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Initial observations from seismometers frozen into a borehole through the McMurdo Ice Shelf.

David Prior (1), Jennifer Eccles (2), Joanna Cooper (1), Lisa Craw (1), Laurine van Haastrecht (3), M. Hamish Bowman (1), Craig Stevens (4), Madi Gamble Rosevear (5), Christina Hulbe (1), Andrew Gorman (1), Huw Horgan (3), and Alex Pyne (3)

(1) University of Otago, Dunedin, New Zealand (david.prior@otago.ac.nz), (2) University of Auckland, Auckland, New Zealand, (3) Victoria University of Wellington, Wellington, New Zealand, (4) NIWA, Wellington, New Zealand, (5) University of Tasmania, Hobart, Australia

A seismometer cable with two, three-component seismometers was frozen into a hot water borehole through the McMurdo Ice Shelf at Windless Bight in late December 2016. The seismometers are at 39m and 189m depth. The upper seismometer lies just below the firn-ice transition (∼37m) and very close to sea level (∼38m). The lower seismometer is positioned ∼30m above the base of the ice shelf (∼222m). The seismometers froze in within 40 (upper) to 60 (lower) hours of the last reaming operation. The temperature evolution during freezing is complicated, particularly for the lower seismometer. The complications are interpreted as the result of brine expulsion and brine pocket migration.

We conducted an active source experiment using the frozen-in seismometers together with a surface seismometer and four lines of geophones radiating from the borehole, at 45-degree angles, to a distance of 240m. Sources included a traditional hammer and surface plate, two types of hammer activated surface shear wave sources (for hard and soft surfaces) and a hammer activated borehole source.

The frozen-in seismometers show excellent separation of P - wave and S – wave arrivals for all sources, particularly on the lower seismometer. The surface shear sources give clearer separation of arrivals on the vertical and horizontal components. For some source to receiver geometries the surface shear sources give no P - wave arrival on the horizontal seismometer components and a very strong S – wave arrival that is partitioned between the horizontal components in correspondence with the source orientation. The borehole source (at 3 to 10m in the firn) also gives clearer separation of P - wave and S – wave arrivals compared to a surface hammer and plate.

The frozen-in seismometers were also used to listen for natural events in the ice. Comparing the same events recorded at the surface and at depth, the latter are much less noisy than the former, leading to more clear interpretation. As in the active source experiments, P-wave and S-wave arrivals are clear and the partitioning onto different components (vertical and horizontal) is very clear.

Using seismology to interpret the physical properties of ice masses is dependent on quality data. The patterns of anisotropy related to ice crystallographic preferred orientations (CPOs) are particularly rich for S – waves and the ability to measure S – wave velocities and shear wave splitting is of particular importance in using seismology to constrain CPOs. Our initial observations suggest that seismometers frozen-in at depth, together with artificial sources with controlled shear wave kinematics have great potential to help us constrain ice CPOs and resultant plastic anisotropy through seismic data.