INDIAN OCEAN CALIBRATION TESTS: CAPE TOWN-COCOS KEELING 2003

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ABSTRACT

A series of hydroacoustic calibration shots were conducted in the Indian Ocean during a research cruise in May/June, 2003. The shots were distributed along an approximate great-circle track from the southern tip of South Africa to Cocos Keeling Island, in the northeast Indian Ocean. The acoustic signals propagated basin-wide in several cases and were recorded at the International Monitoring System (IMS) hydrophone stations off Isles Crozet, Diego Garcia, and Cape Leeuwin. Two-pound Signals, Underwater Sound (SUS) charges were fired at depths of ~600 m and ~900 m and imploding glass spheres were triggered at ~700 m water depth. Single-sphere glass imploders and 5-sphere imploders were each deployed at four stations. Often, both SUS and glass spheres were deployed at the same location so that a comparison of the signals received at each IMS hydrophone station could be made for a constant source-receiver path. The attenuation along most of each path is quite low as the signal travels within the oceanic sound channel. However, a number of shallow bathymetric features that protrude up into the channel do cause significant signal loss: Walters Shoal, the ridges where plate spreading is centered, the Ninety East Ridge, and the slope around Cocos-Keeling Island. The nature of the signal attenuation due to interaction with the seafloor varies, as expected, with the character of a given bathymetric feature and with the depth of the source in the sound channel. We analyze such effects in terms of variations in frequency content of the recorded signals as well as shifts in the position of peak amplitude within the wavetrain. Initial processing to assess the accuracy with which our small sources can be located using IMS recordings indicates that azimuth estimates can be within 2° in many cases. Thus far, we have only worked with the Diego Garcia and Cape Leeuwin data. Complete determination of IMS location capabilities for small sources in the Indian Ocean awaits the availability of data from Crozet.

OBJECTIVE

The hydrophone stations that comprise the International Monitoring System (IMS) within the Indian Ocean basin have recently become fully operational. The completion of stations off Crozet (H04) in early 2003 makes it possible to document the event detection and location capabilities of the full system using small man-made sources with well-known origin time and location. The present study builds on the results from a similar cruise undertaken in 2001 where a large airgun array and several glass sphere shots were recorded at Diego Garcia (H08) and Cape Leeuwin (H01). The intent of our work during the 2003 R/V Melville cruise was to test additional types of calibration sources, to test source-receiver paths from a different ship track than had been followed in 2001, and to provide some of the first well known signals for assessment of performance at the Crozet hydrophones. By firing each source within the sound channel, long-distance propagation was achieved. However, regions of shallow seafloor within the basin resulted in variable signal loss. Since each source-receiver paths were characterized by distinct bathymetry, the amount of interaction with the seafloor ranged from paths that were completely unblocked, to paths containing some features that caused diffraction and some attenuation, to paths with total blockage for one or both arms of a station. One goal of this study is to document regions within the Indian Ocean basin that result in more (or less) attenuation or blockage than is expected based on typically employed elevation and propagation models.

RESEARCH ACCOMPLISHED

The three source types that were planned for the 2003 Melville experiment were an electroacoustic projector system, imploding glass spheres, and small explosive depth charges. The receivers were permanently installed hydrophones that are part of the International Monitoring System that is overseen by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) of the United Nations. During the cruise, source information was sent to colleagues onshore and at the CTBTO and they checked the IMS data and reported detections, or lack thereof, back to the ship via emails. At the time of this report, we have begun systematic analysis of the Diego Garcia and Cape Leeuwin data. Initial findings are discussed below. Data from Crozet is still in a test phase due to the very recent installation of that station. We are in the process of working with the CTBTO to determine whether access to those data will be granted for short time periods on either side of our calibration shots. For the September 2003, meeting we expect to report the results based on a more detailed analysis.

Source Information

The SUS charges used were model MK94 with 1.8 lb explosive. For our experiment, the shear disks that triggered detonation were set to 610 m (2000 feet) or 915 m (3000 feet). At these detonation depths, the peak energy density of the source is at about 100 Hz at a level of about 270 dB, re 1μPa at 1-meter range (Urick, 1967). Scott Jenkins, Indian Head Division, US Navy, oversaw the manufacture and deployment of the SUS. Twelve each of the 610 m and 915 m charges were used. The time required for the charges to sink after deployment was ~2 minutes for 610 m charges and ~3 minutes for 915 m charges. The ship held position during this time so the Global Positioning Satellite (GPS) fix is a valid source location, accurate to within 10 m.

Two versions of the Lawrence Livermore National Laboratory (LLNL) imploding glass sphere system were used — a single-sphere device and a 5-sphere device (Harben *et al*., 2000; 2001). The single sphere device uses a 22-liter glass sphere and a piston driven smashing system that causes sphere failure at a pre-determined depth through failure of a ruptured disk. The 5-sphere device uses the same piston driven smashing system as the 1-sphere device. The remaining 4 spheres fail as a direct result of the first one. The spheres imploded quite reliably although there was some variation in the depth (690-731 m) at which the discs ruptured. Prior near-source recordings indicate that the peak output (250-270 dB re μPa at 1 meter range) of the imploding spheres was in the 300-500 Hz band, however several shots recorded at the IMS hydroacoustic stations in 2001 showed that signal-to-noise ratio (SNR) of the arrivals is sufficient for it to be seen above the noise at 40-125 Hz (Blackman *et al*., 2003). As for the SUS deployments, ship GPS fixes were used to determine the location of each glass sphere implosion since the instruments were lowered on a winch line while the ship held position.

Our intent was to operate the University of Washington, Applied Physics Lab (APL) electroacoustic projector system at several stations during the cruise, with depths ranging from 1300-300 m, so as to generate signal within the 40-100 Hz band with an output level of 195 dB re μPa at 1 meter. A self-contained winch was designed and built by APL so that the system can be used on any vessel with enough deck space to accommodate a standard container van centered on an A-frame. The electroacoustic source is fundamentally the same as those used previously for acoustic thermometry (ATOC) experiments (ATOC Consortium, 1998; ATOC Instrumentation Group, 1995; Dushaw *et al*., 1999). Following a series of deck tests the system was deployed to 1300 m depth during our cruise. Unfortunately, the attempt to pressurize the source at depth was not successful. In this state, the system failed upon receiving a command to begin generating a series of test signals to calibrate the program that would drive the source. The reason for the failed pressurization was determined immediately upon recovery of the instrument. After a series of tests with the system open, it was determined that one ceramic stave needed to be replaced (an operation that was not possible at sea). Thus, it is expected that the source will be repaired and that it will be operational for future use, but we were not able to use it during our 2003 experiment.

Accurate source times were determined from recordings made with a portable hydrophone deployed over the side of the ship. This hydrophone was intended for use with the electroacoustic source so its sensitivity was too great for useful waveform recording of the SUS and glass sphere shots, most of which were clipped. However, the onset of the arrivals can be picked with accuracy to within 0.002 seconds. GPS time was integrated with the recording of the near-source hydrophone and these data were sampled at 3000 Hz then low-passed by a filter with corner at 500 Hz. Local seawater velocity was determined from a CTD cast (conductivity, temperature, depth measurements in the water column) to 1000 m depth in the vicinity of each acoustic source deployment. The source time was determined by correcting the arrival time for the sound travel between the source (whose trigger depth was known to within 2-3 m for the glass spheres, and 6-9 m for the SUS) and the hydrophone. Table 1 lists the location and time of all the calibration shots.

Table 1. Acoustic source times, locations and initial IMS detections (H04S/N, H08N/S, H01).

Source	Time jd hr:mn:sec	Latitude S	Longitude E	Z (m)	4S	4N	8N	8S	1
A1 sph1	140 13:26:23.33	34°03.381'	40°30.159'	710					
A1 sus3	140 13:55:09.15	34 03.382	40 30.157	915					
A1 sus2	140 14:04:59.23	34 03.384	40 30.156	610					
A2 sus3	142 13:35:02	32 51.157	47 44.150	915			+		
A2 sus2	142 13:39:47.39	32 51.142	47 44.139	610			+		
A3 sph1	143 13:47:29.06	31 49.640	52 36.594	690					
A4 sph5	144 10:23:11.56	30 52.227	56 19.051	715					
A4 sus3	144 10:54:57.77	30 52.227	56 19.046	915		+	+	+	
A4 sus2	144 10:59:49.04	30 52.223	56 19.049	610		+	+	+	
A5 sph5	146 06:18:34	28 44.111	63 24.094	726					
A5 sus3	146 06:48:38	28 44.104	63 24.095	915				m	+
A5 sus2	146 06:52:38	28 44.115	63 24.097	610				+	~
A6 sus3	149 04:20:21.90	22 05.089	72 44.529	915	+	+		+	+
A6 sus2	149 04:25:51.21	22 05.089	72 44.529	610	+	+		+	~
A7 sph5	151 04:20:17.85	18 26.050	80 55.093	713		~		+	~
A7 sus3	151 11:52:11.75	18 26.045	80 55.091	915			+	+	+
A7 sus2	151 11:58:15.81	18 26.045	80 55.091	610			+	+	+
A8 sph1	152 08:46:44.89	17 10.552	83 40.514	725					
A8 sus2	152 09:13:59.37	17 10.555	83 40.506	610	+	+	~	+	+
A8 sus2	152 09:19:59.23	17 10.555	83 40.506	610	+	+	~	+	+
A9 sus3	156 10:48:48.10	13 29.673	91 41.316	915	?	?		+	+
A10sus3	158 03:55:21.68	12 12.799	96 47.799	915	?	?		+	+
A11 sus	160 00:37:33.83	13 11.878	104 41.661	915	?	?		+	+
A11sph5	160 01:37:39.90	13 11.875	104 41.665	731					

sph1/5 is glass implosion (1/5 sphere); sus2/3 is SUS 2000'/3000' charge. Z is source depth. + indicates signal detected; ~ indicates a weak but apparent signal; m indicates that another signal masked the arrival. Blank means no signal was detected. ? indicates that we have not yet received word one-way or the other.

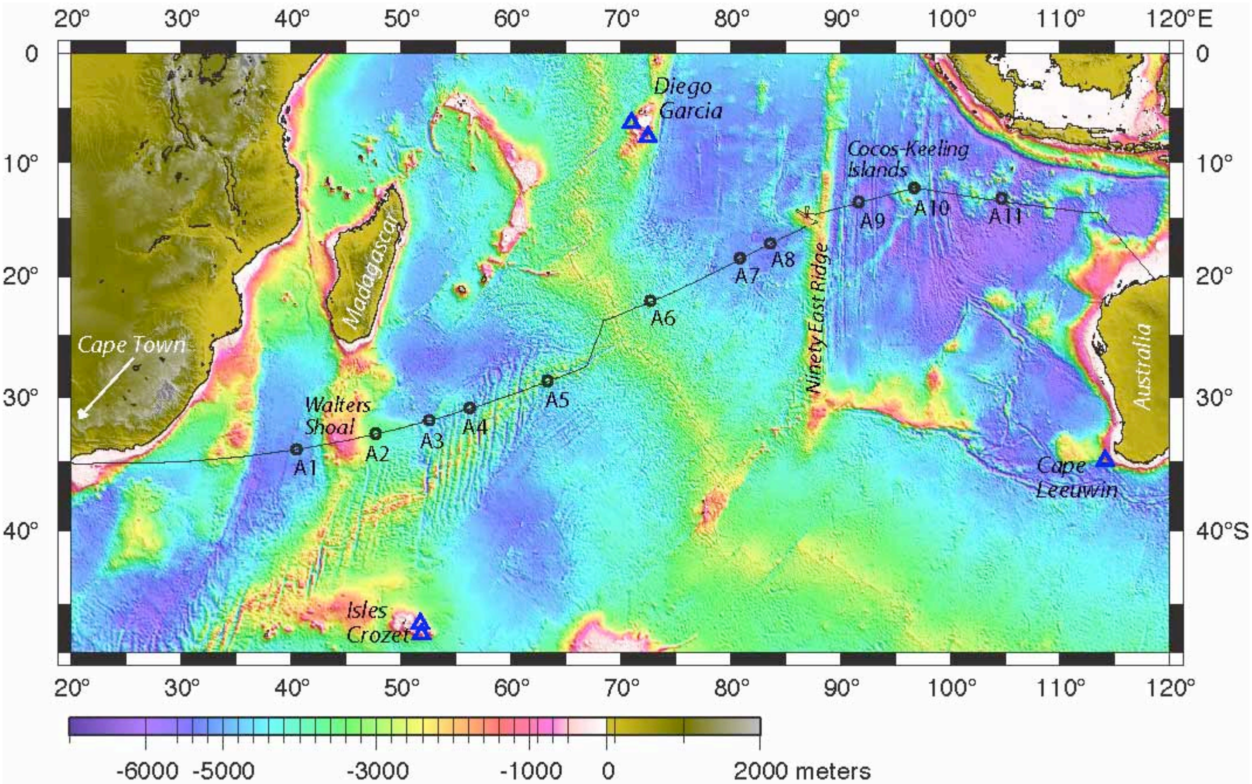

Figure 1. Track of the R/V Melville cruise in May/June 2003 overlain on shaded bathymetry of the Indian Ocean basin. IMS hydrophone stations are shown by triangles (individual tripartite arms). Source locations are shown by circles and corresponding labels identify the sites as listed in Table 1.

IMS Recordings of Calibration Shots

Each arm of the IMS hydrophone stations consists of 3 sensors, spaced 1-2 km apart. Both Diego Garcia and Crozet stations are comprised of a north and south arm (Figure 1). Cape Leeuwin has a single tripartite layout. Data for the IMS hydrophone stations is archived at 250 samples per second and instrument response is essentially flat in the 5-115 Hz band.

Based on the predicted range for each source-receiver pair the expected arrival time for the calibration shots was computed using a sound speed velocity of 1.49 km/s. Sections of data, ten minutes either side of the expected arrival, have been analyzed thus far. Background noise levels vary both between stations and with time during the cruise so at this stage we simply discuss how the recorded signals compare to concurrent noise. In general, the SUS recordings had energy in the 40-120 Hz band, with the weaker signals typically lacking in the lower 40 Hz of this band. Initial analyses indicate that the recorded signal for the 915 m SUS recordings was commonly somewhat stronger than that of the 610 m SUS shot. This is sensible in view of the fact that at most source sites, the axis of the sound channel were at 1000-1200 m depth. The difference in frequency content of signals from the different SUS depths does not appear, under initial analysis, to be consistent. This probably reflects a combination of variable bathymetric losses as well as the fact that the bubble pulse frequency for charge depths that we had were at the upper end, or just above, that of the IMS hydrophone recording range. Figure 2 illustrates how the SUS signal can vary as a function of charge depth as well as source-receiver path. The case shown is for site A6 to Diego Garcia, south, and Cape Leeuwin. The 915 m SUS signal at H08S has peak energy early in the arrival whereas at H01 the peak is at the end of the arrival. Frequency content and amplitudes for the 915 m and 610 m signals are similar at H08S, though somewhat more energy occurs in the 30-50 Hz band for the shallower charge. In contrast, at Cape Leeuwin, the signal for the two depths differs markedly. Whereas the 915 m signal is quite clear in the 40-120 Hz band, only a faint signal is apparent in the 60-110 Hz range for the 610 m charge.

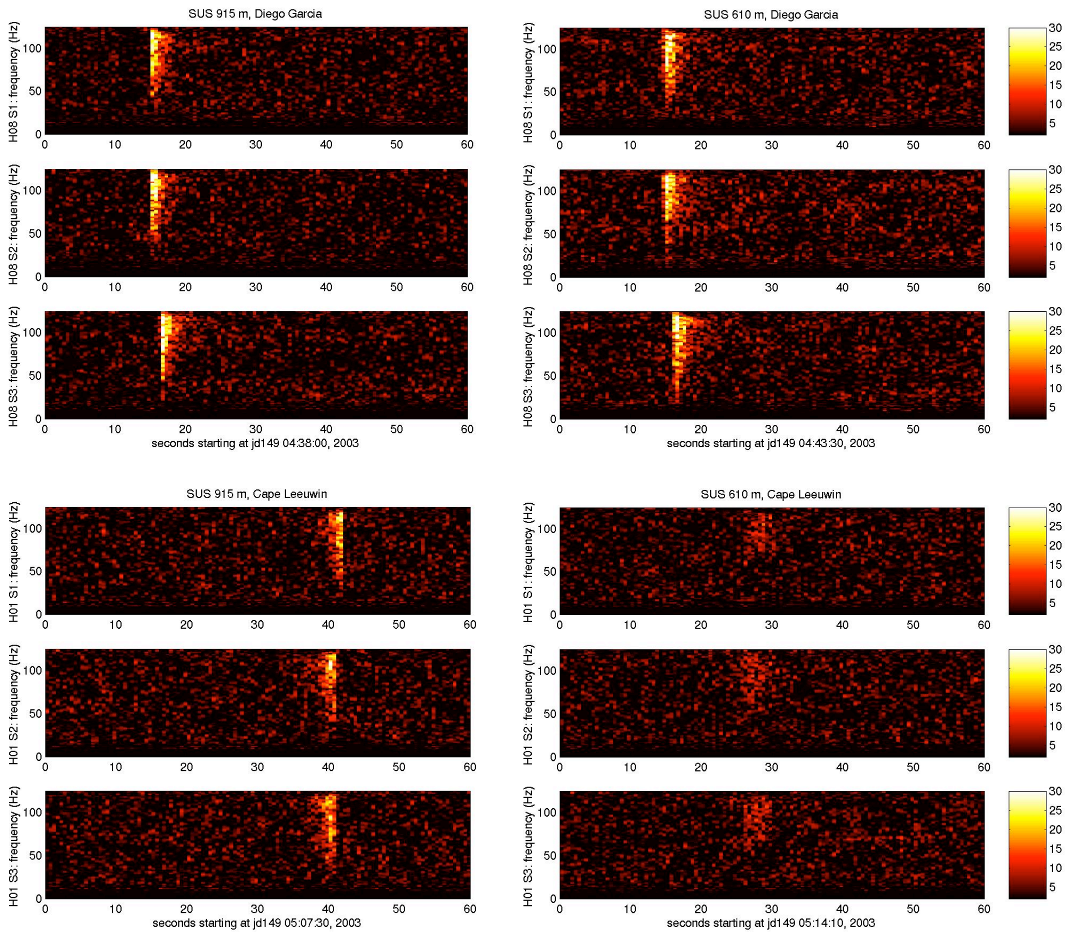

Figure 2. Spectragrams illustrate SUS signals recorded by IMS hydrophone stations in the Indian Ocean. The location of the shots (A6) is listed in Table 1 and shown in Figure 1. Mean (background) spectral level at each frequency, for each time section, has been subtracted so that signal relative to noise is shown in deciBels. Color scale is the same for all panels. Top panels show data from Diego Garcia, south arm (H08S), sensors 1-3; lower panels are for Cape Leeuwin sensors (H01). Left panels show the signal generated by a SUS charge at depth 915 m; right panels show SUS charge at 610 m depth. Significant attenuation occurs for the latter at Cape Leeuwin. In contrast, at Diego Garcia the 610 m SUS arrival has slightly more energy at lower frequencies (30-50 Hz) than does the signal from the deeper SUS. Source-receiver range to H08 is 1608 km; to H01 it is 4259 km.

Most of the glass sphere implosions were not detected. This contrasts with our findings in 2001 when both 5-sphere shots were observed at range greater than 4000 km and single-sphere shots were detected at ranges on the order of 1000 km (Blackman *et al*., 2003). One sphere shot that was detected is shown in Figure 3, where the source-receiver range was 1510 km to H08S, 1724 to H08N, and 3750 km to H01. Blockage to the north arm of Diego Garcia clearly stripped a lot of the energy, but some signal is apparent in the 80-100 Hz band. Signal-to-noise ratio in the Cape Leeuwin recording is only about a factor of two and the loss, relative to Diego Garcia, south, is probably due to attenuation at the Ninety East Ridge. Our 1500 km and greater source-receiver ranges may have precluded detection of the single sphere shots. Instrumental factors probably played a role in the reduced detectability of the 5-sphere shots, compared with 2001. The 5-sphere frame degraded significantly with each use due to the impact suffered during the implosions. A number of welding fixes were required and at one site, the frame had bent far enough out of shape that the lower sphere was able to move out of the way of the piston-triggered ram, rather than be shattered by it. Minor modifications allowed for successful firing at the next site but these experiences suggest that the 5-sphere signal may not have been as coherent as it was in the 2001 shots, when the frame was new. Upgrades of this system are currently being discussed at Lawrence Livermore National Laboratory.

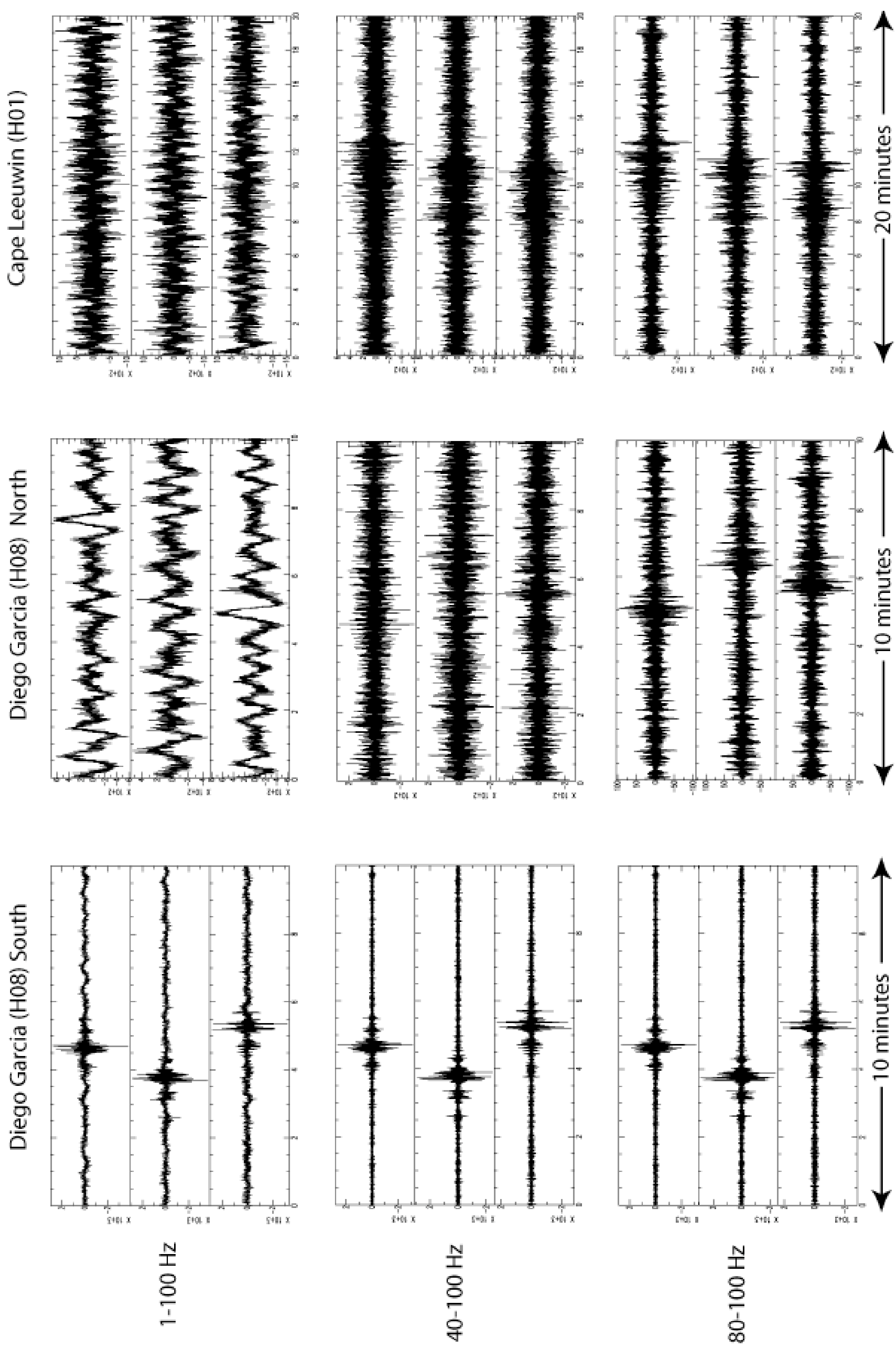

Figure 3. Recordings of the 5-sphere glass implosion at site A7. Each group of 3 panels shows data for the 3 sensors of a single arm of an IMS station (labeled at top). Band pass applied to the data varies from top to bottom (labeled at left).

CONCLUSIONS AND RECOMMENDATIONS

The calibration shots that we produced will be useful for assessing IMS location capabilities for small sources with energy in the 40-120 Hz range. One of the shots produced notable energy in the 10-20 Hz band, as well as at higher frequencies, so this may provide useful tests of discrimination algorithms. Our initial results are sufficiently interesting that complete analysis of the data is warranted and we plan to achieve this in the coming 6 months. A variety of topographic losses were encountered along the series of paths between our shots and the IMS hydrophones. Characterization of these losses, as a function of frequency and topographic roughness, should provide constraints on the resolution at which propagation models need to incorporate bathymetry in order to obtain loss predictions within the desired accuracy.

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