New modeling tools under development

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Information meeting on the R&D project Snow Avalanches
Gardermoen, 2016-11-02
The most important slide

- Avalanche models are but one tool among several that support the experts in their assessment of avalanche problems.
- Models are by definition simplifications of the real world.
- They follow the GIGO principle: Garbage In — Garbage Out.
- It is the experts’ duty to be aware of the models’ limitations!
- DO NOT BELIEVE A PLOT JUST BECAUSE IT HAS NICE COLORS!
Main types of dynamical models

- Mass-point models (0D):
  - Avalanche treated as mass point, based on $a(s) = g \sin \theta(s) - \frac{F_f(s,v)}{m}$. 

![Diagram showing the dynamics of an avalanche](image)
Main types of dynamical models

«Mass-cloud» models with internal structure (0.5D):
- E.g. density or mass change due to internal pressure or entrainment.
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   - Avalanche treated as mass point, based on \( a(s) = g \sin \vartheta(s) - F_f(s,v)/m \).

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➤ Discrete element models (1D, 2D, 3D):
   - Track (very many) particles, compute their collisions explicitly.

➤ Continuum models (2D, 3D):
   - Local balance equations for mass, momentum (and granular temperature)
     \[
     \partial_t \rho + \nabla \cdot (\rho u) = 0
     \]
     \[
     \partial_t (\rho u) + \nabla \cdot (\rho uu) = -\nabla p + \nabla \cdot \sigma + \rho g
     \]
Main types of dynamical models

Depth-averaged continuum models (1.5D, 2.5D):
- Average continuum model over bed-normal direction: 1D, +1 variable

\[ \partial_t (h \rho) + \nabla \parallel \cdot (h \rho \mathbf{u} \parallel) = q_e \]

\[ \partial_t (h \rho \mathbf{u} \parallel) + \nabla \parallel \cdot (h \rho \mathbf{u} \parallel \mathbf{u} \parallel) = h \rho \mathbf{g} \parallel - \nabla \frac{\rho h^2 g \perp}{2} + \nabla \cdot \mathbf{\tau}_b + q_e \mathbf{u}^{(i)} \parallel \]

- Constitutive equation for bed shear stress: \( \mathbf{\tau}_b = f(\rho, h, \mathbf{u}) \)
- If \( \rho \neq \text{cst.} \), need an equation of state: \( \rho = f(\rho, \ldots) \).
- Entrainment rate: \( q_e = f(\rho, h, \mathbf{u}, \text{snow-cover parameters}) \)
Dynamical models developed at NGI

- Mass-point models (Coulomb, **PCM**, Bingham, Herschel–Bulkley)
- Mass-cloud model with variable density and friction law derived from Norem–Irgens–Schieldrop (NIS) model
- 1.5D NIS model
- **MoT-Voellmy** (2.5D, similar to RAMMS)
- **D2FRAM** (Dynamical 2-Flow-Regime Avalanche Model, 2.5D)
- BingClaw (2.5D, Bingham and Herschel–Bulkley rheology, automatic mesh refinement; developed in another project)

Models shown in blue are frequently used at NGI at this time (besides α-β, RAMMS).
Block models in a GIS environment:

- Quick and easy
- Ideal for exploring suitable friction parameter values
- Velocity and pressure color-coded along the path
MoT-Voellmy: Basic features

Based on Voellmy friction law: Assume bed shear stress is

$$\tau_b = \frac{u}{|u|}[\mu gh \cos \theta + k u^2]$$

- $\mu$ = dry-friction coefficient (typically 0.15–0.4)
- $k = g/\xi$ = «turbulent» friction coefficient (typically $10^{-3}$–$10^{-2}$)

Very similar to RAMMS, but uses simplified Method of Transport to solve mass and momentum balance equations.

Can be used stand-alone or tightly integrated in GIS.
MoT-Voellmy: Input

- Command file specifying input files and model parameters
- Digital terrain model with square grid (2–10 m resolution)
- Raster file with release area(s) and fracture depth
- Optional raster files with snow-cover depth, shear strength, local friction coefficients, forest density × avg. tree diameter

Choice of friction parameters:
- If no entrainment, same values can be used as with RAMMS.
- Use alternative calibration for more realistic velocity (larger $\mu$, smaller $k$).
MoT-Voellmy: Output

- Raster files with spatial distribution of maximum flow depth and speed

- Raster files at selectable time intervals with
  - flow depth, speed,
  - optionally snow cover depth (erosion), velocity components
  - Can be animated
MoT-Voellmy: Entrainment

- Options to run simulations with
  - no entrainment,
  - RAMMS entrainment model (specify erodible snow depth and $0 < \lambda < 1$),
  - IsJo model (specify erodible snow depth, snow shear strength $\tau_c$)

- IsJo model assumes entrainment rate $q_e$ to be given by how much snow the excess bed shear stress, $\tau_b - \tau_c$, can accelerate to avalanche speed:

$$q_e = \frac{\tau_b - \tau_c}{\rho_s u} \quad \text{if} \quad \tau_b > \tau_c$$

Not unique, but at least dynamically consistent and reasonable.
Dynamical 2-Flow-Regime Avalanche Model

Basic field observations:

- Three different deposit types corresponding to dense flow, intermediate-density flow (IDF), and powder-snow cloud.
- IDF contains large particles at high speed.
- Avalanche front tends to have lower density than main body.
- Highest velocities associated with IDF.
- IDF often has much longer run-out than main body.
Characteristic field observations

1995 Albristhorn avalanche, Switzerland

- Deposit area of dense flow
- Deposit of fluidized part

Photo S. Keller
Massive erosion (approx. 1 m), no deposit.
Deposit of a small mixed avalanche, photo taken in a region not reached by the dense flow (after sharp bend of gully).

Photo Mark Schaer, SLF
Radar data

FMCW-radar shows that avalanche front is less dense (light blue) than core (dark blue) and can be far ahead of the core.

Measurement data from Vallée de la Sionne, Switzerland, Febr. 1999.
D2FRAM – Fluidization mechanisms (1)

From granular flow experiments:

- Effective friction increases (moderately) with shear rate.
- Density *decreases* with increasing shear rate.
- Both effects are due to *particle collisions*. 
Norem–Irgens–Schieldrop (NIS) model contains a full rheological description of constant-density granular flowing snow:

- Quasi-static friction (friction coefficient \( \mu \))
- Dispersive normal and shear stresses \( \propto \dot{\gamma}^2 \)
- If dispersive normal stress exceeds avalanche weight, fluidization occurs.

But NIS model does not describe the fluidized flow and the density dependence of the rheological parameters.
Towards the Dynamical 2-Flow Regime Avalanche Model

D2FRAM can be seen as an extension of the NIS model:

- Density-dependent coefficients $\nu_n$, $\nu_s$ from theoretical calculations and discrete-element simulations in the literature.
- Above fluidization threshold, density is continually adapted to balance weight against dispersive normal stress.
- Dry friction ($\mu$) is irrelevant in the fully fluidized regime!
- So far implemented only as block model describing the avalanche front.
Concentration/density dependence of the coefficients of $\dot{\gamma}^2$ for normal and shear stress following theoretical calculations and numerical simulations.

Flow tends to the concentration that leads to balance between gravity and friction.
Block-model implementation

Promising results, but fluidization is too weak!

If avalanche density drops to 30–100 kg m$^{-3}$, air must enter the avalanche mass. Where does this air come from?

Mixing with ambient air is a likely mechanism:
- Stagnation pressure at the snout
- Suction at the top of the head
- Pressure gradient across the head

Included in block model through lift force, but does not seem to be sufficient with realistic lift coefficient.
Are avalanches hovercrafts?

- Snow cover collapses under weight and shear of avalanche.
- Snow compression by 10% creates $O(10 \text{ kPa})$ overpressure.
  - Air in snow cover tries to escape through avalanche, pore-air pressure lifts avalanche.
- Permeability of avalanche determines how quickly air escapes, i.e., how much of the avalanche rides on air cushion.
- Air cushion can reduce friction near front dramatically
  - long run-out!
Fluidization by snow-cover collapse: implications

- Excess pore pressure is a fraction of the overburden.
- Density of snow cover is important for air content and compression ratio.
- Pressure gradient across avalanche diminishes from head to tail.
  - Corresponding decrease of velocity and increase of density.
- Air escape time increases with snow-cover depth.
  - Larger fraction of avalanche is fluidized.
- Fluidization lets air escape more quickly.
The most important slide, once again…

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