Measuring Rayleigh Wave Phase Velocity in the Antarctic Upper Mantle from Ambient Seismic Noise

Background and Motivation

Two compelling questions make the Antarctic region worth studying: 1) Why is there a significant age difference between West and East Antarctica? And 2) How exactly will global sea-levels rise in the future? Divided by the Transantarctic Mountains, West Antarctica is significantly younger than the East Antarctica craton (Hansen et al., 2014). Resolving the age difference between Antarctica's two halves will help us understand the tectonic history and evolution of the Antarctic region. On the other hand, sea-level rise has serious implications on infrastructure displacement as we lose land surface area. Simulations of global sea-level rise have high uncertainty but could benefit from incorporating bedrock uplift, mantle viscosity, and geothermal heat flux (Gomez et al., 2015). Approaching both questions requires better constraints on mantle properties underneath Antarctica.

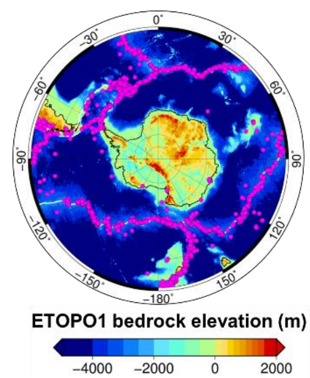

Figure 1: Topography map of the Antarctic plate. Colors represent bedrock elevation in meters and pink dots are earthquakes that occurred in 1966-2017. Tectonic plate boundaries are plotted as white lines.

Investigating Antarctica poses unique challenges for many traditional measurement techniques. About 98% of Antarctica's land surface area is underneath a thick ice-sheet (Fretwell et al., 2013), and uncertainty in mantle viscosity convolutes anticipating changes in the Earth's surface in response to ice-sheet melting and growth. These two factors make measuring geothermal heat flux impractical. Furthermore, traditional seismic tomography methods rely on earthquakes for seismic signals which are scarce in and around the Antarctic region.

An emerging approach in seismic tomography is to use ambient seismic noise – signals primarily generated from interactions between ocean water waves and solid Earth – in addition to earthquake data to characterize mantle properties. This method has been published by Bensen et al. (2007) and has been widely adopted by seismologists with over a thousand citations. One study shows incorporating ambient noise can increase phase-velocity map resolution in the Indian Ocean by 20% relative to maps generated by relying solely on earthquake data (Ma & Dalton, 2016). While there exists many studies employing ambient noise, the number of similar studies on the Antarctic region are relatively scarce.

Proposed Methodology

I will obtain long-period vertical component data from the Incorporated Research Institutes of Seismology (IRIS) for all active, unrestricted stations south of -55 degrees latitude which encompasses all of Antarctica. The data will be processed in 4 h stackable (i.e. able to be combined through addition via linearity) windows. To ensure a high signal-to-noise ratio in our phase arrival time measurements, I will discard 4 h windows that are not entirely full. Correlation measurements between all station pairs will be done in the frequency domain by computing the cross-spectrum $\rho_{ijk}(\omega)$ as done in Ekström (2014):

$$\rho_{ijk}(\omega) = \frac{u_{ik}(\omega)\, u^*_{jk}(\omega)}{\sqrt{u_{ik}(\omega)\, u^*_{ik}(\omega)}\sqrt{u_{jk}(\omega)\, u^*_{jk}(\omega)}}$$

The letter *u* represents a 4 h seismogram passed through a fast Fourier transform. ω is frequency, *i* and *j* are station indices, and *k* is a 4 h window index. The asterisk * denotes a complex conjugate. Performing an inverse fast Fourier transform on the cross-spectrum yields a cross-correlation in the time domain.

Measurements of phase arrival times can be made from cross-correlations. These arrival times will be used to perform inversion and thus yield phase-velocities for many small, discrete regions in Antarctica. Earthquake data can be incorporated with ambient noise data to account for regions with low data count (i.e. not many paths traversing the discrete region). Additionally, the smoothing of our inversion will account for regions with little data and can be adjusted to yield the best results. I will conduct numerous tests to identify optimal smoothing parameters and relative weighing between ambient noise and earthquake-based data. These steps result in a 2D phase-velocity map and can be repeated to map varying depths of the Antarctic upper mantle.

Anticipated Results

The speed at which wave phases propagate through solid Earth is related to material properties such as temperature, composition, and partial melt. I expect to see West and East Antarctica to be dominated by slow- and fast-velocity anomalies, respectively, which should agree with past studies using p-waves to image the Antarctic mantle. Improved resolution in tomographic maps of the Antarctic upper mantle may help me observe undiscovered geological features such as cratons and oddly pronounced and heterogenous velocity anomalies.

Proposed Timeline:

Year 1: Download and process seismogram data from IRIS from 1900 to 2017.
Year 2: Generate 2D seismic tomography maps.
Year 3: Identify optimal smoothing parameters and relative weights. Repeat mapping process for varying depths of the Antarctic upper mantle.

References

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