

Interactive comment on “Spatial and temporal variations in basal melting at Nivlisen ice shelf, East Antarctica, derived from phase-sensitive radars” by Katrin Lindbäck et al.

Anonymous Referee #2

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In this manuscript, the authors use an exciting ApRES data set to investigate basal melt rates underneath the Nivlisen ice shelf, East Antarctica. While repeat measurements of 29 ApRES sites distributed across and along ice-flow direction result in only 'moderate (0.8 m/yr)' annual basal melt rates, continuous records from two ApRES sites reveal a seasonal signal with 'highest daily' basal melt rates of up to 5.6 m/yr near the ice front. This seasonal signal cannot be observed at the second continuous ApRES site further upstream, which leads the authors to conclude that the presence of warm ocean surface water in summer and its interplay with the dominant winds in the area is the cause for the increased melt, rather than the intrusion of circumpolar deep water that causes very high basal melt rates in other parts of Antarctica. The authors support

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their hypothesis with three GPR profiles, atmospheric data from both a nearby AWS and re-analysis data; and attempt the link of ApRES data to satellite imagery from MODIS.

In my opinion, the ApRES data set and the consequent quantification of basal melt rates in this area is required by the community to evaluate and improve current modelling efforts and I would very much like to see the manuscript published soon. The processing of the ApRES data is methodologically sound which makes this manuscript a valuable contribution to the study of ice-ocean interaction around Antarctica. I particularly enjoyed the thorough phase analysis between the two continuous ApRES records to display the seasonality in basal melting. The manuscript is mostly well organized but: (1) some parts of the extensive discussion can be shortened and belong to the description of the study area. Similarly, the writing style can be improved in many places. (2) The link to satellite data that is even underlined in the conclusion is weak which doesn't align with the author's very elegant analysis of ApRES data. (3) Some statements about the present pinning-points and their effect on ice-shelf stability can't be made with the data set presented. I recommend the manuscript for publication after minor revisions that include a revisit to the last part of the discussion section. I'm looking very much forward to it.

Minor comments:

I. 29-30: Including a statement about pinning points and their stabilizing effect made me anticipate a corresponding analysis in the main text. Without this analysis the statement is a bit too speculative to be included in the abstract. Reword

I. 35-36: I think with 'shrinking' you mean 'thinning'. I suggest changing to '...thinning glaciers in West Antarctica that lost back-stresses from their buttressing ice shelves.'

I. 40-41: Change 'input of grounded ice upstream' to 'from ice across the grounding line' as it is a flux-gate calculation at the boundary between floating and grounded ice. Include 'underneath the floating ice shelf' after 'ocean' and 'at the ice front' after

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'calving'. Also surface mass balance can be negative and represent ice loss. Please include in this list.

I. 43: Change to '...stresses on grounded ice upstream, leading the tributaries to flow faster' as there are more than one stress component to provide buttressing.

I. 45: Change to 'therefore the key to gain a...'

I. 52,62,75: I like the review of Jacobs melt modes and its link to basal melting around Antarctica. However I had to read these three paragraphs twice to follow. Reword to 'In mode 1,...' then 'In mode 2,...' and 'In mode 3,...' each followed by examples from the literature to help the reader. How about the high melt rates that have been observed in basal channels and lake drainage on Roi Baudouin or underneath the Whillans Ice Stream? Please include in this review section.

I. 68: Change to 'Totten'

I. 81-82: This is hard to read. Change to '...reflect the integrated response to changes in circumpolar deep water temperatures and coastal processes that control its access onto the continental shelf (Thompson et al., 2018)' and please remove 'and the local upper ocean heat supply' as it doesn't add anything to the sentence. I. 99: Change 'resolution' to 'accuracy' or do you really mean vertical spatial resolution here? Also change 'over' to 'and'

I. 104: Change 'explain' to 'interpret' as you only analyse the data at this section of the paper.

I. 106: Change 'were' to 'are'. General convention is to use past tense for everything that was done and present tense for everything that you have found out.

I. 107: Change to 'complement' as your data is plural

I. 108: Change to 'data source'

I. 112-113: Remove the first sentence as it doesn't add to the paper.

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- I. 117: Change to 'Basal melt rates from satellite data in. . .' to avoid the long concatenation
- I. 121-124: Remove '100 km...ponds.' as this is trivia in the context of the paper.
- I. 125-126: Change to '... has an estimated potential of raising global sea level by 8 cm.'
- I. 132: you haven't introduced/defined the grounding zone yet. What do you mean exactly or can 'in the grounding zone' be removed? For me a grounding zone is caused by tidal variability of ice mechanics downstream of the grounding line where ice detaches from the bed and becomes afloat.
- I. 136: Change 'the shelf' to 'its stability'
- I. 146: Include 'gradients' or 'heterogeneity' after 'surface mass balance'
- I. 148: again 'in the grounding zone'
- I. 157: Change '...remaining 25% coming from...' to '...residual 25% attributed to...' to avoid colloquial language
- I. 158-165: This would be very interesting to see in your Fig. 1B (see specific comment below)
- I. 170: Remove 'summertime' and change 'minimum' to 'minima' as you also have 'maxima' earlier
- I. 172: Reword 'dominant modes' as you introduced Jacobs modes earlier and you don't want to confuse the reader with additional modes
- I. 177: Change 'then' to 'consequent'
- I. 178: Change to 'remains'
- I. 181-183: Include 'the' before 'Antarctic' and 'end'. The sentence about logistical support can be removed (you have it in the Acknowledgements already)

- I. 185-186: Remove 'Below,...melt rates' as it doesn't add to the paper
- I. 187: Change 'studied' to 'measured'
- I. 189: Include 'all 29' after 'measured at' and change 'stake locations' to 'ApRES sites'
- I. 190: Change to 'Autonomous phase-sensitive Radio Echo Sounder'
- I. 191: Change 'speed' to 'velocity' as you mention the calculation of strain rates which require a direction. Velocity is speed with direction, speed doesn't have a direction.
- I. 193: Change 'shelf' to 'flow'
- I. 195-196: 'Ice tongue' is this a common expression for this particular part of the ice shelf ? For me an ice tongue is a glacier that sticks out into the ocean without lateral thinning (for example the Drygalski Ice Tongue) and not a part of the floating ice shelf that is pushed through two ice rises like the one here.
- I. 200 and elsewhere: 'stake sites' is confusing. Please reword throughout the paper
- I. 217: Remove one of the two 'that'
- I. 223-226: Reword this very long sentence. Also the word 'both' is used two times (the first one refers to actually three nouns). Maybe break it up into two sentences.
- I. 233: Change 'returns' to 'reflector' and start a new sentence after 'processing' with 'This allowed us to...'
- I. 236: The 36 h window size needs explanation.
- I. 241: Include 'also' after 'we'. Sounds like 2016 was a busy field season !
- I. 242: Remove 'across...structure' and replace with '...measurements on Nivlisen ice shelf (profiles A,B and C in Fig. 1b) as you have mentioned the orientation of the profiles already.
- I. 246: there are three times the word 'with' in one line. Please reword

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- I. 248: Replace 'traces' with 'measurements'. Is 'code-phase' GPS special and improves your accuracy ? If it isn't I suggest removing it
- I. 260-262: This sounds strange. Why is there such a big difference between the two methods to determine firn depth ? Also why is this important ? Did you use a 2-layer velocity model to convert travel time to depth ? I assume not. How did you determine 50 m firn from the ApRES data you present in Fig. S1 ? Please add some information here.
- I. 262-263: Please add a sentence why the calculation of ice draft is necessary in this context. Also, for your freeboard calculation you require a sea level right ? Where does this come from ? A geoid model ?
- I. 274: Remove 'We...Nivlisen.' as it doesn't add to the paper and is mentioned in Data and Methods section already
- I.281: Change 'speed' to 'velocity'
- I. 294: Again 'melt rates at stake locations'. Please reword
- I. 294,296,297: It's called 'average annual'
- I. 299-300: Reword and start the sentence with 'In 2018' to conform with the start of the paragraph
- I. 304: 'low strain rates' compared to what ? Please add
- I. 314: somewhere around here you move from using 'basal melt rates' to only 'melt rates'. Please remain consistent
- I. 315: Include 'as' after the comma
- I.316 and elsewhere: your 14 moth record ends in 2018 and not in 2017. Please change here and also in Figure captions.
- I. 461-473: Most of this belongs to Section 2 Study Area where you explain the oceano-

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graphic setting. Please move this paragraph, but still discuss earlier studies in a 'this confirms/is against the findings of way" at this stage.

I. 503-504: Same here, move to Section 2

I. 511-517: This is a nice paragraph and should also discuss potential links to Steward et al., 2019. Is this the same mechanism at play ?

I. 521: Change 'Fig. 7d' to 'Fig 7c'

I. 531-532: This statement needs to be defended with the right figure ! I suggest to change Fig. 7 (see below)

I. 533: Reword to '...was pushed by wind under the front of Nivlisen ice shelf'

I.534-539: I would swap these two sentences and begin with 'Surface wind' then say something about 'Surface warming' to get the order of processes right. End this paragraph here and remove the last sentence 'Natural...sea ice' as this more general statement that doesn't really fit here and creates an impression that actually weakens your results.

I. 548,551: Add values (0.8 and 5.6 m/yr) in braces after 'moderate' and 'summer'. Also add 'relatively' before 'high melt rates' as 5.6 m/yr are not high melt rates when I think of the Amundsen Sea.

I. 549: 'Daily' ? As far as I thought the temporal resolution of the data is much higher. More information is required on how you acquired the continuous ApRES data. Number of bursts/averaging/etc

I. 558: Change 'of' to 'in'

I. 559: Include 'temporally' before 'higher'. Also be consistent with 'basal melt rates' as it is called here 'rates of melting'

I. 564-565: Again 'pinning points'. I don't think that there is enough analysis on their

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stability and how this might be affected by your measurements to include a statement like this in the conclusion. Please reword or move this to the discussion.

l. 570-571: Change 'important' to 'crucial' and remove 'which in turn is important for ice sheet models' as understanding the driving mechanism is much more important than including it into a model. By removing the last bit you put more emphasis on this.

Specific comments throughout the paper:

1. hyphenations in compound expressions are sometimes wrong or missing. For example l.131 'ice-shelf flow'. Hyphenation is wrong if no noun follows: 'the ice shelf flows' versus 'the ice-shelf flow'

2. 'Stake locations' I know that this comes from locating the ApRES antennas in the field over several years but somehow it sounds like you measure basal melting with stakes only. Can you reword 'Stake locations' to 'ApRES sites' and mention stakes only where you use them for the GPS survey and strain calculation ?

Figures: Figures are all way to small (see individual comments below)

Fig. 1) (a) what is the gray shaded area in the lower right ? (b) The ice-shelf front and the Landsat mosaic don't match up. Why is approx 1/3 of the ice shelf missing ? I suggest replacing the Landsat part of the figure with a schematic of what you know about the bathymetry (ridges, troughs, continental shelf edge) and the dominant oceanographic currents as you describe nicely in the main text (l. 158-165). Where was the carbon dating site ? Maybe remove the 'Ice structure' as you don't refer to them in the analysis of profile A-Aprime. (caption) Change 'made' to 'located'

Fig. 2) (a) colorbar for REMA DEM is missing, I like the absolute values of basal melt rates. (b) plot the difference of your GPR measurements to the Bedmap2 product and replace the colorbar with the new values. The contours stay the same, but you can tell where they match and where they don't. (c) similar here, color-code the stake sites with the difference to Measures and annotate the absolute measured value of Ice flow

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velocity. (d) Same here, I'd display the difference in the markers and write the absolute measured SMB next to the stake sites. (caption) remove 'hill shade'

Fig. 3) Font size is incredibly small! First remove all repeated text from each of the three subplots. Each of the individual panels of the subplots use the same Distance so you only need to display that at the lower panel. The x-axis label 'Distance (km)' only needs to go below the third subplot. Also, all three surface elevation panels should have the same yaxis limits to be comparable. The radargram in the middle misses the blue surface elevation curve.

Fig. 4) (a) the start of the gray box c doesn't match with the start of your third subplot. (b) what do the white shaded areas in lower left and right mean ? (c) good (d) You don't need to write 'Time' when it is clear from the xaxis ticklabels. Maybe change 'Time' to '2017' (caption) the first 2017 is a 2018, right ? Ylabels 'melt rate' versus 'basal melt rate' earlier, pick one.

Fig. 5) (a) Consider writing '2017' and '2018' left and right next to the gray bars. (b and c) good (d) This looks like a spring-neap tidal signal over 14 days. Xticklabels should be the same as for Fig 4d. Consider replacing 'Time' with '2017'

Fig. 6) Very nice plot ! Don't use the same colormap as for Figs 4b and 5b as this is a different variable. Consider including a Legend with the arrow directions and 'in phase', 'seawards leads' and 'landward leads'. What do arrows pointing left stand for ? Also, has there been a threshold in coherence when you display the arrows ? What are the shaded areas in lower left and right ?

Fig. 7) I think this plot doesn't really show what you say in the main text. Both the temperature and sea-ice cover subplots didn't really help my understanding and could be moved to the supplements. Also, the interpretation of using dashed lines is to subjective to say that satellite data can't capture high melt events. I suggest: (l) using the space of subplots c and d and replace with a scatterplot of summertime wind speeds vs basal melt rates on the seaward site, where the dots are color-coded to wind direction

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(similar to Fig. S5). (II) shade areas in (a) when you see open water in satellite data. Has the time lag between peaks in wind and basal melt rate only been estimated from the dashed lines ? That's ok, but it must be stated in the main text. (caption) Include 'nearby' before 'weather station'

Fig. S1) I can't see how a firn depth of 50m is derived from this plot, where does it come from and why is this important ? Change xaxis label to 'Depth below surface (m)'

Fig. S2) Comparing (c) to (d) indicates that there was less melt in 2018.

Fig. S3) (a) yaxis label is missing (b) include two xaxis labels '2017' and '2018'

Fig. S4) good

Fig. S5) (caption) Change '2017' to '2018'

Fig. S6) can you include the information about open water availability in your analysis ?

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