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The Cryosphere Discussions

Interactive comment on "A particle based simulation model for glacier dynamics" *by* J. A. Åström et al.

Anonymous Referee #1

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General Statement:

This paper addresses a new model for the dynamics of glaciers. Existing models are usually based on continuum mechanics. In contrast, the one presented in this paper is based on a granular description of ice, i.e. ice is seen as a network of particles, each one being governed by a motion equation. As an advantage – and in contrast with continuum models – this model can handle naturally the fracturing processes such that crevasse opening, calving, ... The authors show two applications in 2D and validate their model against Elmer's model (full Stokes), which can provide reliable solutions assuming no fracture occurs in ice.

Continuum models remain physically limited to describe ice fracturing. As a consequence, it is of a great interest to develop more general models, which can handle both

together i) the non Newtonian behaviour of ice at a large time and space scale and ii) the brittle behaviour of ice at a much smaller scale. Among them, particle-based methods proved to be relevant in many fields dealing with fluids. As a consequence, the approach of the paper is relevant and promising.

However, I believe that the paper still requires developments to be publish. For such a new topic, the paper should be several pages longer. I focus my review mainly on the model, which is the key/central part. The model needs further details to be understood considering that the particle-based approach is absolutely new in the framework of glaciology. Some parts (see "Specific comments" below) of the model are still unclear to me, in particular, the most important: the bridge between the two models (particles and Glen's law). Moreover, numerical / computational aspects are totally absent ; they should be discussed in details too.

For these reasons, I recommend the authors to extend the paper in a more educational way.

Specific comments:

- (Section 2) The model part should provide further references. It would be helpful to propose some general references (review papers) about particles methods that can "imitate" Newtonian fluid.
- (Eq. (1)) Would it be possible to explicit M, C, C', K and F ? The text explains what these quantities contain, why not writing the exact relations ?
- (l 18 - l 25 p. 925) Do all values come from (Schulson, 1999) ? If not, could you motivate the choice of such values ?
- (l 16 - l 25 p. 926) Why using an exponential distribution law instead of any other probability distribution ?
- (l 18 - l 25 p. 926) "This implies that ... $\xi \approx \frac{\sigma}{E}\lambda$". Could you explain this ? Over a big numbers of particle interactions, one has either $\xi = 0$ (frozen) or $\xi = \frac{\sigma}{E}\lambda$ (not frozen), each one with the exponential probability distribution with λ as expected value, such asymptotically we have $\xi \approx \frac{\sigma}{E}\lambda$? Am I right ? Also, define what the symbol $\approx$ means ?
- (l 18 - l 25 p. 926) Why $2A\frac{U}{a^2}E^2 \approx A\sigma^2 E$?
- It is not clear to me if the nonlinearity of Glen's law is accounted for when one mimics Glen's law by choosing an adequate λ. Would it be different if Glen's exponent would be 1 instead of 3 ? For continuum model, such non linearity is solved by some iterations on the viscosity. What about particle method ?
- (l 22 - l 25 p. 926) "The probability can be adjusted so that the desired viscosity can be acquired". The sentence needs to be explained. How such tuning is done ?

- (l 22 - l 25 p. 926) Explain why the difference in time scale between calving and undamaged ice shearing leads to some computational problems ?
- (l 25 - l 30 p. 926) Neither the first nor the second approach is clear to me.
- Computational aspects are really missing. Please discuss the model implementation, the computational limitations and costs. Also how many particles do you use ? How sensitive are your results with respect to the particle size ? What code do you use (home-made, academic, commercial) for the particles ? The equations of motion (1) consist of a stiff system of ODEs. How do you solve such a system ? How do you adapt the time step ?
- (l 9 to 10 p 928) Could you show the results of the separated shear tests ?
- (l 8 p. 929) Define the kinematic energy. Is it the sum of local energies over all particles interaction ? i.e. non zero only if collision or breaking of beam ?
- (Fig. 2) Calving occurs on the left-hand-side. Was this side expected ? Does it depend on the initial distribution of (possibly non symmetric) particle ? Also, all simulations (particle based) rely on random variables, so discrepancies are expected between simulations anyway. How big are these discrepancies if you run 100 times the model ?
- (Fig. 7) To what corresponds the 3 curves (line) and 3 or 4 others (marked) ?
- Do the fragment size change when using an other particle size ?

Technical comments:

- (l 15 p.922) typo: dimension
- (l 1-2 p. 925) "The detailed ... modelled", not clear what this sentence means.

- (l 3 p.925) typo: overlapping
- (l 2 p.926) typo: form
- (eq (2)) Could you define the notation $n(s)$? Does $n(s)$ have a unit ? and also the fish-symbol (proportional I suppose ?) ?
- (Fig. 3) The legend and figure are hard to read (too small). Please provide the units to the axis.
- (Fig. 4) Caption: Could you write directly on the figure the time steps 0, 3, 5 and 7 years like in Figure 2 ? What is the time span ? i) the simulation time, then why both are different ? ii) the computational time, was 10^8 seconds , i.e. about 3 years !? 'yr' and 's' should not be abbreviated.
- The fonts used in the figures and the text should be the same.

Interactive comment on The Cryosphere Discuss., 7, 921, 2013.