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The Cryosphere Discussions

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

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Synopsis

In "Glacier thickness estimations of alpine glaciers using data and modeling contraints", Langhammer and colleagues present a new mathematical formulation of a long-standing problem. They formulate the problem of physics-based interpolation to finding ice thickness values between radar flight lines as a system of linear equations, and perform an exploration of the hyper-parameters that can be adjusted to yield different results. This system of equations includes components representing the contribution of observations, physical constraints based on the shallow-ice approximation, geometric constraints on glacier extent, and regularization of spatial gradients. The authors apply their method to the problem of determining an ideal distribution of expensive ice thickness observations, yielding guidance on how to construct GPR campaigns.

Comments

Thickness Estimation Method

While the explicit formulation of the problem as a sparse system of equations is new, each component of the model is not. Looking as far back as Morlighem, 2011, the problem is specified as a minimization problem in which there exists a data misfit function over flightlines, a physical misfit function over the entire glacier domain, and a spatial regularization to impose smoothness. The difference here is the substitution of the shallow ice approximation for mass-conservation, which alleviates the need for velocity and surface mass balance observations. We note that this physical model was already developed for use in physics-based interpolation by Farinotti and Huss (2009), including an application in which corrections based on GPR were performed (Huss and Farinotti, 2014). There is nothing inherently problematic in replication of previous methods: however, it would be useful to have a specific discussion of how GlaTE is different from methods to solve this problem that have gone before.

The exploration of the weights on specific model components lacks sufficient rigor. Why are the various values of λ set the way that they are? It makes little sense to explore these parameters heuristically, since they have a clear probabilistic meaning ($\lambda = \frac{1}{\sigma}$, which is to say that the equations should be weighted in inverse proportion to measurement/model uncertainty). Such a probabilistic formulation of the problem was explored in Brinkerhoff et al. (2015). I would like to see more of an effort to place the various λ in a real-world context so that they can be specified objectively.

Despite the criticism of the last paragraph, I think that the explicit nature by which the strengths of the various model objectives are imposed produces a consistent and efficient platform for exploring modelling choices. The linear nature of the system of equations means that a large number of realizations of ice thickness could be generated for different parameter choices, which the authors acknowledge in Section 4 is both an advantage and a drawback. Given the model's efficiency, why not take the next step in determining hyper-parameter values and run cross-validation on held-back radar flightlines? This is almost what is done in the Experimental Design section, but not quite. This procedure would capitalize on the model's strengths, and would also yield a sort of guidebook on how the algorithm might be used without having to make a lot of choices about λ that might be only marginally defensible.

Finally, I'm confused about the computation of α. This method seeks to find alpha that yields a mean misfit which is as close to zero as possible. However, this admits very large pointwise deviations between modelled and observed thickness. Perhaps a better metric might be sum squared error between modeled and measured thickness. Better yet, instead of optimizing on α, why not minimize with respect to , A, and/or n directly? Uncertainty in these values is the reason behind introducing α, yet their combined influence is only poorly captured by a linear approximation.

Experimental Design Procedure

The methods presented in this section are both novel and make good sense, and yield interesting insights into the degree of coverage necessary to yield a good model of the glacier bed. The idea of sequentially finding the profile that would yield the greatest change from an unconstrained inversion method is very general and could be applied to all types of physical models.

One thing that would help to understand what lessons might be learned from this analysis is a more in depth discussion of the nature of the automatically selected profiles. Why, for example, in the synthetic case is there a dominant flightline orientation that differs between glaciers? I would suspect it has something to do with the relative information content of cross- versus along-slope profiles, but it's hard to say. The authors are in a good position to explore this question more fully, and answering the question of which orientation is better for constraining glacier thickness would be an important advance.

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