Seismics on a cold Alpine saddle – limits and challenges

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Abstract

The Colle Gnifetti is a glacier plateau at about 4450 m altitude in the Monte Rosa, Swiss Alps. Due to the altitude and a mean annual air temperature of around -14°C hardly any melting occurs. Colle Gnifetti therefore resembles very well polar ice conditions and gives the opportunity to test and optimize geophysical methods for polar deployment close by with a comparable low logistic effort. Seismic as well as radar measurements were carried out in August 2008 next to the ice core KCI. So far it has not been very common to use seismics on a cold alpine glacier with such a thick firn layer. The aim was to gain results about the ice properties and ice structures using these geophysical techniques.

For the seismic data this proved to be difficult. Because of the comparably shallow character of the glacier in respect to the seismic wavelength the ground roll as well as the refractions were overlaying the reflections. As it turned out it was already a challenge to be able to see the bed reflection, suggesting the need for a different shot-receiver geometry. Besides this, ringing of the geophones at the spurious frequency occurred, showing the upper limit for the recordable frequencies at 200 Hz.

Field Site

- Colle Gnifetti: glacier plateau, Monte Rosa, Switzerland
- Altitude: 4450 m, thickness glacier ≈ 60 m, firn pack ≈ 30 m
- Ice core density data from KCI
- Radar data

Measurements

- Two seismic lines, perpendicular to each other, North-South, East-West
- Crossing point at ice core KCI
- 24 geophones, 3 m spacing (offset ±1.5, ±4.5, …, 34.5 m)
- Shots: SISSY (Seismic Impulse Source System), through geophone line (Shot 1 – south, respectively west) 3 m spacing (offset 0, ±3, …,±45 m), far offset shots at 75, 90 m
- P-wave velocity profile obtained using the density profile of KCI and the formula by Kohnen(1972):

$$\rho(z) = \frac{0.915}{1+\left(\frac{v_i - v(z)}{2.25}\right)^{1.22}}$$

ρ density, v in km/s at depth z, v_i velocity in ice

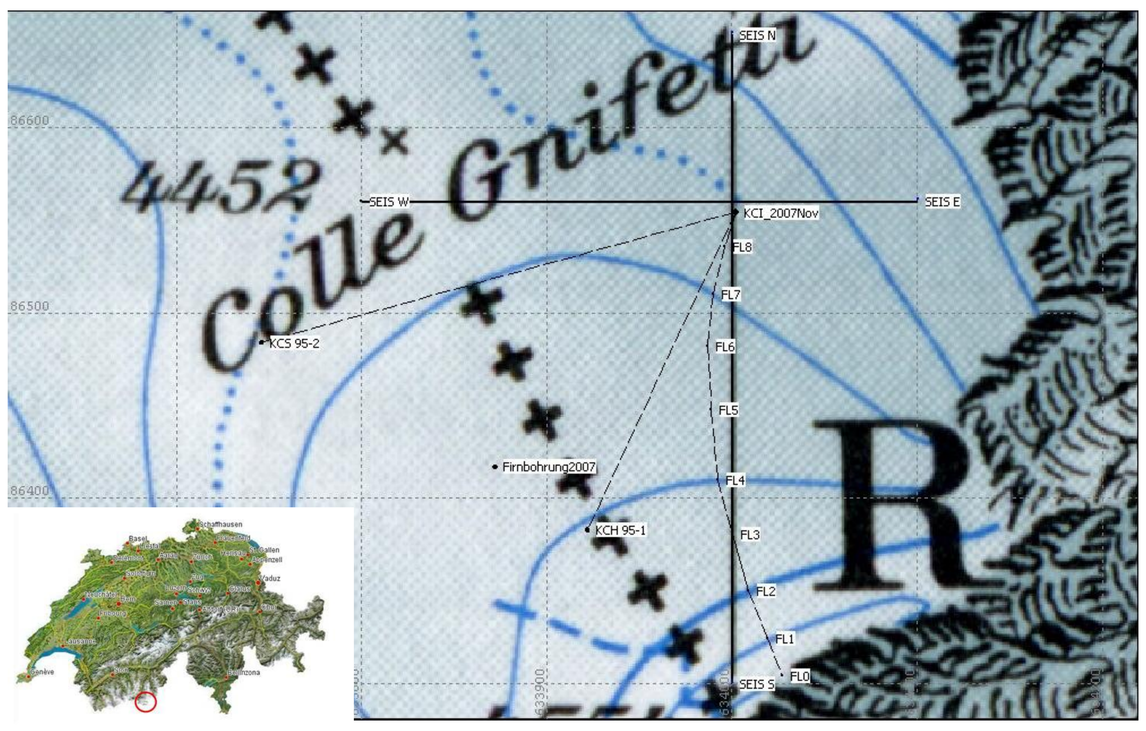


Fig.1: Region of interest, lower corner: location in Switzerland, big picture: seismic setup on Colle Gnifetti

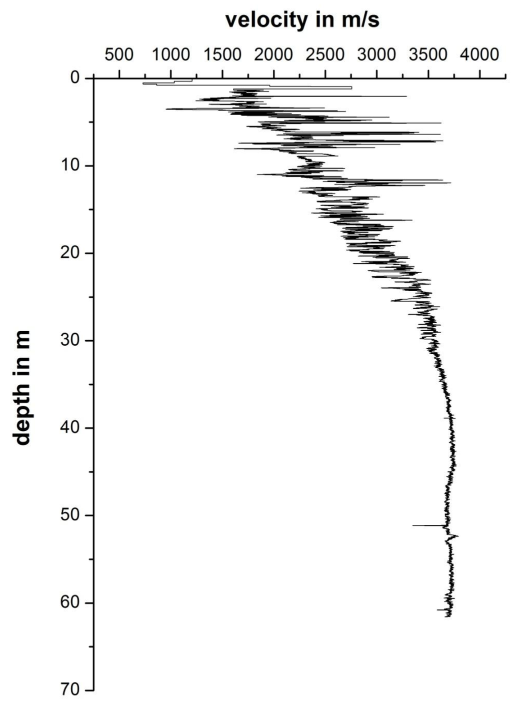
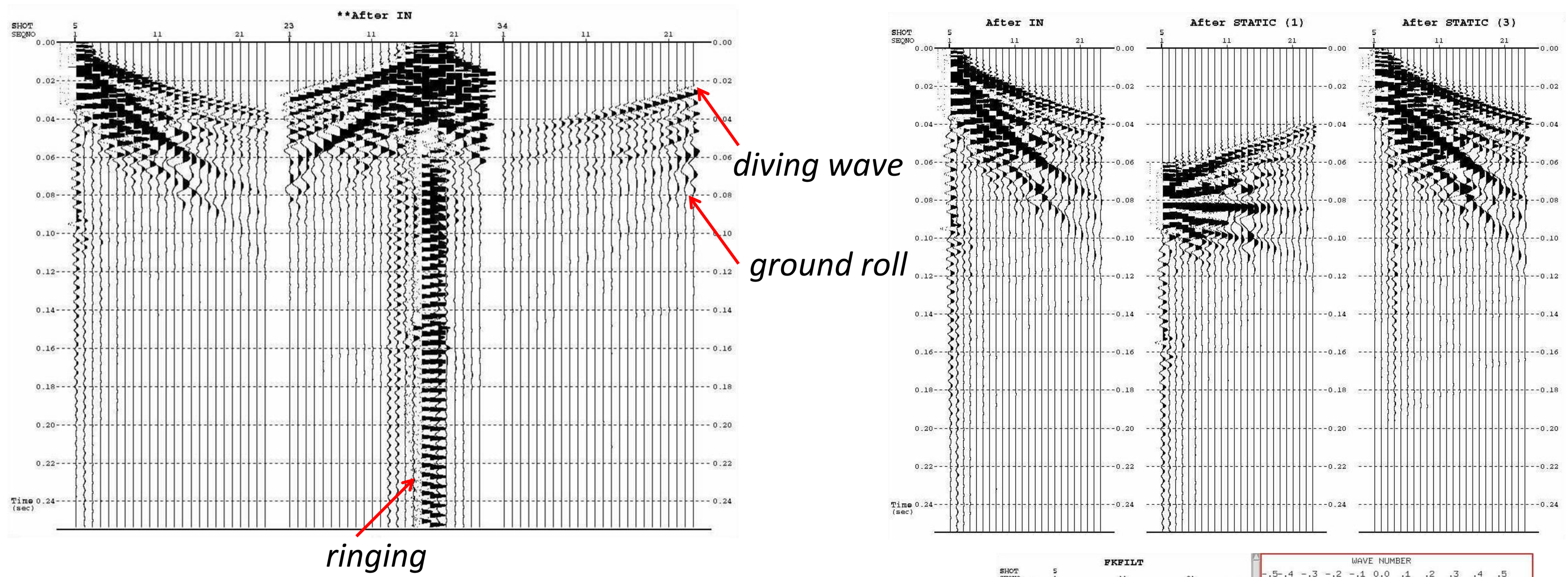
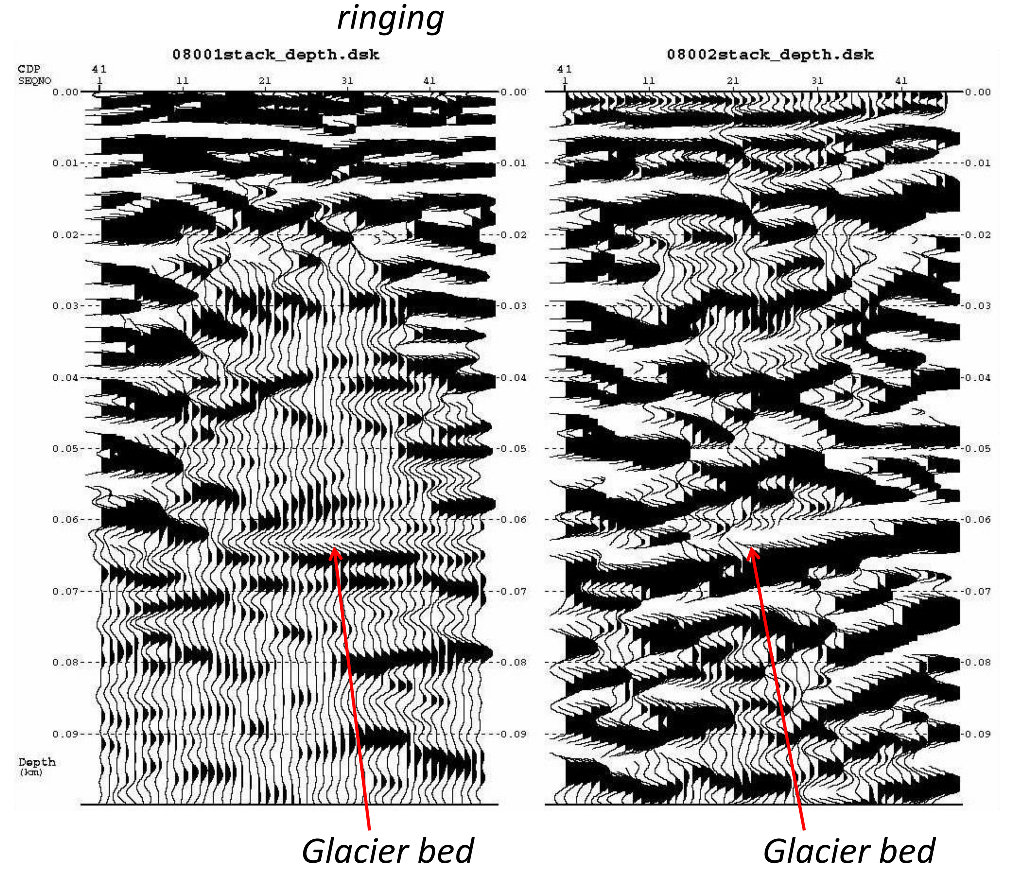


Fig.2: Velocity profile obtained from density data of KCI, velocities calculated by formula of Kohnen





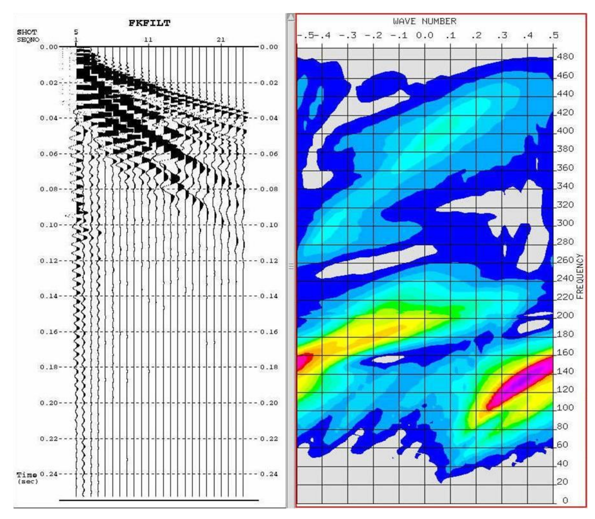


Fig.3: Top Row, left: Shot example for each data set – near offset, within geophone line, far offset; Top Row, right: Example for KL-transformation without benefit; Left: Final stack for line 08001 (CDP 41-87) 69 m, line 08002 (CDP 41-86) 67,5 m, fold ≥ 6; Above: Example for FK-domain (shot 5), problem of spatial aliasing

Data

The data from the shot can be divided into three sets by their characteristics:

- Far offset (Shot 1, 2, 34): possible to filter out reflections
- Near offset (Shot 3-6, 30-33): spatial aliasing of ground roll
- Within geophone line (Shot 7-29): strong ringing

Problems

- Ground roll, spatial aliasing -> overlying reflections
- Diving wave-> overlying reflections
- Refracted wave -> overlying reflection
- Ringing of traces with offset < 4.5 m -> spurious frequency
- Bending of waves, because of densification of the snowpack
- Frequencies of ground roll, and refracted waves within the same domain as reflection -> known from Shot 34, where it was possible to filter out the reflected wave using a FK–Filter

Used filter

- Frequency-Wavenumber (FK)-Filter
- Frequency-Filter: Bandpass-, Notch - Filter
- Karhunen-Loève (KL)-Transformation
- Deconvolution

Processing Steps

Raw data
↓
Sorting, Geometry Information
↓
BP: 10 -450 Hz
↓
Kill near offset traces
↓
CMP sorting, NMO correction
↓
Medianstack
↓
BP: 120-450 Hz
↓
FK-Filter
↓
Final result

Spurious frequency/parasitic resonance

What it is:

The coil in the geophone can not only move in vertical direction but has more degrees of freedom in horizontal direction or by turning. Because of this, the transient function has discontinuities above the natural frequency, with the lowest mode at the spurious frequency. As there is a phase shift and a variation in sensitivity due to these discontinuities the spurious frequency sets the upper limit of the usable frequency band of a geophone.

What it looks like:

- Is activated for example by the high amplitudes of the ground roll
- Strong ringing can be seen in the seismogram, lasting for quite a while
- Jump in the amplitude spectrum of the seismogram

What it means for the Colle Gnifetti data:

- Ringing can be observed in all shots for the traces with small offsets (1.5 m, 4.5 m)
- Frequencies of ringing between 205 – 208 Hz
- Frequencies of shots between 100 – 300 Hz

→ Partly phase shift and variation in transmission of amplitudes within the frequency band of waves

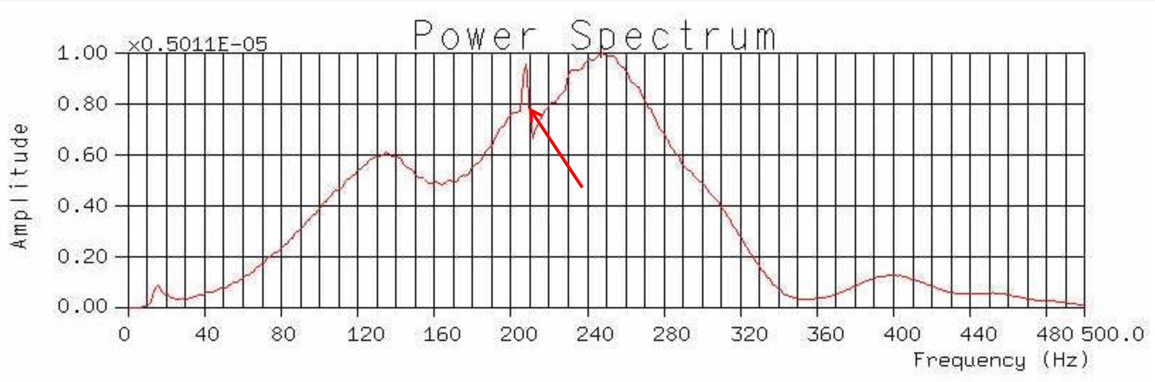


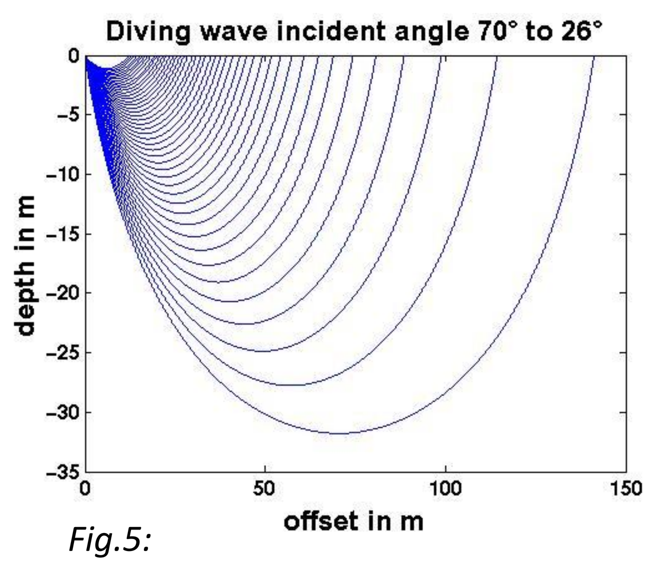
Fig.4: Amplitude Spectrum of line 08001, shot 13, offset 1.5 m with parasitic resonance at 210 Hz

Density profile obtained from diving wave

Diving wave:

Continues refraction occurs, because of densification of firn layer (Fig. 5)

→ For different offsets, different depth with correlating depth
→ Fitting exponential function to arrival times of diving wave
→ Using Herglotz-Wiechert inversion formula to **calculate depth-velocity profile**
→ Using formula by Kohnen to calculate **density-depth profile**



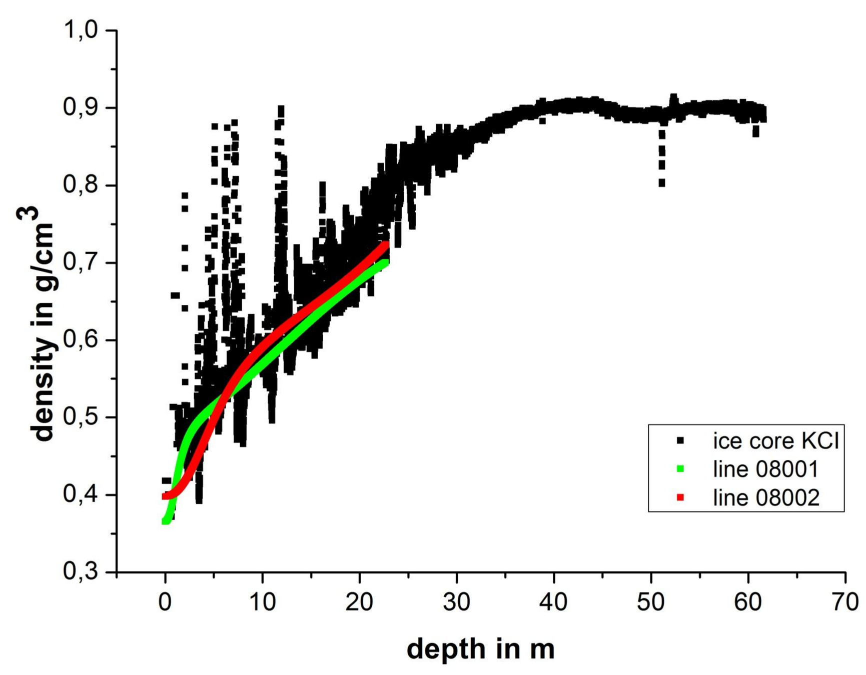


Fig.5: Left: Diving waves for different offsets using density profile from KCI, and Snelliu's law Right: Calculated density for line 08001 (green) and 08002 (red) using diving wave on density data from KCI

Possible improvements of measurements

- High frequency geophones, spatial frequency > 400 Hz
- More far offset shots
- No shooting within geophone line
- Shooting in deeper boreholes
- Use of vibroseismic source

Outlook: Repetition of measurements in summer 2010 with altered geometry setup, using additional source types, such as P- and S-wave vibroseismic sources

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