Measuring snow weak layer collapse propagation with distributed fiber-optic sensing

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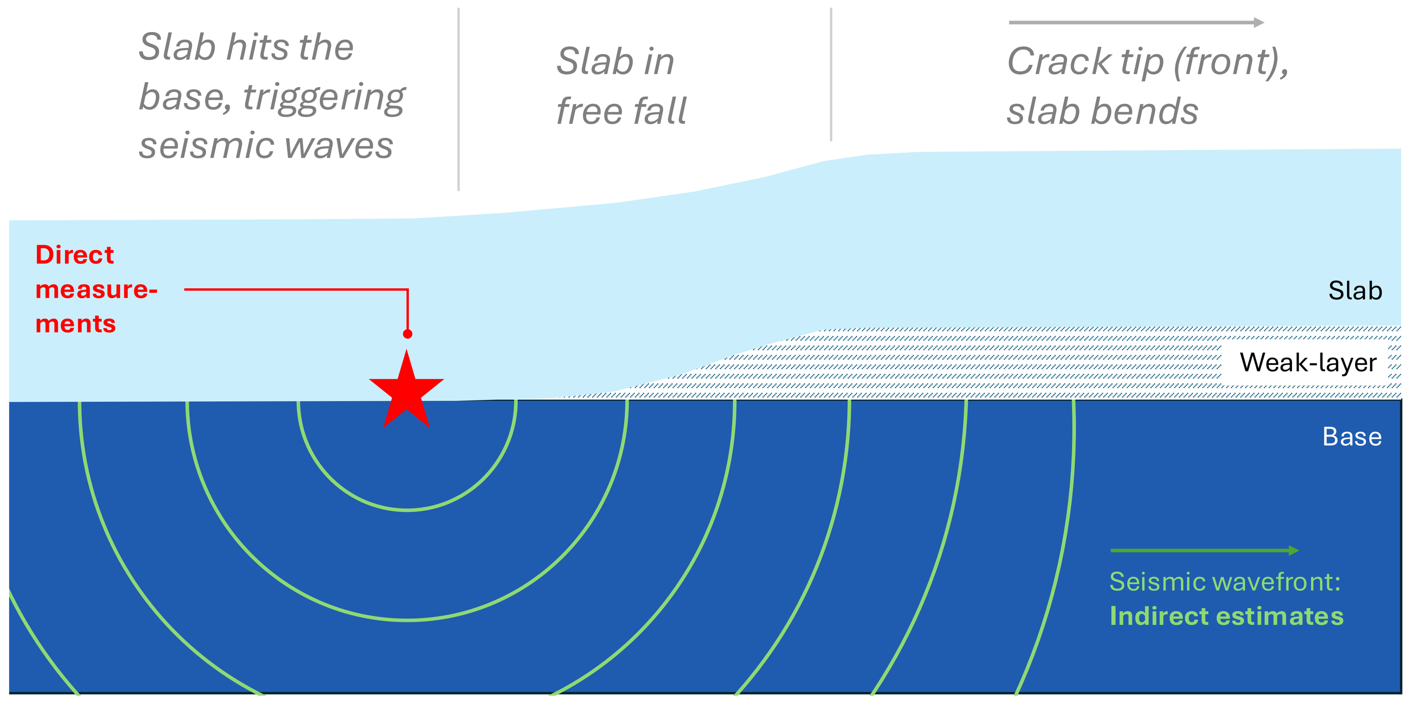
We use fibre-optic sensing to show that the seismic waves caused by an anticrack in a snow weak-layer provide *indirect* distance and speed estimates of its propagation. With a simple model we **estimate speed at 35.1 m/s over a distance of >800m**. We verify the estimate with a direct measurement of the anticrack. Fibre-optic seismology can be useful to improve mechanical models of snow weak layer collapse

Introduction

Snow slab avalanches are dangerous but fascinating. The collapse of a snow weak layer below a slab can self-propagate and release the slab as an avalanche

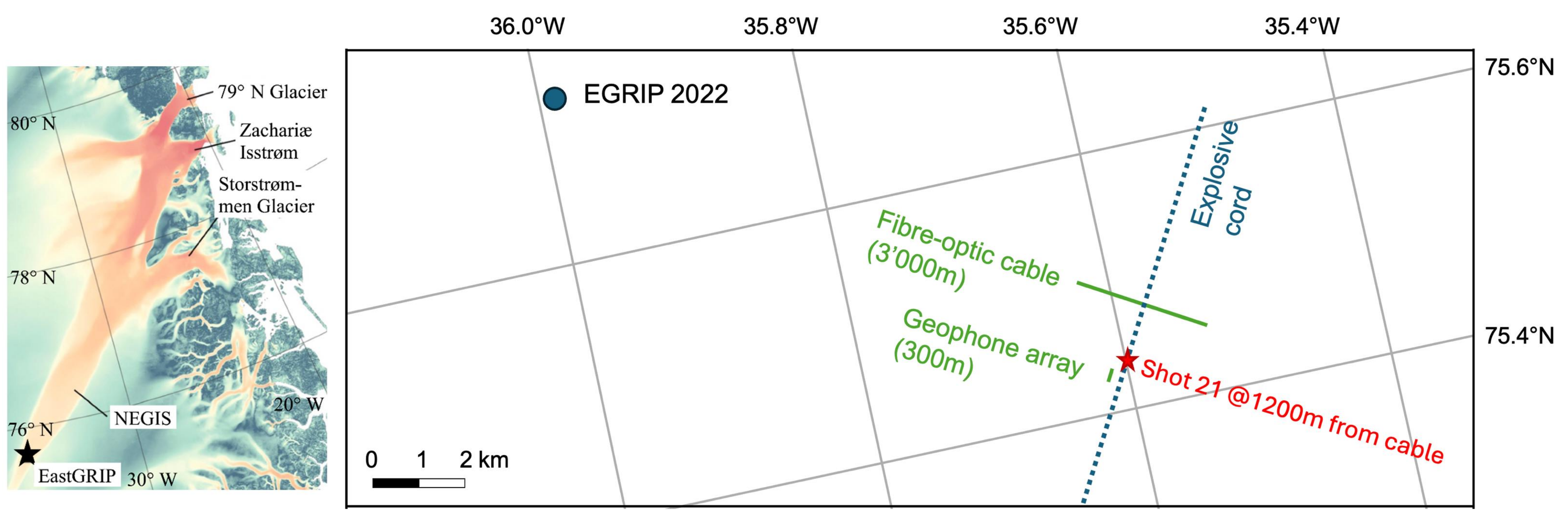
- Dynamics of weak-layer collapse can be controlled by anticrack or (super)shear propagation (Gaume et al., 2018; Heierli, 2008; Trottet et al., 2022). In flat terrain, it is only anticrack ("whumpf")
- Speed of propagation is essential to determine the dynamics. Knowing the propagation distance helps to predict avalanche size (van Herwijnen, 2023)
- Previous research has used seismometers to take the time between fracture initiation and vertical displacement of the slab and used this for *direct* speed measurements (e.g. van Herwijnen & Schweizer, 2011)



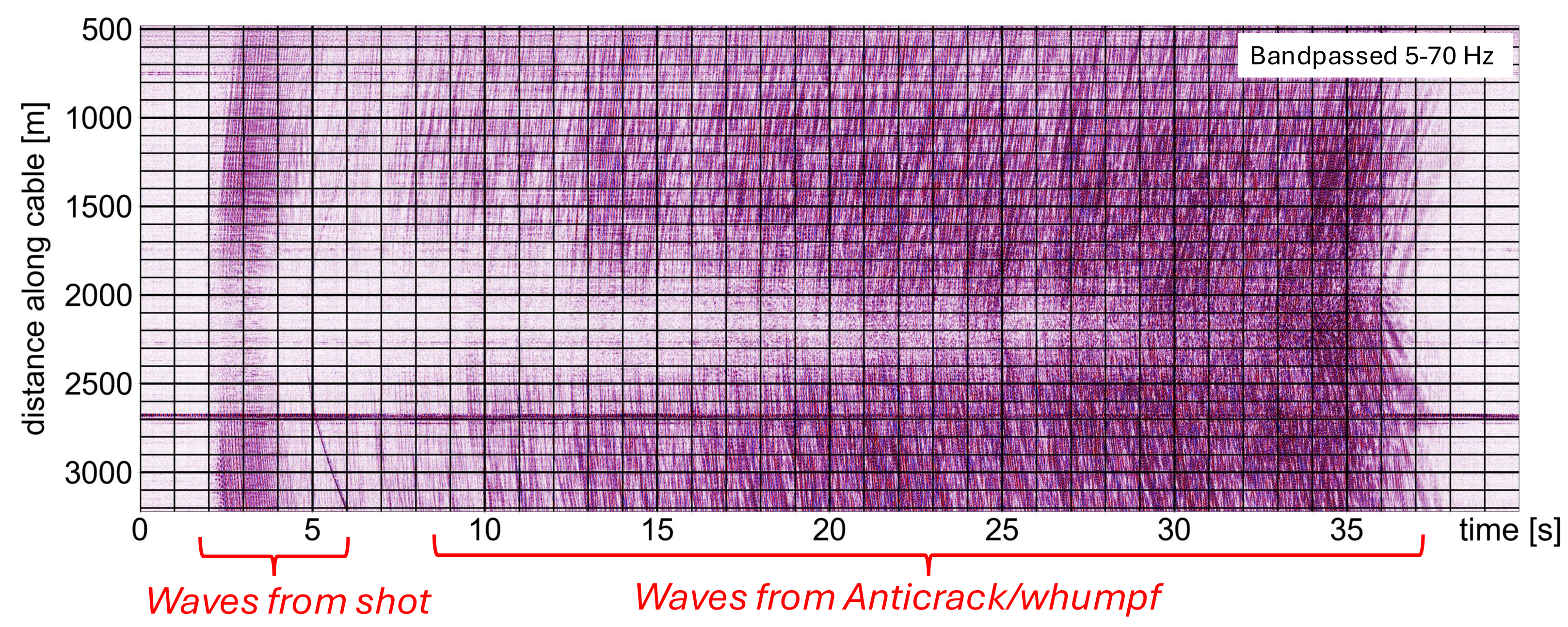
Data

The data was recorded in the upper part of the Northeast Greenland Ice Stream (NEGIS) in July 2022 by Fichtner et al. (2023). Recording the whumpfs was coincidental

- **Homogenous snowpack in flat terrain** – Can expect large propagation distances. No snowpack measurements during this data collection, nearby available
- **Recordings with fibre-optic and geophones** – Fired a series of shots and recorded the signal with a fixed fibre optic cable and a geophone array always behind the shot



- **Whumpfs in the seismogram** – Eight shots were followed by snowpack settling which we identified as "whumpfs". Here we show the fibre-optic recording from an example shot (figure below)



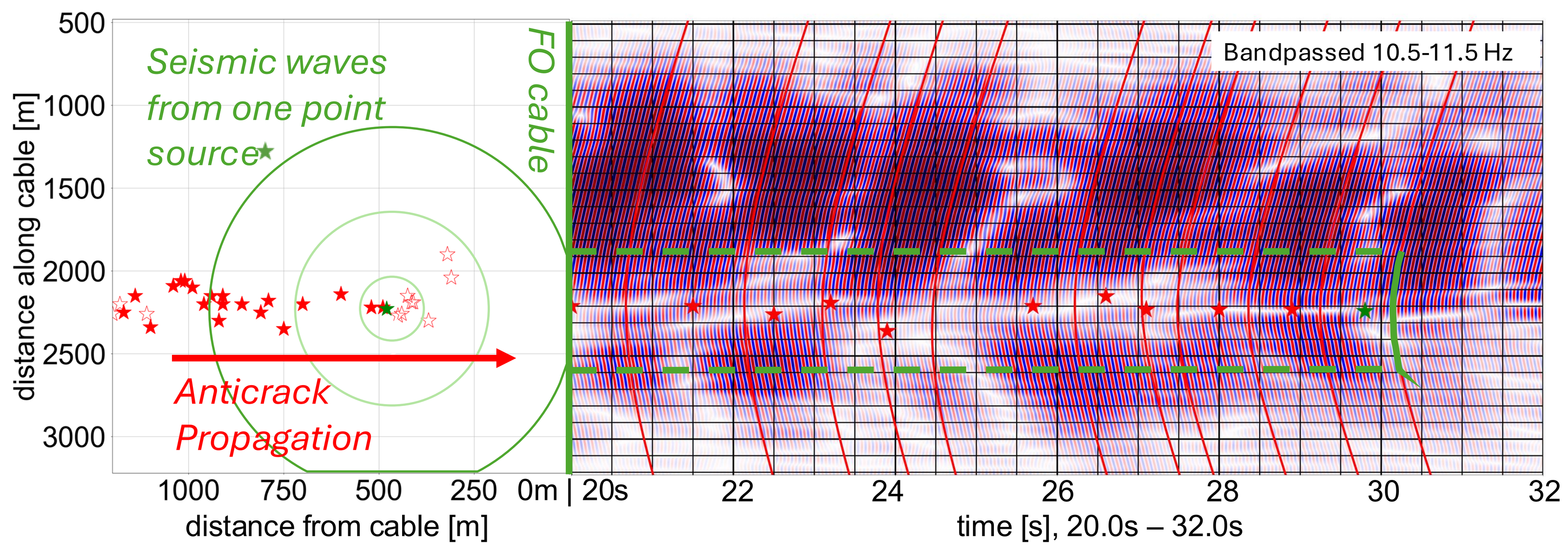
- **Snowquake?** – From a seismology point of view, the anticrack propagation is a moving seismic source, like a small earth-, or snowquake. After the direct signal of the shot, there are about 25s of pure anticrack/whumpf seismic signal

Preliminary Analysis

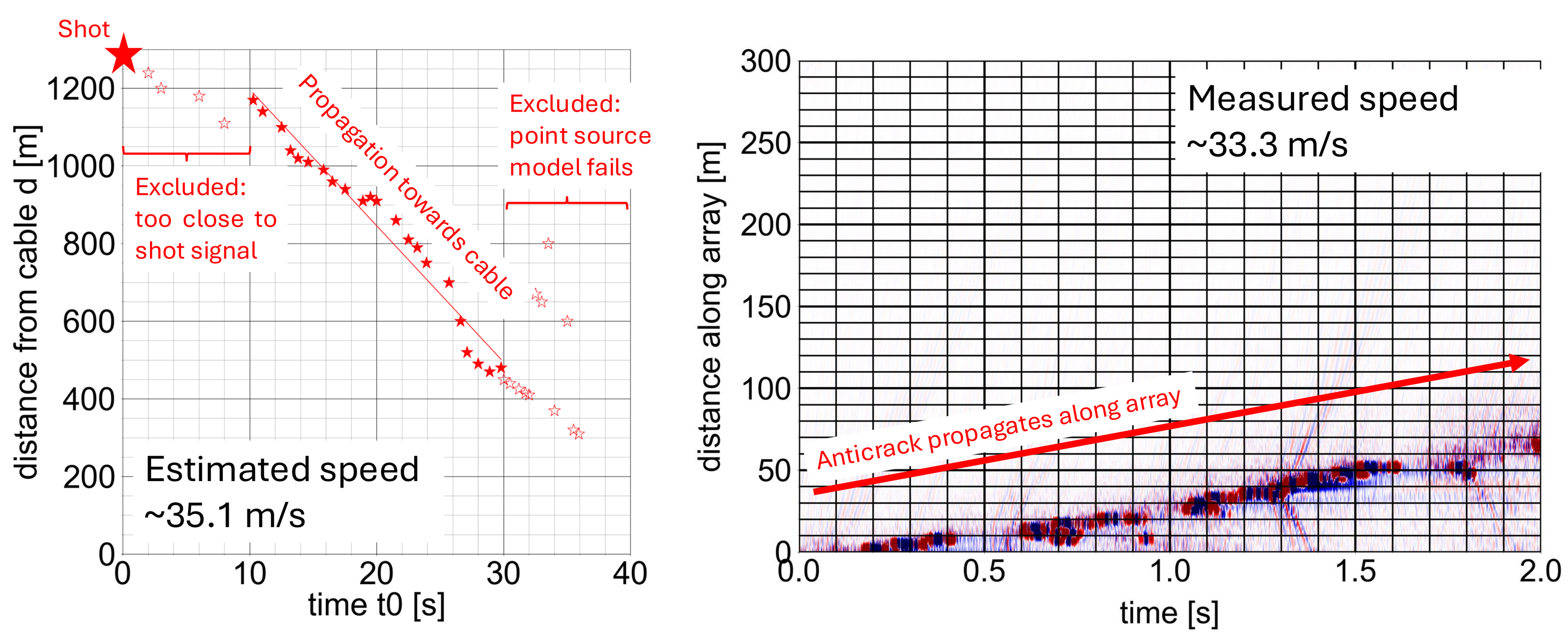
Some signal processing and a simple model can be applied to invert for the anticrack location over time and derive an estimate of its propagation speed

- **Filtering of the seismic signal –** Rayleigh waves travelling through the firn and ice are highly dispersive. Thanks to a clear signal, the fundamental mode can be filtered out (mode identification based on Fichtner et al., 2023). Applying a narrow bandpass filter allows us to pick a single phase velocity
- **Calculating seismic wavefront arrival times** – The shape of seismic wavefronts in the seismogram can inform about the location of the anticrack propagation front

1. Discretize the anticrack propagation as a series of point sources ★
2. Anticrack closer to the cable → less parabolic, more linear arrival times
3. Tune point sources' locations to fit the recorded data



- **Anticrack propagation estimates**
  - Speed of 35.1±1.7 m/s. Given by the slope of the distance/time plot. Direct near-field measurements with a geophone array confirm our estimate
  - Distance >800m. Point source model cannot reconstruct where the anticrack stopped, but it must have propagated at least 800m



- **Data selection** – Estimate based on point sources between 10s and 30s. Early part contaminated by waves from shot. Later, the anticrack is too close to the cable to use a point source model

Next steps

Accuracy and resolution of forward model. Finite no. of point sources is approximation

- Point source model only valid when the anticrack front is far from the cable
- In reality, the anticrack front should be circular. Higher discretization resolution. Ideally: Integrating mechanical models with a seismic wave propagation model

Fibre optic seismology can be used in other terrains or geometric setups to track the dynamics of weak layer collapse propagation

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