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Discussions

Interactive comment on "Glacier thickness estimations of alpine glaciers using data and modeling constraints" *by* Lisbeth Langhammer et al.

Ben Pelto (Referee)

pelto@unbc.ca

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Langhammer and colleagues present a new algorithm to optimally combine modeled ice thickness and measured ice thickness using an inversion procedure to obtain distributed ice thickness. They also introduce a method to cost-optimize helicopter-borne GPR survey design. I found this manuscript well thought out, well detailed, and relevant. There are a few points that require greater explanation or justification critical to the results of this study. Both deliverables of this project, the GlaTE algorithm for combining model results and GPR measurements, and the sequential optimized experimental design for determining cost-optimized GPR survey transects contribute scientifically to

methods pertaining to glacier ice thickness. The manuscript does not mention whether the GlaTE algorithm will be made publicly available, yet both sections of this manuscript primarily offer value as tools for planning future studies of ice thickness and optimizing data collected in such studies. I would recommend the paper to be considered for publication after consideration of the following points and a list of suggestions for minor corrections and clarifications:

Will GlaTE be made publicly available? This manuscript is presented as a methods paper introducing two frameworks, one (GlaTE algorithm) for creating distributed ice thickness from GPR measurements and model results, and one (SOED techniques) for cost-optimizing GPR surveys. For this study to be of greatest value it is critical these methods are made available so that others may use them.

E_GPR was estimated to be 5 m. I can find no justification for this value. Five meters may be a reasonable value for E_GPR, but this value assumes great importance in the system of equations L203-228, and is used to draw conclusions: e.g. L316, L392-394. While the point of lines L392-394 would likely remain unchanged, the percentages listed in L392-394 would undoubtably be higher were E_GPR higher. A low value (5 m) may tend to overfit the available GPR data despite the attempt to avoid doing so via the system of equations. Literature examples of estimated uncertainty in GPR measurements (one method to determine E_GPR):

From Gartner-Roer et al 2014: "A direct comparison of radar measurements with hot water drillings and borehole electrodes indicated that thicknesses derived from radar measurements are usually within ± 5% of the measured ice thickness (Haeberli and Fisch, 1984). Fischer (2009) estimated the uncertainty of thicknesses for the Austrian glaciers as 5–10% of the measured value. Zamora et al. (2009) applied airborne GPR on Tyndall glacier (Patagonia, Argentina) and observed a maximum ice thickness of 670 m, with an accuracy of ± 50 m when comparing the results to existing thickness information."

From Sanders et al. 2010: "Comparison with the depths of six boreholes drilled through the glacier (using a hot-water system) showed that the thickness map obtained by radar was generally accurate to better than 10 percent of the ice depth (7 +/- 4 m). Near the steeply-sloping marginal walls, however, where the ice is thin and the topography complex, errors increased to 13 +/- 2 m (27 +/- 8%). The survey revealed an average glacier depth of about 70 m, and maximum depth of about 185 m."

From Marcer et al. 2017: "The error of the interpretation of GPR profiles was evaluated through quantification of the residuals in ice thickness at all intersecting profiles, that is, by crossover analysis. The total number of intersections is 16, and the standard deviation of the differences is 1.9 m."

Specific comments:

L39 Change recourses to resources.

L52 RES acronym not necessary as there is currently no usage throughout the document.

L58 'Un-aliased' was previously written as 'unaliased'.

L95 Awkward phrasing.

L105 Is this regular grid (R) a 10 m grid with the same posting as the resampled DEM described in L264?

L122-131 Were the mass balance/height change estimates (\dot{b} and dh/dt) computed via eqn. 3 and the method of Farinotti et al. (2009) in broad agreement with regional height/mass change gradients as measured by other studies? This region contains a wealth of geodetic and glaciological mass balance observations with which to verify.

L244 Please list glacier area for this site, and at least for the Hohbärggletscher (L250). Perhaps it would be useful to have a small table with glacier attributes, name, size,

range etc.

L245 Should this: '...with slope angles less than 4ËŽ' be rephrased to average slope angle? It is likely that some of the surface slope of the glacier exceeds 4ËŽ, particularly on the 'short glacier tongue'.

L254-257 It is stated that the GPR data are a composite of several campaigns. For a given site were these campaigns all within the same year? If over multiple years for a given site, was height change due to mass change accounted for in any way? This may be a small impact on ice thickness, but not given a 5 m ÆŘGPR threshold.

L328, 353,358 Perhaps it would be valuable to have a table containing ice thickness information for each glacier e.g. maximum + mean measured thickness, number of point obs., km of transects, etc.

L454 Excellent figure.

L603-608 These lines accurately depict that cross profiles are of value. Some studies use them to assess GPR profile interpretation error (e.g. Marcer et al. 2017). Would it not be of value to be able to designate a minimum amount of cross profiles in the cost-optimization scheme? As the authors point out, in areas with poor signal to noise ratio, having cross profiles are very valuable. As cross profiles are always built into GPR survey designs, a cost-optimization which may not include them is of lesser value. One could simply add a few cross profiles to the SOED output, but if the SOED were allowed to incorporate these transects, perhaps the SOED technique would change the designed survey.

L629 Will these GPR data be added to the Glacier Thickness database, GlaThiDa (Gärtner-Roer et al., 2014)?

Gärtner-Roer, I., Naegeli, K., Huss, M., Knecht, T., Machguth, H. and Zemp, M.: A database of worldwide glacier thickness observations, Glob. Planet. Change, 122, 330–344, doi:10.1016/j.gloplacha.2014.09.003, 2014.

Marcer, M., Stentoft, P. A., Bjerre, E., Cimoli, E., Bjørk, A., Stenseng, L. and Machguth, H.: Three decades of volume change of a small Greenlandic glacier using ground penetrating radar, Structure from Motion, and aerial photogrammetry, Arct. Antarct. Alp. Res., 49(3), 411–425, 2017.

Sanders, J., Cuffey, K., MacGregor, K., Kavanaugh, J. and Dow, C.: Dynamics of an alpine cirque glacier, Am. J. Sci., 310(8), 753–773, 2010.

Zamora, R., Ulloa, D., Garcia, G., Mella, R., Uribe, J., Wendt, J., Rivera, A., Gacitúa, G. and Casassa, G.: Airborne radar sounder for temperate ice: initial results from Patagonia, J. Glaciol., 55(191), 507–512, doi:10.3189/002214309788816641, 2009.

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