Simulating the propagation of wet snow avalanches: challenges and perspectives

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Wet snow avalanches

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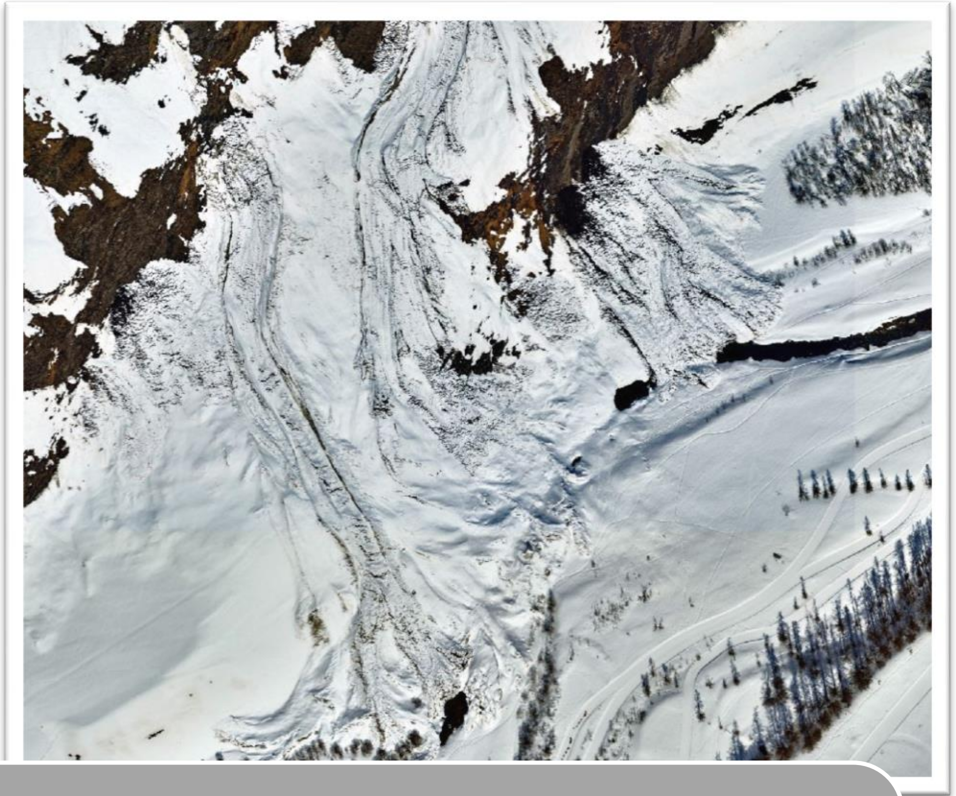


Distinctive characteristics:

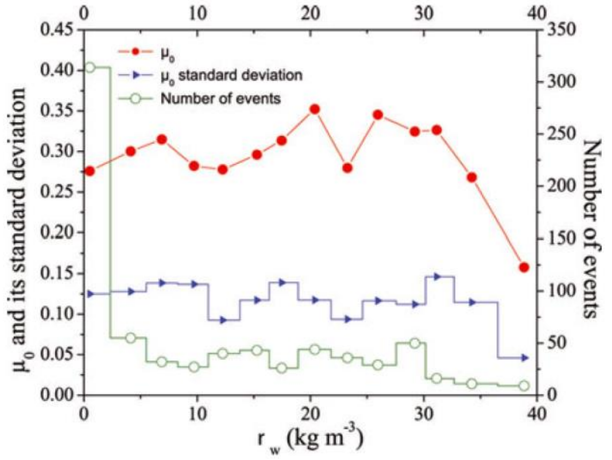
- strong channelization (topography control)
- levées, ridges, fingering
- slow, pasty-like dynamics

Can we model these flows?

- *issue of appropriate rheology*
- *need for careful validation benchmarks before scaling up to field applications*

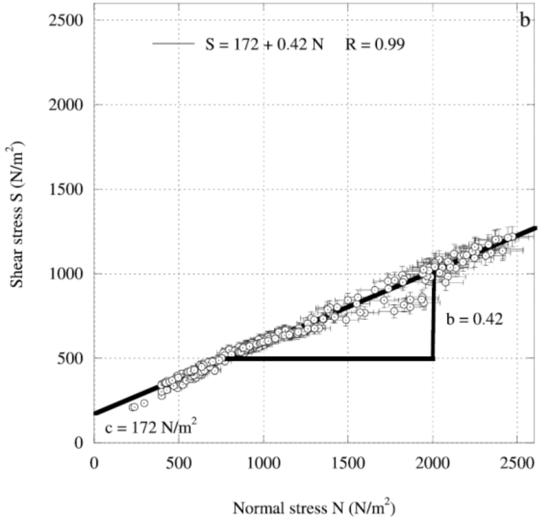
Flow rheology : basal shear-to-normal stress ratio (S/N)

Different proposals in the literature:



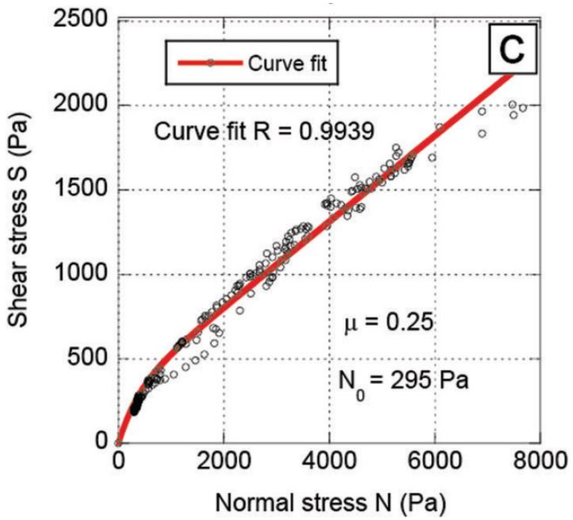
Naaim et al. (J. Glaciol., 2013):

Voellmy-Salm model with coefficients (μ, ξ) depending on liquid water content r_w



Platzer et al. (Geophys. Res. Lett., 2007):

Introduction of a cohesion for wet snow



Bartelt et al. (J. Glaciol., 2015):

Effect of cohesion vanishing for $N \to 0$

- **Objectives of our study:**
  - **test of a simple cohesive Voellmy model:**

viscous contribution

$$S = \left(\tau_c + K \frac{|\bar{\boldsymbol{u}}|}{h} + \underbrace{\mu \rho g_z h + \frac{\rho g}{\xi} |\bar{\boldsymbol{u}}|^2}_{\textit{Voellmy-Salm}} \right) \frac{\bar{\boldsymbol{u}}}{|\bar{\boldsymbol{u}}|}$$

cohesion

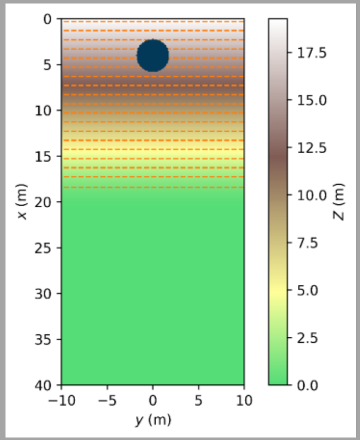
  - **analysis of cohesion influence**

Benchmark numerical simulations

Depth-averaged modelling approach:

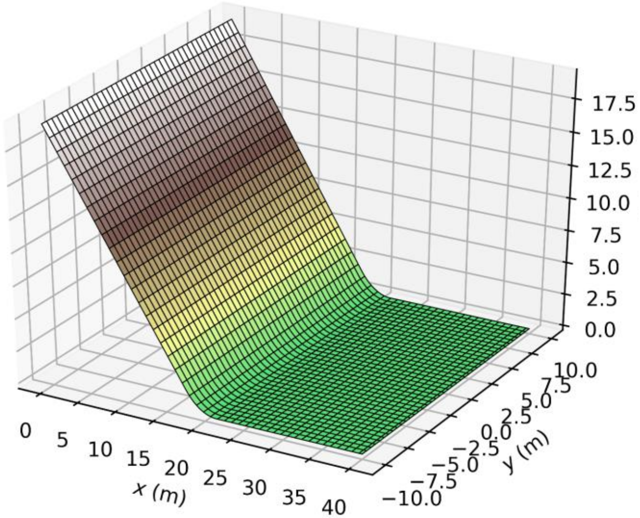
- robust, shock capturing numerical scheme
- three toy topographies
- systematic sensitivity analyses

- Initial condition:
  - cylindrical pile
  - $h_0 = 0.6$ m

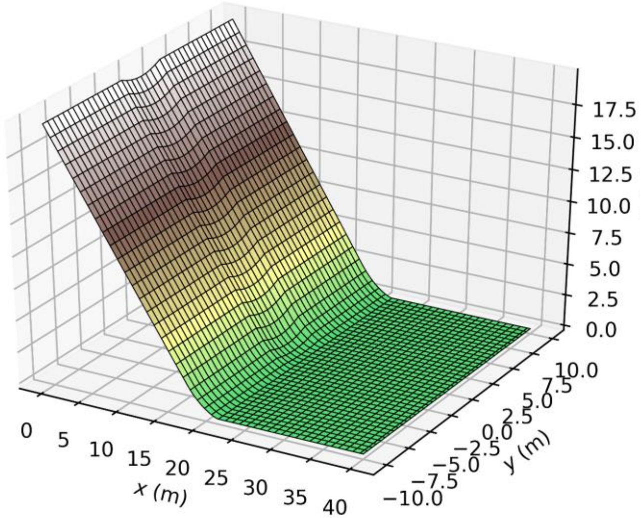


- $V \approx 8.5\ \mathrm{m}^3$
- $\mu = 0.5,\ \xi = 2000\ \mathrm{m.s^{-2}}$
- $\tau_c = 0 - 200$ Pa

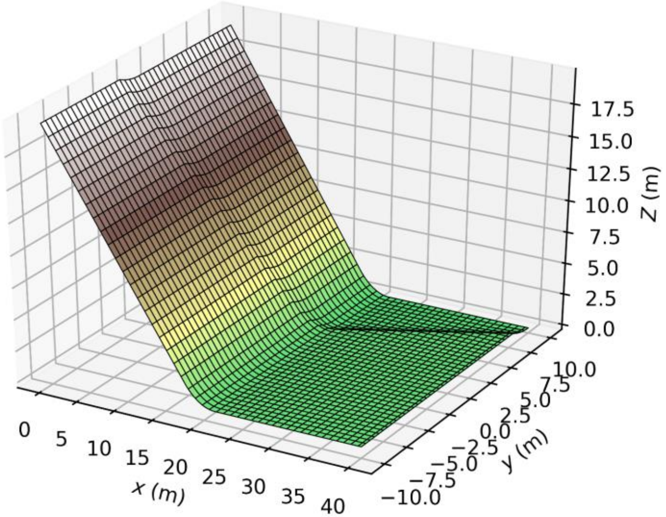
Incline with smooth transition



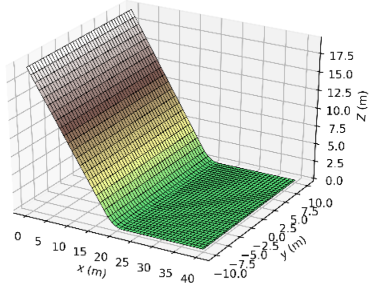
Channeled slope



Oblique ridge

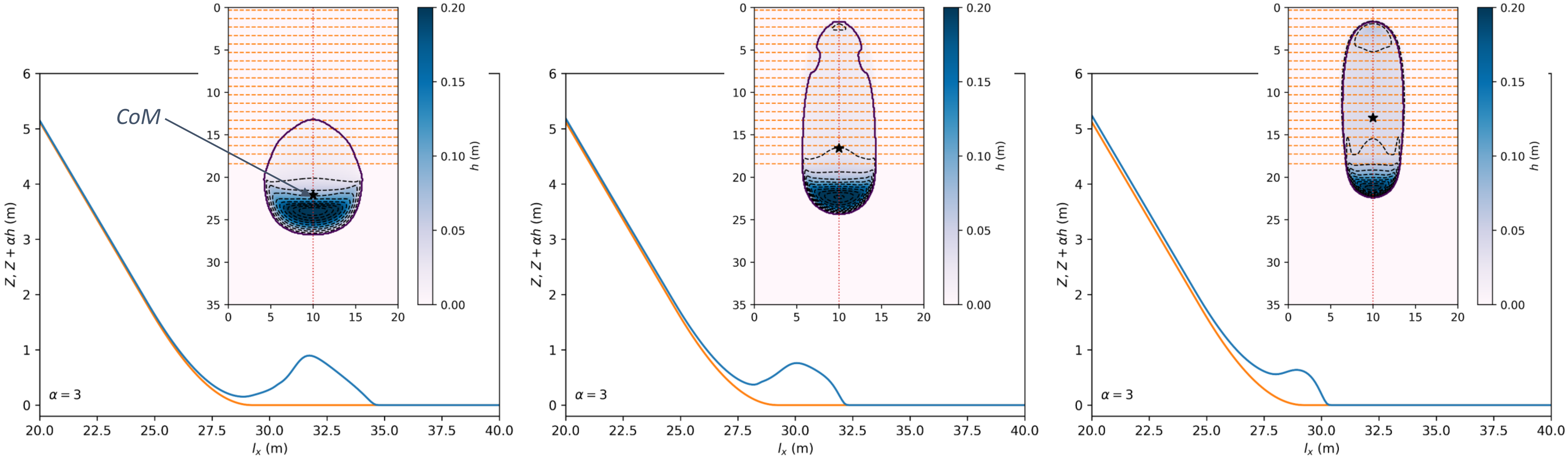


Avalanche runout



__Longitudinal profiles:__

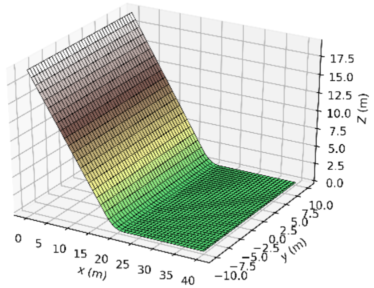
$\tau_c = 0$ Pa $\quad$ $\tau_c = 50$ Pa $\quad$ $\tau_c = 100$ Pa



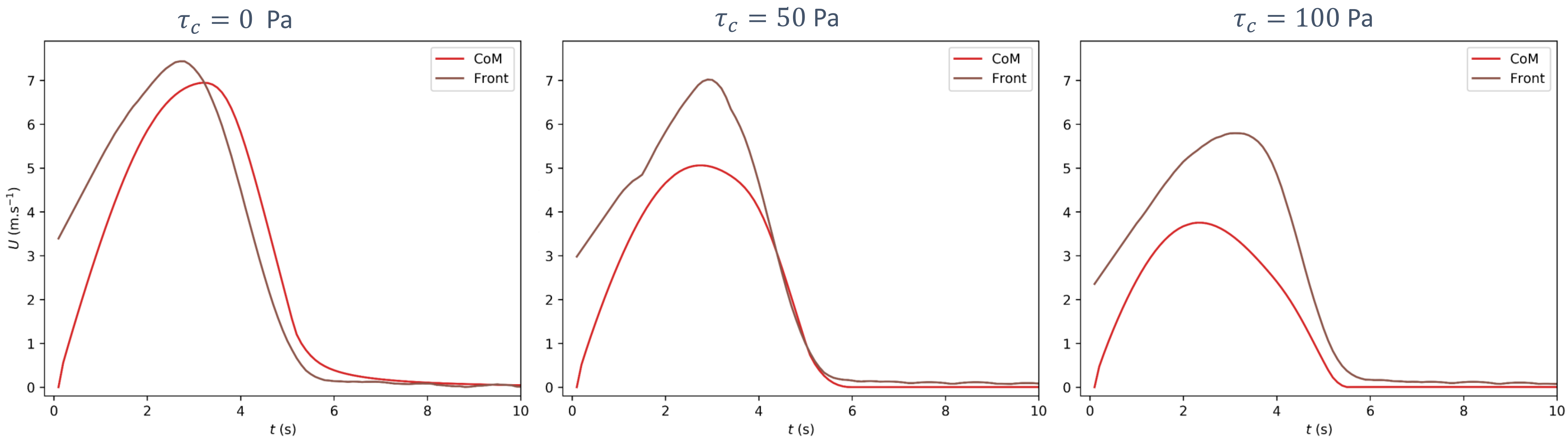
- ➢ Cohesion induces shorter runouts …
  … and longer tails

❖ *Note progessive shift in center of mass (CoM) location*

Avalanche dynamics



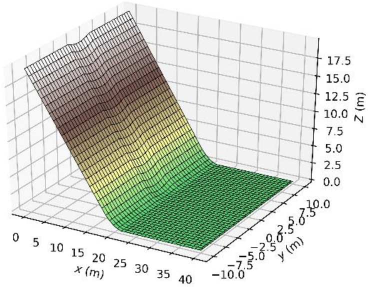
Front and center-of-mass (CoM) velocity:



- Cohesion slows down flow dynamics …
  … and freezes slow rearrangements of the deposit

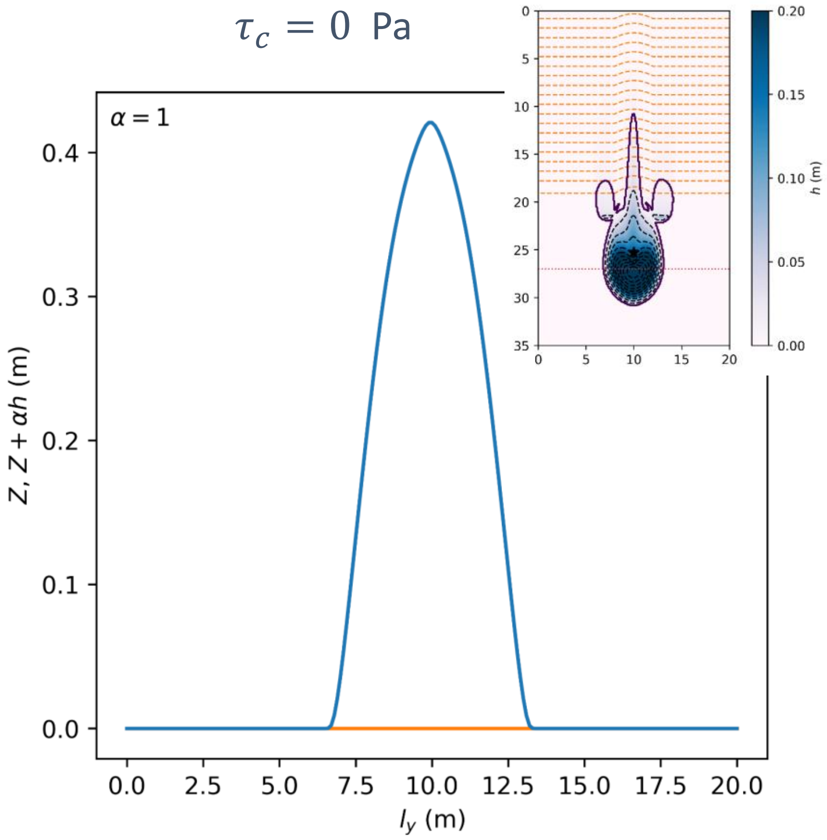
❖*Note CoM comes to a halt before the front in presence of cohesion*

Channelization

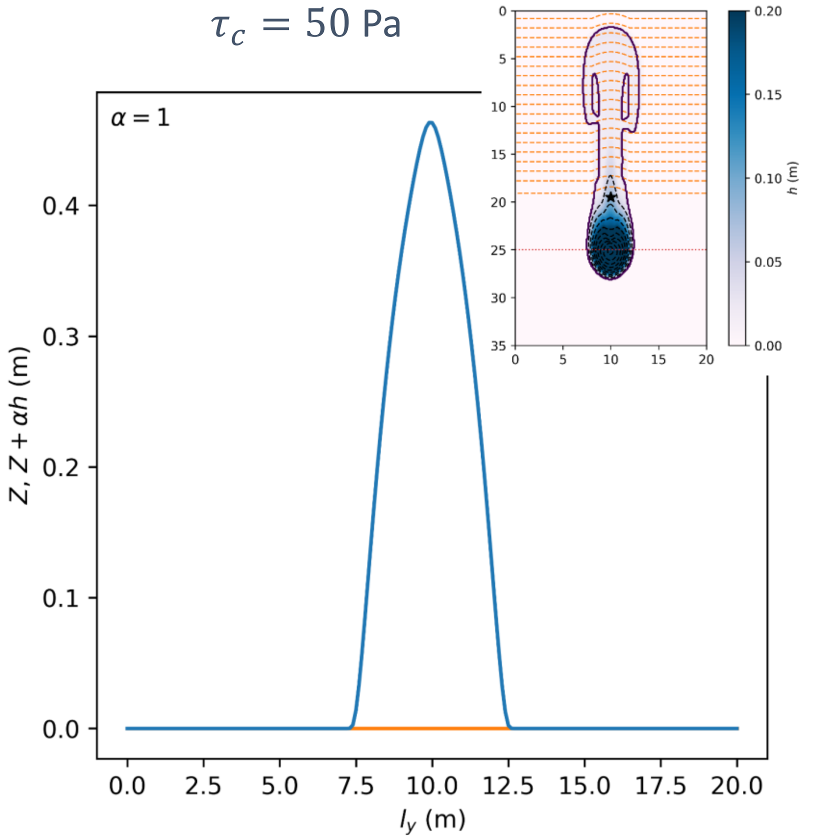


Transversal profiles:

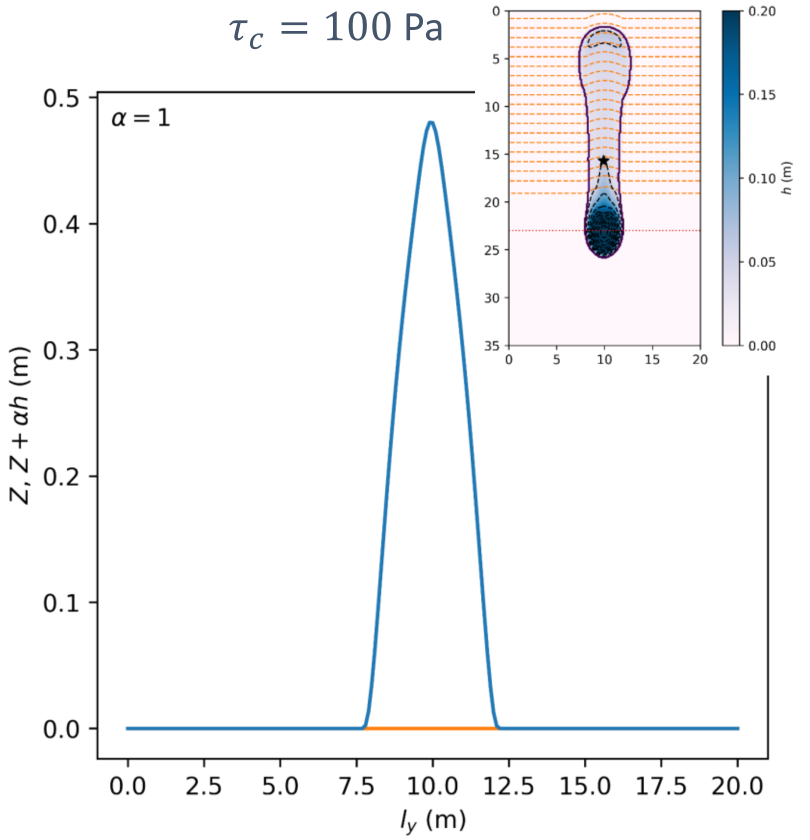
$\tau_c = 0$ Pa



$\tau_c = 50$ Pa



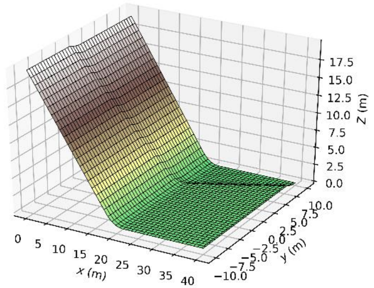
$\tau_c = 100$ Pa



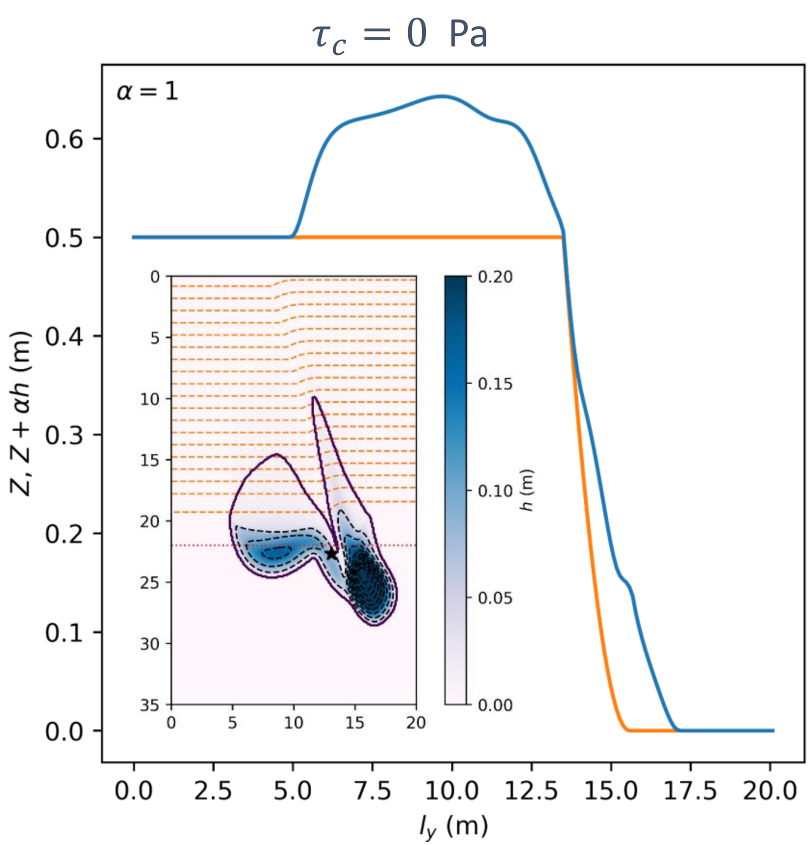
- Cohesion promotes flow channelization

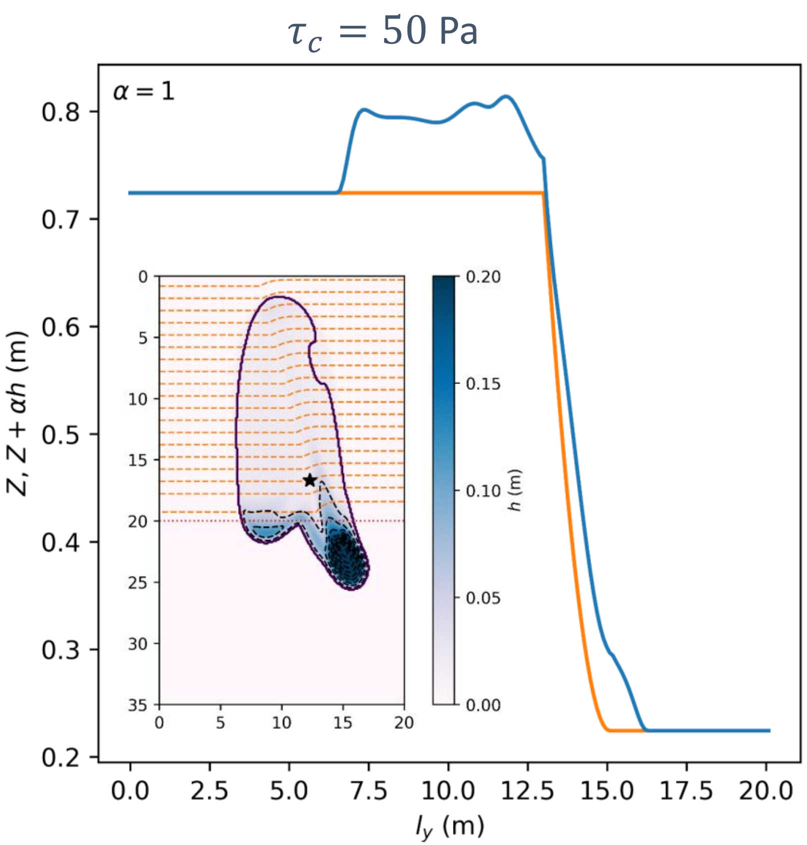
❖ *Note progressive concentration of the deposit (fingering)*

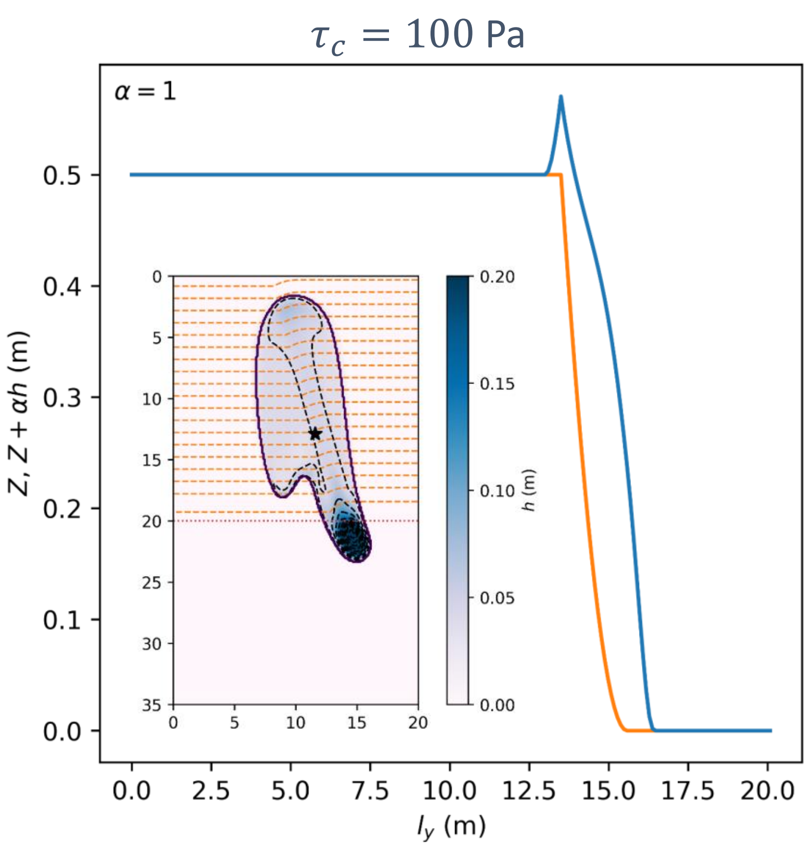
Influence of topography



<u>*Transversal profiles:*</u>







➢ Cohesion promotes topographical control of the flow

❖*Note decrease in deposit lateral spread*

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Simulating wet avalanches

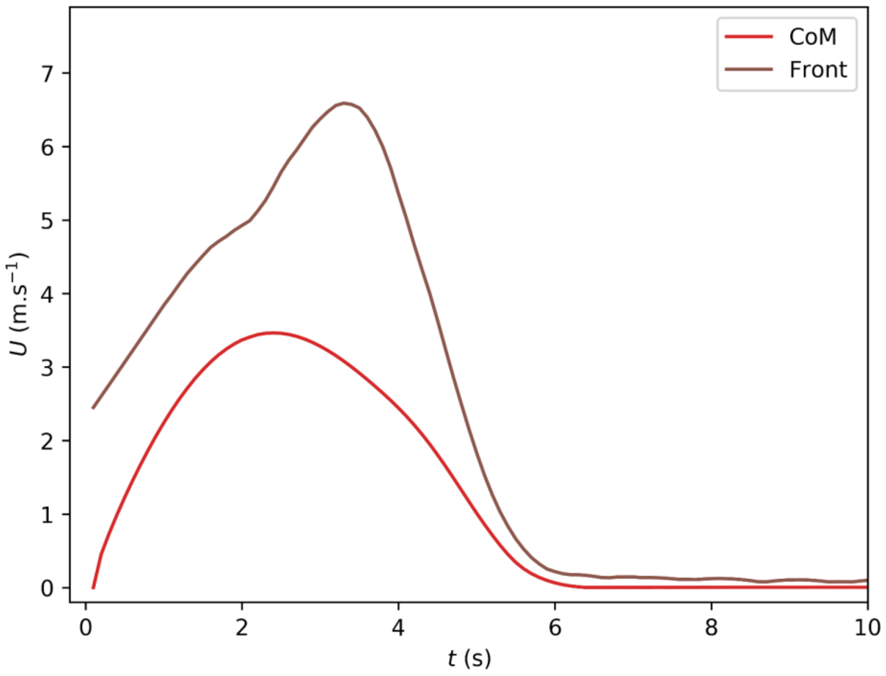
Specificity of cohesive flows

Can we approach cohesion effects with a plain Voellmy model?

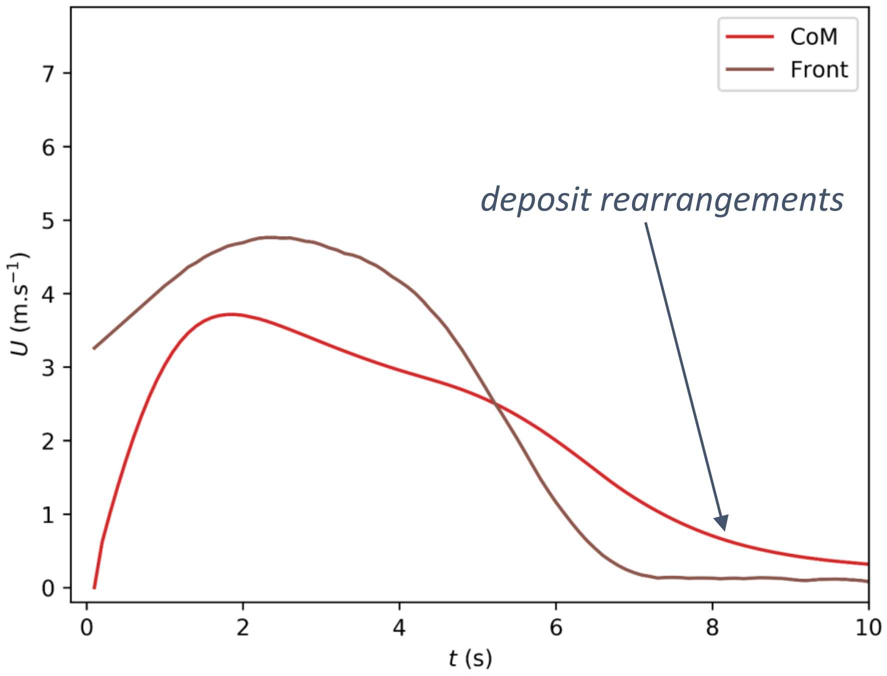
Find best-matching simulation couples:

- same runout
- same maximum kinetic energy

$\mu = 0.5, \xi = 2000$ m.s^{-2}, $\tau_c = 100$ Pa



$\mu = 0.41, \xi = 200$ m.s^{-2}, $\tau_c = 0$ Pa



- Voellmy model overestimates flow duration…

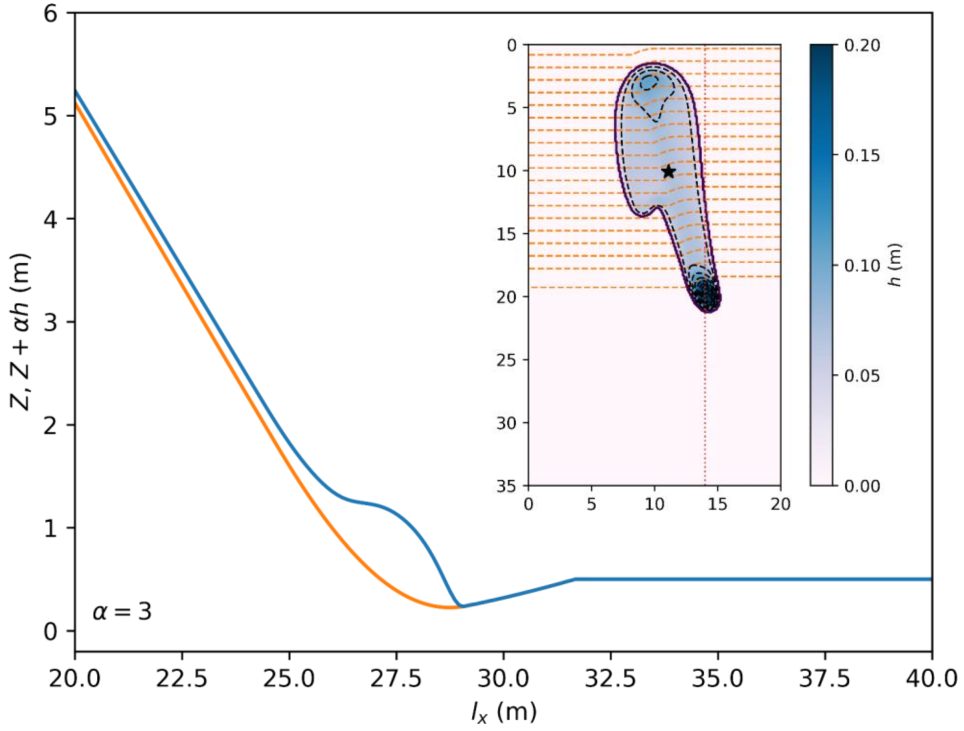
  … while it underestimates max front velocity

Note also the pronounced slow rearrangements of the deposit (artifact?)

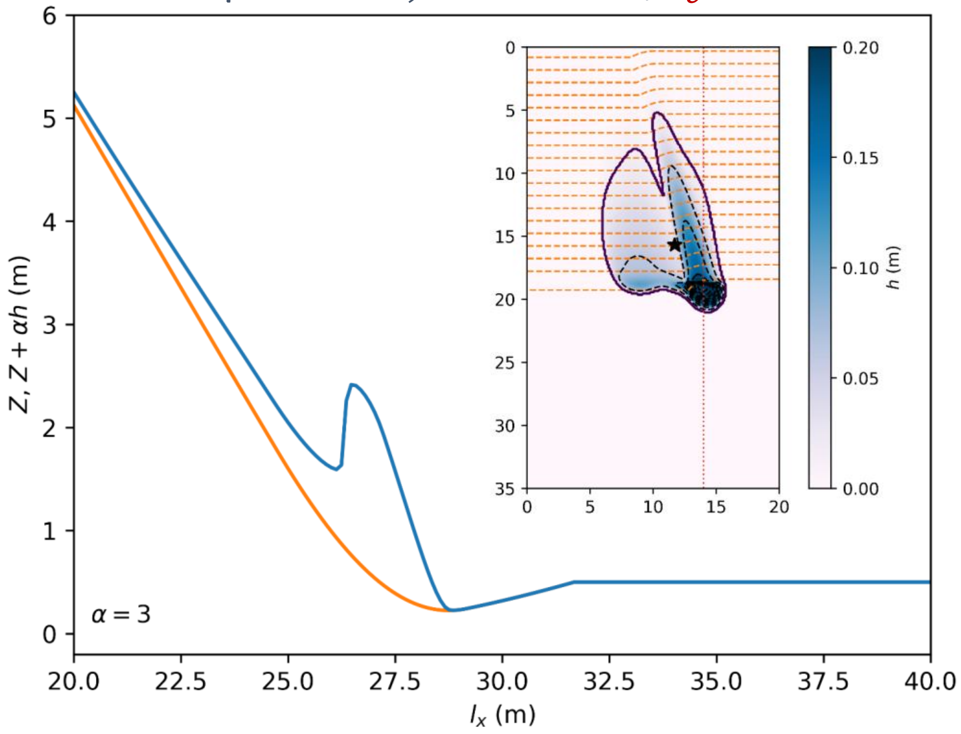
Specificity of cohesive flows

Can we approach cohesion effects with a plain Voellmy model?

$\mu = 0.5, \xi = 2000$ m.s^{-2}, $\tau_c = 150$ Pa



$\mu = 0.74, \xi = 400$ m.s^{-2}, $\tau_c = 0$ Pa



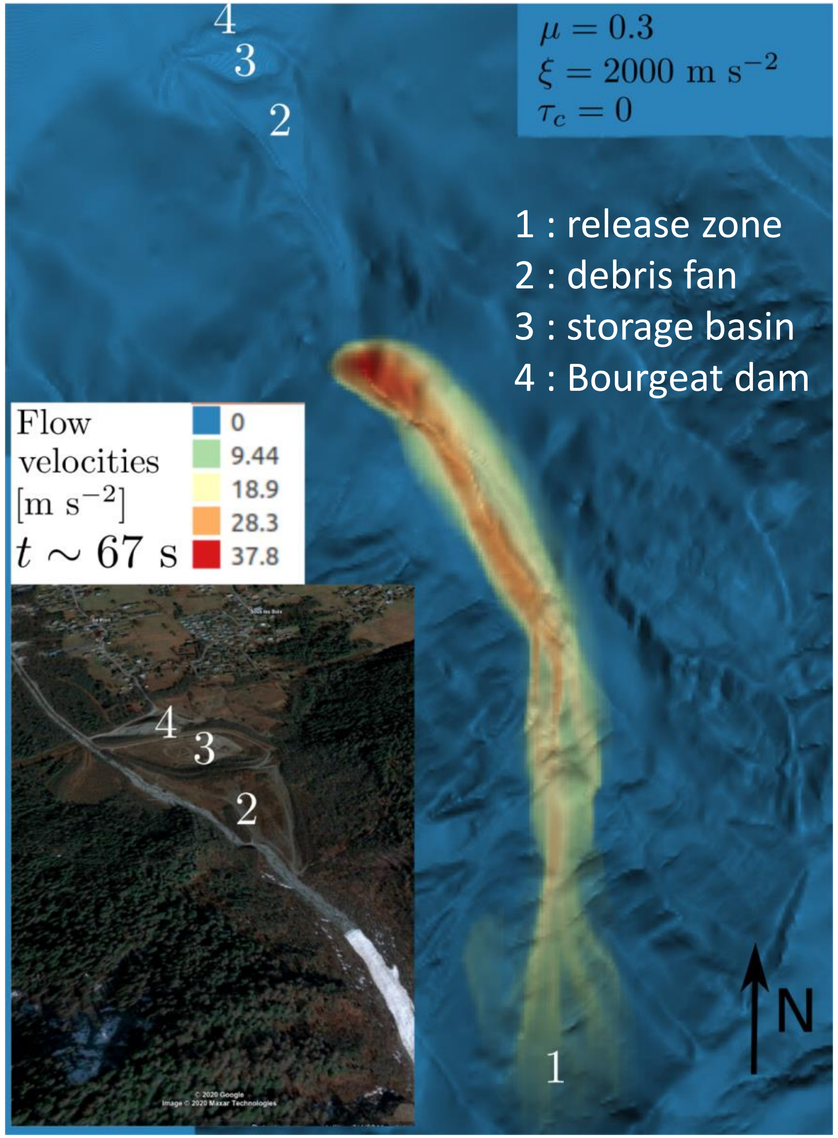
- ➢ Voellmy model leads to wider and steeper deposits

  ❖ *Note the steep jumps that lead to slow deposit rearrangements*

Full-scale simulations of snow avalanches

Same depth-averaged modelling approach:

- robust, shock capturing numerical scheme
- Bourgeat avalanche track and protection dam (Chamonix, France)
- systematic sensitivity analyses



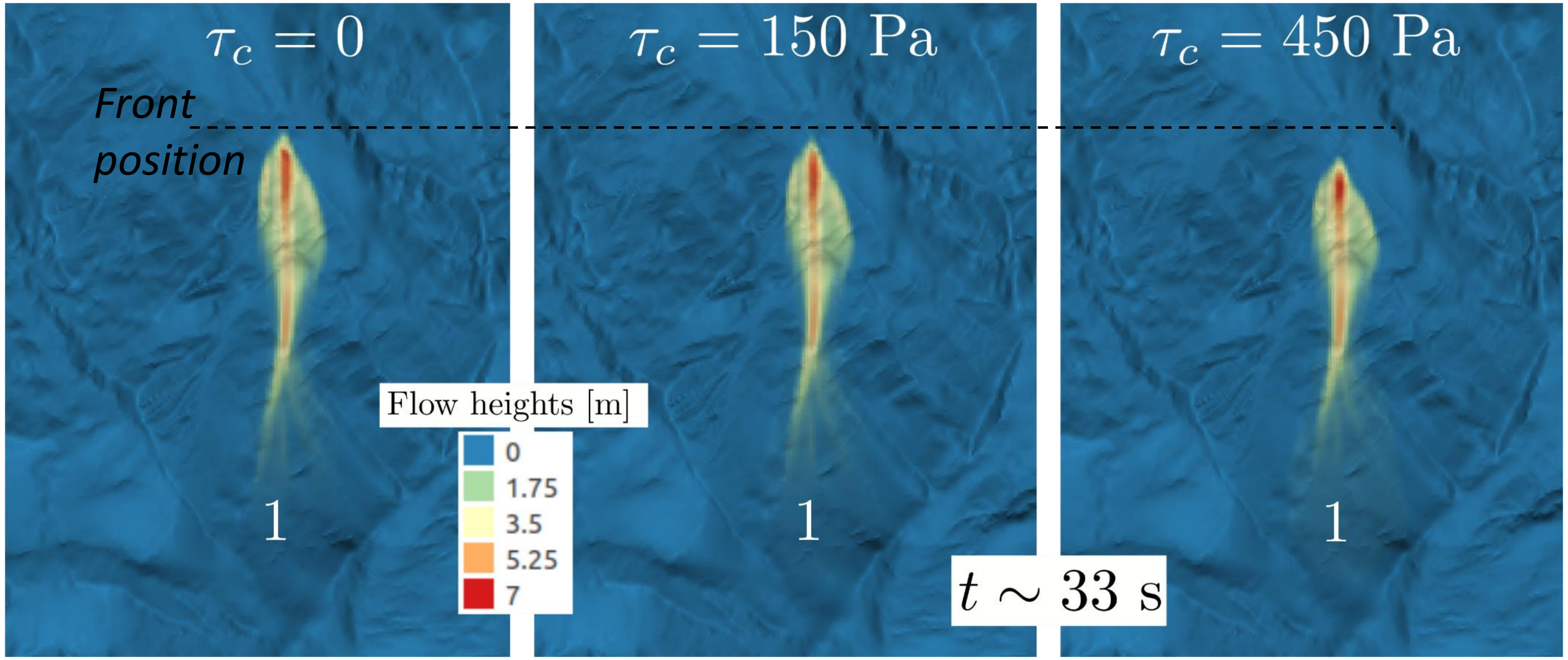
- Initial condition:
  - Release area of about 175 000 m^2
  - $h_0 = 2.0$ m

- 10 m digital terrain model
- $\mu = 0.3$, $\xi = 2000$ m.s^{-2}
- $\tau_c = 0 - 600$ Pa

Full-scale simulations of snow avalanches

Flow heights during avalanche propagation:

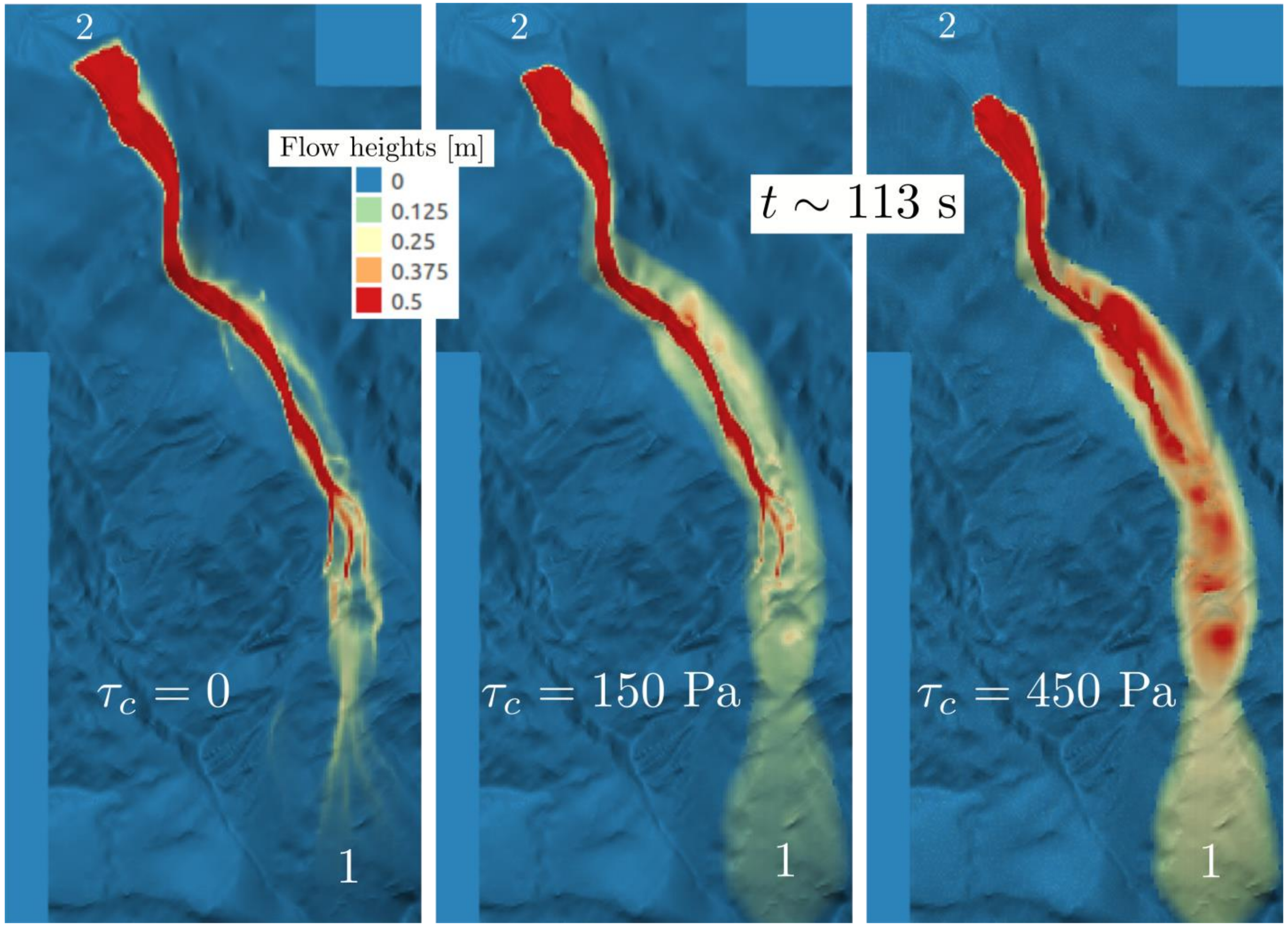
- ❖ about half a minute after avalanche release



➢ Voellmy model leads to thinner and faster flows in the starting zone

❖ *The differences are not so pronounced (steep slope and initial times of the flow)*

Full-scale simulations of snow avalanches



Flow heights during avalanche propagation:

- ❖ in the run-out zone (debris fan), upstream of the storage basin and Bourgeat dam
- ❖ nearly two minutes after avalanche release

➢ Cohesive flow induces much longer tails

❖*Note the significant time lag between Voellmy model flow and cohesive flows*

Conclusions

How to model wet snow avalanches?

- Cohesion can explain certain distinctive features of wet snow avalanches:
  - *flow channelization and concentration*
  - *topographical control*
  - *slower dynamics*

- Voellmy model with increased dissipation can reproduce overall behavior of cohesive flows (runout, max velocity), but fails to capture flow duration and deposit morphology

- To go further:
  - *detailed comparisons with experimental and field data*
  - *introduction of a viscous contribution to the rheology (pasty dynamics)*
  - …