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
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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 ́keep 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.