Geosci. Model Dev. Discuss.,
doi:10.5194/gmd-2016-9-RC2, 2016

Geoscientific Model Development Discussions
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Interactive comment on "ICESHEET 1.0: A program to produce paleo-ice sheet models with minimal assumptions" *by* E. J. Gowan et al.

Anonymous Referee #2

Received and published: 19 February 2016

This paper describes an ice-sheet reconstruction technique, that estimates ice surface elevations given the 2-D margins of the ice sheet. It is based on two assumptions: steady state, and perfect plasticity, i.e., the basal shear stress is a given yield value. Both the bedrock topography and the basal yield stress (which can be uniform or spatially varying) need to be specified, but if they are not known, one or both can be adjusted iteratively to fit surface elevations (or ice sheet thicknesses) that may be known to some extent by independent means.

The reconstruction uses the method of characteristics, making direct use of two earlier studies: Reeh (1982) and Fisher et al. (1985). The authors have coded the method into a usable general-purpose program, which includes the capability to automatically correct for topographic barriers and contour crossovers. Although I have some reservations as described below, I think the study will be suitable for GMD, and the program

may be an interesting and worthwhile tool for some glaciological situations.

General comments:

Several significant aspects are not well explained, leaving some questions hanging, as described in points 1-3. Much of this can probably be corrected by clarification and additional text to provide more information and context.

1. The overall purpose and outcomes of the study and the program are not clearly defined. Given a map of ice-sheet margins, basically there are 3 unknowns: surface elevation, basal shear (yield) stress, and bedrock elevations (all 2-D maps). Eqs. 5 to 9 and the method of characteristics relate the latter two fields to the first. But if only one of the 3 is known or is available from some external means, the other 2 cannot both be determined uniquely. 2 of them have to be known to determine the 3rd. In the examples given, Greenland's bed topography and surface elevations are known from independent data, and the method determines (iteratively) the basal shear stress map. For the Barents, bed topography is given from a modern dataset (which neglects depression under paleo grounded ice), and basal stress is "adjusted" to yield GIA-estimated paleo ice thicknesses or equivalently surface elevations.

These applications confuse what many readers may assume up front is the main goal, which is to reconstruct paleo-ice sheet elevations (or thicknesses) given the margins. It would help to put all this in perspective, and to clarify the main outputs and purpose of the program.

The basic problem of constraining both basal topography and basal stresses crops up in many related papers, mostly using process-based physical ice sheet models (e.g., van Pelt et al., The Cryo., 2013 and references therein). Some perspective discussing the connection to these types of studies could be given.

2. Perhaps related to point # 1: if basal topography and/or basal stresses are unknown, and have to be iteratively adjusted so that the simulated surface elevations match those

from another data source, then what is learned from the exercise? In other words, if the surface elevations (or thicknesses) need to be known a priori, then why re-simulate them? There may be good reasons: perhaps to produce a higher-resolution surface elevation map, or to produce an iterated map of basal stresses which provides insights into bedrock geology or basal liquid/thermal regimes. But these issues are not clearly addressed and should be discussed clearly.

3. The basic sequence of using the method of characteristics to step elevation contours incrementally upwards from one contour to the next is clearly explained here, as it is in the previous papers. However, the procedures used to handle topographic barriers (nunataks), and crossovers in the contours, are very opaque. Fig. 1 does not explain them well. For instance, in Fig. 1 and its caption: - it would help to say that a topographic barrier is the result of E becoming < B (where E is ice surface elevation along a flowline and B is bedrock elevation). - What are the triangles and the orange lines in Fig. 1? - What is "resampling"? This should be described in more detail.

I suggest splitting Fig. 1 into two or even three separate figures: one for the basic stepping algorithm with no complications, one for a nunatak, and one for a crossover. This could greatly improve its potential to be understood.

Along with Fig. 1, the text describing some of the procedural steps in section 2.2 could be expanded and clarified, especially steps 6 and 7. Also, the connections between steps 1 to 14 in the text and the parts of the figure(s) could be specified more thoroughly.

4. The authors are probably well aware of the limitations of the basic assumptions of steady state and perfect plasticity, and that there are some ice sheet regions and intervals where they may be seriously in error (e.g., Laurentide during deglaciation, West Antarctic ice streams). These should be mentioned as caveats.

5. I think the term "ice-sheet models" in the title and text is misleading. To many readers, this implies process-based time-stepping ice sheet models based on conservation

equations of mass, momentum and heat. Instead I would suggest "reconstructions", as used for instance in Fisher et al.'s title ("...objective reconstructions").

Specific comments:

a. Text could be added to note how this study goes beyond Reeh (1982) and Fisher et al (1985), besides providing a program. For instance, bed topography can be iteratively adjusted here (pg. 4, line 110), rather than modifying the equations to represent isostatic equilibrium with the ice load.

b. It might be helpful to some readers to add hints for the derivation of Eq. 8 and 9, to give them a better chance of deriving them themselves if they are so inclined. The derivations of Eqs. 6 and 7 are straightforward, but Eq. 8 is more challenging. Just saying "As in the development of A6, one starts dq/dx = ..." in Fisher's Appendix would help a lot.

Also, a couple of features of the equations could be stated which, although fairly obvious, might be helpful to readers on first perusal: (1) The flowline direction determined by Eq. 6 is the direction of local steepest ascent of the ice surface. (2) If x, y, E, p, q are known at a point on a flowline (and B and Hf are known everywhere), then Eqs. 6 to 8 (or 9) yield the next y, E, q along the flowline for a given increment in x. And then the next p is known from Eq. 5.

c. In the Greenland example, it would be interesting to iterate on Greenland bed topography starting from a flat surface, instead of using modern bedrock data, and not iterate on basal stresses. That would be more analogous to a Laurentide application.

d. Does Fig. 2c show the initial basal stresses, or the final iterated values? (see pg. 7, line 183).

e. In Fig. 4, it is unclear what is plotted. The caption says "changes" in basal topography and shear stress, but the plots are absolute fields.

Technical corrections:

pg. 2, line 26: "each flowline ray *is* allowed..."

pg. 2, Eq. 2: Note that this is only true for flat bedrock, B=0.

pg. 4, line 105: What does "time interval" mean, given that everything is in steady state?

pg. 5, line 136: Instead of "too steep", "too high" would be more precise. And perhaps add "where E < B".

pg. 9, line 265: "dependence of ice volume on the Earth model..." (?)

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