Dear Etienne Berthier,

Thank you very much for editing our manuscript.
Please find my answers to the reviewer comments as well as manuscript and the supplement in "tracking"-mode on the following pages. Please ignore the comments (usually regarding format) on the right side, which were automatically created by Word 2016.
We revised the manuscript carefully, according to the reviewers suggestions. Moreover, the English was revised again and we would like to ask you, if we could change the title to:
"Changes in glacier dynamics in the northern Antarctic Peninsula since 1985"

Kind regards

Thorsten Seehaus

Response to the
Interactive comment on

"Changes in glacier dynamics in the northern Antarctic Peninsula since 1985"

by Thorsten Seehaus et al.

Anonymous Referee #1
Received and published: 20 April 2017

First of all we want to thank the reviewer for constructive comments on our manuscript. All comments have been taken into account and a list of answers and actions undertaken is given below. Answers are indented and in bold face type and changes in manuscript are indented in *blue*.

General Comments from the paper for the Authors –
The authors are to be appreciated for assembling an extensive array of illuminating data sets for a fairly large portion of the Antarctic Peninsula. By extending and expanding a previous study (Seehaus et al., EPSL 2015), it is clear that the hope was to illuminate many more glacial basins in this area of ongoing response to climate change. The use of the 5- parameter cluster analysis was a brave attempt to derive common themes across the area. Unfortunately, the complexities of the areas being investigated and the shorter/irregular nature of the velocity data appear to have confounded confident conclusions as the authors note on Page 14. A carefully edited paper with improved figures focusing on what is clearly known over the 1985 to 2015 area change period and the ∼1992 to 2014 velocity data time frame will likely be publishable in TC.

Specific Comments from the text for the Authors –

Abstract
(Page 1 Line 9): The first three sentences should emphasize that this study will attempt a comprehensive analysis rather than 'other analyses have been lacking/missing' or too focused on the shelf collapse glaciers.

Thank you for this advice. We changed/adjusted the wording of the respective sections to better emphasize that we are presenting a comprehensive study.

The climatic conditions along the northern Antarctic Peninsula have shown significant changes within the last 50 years. Here we present a comprehensive analysis of temporally and spatially detailed observations of the changes in ice dynamics along both the east and west coastlines of this region.

Page 1 Line 13: The <65◦ latitude limit would include some of the Larsen B's major tributary glaciers so a less ambiguous way of defining the basins chosen for study is needed here and in the Introduction.

We changed the definition of the study region (here and in the Introduction) in order to avoid ambiguity.

Abstract: <65° S along the west coast and north of the Seal Nunataks on the east coast
Introduction: (<65° S along the west coast and north of the Seal Nunataks on the east coast, Fig. 1b colored polygons)

Page 1 Lines 15/16: Here and elsewhere the area changes need to be attributed to a specific year or by 'the end of the study period' or similar text. The Prince Gustav Channel ice shelf's northern limit is from what year? What is the standard deviation of the average velocity for those glaciers? 'Whereat' appears to be an archaic term.

We added information on the observation periods for area change data and information on the data of the northern limit of Prince Gustav Channel Ice shelf extent.
We did not provide a standard deviation of the average velocity of those glaciers, since not all glaciers in this sector showed a similar trend. We intended to provide general information about the ice dynamic trend of each sector to the reader. More details of the individual glaciers are addressed in the Section "Discussion".
"Whereat" is replaced by "Whereas"

Glaciers on the east coast north of the former Prince Gustav Ice Shelf extent in 1986 receded by only 21.07 km² and decelerated by about 69 % on average (1985-2015).

Page 1 Line 19: Similarly, what is the standard deviation of the average velocity?

See comment above

1.0 Introduction –

Page 1 Line 29: It seems important to have the word 'estimated' before mass balance given that IMBIE was a 'consensus' report.

We replace "The authors reported..." by the "The authors estimated…."

Page 2 Line 9: Here and elsewhere it seems more appropriate to put references chronologically from early to later.

We appreciate the reviewer's comment, and did some editing of the manuscript according to his/her suggestion. However, at some sections it is more appropriate to keep the reference order for better storytelling.

Page 2 Line 23: 'The collected observations reported in these studies suggest' rather than 'the observations suggest'...

The sentence was adjusted according to the reviewer's suggestions

Page 2 Line 28: 'methodologically' rather than 'methodically'

We exchange the word according to the reviewer's comment

2.0 Study Site

Page 3: This section MUST explain why a region that is only about 25% of the total AP was chosen for study. This should also include why sections of even the 330 km long area are excluded. Vague phrasing such as 'apart from those that are ice shelf tributaries, nearly all glaciers on the AP are marine-terminating' doesn't explain why much of the west coast + nearby major islands are excluded from this study.

Thank you for the advice. We added a justification for the definition of the study region, and an explanation for why some sections were excluded. We did not include the nearby islands, since they are also not covered by most other studies and are not included in the basin definitions of IMBIE (Zwally Basins, Rignot Basins)

This facilitates the analyses of the long-term response (~20 years) of tributary glaciers to ice shelf disintegration at the former Larsen A and Prince-Gustav ice shelves on the east coast, the investigation of glaciers north of the former Prince-Gustav Ice Shelf, where no information on change in ice flow is currently available, and the comparison with temporal trends in ice dynamics along the west coast at the same latitude….
… Due to the sparse data coverage (fewer than three good quality velocity measurements), no

time series analysis of the glaciers at the northern tip of the AP or at some capes and peninsulas (e.g. Sobral Peninsula, Cape Longing) is possible.

Page 3 Lines 3/4: ‘high precipitation’ and ‘orographic barrier’ could use numerical support. Does the whole selected study site act as the barrier or just the broad plateaus? Better graphics and labeling will help as noted further below.

We added information about the typical height of the AP’s mountain chain and the extreme rates of precipitation. According to the precipitation fields in van Wessem et al. 2016 the whole study region acts as a barrier.
Regarding the revision of the graphics see further down.

The AP’s mountain chain (typically 1500-2000 m high) acts as an orographic barrier for the circumpolar westerly air streams leading to very high precipitation values on the west coast and on the plateau region of up to 5000 mm we yr −1, as well as frequent foehn type wind occurrences on the east coast (Cape et al., 2015, Marshall et al., 2006, van Wessem et al. 2016).

Page 3 Line 11: Order the shelf areas chronologically.

We followed the reviewer's suggestion.

Page 3 Line 12: The Scambos et al. (2003) sentence needs to be balanced with a more recent reference such as Holland et al. (2015).

As suggested we added a brief description of the findings of Holland et al. (2015).

A more recent study by Holland et al. (2015) discovered that significant thinning of the Larsen C Ice Shelf is caused by basal melting and that ungrounding from an ice rise and frontal recession could trigger its collapse.

Page 3 Line 14: Insert ‘frequently’ before ‘experiences melting’; other areas in Antarctica experience periodic melt events, especially a number of shelf areas (see just published work in Nature).

Thank you for this advice. We added “frequently” as suggested.

Page 3 Line 16: ‘Narrow’ seems an odd choice given the adjacent/excluded islands and smaller peninsulas and the broad plateaus (named elsewhere) in the study area.

We removed “narrow”

Page 3 Line 20: Making composite glaciers because they have ‘laterally connected termini’ needs to be better justified given the Seehaus et al. (2015) paper on DBE.

According to the reviewer's advice a justification was added

Neighboring basins with coalescing ice flow at the termini are merged (many are already merged in the ADD 6.0), as the delineation of the individual glacier sections is not always possible and the width can vary temporally (due to changes in mass flux of the individual glaciers).

Page 3 Line 22: ‘Sparse data coverage’ needs to be clarified.

We added a statement to clarify the data coverage.

Due to the sparse data coverage (fewer than three good quality velocity measurements), no time *series analysis of the glaciers….*

Page 3 Line 24: The three sectors being defined by their ‘different climatic settings’ needs some additional justification. Some of the ‘west’ glaciers are shielded to some extent by large/high islands?

The sectors were defined by
the climatic settings and drainage orientation → separation of east and west coast
and the former ice shelf extent → separation of the east coast in 2 sectors.
We adjusted the wording to be more clear.

Furthermore, the study region is divided into three sectors, taking into account the different climatic settings and drainage orientation as well as former ice shelf extent: ….

3.0 Data and Methods –

3.1 Area changes –

Page 4 Line~1: I find sections that begin with no or abbreviated text frequently can be more clearly written. The ‘Data and Methods’ section needs an introductory paragraph that indicates why these specific data sets in the study are being utilized.

An introduction for this section “Data and Methods” was added.

A large number of various remote sensing datasets are analyzed in order to obtain temporally and spatially detailed information on changes in ice dynamics in the study area. Glacier area changes are derived from satellite and aerial imagery. Repeat-pass Synthetic Aperture Radar (SAR) satellite acquisitions are used to compute surface velocity fields in order to obtain information on changes in glacier flow speed. Auxiliary data from sources such as a digital elevation model and glacier inventory are included in the further analyses and discussion of the results.

Page 4 Lines 4/5: The two sentences can easily be merged with lines below them.

We merged the two paragraphs.

Page 4 Lines7/8: Distinguish sensors and satellites explicitly.

Thank you for this comment. We removed “sensors”

…. using imagery from various satellites (e.g. Landsat, ERS) ….

Page 4 Line 13: Given the retreat processes for the PG Channel, is limiting all of the glaciers to 1995 appropriate?

Only one glacier (ADD ID: 2668) was affected by the gradual retreat of PGIS between 1985 and 1995. During this process, the PGIS retreated gradually along the frontal section of this glaciers (see Fig. 1). Therefore we think it is appropriate to refer the area changes to 1995.

Page 4 Line 20: Were ratings of 4 and 5 not needed or was any such data discarded?

There were no ice fronts mapped with such ratings within the study region. We changed the wording to be more clear

No ice fronts with reliability ratings of 4 and 5 are mapped in the study area.

3.2 Surface velocities

Page 4 Line 24: Table 2 lacks SAR resolution information.

See comments on Tables. This information was added.

Page 4 Line 28: Does the mentioned masking eliminate glacier areas from having their full velocity patterns mapped? I think this and Line 30 could be clarified.

The glacier areas are just masked out during the co-registration process (tracking was done on the full image), and the concatenation of images improves the co-registration in coastal areas, because more stable areas can be used to perform the co-registration. We adjusted the wording to be more clear.

In order to improve the co-registration of the image pairs, we mask out fast moving and unstable regions such as outlet glaciers and the sea during the co-registration processes. Furthermore, single SAR image tiles acquired during the same satellite flyover are concatenated in the along-track direction. This helps to further improve the co-registration in coastal regions (by including more stable areas in the co-registration process) but also simplifies the analysis of the final results as no mosaicking of the results is needed.

Page 5 Line 7: Put a period after 'topography' and start the next sentence with 'The results are then geocoded...'

We changed the structure according to the reviewer's advice.

…. incidence angle by the topography. The results are then geocoded, orthorectified and converted into …..

Page 5 Lines 8-10: Some discussion of the limitations of the ASTER DEM is needed (this also potentially impacts the cluster analysis).

We added a short summary of the quality of the ASTER DEM.

It has a mean elevation bias of -4 m (±25m RMSE) from ICESat data and horizontal accuracy better than 2 pixels. It is currently the best available digital elevation model of the Antarctic Peninsula.

Page 5 Line 11: Are there no reference for the text in this paragraph? Is this a unique approach or are there any similar analyses? Does any of this approach depend on the native resolution of the SAR sensor utilized (add column in Table S2)?

We added a reference regarding the tracking window size. However, usually only one tracking window size is used to calculate surface velocity fields. Due to the heterogeneous glacier flow, we applied different tracking window sizes and stacked them in order to improve the spatial coverage. Moreover, the window size depends on the SAR sensor resolution. We have changed the wording to be more precise. Regarding Table S2 see further down.

Depending on the displacement rate and resolution of the SAR sensor, the tracking window size needs to be adapted (de Lange et al. 2007).

Page 6 Line 1: Please give the time frame for when the terminus profiles were defined. The phrase "taking into account temporal changes' suggests there is a broad range of profile times rather than a consistent time.

For each glacier only one profile was defined. "Taking into account the temporal changes of the ice front" means, that the profile was defined behind the glacier front of the maximum retreat state. We changed the wording to be more clear.

A profile is defined (red lines in Fig. 1) close to the terminus of each glacier basin, behind the maximum retreat state of ice front position in the observation period.

Page 6 Lines 2/3: The second sentence needs to be clarified.

We change the wording to be more clear.

The results are visually inspected in order to remove unreliable measurements, based on the magnitude and direction of ice flow along the profiles. Datasets with partial profile coverage or large data gaps, as well as those with still remaining tracking errors, are rejected.

Page 6 Lines 7-9: Change text to ‘three or more’ rather than ‘more than two’ and discuss if 3 observations in 10 years is adequate to ‘classify’ a basin as in Table 3 (with potential impact to the cluster analysis). Clarify if any of the ’74 basins’ were specifically excluded or does this apply only to the smaller areas that appear to be excluded (see Figure 5). Also, a plot showing the number of velocity observations as a function of (named) basin size with indications of latitude may be useful given the ‘sparse’ coverage of the northern Trinity Peninsula (Page 3 Line 22).

We changed the wording of this section and added more detailed information.
The number of velocity measurements is listed in Table S1 and does not depend on the basin size, only on the spatial coverage by the SAR acquisitions. Therefore we did not perform a plot as suggested by the reviewer.

Only glaciers with three or more observations and an observation period of more than 10 years are considered in the categorization, resulting in 74 categorized glacier basins (colored polygons in Fig. 1b. There is a minimum of seven velocity measurements per categorized basin and the shortest observation period is 14.83 years (see Table S1; average number of velocity measurements per glacier is 33.8 and average observation period is 19.40 years).

3.3 Catchment geometries and settings

Page 6 Lines 12-14: It seems appropriate to mention this analysis and how/why it differs from the earlier work led by Cook (Huber et al., 2017) http://www.earth-syst-sci- data.net/9/115/2017/essd-9-115-2017.pdf

We added the reference to Huber et al. (2017) and mentioned the additional parameters that were derived. Why we derived this attributes is explained in the subsequent paragraphs.

In addition to glacier attributes derived by Huber et al. (2017), we calculated the Hypsometric Index and the ratio of the flux gate cross section divided by the glacier catchment area.

Page 6 Line 17: Does accumulation increase with higher altitude on both sides? Does this apply mostly to the plateaus? Please clarify.

The accumulation increases towards higher altitudes on both sides and this trend is not only limited to the plateaus (please see also Turner, 2002; van Wessem et al. 2016)
We have changed the wording to be more clear.

The climatic mass balance at the northern AP shows a strong spatial variability, with very high accumulation rates along the west coast, significantly lower values on the east coast and an increase towards higher altitudes along both coast lines (Turner, 2002; van Wessem et al. 2016).

Page 6 Line 20: Add the Jiskoot et al. reference(s) here, not just in Table 4.

We added the reference as suggested.

Page 6 Lines 23-25: These two sentences need some expansion, perhaps to include the impact of the DEM's uncertainty and or any issues in defining the flux gates.
A plot would be better than just stating 'lower values indicate a channelized outflow'.

In **order to be clearer we have expanded the description of the FA ratios and the definition of the flux gates. We hope the reader will understand it without an additional plot.**

In order to characterize the catchment shape, the ratios (FA) of the flux gate cross sections divided by the glacier catchment areas are calculated. The flux gates are defined along the profiles used for the glacier flow analysis (Section 3.2). Lower values of FA indicate a channelized outflow (narrowing towards the glacier front), whereas higher FA ratios imply a broadening of the glacier towards the calving front. Ice thickness at the flux gates is taken from the AP Bedmap dataset from Huss and Farinotti (2014).

3.4 Cluster analysis –

Page 6 Line 26: Given that uncertainties in several of the five variables underlying the cluster analysis have not been explored, it is difficult to accept this approach. If this technique has been utilized practically in other similar glaciologic studies, please provide a reference(s).

See answer to reviewer comment further down (Results)

The standardization technique described (Page 7 Lines 2/3) could use some clarification and also a reference.

We added a reference and extended the description of the standardization.

The variables are standardized in the traditional way of calculating their standard scores (also known as z-scores or normal scores). It is done by subtracting the variables mean value and dividing by its standard deviation (Miligan and Cooper, 1988).

Page 7 Lines 4-7: This is rather unclear and this technique could very much use an analogy or similar technique to make it clearer to the reader what is actually being done to 'sort the basins' into groups with common parameters.

We are sorry, we do not understand what the reviewer actually wants. We applied a standard statistical analyses method and the reader can find more details regarding this method in the references provided.

4.0 Results

4.1 Area changes
Page 7 Line 8: This section also needs an introductory paragraph that summarizes what will be discussed in the sub sections.

We do not think that an introduction is needed, since the sub sections are in the same structure as in the "Data and Methods" Section and the names of the sub sections clearly represent the topic of the sub section and what will be discussed in the sub sections.

Page 7 Lines 10/11: Explain why these glaciers were chosen (all but one are from the 'West' region). It appears that they illustrate not just the three 'area change groups' but also the six 'velocity change groups' (Table 3). Is this correct? If using 'Figure' within a sentence, please spell it out. Use 'Fig.' as in (Fig. 3).

The reviewer is right. The glaciers were selected in order to illustrate the three "area change groups" and the six "velocity change groups"(see Section 4.2 "Figure 2 shows by example

the temporal evolution of the ice flow for each velocity change category"). We changed the wording of this section to be more clear.
It happened by chance that most glaciers are from the west coast.
According to the author guidelines of TC the abbreviation "Fig." should be used in running text.

> **"The abbreviation "Fig." should be used when it appears in running text and should be followed by a number unless it comes at the beginning of a sentence, e.g.: "The results are depicted in Fig. 5. Figure 9 reveals that...".**

Area changes relative to the measurements in the epoch 1985-1989 of all observed glaciers are plotted in Fig. S1-S74 (supplement). The glaciers are classified in three groups based on the latest area change measurements, which are illustrated in Fig. 2:….

Page 7 Line 16: Assume you mean '238 km2'. Also, see comments on Figure 4 that seem designed to greatly accentuate the '2.2%' loss between 1985 and 2015.

See answer to comment on Fig. 4.

Page 7 Line 17: You could usefully add the individual loss % values here.

Thank you for this advice. We added the the area loss values (in %) for each sector.

…. of which the area loss by 5.7% at sector "East-Ice-Shelves" clearly dominates. The glaciers in sector "West" and "East" recessed by 0.2% and 1.4%, respectively.

4.2 Surface velocities

Page 7 Line 22: 'A total of' 282 etc...

We appreciate this comment. We replaced "In total" by "A total".

Page 7 Lines 23-26: Are the 'average' uncertainties of the velocity fields meaningful given the array of different sensors used? The text suggests not. Perhaps the average uncertainty of each sensor (and its standard deviation) could be stated instead and also added to Table 2? This information is too deeply buried in Table S2.

We appreciate this advice and have added the average uncertainty of each sensor to Table 2. We kept the average value of all datasets in the text and included a reference to Table 2.

The average total uncertainty of the velocity fields amounts to 0.08 ± 0.07 m d^{-1} and the values for each SAR sensor are provided in Table 2.

Page 7 Lines 26-28: If these data are unreliable, explain how they were or were not used in the study and all the Figures S1-74? This is unclear.

The ERS datasets with 1 day repetition frequency are not necessarily unreliable or of bad quality. The total intensity tracking accuracies of these datasets was obtained by only considering the mismatch of the coregistration, since the applied approach to estimate the accuracy of the tracking algorithm is strongly biased by the very short temporal baseline of these data sets. This applies only to seven datasets out of 382. We rephrased this section to be more clear.

ERS image pairs with time intervals of one day have very large estimated tracking uncertainties, biased by the very short temporal baselines. Therefore, only the errors caused by the mismatch of the coregistration are considered in the total error computations of the seven ERS tracking results with one day temporal baselines.

Also, was there any attempt to do curve fitting through the data that passed the quality criteria? Given the range of velocity (and area change) axes used, I find it very difficult to visually assess (Page 8 Lines 1-3) the Table 3 categories.

We attempted to do curve fitting in order to automatically derive the velocity change categories but we were not satisfied with the results. Therefore, we did a manual classification. A statement to clarify this was added in Section 3.2.

The glaciers are manually classified in six categories according to the temporal evolution of the ice flow speeds (see Table 3), since automatic classification attempts did not succeed.

Page 8 Lines 6/7: The 'local clustering' should be identified even if it is explored further in the Discussion section (see comments on location indicators of Figures).

We added a location reference for the local clustering.

…a local clustering of accelerating glaciers can be observed at Wilhelmina Bay.

Page 8 Line 9: Table S2 should be S1 and there is an error in one of the subscripts and 'd' should apparently be Δ, here. Also see comments on Table 5.

Thank you for this advice. We have corrected it accordingly. Regarding "d" and "Δ" see further down.

Page 8 Line 13: You might as well give the longest period for velocity and also the standard deviation.

According to your advice we added information on the longest period and the standard deviation.

The shortest observation period is 14.83 years at DBC31 Glacier, the longest observation period is 21.99 years at TPE31 and Sjögren glaciers and on average velocity changes are analyzed over a period of 19.40 years (σ = 1.97 years).

4.3 Catchment geometries and settings

Page 8 Lines 15/16: The HI values are in Table S1, not S2, and appear to vary quite a bit more than in Jiskoot et al. (2009).

We corrected the references to the tables in the supplement. We applied the same classification as Jiskoot et al. (2009), in order to be consistent/comparable with/to another study that also applied it at the Antarctic Peninsula (Davis et al. (2012)

Figure 3 is very difficult to read for both velocity and HI categories. Given that this section is 'Results', perhaps the unmapped areas should be mentioned.

See answer to comment on Figure 3 further down.

4.4 Cluster analysis

Page 8 Lines 19-21: In part due to the preceding text (Lines 16/17) "No clear distribution pattern can be identified, reflecting the heterogeneous topography of the AP.", my concerns about the cluster analysis remain unresolved. The limited text here, regard less of Section 5.3, seems to emphasize an uncertain result.

"No clear distribution pattern can be identified, reflecting the heterogeneous topography of the AP." refers to the HI, which does not need to have a clear distribution pattern.

Because it is hard to manually identify clear distribution patterns of individual glacier variables along the west coast or identify relations between the variables, the cluster analysis approach was applied and lead in our opinion to reasonable results.
See also answer to reviewer comment on the cluster analyses further down.

5.0 Discussion

Page 8 Line 25: The result that all glaciers on the east coast receded should be clarified to state 'since 1985'. Does Davies et al. (2012) overlap in terms of area with this study?

We added "since 1985". The study area of Davies et al. (2012) overlaps with our study area on Trinity Peninsula.

Only glaciers along the west coast showed stable or advancing calving fronts and all glaciers on the east coast receded since 1985. This heterogeneous area change pattern was also observed by Davies et al. (2012) on western Trinity Peninsula.

Page 8 Line 27: Superscript for area is missing.

We are sorry, but we could not identify the missing superscript, since no variable is mentioned in this section.

Page 9 Lines 3/4: This is very difficult to ascertain from Figure 4c and seems to be an overreach of the results, the text seems speculative. See the small deviations in the area change trend for the 1995-2005 'blocks'.

We are aware, that the recession in 1995-2005 was just slightly increased and that the relation between the ice shelf break-up and the increased retreat rates is just a speculation. We adjusted the wording to better emphasis that it is just a slight increase in the retreat rates and that our explanation is speculative.

Moreover, slightly increased recession is also found in the time period (1995-2005, Fig. 4) at sector "East". Davies et al. (2012) and Hulbe et al. (2004) supposed that the disintegration of an ice shelf affects the local climate. The air temperatures would rise due to the presence of more ice free water in summers. This might explain the slightly higher retreat rates at sector "East".

Page 9 Lines 6-8: Seehaus et al. (2015, Figure 3) shows warming for Marambio for 1998 to 2006 not 1997 to 2007. That time range appears to be from the Oliva et al. (2017) broader analysis who shows the locations of all the available records and their variation over a longer time frame. And it isn't clear what "Unfortunately, no temperature records are available in sector "East" covering this period." means as all the temperature data appears to be from outside this paper's study area.

We corrected the time specification and included only information from Oliva et al. (2017). "Unfortunately……" means, that no temperature data recorded within this sector. We changes the wording to be more clear.

At Base Marambio, ~100 km east of this sector, approximately 2°C higher mean annual air temperatures were recorded in the period 1996-2005 as compared to the period 1986-1995 (Oliva et al., 2017). Unfortunately, no temperature data recorded within sector "East" is available covering this period that could be used to validate this theory.

Page 9 Lines 11-13: Clarify that the 'frames' correspond to ESA conventions for identifying ERS coverage and that frame 4923 covers 'the central and much of the northern part of sector "West"'.

Thank you for this advice. We changed the wording accordingly.

Pritchard and Vaughan (2007) reported an increase in mean flow rate of 7.8% in frame 4923 (the *central and much of the northern part of sector "West") and 15.2% in frame 4941 (the southern part of sector "West") for the period 1992-2005 (frame numbers correspond to European Space Agency convention for identifying ERS coverage).*

Page 9 Lines 14-19: Is this really a 'discovery' since you go on to show that the 'discrepancy' has a logical explanation?

We replaced "discovered" by "derived"

However, for the same observation period we derived a mean increase in flow velocity by 18.9 % in sector "West", which is an approximately 1.6 times higher acceleration.

5.1 East ice shelf 'sector' (no reason to capitalize)

Page 9 Line 22: Given Figures S1-13 describe sector "East" why start with the ice shelf loss area basins detailed in S14-26? Please add the date or dates that detail when the basins lost the ice shelf area in front of them (e.g. paragraphs on Page 10).

We appreciate this advice and exchanged Section 5.1 and 5.2 ("East" and "East-Ice-Shelf") in order to match the order of Figures S1-S74. We added information on the dates of the loss of the ice shelf area in front of the glaciers.

In the sector "East-Ice-Shelf" the tributary glaciers in the Larsen A embayment ("2558", Arron Icefall, DBE, Drygalski, LAB2, LAB32, TPE61 and TPE62; Fig. S14, S17, S19-S22, S25 and S26) and Sjögren-Inlet (Boydell, Sjögren and TPE114; Fig. S18, S23 and S24) lost the downstream ice shelves in 1995....
In the 1980s, Prince Gustav Ice Shelf gradually retreated (see Fig. 1) and "2668" Glacier (Fig. S15) has not been buttressed by the ice shelf since the early 1990s..
The ice shelf in Larsen Inlet disintegrated in 1987-1988 and earliest velocity measurements are obtained in 1993. Therefore, a potential peak in the flow speed after ice shelf break-up cannot be detected at APPE glaciers.

Page 9 Line 26: Here and elsewhere, hyphens are not needed for 'Larsen-A/B'.

We appreciate this advice and removed the hyphens throughout the manuscript.

Page 9 Line 30: It is good that you can resolve differences due solely to methodology but please clarify what 'equal temporal trends' means in this context.

"equal temporal trends" means that comparable temporal changes in glacier flow speed were observed in both studies. We adjusted the wording to be more clear.

The different approaches result in different absolute values, but comparable temporal trends in glacier flow speeds are observed in both studies.

Page 10 Lines 2-5: It is difficult to conclude that the stated variation in the behavior of these basins shows they are still 'adjusting to the new boundary conditions' as opposed to responding to purely localized forces acting on them. On Line 3, do you mean 'medial' as opposed to the statistical 'median'?

We supposed that this glaciers show a prolonged response to the ice shelf break-up caused by the local settings. We extended the discussion to be more clear and removed "median".

At "2558", Boydell, DBE and Sjögren glaciers the deceleration is ongoing and Boydell and DBE glaciers still show increased flow speeds at the glacier fronts. We suppose that these tributary glaciers show a prolonged response to ice shelf disintegration, caused by local settings (e.g. bedrock topography or fjord geometry), and are still adjusting to the new boundary conditions, as *suggested by Seehaus et al. (2015, 2016).*

Page 10 Lines 6-15: Some interesting details are discussed here but they seem to be overly specific rather than useful indicators. The discussion of Pyke Glacier vs the composite APPE basin, including Pyke, suggests a concern about this analysis combining individual flow systems in composite basins. Does averaging over multiple smaller glaciers blur a discernable signal? The lack of sufficient temporal coverage of the available velocity data appears to be a common issue here.

The observations by Rott et al. (2014) at Pyke Glacier show the same trend as our measurements. We changed the wording to better emphasize this.
The reviewer is right the temporal coverage at Larsen Inlet (APPE) and "2668" Glaciers is a limiting factor. However, there is no data available to obtain reasonable information about glacier flow speeds at this glaciers for the 1980s. A statement on this issue was added.

As for "2668" Glacier no sufficient cloud free coverage by Landsat imagery is available which facilitates the computation of surface velocities for the 1980s. The ice flow at APPE glaciers shows a nearly stable trend with short term variations in the order of 0.2-0.5 m d^{-1} between 1993 and 2014. Rott et al., (2014) also found nearly constant flow velocities at Pyke Glacier.

5.2 East 'sector' (see comment above on order of discussion)

Page 10 Lines 20-28: It would seem that a good bit of this discussion might fit better in the introductory section. The specific figures in the Supplement would be useful to point out for the named basins. Depending on whether you choose to interpret Turner's or Oliva's figures allows you to vary the point when cooling began in the 21st century, what specific date do you prefer?

According to the reviewer's advice we moved some parts to the "Introduction". The numbers of the specific figures in the Supplement were added in this section and section 5.1.
Oliva et al. (2017) stated "Our results also indicate that the cooling initiated in 1998/1999 has been most significant in the N and NE of the AP..." which is nearly similar to Turner et al. (2016) "… to show an absence of regional warming since the late 1990s." Therefore, we decided to use the phrase "However, a recent cooling trend on the AP was revealed by Oliva et al. (2017) and Turner et al. (2016) since the late 1990s." (now in the Introduction)

Page 11 Lines 1-4: Does the analysis of Oliva et al. (2017) not allow more precision than 'before earliest velocity measurements'? Does the area change time series going back to 1985 (in this sector) not provide additional insight?

We appreciate this advice and referenced our discussion to the date from Oliva et al. (2017) and Skvarca et al. (1998).
The area change time series shows a frontal stabilization after 1985, but every glacier started to maintain its front positions at different periods.

Hence, we assume that the initial recessions of the glaciers in sector "East" were forced by the warming observed by Oliva et al. (2017) and Skvarca et al. (1998) since the 1970s. Therefore, this initial frontal destabilization and retreat led to high flow speeds at the beginning of our ice dynamics time series (earliest velocity measurements from 1992) and the subsequently observed frontal stabilization (after 1985) caused the deceleration of the ice flow.

Page 11 Lines 8-10: Please be more specific as to what/how the visual imagery was used to identify the 'bump'.

We identified some small rock outcrops that indicate a shallow bedrock bump. The wording was adjusted to be more precise.

No nunatak is present at the terminus, but small rock outcrops, indicating a shallow bedrock bump, are identified north of the center of the ice front by visual inspection of optical satellite imagery.

Page 11 Lines 13-19: Some of this material should be in the introductory material and the analysis seems speculative given the stated need for more observations. Page 11: Also highlights the difficulties in reading Figure 3 for specific locations (or interpreting symbols) even after magnification of the pdf.

We would like to ќeep this material in this section, since the description of the surge cycle is quite specific for only these 2 glaciers.
We adjusted the wording to emphasize that it is speculative, but we would like keep to his sections in the paper, since it provides a motivation to further continue the observation of glaciers in this region.

Diplock and Victory glaciers (Fig. S5 and S13) show a decrease of flow speed during retreat followed by an acceleration combined with frontal advance. Surge-type glaciers, found for example in Alaska (tidewater) (Motyka and Truffer, 2007; Walker and Zenone, 1988) or Karakoram (land terminating) (Rankl et al., 2014), show similar behavior. They are characterized by episodically rapid down-wasting, resulting in a frontal acceleration and strong advance. Regarding tidewater glaciers the advance can be strongly compensated by increased calving rates in deepwater in front of the glacier. It is therefore possible that these glaciers may have experienced a surge cycle in our observation period; however, a longer time series analysis is necessary to prove this hypothesis.

5.3 West 'sector'

Page 11 Line 24: See previous comment on Turner vs Oliva temperature studies.

See answer to previous comment

Page 11 Lines 24/25: Clarify what is meant by 'constant trend'? Do you mean in both space and time? If so, can the ocean temperature differences be reconciled?

The reviewer is right. The climatic trends on the AP are not constant in space and time. We have changed the wording to be clearer and added a statement on the link between ocean temperatures, sea ice concentration and the deceleration of the warming.

However, Cook et al. (2016) reported cool ocean temperatures along the north-western AP for the period 1945-2009, and an absence of the atmospheric warming, especially pronounced at the northern AP, since the turn of the millennium was found by Oliva et al. (2017) and Turner et al. (2016), which correlates with an increase of sea ice concentration and the cool ocean temperatures at the northern AP.

Page 11 Lines 25/26: Does 'southern part' apply to both West and East or only 'West"? What abut the coastline makes it 'fractal' and does that aid understanding? Clarify 'These' factors lead (cause?)...

"southern part" refers to sector "West" and "fractal" was replaced by "jagged". We hope to be more clear now. "This factors lead" was replaced by "These factors cause"

Moreover the glacier geometries differ strongly, and especially in the southern part of sector "West", the coastline is more jagged. These factors cause the heterogeneous pattern of area and flow speed changes in sector "West" as compared to the eastern sectors.

Page 11 Lines 28/29: Clarify if the 12 glaciers studied by Kunz et al. (2012) included basins and years overlapping this study. Which 'authors' are being referred to here?

We included information about the glaciers located in our study area, analyzed by Kunz et

al. (2012). We referred to the “authors” of Benn et al. (2007). We change the wording to be more clear.

Kunz et al. (2012) observed thinning at the glacier termini along the western AP, by analyzing airborne and spaceborne stereo imagery in the period 1947-2010. Two of the twelve studied glaciers are located within our study area; Leonardo Glacier (1968-2010) and Rozier Glacier (1968-2010). …
However, Benn et al. (2007) also….

Page 11 Line 31: The fact that fjord and glacier geometries may be uncertain should probably be mentioned here, especially for smaller basins.

According to the reviewer's advice we added a statement on this issue

However, Benn et al. (2007) also point out that changes in ice thickness do not necessarily affect the ice flow and that calving front positions and ice dynamics are strongly dependent on the fjord and glacier geometries, derived from modeling results which have higher uncertainties especially for smaller basins.

Page 12 to Page 13 Line 13: As indicated above, I find the cluster analysis to be of uncertain value and will refrain from further comment on it. Other reviewers and/or the Editor can decide if it should remain in the paper.

We would like to keep the cluster analysis in the paper, since it significantly helped to categorize the glaciers along the west coast and led to reasonable results(in our opinion). This work was also presented at the EGU General Assembly 2017 and we received positive feedback by the community also regarding the cluster analysis. Therefore, we think this approach might be a useful tool for the analysis of long-term chances in ice dynamics in combination with glacier geometry parameters at other study sites. Time series calculations are becoming more feasible with better temporal and spatial coverage of the cryosphere by the current sensors like TerraSAR-X/TanDEM-X and Sentinel-1A/B and future missions.

6.0 Conclusions

Page 13 Lines 15/16: The usage of ‘northwestern’ to define the study area is quite imprecise as is the usage of ‘north of 65◦S’ as was previously commented.

We adjusted the wording to be more precise.

Our analysis expands on previous work on ice dynamic changes along the west coast of AP between TPE8 and Bagshawe-Grubb Glacier, both in regard to temporal coverage and analysis methods. It also spatially extends previous work on changes in ice dynamics along the east coast between Eyrie Bay and the Seal Nunataks.

Page 13 Line 18: The ‘dynamics’ were observed most clearly only during ∼1992 to 2014 through the repeated velocity observations. This text should be clarified.

According to the reviewer’s advice, we added information on the study periods for each method.

The spatially and temporally detailed analysis of changes in ice flow speeds (1992-2014) and ice front positions (1985-2015) reveal varying temporal trends in glacier dynamics along the northern AP.

Page 13 Line 19:Clarify if ‘significantly higher’ is simply due to differences in the methodology relative to Pritchard and Vaughan (2007) for the same period. If so, should this simply say ‘higher’ velocities were observed?

As mentioned in the "Discussion", differences could be caused by the different methodologies. We removed "significantly".

Page 13 Line 22: Be clear that all 'East' glacier fronts retreated relative to 1985 (or 1995 after shelf losses).

We adjusted the wording to be more clear.

On the east side all glacier fronts retreated in the study period (relative to 1985), with highest retreat rates observed at former tributaries of the Prince Gustav, Larsen Inlet and Larsen A ice shelves (relative to the year of ice shelf disintegration)..

Page 13 Line 28: The 'cooling since 2000' depends on how you read the Seehaus et al. (2015), Turner et al. (2016) or Oliva et al. (2017) analyses. Mid-2000s seems to be a more reasonable number for much of your study area.

According to the reviewer's suggestion we change the wording.

Based on the observed warming trend since the 1960s and the subsequent cooling since the mid-2000s in the northern AP ….

Page 14 Lines 3-5: See previous concerns about how well the cluster analysis with 5 variables can discriminate across such a broad swath of the western AP. It appears that this study needs to include additional parameters rather than attributing groups to basin geometry alone (as is clearly indicted in their next paragraph).

We tried to include a broad variety of data, but also to keep the focus on the remote sensing part and the ice dynamics analysis. Therefore, we gave the suggestion in the next paragraph how the results of this study could be used to further investigate the processes at the Antarctic Peninsula.

Figures -

Figure 1: This figure needs to be redesigned with a small Antarctic map in the corner of the 'general peninsula region' map showing the specific study area on the ∼1300 km long Antarctic Peninsula. Major landscape features and adjacent water bodies should be clearly labeled on both of the panels especially (c) if mentioned in the text (e.g. Bruce and Detroit plateaus, James Ross Island, Charcot, Charlotte, Andvord, Wilhelmina bays, not just on Figure 5). The LIMA credit is incorrect, should be USGS,NASA, BAS, NSF. Further, the scale of the third panel should be sufficient to clearly discern ice front positions and related color choices of lines (shades of orange, red on red?) may need to be revised. It is appropriate to specify in the caption why ADD 6.0 is being used for glacier fronts instead of the data from the study. Also, areas mostly or totally excluded from the study (e.g. Trinity, Longing, Sobral peninsulas) should be identified here. Also, Bellingshausen Sea is misspelled and inaccurately located.

We appreciate the reviewer's comment and revised the figure. Additional labels of landscape features and water bodies were included as far as possible, in order to keep the figure clear. The color of some layers were also revised. We used only the "coastline dataset" from ADD 6.0 to display the ice shelf extents. We adjusted the caption to be more clear and corrected the LIMA credit. The regions/glaciers which were excluded from the study are not included in the polygons indicating the three sectors.

Figure 2: The caption seems to need to include "for each velocity change category (see Table 3)." And it does seem odd that there is only one example that is not from 'West'. As with S1 to S74, it seems appropriate to ask for both velocity and area change data to be plotted at the same scales or a compelling argument advanced as to why this is not more appropriate. This would likely greatly reduce the size of the error bars that distract the eye in many instances. Also, as mentioned

in text comments, was curve fitting of the velocity data attempted?

We revised the caption. Regarding the selection of glaciers and the curve fitting see answer to review comment further up. Of course some error bars of e.g. area changes (e.g. in Fig. 1b) seems to be quite large compared to error bars of glaciers with large area changes (e.g. Fig. 1c). However, due to the large diversity and variability of glacier velocities and area changes, we do not want to used fixed scales for all glaciers.

Figure 3: Even after magnification of the pdf, Figure 3 is difficult to read for locations and symbols and these also cannot be searched. This makes the text discussion of small features very difficult. Also, see above for the need for locations mentioned in the text to be labeled. Close inspection reveals that smaller areas appear to be excluded along with the larger Sobral and Longing peninsula regions and such areas need to be mapped/explained (also see text comments). Also, discerning the color scale for the HI outlines of each basin are challenging especially where they overlap.

As for Fig. 1 we added additional labels landscape features and water bodies. Regarding the size and scale of Fig.3, we tried different labeling options and increased the size of the glacier labels. We could ask the editor if it might be possible to spread it over 2 pages in order to magnify it.
Excluded area are not covered by the HI polygons. See also answer to comment on Fig.1. We changed the HI outline color scale and removed the overlap by using buffered polygons.

Figure 4: It is positive to note that this figure's caption points out that the left y-axis (not the right one) has different scaling for each of the plots. It is appropriate for the area change y-axis to be consistently scale as that allows the reader to quickly detect the magnitude of change from region to region. It is not clear why the left y-axis doesn't start at zero in all cases and use some distinct maximum thousands value to clearly show that the changes are still small relative to the total area in each sector, especially for 'all glaciers'. The editor may wish to provide guidance here.

The reviewer is right. The area changes are quite small compared to the total area, but this is usually the case, since glacier area changes are mostly in the order of a few %. We did not start the left y-axis at 0 because we want present the temporal trend of area change, which can not be seen, if we start the y-axis at 0. If it is OK for the reviewer's and the editor we would like to keep the figure as it is. Another option could be, that we just show the "Area change".

Figure 5: See comments on the text regarding the cluster analysis. The caption needs to clarify that all polygons in the figure are colored (see previous comment on over lapping basin outlines) but that the sectors are (somewhat) defined with three colors. Also, 'dA' should apparently be ΔA. This figure finally provides some location pointers to the Trinity Peninsula (partial) and the bays missing from Figure 1 but, oddly, doesn't label any of the glaciers? This figure also highlights that 3 of the 'composite' basins are quite large (APPE, CLM, and DBE) and a fourth (SBG) is much larger than some of the investigated 'west' basins. This makes one wonder why they could not be similarly subdivided. "Laterally- connected' is not clearly explained in the text as the reason to composite these basins (how much of each glacier?).

According to the reviewer's advices, we revised the caption to be clearer, and removed the overlap of the sector outlines. Moreover, we added location and glacier labels.
Regarding the "composite" basins please see answer to reviewer comment further up.
Regarding "d" vs. "Δ" see answer to reviewer comment on Table 5.

Figure 6: See comments on the text regarding the cluster analysis. Add numbers for each cluster group to each red box if the figure is included in the revised paper. The third sentence could be reduced to "(see Section 5.3)" at the end of the caption.

We appreciate the comment and revised the caption and added numbers for each cluster group

Figure 7: See comments on the text regarding the cluster analysis. Add ‘N’ to each group in the plot if figure is included in revised paper. Also, the ‘FA’ plot y axis label needs to be changed to include ‘ratio (FA)’ at its end. The symbols should probably be removed and only numerical values shown on the y-axes on two of the plots.

We adjusted the figure according to the reviewer’s suggestions. We would like to keep the symbols on the y-axes (velocity change and FA). We guess it helps the reader to a better understand/interpret the graphs. Moreover we added numerical values to the y-axes of the FA plot.

Tables

Table 1: The title should be simplified “Abbreviations of glacier names”, delete “Used”. Also, ensure that the plural ‘glaciers’ is used whenever the acronym is used in the text and/or figures (e.g. S27, S57, also S29, S58, others).

Thank you for this comment, we revised the title and checked the manuscript for the plural “glaciers”.

Table 2: The title should be simplified and limited to the first part of text “Overview of SAR sensors and relevant specification”. The second part should be a footnote to the table and specify which columns are relevant. Also, there needs to be a column that shows the spatial resolution of the SAR sensor.

According to the reviewer's advices (see also above) we added a column that shows the nominal spatial resolution and the mean uncertainty of the tracking results.

Table 3: The title should be limited to the first part of text. The second part should be a footnote to the table and specify which column is relevant. Also, ‘Long-term’ is not appropriate for a time period that is ∼20 years or less in some cases.

We appreciate the comment and put the second part of the title in the footnote. “Long-term” was replaced by “general”.

Table 4: The title should be “Hypsometric Index and glacier basin category descriptions”. The part “After Jiskoot et al. (2009)” should be a footnote to the table and should include the full range of HI values in the study (apparently much larger than for the Jiskoot study), including mean and standard deviation. The table could probably use at least a third column with the number of glaciers of each category.

We revised the table following the reviewer’s suggestion and added a column listing the number of glaciers of each category. We decided to not show the range of HI values, mean and standard deviation in the footnotes, but added this information in the results (Section 4.3).

The HI values range between -4.6 and 9.1 (mean: 0.88, σ: 2.10).

Table 5:

Similarly, the title should be simplified and much of the header text moved to footnotes. Further, the table needs to be reformatted so that ‘Sector’ applies to not the first column (Parameters) but the subsequent four columns. Superscripts are missing for area rows. Consistent use of ‘d’ (italicized) or Δ for ‘delta’ would be appreciated through the paper. The mean velocity measurements should have a standard deviation as well given the larger uncertainties of some of the observations. This also applies to Table S1/S2.

According to the reviewer's suggestion we moved most of the title to footnotes, and re-formated the table to better indicate that sector applies to the subsequent for columns. We are sorry, but we do not understand which superscripts are missing for area rows. we used subscripts to indicate the observation intervals. We checked the paper and used “d” for “delta” through the paper. Table S1/S2 were also revised accordingly.

Supplement “to:” -
Figures S1 to S74: As with Figure 2, it seems appropriate to ask for both velocity and area change data to be plotted at the same scales or a compelling argument advanced as to why this is not appropriate other than the effort involved. This would likely greatly reduce the size of the error bars that distract the eye in many instances and also clarify the ‘patterns’ more consistently. Paired and ‘acronym’ glaciers should be plural and with a lowercase ‘g’.

Please see answer to reviewer comments further up (regarding the scale). We revised the glacier labels according to the reviewer’s advice.

Table S1: See comment above, simplify the title, move parameter descriptions to footnotes or a header box as the editor prefers. Also ensure that the related text points to the correct table for specific parameters (Page 8, Line 15). Include a numbering scheme so it is obvious that there are far more ‘West’ glaciers than in any other category (split composite glaciers as required).

According to the reviewer's suggestion we simplified the title and checked the cross references in the text. We decided to not include a numbering scheme in Table S1, but to add a row to Table 5 which shows the number of glaciers in each sector.

Table S2: Add an appropriate title and move parameter descriptions to footnotes or a header box as the editor prefers. The Δt values = 1d should be flagged in bold and the reader pointed to a specific text section of the paper and/or a footnote that explains why they need to be flagged.

We moved the parameter description to the footnotes. We added “*” to highlight the dt values =1 and linked the footnote to the text section in the paper.

Response to the
Interactive comment on

“Changes in glacier dynamics in the northern Antarctic Peninsula since 1985”

by Thorsten Seehaus et al.

J. Wuite Referee #2
Received and published: 20 April 2017

First of all we want to thank the reviewer for constructive comments on our manuscript. All comments have been taken into account and a list of answers and actions undertaken is given below. Answers are indented and in bold face type and changes in manuscript are indented in *blue*.

General Comments This paper provides an analysis of comprehensive satellite data sets to study changes in glacier area (over the period 1985-2015) and glacier surface velocity (1992-2014) on the northern Antarctic Peninsula, highlighting the complex temporal pattern of glacier retreat and ice flow dynamics in this region. This is a topic of great relevance for exploring factors that are controlling the varying response to climate change for the glaciers in this region. The hierarchical cluster analysis applied for the west coast glaciers is an inventive effort to provide insight into various flow controlling factors. I have, however, some major concerns that would need to be addressed, more specifically there appear to be some serious deficiencies regarding technical matters, as well as in the presentation of the work and discussion of the results, requiring in depth checks and major revisions and/or re-analysis of data.

Referee #1 provides detailed comments and suggestions for improvements regarding the presentation of the study sites, the description of methods, the presentation of results, as well as on the contents in discussion and conclusions sections. Complementary to this careful and well-founded review, I am addressing below additional critical issues with emphasis on analysis, presentation and discussion of velocity data. I am focusing on the glaciers draining into the embayments of the former Larsen-A and Prince-Gustav-Channel (PGC) ice shelves because published data on these glaciers (based on various data sources) enable comparisons and checks of the various results.

The statement (Abstract P1L18, Results P8L11) “In 2014, the flow speed of the former ice shelf tributaries was 16.8% higher than at the beginning of the study period.“ implies that the outlet glaciers into the Larsen-A and PGC embayments are close to balance. This is in contradiction to other observations, showing prevailing large mass imbalance of these glaciers derived from geodetic data, and also to the much higher velocities compared to pre-collapse state. For example Rott et al. (2014) report for the period 2011 to 2013 a rate of mass depletion of 4.2±0.4 Gt/year based on topographic data of the TanDEM-X satellite mission. The largest contribution is supplied by Drygalski Glacier (deficit 2.2±0.2 Gt/year). Scambos et al. (2014) report a mass depletion of 5.6 Gt/year for the same area for the period 2003 to 2008. Analysis of TanDEM-X data from 2013 to 2015 show somewhat reduced mass deficit for these glaciers, but still a large imbalance (Rott et al., 2016), impossible to be maintained by a velocity that is only 16.8 % higher than in the precollapse state.

We understand the reviewer's concerns, but here we present the average of the changes in flow speed of all glaciers in this sector (ignoring the different size or mass discharge). Therefore, this value is biased by the small glaciers, which were not so strongly affected by the disintegration of the ice shelf disintegrated, compared to the larger more inertially glaciers (like Drygalski, DBE, Boydell, Sjögen glaciers). Moreover, the changes in flow speeds do not directly reflect the changes in ice discharge, which also strongly depends on the spatial distribution of the ice thickness at the flux gate. However, a rough approximation of the ice discharge (using our median velocity values and average ice thickness information from Huss and Farinotti 2014 along the profiles) leads to an ice discharge of

~9.4 Gt/a in this sector, whereof 16.8% (our observed average increase of flow speed) correspond to 1.6 Gt/a. This number is lower than the values reported by Rott et al. (2014) or Scambos et al. (2014), but at a comparable level (assuming no change in SMB). Moreover, a recent study by Hogg et al. (2017) points out that only ice discharge across the grounding line can not necessarily explain the deflation. They attribute 35% of the imbalance to increased ice discharge, and hypothesized that ocean driven melting may have forced the dynamical thinning of the glaciers at Western Palmer Land.
The presented study has put the focus on the temporal changes in ice dynamics. However, a detailed study on the changes in ice discharge and mass balance using the "Input-Output" Method or "Flux-Gate" Method is currently in preparation and We change the wording in Section 4.2 to provided additional information to the reader regarding the average flow speed changes.

The presented average flow speed change values are based on the observed changes of all glaciers in the respective sector (Table S1), ignoring the different size of the individual glaciers.

In Section 5.1 (Discussion East-Ice-Shelf) the authors discuss possible reasons for differences in velocities of glaciers in this sector compared to velocities reported by Rott et al. (2014). They argue that these differences are due to different approaches for reporting velocities (location in the centre of the glacier near the front vs. the median velocities at cross profiles close to the glacier fronts). Also, they are claiming that "equal temporal trends are observed in both studies" (P9L30). This is incorrect as evident by comparing the velocity data in Table 2 of Rott et al. (2014) for several dates between November 1995 and November 2013. On Drygalski Glacier for example velocity near the centre of the 2013 front is reported to be 280% higher in November 2013 than in November 1995, and on Sjögren Glacier 410%. When referring to the pre-collapse state, the increase of velocity on Drygalski Glacier is even higher, because in November 1995 the lower glacier terminus had already accelerated significantly compared to precollapse state, as the time series of velocities starting in January 1993 shows (Rott et al., 2015). This acceleration 10 months after ice shelf collapse was already reported by Rott et al. (2002). In order to clarify the discrepancies addressed above, it is necessary to better explain the methods used, check and revise the error estimates, and provide full traceability on the geographic location of the selected profiles for velocity retrieval and the epochs, and quantify the impact of using median values for quantifying velocities of glacier fronts for the different sensors. It would for example be very valuable to present cross profiles and/or profile time series used to derive the median values (and not only for East-ice-Shelf), in particular for the earlier pre-collapse estimates.

The difference between measuring velocities at one point at the center of the terminus compared to averaging along a profile at the terminus were already reported in Seehaus et al. (2015) The authors also observed deviations between velocity measurements at the center of the terminus and measurements along profiles across the terminus. They attribute it to the the fact, that highest flow speeds are found at the center of terminus, but this maximum values are suppressed by averaging across the terminus. We added the lit. reference at the description of this issue. See also the figure below. It shows the surface velocity across the terminus of Drygalski Glacier at similar dates as shown in Rott et al. (2015). We observed comparable velocities at the center of Drygalski Glacier's terminus as reported by Rott et al. (2015) (unfortunately the position of the profile is not plotted/provided in this paper). This plot is also added to the "Supplement" and an statement on this issue is added in the manuscript. Regarding the error estimates, geographic location see answers to reviewer comments below.

The velocities reported by Rott et al. (2014) at Sjögren, Pyke, Edgeworth and Drygalski glaciers are generally higher than our findings. The authors measured the velocities at locations near the center of the glacier fronts, where the ice flow velocities are typically highest, whereas we measured the median velocities at cross profiles close to the glacier fronts (Seehaus et al. 2015). The different approaches result in different absolute values, but comparable temporal trends in glacier flow speeds are observed by both author groups. For example Rott et al. (2015) presented surface velocity measured along a central flow line of Drygalski Glacier. Figure S75 shows our *surface velocity measurements across the terminus of Drygalski Glacier. Both studies show comparable values at the center of the terminus.*

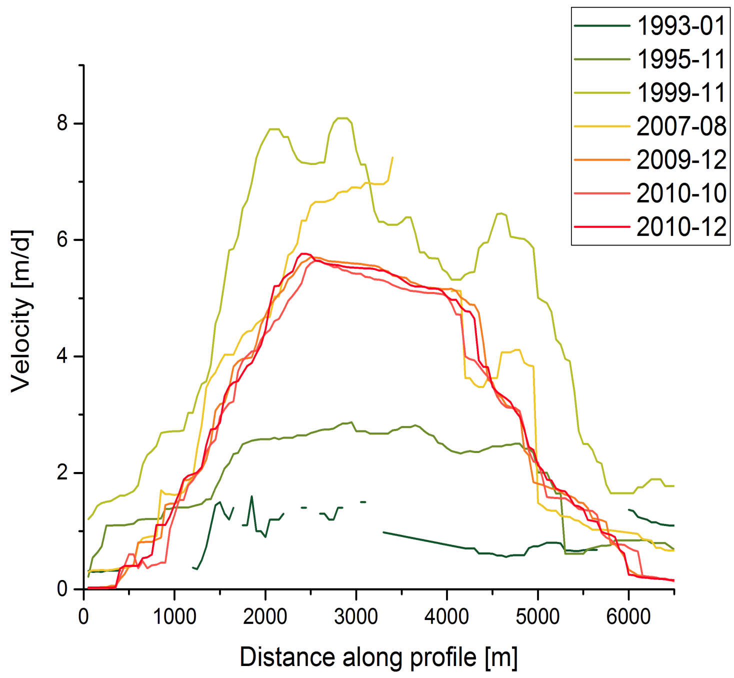

Figure S75: Surface velocity across the terminus of Drygalski Glacier

Regarding velocities, these are the main issues to be checked.
-Cross sections: Cross section poorly defined and not well visible in Fig.1. Possibly define in supplement the coordinates of profile start/end.

Since some of the profiles are kinked and not straight (coordinates of more than 2 points needs to be provided), we could provide the profiles as shapefiles in the supplement or upload them on PANGAEA (which is planed for some of the obtained results after acceptance of this manuscript)
(as the editor prefers).

-Median value: How does median compare to velocity profiles of glacier cross section near the terminus. From which statistical sample is the median selected (A certain area close to the front? How far inland? Does it vary with sensor & patch size?). Impact of different sensor resolution, impact of different tracking patches to be checked.

The median is calculated based on the velocity measurements extracted along the profiles, including a 200 m buffer zone around each profile for all sensors. We changed the wording to be clearer.

In order to reduce the number of data gaps along the profile due to pixel size data voids in the velocity fields, the velocity data is extracted within a buffer zone of 200 m around the profiles.

The results of the different patch sizes were stacked ("The results of each image pair are stacked by starting with the results of smallest tracking window size and filling the gaps with the results of the next biggest tracking window size.") and the step size of the tracking process and the geocoding parameters were adjusted in order to obtain velocity field with

100 m pixel spacing for all sensor. Information on this issue was added.

The results are then geocoded, orthorectified and converted into velocity fields (with 100m pixel spacing for all sensors) by means of the time span between the SAR acquisitions.

-Table 2: Specify patch size on ground (metre), or specify pixel size (range, azimuth) for each sensor.

As also requested by reviewer #1 we added a the nominal ground resolution of the sensors

-Error analysis (Section 3.2 and Supplement Table S2): The procedure applied for estimation of uncertainty seems to refer to the optimum case (smooth velocity fields and good temporal stability of the surface features). A rather generic procedure is applied for specifying the uncertainty of velocity fields, whereas the uncertainty estimates should be provided for the single numbers (median values) presented in the paper. The velocity cross sections near calving fronts outlet often show strong velocity gradients. For these cases large tracking templates (in particular for the sensors with comparatively low spatial resolution) cause increased uncertainty in velocity. The constant factor (C= 0.2) for specifying the accuracy of the tracking algorithm (P5L26) is a value for the optimum case. McNabb et al. (2012) use C = 1-2. The actual values of C can be quite different, depending on time span, spatial resolution of the sensor, and temporal stability of the surface features. Many data sets were acquired during the summer period (Table S2), when surface melt and possibly also temporary refreeze cause changes of amplitude features, impairing the quality of correlation products. Another point to be reconsidered for the uncertainty estimate (Eq. 1, P5L25) is the oversampling factor z which reduces the uncertainty significantly if independence between (partial) overlapping template patches is assumed (which is not the case). This factor is not clearly explained in the paper.

The reviewer is right, that the error due to the tracking algorithm depends on the template size as well as other parameters and can vary spatially, which is difficult to assess. McNabb et al. (2012)'s analysis is mainly based on optical satellite data and using manual feature tracking, which explains the different value of C. We selected the value of C=0.2 according to personal communication with the software provider (GAMMA Remote Sensing). Rignot et al. (2011) applied a value of "1/128th" (0.0078125) for speckle tracking, which has typically an order of magnitude higher accuracies as intensity tracking (Gray et al. 1998; DOI 10.1080/07038992.2001.10854936). Therefore, our estimate is quite conservative. Wuite et al. (2015) estimated the uncertainty to 0.2 to 0.3 pixels and their resulting uncertainties are quite similar to our estimations (Table 2).
We applied an oversampling factor of two (Seehaus et al. 2015) for the tracking windows (tracking chips), which is suggested by the software provider in order to increase the accuracy of the tracking process. We added a statement on this issue to be clearer.
Finally there is to say, that in several studies in this region no error estimates are provided for glacier velocities. Thus, to provide just "a rather generic" error estimation, addressing the ascertainable values, is better than no estimation (in our opinion).

The accuracy of the tracking algorithm is estimated to be 0.2 pixels and an oversampling factor z=2 is applied to tracking patches in order to improve the accuracy of the tracking process.

-The specified numbers of uncertainty for image coregistration (Table S2) apparently refer to full images, whereas the velocity data are derived from points near the coastline. Due to the lack of points on the ocean the coregistration accuracy near the coast lines might be impaired. The coregistration accuracy should be determined for the relevant image segments near the coast.

we stated in the paper (Section 3.2, P5) "single SAR image tiles acquired during the same satellite flyover are concatenated in the along-track direction.... to further improve the co-registration". At coastal regions this helps to increase the area land masses used for the co-registration. Moreover, the still remaining co-registration offset is measured on stable ground close to the coastline (glacier fronts) where most of the rock out crops and

nunataks are found. We adjusted the wording to be more precise.

Furthermore, single SAR image tiles acquired during the same satellite flyover are concatenated in the along-track direction. This helps to further improve the co-registration in coastal regions (by including more stable areas in the co-registration process) but also simplifies the analysis of the final results as no mosaicking of the results is needed......
The mismatch of the coregistration σ_v^C is quantified by measuring the displacement on stable reference areas close to the coast line, such as rock outcrops and nunataks.

Additional comments:
P1L12 'However...missing' -> the statement as written neglects previous research by various authors

This section was revised and this statement removed. See also comments by reviewer #1

The climatic conditions along the northern Antarctic Peninsula have shown significant changes within the last 50 years. Therefore we present a comprehensive analysis of temporally and spatially detailed observations of the changes in ice dynamics along both the east and west coastlines of this region.....

P1L17 'Whereat … trends' -> the statement as written implies that the ice shelf tributary glaciers also decelerated by something in the same order of 69% since 1992 which is not the case.

We revised this section to be clearer.

A dramatic acceleration after ice shelf disintegration with a subsequent deceleration is observed at most former ice shelf tributaries on the east coast, combined with a significant frontal retreat.

P8L10 'On ...1.6%' -> this is a very surprising number and requires explanation as it implies on average no change at all.

This is because some glaciers/sectors showed significant increase, whereas others showed a decrease. We added a statement, to point out that the changes in the individual sectors were significant. In the next lines the change values of the individual sectors are presented.

On average the ice flow in the study region increased by 1.6%, but the glaciers in the individual sectors showed on average significant change. Along the west coast an average acceleration by 41.5% occurred and the former ice shelf tributaries on the east coast accelerated by 16.8%. In the sector "East" the glaciers decelerated resulting in a mean velocity change of -69%. The presented average flow speed change values are based on the observed changes of all glaciers in the respective sector (Table S1), ignoring the different size of the individual glaciers.

P13L13 'Group 3' -> I assume Group 4 is meant here.

Thank you for this advice. The reviewer is right. We meant group 4 and corrected it.

Changes in glacier dynamics ~~at~~in the northern Antarctic Peninsula since 1985

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Abstract. The climatic conditions along the northern Antarctic Peninsula have shown significant changes within the last 50 years. ~~Therefore~~Here we present a comprehensive analysis of temporally and spatially detailed observations of the changes in ice dynamics along both the east and west coastlines of this region. Temporal trends of glacier area (1985-2015) and ice surface velocity (1992-2014) ~~changes~~ are derived from a broad multi-mission remote sensing database for 74 glacier basins on the northern Antarctic Peninsula (<65° S along the west coast and north of the Seal Nunataks on the east coast). A recession of the glaciers by 238.81 km² is found for the period 1985-2015, ~~whereas~~of which the glaciers affected by ice shelf disintegration showed the largest retreat by 208.59 km². Glaciers on the east coast north of the former Prince Gustav Ice Shelf extent in 1986 receded by only 21.07 km² and decelerated by about 69 % on average (1985-2015). ~~Whereas, the former ice shelf tributary glaciers on the east coast showed similar temporal ice dynamics trends.~~ A dramatic acceleration after ice shelf disintegration with a subsequent deceleration is observed at most former ice shelf tributaries on the east coast, combined with a significant frontal retreat. In 2014, the flow speed of the former ice shelf tributaries was 16.8 % higher than at the beginning of the study period. Along the west coast the average flow speeds of the glaciers increased by 41.5 %. However, the glaciers on the western Antarctic Peninsula revealed a strong spatial variability of the changes in ice dynamics. By applying a hierarchical cluster analysis we show that this is associated with the geometric parameters of the individual glacier ~~basin~~basins. The heterogeneous pattern of ice dynamic trends at the northern Antarctic Peninsula ~~points out~~shows that temporally and spatially detailed observations as well as further monitoring are necessary to ~~reveal the full picture of~~fully understand glacier change in regions with such strong topographic and climatic ~~gradients~~variances.

1 Introduction

During the last century, the Antarctic Peninsula (AP) has undergone significant warming (Carcass et al., 1998; Turner et al., 2005), leading to substantial glaciological changes. Skvarca et al. (1998) reported a significant increase in surface air temperatures at the north-eastern AP in the period 1960-1997 and correlated it with the recession of the Larsen and Prince-Gustav Ice shelves (Fig. 1) and the observed retreat of tidewater glaciers on James Ross Island in the period 1975-1995

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(Skvarca et al., 1995). However, a recent cooling trend on the AP was revealed by Oliva et al. (2017) and Turner et al. (2016) since the late 1990s. Shepherd et al. (2012) compiled a comprehensive glacier mass balance database of the polar ice sheets. The authors estimated a mass loss on the whole AP (<73° S) of -36±10 Gt a-1 for the period 2005-2010, which corresponds to 35% of the total mass loss of Antarctica. A projection of sea level rise contribution by the AP ice sheet amounts to 7-16 mm sea-level equivalent by 2100 and 10-25 mm by 2200 (Barrand et al., 2013a). However, along the western AP and on the higher elevation regions an increase in snow accumulation in the late 20th century was derived from ice cores (e.g. at Palmer Land, 73.59° S, 70.36° W, Thomas et al., 2008; Detroit Plateau, 64.08°S, 59.68° W, Potocki et al., 2011; at Bruce Plateau, 66.03°S, 64.07°W, Goodwind, 2013) and climate models (e.g. Dee et al., 2011), whereas van Wessem et al. (2016) obtained insignificant trends in precipitation.

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Numerous ice shelves along the AP (e.g. Larsen A/B, Prince Gustav and Wordie) have retreated widely or disintegrated in recent decades (Cook and Vaughan, 2010). As a consequence to the reduced buttressing, former tributary glaciers showed increased ice discharge and frontal retreat (e.g. De Angelis and Skvarca, 2003; Rack and Rott, 2004; Rignot et al., 2004; Seehaus et al., 2015; Wendt et al., 2010). For the northern AP (<66° S), a mass loss rate of -24.9±7.8 Gt a-1 was reported by Scambos et al. (2014) for the period 2003-2008, indicating that major ice mass depletion happened at the northern part of the peninsula, especially along the eastern side where numerous glaciers have been affected by ice shelf collapses. Seehaus et al. (2015, 2016) quantified the ice loss of former ice shelf tributaries. Mass loss rates of -2.14±0.21 Gt a^{-1} (1995-2014) and -1.16±0.16 Gt a^{-1} (1993-2014) were found at Dinsmoor-Bombardier-Edgeworth Glacier System and Sjögren-Inlet glaciers, respectively. Glaciers that were not terminating in an ice shelf also showed considerable changes. Cook et al. (2005, 2014) have analyzed the variations of tidewater glacier fronts since the 1940s. The authors reported that 90% of the observed glaciers retreated, which they partly attributed to atmospheric warming. A more recent study revealed a mid-ocean warming along the southwestern coast of the AP, forcing the glacier retreat in this region (Cook et al., 2016). Pritchard and Vaughan (2007) observed an acceleration of ice flow by ~12% along the west coast of the AP (1995-2005) and linked it to frontal retreat and dynamic thinning of the tidewater glaciers. Observations by Kunz et al. (2012) support this supposition. The authors analyzed surface elevation changes ~~at~~of 12 glaciers on the western AP based on stereoscopic digital elevation models (DEM) over the period 1947-2010. Frontal surface lowering was found at all glaciers, whereas~~,~~ area-wide surface lowering was observed on the north-eastern AP by various author groups (e.g. Berthier et al., 2012; Rott et al., 2014; Scambos et al., 2004; Wuite et al., 2015) as a consequence to ice shelf disintegration.

The collected observations suggest that the ice masses on the AP are contributing to sea level rise and show that glaciers' response to climate change on the AP is not homogeneous and that more detailed knowledge of various aspects on the glacier changes are required. Previous studies often ~~just~~only cover a specific period or region, or focus on one particular aspect of glacier change. Therefore, we study the changes in glacier extent in combination with detailed investigations on ice dynamics as well as other derived geometrical attributes of glaciers on the northern AP (<65° S along the west coast and north of the Seal Nunataks on the east coast, Fig. 1b colored polygons) between 1985 and 2015. We analyze various multi-mission remote sensing datasets in order to obtain methodologically consistent and temporally detailed time series of ice dynamic trends of 74 glacier basins. The observations are individually discussed for the sub regions, considering the different atmospheric, glaciological and oceanic conditions and changes.

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2 Study site

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The AP is the northern-most region of Antarctica. It covers only 3% of the entire continent in area, but receives 13% of the total mass input (van Lipzig et al., 2002, 2004). ~~The AP~~The AP's mountain chain (typically 1500-2000 m high) acts as an orographic barrier for the circumpolar westerly air streams leading to very high precipitation values on the west coast and on the plateau region of up to 5000 mm we yr −1, as well as frequent foehn type wind occurrences on the east coast (Cape et al., 2015, Marshall et al., 2006~~).~~, van Wessem et al. 2016). The foehn events are characterized by strong winds and high air temperatures. Consequently, the climatic mass balance (b_{clim}) shows a strong gradient across the mountain chain (Turner, 2002; van Wessem et al., 2016). ~~Apart~~Aside from those that are ice shelf tributaries, ~~nearly~~almost all glaciers on the AP are marine terminating, and ~~most~~the majority of the glacier catchments extend up to the high elevation plateau regions. ~~Usually~~Typically the AP plateau is separated from the outlet glaciers by escarpments and ice-falls. Glaciers on the west coast drain into the Bellingshausen Sea and on the east coast into the Weddell Sea. Since the 1980s, the ice shelves along the east coast have substantially recessed and disintegrated (Larsen Inlet in 1987-89, Prince Gustav and Larsen~~-~~ A in 1995~~, Larsen Inlet in 1987-89~~ and Larsen~~-~~ B in 2002) (Cook and Vaughan, 2010; Skvarca et al., 1999~~).~~), which Scambos et al. (2003) attributed ~~the retreat and collapse of ice shelves~~ to higher summer air temperatures and surface melt. A more recent study by Holland et al. (2015) discovered that significant thinning of the Larsen C Ice Shelf is caused by basal melting and that ungrounding from an ice rise and frontal recession could trigger its collapse. The northern AP has a maritime climate and is the only region of Antarctica that frequently experiences widespread surface melt (Barrand et al., 2013b; Rau and Braun, 2002).

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Our study site stretches ~~about~~approximately 330 km from the northern tip of the AP mainland southwards to Drygalski Glacier on the east coast and Grubb Glacier on the west coast (Fig. 1). This ~~narrow mountain chain~~facilitates the analyses of the long-term response (~20 years) of tributary glaciers to ice shelf disintegration at the former Larsen A and Prince-Gustav ice shelves on the east coast, the investigation of glaciers north of the former Prince-Gustav Ice Shelf, where no information on change in ice flow is currently available, and the comparison with temporal trends in ice dynamics along the west coast at the same latitude. The study region covers an area of ~11,000 km² with altitudes stretching from sea level up to 2220 m. The glacier basin delineations are based on the Antarctic Digital Database ADD 6.0 (Cook et al., 2014). Glacier names are taken from the Global Land Ice Measurements from Space (GLIMS) project database. The local GLIMS glacier IDs (e.g. TPE62, LAB2) are used for unnamed glaciers and further missing glacier basin names are substituted with the ADD 6.0 glacier IDs.

~~Some basins with lateral connected termini are merged and in~~Neighboring basins with coalescing ice flow at the termini are merged (many are already merged in the ADD 6.0), as the delineation of the individual glacier sections is not always possible and the width can vary temporally (due to changes in mass flux of the individual glaciers). In these cases, the names of the glaciers are also merged (e.g. Sikorsky-Breguet-Gregory – SBG, see Table 1 for abbreviations of glacier names). Due to the sparse data coverage~~,~~ (fewer than three good quality velocity measurements), no time series analysis of the glaciers at the northern tip of the AP or at some capes and peninsulas (e.g. Sobral Peninsula, Cape Longing) is possible. Therefore, the northern-most analyzed catchments are Broad-Valley Glacier on the east coast and TPE8 Glacier on the west coast, resulting in 74 studied glacier basins. Furthermore, the study region is divided into three sectors, taking into account the different climatic settings~~,~~ and drainage orientation ~~and~~as well as former ice shelf extent: sector “West” - Glaciers on the west coast, draining into the Bransfield and Gerlache Strait~~,~~; sector “East” – Glaciers on the east coast, draining into the Prince Gustav Channel; and sector “East-Ice-Shelf” – Glaciers on the east coast, that were former tributaries to the Larsen~~-~~ A, Larsen~~-~~ Inlet and Prince Gustav Ice Shelf.

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3 Data & Methods

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A large number of various remote sensing datasets are analyzed in order to obtain temporally and spatially detailed information on changes in ice dynamics in the study area. Glacier area changes are derived from satellite and aerial imagery. Repeat-pass Synthetic Aperture Radar (SAR) satellite acquisitions are used to compute surface velocity fields in order to obtain information on changes in glacier flow speed. Auxiliary data from sources such as a digital elevation model and glacier inventory are included in the further analyses and discussion of the results.

3.1 Area changes

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Changes in glacier area are derived by differencing glacier outlines from various epochs. All observed glaciers are tidewater glaciers and only area changes along the calving front were considered.

Information on the ~~position~~positions of the glacier fronts ~~at~~in the study region are taken from Cook et al. (2014), and are available for the whole AP in the ADD 6.0 (1945-2010). This coastal-change inventory is based on manually digitized ice front positions using imagery from various ~~satellite sensors~~satellites (e.g. Landsat, ERS) and aerial photo campaigns. This dataset is updated (up to 2015) and gaps are filled by manual mapping of the ice front positions based on SAR~~, Landsat~~ and ~~ASTER~~optical satellite images. ~~According to~~Consistent with Cook et al. (2014~~)~~), the ice-front positions are assigned to 5-year intervals in order to analyze temporal trends in glacier area changes in the period 1985-2015. Before 1985, only sparse information on ice front positions for the whole study region is available, and the coverage by SAR data for analyzing glacier flow starts in 1992. ~~The~~ Additionally, the analysis of the area changes for the Larsen~~-~~ A and Prince Gustav Ice Shelf tributaries is limited to the period 1995-2015, ~~since~~as the ice shelves disintegrated in 1995.

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The uncertainties of the glacier change measurements strongly depend on the specifications of the imagery used (e.g. spatial resolution, geodetic accuracies) as well as the methods used. To each record in the coastal-change inventory from the ADD 6.0, a reliability rating is assigned according to Ferrigno et al. (2006). The rating ranges from 1 to 5 (reliability within 60 m to 1 km) and takes into account errors due to manual digitization and interpretation (see Ferrigno et al., 2006 for a detailed description). This approach is also applied on the updated ice-front positions. Nearly all mapped ice fronts in the study region have a good reliability rating of 1 (76%) and 2 (21%). Only a few glacier fronts (3%) have a rating of 3. ~~Reliability~~No ice fronts with reliability ratings of 4 and 5 are ~~not applied~~mapped in the study area.

3.2 Surface velocities

Surface velocity maps are derived from repeat-pass Synthetic Aperture Radar (SAR) acquisitions. SAR image time series of the satellite missions ERS-1/2, Envisat, RadarSAT-1, ALOS, TerraSAR-X (TSX) and TanDEM-X (TDX) are analyzed, covering the period 1992-2014. Specifications of the SAR sensors are listed in Table 2. The large number of SAR images was provided by the German Aerospace Center (DLR), the European Space Agency (ESA) and the Alaska Satellite Facility (ASF). To obtain displacement fields for the glaciers, the widely used and well approved intensity offset tracking method is applied on co-registered single look complex SAR image pairs (Strozzi et al., 2002). In order to improve the co-registration of the image pairs, we mask out fast moving and unstable regions such as outlet glaciers and the sea~~.~~ during the co-registration processes. Furthermore, single SAR image tiles acquired during the same satellite flyover are concatenated in the along-track direction. This helps to further improve the ~~coregistration~~co-registration in coastal regions (by including more stable areas in the co-registration process) but also simplifies the analysis of the final results as no mosaicking of the results is needed. Image pairs with low quality ~~coregistration~~co-registration are filtered out. A moving window technique is used by the intensity offset tracking method to compute the cross-correlation function of each image patch and to derive its azimuth and slant range displacement. Less reliable offset measurements are filtered out by means of the signal-to-noise ratio of the normalized cross-correlation function. Moreover, we apply an additional filter algorithm based on a comparison of the magnitude and alignment of the displacement vector relative to its surrounding offset measurements. This technique removes more than 90% of incorrect measurements (Burgess et al., 2012). Finally, the displacement fields are transferred from slant range into ground range geometry, taking into account the effects on the local incidence angle by the topography~~,~~. The results are then geocoded, orthorectified and converted into velocity fields (with 100m pixel spacing for all sensors) by means of the time span between the SAR acquisitions. The mean date of the consecutive SAR acquisitions is assigned to each velocity field. The ASTER Global Digital Elevation Model of the Antarctic Peninsula (AP-DEM, Cook et al., 2012) is used as elevation reference. ~~The mean date of the consecutive SAR acquisitions is assigned to each velocity field~~It has a mean elevation bias of -4 m (±25m RMSE) from ICESat data and horizontal accuracy better than 2 pixels. It is currently the best available digital elevation model of the Antarctic Peninsula.

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Depending on the displacement rate and resolution of the SAR sensor, the tracking window size needs to be adapted~~.~~ (de Lange et al. 2007). For the fast flowing central glacier sections, larger window sizes are needed since large displacements cannot be tracked by using small correlation patches. Small tracking window sizes are suitable for the slow moving lateral sections of the outlet glaciers. Wide parts of large tracking patches cover the stable area next to the glacier, which biases the tracking results towards lower velocities. Consequently, we compute surface velocity fields of the same image pairs for different correlation patch sizes in order to get the best spatial coverage. Table 2 shows the different tracking window sizes for each sensor. The results of each image pair are stacked by starting with the results of smallest tracking window size and filling the gaps with the results of the next biggest tracking window size.

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The accuracy of the velocity measurements strongly depends on the coregistration quality and the intensity offset tracking algorithm settings. The mismatch of the coregistration $\sigma_v{}^C$ is quantified by measuring the displacement on stable reference areas~~, like~~ close to the coast line, such as rock outcrops and nunataks. Based on the Bedmap2 (Fretwell et al., 2013) and ADD 6.0 rock outcrop masks, reference areas are defined and the median displacements magnitude of each velocity field is measured at these areas. The uncertainty of the tracking process $\sigma_v{}^T$ is estimated according to McNabb et al. (2012) and Seehaus et al. (2015) depending on accuracy of the tracking algorithm C, image resolution $\cancel{\Delta x}dx$, oversampling factor z, time interval $\cancel{\Delta t}dt$.

$$\sigma_v^T = \cancel{\frac{C\Delta x}{z\Delta t}}\frac{Cdx}{zdt} \qquad (1)$$

The accuracy of the tracking algorithm is estimated to be 0.2 pixels and an oversampling factor z=2 is applied to tracking patches in order to improve the accuracy of the tracking process. Both independent error estimates are quadratically summed to compute the uncertainties of the individual velocity fields σ_v.

$$\sigma_v = \cancel{\sqrt{(\sigma_v^T)^2 + (\sigma_v^C)^2}}\sqrt{(\sigma_v^T)^2 + (\sigma_v^C)^2} \qquad (2)$$

~~Profiles are~~A profile is defined (red lines in Fig. 1) close to the terminus of each glacier basin, ~~taking into account~~behind the ~~temporal changes~~maximum retreat state of ice front position~~.~~ in the observation period. The results are visually inspected in order to remove unreliable measurements, based on the magnitude and direction ~~(relative to north direction)~~ of ice flow along the profiles~~ of each tracking result are visually inspected in order to check the quality~~. Datasets with partial profile coverage or large data gaps, as well as those with still remaining tracking errors, are rejected. The changes in the ice flow of each glacier are analyzed by measuring the surface velocities ~~within a buffer zone of 200m~~ along the profiles~~, in~~. In order to reduce the number of data ~~gap~~gaps along the profile due to pixel size data voids in the velocity fields, the velocity data is extracted within a buffer zone of 200 m around the profiles. To minimize the impact of potential outliers, median velocities along the profiles are calculated and the temporal trends are plotted. The glaciers are manually classified in six categories according to the temporal evolution of the ice flow speeds (see Table 3~~).~~), since automatic classification attempts did not succeed. Only glaciers with three or more~~ than two~~ observations and an observation period of more than 10 years are considered in the categorization, resulting in 74 categorized~~.~~ glacier basins (colored polygons in Fig. 1b. There is a minimum of seven velocity measurements per categorized basin and the shortest observation period is 14.83 years (see Table S1; average number of velocity measurements per glacier is 33.8 and average observation period is 19.40 years). The GAMMA Remote Sensing software is used for processing of the SAR data.

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3.3 Catchment geometries and settings

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Glacier velocities and area change measurements provide information on the ice dynamics of the individual glaciers. To facilitate a better and comprehensive interpretation of these observations, additional attributes regarding the different geometries and settings of the glaciers are derived. In addition to glacier attributes derived by Huber et al. (2017), we calculated the Hypsometric Index and the ratio of the flux gate cross section divided by the glacier catchment area.

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Mass input strongly affects the dynamics of a glacier. The climatic mass balance at the northern AP shows a strong spatial variability, with very high accumulation rates along the west coast, significantly lower values on the east coast and an increase towards higher altitudes along both coast lines (Turner, 2002; van Wessem et al. 2016). Consequently, the mass input depends on the elevation range and the hypsometry. For each glacier basin a Hypsometric Index (*HI*), defined by Jiskoot et al. (2009), is calculated by means of surface elevations from the AP-DEM. Based on this index the glaciers are grouped into the five categories according to Jiskoot et al. (2009), ranging from very top-heavy to very bottom heavy (Table 4). Moreover, the maximum elevations of the individual glacier catchments are derived from the AP-DEM, which represents the altitude range of the catchment, since all observed glaciers are marine terminating.

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In order to characterize the catchment shape, the ratios (*FA)* of the flux gate cross sections divided by the glacier catchment areas are calculated. The flux gates are defined along the profiles used for the glacier flow analysis (Section 3.2). Lower values of *FA* indicate a channelized outflow (narrowing towards the glacier front), whereas higher *FA* ratios imply a broadening of the glacier towards the calving front. Ice thickness at the flux gates is taken from the AP Bedmap dataset from Huss and Farinotti (2014).

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3.4 Cluster analysis

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The glaciers in the sector "West" (Fig. 1, red shaded area) show a heterogeneous pattern of ice dynamics as compared to the other sectors changes (Section 4.1, 4.2). In order to analyze the influence of the glacier geometries on the glaciological changes and to find similarities, a cluster analysis is carried out in sector "West". Variables of the glacier dynamics used are the derived area changes (in percent) and velocity changes (ratings of the categories, Table 3). The glacier geometry parameters used are the Hypsometric Indexes *HI*, maximum surface elevation h_{max} of the basin and the flux gate to catchment size ratio *FA*. The variables are standardized in the traditional way of calculating their standard scores (also known as z-scores or normal scores). It is done by subtracting the variables mean value and dividing by ~~it's mean absolute~~its standard deviation~~.~~ (Miligan and Cooper, 1988). Afterwards a dissimilarity matrix is calculated using the Euclidean distances between the observations (Deza and Deza, 2009). A hierarchical cluster analysis (Kaufman and Rousseeuw, 1990) is applied on the dissimilarities using Ward's minimum variance method (Ward, 1963). At the start, for each glacier a cluster is defined and then the most similar clusters are iteratively ~~joint~~joined until only one cluster is left. The distances between the clusters are updated in each iteration step by applying the Lance-~~Wiliams~~Williams algorithms (Lance and Williams, 1967).

4 Results

4.1 Area changes

Area changes relative to the measurements in the epoch 1985-1989 of ~~selected glaciers are plotted in Fig. 2 and of~~ all observed glaciers are plotted in Fig. S1-S74 (supplement). The glaciers are classified in three groups based on the latest area change ~~measurement~~measurements, which are illustrated in Fig. 2: retreat (Fig. 2a, b, c, f) – loss of glacier area by frontal retreat; stable (Fig. 2e) – no significant area changes (within the error bars); advance (Fig. 2d) – gain of glacier area by frontal advance. In Fig. 3 the spatial distribution of the area change classification is illustrated. All glaciers along the east coast, including the former ice shelf tributaries, retreated, whereas along the west coast, numerous glaciers show stable ice front positions and some glaciers even advanced. In total, 238 km² of glacier area was lost ~~at~~in the study ~~site~~region in the period 1985-2015, which corresponds to a relative loss of 2.2%. All sectors show glacier area loss (Table 5), of which the area loss by 5.7% at sector "East-Ice-Shelves" clearly dominates. The glaciers in sector "West" and "East" recessed by 0.2% and 1.4%, respectively. The temporal trends of total glacier area and area loss of all observed glaciers and of each sector are presented in Fig. 4. Catchment areas and changes between 1985 and 2015 of the individual basins are listed in Table S1 (supplement) and relative changes are illustrated in Fig. 5.

4.2 Surface velocities

~~In~~A total of 282 stacked and filtered velocity fields are derived from the SAR acquisitions covering the period from 25th December, 1992 until 16th December, 2014. The average total uncertainty of the velocity fields amounts to 0.08 ~~m d^{-1}.~~ ± 0.07 m d^{-1} and the values for each SAR sensor are provided in Table 2. In Table S2 (supplement) the error estimates of each velocity field are listed. The mean sample count to estimate the coregistration quality is 11717 and the average mismatch amounts to 0.07 m d^{-1}. The error caused by the tracking algorithm strongly varies depending on the source of the SAR data (sensor). A mean value of 0.05 m d^{-1} is found. ERS image pairs with time intervals of one day have very large estimated tracking uncertainties, ~~due to~~biased by the very short temporal baselines~~, and~~. Therefore, only the errors caused by the

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mismatch of the coregistration are ~~not~~ considered in the total error computations of the seven ERS tracking results with one day temporal baselines.

All measured velocity profiles of the 74 observed glaciers are visually inspected and ~~finally~~in total 2503 datasets passed the quality check (on average ~34 per glacier). Figure 2 shows by example the temporal evolution of the ice flow for each velocity change category (see Table 3). The temporal trends of the surface velocities at the termini of each glacier are plotted in Fig. S1-S74 (supplement) and the related categories are listed in Table S1 (supplement). The spatial distribution of the categories is illustrated in Fig. 3. At nearly all glaciers in sector "East-Ice-Shelf" a peak in ice velocities is observed. In the sector "East", most glaciers showed a decrease in flow velocities in the observation period. The glaciers on the west coast show a more irregular distribution than along the east coast, but ~~some~~a local clustering of accelerating glaciers can be observed at Wilhelmina Bay.

For each glacier the flow velocities in the first v_S and last year v_E of the observation period as well as the absolute and relative change dv is presented in Table ~~S2~~S1 (supplement). The mean values of v_S, ~~v_S~~v_E and dv of all analyzed glaciers and for each sector are listed in Table 5. On average the ice flow in the study region increased by 1.6~~%.~~%, but the glaciers in the individual sectors showed on average significant change. Along the west coast an average acceleration by 41.5% occurred and the former ice shelf tributaries on the east coast accelerated by 16.8%. In the sector "East" the glaciers decelerated resulting in a mean velocity change of -69%. The presented average flow speed change values are based on the observed changes of all glaciers in the respective sector (Table S1), ignoring the different size of the individual glaciers. The shortest observation period is 14.~~8~~83 years at DBC31 Glacier, the longest observation period is 21.99 years at TPE31 and Sjögren glaciers and on average velocity changes are analyzed over a period of 19.~~4~~40 years~~.~~ (σ = 1.97 years).

4.3 Catchment geometries and settings

The spatial distribution of Hypsometric Indexes and categories of the glacier basins is presented in Fig. 3 and the values are listed in Table ~~S2~~S1 (supplement). The HI values range between -4.6 and 9.1 (mean: 0.88, σ: 2.10). No clear spatial distribution pattern can be identified, reflecting the heterogeneous topography of the AP. The maximum elevation of the catchments and the *FA* factors are also listed in Table ~~S2~~S1 (supplement).

4.4 Cluster analysis

The resulting dendrogram of the hierarchical cluster analysis is plotted in Fig. 6. Four groups are distinguished. The boxplots of each input variable are generated based on this grouping and are shown in Fig. 7. The characteristics of the groups are discussed in Section 5.3.

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5 Discussion

Most of the observed glaciers (62%) retreated and only 8% advanced in the study period. These findings are comparable to the results of Cook et al. (2005, 2014, 2016). Only glaciers along the west coast showed stable or advancing calving fronts and all glaciers on the east coast receded since 1985. This heterogeneous area change pattern was also observed by Davies et al. (2012) on western Trinity Peninsula. Most significant retreat occurred in the sector "East-Ice-Shelf". In the period 1985-1995, the Larsen~~-~~ Inlet tributaries (APPE-glaciers) lost 45.0 km² of ice. After the disintegration of Prince-Gustav and Larsen~~-~~A Ice Shelf, the tributaries rapidly retreated in the period 1995-2005. The recession slowed down in the latest observation interval (2005-2010). This trend is comparable to detailed observations by Seehaus et al. (2015, 2016) at individual glaciers (DBE glaciers and Sjögren-Inlet glaciers). At sector "East" the highest area-loss is found in the earliest observation interval (1985-1990). Davies et al. (2012) also reported higher shrinkage rates for most of the glaciers in this sector in the period 1988-2001 than in the period 2001-2009. Moreover, slightly increased recession is also found in the time period (1995-2005, Fig. 4) at sector "East". ~~This could be indirectly caused by the disintegration of Larsen A and Prince Gustav ice shelves.~~ Davies et al. (2012) and Hulbe et al. (2004) ~~proposed~~supposed that the disintegration of an ice shelf affects the local climate. The air temperatures would rise due to the presence of more ice free water in summers. This might explain the slightly higher retreat rates at sector "East". At Base Marambio, ~100 km east of this sector, ~~about~~approximately 2°C higher mean annual air temperatures were recorded in the period ~~1997-2007~~1996-2005 as compared to the period ~~1985-1996 (e.g. Seehaus et al., 2015;~~ 1986-1995 (Oliva et al., 2017). Unfortunately, no temperature ~~records are~~data recorded within sector "East" is available ~~in sector "East"~~ covering this period that could be used to validate this theory.

The average changes of flow velocities at each sector also vary strongly (Table 5) in the observation period 1992-2014. On the west coast an increase of 42% is found, whereas in sector "East" the glaciers slowed down by ~~about~~approximately 69% and at the ice shelf tributaries the ice flow increased on average by 17%. Pritchard and Vaughan (2007) reported an increase in mean flow rate of 7.8% in frame 4923 (the central and much of the northern part of sector "West") and 15.2% in frame 4941 (the southern part of sector "West") for the period 1992-2005~~.~~ (frame numbers correspond to European Space Agency convention for identifying ERS coverage). This spatial trend corresponds to our observations, since most of the glaciers with a clear positive velocity trend are located at the southern end of sector "West". However, for the same observation period we ~~discovered~~derived a mean increase in flow velocity by 18.9 % in sector "West", which is an ~~about~~approximately 1.6 times higher acceleration. Pritchard and Vaughan (2007) estimated the mean velocity change by measuring the flow speed at profiles along the flow direction of the glacier, whereas we measured ~~at~~the velocity across glacier profiles at the terminus. If a tidewater glacier speeds~~-~~ up due to the destabilization of its front, the highest acceleration is found at the terminus (see Seehaus et al., 2015, Fig. 3). Consequently, the different profile locations explain the deviations between both studies.

In the following section the observed changes in the individual sectors are discussed in more detail.

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5.1 ~~East Ice Shelf~~

~~In the sector "East Ice Shelf" nearly all glaciers showed a rapid and significant acceleration after ice shelf break-up and a subsequent slow down (Fig. S14-S26, supplement). A gentle peak in flow speeds is obtained at LAB32 and TPE114 glaciers. They are classified as "stable", since the variations are below the threshold of 0.25 m d^{-1}, according to the categorization in Table 3. Dramatic speed up with subsequent deceleration of former ice shelf tributaries was reported by various authors; e.g. in this sector by Seehaus et al., (2015, 2016) at DBE and Sjögren-Inlet glaciers and further south at Larsen B embayment by Rott et al. (2011) and Wuite et al. (2015). The velocities reported by Rott et al. (2014) at Sjögren, Pyke, Edgeworth and Drygalski glaciers are generally higher than our findings. The authors measured at locations near the center of the glacier fronts, where the ice flow velocities are typically highest, whereas we measured the median velocities at cross profiles close to the glacier fronts. The different approaches result in different absolute values but equal temporal trends are observed in both studies. Highest peak values of 6.3 m d^{-1} are found at TPE61 Glacier in November 1995 and January 1996. Most glaciers (Arron Icefall, Drygalski, LAB2, TPE61, TPE62) decelerated towards pre-collapse values and show almost constant flow speeds in recent years, indicating that the glaciers adjusted to the new boundary conditions. At "2558", Boydell, DBE and Sjögren glaciers the deceleration is ongoing and Boydell and DBE glaciers still show increased median flow speeds at the glacier fronts. Thus, these tributary glaciers are still adjusting to the new boundary conditions, as suggested by Seehaus et al. (2015, 2016).~~

~~In the 1980s, Prince Gustav Ice Shelf gradually retreated (see Fig. 1) and "2668" Glacier has not been buttressed by the ice shelf since the early 1990s. A deceleration is found in the period 2005-2010 (Fig. S15, supplement). Hence, this glacier may also have experienced a speed up in the early 1990s due to the recession of Prince Gustav Ice Shelf in the 1980s. However, the earliest velocity measurement at "2668" Glacier is only available from February 1996.~~

~~The ice shelf in Larsen Inlet disintegrated in 1987-1988 and earliest velocity measurements are obtained in 1993. Therefore, a potential peak in the flow speed after ice shelf break-up cannot be detected at APPE glaciers (Fig. S16, supplement). The ice flow shows short term variations in the order of 0.2-0.5 m d^{-1} between 1993 and 2014, but no clear long term trend is obvious. Rott et al., (2014) also found nearly constant flow velocities at Pyke Glacier. The authors suggest that the ice flow of APPE glaciers was not strongly disturbed by the ice shelf removal due to the steep glacier surfaces and shallow seabed topography at the glacier fronts (Pudsey et al., 2001).~~

~~5.2~~ East

The glaciers north of the former Prince-Gustav Ice Shelf show a general trend towards lower flow velocities. Eyrie, Russell East, TPE130, TPE31, TPE32, TPE34, ~~TPE130~~ and "2731" glaciers experienced a rapid decrease and, except "2731" Glacier, a subsequent stabilization or even gentle acceleration of flow velocities~~.~~ (Fig. S2, S6, S7 and S9-S12). A significant

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Diplock and Victory glaciers (Fig. S5 and S13) show a decrease of flow speed during retreat followed by an acceleration combined with frontal advance. ~~This behavior is similar to surge~~Surge-type glaciers, found for example in Alaska – (tidewater ~~glacier –~~) (Motyka and Truffer, 2007; Walker and Zenone, 1988) or Karakoram ~~–~~(land terminating~~–~~) (Rankl et al., 2014~~). Surge-type glaciers~~), show similar behavior. They are characterized by episodically rapid down-wasting, resulting in a frontal acceleration and strong advance. ~~At~~Regarding tidewater glaciers the advance can be strongly compensated by increased calving rates in deepwater in front of the glacier. ~~Thus, both~~It is therefore possible that these glaciers may have experienced a surge cycle in our observation period; however, a longer time series analysis is necessary to prove this hypothesis.

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5.2 East-Ice-Shelf

In the sector “East-Ice-Shelf” the tributary glaciers in the Larsen A embayment (“2558”, Arron Icefall, DBE, Drygalski, LAB2, LAB32, TPE61 and TPE62; Fig. S14, S17, S19-S22, S25 and S26) and Sjögren-Inlet (Boydell, Sjögren and TPE114; Fig. S18, S23 and S24) lost the downstream ice shelves in 1995. Nearly all glaciers showed a rapid and significant acceleration after ice shelf break up and a subsequent slow down. A gentle peak in flow speeds is obtained at LAB32 and TPE114 glaciers. They are classified as “stable”, since the variations are below the threshold of 0.25 $m\ d^{-1}$, according to the categorization in Table 3. Dramatic speed up with subsequent deceleration of former ice shelf tributaries was reported by various authors; e.g. in this sector by Seehaus et al., (2015, 2016) at DBE and Sjögren-Inlet glaciers and further south at Larsen B embayment by Rott et al. (2011) and Wuite et al. (2015). The velocities reported by Rott et al. (2014) at Sjögren, Pyke, Edgeworth and Drygalski glaciers are generally higher than our findings. The authors measured the velocities at locations near the center of the glacier fronts, where the ice flow velocities are typically highest, whereas we measured the median velocities at cross profiles close to the glacier fronts (Seehaus et al. 2015). The different approaches result in different absolute values, but comparable temporal trends in glacier flow speeds are observed by both author groups. For example Rott et al. (2015) presented surface velocity measured along a central flow line of Drygalski Glacier. Figure S75 shows our surface velocity measurements across the terminus of Drygalski Glacier. Both studies show comparable values at the center of the terminus.

Highest peak values of 6.3 $m\ d^{-1}$ are found at TPE61 Glacier in November 1995 and January 1996. Most glaciers (Arron Icefall, Drygalski, LAB2, TPE61, TPE62) decelerated towards pre-collapse values and show almost constant flow speeds in recent years, indicating that the glaciers adjusted to the new boundary conditions. At “2558”, Boydell, DBE and Sjögren glaciers the deceleration is ongoing and Boydell and DBE glaciers still show increased flow speeds at the glacier fronts. We suppose that these tributary glaciers show a prolonged response to ice shelf disintegration, caused by local settings (e.g. bedrock topography or fjord geometry), and are still adjusting to the new boundary conditions, as suggested by Seehaus et al. (2015, 2016).

In the 1980s, Prince Gustav Ice Shelf gradually retreated (see Fig. 1) and “2668” Glacier (Fig. S15) has not been buttressed by the ice shelf since the early 1990s. A deceleration is found in the period 2005-2010. Hence, this glacier may also have experienced a speed up in the early 1990s due to the recession of Prince Gustav Ice Shelf in the 1980s. However, the earliest velocity measurement at “2668” Glacier is only available from February 1996.

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The ice shelf in Larsen Inlet disintegrated in 1987-1988 and earliest velocity measurements are obtained in 1993. Therefore, a potential peak in the flow speed after ice shelf break-up cannot be detected at APPE glaciers (Fig. S16). As for “2668” Glacier no sufficient cloud free coverage by Landsat imagery is available which facilitates the computation of surface velocities for the 1980s. The ice flow at APPE glaciers shows a nearly stable trend with short term variations in the order of 0.2-0.5 m d^{-1} between 1993 and 2014. Rott et al., (2014) also found nearly constant flow velocities at Pyke Glacier. The authors suggest that the ice flow of APPE glaciers was not strongly disturbed by the ice shelf removal due to the steep glacier surfaces and shallow seabed topography at the glacier fronts (Pudsey et al., 2001).

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5.3 West

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Meredith and King (2005) reported an increase of surface summer temperatures by more than 1°C in the ocean west of the AP since the 1950s. The authors attributed this to atmospheric warming and reduced sea ice production rates. However, Cook et al. (2016) reported cool ocean temperatures along the north-western AP for the period 1945-2009, and an absence of the atmospheric warming, especially pronounced at the northern AP, since the turn of the millennium was found by Oliva et al. (2017) and Turner et al. (2016~~).~~), which correlates with an increase of sea ice concentration and the cool ocean temperatures at the northern AP. Thus, the climatic conditions do not show a spatially and temporally constant trend. Moreover the glacier geometries differ strongly, and especially in the southern part of ~~the study region,~~sector “West”, the coastline is ~~dominated by a fractal structure. This~~more jagged. These factors ~~lead to~~cause the heterogeneous pattern of area and flow speed changes in sector “West” as compared to the eastern sectors.

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Kunz et al. (2012) observed thinning at the glacier termini along the western AP~~.~~, by analyzing airborne and spaceborne stereo imagery in the period 1947-2010. Two of the twelve studied glaciers are located within our study area; Leonardo Glacier (1968-2010) and Rozier Glacier (1968-2010). An acceleration and terminus retreat can be caused by ~~this process~~frontal thinning as shown by Benn et al. (2007). However, ~~the authors~~Benn et al. (2007) also point out that changes in ice thickness do not necessarily affect the ice flow and that calving front positions and ice dynamics are strongly dependent on the fjord and glacier geometries, derived from modeling results which have higher uncertainties especially for smaller basins.

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The large number of glaciers in this sector is analyzed by means of a hierarchical cluster analysis (Section 3.4) and assorted into four groups based on the dissimilarities, resulting in the dendrogram plotted in Fig. 6. Boxplots of the individual input variables of each group are shown in Fig. 7. The correlation between the observed ice dynamics and the glacier geometries of each group are discussed in the following sections (see also Fig. 7).

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Group1 (14 glaciers):

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Most glaciers experienced ~~an~~ acceleration over the study period. The majority of the glacier basins are "very top-heavy" or "top-heavy" (median HI = -1.8), stretching from sea level up to 1892 m on average. The b_{clim} increases toward higher altitudes (van Wessem et al., 2016) and highest values are found in regions between 1000 and 1700 m a.s.l.. Consequently these glaciers receive high mass input in their large high altitude accumulation regions. The accumulation is known to have significantly increased on the AP by 20% since 1850 (Thomas et al., 2008). Pritchard and Vaughan (2007) reported that only a small fraction of the acceleration can be attributed to glacier thickening due to increased mass input. Up-glacier thickening combined with frontal thinning (reported by Kunz et al., 2012) leads to a steepening of the glacier and an increase in driving stress, resulting in faster ice flow (Meier and Post, 1987) as observed in this study. Moreover, a thinning of the terminus reduces the effective basal stress of a tidewater glacier and facilitates faster ice flow (Pritchard and Vaughan, 2007). The flux gate cross sections to catchment size ratios are relatively small, indicating narrowing catchments towards the ice front. The channelized increased ice flow almost compensates for the increased calving rates (due to frontal thinning), resulting in an average shrinkage of the glaciers by only 0.2% in the period 1985-2015. The high flow speeds may outweigh the calving and lead to ice-front advances as measured at Krebs and TPE46 Glacier. The glacier termini of this group are typically located in narrow fjords (Fig. 5) and are clustered in Charcot, Charlotte and Andvord Bay.

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Group 2 (19 glaciers)

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Glaciers of group 2 are spread all over the study region, with a local clustering in Wilhelmina Bay. Group 2 shows similar h_{max} and FA characteristics to group 1. Area changes are also quite small (-0.1%). Most of the glaciers experienced positive or "peaked" velocities trends. In contrast to group 1 the catchments are in general "bottom-heavy" and some are even "very bottom-heavy". We assume that the constraints are similar to group 1 (increasing b_{clim}, frontal thinning and steepening). However, the additional mass accumulation in the upper regions is smaller due to the "bottom-heavy" glacier geometries. Consequently, the imbalance due to the frontal thinning and up-glacier mass gain is less pronounced as in group 1 and numerous glaciers ("peak" type) started to decelerate after the speed-up, indicating that these glaciers are adjusting to the new boundary conditions.

Group 3 (13 glaciers)

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These basins typically show a "bottom-heavy" hypsometry and smaller elevation ranges (in average up to 1103 m a.s.l.). Thus, b_{clim} is relatively low. The smaller mean ice thickness at the termini (161 m, compared to 211 m of all glaciers) of group 3 implies less interaction with the ocean, leading to a small average frontal retreat of ~0.1%. The low frontal ablation does not significantly affect the ice flow, probably due to the flat glacier topography and the low mass input. Consequently, the flow speed is in general stable or even slightly decreases in the observation period. Glaciers of group 3 usually face the open ocean, and do not terminate in narrow fjords (especially in the northern part, Trinity Peninsula).

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Group 4 (3 glaciers)

All basins in this group have a "very bottom-heavy" hypsometry and an elevation range comparable to group 3 glaciers. The *FA* factors are in general higher than in group 3, implying that outflow of the catchments is less channelized and the glacier fronts are long compared to the catchment sizes. Therefore, the largest relative area changes, in average -5.1%, are found at glaciers in group 4. However, the absolute frontal retreat is small and does not significantly affect the glacier flow. Note: Group ~~3~~4 consists of only three samples, limiting the significance.

6 Conclusions

Our analysis expands on previous work on ice dynamic changes ~~at the north-western AP~~along the west coast of AP between TPE8 and Bagshawe-Grubb Glacier, both in regard to temporal coverage and analysis ~~method~~methods. It also spatially extends previous work on changes in ice ~~dynamic to~~dynamics along the ~~whole~~ east coast ~~north of 65° S.~~between Eyrie Bay and the Seal Nunataks. The spatially and temporally detailed analysis of changes in ice flow speeds (1992-2014) and ice front positions ~~revealed different~~(1985-2015) reveal varying temporal trends in glacier dynamics along the northern AP~~ in the period 1985-2015~~. The results are in general in line with findings of the previous studies, however along the west coast ~~significantly~~ higher glacier flow was determined and on the eastern side trends in ice dynamics of ~~numerous~~21 glaciers were observed for the first time. A large variety of temporal trends in glacier dynamics were observed in our study region and attributed to different forcing and boundary conditions.

On the east side all glacier fronts retreated in the study period~~,~~ (relative to 1985), with highest retreat rates observed at former tributaries of the Prince Gustav, Larsen Inlet and Larsen~~-~~ A ice shelves~~.~~ (relative to the year of ice shelf disintegration). Moreover, nearly all the glaciers affected by ice shelf disintegration showed similar temporal trends of ice velocities. The glaciers reacted with a strong acceleration to ice shelf break up followed by a deceleration, indicating that the glaciers adjusted or are still adjusting to the new boundary conditions. Glaciers on the east coast north of the former Prince Gustav Ice Shelf showed in general a significant deceleration and a reduction in frontal ablation. Based on the observed warming trend since the 1960s and the subsequent cooling since ~~2000~~the mid-2000s in~~ on~~ the northern AP, we conclude that the initial recession and speed up of the glaciers took place before the start of our observation and that the glaciers are now close to a new equilibrium.

The average flow speed of the glaciers along the west coast of the Antarctic Peninsula significantly increased in the observation period but the total frontal change was negligible. No general pattern is obvious in the ice dynamic changes. However, correlations between the changes in ice dynamics and the glacier geometries of the individual catchments were

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obtained by applying a hierarchical cluster analysis. Thus, the geometry of the individual glacier basin ~~significantly~~strongly affects the reaction of the glacier to external forcing.

We conclude that for regions with such a strong spatial variation in topographic and climatic parameters as the AP, it is impossible to derive a regional trend in glacier change by ~~just~~simply analyzing ~~single~~individual glaciers in this region. Therefore further detailed observation of the~~ current~~ glaciological changes along the AP is needed. Future activities should link remote sensing derived ice dynamics and glacier extent with ocean parameters and ocean models, as well as ~~results of~~ regional climate models ~~or~~and ice dynamic models, in order to provide a better quantification of mass changes ~~as well as~~and physical processes leading to the observed changes.

Author contributions. T.S. designed the study, processed the SAR data, performed the data analysis and led the writing of the manuscript, in which he received support from all authors. A.C. and A.S. compiled and provided glacier front position data sets. MB initiated the project and coordinated the research.

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Competing interests. The authors declare no competing financial interests.

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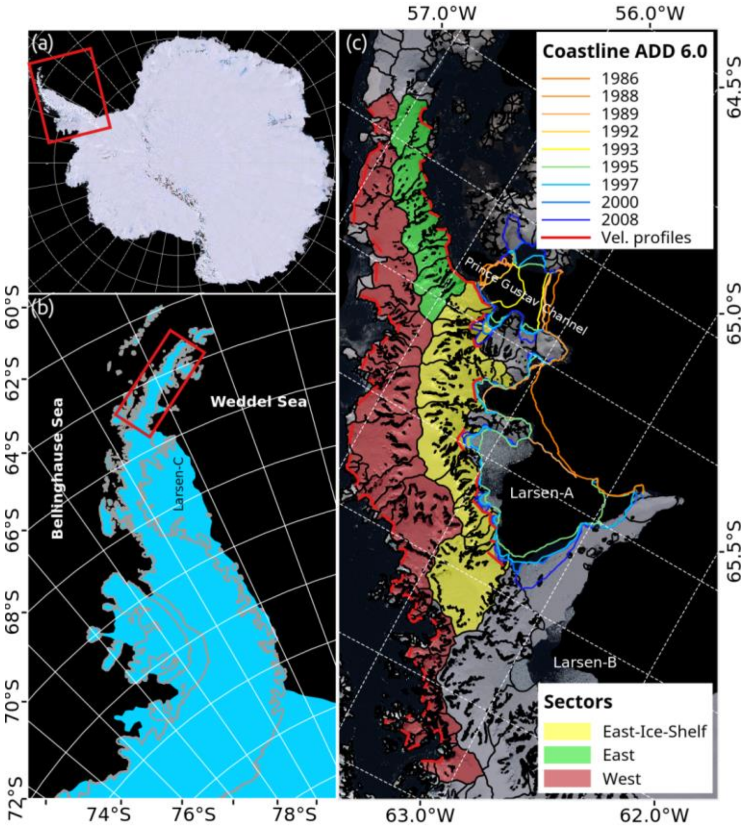
Figures



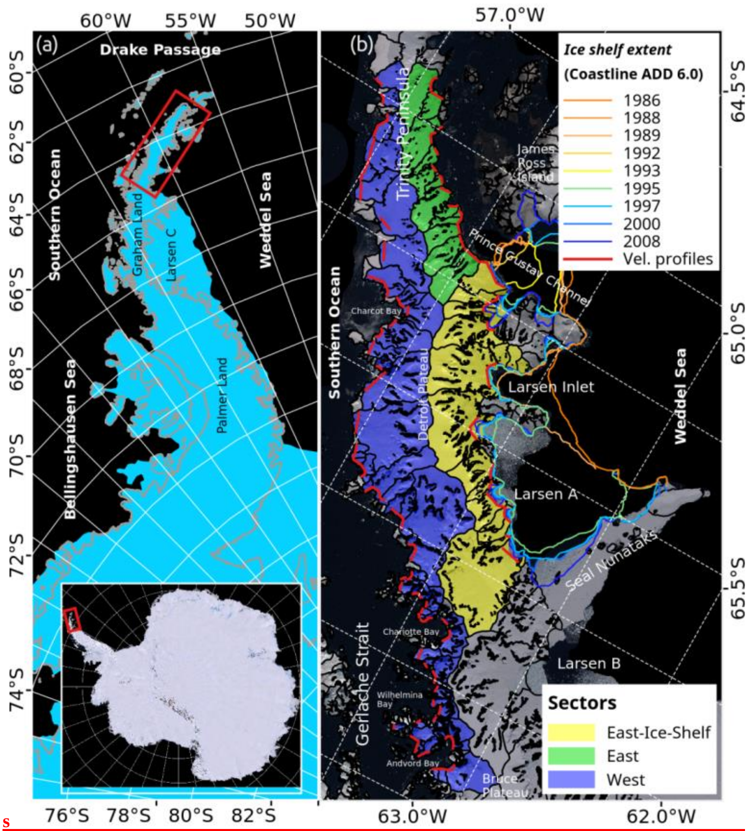


Figure 1. Panels **(a)** ~~and (b).~~ Location of study site on the Antarctic Peninsula~~.~~ and on the Antarctic continent (inset). Panel **(~~c~~b)**. Separation of study site in 3 sectors and retreat states of Prince-Gustav and Larsen~~-~~ A ice shelves. Red lines: profiles at glacier front for velocity measurements. Map base, Landsat LIMA Mosaic © USGS, NASA, BAS, NSF, coastlines (ice shelf extent) and catchment delineations from SCAR Antarctic Digital Database 6.0.

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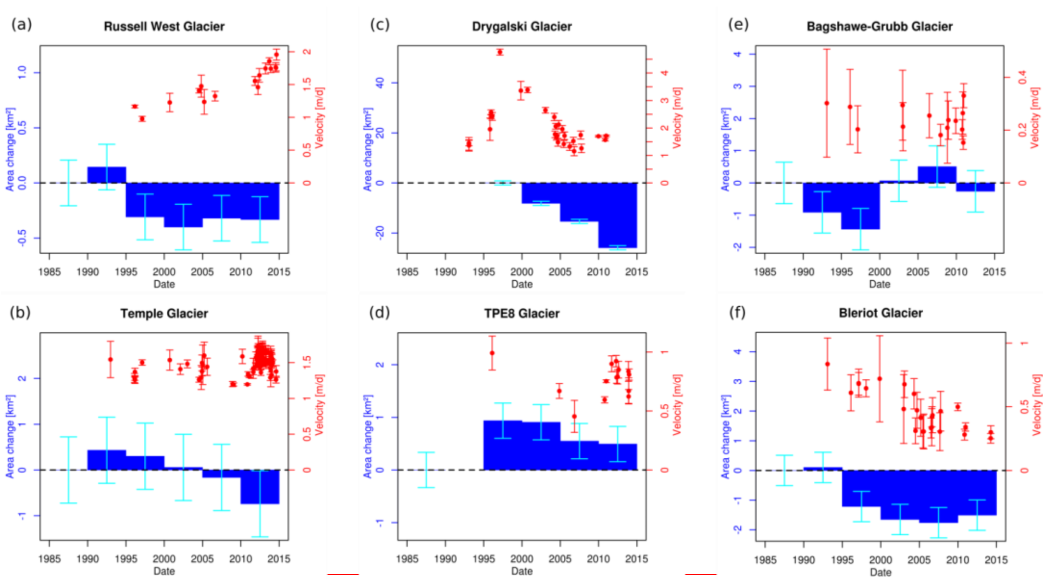

(a)
Russell West Glacier
(b)
Temple Glacier
(c)
Drygalski Glacier
(d)
TPE8 Glacier
(e)
Bagshawe-Grubb Glacier
(f)
Bleriot Glacier
Area change [km²]
Velocity [m/d]
Date

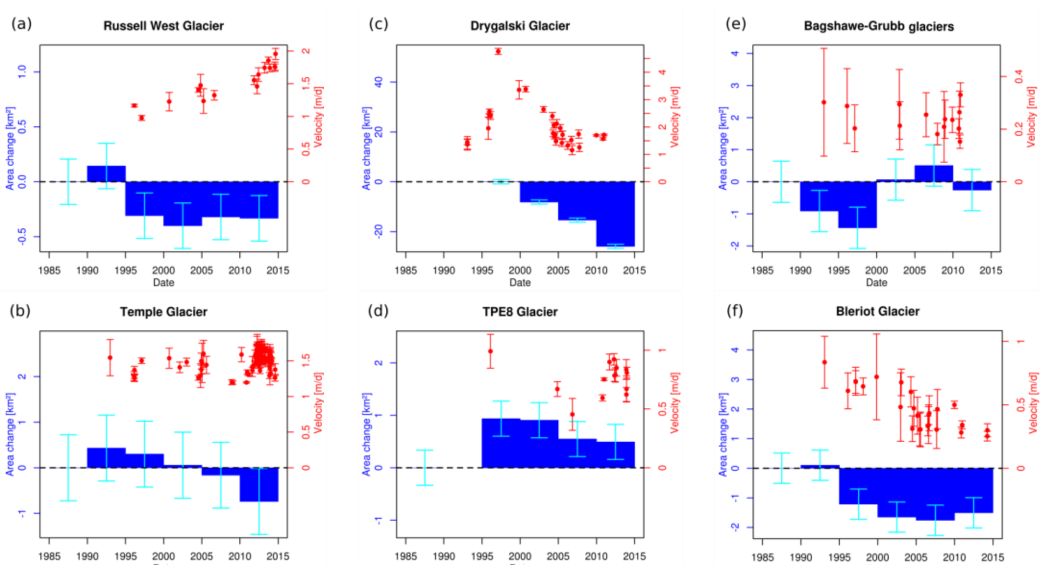
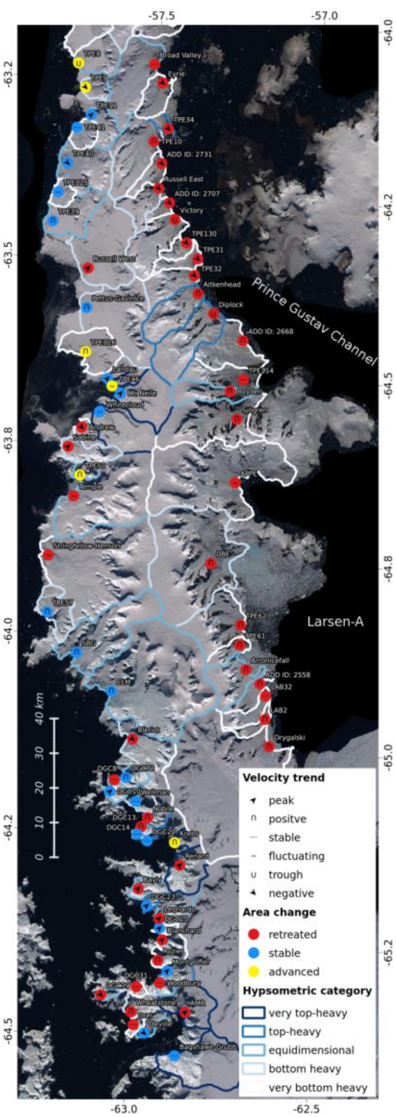

(a)
Russell West Glacier
(b)
Temple Glacier
(c)
Drygalski Glacier
(d)
TPE8 Glacier
(e)
Bagshawe-Grubb glaciers
(f)
Bleriot Glacier
Area change [km²]
Velocity [m/d]
Date

Figure 2. Temporal trend of surface velocity (red) and area (blue) changes of selected glaciers in the study region~~.~~ for each velocity change category (see Table 3).



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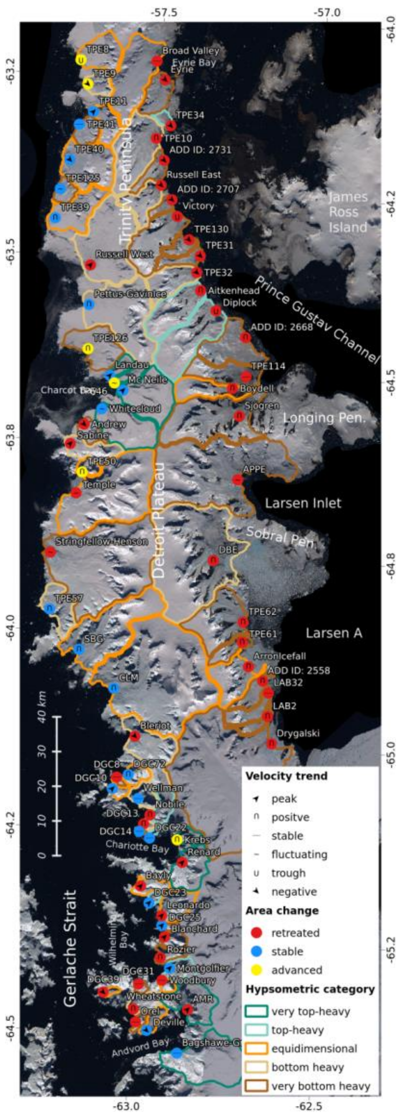
-57.5
-57.0
-64.0
-63.2
-64.2
-63.5
-64.5
-63.8
-64.8
-64.0
-65.0
-64.2
-65.2
-64.5
-63.0
-62.5
TPE8
TPE9
TPE11
TPE41
TPE40
TPE125
TPE39
Broad Valley
Eyrie Bay
Eyrie
TPE34
TPE10
ADD ID: 2731
Russell East
ADD ID: 2707
Victory
TPE130
TPE31
TPE32
Trinity Peninsula
James Ross Island
Russell West
Pettus-Gavinice
Aitkenhead
Diplock
Prince Gustav Channel
ADD ID: 2668
TPE126
Landau
TPE114
Mc Neile
Boydell
Whitecloud
Sjogren
Longing Pen.
Andrew
Sabine
TPE50
Temple
APPE
Larsen Inlet
Detroit Plateau
Stringfellow-Henson
Sobral Pen.
DBE
TPE57
TPE62
TPE61
Larsen A
SBG
Arronlcefall
ADD ID: 2558
CLM
LAB32
LAB2
40 km
30
20
10
0
Bleriot
Drygalski
DGC8
DGC72
DGC10
Wellman
Nobile
DGC13
DGC14
DGC22
Krebs
Charlotte Bay
Renard
Bayly
DGC23
Leonardo
DGC25
Blanchard
Rozier
Gerlache Strait
Wilhelmina Bay
Montgolfier
DGC31
DGC39
Woodbury
Wheatstone
AMR
Orel
Deville
Andvord Bay
Velocity trend
peak
positve
stable
fluctuating
trough
negative
Area change
retreated
stable
advanced
Hypsometric category
very top-heavy
top-heavy
equidimensional
bottom heavy
very bottom heavy

Figure 3. Categorizations of glaciers to temporal trends in area changes (dots) and flow velocities (symbols). Colors of catchment delineation indicate Hypsometric categories according to Jiskoot et al. (2009). Background: Landsat LIMA Mosaic © USGS, NASA, BAS, NSF

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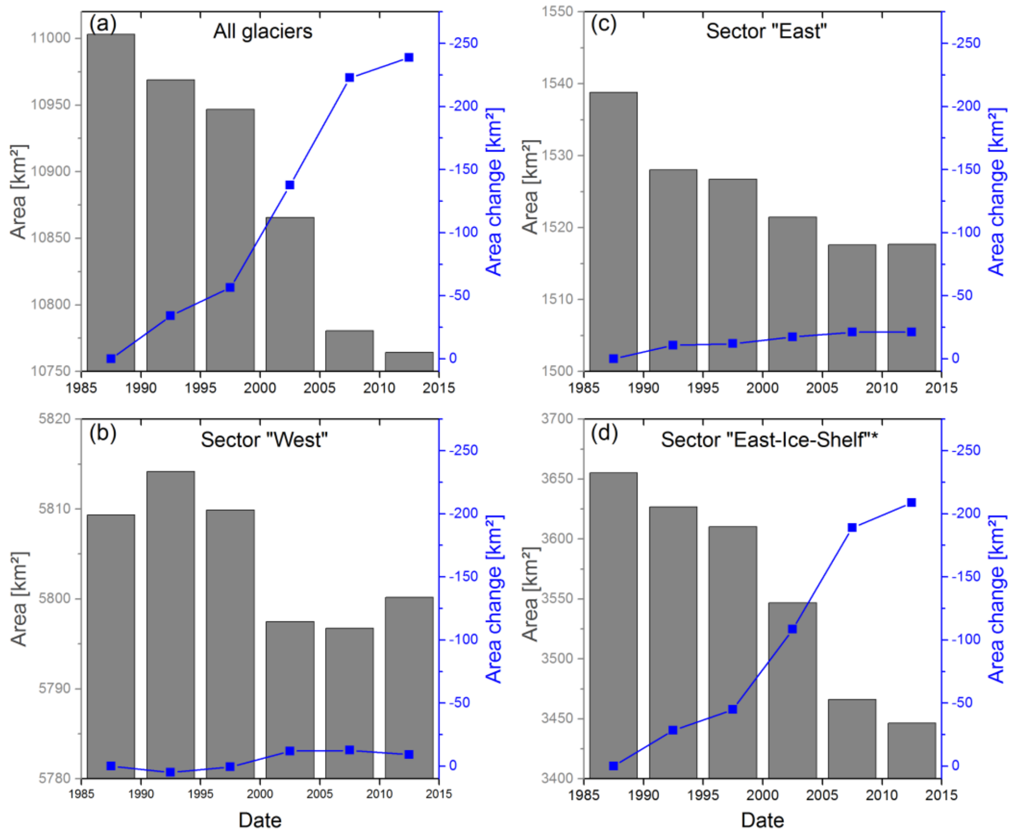

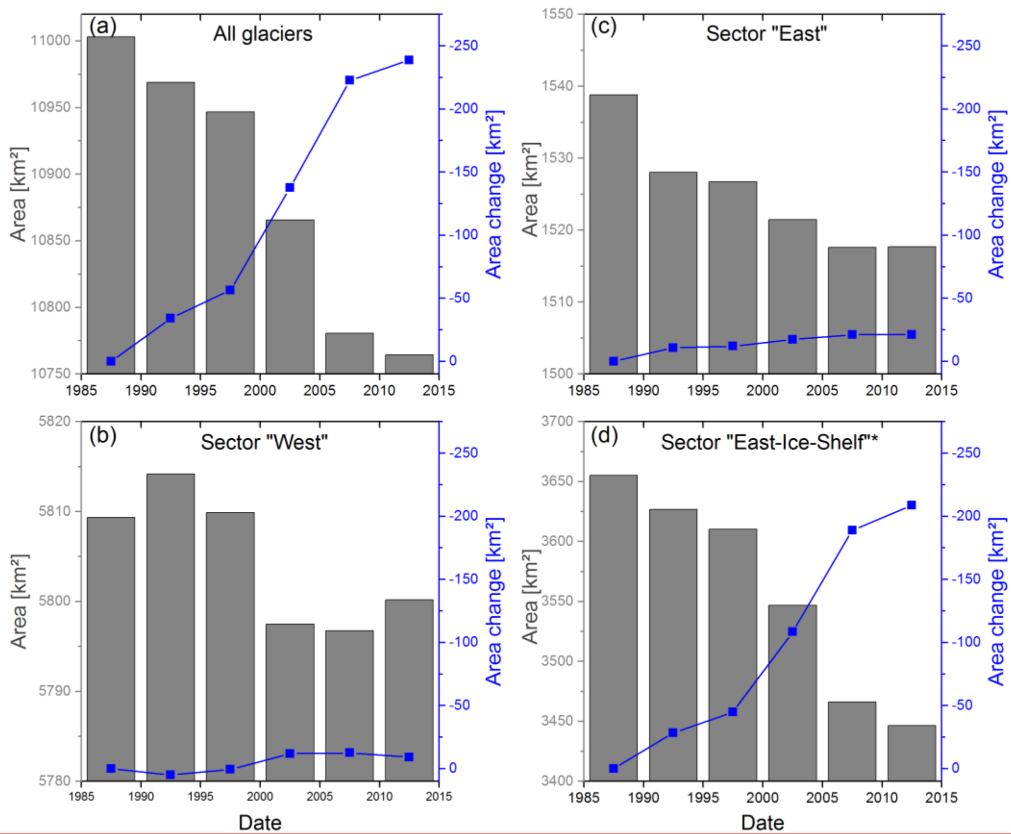

Figure 4. Total glacier area (gray bars) of the whole study site (Panel **(a)**) and of the individual sectors (Panels **(b)**-**(d)**) in the period 1985-2015. Changes in glacier area (blue points) are relative to the measurements in time interval 1985-1990. Note the different scaling of the lest y-axes. In sector "East", area changes before 1995 are only measured at Larsen- Inlet tributaries (APPE glaciers).

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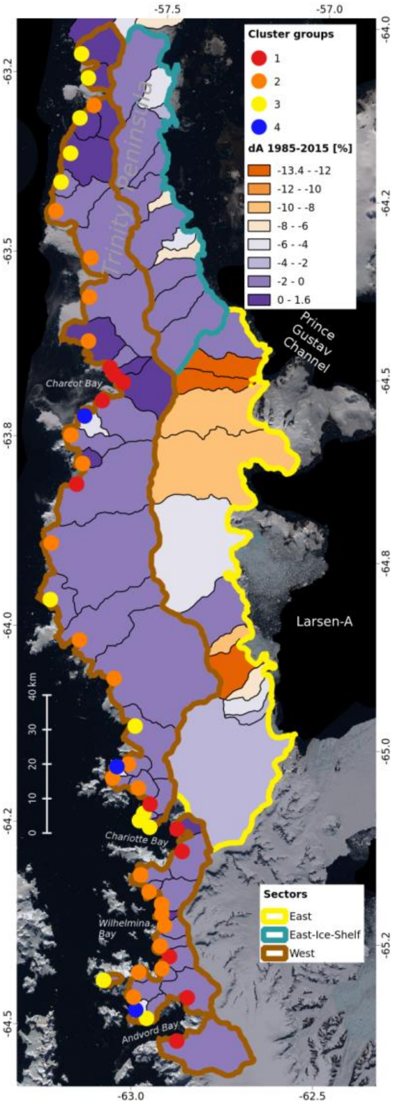

-57.5
-57.0
-64.0
-63.2
Cluster groups
1
2
3
4
dA 1985-2015 [%]
-13.4 - -12
-12 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 1.6
Trinity Peninsula
-64.2
-63.5
Prince Gustav Channel
Charcot Bay
-64.5
-63.8
-64.8
Larsen-A
-64.0
40 km
30
20
10
0
-65.0
-64.2
Charlotte Bay
Sectors
East
East-Ice-Shelf
West
Wilhelmina Bay
-65.2
-64.5
Andvord Bay
-63.0
-62.5

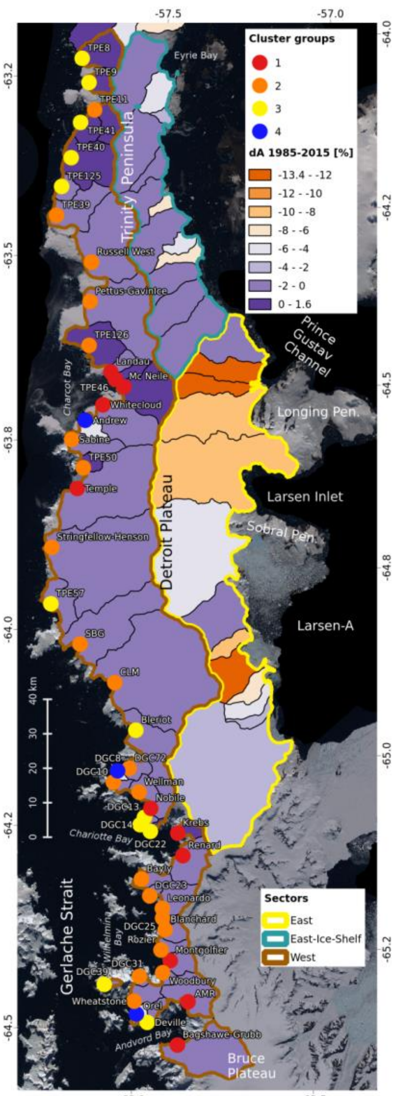

Figure 5. Spatial distribution of glacier types along the west coast. Glaciers are group based on a hierarchical cluster analysis (dots). In Section 5.3 the characteristics of the groups are discussed in detail. ~~Catchment~~Individual glacier catchment colors: relative area change in

the period 1985-2015. Colored ~~polygons:~~ polygon outlines: Boundaries of the three regional sectors. Background: Landsat LIMA Mosaic © USGS, NASA, BAS, NSF.

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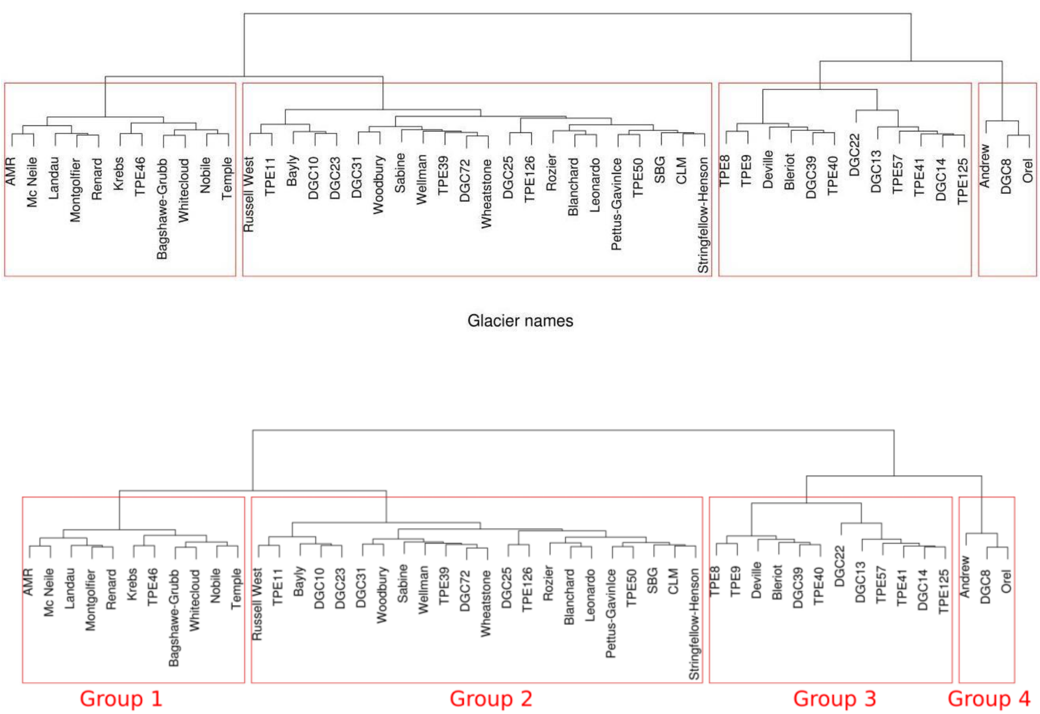

Figure 6. Dendrogram of hierarchical cluster analysis of glaciers in sector "West". The glaciers are assorted in four groups (red rectangles). ~~In~~See also Section 5.3~~the characteristics of the groups are discussed in detail~~.

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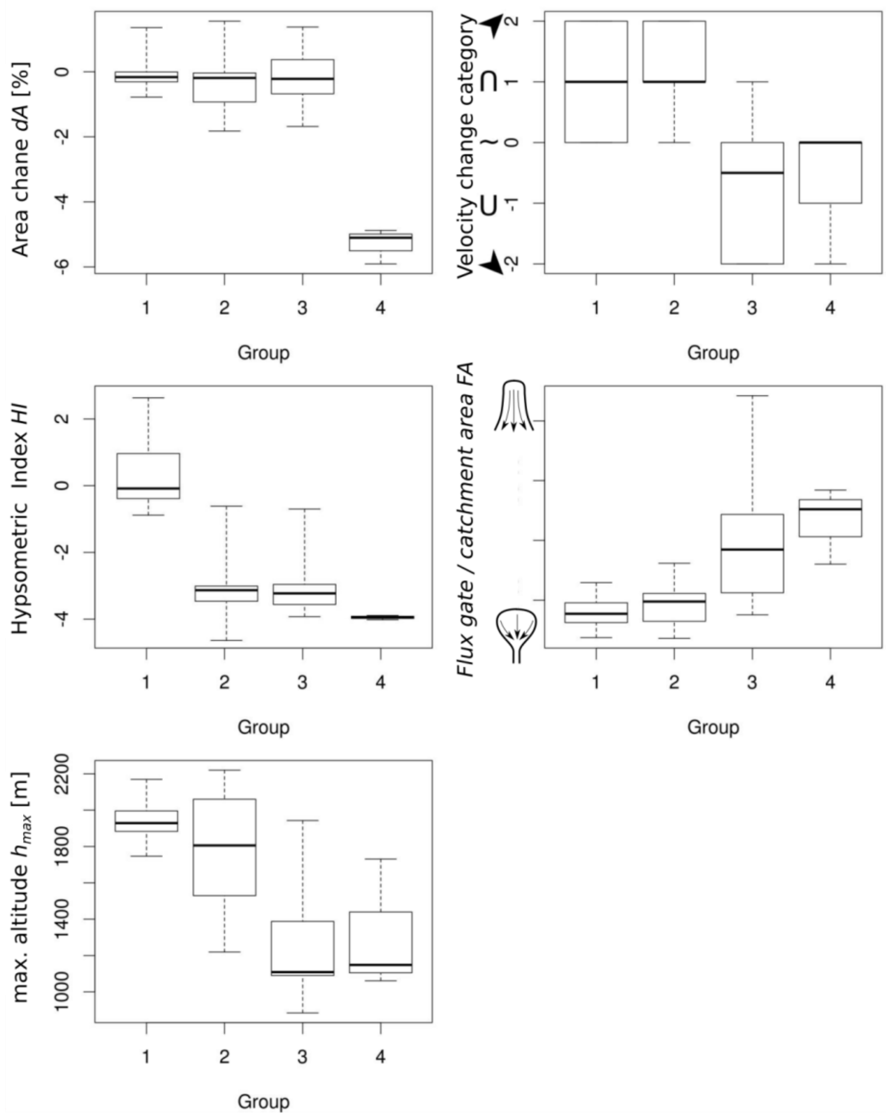

Area chane dA [%]
0
-2
-4
-6
1
2
3
4
Group
Velocity change category
2
1
0
-1
-2
1
2
3
4
Group
Hypsometric Index HI
2
0
-2
-4
1
2
3
4
Group
Flux gate / catchment area FA
1
2
3
4
Group
max. altitude h_{max} [m]
2200
1800
1400
1000
1
2
3
4
Group

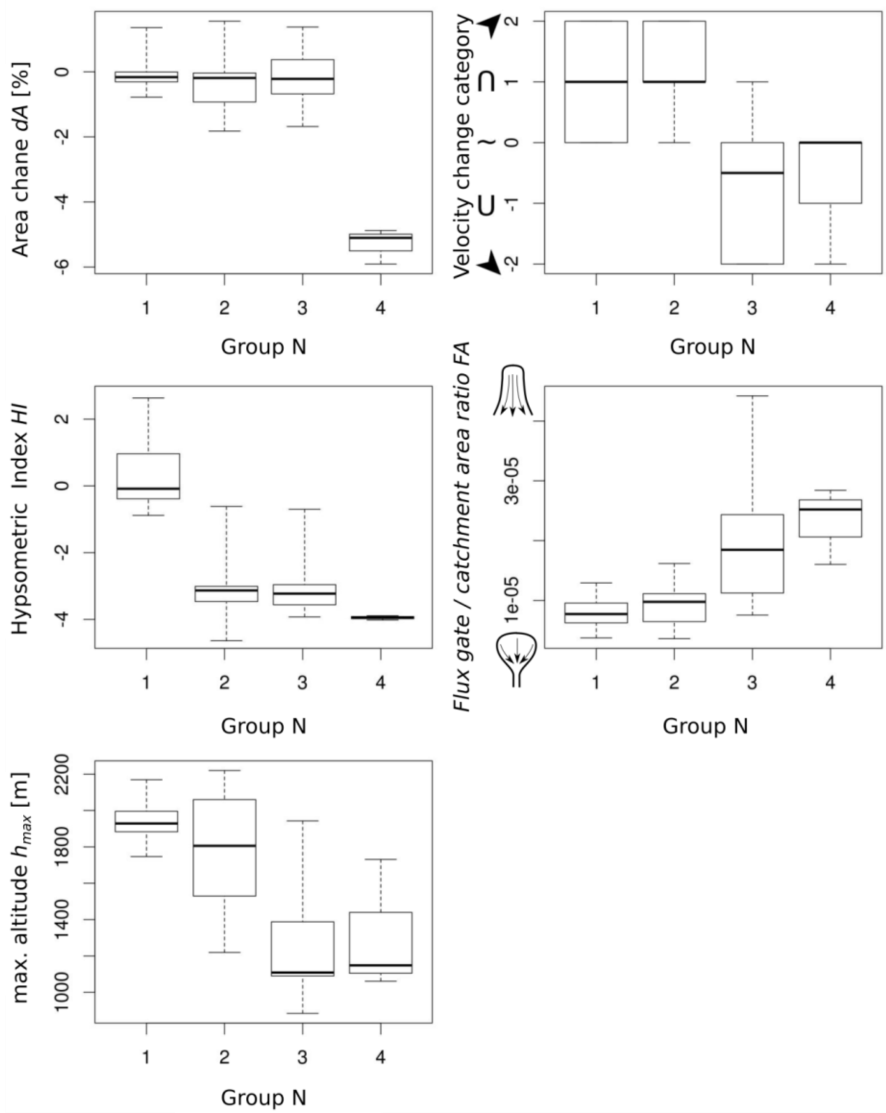

Figure 7. Boxplots of cluster analysis input variables (Sector "West") for each group. Whiskers extend to the most extreme data points.

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Tables

Table 1. ~~Used abbreviations~~Abbreviations of glacier names

Abbreviation	Glacier names
AMR	Arago-Moser-Rudolph
APPE	Albone-Pyke-Polaris-Eliason
CLM	Cayley-Lilienthal-Mouillard
DBE	Dinsmoor-Bombardier-Edgeworth
SBG	Sikorsky-Breguet-Gregory

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Table 2. Overview of SAR sensors and specifications used in this study. ~~Intensity tracking parameters are provided in pixels [p] in slant range geometry.~~

Platform	Sensor	Mode	SAR band	Repetition cycle [d]	Time interval	Ground range resolution [m]*	Tracking patch sizes [p x p~~]~~]+	Tracking step size [p x p~~]~~]+	Mean uncertainty of tracking results [m/d]
ERS-1/2	SAR	IM	C band	35/1	08. December 1992 – 02. April 2010	30	48x240 64x320	5x25	0.15±0.10
RADARSAT 1	SAR	ST	C band	24	10. September 2000 – 03. September 2006	30	48x192 64x256 ~~64x256~~	5x20	0.11±0.03
Envisat	ASAR	IM	C band	35	05. December 2003 – 16. August 2009	30	32x160 64x320 128x640	5x25	0.12±0.05
ALOS	PALSAR	FBS	L band	46	18. May 2006 – 17. March 2011	10	64x192 96x192 128x384	10x30	0.05±0.06
TerraSAR-X TanDEM-X	SAR	SM	X band	11	14. October 2008 – 22. December 2014	3	128x128 256x256 512x512	25x25	0.06±0.04

[*] nominal resolution; depending on the incidence angle.

[+] Intensity tracking parameters are provided in pixels [p] in slant range geometry.

Table 3. Description of velocity change categories. ~~*Ratings used for cluster analysis~~

Category	Description	Rating*
positive	~~Long term~~General increase of flow speed	2
peak	Increase of flow speed with subsequent deceleration	1
stable	Variability of measurements < 0.25 m d^{-1}	0
fluctuating	Short term speed-ups and deceleration, no clear trend	0
trough	Decrease of flow speed with subsequent acceleration	-1
negative	~~Long term~~General decrease of flow speed	-2

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Formatiert: Hochgestellt
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[*]Ratings used for cluster analysis Section 3.4

Table 4. ~~Hypsometric categories based on the~~ Hypsometric Index ~~according to Jiskoot et al., (2009)~~and glacier basin category descriptions.

Hypsometric Index (*HI*~~)~~)[*]	Hypsometric categories	Number of Glaciers
HI < -1.5	Very top-heavy	8
-1.5 < *HI* < -1.2	Top-heavy	7
-1.2 < *HI* < 1.2	Equidimensional	18
1.2 < *HI* < 1.5	Bottom-heavy	13
HI > 1.5	Very bottom-heavy	28

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Formatiert: Englisch (USA)

Formatiert: Englisch (USA)

Formatiert: Englisch (USA)

*according to Jiskoot et al., (2009)

Table 5. Summary of observed parameters for each sector and all glaciers. ~~l_f – length of ice front; A – Glacier area in the respective period; dA – Change in glacier area between 1985 and 2015; dt: mean time period of velocity measurements, v_S – mean of earliest velocity measurements (1992-1996); v_E – mean of latest velocity measurements (2010-2014), dv – mean velocity change; n_v – sum of velocity measurements in the observation period (dt)~~

Sector	East	East-Ice-Shelf	West	All glaciers
N	13	13	48	74
l_f [m]	85114	127909	268763	481786
$A_{1985\text{-}1990}$ [km²]	1538.78	3655.13	5809.33	11003.23
$A_{2010\text{-}2015}$ [km²]	1517.71	3446.54	5800.18	10764.42
dA [km²]	-21.07	-208.59	-9.14	-238.81
dt [a]	18.79	19.05	20	19
v_S [m d^{-1}]	0.995	0.480	0.427	0.537
v_E [m d^{-1}]	0.307	0.561	0.605	0.545
dv [m d^{-1}]	-0.688	0.081	0.177	0.008
n_v	319	584	1600	2503

N – number of studied glaciers

l_f – length of ice front

A – Glacier area in the respective period (subscript)

dA – Change in glacier area between 1985 and 2015

dt: mean time period of velocity measurements

v_S – mean of earliest velocity measurements (1992-1996)

v_E – mean of latest velocity measurements (2010-2014)

dv – mean velocity change

n_v – sum of velocity measurements in the observation period (dt)

Supplement ~~of~~to

Detailed analysis of changes in glacier dynamics ~~at~~in the northern Antarctic Peninsula since 1985

Thorsten Seehaus[1], Alison Cook[2], Aline B. Silva[3], Matthias Braun[1]

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[2] Department of Geography, Durham University, Lower Mountjoy South Road, Durham DH1 3LE, United Kingdom
[3] Laboratório de Monitoramento da Criosfera, Universidade Federal do Rio Grande, Av. Itália, km 8, 96203-900, Rio Grande – RS. Brazil

Correspondence to: Thorsten Seehaus (*thorsten.seehaus@fau.de*)

Formatiert: Abschnittsbeginn: Fortlaufend, Vom Text: 0"

Feldfunktion geändert

Overview:

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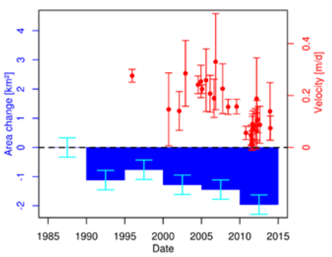

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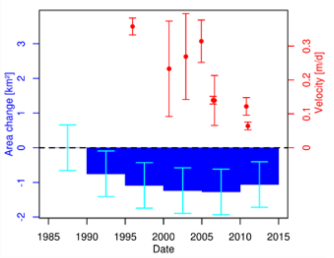


Fig.: S3 Aitkenhead Glacier

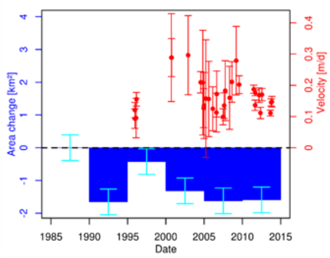


Fig.: S4 Broad Valley Glacier

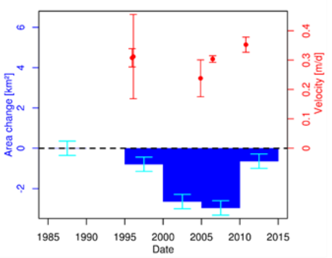


Fig.: S5 Diplock Glacier

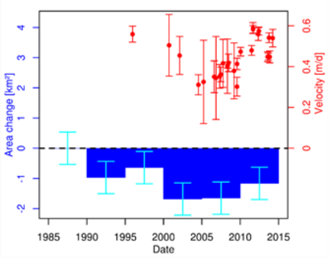


Fig.: S6 Eyrie Glacier

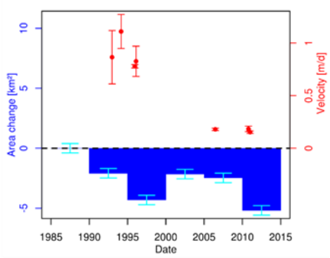


Fig.: S7 Russell East Glacier

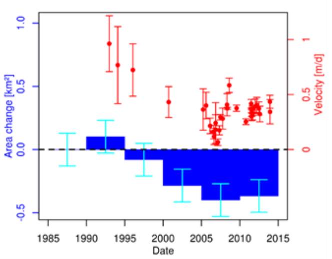
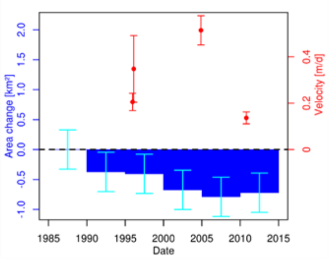


Fig.: S8 TPE10 Glacier



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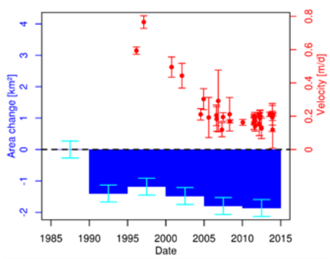

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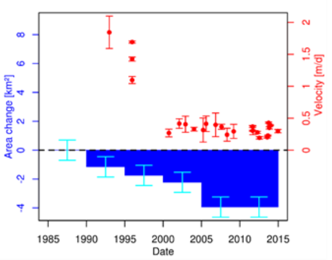

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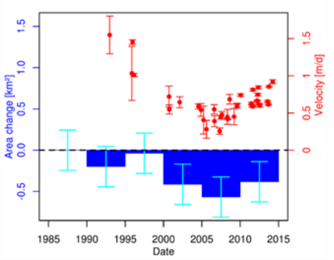

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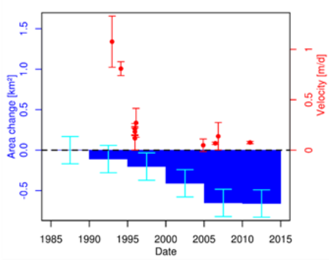

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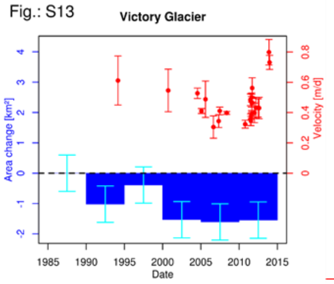

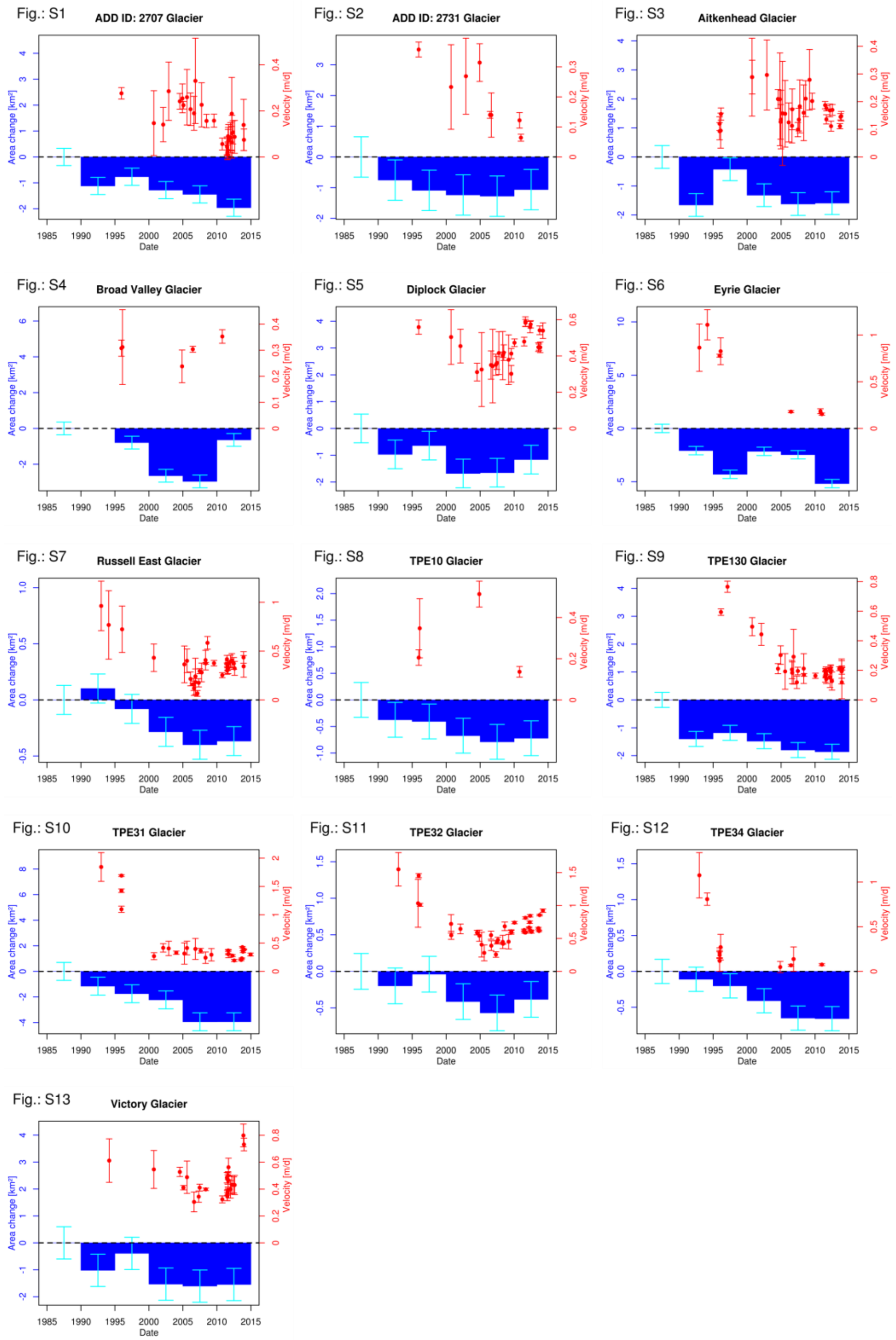

Figure S1-S13: Temporal trend of surface velocity (red) and area (blue) changes of glaciers in sector "East".

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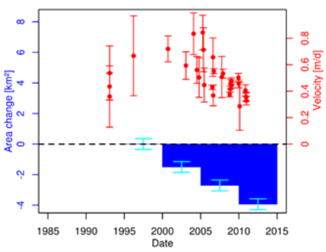

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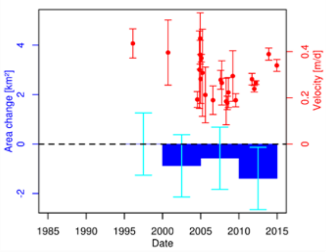

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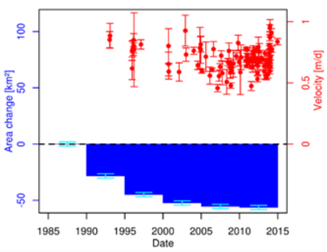
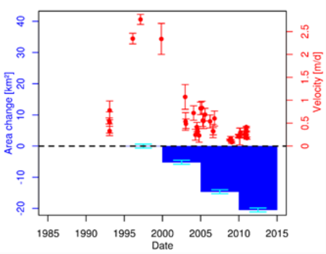


Fig.: S17 **ArronIcefall Glacier**



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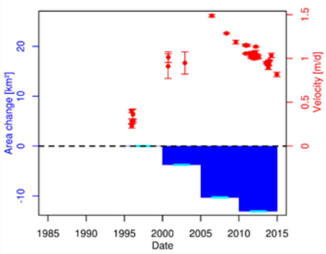


Fig.: S19 **DBE Glacier**

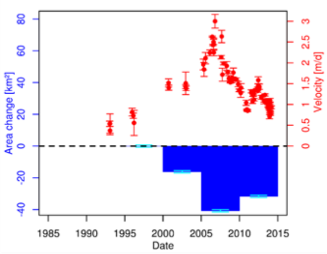
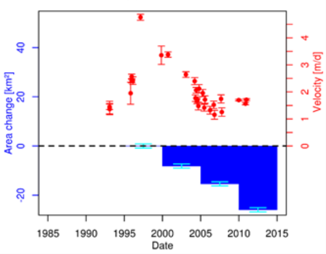


Fig.: S20 **Drygalski Glacier**



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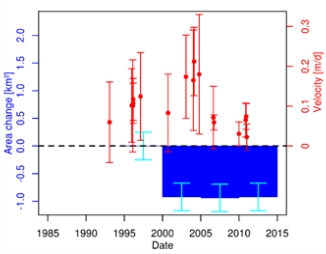

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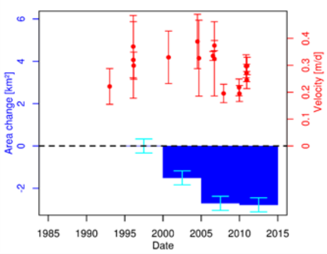

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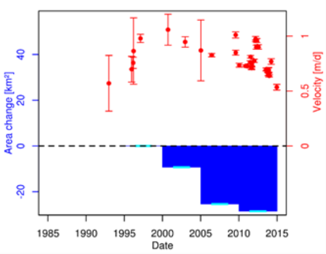

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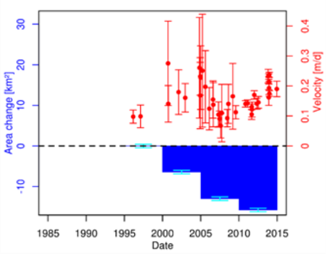

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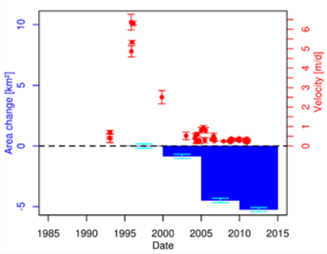
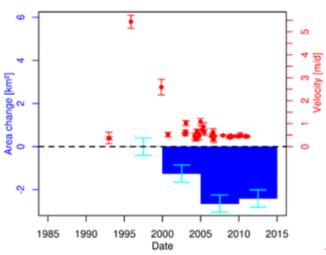


Fig.: S26 **TPE62 Glacier**



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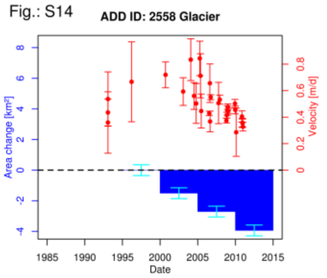

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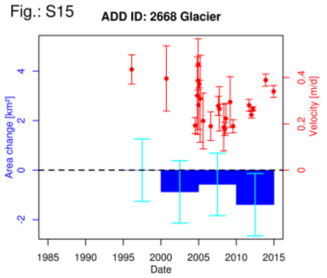

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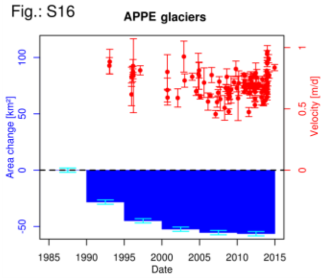

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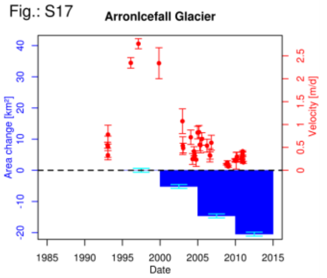

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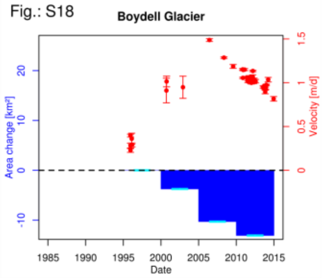

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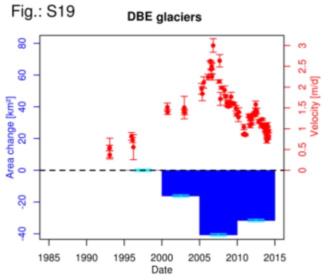

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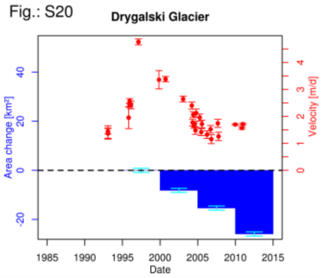

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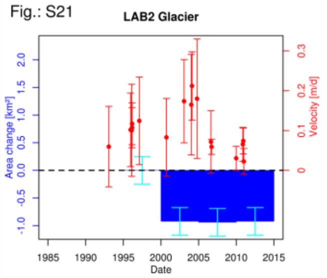

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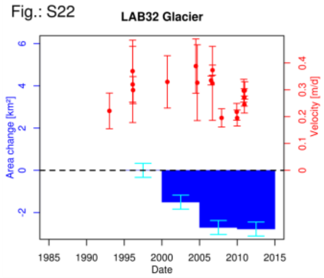

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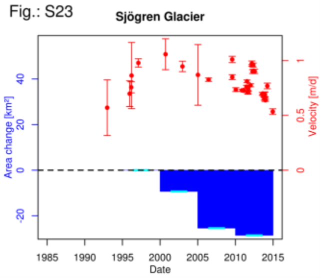

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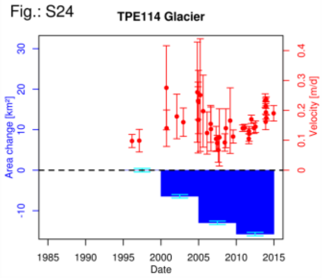

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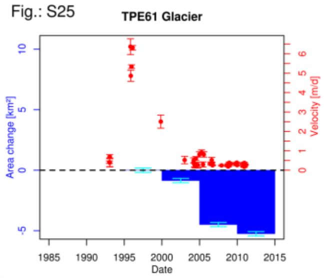

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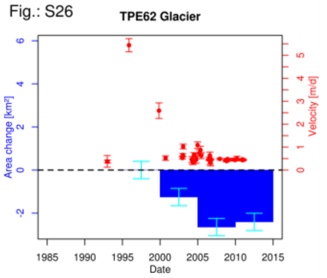
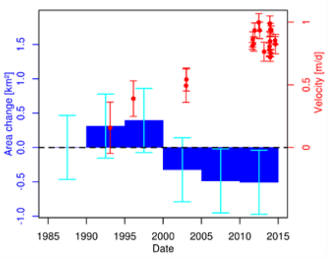


Figure S14-S26: Temporal trend of surface velocity (red) and area (blue) changes of glaciers in sector "East-Ice-Shelf".

Fig.: S27



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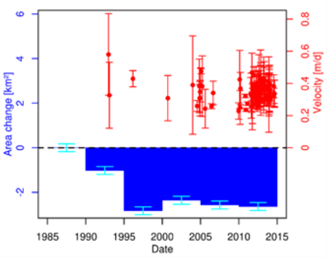

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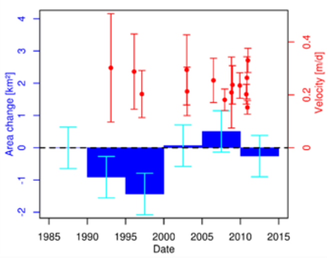

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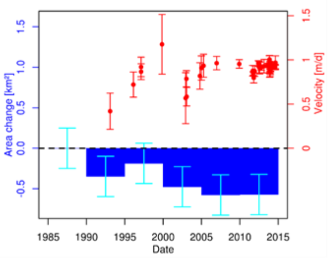

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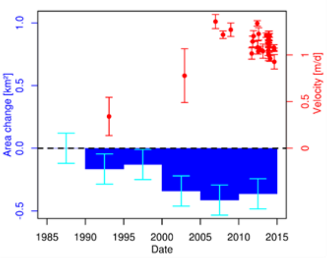

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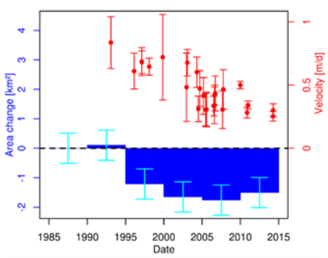

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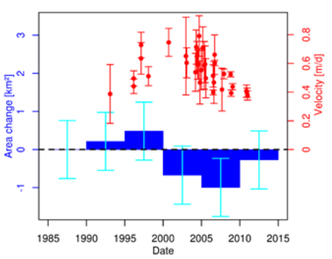


Fig.: S34

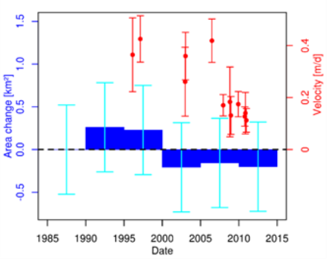
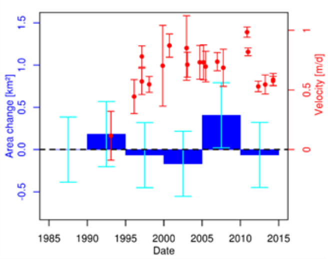


Fig.: S35



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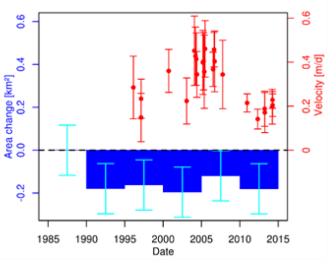
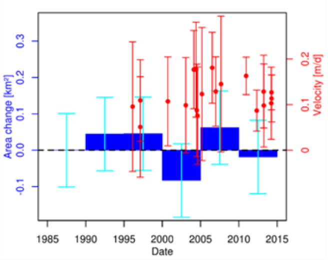


Fig.: S37



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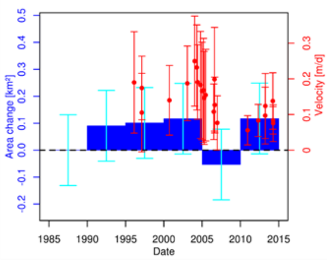

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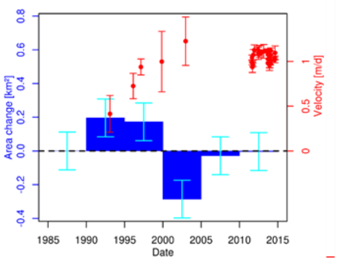


Fig.: S40

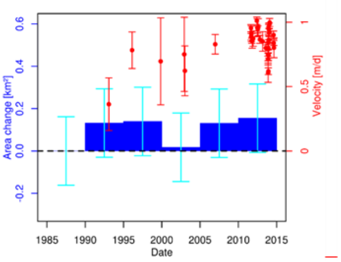
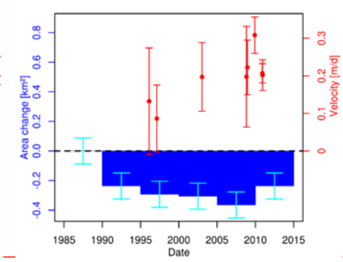


Fig.: S41



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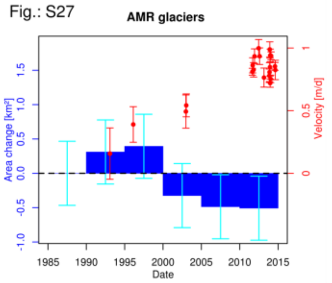

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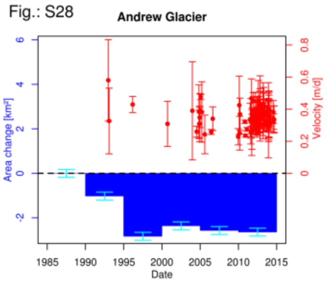

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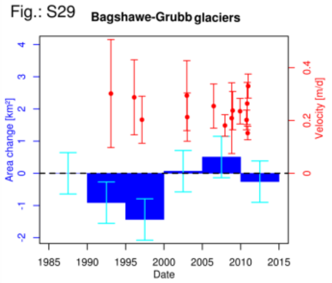

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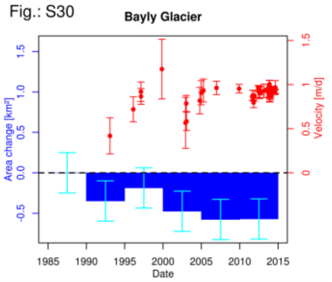

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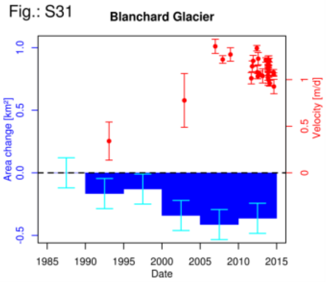
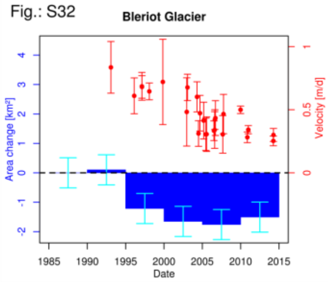


Fig.: S32


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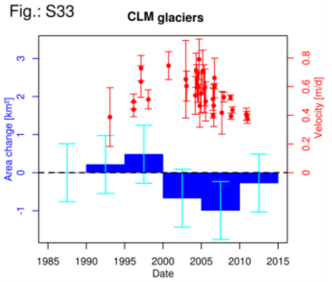

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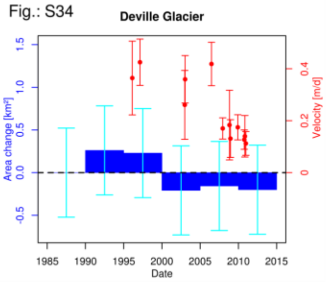

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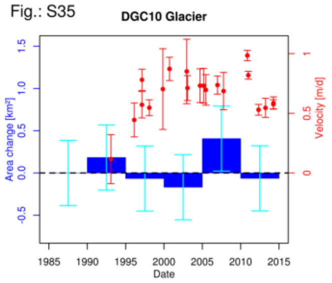

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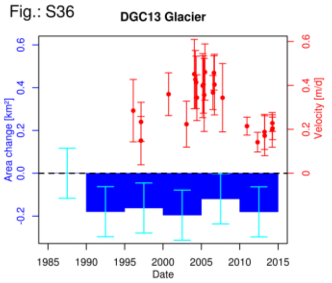

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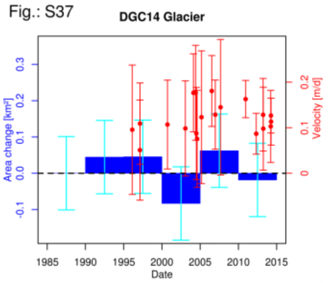

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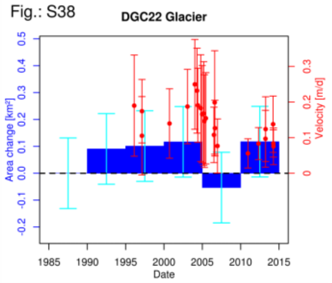

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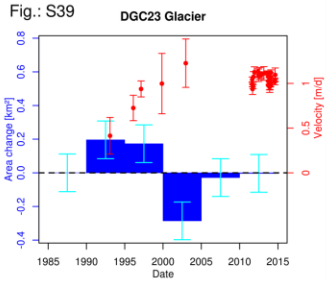


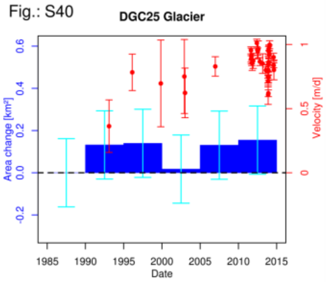
Fig.: S40


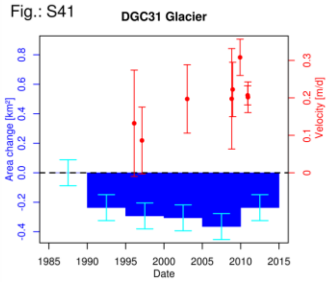
Fig.: S41


Figure S27-S41: Temporal trend of surface velocity (red) and area (blue) changes of glaciers in sector "West".

Fig.: S42

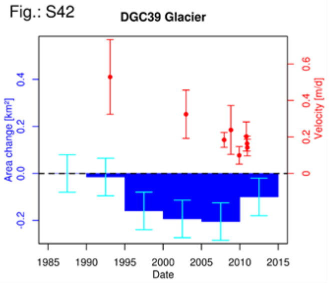


Fig.: S43

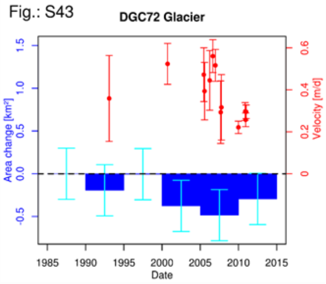


Fig.: S44

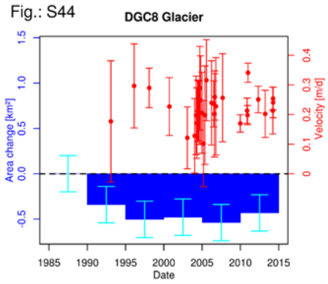


Fig.: S45

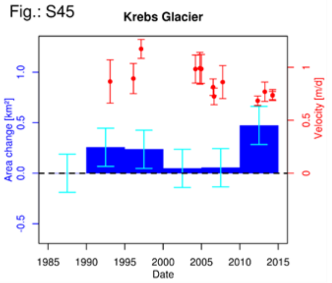
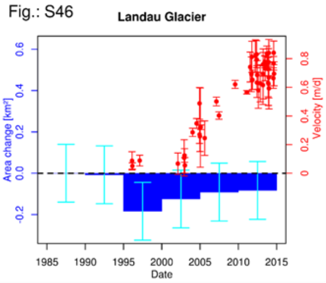


Fig.: S46



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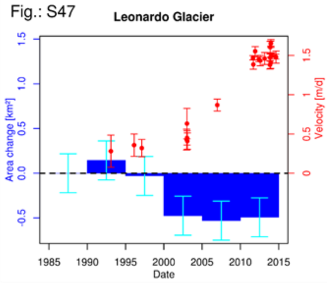
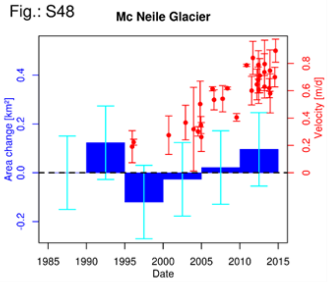


Fig.: S48



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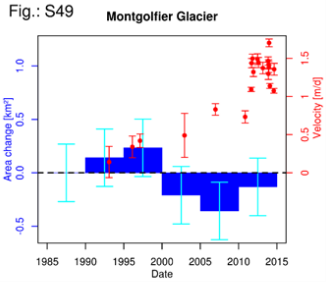


Fig.: S50

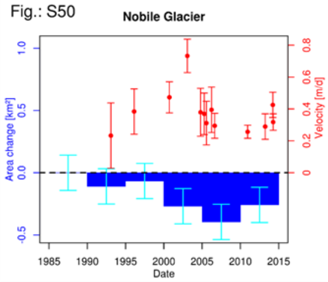


Fig.: S51

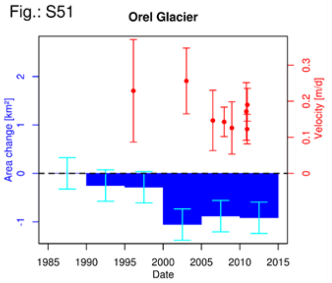


Fig.: S52

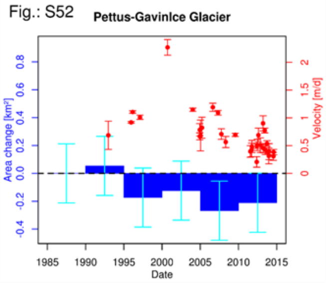


Fig.: S53

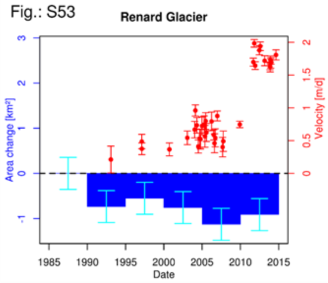


Fig.: S54

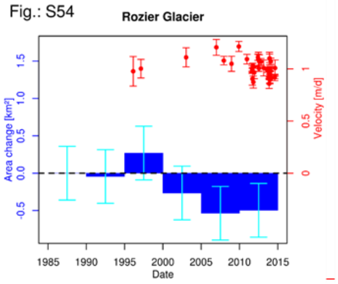


Fig.: S55

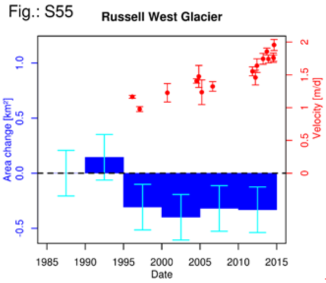
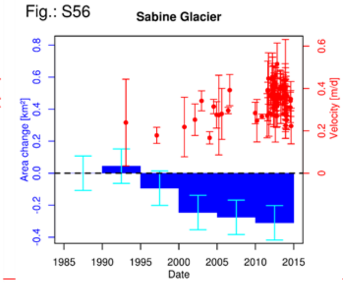


Fig.: S56



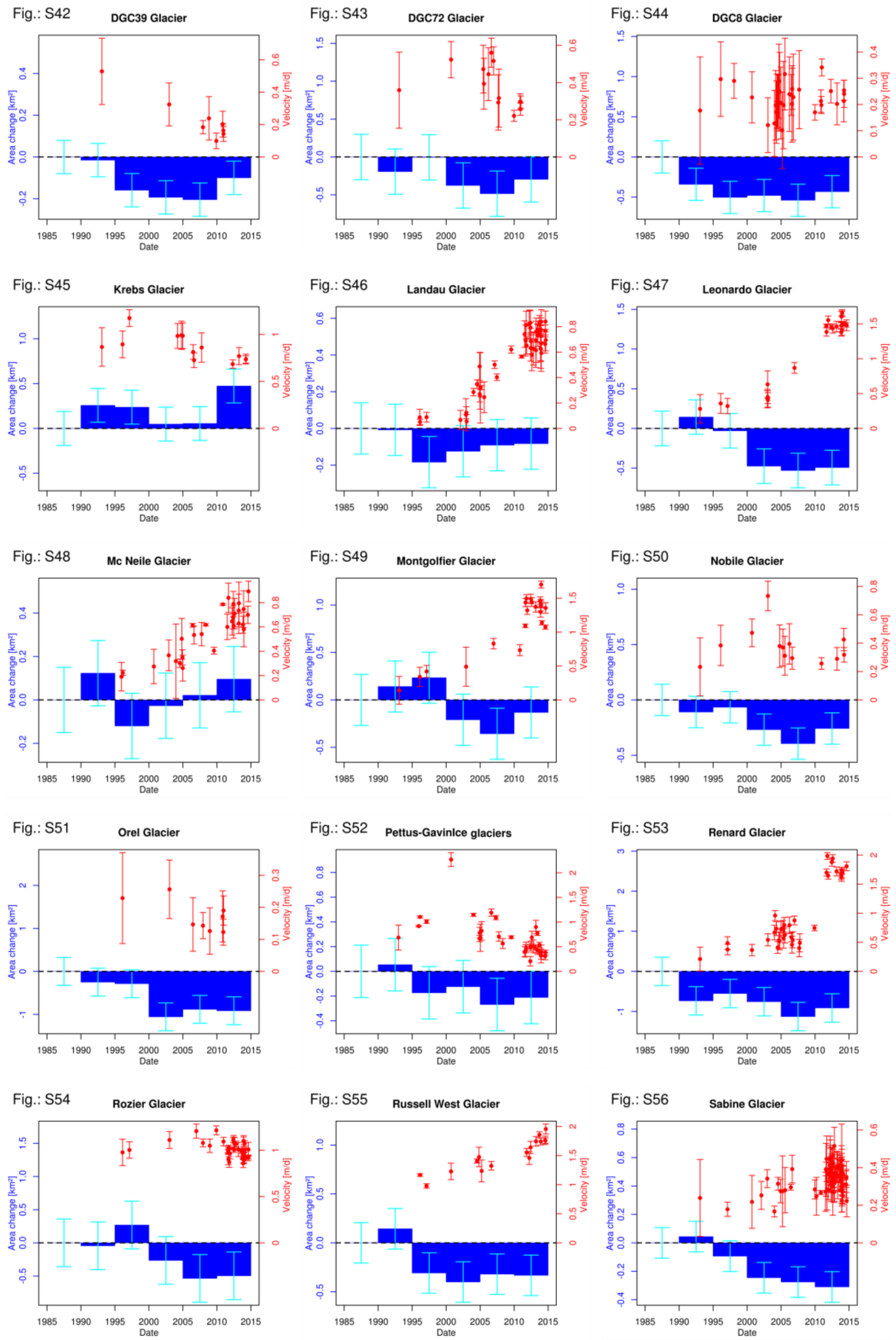


Figure S42-S56: Temporal trend of surface velocity (red) and area (blue) changes of glaciers in sector "West".

Fig.: S57

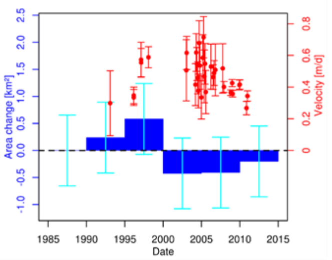


Fig.: S58

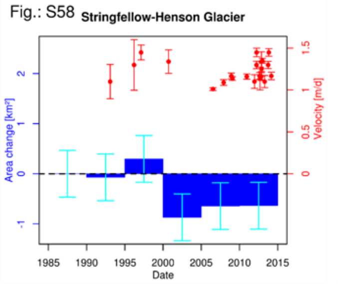


Fig.: S59

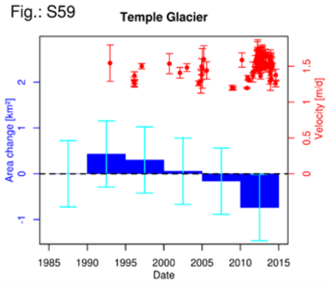


Fig.: S60

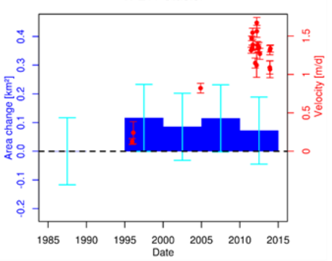


Fig.: S61

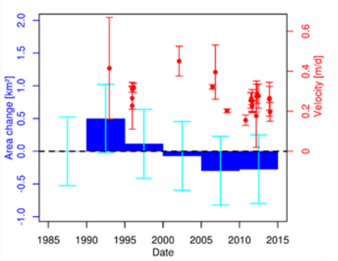


Fig.: S62

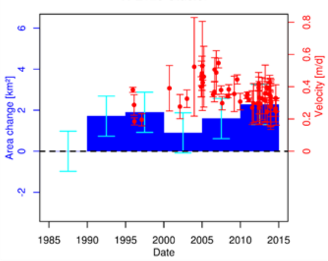


Fig.: S63

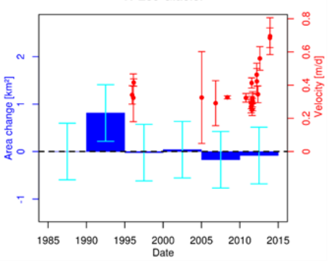


Fig.: S64

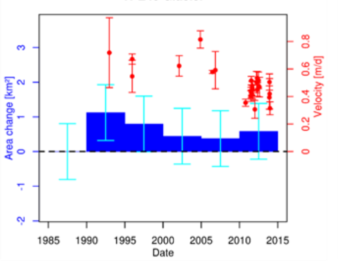


Fig.: S65

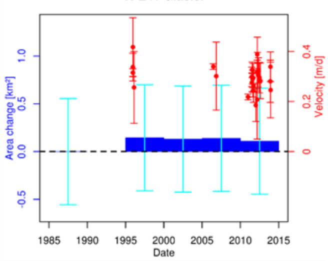


Fig.: S66

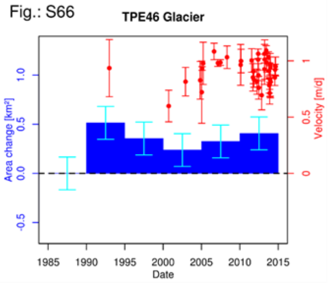


Fig.: S67

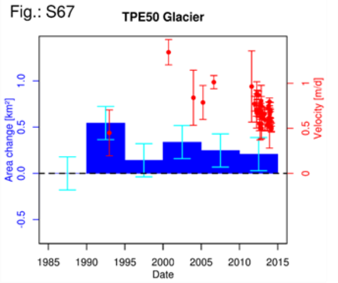


Fig.: S68

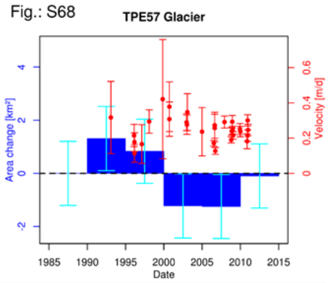


Fig.: S69

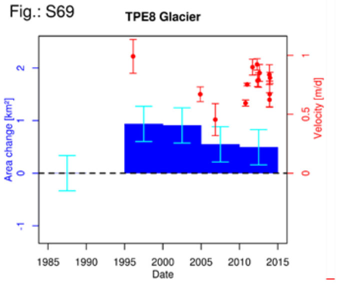


Fig.: S70

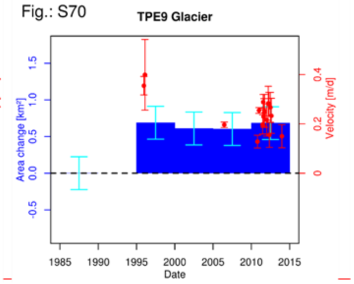
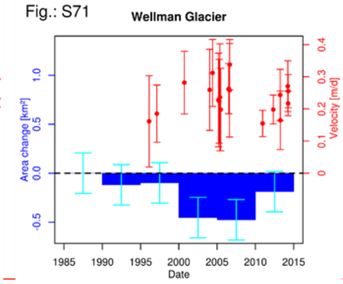


Fig.: S71



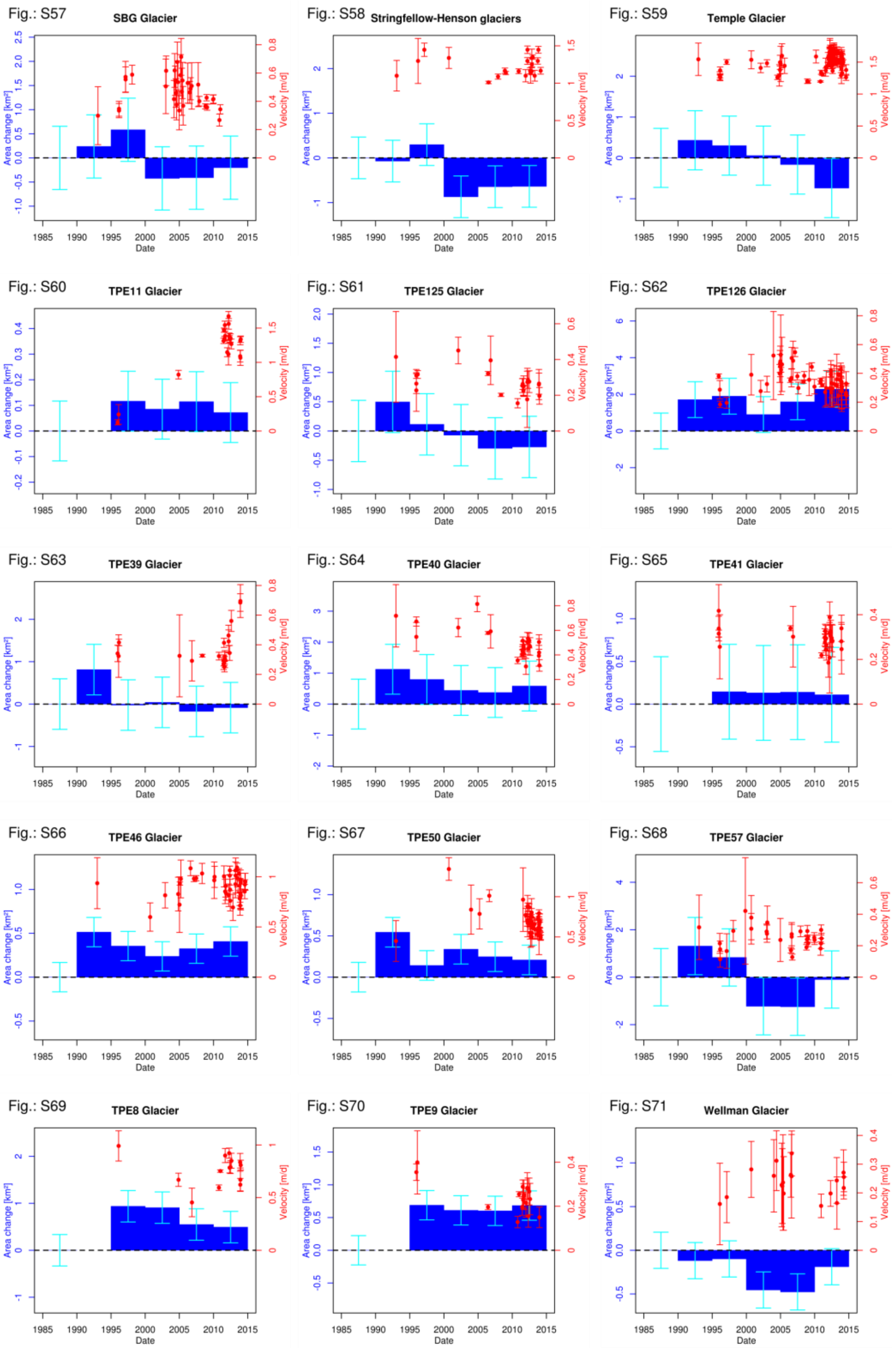
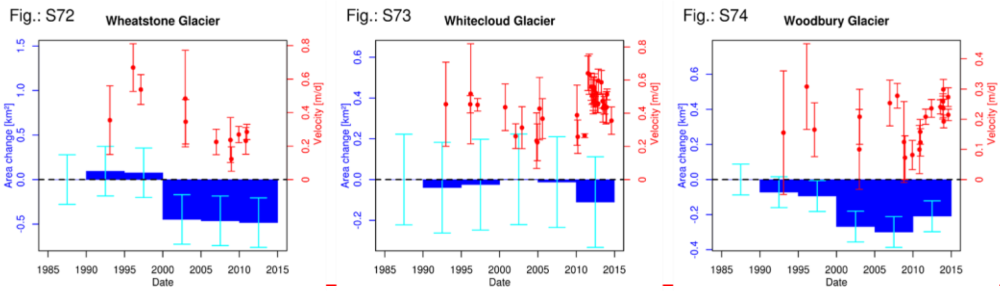


Figure S57-S71: Temporal trend of surface velocity (red) and area (blue) changes of glaciers in sector "West".



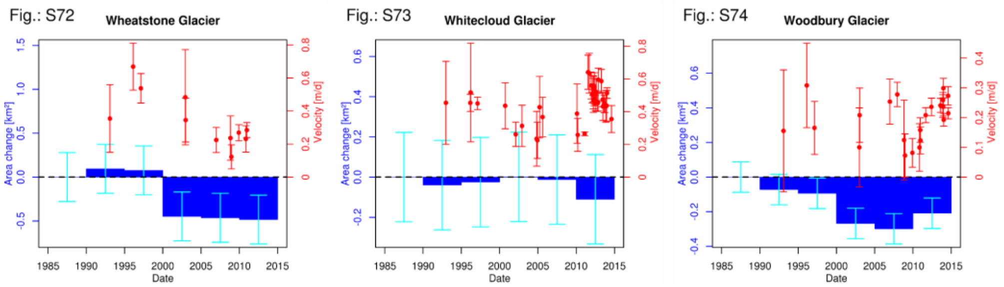


Figure S72-S74: Temporal trend of surface velocity (red) and area (blue) changes of glaciers in sector "West".

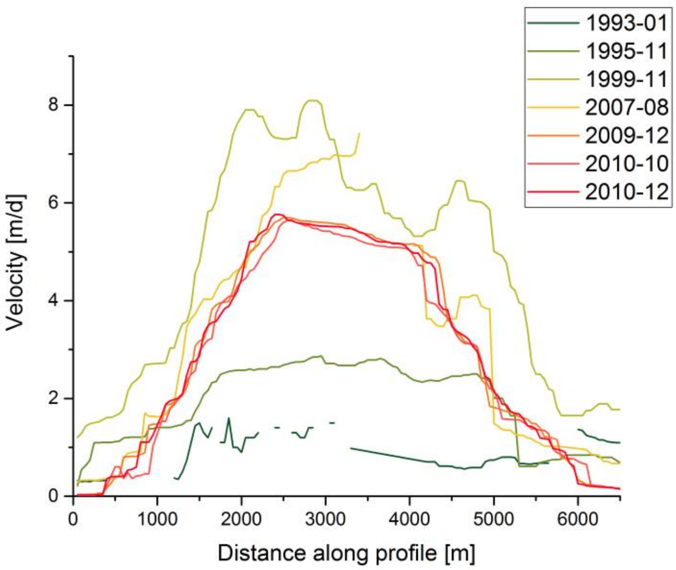


Figure S75: Surface velocity across the terminus of Drygalski Glacier

Table S1~~: Observed parameters of the individual glaciers. l_f – length of ice front; A – Glacier area in the respective period; dA – Change in glacier area between 1985 and 2015; Area change category – see definition in Section 4.1; Date v_S - date of first velocity measurement; Date v_E – date of last velocity measurement; dt - mean time period of velocity measurements, v_s – mean of earliest velocity measurements (1992-1996); v_E – mean of latest velocity measurements (2010-2014), dv – mean velocity change; n_v – sum of velocity measurements in the observation period (dt); Velocity change category – see definition in Table 3; h_{max} – average maximum altitude of individual basins, HI – Hypsometric Index of the basin; Hypsometric category – see Table 4; FA – Flux gate to catchment size ratio;~~ : Observed parameters of the individual glaciers. Table continues on next page.

~~Group – Classification of glaciers in sector "West" according to the hierarchical cluster analysis in Section 4.4.~~

Sector	Basin	l_f [m]	$A_{1985-1990}$ [km²]	$A_{2010-2015}$ [km²]	dA [km²]	Area change category	Date v_S [yyyy-mm-dd]	Date v_E [yyyy-mm-dd]	dt [a]	v_S [m d^{-1}]	v_E [m d^{-1}]	dv [m d^{-1}]	dv [%]	n_v	Vel. change category	h_{max} [m a.s.l.]	HI	Hypsometric category	FA	Group
East	ADD ID: 2707	5535	28.78	26.82	-1.96	retreated	1994-02-01	2013-12-24	19.91	0.553	0.107	-0.446	-80.690	35	decreased	1278	5.14	very bottom-heavy	0.0056	
	ADD ID: 2731	10955	56.92	55.85	-1.06	retreated	1995-12-18	2010-12-31	15.05	0.358	0.093	-0.265	-73.985	12	decreased	1327	2.93	very bottom-heavy	0.0055	
	Aitkenhead	6532	156.70	155.11	-1.59	retreated	1995-12-18	2014-03-27	18.28	0.108	0.147	0.039	36.646	46	peak	1746	-1.23	top-heavy	0.0024	
	Broad Valley	5948	246.73	246.08	-0.64	retreated	1994-02-01	2010-12-31	16.92	0.743	0.230	-0.512	-68.969	10	stable	1118	-1.02	equidimensional	0.0005	
	Diplock	8916	235.30	234.14	-1.16	retreated	1995-12-18	2014-12-16	19.01	0.559	0.618	0.059	10.626	33	trough	1845	-1.44	top-heavy	0.0017	
	Eyrie	6570	89.53	84.35	-5.18	retreated	1992-12-25	2010-12-31	18.03	0.865	0.169	-0.696	-80.499	7	decreased	1076	2.39	very bottom-heavy	0.0035	
	Russell East	2156	93.75	93.38	-0.37	retreated	1992-12-25	2013-12-07	20.96	0.963	0.389	-0.573	-59.559	34	decreased	1370	1.48	bottom-heavy	0.0035	
	TPE10	5465	225.96	225.24	-0.72	retreated	1994-02-01	2010-12-31	16.92	0.633	0.102	-0.531	-83.928	9	peak	1386	1.43	bottom-heavy	0.0033	
	TPE130	4493	40.58	38.72	-1.86	retreated	1994-02-01	2013-12-24	19.91	0.244	0.201	-0.043	-17.777	36	peak	983	2.07	very bottom-heavy	0.0076	
	TPE31	11684	52.70	48.76	-3.94	retreated	1992-12-25	2014-12-16	21.99	1.844	0.344	-1.500	-81.352	25	decreased	1490	3.50	very bottom-heavy	0.0076	
	TPE32	4071	108.63	108.24	-0.38	retreated	1992-12-25	2014-03-27	21.27	1.549	0.755	-0.794	-51.271	36	decreased	1646	1.46	bottom-heavy	0.0037	
	TPE34	2814	22.91	22.25	-0.66	retreated	1992-12-25	2010-12-31	18.03	1.076	0.076	-1.000	-92.937	10	decreased	500	-1.37	top-heavy	0.0023	
	Victory	9975	180.30	178.75	-1.55	retreated	1995-12-18	2013-12-24	18.03	3.448	0.765	-2.683	-77.809	26	trough	1645	2.11	very bottom-heavy	0.0041	
Summary	mean								18.79	0.995	0.307	-0.688	-69.121			1339				
East	sum	85114	1538.78	1517.71	-21.07									319						
East-Ice-Shelf	ADD ID: 2558	5890	60.2433	56.31	-3.94	retreated	1993-01-29	2010-12-29	17.93	0.435	0.353	-0.082	-18.758	30	peak	1840	9.08	very bottom-heavy	0.0067	
	ADD ID: 2668	20996	162.324	160.93	-1.39	retreated	1996-02-13	2014-12-16	18.85	0.435	0.340	-0.095	-21.821	27	peak	1342	2.88	very bottom-heavy	0.0041	
	APPE	31872	696.24	639.85	-56.39	retreated	1993-01-12	2014-12-16	21.94	0.869	0.853	-0.015	-1.766	114	fluctuating	1964	1.82	very bottom-heavy	0.0003	
	Arron Icefall	10557	152.356	131.88	-20.48	retreated	1993-01-12	2011-01-22	18.04	0.532	0.288	-0.244	-45.793	39	peak	1979	-1.08	equidimensional	0.0061	
	Boydell	1954	108.039	94.95	-13.09	retreated	1995-12-18	2014-12-16	19.01	0.290	0.975	0.685	236.007	38	peak	1842	-1.07	equidimensional	0.0009	
	DBE	12140	658.91	627.24	-31.67	retreated	1993-01-12	2014-02-27	21.14	0.535	0.950	0.415	77.569	88	peak	2167	1.37	bottom-heavy	0.0011	
	Drygalski	14018	990.41	964.49	-25.92	retreated	1993-01-29	2010-12-29	17.93	1.422	1.641	0.219	15.374	29	peak	2043	1.60	very bottom-heavy	0.0003	
	LAB2	4157	38.3889	37.47	-0.92	retreated	1993-01-29	2010-12-29	17.93	0.060	0.065	0.006	9.726	17	peak	1779	3.76	very bottom-heavy	0.0046	
	LAB32	5534	66.3816	63.60	-2.78	retreated	1993-01-12	2010-12-29	17.97	0.221	0.284	0.063	28.300	19	stable	1841	3.21	very bottom-heavy	0.0046	
	Sjögren	3838	329.298	300.73	-28.57	retreated	1992-12-25	2014-12-16	21.99	0.570	0.638	0.068	11.897	42	peak	1926	1.97	very bottom-heavy	0.0014	
	TPE114	7310	126.385	110.61	-15.78	retreated	1996-02-29	2014-12-16	18.81	0.098	0.183	0.084	85.924	56	stable	1759	2.96	very bottom-heavy	0.0014	
	TPE61	2943	54.3413	49.09	-5.25	retreated	1993-01-12	2011-01-22	18.04	0.406	0.276	-0.130	-31.942	42	peak	1981	2.78	very bottom-heavy	0.0022	
	TPE62	6700	211.811	209.40	-2.41	retreated	1992-12-25	2011-01-22	18.09	0.372	0.448	0.076	20.424	43	peak	2118	2.43	very bottom-heavy	0.0013	
Summary	mean								19.05	0.480	0.561	0.081	16.811			1891				
East-Ice-Shelf	sum	127909	3655.13	3446.54	-208.59									584						
West	AMR	7773	137.24	136.73	-0.51	retreated	1993-02-01	2014-08-22	21.57	0.157	0.837	0.679	431.515	21	increased	1884	-3.82	very top-heavy	0.0021	1
	Andrew	2951	47.05	44.41	-2.64	retreated	1992-12-25	2014-08-27	21.68	0.453	0.358	-0.095	-21.030	119	decreased	1731	1.99	very bottom-heavy	0.0057	4
	Bagshawe-Grubb	10720	280.43	280.17	-0.26	stable	1993-02-01	2010-12-22	17.90	0.302	0.233	-0.069	-22.782	14	stable	2169	-2.88	very top-heavy	0.0019	1
	Bayly	4149	47.89	47.32	-0.57	retreated	1993-02-01	2014-08-22	21.57	0.419	0.912	0.493	117.584	42	increased	1529	-1.06	equidimensional	0.0027	2
	Blanchard	2005	38.00	37.63	-0.36	retreated	1993-02-01	2014-08-22	21.57	0.341	1.084	0.744	218.153	31	increased	2060	1.53	very bottom-heavy	0.0025	2
	Bleriot	8527	182.20	180.69	-1.50	retreated	1993-02-01	2014-04-10	21.20	0.836	0.300	-0.536	-64.134	30	decreased	1943	1.28	bottom-heavy	0.0019	3
	CLM	12682	809.85	809.58	-0.27	stable	1993-02-01	2010-12-29	17.92	0.388	0.396	0.008	2.157	34	peak	2191	1.13	equidimensional	0.0016	2
	Deville	8699	34.99	34.79	-0.20	stable	1996-02-15	2010-12-22	14.86	0.364	0.127	-0.237	-65.116	12	decreased	1389	-1.19	equidimensional	0.0025	3
	DGC10	6423	23.47	23.40	-0.06	stable	1993-02-01	2014-04-10	21.20	0.116	0.580	0.465	401.477	24	increased	1219	-1.10	equidimensional	0.0064	2
	DGC13	1950	10.95	10.76	-0.18	retreated	1996-02-15	2014-04-10	18.16	0.285	0.205	-0.081	-28.256	27	peak	901	1.28	bottom-heavy	0.0071	3
	DGC14	1684	5.66	5.64	-0.02	stable	1996-02-15	2014-04-10	18.16	0.096	0.113	0.018	18.626	25	stable	884	1.90	very bottom-heavy	0.0109	3
	DGC22	2188	8.98	9.10	0.12	stable	1996-02-15	2014-04-10	18.16	0.190	0.084	-0.106	-55.993	31	stable	1113	-1.24	top-heavy	0.0148	3
	DGC23	1868	15.92	15.91	0.00	stable	1993-02-01	2014-08-22	21.57	0.414	1.025	0.611	147.314	37	increased	1379	-1.33	top-heavy	0.0023	2
	DGC25	2693	14.12	14.27	0.15	stable	1993-02-01	2014-08-22	21.57	0.363	0.820	0.457	125.807	37	increased	1850	1.52	very bottom-heavy	0.0028	2
	DGC31	1466	13.30	13.06	-0.24	retreated	1996-02-15	2010-12-11	14.83	0.132	0.204	0.072	54.579	10	stable	1488	1.86	very bottom-heavy	0.0029	2
	DGC39	1331	15.07	14.97	-0.10	retreated	1993-02-01	2010-12-22	17.90	0.529	0.164	-0.365	-69.044	8	decreased	1472	1.02	equidimensional	0.0040	3

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	DGC72	4990	38.39	38.09	-0.30	stable	1993-02-01	2014-04-10	21.20	0.359	0.695	0.336	93.651	19	peak	1706	1.17	equidimensional	0.0027	2
	DGC8	3340	9.34	8.91	-0.43	retreated	1993-02-01	2014-04-10	21.20	0.177	0.241	0.064	36.012	32	stable	1061	2.07	very bottom-heavy	0.0094	4
	Krebs	3152	34.80	35.27	0.47	advanced	1993-02-01	2014-04-10	21.20	0.866	0.738	-0.128	-14.780	16	peak	2029	-2.00	very top-heavy	0.0006	1
	Landau	2330	33.99	33.90	-0.08	stable	1996-02-13	2014-08-27	18.55	0.069	0.727	0.658	954.866	49	increased	1747	-1.79	very top-heavy	0.0027	1
	Leonardo	3632	84.22	83.72	-0.49	retreated	1993-02-01	2014-08-22	21.57	0.281	1.493	1.212	431.732	24	increased	2106	1.06	equidimensional	0.0009	2
~~Sector~~	~~Basin~~	~~l_f [m]~~	~~$A_{1985-1990}$ [km²]~~	~~$A_{2010-2015}$ [km²]~~	~~dA [km²]~~	~~Area change category~~	~~Date v_s [yyyy-mm-dd]~~	~~Date v_E [yyyy-mm-dd]~~	~~dt [a]~~	~~v_S [m d^{-1}]~~	~~v_E [m d^{-1}]~~	~~dv [m d^{-1}]~~	~~dv [%]~~	~~n_v~~	~~Vel. change category~~	~~h_{max} [m a.s.l.]~~	~~HI~~	~~Hypsometric category~~	~~FA~~	~~Group~~
~~West~~	Mc Neile	2507	184.56	184.66	0.10	stable	1995-12-19	2014-08-27	18.70	0.207	0.699	0.492	237.738	30	increased	1882	-4.58	very top-heavy	0.0006	1
	Montgolfier	4486	55.20	55.06	-0.13	stable	1993-02-01	2014-08-22	21.57	0.141	1.371	1.230	872.806	21	increased	1929	-1.32	top-heavy	0.0022	1
	Nobile	2361	57.04	56.78	-0.26	retreated	1993-02-01	2014-04-10	21.20	0.233	0.372	0.139	59.586	13	peak	1901	-1.28	top-heavy	0.0018	1
	Orel	5399	19.02	18.11	-0.92	retreated	1996-02-15	2010-12-22	14.86	0.229	0.172	-0.057	-25.010	9	stable	1148	1.95	very bottom-heavy	0.0066	4
	Pettus-GavinIce	3535	330.88	330.67	-0.21	stable	1992-12-25	2014-08-05	21.62	0.686	0.385	-0.301	-43.827	33	peak	1846	1.24	bottom-heavy	0.0030	2
Sector	Basin	l_f [m]	$A_{1985-1990}$ [km²]	$A_{2010-2015}$ [km²]	dA [km²]	Area change category	Date v_s [yyyy-mm-dd]	Date v_E [yyyy-mm-dd]	dt [a]	v_S [m d^{-1}]	v_E [m d^{-1}]	dv [m d^{-1}]	dv [%]	n_v	Vel. change category	h_{max} [m a.s.l.]	HI	Hypsometric category	FA	Group
	Renard	5904	118.15	117.24	-0.91	retreated	1993-02-01	2014-08-22	21.57	0.212	1.698	1.486	699.238	36	increased	2043	-1.82	very top-heavy	0.0011	1
	Rozier	5984	35.57	35.07	-0.50	retreated	1996-02-15	2014-08-22	18.53	0.977	0.944	-0.033	-3.420	41	peak	2061	2.70	very bottom-heavy	0.0036	2
	Russell West	3450	329.28	328.95	-0.33	retreated	1996-02-29	2014-08-27	18.50	1.072	1.759	0.687	64.111	18	increased	1645	1.44	bottom-heavy	0.0028	2
	Sabine	1795	83.09	82.78	-0.31	retreated	1993-02-01	2014-08-27	21.58	0.239	0.348	0.109	45.520	82	increased	1843	1.21	bottom-heavy	0.0070	2
	SBG	10917	327.95	327.75	-0.20	stable	1993-02-01	2010-12-29	17.92	0.298	0.306	0.007	2.395	35	peak	2220	1.08	equidimensional	0.0047	2
	Stringfellow-Henson	7775	670.38	669.74	-0.64	retreated	1993-02-01	2014-02-28	21.09	1.100	1.233	0.132	12.029	24	fluctuating	2167	1.55	very bottom-heavy	0.0026	2
	Temple	12056	453.96	453.22	-0.74	retreated	1992-12-25	2014-08-11	21.64	1.544	1.516	-0.028	-1.821	92	fluctuating	1962	-1.06	equidimensional	0.0031	1
	TPE11	1947	70.06	70.13	0.07	stable	1995-12-20	2013-12-24	18.02	0.184	1.203	1.018	552.655	21	increased	1268	1.05	equidimensional	0.0028	2
	TPE125	8741	40.41	40.13	-0.27	stable	1992-12-25	2013-12-24	21.01	0.415	0.260	-0.155	-37.319	23	fluctuating	1104	1.82	very bottom-heavy	0.0116	3
	TPE126	16295	145.52	147.80	2.28	advanced	1995-12-19	2014-08-27	18.70	0.287	0.306	0.019	6.542	58	peak	1655	2.20	very bottom-heavy	0.0060	2
	TPE39	9931	139.49	139.40	-0.08	stable	1995-12-19	2013-12-07	17.98	0.341	0.690	0.348	102.092	21	peak	1384	1.13	equidimensional	0.0051	2
	TPE40	13405	184.11	184.69	0.58	stable	1992-12-25	2013-12-24	21.01	0.718	0.406	-0.312	-43.414	27	decreased	1386	1.01	equidimensional	0.0059	3
	TPE41	9256	53.13	53.24	0.11	stable	1995-12-19	2013-12-07	17.98	0.326	0.281	-0.046	-13.987	26	stable	1094	1.98	very bottom-heavy	0.0107	3
	TPE46	2785	33.94	34.34	0.41	advanced	1992-12-25	2014-08-27	21.68	0.935	0.881	-0.054	-5.756	43	fluctuating	1843	-1.86	very top-heavy	0.0026	1
	TPE50	2987	31.32	31.53	0.21	advanced	1992-12-25	2014-08-27	21.68	0.450	0.517	0.067	14.899	114	peak	1839	1.13	equidimensional	0.0023	2
	TPE57	20111	100.43	100.34	-0.10	stable	1993-02-01	2010-12-29	17.92	0.317	0.230	-0.087	-27.382	32	peak	1132	1.31	bottom-heavy	0.0090	3
	TPE8	5582	111.74	112.24	0.49	advanced	1996-02-11	2013-12-24	17.88	0.991	0.739	-0.252	-25.395	17	trough	1104	1.19	equidimensional	0.0035	3
	TPE9	3735	48.96	49.64	0.68	advanced	1995-12-19	2013-12-24	18.03	0.355	0.150	-0.205	-57.744	20	decreased	1085	1.41	bottom-heavy	0.0057	3
	Wellman	3449	48.67	48.48	-0.19	stable	1996-02-15	2014-04-10	18.16	0.161	0.255	0.094	58.300	25	stable	1772	1.47	bottom-heavy	0.0037	2
	Wheatstone	4642	52.66	52.18	-0.48	retreated	1993-02-01	2010-12-22	17.90	0.355	0.258	-0.097	-27.262	11	peak	1569	1.21	bottom-heavy	0.0029	2
	Whitecloud	3711	177.77	177.66	-0.11	stable	1992-12-25	2014-08-11	21.64	0.454	0.481	0.027	5.848	59	fluctuating	1950	-2.94	very top-heavy	0.0013	1
	Woodbury	1464	20.24	20.03	-0.21	retreated	1993-02-01	2014-08-11	21.54	0.155	0.239	0.084	53.784	27	stable	1862	1.02	equidimensional	0.0024	2
Summary	mean								20	0.427	0.605	0.177	41.487			1636				
West	sum	268763	5809.33	5800.18	-9.14									1600						
Summary	mean								19	0.537	0.545	0.008				1629				
all glaciers	sum	481786	11003.23	10764.42	-238.81									2503						

l_f – length of ice front

A – Glacier area in the respective period

dA – Change in glacier area between 1985 and 2015

Area change category – see definition in Section 4.1

Date v_S - date of first velocity measurement

Date v_E – date of last velocity measurement

dt - mean time period of velocity measurements

v_S – mean of earliest velocity measurements (1992-1996)

v_E – mean of latest velocity measurements (2010-2014)

dv – mean velocity change

n_v – sum of velocity measurements in the observation period (dt)

Velocity change category – see definition in Table 3

h_{max} – average maximum altitude of individual basins

HI – Hypsometric Index of the basin

Hypsometric category – see Table 4

FA – Flux gate to catchment size ratio

Group – Classification of glaciers in sector “West” according to the hierarchical cluster analysis in Section 4.4.

Formatierte Tabelle

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Formatiert: Standard, Links

Formatiert: Schriftart: Fett

Table S2: Uncertainty σ_v of intensity tracking results. ~~Date: Mean date of SAR acquisitions; Δt: Time interval in days between consecutive SAR acquisitions; σ_v^C: Uncertainty of image coregistration; σ_v^T: Uncertainty of intensity tracking process; If Δt = 1d -> $\sigma_v^T = \sigma_v^C$ see manuscript.~~ Table continues on next pages

~~Date [yyyy-mm-dd]~~ Date [yyyy-mm-dd]	~~Satellite~~ Satellite	~~Δt [d]~~ dt [d]	~~σ_v^C [m d^{-1}]~~ σ_v^C [m d^{-1}]	~~n~~ n	~~σ_v^T [m d^{-1}]~~ σ_v^T [m d^{-1}]	~~σ_v [m d^{-1}]~~ σ_v [m d^{-1}]
1992-12-25	ERS	35	0.13	9721	0.05	0.14
1992-12-25	ERS	35	0.25	23678	0.05	0.26
1993-01-12	ERS	70	0.07	9880	0.02	0.07
1993-01-29	ERS	35	0.10	6090	0.05	0.11
1993-01-29	ERS	35	0.23	4533	0.05	0.24
1993-02-01	ERS	35	0.20	6321	0.05	0.21
1994-02-01	ERS	21	0.35	22007	0.08	0.36
1994-02-18	ERS	54	0.07	28834	0.03	0.08
1994-02-28	ERS	33	0.16	26276	0.05	0.17
1995-10-31	ERS	1*	0.41	150	1.60	0.41
1995-11-14	ERS	1*	0.36	1961	1.60	0.36
1995-11-16	ERS	1*	0.29	448	1.60	0.29
1995-12-18	ERS	71	0.02	68711	0.02	0.03
1995-12-18	ERS	70	0.03	77246	0.02	0.04
1995-12-19	ERS	71	0.02	70974	0.02	0.03
1995-12-19	ERS	70	0.06	67287	0.02	0.06
1995-12-19	ERS	69	0.12	66877	0.02	0.12
1995-12-20	ERS	70	0.04	70897	0.02	0.04
1995-12-21	ERS	70	0.08	10755	0.02	0.08
1995-12-21	ERS	69	0.09	9000	0.02	0.10
1996-01-22	ERS	1*	0.24	49973	1.60	0.24
1996-01-23	ERS	1*	0.34	546	1.60	0.34
1996-02-11	ERS	35	0.12	10215	0.05	0.12
1996-02-11	ERS	35	0.14	8164	0.05	0.15
1996-02-13	ERS	35	0.06	23882	0.05	0.08
1996-02-15	ERS	35	0.14	9379	0.05	0.15
1996-02-29	ERS	35	0.02	39573	0.05	0.05
1996-03-03	ERS	34	0.05	18324	0.05	0.07
1996-03-03	ERS	35	0.05	18395	0.05	0.07
1996-03-20	ERS	1*	0.30	9049	1.60	0.30
1997-02-13	ERS	35	0.04	44246	0.05	0.06
1997-02-15	ERS	35	0.11	14969	0.05	0.12
1997-02-18	ERS	35	0.09	6705	0.05	0.10
1998-02-03	ERS	35	0.07	3176	0.05	0.08
1999-11-09	ERS	1*	0.34	4022	1.60	0.34
2002-02-07	ERS	35	0.07	9893	0.05	0.09
2002-11-29	ERS	35	0.13	61073	0.05	0.13
2002-12-03	ERS	35	0.13	19079	0.05	0.13
2002-12-08	ERS	35	0.29	1965	0.05	0.29
2002-12-21	ERS	70	0.05	21331	0.02	0.05
2002-12-21	ERS	35	0.27	3396	0.05	0.27
2002-12-26	ERS	70	0.13	2437	0.02	0.13
2003-01-07	ERS	35	0.05	24658	0.05	0.07
2003-01-08	ERS	70	0.19	4794	0.02	0.19
2003-01-12	ERS	35	0.09	2548	0.05	0.10
2003-01-25	ERS	35	0.10	14207	0.05	0.11
2004-11-01	ERS	35	0.17	30346	0.05	0.17
2004-11-17	ERS	70	0.06	71277	0.02	0.07
2004-11-19	ERS	70	0.08	32153	0.02	0.09
2004-12-06	ERS	35	0.11	33520	0.05	0.12
2004-12-24	ERS	70	0.11	34409	0.02	0.11
2004-12-25	ERS	35	0.14	12592	0.05	0.14
2005-01-10	ERS	35	0.28	23466	0.05	0.28

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Date [yyyy-mm-dd]	Satellite	Δt dt [d]	σ_v^C [m d^{-1}]	*n*	σ_v^T [m d^{-1}]	σ_v [m d^{-1}]
2006-11-03	ERS	35	0.19	56628	0.05	0.19
2006-11-04	ERS	35	0.14	70277	0.05	0.14
2008-10-29	ERS	35	0.07	9881	0.05	0.08
2010-02-08	ERS	35	0.18	18041	0.05	0.19
2010-02-26	ERS	70	0.11	19172	0.02	0.11
2010-03-15	ERS	35	0.10	23486	0.05	0.11
2000-09-22	R1	24	0.10	20810	0.06	0.12
2000-09-22	R1	24	0.14	33870	0.06	0.15
2000-10-01	R1	24	0.06	30397	0.06	0.09
2006-08-22	R1	24	0.07	57259	0.06	0.10
2006-08-22	R1	24	0.08	21635	0.06	0.10
2003-12-22	ENVISAT	35	0.31	38866	0.05	0.31
2004-01-09	ENVISAT	70	0.03	61495	0.02	0.04
2004-01-10	ENVISAT	35	0.13	1790	0.05	0.13
2004-01-28	ENVISAT	70	0.16	1510	0.02	0.16
2004-02-14	ENVISAT	35	0.09	1898	0.05	0.10
2004-03-20	ENVISAT	35	0.13	3299	0.05	0.14
2004-04-24	ENVISAT	35	0.12	3505	0.05	0.13
2004-05-29	ENVISAT	35	0.10	3623	0.05	0.11
2004-07-03	ENVISAT	35	0.10	3546	0.05	0.11
2004-07-19	ENVISAT	35	0.03	60612	0.05	0.06
2004-08-07	ENVISAT	35	0.11	3418	0.05	0.12
2004-09-11	ENVISAT	35	0.14	3400	0.05	0.15
2004-10-16	ENVISAT	35	0.15	3449	0.05	0.16
2004-12-06	ENVISAT	35	0.06	63965	0.05	0.08
2005-01-28	ENVISAT	70	0.02	62239	0.02	0.03
2005-03-05	ENVISAT	35	0.15	2744	0.05	0.15
2005-03-21	ENVISAT	35	0.19	64254	0.05	0.19
2005-04-09	ENVISAT	35	0.13	2904	0.05	0.14
2005-05-14	ENVISAT	35	0.17	3016	0.05	0.17
2005-06-18	ENVISAT	35	0.13	3631	0.05	0.14
2005-07-23	ENVISAT	35	0.14	2943	0.05	0.14
2005-08-08	ENVISAT	35	0.12	68061	0.05	0.13
2006-02-15	ENVISAT	35	0.07	61205	0.05	0.08
2006-03-25	ENVISAT	35	0.14	2755	0.05	0.15
2006-07-08	ENVISAT	35	0.08	3488	0.05	0.09
2006-08-09	ENVISAT	35	0.06	60954	0.05	0.08
2006-08-12	ENVISAT	35	0.15	3302	0.05	0.15
2006-09-16	ENVISAT	35	0.14	3295	0.05	0.15
2006-10-21	ENVISAT	35	0.16	2741	0.05	0.17
2007-02-18	ENVISAT	70	0.03	71538	0.02	0.04
2007-04-29	ENVISAT	70	0.04	65692	0.02	0.05
2007-06-20	ENVISAT	35	0.03	63862	0.05	0.05
2007-08-12	ENVISAT	70	0.04	61079	0.02	0.05
2007-09-01	ENVISAT	35	0.15	3391	0.05	0.16
2007-10-03	ENVISAT	35	0.10	61336	0.05	0.11
2007-10-06	ENVISAT	35	0.16	3255	0.05	0.16
2008-04-30	ENVISAT	35	0.10	63576	0.05	0.11
2008-06-22	ENVISAT	70	0.03	57922	0.02	0.04
2008-08-13	ENVISAT	35	0.07	60539	0.05	0.08
2009-03-11	ENVISAT	35	0.11	64638	0.05	0.12
2009-07-29	ENVISAT	35	0.03	61130	0.05	0.05
2006-06-10	ALOS	46	0.02	15503	0.02	0.02
2006-06-17	ALOS	46	0.01	61958	0.02	0.02

2006-06-25	ALOS	46	0.08	581	0.02	0.09
2006-07-14	ALOS	46	0.02	9476	0.02	0.02
2006-09-21	ALOS	92	0.02	9912	0.01	0.02

Date [yyyy-mm-dd]	Satellite	~~Δt~~ dt [d]	σ_v^C [m d^{-1}]	n	σ_v^T [m d^{-1}]	σ_v [m d^{-1}]
2006-12-23	ALOS	46	0.08	5135	0.02	0.08
2007-12-04	ALOS	46	0.03	10220	0.02	0.04
2007-12-14	ALOS	46	0.04	2193	0.02	0.04
2008-05-14	ALOS	46	0.01	43889	0.02	0.02
2008-10-21	ALOS	46	0.02	10711	0.02	0.02
2008-10-31	ALOS	46	0.13	2461	0.02	0.13
2008-11-13	ALOS	92	0.02	10861	0.01	0.02
2008-11-14	ALOS	46	0.02	33136	0.02	0.02
2008-12-06	ALOS	46	0.04	10213	0.02	0.04
2008-12-07	ALOS	92	0.02	36230	0.01	0.02
2008-12-16	ALOS	46	0.07	2291	0.02	0.07
2008-12-29	ALOS	92	0.02	10998	0.01	0.02
2008-12-30	ALOS	46	0.04	37661	0.02	0.04
2009-01-21	ALOS	46	0.02	10677	0.02	0.03
2009-12-02	ALOS	46	0.05	3484	0.02	0.05
2009-12-09	ALOS	46	0.03	9707	0.02	0.03
2009-12-21	ALOS	46	0.05	2455	0.02	0.05
2009-12-26	ALOS	46	0.03	9385	0.02	0.03
2010-01-19	ALOS	46	0.02	15505	0.02	0.02
2010-10-08	ALOS	46	0.04	620	0.02	0.04
2010-10-17	ALOS	46	0.03	79294	0.02	0.03
2010-11-06	ALOS	46	0.08	2212	0.02	0.08
2010-11-08	ALOS	46	0.01	16076	0.02	0.02
2010-11-10	ALOS	46	0.02	422	0.02	0.03
2010-11-13	ALOS	46	0.04	9956	0.02	0.05
2010-11-29	ALOS	92	0.03	2069	0.01	0.03
2010-12-01	ALOS	92	0.01	18027	0.01	0.01
2010-12-03	ALOS	92	0.40	426	0.01	0.40
2010-12-06	ALOS	92	0.03	10352	0.01	0.03
2010-12-11	ALOS	92	0.04	4683	0.01	0.04
2010-12-12	ALOS	46	0.03	9480	0.02	0.04
2010-12-22	ALOS	46	0.05	1992	0.02	0.05
2010-12-26	ALOS	46	0.02	411	0.02	0.03
2010-12-29	ALOS	46	0.03	10478	0.02	0.04
2010-12-31	ALOS	46	0.01	46824	0.02	0.02
2011-01-18	ALOS	92	0.16	430	0.01	0.16
2011-02-08	ALOS	46	0.01	17569	0.02	0.02
2011-02-10	ALOS	46	0.01	394	0.02	0.02
2008-10-19	TSX/TDX	11	0.05	4560	0.02	0.05
2008-10-25	TSX/TDX	22	0.02	4362	0.01	0.02
2008-10-30	TSX/TDX	11	0.03	4507	0.02	0.04
2009-08-01	TSX/TDX	11	0.02	11170	0.02	0.03
2009-10-28	TSX/TDX	11	0.06	4220	0.02	0.07
2010-10-26	TSX/TDX	33	0.02	2678	0.01	0.02
2010-11-01	TSX/TDX	44	0.02	3442	0.01	0.02
2010-11-17	TSX/TDX	22	0.01	5995	0.01	0.01
2010-11-17	TSX/TDX	11	0.06	3599	0.02	0.07
2010-11-28	TSX/TDX	99	0.01	3063	0.00	0.01
2010-12-15	TSX/TDX	66	0.02	3476	0.00	0.02
2010-12-20	TSX/TDX	77	0.01	3524	0.00	0.01
2010-12-20	TSX/TDX	55	0.01	4297	0.00	0.02
2010-12-26	TSX/TDX	66	0.01	4341	0.00	0.01
2011-01-22	TSX/TDX	11	0.02	4722	0.02	0.03

2011-06-25	TSX/TDX	22	0.01	15556	0.01	0.02
2011-06-25	TSX/TDX	22	0.04	9886	0.01	0.04
2011-07-06	TSX/TDX	44	0.04	10380	0.01	0.04
2011-07-16	TSX/TDX	22	0.04	3582	0.01	0.04

Date [yyyy-mm-dd]	Satellite	~~Δt~~ dt [d]	σ_v^C [m d^{-1}]	n	σ_v^T [m d^{-1}]	σ_v [m d^{-1}]
2011-07-17	TSX/TDX	22	0.01	15712	0.01	0.02
2011-07-16	TSX/TDX	22	0.10	1421	0.01	0.10
2011-07-17	TSX/TDX	22	0.03	10450	0.01	0.03
2011-07-28	TSX/TDX	44	0.02	10607	0.01	0.02
2011-08-03	TSX/TDX	22	0.40	614	0.01	0.40
2011-08-08	TSX/TDX	22	0.03	10394	0.01	0.04
2011-08-14	TSX/TDX	44	0.14	1556	0.01	0.14
2011-08-19	TSX/TDX	44	0.03	10054	0.01	0.03
2011-08-19	TSX/TDX	55	0.04	2385	0.00	0.04
2011-08-24	TSX/TDX	22	0.03	1894	0.01	0.03
2011-08-24	TSX/TDX	55	0.03	10578	0.00	0.03
2011-08-29	TSX/TDX	33	0.03	1856	0.01	0.03
2011-08-30	TSX/TDX	22	0.02	15605	0.01	0.02
2011-08-30	TSX/TDX	22	0.06	7157	0.01	0.06
2011-09-04	TSX/TDX	33	0.01	15878	0.01	0.01
2011-09-09	TSX/TDX	11	0.06	2325	0.02	0.06
2011-09-14	TSX/TDX	11	0.05	3667	0.02	0.05
2011-09-14	TSX/TDX	11	0.12	1279	0.02	0.12
2011-09-15	TSX/TDX	11	0.03	15546	0.02	0.03
2011-09-15	TSX/TDX	11	0.07	7819	0.02	0.07
2011-09-27	TSX/TDX	44	0.14	2001	0.01	0.14
2011-10-01	TSX/TDX	33	0.02	1956	0.01	0.02
2011-10-01	TSX/TDX	44	0.04	3582	0.01	0.04
2011-10-06	TSX/TDX	33	0.04	3602	0.01	0.05
2011-10-06	TSX/TDX	33	0.11	1353	0.01	0.11
2011-10-12	TSX/TDX	66	0.02	3453	0.00	0.02
2011-10-17	TSX/TDX	55	0.03	3541	0.00	0.03
2011-10-23	TSX/TDX	11	0.06	2018	0.02	0.06
2011-11-03	TSX/TDX	22	0.05	3533	0.01	0.05
2011-11-03	TSX/TDX	22	0.07	1209	0.01	0.07
2011-11-25	TSX/TDX	22	0.03	3507	0.01	0.03
2011-12-06	TSX/TDX	11	0.06	2432	0.02	0.06
2011-12-12	TSX/TDX	33	0.01	13467	0.01	0.01
2011-12-13	TSX/TDX	44	0.05	2328	0.01	0.05
2011-12-17	TSX/TDX	22	0.01	4172	0.01	0.02
2011-12-18	TSX/TDX	33	0.08	2365	0.01	0.08
2012-01-03	TSX/TDX	11	0.01	16220	0.02	0.03
2012-01-03	TSX/TDX	11	0.07	8576	0.02	0.07
2012-01-31	TSX/TDX	55	0.05	2338	0.00	0.05
2012-03-09	TSX/TDX	11	0.02	13279	0.02	0.03
2012-03-09	TSX/TDX	11	0.16	7483	0.02	0.16
2012-03-10	TSX/TDX	22	0.07	2343	0.01	0.07
2012-03-15	TSX/TDX	22	0.01	15451	0.01	0.01
2012-03-15	TSX/TDX	33	0.05	2290	0.01	0.05
2012-03-15	TSX/TDX	22	0.07	7142	0.01	0.07
2012-03-20	TSX/TDX	11	0.08	6422	0.02	0.08
2012-03-21	TSX/TDX	44	0.05	2265	0.01	0.05
2012-03-25	TSX/TDX	22	0.11	1258	0.01	0.11
2012-03-26	TSX/TDX	55	0.05	2143	0.00	0.05
2012-03-26	TSX/TDX	11	0.19	2259	0.02	0.19
2012-04-01	TSX/TDX	22	0.14	2362	0.01	0.14
2012-04-06	TSX/TDX	33	0.06	2248	0.01	0.06

Date [yyyy-mm-dd]	Satellite	Δt dt [d]	σ_v^C [m d^{-1}]	n	σ_v^T [m d^{-1}]	σ_v [m d^{-1}]
2012-04-06	TSX/TDX	11	0.10	2316	0.02	0.10
2012-04-12	TSX/TDX	22	0.05	2100	0.01	0.05
2012-04-17	TSX/TDX	22	0.02	15486	0.01	0.02
2012-04-17	TSX/TDX	22	0.05	7244	0.01	0.05
2012-04-30	TSX/TDX	11	0.04	1747	0.02	0.05
2012-05-08	TSX/TDX	66	0.02	3381	0.00	0.02
2012-05-09	TSX/TDX	22	0.02	15305	0.01	0.02
2012-05-09	TSX/TDX	55	0.04	2344	0.00	0.04
2012-05-09	TSX/TDX	22	0.05	6241	0.01	0.05
2012-05-13	TSX/TDX	77	0.02	3656	0.00	0.02
2012-05-15	TSX/TDX	44	0.04	2221	0.01	0.04
2012-05-19	TSX/TDX	22	0.03	3672	0.01	0.03
2012-05-19	TSX/TDX	22	0.10	1275	0.01	0.10
2012-05-20	TSX/TDX	55	0.04	2375	0.00	0.04
2012-05-24	TSX/TDX	33	0.04	1210	0.01	0.04
2012-05-30	TSX/TDX	33	0.03	2544	0.01	0.03
2012-06-04	TSX/TDX	11	0.05	3532	0.02	0.06
2012-06-04	TSX/TDX	11	0.10	1351	0.02	0.11
2012-06-05	TSX/TDX	33	0.01	15558	0.01	0.01
2012-06-11	TSX/TDX	11	0.09	2222	0.02	0.09
2012-06-15	TSX/TDX	11	0.08	3328	0.02	0.09
2012-06-15	TSX/TDX	11	0.10	1280	0.02	0.10
2012-06-21	TSX/TDX	11	0.07	2621	0.02	0.07
2012-06-27	TSX/TDX	11	0.06	7647	0.02	0.06
2012-06-28	TSX/TDX	44	0.04	2293	0.01	0.04
2012-07-03	TSX/TDX	55	0.04	2350	0.00	0.04
2012-07-03	TSX/TDX	33	0.05	2292	0.01	0.05
2012-07-09	TSX/TDX	44	0.04	2389	0.01	0.04
2012-07-13	TSX/TDX	33	0.03	2765	0.01	0.03
2012-07-19	TSX/TDX	33	0.02	15662	0.01	0.02
2012-07-25	TSX/TDX	11	0.09	2122	0.02	0.09
2012-08-04	TSX/TDX	11	0.07	2545	0.02	0.07
2012-08-09	TSX/TDX	11	0.07	3577	0.02	0.07
2012-08-09	TSX/TDX	11	0.12	1204	0.02	0.13
2012-08-10	TSX/TDX	11	0.07	7151	0.02	0.07
2012-08-11	TSX/TDX	44	0.08	2444	0.01	0.08
2012-08-16	TSX/TDX	55	0.04	2374	0.00	0.04
2012-08-22	TSX/TDX	44	0.04	2230	0.01	0.04
2012-09-07	TSX/TDX	11	0.14	1690	0.02	0.14
2012-09-23	TSX/TDX	33	0.05	1078	0.01	0.05
2012-09-29	TSX/TDX	55	0.04	1597	0.00	0.04
2012-09-29	TSX/TDX	33	0.06	2397	0.01	0.06
2012-10-05	TSX/TDX	44	0.08	2401	0.01	0.08
2012-10-10	TSX/TDX	55	0.05	2372	0.00	0.05
2012-10-20	TSX/TDX	33	0.03	2520	0.01	0.03
2012-10-21	TSX/TDX	11	0.09	2179	0.02	0.09
2012-10-27	TSX/TDX	22	0.08	2296	0.01	0.08
2012-11-01	TSX/TDX	11	0.10	2327	0.02	0.10
2012-11-01	TSX/TDX	33	0.17	1923	0.01	0.17
2012-11-05	TSX/TDX	11	0.05	3446	0.02	0.05
2012-11-05	TSX/TDX	11	0.13	1186	0.02	0.13
2012-11-07	TSX/TDX	44	0.05	2312	0.01	0.05
2012-11-12	TSX/TDX	33	0.05	2364	0.01	0.06
2012-11-12	TSX/TDX	11	0.12	2354	0.02	0.12
2012-11-18	TSX/TDX	22	0.07	2419	0.01	0.07
2012-11-23	TSX/TDX	11	0.08	2204	0.02	0.09

Date [yyyy-mm-dd]	Satellite	~~Δt~~ dt [d]	σ_v^C [m d^{-1}]	n	σ_v^T [m d^{-1}]	σ_v [m d^{-1}]
2012-12-26	TSX/TDX	55	0.03	2141	0.00	0.03
2013-02-23	TSX/TDX	77	0.01	3503	0.00	0.01
2013-03-01	TSX/TDX	11	0.08	2802	0.02	0.08
2013-03-17	TSX/TDX	11	0.06	3749	0.02	0.07
2013-03-17	TSX/TDX	11	0.14	1255	0.02	0.14
2013-03-23	TSX/TDX	22	0.03	3632	0.01	0.03
2013-03-23	TSX/TDX	22	0.08	1196	0.01	0.08
2013-03-26	TSX/TDX	11	0.08	1992	0.02	0.08
2013-03-28	TSX/TDX	11	0.17	1347	0.02	0.18
2013-03-29	TSX/TDX	33	0.05	1148	0.01	0.05
2013-04-03	TSX/TDX	33	0.09	2117	0.01	0.09
2013-04-10	TSX/TDX	22	0.06	2172	0.01	0.07
2013-04-15	TSX/TDX	33	0.07	2237	0.01	0.07
2013-04-26	TSX/TDX	55	0.05	2275	0.00	0.05
2013-04-26	TSX/TDX	11	0.12	2379	0.02	0.13
2013-04-30	TSX/TDX	55	0.02	3261	0.00	0.03
2013-06-08	TSX/TDX	22	0.03	3820	0.01	0.03
2013-06-08	TSX/TDX	22	0.04	1021	0.01	0.04
2013-06-19	TSX/TDX	44	0.02	3719	0.01	0.02
2013-06-30	TSX/TDX	22	0.03	3813	0.01	0.03
2013-06-30	TSX/TDX	22	0.09	1258	0.01	0.09
2013-07-28	TSX/TDX	33	0.01	15233	0.01	0.02
2013-08-02	TSX/TDX	33	0.02	2763	0.01	0.02
2013-08-25	TSX/TDX	33	0.05	2311	0.01	0.05
2013-08-30	TSX/TDX	33	0.01	15399	0.01	0.01
2013-09-20	TSX/TDX	33	0.03	3602	0.01	0.03
2013-09-20	TSX/TDX	33	0.05	1292	0.01	0.05
2013-09-27	TSX/TDX	33	0.04	2235	0.01	0.04
2013-10-02	TSX/TDX	33	0.01	15262	0.01	0.01
2013-10-23	TSX/TDX	33	0.02	3578	0.01	0.02
2013-10-23	TSX/TDX	33	0.05	1283	0.01	0.05
2013-10-30	TSX/TDX	33	0.05	2317	0.01	0.05
2013-11-02	TSX/TDX	11	0.02	9090	0.02	0.03
2013-11-02	TSX/TDX	11	0.07	484	0.02	0.07
2013-11-04	TSX/TDX	33	0.02	15102	0.01	0.02
2013-11-09	TSX/TDX	11	0.05	2652	0.02	0.06
2013-11-10	TSX/TDX	55	0.04	2294	0.00	0.04
2013-11-15	TSX/TDX	22	0.04	2878	0.01	0.05
2013-11-20	TSX/TDX	22	0.03	3538	0.01	0.04
2013-11-20	TSX/TDX	33	0.04	2955	0.01	0.04
2013-11-20	TSX/TDX	11	0.08	2846	0.02	0.08
2013-11-20	TSX/TDX	22	0.10	1321	0.01	0.10
2013-11-21	TSX/TDX	11	0.08	2180	0.02	0.08
2013-11-25	TSX/TDX	33	0.02	3312	0.01	0.02
2013-11-25	TSX/TDX	33	0.05	1125	0.01	0.05
2013-11-26	TSX/TDX	11	0.03	15060	0.02	0.03
2013-11-26	TSX/TDX	22	0.04	2825	0.01	0.04
2013-11-26	TSX/TDX	11	0.08	6708	0.02	0.09
2013-11-27	TSX/TDX	22	0.08	2346	0.01	0.09
2013-11-30	TSX/TDX	44	0.00	8207	0.01	0.01
2013-12-01	TSX/TDX	44	0.02	3438	0.01	0.02
2013-12-01	TSX/TDX	33	0.03	2670	0.01	0.03
2013-12-01	TSX/TDX	11	0.06	2893	0.02	0.06
2013-12-02	TSX/TDX	22	0.01	14680	0.01	0.01
2013-12-02	TSX/TDX	33	0.04	2079	0.01	0.04
2013-12-02	TSX/TDX	22	0.06	6620	0.01	0.06
2013-12-02	TSX/TDX	11	0.23	1957	0.02	0.24

2013-12-06	TSX/TDX	11	0.05	3548	0.02	0.06
2013-12-06	TSX/TDX	11	0.15	1322	0.02	0.15
2013-12-07	TSX/TDX	11	0.02	14924	0.02	0.03
2013-12-07	TSX/TDX	22	0.04	2905	0.01	0.04
2013-12-07	TSX/TDX	11	0.11	8347	0.02	0.11
2013-12-08	TSX/TDX	22	0.08	2021	0.01	0.08

Date [yyyy-mm-dd]	Satellite	~~Δt~~ dt [d]	σ_v^C [m d^{-1}]	n	σ_v^T [m d^{-1}]	σ_v [m d^{-1}]
2013-12-12	TSX/TDX	22	0.03	3508	0.01	0.03
2013-12-12	TSX/TDX	33	0.03	2814	0.01	0.03
2013-12-12	TSX/TDX	11	0.07	3039	0.02	0.08
2013-12-12	TSX/TDX	22	0.09	1242	0.01	0.09
2013-12-13	TSX/TDX	33	0.06	2306	0.01	0.06
2013-12-13	TSX/TDX	11	0.07	2024	0.02	0.08
2013-12-17	TSX/TDX	11	0.02	3978	0.02	0.03
2013-12-17	TSX/TDX	33	0.03	3323	0.01	0.03
2013-12-17	TSX/TDX	11	0.14	1290	0.02	0.14
2013-12-18	TSX/TDX	33	0.01	13920	0.01	0.01
2013-12-18	TSX/TDX	22	0.03	2741	0.01	0.04
2013-12-23	TSX/TDX	22	0.03	3725	0.01	0.03
2013-12-23	TSX/TDX	11	0.05	2877	0.02	0.06
2013-12-23	TSX/TDX	22	0.09	1118	0.01	0.10
2013-12-24	TSX/TDX	22	0.01	14893	0.01	0.01
2013-12-24	TSX/TDX	22	0.05	7587	0.01	0.05
2013-12-24	TSX/TDX	11	0.09	2342	0.02	0.09
2013-12-28	TSX/TDX	11	0.05	3475	0.02	0.05
2013-12-28	TSX/TDX	11	0.14	1096	0.02	0.15
2013-12-30	TSX/TDX	44	0.03	2034	0.01	0.03
2014-01-03	TSX/TDX	33	0.02	2819	0.01	0.02
2014-01-04	TSX/TDX	55	0.04	2128	0.00	0.04
2014-01-04	TSX/TDX	33	0.05	1939	0.01	0.05
2014-01-09	TSX/TDX	22	0.03	2828	0.01	0.03
2014-01-10	TSX/TDX	44	0.03	2083	0.01	0.03
2014-01-10	TSX/TDX	22	0.10	2104	0.01	0.10
2014-01-14	TSX/TDX	44	0.01	3685	0.01	0.01
2014-01-15	TSX/TDX	33	0.05	2236	0.01	0.05
2014-01-19	TSX/TDX	33	0.02	3652	0.01	0.02
2014-01-31	TSX/TDX	22	0.03	2647	0.01	0.03
2014-02-27	TSX/TDX	44	0.03	3163	0.01	0.03
2014-02-28	TSX/TDX	55	0.05	2235	0.00	0.05
2014-03-24	TSX/TDX	11	0.08	1958	0.02	0.08
2014-03-27	TSX/TDX	11	0.03	15610	0.02	0.03
2014-04-04	TSX/TDX	33	0.04	1921	0.01	0.04
2014-04-10	TSX/TDX	22	0.05	1895	0.01	0.05
2014-07-25	TSX/TDX	11	0.07	1184	0.02	0.08
2014-08-05	TSX/TDX	33	0.05	1130	0.01	0.05
2014-08-06	TSX/TDX	22	0.03	2495	0.01	0.03
2014-08-11	TSX/TDX	33	0.02	2649	0.01	0.02
2014-08-11	TSX/TDX	22	0.08	1340	0.01	0.08
2014-08-22	TSX/TDX	11	0.08	3049	0.02	0.08
2014-08-27	TSX/TDX	11	0.08	1215	0.02	0.09
2014-12-16	TSX/TDX	11	0.03	15265	0.02	0.03

datasets	Mean values:					
382	All		0.07	11717	0.05	0.08
59	ERS		0.14	26475	0.04	0.15
5	R1		0.09	32794	0.06	0.11
41	ENVISAT		0.11	30240	0.04	0.12
43	ALOS		0.05	13868	0.01	0.05

234	TSX/TDX	0.06	4414	0.01	0.06

Date - Mean date of SAR acquisitions

dt - Time interval in days between consecutive SAR acquisitions

σ_v^C - Uncertainty of image coregistration

σ_v^T - Uncertainty of intensity tracking process

[*] if dt = 1d -> $\sigma_v = \sigma_v^C$ see manuscript Section 4.2

Formatierte Tabelle

Formatiert: Einzug: Links: 1"

Formatiert: Schriftart: Arial