An Integrated Hydrophone Calibration System for Ocean Observing: ONC HydroCal

Ben Biffard, Manuel Morgan, Lanfranco Muzi
Ocean Networks Canada
University of Victoria
Victoria, Canada
bbiffard@oceannetworks.ca;
ORCID: 0000-0002-7972-9499

Tom Dakin
Sea to Shore Systems Ltd.
Victoria, Canada

Peter Van Buren
Fisheries and Oceans Canada
Sidney, Canada

***Abstract*— In this paper, we present a hydrophone calibration system and its integration within an ocean observatory network to provide near-live calibrated hydrophone data. Ocean Networks Canada (ONC), an initiative of the University of Victoria, operates world-leading ocean observatories on Canada's three coasts. ONC's data infrastructure, collectively known as Oceans 3.0, archives and serves data collected from many devices, particularly hydrophones. Calibrated passive acoustic data facilitates significant research, however, gathering and maintaining hydrophone calibration and data quality is a process under on-going improvement. ONC has developed a hydrophone calibration system, known as ONC HydroCal, to provide calibrations as part of ONC's regular maintenance cycle. Recent improvements include integrating ONC HydroCal calibration into Oceans 3.0, where the calibration is used in a variety of data products.**

Keywords—integrated ocean observing, passive acoustics, hydrophone, calibration

I. INTRODUCTION

Ocean Networks Canada (ONC) operates ocean observatories comprised of over 6000 data generating devices, including 465 different device types, generating approximately 400 GB of data per day (at this time). The largest single source of data from the observatories are hydrophones, currently occupying over 590 TB of data in the archive, spanning 16 years of observation. Hydrophones are a vital instrument for ocean observing, comprising the bulk of passive acoustic data collection, supporting marine mammal observation, vessel and sound scape monitoring and more. ONC's hydrophone data archive includes 169 hydrophones, among 11 different types. The most numerous type of hydrophone in the archive by both number and by data stored is the Ocean Sonics icListen HF. The icListen HF is a broadband digital hydrophone, sampling at up to 512 kHz and capable of being deployed at ONC's deepest locations (2660 m).

ONC's software data infrastructure is known as Oceans 3.0. Oceans 3.0 serves many functions, including device control, data acquisition, quality assurance and control, archiving, analysis, discovery and distribution. A full description of Oceans 3.0 is available in Owens et al. [1]. Oceans 3.0 collects hydrophone data through specialized and secured driver software separate from the main system; this is the file-based data acquisition pathway described in Owens et al. [1]. Data from most other devices is collected directly by the data acquisition and control module within Oceans 3.0. Source hydrophone files are generated by the hydrophones in five minute intervals in FLAC audio format, making them compact and relatively easy to handle, with typical file sizes of 60 MB. These files are transferred over the network to the file archiver postprocessor task running on the task server pool.

Hydrophone audio data files (FLAC, and prior to Aug. 8, 2020, compressed WAV audio) contain the raw data with no calibration or relation to actual measurement in units of pressure. Without calibration, comparing data from different hydrophones is not possible, either between devices at the same location before or after device swaps or between different locations. Calibrated data is necessary for most research using passive acoustics: sound level and noise measurements, sound propagation modelling and to a lesser extent marine mammal identification and monitoring. Hydrophone manufacturers generally provide either a single sensitivity value for their calibrations, assuming a uniform sensitivity over their operating bandwidth, or a multi-point calibration, containing sensitivity as a function of frequency. Multi-point calibrations correct for sensitively variation, allowing for more accurate data and for use of a wider bandwidth, i.e. for lower frequencies where sensitivity rolls off, and at high frequencies where piezoceramic element size affects the sensitivity due to in water wavelength and hydrophone resonant modes.

In addition to calibration, hydrophone data quality must be continually assessed and maintained for long-term monitoring on cabled observatories. Data acquired by regular, repeated calibrations shows that hydrophone sensitivity can decrease over time. As part of scheduled annual or semi-annual maintenance (the latter is the case of shallow-water coastal observatories), hydrophones are swapped out, with testing, repair and calibration carried out before being returned to service. ONC has recently added automated live data quality analysis as described by Enigada et al. [2], and a description of the overall data quality practice appears in Wolf et al. [3].

With reliable, calibrated data, users may access a suite of data products via Oceans 3.0 that make use of the calibration. Near-live previews, summaries and on-demand specialty products are available. Upon archiving the raw audio data, post-processing occurs to generate and archive calibrated spectra as the basis for these data products, greatly speeding up their on-the-fly generation time.

II. Hydrophone Calibration with ONC HydroCal

ONC originally developed a hydrophone calibration system, ONC HydroCal, to calibrate digital and very low frequency hydrophones, capabilities that were not readily available at the time. ONC HydroCal has been described by Dakin et al. [4], [5] with U.S. and Canada patents issued [6], [7].

ONC HydroCal consists of a bench-top apparatus for very low frequency (VLF) calibration (Fig. 1), a small boat-deployed jig for high-frequency (HF) calibration, supporting electronics (Fig. 2) and software (Fig. 3). ONC HydroCal is a stand-alone system, useful for calibrating any hydrophone, in frequencies ranging from 0.1 Hz to 700 Hz (VLF mode) and 2 kHz to 200 kHz (HF mode), without the need for a large test tank or complex at-sea deployment. For both VLF and HF modes of operation, the overall system works in the same way: a series of interrogating monotonic signals are produced from a source, driven by the software, then the hydrophone under test and a reference sensor receive the signals simultaneously at the same distance. The data is processed for sound pressure level from the reference, and the calibration, or sensitivity, is then effectively a scaling factor, expressed in dB relative to $V^2/\mu Pa^2$ (analogue hydrophones) or full $scale^2/\mu Pa^2$ (digital hydrophones, counts may also be used). In the VLF mode, the reference sensor is a manually calibrated differential pressure sensor, while in the HF mode, the reference sensor is a calibrated analogue hydrophone. The calibration of the pressure sensor is done in-house prior to running VLF calibrations (procedure described in [8]), while the reference hydrophone for HF mode relies on calibration provided by the manufacturer. The same software is used for both modes, while also supporting both digital and analogue hydrophones. Users enter all of the necessary metadata and choose the calibration frequency bins; best practice is to match the bins that will be generated in the Oceans 3.0 spectrogram post-processor. The output of an ONC HydroCal calibration run is a calibration sheet in .xslx format, a CSV text file format and data file outputs, containing all of raw data, metadata, configuration, etc., everything needed to plot, diagnose and re-run the analysis.

Fig. 1. ONC HydroCal VLF bench-top chamber.

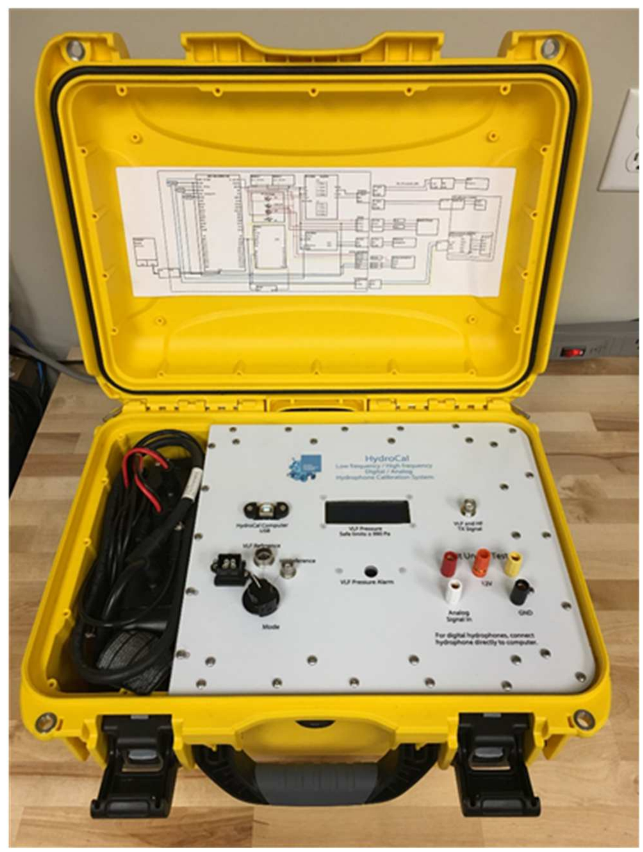

Fig. 2. ONC HydroCal electronics case, containing data acquisition electronics and batteries for signal broadcast and reception.

A. *Recent ONC HydroCal Improvements*

Recent improvements to ONC HydroCal are primarily focused on making the system operational. Since the last publication on ONC HydroCal in 2014 [5], the VLF chamber has been improved: it is simpler to construct, operate and maintain. It is also less prone to interference from bubbles and overpressure difficulties. A rugged case containing all the supporting electronics has been developed, which contains batteries, the multifunction data acquisition and signal generating board, power amplifier for the sources (both the piston driver for the VLF setup and the omni-directional source for the HF calibration), plus switching and wiring for all the above, making it user friendly and field-capable. The data acquisition board inside the electronics case interfaces (via USB) with a laptop running the ONC HydroCal. The software was re-written and compiled into a single stand-alone Windows™ application, supporting all the modes of operation, running on compiled MATLAB code. The HF acquisition mode was added after 2014, and with new electronics, frequency bins of up to 200 kHz can be calibrated. A user manual was prepared and is available on the ONC HydroCal home page [8]. Software changes also include a user interface to adjust the source levels to avoid saturation and achieve good signal to noise levels. The workflow was also improved, allowing re-processing for metadata updates and processing of offline, asynchronous data, which is particularly useful for saving boat time when running HF calibrations. Time alignment of the data from the unit under test and the reference is crucial for digital hydrophones that acquire their own data. To that end, the use of synchronizing tones was expanded so that the software can easily find and align the data, even over file breaks. The scheme of interrogating tones has been altered to provide better results at very low (< 1 Hz) frequency and to better work with the capabilities of the computing hardware (i.e. avoiding using too much computer memory or overloading the data acquisition board on transmit). Plotting and operator feedback has been improved to aid in detecting issues like bubble resonances and saturation. Overall, most difficulties have been resolved and the system is operational.

B. *ONC HydroCal Results*

Practical experience operating ONC HydroCal has shown the importance of on-the-fly adjustments to the source level, as well the importance of monitoring for quality control. Repeatability is satisfactory: in the VLF mode, a run-to-run standard deviation of 0.05 dB re counts^2/μPa^2 was measured by Dakin et al. [4] over the range of 0.05 to 100 Hz.

Reliability and accuracy of HF calibrations is an on-going topic of investigation. The comparison in Fig. 4 is presented as a preliminary result for qualitative discussion. The HF calibrations demonstrate very good run-to-run consistency, similar to the consistency quantified for VLF calibrations in Dakin et al. [4]. The VLF calibrations agree well with manufacturer-supplied calibrations.

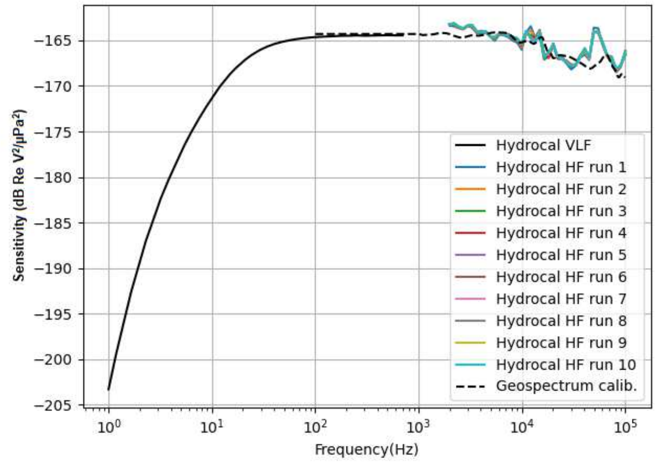

Fig. 4. Comparison of a manufacturer-supplied calibration (dashed line) with ONC HydroCal VLF (solid line) and multiple runs of HF calibrations (coloured lines), for a GeoSpectrum Technologies Inc. hydrophone model M36-V36-100, serial number F000050. Data collected February 2022.

Although the HF calibrations correlate well with the manufacturer's calibration, some differences are apparent. We suspect the reference analogue hydrophone may be the cause of the discrepancy. Future experiments will include running a

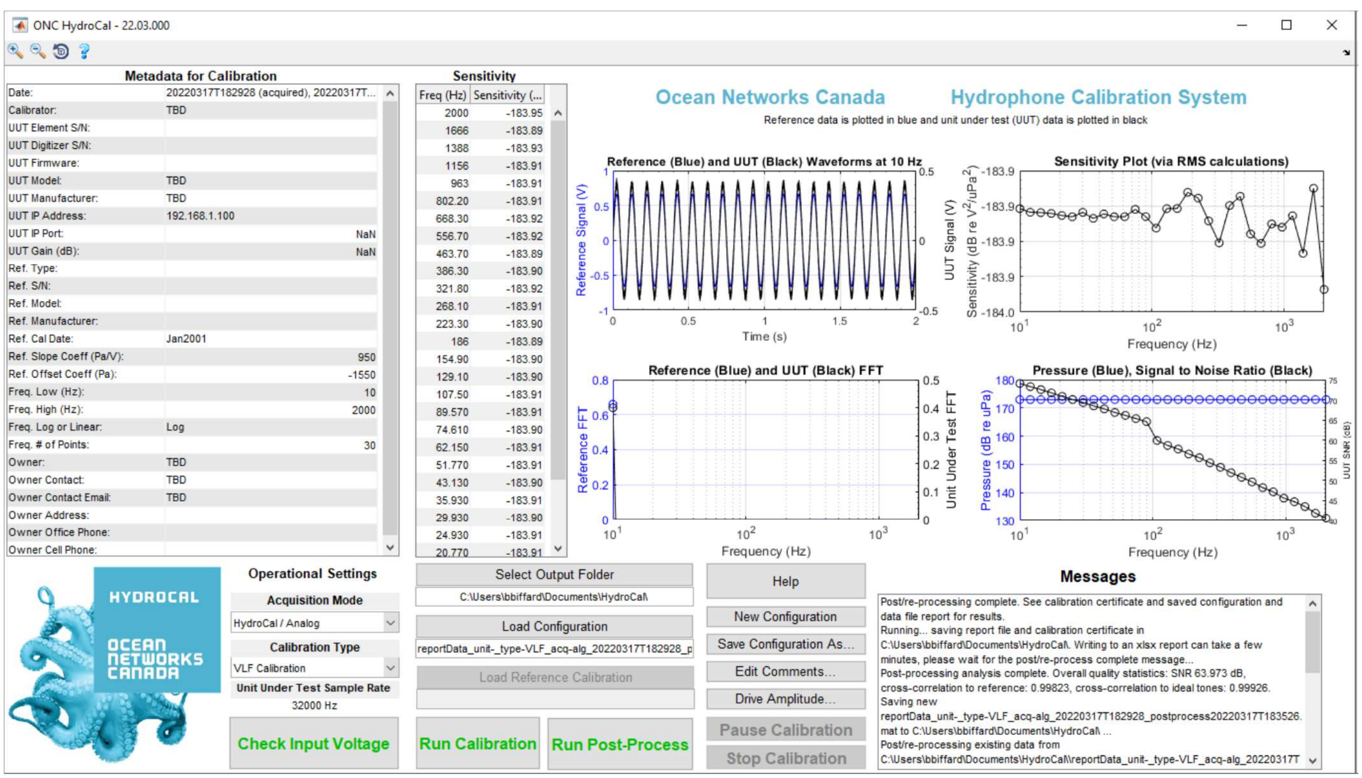

Fig. 3. ONC HydroCal software main user interface, with metadata entry (left table), controls (bottom left to bottom centre), messages (bottom right), sensitivity results (centre left table) and results plotting (upper centre to upper right). Simulated data shown.

series of calibrations comparing different reference hydrophones from different manufacturers. This will be possible once the software is upgraded to support digital reference hydrophones. Another upgrade may be the addition of a built-in function to combine VLF and HF calibrations, bridging the gap in frequencies between them by interpolation.

Since the last major round of improvements to ONC HydroCal, ONC has been regularly calibrating hydrophones for internal maintenance at a rate of about 20 per year, not including occasional batches of calibrations ONC performs for partner organizations. Fisheries and Ocean Canada also uses ONC HydroCal to maintain their passive acoustic monitoring program, calibrating up to 60 hydrophones per year.

III. Integration with Oceans 3.0

ONC HydroCal's CSV text file output contains calibration sensitivities and frequency bin values. As of April 2022, Oceans 3.0 supports ingesting these CSV data files directly via a simple user interface (Fig. 7), including parsing and storing the calibration in the Oceans 3.0 database as device attribute metadata. Each calibration record has a date range of applicability, comment fields and change tracking. Pre- and post-deployment calibrations are both supported and differentiated, with pre-deployment calibration being applied as the calibration of record for each deployment, while the post-deployment calibrations are used mainly for data quality checks. Manufacturer supplied calibrations are also ingested by this process and are often used as pre-deployment calibrations. All applicable calibration data is included with audio file downloads from Oceans 3.0 Data Search and API. ONC Instrument workflows include tasks, checks and tracking of issues related to or detected by the calibrations; see Wolf et al. [3] for an example workflow and Owens et al. [1] for an overview of the Oceans 3.0 workflow features.

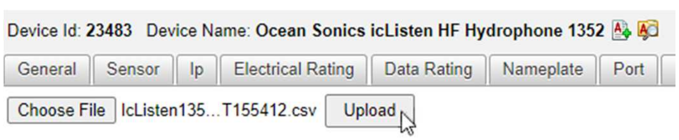

Fig. 7. Oceans 3.0 interface for ingesting ONC HydroCal calibration data.

One of the major benefits of developing ONC HydroCal has been the ability to perform calibrations promptly within the observatory maintenance cycle, without having to send hydrophones back to their manufacturers. The VLF calibration is particularly useful as it is a bench test that does not require field or tank time, and tends to detect degradation in hydrophone sensitivity quite well. Two recent examples are shown as Fig. 5 and Fig. 6, comparing VLF calibrations before and after deployment. In both cases, the instruments were returned to the manufacturer for service. In the case of Fig. 5, the degradation was more severe, while in Fig. 6, the problem was caught early enough to not appreciably affect the data.

A. Calibrated Hydrophone Data Products

As noted earlier, calibrated spectra are generated by post-processor tasks running on the Oceans 3.0 task machine pool. For each five-minute long audio source file, a spectral data file

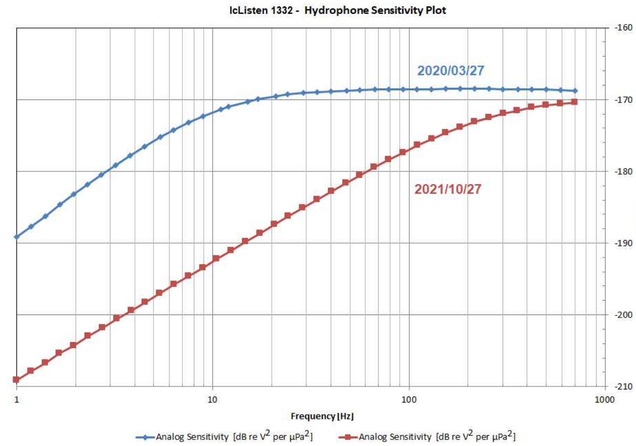

Fig. 5. A comparison of pre (blue) and post (red) deployment ONC HydroCal VLF calibrations for an Ocean Sonics Ltd. icListen HF hydrophone (serial number 1332) for a deployment in 2020. Dataset information available, see [9].

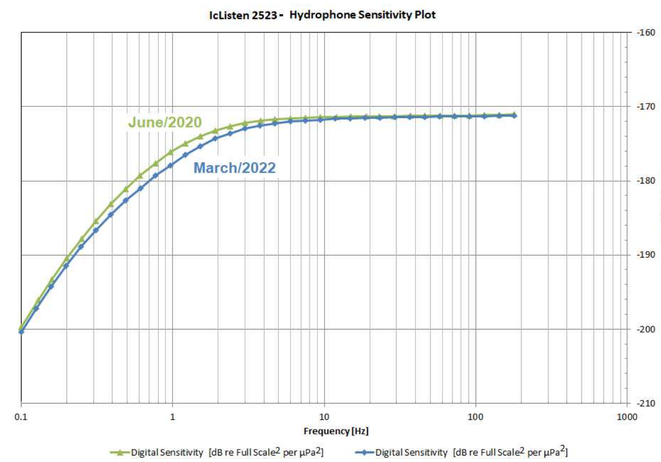

Fig. 6. A comparison pre (green) and post (blue) deployment ONC HydroCal VLF calibrations for an Ocean Sonics Ltd. icListen AF hydrophone (serial number 2532) for a recent deployment. Dataset information available, see [10].

and spectrogram plot are generated and archived. The system is able to handle source files of varying length by padding or breaking the spectrogram plots, so that each pixel in the plots are always the same temporal extent, this allows the system to stitch together spectrograms for the scrollable Oceans 3.0 Acoustic Instruments Data Viewer (beta version not yet publically accessible). The spectrograms are also viewable on the Oceans 3.0 Search Hydrophone Data page. The calculation of the spectra follows Merchant et al. [11]. The spectral data files contain one-minute averaged spectra to be used by a number of subsequent summary products. Of particular use for data quality monitoring are long-term spectral average (LTSA) plots and spectral probability density (SPD) plots, examples of which are shown as Fig. 8 and Fig. 9, respectively. These examples are from the Oceans 3.0 Data Preview page, they span one week each and are updated daily. These data products are also available on-demand and highly configurable in Oceans 3.0 Data Search and API. SPD plots were introduced in Merchant et al. [12], showing the distribution of acoustic energy, which is usually dominated by ambient noise. As a data quality tool, SPD plots are useful for detecting problems in hydrophone sensitivity, such as the example in Figure 4, and in detecting outliers, complementing the time series shown in LTSA plots.

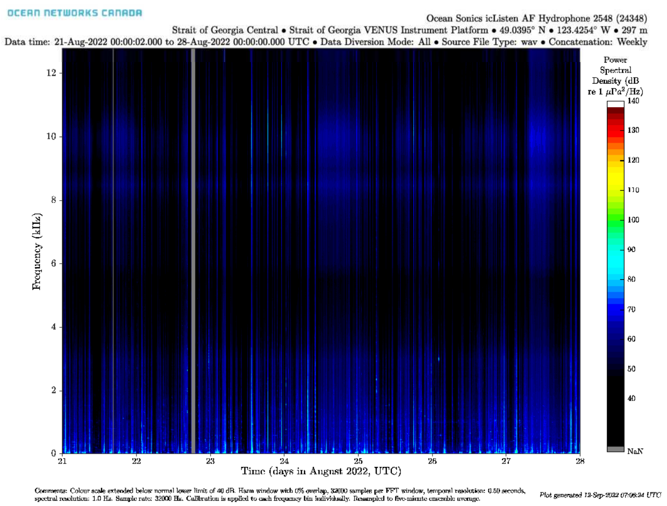

Fig. 8. Operational long-term spectral average plot for the on-going icListen HF hydrophone deployment to Strait of Georgia Central, showing a horizontal band of decreased sensitivity between 3 and 6 kHz. Dataset information available, see [13], also available on [Oceans 3.0 Data Preview](https://data.oceannetworks.ca).

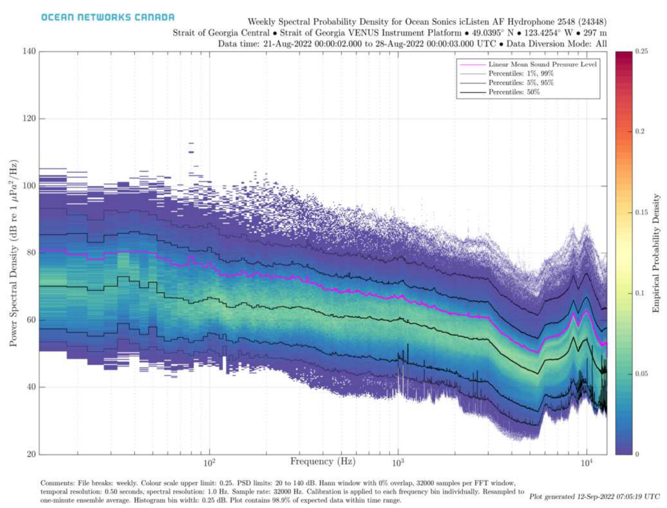

Fig. 9. Operational spectral probability density for the on-going icListen HF hydrophone deployment to Strait of Georgia Central. The low sensitivity anomaly is visible on the right side of the plot, between 3 and 6 kHz. Dataset information available, see [13], also available on Oceans 3.0 Data Preview.

IV. Conclusion

The development and integration of a hydrophone calibration system has become essential to the success of ONC's passive acoustic data acquisition and monitoring program. The long time series of data (over 16 years of data in some locations) has enabled research into ship and ambient noise, marine mammal behaviour and more. Improvements to ONC HydroCal will continue; plans include adding support for digital reference hydrophones and further quantifying the accuracy and reliability of the HF calibration mode. Further developments in Oceans 3.0 include dynamically generated soundscape data products, public availability of the acoustic data viewer application and continued expansion of automated detection of acoustic events, through machine-learning software.

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