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

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Author Response

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Response to editor:

Comments to the Author:

Dear authors,

Your manuscript has been reviewed a second time by one of the original reviewers. This reviewer remains very critical about your work, and still sees major issues that prevent her/him to recommend your manuscript for publication (in fact, the anonymous reviewer suggests a "rejection" at this point). Given the contrasting views on the manuscript, with one reviewer (Ted Scambos) supporting your submission and the other one (anonymous) being very critical, the review process will be continued.

I first invite you to answer all new queries raised by the anonymous reviewer, after which the manuscript will be sent out for review again. In answering the issues raised by the critical reviewer, it is important to go in detail and provide quantitative information where possible. In particular, pay attention to the comment by the reviewer stating that: "Secondly, the response by the authors is brief and no effort is put in backing-up their argument. The majority of answers include phrases like, "we find little difference", "we found no clear improvement", but results or information is lacking. Thus it is difficult to get convinced, especially since the points I have raised are backed up by references. One can not expect me to run the test for you, in my opinion the burden of proof needs to be at the side of the authors". When answering this question, I would also like you to expand on some of the answers you previously gave, by providing additional quantitative information (and update the manuscript accordingly) on:

• "we find little difference between 8 bit and 10 bit 70 data even in shadowed/clouded areas. The orientation filter tends to cancel out contrasts within the data. The 10 bit data may prove advantageous where orientation filtering is not suitable and simple low-pass filtering and/or contrast limited histogram equalization (CLAHE) is used

o What is ‘little difference’?

• "On some glaciers we have found that near infrared Band 8 of Sentinel 2 (842 nm) may produce a better feature contrast than other bands on some glaciers. We have also found that shortwave infrared bands 10 and 11 (1375 and 1610 nm) can be suitable in some cases (high contrast between ice and supraglacial debris), however suffer from a lower spatial resolution"

o ‘may produce better feature contrast’: by how much? And can you specific about the resolution where the problems originate for the shortwave IR?

• "We found no clear improvement in matches relative to frequency domain cross correlation even in areas with significant ice shear (glacier margins with around 1000 m/yr velocity gradient across one kilometre). We also found that the multi-pass frequency domain matching would usually outperform single passes in both frequency and spatial domain. However, we found that changes to the pre and post-processing would often have the greatest improvement on final velocity maps, so have emphasized this aspect in GIV. This is indeed less of an issue within fluid dynamics where the sampling rate, tracers and illumination 110 may be controlled."

o You discuss the (lack of) ‘improvement’, several times. Can you be more specific / quantify the (lack of) improvement

• "We test an implementation of ‘neighbourfilter.m’ using nlfilter, however it results in little overall speed-up and some unexpected artefacts. "

o Can you quantify the speed up and describe the unexpected artefacts

The comment about the suitability of the journal (‘The Cryosphere’) has been addressed sufficiently in my opinion, and will not be a point of debate in the final decision (as I already indicated before). I agree that the study could have been considered for a more technical journal, like Geoscientific Model Development, but I am still convinced that The Cryosphere is a suitable journal (given that the study fulfils the scientific standards of this journal, which needs to be further assessed through peer review).

Thank you for your efforts,

Best regards,

Harry

Dear Dr. Harry Zekollari,

We thank you for the comments above, and for the opportunity to respond to anonymous reviewer 2's comments. We have designed two additional experiments to quantitatively back up our answers to the reviewer's questions, which are presented in the response below and will be uploaded to the supplementary materials of our paper. These experiments are designed to evaluate the relative quality of velocity maps derived from different processing parameters and Sentinel 2 image bands.

We update the manuscript to include mentions of this additional information, although it is largely outside of the main objective of our manuscript. We are not aiming to provide an evaluation of different parameter options and choices in feature tracking, but rather to present a new feature-tracking toolbox to the glaciology community. We worry that making major modifications to the manuscript towards the latter of these objectives (as the reviewer appears to suggest) may detract from the first objective. In order to fully evaluate the accuracy of feature tracking under different parameter choices, comparison of model results to ground-based datasets (e.g. GPS and/or ground based camera datasets) would be ideal. An effort is currently underway to compare different toolboxes (GIV, vmap, CARST, Auto-RIFT, possibly more) to a glacier-surface GPS dataset, which will be build on the work conducted in this manuscript.

We hope that our detailed response helps convince reviewer 2 of the benefit of the filters and methods presented in this paper and available in GIV. The reviewer's most severe criticism relates to the choice of TC as a venue for this paper, which we hope is mitigated by your comments on the matter. We strongly disagree with the characterisation of GIV as a "straightforward copy" of Thielicke (2014)'s toolbox. While some of the core computational techniques are similar, neither the objectives nor code of GIV are alike. Minor sections of the PIVlab toolbox are included (and clearly acknowledged) in GIV, but these make up <1% of the total code.

We have made minor additional changes to the code to improve clarity and computational speed, and will continue to regularly update the code. Notable changes include the replacement of the function discussed in the previous review (neighbourfilter.m) and replacement with an alternative outlier filter, changes to the signal-to-noise ratio computation and addition of circular colormaps for directional data.

Overall, we hope that the additional experiments make a useful addition to the paper and to other remote sensors, and retain much of the current manuscript structure (as per reviewer 1 Dr. Ted Scambos' comments).

Many thanks for your continued time and comments-

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

Response to reviewer 2

We thank the reviewer for the comments, and respond below. We hope that the comments and additional experiments presented below help:

1) Justify some of the parameter choices in the model and provide quantitative background to some comments made in the response to reviewer.
2) Confirm that TC is a suitable journal for this manuscript, as noted by the editor.
3) Highlight our vision for this manuscript. We do not aim to provide a detailed assessment of the optimal choices for feature tracking of glaciers, but rather describe a new toolbox and its potential uses to this community.

In essence the authors have taken the code and design principles of (Thielicke, 2014) and applied this to satellite imagery of glaciers. Therefore, implementations like "intensity capping" and "CLAHE" are present. The work of Thielicke (named "The flapping flight of birds: Analysis and application") has been tailored towards PIV data, and in his thesis work the design issues have been tested against others, so a justification can be made to a specific implementation, as presented in (Thielicke & Stamhuis, 2014). Fore-mostly, I think this straightforward copy needs to be emphasized more clearly in the manuscript, in this sense the toolbox is a similar implementation as SenDit, though (Nagy et al.2019) give clear credit to the feature tracking pipeline they have wrapped their toolbox around. This is in stark contrast to the presented manuscript.

We have not based our toolbox on Thielicke and Stamhuis's code. We have implemented small parts of their pre-processing in GIV (~20 lines of code out of ~5000), but the overall objectives are different. Our code is not a straightforward copy of theirs, and we have acknowledged them in both the manuscript and code.

As we have mentioned in the previous response to review, there are scenarios in which these pre-processing options are valuable in glacier settings. In experiment 1 below, we evaluate image pre-processing and show that both the 'near-anisotropic orientation filter' and 'contrast limited histogram equalisation, followed by high-pass filtering' improve feature tracking results relative to raw imagery in several test cases.

Secondly, the response by the authors is brief and no effort is put in backing-up their argument. The majority of answers include phrases like, "we find little difference", "we found no clear improvement", but results or information is lacking. Thus it is difficult to get convinced, especially since the points I have raised are backed up by references. One can not expect me to run the test for you, in my opinion the burden of proof needs to be at the side of the authors.

We include several tests below to back up the points made in this and the previous response. We would like to note that we did carefully evaluate the points made the reviewer in the previous comment, including editing portions of the toolbox source code and increasing documentation quality. Furthermore, we would like to note that the objective of this manuscript is not to provide a review of different feature-tracking options. We hope that the experiments presented below help clarify and back-up the points we make in this response but are for the most part beyond the scope of this paper. We hope that the detailed response below dispels the notion that we are not taking the reviewer's responses into consideration or putting effort into our responses.

The authors have doubts themselves if the Cryosphere is the correct journal for this manuscript. I have the same but stronger doubts. There is no clear scientific finding present in the paper, nor is a new method developed. We also agree upon the other point: there is a lot of overlap between the intended readers and the audience of The Cryosphere, but I think exposure for the GIV MATLAB toolbox can also be achieved through Cryolist. For example, after the release of IMGRAFT announcements have been posted there and it is now a common toolbox in teaching and research. Hence the Cryosphere might not be the correct journal for this work and better journals exist.

The editor has stated "*the suitability of the journal ('The Cryosphere') has been addressed sufficiently in my opinion, and will not be a point of debate in the final decision … I am still convinced that The Cryosphere is a suitable journal*". We hope that this reassures the reviewer about the suitability of the manuscript for this journal, and will not be a factor in further reviews.

Detailed comments:

- The authors claim to see no difference between 10 and 8 bit data, contradicting two other studies. They say the changes are "little", their assessment not based upon the individual building block. So, if isolation is done these pattern will likely emerge.

Thank you for this comment. According to ESC, Sentinel 2's full bit depth imagery is 12 bit rather than 10 bit, which is then saved as 16 bit files (https://sentinel.esa.int/web/sentinel/user-guides/Sentinel%202-msi/resolutions/radiometric). We ran a set of experiments (see discussion below) on these, and found that the 12-bit data did improve the correlations on regions containing bedrock, but that these did not significantly improve the correlations on regions containing ice. See the experiments below for discussion of this.

- "The visible bands are correlated, which is why we sum them into a single band", What is the rationale, I can't understand why this should be evident? You're now only turning my question into your answer....?

- There is a vague comment about the use of different bands, please see (Redpath et al.) for more detailed analysis.

Choice of bands is not a parameter option in the code; it is a choice made by the users prior to loading images into GIV. It is beyond the scope of this paper to evaluate the relative value of different bands, particularly as they differ between Sentinel 2, Landsat, Planet and other satellites that may be used in this code.

We have focussed on Sentinel 2 imagery, and so present a comparison between different bands below. This is only a brief overview of this topic, that could probably be the focus of an entirely separate paper.-

NCC vs.Freq. this seems to contradict to (Heid & Kaab, 2012), at least they hypothesise this to be the case.

See experiments below for discussion of this. Our results are not inconsistent with Heid and Kääb (2012), who find generally good results with their orientation filtered frequency domain matching ‘CCF-O’.

- nlfilter, you seem to use small image sniplets and not whole Sentinel-2 or Landsat scenes. When this is the case, such functions do much better.

The objective of this function is to detect and remove noisy pixels that differ from their immediate neighbours by a certain threshold. As such, we compare pixels to their immediate neighbours. We are not entirely sure what the reviewer means in this comment, but we could not accomplish this using the whole image/Sentinel-2 scene. Later filters in the code do remove pixels based on an absolute threshold (e.g. maximum velocity filter in myfilter.m or overall scene filter in filtall.m).

In a revised version of the code, we have replaced the function neighborhoodfilter with an alternative outlier removal function. Note this code has been updated in our github repository (github/MaxVWDV/glacier-image-velocitmetry). This includes no loops, and runs about one order of magnitude faster (0.116 seconds vs 1.4 seconds total runtime for a 2500x1174 image pair of Glaciar Perito Moreno). This makes a small difference to the overall runtime, given that this function generally accounted for <10% of the total runtime. The new function is more easily customisable if advanced users wish to expand/reduce outlier detection between the multiple passes of the feature tracking algorithm.

- It is still unclear what the authors envision with their toolbox. Their open source argument is for attracting others to improve upon their work. Though on contrary, they also "do not believe code commenting is an important factor". Why is this contradiction there?

We envision a majority of GIV’s users running the code through the user interface, although some users may wish to add their own functions or edit as required. As such we have improved the clarity of the code as recommended in this reviewer’s first review, including adding many comments throughout.

- The argument that "Other good feature-tracking toolboxes" "can be challenging to use" is subjective, and not an argument why not improve upon them. Secondly, many of the listed toolboxes have a GUI and are used in courses.

We agree that this statement is subjective, and do not discourage readers from using other toolboxes. On the contrary, we provide a table listing many previously designed toolboxes, and provide links for readers to access these. GIV does not seek to replace these toolboxes, but rather provide a practical GUI based feature tracking toolbox for glaciologists and students. GIV allows users to run thousands of images pairs, automatically generate plots and adjust parameters all through a GUI.

To our knowledge, the main other tools with user interfaces are Cosi-Corr (requires ENVI, which is an expensive commercial platform to which fewer scientists have access), PIVlab (intended for particle image velocimetry rather than glacier feature tracking), and some of the ground-based camera tools (e.g. Poincatcher, PyTrx). While not having a user interface, IMGRAFT is also easy to use in a few lines of code. SenDiT is also easy to use, but is more complex to install (requires command-line installation of Imcorr). We believe GIV's expanded capabilities, larger filtering options, and ability to analyse a time-series of images fills the need for a feature-rich and GUI-enabled glaciological package.

- In the previous implementation the geo-referencing consisted of a simple multiplication of the pixelsize by 10. In the newer version the authors have included the possibility of reading geotiff-files, but it seems the same irregularities are also included in the code. For example, some parameters are hard coded: 'xtick',10 . When other bands of Sentinel-2 are used, this will break down. Similarly, when Landsat8 data is used. Secondly, the authors build on top of there strange angular-metric transformations, for example, by integrating functions like "coordtom" (based upon matlabcentral/fileexchange/38812-latlon-distance). This ratio might work for a single line, but for a high (Ant)arctic scene this ratio changes extensively over a scene. Though there is a mapping toolbox present in Matlab, why is this not used?

'xtick',10 is a graphical display option, defining the number of vertical gridlines in output figures. It has no relation to input image resolution. The georeferencing in GIV has never consisted of a multiplication of the pixel size by 10. The resolution is calculated from the geographic corner coordinates, which are either inputted by the user (for raw jpg or png image inputs) or obtained directly from the metadata included with the geotiffs. The maximum error for a 10 km * 10km scene at the Arctic circle (66N) from this calculation is 0.35% (as latitudinal variation in longitude spacing is neglected), well below the noise level from other sources. MATLAB's mapping toolbox is used to handle the geotiff inputs, where relevant.-

Although the authors do not respond to my suggestion, I still believe a workflow plot might benefit this work, a screenshot of the guy is less informative.

We responded to this suggestion in the 'response to editor' of the previous review. We have made changes to figure 1 to better fulfil the role of a workflow figure, including tying it in with the code file names.

- Matlab should be in the title, as IDL, Python and Julia are (decreasingly or increasingly more) populair.

The toolbox can be used without a MATLAB license through the standalone app, and knowledge of MATLAB is not a prerequisite for its use. We do not believe that including this in the title is necessary but have made minor edits to the abstract to highlight that the source code is written in MATLAB.

references:

Heid & Kaab, 2012. 10.1016/j.rse.2011.11.024

Nagy et al. 2019. 10.3390/rs11101151

Thielicke, 2014. hdl.handle.net/11370/31931f33-4aa0-4280-892e-93699af0e9b6

Thielicke & Stamhuis 2014. 10.5334/jors.bl

Experiment I: pre-filters, bit depth and FCC vs NCC

In this experiment, we evaluate the effect of different options on feature tracking results. We vary three different model choices:

1 Image pre-filter: Raw (unfiltered) image pairs, images filtered with a highpass filter and contrast limited histogram equalization, and images filtered with the near anisotropic orientation filter (NAOF)
2 Bit depth: We test both 8 bit jpg image pairs, and full bit depth (12 bit) geotiff image pairs
3 Feature tracking domain: We test the multipass FCC (frequency cross correlation) used in GIV and a normalized cross correlation feature tracking algorithm (templatematch, from Messerli and Grinsted, 2015' IMGRAFT)

We use three different image pairs from Glaciar Perito Moreno (50.48°S, 73.11°W) to evaluate the above parameters. We choose one image pair containing no clouds, one with a small number of clouds and one with many clouds to evaluate the effect of these on the above parameters. These images are shown in Figure S1. All images use band 8 of Sentinel 2.

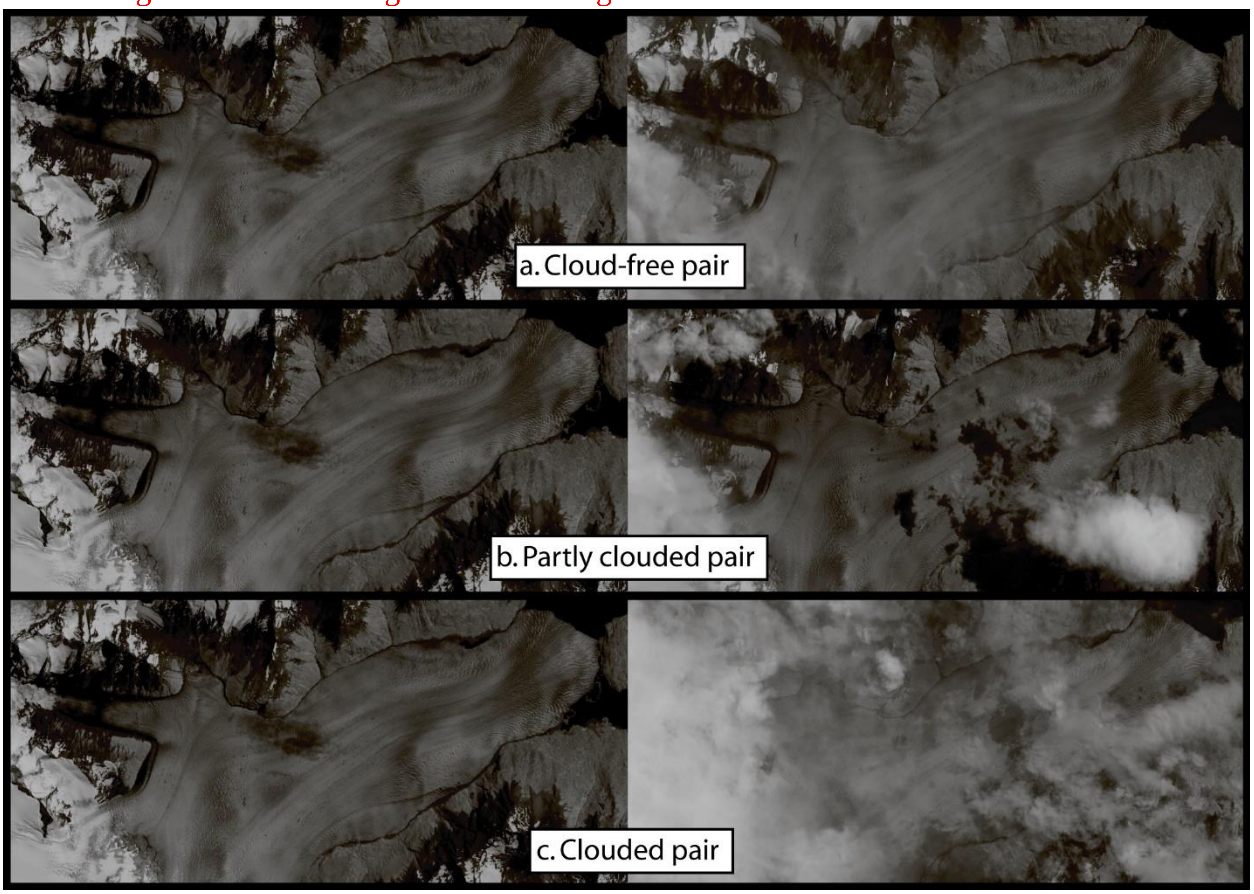

Figure S1: Imagery used. The cloud free pair dates are 20200101-20200131, partly clouded dates are 20200101-20200121 and clouded dates are 20200101-20200123.

The total number of parameter options is 3*3*2*2 (clouds, filters, bit depth, feature tracking domain), or 36 total options. For each of the 36 parameter options, we calculate a velocity map, a map of signal to noise ratio and a map of peak ratio. Signal to noise ratio and peak ratio are two possible ways of evaluating the reliability of a feature tracking result. Signal to noise ratio is defined as:

$$Snr = \frac{C_{peak}}{\overline{C}}$$

With C_{peak} the correlation coefficient of the peak ('correct match') and $\overline{C}$ the mean correlation coefficient of the whole search domain. The peak ratio is defined as:

$$Pkr = \frac{C_{peak}}{C_{secondary}}$$

With $C_{secondary}$ the correlation coefficient of the second highest peak in the search area (excluding a buffer zone around the primary peak). A high Snr and Pkr indicates a reliable match, a high Snr and low Pkr indicates two possible matches and low Snr and Pkr corresponds to an unreliable match.

The figures below present the results of this experiment. In each the parameter options are highlighted: NAOF = 'Near anisotropic orientation filter', CLAHE = 'Contrast limited histogram equalization', Hipass = 'High-pass filter', FCC = 'Frequency cross correlation', NCC = 'Normalized cross correlation'. No post-processing has been applied to the velocity maps, except for cropping the output to an ice mask for histogram calculation.

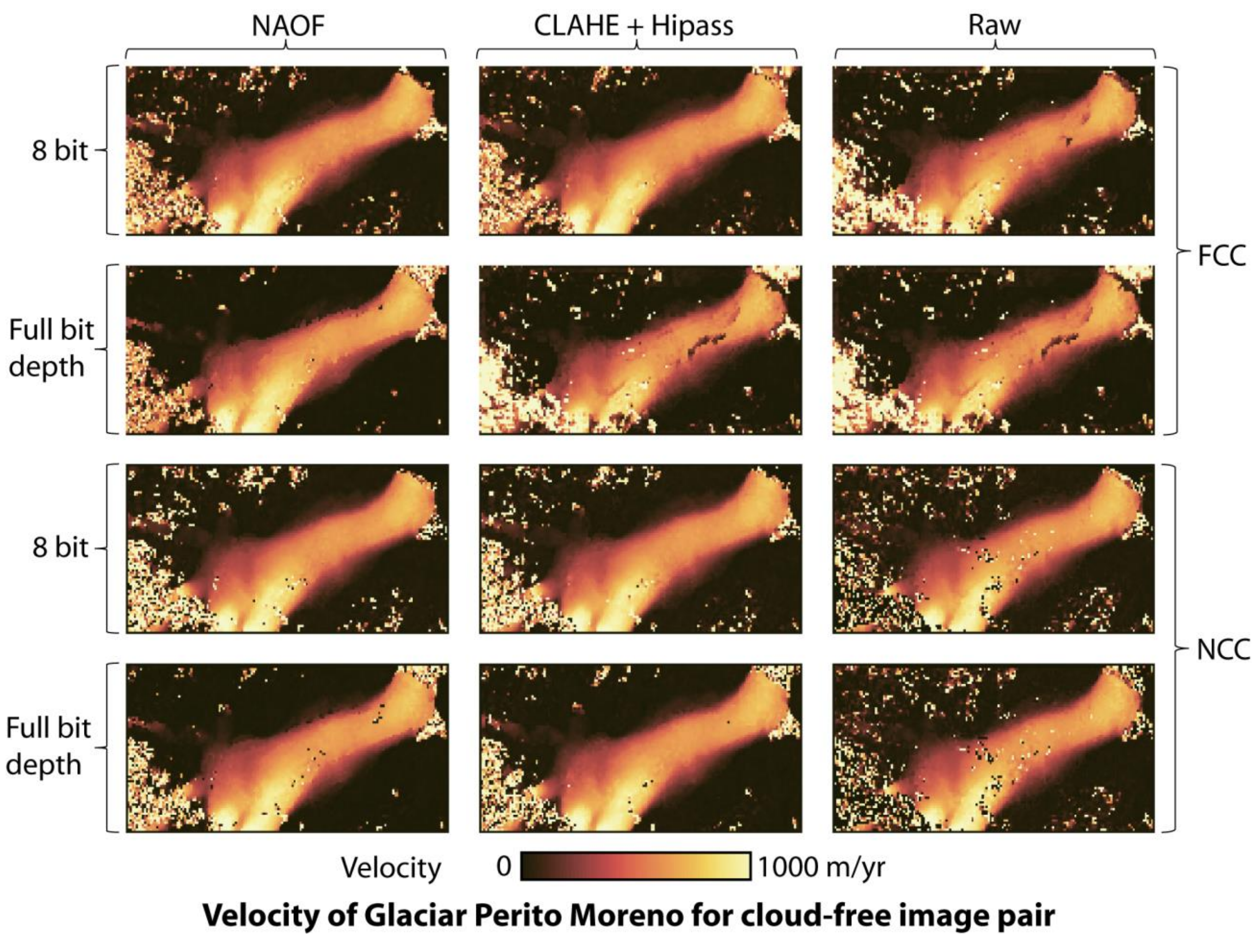

Figure S2: Velocity of cloud free imagery.

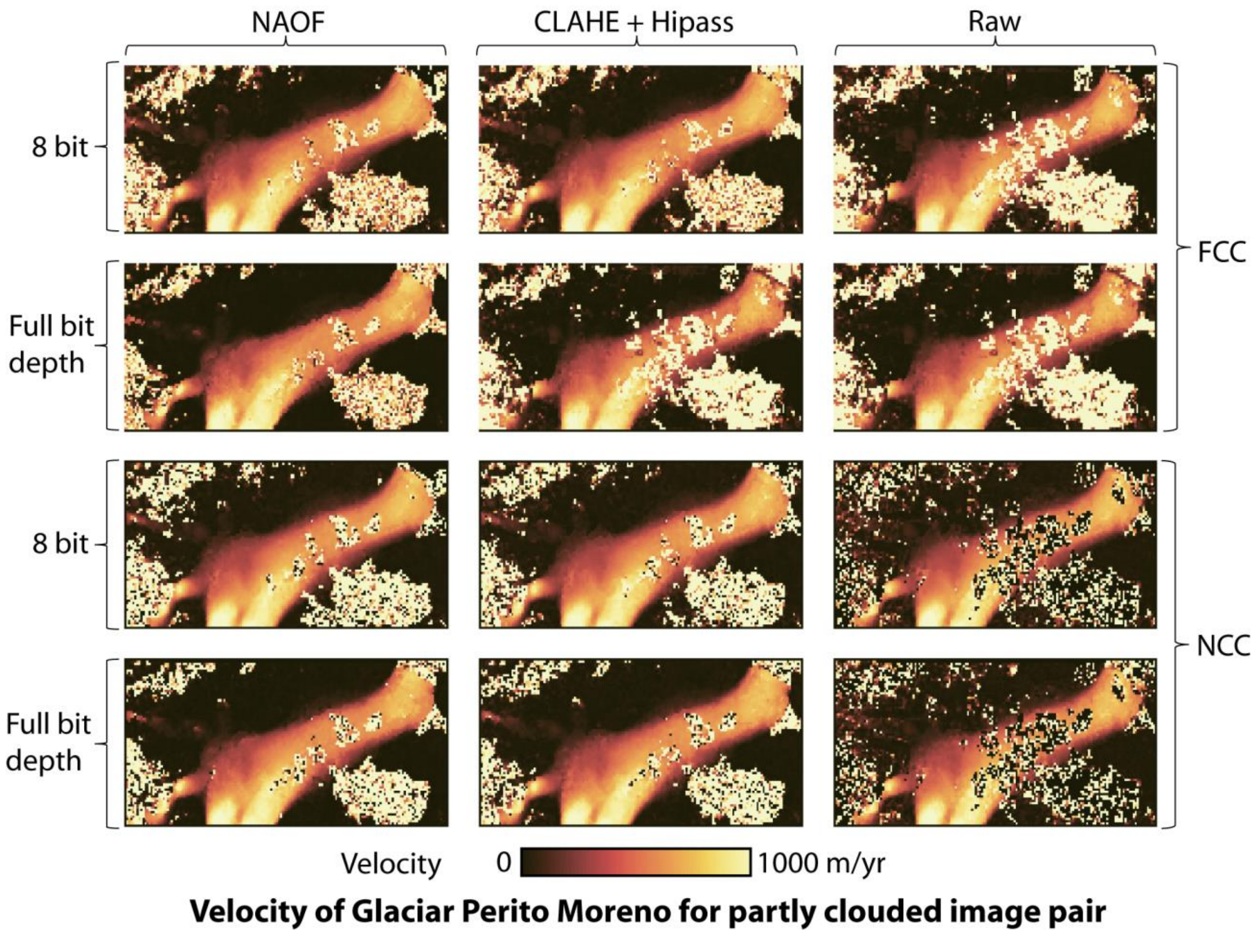

Figure S3: Velocity of partly clouded imagery.

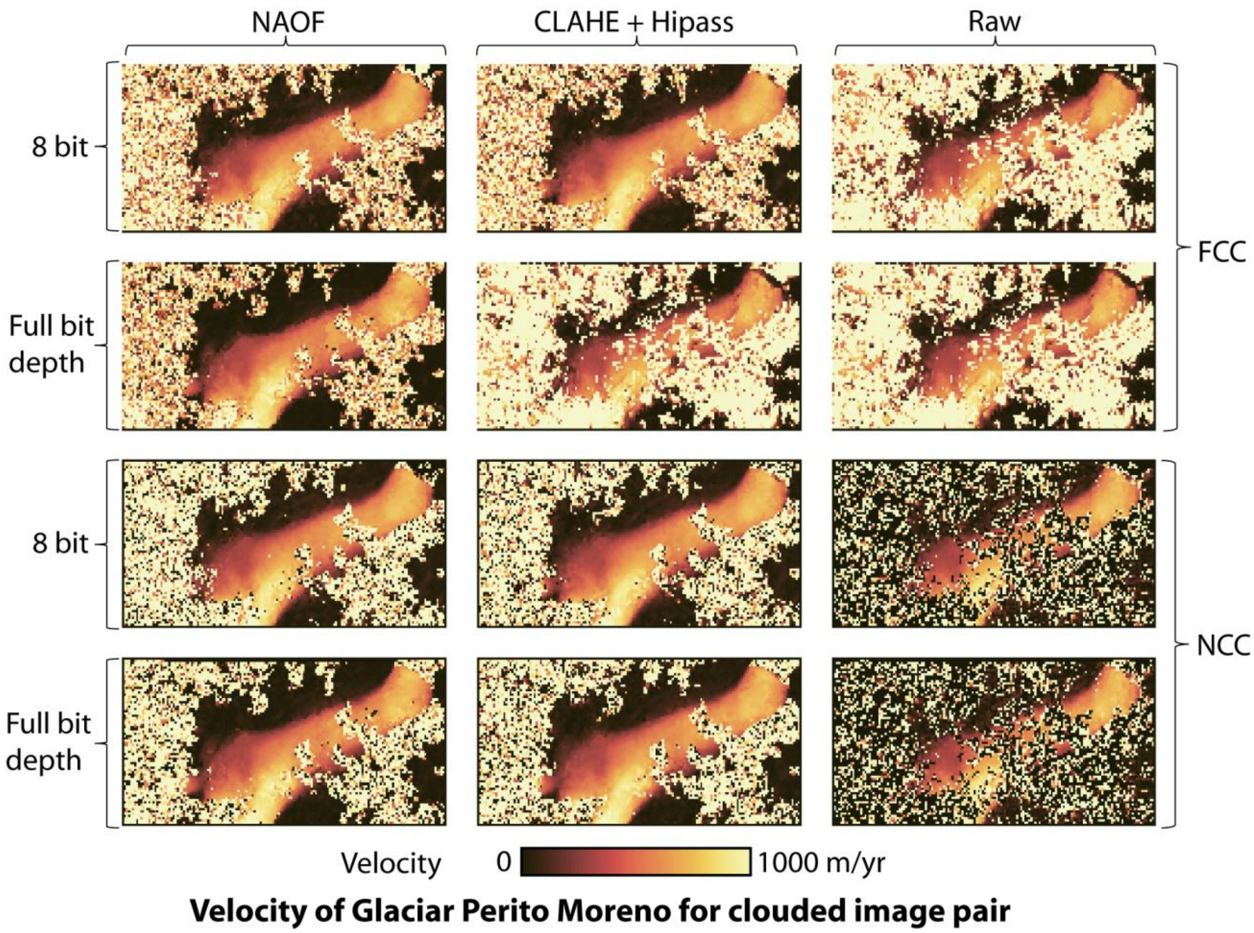

Figure S4: Velocity of clouded imagery.

Note that in the clouded pair, many parameter options are able to recover velocities over a large portion of the glacier despite around 80% cloud cover in the second image. An initial examination of the results suggests that NAOF recovers the most information in clouded scenes, and that FCC generally produces a less noisy result than NCC. The difference between 8 bit and full bit depth images appears minor. We may further evaluate this by considering the signal to noise ratio and peak ratio of the image pairs, shown in figures S5-7 and S8-10 respectively.

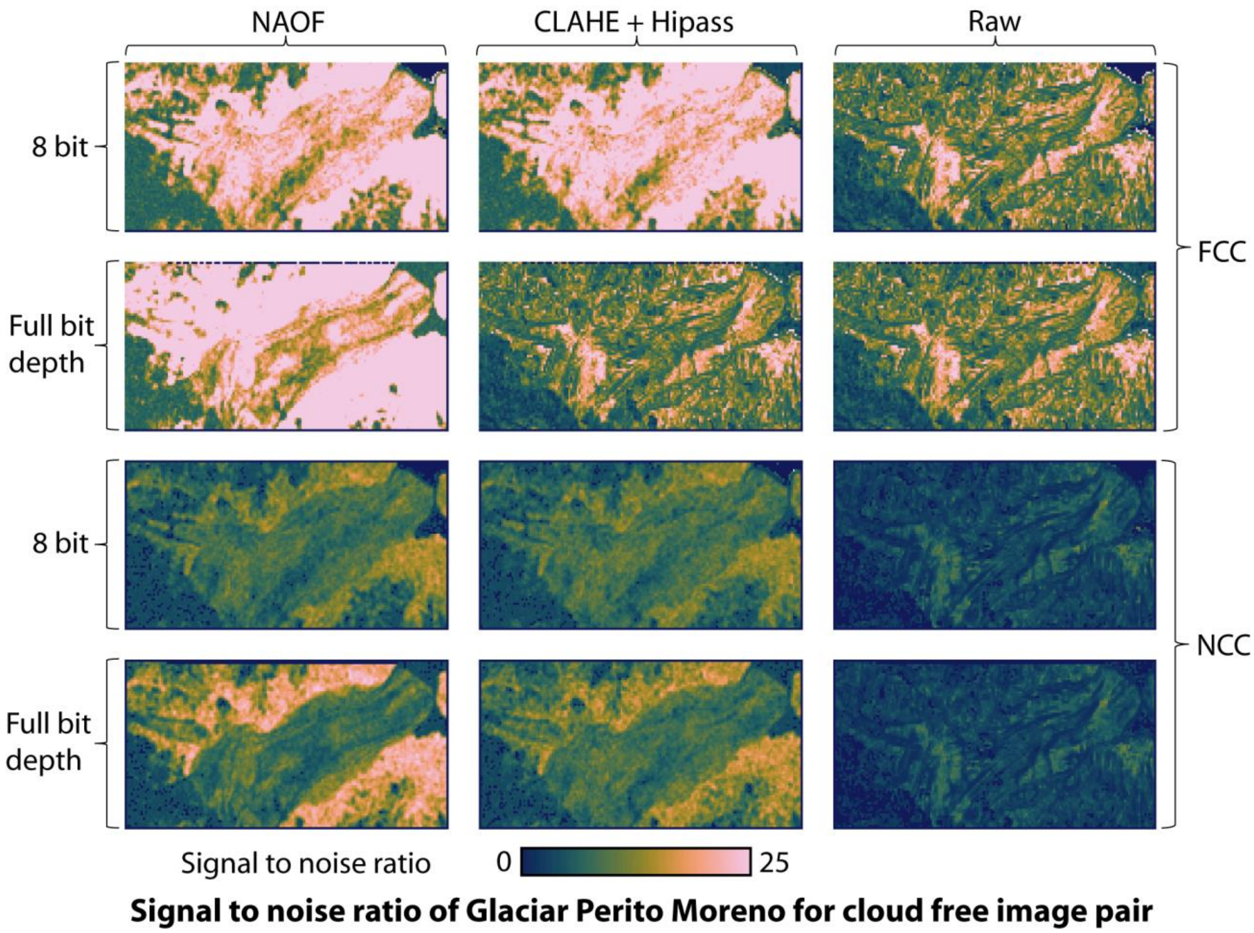

Figure S5: Signal to noise ratio of cloud free imagery.

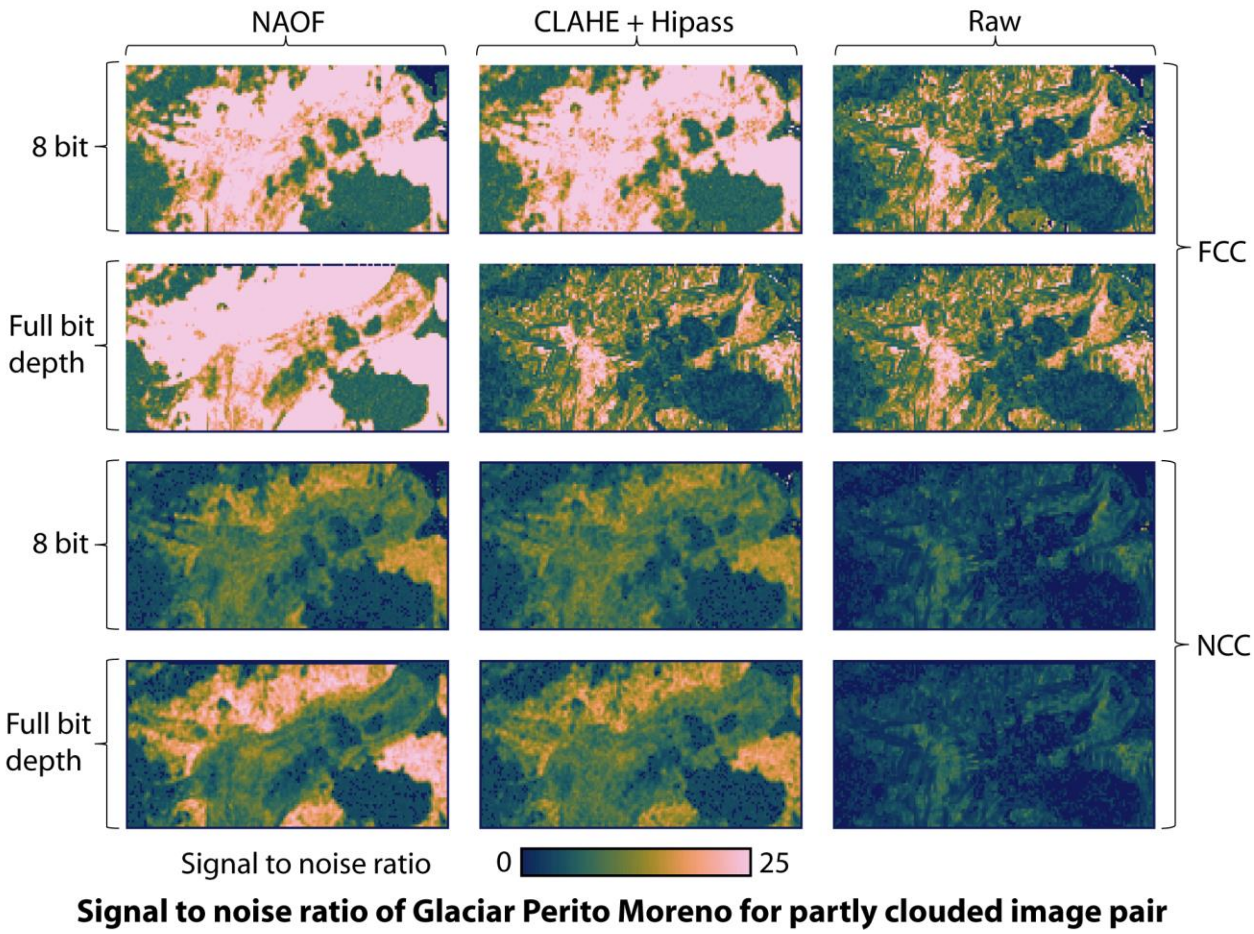

Figure S6: Signal to noise ratio of partly clouded imagery.

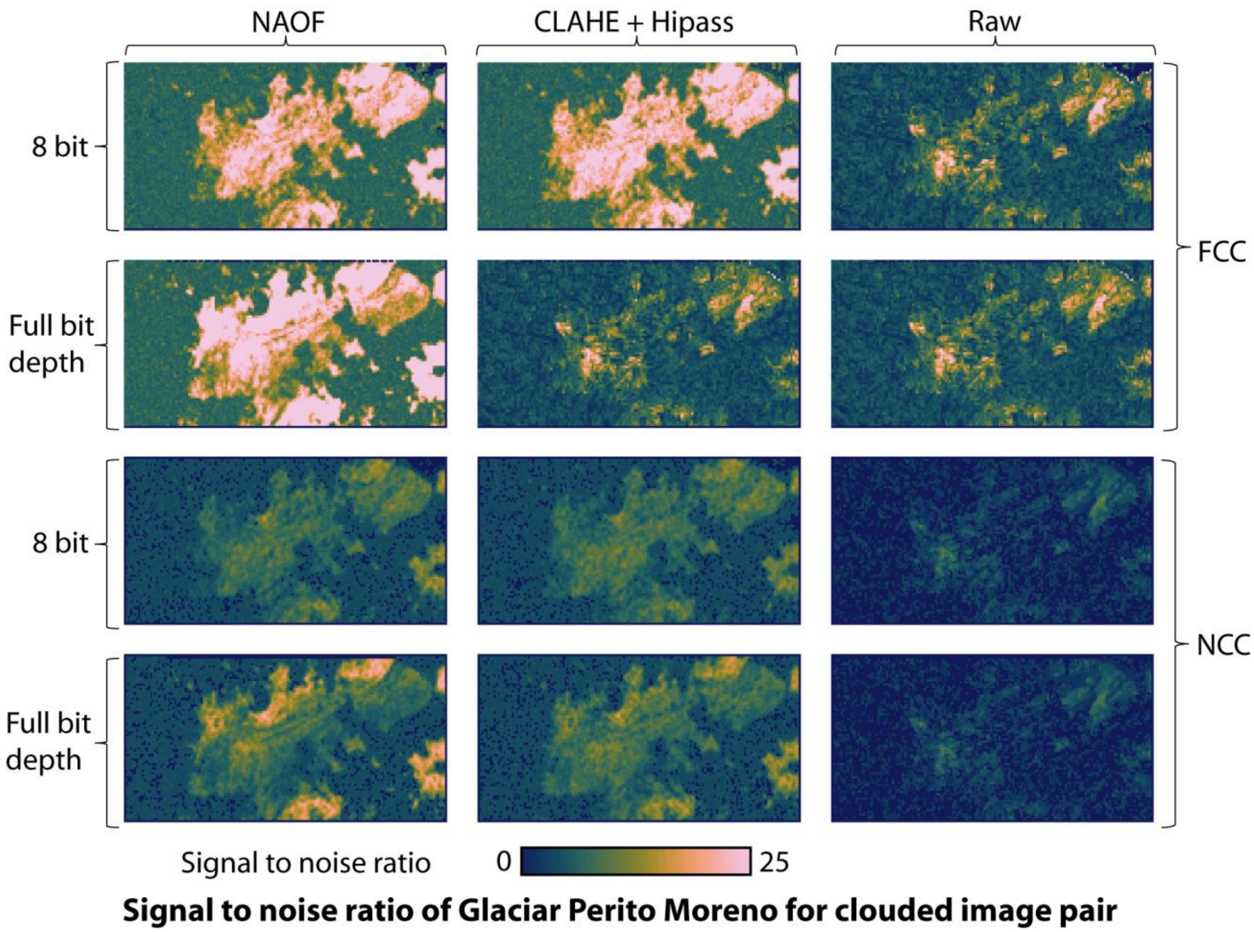

Figure S7: Signal to noise ratio of clouded imagery.

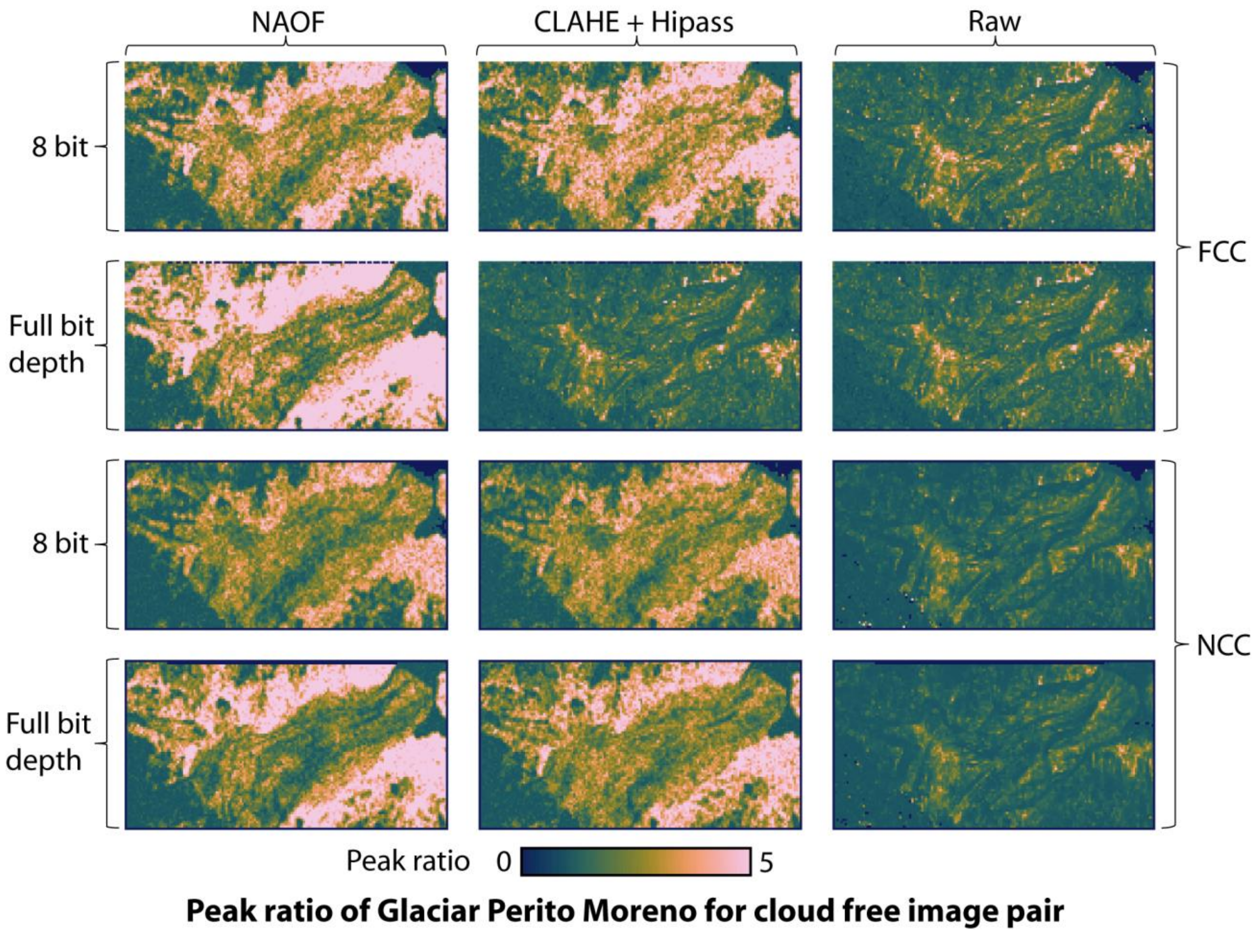

Figure S8: Peak ratio of cloud free imagery.

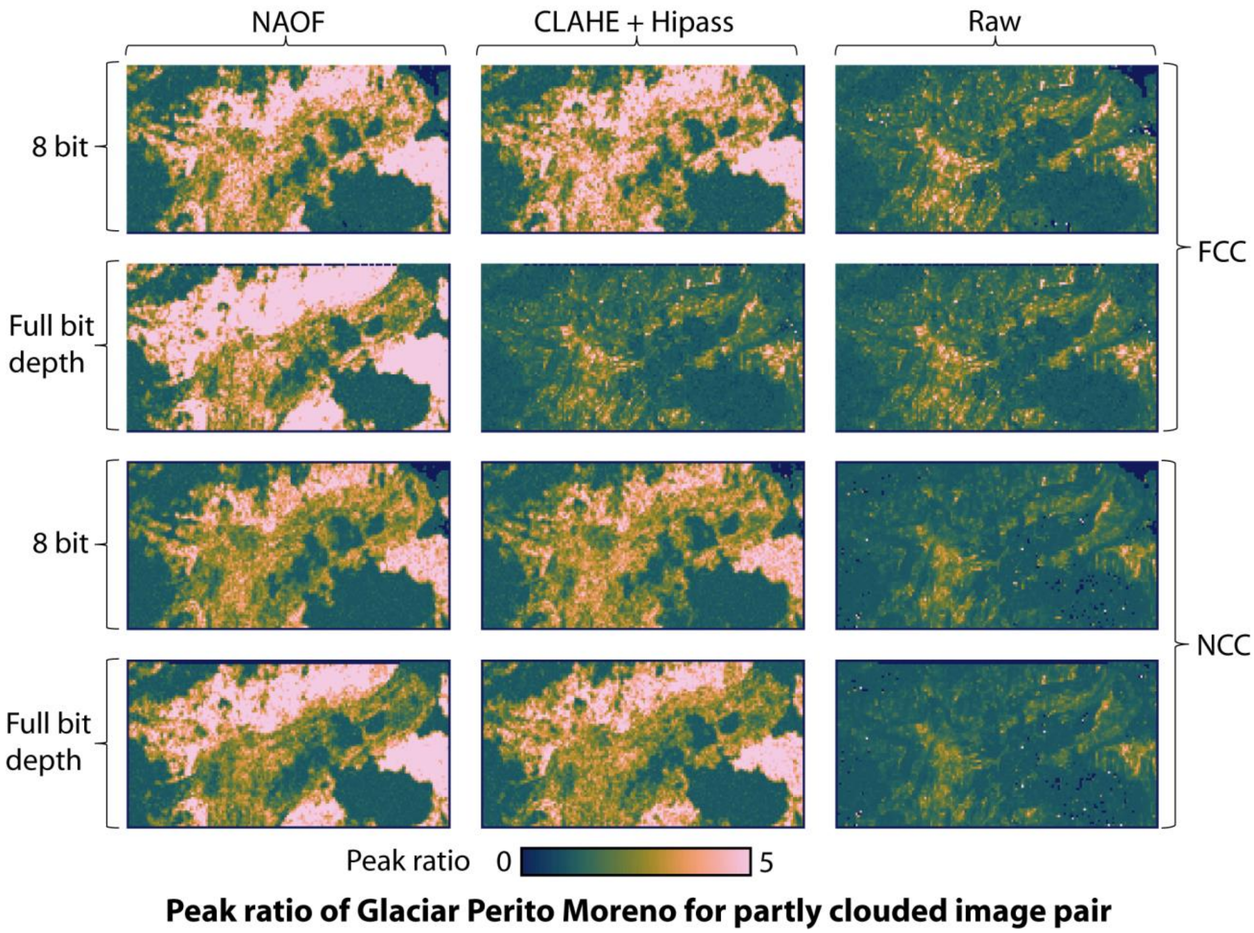

Figure S9: Peak ratio of partly clouded imagery.

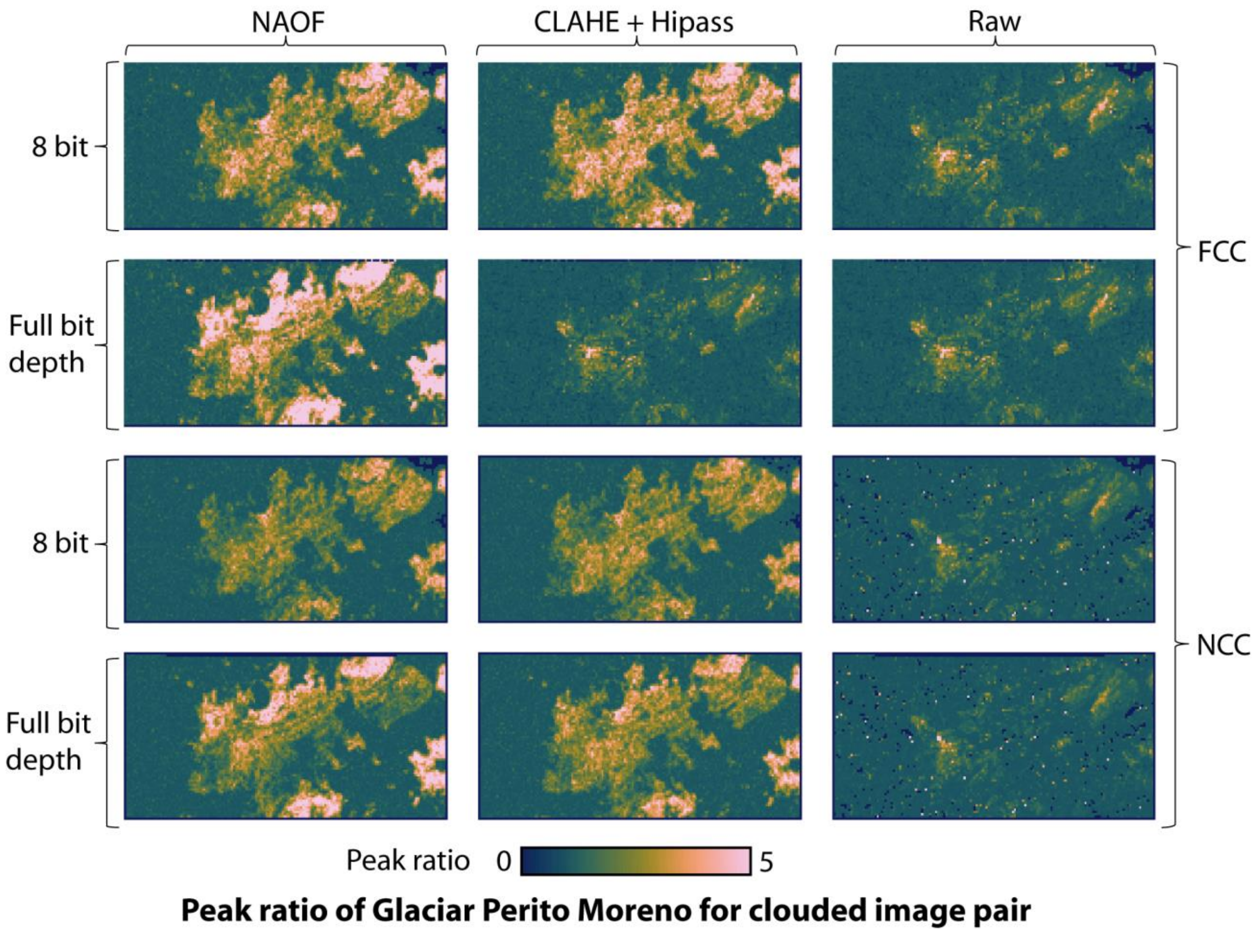

Figure S10: Peak ratio of clouded imagery.

These maps show that FCC and NAOF generally produce the highest signal to noise and peak ratios on the glacier. Applying an image filter (NAOF or CLAHE+Hipass) always improves results relative to raw images. We may also plot histograms of signal to noise ratio and peak ratio in each case, shown in figures S11-S13 and S14-S16. Maps have been cropped to an ice mask prior to calculation of signal to noise ratio and peak ratio histograms.

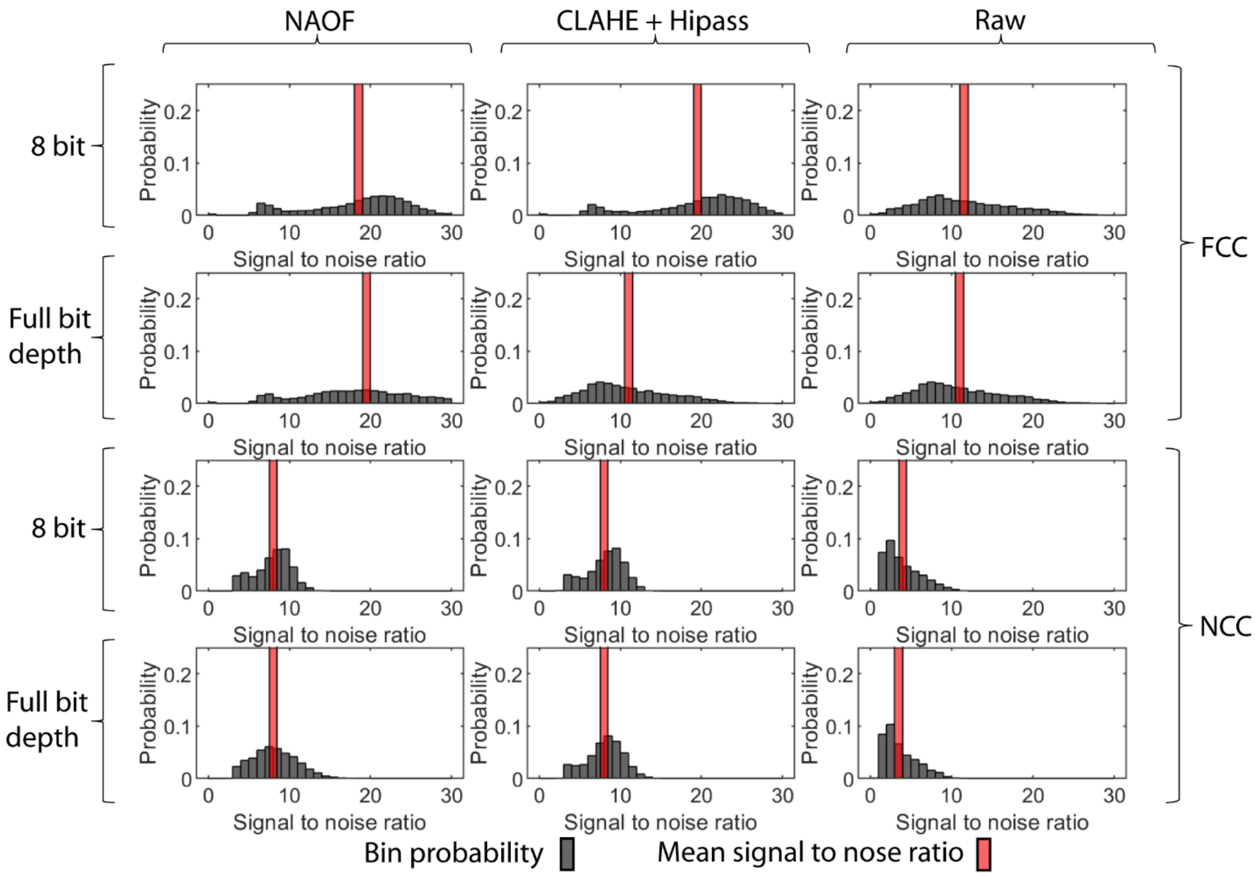

Figure S11: Histogram of signal to noise ratio for cloud-free imagery, cropped to the glacier areal extent.

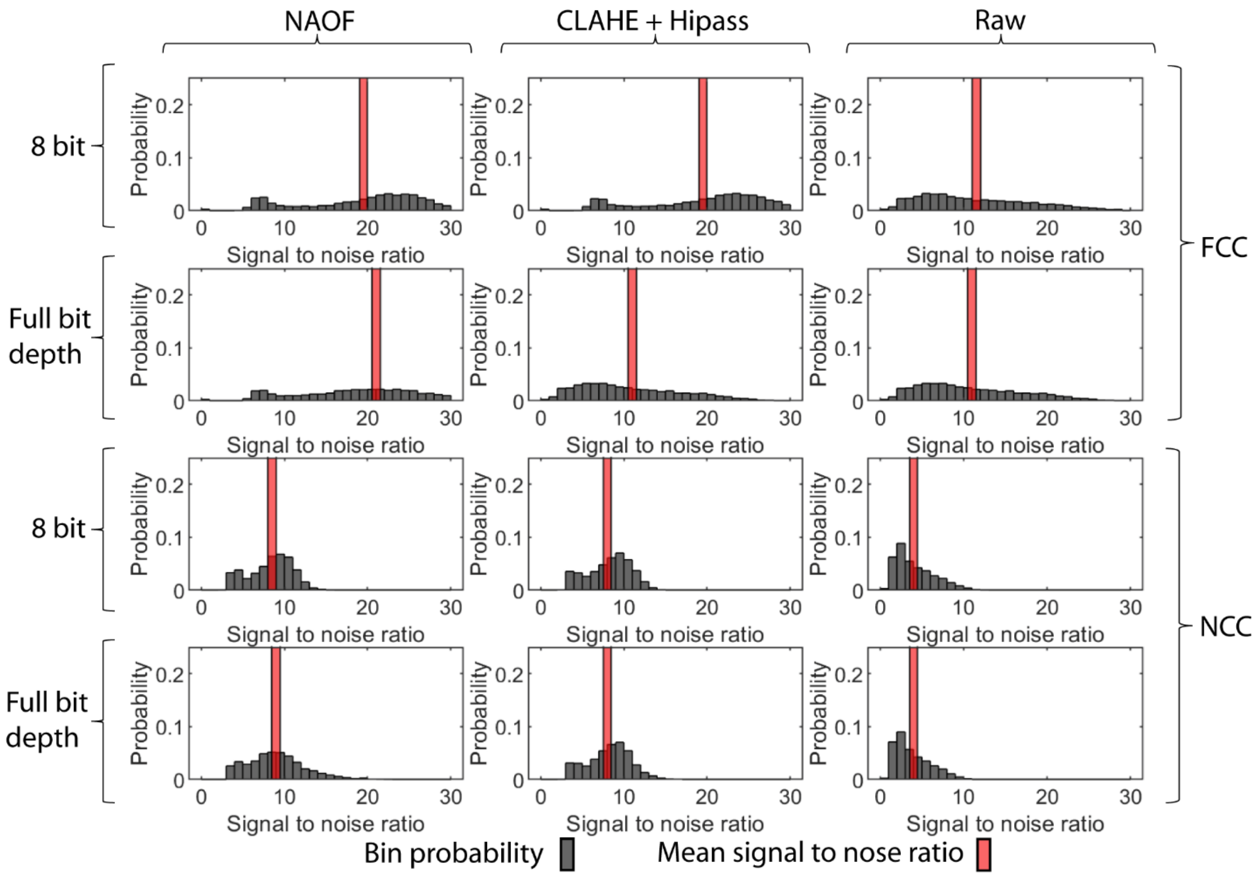

Figure S12: Histogram of signal to noise ratio for partly clouded imagery, cropped to the glacier areal extent.

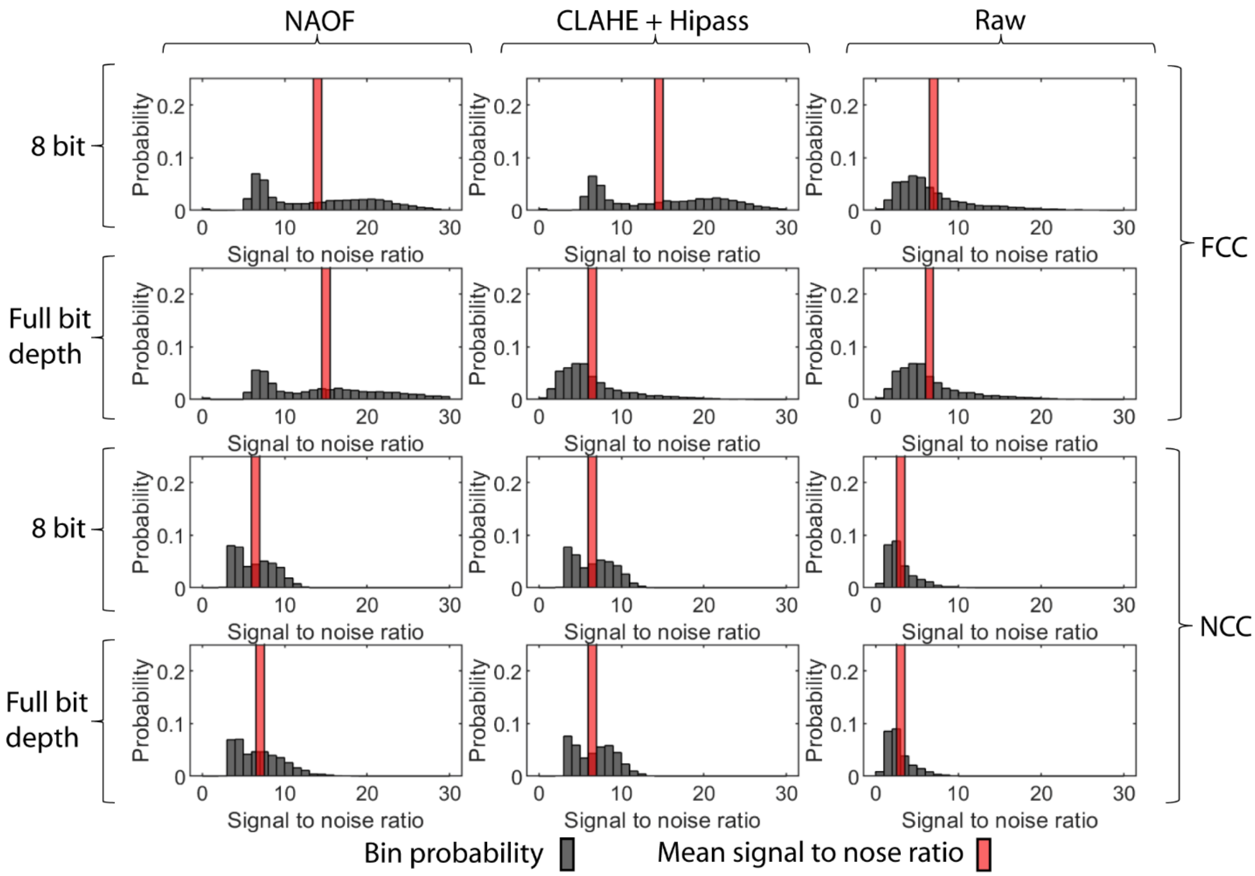

Figure S13: Histogram of signal to noise ratio for clouded imagery, cropped to the glacier areal extent.

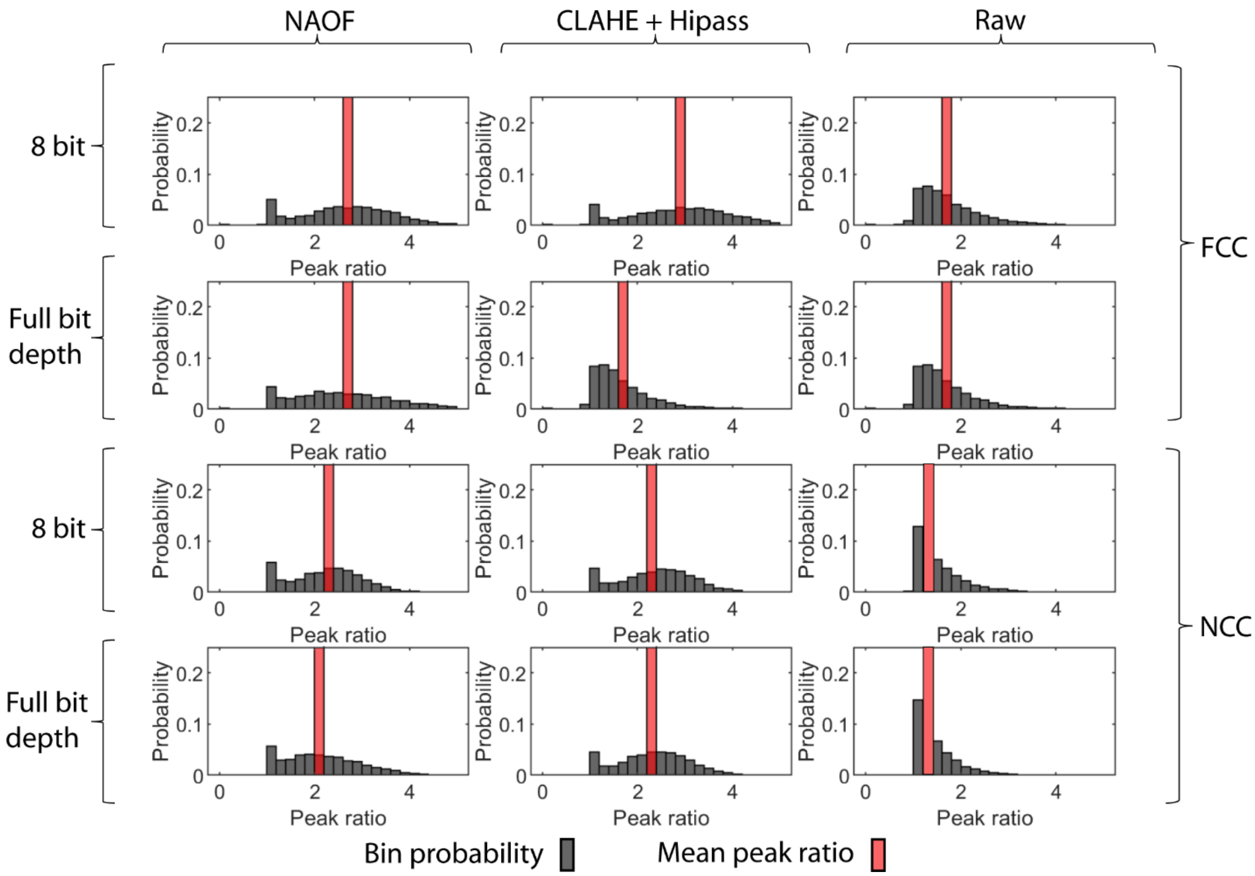

Figure S14: Histogram of peak ratio for cloud free imagery, cropped to the glacier areal extent.

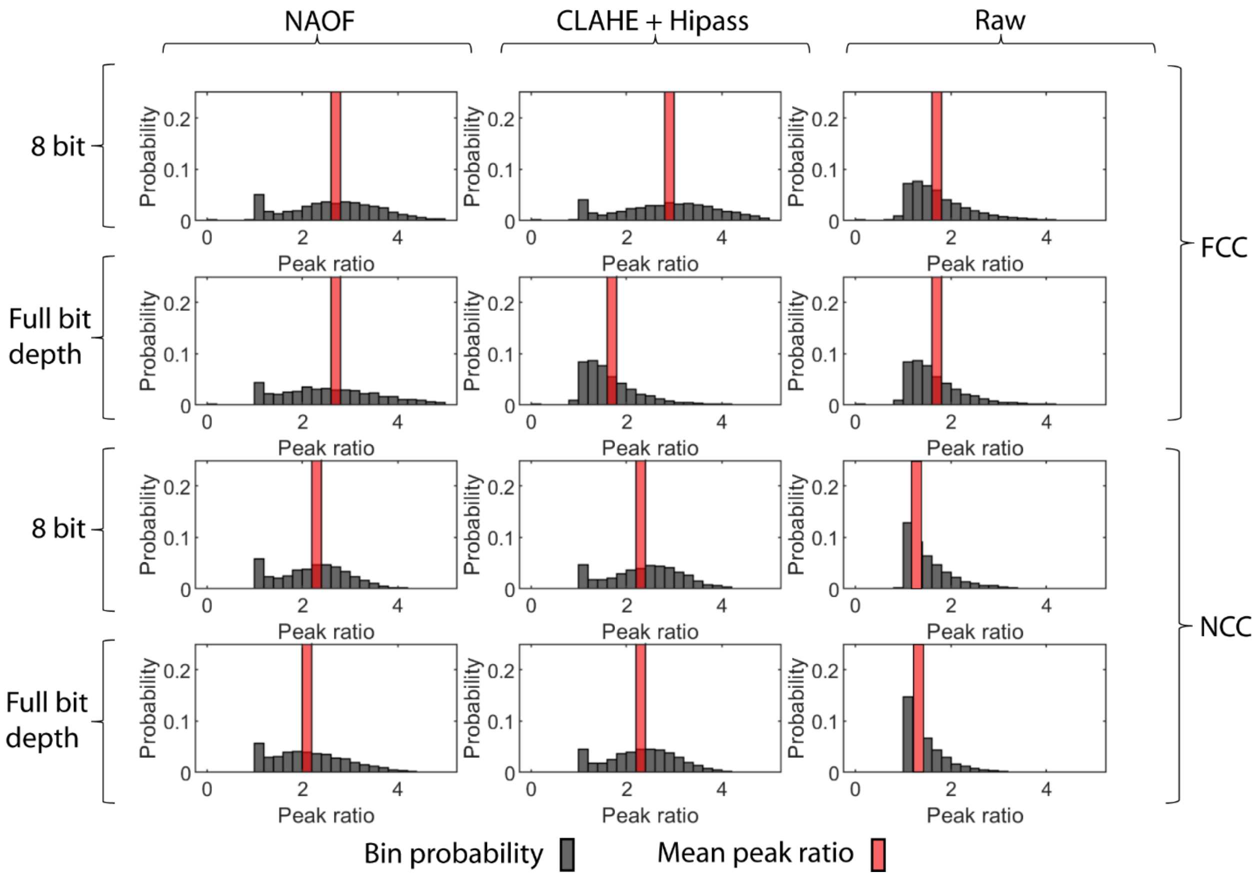

Figure S15: Histogram of peak ratio for partly clouded imagery, cropped to the glacier areal extent.

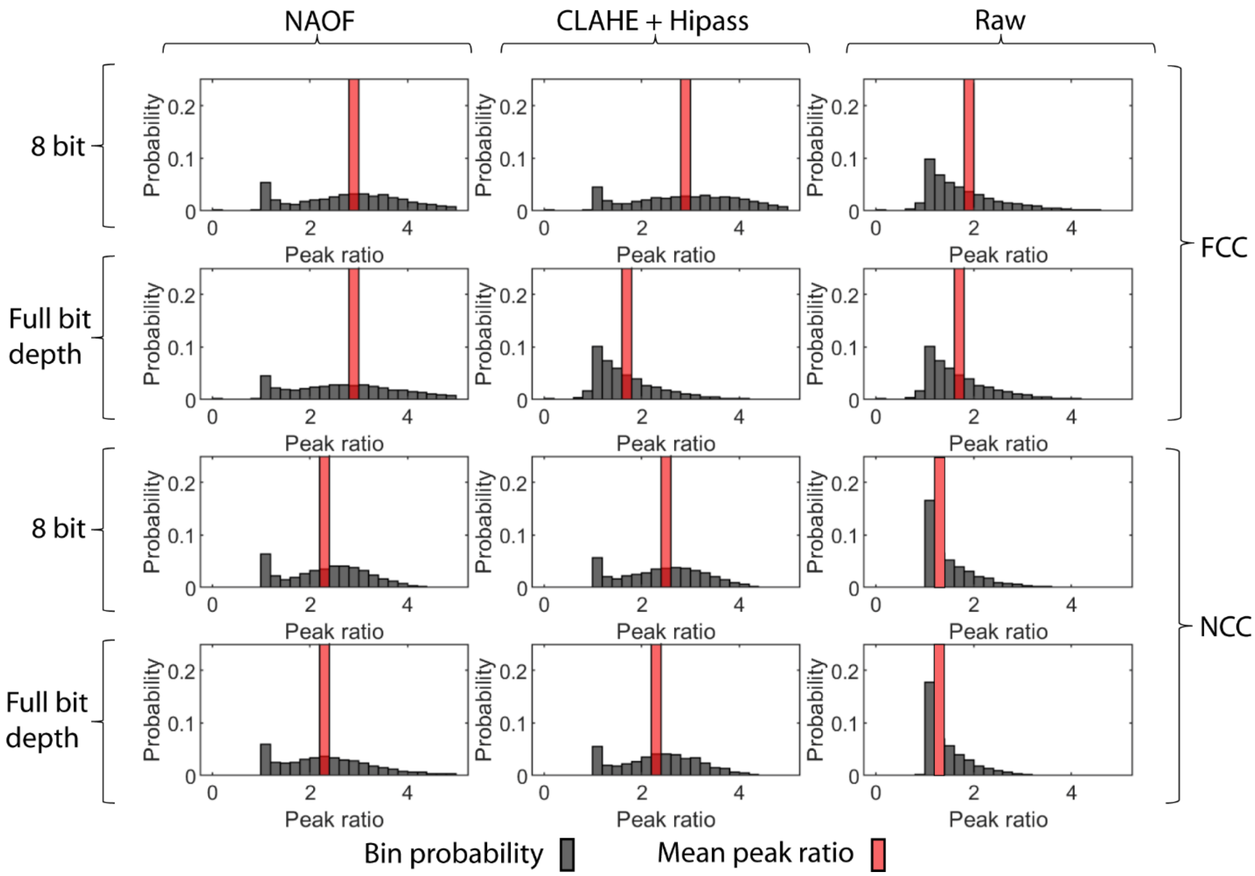

Figure S16: Histogram of peak ratio for clouded imagery, cropped to the glacier areal extent.

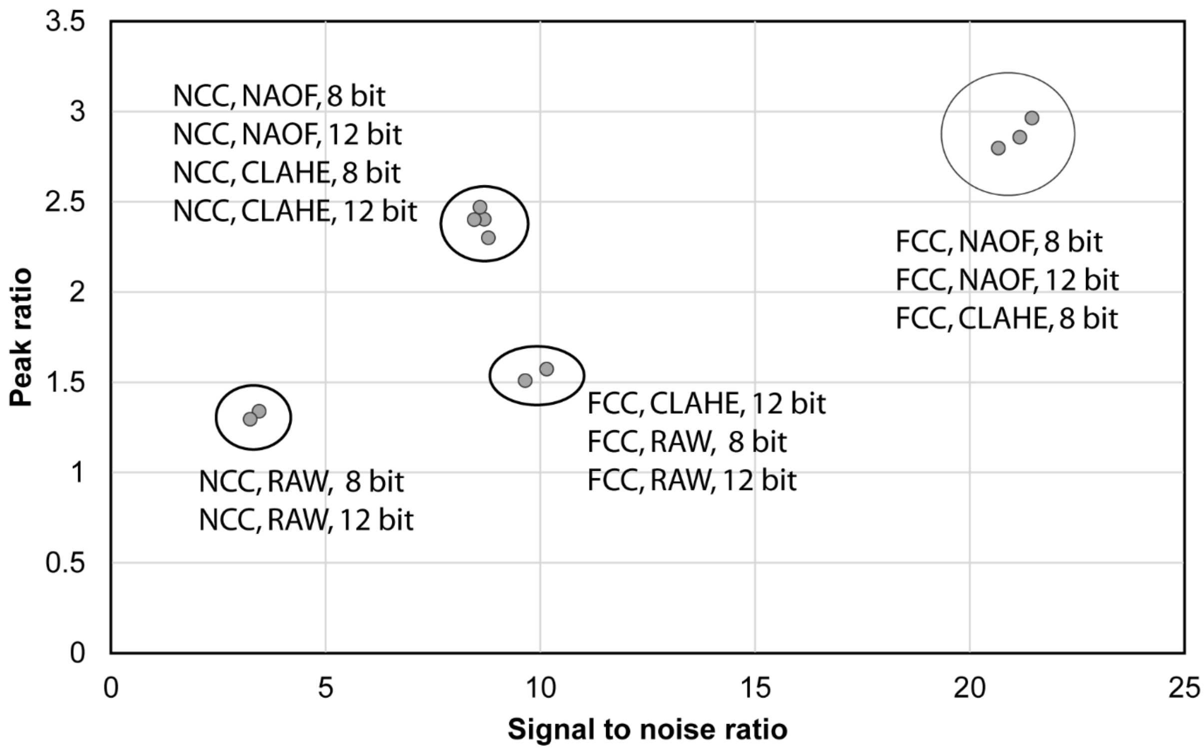

Figure 17: Effect of different parameters on peak and signal to noise ratio over the glacier for the partially clouded case. Points labeled from left to right.

FCC, NAOF and Full bit depth, FCC, NAOF and 8 bit and FCC, CLAHE and 8 bit consistently provide the highest mean signal to noise and peak ratio across the three image pairs. The multipass frequency domain solver leads to more reliable matches than the normalized cross correlation algorithm. NAOF and CLAHE+Hipass outperform raw images, with NAOF producing equal or superior results to CLAHE and Hipass. Figure 17 shows the grouping of different parameter sets for the partially clouded image pair: FCC and image filtering produce the largest increase in signal to noise ratio and peak ratio.

Limitations: This experiment does not compare feature tracking velocities to an externally determined velocity field (e.g. GPS timeseries), and as such the mis-match with ‘true’ glacier velocities cannot be determined. Visual examination of velocity fields, signal to noise ratio and peak ratio all provide a relative measure of how good the velocity fields are.

We only provide an evaluation of feature tracking parameters at one glacier, and the relative effect of different filters may differ for other glacier geometries, debris cover levels and sizes.

Experiment 2: Sentinel 2 bands

In this experiment, we evaluate the effect of different satellite image bands on feature tracking results. We evaluate feature tracking results for all 13 Sentinel bands using the cloud-free image pair presented in image 1 (20200101-20200131). The bands are:

B01: 443 nm (‘Coastal aerosol’)

B02: 490 nm (‘Blue’)

B03: 560 nm (‘Green’)

B04: 665 nm (‘Red’)

B05: 705 nm (‘Vegetation red edge’)

B06: 740 nm (‘Vegetation red edge’)

B07: 783 nm (‘Vegetation red edge’)

B08: 842 nm (‘Near infra-red’)

B8A: 865 nm (‘Vegetation red edge’)

B09: 945 nm (‘Water vapour’)

B10: 1375 nm (‘Short-wave infra-red, cirrus’)

B11: 1610 nm (‘Short-wave infra-red’)

B12: 2190 nm (‘Short-wave infra-red’)

We use two different parameter sets to evaluate the above bands: 8bit-FCC-NAOF and 8bit-FCC-raw (see experiment 1 above for details). We choose one image pair containing no clouds, one with a small number of clouds and one with many clouds to evaluate the effect of these on the above parameters.

The figures below present the results of this experiment. No post-processing of the maps was carried out. Figures S18 and S19 show the velocities, S20-S21 show the signal to noise ratio maps, S22-23 show the peak ratio maps, and S24-27 show histograms.

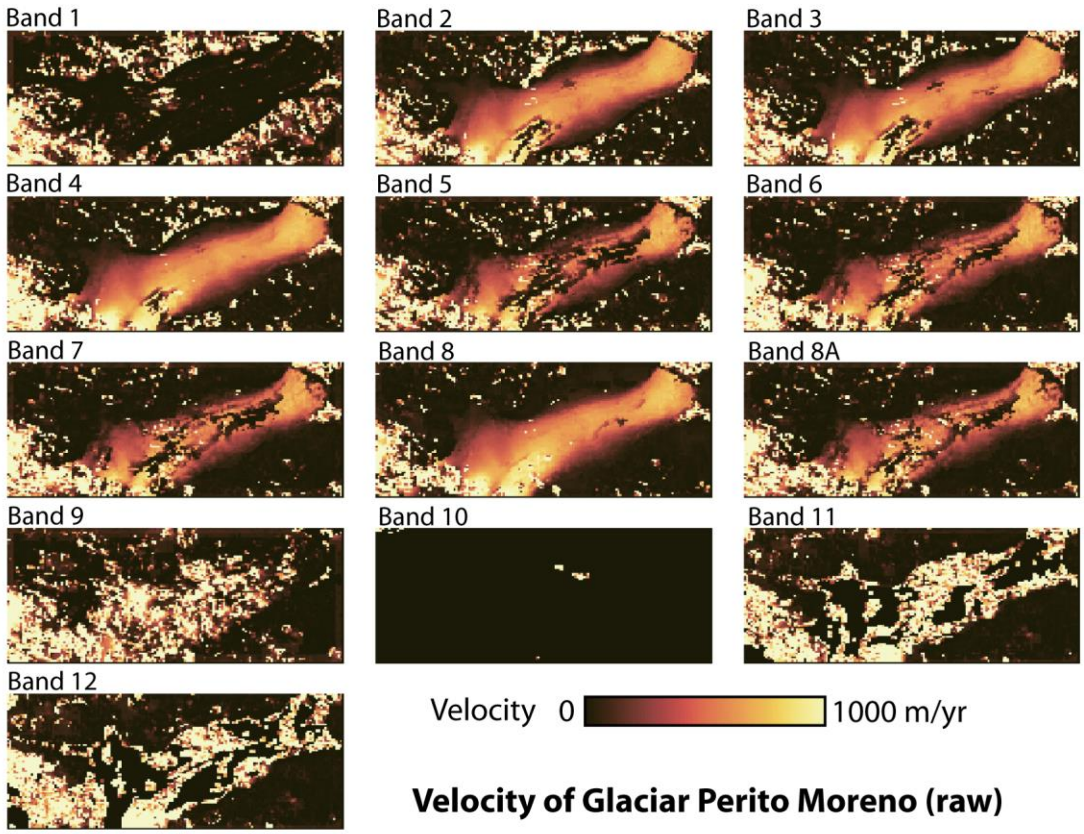

Figure S18: Velocity of non-filtered image

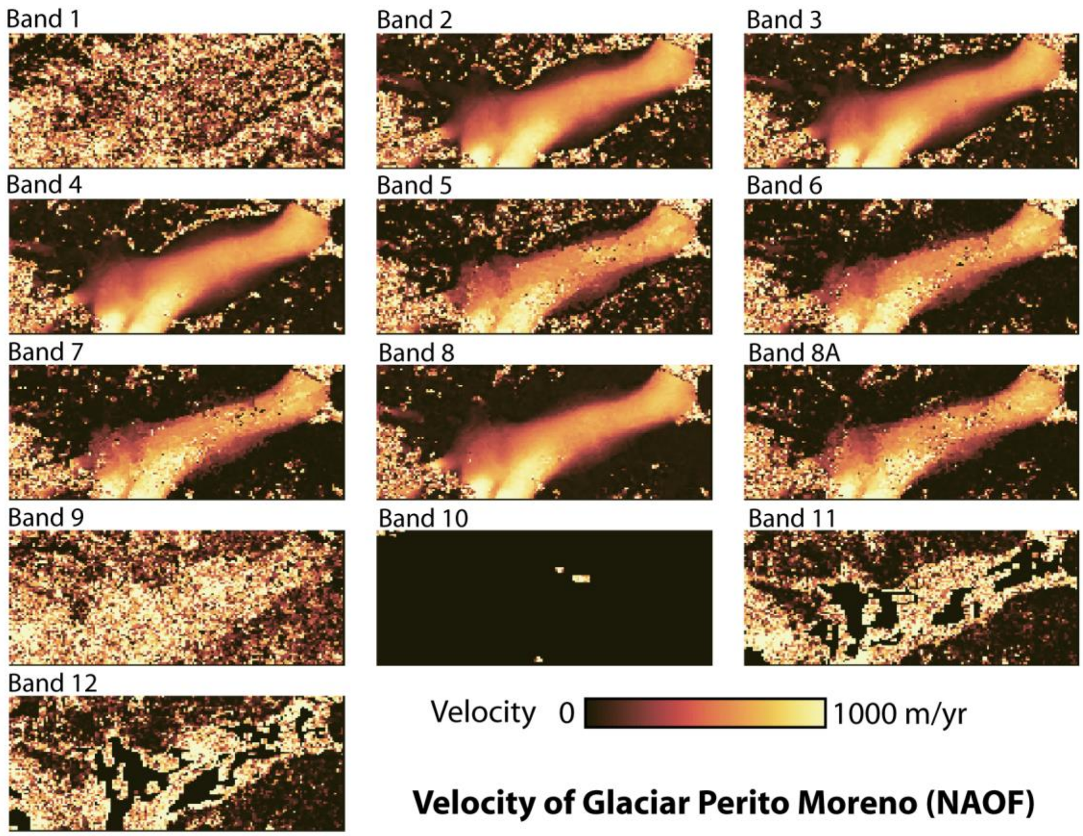

Figure S19: Velocity of NAOF filtered image.

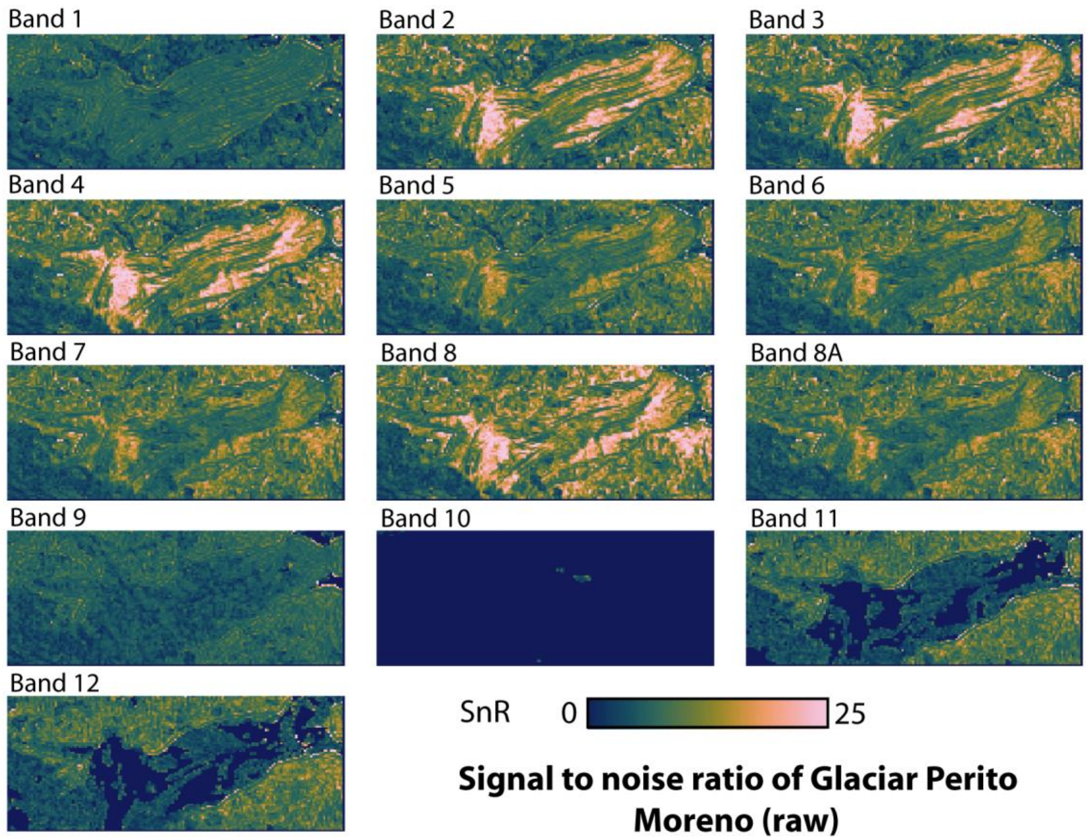

Figure S20: Signal to noise ratio of unfiltered images.

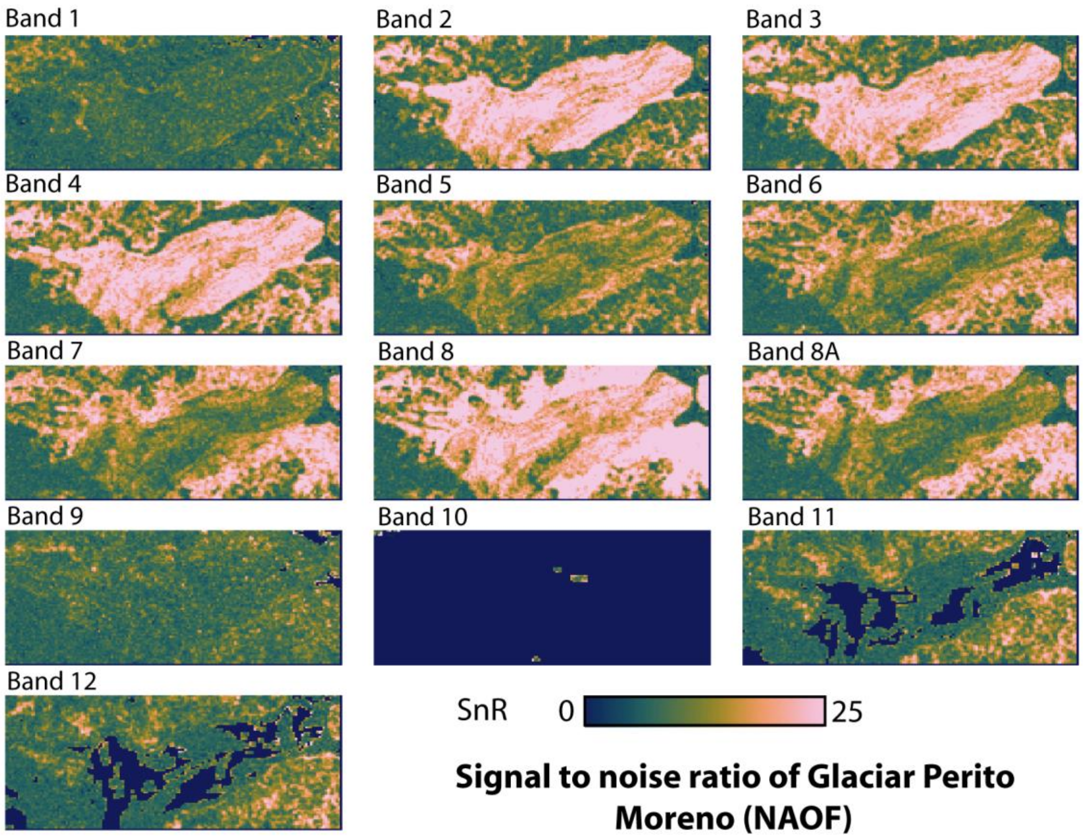

Figure S21: Signal to noise ratio of NAOF filtered imagery.

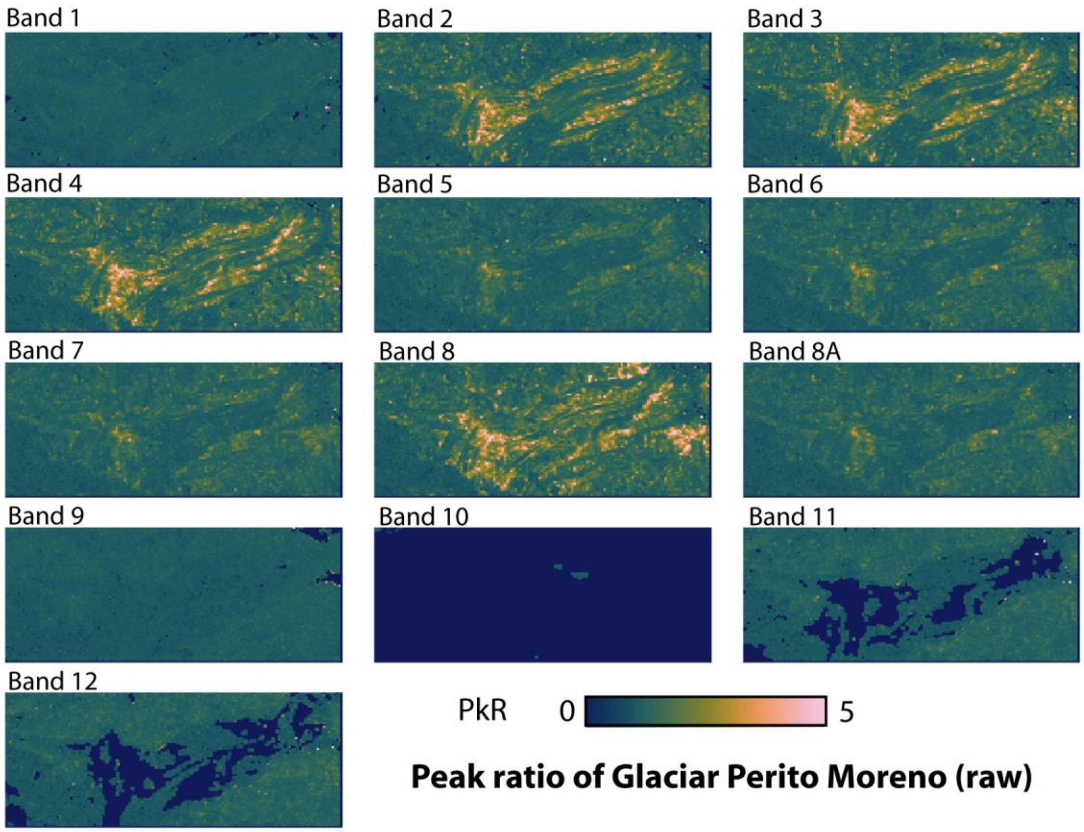

Figure S22: Peak ratio of unfiltered imagery.

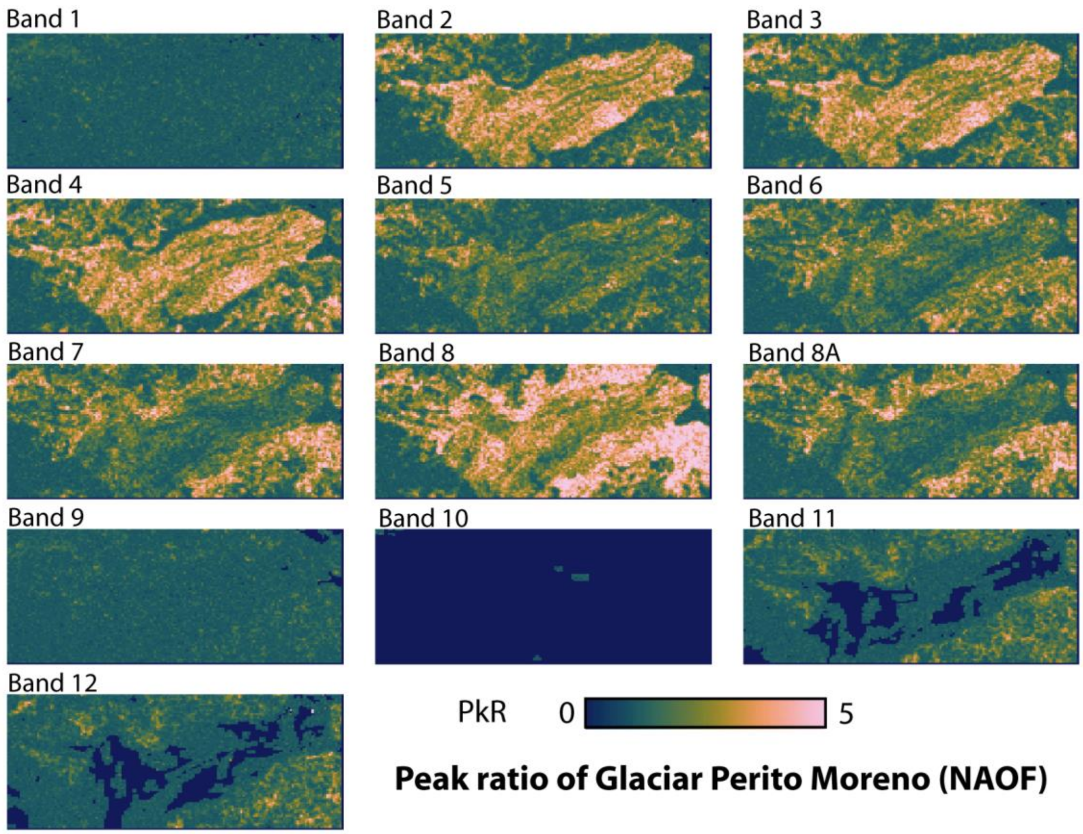

Figure S23: Peak ratio of NAOF filtered imagery.

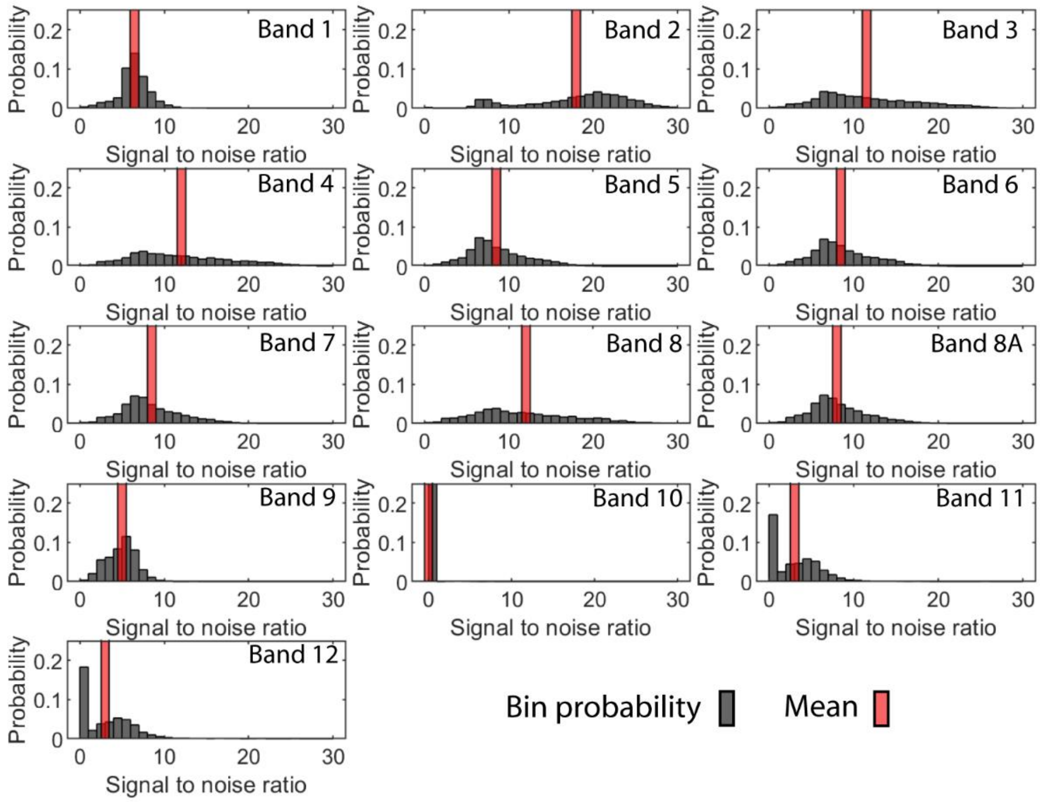

Figure S24: Histogram of signal to noise ratio for unfiltered imagery, cropped to the glacier areal extent.

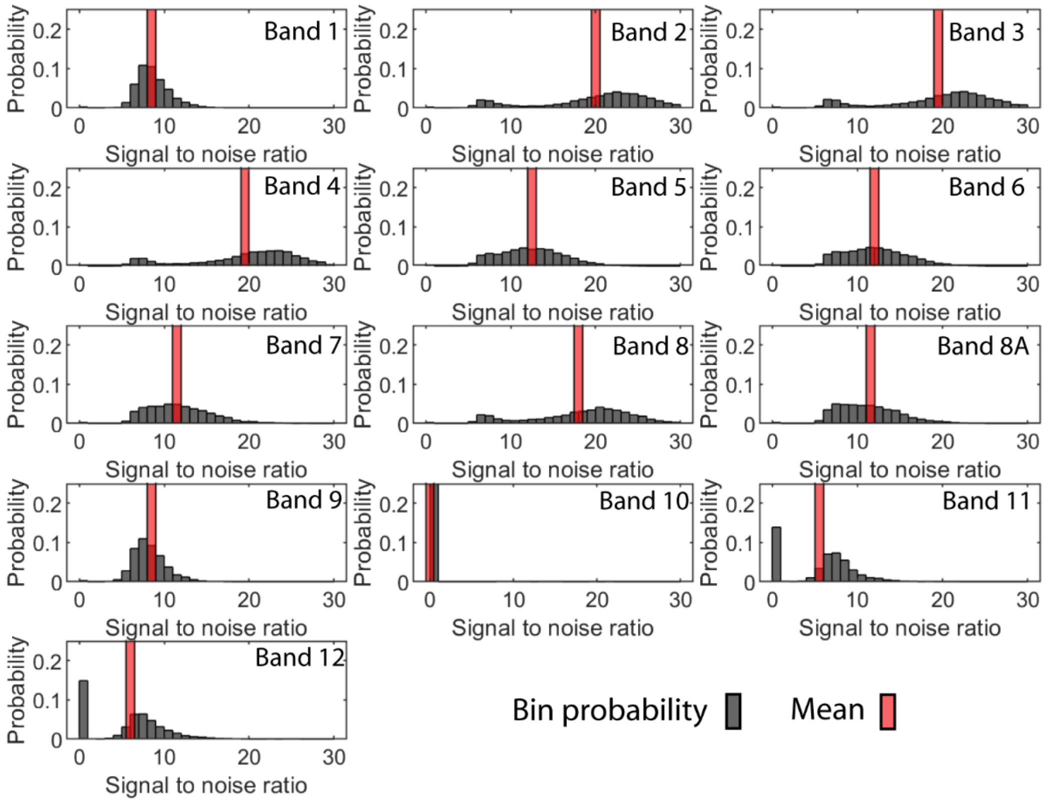

Figure S25: Histogram of signal to noise ratio for NAOF filtered imagery, cropped to the glacier areal extent.

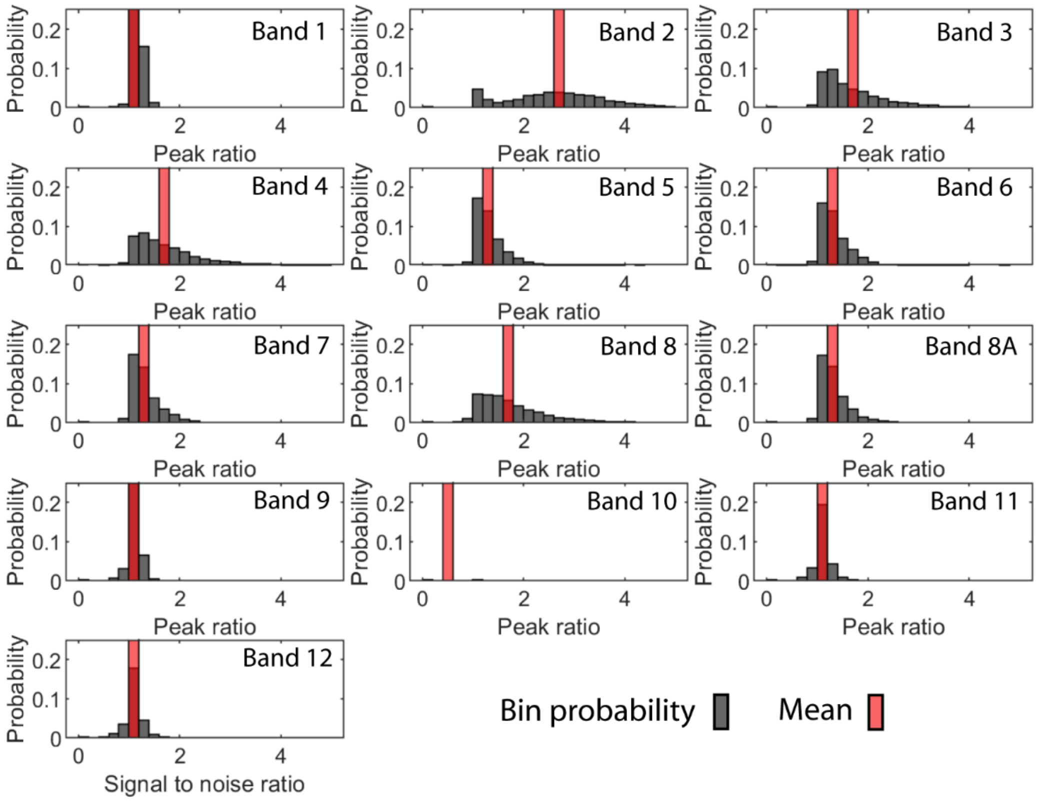

Figure S26: Histogram of peak ratio for unfiltered imagery, cropped to the glacier areal extent.

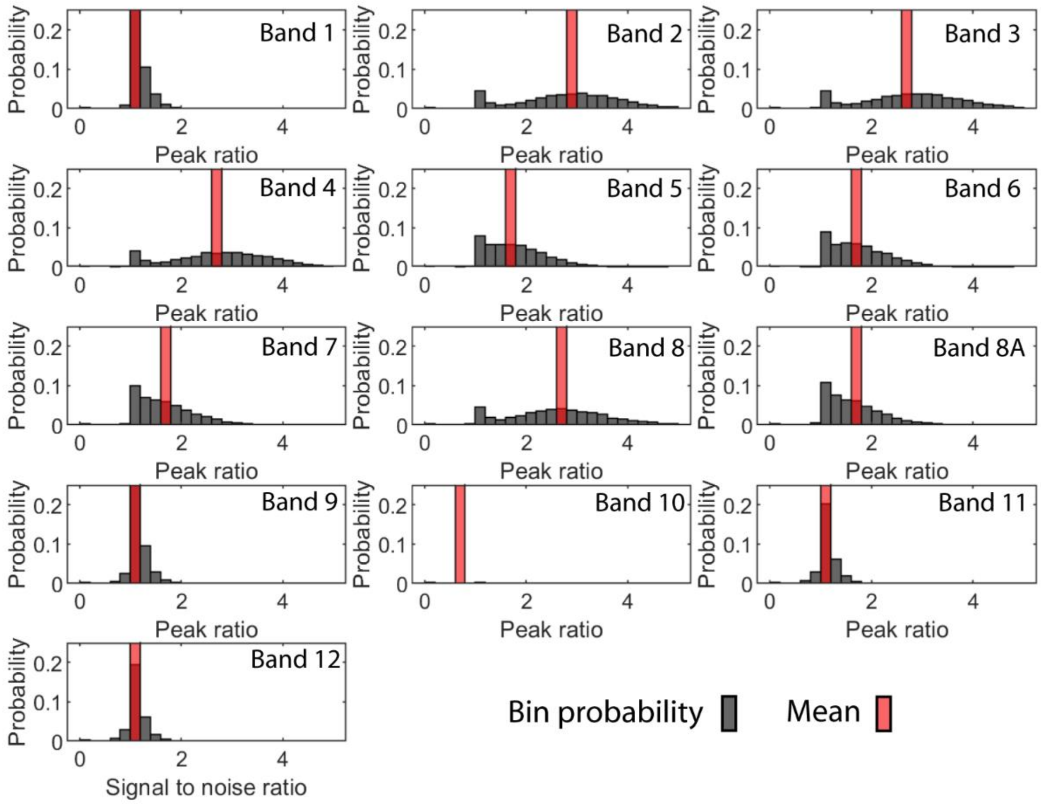

Figure S26: Histogram of peak ratio for NAOF filtered imagery, cropped to the glacier areal extent.

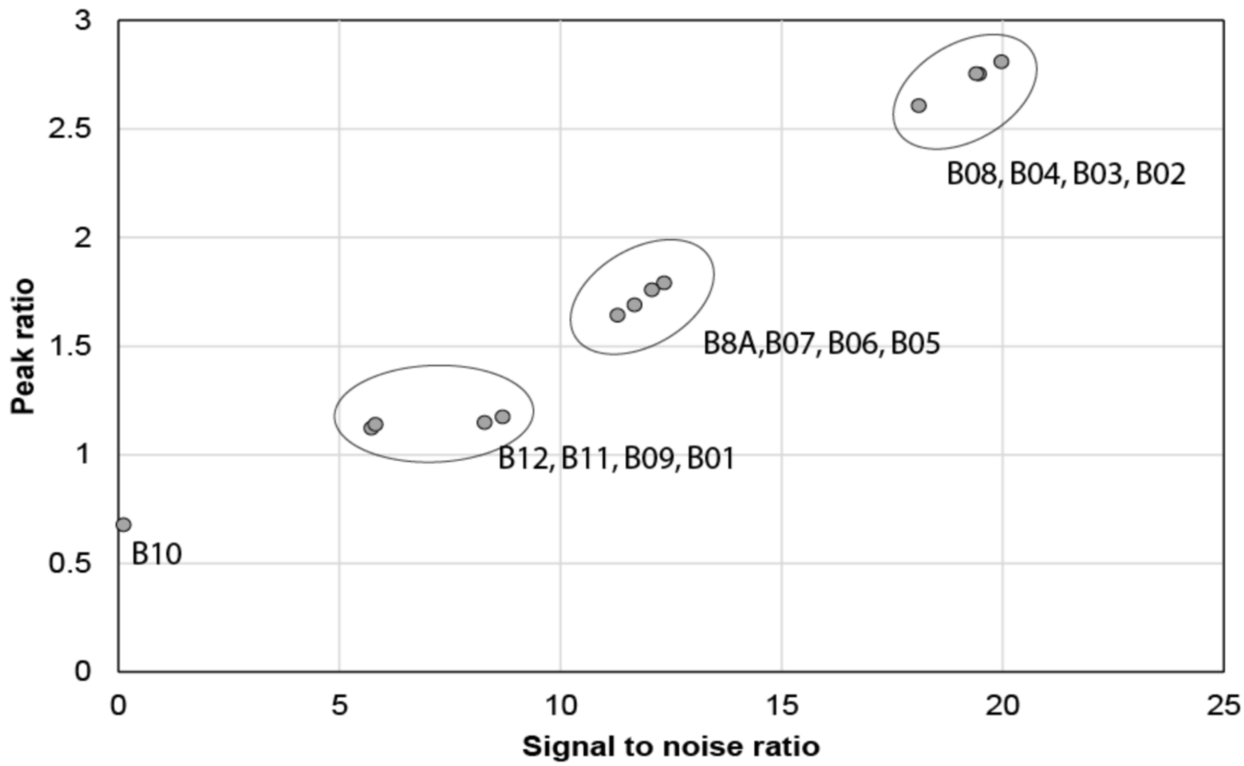

Figure 28: Effect of different Sentinel 2 bands on peak and signal to noise ratio over the glacier (NAOF filtered). Points labeled from left to right.

Band B08 consistently has the highest mean signal to noise and peak ratio across the different tests on whole scenes. Once images are cropped to an ice-mask however, B08, B02, B03 and B04 have very similar peak and signal to noise rations (Figure 28) and provide relatively noise free velocity maps. B05, B06, B07 and B8A also provide velocities, however the signal to noise ratio is lower and velocity fields are less smoothly varying. B01, B09, B11 and B12 provide occasional correct matches with a very high noise level, and B10 provides no results (too many constant cells).

Limitations: The limitations of experiment 1 also apply here. In addition, we do not consider any combinations of bands, and do not test the full range of parameter options (e.g. image filters). In particular, we note that Glaciar Perito Moreno has very minor debris cover, and that results may differ on highly debris covered glacier. Redpath et al., (2013) found that ASTER band 1 (520-600 nm) performed best on debris covered Tasman glacier in New Zealand, while band 3 (780-860 nm) performed poorly. A composite of bands 2, 3 or 4 and 8 may therefore be best for situations with mixed debris cover, or large regions encompassing both debris covered and non-debris covered glaciers.

Overall, Experiments 1 and 2 show that NAOF is usually the optimal image filter, although CLAHE and Hipass can also be used (and both always provide an improvement over raw imagery). The multipass FCC algorithm consistently produces better results than the NCC algorithm. Using full bit depth imagery may provide a small advantage over 8 bit data, however this is small compared to the improvement of image filtering.

Sentinel 2 bands 2, 3, 4, 8 or some combination of these bands is likely to produce the best feature tracking results. We note that these experiments are limited in scope, cannot be ground-truthed with GPS velocities and cannot be applied to all glaciers.

Reference:

Redpath, T. A. N., et al. "Accuracy assessment for mapping glacier flow velocity and detecting flow dynamics from ASTER satellite imagery: Tasman Glacier, New Zealand." Remote Sensing of Environment 133 (2013): 90-101.