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(2) SF298 for Enclosure

Enclosure (1) is the Final Technical Report for the subject grant. Enclosure (2) is the SF 298 form. These documents constitute the Final Technical Report and deliverable for ONR Grant# N00014-18-1-2213

cc: Grant & Contract Administrator, APL-UW  
Office of Sponsor Programs, UW  
ONR Seattle  
Naval Research Laboratory  
Defense Technical Information Center

## **APL-UW Next Generation Oceanic Noiseology**

### **Final Report**

Awards N00014-18-1-2213

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## Abstract

Multiple efforts involved measurement and characterization of oceanic ambient noise. Data from the Comprehensive Test Ban Treaty Organization hydroacoustic station HA11N1, Wake Island, showed a decreasing trend in noise levels around 40 Hz from 2008, but a recent change to an increasing trend. The decreasing trend corroborates previous reports using data collected elsewhere in the N. Pacific. Additionally, HA11N1 monthly measurements in early 2020 showed a slight decrease of about 1 dB from the year before, possibly due to the global economic slowdown caused by the SARS-Cov-2 pandemic, but this effect disappeared by August 2020. Measurements made from a SeaGlider showed that observed ocean noise from about 100 to 300 Hz was biased when the vehicle was moving relative to the water, ostensibly from flow noise. Incomplete and incorrect system calibrations for low-frequency hydrophone channels in the Ocean Observatories Initiative's Regional Cable Array were identified and corrected. Fieldwork off Kauai in 2019 demonstrated that the HX554 electro-acoustic transducer remains viable.

## Objectives

Pursue further studies of oceanic ambient noise; diagnose problems with the HX554 Kauai electro-acoustic projector and determine its viability.

## Summary of Results

***Oceanic Ambient Noise*** Primary activities on this grant involved measurement and characterization of oceanic ambient noise. Data from the Comprehensive Test Ban Treaty Organization (CTBTO) hydroacoustic station HA11, Wake Island, were used in several studies. The viability of ambient noise collected on SeaGliders was assessed. Engineering support to determine end-to-end acoustic channel calibrations was provided. Details are given below.

***Kauai Source Reconnaissance*** Efforts focused on assessing the viability of the HX554 electro-acoustic projector, and scoping the dimensions of a possible cable repair. An opportunity arose to piggy-back onto the annual cruise of Prof. Bruce Howe (University of Hawaii at Manoa) off Oahu to use the R/V *Kilo Moana* and its ROV *Lu'ukai* to tap into the seacable and interrogate the HX554. The device was found to still be in nominal condition. Details below.

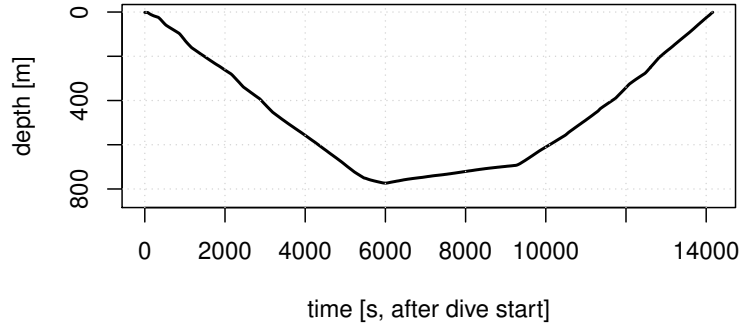


Figure 1: SeaGlider dive profile, demonstrating a new loiter maneuver. The loiter was from about 6000 to 9000 s after dive start. The vehicle had a slightly positive buoyancy trim.

## Detailed Results

### *Oceanic Ambient Noise*

- ***Ambient Noise Workshop*** Attended the ONR Ambient Noise Workshop, NRL, 2018.
- ***Gliders for Measuring Ambient Noise*** Utilizing the hydrophone mounted on APL-UW SeaGlider SG178, it was possible to address whether or not the measurements captured while the SeaGlider was underway were legitimate observations of ambient noise. This comparison is possible because the SeaGliders have been outfitted with a “loiter” maneuver (C.f. Fig. 1), in which the vehicle trims to neutral buoyancy and drifts with the current. In such a maneuver, there should be no hydrodynamic flow over the hydrophone, and the output of the hydrophone should be due solely to the impinging acoustic field.

Power spectral density estimates during the loiter and afterwards, when the SeaGlider was rising and hence experiencing flow over the vehicle and notably over the hydrophone, show (c.f. Fig. 2) that the flow noise makes a contribution as large as a couple of decibels.

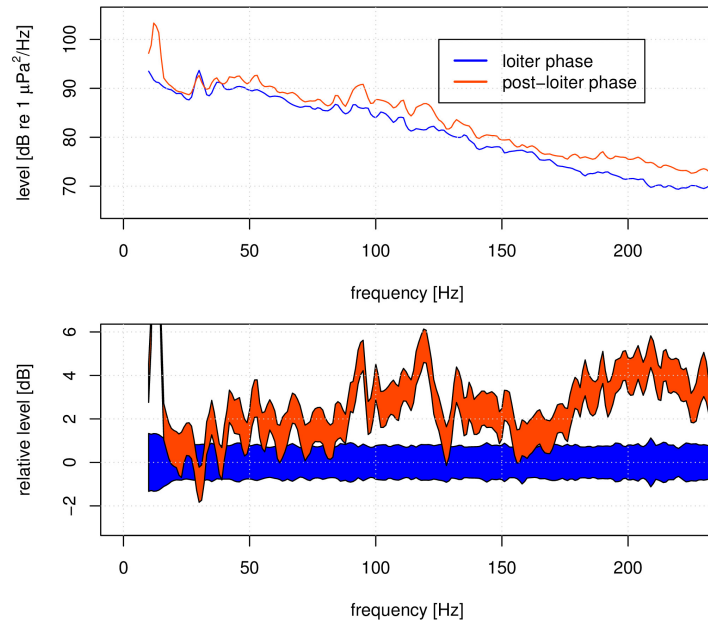


Figure 2: Top panel: Power spectral density estimates of the ambient noise, stationary w.r.t to the local current (blue, a.k.a. “loiter phase”) and incurring flow noise (orange, a.k.a. “post-loiter” phase.) Bottom panel: The excess spectral energy incurred by flow noise, rendered by subtracting the “loiter phase” PSD. The widths of the estimates represent  $\pm 1$  standard errors.

- ***North Pacific Low-Frequency Ambient Noise***

The unique value of a cabled observatory was emphasized at a special session on Ocean Observatories at the 176th Meeting of the Acoustical Society of America, Victoria, B.C., 2018, with a presentation of long term, low-frequency trends measured on cabled systems in the N. Pacific.[1].

These trends show that ambient noise in the roughly 25 - 50 Hz range has been decreasing over roughly 1994 - 2013. This decrease is consistent with data collected at the Wake Island CTBTO systems from 2008 to about 2016. Fig. 3 shows both the daily aggregated levels and a yearly average for decidecade band  $-14$  (centered at 40 Hz) for CTBTO hydroacoustic site H11N1. The negative slope in the yearly aggregated data is about  $-0.5$  dB/year, and is statistically significant. This corroborates earlier observations[2, 3].

Also, it is interesting to note the upturn in the noise level around 2016.

The mechanisms causing these trends remain unknown.

These results were presented at the 180th Meeting of the Acoustical Society of America, San Diego, 2019[4].

- ***Ocean Noise during the SARS-CoV-2 Pandemic***

The SARS-CoV-2 global pandemic provided world-wide disruption of the global economy, and an opportunity to pursue an investigation into whether, and to what degree, disruption in trans-oceanic shipping affected the ocean soundscape.

I considered a comparison study between years, and assumed (1) that the radiation signatures from ships remain the same, but that (2) the number of at-sea ships depends on the total transported cargo. A covariate for cargo transport in the North Pacific is the monthly count of international "twenty-foot equivalent units" (TEUs) from the Northwest Seaport Alliance (NWSA)[5]. NWSA cargo statistics, therefore, served as a proxy for the level of east-west trans-Pacific shipping traffic.

The ocean soundscape was measured using CTBTO station HA11 (Wake Island) data, which cover roughly 5 to 100 Hz, a band that includes the contributions of transoceanic merchant ships. To associate acoustic data from HA11 with monthly NWSA shipping statistics, and to compare across recent years, "decidecade" band levels were aggregated into monthly values. The energy in a standard decidecade band 7 Hz wide centered near 32 Hz is used as an example. The band about 40 Hz shows similar trends.

Monthly levels for the entire year 2020 are shown in Fig. 4. Monthly levels from previous years are also shown. The 2020 levels, starting in February, begin to show a

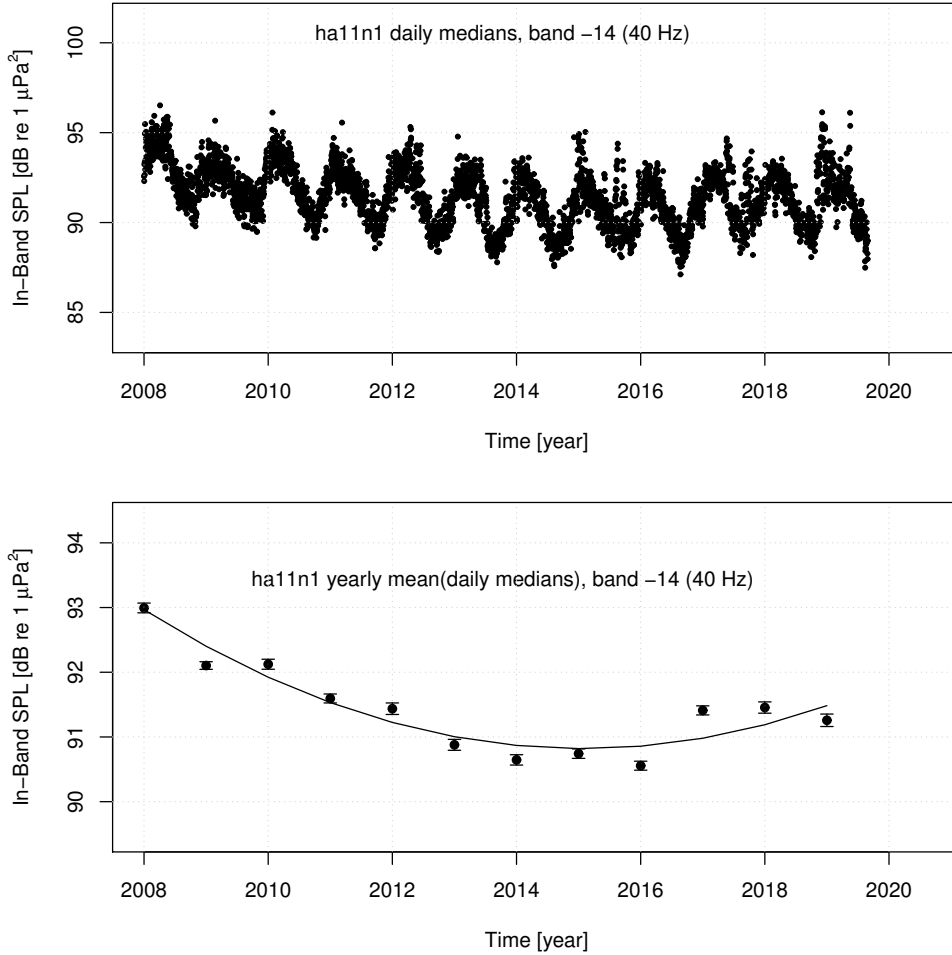


Figure 3: Spectral level time series from CTBTO hydroacoustic site HA11N1. The levels correspond to decidecade band  $-14$ , centered at 40 Hz, and about 9 Hz wide. The raw data consisted of one measurement every 25 s. (Top) The “daily” points are medians of the raw data. A distinctive seasonal cycle is evident. (Bottom) Yearly averages of the daily medians, with one standard error error bars assuming (incorrectly) that the daily values are mutually independent. The solid curve is a second-order polynomial fit to the data in the least-squares sense.

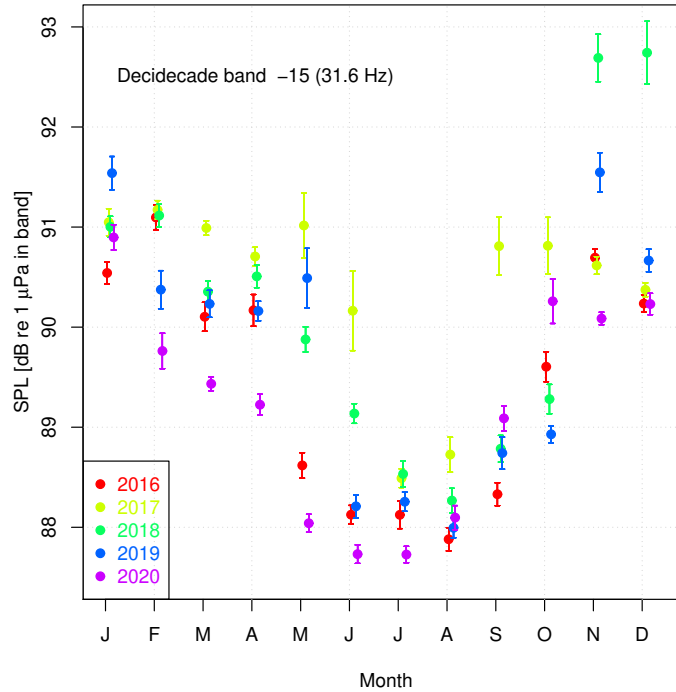


Figure 4: Monthly average values of daily medians for decidecade band  $-14$ , center frequency about 32 Hz. The error bars are standard errors. System HA11N1 (Wake Island).

statistically significant decrease, as much as 1 dB, compared to the levels observed in 2019. This difference fades away in about July.

The relative year-to-year comparison of monthly TEU transport, converted to decibels, is shown in Fig. 5. Starting in March, the TEU traffic in 2020 has decreased by about 1.5 dB compared to 2019. This decrease has been attributed to both a trade war between the United States and China, and, very recently, the global economic slowdown caused by the SARS-CoV-2 pandemic [5]. After roughly August, the TEU traffic regained more typical volumes compared to previous years.

- ***OOI Low-frequency Hydrophone Calibration***

The PI assisted Prof. Peter Dahl, APL-UW, in interpreting the ambient noise levels measured with hydrophones of the Ocean Observatories Initiative’s Region Cable Array (OOI RCA) off the west coasts of Washington and Oregon states. Prof. Dahl obtained

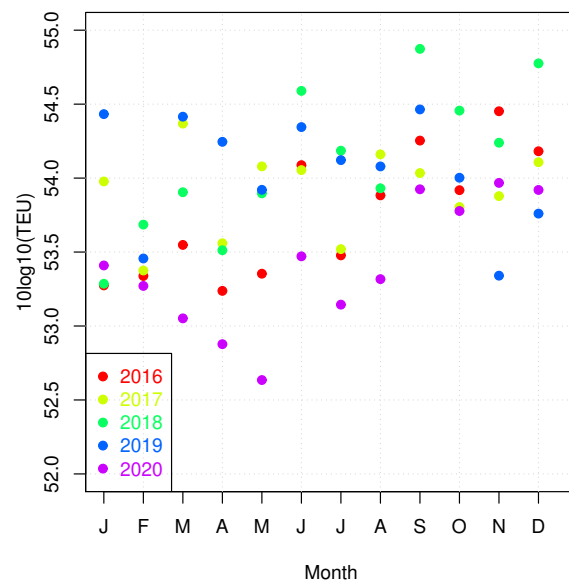


Figure 5: Twenty-foot Equivalent Units (TEUs) for international shipping from CONUS northwest seaports, on a logarithmic scale for all months of 2020, with comparison values from the previous four years.

the data directly from the RCA group in the APL-UW EPS department. These data are also made available via IRIS[7]. This exercise revealed that the “calibration” published on IRIS was inaccurate. (C.f. <https://ds.iris.edu/mda/00/AXCC1/--/HDH/>.)

Using multiple sources (Herrington, Manalang, Denny @ APL-UW; Ruef @ UW OOI; Spychalski @ HighTech, Inc.; “Fish” @ Guralp Systems), the PI was able to reconstruct the hardware chain from the hydrophone, through the A/D to digital “bits” and determine the end-to-end system terminal sensitivity and hence produce calibration correction spreadsheets and curve plots for the low-frequency hydrophones within the RCA.

These results and associated discussion are available at [http://staff.washington.edu/rxandrew/rca/00I\\_RCA\\_acoustics.html](http://staff.washington.edu/rxandrew/rca/00I_RCA_acoustics.html). These results were transmitted to the OOI group at UW, for ultimate transmittal to IRIS to correct their on-line information.

- ***Ainslie: Sea surface temperature and seasonal ambient noise variation***

Motivated by the published ATOC/NPAL trends in ambient noise measured on 4 coastal systems[2], Dr. Michael Ainslie (formerly at TNO, now at JASCO) devised a theory based on sea surface temperature to account for seasonal fluctuations in ambient noise levels measured at mid-depth, mid-latitude hydrophones in the N. Pacific. The PI contributed data and figures and discussion throughout the development of the paper. This paper has been published in the Journal of the Acoustical Society[8]. To quote one of the reviewers:

From my perspective, I admire the far reaching results that are obtained with the simple model for sound propagation, . . . . The concept of the critical surface angle, which provides seasonally dependent coupling of near sea surface generated sound with distant receivers, is a clever idea.

### ***Kauai Source Reconnaissance***

In early 2017, system diagnostics indicated a significant electrical fault with APL-UW’s HX554 Kauai source. Subsequent measurements made from Bldg 515 (the “Cal Lab” at the Pacific Missile Range Facility, PMRF, Kekaha, Kauai) showed that the fault was in the armored section of the subsea cable.

As the cost of replacing the armored cable was very high, the PI organized a reconnaissance of the HX554 source to judge whether the effort could be successful. A preliminary cruise was made in May 2019 with support of Sea Engineering, Inc, Honolulu. The team



Figure 6: Image captured of the SDL1 (unarmored) cable partially buried in the sand ripples along the submerged shelf. Picture supplied by Sea Engineering, Inc., using their Seamoor Chinook ROV suspended from the workboat *Huki Pono*.

used a small ROV to find the exact location of a segment of the unarmored cable in about 80 m of water. (See Fig. 6.)

Confident that the unarmored cable could be located visually in the sand ripples, the PI joined Prof. Bruce Howe, University of Hawaii at Manoa, on an annual cruise aboard the R/V *Kilo Moana*. The last leg of this cruise took the team to the location of the HX554, and the UH's ROV *Lu'ukai* was lowered to the seafloor at 810 m and swam to and around the HX554 for a visual inspection. The package showed no obvious signs of deterioration or breakage. (Fig. 7.)

Following this visual inspection, the R/V *Kilo Moana* relocated to a place along the west coast over the unarmored section of cable, in about 80 m, roughly partway between the shore and the HX554. The *Lu'ukai* was again used to visually locate the cable, but this time the manipulator arms girth-hitched a sling around the cable, and attached 500' of AmSteel blue recovery rope. The *Lu'ukai* was then recovered to the deck and stowed, and then the cable was brought to the surface and made fast to the railing. The PI and APL-UW assistant Ramirez cut the cable, stripped back the jacket and attached clamps to the two conductors for testing.

All diagnostic measurements made of the HX554 gave nominal results. Several examples

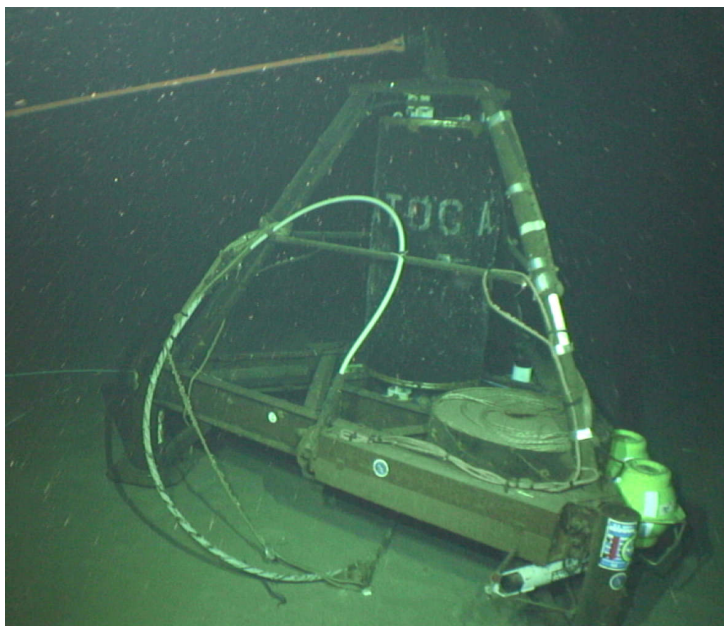


Figure 7: Image captured of the HX554 package at 810 m, from the ROV *Lu'ukai*.

are given below. Admittance loops are shown in Fig. 8 (as observed in 2016) and Fig. 9 (observed). Impedance loops are shown in Fig. 10 (as observed in 2016) and Fig. 11 (observed). The raw data curves are shown from the 2019 cruise; the older, historical figures are smoother because the data were routinely smoothed for better presentation. The 2019 loops and the older loops are not exactly the same because the older measurements utilized the full shore cable, while the 2019 measurements intersected the cable partway along its path.

After determining that the HX554 appears to be healthy, the PI began preparations for a more extensive “revivification” effort. Initially, the scope of this effort involved two workboats from Sea Engineering, Inc., out of Honolulu, with the intent of (again) recovering the sea cable to the deck, but this time powering it with APL-UW’s Instruments, Inc., L50 power amplifier, to determine if the HX554 could still support transmissions at full power.

Late in the grant, support from N974 was realized. A suitable section ( $\approx 11$  km long) of armored SDL3 cable was located in a Baltimore cable depot, and the effort shifted to completely overlaying the existing, deteriorated SDL3 with the Baltimore cable, thus re-establishing full connection from the shore station to the HX554.

Both efforts required substantial refurbishment of existing APL-UW hardware, much of

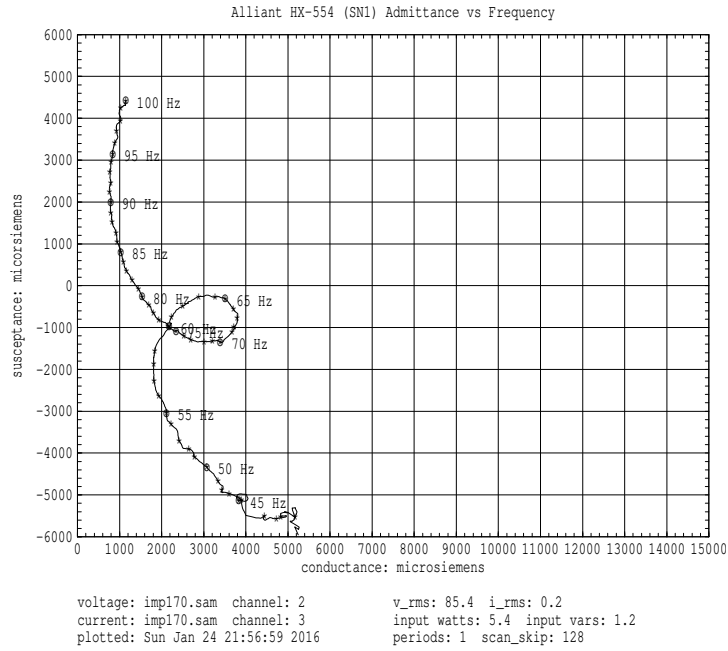


Figure 8: The last valid admittance plot captured from the Cal Lab, dtd 20160124. While a bit ratty, this is the appearance of an admittance loop when the Kauai source system is functioning properly.

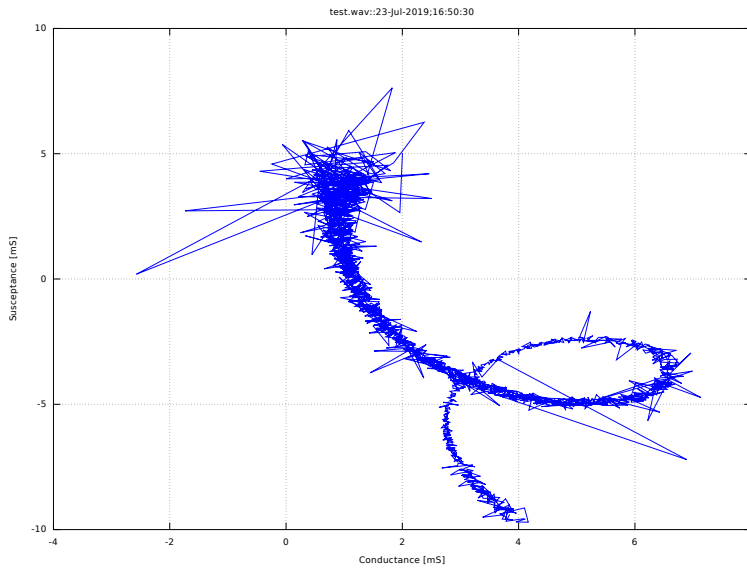


Figure 9: Measured admittance loop captured aboard the R/V *Kilo Moana*.

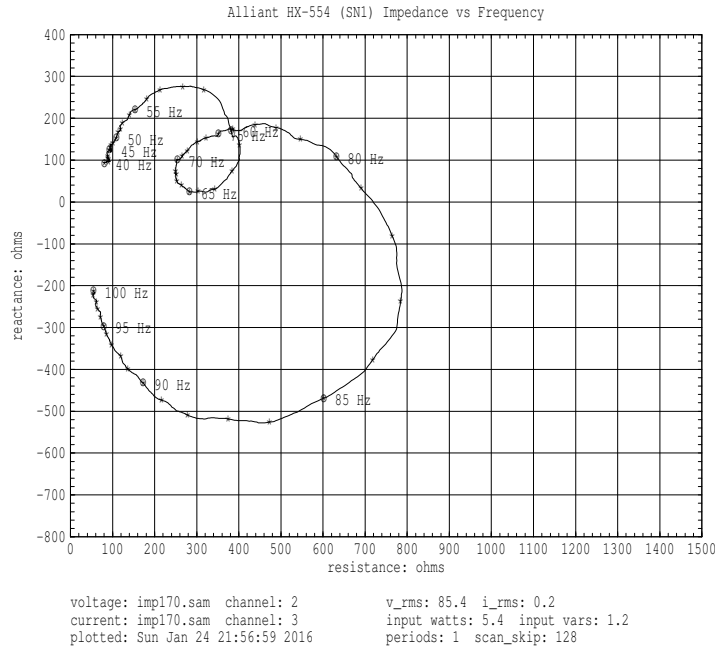


Figure 10: The last valid impedance plot captured from the Cal Lab, dtd 20160124. While a bit ratty, this is the appearance of an admittance loop when the Kauai source system is functioning properly.

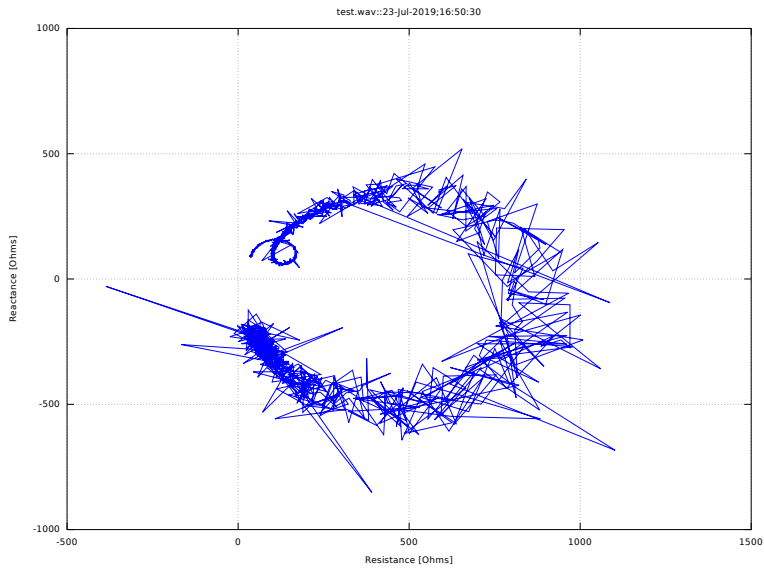


Figure 11: Measured impedance loop captured aboard the R/V *Kilo Moana*.

it 20+ years old. Refurbishment activities:

- Replaced the Condor power supply in VLA chassis 1 ;
- Repaired broken wiring in VLA chassis 1 ;
- Cleaned up the APL-UW science van (unused since 2010);
- Set up a GPS antenna near the science van;
- Assembled and powered up the instrument rack in the science van (CPU NPAL13 and VLA chassis # 1);
- Assembled and tested VLA chassis # 2 as back-up;
- Repaired severed leads on both “relay/misc” boards in order to re-enable the 175 Hz Bessel filter (filters disabled for PhilSea09 and PhilSea10);
- Recovered two APL-UW NPAL CPU units from NAVOCEANPROFAC at Whidbey Naval Air Station;
- Salvaged an Antec power supply from Whidbey CPU for CPU NPAL05;
- Assembled and tested a back-up CPU “NPAL05”;
- Built a 200’ extension power cable for the ship;
- Built a new clamp for the SDL1 cable to fit on the end of the extension cable;
- Removed the “dummy load” from storage, tested it for proper operation;
- Found stored CPUs and salvaged time boards;
- Swapped out malfunctioning timeboards;
- Powered up the Instruments Inc. L50 power amplifier and tested it into the dummy load;
- Tested Zyxel modems for operability: 3 (out of 6) no longer seem to work.
- Reconstructed and tested ability to dial in from APL-UW to Cal Lab CPU;
- Prepared replacement and backup harddrives for the Cal Lab CPU;
- Purchased a replacement L50 manual, making two hardcopies.

Software improvements deemed necessary:

- Devised a “ramp” that included 2 complete m-sequences;
- Added a “chain buffer” to accommodate arbitrary length signals (i.e. acommes messages)
- Upgraded the .wav library to conform to more modern meta data formats;
- Built a utility to glue .wav files together;
- Built a utility to scale .wav files up or down;

- Built a full power drive signal (195dB) identical to the original ATOC Kauai tomography signal;
- Built a new, shorter m-sequence signal for diagnostic work;
- Uploaded m-sequence “test signals” to Youtube (intended to support development of streaming processing software for realtime processing of UH’s ACO data stream). (URLs <https://youtu.be/oEFHZbFvtKM> and <https://youtu.be/EwZPr4ehTs4>.)

The PI coordinated with N974, PMS485 and Subcom teams to define and refine a practical plan to revitalize the HX554. Documents written included:

- “Kauai Cable Replacement Package”, 2020.12.06;
- “Details — Kauai ATOC Cable Repair”, 2021.01.03.

Further conferencing with the PMS485/Subcom teams indicated the need for additional APL-UW personnel shoreside (Kauai) during the cable operation. Additional training was required:

- Updated the manual for the system at the Cal Lab.
- Wrote a Cal Lab “cheat sheet”.
- Trained several personnel from APL-UW’s OE dept in the use of the transmit hardware.

## Collaborations

- Prof. Howe (UH) was and continues to be considerable help in revivifying the HX554.
- The PI worked with Dr. Tarun Chandrayadula of the India Institute of Technology, and Prof Kathleen Wage of George Mason University on analysis and interpretation of long range low-frequency data collected during the 2004 LOAPEX experiment. The effort involved acoustic tomography using the low-frequency (62-75 Hz) APL-UW signal and normal modes, over ranges from 250 to 500 km, with support from APL-UW SeaGlider environmental measurements. Multiple extensive revisions of the manuscript occurred. This resulted in a JASA paper. [9].
- The PI assisted a team at the University of Colorado, Boulder, in using PhilSea10 acoustic data for demonstrating the performance of a novel long range acoustic ranging

algorithm. The PhilSea10 experiment had excellent transmitter and receiver navigation, and thereby provided an excellent dataset for the performance evaluation. The PI provided the acoustic data, assisted in reading the data files, provided the source and receiver navigation, and explained how to do pulse compression. The algorithm involved “synthetics” based on modal propagation in the corresponding May 2010 HYCOM ocean model. The work resulted in an AGU presentation [10], and a paper in the Journal of the Acoustical Society[11].

- The PI collaborated with Dr. Fannie Shabangu, University of Pretoria, S. Africa, to estimate detection ranges for marine mammals for several locations off the southwest coast of S. Africa, and a location off Antarctica. These studies were motivated by long-time-series acoustic recordings made by Dr. Shabangu using AURAL acoustic recorders deployed on oceanographic moorings.

In general, the detection range estimation problem involved (a) channel characterization using sound speed climatology derived from World Ocean Atlas 2013 and Smith-Sandwell bathymetry, (b) incoherent transmission loss modeling using Bellhop, (c) *in-situ* ambient noise measurements, (d) published values of marine mammal vocalization source levels, and (e) a “detection threshold”. The PI automated these calculations using python, bash scripting, R, octave and C++. (BELLHOP was coded in Fortran.)

Early efforts sought to characterize detection range with qualitative figures demonstrating detection at various ranges and bearings, c.f. Fig. 12

Subsequently, questions arose regarding the variability of ambient noise levels and the variability of sound speed profile (i.e., with season) on these measures. Reviewers posed questions involving an ever-expanding array of parameters. To address this, the PI developed a method for quantifying the “optimal” detection range at a single bearing, i.e., at a single bearing in one of the plots in Fig. 12. This allowed for condensing results over many seasons, and also made feasible the addition of error bars.

A typical example is shown in Fig. 13.

Altogether, four papers resulted from these efforts:

- Blue and fin whales off the west coast of South Africa[12]:
  - Sperm whales off the west coast of South Africa[13]:
  - Southern Right whales off the west coast of South Africa[14]:
  - Blue and fin whales off Antarctica[15]:
- Collaboration with Dr. Dara Farrell. (Ph.D., civil engineering, University of Washington ‘2018, advisor P. Dahl.) Dr. Farrell has been isolated (and working remotely) at

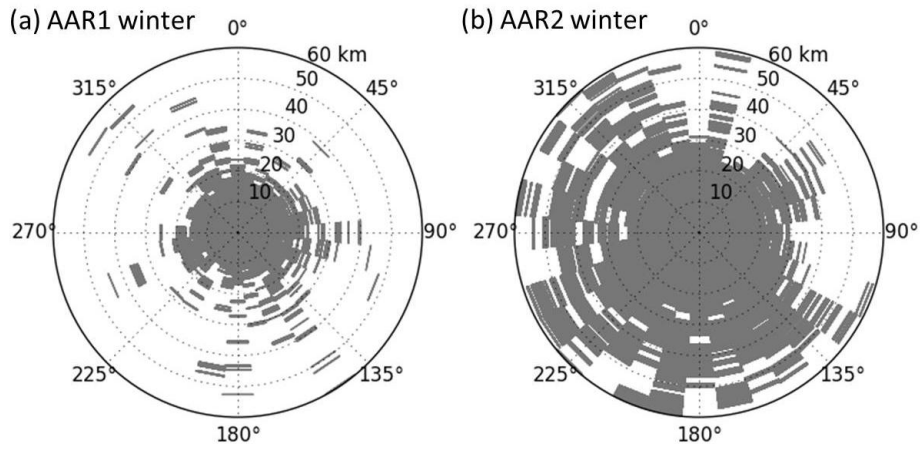


Figure 12: Detection range, blue and fin whales off the west coast of South Africa. A “detection” is defined by an SNR > 0 and is indicated by a grey patch. From[12].

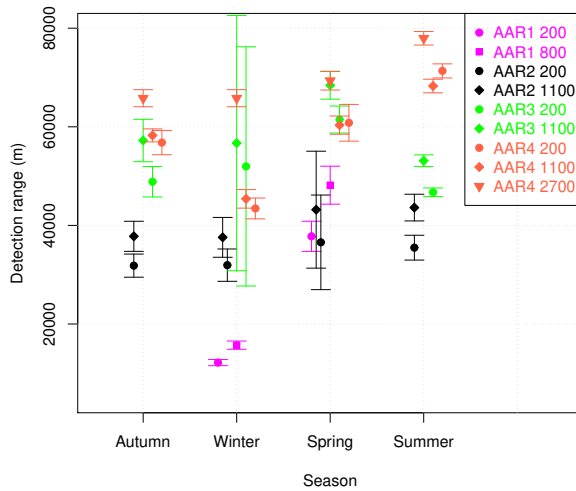


Figure 13: Average detection ranges of sperm whale clicks at various vocalizing depths: autonomous acoustic recorder (AAR) 1 at 200 and 800 m, AAR2 at 200 and 1100 m, AAR3 at 200 and 1100 m, and AAR4 at 200, 1100 and 2700 m at 2000 (AARs 1 and 2) and 4000 (AARs 3 and 4) Hz. Error bars represent standard deviations. From[15].

her family home in Trinidad during the pandemic. She is keen to take over the type of modeling requested by Dr. Shabangu.

- Collaboration with Ms. Divya Panicker (PhD graduate student, Dr. Kate Stafford, APL-UW, advisor) regarding power spectral density estimation algorithms.
- Collaboration with Ms. Nikita Pinto, (PhD graduate student, Indian Institute of Technology - Madras, Prof. Tarun Chandrayadula advisor) regarding power spectral density estimation algorithms and calibration of CTBTO data, notably Diego Garcia.
- Collaboration with Prof. Ashwin Sarma to prepare an ASA paper (which became a video presentation after the June 2020 Meeting was canceled). This involved performance characterization of a algorithm that collated ray trace data products from a ray tracing code (RAY, <https://oalib-acoustics.org/Rays/ray-1.49.zip>) that traced rays through random realizations of a perturbed ocean, generated by the Henyey-Reynolds internal wave perturbation model[16]. (Follow-on effort from POSYDON.) This was presented at the 179th Meeting of the Acoustical Society of America[17].

## Auxiliary Activities

- IQOE Working Group on Standards
- Manuscript Reviews – various journals.

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<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b> Multiple efforts involved measurement and characterization of oceanic ambient noise. Data from the Comprehensive Test Ban Treaty Organization hydroacoustic station HA11N1, Wake Island, showed a decreasing trend in noise levels around 40 Hz from 2008, but a recent change to an increasing trend. The decreasing trend corroborates previous reports using data collected elsewhere in the N. Pacific. Additionally, HA11N1 monthly measurements in early 2020 showed a slight decrease of about 1 dB from the year before, possibly due to the global economic slowdown caused by the SARS-Cov-2 pandemic, but this effect disappeared by August 2020. Measurements made from a SeaGlider showed that observed ocean noise from about 100 to 300 Hz was biased when the vehicle was moving relative to the water, ostensibly from ow noise. Incomplete and incorrect system calibrations for low-frequency hydrophone channels in the Ocean Observatories Initiative's Regional Cable Array were identified and corrected. Fieldwork off Kauai in 2019 demonstrated that the HX554 electroacoustic transducer remains viable.					
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