

# Glacier Image Velocimetry: an open-source toolbox for easy and rapid calculation of high-resolution glacier-velocity fields

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## Author Response

Dear Dr. Harry Zekollari,

Many thanks for the detailed comments. You have raised some important points about the text and figures, which we have carefully addressed in the final version of the manuscript submitted alongside this response. We have responded to each comment between the lines below.

Dear Maximillian Van Wyk de Vries and Andrew Wickert,

Many thanks for sending in a new version of your manuscript and accompanying rebuttal letter. Your manuscript is now in a good shape and almost ready acceptance. I have formulated a list of mostly minor and technical comments that I would like you to address when resubmitting your manuscript, before proceeding to a final acceptance. Pay particular attention to the remarks related to the figures, which will need some reworking in some cases:

- l. 4: "...and often a safety risk": sounds a bit odd to me. Maybe change to: "...and often associated with safety risks"

We have edited the text based on this suggestion.

- l. 6: "...hence, velocity over time.": just to make this entirely clear, suggest referring to "...hence, surface velocity over time"

We have added this clarification to the text.

- l.8-10: please be consistent when referring to glaciers and ice caps. You should refer to all ice bodies as glaciers (in line with IPCC) or instead consistently refer to certain ice bodies as ice

caps (in line with for instance EGU, which mentions ‘ice caps’ in session titles and has a ‘science officer for ice caps’): you now refer to Vavilov ice cap as a “very large glacier”. Probably easiest to not refer to ice caps (in line with IPCC): i.e. “...as well as a tropical glacier (Volcán Chimborazo)”. Please make sure that this is consistent throughout the manuscript.

Many thanks for raising this potentially confusing point about terminology. We have removed all mentions of ‘ice caps’ for both Vavilov and Chimborazo and replaced them with the term ‘glacier’. We have retained the name ‘Vavilov Ice Cap’ as it is used in prior literature, and ensured it is capitalized throughout.

- introduction: is really very broad and elaborately touches upon topics that are not treated at all in this manuscript. You can have a general introduction, but it should become more compact: l.15-37 should ideally be compacted to max 10 lines, where the only part really relevant here seems to be around l. 28-32 + l. 35-37 (add references for these statements)

We have re-arranged the first three paragraphs, removing the less relevant material and consolidating them into one single paragraph ~12 lines long. The paragraph could be further shortened by reducing the number of references, but we hope these will provide useful context for any reader seeking additional details on this background.

- l. 31-32: ‘Wal et al., 2008’ should be ‘van de Wal et al., 2008’. Could also refer to some more recent works that focus on remotely sensed velocities on glaciers here, as this is the main topic of your paper (vs. ice-sheets): e.g. Altena and Kääb (2017, *Frontiers in Earth Science*), Altena et al. (2019, *The Cryosphere*) and Dehecq et al. (2019, *Nature Geoscience*).

We have added Millan et al 2019 and Altena et al. 2019 to provide some recent context, and corrected van de Wal et al., 2008’s citation. I should have noticed this given that my own name often ends up as ‘Vries M.V.W.D.’ in these lists...

- l. 76: “...and lighting conditions depend strongly...”: maybe also explicitly mention the shadow(ing)?

We have added a mention of shadowing to this line.

- Table 1: very useful table for the reader! A few remarks. For EMT: any indication about the environment/language in which the ‘worklfow’ is? Should ‘matpiv’ not be ‘MatPIV’? I found it a bit strange to have the explanation in the caption go from 3 to 1: maybe change order from 1 to 3?

We are glad that this table is helpful. EMT is distributed as precompiled binaries (e.g. <https://wwwpub.zih.tu-dresden.de/~photo/emt/index.php>) and I could not find a mention in either the paper or website as to the language these were originally written in (C++ is my best guess). We have updated the numbering to run from 1 to 3 rather than from 3 to 1.

- Figure 1: width of the individual boxes seems a bit random: why having them smaller in steps 1-3-4, then wider for step 5, and then smaller again: suggest having the same width (except step 5 maybe, as you want to emphasize this I guess? Maybe here also explain in caption why this is

shown in bold) or having different widths to have content on single line (e.g. for step 8 and step 9)

We have adjusted the formatting in this figure such that the different boxes are now the same width, except for the feature tracking step which we leave in bold for emphasis. This is not explained in the figure caption.

- section 2.2: was easy to follow in general, also as a non-specialist. I was wondering if the readability would not further improve by subdividing this section in several subsections, as quite different things are treated here: e.g. l.118-131: frequency-domain matching, l. 132-144: single- and multiple pass approaches, l.145-148: move this to part where FFT is introduced, l.149-156: parallel computing, l. 157-161: non-consecutive imaging, l. 162-178: accuracy assessment and final velocity map improvement, l.179-200: temporal resampling through iteration, l.201: georeferencing

We like the suggesting of adding subsections to this part of the paper, and have added them in (and rearranged the text accordingly).

- l. 139: 'matpiv' (two occurrences) should be 'MatPIV'

Thanks for catching this, we have updated matpiv to MatPIV throughout.

- Figure 2: nice visualization! Could you indicate which area/glacier we are looking at here? Add this information in caption, and potentially complement with coordinates (lon-lat) in image.

The images are taken from Amalia Glacier in the Pacific side of the Southern Patagonian Icefield. I have added the name and lat-lon of the images to the figure caption.

- l. 149-156: very nice to read about this option to parallelize the code. Small question here, which may be related to my misunderstanding: how are you accounting for displacement that occurs between the different image pairs (which are treated on different cores)? Maybe add a short 1-2 sentence description of this, or explain how this is not a problem (I guess others may have the same question?)

I am not sure if I fully understand your question here. The image pairs (both consecutive and non-consecutive) are assembled prior to calculation of displacements between them. The displacements are then calculated on different cores, and re-assembled into one single output matrix (storing all velocity outputs) following calculation. This way the large output matrix is not passed to individual cores (causing memory issues and slowing performance), but the rate limiting step of calculating displacements can be performed on multiple image pairs simultaneously. The output matrix of all velocities (MATLAB array named 'images', for reference for anyone looking at the code) is then post-processed as described in the rest of this section.

- l. 177: "if the dataset is smooth enough to allow it": how is this determined? Criterion for this? If so, could you give a short indication about how this is done?

We have removed this part of the sentence, as it is confusing and not necessary. We were referring to the fact that data cannot be interpolated if a too large number of ‘not a number’ (empty) values are present. The ‘smoothness’ of the surface is not calculated at this stage (although filters based on local standard deviation are used, as described in the text).

- Figure 3: please do replace the red or green color by another: is problematic to have both colors for line data for color-blind people (deuteranopia) (I noticed that you took this into account for other figures as e.g. mentioned in 1.203-204: nice!). In panel b: how is the speed-up defined? As a fraction I guess? If so, probably more intuitive to formulate as % speed up.

We have replaced the color scheme with a colour-blind friendly qualitative color scheme from ColorBrewer (<https://colorbrewer2.org/#type=qualitative&scheme=Dark2&n=3>). We have also changed speed-up to % speed up for clarity.

- 1.190-192: found this sentence difficult to follow as it is lengthy + use of numbers for weight, while ‘one’ is used to refer to velocity as well. Consider splitting sentence in two and reformulating second part for clarity.

We have re-written this sentence for clarity, it now reads “The weighting parameter is determined by the proportion of the individual map contained within a given month. For instance, a velocity entirely within one month will be weighted 1, while a velocity spread evenly over four months will be weighted 0.25.”

- 1.195-196: “Outlier detection and maximum velocity filters are implemented”: could you provide some (even compact) information about how this is done / based on which criteria?

We have split this sentence into two and provided additional details. The maximum velocity threshold is the same as that used for the initial velocity calculations, and is defined by the user in the GUI.

- 1.197-198: ” ... are not be adapted...” should be “...are not adapted...”

Thanks for catching the typo, we have corrected this sentence.

- Figure 5a: change the color scheme to one that is suited to represent sequential data! The color scheme that you use here is suited for diverging data. See e.g. <https://colorbrewer2.org/> This is of large importance, as you refer to this as: ‘generation of publication-quality images of the velocity and flow direction maps’. I agree that the figure looks nice, but the color scheme you use does not align with your purpose.

This is an important point, thanks for picking it up. We have replaced the diverging colour scheme with a suitable sequential color scheme for the figure, and made the same change within the code. We have also edited the relevant function within the source code (save\_images.m) such that users can easily select other preferred colormaps with only a single change in the code. We have set the default to be Crameri’s ‘Batlow’ sequential color map, which should be appropriate for most conditions. Crameri’s ‘lajolla’ and ‘oslo’ color maps also work well, as well as ColorBrewer’s ‘YlGnBu’ sequential map. (The cyclical color map for the flow direction plots can now also be changed at the same point in the code).

- l. 219: write out the two occurrences of '3': 'three'
- l. 221: 'based off of...' : should this be 'based on...'?

We have made both changes to the text.

- figure 6: in the text you refer to the real names of the glacier (Spanish), while in the figures you use the English names: be consistent. For the location map: would it maybe make sense to have this a bit more focused on Patagonia? I guess most people know where Patagonia is, but have little idea where the two glaciers are in Patagonia (e.g. are they 20 km apart from one another or 500 km?)

We have modified the glacier names to the original Spanish, and added a small inlay of the Southern Patagonian Icefield to show the location of the two glaciers discussed.

- figure 7: same remark as for figure 6 concerning the location map. Where in the European Alps is this glacier vs. where are the European Alps.. On main map: very hard to see where North is: could you make this clearer? I find it quite counterintuitive to not have the north points upwards, as is the case in other studies focusing on this glacier (e.g. see figs. 1b and 2 in Rabatel et al., 2018, *Frontiers in Earth Science*).

Similar to Figure 6, we have added a small inset showing the location of Glacier D'Argentiere within the European Alps. The N arrow has been changed in both maps to be more visible, and the full-glacier inset has been flipped such that N points upwards.

- l. 250: "Validating GIV...": you cannot really 'validate' your model by 'observing' dynamics of a glacier. I would rather refer to this as an evaluation, and would in fact suggest to simply remove this part to be consistent with other section heading: i.e. renaming this to '3.3 Vavilov ice dynamics'

We have changed the word 'validate' to 'evaluate' throughout, and agree about the limitations of this comparison as a 'validation'. We nevertheless believe the comparison is useful for readers (and that a full comparison between various feature tracking codes and ground based data should be the object of a future study). We have renamed the section according to you suggestion.

- l.252: You refer to 'Arctic land-ice' here: not clear if this includes the Greenland ice sheet (which is also Arctic land-ice...) or not, as seems to be the case when reading the next sentence (if so: be more specific and refer to the glaciers and ice caps explicitly)

We have used the terminology from the associated reference (Box et al., 2018) who include the Greenland Ice Sheet in this assessment. We have added a few words to the sentence to clarify this terminology.

- l. 255-266: many of the elements you mention here are really based on our knowledge of glacier surge: would be good to also refer to more general which this is explained, such as Sevestre and Benn (2015, *JGlac*; which also explains the phenomenon of glacier surging for glaciers in the Russian Arctic)

We have added a reference to Sevestre and Benn's paper in this section for readers searching for more background on surge type glaciers in general. Willis et al and Zheng et al's papers on Vavilov ice cap specifically also provide a nice summary of these processes.

- figure 8: same remark as for figure 6 and 7 for the location map. Why did you choose this color bar for the velocities? Very difficult to interpret and seems to be a color scheme that is meant to plot landscapes in fact.. Please change the color scheme to a more classic one that is meant for sequential data! In the caption of the figure, remove 'present', 'displays' and 'present'.

We have modified the color scheme to the same as Fig 7 (ColorBrewer YlGnBu, which should be both print and colorblind friendly). We have also added a small inlay of the broader region (October Revolution Island) and modified the caption as suggested.

- l. 283: '...if associated changed in...' should be '...if associated changes in...'

We have corrected the text.

- l. 284: '...'whether a similar peak occurs in 2020': not up to date anymore: incorporate 2020 in your explanation / figure above, or change the text here, possibly referring to 2021 instead of 2020.

We have updated the text to read 'in subsequent years'.

- l. 286: 'Method validation': comparing your results to those from another study is not a validation, but rather an evaluation. Moreover, it may be questioned whether you can evaluate your results by comparing them to another product which also has substantial uncertainties and potential large artefact (as you also mention, in e.g. l. 297-298). A real evaluation would for instance compare the GIV velocities to on-site high-precision velocity measurements based on GPS. Suggest removing the subsections 3.3.1 and 3.3.2 here and having the entire explanation under the section 3.3.

As mentioned in the comment above, we agree with the limitations of this comparison, and have reworded it as an 'evaluation'. We have also remove the subsections as recommended.

- l.300: 'Many tropical glaciers and ice caps have limited to no ice-flow data': well, they have a lot of data based on techniques such as the ones you present here. So be more specific here, e.g.: '...have limited to no ice-flow data from direct field measurements'

That is a good point, we have corrected the sentence to "Many tropical glaciers have limited to no ice-flow data from direct field measurements..."

- l.303: making the bridge from ice velocity to 'practical decision making' is quite a big step: how are these connected? Or maybe reword to: '...provide information on glacier state, which can contribute...'

We have adjusted the sentence as you recommend. This link was clearer in an older version of this manuscript, which included an inversion for ice thickness and volume.

- figure 9: remove the 'shows' and 'is' from the caption.

We have edited the caption to remove these words.

- l. 305: "...capped with an ice cap": maybe "...covered with an ice cap"

We have changed this sentence to "covered with 17 glaciers", as per the comment above about ice cap terminology.

- l. 317: you mention the runtime for this simulation, but you did not mention it for the other examples. Be consistent. Ideally, summarize all the runtime information in a single table, which could be added to the suppl. mat. Would also be useful, as directly after this (start of Discussion) you mention the computational aspect.

We have removed the mention of runtime. This value is computer-dependant, and is displayed by the toolbox itself at the start of a run (i.e. GIV will let users know how long a given run will take).

- l. 328-340: summary of other feature tracking algorithms: this information should appear earlier, in the introduction. In the discussion section, you should really focus on... the discussion (l.341-349), instead of giving a long summary of existing toolboxes. In fact, the real discussion is now very short (as is the conclusion): suggest merging the discussion and the conclusion in a single section.

We have moved a modified version of this discussion about other toolboxes to the introduction, and combined the discussion and conclusions section. Please see the tracked changes version of the manuscript for the full differences.

- l. 376: mention that this is a PhD thesis

We have updated this reference.

Thanks a lot for going through this list of comments and updating the manuscript accordingly. I look forward to receiving a new version of the manuscript, which could then be considered for final acceptance.

Once again, many thanks for all of the comments (and support for our choice to publish in The Cryosphere). We hope the substantial changes and supplements which we have added are also of use for other glaciologists and remote sensors working in this field.

Also, I just want to express my appreciation for the open review and pre-print publication approach taken by The Cryosphere (and similar journals). It has been very welcome to be able to share an earlier version of this paper with colleagues while it is in review, and the associated article metrics show that just over 1000 people have read the article online! This is always encouraging to see while working on revisions and edits, and I hope can widen the audience of this toolbox.

Many thanks,

M. Van Wyk de Vries and A. D. Wickert

Best regards,

Harry