The Dynamics of Avalanches

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Plan of Talk

- Types of Avalanche
- Avalanche Initiation
- Avalanche Defences
- Avalanche Flow
  - Theory
  - Observations
  - Experiments
  - Simulations
- Avalanche Deposition
Manda III, 6529m
NW Face Manda III
Powder Avalanche on K2

Pierre Beghin, film
Head of Powder Snow Avalanche

Cemagref
Slab Avalanche Fracture Line, film
Skier in Slab Avalanche Debris  Cemagref
Patreksfjörður 1983, a Slush Flow Killed 3 People
Destroyed House at Saint Colomban Les Villars, film
Destroyed Buildings at La Morte
Damage by a flood wave at Súgandafjörður
CO₂ Avalanche on Mars
Current Avalanche Research

- Huge variety:
  - speeds 25–250 km/h
  - densities 5–500 kg/m$^3$
  - masses $10^2$–$10^9$ kg

- Three dimensional terrain and structure
- Snow properties are complicated and ill-defined
- Unpredictable, destructive, unreproducable
- Current theories are phenomenological
- Genesis of powder snow avalanches not understood
雪崩に巻き込まれて女性死亡
1人軽症、2人無事
ニセコの立入禁止区域で
Location of Niseko in Japan (N 42’ 52" E 140’ 42")
Haru no Taki
Accident Site
Snow Morphology

The diagram illustrates the relationship between supersaturation (g/m³) and temperature (°C) to show different types of snow morphology. The x-axis represents temperature ranging from 0°C to -35°C, while the y-axis represents supersaturation from 0 to 0.3 g/m³. Different types of snow crystals are represented at various supersaturation levels and temperatures:

- Plates
- Columns
- Dendrites
- Needles
- Hollow columns
- Sectored plates
- Thin plates
- Solid plates
- Solid prisms
- Water saturation

The diagram shows how these different types of snow crystals form under specific supersaturation and temperature conditions.
Meteorological Data 17th to 29th January, 1998

Temperature (°C)

Wind speed (m/s)

Solar radiation (W/m²)

Snow depth (m)

Snow count
Snow Pit Profiles

January 1998, at 10:00

Photos: Dr. Libbrecht
What is This?
Avalanche Accidents in Iceland
Icelandic Coast
Flateyri in Summer
Flateyri Avalanche 1999
Large Scale Defence Structures
Defence Structures in the Starting Zone
Church in Davos
Flateyri Deflecting Dam, $5.5m

© Mats Wibe Lund
Flateyri Simulations With and Without Deflecting Dam
Test Chute in Davos
Laboratory Experiments

- Air pressure sensor

*front view*

*side view*
Side View 8 Litre Avalanches

- 31.5° slope
- 58.5° slope
- 91.0° slope

100 ml side
8000 ml side
Non-Dimensional Velocity \( \tilde{u} = \frac{u}{\sqrt{\frac{1}{6} g}} \).
Direct Numerical Simulations

- 2d spectral with compact finite differences
  Meiburg Code
- Simulation region $8 \times 1$
- Release area $2 \times 0.5$
- Slope angles $0–90^\circ$
- Boussinesq and non-Boussinesq

Test hypothesis:

**stagnation point is lowest point as $Re \rightarrow \infty$**
Time evolution, Re=32,000, Slope=10°
Time evolution, $Re=32,000$, Slope=$60^\circ$
Re Comparison at slope 20°
Re Comparison at slope 40°
Front Speed

![Graph showing the relationship between Front Speed and Slope angle for different DNS pressures (2k, 4k, 8k, 16k, 32k, 64k). The graph indicates that as the slope angle increases, the front speed decreases.](image_url)
Vallée de la Sionne Test Site

- Artificial and Natural Releases
- 1000–1 000 000 kg
- 10–100 m s$^{-1}$
- Instrumentation
  - Video
  - Laser Scanning
  - Impact & air pressure
  - Dopper & FMCW Radar
  - Density
  - Velocity profiles
Mast and Thermal Imaging

[Image of snow-covered mountain landscape with a mast in the foreground]

[Thermal imaging images of mountain top with temperature readings]
Ping-Pong Ball Avalanches
Front Velocities at the K-Point

- Number of balls (log scale)
- Velocity \((\text{ms}^{-1})\) (log scale)

\[ v = 1.8n^{1/6} \]

experiment
A One Equation Model

Constant length scale $L$
Conservation of linear momentum

\[ \frac{dv}{dt} = g \sin \theta - g \mu \cos \theta + \mu \kappa v^2 - \frac{v^2}{L} \]

where $m$ is mass
$v$ - speed
$s$ - distance
$\theta$ - slope angle
$g$ - densimetric gravity
$\kappa = d\theta/ds$ - curvature
$\mu$ - friction
$L$ - drag length
Comparison with Model

- 10,500 balls
- 21,000 balls
- 42,000 balls
- 84,000 balls
- 168,000 balls
- 320,000 balls

Velocity (m/s) vs. Flow distance (m)

- Measurements
- With curvature
- Without curvature

- Comparisons for different ball counts.
Comparison with Velocity Data From VdIS

Avalanche no. 200

Avalanche no. 509

Avalanche no. 628
Deposition
Riegl LMS-Q240i laser scanner

- time of flight principle
- 10,000 points per second
- horizontal resolution 500 mm
- vertical resolution 100 mm
- high density of points
- inertial measurement
- GPS
Snow depths variations $h_\delta$
Bunker Rescue
Average snow depth variation $\bar{h}_\delta$
Deposit depth

\[ \rho gd \sin \theta = c + \mu \rho gd \cos \theta \]
Conclusions

- Simple theories can be very effective for flow and deposition
- Avalanche initiation is very complicated
- Synergy between Simulations, experiments and field observations
- Advances in instrumentation can really test models quantitatively
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Chute Experiments

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*Images of chute experiments showing various stages of snow deposition.*