DEPLOYMENT OF AUTONOMOUS HYDROPHONE ARRAY IN THE SCOTIA SEA

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ABSTRACT

The remote area of the Atlantic Ocean near the Antarctic Peninsula and the South Scotia Sea is a region where acoustic surveillance by International Monitoring System (IMS) hydrophones is at best limited. Sound originating in this area is either blocked or hindered by the South Georgia Islands (SGI) and the associated seafloor ridge system, making the region a potential hydroacoustic blind spot for IMS stations. In the spring of 2008, we successfully completed the deployment of a hydrophone array consisting of six autonomous underwater hydrophones (AUHs) in the Scotia Sea area. The array configuration is optimum to study sound propagation through the Antarctic Convergence Zone (ACZ), as well as acoustic blockage and reflection caused by islands and associated seafloor topography. Regional seismo-acoustic signals and episodic harmonic tremor from large icebergs will be utilized as natural sound sources.

Since the acoustic data will not be available until the recovery cruise takes place in early 2009, this paper reports the progress we have made so far in evaluating International Data Centre (IDC) and National Earthquake Information Center (NEIC) earthquake data, as well as satellite-derived (NSIDC) information on the distribution of icebergs in the South Atlantic Ocean. We also describe the ice tremor and T-wave signals observed by a similar AUH array deployed near the Antarctic Peninsula in 2006–2007. This region is characterized by surface-limited propagation conditions similar to the Scotia Sea. Our focus is on the T-wave generated by an m_b 7.0 earthquake along the South Scotia Ridge (61^{o}00.36’S, 34^{o}23.46 W) and the associated T-phase reflection from the SGI, as well as the characteristics of the ice tremor from iceberg uk213 during the time when it was positioned near Clarence Island (61^{o}19’S, 54^{o}16’W).

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OBJECTIVES

Monitoring underwater low-frequency sound is one of the critical components of the global nuclear explosion monitoring effort lead by the National Nuclear Security Administration, the Air Force Research Laboratory, and the Army Space Missile Defense Command. Their objective is to ensure that any nuclear weapon tests conducted in the ocean or near the surface above the ocean do not go undetected. One area where such a signal can be hidden from the eyes of the international community is the Scotia Sea in the south Atlantic. In the Scotia Sea propagation across the ACZ is poorly understood and the sound path to the IMS hydrophones is partially or completely blocked by the islands and associated seafloor ridge system that delineate the Scotia Plate.

With an array consisting of six AUHs successfully deployed in early 2008, a continuous recording of acoustic signals has begun in the Scotia Sea. The array will monitor the T-phases and ice tremors occurring in the Southern Ocean. Upon the recovery of hydrophones, which is scheduled in early 2009, our goals is to undertake a detailed study of acoustic signals received at the AUHs and IMS stations, investigating spectral characteristics and received levels affected by the ACZ, regional bathymetry and island blockages. Based on the acoustic data we will catalog source locations, source levels and origin times, along with associated arrival time and received signal level information. To assess our ability to accurately model the source level of signals originating in the remote southern ocean, the observational data will be compared with predictions derived from range dependant propagation models.

RESEARCH ACCOMPLISHED

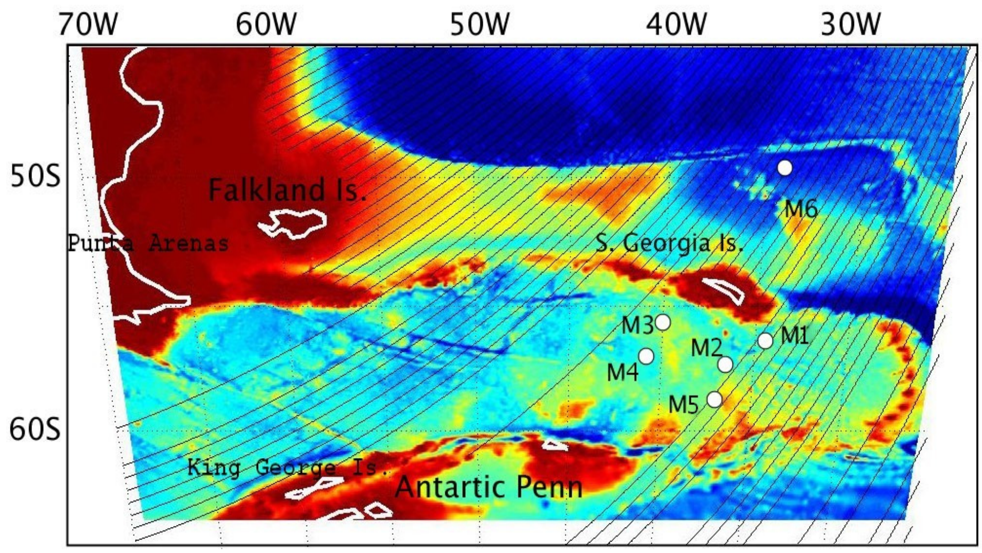
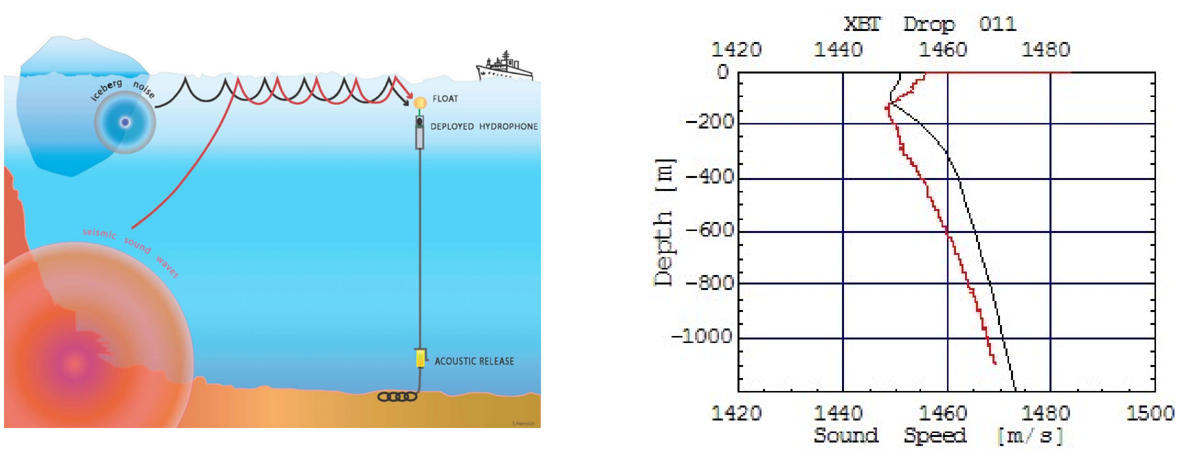


Figure 1. 2007-2008 array configuration for detecting acoustic events and investigating propagation in the Scotia Sea area. Black lines show acoustic paths for Ascension Island, with a <500 m line-of-sight blockage criteria applied.

In December 2007, as part of a collaboration between the Korea Polar Research Institute (KOPRI), the National Oceanic and Atmospheric Administration (NOAA), the Cooperative Institute for Marine Resource Studies (CIMRS) at Oregon State University and North Carolina State University (NCSU), a five-station AUH array (M1-M5, Figure 1) was deployed in the Scotia Sea region. With ship support from the British Antarctic Survey (BAS), we later deploy a sixth hydrophone to the north of SGI in April of 2008 (M6). When we recover all of the hydrophones in early 2009, the observation period will be approximately one year and the amount of acoustic records digitized at 250 Hz will be 16 GB per hydrophone (total of 96GB). As the data have not yet been recovered, this paper discusses the preliminary earthquake and iceberg data that we intend to use as sound sources in year two of this project. These data include seismic information from both the IDC and NEIC, and satellite derived information on the distribution of icebergs and sea ice obtained from the National Snow and Ice Data Center (NSIDC).

The five-AUH array configuration on the south side of SGI (M1 through M5) will allow us to accurately locate the acoustic events including seismic events below m_b 3 originating from the south side of the island, namely the Scotia Sea, portion of the Drake Passage and the Weddell Sea. This area is acoustically blocked from the IMS hydrophones by the seafloor features associated with the SGI. We will first identify the sound sources by associating the spectral characteristics of the acoustic events at each hydrophone, and applying nonlinear least square technique to locate the sources based on travel times derived from GDEM (Generalized Digital Environmental Model) (Fox, 2001). Each hydrophone independently maintains the timing by an internal clock that is accurate to 1 sec/year. Source levels are then estimated based on propagation loss (Dziak 1997). A lone hydrophone on the north side of the SGI (M6) will allow us to examine the interference effect of SGI and associated seafloor features on the acoustic signals originating from the south of the island (e.g., earthquakes and ice tremors). This will be accomplished through comparisons with observations at the other hydrophone stations (M1-M5), which lie along unblocked paths from such sources.

Although in principle only three single-channel AUHs are needed to determine the locations and origin times of the events, two redundant hydrophones were added to improve the accuracy as well as insurance against possible instrument loss by the strong current of Antarctic Circumpolar Current (ACC) (Gabarato, 2003) and potential high concentrations of sea ice during the recovery. In the northern Weddell Sea during the austral winter, the area is partially covered by sea ice and the ice edge may extend as far north as 55°S. During the austral summer, the sea ice typically recedes to 65°S (Wolff, 2007). The mooring depth of all the hydrophones is 500 m below the surface (Figure 2A), which is shallower than the lower latitude hydrophone depth (typically 1,000 m). The 500-m hydrophone depth is not ideal but rather is a compromise between minimizing a risk of losing the system by large icebergs and keeping it close to the sound propagation layer near the surface in the high latitude waters.



(A) (B)

Figure 2. (A) Diagram of AUH mooring customized in the ACZ propagation study. The hydrophone is moored within this surface layer to take advantage of this relatively effective transmission. The spherical float (syntactic foam) is to keep the mooring line rigid while minimizing the drag force. The top 1000 m of the mooring line is made of a high tensile strength cable with low-flow-noise characteristics (Vectran@). The rest of the mooring lines are of Very Low Stretch (VLS) line. (B) The vertical temperature profile unique to the polar region makes the sound propagation "surface-limited." The sound speed (in red) is based on the XBT data taken at 57°28.5'S, 41°32.8'W on December 12, 2007 during R/V Yuzhmorgeologiya. Black solid line is based on typical temperature and salinity data from GDEM data set.

During the deployment cruise, XBT casts were made at each mooring site to estimate the sound velocity profiles. Figure 2B shows one of the velocity profiles based on an XBT cast near the M4 mooring. In most propagation modeling environments, GDEM is sufficient. However, in the case of ACZ propagation within the Southern Ocean, sound speed profiles based on XBT data and GDEM indicate some differences (~4m/s), suggesting the need to incorporate additional water column data/field (e.g., Argo float and CTD data from other cruises) where available.

In 2006, a separate hydrophone array deployed for another experiment detected a series of ice tremors originated by the Clarence Island in the Bransfield strait near the Antarctic Peninsula (Figure 3). The signals originated from a 10x5 km iceberg (uk213), which was too small to be tracked by the NSIDC. The signal intensity was large enough to be heard by all the hydrophones in the area and the estimated sound intensity was equivalent to a m_b 5.0 earthquake. The uk213 ice tremors resemble the "Variable Harmonic Tremor" described by Chapp et al. (2005), but they have a relatively short duration of 60–180 seconds. The uk213 tremors also exhibit harmonics with a much wider spectral range, up to 400 Hz, relative to those observed by the IMS hydrophones. The typical ice tremor bandwidth observed by the IMS hydrophones in the Indian Ocean was much narrower than this, including those described by Chapp et al.,(2005) which were less than 100 Hz. The ice tremors reported by Talandier et al. (2006) were less than 14 Hz. The uk213 tremors in the Bransfield also lack low frequency energy below 40 Hz. It appears that short-range propagation (~125 km) helped retain most of the high frequency components, which otherwise would be dissipated as the sound traveled over long ranges out to the open sea.

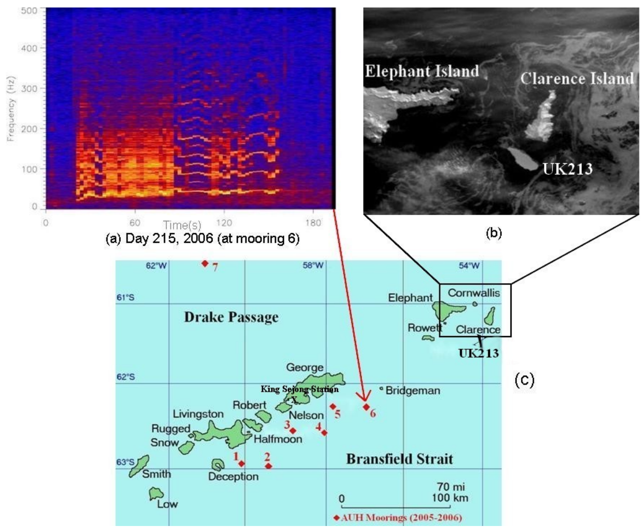
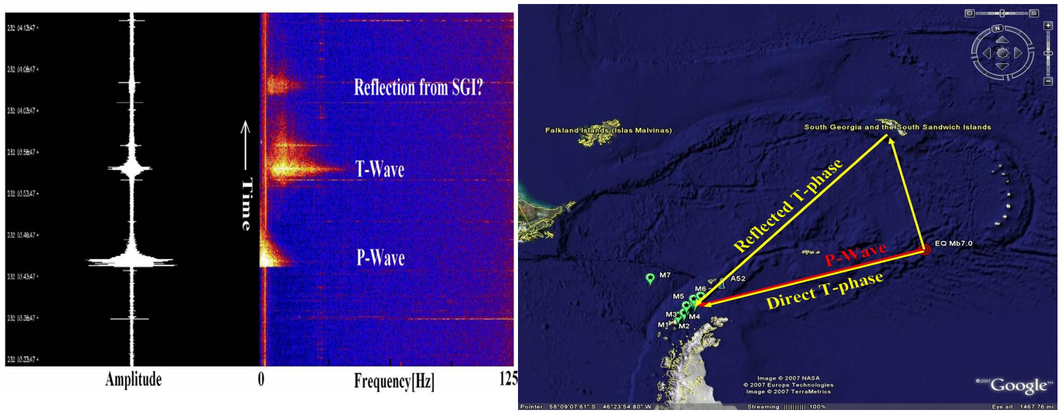


Figure 3. (A) Harmonic tremor recorded by one of the NOAA/PMEL AUHs in the previous experiment (2006) in the Bransfield Strait (1kHz sampling rate). (B) Satellite image of uk213 iceberg (5km x 10km) on day 216, 2006. The iceberg was by Clarence Islands, at 61°20"S-54°W, 125km NE from the AUH 6. (C) Map of the South Shetland Islands Chain.

On August 20, 2006, at 03:41:47 (UTC), an earthquake of m_b 7.0 was detected in the area by the Global Seismic Network (GNS). Figure 4 shows the P-wave and T-wave that propagated 1,250 km from the epicenter and were recorded by the NOAA Bransfield AUH array. The epicenter was 61°00.36'S, 34°23.46'W at the boundary of the Scotia and the Antarctic plates. All AUHs recorded P-waves (P_n phase) and T-waves generated by the earthquake including the AUH in the Drake Passage, although Elephant and Clarence Islands were directly in the line of sight from the epicenter. The third signal in Figure 4A arrived about 600 seconds later than the T-wave and was much weaker than the other two arrivals. Because of its relatively wide-band spectral content, the similarity of the spectral contents to the first T-wave and the timing of the arrivals (24 min 13 sec after the earthquake origin time), we believe that the third signal is a reflected T-wave off the steep slope of the South Georgia Island (Figure 4B), a phenomenon that also has been observed on the IMS signals in the Indian Ocean (e.g., Hansen and Bowman, 2006).

Relative to their low-to-mid latitude counterparts, all T-wave signals recorded by the Bransfield array are deficient in low frequency energy below 5 Hz. This observation is likely linked to the cut-off frequency of the shallow surface duct, a well-known phenomenon in ocean acoustics (Urick, 1983). However, we note that ice-generated signals recorded in the Indian Ocean at long ranges typically have fundamental harmonics < 5 Hz (Chapp et al., 2004). Consequently, the frequency-dependant coupling of ocean sounds may also be sensitive to the source depth.



(A) **(B)**

Figure 4. (A) M_b 7.0 earthquake signals detected by the AUH 5 in the Bransfield Strait. (B) T-wave originated by Mb 7.0 earthquake in the S. Scotia Ridge was reflected by SGI arriving 600 seconds later after the direct T-wave arrival.

As of July 2008, six large icebergs (>10NM on one side) have been registered by NSIDC in the Scotia Sea region based on satellite images. Figure 5A shows these iceberg locations indicated by blue triangles, which include A43F (53°21'S-36°13'W), A43K (58°51'S-42°43'W), B15D (55°01'S-42°24'W), uk248 (54°06'S-39°03'W), uk177 (59°05'S-45°01'W, and D18 (58°59'S-39°32'W). There are numerous other icebergs too small to be registered and tracked by NSIDC, but any one of these icebergs can potentially generate large ice tremor signals (Müller et al., 2005, Talandier et al., 2006) that we can utilize as the sound sources to study the sound propagation through the ACZ and interferences by bathymetry and island features. It also shows 111 accumulated earthquakes (red circles) registered since the Scotia Sea hydrophone deployment, January 1, 2008, through July 7, 2008, on the NEIC catalog. Earthquakes occurred mostly in the Scotia arc region where the South American plate is being subducted under the Sandwich microplate. Several T-phases originated in this arc region were large enough (m_b> 5.6) to be detected by the Ascension Island IMS hydrophone. None of the earthquakes that occurred in the south and southwest of the SGI were detected by the Ascension Island hydrophones, indicating that the earthquakes were either too small or that seafloor features were effective at blocking T-wave propagation across the SGI region.

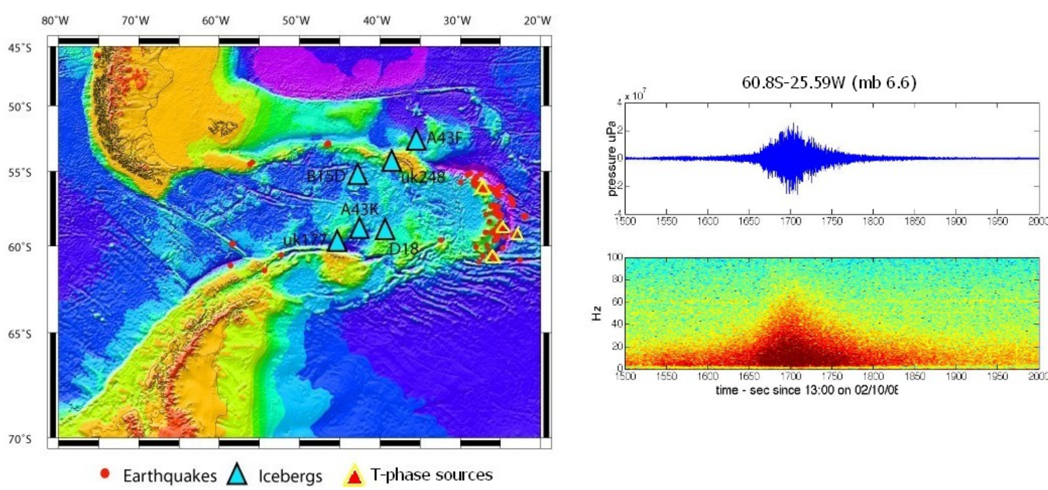


Figure 5. Iceberg locations (blue triangles) as of July 07, 2008, from NSIDC and accumulated epicenters map (red circles) since January 1, 2008, based on the NEIC catalog. Four T-phase sources were identified during the same period by the Ascension Island IMS hydrophones (yellow triangles). One of the T-phases is displayed on the right-hand side. Most earthquakes are located near the arc. Several earthquakes were located near the Western Antarctic Peninsula area where the plate is old but volcanically is still active.

CONCLUSIONS AND RECOMMENDATIONS

- Successful deployment of all six hydrophones was accomplished in December 2007/April 2008. Recovery operations are planned for December 2008/April 2009, resulting in approximately one year of continuously recorded acoustic information.
- Preliminary analysis of the signal from the Scotia Sea detected by the IMS hydrophone is promising. NSIDC data indicate that there are numerous large icebergs located within and moving through the study area. We have identified several large earthquake sources with blocked and unblocked paths to the M6 hydrophone and the IMS station at Ascension Island.

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