Response to Reviewer #1's comment on "Detrainment and braking of snow avalanches interacting with forests"

Louis Védrine, Xingyue Li*, and Johan Gaume
*Correspondence: xingyueli@tongji.edu.cn
January 26th, 2022

We want to thank Referee #1 for his or her valuable comments and constructive suggestions that helped us to improve the quality of our paper. In the following, we provide detailed point-by-point answers to the comments raised by the reviewer.

The authors present an approach to quantify the effect of forest on a (slow) moving avalanche. To this end, they study the detrainment and braking due to trees by using a 3d model approach based on the material point method and a rheology previously proposed by one of the author.

They study varying forest stand composition and derive an empirical formula for practical use. The newly proposed formula is compared to one proposed by Feistl (2015).

The paper presents an important step to describe and quantify the interaction between avalanches and the efficiency of a forest to mitigate moving avalanches.

Reply: We thank the reviewer for this positive evaluation of our paper.

General comments:

The authors refer to the approach by Feistl (2015). At this point it would be valuable for the reader to get some more information about this approach without to have to look the full thesis.

Reply: The detrainment model proposed by Feistl (2015) aims to be implemented in a depth-average model like RAMMS (Christen et al., 2010). To reproduce the effect of forest with this model, the mass and momentum of the snow stopped behind the trees are directly removed from the flow. To do this, assuming that no mass is entrained in the forest area, the detrainment rate $\dot{Q}_d = -\frac{1}{\rho}\dot{M}_d$ is added to the mass balance, with M_d the detrainment mass which corresponds to the mean mass stopped in the forest per unit of area. The rate of detrainment is quantified with a detrainment coefficient K (Feistl et al., 2014), which links the temporal derivative of the detrainment mass with **V**, the depth-averaged velocity of the avalanche as follows: $\dot{M}_d = -\frac{K}{||\boldsymbol{V}||}$.

Following the reviewer's suggestion, the clarification above has been added to the revised manuscript.

To enhance the practical usefulness, it would be nice, if the parameter study would cover more typical parameter combinations of forest stands. Firstly a tree diameter of 1 m refers to a rather very mature forest. Secondly, the stand density index (Reineke, 1933) in their example (figure 9) covers a range from SDI = [900, 3600], whereby the later sound rather high. Using a combination of 1 m diameter and 400 trees per hectare suggests an efficiency that a natural forest probably doesn't fulfill.

Reply: We thank the reviewer for pointing out the importance of using the Stand Density Index to enhance the practical usefulness of this study. Following the reviewer's suggestion, we have conducted new simulations using a smaller tree diameter (0.6 m) and a stand density index between 400 and 1347 tree /ha, which corresponds to a normal to a very dense forest (Abegg et al., 2020). The newly obtained results are shown as Fig. R1, which demonstrates similar trends as the original Fig. 9 in the manuscript. We have replaced the original Fig. 9 with the figure below.

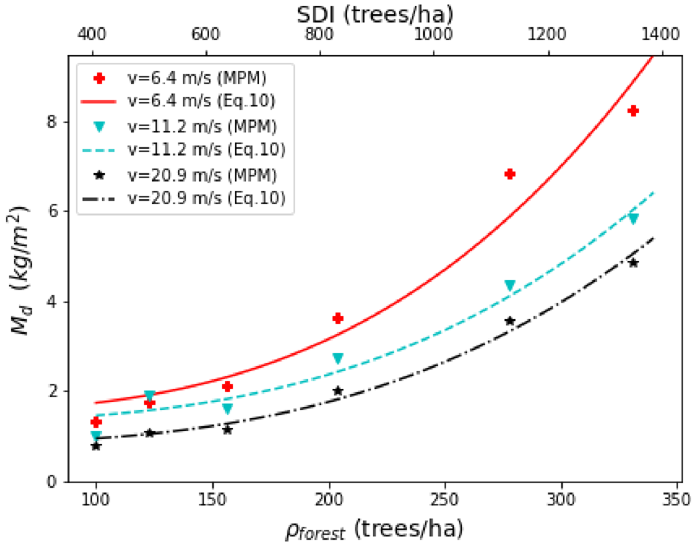

Figure R1. Evolution of the detrainment mass per unit of area with the forest density for different front velocities (regular staggered forest, snow properties: Case 2, $d = 0.6$ m).

The SDI would, properly, serve also better as fixed value for the comparison in figure 8 than the forest density.

Reply: Thanks for the suggestion. Initially, we chose to study the tree diameter at a fixed forest density because this allows us to obtain a simple and easily identifiable law from Fig. 8, in contrast to the case of a fixed stand density index. Following the reviewer's comment, we have added a new figure showing the effect of tree diameter with a fixed SDI as demonstrated in Fig. R2. This new plot allows us to check the predictability of the proposed model (e.g. Eq. 11 in the manuscript) and demonstrates that it is possible to use the model with the Stand Density Index parameter in Eq. 11.

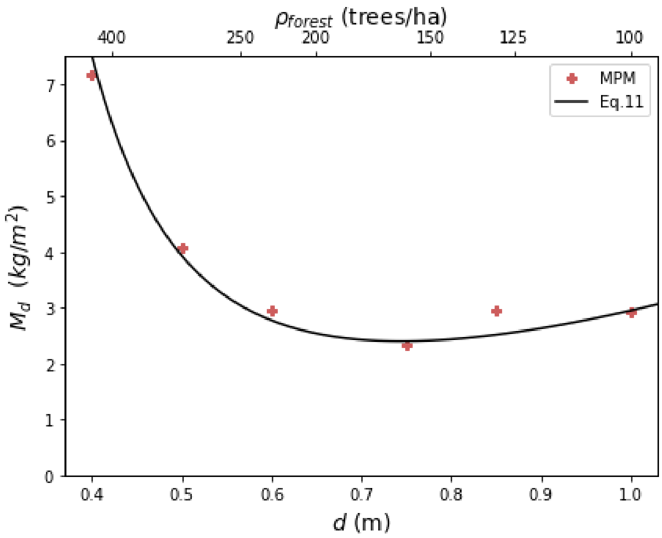

Figure R2. Evolution of the detrainment mass per unit of area with the tree diameter for a constant Stand Density Index, SDI = 925 trees/ha, (regular staggered forest, $v_0 = 10$ m/s, snow properties: Case 2).

By the way, for practitioners it is properly more common to speak of number, N, of trees per hectare, instead of density.

Reply: We use the term forest density to be consistent with the referred studies (Teich et al., 2012 a, b, 2014; Feistl et al., 2012, 2014; Casteller et al., 2018; Perzl et al., 2021). We have further clarified the definition of the forest density as the number of trees per hectare in the revised manuscript.

Instead of using the ambiguous expression forest cover, it is the basal surface area per hectare that is meant here.

Reply: Revised.

Otherwise, the paper is well written and is a valuable contribution to an important question in respect to avalanche hazards and its mitigation.

Reply: We thank the reviewer for this positive comment.

References:

- Abegg, M., Brändli, U.-B., Cioldi, F., Fischer, C., Herold, A., Meile, R., Rösler, E., Speich, S., and Traub, B.: Swiss national forest inventory- Result table No. 815491: forest area Birmensdorf, Swiss Federal Research Institute WSL, https://doi.org/10.1103/PhysRevLett.86.71,2020.
- Casteller, A.; Häfelfinger, T.; Donoso, E.C.; Podvin, K.; Kulakowski, D.; Bebi, P. Assessing the interaction between mountain forests and snow avalanches at Nevados de Chillan, Chile and its implications for ecosystem-based disaster risk reduction. Natural Hazards and Earth System Sciences.2018,18, 1173–1186, https://doi.org/10.5194/nhess-2017-348, 2018.
- Christen, M., Kowalski, J., and Bartelt, P.: RAMMS: Numerical simulation of dense snow avalanches in three-dimensional terrain, Cold Regions Science and Technology, 63, 1–14, https://doi.org/https://doi.org/10.1016/j.coldregions.2010.04.005, 2010.
- Feistl, T.: Vegetation Effects on Avalanche Dynamics, Ph.D. thesis, 2015.
- Feistl, T., Bebi, P., Bühler, Y., Christen, M., Teich, M., and Bartelt, P.: Stopping behavior of snow avalanches in forests, in: Proceedings of the International Snow Science Workshop ISSW. Anchorage, Alaska, pp. 420–426, 2012.
- Feistl, T., Bebi, P., Teich, M., Bühler, Y., Christen, M., Thuro, K., and Bartelt, P.: Observations and modeling of the braking effect of forests on small and medium avalanches, Journal of Glaciology, 60, 124–138, https://doi.org/10.3189/2014JoG13J055, 2014.
- Perzl, F., Bono, A., Garbarino, M., and Motta, R.: Protective Effects of Forests against Gravitational Natural Hazards, https://doi.org/10.5772/intechopen.99506, 2021.
- Reineke, L. H.: Perfection a stand-density index for even-aged forest, Journal of Agricultural Research, 46, 627–638, 1933.
- Teich, M., Bartelt, P., Grêt-Regamey, A., and Bebi, P.: Snow Avalanches in Forested Terrain: Influence of Forest Parameters, Topography, and Avalanche Characteristics on Runout Distance, Arctic, Antarctic, and Alpine Research, 44, 509 – 519, https://doi.org/10.1657/1938-4246-44.4.509, 2012a.
- Teich, M., Vasella, I., Bartelt, P., Bebi, P., Feistl, T., and Grêt, A.:Avalanche simulations in forested terrain: a framework towards a Bayesian probabilistic model calibration, In Proceedings, 2012 International Snow Science Workshop ISSW, Anchorage, Alaska, p. 632, 2012b.
- Teich, M., Fischer, J.-T., Feistl, T., Bebi, P., Christen, M., and Grêt-Regamey, A.: Computational snow avalanche simulation in forested terrain, Natural Hazards and Earth System Sciences, 14, 2233–2248, https://doi.org/10.5194/nhess-14-2233-2014, 2014.