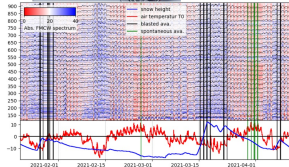
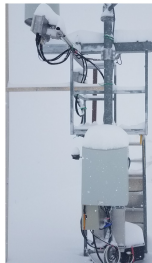
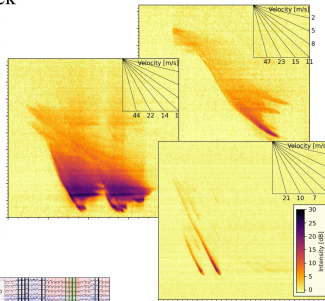




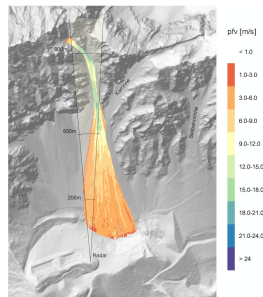
I) mGEODAR radar is installed autonomously at Nordkette/Innsbruck



II) Range-Time data of ~50 avalanches show very different flow evolution



III) Simulation studies with synthetic radar data to reproduce the variability



IV) Microwave snow cover scanning - a practicable ground-truth application for satellite based observations and potential avalanche precursors?

[Read full abstract](#)



Radar imaging has become increasingly important in either the detection of avalanches or in the scientific characterization of the avalanche flow. Detection radars usually base on the Doppler radar principle that is sensitive to the velocity of moving object but lack sufficient resolution which can be circumvented with frequency-modulated pulsed radars. We present a new radar device as a follow up of the successful GEODAR radar that suit the need for both applications low resolution detection and high resolution observation. While the original radar is permanently installed in the full-scale avalanche Test site “Vallée de la Sionne” in Valais, Switzerland, the new device mGEODAR is smaller and can be deployed in response to the metrological forecast and avalanche situation. Currently the mGEODAR is installed at Nordkette ski resort above Innsbruck that is known for its frequent artificial avalanche releases. The new radar features a versatile frequency generation scheme using direct digital synthesis and can be quickly reprogrammed into a low-resolution detection mode for continuous data recording that switches to a high-resolution observation mode as soon as an avalanche is detected.

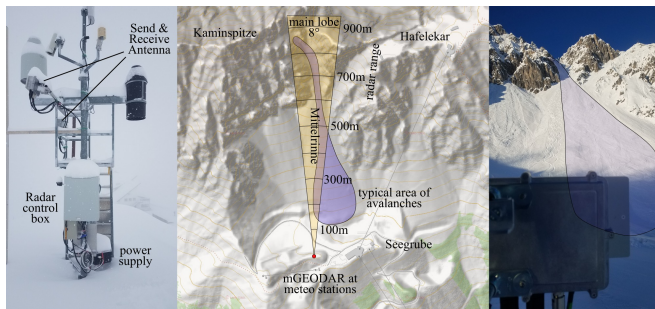
Beside the radar system itself, avalanche data are presented of the winter season 2020/21. A focus is on small to medium sized avalanches that are just on the limit to develop into a powder snow avalanche which is characterized by surging in the intermittent frontal region. Connecting the radar data of the dynamic flow evolution with snow conditions will lead to drivers of this flow regime transition. The snow conditions are taken from nearby weather stations and manual snow profiles but also from the radar itself. A continuous scanning of the resting snow cover in the avalanche path during the season further allows snow cover monitoring. This application allows to identify new snow fall, warming and wetting of surface layers as well as diurnal melt-freeze cycles.

The radar data should be consequently used for model validation, calibration, and development. With the current measurement campaign of small to mid-sized avalanches, we aim to close a gap in data availability for those events as they are increasingly the object of simulation scenarios, but current modelling and simulation tools are usually calibrated for larger and extreme events. In the future, we expect the mGEODAR radar to be deploy on other gravitational mass-movements phenomena like soil slides and rock-fall.



mGEODAR is a frequency modulated radar (FMCW) at 10.4 GHz (~ 2.5 cm wave): temporal ($\Delta t < 200$ pulses/s) and spatial resolution ($\Delta r > 0.35$ m) can be digitally set.

Nordkette above Innsbruck typically receives snow with northern weather systems. Frequent avalanche blastings secure ski resort and yield many small to mid-sized avalanches.

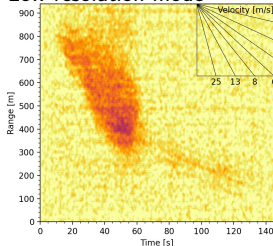


Note: Radar location not ideal as runout area is barely in the antenna beam.

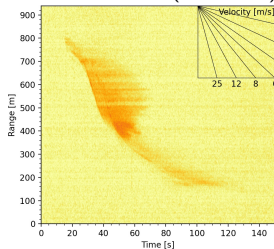
Köhler et al. (2020). mGEODAR - A Mobile Radar System for Detection and Monitoring of Gravitational Mass-Movements. *Sensors*, 20(21), doi: 10.3390/s20216373



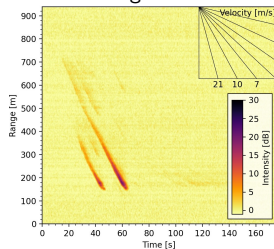
Low resolution mode



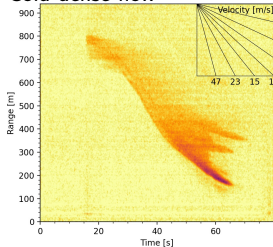
Warm shear flow (snowballs)



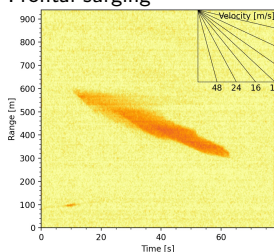
Thin shooting flows



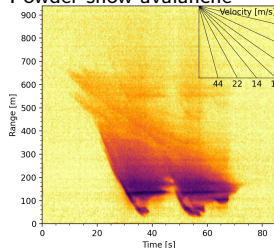
Cold dense flow



Frontal surging



Powder snow avalanche

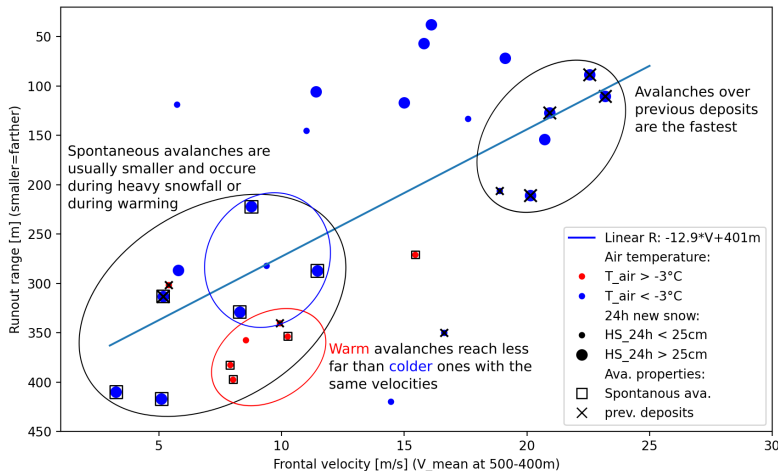


Same avalanche path can have very different avalanche flow types:

[See some statistics ...](#)

32 avalanche have been recorded along Mittelrinne avalanche path. Avalanches at warm temperatures are rare as they are usually spontaneous events and were missed.

The figure shows the runout range as a function of front velocity between 500–400 m. Size and colour represent 24h new snow and air temperature, respectively.

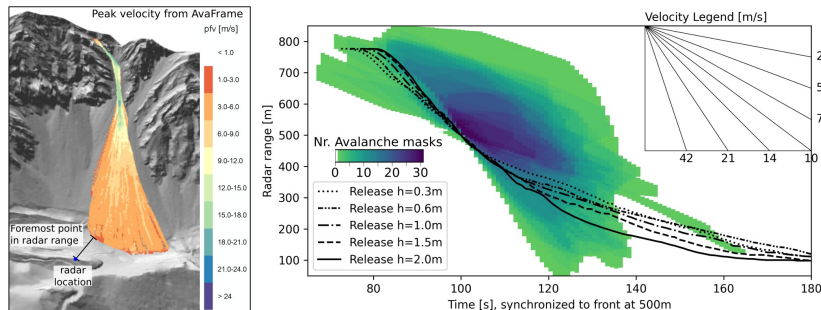




Avalanches in the range-time radar data are masked binarily. Flow variability is indicated by the sum of all masks that are synchronized when the front reaches 500 m range.

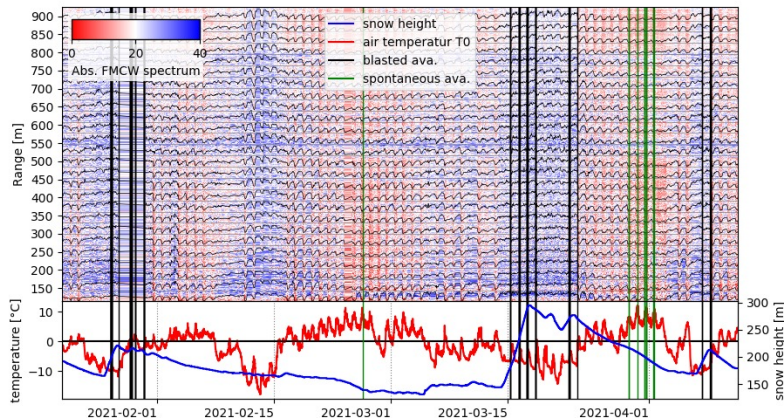
Preliminary simulations on 3D-terrain are performed with AvaFrame (avaframe.org): $\mu = 0.15$, $\rho = 200 \text{ kg m}^{-3}$, release area is fixed to 300 m^2 , no entrainment.

Simulations yield the foremost point at each timestep in radar range coordinates (lines)



Future: Reproduce the observed velocities ($5\text{--}25 \text{ m s}^{-1}$) and runouts (80–400 m), e.g. balance entrainment / deposition / lateral spread in the runout area ($< 500 \text{ m}$).

Hourly acquired scans of the static snow cover over the winter. Wet snow cover absorbs microwaves, dry snow yield higher reflectivity. Diurnal melt-freeze cycles are obvious.



Absence of refreeze at night indicates increased likely-hood for spontaneous wet avalanches.

Future: Combination of radar scans with snowpack models for avalanche forecast?

Local ground-truth validation for satellite based regional snow scanning missions.



Radar project *mGEODAR* is a great success and opens several directions for research

- ▶ mGEODAR development and data preprocessing :
 - ▶ Detection and high-resolution monitoring of gravitational hazards: avalanches, rockfall
 - ▶ Future real-time detection requires specific signal processing hardware
 - ▶ Narrow antenna beam could be circumvented with electro-mechanical pan/tilt mount
- ▶ Avalanche test-site “Nordkette” is ideal for small to mid-sized avalanche studies
 - ▶ Lots of snow = lots of artificial avalanches per season (2021: ~ 50)
 - ▶ Avalanche variability (sizes and flow types) is great and pose a challenge for ...
- ▶ Simulation studies over large parameter space
 - ▶ Which flow processes are relevant / missing / need improvement in models?
 - ▶ The simulated synthetic radar data can enhance interpretation of the radar data itself
- ▶ Microwave snow-cover scanning
 - ▶ Presented a qualitative result, quantification is much more challenging...
 - ▶ Interpretation/validation with chain of coupled snowcover and microwave model

Don't hesitate to get in touch for in-depth discussions, collaborations and data sharing!