Review

Title: A quasi-one-dimensional ice melange flow model based on continuum descriptions of granular materials

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This work presents a study of the dynamics of an ice melange within the framework of a granular material in the quasi-static regime. The problem is simplified by a double averaging in depth and width. This makes it possible to study the ice melange dynamics in the streamwise direction by leveraging a non local granular rheology. Particularly, the authors explored the sensitivity of the model to physical and geometrical parameters to understand the role of the ice melange on the buttressing force. Here, as I understand it, a significant advantage of implementing the granular fluidity model is that it allows for a more accurate estimation of the ice melange thickness at the calving front. Consequently, this leads to a more precise calculation of the buttressing force. Then, the authors investigated two cases: a steady state where the calving flux equal the flux of icebergs at the outlet of the ice melange and a quasi static state where there is no calving and no flux at the end of the ice melange. In the quasi-static case, the velocity is found to be constant along the fjord and the thickness profile is supposed to be exponential along the fjord. In the steady state, the buttressing force depends on surface and basal melting rate, decreases with fjord width and increases with calving flux. For the latter, it is found that it is because the buttressing force which depends on glacier thickness, increases more rapidly than the force needed to capsize icebergs. It is therefore suggested that glacier with small calving fluxes would be less influenced by buttressing that the glacier with high calving fluxes.

I would like to thank the authors for this interesting paper. Indeed, I truly appreciate the combination of granular physics and glacier modeling, which I believe offers a more nuanced consideration of the mechanisms within the ice melange. This approach could significantly enhance our understanding of the role of ice melange in calving dynamics, as well as the velocity at which icebergs are released from the fjords. The simplified model represents a crucial initial step toward achieving these objectives, and I would encourage the authors to further develop their modeling in the future. Specifically, I suggest exploring the development of a multi-phase flow model to facilitate the incorporation of the effects of seawater and wind while considering the full 3D granular velocity field.

I found the modeling part of the paper to be interesting, well-written, and comprehensive. Therefore, I have only a few minor comments to offer. However, I have more suggestions regarding the sensitivity analysis, which I found to be occasionally briefly discussed or explored. This is understandable given the wide range of scenarios you decided to explore. It seems one must choose between thoroughly exploring all sensitivities of the model or focusing on a specific aspect for a more detailed treatment. Due to the extensive range of parameters you are exploring, I found it sometimes difficult to follow. This is also because figures you are discussing are not mentioned clearly. Therefore my comments are essentially linked to the clarity of the different messages.

1 Comments on the model

1. Line 60, you define $\sigma_{ij} = R_{ij} - \tilde{p}\delta_{ij}$ with the pressure positive in extension. In Cuffey and Paterson's book, it is rather $R_{ij} = \sigma_{ij} - \tilde{p}\delta_{ij}$ with the same sign convention. Is it a mistake or do you define the overburden pressure differently? Make sure that it is correct and that it doesn't change expressions. In particular, with the formulation in line 60, I cannot recover equation (5).

2. How you recover equation (2) from equation (1) is not entirely clear to me. Is it by integrating the equation line 66 with the definition of the gravity of equation (1)? In this case, the statement line 71 should be modified. Then, how do you integrate it? This is related to another comment: I have the feeling that a scheme of the problem considered with characteristic parameters could help the reader to figure out the configuration more directly. For example, line 154 to 158 it could help to visualize the boundary conditions etc...This is just a suggestion.

3. Equation (22) is not obvious to me. Could you please cite or explain from where it comes from?

4. From what I understand, μ_w is here an effective friction coefficient and not the usual threshold for movement, which depends on the properties of the material in contact. Is it correct? Then, it is not very clear how you calculate μ_w. From my understanding, you calculate the granular fluidity g^y to solve the averaged transverse velocity field of equation (24) and obtained by averaging equation (23) over the width. But how do you find μ_w since it is not a constant parameter?

2 Comments on the analysis

5. Line 231 you stated $dL/dt = 0$ with a full derivative. What is the reason? What are the parameters that affects L? Is it only the ice thickness?

6. Line 238 to 246 I really like the discussion but you should may be refer the reader to the different subfigures you are analysing. It would make the analysis straightforward to understand. Same for line 262, you should cite figure 2b.

7. Line 244, the "roughly exponential thickness" for the quasi-static limit is not obvious to me. Why is it so different from the steady state?

8. In the sensitivity analysis I have the feeling that you clould sometimes discuss more the behavior of the ice melange in light of the physical model. It could allow one to better identify the processes at play. For example, Line 267, you say: " Increasing b makes the ice mélange more stiff and extensive". First I am not sure to understand what you intend by "stiff and extensive". Then, you could may be discuss a bit more why is that so? Ii it because b diminishes the local source term in the diffusion equation of the granular fluidity (equation 14), therefore there is less capacity to diffuse fluidity in the melange?

9. Line 277, it is mentioned that ice melange geometries and velocity profiles appear to be roughly consistent with field observations. In figures 2a to 2e, would it be of interest to add a profile from field observations allowing for a rapid comparison? I agree that it is not easy to determine the best calibration as there are different possible combinations of values for the parameters to recover field observations. It would require a deeper analysis that seems to go beyond the purpose of this work.

10. I found section **3.1.2 Sensitivity to external forcings and fjord geometry** difficult to follow. In line 284 you say that you will investigate the impact of calving fluxes on ice melange flow and geometry, but then, in line 288 it seems that you do the contrary: you investigate how ice melange plays a role on calving fluxes and start to study the buttressing. Therefore you never discussed clearly your results in light of the different panels of figure 3. Also, I found the discussion from line 285 to 296 sometimes difficult to understand. Here are the main reasons:

- line 286: "The ice mélange becomes more extensive as the fluxes increase (Figure 3), implying that ice mélange produced by highly active glaciers is more likely to exert high resistive stresses against the glacier termini and to persist year round." By extensive you mean longer or thicker? From my understanding of equation (28) only ice melange thickness plays a role. But on the contrary, to me the word "extensive" suggests longer but not thicker.

- line 292, it is not clear how you find these percentages? It increases compared to what?
- The issue linked with icebergs that capsize is not very clear. Is it because once capsized, an iceberg generates thinner ice melange?

I would suggest to rewrite this section more clearly to highlight the messages and be better articulated with the study of the butressing in section 3.2 and 3.3. I have the feeling that it would make the end of the paper more straightforward to follow.

11. In the conclusion, line 361, you say that the NSMA produces realistic thickness and velocity profiles. I do not doubt about it but you never showed profiles from the field for a qualitative comparison. This is related to comment 9.

3 Minor comments

1. I really like that you mention the estimated value for the inertial number. I do not know if this number is largely known in the glaciological community. May be you could define it rapidly and cite work like Gdr Midi 2004?

2. Line 253,would it be clearer to say "explore how adjusting these parameters affects the steady-state"?

3. Line 262, please cite the figure that allows you to say that "the size of iceberg allows the ice melange to thin and advance". This will be easier to follow the argument.

4. You should may be identify the different cases (small glacier, medium glacier and large glacier) in the caption of figure 3. I suppose the first case is for the small glacier, then the medium glacier and lastly the large glacier, but it would make the identification straightforward.

5 Suggestion: in the appendix, you could may be provide a scheme for the successive steps of your algorithm?