Response to Referees on tc-2021-169

We appreciate the reviews and comments from both Referees. Please find the response to Referee 1 on pages 1-17, and the response to Referee 2 on pages 18-20.

Response to Referee 1 on tc-2021-169

First, we would like to thank the Referee for reviewing and commenting the manuscript, which improves the quality of the manuscript. Please find the item-by-item reply below, with the original comments in *italics* and the responses in blue. The suggested changes have been implemented in the revised text.

General Comments
My main concern pertains to the overall readability of the manuscript. While it is clear that the authors understand the background literature, methods, key results and implications of their research, their writing style is in general unconventional for a piece of scientific writing, insofar as it is highly verbose, often grammatically and/or typographically incorrect and, hence, difficult to follow/comprehend from a reader's point of view. This is further confounded by what appears to be inconsistencies in the clarity/style of writing adopted in different sections of the manuscript, missing information needed to fully understand the datasets and/or logic of arguments presented, and the occasional lack of relevant citations throughout the text (see my specific and technical comments for further details).
To address these issues, I recommend that all coauthors take the time to carefully restructure the wording of the manuscript to: a) more logically explain (and justify fully) the choice of all techniques and methodological decisions used/taken, b) correct typographical/grammatical errors and, c), cut down and hence improve the overall focus/narrative of the text. To assist the authors in this regard, I have made some suggestions on how the first two paragraphs of the introduction could be rewritten (see bottom of this document). If needed, the authors may also find the following resource (https://www.the-cryosphere.net/submission.html#english) and links therein helpful.

We appreciate the suggestions and the text has been modified according to the specific comments. Generally, changes that are made include:
- Data and method section is elaborated.
- En dashes instead of hyphens are used to show time/value ranges.
- Verbose/incorrect/redundant sentences are rewritten/removed.
- Redundant definite articles have been moved.

Title. *'InSAR' is an abbreviation and hence inappropriate for use in a title. Suggest rephrasing title to: 'The potential of synthetic aperture radar interferometry for assessing meltwater lake dynamics on Antarctic ice shelves' or similar instead. (see also my comments regarding Line 246).*

This has been changed in the revised text (in this case the title).

Line 2. *Suggest replacing 'Yet' with 'Despite these phenomena'. Replace 'or' with 'and'.*

This has been implemented in the revised text. All comments regarding rephrasing/grammatical corrections will be replied as 'done' in the following text of this reply.

L3. Suggest either ending sentence after 'limited', or briefly explaining what the limitations of optical satellite imagery are here.

Added 'during polar night and in cloudy conditions' after 'optical satellite imagery'.

L8. Change 'The analysis' to 'Our analysis'. At end of this sentence, change 'confounded' to either 'hard to distinguish' or 'indistinguishable'. Then change next sentence to: 'Despite this finding, we show using a combination of backscatter and InSAR observations that lake dynamics can be effectively captured during other non-summertime months'.

(Now L9) Done.

L11. Sentence beginning 'In particular'. For conciseness, suggest merging this and next sentence to: 'Moreover, our findings highlight the utility of InSAR-based observations for discriminating between refrozen ice and subsurface meltwater, and indicate the potential for phase-based detection and monitoring of rapid meltwater drainage events'.

(Now L12) Done.

L56. Remove 'The' and begin sentence 'Coherence is considered an indicator of changes'. Note also that phase difference does not correspond to the 'average' difference, but a very precise measurement of whole wavelength (and some fractional component) range difference. Suggest editing the rest of the sentence to reflect this.

(Now L43) Done.

L59. Sentence beginning 'This combination'. Who expects this? Add a reference to back up this claim, otherwise say 'We expect this' or similar.

(Now L48) Changed to 'We expect this combination…'

L67. Suggest changing to: "However, the value added using InSAR for such applications has not yet been examined".

(Now L52) Done.

L68-71. The structure of this paragraph is rather difficult to follow. Suggest beginning with "In this paper, we assess the potential of C-band backscatter and InSAR data to ... For this purpose, we use a combination of backscatter, coherence and phase information to monitor recent meltwater features over two East Antarctic locartions – the Amery and Roi Baudouin (RBIS) ice shelves – using data collected by Sentinel-1a/b in 2017/2018. To supplement the interpretation of our (In)SAR-based analyses, we also utilize spatially and temporally collocated optical satellite data.

(Now L54-58) The whole paragraph has been changed as suggested.

L75. *Sentence is very long and could be split in two after reference to Lenaerts et al. (2016).*

(Now L63) Paragraph has been rewritten.

L81. *Why was a lake dataset not available? The reader shouldn't need to guess this, so state explicitly here. (I think you mean that no previously published dataset exists?). When mentioning Landsat data, also point readers to Section 2.2 for reference.*

(Now L68) Changed from 'a reference lake data set was not available' to 'no previously published dataset from in situ studies is available'. Reference to Section 2.2 is added.

L83. *Sentence beginning 'Our lake class'. If my understanding of the above is correct, then this sentence is confusing as it suggests that a preexisting lake dataset does indeed exist. If so, why didn't you use that here? Please either edit sentence of clarify or remove from the text.*

Previous studies observed the Amery Ice Shelf with satellite imagery, but no in situ dataset is available. A modification in Line 68 has been implemented to clarify this.

Figure 1. *This is a nice figure, but please add latitude/longitude information to each panel so that readers can easily deduce locations. Please also consider showing two additional, zoomed out panels showing the location of each subset within both ice shelves, and (if necessary) in these and all pre-existing panels, add the ice sheet grounding line for reference (e.g. https://doi.org/10.7280/D1VD6G). (I know that the lower right panel shows this to a certain extent, but it's difficult to see details. In general, I also find the labels rather small and difficult to locate, so these could also be enlarged (plenty of space on figures to do this).*

The suggestions have been implemented. After adding the extra panels it is indeed clearer, but the pre-existing panels become too small. We hope it is still readable after the modification.

Figure 1 caption. *Please define RBIS in full in caption. Replace 'close ups' with 'inset' or 'detail'. Insert comma after 'panels'. Change 'delineated in black curves' to 'delineated as black curves'. In next sentence, what does 'indices' refer to? Labels? If so use 'labels' instead for clarity. Suggest rephrasing following sentence to read: "...are also delineated for comparison against backscatter intensity and coherence values observed over lakes (Fig. 2)' or similar. For general readability, next sentences could/should read: 'Panel R2 illustrates the lake feature shown in Figure [insert number here]. Inset shows location of the analyzed locations'. Please also state in caption which band/band combinations are shown (Landsat).*

Done.

Table 1 caption. *Should read '... used in this study'.*

Done.

L99. Please add more information (and references if necessary) on how the images were denoised, calibrated and corrected here. (The reader shouldn't have to look it up for themselves).

(Now L93-98) Information on calibrated top-of-atmosphere (TOA) reflectance (Chander, 2009) Landsat images has been added in the revised script.

L92. I presume this is a typo and should say 10x10 m resolution (i.e. the native resolution of IW GRDH; https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-1-sar/products-algorithms/level-1-algorithms/ground-range-detected/iw)? If not, then how does this impact the rest of your backscatter analyses?

Also, if my understanding is correct then NRCS is identical to radiometrically calibrated, sigma-nought (σ0) backscatter imagery. Sigma-nought backscatter is the much more commonly adopted term in the geosciences (RCS more so in engineering), so given the likely readership of The Cryosphere, I would instead refer to σ0 in place of NCRS here and universally throughout the manuscript. Following this point, be careful that the imagery you downloaded from Google Earth Engine isn't already in sigma-nought format, as the 'radiometric calibration' you mention GEE perform above may imply.

About the resolution, the Single Look Complex images of Sentinel-1 have a 20 m (azimuth) x 4.5 m (ground range). The GRDH are derived by averaging around 4.4 looks in range to make the resolution approximately 20 x 20 m. The products are then provided in an upsampled format, with pixel spacing/posting of 10 m. So we believe that the value of 20 m reported in the manuscript (that is the relevant one for the equivalent number of looks, or else for the radiometric precision when averaging areas of distributed targets such as ice, snow and water) is correct.

The resolution does not really affect the analyses. We specify the resolutions to clearly introduce the datasets. This could be removed if it is not necessary.

We appreciate the advice of using a consistent nomenclature throughout the manuscript. In the revised version 'NRCS' is therefore changed into 'σ0', including the figures. About the calibration, our understanding (see https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S1_GRD) is that GEE already provides radiometrically calibrated GRD images, and, as such, in σ0 format.

L95. Confusing. If you have multi-looked the SLC to create your own GRD/Sigma-nought imagery then why did you bother downloading GRD imagery from GEE? Clarify here.

The main difference between our products and the imagery downloaded from GEE is that our analysis on the RBIS focuses on ascending track 59, whose data were not available on the rolling archive of Sentinel Scihub before July 25, 2017. To analyse the lake formation since 2016 (shown in Figure 3), we conveniently made use of the imagery available on GEE. This has been clarified in L75-77 of the revised manuscript.

L97. Why is a geoid only used for Amery? I expect this is a typo?

At the moment of processing we lacked a detailed DEM for Amery and therefore used the Geoid as this closely resembles the ice shelf surface. Although we agree that this could be improved (e.g. by using REMA), we expect it will not change any of the conclusions of the analyses. This is proven in Fig. 4 and Fig. 7, as the meltwater features in the InSAR images are in the same location as in Landsat images. The use of DEMs has been detailed in L89-92.

L98+ This is a good example of missing methods I mentioned in my general comments. Here, I am surprised to see absolutely no information about how the authors generated their interferograms. This must be added, including, as a minimum, information on e.g. temporal/perpendicular baselines used, type of processing performed (I assume single-pass DInSAR?) and (if used) any DEM used to remove topographical phase.

The overview of DORIS has been added in the revised manuscript (L83+ and new Fig. 2).

L99-100. Again, for clarity/reproducibility purposes, much more info should be included here on e.g. the band/band combinations used, pixel resolutions of the data, and any relevant pre-processing steps you applied to your Landsat imagery. Stating that you simply downloaded them off GEE is not appropriate for a scientific paper.

TOA Tier 1 Landsat surface reflectance data (Chander) of bands (RGB) were downloaded from GEE at their native 30 m pixel resolution without any additional pre-processing steps. This has been added in the revised manuscript (now L93-98).

L105. I think it's important to explicitly state here that for each class type analyzed, you calculated the mean and standard deviation backscatter for all observed features. As written this is not obvious, and leads to confusion over what the difference is between 'lake class' and the 'individual lakes' (for this reader at least ...). This could also be made more explicit in the caption of Figure 2.

(Now L109) The sentence has been completed as 'For this purpose, the temporal variations in $\sigma 0$ and coherence are compared per lake, snow, ice class by analysing their time series of the mean and standard deviation for each class (i.e. lakes, snow and ice).' Also added 'Mean and standard deviation are calculated for all features presented.' to the caption.

L106. For clarity, 'mono-dimensional' should be changed to 'cross-sectional'.

(Now L112) Done.

L107. Repetition of coherence, NCRS and phase. Suggest restructuring sentence to avoid this.

(Now L114) Changed from '…combining NRCS, coherence and phase information...' to '...combining SAR backscatter intensity with InSAR information...'

L112. Suggest changing to: 'The mean sigma-nought timeseries of lakes, snow and ice (cf. Section 2.2) display strong seasonal variability, consistent with the changing nature of both

surface snow and ice properties and the evolution of supraglacial lakes through time (Figure 2). On Amery Ice Shelf, our observations reveal…'.

(Now L127) Done.

L113. This is written in an odd manner which implies that snow transforms into lakes and then ice, which is not what the authors intend to say. What I think they mean to say is that snow, lakes and ice for the most part display different (though reasonably constant) backscatter properties throughout the year, with the exception of JF when the backscatter associated with snow and lakes fall rapidly.

(Now L128) Now the sentence has been changed from 'The results on Amery ice shelf show that the NRCS decreases from snow (˜0 dB) to lakes (˜-5 dB) and ice (˜-10 dB) during fall, winter, spring…' to 'On Amery Ice Shelf, our observations reveal that the $\sigma 0$ has different levels for snow ~0 dB), lakes (~-5 dB) and ice (~-10 dB) and is relatively constant (fluctuations within ~1 dB)…'.

L116-125. To shorten the text here, I question whether the authors even need to discuss (and, in Figure 2, show) the individual lakes because for the most part, the average of multiple mapped lakes makes seems to support their arguments just as well. In this regard the individual lake observations are a slight distraction from the overall story revealed by the class averages, so I think they could probably be removed. (as the authors show, there is significant variability from one lake to the next, so focusing in on specific lakes only serves to deviate from what's happening on the whole). This is also largely true for the coherence discussion of RBIS a and f in Section 3.2, as your later coherence images (Figure 7) in any case demonstrate the process of refreezing in a much more convincing way).

(Now L132 onwards) We agree. Now the discussion is removed and the figure (now Fig. 3) has been modified by removing the curves of the individual lakes.

L126-134. For clarity, suggest editing sentence to say '…of select cross-sectional transects. In the case of both RBIS 'a' and Amery 'd' (location shown in Figure 1), for example, backscatter timeseries show significant inter-annual variation (Figure 3)'.

(Now L135-137) Done.

L129. 'Border of low NRCS and inner areas of high NRCS'. Revise this sentence to explicitly state that this refers to the edge and central regions of the lake, respectively.

(Now L139) Changed from 'After this, a clear spatial pattern emerges with borders of low NRCS and inner areas of high NRCS, followed again by a new area wide decrease in NRCS in the Dec. 2017 - Jan. 2018 melting season.' to 'Subsequently, a clear spatial pattern emerges with borders of low $\sigma 0$ at the edges and high $\sigma 0$ in the central regions, which respectively refer to the edge and central regions of the lake. This pattern is followed again by a new area-wide decrease in $\sigma 0$ in the Dec. 2017 - Jan. 2018 melting season.'

L136-152. *These are clear, well written paragraphs. They are logical and concise, and could be considered a model for how the rest of the manuscript should be written.*

(Now L146-160) We appreciate the suggestion.

Figure 2. *See my comments regarding L116-125 above. If the authors choose to retain the analysis of individual lake features, then they should make the lines thicker as these are currently very difficult to see both on-screen and in print. To enhance visibility of these lines, I'd also consider making the standard deviation ribbons more transparent as these currently dominate/clutter the figure. As per Figure 1, I also think the labels (and legend especially) should be made bigger/more prominent.*

For the coherence plots (and to a lesser degree sigma-nought), I wonder if the high frequency variability discussed by the authors could be smoothed out using something like a running mean? While this variability is interesting, it's a little distracting, and is later largely ignored in the text anyway.

(Now Figure 3) The individual curves are removed from the figure. However, we decided not to smooth the curve, because the gaps in the data become the obstacle of computing the running mean. If there were no such high frequency variability, filling the gaps via interpolation would be a nice idea. But due to this variability, interpolating will also be unreliable.

Figure 2 caption. *Sentence should read '... over the Amery and Roi Baudouin ice shelves (see Fig. 1 for locations). Change 'Moments ...' with 'Times with a lack of 6/12-day...'.*

(Now Figure 3) Done.

Figure 3. *As per Figs 1 and 3, please make all labels larger. Please also add lat/longs to both maps along with scalebars. Also consider zooming both images to show more detail over lakes (bottom right panel especially).*

(Now Figure 4) This has been implemented to the revised script.

Figure 4. *Nice figure! As above regarding label size.*

(Now Figure 7) Thanks for the suggestion. Label size has been increased and location and scale bar have been added.

Figure 4 caption. *Remove 'synoptic' (incorrect usage in this context) in first sentence, and cross-reference Fig. 1 for location at end. In next sentence, remove 'the' proceeding coherence, and add '... and resulting phase difference interferograms are shown ...'. In next sentence, should say 'The high frequency fringes surrounding each lake represent a convolution of both ice flow and tidal motion'. In the last sentence, please state which band/band combinations are shown (Landsat).*

(Now Figure 7) Done. Thanks for the correction.

Figure 5. *Really nice figure, but please add lat/longs and scalebars.*

(Now Figure 8) These have been added.

Figure 5 caption. *Unnecessary use of 'right' which should be removed. In the next sentence, change 'hereby' to 'hereafter'. In the following sentence, change 'reported' to 'shown (right panels)'. Please also state which band/band combinations are shown.*

(Now Figure 8) Done.

L147. *I think this should say 'between Oct. 2017 and Jan. 2018'. Change 'polygons' to 'surveyed snow, ice and lake areas'.*

(Now L158) This has been corrected.

L154. *Amery Ice Shelf.*

(Now L163) Done.

L159. *Replace 'brighter' with 'greater'.*

(Now L168) Done.

L172. *Why 'possibly'? Provide evidence to justify claims here. (Also, RBIS is a rather slow flowing ice shelf, so horizontal displacement should not influence phase coherence over 12 days as much as one might think (see Mohajerani et al. (2021) who were able to map GLs across this region Antarctica with good coverage using double difference InSAR. This technique requires almost perfect coherence, suggesting 12 days is more than sufficient here).*

In the next sentence (beginning 'In Oct. 17...'), I think better referencing to Figures 2 and 5 is needed as I don't see any change in coherence from Figure 5 alone.

First, we would like to clarify that here it is a mistake that 'coherence in this region drops in winter', as it should be summer in Antarctica. To justify the observations, we used wind and precipitation from ERA5, and derived melt factor with radiometer data (SSMIS). The data and methods have now been described in L99-105, and L117-124. The figures (new Fig. 5 and Fig. 6) together show that the coherence drop can be due to precipitation in Oct.–Nov., and due to melt in Dec.–Jan. Therefore, it is true that claiming coherence drop is due to the 12-day revisit time is not discreet, and we have modified the text (now L184-186) to better analyze this.

Reference to the figures has been added.

L176. *Change tense to be consistent with the rest of the paragraph. Also, while what you go on to say in Lines 176-177 is technically true, visually I can't tell the difference between the lakes you are discussing and the drainage network. Suggest rewriting this sentence for clarity*

to specifically emphasize the observed change from a lake to a (presumably) connected drainage network through time.

This is a really nice observation by the way, demonstrating in a compelling manner the utility of coherence to see what simple optical and/or backscatter images cannot.

(Now L188) The tense has been corrected. Changed from '…which is not straightforward to see in the NRCS or optical imagery. This highlights the increased potential for coherence over the backscatter intensity in delineating the lake network.' to '...which is shown as dark strips between the highlighted lakes in the lower middle panel of Fig. 8. The patterns are clearly newly formed compared to the lower left panel of Fig. 8. This change is not straightforward to see in the $\sigma 0$ or optical imagery.'

L179. *Suggest rewriting to begin: 'Interferometric phase difference maps (Figure 4) emphasize... Amery ice Shelf.*

(Now L194) Done.

L180. *Initially I didn't see any fringes you refer to (c/w Amery c for example) given the dominance of the high frequency (ice flow) fringes surrounding the lakes, but then I realized you meant the very low frequency fringes on the lakes themselves (~1 cycle of -π to π only). I suggest you state this more clearly (and perhaps label the figure accordingly) so that readers don't incorrectly focus in on the high frequency fringes.*

(Now L195) The low-frequency fringes in the lake centre and the high-frequency fringes surrounding the lakes have been specified in the revised text.

L182. *Edges of what? I can work out what you mean, but this can be written more clearly for ease of reading. Possibly also consider citing appropriate figures and panels.*

(Now L197) Edges of lake Amery b. This has been added to the sentence. And the whole sentence has been changed to 'This pattern of discontinuity is consistent with lower coherence at the edges of lake Amery b, which most clearly follows the orange delineation curve in the Oct. 2017 coherence panel of Fig. 7.'

L183. *Suggest writing as '...... increase through time indicates the presence of lakes until October 2017, followed... in November of that year. Consistent with our InSAR-based observations Landsat ...'.*

(Now L199) Done.

L179-203. *In general, this is another clearly written and easy to comprehend series of paragraphs compared with the earlier section of the manuscript.*

(Now L194-224) Thank you for the suggestion.

L179-186. *Regarding Amery Ice Shelf, what (if anything) can we learn about the detection of the hydrological network that is clearly visible in Figure 4 (top row), and which disappears after March 2017 in the coherence images? (suggesting formation between Mar 11 and 17th and persistent presence (freezing?) thereafter). This is a visually striking feature in the center of these panels that I was surprised to see no discussion of here and/or in Section 3.2.*

We appreciate the suggestion, and the discussion has been added in L177-179 of the revised manuscript as 'Moreover, between Amery b and c, a hydrological network that is clearly visible as high $\sigma0$ in the $\sigma0$ panels is present only in the Mar. 2017 coherence panel as low coherence. This could suggest the surface refreezing between Mar. and Jul. 2017, similar to that discussed by Antonova et al. (2016).'

L187. *I'm not quite sure I follow this, as the color scheme always goes from blue to blue. Suggested rewriting for clarity.*

(Now L205) This has been spcified as 'from right to left of the Dec. phase image, fringes change from red--blue--green--yellow to red--yellow--green--blue, forming a whirl-like feature'.

L198. *How big was this uplift? I think that would be a valuable addition here, and can be estimated either through unwrapping the phase or counting the fringes.*

We agree that it would indeed be very interesting. By counting the fringes, the result is approximately 7 fringes, each measuring 2.8 cm in the line-of-sight. Assuming a vertical movement, this corresponds to an uplift of approximately 24 cm (taking into account an incidence angle of approximately 35°). However, without data for validation, we were cautious in providing an exact number.

L190. *And presumably some tidal component, as *I think* tides haven't been removed? (see also my comments on the omission of any methods detailing exact InSAR processing above).*

(L209) We agree. This has been added to the revised script.

L194-203. *Great series of observations.*

(Now L213-224) Thank you.

Figure 6. *Nice figure, but please add lat/longs and scalebars to all panels.*

(Now Figure 9) Since all images are in the same scale, we added lat/longs and scalebar to the Landsat panel for simplicity.

Figure 6 caption. *Replace 'interferometric phases' with 'interferometric phase'. For brevity, suggest rewording next sentence as 'Two near-contemporaneous Landsat 8 panchromatic (band 8) images are also shown (right panels)'.*

(Now Figure 9) Done.

L201. *Replace 'starting at the edges' with 'towards the center of the lake' or similar.*

(Now L221) Done.

Figure 7. *Very nice series of observations! Enlarge labels and add lat/longs and scalebar, though.*

(Now Figure 10) This has been implemented.

Figure 7 caption. *Replace 'interferogram phases' with 'interferograms' or similar. Please also state which band/band combinations are shown for Landsat imagery.*

(Now Figure 10) Done.

L204. *I'm not sure I completely follow what you're trying to say here, as the sentence contains a grammatical error. Suggest rephrasing for greater clarity.*

(Now L222) Changed from 'The interferogram shows similar results here, but with the added value that the interpretation of high-low backscatter compared to the surroundings is less ambiguous.' to 'The interferogram shows similar results here. However, compared to interpreting the refreezing of the lake solely based on backscatter intensity, adding interferograms to the observation helps reduce ambiguities in the interpretation.'

L205. *Suggest beginning this section like: 'Using SAR-based observations acquired across two East Antarctic ice shelves, we present evidence of the utility of backscatter ...'.*

(Now L226) Changed into 'Using SAR-based observations acquired across two East Antarctic ice shelves, this study presents evidence of the utility of backscatter intensity and coherence to assess meltwater lake dynamics.'

L213. *Change 'Coherence' to 'Interferometric coherence'.*

(Now L234) Done.

L215. *And all other types of SAR SLC data ... not just that acquired by Sentinel-1.*

(Now L236) Sentinel-1 has been removed from the sentence.

L222. *I think its important to stress here that low coherence isn't just about refreezing (or not). Radar waves are fully attenuated by water, so you will always get poor coherence as long as there is water. The authors should rephrase this sentence to reflect this point.*

(Now L243) This has been changed from '…while meltwater lakes show a low coherence due to the constantly changing ice/water interface', to '…while meltwater lakes show a low coherence due to the constantly changing ice–water interface and the increased attenuation due to the presence of water'.

L229. This sentence may lead to confusion as it implies water volumes can be calculated using InSAR techniques. Suggest rephrasing to articulate the intended point more clearly.

(Now 249) We intended to say that estimating the water volumes is not within the scope of this study. To avoid confusion, this sentence has been removed.

L232. For consistency with the text above, suggest changing to 'affected by tidal and horizontal motion'.

(Now L252) Done.

L237. Again, I think it'd be really nice to see an estimate of the uplift here, derived from either fringe counting or unwrapping the phase (see also my comments on L198).

The reply is the same as for L198.

L241. Amery Ice Shelf.

(Now L261) Done.

L243. Argument regarding line-of-sight observations only. This is actually only true for Sentinel-1 which, at present, only has one look direction over these ice shelves. Sentinel-1 (or any other sensor for that matter) collected in both ascending and descending orbit could deconvolve those parameters potentially yielding a better impression of subsidence/uplift, or at the very least a different (and possibly validatory) view of the lake dynamics relative to that gleaned from a single look direction.

Suggest rephrasing the sentence to stress these points, and refocus the sentence away from Sentinel-1 'only' towards a more broad discussion of the different SAR sensors that could possibly be used.

(Now L268) Added 'With SAR acquisitions from sensors in both ascending and descending orbits, it is however possible to better quantify the lake subsidence/uplift.' to the paragraph.

L244. I wonder to what extent this sentence is true, since more complicated processing techniques like double-difference InSAR (e.g. Mohajerani et al.; 2021) could presumably help to cancel out ice flow signals. De-tiding observations using a tidal model could also remove vertical motion due to tide (see, for example, MacMillan et al., 2012). Did the authors investigate the applicability of these techniques for improving signal-to-noise over the lake areas? (I'm not suggesting this necessarily needs to be done if not, but I feel a more nuanced/careful discussion of how ice/tide displacement could possibly be mitigated to lake detection easier should be included here).

(Now L265) This discussion has been included as 'Second, the interpretation of phase change should be done relative to the displacement of the lake surroundings in the line-of-sight. As the meltwater lakes typically develop on locations with strong ice and/or tidal displacement, interpretation should be done relative to that displacement. Therefore, to better derive the

exact height change of lake ice lids, additional processing is needed to cancel out ice movements (Mohajerani et al., 2021) and to filter out signals due to tidal movements (McMillan et al., 2012).'

L246. To conclude this section, I think there's big scope to include one or two sentences on the potential advantages of 'next-generation SAR' remote sensing capabilities for lake monitoring. This could involve a discussion of the <6-day imaging capabilities afforded by the launch of Sentinel-1c (~2022), and/or the upcoming (2023) launch of the NASA-ISRO SAR mission (NISAR). While the latter will have a repeat pass time of 12 days over the polar regions, its dual-wavelength (L- and S-band) imaging capabilities may have good potential to circumvent confounding issues such as snow blow and other atmospheric effects, quantify thin/forming ice lid thicknesses etc.

If the authors do not wish add such a discussion, then I recommend editing the title of the study to be sensor specific, e.g. 'The potential of Sentinel-1a/b synthetic aperture radar interferometry for assessing meltwater lake dynamics on Antarctic ice shelves'. (see also my comments regarding the title, L243 and L261-265 above).

This has been added to the discussion (Now L270-274).

L248. I think this sentence could (and should) be snapper. Suggest rephrasing to 'This study has provided insight into the utility of InSAR for monitoring meltwater lake dynamics' or similar.

(Now L276) Done.

L261-265. This is largely repetition of Lines 238-246 which I think can probably be significantly shortened and merged with Lines 266-268. Suggest something like: 'Despite noted limitations to current Sentinel-1 InSAR imaging over parts of Antarctica, we show that InSAR provides promising potential for monitoring meltwater lake dynamics beyond that afforded by conventional, backscatter-only, analyses. Such potential could pave the way for …'.

(Now L290-292) Done.

Referencing. I have noticed multiple inconsistencies in the manuscript. Please ensure referencing style is consistent throughout and adheres to The Cryosphere's specific referencing format (https://www.the-cryosphere.net/submission.html#manuscriptcomposition).

Thanks for the suggestion. This will be double-checked in the revised script.

L5. Incorrect grammar and sentence structure. Suggest rephrasing to: 'In two case study regions over the Amery and Roi Baudouin ice shelves, East Antarctica, we examine spatial and temporal variations in SAR backscatter intensity and interferometric (InSAR) coherence and phase over several lakes derived from Sentinel-1a/b C-band SAR imagery.

(Now L6) Done.

L15. *Insert commas before and after 'however'.*

(Now L14) Done.

L55. *'By a certain time' is colloquial. Suggest 'by a particular temporal baseline' or similar instead.*

(Now L42) Done.

L65. *Remove 'basically' (colloquial usage inappropriate for scientific writing).*

(Now L51) Done.

L75-79. *These sentences are repetitive and could easily be merged for conciseness. Also, in the last sentence, I think it's important to explicitly state why you delineated polygons of surrounding snow and ice, as this is unclear.*

(Now L61-66) Added '…manually delineated sample polygons of snow and ice surfaces based on Landsat imagery for studying the difference between meltwater lakes and the solid surrounding regions'.

L88. *Insert comma after 'For both products'. At end of sentence, also add citation to back up this statement.*

(Now L77) Done. This statement (that only HH-polarisation is available) comes from our random searching over several locations in Antarctica. For reliability, we have changed 'Antarctica' into 'the studied ice shelves'.

L99. *Pronouns are not to be preceded by 'the', so remove 'the' before Google Earth Engine. (Also true for the likes of 'the Amery Ice Shelf', 'coherence' etc.).*

(Now L96) Thanks for the correction.

L102. *Add comma after 'dynamics'. At end of sentence, explicitly state where you perform this analysis (i.e. over the lakes and control (snow/ice) sites). For clarity, this should probably also involve merging the following sentence.*

(Now L107) Done.

L105. *Insert comma after 'purpose'. (Note: punctuation errors of this type are a recurring issue and one that I encourage the authors to carefully correct for throughout the manuscript).*

(Now L109) Done.

L136. *'Amery ice shelf' is a pronoun and so should be capitalized. Note that this correction should be carefully applied to all pronouns in the manuscript.*

(Now L128) This has been corrected.

L150. *Insert commas before and after 'however'.*

The discussion of the time series of individual lakes has been removed.

L166. *Insert comma after 'gradual'. Regarding the next sentence, I suggest also labelling the circular feature you refer to in the figure, as it took me a while to recognize exactly what you mean.*

(Now L174) Done. An arrow to the feature has been added.

L169. *Reference Fig. 5 in the first sentence. The second sentence is also grammatically incorrect and should be edited to state that routine Sentinel-1 coverage commenced in 2017 and to date only acquires data with a repeat-pass of 12 days.*

(Now L180) Reference has been added. Changed sentence from 'Since the Sentinel-1 SLC temporal coverage is lower than for Amery, SLC coverage only started in July 2017 (Fig. 5).' to 'Differently from data on Amery Ice Shelf, the Sentinel-1 SLC acquisition only started in July 2017, with a 12-day revisit (Fig. 5).'

L172. *Should read '…, with only intermediate sigma-nought values'.*

(Now L183) Done.

L214. *Should say 'assess'.*

(Now L235) Done.

L215. *Remove 'such as Sentinel-1'.*

(Now L236) Done.

L228. *To maintain the flow of the text here, suggest rephrasing this sentence to: 'Beyond coherence, we also demonstrate the potential of interferometric phase for assessing … in areas of high coherence'.*

(Now L249) Done.

L231. *Suggest changing 'instant' to 'rapid (sub-weekly) meltwater events', since changes over 6 days can hardly be classified as instant.*

(Now L250) Done.

L233. *I think this should say '…an easier detection of stable ice and lake refreezing than coherence and backscatter intensity …'?*

(Now L252) This has been corrected.

L235. *Incorrect grammar/sentence tense. Suggest rewording to: "While InSAR-based techniques show clear potential for monitoring meltwater lake evolution, there are several key limitations associated with this technique compared with conventional optical- and SAR backscatter-based imaging. First, InSAR requires …'.*

(Now L257) Done.

L240. *Replace 'may' with 'can'.*

(Now L261) Done.

L241. *'day' should read 'days'. Also, suggest rewording 'Due to this difference' to 'Due to these differing imaging times' or similar.*

(Now L262) Done.

L253. *Sentence beginning 'A generalization'. Reword to 'We show that meltwater detection using backscatter is, however, not straightforward, as meltwater lakes often …'.*

(Now L281) Done.

L255. *Replace 'context' with 'circumstance'. Also suggest removing 'i.e. the coherence and interferogram phases'. (this is unneeded technical info for the conclusion).*

Above, the authors could also consider rephrasing the text to offer a more well-rounded discussion on the application of SAR in general, rather than specific application of Sentinel-1 data (see my comments regarding title, L243 and L246).

(Now L283) Done.

L256. *'Besides' should not be used to begin a sentence. Replace with: 'In addition, we show that InSAR-derived information can also be used to observe meltwater lake evolution (and potential drainage) with high accuracy beyond that afforded by conventional backscatter or optical satellite imaging' or similar. Then begin next sentence with: 'Specifically, InSAR coherence information allows for the detection of changes in the …, while interferometric phase can effectively track the spatial and temporal evolution of ice refreezing. Maps of interferometric phase moreover allow for the detection of abrupt lake drainage (or filling) events via changes in the relative displacement of the surface between successive SAR passes'.*

(Now L284) Done.

L274. *I think this should say 'WL was responsible … processing and analyzing the results …'.*

(Now L298) Done.

L278. *Remove NSF-OPP awards and rest of lines 279 and 280 as these are not relevant to this study.*

That was the standard citation format required by the publisher (please refer to the PGC acknowledgement site https://www.pgc.umn.edu/guides/user-services/acknowledgement-policy/).

L322. *Please cite final (non-TCD) publication.*

This paper gives the following information: Review status: this preprint was under review for the journal TC. A revision for further review has not been submitted. Therefore, this citation has been removed.

References

Chander, G., Markham, B. L., and Helder, D. L.: Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors, Remote Sensing of Environment, 113, 893–903, https://doi.org/https://doi.org/10.1016/j.rse.2009.01.007, 2009.

Response to Referee 2 on tc-2021-169

Thank you for reviewing and commenting the manuscript. Please find the item-by-item reply below, with the original comments in *italics* and the responses in blue.

General comments: This paper evaluated the beneficial of combining SAR amplitude, InSAR coherence and phase information for meltwater lake dynamics. The topic fits well with The Cryosphere journal and it provides useful information for investigation for lake dynamics in Antarctic environment. The selected cases over Amery and Roi Bauouin ice shelves (RBIS) shows that SAR amplitude, InSAR coherence and phase are complimentary for lake dynamics monitoring. However, I think the presented examples may oversimplify the interpretation of SAR amplitude, coherence and phase for monitoring meltwater lake dynamics, as we know other factors, other than seasonal melting-refreeze process, such as weather event (snow, rainfall, et,al) and sensor acquisition geometry (descending/ascending) could also affect amplitude/coherence/phase variation. There are also some other issues with this paper, such as convincing evidence about the lake status in the analysis, and incomplete/confusing data information that were used in the study.

We would like to thank Referee 2 for the positive comments on the potential. We agree with the arguments that other factors such as changes in snow properties and sensor effects also may impact the signals. This was in fact mentioned already in the manusript, but it was perhaps not given the proper weight. In the revised version, we have added precipitation data and melt estimations in the assessment, and possible improvements based on sensor acquisition geometry in the discussion.

Specific comments
1) Instead of just few selected data, please provide a complete time series amplitude, coherence and phase analysis for the cases in Fig 4 & Fig 5. I think this would still show the benefits of different information (amplitude, coherence and phase), but it would provide a more objective sense/perspective for reader to understand potential drawbacks of each different information. Incomplete data also make some of the statements confusing in the paper. For example, Line 155-157, it talked about amplitude/coherence for summer melting, but there are no SAR data shown in the Fig 4.

Starting from lines 155-157, we perhaps caused confusion by mentioning the melt of the ice. The lines refer to the background blue ice area, rather than the lakes. And the blue ice features are shown in the second panel at the bottom of Fig. 4 (RGB bands of Landsat image). However, it is true that our discussion of melt could be improved by providing a climate/melt time series (added in methods, Fig. 5 and Fig. 6).

As for the complete time series, it has 60 days of acquisition, and showing all the backscatter intensity, coherence and phase images will result in 3*60=180 images. This is not ideal to show in one figure. However, the selected images can already show characteristics under different distinct circumstances.

2) Please provide evidence when refer to melting/refreeze/frozen status of the lake to make your statement convincing. For example, the authors explained the decorrelation in Jan 2017

data is due to melting (Line 195-196) in Fig 7. However, in this same figure, we see the Jan 2018 shows very good coherence and phase pattern. I would assume the area would be in similar freeze/melt status at approximate same time of different years. I am not sure whether the low coherence in Jan 2017 is due to melting or maybe other weather events. I think it would be helpful to collect some other information, such as temperature information from other sources, to support your statement. For all other data analysis, if it's possible to collect some external information such as temperature or optical imagery, I would suggest doing so that it's more convincing when you state its under melt or refreeze or frozen status.

We appreciate the referee's suggestion in using other external data sources. It is difficult, however, to acquire completely concurrent Landsat images due to the cloud cover. We have therefore included ERA-5 data and radiometer-derived melt time series in the revised manuscript to show it more clearly. It is true that low coherence can be due to both melt and precipitation. This has been added in results and discussion.

3) Incomplete data information. For the time series of mean and standard deviation over selected polygons mentioned in Fig 2, How many SAR data are used for this calculation and what are their acquisition times? are the mean and std for all the polygons shown in Fig 1? It might be helpful to provide complete data list in text or supplement. Are the coherence data for Amery all 12-days product? It would be not meaning to mix 6-days or 12 days data together to analyze lake-related information, as temporal difference would change that a lot.
Please show the outline of the sentinel-1 data in the last panel of Fig 1. What is the data coverage used in this study? Table 1 shows RBIS SLC data is from 2017/7/25—2018/4/15, however, in fig 2, the data coverage for RBIS is from 2017/1-2018/1, it is so confusing. Please provide accurate info for data you used. Also, the GRD and SLC time coverage are different as shown in fig 2, not sure how does this happen. I would assume you need to analyze amplitude/coherence/phase comparison for all data.

We are sorry to hear that this information seems incomplete. The line/fill plot in Fig.2 with the lakes' means and standard deviations refers to all the polygons shown in Fig. 1. Analogously, the snow and ice polygons plotted in Fig. 3 are the ones already highlighted in Fig. 1. This information is briefly contained in the caption of Fig. 3, but perhaps the amount of data (number of lakes and snow/ice samples) is not explicit. We have detailed the caption of Fig. 3 and Table 1 further in the revised manuscript regarding the missing data. It is instead true that the Amery series have mixed 6-day and 12-days coherence. More specifically, the first pair (04-Jan-2017 -> 16-Jan-2017) is separated by 12 days, whereas the rest of the Amery acquisitions is characterized by 6-days repeat. We have clarified this in Table 1. In conclusion, although we agree with the reviewer that the mixing 6 days and 12 days coherences should be done with caution, we believe that in the case of Amery, the impact of this temporal heterogeneity is negligible. Also, in interpreting the coherence differences between Amery and RBIS, we highlighted the fact that the latter have lower values also due to the longer (12 days) interval (lines 151-156).

The second part of the comment is not clear to us. Regarding the time span of the plots in Fig. 3 for the two different areas, we believe that they are coherent with the dates specified in Table 1. The first and third plot refer the Amery, whereas the second and the forth refer to

RBIS. There is inconsistency regarding the GRD acquisition dates in Table 1 and Fig. 4, and this has been corrected.

4) Are there any different characteristics in amplitude/coherence/phase between supraglacial and englacial lake?

Sentinel-1 has only limited penetration depth of several meters, so only shallow englacial lakes can be detected. However, our time series of Fig. 10 might actually be some sort of englacial lake (by developing a frozen lid). In general, we expect longer wavelength SAR to provide improvements in this aspect, and this has been added to the discussion (L270+).

Technical correction:
Line 113, 'the results', please be more specific.

It refers to Fig. 2.

Fig 2. Please provide complete legends for subplots 2-4. Fig caption are not complete. It only takes about the time series, but not the specific amery a, b, d and RBIS examples.

(Now Fig. 3) The examples are labelled by the legend. The caption has been extended.