CALIBRATION OF T-PHASE RECORDINGS AT ASCENSION ISLAND: SIGNATURES OF NATURAL AND MAN-MADE SOURCES

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ABSTRACT

The Ascension Island experiment in May 1999, comprised several elements, each contributing new information about the propagation and coupling of T-phases around an island slope and the subsequent attenuation of seismic energy during propagation to on-shore receivers. Off-shore sensors for which data acquisition was successful include the three bottom-moored (MILS) hydrophones, monitored in real-time, and three temporary, autonomous hydrophones (one deployed on the seafloor northwest of the island, two moored at about the depth of the sound channel axis - one each northeast and southwest of the island). Initial analysis of data from two of these temporary hydrophones is the main focus of this paper.

Three types of source were available during the experiment: airgun shots, an imploding sphere, and numerous natural events that fortuitously occurred during the 3-5 day recording period. These natural events occurred at regional distances to the south of the island and generated T-phases that are clear in both off-shore and on-shore records. The frequency of the arrivals can exceed 50 Hz, suggesting that that a volcanic gas phase may have been released. These are ideal sources for calibration of T-phase coupling at the ocean/island interface for a limited range of southern azimuths, so we will quantify the character of representative T-waves as a function of off-shore location and seafloor topography. These parameters will then be available for comparison to the onshore recordings of the seismic phases whose character will reflect the nature of the slope where acoustic-seismic conversion occurs as well as any losses due to crustal heterogeneity.

One of our goals was to assess the azimuthal dependence of acoustic-to-seismic coupling of T-phases that encounter the rough slopes of a volcanic island. The 6000 cubic inch airgun array towed by the RRS James Clark Ross provided large, impulsive signals, but the 20-m depth of this source is not ideal for generating phases that propagate mainly within the sound channel. The rough seafloor does scatter energy into the sound channel so the extent to which these signals can be used for calibration purposes will be illustrated. The clear advantage of the airgun source is that it can be located at any desired range and, in the short time available, we were able to complete a track pattern that encircled the island.

Key Words: T phase, hydrophone, hydroacoustic monitoring

OBJECTIVE

Island T-stations are an integral part of the monitoring system for the nuclear-test-ban treaty verification. A blast that occurs in the ocean, just above the seasurface, or onshore but near a steeply sloping shoreline, will produce an acoustic wave that can travel long distances in the oceanic sound channel. Ideally this sort of test would be detected by a network of monitoring hydrophones but the cost of deploying cables and maintaining real-time data streams from offshore instruments is significant. Alternatively, seismic stations on remote islands can provide recordings of the acoustic wave after it has been converted to seismic phases at the ocean-island interface and this information can be used to help locate and, perhaps, characterize the event. Detection of converted T-phases from natural events (earthquakes and volcanic sources) has been demonstrated for volcanic island seismic stations (e.g. Hanson, 1998; Talandier and Okal, 1998). The goal of this project at Ascension Island is to begin a systematic, quantitative study of the amount and nature of the losses that occur during the acoustic-seismic conversion. Increased understanding of this process should lead to an improved level of information extraction from the T-station data and, therefore, additional contribution to the IMS.

RESEARCH ACCOMPLISHED

The Ascension Island experiment comprised onshore and offshore deployments of instruments during a one-week period of May, 1999, within which we conducted 3-days of airgun shooting along tracks that surround the island (Figure 1). The British Antarctic Survey ship RRS James Clark Ross was returning from the field season in Antarctica and we were able to contract the ship for 4 days to conduct a combined tomographic and hydroacoustic experiment. Tim Minshull instigated the project with the aim of characterizing the crustal structure of the island after earlier studies (Minshull and Brozena, 1997) suggested the presence of a low elastic strength region at fairly shallow levels which could be interpreted as a magma reservoir. In an effort to follow-up on issues of data access and quality for both the IDA seismic station (ASCN) and the U.S. Air Force MILS hydrophones offshore , Tim contacted me and we established a collaboration for the project with the additional goal of attempting to use the airgun signals to calibrate the degree of signal reduction and alteration due to coupling of the acoustic wave to seismic waves at the island slope. The project was expanded to include deployment by Lawrence Livermore National Labs of portable seismic stations on the island so that changes in the waveform of the converted T phases with distance from the shoreline could be measured. Differences in the coupling mechanism associated with differences in the geologic character of the slope as a function of source-receiver azimuth would be measured as the ship towed the airgun array around the island.

Two of the MILS hydrophones (ASC23 and ASC24) are moored in the sound channel about 50 km off the south shoreline of the island and within about 5 km of each other. These data, as well as that from ASC26 about 100 km further south, are routinely archived at the PIDC. For this project the Center for Monitoring Research put special effort towards real-time monitoring of the data quality and compilation of the continuous data throughout the experiment. The data were then made available in an ftp site shortly after the study.

Four temporary hydrophones were deployed from the JC Ross. Two were Scripp's LCHEAPO instruments that were moored in the sound channel to provide source characterization. Due to their age, the instrument response of the MILS phones is not well known. The PTS underwrote this part of the experiment. The LCHEAPOs (named 'maggie' and 'lisa') were deployed in locations that extended the main NE/SW profile of seismic stations onshore. Two Cambridge University, U.K., ocean bottom hydrophones (OBH27 and OBH29) were deployed to the NW and SE of the island. Unfortunately we failed to recover OBH29 at the end of the experiment when its pressure case leaked and it sank permanently.

The airgun array was quite large (6186 cu inch) and contained 11 individual guns tuned to optimize source impulsiveness. Shooting for the main part of the experiment commenced on Julian day (jd) 134 at 02:30 and, after an initial testing period, continued at 1-minute intervals firing at 50 msec after the even minute until jd 137 at 16:00. A final series of 8 shots were made at 5-minute intervals until 16:40 with the intent to allow complete dissipation of shot energy in the water column between these shots.

The data quality on the LCHEAPOs is good and we can accomplish our goals with it. There are intermittent spikes that occurred when the instrument thought it was being acoustically interrogated (as it

normally is during deployment and recovery) and it pinged in response. Since the ping response was not disabled after deployment, whenever a fairly impulsive, broadband signal was received by the instrument it essentially immediately responded and the sound of its own ping swamps whatever the incoming signal was. The only time this is a problem is when the glass sphere imploded 8 km from instrument maggie. The spike provides a useful time stamp for the implosion but we cannot determine the source signature in this case. The spikes occur most commonly when the ship is in the vicinity of the instrument but are infrequent overall and do not interfere with analysis of the airgun shots. We are continuing to investigate the times of the ping responses so that we can make sure they were not caused by something other than just ship noise. Several of the natural events are well recorded by the LCHEAPOs although several times more of these events are seen in the MILS data. This may be due to the exact position within the sound channel that the instruments were moored.

Ocean currents can cause the LCHEAPO to drift a few hundred meters from the position at which it enters the water column at the seasurface and the position that the anchor settles on the seafloor. Such mislocation is large enough to bias inversion of body-wave travel-times (in the crustal tomography part of the experiment) so we relocated the instruments. The position and timing of the airgun shots is well known (to msec accuracy) and the crossing track pattern is optimal for a seafloor instrument relocation. In our case, the mooring line can continue to move somewhat in the tidal current so we expect a higher level of uncertainty than the usual several-msec values obtained for seafloor relocations. The arrival time of the water wave was picked out to ranges ~10km on each of the three local lines for Lisa and Maggie. These travel-times formed the data vector for a least-squares inversion in which up to five parameters could be varied: x, y, depth, average speed of sound, static time shift. The latter was held constant to account for the 50 msec shift between the airgun trigger and actual fire after initial tests showed this value was stable as expected. The starting position was set to the GPS coordinates at the drop site and the difference in seafloor depth and mooring line length. Starting water velocity was 1501 m/s based on the annual sound velocity profile from the World Ocean Atlas 1° model. Hydrophone depth could vary up to ~100 m given the mooring line lengths and expected currents so we inverted for this parameter as well as letting average water velocity vary if the inversion required it. Maggie, to the NE of the island appears to have drifted ~150m to the north and ~80 m east; Lisa, SW of the island, appears to have drifted ~30 m north and ~150 m west. The preferred depth for both instruments was 10-30 m greater than the simple difference between seafloor and mooring line length predicted. The change from starting to preferred average water velocity was small (1500 m/s preferred at Maggie; 1491 m/s preferred at Lisa). The RMS travel-time residuals for the water wave arrivals were reduced significantly for the relocated positions

Table 1. Information for LCHEAPO Hydrophones on Cruise JR42

Latitude	Longitude	Sensor Depth	Mooring Height	Record (jday/hr:min) Start - stop	Original Residual	Inverted Residual	Name
8° 2.39'S	14° 31.11'W	923 m	730 m	134/14:30 - 137/20:00	63 msec	21 msec	Lisa
7° 50.35'S	14°12.66'W	1347	1460	134/22:00 - 137/20:00	100	26	Maggie

Examples of LCHEAPO recordings of the natural events and the airgun shots are shown in Figures 2 and 3 for shot-receiver ranges of about 25 kms. The airgun shots often have a sharp onset but there are periods in which the water-borne energy is more spread out in time. For some near-source seafloor morphologies, body-waves couple into T-waves at local highs ('radiators') in the sound channel and these arrivals precede the phase that is solely water borne. Systematic study of these situations is underway but initial analysis shows that this clearly happens when the airgun source is near small, isolated highs. The airgun source has high energy in the 5-50 Hz frequency band. In the 2-7 Hz band, the natural events have more energy (Figure 3). This difference will provide interesting comparison of the efficiency of acoustic-seismic

coupling at the island slope. The airgun array shots clearly produce a decent sized signal at sound channel depths for ranges up to at least 40 kms. Some of this energy is reverberating between the sea surface and the seafloor rather than being guided completely within the sound channel. Again, this will provide interesting comparison with the natural events where essentially all the energy is guided so incidence angles should be closer to horizontal.

Initial analysis of the T-wave arrival times at the MILS and LCHEAPO hydrophones suggest that the natural events could have occurred on the Mid-Atlantic Ridge just north of a small right-lateral transform fault at 9° 45'S. The difference in arrival times between ASC26 and the hydrophones closer to Ascension Island is consistently 70 s (Figure 4) but the difference between the near island hydrophones is noisier (although arrivals at Maggie are consistently later than at the rest). More detailed analysis will be required to completely rule out other possible source locations for the natural events. T-phases for 41 events were picked on the MILS data for the time period jd 133-137. All but two of them appear to have come from this same source area.

CONCLUSIONS AND RECOMMENDATIONS

The Ascension Island experiment was successful. More complete analysis to determine just how well the airgun shots can be used to characterize T-phase coupling at a rough island slope is underway. For the meeting, absolute calibration of the shot source signature should be complete and characterization of the natural event T-phases as they approach the island will have been achieved. With this information we can begin the modeling the coupling mechanisms using the onshore seismic data as a guide.

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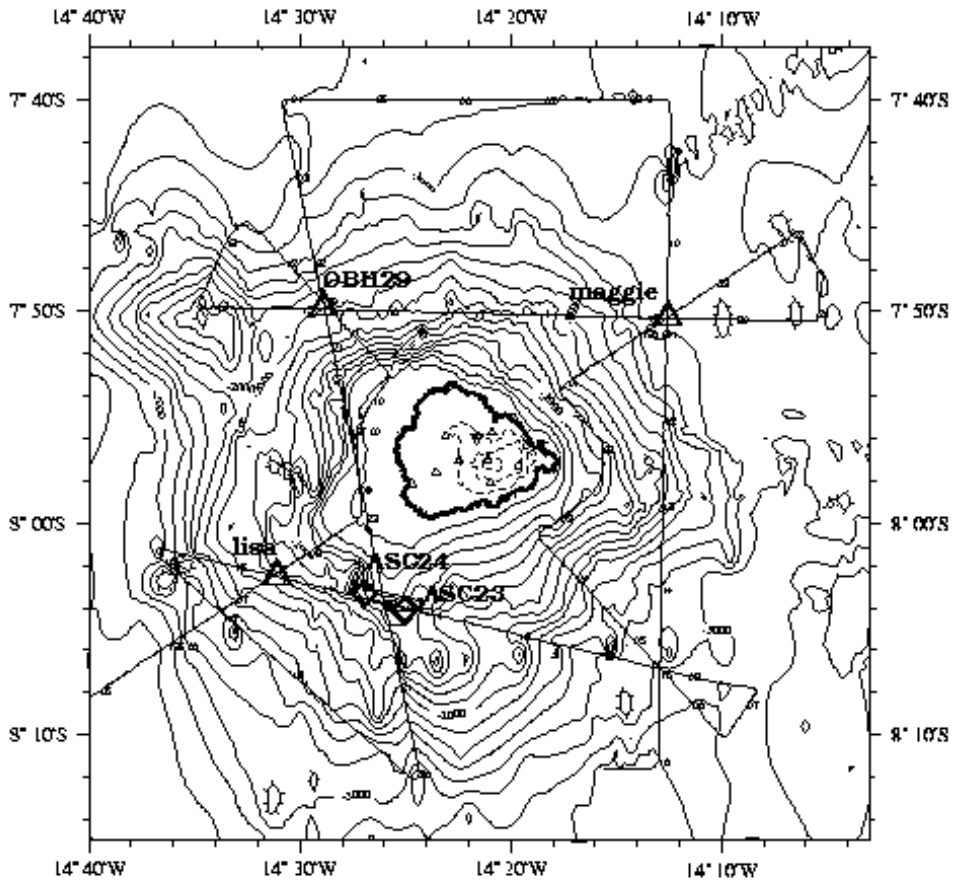

Figure 1. Instrument locations and airgun shotlines for the Ascension Island Experiment in May 1999. Diamonds show the 2 MILS hydrophones (ASC26 is ~100 kms further south); Large triangles show temporary hydrophones: OBH29 was deployed on the seafloor; the Scripps hydrophones lisa and maggie were moored in the sound channel. Onshore seismic stations are shown by small triangles; Inverted triangle shows permanent station ASCN. Airgun shots were fired at 1-minute intervals along the tracks shown. Time (Julian day and hour) is indicated along the track. Bathymetric contours, and dotted topographic contours onshore, are at 200 m intervals.

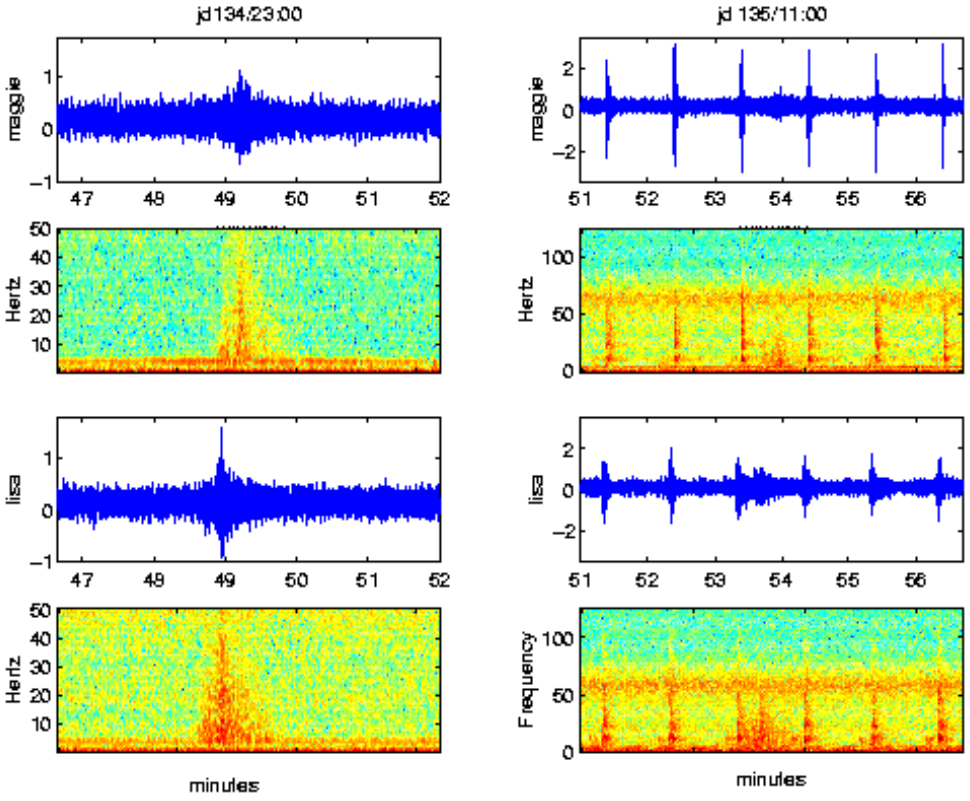

Figure 2. Examples of T-waves and airgun shots recorded on the LCHEAPO hydrohphones. Left panels show a regional natural event with unfiltered record sections above corresponding spectrograms. Ship noise shows up in the 3-5 Hz band. Right panels show both a series of airgun shots and a natural event in the center of the section. Man-made 60 cycle noise is evident in these spectrograms. The airgun shots have significant energy up to 100 Hz.

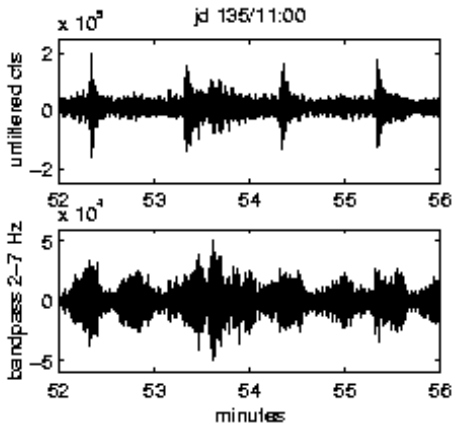

Figure 3. Illustration of the frequency content of the airgun signals vs the natural events. Same section as in right panels of Figure 2. Natural events have more energy than the shots in the 2-7 Hz range.

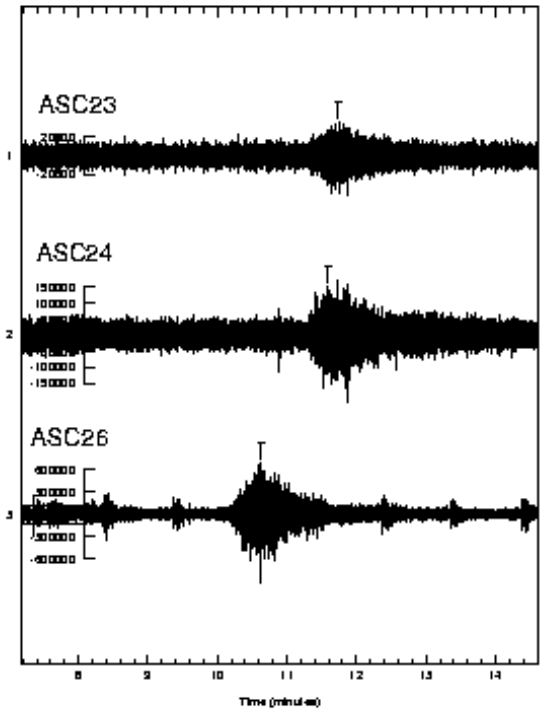

Figure 4. Record sections of the same natural event shown in left panels of Figure 2 from MILS hydrophones. A bandpass filter of 2-20 Hz has been applied.