# Short period Rayleigh wave group velocities in Antarctica determined by the cross-correlation of ambient seismic noise from the TAMSEIS array

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**Summary** We cross-correlate ambient seismic noise from the TAMSEIS experiment to obtain estimates of the Rayleigh wave green's function and measure group velocity dispersion curves. Preliminary results demonstrate that good quality green's functions can be obtained using this technique in Antarctica and that they can be used to examine shorter period Rayleigh waves and the structure of the crust and uppermost mantle in the region of the Transantarctic mountains in more detail than previous studies. Dispersion curves measured in East Antarctica show good agreement and no indication of a thick sediment layer. Velocities measured from other station pairs suggest the fastest velocities at short periods occur in East Antarctica while the fastest velocities at periods longer than 15 seconds occur beneath the Ross Sea. The study will continue by extending this technique to all station pairs and then examining Rayleigh wave group velocities in the region using seismic tomography.

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## Introduction

The Transantarctic Mountain Seismic Experiment (TAMSEIS) is the largest broadband seismometer deployment thus far located in Antarctica. The experiment ran from December 2000 until December 2003 with seismometers using batteries and solar power to run during the summer months and shut down during the winter months. Forty-one broadband instruments were placed between the Ross Sea and the Vostok highlands (Figure 1). The experiment was designed to examine the transition between the East Antarctic highlands and the West Antarctic Rift System along the Transantarctic Mountains.

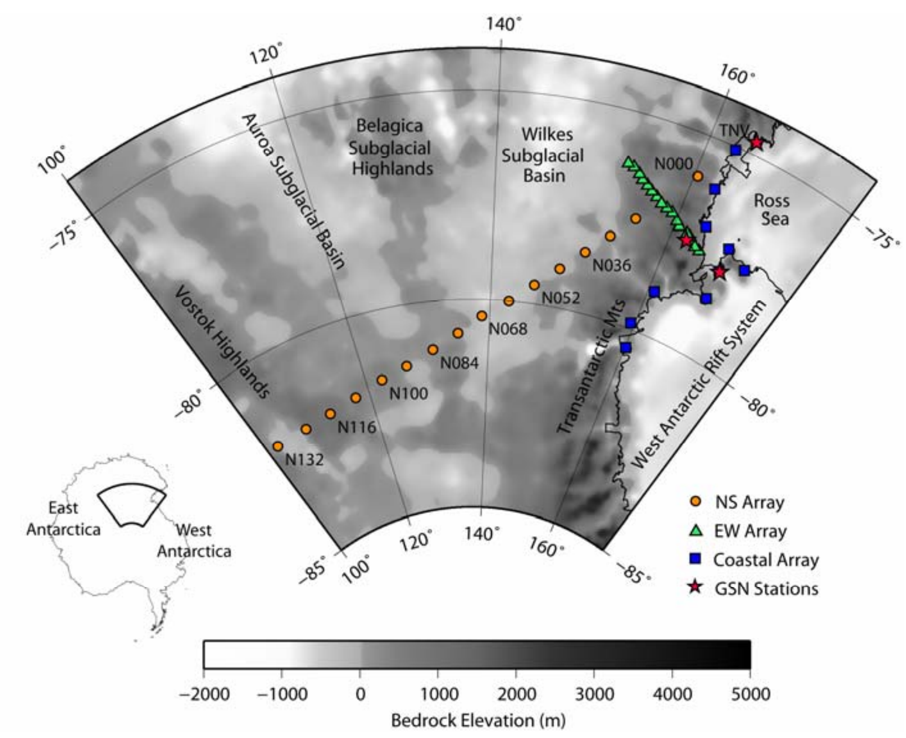


**Figure 1.** Location of stations in the TAMSEIS array and the subglacial bedrock topography of the surrounding region.

Previous surface wave studies of the region are limited by the lack of seismometers in the interior of the continent and are restricted to continental and global studies or studies using the few stations from the Global Seismographic Network (GSN) in the area (Danesi and Morelli, 2001; Ritzwoller et al., 2001; Bannister et al., 2000). Lawrence et al.

(2006) used the TAMSEIS data to perform a new Rayleigh wave phase velocity study in the region with much higher resolution due to the significant increase in instrumentation and data. As is typical with traditional surface wave studies, however, Lawrence et al. (2006) only obtained results at periods of 16 seconds and higher with best results above 20 seconds.

Recent work (Shapiro and Campillo, 2004; Sabra et al., 2005a) has shown that the cross-correlation of long time periods of ambient seismic noise can be used to obtain an estimate of the Rayleigh wave green's function. This green's function can then be used to measure group and phase velocities and perform seismic tomography in a region (Shapiro et al., 2005; Sabra et al. 2005b). Because the dominant source of this noise is in the microseism band (7.5 and 15 seconds), this method is particularly useful for looking at the shorter periods, and thus shallower depths in the mantle and crust where traditional surface wave methods start to falter. We are able to apply this technique to the TAMSEIS data to obtain Rayleigh wave group velocity measurements from periods of 7.5 seconds to up to 30–40 seconds, depending on the distance between stations. Thus we can look in more detail at the structure of the crust and the uppermost mantle at shallow depths in this region than could be done in previous studies.

## Data Processing

We follow the basic procedure outlined in Bensen et al. (2007) to cross-correlate six months of ambient seismic data (from the months of Dec 2001, Jan and Feb 2002, Dec 2002, Jan and Feb 2003) from the TAMSEIS array. We cross-correlate day-long segments of data and for each station pair we require that for a day to be included both stations must have at least 23 hours of continuous data recorded. Due to the difficulty in running seismic stations in such extreme conditions we often obtain only about 40-60 or fewer useful days of data for a station pair from these 6 months.

For each day-long time series we first remove the instrument response, de-mean and de-trend the data, and apply a bandpass filter between 3-80 seconds. Next we remove the effect of any earthquakes which might dominate the correlation by normalizing the time series with a running absolute mean. This method of normalization inversely weights the data by a running average of the absolute value of the data. Finally, each trace is spectrally whitened before cross-correlation in order to increase the range of frequencies at which we can measure the ambient seismic noise.

We cross-correlate each day-long segment in the frequency domain and then stack the data in the time domain. After stacking the data, we average the positive and negative lags of the correlelogram and then compute the derivative to find the estimated green's function. We then use multiple filter analysis (Dziewonski et al., 1969) where the estimated green's function is filtered with a series of narrow-band filters in order to measure the group velocity at different periods.

## Preliminary Results

We obtain good green's functions with strong frequency content between 7.5 seconds and up to 30-40 seconds depending on the distance between each station pair. Figure 2 demonstrates the good-quality waveforms at 7.5 seconds obtained from the noise cross-correlation along the line of 17 seismometers with ~80 km spacing that ran roughly north-south from the GSN station Terra Nova (TNV) 1400 km in to the interior of the Antarctic continent (Figure 1). Each trace is obtained from the cross-correlation of the first station in this line (N000) to each successive station (N020, N028, etc.). The data are filtered between 0.11 and 0.15 Hz and plotted with increasing distance. The moveout of the waveform along the line is clearly visible.

Figure 3 exhibits the group velocity dispersion measurements that can be obtained from these waveforms. In this figure we plot the dispersion curves measured from each of the station pairs shown in Figure 2. The curves show good agreement with each other. We also plot an example model which fits the average trend of the data. The model includes a 2 km thick ice layer, a thin (~1 km) sediment layer and then bedrock to a depth of 40 km.

Preliminary results from other station pairs show trends that are consistent with results from previous studies. At 9 seconds (corresponding to a depth of roughly 12 km), for example, the slowest velocities appear to lie mainly east of the Transantarctic mountains, in the West Antarctic Rift System and the Ross Sea. This agrees well with studies that find large amounts of sediment that have filled this region (Hamilton et al., 2001). At 15 seconds (corresponding to a depth of ~20 km), this area begins to show faster velocities than those west of the Transantarctic mountains. Lawrence et al. (2006) also found phase velocities in the West Antarctic Rift System to be faster than those in East Antarctica at 16 seconds.

## Discussion

Our preliminary results show that good Rayleigh wave green's functions and group velocity dispersion curves can be obtained by the cross-correlation of ambient seismic noise in Antarctica. The use of this technique allows us to look at the shallow crustal structure and the upper mantle underneath the Transantarctic mountains and the transition between East and West Antarctica with detail never before possible. Initial results at 9 seconds show slower velocities beneath the Ross Sea and faster velocities in East Antarctica. By 15 seconds this trend switches to slower velocities in East Antarctica and faster velocities in the Ross Sea. Since crustal thickness estimates are about 19 km in the Ross Sea

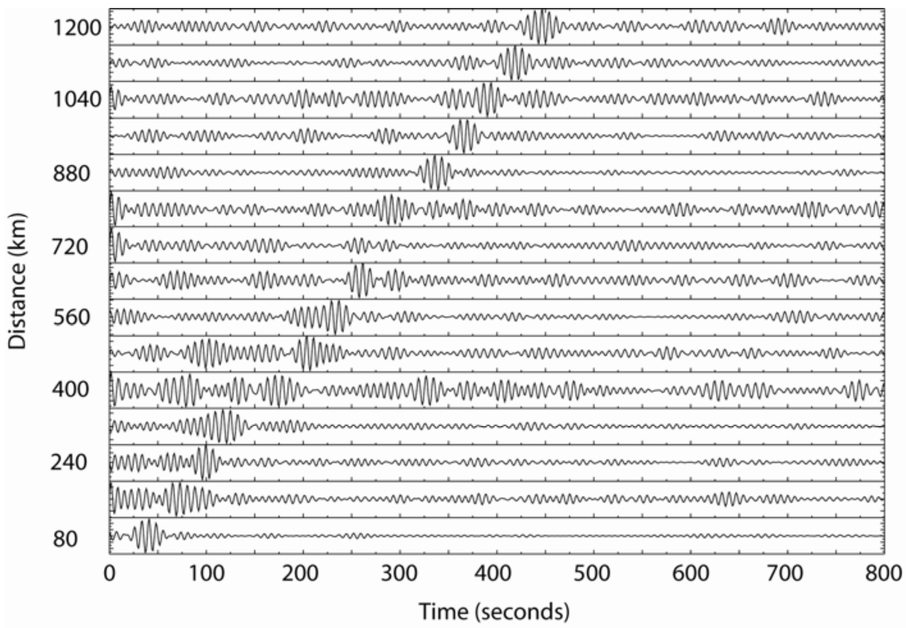


**Figure 2.** Waveforms at a period of 7.5 seconds produced by the cross-correlation of 6 months of seismic noise from the TAMSEIS array along the North-South subarray. Correlelograms are filtered between 0.11 and 0.15 Hz..

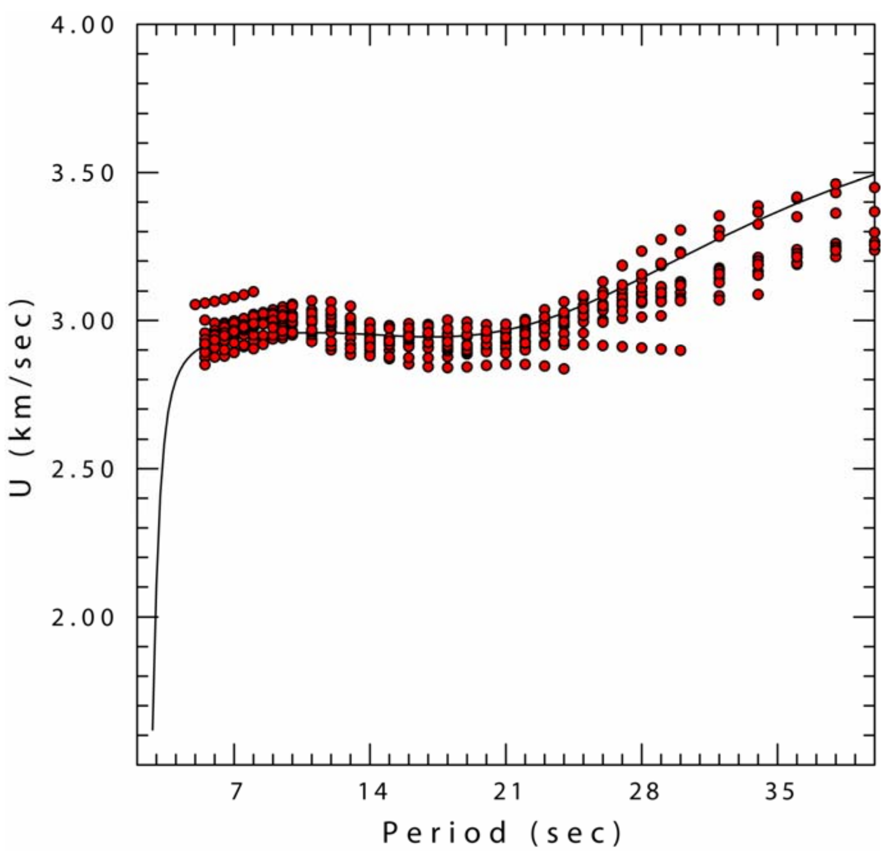


**Figure 3.** Dispersion curves measured from station pairs in Figure 1. Solid line represents a model with a 2 km-thick ice layer, a 1 km-thick sediment layer and bedrock to a depth of 40 km.

(Trehu, 1989; Cooper et al., 1997) while East Antarctica is estimated to have a crustal thickness of 35 to 45 km (Bentley, 1991), this may indicate that group velocities are beginning to sample faster mantle velocities beneath the crust in the Ross Sea and West Antarctic Rift System while in East Antarctica group velocities are still sampling crust. The dispersion curves measured along the long North-South subarray show good agreement with each other and initial forward modeling of the curves suggest that there is very little sediment in East Antarctica in the study area.

We will continue the study by using all possible data from the duration of the TAMSEIS experiment to compute the green's functions for all possible station pairs. By using as much data as possible we will hopefully be able to obtain green's functions for station pairs where one station had large amounts of down time. We will measure the dispersion curves from each station pair and then we will use seismic tomography to image the Rayleigh wave group velocity at various depths. Results at the longer periods in our study (greater than 16 seconds) can be compared to Lawrence et al. (2006) for interpretation. Our results should allow us to study shallower depths and it is our hope that this technique can be used to identify any region of thick sediment that may lie beneath the ice.

## Summary

We performed the cross-correlation of ambient seismic noise on data from the TAMSEIS experiment in order to obtain Rayleigh wave green's function and measure group velocities between station pairs. Our preliminary results show that good waveforms and dispersion curves can be obtained in Antarctica and we intend to continue the study by calculating the green's function and dispersion curves for all possible station pairs and then to construct tomographic images of the Rayleigh wave group velocities over the study region.

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