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Interactive comment on "Role of friction terms in two-dimensional modelling of dense snow avalanches" *by* Marcos Sanz-Ramos et al.

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Author's response to short comments of Marc Janeras:

COMMENT 1:

Congratulations on this research and development of this very useful tool. It is of great interest for practitioners to spread the tools for granular flows analysis in a well-balanced way: realistic physically based and easy understand and use.

(Line 541): I completely agree that 2D models are useful for avalanche hazard analysis and assessment.

ANSWER:

The authors want to firstly thank Mr. Janeras the time and dedication for reading the manuscript, besides his interest for Iber and its usefulness for practitioners. Regarding the specific comment: Line 541: As we indicated in https://doi.org/10.5194/nhess-2019-423-AC1, there are two possibilities to simulate avalanche dynamics: to use "simple" 2D-SWE based models; or to use much more complex Computational Fluid Dynamic (CDF) models. From our point of view, "simple" models can be good enough to analyse the hazard and risk due to dense-snow avalanche in most situations. This manuscript explores the capabilities and behaviour of 2D-SWE-based models for other applications out of the "common" fields, such us simulating the avalanche dynamics.

COMMENT 2:

It is very promising the implementation of these 3 friction terms in IBER, not only both original of Voellmy-Salm model.

(Line 45): If I understood correctly, it could be said that the stopping criterion based on momentum (user-defined fraction of achieved maximum momentum as lower threshold) corresponds to a macroscopic point of view, which stops whole calculation. In contrast, the additional friction term related to snow cohesion is a real physical snow property, which has an effect of retention and can stop the avalanche locally, where is needed due concavity or other issues along the avalanche path. Daring suggestion: the friction–cohesion model could be called Voellmy–Salm-Bartelt friction model. Even more, if we want to summarize the evolution in such avalanche models, it could be used also the name Voellmy-Salm-Gruber-Bartelt snow avalanche model.

ANSWER:

The frictions terms can be implemented in many ways (see Eq. 2), and in Iber it has been considered by Voellmy-Salm model and the new cohesion model presented by Bartlet, among others. The cohesion adds "more resistance" against to the fluid motion, but this friction model depends also on the solid-phase.

As we show in Section 3.2, Iber is able to stop the avalanche without considering the cohesion effect. The fully conservative numerical scheme used (see Section 2.2) ensures that when the tractive forces do not exceed the resisting ones the avalanche stops. This happens whether the cohesion is considered or not. Anyway, cohesion is a physical snow property that can be worth considering. Thus, it is not necessary to consider any additional stopping criterion, such as one based on the maximum momentum achieved in the bulk during the avalanche evolution.

As suggested, it could be interesting to grouping or re-named the frictional model that includes Voellmy-Salm friction model and the cohesion model of Bartelt. In the final version of the document the naming of the models will be re-considered, or at least a discussion on the different naming options will be included. Iber includes all the terms in the referred models.

COMMENT 3:

It seems that cohesion term plays a main role where the slope changes rapidly. Is that right? In the paper, only a real avalanche case is tested. It will be very interesting to see further examples, and I suggest testing run-up problems, for instance with a protection dam. Keeping in mind the hydrological origin of IBER it will be of great interest the analysis of avalanche dynamics across a concrete dam placed on a channel in a gully part of the path still in steep terrain. These are typical solutions of the first half of XXth century in the Pyrenees. Under these conditions, the effect of the dam is the lamination of the flow pulse, not only the deposit of part of the mass. How is that reproduced by IBER? Does the cohesive-friction term play an additional effect of velocity reduction, that could be critical in this kind of configurations?

ANSWER:

The analysis of the friction–cohesion models revealed that the Voellmy–Salm model dominates the avalanche dynamics, whereas the cohesion model plays a relevant role in the definition of the avalanche tail.

The authors want to thank the interest of simulating different casuistry with Iber, such as dam-like protections. Iber, as a hydraulic model, can simulate dam breaks (Sánchez-Romero et al. 2019; Sanz-Ramos et al. 2019) and, thus, the effectiveness of a protection dyke in terms of reduction of the "peak" discharge can be assessed. Surely the cohesion term will affect the inertia terms reducing the peak, but it cannot be stated that in general the cohesion term plays a critical effect on velocity reduction, more than the other friction terms. Deeper analysis and comparison with theoretical and real case studies is advisable. Some analysis of protection structure effects have been already carried out in Flumen Institute (Torralba-Conill 2017), and also some cases with avalanche run up (Castelló 2020), but these are not the aims of the manuscript, which is focussed in analysing the friction parameters. The authors will consider this casuistic for future works. We expect to continue working on that.

COMMENT 4:

Another avalanche case that could be interesting and useful for testing the application of avalanche formulation in IBER is the catastrophic avalanche sequence in Sewell (Chile). The avalanches occurred in 1914, 1926, 1941 and 1944 offer different scenario: wet and dry snow conditions, run-up or deflection, etc.

(Line 106): IBER uses a first-order Godunov-type upwind scheme for convective fluxes and the geometric slope source term, in particular the Roe scheme, and a centred scheme for the turbulent diffusion friction source term. Therefore, the scheme achieves balancing of the bottom slope source term with the flow tensor, thereby avoiding spurious oscillations of the free surface and retaining quiescent water even when working with complex irregular geometries. According to that, it will be interesting to explore if run-up problems need some variation in these schemes, or they are already properly solved.

ANSWER: The authors want to thank for the suggestion of a well-documented real case to compare it in deep with the simulated results from Iber. We will consider this

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real case for future works.

Line 106: the numerical scheme used in Iber was developed focusing into avoid numerical instabilities, balancing the source term and the flow vectors (further information can be found in Sanz-Ramos et al. 2020). In the previous reference, some theoretical case studies were simulated and, as it also shown in this manuscript. The scheme can deal with run up problems with no numerical instabilities or scheme limitations. Obviously, the adjustment of the involved parameters is still critical, and the limitations on the model approximation (2D) are still there.

COMMENT 5:

(Line 106): “IBER solves the described 2D-SWE through a conservative finite volumes scheme and on unstructured meshes of triangles and quadrilaterals.” This could be a strong point for IBER in avalanche analysis, allowing a better description of topography roughness, channels... in comparison to the raster based models.

ANSWER:

From its beginnings, Iber can discretize the domain by means of meshes formed by triangles, quadrilaterals or combination of both. But it is also able to generate raster-based meshes, and for sure combination of all of them thanks to the mesh generator integrated in GiD (Ribó et al. 1999) the pre and post-processing package used by Iber. There are also several possibilities not only to generate meshes, but also to import different king of meshes such as *.stl, raster GDAL, RTIN, etc. All this is indeed an advantage when representing complex geometries, or particularities of the users, widening the possibilities to carry out more realistic simulations.

COMMENT 6:

“IBER was initially developed for hydrodynamic and sediment transport simulations: : : Iber has been recently enhanced to simulate snow avalanches and a specific numerical treatment of the friction–cohesion model was implemented to adapt it to the particularities of the numerical scheme used by Iber." As far as Iber is used for flooding risk analysis, it will be a natural way to make easier the implementation of debrisflood and debrisflow scenarios in such studies. Are you planning to apply Iber to debrisflow?

ANSWER:

The current version of Iber has some capabilities to simulate debris flows as it implements the Voellmy-Salm friction model, which has been used to carry out this kind of analysis. Iber additionally has implemented a simplified Bingham model and a Manning-like model (Ruiz-Villanueva et al. 2019). Although the authors focused the development of this non-Newtonian module in dense-snow avalanches, we also have in mind the possibility to widen the model to simulate this kind of fluids. Anyway, it has to be mentioned that the utility of a simulation software depends on its intrinsic capabilities (numerical methods, interface) but also in the expertise acquired by the user's community along time. The application of the tool to new fields has to be done with caution, progressively, and with a rigorous results analysis.

COMMENT 7:

(Line 180): When you mention the Avalanche Database of Catalonia (BDAC) could be referred to the reference:

https://www.researchgate.net/publication/318724068_THE_AVALANCHE_DATA_IN_THE_CATALAN_PYRENEES_20_YE

https://www.researchgate.net/publication/318723626_AVALANCHE_MAPPING_IN_THE_CATALAN_PYRENEES_BALAN

ANSWER:

We want to thank to provide these manuscripts, and we will include them in the references.

COMMENT 8:

Is Iber able to consider friction parameters varying along space/time? It could be a next step? For instance, in a wet avalanche, friction parameters increase at deposition zone... In case 3, could this fact improve the result reducing the lateral spreading in the east part of deposit?

Line 418: to reproduce slab avalanche it is also possible to introduce higher value for cohesion at initial steps?

ANSWER:

Iber is able to vary the friction parameters along the space, but not in time. Implementing time-variations could be an improvement on one hand, but on the other it might increase the difficulty to carry out a simulation because of the need of calibration of the parameters describing this temporal variations.

The simulations of the case study of Coll de Pal (section 2.3.3 and 3.4) show, effectively, that the deposit is always shifted slightly to the east part. Although space-time variations of the friction-cohesion parameters could improve the solution, we attributed the differences to the assumptions on the release area (shape, extension, and depth) and the use of summer topography, which can retain snow in some areas, and would probably be smoother in winter topography.

Line 418: in the current version of Iber it is not possible to introduce an initial value of cohesion at initial steps.

COMMENT 9:

Line 406: “1. The pivoting point of the free surface is the same for all simulations, maintaining the length and depth positions in approximately 5 m and 0.9 m, respectively.” What is the sense of this pivoting point in Fig. 12? Is it related to the instability degree in the starting zone (balance of topographic slope and friction slope)? If Kp factor is influencing the inertia term at the beginning, it could have a big influence on tiny avalanche simulation?

ANSWER:

Line 406: In this part of the manuscript we wanted to highlight the relevance of the pressure terms during the avalanche dynamics, but specially during the avalanche release, because the assumption of hydrostatic isotropic pressure distribution could not be realistic in this phase. Figure 12a shows a profile of the fluid elevation across its direction, and the pivoting point is a stable point that is "not affected" by the upstream and downstream conditions. With that point, and the shape of the free surface, we wanted to highlight that the snow-like fluid behaves in a similar way to water flows, even for Kp factors equal to 1 or 0.5, if only the turbulent friction contribution was considered. The Kp factor will affect more the fluid behaviour, the deeper the avalanches are (see Eq. 3), because this parameter directly affects the pressure terms, which depends on the square of the fluid depth (gâĂćh2/2)

COMMENT 10:

I've found 2 minor errors: Figure 13: the caption says kp=0,5 instead of 0,1 Line 430: xi=2000 is also considered and shown in the figure 13

ANSWER:

Regarding the Figure's 13 caption, the Kp factor used for the simulations was 0.1, which is in accordance with the text.

Line 430: We will correct it accordingly.

COMMENT 11:

Line 500: Gaume et al 2019 are implementing the Material Point Method, which is especially able to describe both the initial instability and movement generation, and also the large scale deformation along the path, considering 3D variability of variables. With 2D-SWE it is clearly not possible to deal with the initial part (describing the activation of movement) ... But it is not necessary for common hazard analysis, where instability is defined by the scenario and the interest is focussed at the bottom of the slope where facilities are placed.

ANSWER:

The authors are in agreement with this comment. However, there are some possibilities to simulate the triggering and the release of the avalanche together with its propagation in the same model, as for example linking a plate or slab structural model (failure) with the hydraulic model (propagation). This is one of our research lines currently in development.

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