Hydroacoustic monitoring of the Bransfield Strait and Drake Passage, Antarctica: A first analysis of seafloor seismicity, cryogenic acoustic sources, and cetacean vocalizations

R. P. Dziak,[1] M. Park,[2] H. Matsumoto,[1] D. R. Bohnenstiehl,[3] J. H. Haxel,[1] D. K. Mellinger,[1] K. Stafford,[4] Won Sang Lee[2]

[1]Oregon State University/NOAA, Newport, OR, U.S.A [robert.p.dziak@noaa.gov].
[2]Korea Ocean and Polar Research Institute, Incheon, R.O.K.
[3]North Carolina State University, Raleigh, NC, U.S.A.
[4]Applied Physics Laboratory, University of Washington, Seattle, U.S.A.

Summary In November 2005, our research consortium deployed an Autonomous Underwater Hydrophone (AUH) array to begin long-term hydroacoustic monitoring of the waters in the Bransfield Strait and the Drake Passage. The array takes advantage of the efficient propagation of sound in the oceans to detect, locate, and analyze the distribution of small- to moderate-size earthquakes along the South Shetland Islands, Bransfield Strait, and Scotia Sea. Preliminary review indicates the hydrophones recorded hundreds of earthquakes from the seafloor spreading centers and submarine volcanoes within the Bransfield Strait, as well as events from the subduction zone off the South Shetland Islands and from throughout the Scotia Sea. Moreover, we have observed harmonic tremor produced by the movement of large icebergs, and have detected the vocalizations of several critically endangered cetacean species.

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Introduction

An array of Autonomous Underwater Hydrophones (AUH) was deployed in December 2005 to record seafloor seismicity, icequakes, and iceberg tremor occurring within the Bransfield Strait and western Scotia Sea (Drake Passage) off the west coast of the Antarctic Peninsula. This paper discusses initial results of this hydroacoustic experiment and presents the acoustic signals associated with submarine earthquakes and volcanism, as well as the breakup and movement of ice and detection of cetacean vocalizations, from throughout the region.

This hydroacoustic monitoring effort takes advantage of the efficient propagation of sound in the oceans to detect, locate, and analyze the distribution of local and regional seafloor earthquakes as well as cryogenic sound sources. Global and regional seismic networks offer critical information on the spatial patterns and source mechanisms of seismicity in the remote ocean basins. However, the relatively high detection thresholds of land-based seismic networks ($M_w > 4$) coupled with the typically low magnitude of earthquakes associated with seafloor volcanic activity and the vast majority of tectonic activity, often results in an incomplete picture of the seismicity or a failure to detect it altogether. In the last decade, hydroacoustic methods have been developed to provide improved monitoring of the tertiary phase or *T*-wave of remote ocean seismic activity (Fox et al., 1995). Since acoustic *T*-waves propagating in the ocean sound-channel, or in the case of the polar regions a surface waveguide, obey cylindrical spreading (r^{-1}) energy loss as opposed to the spherical spreading (r^{-2}) of solid-earth seismic *P*-waves, hydrophones can often detect smaller ($M < 4$) and therefore more numerous earthquakes than land-based seismic networks (Dziak et al., 2004).

Geologic and geophysical background

The South Shetland Island (SSI)–Antarctic Peninsula region is a rapidly changing geodynamic system driven by the interaction of the Antarctic, Scotia, and South American plates (Figure 1). The Scotia volcanic arc and trench to the east and two large east-west trending transform faults produce frequent, large magnitude earthquakes throughout the region. The South Shetland Trench (SST) off the west coast of the Antarctic Peninsula is the last surviving segment of a subduction zone that once extended along the peninsula's entire western margin (e.g., Cande et al., 1982). The tectonic setting of this subduction zone is very unusual since the trailing flank of the source ridge and overriding lithosphere at the trench were both part of the Antarctic plate (Barker and Austin, 1998). Therefore there was no relative motion between the plates, and the ridge-trench collision caused the cessation of subduction at each segment (Robertson-Maurice et al., 2003). In contrast to global records which indicate sparse seismicity in the SSI, a regional seismic study using both land-based and ocean-bottom seismometers indicated a high level of local seismicity (m_b 2–5; Robertson-Maurice et Al., 2003) even though the OBS deployment was relatively short (6 months). Many of the earthquakes occur at locations and depths indicative of ongoing subduction in the SST.

The Bransfield Strait is a Quaternary, ensialic back-arc basin at the transition from rifting to spreading (Barker and Austin, 1998). The Bransfield Strait is one of only two back-arc basins forming in continental crust that are opening without a large strike-slip component (Lawver et al., 1996). Many earthquakes have been located in the Bransfield Strait back-arc, occurring either on large submarine volcanoes or along regions of previously observed rifting. Indeed, a swarm of shallow earthquakes was located along the Orca submarine volcano, indicating either magmatic or eruptive activity (Robertson-Maurice et al., 2003). We plan to build on this OBS experiment by monitoring during a longer period of time (2 total years versus 6 months), and by using hydroacoustic techniques, thereby covering a much larger spatial scale from the South Shetland Islands, Scotia Sea, and as far east as the South Sandwich Islands. We anticipate this research will identify first-order correlations between the spatio-temporal distribution of earthquakes and major geologic features in the region. Such observations will provide insights into the dynamics of subduction and back-arc spreading, as well as the levels of otherwise unobserved submarine volcanic activity in the region.

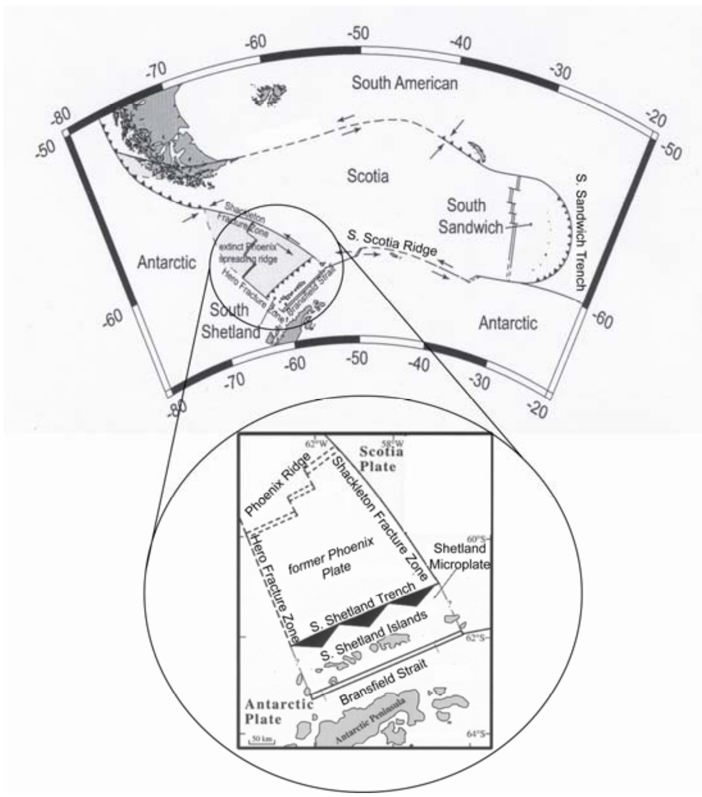

Figure 1. Tectonic setting of the South Shetland Islands and Bransfield Strait region.

Hydrophone instrumentation

The seven hydrophone moorings deployed in the Bransfield Strait and Drake Passage in 2005 were successfully recovered and re-deployed at the same location as the previous year. The hydrophone recovery/redeployment operations were conducted onboard the R/V *Yuhzmorgeologiya* and all hydrophones were successfully ranged and recoveries occurred within an hour of initial communication with the mooring. All seven hydrophones continuously recorded data throughout the year for a total of 155 GB of hydrophone data sampled at 250–1000 Hz with 16-bit A/D resolution.

The hydrophones were moored to the seafloor and suspended via flotation at a depth appropriate for a surface-reflected propagation path. The design includes a combination of a very low stretch 5/16-inch Yalex and ¼ inch Vectran mooring cable to eliminate noise from cable vibration due to strong currents, and a hydrophone instrument package and a Syntactic foam float that are retrievable using an acoustic release, leaving only a degradable metal anchor on the seafloor. Following each deployment, an accurate transponder-derived location is recorded for each instrument. The hardware package consists of a single ceramic hydrophone, a pre-amp filter to whiten the ambient noise, an accurate Q-tech clock (<1 s/yr drift) that is GPS synchronized before and after deployment, logging computer, and a set of solid-state memory cards for data storage that are suitable for cold temperature operations. Power is supplied using standard alkaline D-cell battery packs, which are replaced between deployments. The extreme, cold water (~0°C) and strong currents of the Drake Passage require modifications to the AUH design used in previous projects. Specifically, we doubled the strength of the mooring line and replaced the standard laptop hard-drives with a sealed industrial drive rated to –20°C.

Hydroacoustic data and discussion

Preliminary review of the data indicates the hydrophones recorded hundreds of seafloor earthquakes from the Bransfield Strait spreading centers, the subduction zone off the South Shetland Islands, as well as earthquakes from throughout the Scotia Sea. Moreover, we are able to discern the unique sounds of ice break-up and the harmonic tremor produced by the movement of large icebergs in the region. Figure 2 shows examples of the time-series and spectrograms of a regional earthquake (left) and harmonic iceberg tremor (right) recorded on hydrophones in the Bransfield Strait. The earthquake occurred on 10 March 2006, had a M_w of 6.1, and was located on the transform fault that forms the

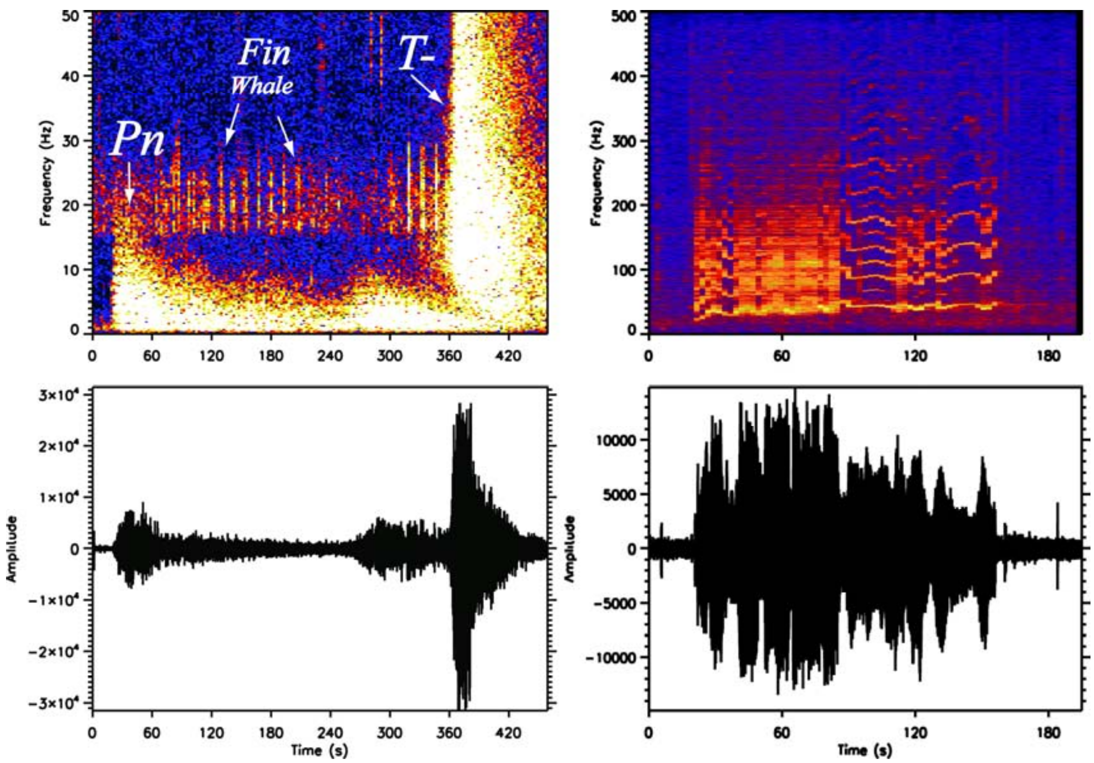

Figure 2. Examples of the time-series and spectrograms of a regional earthquake (left) and harmonic iceberg tremor (right) recorded by Bransfield Strait hydrophones.

South Scotia Ridge. The first arriving phase is the regional seismic *P*-wave (*Pn*) locally converted to an acoustic phase at the hydrophone mooring, with the high-amplitude acoustic water-borne *T*-wave arriving ~330 sec later.

To date we have detected two large swarms of moderate-sized earthquakes within the Bransfield Strait (Figure 3). The first swarm occurred on 4 August 2006 and produced 2,535 earthquakes during a 12-hour period. The earthquakes (green circles) were centered on and near the “Three-Sisters” back-arc spreading center located in the southwestern section of the Bransfield Strait. The second swarm occurred on 28 August 2006 and produced roughly 1,000 earthquakes during a 4-hour period (yellow circles). The locations of these earthquakes were distributed along the neovolcanic spreading zone of the back-arc basin from King George Island to north of Bridgeman Island up to the Scotia Ridge Transform Fault. The size, intensity, and low-magnitude of both swarms, in addition to brief periods of harmonic tremor visible in the earthquake arrivals, indicates the swarms were volcanic in origin, and their close spatio-temporal proximity suggests the volcanic activity at the two sites may be linked.

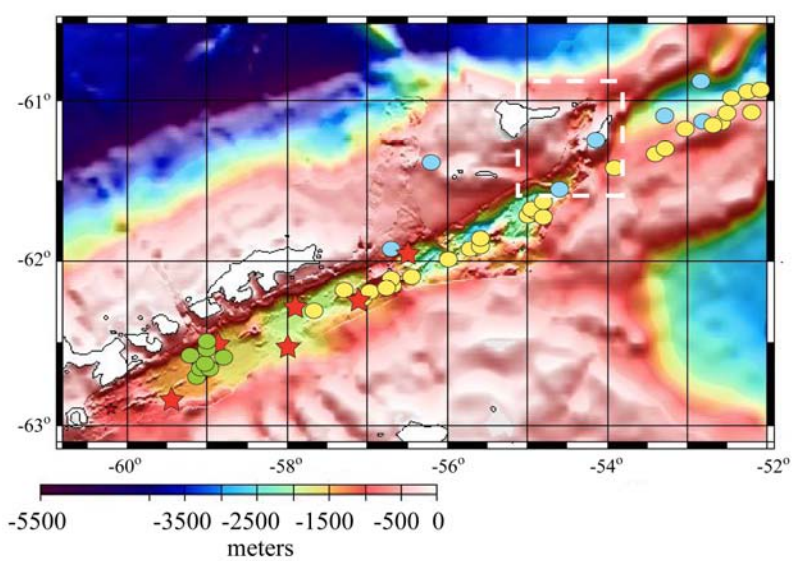

Figure 3. Bransfield bathymetry, hydrophone (stars), earthquake (green/yellow circles) and ice tremor (blue circles) locations shown. Dashed box shows location of Figure 4.

The iceberg tremor shown was recorded on 3 August 2006 and is ubiquitous during the

Figure 4. Satellite image of Iceberg A-53.

following 4 days. We were able to use these tremor signals to locate their source which corresponded to a large (>10 km long) iceberg in the northern Bransfield region identified and named from satellite images as A-53 (Figure 4). The tremor from large (>10 km) icebergs have been recorded previously and have typically produced signals with a fundamental (lowest) frequency of between 2–10 Hz (Talandier et al., 2002; Chapp et al., 2005). The fundamental frequency of A-53 was 40 Hz, placing it within the upper frequency range of ice-generated tremor signals previously recorded (Chapp et al., 2005). The fundamental frequency recorded from this iceberg implies a signal source size of 37.25 m at a 1490 m s^{-1} mean sound velocity. The iceberg is ~10 km in length and likely a few hundred meters thick, which suggests the harmonic tremor is produced by resonance of a small chamber or pocket of fluid within the iceberg rather than by resonance of the entire berg itself. We anticipate that as we process this complex hydrophone dataset we will be able to discern long-term variations in ice sounds that may be related to seasonal and climatic effects, as well as discern what the contribution to large ice breakup might be from natural (i.e., volcanic and tectonic) phenomena.

Lastly, we have also identified the vocalizations of several species of large baleen whales in the Bransfield Strait, including Humpback and Fin whales and the globally endangered Blue Whale. In the left spectrogram of Figure 2, the impulsive vocalizations of Fin whales can be seen continuously in the 15–25 Hz band. Because of the close spacing of the hydrophone array, we may be able to detect a vocalizing whale on all hydrophones, allowing us to track the path of a baleen whale as it moves through our hydrophone array. Moreover, we have established that the largest number of Blue Whale calls were present in the Drake Passage during the Fall-Winter (May) migration/mating season. Calls were not as numerous as previously suspected in the Bransfield or during the Summer.

Summary

This paper describes the preliminary results from the deployment of an array of underwater hydrophones within the Drake Passage and Bransfield Strait off the west coast of the Antarctic Peninsula. The hydrophones recorded hundreds of earthquakes, harmonic tremors produced by the movement of large icebergs, and the vocalizations of several critically endangered cetacean species.

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