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Geoscientific Model Development Discussions

Interactive comment on "A stabilized finite element method for calculating balance velocities in ice sheets" *by* D. Brinkerhoff and J. Johnson

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1 A note to the editor

In response to the anonymous reviewer's significant criticism regarding a lack of scientific application, we have added a new section to the manuscript containing a non-trivial application. We understand that this may prompt an additional round of review. However, the technique presented is in fact a straight-forward application of our new method for determining balance velocity, combined with well documented, previously reviewed methods for numerical optimization (*Brinkerhoff and Johnson* (2013) and *Morlighem et al.* (2011)). We do apologize that this type of example requires significant explanation and mathematical preliminaries which have made the document longer. In ad-

dition, the example we provide directly addresses many of the anonymous reviewers other (very helpful) major criticisms. As such, we hope that it will be viewed as a substantial, yet highly beneficial addition.

2 Response to James Fastook

We thank Dr. Fastook for his comments.

2.1 Major Points

Dr. Fastook suggested that we make our results available in netcdf format. Since we use a non-structured grid, it is somewhat difficult to share results as a publicly available 'data set,' so to speak. Rather, we have made available a fully commented script that performs the computations outlined in the new section on data assimilation. The script is housed in the same code repository as the ice sheet model VarGlaS. We hope that having access to this script will allow researchers to incorporate the method into their own codes, or to run the algorithm using their own meshes. VarGlaS does include methods for interpolating unstructured meshes onto regular grids, and exporting them as text or Matlab files.

2.2 Minor Points

Dr. Fastook suggested that we include a higher resolution format for Figure 2. We have significantly increased the resolution of the figure. We have also included another section on using balance velocities as a smoothing algorithm, and this section contains a more detailed view of several major outlets.

The typo has been corrected.

3 Response to anonymous reviewer

We also thank the anonymous reviewer for their comments, paricularly their enforcement of mathematical rigor. We also feel that we owe the reviewer an apology; a version of this manuscript had already been redrafted with many of the reviewer comments in mind, particularly the typos. We erroneously failed to submit this reviewed manuscript, instead submitting the draft which had been initially submitted to Geophysical Research Letters. The reviewer's comments during that review process were much appreciated then, as now, and we did not intend to disregard them.

3.1 Major Points

The reviewer correctly notes that this paper does not attempt to address new scientific findings (e.g. why does the balance velocity calculation produce a less robust northeast ice stream than InSAR products?). This was deliberate, as we intended this to be a methods paper. Given that context, we do not believe a glaciologically informed discussion of results was needed. The addition of an application of the new method provides a robust means of smoothing InSAR products for model inversion, a claim we had made that was challenged by the reviewer. We hope the application demonstrates that the interpolation is possible, and that glaciologically meaningful discussions arise from comparing the results of our application to other data sets.

The application works by systematically exploring the uncertainty in the data inputs to the balance velocity calculation, and varying them such that velocity misfit is minimized relative to InSAR velocity data. This is similar to the approach of *Morlighem et al.* (2011), except that we are interested in balance velocities rather than balance thickness. We believe that this addition also addresses another of the reviwer's major points, which is that the balance velocities that we show in the manuscript are not 'significantly higher quality.' This new section demonstrates that by correctly incorporating

error in input parameters, we can recover velocity fields similar to those derived from InSAR, but without gaps and other discontinuities.

3.2 Minor Points

We are aware of the newer thickness data products that are informed by more observations. However, for our initial illustration of the balance velocity computation method, this choice is somewhat irrelevant. What's more, neither of those datasets were publicly available during preparation of this MS. We do, in the application, use the DEM from *Bamber et al.* (2013). Using thicknesses from *Morlighem et al.* (2014) would not be viable in this context due to the circularity of using a mass conservation derived bed as input to find a mass conservation derived velocity. There would also be issues arising from not having the altered mass balance and velocity fields produced by Morlighem's methods, but not distributed with the data set.

Page 5185, Line 8: Although a naive application of balance velocity with influx or outflux defined by another velocity dataset would indeed be overspecified, this statement can be mathematically correct in certain contexts, namely in the context of varying input datasets to find a globally consistent solution. Regardless, it is somewhat imprecise, and as such we have removed the statement. Rather than simply stating the possibility of filling gaps, our new application section shows how this can be done.

Page 5185: We concur, and have changed the notation in the paper.

Page 5186: We cited the wrong paper here, should have been *Morlighem et al.* (2011).

Page 5186: We have included a line that specifies that $\|\cdot\|_2$ implies the $\mathcal{L}^2$ norm, but the meaning of the latter should be clear from context.

Page 5187, Line 21: We meant to say that the operators are self-adjoint. We have changed the text to reflect this.

Page 5187, Eq 10: We agree, and have included a specification of the boundary condition along with the strong form.

Page 5187, Eq 11: We noted in the strong form the boundary conditions. We have specified appropriate solution spaces to take this into account.

Page 5192: Fixed reference formatting. $\mathcal{L}^2$ norm is defined. We choose to illustrate independence under refinement and regularization relative to a grid size where all grid sizes produce the same result regardless of regularization. This is noted in the text.

References

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Interactive comment on Geosci. Model Dev. Discuss., 7, 5183, 2014.