Velocity distributions in the head of cold-dry snow avalanches

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Motivation, Research Question and Hypothesis

▷ Understand the characteristics of a fully developed powder snow avalanche

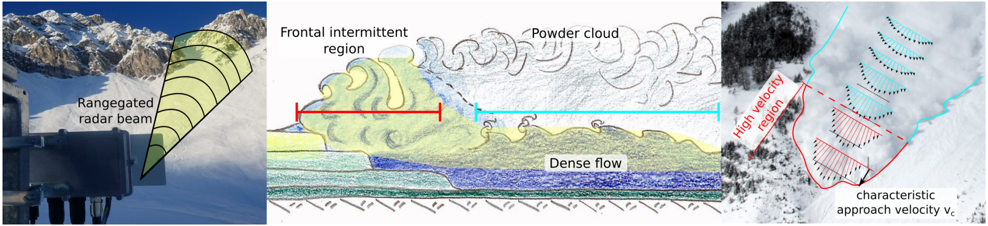
? When does a cold-dense avalanches **evolves** into a powder snow avalanche?

? Is the **front velocity** a **representative measure** for dry snow avalanches

! Above a certain velocity / size:
A **high-velocity head** develops

Radar observations of cold-dry snow avalanches

- We measure avalanche velocities with a range-gated Pulse Doppler Radar
- analyze 30 avalanches from 3 pathes with dropheights 400, 900 & 1200 m

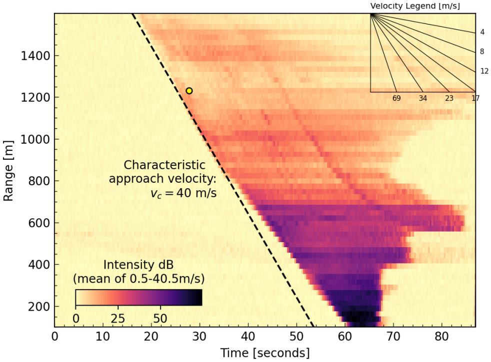


- The radar "sees" all material larger $\lambda \approx 5\,\mathrm{cm}$, averaged in range-gates:

Powder cloud ✗, intermittent/fluidized layer ✓, dense flow ✓(mostly surface)

$\rightarrow$ Mass, volume & density are difficult to infer from radar cross-section

Range-Time Diagram of Radar intensities

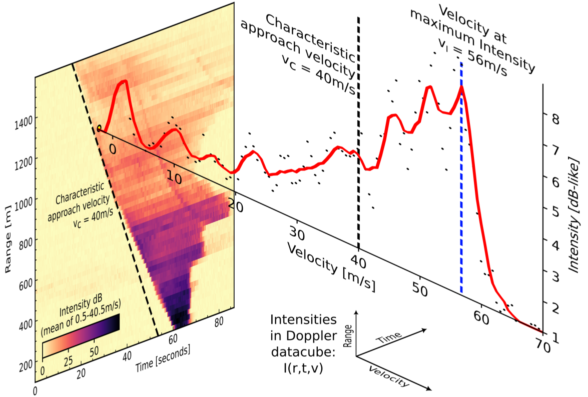


- Approaching avalanche with time
- sampled in 25 m range-gates at 10 Hz
- Slope of features → velocity
- **characteristic approach velocity** v_c from a manually defined tangent at highest velocity (steady state) (not valid for accel-/decceleration)

But Doppler radar gives more: velocity distribution ...

Velocity distribution inside a Doppler datacube

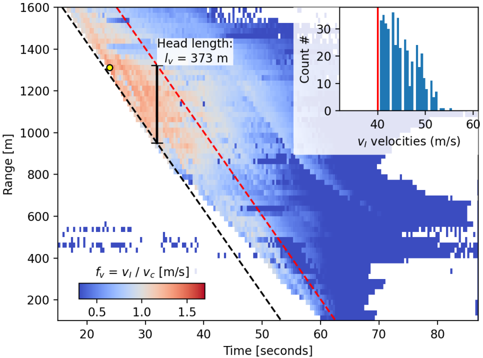
A velocity spectrum $I_{r,t}(v)$ is measured for each range-gate r and pulse t over a spatial slice through the full avalanche width



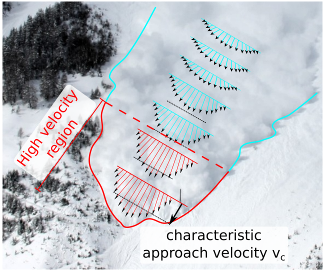
- Velocity at which "most" material flows: Velocity at maximum intensity v_I

▷ Definition of **velocity factor** $f_v = \frac{v_I}{v_c}$ between material and approach velocity

Range-Time diagram indicates high velocity region



- High-velocity head for $f_v > 1$ (red)
- Distribution of head velocities v_I (inset)
- **Head length** l_v is distance to front
- **Maximum head velocity** $\widehat{v_I}$ (yellow dot)

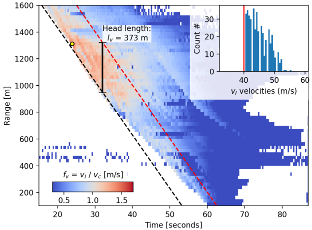


High velocities define the avalanche head and promote frontal surging

Avalanche head for three avalanche sizes

Examples from 3 avalanche pathes:

Vallee de la Sionne (1400Hm)



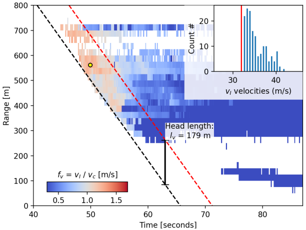
$v_c = 40\,\mathrm{m/s},\ \widehat{v_I} = 56\,\mathrm{m/s}$

$f_v = 1.4$

$l_v = 373\,\mathrm{m}$

$\rightarrow$ large head

Ryggfonn (900Hm)



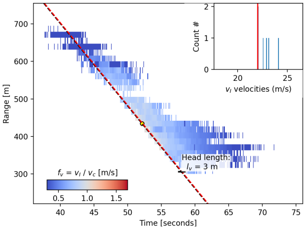
$v_c = 32\,\mathrm{m/s},\ \widehat{v_I} = 42\,\mathrm{m/s}$

$f_v = 1.3$

$l_v = 179\,\mathrm{m}$

$\rightarrow$ medium head

Nordkette (400Hm)



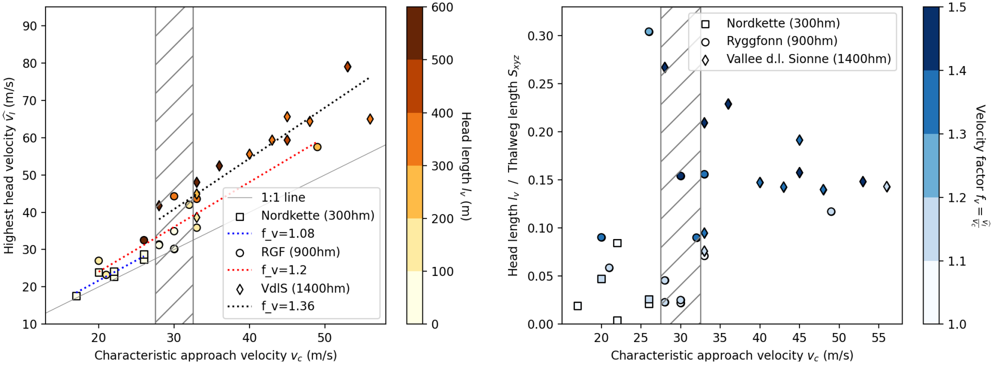
$v_c = 22\,\mathrm{m/s},\ \widehat{v_I} = 24\,\mathrm{m/s}$

$f_v = 1.1$

$l_v = 3\,\mathrm{m}$

$\rightarrow$ no head

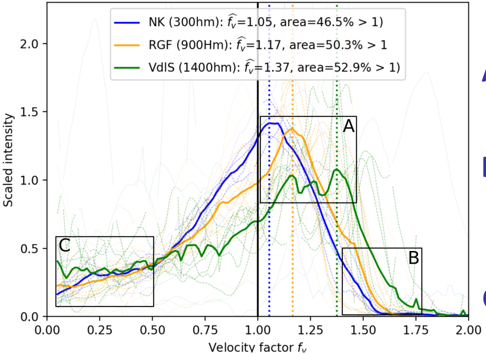
Head formation: velocity as requirement



- Formation of high-velocity head above $\approx 30\,\mathrm{m/s}$ $\rightarrow$ min. velocity for PSA
- But environmental conditions (snow temperatures, volumes, etc.) are crucial

Intensity distribution at maximal velocity $\widehat{v_I}$

Looking at the spectrum of points with heighest material velocities in the head:



◁ Averaged distribution for all avalanches

A distribution peak shifts with size
→ main material flow

B maximal velocities are 50-80% higher than characteristic approach velocity v_c
→ small scale features

C always low velocities
→ rangegate volume average

Is **A** or **B** the most destructive zone in the avalanche?

→ We miss the density ρ to estimate impact forces that are $\propto \rho v^2$

Conclusions and summing up

- High-velocity head develops above $\approx 30\,\mathrm{m/s}$ in powder snow avalanches:

$\rightarrow$ approach velocity underestimates **material velocities up to 30-40%**

$\rightarrow$ approach velocity underestimates **highest velocities up to 50-80%**

- High-velocity head supports frontal surging and may explain the high mobility of fully-developed powder snow avalanches
- Approach velocity is a limited design parameter for impact forces (density?)

Further open question:

? Which conditions (volume, topographie, snow properties) favour the growth and maintenance of the head?

? How can we incorporate the results in current numerical models?