The Cryosphere Discussions

The Cryosphere Discuss., referee comment RC1
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Comment on tc-2021-202

Anonymous Referee #1

Referee comment on "Correlation dispersion as a measure to better estimate uncertainty in remotely sensed glacier displacements" by Bas Altena et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-202-RC1, 2021

In "Correlation dispersion as a measure to better estimate uncertainty of remotely sensed glacier displacements", Altena et al. present an efficient and straightforward method for quantifying spatially-varying precision associated with displacement maps derived from pattern matching (pixel tracking) techniques. These techniques have become ubiquitous in glaciology and are the foundation for most contemporary velocity fields derived from remote sensing data. Here, Altena et al. utilize the topology of local cross-correlation surfaces to estimate the offset precision, which plugs in nicely to most existing workflows and should be robust for most datasets used in glaciology. Importantly, they show how these uncertainties can be linked to distinct classes of surface features, such as crevasses or shear patterns.

Overall, this manuscript represents an important and long overdue contribution to the field and to any researcher using remotely-sensed velocity fields. In particular, any work on data assimilation or inverse modeling absolutely needs to properly account for spatially-varying uncertainties. My comments are mostly minor/moderate and are mostly concerned with improving the presentation of the results and placing the results within the context of prior techniques and uncertainty measures.

Summary comments:

1) Most of the uncertainty metrics presented in the main text are those quantifying correlation surface orientation and degree of asymmetry. However, as a user of velocity fields reading a manuscript on uncertainty quantification, I did not actually see a map of velocity uncertainties for any of the study sites! I believe these maps should be front-and-center in the main text so the readers can immediately obtain an intuition on the spatial distribution of uncertainties and their relation to glacier flow speed. In my opinion, the other uncertainty metrics (e.g., correlation peak orientation and elongation) are interesting auxiliary results which should exist to enhance the presentation of the

uncertainties themselves, since the latter are what most people working on data assimilation will be interested in.

2) When showing the maps of uncertainties, it would also be very useful to show how uncertainties change for different window sizes. For users wanting to adopt the methods in this manuscript, a demonstration of uncertainties for common window sizes (64x64, 128x128, or adaptive window sizes) would go a long way towards bringing awareness to window size effects on both velocity field noise levels and uncertainties.

3) Pattern matching/pixel tracking has a long history in fluid mechanics (PIV, as the authors mentioned) and geosciences. For the task of deriving velocity fields over terrestrial ice, these methods have been used extensively for over 20 years, and several of the largest projects (e.g., MEaSUREs) also provide maps of velocity errors for their velocity products. While a brief discussion on previous uncertainty quantification methods was included in the introduction, there needs to be additional discussion and comparison of the uncertainties for methods that also go beyond the homoscedastic assumption. For example, the method used by Joughin, 2002, "Ice sheet velocity mapping..." computes the statistical offset variance for a local window centered on a given pixel. Thus, the scatter in the estimated correlation peak represents an aggregate of the different noise factors for the local window. My intuition is that the method used here (fitting the correlation surface) is a more robust approach, especially for smaller window sizes, but without a comparison of uncertainty maps for the different methods, it's hard to know for sure. Thus, related to comment (1), my suggestion is to include an uncertainty map (at least for Sermeq Kujalleq) and compare that map with a similar map from the Greenland Ice Sheet Mapping Project (GIMP).

4) Related to comment (3), estimation of pattern matching uncertainty by quantifying the topology of the cross-correlation surface has been around for a while. In the field of InSAR, software packages like the Repeat Orbit Interferometry Package (ROI_PAC) and InSAR Scientific Computing Environment (ISCE) estimate the curvature of the oversampled cross-correlation surface as an uncertainty proxy, similar to what's done here (see Rosen et al., 2004, "Updated repeat orbit interferometry package released" and the appendix of Casu et al., 2011, "Deformation Time-Series Generation..."). At a minimum, these should be cited in the manuscript.

Line-by-line Comments:

- Line 61: A comparison of most of these methods has been done in the field of PIV, and at least one citation should be included (e.g., see Xue et al., 2014, "Particle image velocimetry correlation signal-to-noise ratio metrics...").

- Section 3.1: Is any oversampling of the cross-correlation surface performed prior to fitting a 2D Gaussian? Oversampling is a common step in pattern matching and can mitigate the effects of "pixel locking" (see autoRIFT paper, Lei et al., 2021, Remote

Sensing; a Gaussian pyramid upsampling scheme is used to reduce pixel locking). Additionally, it would likely provide more data points for the 2D Gaussian fit. Without oversampling, wouldn't there be situations where the cross-correlation surface is highly concentrated at a single location (i.e., a high SNR case), in which case the 2D Gaussian fit would be poorly conditioned.

Also, what is a typical zoom window size (centered around the peak) for fitting the Gaussian? I assume the entire cross-correlation surface is not used for the fit. If the zoom window size encompasses multiple peaks (primary + secondary peaks), how is that situation handled in the processing chain?

- Line 119: I think care should be taken when referring to general covariance matrices. In general, off-diagonal elements describe dependences between variables. The temporal/spatial relational dependencies mentioned on this line are for a completely different set of variables.

- Figure 2: This figure could likely go into Appendix B since, by itself, it doesn't add too much to the discussion.

- Line 152: It's a bit incomplete to say that co-registration is not applied to the image pair beforehand. Nominally, users will use the image metadata to approximately co-register the images in order to reduce the need for large search windows. Are the authors referring to refinement of image registration over stable ground? If so, that should be stated more clearly.

- Line 163-164: What does "extensive flow" mean? Extensive extensional strain?

- Figure 3/4: I suggest moving the Radon crevasse orientation in Figure 3 to Figure 4 to better compare with the correlation peak orientation.

- Figure 8 caption: Please also include that these results are for Sermeq Kujallec.

- Line 212: Doesn't strong shear flow generally result in crevasse formation? It seems a little odd to categorize these features into two distinct classes.

- Line 221-222: If I'm not mistaken, pixel/peak locking is a consequence of estimating the center of mass of a few discrete pixels. Methods that fit the correlation surface with a model (as is done here) should thus avoid those issues, right? Can't peak locking also be

mitigated by oversampling of the cross-correlation surface? (see my comment above about oversampling of the cross-correlation surface).

- Line 224: Please add a few words on what least squares matching is. What do "intensities" refer to here?

- Line 232: describtor -> descriptor

- Line 234-238: These sentences are a bit confusing to me. I don't quite understand how the sub-pixel displacements influence the correlation score. Is it because a correlation peak's energy becomes evenly distributed across multiple pixels in the cross-correlation surface? If so, this seems similar to the pixel locking effect and could perhaps be mitigated by oversampling of the cross-correlation surface (see my earlier comment).

- Line 239: precisioin -> precision

- Line 247 and Figure 11: Actually, to my eye, it seems like the signal-to-noise ratio and major axis have a reasonable correlation, e.g. high SNR is inversely proportional to major axis. This would make sense as this means the cross-correlation peak is more concentrated and compact relative to the noise floor. Again, a map of total uncertainty (or even just major axis) would be illuminating when compared to the maps of SNR and correlation coefficient.

- Line 257: How do frequency domain methods prescribe displacement at integer resolutions? It's well known that a real-valued shift between two signals in the time/spatial domain will lead to a ramp in the frequency domain. This ramp can be estimated to achieve sub-pixel resolution (Leprince et al., 2007).

- Line 275: It would probably be useful to specify "physical signal" if one is referring to improvement of data assimilation/inverse methods.