Review of *« A numerical framework for modeling iceberg calving and ice-front migration of grounded glacier tongues »* submitted to TC by V. Prasad et al.

This paper present the implementation of a level-set method into the Instructed Glacier Model to track the calving front position.
It is now well recognised that ice front dynamics has a major impact on the flow and mass budget of glaciers terminating in water. Including this process in ice flow model is challenging both in term of numeric and physics. The level-set method is a popular numerical method to track moving interfaces especially with unstructured grids and it has been first applied to track calving front position by Bondzio et al. (2016). The topic of the paper is then relevant and in the scope of TC.
After a description of the level-set equations and caving rate parameterisation, the authors test their implementation on 2 synthetic cases and one real world experiment.
In general I find that the paper lacks precisions in many places and shows some inconsistencies.

However, my main criticism is that there is no presentation of the coupling of the level-set with the force balance equation used to compute the velocities, here according to sec. 2.1.1 the Blatter-Pattyn approximation. At a calving front, the boundary condition in the normal direction should be stress free above sea level and should be the pression from the water below sea level. So that particular attention must be paid to correctly apply the boundary condition when the front is moving. Looking at the results of the synthetic glacier domain in Fig. 4, I'm very sceptical that the correct boundary condition is properly set. Indeed when the front advances the thickness is important (> 150m) with a water level of 10m. The stress difference at the ice front is so important that the velocity cannot be 0 as shown by the results.
Moreover, I don't think this experience is very designed for something that's supposed to be a realistic synthetic glacier. Even if the purpose of this experiment is not to test the caving rate, the velocity used to advect the caving front is totally unrealistic. First, it is said in Eq. 4 that vf should be perpendicular to the calving front (which is not correct, in general the caving rate is given perpendicular to the calving front, but the calving front velocity does not have to be. However in general the ice velocity at the front will be also close to the perpendicular), but here vf is directed along the x-direction. Second, for the advance, as the flow velocity falls to 0, this implies a calving rate of -400 m a-1, i.e. an accretion of 400 of ice at the calving front. It would be more realistic to let the front advance at the ice flow speed, which as said above should not be 0 at a caving front interface.
Finally, as the synthetic experiments are presented as a way to assess mass conservation, symmetry preservation, and accuracy of initialization and re-initialization, I would expect to have some quantifications of the errors, and maybe some sensitivity tests to some numerical parameters, and not only 2D plan view plots.

Detailed remarks:

- **Line 25:** 559.0 +/ **19.1** is the total frontal ablation for all glaciers in the northern hemisphere, not only Greenland. Moreover the frontal ablation is quantified as ice Discharge + mass change rate associated with changes in front position. The cited mass loss for Greenland is the cumulative anomaly of surface mass balance – ice Discharge, so that the 2 numbers can not be compared in the same sentence.
- **Line 31 "Many existing studies…**": Clarify the sentence. Many studies only quantify ice discharge and not frontal ablation, i.e. do not quantity mass change associated with front position change?

- **Line 32 "Future calving …":** Preceding sentences refer to observations while this sentence and reference are for prediction. The link is not straightforward, and modelling is discussed in the next paragraph.
- **Line 58 "Recent studies also":** This sentence is used to introduce the numerical difficulties in tracking moving fronts. But the "also" is a bit misleading. Reformulate.
- **Line 85 :** I don't think that the given references introduce or give details on the LSM in Kory. Reformulate.
- **Line 93 "numerical optimisation":** what is numerical optimisation here? Reformulate the paragraph as it is said 2 sentences above (before the description of the SMB) that the ice dynamics rely on a classical solver of IGM. As mentioned in the main remarks give a description of the boundary condition at the calving front for the ice dynamics.
- **Sec. 2.1.2:** As I understand the fast marching method is used only for the initilisation, so use t=0 or some notation for initialisation time to avoid confusion with the procedure to compute the evolution of the LS. Give a reference for the fast marching method, and I think it computes the signed distance function from the front not only "outward".
- **Line 107 "differentiating …**": Eq. 3 is the material derivative of the LS?
- **Eqs. 3 and 4:** Use different notations for vectors and scalars. vf in eq. 3 is a vector, but a scalar in eq. 4. As mentioned above vf does not have to be normal to the front.
- **Line 114:** the narrow band. There is no mention here or in the experiments of the width of the narrow band.
- **Eq.** 6: Use the dot only for the dot product between vectors (or tensors) and not for scalars to avoid confusion. The velocity (and thus strain rate fields) is 3D. Are the strain-rates used to compute the calving rate vertical averages?
- **Eq.** 7: The equation is solved to steady-state?
- **Line 141 "The control parameters are finalized":** What are the control parameters? Time step and criteria to define steady state. I don't find real discussion of this in the experiment results.
- **Line 151 "…** the thickness distribution remains consistent": Define "consistent" more precisely. The extension is not mass conservative, and you could assume that the thickness (and not the surface) is exported.
- **Eqs. 9 and 10 :** Is the eq. 9 correct? What is nx? I understand x_c=10km? topg is equal to 3250 for x=x_c and y=0, which is not the case in Fig. 1. Give the value for alpha.
- **Line 179 :** define "sufficiently stable".
- **Line 182 "more realistic ice cliff":** define what should be a realistic ice cliff.
- **Line 183 "vf=200":** I understand that you impose a retreat so should be -200. Is vf normal to the front or along x as in following experiment?
- **Lines 189-**190: This is confusing. I understand from sec. 2.1.5 that this is used to initialise the ice thickness in grid points where the front advances, but after it remains part of the solution of the ice thickness equation. As mentioned in the main remarks, describe of the level set is coupled to the IGM equations (i.e. how the domain change is taken into account in IGM).
- **Sec.** 2.2: there is no description of the parameters for the ice dynamics. Friction parameter? The densities used for ice and water should also be given as they have an impact on the boundary condition at the front.
- **Fig.**2 : Clarify the workflow. I understood that IGM-SHOP will provide observations of ice velocity and topography, so that the calving law should not depend on the initialisation but on the velocity from IGM. Why is there an arrow from the Re-initialisation to the initialisation? It is a bit confusion that the arrow from IGM to the caving module comes from the SMB.

- **Sec.** 2.3.2: Improve the description of the friction field. Is the coefficient above seal level constant or increasing (linearly?) with elevation?
- **Line 220 “after this inversion, a 10 year relaxation” :** Consistently use calibration instead of inversion. Constant thickness field? Usually a relaxation is used to dissipate ice flux divergence anomalies by relaxing the ice thickness field. What is evolving during the relaxation if not the thikness?
- **Sec 3.**1: as mentioned in the main remarks, I found very suspicious that the velocity falls to 0 with a very thick calving front mainly above sea-level.
- **Sec 3.**2 the description of the results is really short and somewhat unprecise. It would be interesting to see the velocity field and maybe the evolution of the ice mass and area?
- **Line 286:** “as is evident…” would be good to give a quantification and not only a plan view.
- **Line 291** “physically consistent fontal ice thickness”: As mentioned above, during the advance, because for the ice equations (thickness and velocity) the domain changes discretely, the thickness initialisation where the front advances is not mass conserving. So not sure what “physically” means here.
- **Line 302 “are controlled by the classical mass conservation”:** Is this meaning that a minimal ice thickness is imposed and that the front position on land is where H reaches this minimum? Again, give details of the coupling of the LS with the ice equations in IGM.