Climate Assessment Report (CAR)

Phase 2 Year 3

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Document status sheet

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0.2	04.04. 2015	Extended draft with examples	
0.3	21.05. 2015	Intermediate version	
0.4	28.07. 2015	Consortium feedback integrated	
0.5	25.07. 2016	Update and consortium feedback integrated	
0.6	22.09. 2016	Comments from TO integrated	
0.7	22.11. 2016	Additional TO comments (after review) integrated	
0.8	10.10. 2017	Year 3 update	
0.9	21.12.2017	Comments from TO integrated	

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1. Purpose of this document

1.1 Aims

This document summarizes the assessment of Glaciers_cci data products by the Climate Research Group (CRG) and other users (e.g. the IACS working group on the RGI), feedback to the Glaciers_cci outreach activities, and the progress in regard to data production and user requirements. We also provide information on the spatial distribution of the products available from the CRDP and report their download statistics. As a measure of our contribution to science and outreach we also list the publications and presentations by Glaciers_cci along with the publications (and their citations) that are based on the datasets provided to other collections (e.g. the Randolph Glacier Inventory, RGI).

1.2 Outline

The report is organized as follows.

- Chapter 2 describes the access and download statistics of the products and highlights results of selected publications pertaining to the datasets;
- Chapter 3 is lists the results of the product assessment by the CRG and other users along with general feedback and discussion topics of non-data products;
- Chapter 4 shows the progress in regard to the URD for each year;
- Chapter 5 is lists the outreach activities of Glaciers_cci in regard to publications and presentations along with citation statistics.

2. Products generated by Glaciers_cci

In this section we provide an overview on the download statistics of products generated by Glaciers_cci and made available for the public at the CRDP web page http://glaciers-cci.enveo.at and http://cryoportal.enveo.at. Note that products made available through other websites (e.g. GLIMS or WGMS) are not considered here. Instead, we will provide for the RGI (where products from Glaciers_cci are integrated) a counting of citations for studies that have used this dataset for their mostly global-scale calculations (see Section 5.3).

2.1 Data products and access statistics

Figure 2.1 provides a spatial overview on the data products being produced in year 1 of Phase 2 or generated earlier and now being made available through the CRDP website for the public (see next page for year 2). Table 2.1 provides the related tabular overview for each dataset.

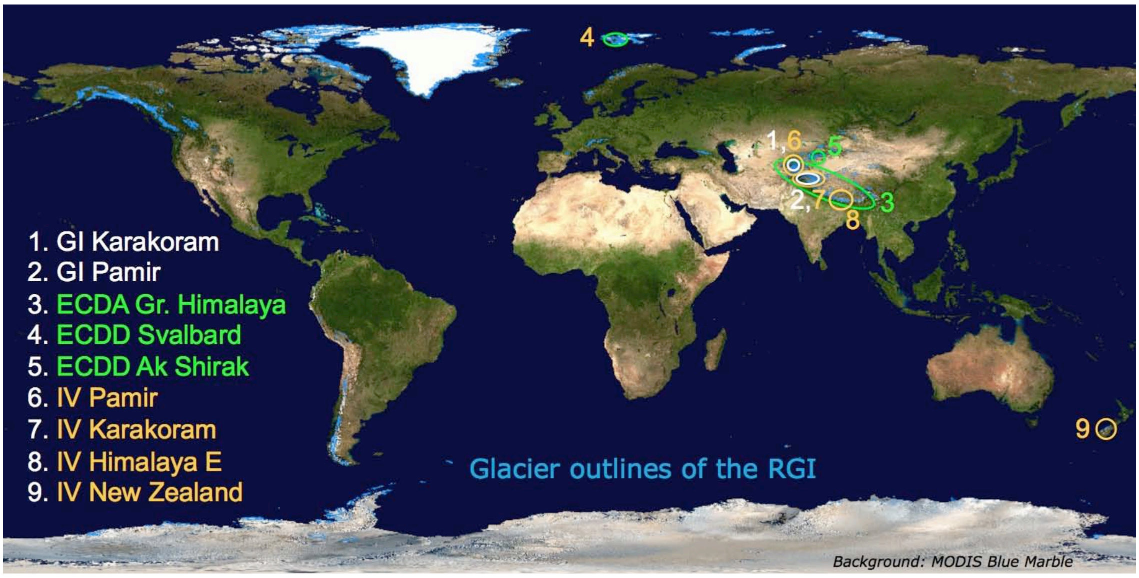


Figure 2.1: Overview of the products generated in year 1 of Phase 2 (white: glacier inventories (GI), green: elevation changes derived from DEMs and altimetry (ECDA) or DEM differencing (ECDD), orange: ice velocity (IV)).

Nr.	Product	RGI	Region	Description	Year
1	GI	13	Pamir	Glacier inventory from Landsat images	1
2	GI	14	Karakoram	Glacier inventory from Landsat images	1
3	ECDA	13-15	Greater Himalaya	Trends from ICESat compared to SRTM DEM	1
4	ECDD	7	Svalbard	DEM from ASTER (14 DMO) and SPOT	1
5	ECDD	13	Ak Shirak (Gl. 354)	DEM from Quickbird and Geoeye	1
6	IV	13	Pamir	from optical and microwave data	1
7	IV	14	Karakoram	from optical and microwave data	1
8	IV	15	Himalaya East	from optical data	1
9	IV	18	New Zealand	from optical data	1

Table 2.1: Overview of the products created by Glaciers_cci in year 1 of Phase 2.

Figure 2.2 provides a spatial overview on the data products produced in year 2 of Phase 2 or generated earlier and now being made available through the CRDP website for the public. Table 2.2 provides the related tabular overview for each dataset.

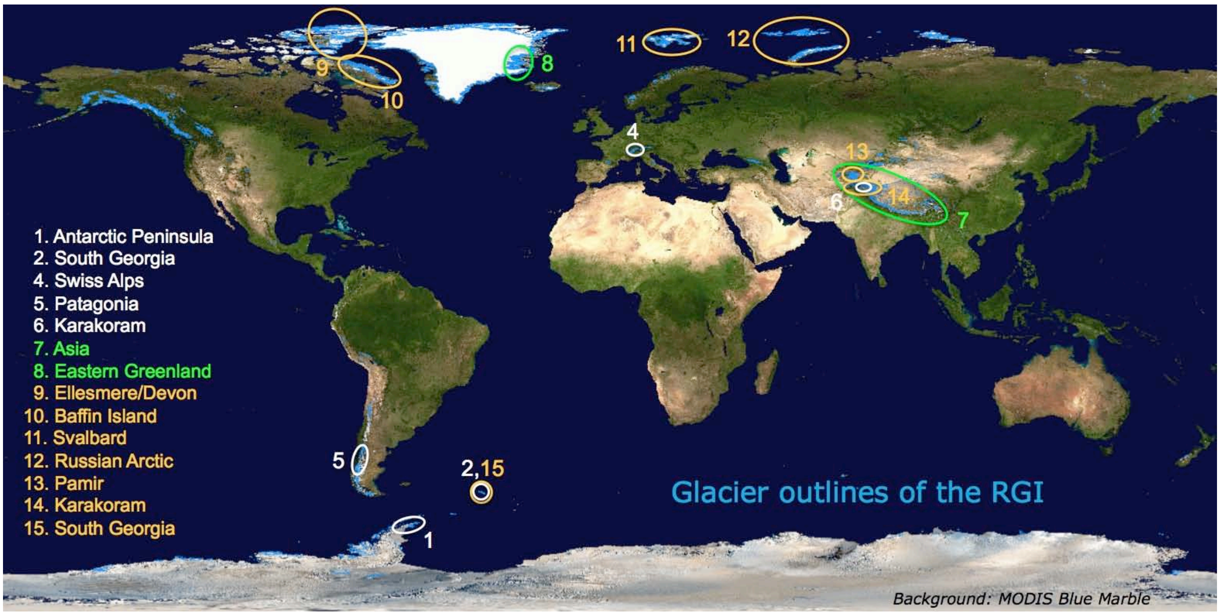


Figure 2.2: Overview of the products generated in year 2 of Phase 2 (white: glacier outlines or inventories, green: elevation change, orange: ice velocity).

Nr.	Product	RGI	Region	Description	Year
1	GI	19	Antarctic Peninsula	Glacier inventory from various sources*	2
2	GO	19	South Georgia	Glacier outlines from Landsat OLI (2016)	2
3	GO	05	Greenland	Ice sheet outline + CL2 merged	2
4	GO	11	Swiss Alps	Area (Outlines 1850)	2
5	GI	17	Patagonia (N)	Multitemporal Inventory (1985-2000-2010)	2
6	images	14	Karakoram	Base images for Animation 1990-2015	2
7	ECAD	13-15	Asia (H-K-H)	Elevation Change (Altimetry & DEM)	2
8	ECDD	5	Western Greenland	DEM differencing	2
9	IV	3	Ellesmere / Devon	Velocity (from Palsar & Sentinel 1)	2
10	IV	4	Baffin Island	Velocity (from Palsar & Sentinel 1)	2
11	IV	7	Svalbard	Velocity (from JERS, Palsar, TSX, S1)	2
12	IV	9	Russian Arctic	Velocity (from JERS, Palsar, S1)	2
13	IV	13	Pamir	Velocity (from Palsar & Sentinel 1)	2
14	IV	14	Karakoram	Velocity (from Sentinel 1)	2
15	IV	19	South Georgia	Velocity (from Palsar TSX)	2

*Table 2.2: Overview of the products created by Glaciers_cci in year 2 of Phase 2. * see details of the datasets in http://www.earth-syst-sci-data-discuss.net/essd-2016-47.*

Figure 2.3 provides a spatial overview on the data products produced in year 3 of Phase 2 or generated earlier and now being made available through the CRDP website for the public. Table 2.3 provides the related tabular overview for each dataset.

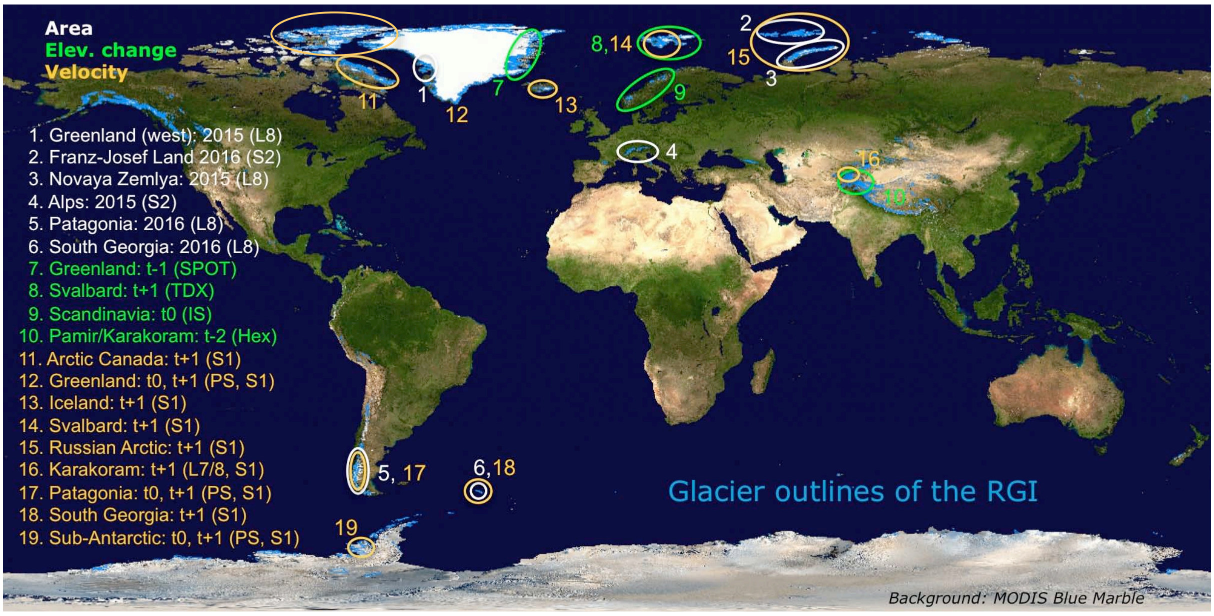


Figure 2.3: Overview of the products generated in year 3 of Phase 2 (white: glacier outlines or inventories, green: elevation change, orange: ice velocity).

Nr.	Product	RGI	Region	Description	Year
1	GI	5	Greenland	Landsat 8 (2015)	3
2	GI	9	Franz Josef Land	Sentinel 2 (2016)	3
3	GI	9	Novaya Zemlya	Landsat 8 (2013/15)	3
4	GI	11	European Alps	Sentinel 2 (2015)	3
5	GI	17	Patagonia	Landsat 8 (2016)	3
6	GI	18	South Georgia	Landsat 8 (2016)	2/3
7	ECDD	5	Eastern Greenland	Elevation Change (NED & SPOT SPIRIT)	3
xx	ECAD	5	Greenland	Elevation Change (Cryosat-2)*	3
8	ECDD	7	Svalbard	DEM differencing (NED& TanDEM-X IDEM)	3
9	ECAD	8	Scandinavia	Altimetry (ICESat)	3
10	ECDD	13/14	Pamir / Karakoram	DEM differencing (SRTM & Hexagon)	3
11	IV	3/4	Arctic Canada N/S	Sentinel 1	3
12	IV	5	Greenland (periph.)	Palsar & Sentinel 1 (one annual merge)	3
13	IV	6	Iceland	Sentinel 1*	3
14	IV	7	Svalbard	Sentinel 1	3
15	IV	9	Russian Arctic	Sentinel 1*	3
16	IV	14	Karakoram	Landsat 7/8, Sentinel 1 (time series Hispar)	3
17	IV	17	Patagonia	Palsar, Sentinel 1*	3
18	IV	19	South Georgia	Sentinel 1	3
19	IV	19	Alexander Island	Palsar, Sentinel 1	3

Table 2.3: Overview of the products created by Glaciers_cci in year 3 of Phase 2.

In Figure 2.4 we have indicated in which regions aimations have been generated from time series of satellite data. They are available form the cryoportal (http://cryoportal.enveo.at) and can be viewed in the CCI Visualisation Tool (http://cci.esa.int/content/tablet-app). Table 2.4 is providing further details for each dataset.

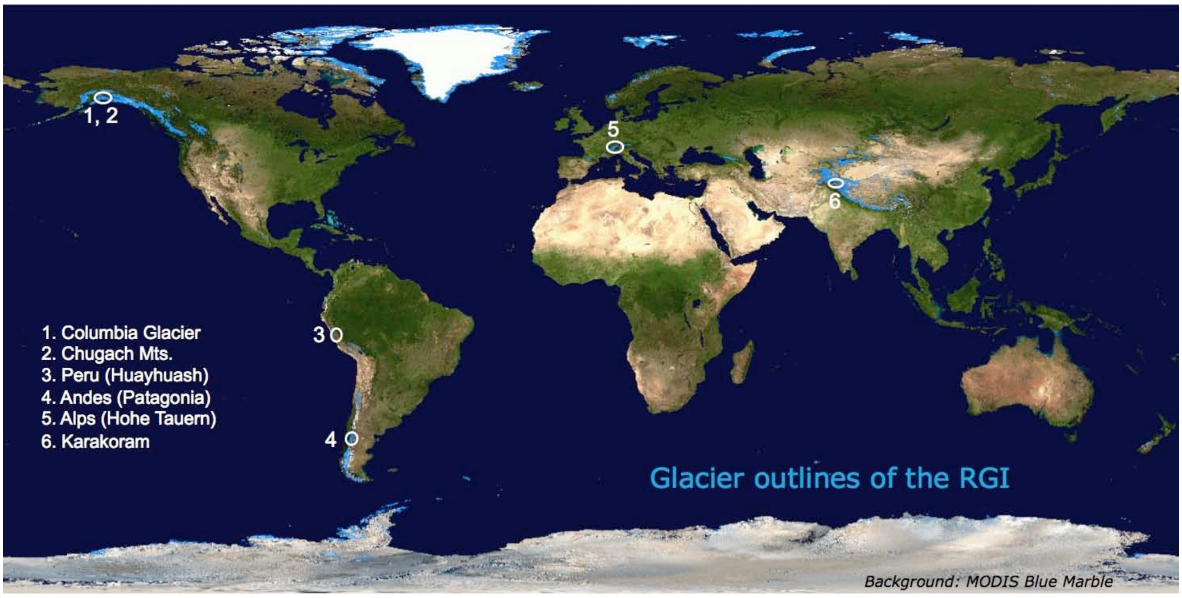
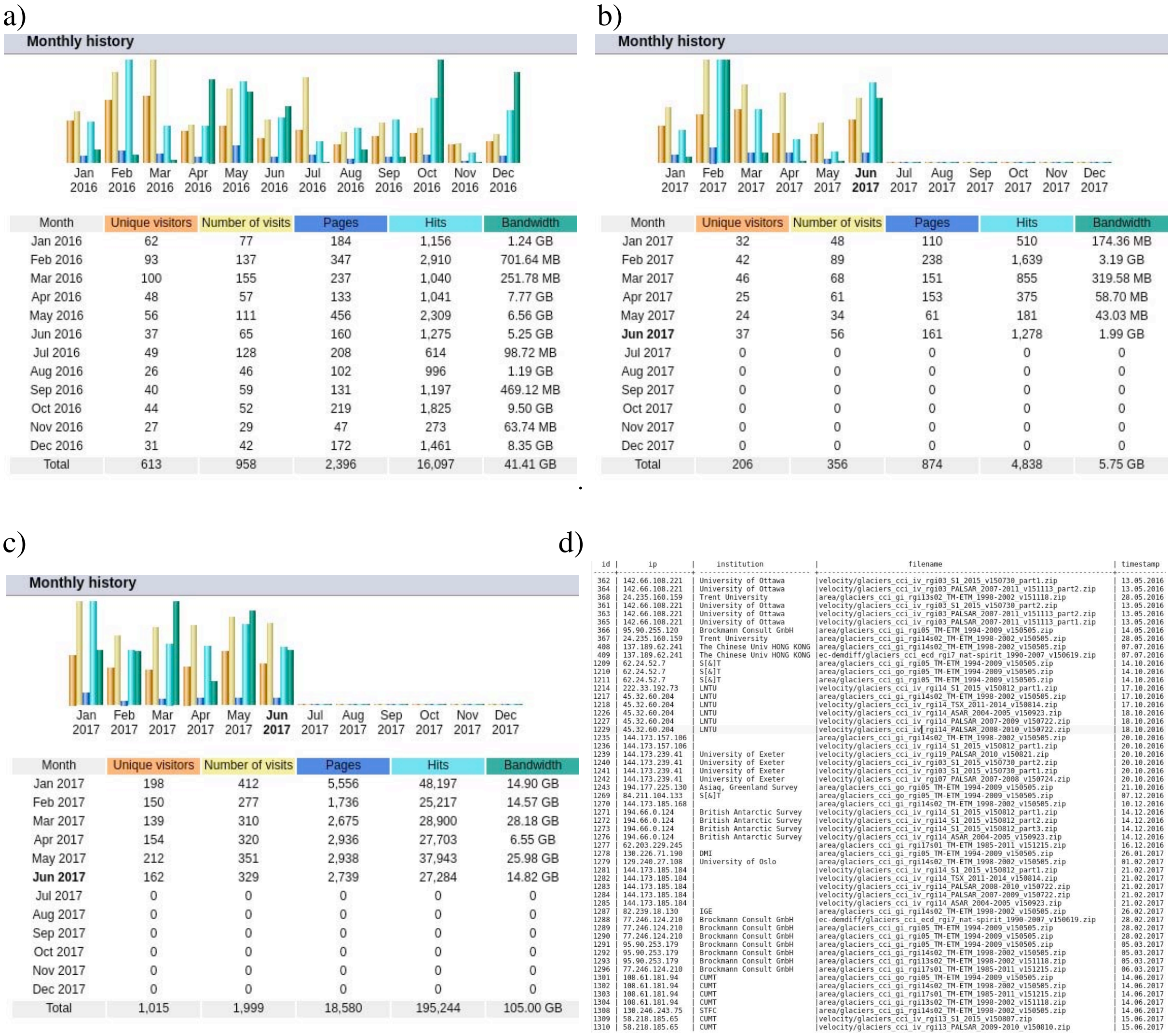


Figure 2.4: Overview of the regions where animations have been created from time-series of satellite images.

Nr.	RGI	Region	Mountain range	Sensor	P-R	Date	Year	Day
1	1	Alaska	Columbia Glacier	TM	067-017	14.09.	1986	257
1	1	Alaska	Columbia Glacier	TM	066-017	16.09.	1995	259
1	1	Alaska	Columbia Glacier	TM	067-017	16.09.	2010	259
2	1	Alaska	Valdez	TM	067-017	14.09.	1986	257
2	1	Alaska	Valdez	TM	066-017	04.08.	1997	216
2	1	Alaska	Valdez	TM	067-017	16.09.	2010	259
3	16	Peru	Cord. Huayhuash	TM	008-067	18.07.	1987	199
3	16	Peru	Cord. Huayhuash	TM	008-067	11.08.	1996	224
3	16	Peru	Cord. Huayhuash	TM	008-067	18.08.	2010	230
4	17	Andes	Inexplorado	TM	232-089	07.03.	1985	066
4	17	Andes	Inexplorado	ETM+	232-089	21.02.	2000	052
4	17	Andes	Inexplorado	TM	232-089	11.02.	2011	042
5	7	Svalbard	Negri & Strongbreen	S1	var.	Time series 2016/17[+]		
6	11	Alps	Venediger	TM	192-027	12.10.	1986	285
6	11	Alps	Venediger	TM	192-027	24.08.	2003	236
6	11	Alps	Venediger	TM	192-027	01.10.	2011	274
7	11	Alps	Findelenglacier	rendered	194-028	Time series 1862-2010		
8	14	Karakoram	Baltoro	TM, ETM+ OLI	148-035 149-035	various*	1990 to 2015[#]	various*
8	14	Karakoram	Panmah					
8	14	Karakoram	Skamri					
8	14	Karakoram	Shaksgam					

*Table 2.4: Overview of the animations created by Glaciers_cci from Landsat image quicklooks for visualization of glacier changes over the past decades. * see full list in Paul (2015). [+] online at http://www.esa-glaciers-cci.org/index.php?q=node/147, [#] online at https://www.egu.eu/news/210/revealing-glacier-flow-with-animated-satellite-images.*

The products generated within Glaciers_cci are stored in the Climate Research Data Package (CRDP), which can be accessed after registration via the website http://glaciers-cci.enveo.at. There is a two-step procedure for accessing the database, related to (i) viewing and selecting of products and (ii) downloading of the products. The first step 'Viewing and selecting' does not require any registration. In the 2nd step 'Downloading of the products' we ask for the approval of a data usage disclaimer by providing name, affiliation and email address, a password is not required (see details in Glaciers_cci-D4.2_CRDP-TD). The entered information is used only for tracking the use of the products. Some products are additionally accessible through ENVEO's Cryoportal Database. Figure 2.4 gives an overview of the access statistics for the http://glaciers-cci.enveo.at and http://cryoportal.enveo.at websites, along with a list of product downloads from glaciers-cci.enveo.at (without names and emails for privacy). For the cryoportal, which went online in January 2016, downloads are not being tracked explicitly but implicitly (IP address).



a)

Monthly history

Month	Unique visitors	Number of visits	Pages	Hits	Bandwidth
Jan 2016	62	77	184	1,156	1.24 GB
Feb 2016	93	137	347	2,910	701.64 MB
Mar 2016	100	155	237	1,040	251.78 MB
Apr 2016	48	57	133	1,041	7.77 GB
May 2016	56	111	456	2,309	6.56 GB
Jun 2016	37	65	160	1,275	5.25 GB
Jul 2016	49	128	208	614	98.72 MB
Aug 2016	26	46	102	996	1.19 GB
Sep 2016	40	59	131	1,197	469.12 MB
Oct 2016	44	52	219	1,825	9.50 GB
Nov 2016	27	29	47	273	63.74 MB
Dec 2016	31	42	172	1,461	8.35 GB
Total	613	958	2,396	16,097	41.41 GB

b)

Monthly history

Month	Unique visitors	Number of visits	Pages	Hits	Bandwidth
Jan 2017	32	48	110	510	174.36 MB
Feb 2017	42	89	238	1,639	3.19 GB
Mar 2017	46	68	151	855	319.58 MB
Apr 2017	25	61	153	375	58.70 MB
May 2017	24	34	61	181	43.03 MB
Jun 2017	37	56	161	1,278	1.99 GB
Jul 2017	0	0	0	0	0
Aug 2017	0	0	0	0	0
Sep 2017	0	0	0	0	0
Oct 2017	0	0	0	0	0
Nov 2017	0	0	0	0	0
Dec 2017	0	0	0	0	0
Total	206	356	874	4,838	5.75 GB

c)

Monthly history

Month	Unique visitors	Number of visits	Pages	Hits	Bandwidth
Jan 2017	198	412	5,556	48,197	14.90 GB
Feb 2017	150	277	1,736	25,217	14.57 GB
Mar 2017	139	310	2,675	28,900	28.18 GB
Apr 2017	154	320	2,936	27,703	6.55 GB
May 2017	212	351	2,938	37,943	25.98 GB
Jun 2017	162	329	2,739	27,284	14.82 GB
Jul 2017	0	0	0	0	0
Aug 2017	0	0	0	0	0
Sep 2017	0	0	0	0	0
Oct 2017	0	0	0	0	0
Nov 2017	0	0	0	0	0
Dec 2017	0	0	0	0	0
Total	1,015	1,999	18,580	195,244	105.00 GB

d)

```
  id |       ip        |      institution           |                          filename                                    | timestamp
-----+-----------------+----------------------------+----------------------------------------------------------------------+-----------
 362 | 142.66.108.221  | University of Ottawa       |velocity/glaciers_cci_iv_rgi03_S1_2015_v150730_part1.zip              | 13.05.2016
 364 | 142.66.108.221  | University of Ottawa       |velocity/glaciers_cci_iv_rgi03_PALSAR_2007-2011_v151113_part2.zip     | 13.05.2016
 368 | 24.235.160.159  | Trent University           |area/glaciers_cci_gi_rgi13s02_TM-ETM_1998-2002_v151118.zip            | 28.05.2016
 361 | 142.66.108.221  | University of Ottawa       |velocity/glaciers_cci_iv_rgi03_S1_2015_v150730_part2.zip              | 13.05.2016
 363 | 142.66.108.221  | University of Ottawa       |velocity/glaciers_cci_iv_rgi03_PALSAR_2007-2011_v151113_part2.zip     | 13.05.2016
 365 | 142.66.108.221  | University of Ottawa       |velocity/glaciers_cci_iv_rgi03_PALSAR_2007-2011_v151113_part1.zip     | 13.05.2016
 366 | 95.90.255.120   | Brockmann Consult GmbH     |area/glaciers_cci_gi_rgi05_TM-ETM_1994-2009_v150505.zip               | 14.05.2016
 367 | 24.235.160.159  | Trent University           |area/glaciers_cci_gi_rgi14s02_TM-ETM_1998-2002_v150505.zip            | 28.05.2016
 408 | 137.189.62.241  | The Chinese Univ HONG KONG |area/glaciers_cci_gi_rgi14s02_TM-ETM_1998-2002_v150505.zip            | 07.07.2016
 409 | 137.189.62.241  | The Chinese Univ HONG KONG |ec-demdiff/glaciers_cci_ecd_rgi7_nat-spirit_1990-2007_v150619.zip     | 07.07.2016
1209 | 62.24.52.7      | S[&]T                      |area/glaciers_cci_gi_rgi05_TM-ETM_1994-2009_v150505.zip               | 14.10.2016
1210 | 62.24.52.7      | S[&]T                      |area/glaciers_cci_go_rgi05_TM-ETM_1994-2009_v150505.zip               | 14.10.2016
1211 | 62.24.52.7      | S[&]T                      |area/glaciers_cci_gi_rgi05_TM-ETM_1994-2009_v150505.zip               | 14.10.2016
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1218 | 45.32.60.204    | LNTU                       |velocity/glaciers_cci_iv_rgi14_TSX_2011-2014_v150814.zip              | 17.10.2016
1226 | 45.32.60.204    | LNTU                       |velocity/glaciers_cci_iv_rgi14_ASAR_2004-2005_v150923.zip             | 18.10.2016
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1229 | 45.32.60.204    | LNTU                       |velocity/glaciers_cci_iv_rgi14_PALSAR_2008-2010_v150722.zip           | 18.10.2016
1235 | 144.173.157.106 |                            |area/glaciers_cci_gi_rgi14s02_TM-ETM_1998-2002_v150505.zip            | 20.10.2016
1236 | 144.173.157.106 |                            |velocity/glaciers_cci_iv_rgi14_S1_2015_v150812_part1.zip              | 20.10.2016
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1241 | 144.173.239.41  | University of Exeter       |velocity/glaciers_cci_iv_rgi03_S1_2015_v150730_part1.zip              | 20.10.2016
1242 | 144.173.239.41  | University of Exeter       |velocity/glaciers_cci_iv_rgi07_PALSAR_2007-2008_v150724.zip           | 20.10.2016
1243 | 194.177.225.130 | Asiaq, Greenland Survey    |area/glaciers_cci_go_rgi05_TM-ETM_1994-2009_v150505.zip               | 21.10.2016
1269 | 84.211.104.133  | S[&]T                      |area/glaciers_cci_go_rgi05_TM-ETM_1994-2009_v150505.zip               | 07.12.2016
1270 | 144.173.185.168 |                            |area/glaciers_cci_gi_rgi14s02_TM-ETM_1998-2002_v150505.zip            | 10.12.2016
1271 | 194.66.0.124    | British Antarctic Survey   |velocity/glaciers_cci_iv_rgi14_S1_2015_v150812_part1.zip              | 14.12.2016
1272 | 194.66.0.124    | British Antarctic Survey   |velocity/glaciers_cci_iv_rgi14_S1_2015_v150812_part2.zip              | 14.12.2016
1273 | 194.66.0.124    | British Antarctic Survey   |velocity/glaciers_cci_iv_rgi14_S1_2015_v150812_part3.zip              | 14.12.2016
1276 | 194.66.0.124    | British Antarctic Survey   |velocity/glaciers_cci_iv_rgi14_ASAR_2004-2005_v150923.zip             | 14.12.2016
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1278 | 130.226.71.190  | DMI                        |area/glaciers_cci_gi_rgi05_TM-ETM_1994-2009_v150505.zip               | 26.01.2017
1279 | 129.240.27.108  | University of Oslo         |area/glaciers_cci_gi_rgi14s02_TM-ETM_1998-2002_v150505.zip            | 01.02.2017
1281 | 144.173.185.184 |                            |velocity/glaciers_cci_iv_rgi14_S1_2015_v150812_part1.zip              | 21.02.2017
1282 | 144.173.185.184 |                            |velocity/glaciers_cci_iv_rgi14_TSX_2011-2014_v150814.zip              | 21.02.2017
1283 | 144.173.185.184 |                            |velocity/glaciers_cci_iv_rgi14_PALSAR_2008-2010_v150722.zip           | 21.02.2017
1284 | 144.173.185.184 |                            |velocity/glaciers_cci_iv_rgi14_PALSAR_2007-2009_v150722.zip           | 21.02.2017
1285 | 144.173.185.184 |                            |velocity/glaciers_cci_iv_rgi14_ASAR_2004-2005_v150923.zip             | 21.02.2017
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1290 | 77.246.124.210  | Brockmann Consult GmbH     |area/glaciers_cci_gi_rgi05_TM-ETM_1994-2009_v150505.zip               | 28.02.2017
1291 | 95.90.253.179   | Brockmann Consult GmbH     |area/glaciers_cci_gi_rgi05_TM-ETM_1994-2009_v150505.zip               | 05.03.2017
1292 | 95.90.253.179   | Brockmann Consult GmbH     |area/glaciers_cci_gi_rgi14s02_TM-ETM_1998-2002_v150505.zip            | 05.03.2017
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1301 | 108.61.181.94   | CUMT                       |area/glaciers_cci_go_rgi05_TM-ETM_1994-2009_v150505.zip               | 14.06.2017
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1310 | 58.218.185.65   | CUMT                       |velocity/glaciers_cci_iv_rgi13_PALSAR_2009-2010_v150810.zip           | 15.06.2017
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Figure 2.4: Access statistics for a) glaciers-cci.enveo.at in 2016; b) glaciers-cci.enveo.at in 2017; c) cryoportal.enveo.at in 2017, and d) download tracker for glaciers-cci.enveo.at updated until June 2017. For a) to c) we list for each month the total number of unique visitors, number of visits, pages visited, number of hits and total bandwidth usage.

2.2 Examples from publications by the consortium

2.2.1 Himalaya (Kääb et al. 2012)

ICESat-derived elevation difference trends from 2003 to 2008 were computed over the entire Pamir–Karakoram–Himalaya, extending a previous study (Kääb et al., 2012) over the geographic region both eastwards and westwards (Fig. 2.5). Glacier thickness loss is most pronounced for the eastern Nyainqêntanglha Shan, followed by the western end of the Great Himalaya Range. Glaciers in and around the western Kunlun Shan are in balance or even gaining volume, and Pamir and Karakoram seem to be on the western limit of this mass balance anomaly rather than its centre, suggesting it could be a meteorological or climatic anomaly (e.g. increasing precipitation). The glacier mass changes in the Tarim and Amu Darya basins of +0.7 ±1.0 and −4.0 ±0.8 Gt yr^{-1} do not contribute to sea-level rise. The combined Ganges, Indus and Brahmaputra basin glacier mass change is −23.7 ±2.1 Gt yr^{-1}, almost 10% of the glacier contribution to sea-level rise. Note, heterogeneous behaviour of individual glaciers in Pamir and Hindu Kush may lead to biases when extrapolating elevation difference trends from particularly sparse ICESat tracks, or areas covered by differential DEMs, to the entire region. Finally, it is important to consider that these results cover only 5 years, 2003–2008, and it remains open how representative they are for longer periods. The forthcoming TanDEM-X DEMs might help extending this period by a further 5-6 years.

Neglecting water losses downstream of the glaciers, the 2003–2008 glacier imbalances amount to ~6 % of the annual discharge of Amu Darya and upper Indus where they leave the mountains. This is a considerable amount given the significance of the rivers for the Aral Sea (Amu Darya) and massive irrigation schemes and household use in these dry climate regions. Maximum glacier imbalance contributions to annual average river run-off of up to ~17% are found for the Shyok (Indus) and ~10% for Vakhsh (Amu Darya), while minimum contributions are only ~1–3% for the monsoon-type catchments in Nepal.

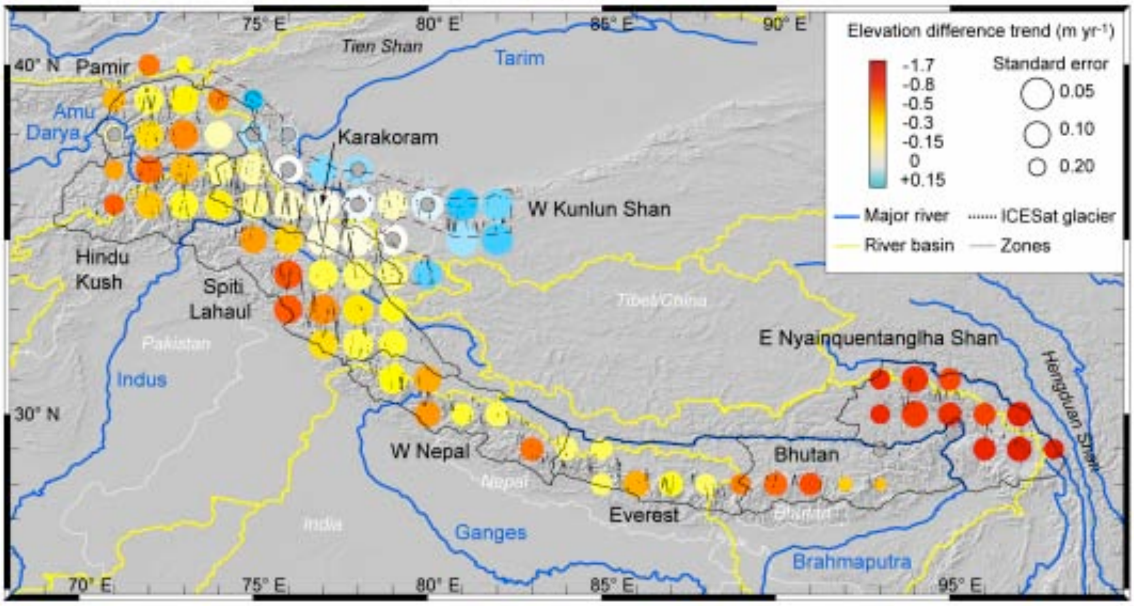

Figure 2.5: Elevation change trends over the Pamir-Karakoram-Himalaya region from 2003-2008 (Kääb et. al., 2015).

2.2.2 Patagonia (Paul and Mölg 2014)

In year 2 of Glaciers_cci Phase 2 change assessment was performed in various key regions. One of the regions was the Andes of Chile and Argentina in northern Patagonia where extreme area loss of large glaciers has been observed (Paul and Mölg 2014). Many characteristics of the region are extreme: topography is very steep resulting in many glaciers with an interrupted profile (regenerated glaciers), precipitation gradients are very high from west to east, pro-glacial lakes form and grow at high rates and most glaciers are very remote and difficult to access. In consquence, there are no in-situ mass balance or length change measurements available and information on glacier change was sparse and only available from remote sensing (e.g. Davies and Glasser 2012).

We have thus analyzed time series of Landsat images and created glacier inventories for three points in time (1985, 2000, 2010) from the best scenes available (2010 has some seasonal snow hiding glaciers). In total we mapped 1664 (1311/1290) glaciers covering an area of 1193 (951/899) km^2 in 1985 (2000/2010), respectively. The overall area loss was thus 25% (or a few per cent more considering wrongly mapped snow cover) in 25 years or 1% per year. In addition, a strong gradient of area loss with elevation was found ranging from 100 to 50% at the lowest elevations (300 to 1000 m) to near-zero above 2000 m. This means that mainly large glaciers with flat and low-lying tongues have lost area whereas smaller glaciers at high elevations remained nearly unchanged. This trend continued in 2016 (Fig. 2.6) and is in strong contrast to most other regions in the world where area loss increases towards smaller glaciers. Further details are provided in the publication.

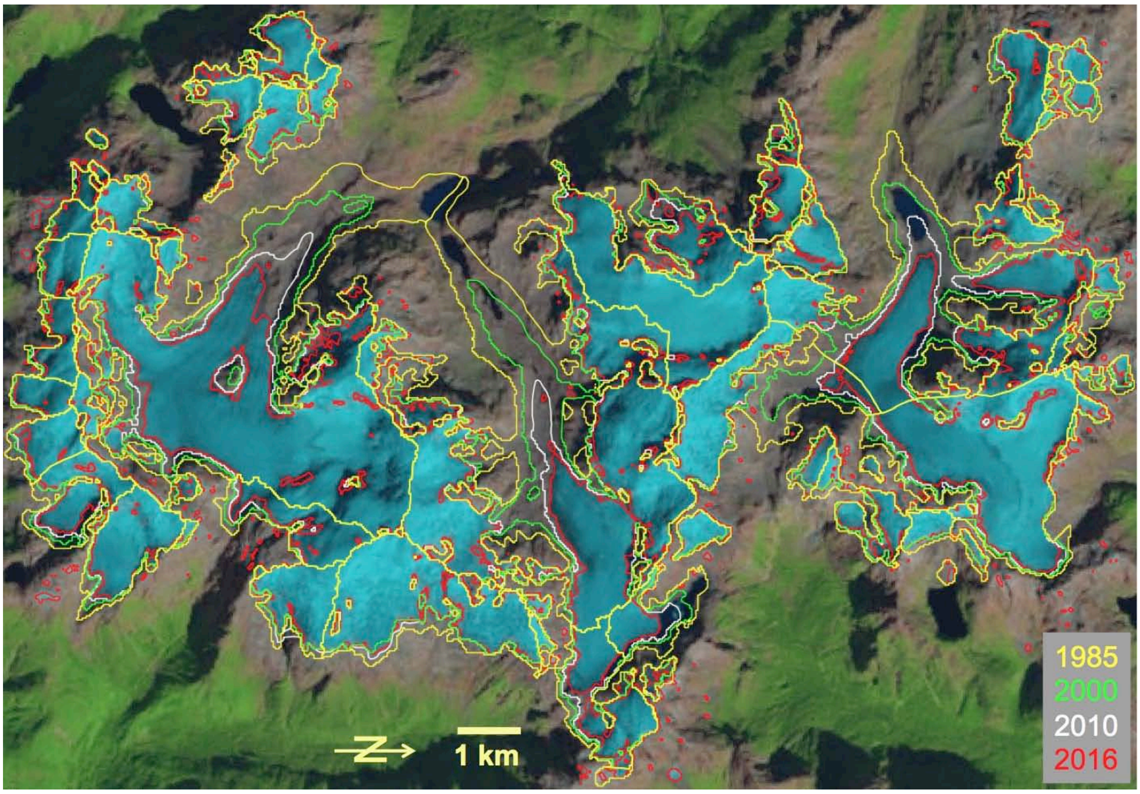

Figure 2.6: Overlay of glacier outlines from four points in time as derived from Landsat TM (1985, 2010), ETM+ (2000) and OLI (2016) data around the vulcano Mt. Inexplorado in northern Patagonia (centre coordinates: 41.95° S, 72.2° W).

2.2.3 Hispar Glacier Surge, Karakoram (Paul et al. 2017)

For year 3 we present an example of today's possibilities to process dense time series of optical and SAR data to derive the spatio-temporal variability of surface flow velocities for a surging glacier in the Karakoram. The comparably high velocities during a surge (up to 10-15 m day) also allows offset-tracking with optical data in about 2-4 week intervals (16 days repeat interval with Landsat). When combining velocities derived from SAR data that work best during winter with results from optical sensors that work best during summer, a dense and complete time series of velocity evolution can be derived. This allows to exactly determine the onset of a surge and to reveal short-term velocity fluctuations that possibly provide information on the surge mechanism. This new application of satellite data was not possible a few years ago and will improve our understanding of cryospheric processes. The results presented below are largely based on Landsat 7/8 panhromatic images and Sentinel 1A/B data. Once Sentinel 2A/B is in its nominal 5 day repeat cycle, data availability and visible details will likely further improve so that even more complex details of glacier flow can be studied.

The analysis of the flow velocities along with the interpretation of optical images revealed several interesting details about the surge (see Paul et al. 2017 for details): a) The surge was likely initiated by a surge of its tributary Yutmaru Glacier in October 2014, b) the surge started during the slow down of the annual higher summer flow velocities (likely due to basal lubrication by meltwater), c) maximum flow velocities reached 15 m / day during spring 2015, d) the surge slowed down considerably in Aug/Sep 2015 but velocities increased again in Winter 2015/16 (see Fig. 2.6), e) the surge ended very sudden in June 2016, f) a surge front moved about 90 m/day during May/June 2016, and g) the surge stopped this time before the confluence with the next northern tributary (Kunyang).

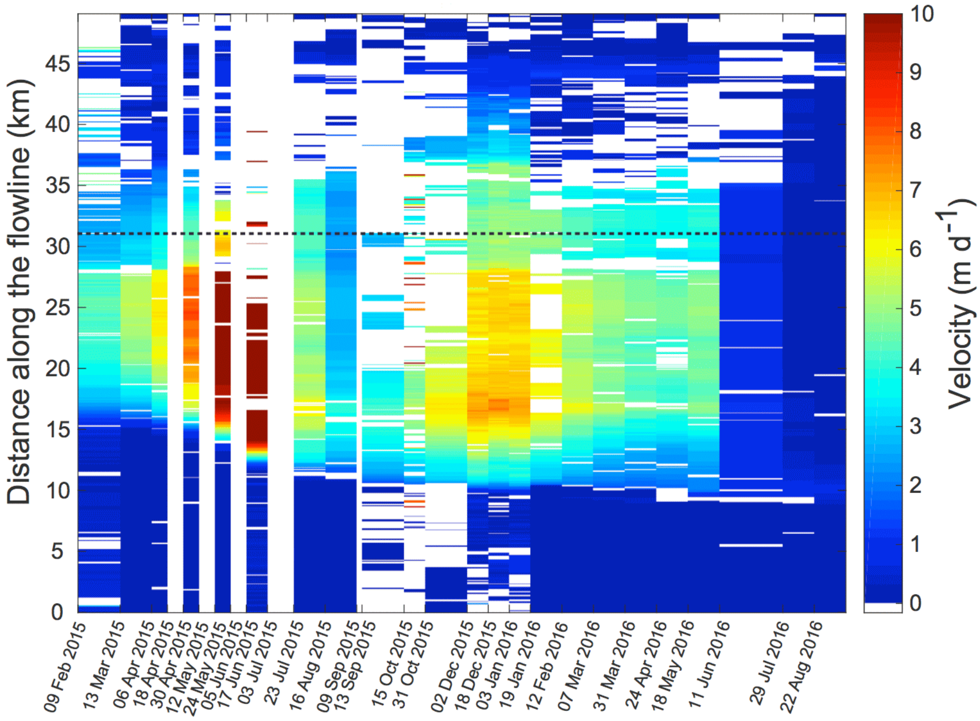

Fig. 2.7: Evolution of flow velocities along the cetral flow line of Hispar Glacier in a time-distance plot. The black-dotted line across all dates shows the position of the confluence with the Yutmaru tributary. Two separated fast flow periods are visible (from Paul et al. 2017).

This time, because the analysis of historic reconnaisance imagery from Corona revealed that Hispar glacier has surged before, likely around 1960 (Fig. 2.8). This study not only revealed that Hispar Glacier is indeed a surge-type glacier (before it was assumed that the glacier is only impacted by surges of its tributaries) with a 55-year surge cycle (and that the 1960 surge was more extended), but the high temporal resolution of the flow field in combination with observations before the surge revealed also the possible surge-mechanism where changes in the basal hydrologic system are responsible for the variability in flow velocities.

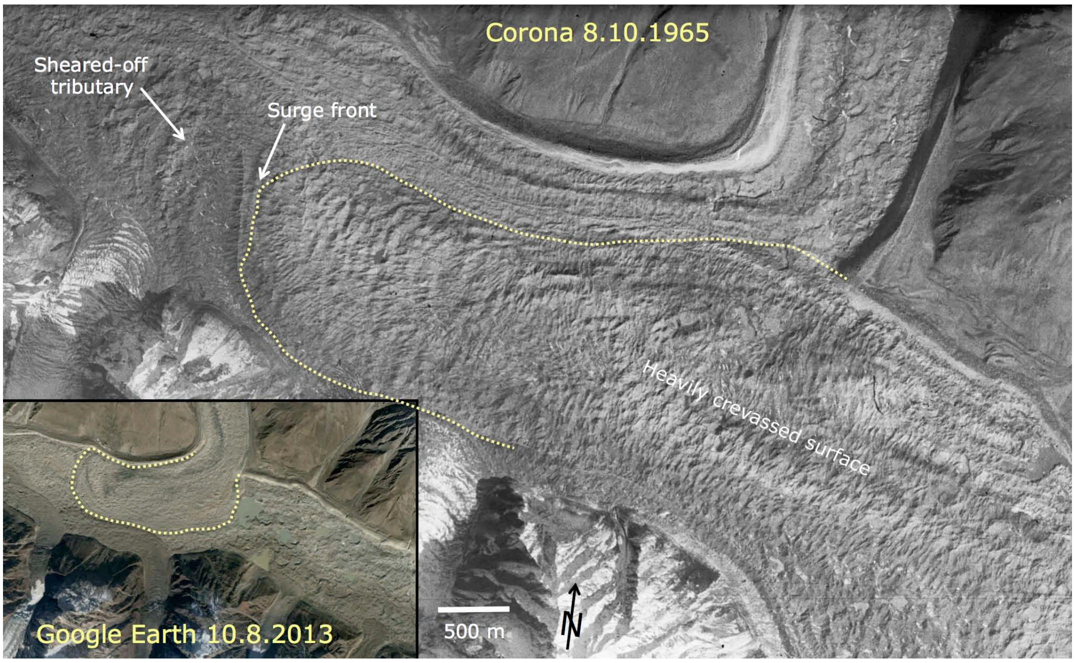

Fig. 2.8: Annotated Corona image from 1965 showing details of the previous surge. For comparison, a screenshot of the same region in 2013 from Google Earth is shown in the inset (from Paul et al. 2017).

2.3 Use of the RGI in publications by others

The glacier outlines created in Phase 1 of Glaciers_cci were provided to the RGI (Pfeffer et al. 2014) and the GLIMS glacier database and used henceforth in several studies for a wide range of global-scale assessments. This includes the calculation of total glacier volume (Huss and Farinotti 2012, Grinsted 2013), future sea-level rise (Giesen and Oerlemans 2013, Marzeion et al. 2012, Radić et al. 2014), past sea-level variability (Marzeion et al. 2012), as well as central flowlines for all glaciers (Machguth and Huss 2014) or global run-off simulations (Bliss et al. 2014). The RGI outlines also serve as a baseline dataset for validation of new algorithms (Selkowitz and Forster 2015, Nagai et al. 2016), to spatially constrain mass change calculations on global (Gardner et al. 2013) to regional scales (Farinotti et al. 2015, Harig and Simmons 2016) and to attribute glacier changes to natural and anthropogenic causes (Marzeion et al. 2014). The above publications are listed along with some others in section 5.3.

The quality of the RGI dataset is continously improved (also by Glaciers_cci) and numerous further applications are likely to follow as more and more raw data and auxiliary datasets become freely available (e.g. DEMs) and easily accessible (e.g. in clouds). For the datasets created in Phase 2 of Glaciers_cci we do not yet have details about their use by the community.

3. Assessment of products and other feedback

Apart from the product validation activities by the Glaciers_cci consortium, the products provided on the CRDP website or via GLIMS/RGI (outlines) and the WGMS (elevation changes) are also analysed by other users, CMUG and the CRG. So far, only the glacier outline product has been used directly by other groups and generated feedback, which is detailed below. However, the specific value of the other two products (elevation changes and velocity) is less on the products itself rather than on the impact of the publications related to them (i.e. how often they are cited) and the scientific knowledge gained about climate change impacts on glaciers. The citations are tracked and detailed in section 5.1 for the consortium publications.

3.1 Products assessed by CMUG

David Gustafsson and colleagues from the SMHI have assessed products from Glaciers_cci and Land_cover_cci “for hydrological modelling of the Arctic ocean drainage basin” and presented their results at the 5th CMUG integration meeting. They found that the class ’Permanent snow and ice’ in the Land_cover_cci dataset is in the mean about 30% higher than in the RGI (140% higher in GlobCover) for the Pan-Arctic region investigated. It was found that the large difference was due to the inclusion of seasonal snow in the class ’Permanent snow and ice’. A possibility to include an additional ’Seasonal snow’ class (= extent of the current class ’Permanent snow and ice’ minus glacier extents from the RGI) is currently discussed. This assessment nicely illustrated the problem of getting satellite images without seasonal snow in polar regions and how large the errors could be if the datasets are used for continental-scale hydrological modelling.

3.2 Feedback of the RGI Working Group

The Karakoram inventory produced by Glaciers_cci was integrated in the latest version of the RGI (v5.0). As first comparisons (and reviews of the related publications) with new inventories from China, ICIMOD and GAMDAM have shown, there are considerable differences in the outlines related to the rules applied for the interpretation of glacier extent. For example, the ICIMOD and GAMDAM inventories have excluded glaciers located on steep slopes or in shadow. These methodological differences have to be considered additionally to interpretation differences related to the visibility of details (e.g. for debris-covered glacier parts). As establishing consistency in the interpretation is a larger issue, it has been decided at the first meeting of the IACS working group on the RGI that a dedicated sub-group (led by F. Paul) should find a solution for this and write a report. Its draft version revealed considerable differences in interpretation of glacier extents and resulted in a new compilation of the GAMDAM glacier inventory. A first direct comparison for four regions revealed large differences (Table 3.1). Most users of the RGI are aware of these differences.

Inventory	Kazakhstan	Kyrgystan	Uzbekistan	Tajikistan	All
GAMDAM	1050	5833	82.3	7920	14885.3
RGI4.0	1145	6287	372	9404	17208.0
CCI	1154	6607	102	8885	16739.0

Table 3.1: Comparison of glacier extents (in km^2) in three recent inventories for different regions in Asia.

3.3 Feedback by WGMS

A first attempt of integrating the glacier specific elevation changes for western Alaska (derived from DEM differencing) obtained in the study by Le Bris and Paul (2015) into the WGMS database failed due to differences in the number and location of registered glaciers. This confirmed the well-known problems of the 'last mile' when results from scientific publications should be integrated in a standardized database to have them readily available for future applications. The work required for integrating this and similar datasets (either from Glaciers_cci or other studies) resulted in a new project that has been performed in the framework of Glaciers_cci as an additional Option.

WGMS has also strongly encouraged and appreciated the engagement of Glaciers_cci in a long-term perspective for GLIMS. As the lifetime of Glaciers_cci is limited, the goal is to establish structures that allow a feasible and long-term support of the community producing and providing such datasets. With the GLIMS executive board (or core team) such a group has now been established and started to work.

3.4 Feedback of the GTN-G advisory board

In the GTN-G (WGMS/NSIDC/GLIMS) evaluation report by its advisory board it is stressed that present funding for GTN-G is not adequate in relation to its importance for the world. This situatuation has slightly improved through year 2 as additional project funding could be obtained (e.g. Glaciers_cci Option 5) to address several of the outstanding issues.

3.5 Year 2 Feedback of the CRG and others

Liss M. Andreassen (NVE)
She is head of the IACS division on glaciers and ice sheets and thus head of the GTN-G advisory board. She is also co-chair of of IACS working group on glacier thickness estimation and helped establishing a GLIMS executive board. She is pleased to see that Glacier_cci in year 2 continues to produce glacier products such as glacier outlines, velocities and surface elevations. The data products provided by Glaciers_cci is a great and very valuable contribution to glacier monitoring, to the glaciological community and all other users of the data. She would like to emphasize that the submission of the Glacier_cci data to standardized databases such as GLIMS and WGMS is very important. In 2016 the GLIMS Executive board /GLIMS core team was established with Frank Paul and Tobias Bolch as board members. Their engagement for the GLIMS core team and the work they do for GLIMS and RGI is highly appreciated.

Michel Zemp (Director WGMS)
He is collaborating with Glaciers_cci in Option 5, which will help bridging the gap between field and remote sensing based observations of glacier mass changes. He is also co-lead of the project related to the glaciers ECV in C3S, which will continue satellite-based glacier monitoring beyond Glaciers_cci. His feedback to the work of Glaciers_cci: "With Glaciers_cci, ESA has made a major contribution to the transformation of glacier monitoring from mainly scientific studies towards operational use of satellite data. The project has not only delivered a corresponding proof of concept, but has significantly contributed towards the completion of a global glacier inventory with a large number of high quality and well attributed glacier outlines now stored in the Randolph and GLIMS glacier inventories. Through Option 5, it finally managed "bridging the last mile" in order to load geodetic volume changes of a few thousand glaciers in Switzerland and Alaska into the Fluctuations of Glaciers database of the WGMS."

Bruce H. Raup (Director GLIMS)
He is head of the recently established GLIMS executive board and in charge of handling the GLIMS glacier database at NSIDC. He is currently integrating the RGI and Glaciers_cci data into the GLIMS database and developing algorithms to deal with multi-temporal glacier outlines and their permanently changing shapes and topologies. His feedback to Glaciers_cci: "I am very pleased with the working relationship between Glaciers_cci and GLIMS. The data products generated by Glaciers_cci have been of high quality and are valuable additions to GLIMS. The Glaciers_cci contributions represent a large component of the GLIMS database contents, and we would not have nearly as valuable a database without Glaciers_cci."

Ben Marzeion (Prof. at Univ. Bremen)
He is using RGI outlines for modeling of past and future glacier changes, their contribution to sea level change and water availability. He is leading a joint paper (Marzeion et al. 2017) on global glacier mass changes that also summarizes main conclusion for satellite-based glacier monitoring by Glaciers_cci. His feedback to Glaciers_cci: "The contribution of Glaciers_cci to the completion of a global glacier inventory has been of tremendous value, also in the modelling community. Accurately dated glacier outlines are a necessary initial condition for any glacier model. Multi-temporal data sets of glacier outlines, as envisioned by Glaciers_cci, add substantially to the value by creating references for model calibration and validation."

J. Graham Cogley (Prof. emeritus at Trent University)
He is editor in chief of the Journal of Glaciology, member of the GTN-G Advisory Board and co-chair of IACS Working Group on the RGI. He was a most important point of contact for further RGI improvements (follow up from last Prague meeting) that helped in selecting the key regions for data production of Glaciers_cci. He notes: "Glaciers_cci has been of fundamental importance for the achievement of global completeness by the Randolph Glacier Inventory (Pfeffer et al. 2014). Inventory work done under the auspices of Glaciers_cci is, together with the long-standing holdings of GLIMS, the largest single source of glacier outlines and attributes in the RGI, which has been received well and has become a de-facto standard for basic information about glaciers in applications ranging from detailed regional studies to global modelling of climate–glacier relations. The Glaciers_cci information is highly reliable and constitutes a notable advance in the technical capacity of glaciologists and others to document and understand cryospheric and environmental change."

Daniel Farinotti (Prof. at WSL Birmensdorf and ETH Zurich)
He is co-chair of IACS working group on glacier thickness estimation and got velocity fields from Glaciers_cci for several of their test regions. His feedback to Glaciers_cci: "By providing surface ice flow velocity data for a set of considered test cases, the results from Glacier_cci were essential for allowing the Ice Thickness Models Intercomparison eXperiment (ITMIX, see http://people.ee.ethz.ch/~danielfa/IACS/rules.html) to be performed."

3.6 Guest editorial for the journal Remote Sensing

F. Paul, K. Briggs, R. McNabb, C. Nuth and J. Wuite have been guest editors of a special issue of the journal Remote Sensing on the topic 'Remote sensing of Glaciers' (http://www.mdpi.com/journal/remotesensing/special_issues/remotesensing_glaciers). In total, 17 papers were published in the special issue of which 6 are authored or co-authered by the Glaciers_cci team. The papers span a wide range of topics centered around the themes glacier flow velocity, elevation change, and snow albedo derived from satellite data.

4. Progress in regard to the user requirements

In Table 4.1 below we repeat the list of user requirements from the URD and added for each year a column to mark the respective status of achievement. It was our goal to get as many requirements as possible to green (i.e. achieved). This has been largely achieved.

ID	Para-meter	Requirements	Source	Type	Y 1	Y 2	Y 3
URq_01	GO	For GO, EO products aim to achieve 15-30 m horizontal resolution, annual archive checking, better than 5% accuracy and 15 m stability.	GCOS	BG	🟨	🟨	🟩 1
URq_04	GO	Prioritise GO production for the peripheral GICs of Antarctica.	IPCC	S	🟨	🟩	🟩 2
URq_05	GO	Greater consistency is required in GO inventories, in particular in the minimum size of glaciers included, the methods for subdivision of contiguous ice masses, provision of time stamps and inclusion of seasonal snow & debris cover.	IPCC	P	🟥	🟨	🟩 3
URq_06	GO	A globally consistent epoch(s) for area change measurements is required.	IPCC, CRG, RGI	P	🟥	🟨	🟩 4
URq_07	GO	Data should be provided in netCDF format (* upon request)	CMUG	D	🟥	🟩	🟩 5
URq_09	GO	Provide GO data to the GLIMS database in the format specified by the RGI working group	GTN-G	D	🟨	🟨	🟩 6
URq_11	GO	Improve the quality of the outlines in the RGI	RGI WG	P	🟨	🟨	🟩 7
URq_12	GO	Include outlines of debris-covered glacier parts	RGI WG	P	🟥	🟥	🟨 8
URq_13	GO	GO of the Antarctic and Greenland peripheral glaciers and ice caps.	IceSheets_cci (Antarctica and Greenland)	S	🟨	🟩	🟩 9
URq_02	SEC-alt	For SEC, EO products aim to achieve 30-100 m horizontal resolution*, 1 m vertical resolution, decadal temporal resolution*, better than 5-10 m m accuracy*, and 1 m stability (* dDEM only)	GCOS	BG	🟨	🟨	🟩 10
URq_04	SEC-alt	Prioritise SEC production for the peripheral GICs of Antarctica.	IPCC	S	🟥	🟨	🟨
URq_08	SEC-alt	Provide SEC data to the WGMS database	GTN-G	D	🟥	🟥	🟥
URq_13	SEC-alt	SEC of the Antarctic peripheral GIC.	IceSheets_Antarctica_cci	P	🟥	🟨	🟨
URq_14	SEC-alt	Mass change estimates of global GICs [**beyond the scope of this project; optional for glaciers]	SeaLevel_cci	-	🟥	🟥	🟥
URq_15	SEC-alt	Produce seasonal and annual SEC product [*** altimetry only]	Phase 1 survey	P	🟨	🟨	🟩 11
URq_16	SEC-alt	Deliver SEC product in UTM coordinate system	Phase 1 survey	D	🟥	🟥	🟥
URq_02	SEC-dd	For SEC, EO products aim to achieve 30-100 m horizontal resolution (*DEM differencing only), 1 m vertical resolution, decadal temporal resolution, better than 5 m accuracy [* better than 5-10 m for DEM differencing], and 1 m stability	GCOS	BG	🟨	🟨	🟩 12

ID	Para-meter	Requirements	Source	Type	Y 1	Y 2	Y 3
URq_04	SEC-dd	Prioritise SEC production for the peripheral GICs of Antarctica.	IPCC	S	🟥	🟥	🟥
URq_08	SEC-dd	Provide SEC data to the WGMS database	GTN-G	D	🟥	🟥	🟥
URq_13	SEC-dd	SEC of the Antarctic peripheral glaciers and ice caps.	IceSheets_Antarctica_cci	S	🟨	🟨	🟨
URq_14	SEC-dd	Mass change estimates of global GICs [**beyond the scope of this project; optional for glaciers]	SeaLevel_cci	P	🟥	🟥	🟥
URq_16	SEC-dd	Deliver SEC product in UTM coordinate system	Phase 1 Survey	D	🟥	🟥	🟥
URq_03	IV	For IV, EO products aim to achieve point to 200 m horizontal resolution, monthly to annual resolution, and better than 5% accuracy.	IGOS/GTOS	BG	🟨	🟨	🟩 13
URq_10	IV	Provide velocity data to the GLIMS database	GTN-G	D	🟥	🟥	🟥 14

Table 4.1: Summary of the Glaciers_cci user requirements organised by product, with source of requirement, and the type of requirement (BG: background; S: selection, P: data production, D: dissemination). The last 3 columns indicate for each year (Y1=year 1 and so forth) of Phase 2 the status of achievement (red: not started, yellow: on-going, green: done). For the nubers in the last column, please see explanations below.

The numbers in the last column of Table 4.1 denote:
1: Achieved by using the 15/10 m bands from Landsat 8 OLI and Sentinel 2 MSI.
2: A glacier inventory for the Antarctic Peninsula has been produced (Huber et al. 2017)
3: This has largely been achieved by writing a new GLIMS Analysis Tutorial (with examples)
4: Achieved by either creating outlines for the epochs around the year 2000 or 2015
5: The RGI was provided in netCDF format. However, the community is using shape files.
6: The datasets produced were submitted to GLIMS.
7: New outlines were created for the year 2000 epoch in Patagonia, Karakoram and Pamir
8: For the new Karakoram/Pamir inventory, regions covered by debris are marked separately
9: see point 2 above.

10: Achieved using CryoSat-2 SIRAL data. The SEC rate of change has a mean RMS uncertainty over all locations of 1.7 m/yr, and standard deviation of 1.5 m/yr.
11: The SEC product is given as a rate of change that applies to the whole period for which data are available, and necessarily smooths out seasonal variation.
12: For the datasets provided, the requirements have been achieved.
13: For the datasets provided, the requirements have been achieved or surpassed.
14: Final hosting of velocity data will be checked later on. Until then they will be available from the Enveo cryoportal.

5. Publications

5.1 ISI Publications by the consortium (after 2011)

Allison, I., W. Colgan, M. King and **F. Paul** (2015): Ice sheets, glaciers and sea level. In Haeberli, W. and C. Whiteman, eds. Snow and Ice-Related Hazards, Risks, and Disasters, Amsterdam, Netherlands, Elsevier, pp. 714-748.

Altena, B. and A. **Kääb** (2017): Elevation change and improved velocity retrieval using orthorectified optical satellite data from different orbits. Remote Sensing, 9 (3), 300 (doi: 10.3390/rs9030300).

Bhambri, R., **Bolch, T.**, Kawishwar, P., Dobhal, D.P., Srivastava, D., Pratap, B. (2012): Heterogeneity in glacier response in the Shyok valley, northeast Karakoram. The Cryosphere, 7, 1384-1398.

Bolch, T., Sandberg Sørensen, L., Simonssen, S.B., **Mölg, N.**, Machguth, H., **Rastner, P.**, **Paul, F.** (2013): Mass loss of Greenland's glaciers and ice caps 2003-2008 revealed from ICESat laser altimetry data. Geophysical Research Letters, 40 (5) (doi: 10.1029/2012GL054710).

Bolch, T., Kulkarni, A., **Kääb, A.**, Huggel, C., **Paul, F.**, Cogley, G., Frey, H., Kargel, J.S., Fujita, K., Scheel, M., Bajracharya, S., Stoffel, M. (2012): The state and fate of Himalayan glaciers. Science, 336 (6079), 310-314.

Brun, F., E. Berthier, P. Wagnon, **A. Kääb** and D. Treichler (2017): A spatially resolved estimate of High Mountain Asia glacier mass balances from 2000 to 2016. Nature Geoscience, 10, 668-673.

Debella-Gilo, M.; **Kääb, A.** (2012) Measurement of Surface Displacement and Deformation of Mass Movements Using Least Squares Matching of Repeat High Resolution Satellite and Aerial Images. Remote Sensing 4(1), 43-67.

Debella-Gilo M.; **Kääb, A.** (2012): Locally adaptive template sizes for matching repeat images of Earth surface mass movements. ISPRS Journal of Photogrammetry and Remote Sensing, 69, 10-28.

Farinotti, D., Brinkerhoff, D. J., Clarke, G. K. C., Fürst, J. J., Frey, H., Gantayat, P., Gillet-Chaulet, F., Girard, C., Huss, M., Leclercq, P. W., Linsbauer, A., Machguth, H., Martin, C., Maussion, F., Morlighem, M., Mosbeux, C., Pandit, A., Portmann, A., Rabatel, A., Ramsankaran, R., Reerink, T. J., Sanchez, O., Stentoft, P. A., Singh Kumari, S., van Pelt, W. J. J., Anderson, B., Benham, T., Binder, D., Dowdeswell, J. A., Fischer, A., Helfricht, K., Kutuzov, S., Lavrentiev, I., **McNabb, R.**, Gudmundsson, G. H., Li, H., and Andreassen, L. M.: How accurate are estimates of glacier ice thickness? Results from ITMIX, the Ice Thickness Models Intercomparison eXperiment. The Cryosphere, 11, 949-970.

Frey, H., Machguth, H., Huss, M., Huggel, C., Bajracharya, S., **Bolch, T.**, Kulkarni, A., Linsbauer, A., Salzmann, N., and Stoffel, M. (2014): Ice volume estimates for the Himalaya–Karakoram region: evaluating different methods. The Cryosphere, 8, 2313-2333.

Gardelle, J., Berthier, E., Arnaud, Y., **Kääb, A.**: Region-wide glacier mass balances over the Pamir-Karakoram-Himalaya during 1999–2011. The Cryosphere 7, 1263-1286.

Gardner, A.S., Moholdt, G., Cogley, J. G., Wouters, B., Arendt, A.A., Wahr, J., Berthier, E., Pfeffer, T.W., Kaser, G., Hock, R., Ligtenberg, S.R.M., **Bolch, T.**, Sharp, M.J., Hagen, J.O., van den Broeke, M.R., **Paul, F.**: (2013): A reconciled estimate of glacier contributions to sea-level rise: 2003 to 2009. Science, 340, 852-857.

Girod L., **Nuth** C., **Kääb** A., Etzelmüller B., and Kohler J. (2017). Terrain changes from images acquired on opportunistic flights by SfM photogrammetry. The Cryosphere, 11, 827-840.

Girod, L., **Nuth, C.**, **Kääb, A.**, **McNabb, R.**, and Galland, O. (2017): MMASTER: improved ASTER DEMs for elevation change. Remote Sensing, 9 (7), 704 (doi:10.3390/rs9070704).

Goerlich, F., T. **Bolch**, K. Mukherjee and T. Pieczonka (2017): Glacier Mass Loss during the 1960s and 1970s in the Ak-Shirak Range (Kyrgyzstan) from Multiple Stereoscopic Corona and Hexagon Imagery. Remote Sensing, 9 (3), 275 (doi:10.3390/rs9030275).

Heid, T., **Kääb, A.** (2012): Evaluation of existing image matching methods for deriving glacier surface displacements globally from optical satellite imagery. Remote Sensing of Environment, 118, 339-355.

Heid T., **Kääb A.** (2012): Repeat optical satellite images reveal widespread and long term decrease in land-terminating glacier speeds. The Cryosphere, 6, 467-478.

Holzer, N., S. Vijay, T. Yao, B. Xu, M. Buchroithner and **T. Bolch** (2015): Four decades of glacier variations at Muztagh Ata (eastern Pamir): a multi-sensor study includ-ing Hexagon KH-9 and Pléiades data. The Cryosphere, 9, 2071-2088.

Huber, J., A. Cook, F. **Paul** and M. Zemp (2017): A complete glacier inventory of the Antarctic Peninsula based on Landsat 7 images from 2000-2002 and other pre-existing datasets. Earth Systems Science Data, 9, 115-131.

Kääb A., Berthier, E., **Nuth, C.**, Gardelle, J., Arnaud. Y. (2012): Contrasting patterns of early twenty-first-century glacier mass change in the Himalayas. Nature, 488(7412), 495-498.

Kääb A., Altena B. and Mascaro J. (2017): Coseismic displacements of the 14 November 2016 Mw 7.8 Kaikoura, New Zealand, earthquake using the Planet optical cubesat constellation. Natural Hazards and Earth System Sciences, 17, 627-639.

Kääb, A., Treichler D., **Nuth C.** and Berthier E. (2015): Brief Communication: Contending estimates of 2003–2008 glacier mass balance over the Pamir–Karakoram–Himalaya. The Cryosphere, 9, 557- 564.

Kääb, A., Winsvold, S.H., Altena, B., **Nuth, C.**, **Nagler, T.**, **Wuite, J.** (2016): Glacier Remote Sensing Using Sentinel-2. Part I: Radiometric and Geometric Performance, and Application to Ice Velocity. Remote Sensing, 8(7), 598 (doi:10.3390/rs8070598).

Kargel, J.S., Leonard, G.J., Bishop, M.P., **Kääb, A.**, *Raup, B.H.* (Eds.) (2014): Global Land Ice Measurements from Space. Springer Praxis Books, 876 pp.*

Köhler, A., **Nuth, C.**; Kohler, J., Berthier, E., Weidle, C. and Schweitzer, J. (2016): A 15 year record of frontal glacier ablation rates estimated from seismic data. Geophysical Research Letters. 43(23), 12155-12164 (doi: 10.1002/2016GL070589).

Kronenberg, M., Barandun, M., Hoelzle, M., Huss, M., Farinotti, D., Azisov, E., Usubaliev, R., Gafurov, A., Petrakov, D. and **Kääb, A.** (2016): Mass balance reconstruction for Glacier No. 354, Tien Shan, from 2003- 2014. Annals of Glaciology, 57(71), 92-102.

Le Bris, R. and **F. Paul** (2015): Glacier-specific elevation changes in western Alaska. Annals of Glaciology, 56 (70), 184-192.

Leclercq, P.W., Weidick, A., **Paul, F.**, **Bolch. T.**, Citterio, M., Oerlemans, J. (2012): Historical glacier length changes in West Greenland. The Cryosphere 6, 1339-1343.

Marzeion, B., N. Champollion, W. Haeberli, K. Langley, P. Leclercq and **F. Paul** (2017): Observation of glacier mass changes on the global scale and its contribution to sea level change. Surveys in Geophysics, 38 (1), 105-130.

McMillan, M., **A. Shepherd**, N. Gourmelen, A. Dehecq, A. Leeson, A. Ridout, T. Flament, A. Hogg, L. Gilbert, T. Benham, M. van den Broeke, J. Dowdeswell, X. Fettweis, B. Noël and **T. Strozzi** (2014): Rapid dynamic activation of a marine-based Arctic ice cap, Geophysical Research Letters, 41, 8902-8909.

Merchant, C.J., **F. Paul**, et al. (2017): Uncertainty information in climate data records from Earth observation. Earth System Science Data, 9, 511-527.

Narama C., M. Daiyrov, T. Tadono, M. Yamamoto, A. **Kääb**, R. Morita, J. Ukita (2017). Seasonal drainage of supraglacial lakes on debris-covered glaciers in the Tien Shan Mountains, Central Asia. Geomorphology, 286, 133-142.

Neckel, N., Kropacek, J., **Bolch, T.**, Hochschild, V. (2014): Glacier elevation changes on the Tibetan Plateau between 2003-2009 derived from ICESat measurements. Environmental Research Letters, 9, 014009, (doi:10.1088/1748-9326/9/1/014009).

Nuth, C., Kohler, J., König, M., von Deschwanden, A., Hagen, J. O., **Kääb, A.**, Moholdt, G., and Pettersson, R. (2013): Decadal changes from a multi-temporal glacier inventory of Svalbard, The Cryosphere, 7, 1603-1621, doi:10.5194/tc-7-1603-2013.

Nuth, C., Schuler, T., Kohler, J., Altena, B. and Hagen, J. (2012): Estimating the long-term calving flux of Kronebreen, Svalbard, from geodetic elevation changes and mass-balance modelling. Journal of Glaciology, 58(207), 119-133.

Paul, F. (2015): Revealing glacier flow and surge dynamics from animated satellite image sequences: examples from the Karakoram. The Cryosphere, 9, 2201-2214.

Paul, F. and **Mölg, N.** (2014): Hasty retreat of glaciers in northern Patagonia from 1985 to 2011. Journal of Glaciology, 60 (224), 1033-1043.

Paul, F., Barrand, N., Berthier, E., **Bolch, T.**, Casey, K., Frey, H., Joshi, S.P., Konovalov, V., **Le Bris, R., Mölg, N.**, Nosenko, G., Nuth, C., Pope, A., Racoviteanu, A., **Rastner, P.**, Raup, B., Scharrer, K., Steffen, S., Winsvold, S. (2013): On the accuracy of glacier outlines derived from remote sensing data. Annals of Glaciology 54(63), 171-182.

Paul, F. and 24 others (2015): The Glaciers Climate Change Initiative: Algorithms for creating glacier area, elevation change and velocity products. Remote Sensing of Environment, 162, 408-426.

Paul, F., S.H. Winsvold, **A. Kääb**, **T. Nagler** and **G. Schwaizer** (2016): Glacier Remote Sensing Using Sentinel-2. Part II: Mapping Glacier Extents and Surface Facies, and Comparison to Landsat 8. Remote Sens., 8 (7), 575 (doi:10.3390/rs8070575).

Paul, F., **T. Strozzi**, T. Schellenberger and **A. Kääb** (2017): The 2015 surge of Hispar Glacier in the Karakoram. Remote Sensing, 9 (9), 888 (doi: 10.3390/rs9090888).

Paul, F., **T. Bolch**, **K. Briggs**, **A. Kääb**, M. McMillan, **R. McNabb**, **T. Nagler**, **C. Nuth**, **P. Rastner**, **T. Strozzi** and **J. Wuite** (in press): Error sources and guidelines for quality assessment of glacier area, elevation change, and velocity products derived from satellite data in the Glaciers_cci project. Remote Sensing of Environment.

Pellicciotti, F., C. Stephan, E. Miles, S. Herreid, W. Immerzeel, **T. Bolch** (2015): Mass balance changes of the debris-covered glaciers in the Langtang Himal in Nepal between 1974 and 1999. Journal of Glaciology. 61 (226), 373-386.

Pieczonka, T., **Bolch, T.**, Wei, J., Liu, S. (2013): Heterogeneous mass loss of glaciers in the Aksu-Tarim Catchment (Central Tien Shan) revealed by 1976 KH-9 Hexagon and 2009 SPOT-5 stereo imagery. Remote Sensing of Environment 130, 233-244.

Pfeffer, W.T., A.A. Arendt, A. Bliss, **T. Bolch**, J.G. Cogley, A.S. Gardner, J.-O. Hagen, R. Hock, G. Kaser, C. Kienholz, E.S. Miles, G. Moholdt, N. Mölg, **F. Paul**, V. Radic, **P. Rastner**, *B.H. Raup*, J. Rich, M.J. Sharp and the Randolph Consortium (2014): The Randolph Glacier Inventory: a globally complete inventory of glaciers. Journal of Glaciology, 60 (221), 537-552.

Pieczonka, T. and **T. Bolch** (2015): Region-wide glacier mass budgets and area changes for the Central Tien Shan between ~1975 and 1999 using Hexagon KH-9 imagery. Global and Planetary Change, 128, 1-13.

Rastner, P., Bolch, T., Mölg, N., Machguth, H., **Paul, F.** (2012): The first complete glacier inventory for the whole of Greenland. The Cryosphere 6, 1483-1495.

Rastner, P., **T. Bolch**, C. Notarnicola, **F. Paul** (2014): A comparison of pixel- and object based glacier classification with optical satellite images. IEEE Journal of Selected Topics of Applied Earth Observation, 7 (3), 853-862.

Robson, B.A., D. Hölbling, **C. Nuth, T. Strozzi** and S.O. Dahl (2016): Decadal scale changes in glacier area in the Hohe Tauern National Park, Austria determined by object-based image analysis. Remote Sensing, 8, 67 (doi: 10.3390/rs8010067).

Robson, B.A., **C. Nuth**, S.O. Dahl, D. Hölbling, **T. Strozzi** and P. R. Nielsen (2015): Automated classification of debris-covered glaciers combining optical, SAR and topographic data in an object-based environment. Remote Sensing of Environment, 170, 372-387.

Schellenberger, T., T. Dunse, **A. Kääb**, J. Kohler, C.H. Reijmer (2015): Surface speed and frontal ablation of Kronebreen and Kongsbreen, NW-Svalbard, from SAR offset tracking. The Cryosphere, 9, 2339-2355.

Shangguan, D. H., **T. Bolch**, Y.J. Ding, M. Kröhnert, T. Pieczonka, H.U.Wetzel, S.Y. Liu (2015): Mass changes of Southern and Northern Inylchek Glacier, Central Tian Shan, Kyrgyzstan, during ~1975 and 2007 derived from remote sensing data. The Cryosphere 9: 703-717.

Shepherd, A., et al. (2012): A reconciled estimate of ice-sheet mass balance. Science, 338, 1183-1189.

Strozzi T., **A. Kääb** and T. Schellenberger (2017): Frontal destabilization of Stonebreen, Edgeøya, Svalbard. The Cryosphere, 11, 553-566.

Strozzi, T., **F. Paul**, **A. Wiesmann**, T. Schellenberger and **A. Kääb** (2017): Circum-Arctic changes in the flow of glaciers and ice caps from satellite SAR data between the 1990s and 2017. Remote Sensing, 9 (9), 947 (doi: 10.3390/rs9090947).

Treichler D. and **Kääb** A. (2017): Snow depth from ICESat laser altimetry - A test study in southern Norway. Remote Sensing of Environment, 191, 389-401.

Wang, D. and **A. Kääb** (2015): Modeling glacier elevation change from DEM time series. Remote Sensing, 7(8), 10117-10142.

Winsvold, S., **A. Kääb** and **C. Nuth** (2016): Regional glacier mapping using optical satellite data time-series. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 9 (8), 3698-3711.

Zemp, M., H. Frey, I. Gärtner-Roer, S.U. Nussbaumer, M. Hoelzle, **F. Paul**, W. Haeberli, et al. (2015): Historically unprecedented global glacier changes in the early 21st century. Journal of Glaciology, 61 (228), 745-762.

*** GLIMS Book Contributions (shortened references):**

Andreassen, L.M., **Paul, F.** and Hausberg, J.E. (2014): Norway. Chapter 19, 427-435.

Kääb, A., **Bolch, T.**, Casey, K.A., Heid, T., Kargel, J., Leonard, G., **Paul, F.** and *Raup, B.* (2014): Glacier mapping and monitoring using multi-spectral data. Chapter 4, 75-104.

Paul, F., Arnaud, Y., Ranzi, R. and Rott, H. (2014): European Alps. Chapter 20, 439-459.

Quincey, D., Bishop, M., **Kääb, A.**, Berthier, E., Flach, B., **Bolch, T.**, Buchroithner, M., Kamp, U., Khalsa, S.J.S., Toutin, T., Haritashya, U., Racoviteanu, A., Shroder, J. and *Raup, B.* (2014): Digital Terrain Modeling and Glacier Topographic Characterization. Chapter 5, 113-144.

Racoviteanu, A., Arnaud, Y., Baghuna, I.M., Bajracharya, S., Berthier, E., Bhambri, R., Bishop, M., **Bolch, T.**, Byrne, M., Chaujar, R.K , Frauenfelder, R., Furfaro, R., **Kääb, A.**, Kamp, U., Kargel, J., Kulkarni, A.V., Leonard, G., Mool, P., Shroder, J.F., Sossna, I. (2014): Himalayan Glaciers (India, Bhutan, Nepal). Chapter 24, 549-582.

Raup, B., Khalsa, S.J.S., Armstrong, R., Sneed, W., Hamilton, **Paul, F.**, Cawkwell, F., Beedle, M., Menounos, B., Wheate, R., Rott, H., Liu, S., Li, X., Shangguan, D., Cheng, Kargel, J., Larsen, Molnia, B., Kincaid, J., Klein, A. and Konovalov, V. (2014): Quality in the GLIMS Glacier Database. Chapter 7, 163-180.

Wheate R., Berthier, E., **Bolch, T.**, Menounos, B., Shea, J.M. , Clague, J.J., Schiefer, E. (2014), Remote Sensing of Glaciers in the Canadian Cordillera, Western Canada, Chapter 14, 333-352.

Zemp, M., Armstrong, R., Gärtner-Roer, I., Haeberli, W., Hoelzle, M., **Kääb, A.**, Kargel, J., Khalsa, S.J.S., **Paul, F.** and Raup, B. (2014): Worldwide glacier monitoring - a long-term task integrating in-situ observations and remote sensing. Chapter 1, 1-16.

Total publications (incl. book chapters) supported by Glaciers_cci as of 8 Oct 2017: 71. Members of the CRG are marked in *italics*.

5.2 Other, non-ISI Publications by the consortium

Bolch, T. (2015): Glacier area and mass changes since 1964 in the Ala Archa Valley, Kyrgyz Ala-Too, northern Tien Shan. Лёд и Снег (Ice and Snow)

Nuth, C., Hagen, J.O., and Kohler, J. (2015): Ch 4. Glaciers in Geoscience Atlas of Svalbard (ed. Dallmann W.K.). Norsk Polarinstitutt Rapport; 148, Tromsø.

Paul, F. (2015): Kartierung von Gletschern mit Satellitendaten und das globale Gletscherinventar. In: Lozán, J.L., H. Grassl, D. Kasang, D. Notz, and H. Escher-Vetter (Hrsg.): Warnsignal Klima: Das Eis der Erde (Kap. 4.1), 103-110.

Raup, B.H., *L.M. Andreassen*, **T. Bolch** and S. Bevan (2015): Remote sensing of glaciers. In: Tedescco, M. (ed.): Remote Sensing of the Cryosphere, John Wiley & Sons, 123-165.

WGMS (2015): Global Glacier Change Bulletin No. 1 (2012–2013). *M. Zemp*, I. Gärtner-Roer, S. Nussbaumer, F. Hüsler, H. Machguth, **N. Mölg**, **F. Paul** and M. Hoelzle (eds.), ICSU(WDS)/IUGG(IACS)/ UNEP/UNESCO/WMO, World Glacier Monitoring Service, Zurich, Switzerland, 230 pp.

5.3 Selection of recent publications using the RGI (not cited in IPCC AR5)

The study by Pfeffer et al. (2014) presenting the RGI is now cited more than 200 times. Most but not all of the citing studies have used the RGI outlines in one or another form for their work. Below are a few randomly selected examples of such studies. For a full list we refer to one of the citation databases.

Bliss, A., Hock, R., and Radić, V. (2014): Global response of glacier runoff to twenty-first century climate change, J. Geophys. Res. Earth. Surf. 119, 717–730.

Collier, E., and W. W. Immerzeel (2015): High-resolution modeling of atmospheric dynamics in the Nepalese Himalaya, J. Geophys. Res. Atmos., 120, 9882–9896.

Farinotti, D., Longuevergne, L., Moholdt, G., Düthmann, D., Mölg, T., Bolch, T., Vorogushyn, S., Güntner, A. (2015): Strong glacier mass loss in the Tien Shan over the past 50 years. Nature Geoscience, 8, 716-723.

Harig, C., and F. J. Simons (2016), Ice mass loss in Greenland, the Gulf of Alaska, and the Canadian Archipelago: Seasonal cycles and decadal trends. Geophys. Res. Lett., 43, 3150-3159.

Marzeion, B., Cogley, J.G., Richter, K. and Parkes, D. (2014): Attribution of global glacier mass loss to anthropogenic and natural causes. Science, 345, 919-921.

Mengel, M., A. Levermanna, K. Frielera, A. Robinsona, B. Marzeion and R. Winkelmann (2016): Future sea level rise constrained by observations and long-term commitment. PNAS, 113 (10), 2597-2602.

Nagai, H., Fujita, K., Sakai, A., Nuimura, T. and Tadono, T. (2016): Comparison of multiple glacier inventories with a new inventory derived from high-resolution ALOS imagery in the Bhutan Himalaya. The Cryosphere, 10, 65-85.

Herreid, S. and M. Truffer (2016): Automated detection of unstable glacier flow and a spectrum of speedup behavior in the Alaska Range. J. Geophys. Res. - Earth Surf., 121, 64-81.

Selkowitz, D.J. and R.R. Forster (2015): An Automated Approach for Mapping Persistent Ice and Snow Cover over High Latitude Regions. Remote Sens. 2016, 8, 16 (doi:10.3390/rs8010016).

Van Wychen, W., J. Davis, D. O. Burgess, L. Copland, L. Gray, M. Sharp and C. Mortimer (2016): Characterizing interannual variability of glacier dynamics and dynamic discharge (1999–2015) for the ice masses of Ellesmere and Axel Heiberg Islands, Nunavut, Canada. J. Geophys. Res. - Earth Surf., 121, 39-63.

Yasuda, T. and M. Furuya (2015): Dynamics of surge-type glaciers in West Kunlun Shan, Northwestern Tibet. J. Geophys. Res. - Earth Surf., 120, 2393-2405.

5.4 Citation statistics of publications that were cited in IPCC AR5

In Table 5.3 we provide an overview on the ISI citations of publications by the consortium or users of Glaciers_cci data (the RGI) that have been cited in IPCC AR5 (IPCC 2013) for three points in time (2015, 2016 and 2017. In about 16 and 15 months the number of citations increased by 436 (or 78%) and 669 (67%), confirming their high relevance and impact of these studies. In total, the six consortium publications cited in IPCC AR5 are now cited 1258 times and those using the RGI are cited 407 times.

The publications cited in IPCC are listed below.

Bolch, T., Kulkarni, A., **Kääb, A.,** Huggel, H., **Paul, F.**, Cogley, J.G., Frey, H., Kargel, J.S., Fujita, K., Scheel, M., Bajracharya, S. and Stoffel, M. (2012): The State and Fate of Himalayan Glaciers. Science, 336, 310-314.

Bolch, T., Sørensen, L., **Mölg, N.**, Machguth, H., and **Paul, F.** (2013): Mass loss of Greenland's glaciers and ice caps 2003-2008 revealed from ICESat data. Geophysical Research Letters, 40, 875-881. doi:10.1002/grl.50270.

Gardner, A.S., G. Moholdt, J.G. Cogley, B. Wouters, A.A. Arendt, J. Wahr, E. Berthier, R. Hock, W.T. Pfeffer, G. Kaser, S.R.M. Ligtenberg, **T. Bolch**, M.J. Sharp, J.O. Hagen, M.R. van den Broecke and **F. Paul** (2013): A consensus estimate of glacier contributions to sea level rise: 2003 to 2009. Science, 340 (6134), 852-857.

Heid T., **Kääb A.** (2012): Repeat optical satellite images reveal widespread and long term decrease in land-terminating glacier speeds. The Cryosphere 6, 467-478.

Kääb, A. , Berthier, E., **Nuth, C.**, Gardelle, J., Arnaud. Y. (2012): Contrasting patterns of early twenty-first-century glacier mass change in the Himalayas. Nature 488(7412), 495-498.

Rastner, P., **T. Bolch**, **N. Mölg**, H. Machguth, **R. Le Bris** and **F. Paul** (2012): The first complete inventory of the local glaciers and ice caps on Greenland. The Cryosphere, 6, 1483-1495.

Giesen, R.H. and Oerlemans, J. (2013): Climate-model induced differences in the 21st century global and regional glacier contributions to sea-level rise. Climate Dynamics,41, 3283-3300.

Grinsted, A. (2013): An estimate of global glacier volume. The Cryosphere, 7, 141-151.

Huss, M., and D. Farinotti (2012): Distributed ice thickness and volume of 180,000 glaciers around the globe. Journal of Geophysical Research, 117, F04010 (doi:10.1029/2012JF002523).

Marzeion, B., A. H. Jarosch, and M. Hofer (2012): Past and future sea-level change from the surface mass balance of glaciers. The Cryosphere, 6, 1295-1322.

Radic, V., A. Bliss, A. C. Beedlow, R. Hock, E. Miles, and J.G. Cogley (2014): Regional and global projections of the 21st century glacier mass changes in response to climate scenarios from GCMs. Climate Dynamics, 42, 37-58.

Nr.	Authors	Year	Journal	ISI-1	ISI-2	ISI-3	Diff. 1-2	Diff. 1-2%	Diff. 2-3	Diff. 2-3%
1	Bolch et al.	2012	Science	165	290	472	125	75.8	182	62.8
2	Bolch et al.	2013	GRL	11	15	35	4	36.4	20	133.3
3	Gardner et al.	2013	Science	105	216	363	111	105.7	147	68.1
4	Heid & Kääb	2012	Cryosphere	17	29	47	12	70.6	18	62.1
5	Kääb et al.	2012	Nature	98	179	299	81	82.7	120	67.0
6	Rastner et al.	2012	Cryosphere	23	31	42	8	34.8	11	35.5
7	*Giesen & Oerlem.*	2013	Climate Dyn.	12	15	27	3	25.0	12	80.0
8	*Grinsted*	2013	Cryosphere	21	38	55	17	81.0	17	44.7
9	*Huss & Farinotti*	2012	JGR	48	71	107	23	47.9	36	50.7
10	*Marzeion et al.*	2012	Cryosphere	44	78	133	34	77.3	55	70.5
11	*Radic et al.*	2014	Climate Dyn.	16	34	85	18	112.5	51	150.0
	Total			560	996	1665	436	77.9	669	67.2

Table 5.3: Citation statistics for publications either by the consortium or users of Glaciers_cci data (in italics) that were cited in IPCC AR5. Statistics were determined on 24.3.2015 (ISI-1), 15.7.2016 (ISI-2) and 10.10.2017 (ISI3).

5.5 Other documents related to the work of Glaciers_cci

Jane Qiu reported in Science about the presentation by F. Paul at the IGS conference in Kathmandu (about the surging glaciers in the Karakoram):
Qiu, J. (2015): Himalayan ice can fool climate studies. Science, 347 (6229), 1404-1405. (link: http://www.sciencemag.org/content/347/6229/1404.full.pdf)
The work of Glaciers_cci is prominently featured in the book Remote Sensing of the Cryosphere by M. Tedesco (see Raup et al. 2015 in Section 5.2).
The animations with surging glaciers in the central Karakorm (Paul 2015) were prominently featured in the UK magazine `WIRED` (March 2016, pages 12/13).

5.6 Further references

Davies, B. and Glasser, N. (2012): Accelerating shrinkage of Patagonian glaciers from the Little Ice Age (~AD 1870) to 2011. Journal of Glaciology, 58 (212), 1063-1084.

IPCC (2013): Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A.

Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

5.7 Outreach activities

- UZH press release on unprecedented global glacier decline
- EGU/ESA/NASA/UZH joint press release for the Paul (2015) paper in TC
- New Global Glacier Change Bulletin also in prep. for upcoming rs data
- Media event at COP21 with presenting also the new WGMS Glacier App
- GUIO meeting with Norwegian mapping institute on CCI experience with Sentinel-2
- C. Nuth: Detailed glacier crevasse morphology mapped by helicopter. Virtual Geoscience Conference 2016, Bergen
- F. Paul: Lecture and exercise on remote sensing of glaciers at ESA Advanced Training Course on RS of the Cryosphere (University of Leeds)
- P. Rastner: Research exchange with Universidad Nacional de Colombia and IDEAM in Bogota – Colombia.
- P. Rastner: Public talk about glacier monitoring from space at the Universidad Nacional de Colombia, at IDEAM in Bogota – Colombia.
- C. Nuth: Elevation changes of glaciers, glacier surges, and snow/firn pack variability from TanDEM-X time series DEMs in Northwest Svalbard. TanDEM-X Science Meeting, German Aerospace Center.
- A. Kääb: Twin glacier collapse in Tibet puzzles scientists and triggers rapid international collaboration (GAPHAZ).
- R. McNabb: Climate and glaciology conversations with second grade classrooms at Steindorf STEAM school, San Jose, CA USA
- R. McNabb: Remote Sensing co-teaching of UNIS Glaciology course (24.2.-2.3.2017)
- F. Paul & P. Rastner: Lecture on ‘Remote sensing of glaciers’ for students at the University of Zurich (26.4. and 3.5. 2017)
- P. Rastner participated in the SNSF Scientific Image Competition with the computeranimation of Findelengletscher
- CCI Webpage: continous updates
- F. Paul, K. Briggs, R. McNabb, C. Nuth, J. Wuite: Guest editors for a special issue of Remote Sensing (‘Remote Sensing of Glaciers’)

5.8 Conference presentations (only CCI phase 2)

5.8.1 Year 2014

- Climate Symposium, Darmstadt, 13.-17. Oct. 2014: T. Nagler: (poster presentation)
- 3rd Pole Environment workshop, Berlin, 8./9. Dec. 2014: T. Bolch, A. Kääb (invited talks)
- AGU Fall Meeting in San Francisco, 14.-18. Dec. 2014: T. Bolch (invited talk)
- ESA-CLIC Earth Observation and Arctic Science Priorities, Tromsø, Norway, 20. Jan. 2015: A. Kääb, K. Langley (invited participation)

5.8.2 Year 2015

- ISSI workshop, Bern 2.-5. Feb. 2015: F. Paul, A. Shepherd (invited talks)
- IGS meeting on Glaciology in High Mountain Asia, Kathmandu, 2-6 Mar 2015: F. Paul and T. Bolch (talks); A. Kääb (keynote talk)
- EGU General Assmebly, Vienna 13.-17.4. 2015: T. Bolch (talk in session CR1.5), F. Paul (talk in Session 2.2), T. Strozzi (poster in session CR4.5)
- Alpine Glaciology Meeting (AGM), Milano, 7.-8.5. 2015: T. Bolch (talk)
- IUGG General Assembly, 23.-20.6. 2015, Prague: N. Mölg (talk in session C03), F. Paul (talk in session C17)
- MultiTemp2015 workshop, 22.-24.7., Annecy (France)
    - F. Paul 'How multi-temporal remote sensing data improve our understanding of climate change impacts on glaciers'
    - P. Rastner et al. 'Mapping snow line altitude for large glacier samples from multitemporal landsat imagery'
- Joint event of the CC&E and DRR network of SDC, 10.9., Bern (Switzerland)
    - F. Paul 'An overview on global glacier decline' (invited)
- Sentinel 2A expert users technical meeting, 29.-30.09.2015, Frascati (Italy)
    - A. Kääb and S.H. Winsvold 'Glacier flow and mapping using Sentinel-2'
    - F. Paul 'Glacier mapping with Sentinel-2 MSI and Landsat 8 OLI'
- PSTG5, 5.-7.10.2015, Oberpfaffenhofen (Germany)
    - F. Paul 'Glacier monitoring from satellite: Status and needs'
- IGS Nordic Branch Meeting, 29.-31.10.2015, Copenhagen (Denmark)
    - B. Altena and A. Kääb 'Increasing information content of multi-spectral imagery for glacier matching'
    - D. Treichler and A. Kääb 'Snow depth estimates from ICESat laser data – a case study in southern Norway'
- Swiss Geoscience Meeting, 21.11. 2015, Basel (Switzerland)
    - F. Paul: 'Fifty years of glacier surges in the central Karakoram'
    - P. Rastner et al. 'A new glacier inventory for the Karakoram and Pamir region'
    - M. Werder et al. 'Towards the volumes of all the glaciers in the world 2.0'
- AGU Fall Meeting, 14.-18.12.15, San Francisco (USA)
    - P. Rastner et al. 'Mapping the snow line altitude for large glacier samples from multitemporal Landsat imagery'
    - P. Rastner et al. 'A new glacier inventory for the Karakoram and Pamir region'

5.8.3 Year 2016

- Copernicus Climate Change Service (C3S), 22.01.2016, Oslo (Norway)
  - A. Kääb: Presentation of the Glaciers_cci project
- Alpine Glaciology Meeting, 24.-25.2. 2016, Munich (Germany):
  - F. Paul 'Glacier mapping with Sentinel 2 MSI & Landsat 8 OLI: Exciting perspectives and new challenges'
- Colloquium in Climatology, 9.3. 2016, University of Bern (Switzerland)
  - F. Paul (invited) 'Application of satellite-based glacier monitoring for improved understanding of climate change imapcts'
- EGU General Assembly, 18.-22.4. 2016, Vienna (Austria)
  - F. Paul 'A comparison of glacier classification with Sentinel 2 MSI and Landsat 8 OLI'
  - F. Paul 'On the 'real' mass loss of some surging glaciers in the central Karakoram'
  - T. Bolch and K. Mukherjee: 'Surge-type glaciers in the Tien Shan (Central Asia)'
- ESA Living Planet Symposium, 9.-13.5. 2016, Prague (Czech Republic)
  - F. Paul and the Glaciers_cci consortium: 'The ESA project Glaciers_cci: Scientific achievements and future outlook'
  - K. Brigss et al. 'Volume change of Greenland's peripheral ice caps from CryoSat-2'
  - T. Strozzi et al. 'Ice surface displacement of glaciers and ice caps from Sentinel-1'
  - T. Bolch et al. H'eterogeneous Mass Changes of Glaciers in the Pamir and Karakoram since the 1970s'
  - F. Paul 'Glacier mapping with Sentinel 2 MSI and Landsat 8 OLI'
  - F. Paul 'Fifty years of glacier surges in the central Karakoram'
  - A. Kääb and S. Winsvold 'The potential of Sentinel-2 for investigating glaciers, permafrost and related natural hazards'
  - G. Bippus et al. 'Exploiting the new Sentinel-2 satellite data for monitoring glacier parameters'
  - S. Winsvold, A. Kääb, C. Nuth 'Glacier mapping using multi-sensor time-series of optical and radar imagery'
- TerraSAR-X/TanDEM-X Science Team Meeting 17-20.10.2016, German Aerospace Center (DLR), DE
  - C. Nuth, A. Kääb et al.: Elevation changes of glaciers, glacier surges, and snow/firn pack variability from TanDEM-X time series DEMs in Northwest Svalbard
- Russian Glaciological Symposium 24-26 May 2016, St. Petersburg, RU
  - T. Bolch: 'Surge-type Glaciers in the Tien Shan'
- Third Pole Environment Meeting 16-18 May 2016 Columbus (Ohio), US
  - T. Bolch: 'Heterogeneous glacier thinning patterns in Langtang Himalaya (Nepal) since 1974'
- Helmholtz Alliance Remote Sensing Days, Garmisch-Partenkirchen, DE
  - A. Kääb: 'Remote sensing of glaciers and permafrost. Needs and opportunities
- Indus forum workshop of the World Bank, 12.10.2016, University of Zurich, Switzerland
  - F. Paul: 'Mapping glaciers and surging glaciers in the Karakoram using satellite data'
  - T. Bolch: 'Snow and Glacier Changes in the Upper Indus Basin'

- IACS Workshop 'Importance of calving for mass budget of Arctic glaciers', 15.-17.10.2016, Sopot, Poland
    - R. McNabb: 'Estimates of calving from Alaska tidewater glaciers'
- TerraSar-X/TanDEM-X Science Meeting, 17-20.10.2016, DLR, Munich, Germany
    - C. Nuth et al.: 'Elevation changes of glaciers, glacier surges, and snow/firn pack variability from TanDEM-X time series DEMs in Northwest Svalbard.'
- IGS Nordic Branch meeting, 26.-28.10.2016, Tromsø, Norway
    - R. McNabb et al.: 'Deriving glacier volume changes from spatially incomplete elevation data'
    - S. Winsvold et al.: 'Glacier mapping using combined optical and SAR time-series'
    - C. Deschamps-Berger et al.: 'Closing the mass budget of Kronebreen combining remote sensing and modelling'
- Norwegian Space Center CCI + meeting, 18.11, Oslo, Norway
    - C. Nuth, A. Kääb: Presentation of the Glaciers_cci project
- Glacier Mass Balance Workshop, 1.-3.11, Ny Ålesund, Norway
    - C. Nuth, L. Girod, S. Winsvold, C. Deschamps-Berger, E. Berthier, J. Kohler: Remote sensing in Ny Ålesund, products, purpose and validation.
- AGU, 12.-16.12. 2016, San Francisco, USA
    - S. Winsvold, A. Kääb, C. Nuth: 'Landsat time-series analysis opens new approaches for regional glacier mapping'
    - A. Kääb et al.: 'On the Karakoram glacier anomaly'
    - D. Treichler, A. Kääb et al.: 'Recent glacier changes in high mountain Asia: A spatially diverse pattern'
    - L. Girod, L.R. Maurice, C. Nuth, A. Kääb: 'Enhanced ASTER DEMs for Decadal Measurments of Glacier Elevation Changes'
    - S. Winsvold et al.: 'Regional glacier mapping by combination of dense optical and SAR satellite image time-series'
    - P. Tepes et al.: 'CryoSat swath altimetry to measure ice cap and glacier surface elevation change'
    - J. Huber et al.: 'A new glacier inventory of the Antarctic Peninsula as compiled from pre-existing datasets'
    - M. Zemp et al. 'Tapping the full potential of geodetic glacier change assessment with air and space borne sensors'
    - S. Nussbaumer et al.: 'Continued strong glacier mass loss in 2015 – an updated overview of available glacier observations

5.8.4 Year 2017

- Swiss Space Centre Meeting, 24.1.2017, University of Zurich, Switzerland
    - T. Bolch, F. Paul, and P. Rastner presented Glaciers_cci related work.
- RSL 3G Meeting, 15.2.2017, University of Zurich, Switzerland
    - F. Paul, and P. Rastner presented Glaciers_cci to the Remote Sensing Laboratories at UZH.
- Alpine Glaciology Meeting (AGM), 2.-3.2.2017, ETH Zurich, Switzerland
    - Glaciers_cci related presentations were given by F. Paul, M. Zemp, F. Goerlich, P. Rastner and M. Werder (details see http://people.ee.ethz.ch/~glacier/agm2017)
- EARSeL SIGLIS workshop, 7.-9.2.2017, University of Bern, Bern, Switzerland
    - T. Nagler, G. Schwaizer and A. Wiesmann attended and presented work from other projects and Option 3.

- 7th CMUG meeting, 13.-14.2.2017, Paris, France
    - F. Paul attended and summarized the work of Glaciers_cci
- VAW Fachgespräche, 23.2. 2017, ETH Zurich, Switzerland
    - M. Werder: Ice thickness maps from surface observations using Bayesian inference
- EGU, General Assembly, 24-28.4.2017, Vienna, Austria
    - R. McNabb, C. Nuth, A. Kääb, L. Girod: 'The effects of void handling on geodetic mass balances'
    - J.J. Fürst, F. Gillet-Chaulet, T.J. Benham, J.A. Dowdeswell, M. Grabiec, F. Navarro, R. Pettersson, G. Moholdt, C. Nuth, et al. 'A two-step mass-conservation approach to infer ice thickness maps: Per- formance for different glacier types on Svalbard'
    - H. Sevestre, D. Benn, A. Luckman, C. Nuth, J. Kohler, K. Lindbäck, R. Pettersson: 'Surges of tide- water glaciers initiated at the terminus: observations and mechanisms'
    - F. Paul, T. Strozzi, T. Schellenberger, A. Kääb: 'Hispar Glacier on the run'
    - F. Goerlich, F. Paul, T. Bolch: 'Further insights into glacier changes derived from declassified re- connaissance imagery (Corona and Hexagon)'
    - H. Machguth, J. Landmann, *M. Zemp*, F. Paul: 'Making geodetic glacier mass balances available to the community – Progress and challenges in modifying the WGMS database'
- FRINGE 2017 workshop, 5.-9.862017, Aalto University, Finnland
    - T. Stozzi, A. Wiesmann, A. Kääb, T. Schellenberger, R. McNabb, F. Paul: 'Time series of surface displacement of Arctic glaciers and ice caps from space-borne SAR data'
- GLIMS workshop, Boulder, CO, USA, 11.-13.8.2017, USA
    - F. Paul: Achievements and future prospects of the ESA Glaciers_cci project
    - T. Bolch: Mapping of debris-covered glaciers and rock glaciers
- IGS Symposium on Polar Ice, Polar Climate, Polar Change, 14.-19.8.2017, Boulder, CO, USA
    - P. Rastner, T. Strozzi, F. Paul: 'New opportunities for creating glacier inventories in the Russian Arctic exemplified for Novaya Zemlya'
    - K. Briggs, T. Bolch, A. Shepherd, M. McMillan, A. Muir, L. Gilbert, X. Fettweis, P. Rastner, F. Paul: 'Changes of Greenland's Peripheral Glaciers and Ice Caps 2010 – 2014 from CryoSat-2'
    - F. Paul and P. Rastner: 'An updated 2016 glacier inventory for central western Greenland and changes since 1985'
- 16th Annual JACIE Workshop, USGS, Reston 19.-21.9.2017, Reston, VA, USA
    - A. Kääb: 'Data Quality from Multiple Satellites to Measure Earth's Cryosphere' (Keynote)
- 15th Swiss Geoscience Meeting, 17.-18.11.2017, Davos, Switzerland
    - Le Bris, F. Paul: 'Glaciers of Patagonia in 2016: A new inventory from Landsat 8 and the TanDEM-X DEM'
    - Rastner P., Notarnicola C., Nicholson L., Prinz R., Sailer R., Paul F.: 'Processing of multi-temporal Landsat images to detect fractional snow cover and the snow line altitude for large glacier samples'
    - Paul F., Rastner P.: 'Recent glacier changes in western Greenland and glacier mapping challenges in mountain topography'

5.9 Specific tasks

- T. Bolch chairing a glacier monitoring session at the AGU meeting in San Francisco, 14.-18. Dec. 2014.
- F. Paul was chairing session C01 and a special Glaciers_cci workshop at the IUGG in Prague (RGI).
- F. Paul, C. Nuth, R. McNabb, J. Wuite and K. Briggs are guest editors for a special issue of Remote Sensing: ‘Remote Sensing of Glaciers’ that has been published in 2017.
- F. Paul and T. Bolch are members of the recently established GLIMS executive board.

5.10 Student teaching and courses

- Introduction to glacier remote sensing at the Univ. of Oslo by A. Kääb (Nov. 2014) to guest students from Norwegian University of Life Sciences, Ås.
- The course 'Remote Sensing of the Cryosphere' was held in January 2015 at the Univ. of Oslo (code: GEO9540). CCI Teachers: A. Kääb, T. Strozzi; Students from Canada, USA, India, Netherlands, Sweden, and Norway attended.
- R. McNabb: climate and glaciology conversations with 2nd grade classrooms at Steindorf STEAM school, San Jose, CA USA.
- F. Paul has given an invited lecture and exercise on optical remote sensing of glaciers at the ‘1st ESA advanced training course on remote sensing of the cryopsphere’.
- F. Paul gave an invited presentation at the IHCAP Teach-the-Teacher workshop on ‘Glaciers and climate change: Responses & change assesment using satellite data’
- P. Rastner: Schoolab (Remote Sensing of glaciers) at the High School in Bruneck-South Tyrol, Italy.
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6. Acronyms

ASTER	Advanced Spaceborne Thermal Emission and Reflection radiometer
AGM	Alpine Glaciology Meeting
AGU	American Geophysical Union
CLIC	Climate and Cryosphere
CMUG	Climate Modelling User Group
CRDP	Climate Research Data Package
CRG	Climate Research Group
DEM	Digital Elevation Model
ECDA	Elevation Change DEM & Altimetry
ECDD	Elevation Change DEM Differencing
EGU	European Geophysical Union
EO	Earth Observation
ESA	European Space Agency
GAMDAM	Glacier Area Mappig for Discharge in Asian Mountains
GCOS	Global Climate Observing System
GLIMS	Global Land Ice Measurements from Space
GO	Glacier Outline
GI	Glacier Inventory
GTOS	Global Terrestrial Observing System
GTN-G	Global Terrestrial Network for Glaciers
IACS	International Organisation for Cryospheric Sciences
ICIMOD	International Centre for Integrated Mountain Development
IGOS	Integrated Global Observing Strategy
IGS	International Glaciological Society
IPCC	Intergovernmental Panel on Climate Change
ISI	Institute for Scientific Information
ISSI	International Space Science Institute
IUGG	International Union for Geodesy and Geophysics
IV	Ice Velocity
NSIDC	National Snow and Ice Data Center
RGI	Randolph Glacier Inventory
SEC	Surface Elevation Change
SPOT	System Pour l'Observation de la Terre
SRTM	Shuttle Radar Topography Mission
URD	User Requirements Document
UTM	Universal Transverse Mercator
WG	Working Group
WGMS	World Glacier Monitoring Service