Vibroseismic measurements on an ice shelf

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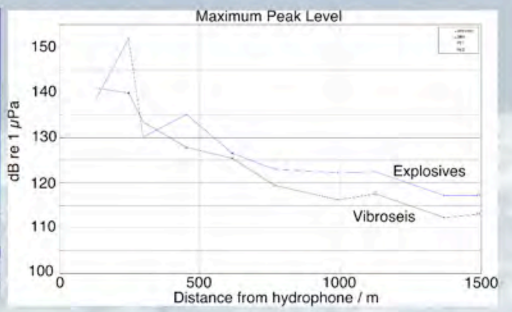
Abstract

We present first-time-ever results of active seismic measurements on an ice shelf with a vibroseismic source. The measurements were conducted in the 2009/10 field season in Dronning Maud Land, Antarctica, within the LIMPICS project. A Failing Y-1100 on skis with a mass of 16 t was used on the Ekströmisen ice shelf where ice is about 100-200 m thick and overlies about the same amount of water. The goal was to investigate the feasibility of vibroseismic operations on a porous firn layer to image the internal structure of the ice and the underlying sediments as well as ice and water column thickness. In comparison with conventional explosive seismics, where explosives are detonated in 10- to 20-m deep boreholes, vibroseimics does not require any drilling and can thus be considered a true surface measurements. In combination with a snow streamer the vibroseismic operation would enable long seismic traverses in comparably short time periods. In addition to comparison with conventional explosive shots we also recorded the signals at the PALAOA observatory with two calibrated hydrophones underneath the ice shelf, which enables the determination of absolute amplitudes, reflection and absorption coefficients.

Recording vibroseismic and explosives signals at PALAOA

What is PALAOA?

The PerenniAL Acoustic Observatory in the Antarctic Ocean (PALAOA, Hawaiian for "whale") close to the ice shelf edge at Neumayer Station is intended to record underwater sounds in the vicinity of the ice shelf edge over several years. These long-term recordings will allow the study of the acoustic repertoire of whales and seals continuously in an almost undisturbed environment. One focus of the research is also the possible effects of the sporadic shipping traffic on the acoustic and locomotive behaviour of marine mammals. Due to the calibrated hydrophones installed at PALAOA, this location provided an ideal situation for comparing the signal intensity of the two seismic energy sources.

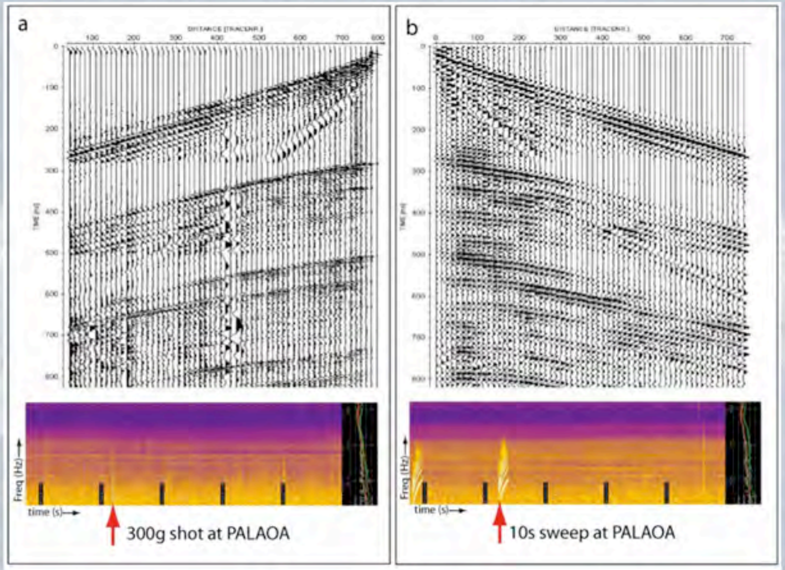


↑ Picture of the PALAOA observatory housing the electronics and the WLAN transmitter for real-time broadcasting the signals to Neumayer III.

↗ Decay of the recorded absolute maximum peak amplitude level as a function of distance between the shot/sweep location and the hydrophones. The explosives have an overall higher peak level. Integrating over the source duration, however, yields a much higher energy transfer for the vibroseismic source.

At what distance could the signal still be detected by the PALAOA hydrophones?

The ice thickness at the observatory is about 100 m and the hydrophones are installed beneath the ice in the water. The vibroseismic sweeps were produced at the ice surface, while the explosives were fired at 10 m firn depth. For explosives, it is difficult to tell the limit of detection by PALAOA as many other impulse events are seen. The signal is very short with frequencies of 10-350 Hz. Because of its unique characteristics, the last noticeable vibroseismic sweeps was identifiable around 7000 m away from PALAOA. For shots close to the geophone cable the signal can also propagate along the cable to the geophone.



Instruments

Viboseismic Truck

- vibrator: Failing Y-1100 mounted on a Ford truck
- peak mass16 tons
- 10 s linear sweep 10-100 Hz
- hydraulic cylinder acts as a free moving reaction mass
- airfilled rubber dampers allow decoupling of vibrator pad and truck
- radio signal initiates an electronic sweep signal controlling the hydraulic cylinder

Snow Streamer

- 60 channels, 1.5 km long
- group distance of 25 m
- group of 8 gimbal suspension geophones
- used as 750 m long streamer, group spacing 12.5 m

Recording instrument

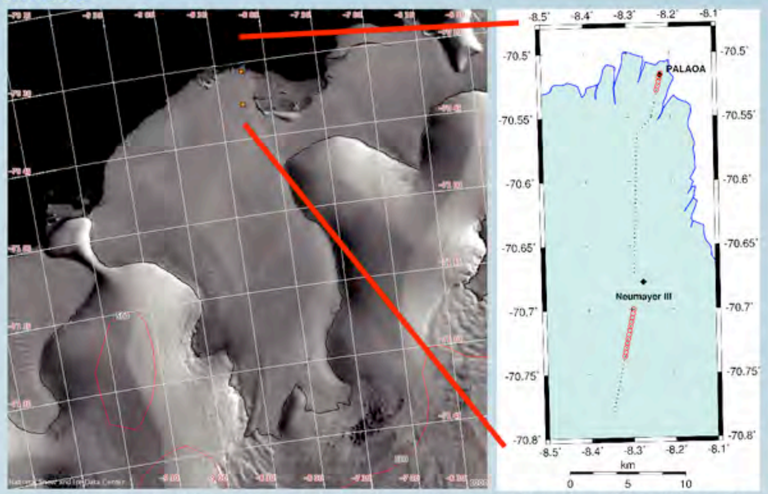
- GEOMETRICS 60 ch. Strataview RX 24 Bit exploration seismograph
- sample rate: 250 ms
- shots every 375 m and 381.25 m yield 6.25 m trace spacing

Explosives

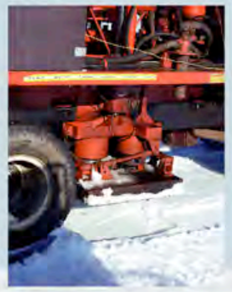
- 300 g Pentolite (PETN-TNT mixture)
- borehole depth 10 m, established by using a portable steam drill

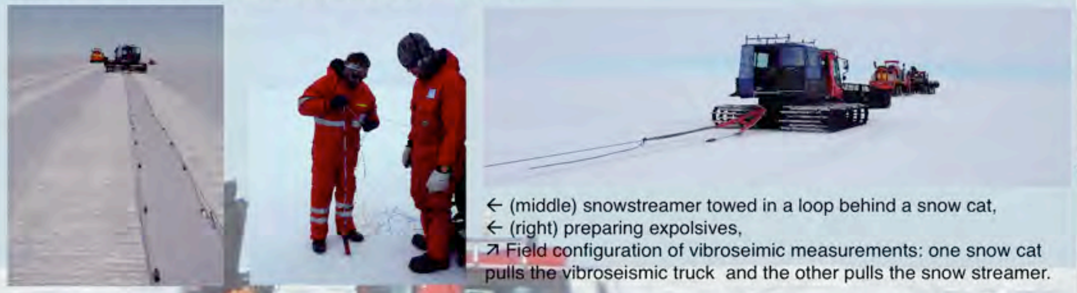
Measurements

- explosives: two shots every 375 m with a streamer offset of 44 m and 37.75 m
- vibrator: shots every 375 and 381.25 m
- yields 6.25 m trace spacing for both source types
- 19 km profile from PALAOA towards Neumayer III, consisting of 5 explosive shots near PALAOA and 49 vibroseismic sweeps (common coverage 1.5 km)
- 9.3 km profile south of Neumayer III with 12 explosive shots and 25 sweeps (common coverage 4.1 km)



↗ Map of the field measurements on Ekströmisen. Crosses show the vibroseismic shot points, red circles the explosive shot locations. The aim was to establish a robust comparison of shot hole seismics and vibroseis techniques. At the same time also a considerable section of the northern ice shelf was covered with a seismic profile. ↙ Vibrator after three sweeps showing the pad footprint

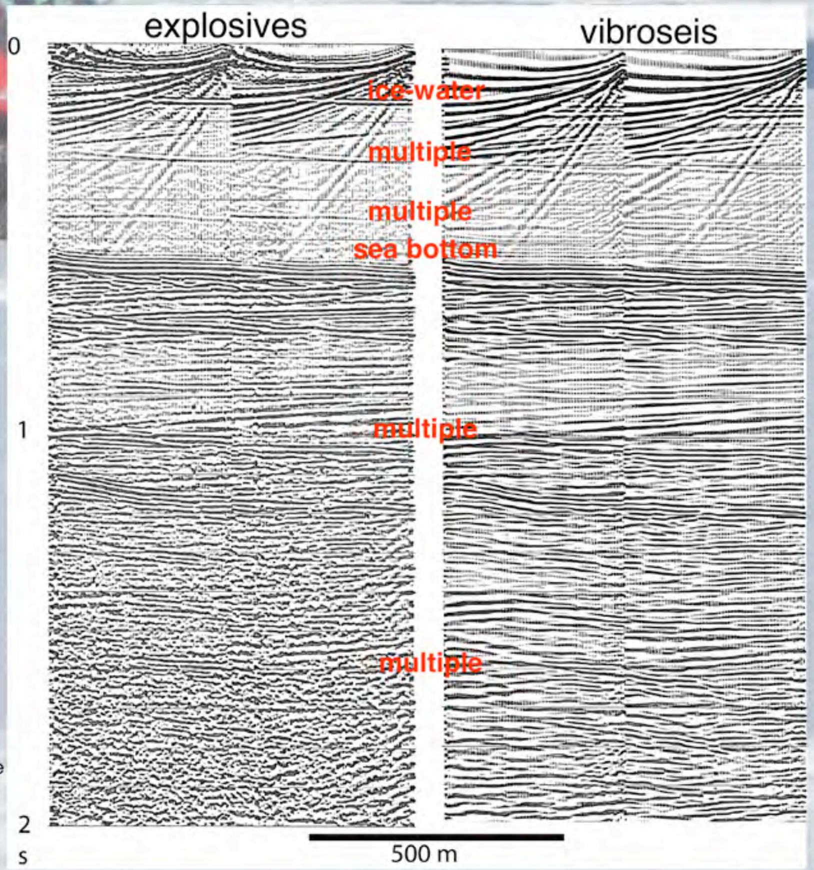




← (middle) snowstreamer towed in a loop behind a snow cat,
← (right) preparing expolsives,
↗ Field configuration of vibroseimic measurements: one snow cat pulls the vibroseismic truck and the other pulls the snow streamer.

Vibrator vs. explosive seismics

The comparion of unprocessed single shots (figure ↘) and processed sections (↙) of explosive and vibroseis data for identical recording length show that both types of data show the primary reflection from the ice-shelf-water interface, its multiple reflections and the reflection from the sea floor.The vibroseismic signal has an overall lower frequency than the explosive signal. However, for the vibroseismic setups, despite being placed at the surface, clear signals are visible still at 2 s two-way traveltime. Clear reflections from the explosive signal cease at about 1.5 s. Whether the vibroseismic multiple signals around 2 s and below overlay real round-trip reflections has still to be analysed. Although small explosive sources seem to be superior in terms of wavelength and resolution, the higher production speed and known source properties of the vibroseismic setup make it a promising new tool for glaciological and geological surveys covering larger areas.



← Comparison of explosive (far left) and sweep (left) single shots as recorded with the snow streamer and at PALAOA (spectrograms at bottom). The explosive shot has a signature comparable to a number of natural events, e.g. as originating from cracking ice and colliding sea-ice flows. The vibroseis signature, in contrast, is very distinct and also shows overtones.
↗ Explosive vs. vibroseis section (two shots each), showing the same events (ice shelf-water interface, sea bottom, sediment layering and numerous multiples).

Acknowledgments

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