observations and their shortcomings, the possibilities of remote sensing, a list of recommended actions and a summary of current/planned capabilities and requirements for satellite based observations (Table 1). From the list of recommendations the relevant issues for the Glaciers_cci project are:

R7.1: The completion of the global glacier inventory was identified as a priority need.
R7.3: continuation of Landsat/ SPOT type missions, …, are needed to obtain global inventories of glaciers and their changes in time intervals of 5 to 10 years.
R7.4: A dedicated mission for precise mapping of glacier topography is a high priority for determining the evolution of changes in glacier mass directly. A further satellite mission that is providing spatially distributed information on accumulation is also needed.
R7.5: It is essential to maintain a solid ground-based glacier observation network to have the required continuation of long time series of key climate parameters and a base for calibration and validation of satellite-derived glacier products.
R7.6: The strengthening of the operational service for the GTN-G with a secured funding.
R7.7: A global 2D glacier inventory (polygon outlines) as a reference for change assessment.

From these recommendations, R7.3 is already under development through e.g. Sentinel 2 and the LDCM, and R7.6 is achieved. Points R7.1 and R7.7 received special attention in the ESA GlobGlacier project (adding 20’000 glacier entities to the GLIMS database) and are core products of the Glaciers_cci project. The work on both points is further supported by ongoing activities of the GLIMS community and other projects (e.g. ice2sea, CryoClim). The work on R7.5 has started and for R7.4 promising satellite missions are in place (Tandem-X, Cryosat 2). So there are quite some achievements for the recommendations of IGOS (2007) in the mean time. From all potential products listed in the Appendix of the report (Table B.6), we have selected those which are relevant for the Glaciers_cci project (Table 1), namely glacier area, velocity, and elevation change (i.e. mass balance in the table). Topographic information is partly also considered, as this is a baseline product that is required to generate all other products. In this regard, topographic information for product generation in Glaciers_cci is used as available from public sources (e.g. SRTM, ASTER GDEM) rather than created by the project. However, for product validation purposes specific aspects of the DEMs (e.g. geolocation, accuracy, artefacts) will be investigated in more detail detail, including generation of local DEMs.

Parameter	COT	Measurement Range			Measurement Accuracy		Resolution				Comment or Principal Driver
							Spatial		Temporal		
		L	H	U	V	U	V	U	V	U	
Area	C				1	%	5	m	30	yr	airborne
	O				3	%	30	m	5	yr	Landsat etc.
	T	0.01		km²	3	%	50	m	5	yr	Hi-res optical
	O	0.01		km²	1	%	15	m	1	yr	
Topography	O										Airborne
	C	0	8500	m sl.	5	m	100	m	5	yr	For models
	T	0	8500	m sl.	0.1	m	30	m	1	yr	Mass balance
Velocity	O				1	%	point		1	yr	In situ
	C	0	10	km/yr	5	%	10	m	1	yr	InSAR, hi-res optical, etc.
	T	0	10	km/yr	1	%	20	m	1	mo	
Glacier dammed lakes	O				1	%	1	m	1	yr	airborne
	C	0.05	10	km²	3	%	50	m	1	mo	SAR, hi-res optical
	T	0.01	10	km²	1	%	15	m	5	day	
Facies, snowline	C						point				In situ
	T			class	200	m	100	m	1	mo	Position of boundary
	O			class	30	m	30	m	10	day	
Accumulation	C				5	%	point				In situ
	T	0.05	8	m	10	%	500	m	1	yr	Ku-, X-SAR
	O	0.10	5	m	5	%	100	m	1	mo	
Mass balance	C				0.10	m	point				In situ
	T	0	±5	m	0.20	m	500	m	1	mo	process model & SAR
	O	0	±5	m	0.05	m	100	m	1	yr	
Ice thickness	C	0	200	m	2-5	m	100	m	30	yr	In situ, airborne

Table 1: Specifications in the IGOS cryosphere theme report (IGOS, 2007) for the glaciers and icecaps ECV. Codes are as follows: C: Current Capability, T: Threshold Requirement (Minimum necessary), O: Objective Requirement (Target), L: Low end of measurement range, U: Unit, H: High end of measurement range, V: Value, mo: month, yr: year.

2.3 Requirements of Key Science Bodies (GLIMS and WGMS)

2.3.1 GLIMS standards and guidelines

The glacier outline product as available in the GLIMS database is in shapefile format (geographic projection, WGS84 datum) and produced from raster data (e.g. satellite scenes, topographic maps and DEMs) that are commonly exchanged in GeoTif format (UTM projection with WGS84 datum). Whereas these formats are common in the hydrological and glaciological communities, the climate modellers mostly use netCDF. For the purpose of directly assimilating glacier information in climate models (e.g. in grid or table format) they can be converted from shapefile (or .dbf) to netCDF. The exact requirements (cell size, projection, etc.) will depend on the purpose of the application and the RCM used.

An extended set of guidelines and tutorials were prepared by the GLIMS community to aid in the analysis of the satellite scenes, establish data format standards and describe the calculation of glacier inventory parameters. Apart from the description of examples and details in the published literature (see 2.6), two kinds of GLIMS documents can be distinguished, (i) those providing practical help in the classification and analysis of satellite scenes, and (ii) those documenting the specifications of the data formats of the final product.

Documents of category (i) include:
- the GLIMS analysis tutorial (Raup and Khalsa, 2007)
- the illustrated glacier classification manual (Rau et al., 2003)
- the data processing recommendations from the GLIMS workshop (Racoviteanu et al., 2009)
- the recommendations for deriving glacier inventory parameters (Paul et al., 2009)
- an online overview of glacier classification algorithms

Category (ii) documents include:
- the GLIMS database transfer specifications
(link: http://glims.org/MapsAndDocs/datatransfer/data_transfer_specification.html)
- the database organization with the entity relation diagram
(link: http://glims.org/MapsAndDocs/DB/glims_db_erd_20080717.png)
- a description of the database design in a paper (Raup et al., 2007)
- the GLIMSView software (link: http://glims.org/GLIMSView/)

Furthermore, for some specific technical details hands-on tutorials and online conversion scripts are available to facilitate the work of the analyst. A currently missing document has to illustrate glacier delineation based on examples from different parts of the world with a particular consideration of problematic issues (debris cover, attached seasonal snow fields, drainage divides in the accumulation area, counting of tributaries, etc.). Such guidelines should be a major outcome of the Glaciers_cci project (based on the foreseen round-robin experiments).

2.3.2 GLIMS database status

The GLIMS database is frequently updated by the GLIMS participants. An overview of the status can be found at: http://glims.colorado.edu/glacierdata/data_completeness_status.php.

The regions that require further work can be distinguished into the categories: (a) completely missing, (b) some data are in the database but are not complete, or (c) regions are included but based on old maps with an often unknown acuracy. Category (a) regions include: Baffin Island, most local glaciers and icecaps on Greenland, Svalbard, Russian Arctic Islands, several regions in the FSU and Islands in the southern hemisphere (e.g. New Zealand, Kerguelen, South Georgia). Nearly all regions with glaciers are in category (b). A more or less complete overview of these regions along with additional information on Landsat path/row and the most suitable acquisition period can be found at:
http://www.emporia.edu/earthsci/gage/glacier7.htm.
Regions in category (c) include China, the Unites States and Nepal. The focus of product generation in Glaciers_cci will be in category (a) regions, whereas category (b) regions (with lots of ongoing work) will get support to submit their data and integrate them in the database. Figure 1 illustrates the current (22. May 2011) status of the GLIMS database.

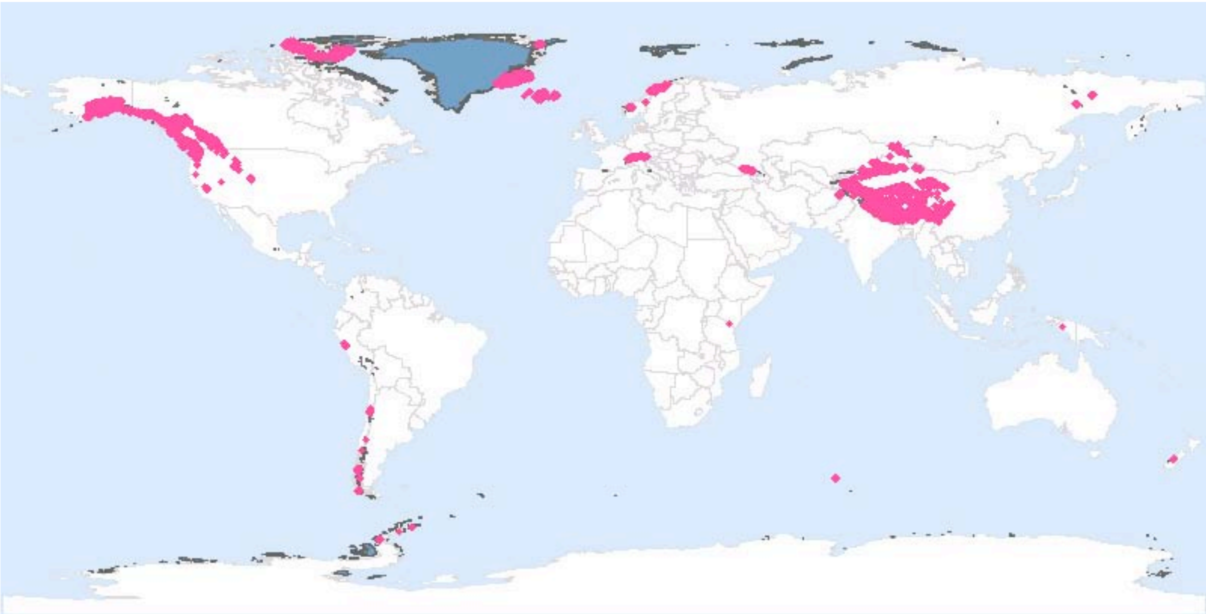

Fig. 1: Current coverage (22. May 2011) of the GLIMS database (pink) compared to regions with glaciers and icecaps from the digital chart of the world (blue). Source: glims.org

2.3.4 WGMS requirements

The world glacier inventory (WGI) that was compiled during the 1960s to 1980s and published by WGMS (1989), contained preliminary information (e.g. area only) for several heavily glacierized regions. The coverage of the detailed information (i.e. with topographic attributes) is depicted in Fig. 2.

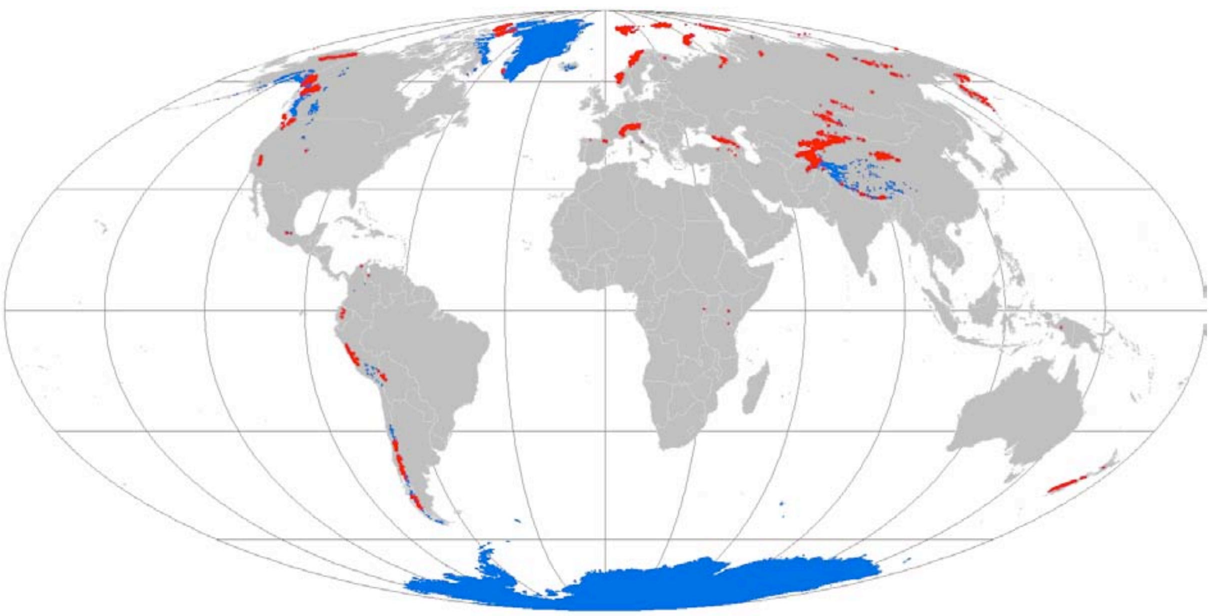

Fig. 2: Coverage of the detailed information in the WGI (red) compared to the land ice layer in the digital chart of the world (blue). The figure was provided by M. Zemp (WGMS).

In view of these data gaps and current scientific demands, the WGMS requests to perform the following major issues in the Glaciers_cci project:

- generating glacier inventory data in yet uncovered but for some reason important regions
- provide glacier outlines, DEMs and satellite imagery for the 30 reference mass balance glaciers, where possible also time series should be included
- help to establish standardized products by creating illustrated guidelines
- perform change assessment (length, area, volume) where appropriate data are available
- enhance the visibility of the GTN-G framework by linking to existing structures

In regard to missing glacier inventory information, WGMS recommended to also check the actual status of work with GLIMS (see 2.3.2) and the work on the extended format of the world glacier inventory (WGI-XF) by J. Graham Cogley (Cogley, 2009). According to this survey and with respect to the WGI (WGMS, 1989), the regions listed in Table 2 were identified as missing. In the meantime, some of these gaps are closed in the GLIMS database. It has to be noted though, that the WGI-XF is a compilation of *point data* for each glacier (like in the WGI) rather than of vector outlines as stored in the GLIMS database.

Region	Area km^2	Availability
South America		
Patagonia	4000	No
Rest	500	No
North America		
Western North America (Canada)	38 000	Yv
Western North America (USA)	74 000	Yv
Queen Elizabeth Islands	84 000	Yv
Greenland	40 000	?Yv
Europe		
Iceland	11 000	GLIMS
Asia		
Chukotka	20	?No
Mongolia	600	Yr
Burma	10	No
Kashmir (India)	4000	Yr
Afghanistan	1000	?No
Iran/Turkey	40	?No
Subantarctic		
South Georgia	2000	Yp
Antarctica		
Peripheral ice bodies	127 000	Yv

Table 2: Glaciers not yet inventoried, or not yet assimilated into WGI-XF. Estimates of area are from WGMS (1989) or from textbooks; some are rough. Availability: No – maps not available or not adequate; Y – maps available from governmental or commercial sources (v: vector format; r: raster format; p: paper format); GLIMS – inventory available in the GLIMS database. Overview modified from Cogley (2009).

Suggestions by WGMS for key regions include: Alaska, Canadian and Russian Arctic, Patagonian Icefields, and local glaciers and icecaps surrounding the two polar icesheets. These regions are also listed in Table 2, but the reference here is to glacier outlines in *vector format*. For elevation change measurements the target should be on mountain ranges with long-term in-situ measurements of mass balance to assess their representativness for the entire mountain range. Velocity fields would be most important for calving glaciers to improve estimates of the calving flux, and for icefields and icecaps to properly determine drainage divides. The time period for analysis might focus on the past four decades as well as on the century time scale when analyzing trimlines of historic (Little Ice Age) glacier extents.

As both WGMS and GLIMS are in the CRG of the project, the required close collaboration to achieve these tasks is given. It is expected that priorities might change through time and new issues emerge in the course of the project.

2.4 Requirements of CMUG and the CRG

2.4.1 CMUG requirements

The link of the glaciers and icecaps ECV to climate is at first hand their role as a climatic indicator. Their sensitive reaction to small changes in climate conditions visualize climate change impacts in a most clearly (length changes) and in its physical principles (more ice melts when temperature increases) also understandable way for the large public. With concerns growing about the future vanishing of glaciers in several mid-latitude mountain ranges (with strong impacts on both regional hydrology and global sea-level rise, among others), scenarios of future climate conditions as provided by GCMs/RCMs become the most important tool for assessing their future evolution (e.g. Radić and Hock, 2011). So glacier changes with time need to be assessed and GCMs/RCMs do provide the required input data for the related modelling approaches (e.g. Reichert et al., 2001; Zhang et al., 2007; Machguth et al., 2009; Paul et al., 2010). Of particular value in this regard is the possibility for a physically consistent dynamic downscaling of coarse resolution global climatologies (e.g. re-analysis data) or GCM output with RCMs. This allows to consider at least partly the steep topography of mountain ranges (where glaciers are located) and their special characteristics in regard to climate parameters such as enhanced precipitation (Kotlarski et al., 2010b). So in this direction climate models are a well established tool in the community.

On the other hand, extents of glaciers and icecaps are not yet assimilated in GCMs. Nevertheless, RCMs have started to incorporate glacier coverage as a lower boundary condition and allow to assess their future evolution directly (Kotlarski et al., 2010a). The major requirements for such calculations are: (i) a spatially complete data set for the model domain and (ii) a close temporal coincidence of all data (a few years) to have consistent initial conditions. As glacier data are aggregated over the scale of an RCM grid box, the latter condition is somewhat relaxed. With the trend towards more sophisticated subgrid parameterization of glaciers in RCMs, accurate topographic information for all glaciers become more important.

As an intermediate goal, a more or less complete glacier inventory can also help in validating climate model output. On the one hand, a direct comparison of modelled perennial surface snow cover at the end of the summer season with the glacier cover is possible (Ghan et al., 2006). On the other hand, the precipitation bias of RCMs in high mountain regions can be assessed in combination with a distributed mass balance model (e.g. Machguth et al., 2009; Paul et al., 2010). As glacier melt is relatively easy to model, precipitation amounts are often used as tuning factor to fit the model results to the observations. Such corrections can be directly related to shortcomings in the modelling of precipitation amounts in RCMs.

For the three products glacier area/topography, velocity fields and snowline the requirements for climate monitoring purposes were summarized in Table 13 of the CMUG URD. This table is repeated below (Table 3) as it provides important additional information compared to the general overview in Table 1. In particular observing cycle, precision and stability in regard to model initialisation and trend monitoring are appended. It has to be noted that climate models do not need 30 m resolution grids for assimilation of global data sets. However, coarser resolution grids can be aggregated from this data set at any time, given that the spatial coverage for the RCM in the respective region is complete. Global hydrologic models do actually already work with data from all individual glaciers (Radić and Hock, 2011).

Parameter	Application	Horizontal Resolution	Observing Cycle	Precisio n	Accuracy	Stability	Types of error
Glacier Area	Initialisation	30 m	1 year	0.01km^2	<5%		SSEOB
	trend monitoring	30 m	5 years	0.01km^2	<5%	0.01km^2/ decade	SSAOB
Glacier Topography	Initialisation	<100 m	1 year	1 m	5 m		SSEOB
	trend monitoring	<100 m	5-10 years	1 m	5 m	1 m/ decade	SSAOB
Velocity	Initialisation	30 m	1-12 months	1 m/yr	10 m/yr		SSEOB
	trend monitoring	30 m	1 year	1 m/yr	10 m/yr	1 m/ decade	SSAOB
Snowline	Initialisation	30 m	1 year	30 m	100 m		SSEOB
	trend monitoring	30 m	1 week / 1 year	30 m	100 m	30 m / decade	SSAOB

Table 3: Specifications for the glaciers and icecaps ECV from the CMUG URD (V1.32). SSAOB: Single sensor accuracy for each observation, SSEOB: Single sensor error for each observation.

2.4.2 Further CRG requirements

The requirements from the CRG members GLIMS (B. Raup) and WGMS (M. Zemp) as well as the IAC-ETHZ (S. Kotlarski) are already given above. We thus present here the response of the CRG members: KfG (L. Braun), NVE (L. Andreassen), and ICIMOD (P. Mool)

The research activities of the Commission for Glaciology (**KfG**) focus on hydrologic assessments in glacierized regions from local to regional scale catchments. A major requirement is exact knowledge of glacier extents and their area elevation distribution (e.g. Weber et al., 2010). Whereas such data are easily available for the Alps, it is much more difficult to get these in remote regions where meltwater from glaciers might play an even more important role. Here the Glaciers_cci project is expected to provide the data for case studies in the requested regions. A close interaction with CMUG is related to the requirement for future assessment of water resources and run-off, i.e. data from regional climate models have to be used to perform the related calculations. When the products of the Glaciers_cci project can help to better quantify the accuracy of the RCMs in high-mountain topography, the confidence in using this data for hydrologic applications can be much enhanced. In this regard the KfG is looking forward to receive the required data and apply them in their models. The Norwegian water resources and energy directorate **(NVE)** is currently working on a complete inventory for entire mainland Norway from Landsat satellite data acquired between

1999 and 2006. This inventory has been compiled in collaboration with the GlobGlacier project and will be submitted to GLIMS in 2011. The analysis of earlier Landsat data (from the mid-1980s) revealed a strongly limited availability of suitable scenes due to adverse snow and cloud conditions. NVE is interested in velocity fields from ice caps in mainland Norway to determine ice divides.

For **ICIMOD**, Samjwal Bajracharya answered the questionnaire. He wrote: 'Right now I feel urgent to answer the Q3. as we had already prepared the Inventory of Glaciers of entire Hindu Kush-Himalayan region covering from Afghanistan, Bhutan, China/Tibet, India, Myanmar, Nepal and Pakistan. The report is on ICIMOD publication pipeline and probably will be published at the end of first quarter of 2011. The glacier boundary delineation was from single source, the Landsat images of 2005 ±3 Years but mostly from 2007 and 2008. The information of Clean Ice and Debris Cover of glaciers will be provided separately including spatial distribution, area, elevation, average slope, six digit and morphological classification, hypsography and also GLIMS ID of each glaciers. The massive glacier data of entire HKH region will fill the data gap for IPCC and will be service to further analysis and research work. The data will be releasing soon from ICIMOD Geo-Portal.'

2.5 User questionnaire (GLIMS mailing list and Cryolist)

To better consider the needs of the wider glaciological community for satellite-based products of glaciers and icecaps, we have prepared a questionnaire that was submitted to the GLIMS mailing list as well as Cryolist on Jan 19, 2011. The text of the questionnaire is provided in Appendix 1. We focussed on questions that are related to spatio-temporal aspects of the products, rather than on their technical specifications as these are largely determined by IGOS (2007) and the satellite sensors to be used for product generation. We arranged the questionnaire around three major questions: (Q1) the region of interest for data production (for all three products), (Q2) the acquisition date (for glacier area), period (for elevation change), and interval (for velocity), and (Q3) the region of currently ongoing work (for glacier area). By January 30, 2011 we received answers from 21 persons (summarized in Appendix 3). We first provide a statistical analysis of the responses and then a summary for each question.

2.5.1 Statistical analysis of the user requirements

Though the number of responses to the first questionnaire were rather small (21), a feedback was received from 4 different continents (Fig. 3a) and 10 different countries (Fig. 3b). At the continental scale, 86% of all responses come from North America and Europe, within these regions the responses per country were rather similar (2-4). Of course, the statistical interpretation of the feedback from such a small sample is rather limited and might not be representative. However, we expect that also with a larger number of feedbacks the relative distribution per continent might not change much as much research on this topic is performed in Europe and North America.

The next point we analysed was the region of interest for each of the three products. Though the response to this question is biased towards the regions were people are actuallly working in, the regions were nevertheless rather diverse and cover the entire globe. In total 12 regions were named (Alaska, Canada (West and Arctic), Greenland (local GIC), Svalbard, Russian Arctic, Tibet, Himalaya (HKH), Afghanistan, Andes, Patagonia, Antarctic Peninsula) with 26 votes for the glacier area product, 20 for elevation change and 13 for velocity.

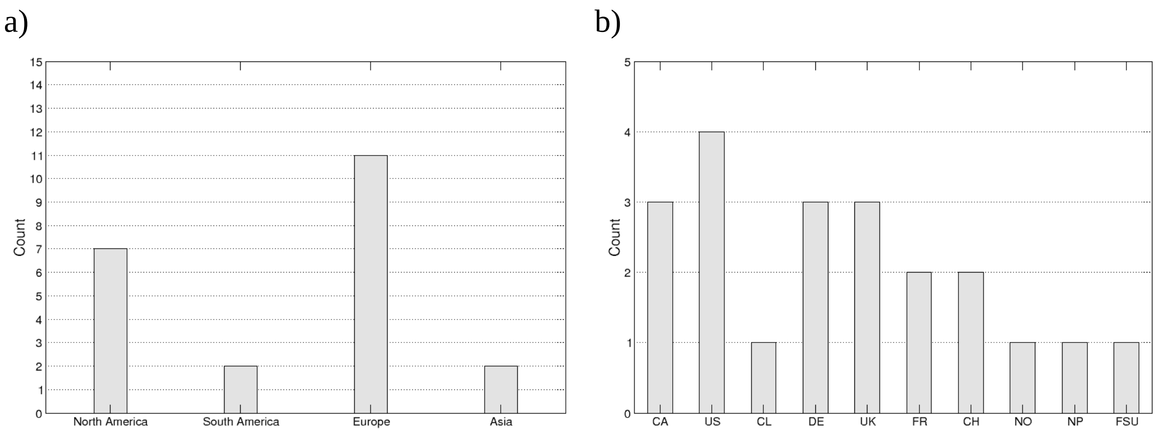

Figure 3: Response to the first questionnaire, a) by continent and b) by country (CA: Canada, US: USA, CL: Chile, DE: Germany, UK: United Kingdom, FR: France, CH: Switzerland, NO: Norway, NP: Nepal, FSU: Former Sowjet Union).

When all votes are counted together, the Himalaya - Hindu Kush (HKH) region received most (12), followed by Alaska and the Antarctic Peninsula (8 each), and Patagonia and Tibet (6 each). Though the small sample of feedbacks might be considered as non-representative, the named regions indeed agree with the regions mentioned in other studies and the largest gaps in the GLIMS database. So we interpret this feedback as (A) a strong argument to proceed with the inventory work in these regions, and (B) to generate also the products elevation and velocity fields. In Fig. 4 we present the results of the key regions survey graphically.

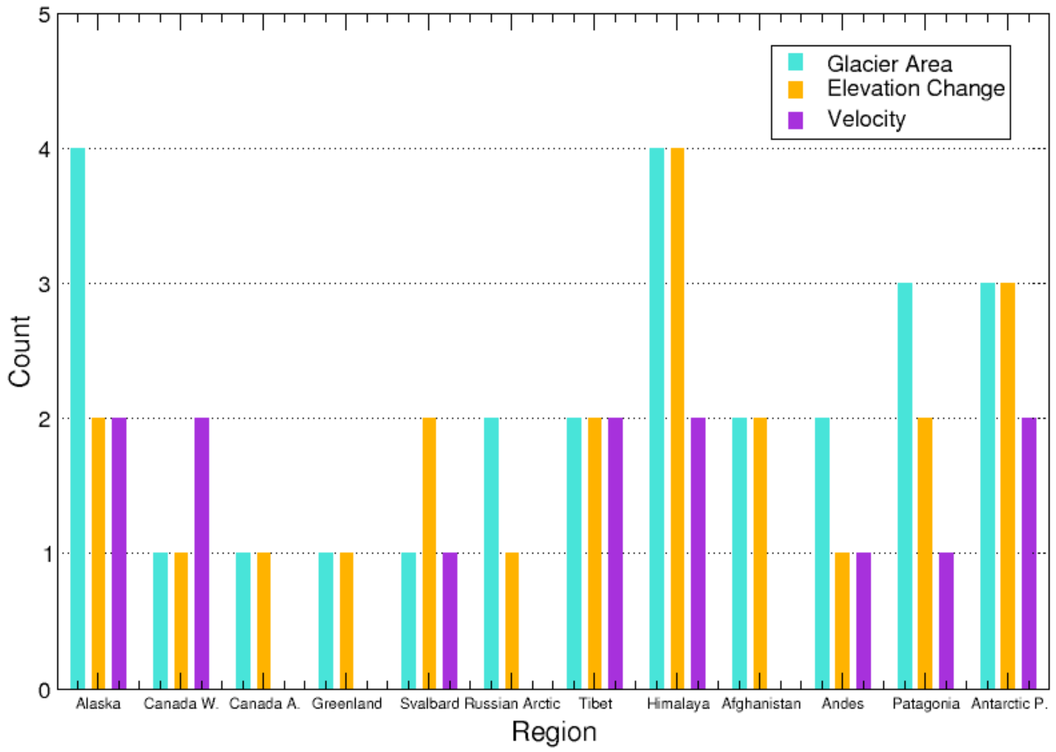

Fig. 4: Count of mentioned key regions for glacier area, elevation change and velocity fields.

The responses to question 2 are more difficult to analyse as the required differention of acquisition date (for area), period (for elevation change) and interval (for velocity) was not always made in the responses. For those answers that fit into the scheme, the highest number of votes (in brackets) were given for:

- glacier area: after the year 2000 (3),
- elevation changes: 1960-2000 (3), and
- velocity fields: annual intervals (4).

These temporal requirements are in agreement with the available satellite scenes for glacier area (Landsat TM/ETM+, ASTER), DEMs for elevation changes (incl. national DEMs, e.g. from USGS) and velocity mapping from repeat optical imagery (annual intervals). As we consider elevation changes from altimeters (period after 2000) and velocity fields from microwave sensors (mean values over a few days to weeks) also as important, we will prepare another questionnaire for these two products. This should also help to get more information about the regions of interest (or specific glaciers and icecaps) for these products.

2.5.2 Summary of the responses

Q1. Most important regions for product generation?
The regions mentioned here are in agreement with those identified in the key regions document (Appendix 2) and obviously missing in the GLIMS database. Apart from the Antarctic Peninsula, Russian and Canadian Arctic, the Hindu-Kush Himalaya (HKH) region and Patagonia, also Afghanistan, Svalbard, SE Alaska (Juneau) and the Andes are named. Additionally, preference should be given to regions where glacier decline will have a serious human impact. Elevation change information was in general requested for the same regions with emphasize on regions where long-term mass balance data already exist. Regions with required velocity information mostly include calving glaciers (e.g. Alaska, Patagonia, Antarctic Peninsula).

Q2. Acquisition period?
The answers range from the time period within a year that are most suitable for image acquisition in a specific region to the time period that should be considered for data generation. The latter encloses in general the entire period covered by satellite data, back to trimline mapping indicating little ice age extents. This gives strong support for the general interest in change assessment from repeat inventories. The use of historic DEMs for determination of long-term elevation changes is also emphasized. Velocity fields derived as an annual average was most often requested.

Q3. Current regions of work?
In several cases the regions of current work were the same as those requested under Q1, basically because the own progress in doing the work was considered as too slow (e.g. Antarctic Peninsula, SE Alaska). However, several further regions were mentioned as well: HKH and Mongolia (based on 1970s maps), HKH (based on Landsat data), Sikkim Himalaya and Himachal Pradesh, French Alps and mainland Norway, Siberia and Russian Arctic, Cordillera Santa Cruz and Apolobamba, Chile Volcanoes, and Kerguelen Island. This feedback indicates that there is regional overlap with some of the previously selected key regions (e.g. for HKH) and further analysis is required to determine which kind of contribution can be made by the Glaciers_cci project (see Section 4).

2.6 Scientific literature

The demand for a globally complete glacier inventory has been repeatedly claimed in the scientific literature, in particular in regard to global scale applications like the total area and volume of glaciers (Ohmura, 2006; Radić and Hock, 2009; Cogley, 2009), calculation of their past (Raper and Braithwaite, 2006; Kaser et al., 2006; Zuo and Oerlemans, 1997) or future contribution to sea-level-rise (e.g. Hock et al., 2009; Dyurgerov et al., 2009; Radić and Hock, 2011), and more regional scale assessments like water resources and/or run-off (Kaser et al., 2010). In recent years, modelling studies that assess future glacier retreat from simplified approaches emerged, mainly to assess the hydrologic impacts of future climate change (e.g. Akhtar et al., 2008; Hagg et al., 2010; Huss et al. 2008 and 2010). Indeed, also such spatially distributed studies require glacier outlines on a regional scale with high accuracy and a clearly defined date.

In several regions with glacier outlines already available, calculations of the regional contributions to sea-level rise were made by combining the glacier extents with information on glacier elevation changes from DEM differencing (Larsen et al., 2007; Schiefer et al., 2007; Van Looy et al., 2006; Berthier et al., 2007 and 2010). With glacier inventory data being available, glacier specific calculations of elevation changes can be performed and help to assess the representativeness of the in-situ mass balance measurements for entire mountain regions (Paul and Haeberli, 2008). Here we identify a large potential for calculating glacier specific elevation changes in regions like western Canada and Alaska, where sufficiently accurate DEMs from the 1960s or 1980s are available from national sources for comparison with more recent DEMs. Also space-borne altimeters were frequently used to assess elevation changes, but mainly for the two ice sheets. The large potential to calculate changes over glaciers and icecaps from repeat altimer data has been shown for ICESat on Svalbard (Moholdt et al., 2010) and the Canadian Arctic (Gardner et al., 2011), and within the GlobGlacier project for RA-2 on EnviSat by Rinne et al. (2011).

Information on glacier surface velocity plays an important role in the determination of glacier mass balance (e.g. Kääb and Funk, 1999), calving flux (e.g. Paterson, 1994), glacier thickness estimation (Farinotti et al., 2009) and characterisation of the state of glaciers (Kääb, 2005). The spatio-temporal consistency of the flow-field does provide information on glacier dynamics and their changes through time (e.g. if surging occurs). Glaciers with such dynamic instabilities are less suitable as a climatic indicator (Yde and Paasche, 2010). If flow fields can be derived also for accumulation regions (e.g. from microwave sensors), they might help to assign correct drainage divides for icefields and other comparable flat regions where DEM analysis alone (e.g using a flowdirection grid) is error prone.

2.7 Cross-ECV requirements

The Glaciers_cci project has a strong link to the Landcover_cci project, as landcover has to include 'perennial surface ice and snow' as a specific type. Regarding the difficulties in classifying this type propoerly at the MODIS/MERIS sensor scale, it was decided to use the glacier outlines as available in the GLIMS glacier database also for the Landcover_cci. This would guarantee the required consistency of the data sets for both ECVs. Such a blended product is likely also more attractive for the climate modelling community as a surface boundary condition.

3. Key regions

3.1 Completeness level for key regions

The principle aim of the Glaciers_cci project is to complete the global glacier inventory. Due to the wide recognition of this urgent task and the related activities in the framework of GLIMS and on a national level, a lot of work has already been done or is ongoing. In this regard 'completing the global glacier inventory' has a wide range of meanings that need to be assessed for each key region on a case-by-case basis. To find a suitable way to characterize the work to be performed in Glaciers_cci, we define different completeness levels (CL):

CL0: nothing is available, either in GLIMS or in the WGI
CL1: there is ongoing work but data have not been submitted to GLIMS, with
  CL1a: there is no intention to do so,
  CL1b: data should be submitted but technical advice is required, and
  CL1c: everything is fine and data will be submitted soon
CL2: data are already in GLIMS but needs to be revised/edited/supplemented, with
  CL2a: data are of poor quality (e.g. geolocation or level of detail),
  CL2b: only a sub-set of all glaciers is covered (e.g. glaciers > 1 km^2),
  CL2c: glaciers are not separated by drainage divides,
  CL2d: glaciers lack topographic attributes required for an inventory.
CL3: data are fine and in the GLIMS data base but only from one point in time, with
  CL3a: a data set from another point in time should be added (change assessment),
  CL3b: a data set from the same time but a different sensor for quality assessment.

3.2 Selection of key regions

3.2.1 Glacier inventory

In Table 3 we provide an overview of the revised key regions, their current completeness level (CL) according to section 3.1 and the work to be done by the Glaciers_cci project.

Region (rough)	Region (detail)	Contact	CL	Action
Canadian Arctic	Ellesmere Island	G. Wolken	1c	add gaps
	Devon Island	Univ. Alberta	1b	submit outlines
	Bylot Island	E. Dowdeswell	1b	submit outlines
	Baffin Island	G. Wolken	0/1	create L1T
Greenland	west, S of 73 N	F. Paul, GEUS	1c	complete region
	east coast	ice2sea	1	complete region
Alaska	Alaska Range	A. Arendt	1c	check status
	Juneau	M. Pelto / M. Beedle	1b	check status
Svalbard	Spitsbergen	NPI, M. König	1c	compare and add
FSU	several	T. Khromova	1b	support submission
	Arctic Islands	C. Stokes	1c	support submission
Himalaya	HKH	ICIMOD	1c	check quality
	Karakoram	J.G. Cogley	3a	check status
Chile/Argentina	Patagonia	CECS	1b	compare & coordinate
Islands	South Georgia	TBD	0	check status
Antarctica	Peninsula	A. Cook / J. Arigony	0	be in touch
Global	Mass balance gl.	WGMS	1c	complete work
GlobGlacier	Several	F. Paul	1	submit data

Table 3: Revised list of key regions with contact information and completeness level (CL).

The column 'Action' in Table 3 indicates the required action in response to the completeness level. As the work in these regions is an ongoing effort by the GLIMS community, this column needs to be frequently updated. The first step towards the identified action will be to contact the person in charge by email. Apart from the work in the listed key regions, one further aim of the Glaciers_cci project is to supplement all data that are already in the GLIMS database with topographic inventory information according to Paul et al. (2009) and values for glacier length, both computed from semi-automated techniques as developed in GlobGlacier. This has also be identified by the glaciological community as an important supplement.

3.2.2 Elevation Change

This product will be derived from two different methods, (1) repeat altimetry and (2) DEM differencing. For (1), the focus will be on the Arctic regions that cover large and flat icefields or icecaps, whereas (2) will be mainly applied in all other regions of the above list (Table 2). This will satisfy the needs of two complementary user groups (sea-level rise modelling and WGMS). As a first step, regions with freely available national DEMs from the past century (e.g. Alaska, Canada) will be processed. With the forthcoming availability of the Tandem-X DEM, several further regions that are covered by the SRTM DEM from the year 2000 will be investigated.

3.2.3 Velocity fields

The feedback on the velocity product revealed a major interest in this product for calving glaciers based on annual averages, consideration of the past four decades and a regional focus in the key regions. As this product has already been derived for several regions in the GlobGlacier project (e.g. Alaska, Baffin Island, Svalbard, Novaya Zemlya) and activities are widespread, we will perform an additional survey with the involved scientists (e.g. as known from publications) before we start product creation in a specific region.

4. Requirements analysis

4.1 Summary of the requirements

Comparing the product requirements from the wider user community with the originally proposed key regions and data products, there are no general corrections that have to be made. All three data products are requested and a particular need is expressed for completing the global glacier inventory. This is in line with the work breakdown structure of the proposal. The largest adjustments have to be made for some of the pre-selected key regions (Appendix 2), as some recent activities have accomplished larger parts of the work. This concerns the Alaska Range, Ellesmere Island and the wider Hindu-Kush Himalaya region where inventories were nearly completed in the meantime. However, according to our separation of different completeness level, spatially complete must not mean that topographic parameters are included, that the quality is sufficient or that the data were submitted to GLIMS. All these issues will be addressed in the Glaciers_cci project, partly by 1-to-1 comparisons of the generated outlines. The lessons learned from these comparisons will be directly used for further improvement of the products. We will be in touch with the listed points of contact to define the works that needs or remains to be done. The feedback on the elevation change and velocity products was considered as being valuable, but further details are needed. An additional user survey will thus be performed for these two products.

4.2 Product accuracy for CMUG

The currently most relevant user group for the products of the Glaciers_cci project are glaciologists and hydrologists that perform modelling of the sea-level rise contribution from glaciers and icecaps (i.e. climate change impact assessment). As this group is not represented in CMUG but has much higher demands in regard to spatial resolution and meta-information on each glacier entity than CMUG, the Glaciers_cci project has a special focus on the requirements of this group (see 1.1). For directly using the derived glacier extents in current regional climate models, the quality of the glacier outlines is certainly sufficient as the uncertainties at a 30 m pixel level does not propoagate into a product that is aggregated over a 10 km (or even larger) scale. In this regard spatial completeness of the data set and a short time period of acquisition (a few years) are much more relevant for proper model initialisation (Kotlarski et al., 2010a).

For hydrological models the situation is somewhat different. In current global applications, the topographic attribute information of each individual glacier can be assimilated by the model (Radić and Hock 2011), so spatial completeness, a vector format of the outline and DEM quality are most important. For regional scale hydrologic applications, the accuracy of the glacier outline at a typically 100 m scale is also important. Depending on the applied aproach (e.g. degree-day versus energy balance), information on the glacier area under debris-cover and a consistent acquisition date are become important as well. So the demands on product accuracy do strongly depend on the field of application. As the Glaciers_cci products will all be produced and evalutaed at the highest possible accuracy level (e.g. 30 m pixels), the foreseen applications by CMUG will be fulfilled.

4.3 Monitoring approach

The technical requirement 3 [TR-3] of the Annex I to the Statement of Work (SoW) asks to identify whether the user requirements 'are achievable with the currently available multi-satellite data records, algorithms and processors'. Based on the feedback and documents analysed for this survey, we consider the requirements as being achievable for the glacier area product. This includes both, the products for the key regions and the GCOS requirements regarding product accuracy and climate monitoring principles. For the other two products (elevation change and velocity) we can only consider technical product specifications as provided by IGOS (2007) as the user feedback on these products was limited. Whereas the technical requirements (observing cycle, accuracy, precision, etc.) are achievable, more information on key regions and product specifications are required. We will thus perform an additional user survey to get more information on these missing details.

The currently applied best practices for product generation as described in the GlobGlacier documents will form the base of the work in Glaciers_cci, but further improvements are certainly possible as well. In response to [TR-4] of Annex I to the SoW (review of the strengths and weaknesses and consistency of current best practices, identification of key issues associated with the existing algorithms and propose strategies to improve on existing approaches), we consider a higher degree of automation in product generation, improved quality assessment, and the preparation of illustrated guidelines (after the round-robin experiments) to further improve the consistency of the products in the database as major issues for further scientific advance. Major weaknesses in current approaches are (as identified for the glacier area product):

(i) the accuracy of the glacier outlines for heavily debris-covered glaciers,
(ii) glacier mapping under frequent orographic clouds and the identification of water surfaces,
(iii) the required work flow interventions by an operator for threshold selection, and
(iv) the missing consistency in the interpretation of what a glacier is or which parts belong together (from a remote sensing perspective).

On the other hand, simple algorithms are in place and freely available global data sets (satellite and DEMs) can be used for product generation with limited computational effort. The good cooperation with the GTN-G key science bodies (WGMS and GLIMS) and their high interest in the project are certainly an additional asset. We are thus optimistic that the ambitious goals of the Glaciers_cci project can be achieved.

Our strategic approach towards satellite-based world-wide glacier monitoring [TR-6 of Annex I] will rest on three pillars:
(1) creating the required products in response to the needs identified by GCOS and the wider user community,
(2) document the work flows for data generation as clearly as possible to achieve a better consistency of the final products (also in terms of error characterization), and
(3) identify the pre-processing requirements and technical specifications of EO data for space agencies to generate these products also in the future.

All three pillars will be investigated in more detail in the course of the project in response to further technical requirements and user needs.

The joint use of in-situ and satellite observations has to be further elaborated and improved in the course of the project. Currently, a number of shortcomings were identified that prevent a direct comparison of glaciological data as obtained from space and in the field (e.g. length changes, mass balance). To reach ECV monitoring goals further joint studies need to be performed and results assessed with the required scientific rigor. To some end, the purpose of the generated data must also be seen in the background of its production goals. For a detailed study of an individual glacier, a product that has been generated with a global perspective might not have the appropriate quality. At the scale of global climate or hydrological models, local inaccuracies do certainly not matter.

References

Akhtar, M., Ahmad, N. and Booij, M.J. (2008): The impact of climate change on the water resources of Hindukush-Karakorum-Himalaya region under different glacier coverage scenarios. Journal of Hydrology, 355, 148-163.

Andreassen, L.M., Paul, F., Kääb, A. and Hausberg, J.E. (2008): Landsat-derived glacier inventory for Jotunheimen, Norway, and deduced glacier changes since the 1930s. The Cryosphere, 2, 131-145.

Berthier, E., Arnaud, Y., Kumar, R., Ahmad, S., Wagnon, P. and Chevallier, P. (2007): Remote sensing estimates of glacier mass balances in the Himachal Pradesh (Western Himalaya, India). Remote Sensing of Environment, 108(3), 327–338.

Berthier, E., Schiefer, E., Clarke, G.K., Menounos, B. and Rémy, F. (2010): Contribution of Alaskan glaciers to sea-level rise derived from satellite imagery. Nature Geoscience, 3, 92-95.

Bolch, T., Menounos, B. and Wheate, R.D. (2010): Landsat-based inventory of glaciers in western Canada, 1985 - 2005. Remote Sensing of Environment, 114, 127-137.

Raper, S.C.B. and Braithwaite, R.J. (2006): Low sea level rise projections from mountain glaciers and icecaps under global warming. Nature, 439, 311-313.

Cogley, J.G. (2009): A more complete version of the World Glacier Inventory. Annals of Glaciology, 50, 8-14.

Dowdeswell, E.K., Dowdeswell, J.A. and Calkwell, F. (2007): On the glaciers of Bylot Island, Nunavut, Arctic Canada. Arctic, Antarctic and Alpine Research, 39, 402-411.

Dyurgerov, M., Meier, M.F. and Bahr, D.B. (2009): A new index of glacier area change; a tool for glacier monitoring, Journal of Glaciology, 55(192), 710-716.

Farinotti, D., Huss, M., Bauder, A., Funk, M. and Truffer, M. (2009): A method to estimate ice volume and ice thickness distribution of alpine glaciers. Journal of Glaciology, 55 (191), 422-430.

Gardner, A.S., Moholdt, G., Wouters, W., Wolken, G.J., Burgess, D.O., Sharp, M.J., Cogley, J.G., Braun, C. and Labine, C. (2011): Sharply increased mass loss from glaciers and ice caps in the Canadian Arctic Archipelago. Nature 473, 357–360.

GCOS (2003): The second report on the adequacy of the global observing systems for climate in support of the UNFCCC. GCOS Report 82, WMO/TD No. 1143, 85 pp.

GCOS (2004): Implementation plan for the global observing system for climate in support of the UNFCCC. GCOS Report 92, WMO/TD No. 1219, 143 pp.

GCOS (2006): Systematic observation requirements for satellite-based products for climate. GCOS Report 107, WMO/TD No. 1338, 103 pp.

GCOS (2008): Climate Measurement Series: Sustainability Ensured. Media release from June 6, 2008. Online: http://www.meteoschweiz.admin.ch/web/de/meteoschweiz/medien/medienmitteilungen/Klima_Messreihen_gesichert.html

Ghan, S.J., T. Shippert and J. Fox (2006): Physically based global downscaling: Regional evaluation. Journal of Climate, 19 (3), 429-445.

Hagg, W., Shahgedanova, M., Mayer, C., Lambrecht, A. and Popovnin, V. (2010): A sensitivity study for water availability in the Northern Caucasus based on climate projections. Global and Planetary Change, 73, 161-171.

Hall, D.K., Bayr, K.J., Schöner, W., Bindschadler, R.A. and Chien, J.Y.L. (2003): Consideration of the errors inherent in mapping historical glacier positions in Austria from the ground and space (1893-2001). Remote Sensing of Environment, 86, 566-577.

Hock, R., de Woul, M., Radić, V. and Dyurgerov, M.B. (2009): Mountain glaciers and ice caps around Antarctica make a large sea-level rise contribution. Geophysical Research Letters, 36, 1-5.

Huss, M., Farinotti, D., Bauder, A. and Funk, M. (2008): Modelling runoff from highly glacierized alpine drainage basins in a changing climate, Hydrological Processes, 22(19), 3888–3902.

Huss, M., Jouvet, G., Farinotti, D. and Bauder, A. (2010): Future high-mountain hydrology: a new parameterization of glacier retreat. Hydrology and Earth System Sciences, 14, 815-829.

IGOS (2007): Integrated Global Observing Strategy Cryosphere theme report - For the monitoring of our environment from space and from Earth. Geneva: World Meteorological Organization. WMO/TD-No. 1405, 100 pp.

IPCC (2001): Third Assessment Report. Intergovernmental Panel on Climate Change, Cambridge and New York. http://www.ipcc.ch/ipccreports/assessments-reports.htm (last date accessed: 22 Feb 2009)

Kääb, A. (2005): Combination of SRTM3 and repeat ASTER data for deriving alpine glacier flow velocities in the Bhutan Himalaya. Remote Sensing of Environment, 94, 463-474.

Kääb, A. (2008): Glacier volume changes using ASTER satellite stereo and ICESat GLAS laser altimetry. A test study on Edgeøya, Eastern Svalbard. IEEE Transactions on Geoscience and Remote Sensing, 46(10), 2823-2830.

Kääb, A. and Funk, M. (1999): Modelling mass balance using photogrammetric and geophysical data. A pilot study at Gries glacier, Swiss Alps. Journal of Glaciology. 45 (151), 575-583.

Kaser, G., Cogley, J.G., Dyurgerov, M.B., Meier, M. and Ohmura, A. (2006): Mass balance of glaciers and ice caps: Consensus estimates for 1961 - 2004. Geophysical Research Letters, 33, doi:10.1029/2006GL027511.

Kaser, G., Grosshauser, M. and Marzeion, B. (2010): Contribution potential of glaciers to water availability in different climate regimes. Proceedings of the National Academy of Sciences, 107, 20223-20227.

Kotlarski, S., Jacob, D., Podzun, R. and Paul, F. (2010a): Representing glaciers in a Regional Climate Model. Climate Dynamics, 34, 27-46.

Kotlarski, S., Paul, F. and Jacob, D. (2010b): Forcing a distributed glacier mass balance model with the regional climate model REMO, Part I: Climate model evaluation. Journal of Climate, 23 (6), 1589-1606.

Larsen, C.F., Motyka, R.J., Arendt, A.A., Echelmeyer, K.A. and Geissler, P.E. (2007): Glacier changes in southeast Alaska and northwest British Columbia and contribution to sea level rise. Journal of Geophysical Research, F01007, doi:10.1029/2006JF000586.

Le Bris, R., Frey, H., Bolch, T. and Paul, F. (in revision): A new satellite-derived Glacier Inventory for Western Alaska (GIWA). Annals of Glaciology.

Machguth, H., Paul, F., Kotlarski, S. and Hoelzle, M. (2009): Calculating distributed glacier mass balance for the Swiss Alps from RCM output: A methodical description and interpretation of the results. Journal of Geophysical Research - Atmospheres, 114, D19106.

Manley, W.F. (2008): Geospatial inventory and analysis of glaciers: A case study for the eastern Alaska Range. In R. Williams and J.G. Ferrigno (Eds.), Satellite Image Atlas of Glaciers of the World.

Meier, M.F., Dyurgerov, M.B., Rick, U.K., O'Neel, S., Pfeffer, W.T., Anderson, R.S., Anderson, S.P. and Glazovsky, A.F. (2007): Glaciers dominate eustatic sea-level rise in the 21st Century. Science, 317, 1064-1067.

Moholdt, G., Nuth, C., Hagen, J.O. and Kohler, J. (2010): Recent elevation changes of Svalbard glaciers derived from ICESat laser altimetry, Remote Sensing of Environment, 114, 2756-2767.

Nuth, C. and Kääb, A. (2011): What's in an elevation difference? Accuracy and corrections of satellite elevation data sets for quantification of glacier changes. The Cryosphere Discuss., 4, 2013-2077.

Ohmura, A. (2006): Changes in mountain glaciers and ice caps during the 20th century. Annals of Glaciology, 43, 631-638.

Paterson, W.S.B. (1994): The Physics of glaciers. Third edition. Oxford, etc.. Elsevier.

Paul, F. and Haeberli, W. (2008): Spatial variability of glacier elevation changes in the Swiss Alps obtained from two digital elevation models. Geophysical Research Letters, 35, L21502.

Paul, F. and Kotlarski, S. (2010): Forcing a distributed mass balance model with the regional climate model REMO, Part II: Downscaling strategy and results for two Swiss glaciers. Journal of Climate, 23 (6), 1607-1620.

Paul, F., Huggel, C., Kääb, A. and Kellenberger, T. (2003): Comparison of TM-Derived Glacier Areas with Higher Resolution Data Sets. EARSeL eProceedings, 2, 15-21.

Paul, F., Barry, R., Cogley, J.G., Haeberli, W., Ohmura, A., Ommanney, C.S.L., Raup, B., Rivera, A. and Zemp, M. (2009): Recommendations for the compilation of glacier inventory data from digital sources. Annals of Glaciology, 50 (53), 119-126.

Racoviteanu, A.E., Paul, F., Raup, B., Khalsa, S.J.S. and Armstrong, R. (2009): Challenges and recommendations in mapping of glacier parameters from space: results of the 2008 Global Land Ice Measurements from Space (GLIMS) workshop, Boulder, Colorado, USA. Annals of Glaciology, 50, (53), 53-69.

Radić, V. and Hock, R. (2009): Regional and global volumes of glaciers derived from statistical upscaling of glacier inventory data. Journal of Geophysical Research, 115, F01010.

Radić, V. and Hock, R. (2011): Regionally differentiated contribution of mountain glaciers and ice caps to future sea-level rise. Nature Geoscience, 4, 91-94.

Raper, S.C.B. and Braithwaite, R.J. (2006): Low sea level rise projections from mountain glaciers and icecaps under global warming. Nature, 439, 311-313.

Rau, F., Mauz, F., Vogt, S., Khalsa, S.J.S. and Raup, B. (2005): Illustrated GLIMS Glacier Classification Manual, 36 pp. Online http://www.glims.org/MapsAndDocs/assets/

Raup, B. and Khalsa, S.J.S. (2007): GLIMS Analysis Tutorial, vers. 22/05/2007, Boulder, 15 pp. Online: http://glims.org/MapsAndDocs/assets/.

Raup, B., Racoviteanu, A., Khalsa, S.J.S., Helm, C., Armstrong, R. and Arnaud, Y. (2007): The GLIMS Geospatial Glacier Database: a new tool for studying glacier change. Global and Planetary Change, 56, 101-110.

Reichert, B. K., Bengtsson, L. and Oerlemans, J. (2001): Midlatitude forcing mechanisms for glacier mass balance investigated using general circulation models, Journal of Climate, 14, 3767-3784.

Rinne, E., Shepherd, A., Muir, A. and Wingham, D. (2011): A Comparison of Recent Elevation Change Estimates of the Devon Ice Cap as Measured by the ICESat and EnviSAT Satellite Altimeters. IEEE Transactions on Geoscience and Remote Sensing, 49 (6), 1902-1910.

Schiefer, E., Menounos, B. and Wheate, R.D. (2007): Recent volume loss of British Columbia glaciers, Canada. Geophysical Research Letters, L16503.

Shepherd, A., Du, Z., Benham, T.J., Dowdeswell, J.A. and Morris, E.M. (2007): Mass balance of Devon Ice Cap, Canadian Arctic. Annals of Glaciology, 46, 249-254.

VanLooy, J., Forster, R. and Ford, A. (2006): Accelerating thinning of Kenai Peninsula glaciers, Alaska. Geophysical Research Letters, 33, L21307.

Weber, M., Braun, L., Mauser, W. and Prasch. M. (2010): Contribution of rain, snow- and icemelt in the Upper Danube discharge today and in the future. Geografia Fisica e Dinamica Quaternaria, 33, 221-230.

Yde, J.C. and Paasche, Ø. (2010): Reconstructing climate change: not all glaciers suitable. EOS, Transactions, American Geophysical Union, 91 (21), 189-191.

Zhang, J., Bhatt, U.S., Tangborn, W.V. and Lingle, C.S. (2007): Climate downscaling for estimating glacier mass balances in northwestern North America: Validation with a USGS benchmark glacier. Geophysical Research Letters, 34, L21505.

Zuo, Z. and Oerlemans, J. (1997): Contribution of glacier melt to sea-level rise since AD 1865: a regionally differentiated calculation. Climate Dynamics, 13, 835-845.

Abbreviations

ALOS	Advanced Land Observing Satellite
ASTER	Advanced Spaceborne Thermal Emission and Reflection radiometer
CCI	Climate Change Initiative
CCRS	Canadian Centre for Remote Sensing
CL	Completeness Level
CMUG	Climate Modelling User Group
CRG	Climate Research Group
DARD	Data Access requirements Document
DEM	Digital Elevation Model
ECV	Essential Climate Variable
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ETH	Federal Institute of Technology
ETM+	Enhanced Thematic Mapper plus
FCDR	Fundamental Climate Data Record
GCM	General Circulation Model / Global Climate Model
GCOS	Global Climate Observing System
GDEM	Global DEM
GLIMS	Global Land Ice Measurements from Space
GTN-G	Global Terrestrial Network for Glaciers
IAC	Institute for Atmosphere and Climate
ICIMOD	International Centre for Integrated Mountain Development
IGOS	Integrated Global Observing Strategy
InSAR	Interferometric SAR
IPCC	Intergovernmental Panel on Climate Change
KfG	Kommission für Glaziologie
L1T	Level 1 T (terrain corrected)
LDCM	Landsat Data Continuity Mission
MODIS	MODerate resolution Imaging Spectrometer
MERIS	MEdium Resolution Imaging Spectrometer
NASA	National Aeronautic and Space Administration
NVE	Norwegian Water Resources and Energy Directorate
PALSAR	Phased Array type L-band SAR
PSD	Product Specifications Document

RCM	Regional Climate Model
RMSE	Root Mean Square Error
SAR	Synthetic Aperture Radar
SoW	Statement of Work
SPOT	System Pour l'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
SWIR	Short Wave InfraRed
TM	Thematic Mapper
URD	User requirements Document
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WC2N	Western Canadian Cryospheric Network
WGI	World Glacier Inventory
WGI-XF	World Glacier Inventory eXtended Format
WGMS	World Glacier Monitoring Service
WGS	World Geodetic System

Appendix 1 (Detailed product specifications)

App. 1 A: Specifications for the glacier area product

Product generation

- in key regions (cf. Table 3), close coordination with GLIMS Regional Centers is required
- automated mapping of clean ice (e.g. using band ratios) with manual threshold selection
- a higher degree of automation should be envisaged (e.g. for threshold, debris, water, clouds)
- raster-vector conversion and manual editing of results (validation against the satellite scene used for mapping, or additional scenes)

Input data

Landsat type sensors (e.g. TM, ETM+, ASTER, SPOT HRV) with
- 15-30 m spatial resolution and one band in the short-wave infrared (around 1.5 μm)
- orthorectified, geometric accuracy: 1 pixel (RMSE) or better (USGS L1T acceptable)
- geotif format, UTM projection with WGS84 datum is convenient, others are possible

Output

- quality controlled vector outlines of all glaciers and icecaps in a region (ice bodies down to a size of 0.01 km^2 under best conditions)
- shapefile format (vector) in geographic projection with WGS84 datum
- attributes according to GLIMS database transfer specification (incl. error flags)

Validation

- internal: by visual inspection in the post-processing stage (during manual editing)
- external: by comparison with outlines derived from higher-resolution datasets (these need to be acquired in the same week due to rapid changes in seasonal snow cover)
- analysts accuracy: at best assessed by multiple digitizing of the same entities, overlay of the outlines and evaluation of comission and omission errors

Technical details

Item	Min - Max	Unit	Accuracy	Remarks
Measurement range	0.01-10'000	km^2	better 5%	Mosaicing might be required
Stability	0.01-0.1	km^2	better 5%	trend per decade
Spatial resolution	1 - 10	m		for validation
	15 - 30	m		for product generation
	100-250	m		outside of Landsat coverage
Temporal resolution	1	yr		each year needs to be tried
Repeat interval	5-50	yr		depending on region and rate of change
Target period	1999-2003	yr		with Landsat ETM+
	1984-2011	yr		with Landsat TM

Table A1-1: Summary of technical specifications for the ***glacier area*** *product.*

Remarks

- for glacier inventory creation in regions with debris-covered glaciers, the consideration of coherence images taken during summer would help to increase product accuracy
- for rapid change assessment, debris-cover correction might not be important

App. 1 B: Specifications for the glacier elevation change product

Product generation

- from two techniques: repeat altimery (on larger icecaps) and DEM differencing (all others)
- accurate co-registration of all data sets is required (processor under development; Nuth and Kääb, 2011)
- processor for GLAS and RA-2 altimeteres developed in GlobGlacier
- DEM source (optical/microwave) important for product quality over glaciers
- artifacts can be seen in hillshade and after differencing DEMs
- void filling or exclusions of glaciers required

Input data

- glacier outlines for data selection (altimetry) and calculation of glacier specific changes (DEM differencing)
- data from altimeters (GLAS, RA-2, Cryosat2)
- DEM for correction of surface slope (altimetry)
- two DEMs from different points in time (typical interval: 10 years) for DEM differencing
- national DEMs from the past as a base and more recent DEMs from SRTM or other
- DEMs can also be generated from digitized contourlines (might have artifacts)
- ASTER GDEM not suitable due to lack of time-stamp

Output

- Altimeters: time series of elevations (at crossover points or along track)
- Altimeter format: x, y, z coordinates of points with date
- (a) maps of the elevation change (EC), (b) mean EC per glacier, (c) EC with height
- (a) geotif in UTM projection with WGS84 datum, (b) value in attribute table, (c) list of values with height (region needs to be exactly described)

Validation

- cross comparison with datasets from the same time period (e.g. airborne laser altimetry)
- DEM quality (for DEM differencing) from ICESat, airborne LIDAR or photogrammetry

Technical details

Quantity	Min - Max	Unit	Accuracy	Remarks
Measurement range	0.01-100	m/yr	<10%	possible range of values
Typical values	0.1-10	m/yr		
Stability	0.1	m/yr		
Spatial resolution	10-100	m		DEM differencing
	170	m		ICESat GLAS footprints
	10	km		RA-2 foorprints
	1-10	m		DEMs for validation
Temporal resolution	1-10	yr		Mean elevation change per year
Repeat interval	1-50	yr		Depending on technique and region
Target period	1950-2010	yr		

Table A1-2: Summary of technical specifications for the ***glacier elevation change*** *product.*

Remarks

Elevation change is not mass balance (density consideration, refreezing, Sorge's law, flux divergence)

App. 1 C: Specifications for the glacier velocity product

Product generation

- in selected key regions with appropriate satellite data (from microwave and optical sensors)
- temporal resolution: from weekly to monthly with microwave sensors (SAR), from annual to seasonal (for fast glaciers) with optical sensors
- methods for both sensor types dependent on recognition of corresponding features (image matching, offset tracking) or phase coherence (InSAR)
- accurate co-registration of all data sets required

Microwave:

- best time period: during winter
- interferometric techniques require winter images and short time periods to retain coherence
- off-set tracking is more flexible (works over longer time-periods and non-winter images)
- SAR offset tracking works often better in ablation areas

Optical:

- best time period: end of summer images
- repeat pass feature tracking over one year, end of summer only, contrast over snow might be too low, resulting often in no information from the accumulation region
- for fast glaciers, also summer seasonal velocities possible, annual velocities could be difficult where visual features change too strong over one year

Input data

- repeat scenes from microwave sensors (ERS-1/2 Tandem, ASAR, PALSAR, TerraSAR-X, Cosmo-Skymed, Radarsat-1/2)
- repeat scenes from optical sensors (Landsat TM/ETM+, ASTER, SPOT)
- DEM for orthorectification (e.g. SRTM, RTM or GDEM), the L1T precision from USGS is usually sufficient but should be examined by visually exploring or matching local differential shifts over stable ground)

Output

- colour coded maps of flow velocities (horizontal means) per year
- geotif format (UTM projection with WGS84 datum)
- raw data: displacement in satellite line-of-sights directions (ASCII or vector format)
- higher level product (under certain flow assumptions): x, y, z coordinates of velocity vector with magnitude and direction (azimuth and inclination)
- ASCII, raster or vector format, geographic coordinates or UTM with WGS84 datum, additional attributes (e.g correlation coefficients) can be added

Validation

- field measurements at stakes
- velocity fields derived from complementary or higher resolution satellite data (SAR and optical)
- glacier outlines

Technical details

Quantity	Min - Max	Unit	Accuracy	Remarks
Measurement range	0.1-10’000	m/yr	< 5%	10 km/yr only for surging glaciers
Typical values	10-200	m/yr		
Precision	1	m/yr		
Stability	0.1	m/yr		for trend monitoring
Spatial resolution	1-100	m		satellite data, typical 10-30 m
	20-500	m		spacing of velocity data points
	10-100	m		input data set
Temporal resolution	0.01-0.1	yr		weekly to monthly with SAR
	0			annual to seasonal with optical sensors
Repeat interval	1	yr		time series possible (each year)
Target period	1970-2010	yr		depends on data availability

Table A1-3: Summary of technical specifications for the ***glacier velocity*** *product.*

Remarks

none

Appendix 2 (Key regions)

As the completeness levels change constantly through time, the work of Glaciers_cci is difficult to plan. However, based on the current state of knowledge of ongoing activities, the following is an overview the key regions and level of work to be conducted in Glaciers_cci. The list of regions takes into account ongoing activities by the GLIMS community, GlobGlacier, ice2sea, CryoClim. The Glaciers_cci consortium has good personal contacts to most of the people or regional centres involved and should thus be able to determine the most useful contribution for reaching a higher level of completeness in each of the key regions listed below.

The following regions will be tackled in the Glacier_cci with the work focusing on delivering both glacier outlines and topographic inventory data per glacier. Elevation changes and velocity fields will be derived for those regions with sufficient data availability and as a function of the demands of the wider glaciological community (see 2.8). The priority will be given to regions which are still missing or poorly covered in the world glacier inventory (WGI) and/or the GLIMS database (see levels above). Velocity information will involve optical approaches in the ablation region and microwave sensors for entire glaciers.

In event of completion of a region by another project, Glacier_cci can shift objectives to either change assessment or another region (depending on data availability).

1. Canadian Arctic. The focus will be on missing regions, specifically on Baffin Island and the Queen Elizabeth Islands.

a. Ellesmere Island. Has an estimated ice area of 77600 km2 but only few data are available on the number of glaciers in selected regions. Data in WGI is for southern parts and 1950s-1960s. Some regions have already been mapped by U Alberta (http://icedata.eas.ualberta.ca/) and can be accessed in the GLIMS data base. Glacier_cci will focus on completion of inventory (CL0 and CL2d) as far north as possible with Landsat data.

b. Baffin Island. Mapped in GlobGlacier (L1G 2000-2002 Landsat ETM+ and some TM) but the location accuracy of L1G was not sufficient to permit the generation of high quality products and the results are at a level of CL2a. This region will be repeated with L1T data that are now available.

c. Devon Ice Cap. Area 14,000 km2 (Shepherd et al 2007) mapped for contiguous area in GlobGlacier but only outline generated. U Alberta work Landsat 7 1999-2000 (http://icedata.eas.ualberta.ca/website/devon.html/) but not yet submitted (not publicly available). Glacier_cci to liaise with U Alberta to ensure submission and inventory creation in GLIMS (CL1b and CL2c activity).

d. Bylot Island. Mapped by Dowdeswell in 2001 (AAAR paper 2007) with Landsat ETM+ data. Glacier_cci aim to reinforce individual submissions to GLIMS by offering help (CL1b).

e. Axel Heiberg. Key WGI region and GLIMS. U Alberta data from 1999. Glacier_cci aim to reinforce activity and ensure addition of topographic attributes (CL2d).

Liaison will be conducted with the National Hydrology Research Institute of Environment Canada (http://atlas.nrcan.gc.ca/auth/english/maps/freshwater/distribution/glaciers) and U Alberta GLIMS Regional Centre for Canada (http://arctic.eas.ualberta.ca) to reach a higher level of completeness in these regions.

The northern parts of the Queen Elizabeth Islands are not covered with Landsat, SPOT, ASTER.

2. Greenland – much work is ongoing for outlet glaciers of the Greenland ice sheet (e.g. monitoring of terminus position and elevation changes), but local glaciers and ice caps remain nearly unconsidered. Glacier_cci will evaluate current activities and identify missing elements and available data sets and focus on generating inventory data for these (mainly at CL2). Liaison is required with ice2sea, GlobGlacier/CryoClim, and GLIMS especially to increase the level of completeness.

3. Alaska – According to a recent overview provided by A. Arendt (U Alaska), recent additions to the GLIMS database include:

Addition of western Canadian glaciers along the border with southeastern Alaska (Bolch et al, 2010)
Completion of the central portion of the Chugach Mountains (Sam Herreid, UAF technician)
Addition of USGS map date outlines for eastern Alaska Range (Manley, 2008)

Already submitted but GLIMS-IDs are not compliant with the former (incomplete) inventory.
Kenai Peninsula, Tordrillo, Chugach and Chigmit mountains (GlobGlacier, Univ. Zurich, Le Bris et al., subm.)

In Progress
Denali Park and the Delta Range in the Alaska Range (nearly completed by Sam Herreid, UAF) Harding Icefield at 3 different time periods (completed by Bruce Giffen and Dorothy Hall, but needs to be converted to GLIMS format)
Yukon Glaciers (completed by Nick Barrand but need to be converted to GLIMS format)

Areas with no outlines yet include the Wrangell Mountains, Brooks Range, Aleutian Range/Islands, Wood River Mountains, Kigluaik Mountains and the Alexander Archipelago. Regions with incomplete outlines include portions of the St. Elias, and Stikine icefields, as well as Glacier Bay.

U Alaska (Anthony Arendt, Alaska Regional GLIMS Centre) to focus on the Wrangell mountains as part of the National Park Service work, Glacier_cci to focus on the Brooks Range and those portions of the Alaska Range which are currently missing (CL0). Other regions to be analysed for CL2 or CL3 work. Alaska Range needs clarification since some data exist and U Alaska has funding to do Denali National Park (CL3).

4. Svalbard – CryoClim to create a new glacier inventory for mainland Norway (Glacier area outline product), that will be submitted to GLIMS when it is complete in 2011. Svalbard is a Cryoclim target area and Cryoclim has had previous close collaboration with GlobGlacier (expert advisor) and Liss Andreassen is a user in GlobGlacier. NVE is now also in the CRG, and Christopher Nuth will work for GUIO as Glacier_cci Postdoctorate. Svartisen submission to GLIMS by GlobGlacier in collaboration with NVE – NVE provided datasets via CryoClim but work was actually performed by GlobGlacier. Cryoclim did all the satelllite preprocessing to L1T. It is currently planned that Svalbard will be covered in Glacier_cci by C. Nuth with optical sensors (glacier outlines, CL0 work) while CryoClim will focus on snow facies with

microwave sensors. Strong coordination will be required for these activities. Prior to any work commencing an MoU is required between CryoClim and Glacier_cci.

5. FSU – Inventory (80-90%) of FSU is due to be provided to GLIMS by Tatiana Khromova (RAS) based on ASTER data. TK wants to be involved in Glacier_cci and can be potentially incorporated into CRG for validation data and quality control. GIUZ will make a request to also include TK. Glacier_cci will identify which are missing parts of the FSU inventory and focus on them or the achievement of higher levels of completeness in already covered regions (CL1 and CL2 work).

6. Himalaya – Himalaya data provided by ICIMOD (Pradeep Mool) already in GLIMS (all sensors – CBERS, ASTER, Topo maps manual digitizing, possible also Landsat and SPOT). A recent and complete inventory based on Landsat and ASTER data is due for release in 2011. In GLIMS original China data from topographic maps was of poor quality and a second inventory is being produced (contact Tobias Bolch via Liu Shiyin) and is planned for GLIMS submission. 8 states bordering Himalaya with different level of completeness, quality and likely provision and quality and political issues are priorities rather than completeness and technical issues for datasets already present. GlobGlacier did Western Himalaya inventory (India-Nepal-Pakistan border areas) with submission via ICIMOD to clear with India government representatives before GLIMS submission. Glacier_cci will work on reassessment of quality, completeness, gap filling where necessary, reinforcing proposed submissions (CL1b and CL2 work) including methodological consistency (e.g. debris covered tongues, accumulation areas). Major funding has recently been injected from various sources for Himalaya so question of overlap is almost impossible to avoid but via ICIMOD and High-Noon the focus will be to get data into GLIMS inventory.

7. Chile/Argentina (Tierra del Fuego, Patagonia) Southern Chile might be in GLIMS soon (Philipp Rastner – CONAE workshop, Buenos Aires for Argentina status). In Patagonia (Chile/Argentina) 50 groups have made small area inventories but dates all variable, sensors all different and not really coordinated. The recent cooperation agreement between ESA and CONAE will aid the process. Glacier_cci will work on coordination, consistency and submission of data to GLIMS.

8. New Zealand, South Georgia, Heard Island, Kerguelen Island (Indian Ocean) – GLIMS promised submission from New Zealand (contact: Wolfgang Rack) but so far this has not been produced. South Georgia, Heard Island, Kerguelen Island all still not in any inventory though some work is known to exist for Kerguelen Island. All these areas need to be discussed with respective Regional Centres prior to consideration in Glacier_cci (basically CL0 and CL1 work).

9. Antarctic Peninsula – will be considered if others cannot be resolved, in agreement with ESA. Currently work all microwave and there are optical viewing limits. PhD student Alison Cook (Swansea) is currently analysing the situation.

10. Peru/Bolivia/Colombia – Christian Huggel is contact and these should be added only after all others. However, obtaining a higher level of completeness (CL2) or provide help in data transfer (CL1b) might be an issue.

Appendix 3 (User questionnaire)

The following text was sent to cryolist and the GLIMS mailing list on 19. Jan 2010:

Dear all

Please apologize for cross-posting!

In the framework of the recently started ESA project Glaciers_cci within the ESA Climate Change Initiative (http://earth.eo.esa.int/workshops/esa_cci/), user requirements are of outermost importance to set-up the project and work towards the needs of the community. To get a most recent feedback on these data needs and maybe also the ongoing work, we would highly appreciate when you can give us a short feedback on the three questions listed below. A major aim of the project is to map glaciers and icecaps from satellite data (mostly Landsat) to further complete the global glacier inventory and contribute the outlines and inventory data to the GLIMS glacier database. For this purpose we have prepared a draft list of key regions that should be updated. The project does further derive glacier elevation changes and velocity fields from repeat satellite data (using altimetry/DEM differencing and optical/microwave sensors) with target regions or time periods yet to be defined. To better serve the glaciological community in this regard, we would like to ask you to give us feedback (per email to frank.paul@geo.uzh.ch) on your regions and time periods of interest for such products. We will prepare a project webpage to keep you updated about the progress of the work and to consider future feedback. A reply before January 28 would be highly appreciated.

Please do not hesitate to contact us when you have any further questions!

With many thanks for your feedback and best regards,
Frank and Tobias

Q1. For which geographical regions (globally) would
production/availability of the following products be most important in
your view:
a) glacier inventory data (outlines with topographic attributes)?
b) elevation changes (either from altimetry or DEM differencing)?
c) velocity fields (either from optical or microwave data)?

Q2. What is your prefered acquisition date / time period / interval for
the three products
a) glacier inventory data (date)?
b) elevation changes (time period)?
c) velocity fields (interval)?

Q3. To avoid overlap with ongoing glacier inventory work that is not yet
visible in the GLIMS database but might be submitted to GLIMS in 2011,
we would like to know, which regions you are currently analysing
(country, mountain range, Landsat path-row and date)?

Appendix 4 (Feedback from the questionnaire)

			Q1 Region			Q2: Time			Q3: Ongoing work
Nr.	Name	Affiliation	Inventory	elevation change	velocity	Inventory	elev. Change	velocity	
1	Mike Willis	Cornell University	Russian Arctic	Arctic Canada, Himalaya	-	ASAP	-	-	elev. Ch. & velocity for Patagonia, Juneau and the Russian Arctic
2	Graham Cogley	Trent University	Afghanistan, Patago-nia	Russian Arctic, Greenland and Antarctic periphery	-	any	any	n/a	Himalaya-Karakoram, Mongolia (from 1970s maps)
3	Antoine Rabatel	LGGE Grenoble	-	-	-	-	-	-	French glacier Inventory with Landsat (1985), ASTER/SPOT (2010)
4	Chris Stokes	Durham University	-	-	-	-	-	-	Siberia (Cherskiy/Kodar), Novaya/Severnaya Zemlya
5	Pablo Zenteno	CECS, Chile	Patagonia without NPI / SPI	Patagonia without NPI / SPI	Patagonia without NPI / SPI	30. March	1960-2000	annual	Chile, southern volcanic zone (P:232/3, R:84-90)
6	Matthias Kunz	Newcastle University	Antarctic Peninsula	Antarctic Peninsula, Svalbard	Antarctic Penin-sula	start 1940	2-5 years	-	Svalbard (SLAKbreen), Porqui Pas Island
7	Mauri Pelto	Nichols College, Dudley MA		SE Alaska	SE Alaska, Mt. Baker	July-Sep	July-Sep	any	Juneau (58-19), Wind River Range, North Cascades
8	Vladimir Kono-valov		all	all	-	1900-2010	1900-2010	-	Panj River (Hindu Kush & Pamir)
9	Michael Zemp	CRG, Uni Zurich	Alaska, Canadian Arctic, Russian Arctic Islands, Patagonian Icefields, around Greenland IS, Antarc-tic Peninsula	all mountain ranges with long-term in-situ mass balance measurement for assessing their representativeness for entire mountain range	tidewater. gl.: determination of calving rate, ice fields & ice caps: ice devides	1970s (steady state), LIA (Holocene maximum), 2000 & later	1970s to 2000	1970s to 2001	check WGI-XF and with GLIMS (B. Raup) and WGI (F. Fetterer)
10	Liss Andreassen	NVE, Oslo	-	-	mainland Norway	-	-	-	Mainland Norway from Landsat 1999-2006, to GLIMS in 2011
11	Matthew Beedle	University of North-ern British Columbia	SE Alaska (Juneau), Glacier Bay	primary importance	Taku	2010	2010	since 1990s, annual period	Juneu and Glacier Bay, but slowly
12	Adina Raco-viteanu	Boulder, NSIDC	HKH, Karakoram, Tibet, Andes	dto.	dto.	Him. E: Nov-Dec, Him. W: Sep-Nov, Andes: July-Aug	decadal	annual to decadal	Sikkim Himalaya 1990, 2000, 2005 (Landsat), Hi-machal Pradesh 2006 (ASTER)

13	Etienne Berthier	CNRS-OMP-LEGOS	Himalaya, Karakorum, Hindukush	Everywhere! But regions with little geodetic mass balance or glaciological mass balance should be targeted.	-	Important is that the time stamp is known	-	-	update Kerguelen Island Inventory
14	Sabine Bau-mann	Uni Würzburg, Germany	South America, Hi-malaya, Svalbard	South America, Himalaya, Svalbard	-	every five years, 2002 and later	at least yearly, best monthly; 2002 until today	-	-
15	Alison Cook	?	Antarctic Peninsula	Antarctic Penins.	Antarctic Penin-sula	-	-	-	Glacier fronts at Antarctic Peninnsula
16	Siri Jodha Khalsa	NSIDC, Boulder	Priority to those areas where glacier decline will have serious human impact (e.g. dependence on glacier meltwater)		-	-	-	-	-
17	Dieter Scherer	TU Berlin, Germany	Svalbard, Tibet and surrounding moun-tains	Svalbard, Tibet and surrounding moun-tains	Svalbard, Tibet and surrounding mountains	2010	as early as possible, since 1970	yearly to five years	Vestfonna ice and De Geerfonna cap
18	Samjwal Ba-jracharya	ICIMOD, Nepal	-	-	-	-	-	-	Inventory for entire Hindu Kush-Himalayan region based on Landsat 2005 +-3 year.
19	Wilfried Hae-berli	UZH, Switzerland	Flowlines are import-ant	-	-	-	-	-	Cordillera Santa Cruz (Landsat 233/072 from 2000), Corrdillera Apolobamba (002/070) in 2012
20	Marco Möller	RTWH Aachen, Germany	-	-	-	-	-	-	-
21	Brian Menounos	UNBC, Canada	As many as possible, preference on west-ern North America, strong need for a debris-cover masks	As many as possible, preference on western North America, special interest in debris-covered glaciers	As many as possi-ble, preference on NW America, special interest in debris-covered glaciers	year 2000 and later	year 2000 and later	year 2000 and later	Volume change in Western Canada, esp. Columbia Icefield