

## ***Interactive comment on “Changes in glacier dynamics at the northern Antarctic Peninsula since 1985” by Thorsten Seehaus et al.***

### **Anonymous Referee #1**

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Review of “Changes in glacier dynamics at the northern Antarctic Peninsula since 1985” by Thorsten Seehaus, Alison Cook, Aline B. Silva, and Matthias Braun as submitted to The Cryosphere Discussions

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

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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. Page 1 Line 13: The  $<65^\circ$  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. 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. Page 1 Line 19: Similarly, what is the standard deviation of the average velocity?

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. Page 2 Line 9: Here and elsewhere it seems more appropriate to put references chronologically from early to later. Page 2 Line 23: ‘The collected observations reported in these studies suggest’ rather than ‘the observations suggest’... Page 2 Line 28: ‘methodologically’ rather than ‘methodically’

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

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of the west coast + nearby major islands are excluded from this study. 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. Page 3 Line 11: Order the shelf areas chronologically. 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). 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). 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. 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. Page 3 Line 22: 'Sparse data coverage' needs to be clarified. 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?

### 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. Page 4 Lines 4/5: The two sentences can easily be merged with lines below them. Page 4 Lines 7/8: Distinguish sensors and satellites explicitly. Page 4 Line 13: Given the retreat processes for the PG Channel, is limiting all of the glaciers to 1995 appropriate? Page 4 Line 20: Were ratings of 4 and 5 not needed or was any such data discarded?

#### 3.2 Surface velocities

Page 4 Line 24: Table 2 lacks SAR resolution information. Page 4 Line 28: Does

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the mentioned masking eliminate glacier areas from having their full velocity patterns mapped? I think this and Line 30 could be clarified. Page 5 Line 7: Put a period after 'topography' and start the next sentence with 'The results are then geocoded...'. Page 5 Lines 8-10: Some discussion of the limitations of the ASTER DEM is needed (this also potentially impacts the cluster analysis). 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)? 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. Page 6 Lines 2/3: The second sentence needs to be clarified. 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).

#### 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> Page 6 Line 17: Does accumulation increase with higher altitude on both sides? Does this apply mostly to the plateaus? Please clarify. Page 6 Line 20: Add the Jiskoot et al. reference(s) here, not just in Table 4. 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'.

#### 3.4 Cluster analysis –

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

#### 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. 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). Page 7 Line 16: Assume you mean '238 km<sup>2</sup>'. Also, see comments on Figure 4 that seem designed to greatly accentuate the '2.2%' loss between 1985 and 2015. Page 7 Line 17: You could usefully add the individual loss % values here.

##### 4.2 Surface velocities

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

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difficult to visually assess (Page 8 Lines 1-3) the Table 3 categories. 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). Page 8 Line 9: Table S2 should be S1 and there is an error in one of the subscripts and 'd' should apparently be  $\Delta$ , here. Also see comments on Table 5. Page 8 Line 13: You might as well give the longest period for velocity and also the standard deviation.

##### 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). 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.

##### 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, regardless of Section 5.3, seems to emphasize an uncertain result.

#### 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? Page 8 Line 27: Superscript for area is missing. 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'. 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

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

#### 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). Page 9 Line 26: Here and elsewhere, hyphens are not needed for ‘Larsen-A/B’. 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. 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’? 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.

#### 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

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specific date do you prefer? 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? Page 11 Lines 8-10: Please be more specific as to what/how the visual imagery was used to identify the ‘bump’. 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.

#### 5.3 West ‘sector’

Page 11 Line 24: See previous comment on Turner vs Oliva temperature studies. 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? Page 11 Lines 25/26: Does ‘southern part’ apply to both West and East or only ‘West’? What about the coastline makes it ‘fractal’ and does that aid understanding? Clarify ‘These’ factors lead (cause?)... 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? Page 11 Line 31: The fact that fjord and glacier geometries may be uncertain should probably be mentioned here, 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.

#### 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. 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. Page 13 Line 19: Clarify if ‘significantly higher’ is simply due to differences in the methodology relative to

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Pritchard and Vaughan (2007) for the same period. If so, should this simply say 'higher' velocities were observed? Page 13 Line 22: Be clear that all 'East' glacier fronts retreated relative to 1985 (or 1995 after shelf losses). 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. 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).

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.

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

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distract the eye in many instances. Also, as mentioned in text comments, was curve fitting of the velocity data attempted?

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.

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.

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 overlapping basin outlines) but that the sectors are (somewhat) defined with three colors. Also, 'dA' should apparently be  $\Delta A$ . 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?).

Figure 6: See comments on the text regarding the cluster analysis. Add numbers for

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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.

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.

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). 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. 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. 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. 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  $\Delta$  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.

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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’. 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). Table S2: Add an appropriate title and move parameter descriptions to footnotes or a header box as the editor prefers. The  $\Delta t$  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.

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Interactive comment on The Cryosphere Discuss., doi:10.5194/tc-2017-50, 2017.

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