EGU25-19048, updated on 29 Aug 2025
https://doi.org/10.5194/egusphere-egu25-19048
EGU General Assembly 2025

Velocity distributions in the head of cold-dry snow avalanches

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Snow avalanches establish several flow regimes ranging from highly turbulent and intermittent flow in cold powder snow avalanches to uniform sliding in warm dense plug flow avalanches. To assess the different flow regimes, radar observations proved useful as they are independent of visibility conditions, but more importantly penetrate through the covering suspension powder cloud and measures the denser flow underneath. Here we focus on data from pulse Doppler radar that tracks the whole velocity spectrum in time and space.

Our analysis allows us to extract several velocity metrics. For each part of the avalanche throughout the duration of the flow, the material velocity is found at the velocity of highest radar intensities and a maximal velocity can be defined. Depending on the flow regime, these velocities reach up to 75 m/s. Additionally, the frontal approach velocity is estimated by tracking the avalanches' leading edge in time and space.

We analyze the Doppler radar data of 30 dry-cold avalanches in three locations covering altitude differences along their thalweg between 1400 m, 900 m and 400 m. For each of the 30 avalanches, we compare their material velocities against their "steady state" or characteristic approach velocity that is derived from the front velocity. For the largest avalanches, we find the head of the avalanche is characterized by material velocities exceeding the front velocity by a factor up to 1.4. This causes an intermittent flow and surges that frequently overtake the avalanche front. Such an avalanche head seems only to exist for fully developed powder snow avalanches, that have a front velocity larger than 30-35m/s.

In contrast, smaller dense avalanches have the highest material velocities directly at the front and the flow dynamics is well-represented by the frontal approach velocity. Nevertheless, we observe for all dry-cold avalanches that at some locations maximal velocities can be up to 50 to 80% higher than the front. Today, common avalanche models used in operational simulation tools do not allow for processes like the frontal surging and likely underestimate velocities and therefore local or point pressures. Our results may support the development of flow regime specific computational avalanche simulation approaches and provide reference data for model evaluation.