

# ***Interactive comment on “Observing traveling waves in glaciers with remote sensing: New flexible time series methods and application to Sermeq Kujalleq (Jakobshavn Isbræ), Greenland” by Bryan Riel et al.***

## **Anonymous Referee #1**

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— General comments —

Using high-temporal-resolution remote sensing of glacier velocity, this paper presents observations of wave propagation along Jakobshavn Isbrae, Greenland. The sampling of the data and the sparsity-regularized linear regression method that the authors employ allow the decomposition of velocity variation signals into two frequency categories: seasonal and multi-annual. This allows the authors to, for the first time measure wave propagation speeds for different forcing frequencies, showing wave dispersion along glacier flow. The paper is very thorough and complete, present-

ing information in multiple ways, which helps the reader to fully grasp the interpretation. Because the results in this paper are very novel and cutting-edge, I appreciate the thoroughness with which the authors provide interpretation, additional hypotheses to be tested in future work, and ideas for how future remote sensing can shed light on the concepts presented. I really enjoyed reading the paper for this aspect in particular, as it helped frame the results that are presented and sparked ideas for potential future work and questions to be answered. The authors should also be commended for putting together an excellent tutorial with an example ([https://github.com/bryanvriel/iceutils/blob/master/doc/time\\_series\\_inversion.ipynb](https://github.com/bryanvriel/iceutils/blob/master/doc/time_series_inversion.ipynb)). I found this resource very useful as I was reading the methods described in the paper.

In my assessment, I found no major flaws in the manuscript. I present five general comments and suggestions here and more detailed line edits below.

1.) I would like more description of how the B-splines are constructed in the methods section (lines 101-116). I am not an expert on this approach to time-series analysis and the description provided may be enough for someone with a deeper background. But, for the non-experts, I suggest adding a couple of sentences to explain, in plain language, that there are a set of seasonal B-splines (with period of 1 year) and a set of transient B-splines (with period of < 1 year) that are simultaneously being fit to the observed velocities, if that is indeed the case. This would then connect nicely with the paragraph describing how the data is detrended on lines 129-137. This is my interpretation and, without looking at the tutorial code, I'm not sure that I completely understand how the B-splines are constructed. For example, are the seasonal B-splines fit to data that falls within a window of 1 year? This is the kind of thing that would clarify for me, the non-expert, how this approach works.

2.) At times, I found it a bit confusing tracking what velocity quantity was being discussed (i.e., seasonal velocity, long-term velocity, etc.). I would like to suggest two ways to address this. First, I suggest adding to the methods section (probably to line 137) a statement such as, "Throughout the paper, reference to seasonal velocity rep-

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resents the quantity  $d_s$  and references to long-term velocity represents the quantity ...". Second, I ask the authors to carefully go through the entire manuscript to ensure that all references to "seasonal velocity" and "long-term velocity" do, in fact, refer to these exact quantities. I appreciate that the authors have likely already done this and I commend them for their writing, which is already for the most part very clear. I only ask that a final pass is done through the text before the resubmission to double-check the references to these different quantities of velocity.

3.) Along the lines of future work, I would like the authors to add some brief discussion on the use of in-situ measurements to measure the propagation of waves. For example, can terrestrial radar or laser scanners be used to provide high-temporal-resolution measurements that can help further constrain glacier waves? This can be added to the end of Section 5.2.

4.) In a few parts of the discussion, it is stated that velocity and surface elevation are responding to changes in calving front position but this causality is not shown by the results of the paper. It is shown definitively that variations initiate at the terminus and propagate upstream and that these variations are well-correlated with terminus motion. However, causality (in one direction or the other) is not shown by the analysis here. The language surrounding this discussion should be revisited and revised. Perhaps I have missed something and this causality can be inferred but, in that case, it needs to be made more explicit and clear in the discussion. Otherwise, the causality wording should be changed to discussing the correlation between terminus position and velocity.

5.) Finally, a minor comment that applies throughout the paper. There are a couple of places where the "southern bend" of the glacier is mentioned and I suggest adding something that indicates this region to all of the map-view figures.

— Minor comments —

[line 50] What are sub-epoch velocity changes?

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[line 137] This sentence can be removed.

[Fig 1] State in the caption that the map coordinates are polar stereographic north (EPSG:3413).

[Fig 1] I suggest replacing the manually drawn white lines in panel A with either the calculated contours of maximum shear strain rate or with the contour where the bed is at sea level. This would be a more accurate depiction of the trough and the main trunk of the glacier.

[Fig 1] The sentence "Mean velocities are added to time series for visual clarity" does not make sense to me. How are the mean velocities depicted in the plots? And what are these means (spatial? temporal)?

[Fig 1] Clarify how the data is detrended in C and D. For example, something like: "white dots indicate (B) observed speeds, (C) observed speeds detrended using seasonal splines, and (D) observed speeds detrended using seasonal and transient splines."

[Fig 2] The approximate solid black lines drawn are very helpful in illustrating wave propagation and it is clear from the differences in panels A and B that phase speeds of seasonal signals are much different from multi-year signals. However, I would like to see calculated contours drawn on each panel. These could be the zero contours or any other arbitrary value and they can be displayed in grey, with the approximate lines in darker black for illustrative purposes.

[line 269] I am confused by the phrase "long-term signals removed." Is removing the long-term signal the same as combining the transient and seasonal signals? In other words:  $d_L = d - d_T - d_S$ , where  $d_L$  is the long-term signal shown in Fig. 1C  $d - d_L = d_T + d_S$  If this is the case, I suggest rewording this from "the velocity data from 2011 to 2018 at each pixel with the estimated long-term signals removed,  $d_S$ " to "the combined seasonal and transient modeled signal,  $d_T + d_S$ "

[line 300] I would replace "classical" with "time-series".

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[line 314] This is the only place in the paper where Fig 3C is referenced and I think it is completely OK to hypothesize about the connection between phase velocity and thickness/bed but, because a figure is provided, I would suggest expanding on this a bit. Please add a sentence that explicitly states the hypothesis about the relationship between these two variables (e.g., higher/lower velocity in thicker/thinner ice).

[lines 332-334] This sentence is accurate but the "while" clause does not make sense to me. I am reading it as "along the trunk there is lowering, while on the slower ice, there is lowering." Please clarify. Perhaps this sentence is meant to say that there is a confined region of high thinning along the trunk and near the front, while on the slower ice there is still thinning but lower magnitude.

[lines 334-336] This sentence makes two claims without providing evidence. First, that the slower ice was thinning before the observation period. Second, that high melt started in 2009. Both of these must be backed up with either a figure or a citation.

[line 360] I would find it helpful to distinguish the results presented in this paper from earlier work here. Adding a clause to this sentence such as, "Consistent with earlier work ..., but at a higher-temporal resolution, we observe ..." or "Consistent with earlier work ..., but using our novel method that is better able to isolate seasonal signals, we observe ..."

[lines 360-361] This paragraph and the corresponding figure describes the relationships between (1) seasonal terminus positions and seasonal velocity variations and (2) long-term terminus positions and long-term velocity variations. Thus, I suggest rewording this sentence from "we observe a strong correlation between the seasonal variations in ice velocity and the year to year variations of the front" to "we observe strong correlations between variations in ice velocity and variations of the front at both the seasonal and long-term time scales"

[Fig 7] I suggest using a sequential colorscale, rather than a divergent one, to represent different years. The current colorscale makes it impossible to distinguish 2009 from

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2018.

[Fig 7] In panel D, in addition to coloring the points according to year, distinguish the two groups separated by terminus position using different symbols (e.g., circles and squares).

[Fig 7] In panel D, it is not clear to me how the seasonal velocity variation quantity is calculated. Please add this to the text or the caption.

[lines 392-395] Strictly speaking, the results do not show that velocity and surface elevation variations are changing in response to changes in the calving front position. They are certainly correlated but causality one way or another has not been shown here. I suggest rewording this.

[line 410] I would add the word "transient": "... as well as the transient response ..."

[lines 410-411] This sentence is a bit confusing to me. What is meant by quantifying "wave propagation to phase velocities and attenuation length scales? Does this mean quantifying the relationship between wave propagation distance(?) to phase velocities and attenuation length scales? Something seems to be missing here.

[lines 412-413] Please reword to be more explicit about what is meant by "broader and more refined constraints". Does broader mean for more glaciers or at more frequencies? Does more refined mean smaller uncertainties? If so, state this explicitly.

[line 489] Can anything more be added about the kinds of waves that are observed on Rutford? Did previous work categorize what kind of waves those are? If so, I would add that here to enhance the contrast between the kinematic waves on Jakobshavn and the other type of wave on Rutford.

[line 597] "IceSat-2" should be changed to "ICESat-2"

[line 631] Please add a sentence describing, briefly, the caveats to the conclusion that the observed waves are kinematic in nature. These caveats are very nicely discussed

in detail in Section 5.1 and I think they need to be summarized in the conclusion.

[Data availability] Please add the DOI for the OMG DEMs  
(<https://doi.org/10.5067/OMGEV-GLNA1>)

Interactive comment on The Cryosphere Discuss., <https://doi.org/10.5194/tc-2020-193>, 2020.

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