



**University of
New Hampshire**

**ADEON Data Processing Specification
Version 1.0**

**Atlantic Deepwater Ecosystem Observatory Network
(ADEON): An Integrated System for Long-Term Monitoring of
Ecological and Human Factors on the Outer Continental
Shelf**

Contract: M16PC00003

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1. Introduction

1.1. ADEON Project

The Atlantic Deepwater Ecosystem Observatory Network (ADEON) for the US Mid- and South Atlantic Outer Continental Shelf (OCS) has been developed and was deployed in fall 2017. The lead principal investigator (PI) for this project is Dr. Jennifer Miksis-Olds, University of New Hampshire (UNH). Dr. Miksis-Olds leads a collaborative research team consisting of individuals from Applied Ocean Sciences, UNH, JASCO, Stony Brook University, Florida Atlantic University, NOAA's Southwest Fisheries Science Center, OASIS, and TNO.

This observatory network is generating multi-year measurements of the natural and human factors active in this region, thus informing the ecology and soundscape of the OCS. Long-term observations of living marine resources and marine sound will assist federal agencies, including the Bureau of Ocean Energy Management (BOEM), the Office of Naval Research (ONR), and the National Oceanic and Atmospheric Administration (NOAA), in complying with mandates in the Endangered Species Act (ESA), Marine Mammal Protection Act (MMPA), and Sustainable Fisheries Act (SFA).

1.2. Objectives

1.2.1. ADEON Project Objectives

The ADEON project objectives are to:

- Establish an ecosystem observation network that provides baseline monitoring and supports predictive modeling of the soundscape and its relationship to marine life and the environment of the Mid- and South Atlantic Planning Areas.
- Develop standardized measurement and processing methods as well as visualization metrics for comparing ADEON observations with data from other monitoring networks.
- Assess baseline soundscape and ecosystem conditions in support of predictive environmental modeling and trend analyzes in the planning areas.
 - How do soundscape and ecosystem components vary with water depth across the OCS?
 - How do the soundscape and ecosystem components vary with latitude along the OCS?
 - Where are the hot spots of human activity that impact ecosystem/habitat health impacts?
- Assess the spatial and temporal distribution of the soundscape and biological scatterers, including their expected variation and correlation with distance from the bottom lander locations.
 - What are the environmental factors that define and constrain the horizontal range of appropriate extrapolation of observations measured at the stationary bottom lander sites?
- Develop and apply new methods to effectively visualize five-dimensional (5D—time, latitude, longitude, frequency, and depth) soundscape data with interactive visual analysis tools that

enable users to explore, analyze, and integrate ancillary ecosystem data streams with the 5D soundscape.

- Develop a robust data management system that archives and provides public access to multiple data streams to encourage future development of ecological models targeted at questions beyond the scope of this study.

1.2.2. ADEON Standardization Objectives

The ADEON standardization objectives are:

- Ensure compatibility within ADEON between soundscapes based on measurements and those based on models.
- Ensure compatibility between measurement data from different researchers or institutes within ADEON.
- Facilitate compatibility between ADEON soundscapes, whether based on measured or modeled prediction, and soundscapes produced by a hypothetical future or parallel project within the US EEZ.
- Facilitate compatibility between metrics used to quantify ADEON soundscapes and those used to monitor ambient sound in the context of the EU's MSFD (Marine Strategy Framework Directive).

This report, the *Data Processing Specification*, is the fourth of five Standardization reports, which together meet the above four objectives. The ADEON project has implemented an autonomous ocean observatory that includes multiple hardware components. This report describes the measurements taken and details the specific steps taken to go from raw observations to the analysis results and ADEON data that is archived and made available to the public.

1.3. Data Processing Specification Overview

In presenting the data processing used for each of the input data sensors and streams in the ADEON project, it may be useful to consult a list of the ADEON Hardware which is specifically listed in the *Hardware Specification Guide*.

1.3.1. Scope of Phase III (Data Processing)

One objective of the *ADEON Data Processing Specification (DPS)* is to define the discrete steps taken during Phase III (Data Analysis) that took the raw data (Level 0) and mapped it into a form which was then distributed amongst the ADEON team for soundscape and ecosystem analysis and synthesis (Phase IV), archived by the University of New Hampshire, and made available to the public. Each system recorded machine-readable raw data that must, in many cases, be processed to calibrated time series (Level 1). This procedure usually included some form of error checking or filtering, some form of statistical or spectral processing, and some form of averaging. The resulting files (Level 2) are then useful to the wider community. Depending upon the level of aggregation, some of the products can reach a maturity of Level 3 and beyond (Table 2).

Table 2. Specification of ADEON data processing levels (column 4) compared with those of IFREMER (column 2) and NASA (column 3).

level	IFREMER ¹	NASA ²	ADEON
0	This so-called instrumental level corresponds to the raw data at full resolution emitted by the sensor. The data are time-ordered but are not always expressed in standardised units. This is why archiving at this level is neither systematic nor permanent.	Reconstructed, unprocessed instrument and payload data at full resolution , with any and all communications artifacts (e.g., synchronization frames, communications headers, duplicate data) removed. (In most cases, the EOS Data and Operations System (EDOS) provides these data to the data centers as production data sets for processing by the Science Data Processing Segment (SDPS) or by a SIPS to produce higher-level products.)	raw, uncalibrated data Examples: binary AZFP files and .wav files before the calibration information is applied
1	For this intermediate level, data are time-referenced and converted into units that comply with international standards . Instrumental specificities and errors may also be corrected. Recent instrumental systems directly provide data at this level.	1A: Reconstructed, unprocessed instrument data at full resolution, time-referenced , and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (e.g., platform ephemeris) computed and appended but not applied to Level 0 data. 1B: Level 1A data that have been processed to sensor units (not all instruments have Level 1B source data).	calibrated times series data . Examples: Data processed using Echoview software, after calibration is applied (Sv); sound pressure on a stationary or moving platform
2	Level 2 data, at georeferenced geophysical level, are dated, spatially located and organised in a format that facilitates their scientific usage . Variations related to the acquisition conditions are also corrected and the data are thus expressed in a reference system that is independent of the measurement platform.	Derived geophysical variables at the same resolution and location as Level 1 source data. eg remove atmosphere; derive product	The first level of processed data from the calibrated data. Only quantitative (temporal or spatial) processing. Examples: decidecade levels; SEL; depth-integrated Sv; beamformed data (individual sensors on an array are treated as if they were at one single location or site)

¹ <http://en.data.ifremer.fr/All-about-data/Data-management/Processing-levels>

² <https://science.nasa.gov/earth-science/earth-science-data/data-processing-levels-for-eosdis-data-products>

level	IFREMER ¹	NASA ²	ADEON
3	Level 3 data are presented in relation to identical and standardised space-time reference scales . The data can thereby be easily compared and aggregated, including between different measurement programmes	Variables mapped on uniform space-time grid scales , usually with some completeness and consistency.	Second order processing, including some qualitative information. Examples: Whale or ship detections; products related to classification of signals; products related to signal localization
4	This level consists of interpolated data , resulting from data analysis.	Model output or results from analyses of lower-level data (e.g., variables derived from multiple measurements). eg primary productivity	Interpolated products Example: density estimation
5	This level refers to synthesis products .		Synthesized products related to soundscape models/maps and predictive habitat modelling. requires additional information (eg AIS, source model)

An example of this processing stream is the soundscape percentiles generated from the hydrophone data collected on the bottom-lander omni-directional hydrophones. The acoustic time series, digitized from the voltage changes of the hydrophone, are the raw Level 0 data. This was then band-passed (outlier rejection) and a calibrated time series generated (Level 1). The data were then processed for quantitative soundscape metrics (Level 2) such as the level in decidecade³ bands or the peak sound pressure level. Event detection and classification of signals, such as marine mammals and ships, were presented below but this is considered Level 3 data. The work of Phase IV may include longer-term averages, but statistics of these averages are considered a use of the processed data and are beyond the scope of this document.

The satellite data aggregated by Dr. Tim Moore and the team at the University of New Hampshire and Florida Atlantic University is included in the DPS for completeness, although it does not involve data processing as outlined above. There was significant effort put forward by the global remote sensing (satellite) community to generate products. These products were generally received in either Level 3 or Level 4. Their description in this document is suitable because this is the position in the analysis where they will be distributed to the ADEON scientific team (for Phase IV analysis), archived by the University of New Hampshire, and then distributed to the public.

A second objective is to document detailed processing for soundscape metrics of the *ADEON Soundscape Specification* (Ainslie et al., 2018). This second objective is met by Section 2, which for this reason has more detail than other parts of this report.

The terminology follows ISO 18405 (ISO, 2017) and the ADEON Terminology Standard (Ainslie et al 2017b).

1.3.2. List of Products from Phase III

The successful execution of Phase III led to an extensive set of data products for analysis. These include:

1. Passive acoustic data from bottom lander moorings (Section 2.1)
2. Passive acoustic data from the towed array sensor (Section 2.2)
3. Active acoustic data from remotely deployed echo sounder systems (Section 3.1)
4. Active Acoustic data from mounted echo sounder systems (Section 3.2)
5. Satellite Data Set Processing (Section 5)

1.3.3. Data processing products

Following the NASA guidelines for data products, the data were categorized based upon the amount of processing and additional information used to generate the resulting processing product. Raw electronic measurement data, usually digitized in non-dimensional bits from an analog-to-digital processor of some kind is referred to as Level 0 (L0) data. This is often the

³ A decidecade is one tenth of a decade. One tenth of a decade is approximately equal to one third of an octave. For this reason, a decidecade is sometimes referred to as a “one-third octave”.

output of a measurement device and is what is recorded on hard-disks as .wav files (for audio). The Level 1 (L1) product was generated by mapping of these bits to a physical quantity, with the application of a calibration factor (going from bits to volts (V) and then on to pascals (Pa) for acoustic signals) and the inclusion of a time-stamp and sample rate. For processing software, as in the Active Acoustic measurements in Section 3, this was often done within the processing suite and is not visible to the user. Level 2 (L2) data were generated when the L1 measurements were processed directly with no additional information. For the passive acoustic processing these products were the decidecade band sound level within a specified time period (1 s). Inclusion of ancillary such as location, ship speed, temperature/salinity (for acoustic travel time) in the processing produces a Level 3 data product.

1.4. Supporting Documentation and Standards

1. Acoustical terminology follows ISO 18405, supported by Ainslie et al (2017). The JIP data processing standard (Ainslie et al., 2018c) is followed.

2. Passive Acoustic Data Recorders

The objective of this section is to define the characteristics of passive acoustic data recorders that are essential for accurately measuring soundscapes.

2.1. Remotely Deployed Passive Acoustic Data Recorders

The *ADEON Soundscape Specification* (Ainslie et al., 2018b) documents the quantitative and qualitative metrics for describing the soundscape. This section contains block diagrams and explanations of the data processing algorithms used to generate those metrics. Descriptions of key file formats used in the analysis and for data outputs are contained in Appendix A.

2.1.1. Quantitative Soundscape Metrics

Table 2 from the *Soundscape Specification* (Ainslie et al., 2018b) defines the Snapshot Durations (duration over which data are integrated) and Data Analysis Durations (duration over which data are reported) for six quantitative soundscape metrics:

1. $L_{p,\Delta t}$: The sound pressure level over the period Δt ;
2. $L_{pk,\Delta t}$: The peak sound pressure level recorded over Δt ;
3. $L_{p,ddec,\Delta t}$: The sound pressure level in decidecade bands over the period Δt ; this includes decade and multidecade bands;
4. $\beta_{\Delta t}$: The sound pressure kurtosis (tailedness of distribution) over the period Δt ;
5. $L_{E,ddec,24h}$: The 24 -hour sound exposure level in decidecade bands; and
6. $L_{E,w,24h}$: The 24 -hour weighted sound exposure level, weighted by the marine mammal hearing group functions ([NMFS] National Marine Fisheries Service (US) 2016) or selected marine mammal audiograms.

The durations of the temporal observation window (TOW) and temporal analysis window (TAW) were 1 and 60, s, 1 h, 1 d, 1 mo, and 1 a (Ainslie et al, 2018b). The definitions of one month (1 mo) and one year (1 a) correspond to calendar months (28, 29, 30, or 31 days) and calendar years (365 or 366 days). For kurtosis estimates only 60 s is computed (based on Martin et al. (2020, in press)). For the sound exposure levels, the TOW duration is always 1 d and the TAW durations is either 1 mo or 1 a. For combinations of TOW and TAW where the TAW duration exceeded the TOW duration, the arithmetic mean is reported. When there were at least 100 TOWs in the TAW, the cumulative distribution function is also reported. The decidecade, decade, and multidecade metrics were computed for frequency bands to be selected from bands BC, BD, CE, DF, BE, and CF (see *Soundscape Specification* tables 5 and 6).

The block diagram for the implementation of the quantitative metrics analysis is shown in Figure 1. The processing was divided into two sections. The upper section (shown in gray) computed the metrics on the “raw” acoustic data recordings and stored the results in an individual ‘.xml’ file for each acoustic data file (shown in green). The second section (shown in light blue) combined processed data from sequential acoustic recordings to generate the TOW and TAW whose durations are longer than one raw acoustic data file. The qualitative soundscape descriptors were also computed from the raw acoustic data and their results stored in the XML file (see Section 2.1.2).

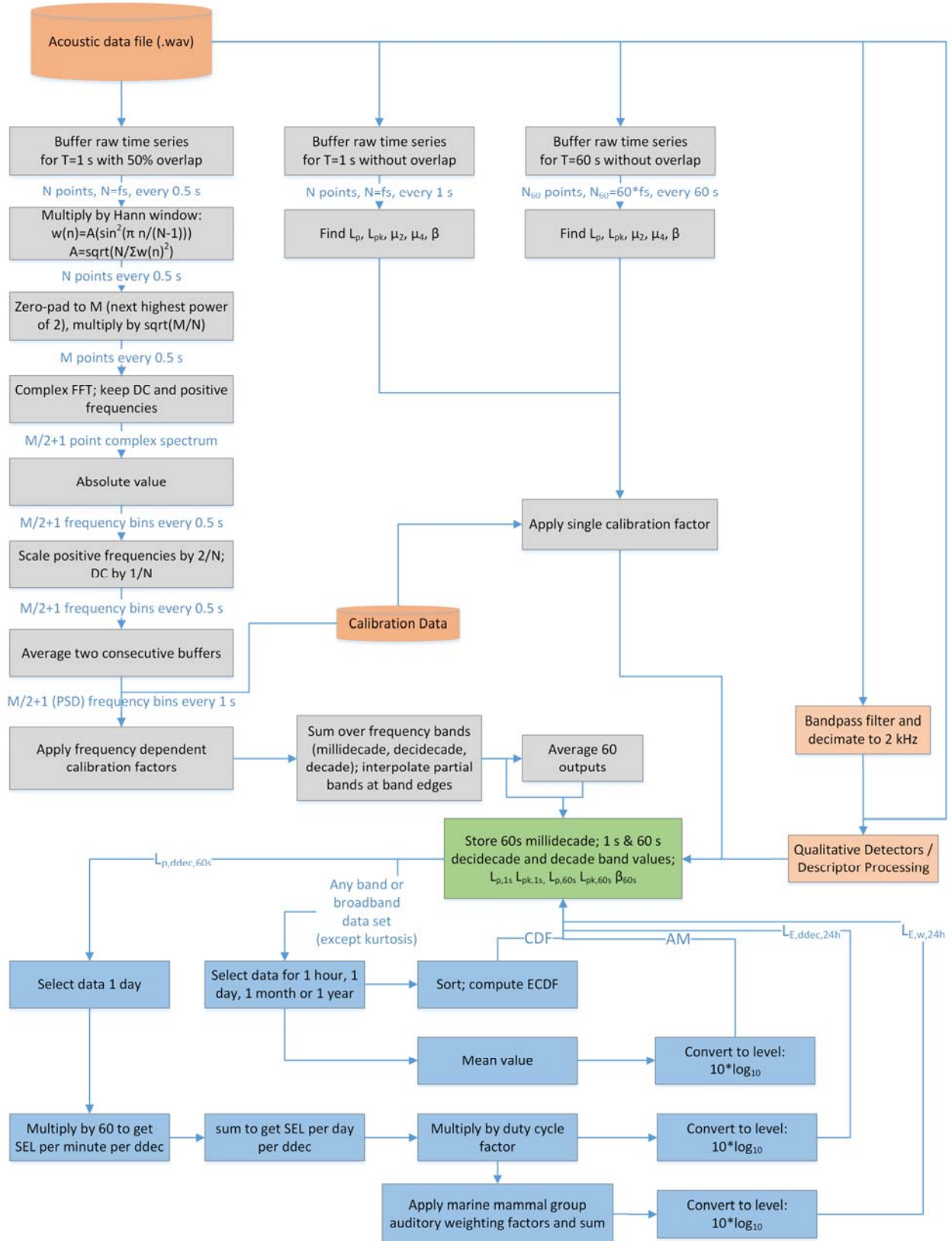


Figure 1. ADEON Quantitative soundscape metrics processing block diagram.

The quantitative processing steps performed on the raw acoustic data files were:

1. **CALCULATE SPECTRA:** Compute the 1 s and 60 s power spectral density and band levels. The left-most gray column in Figure 1 computes the frequency-dependent quantitative soundscape metrics. The first seven blocks implement the Welch (1967) method for estimating power spectra with a 1 second data sample and Hann window (see Heinzl et al. 2002). A power-of-2 fast Fourier transform (FFT) is employed, which yields a frequency resolution of 0.97 Hz for the AMAR sampling rates. See the Hardware Specification, Appendix A, for information on how to compute and apply the frequency dependent calibration values.
2. **CALCULATE BAND LEVELS:** Millidecade, decidecade, decade, and multidecade frequency band metrics: Frequency band metrics are computed from the 1 second, 0.97 Hz resolution spectral data. The spectra are summed between the band start and stop frequencies (see Soundscape Specification Tables 5 and 6) to obtain the 1 s band-limited sound pressures. Since the ~1 Hz bands do not align with the decidecade band start and stop frequencies, the PSDs in the bins that straddle two decidecade bands are divided according to the percentage overlap with the stop and start frequency of the adjacent bands. The 1 s band-limited squared sound pressures are then averaged over 60 s to obtain the metrics at that temporal resolution. The 0.97 Hz resolution PSDs are not stored; millidecades are used instead. The results are converted to decibels and stored for later use and / or further analysis. Software to compute band limits and then divide the PSD into the bands is provided in Appendix C.
3. **CALCULATE SYSTEM WEIGHTED LEVELS:** $L_{p,1s}$, $L_{pk,1s}$, $L_{p,60s}$, $L_{pk,60s}$ and β_{60s} are computed directly from the time series and converted to pascals using the single representative calibration value for the response of the system at 250 Hz. This leaves the data as system weighted.

The metrics generated by the first stage of analysis were stored for later use by plotting and reporting software. The results were also used to compute the soundscape metrics for the longer TAW durations:

1. **Arithmetic Means (AM):** the arithmetic means were computed on the linear values of any metric, then the $10 \cdot \log_{10}(\text{mean})$ to obtain the level of the mean value.
2. **Empirical Cumulative Distribution Functions (ECDF):** the level data were sorted from smallest to largest values, which were then used to generate a cumulative distribution function for the measurements.
3. $L_{E,ddec,24h}$: This metric was computed from the one-minute decidecade SPL values ($L_{p,ddec,60s}$) by converting the values back to linear units, multiplying by 60 s to obtain the sound exposure per decidecade, then summing each decidecade over the 24 h period to obtain the daily sound exposure per decidecade. If the recordings were made on a duty cycle, then the sum was multiplied by a correction factor of total duty cycle duration divided by duty cycle 'on' time. For example, if the recorder was on for 10 minutes out of every 15, then the sound exposure was multiplied by 15/10. The values were stored as levels.
4. $L_{E,w,24h}$: The weighted daily SELs were computed from the daily decidecade values in linear space. The sound exposure values were multiplied by the auditory frequency weighting functions (ISO 18405), for example from Southall et al. (2019), at the center of each decidecade and then all of the decidecade contributions were summed. The metric was stored as a level.

For duty cycled recordings, the $L_{E,ddec,24h}$ and $L_{E,w,24h}$ metrics are approximate. In particular, recordings at 8 or 16 kHz and 375 or 512 kHz were made at different duty cycles depending on the deployment. The method for combining duty cycles and the resulting range of daily SEL errors are described in Martin et al. (2019a). Two common cases where the daily SEL can be particularly in error for the higher frequencies are when there are naval sonars or echosounders above the Nyquist frequency corresponding to the low sampling rate, or if a vessel or other loud source passes close to the recorder during the high sampling rate phase of the duty cycle.

2.1.2. Qualitative Soundscape Metrics

By definition, a soundscape includes qualitative information concerning “the types of sources contributing to the sound field”. For ADEON we strive to quantify the contribution from different sources. With a prediction, one can attribute a proportion of the sound energy (in a specified volume) to a given source (Sertlek, 2016; Sertlek et al, 2019), but we cannot precisely measure this proportion. What can be measured instead is the proportion of time for which the contribution from a specified source dominates, for a specified snapshot duration (e.g., 1 min). When the detectors for different sources rely on an energy increase compared to the background, the daily sound energy associated with different source types can then be accumulated to estimate $L_{E,w,24h}$ by source type.

Developing detectors for different sound sources is an on-going area of investigation for many researchers, including the ADEON team. The algorithms used for identifying sound sources are expected to evolve over the course of the project. This Specification will be updated as necessary when the algorithms are improved. All data sets will be reprocessed with the current algorithms to ensure consistency in the methods and results.

2.1.2.1. *Biological sources*

We applied automated analysis techniques to detect sounds from odontocetes and mysticetes in the acoustic data (neither pinnipeds nor sound-producing fish or invertebrates are expected in the ADEON project area). Targeted signals for odontocetes are echolocation clicks and tonal whistles. Echolocation clicks are high-frequency impulses ranging from 5 to over 150 kHz (Au et al. 1999, Mohl et al. 2000), while the whistles are commonly between 1 and 20 kHz (Steiner 1981, Rendell et al. 1999). Baleen whales are lower in frequency and range predominantly between 15 Hz and 4 kHz (Berchok et al. 2006, Risch et al. 2007).

Biological sources were detected in each .wav file, and the detections were stored in the file’s corresponding .xml file (see Section 2.1.1). The number of detections per species may be summarized per minute, per recording file, or per day.

2.1.2.1.1. *Click Detection*

We applied an automated click detector/classifier to the high-frequency data to detect clicks from sperm whales, beaked whales, porpoise, and delphinids (Figure 2, Martin et al. (2019b)). This detector/classifier was based on the zero-crossings in the acoustic time series. Zero-crossings are the rapid oscillations of a click’s sound pressure waveform above and below the signal’s normal level (e.g., Figure 2). Clicks are detected by the following steps (Figure 2):

1. The raw data were high-pass filtered to remove all energy below a species-specific threshold: 5 kHz for sperm and killer whales, 50 kHz for Sowerby’s beaked whales, kogia spp, porpoise and very high frequency dolphins (Southall et al. (2019)), and 25 kHz for all

other species. This removed most energy from other sources such as shrimp, vessels, wind, and cetacean tonal calls, while allowing the energy from marine mammal click types to pass.

1. The filtered samples were summed to create a 0.334 ms 'energy' time series. Most odontocete echolocation clicks have a 0.1–1 ms duration.
2. Possible click events were identified with a split window normalizer detector that compares the energy in the 'test' bin of the time series to the mean of bins' adjacent cells with a padding of one bin.
3. The maximum peak within 1 ms of the detected time bin was found in the high-pass filtered data.
4. The high-pass filtered data were searched backwards and forwards to find the time span where the local data maxima were within 9 dB of the maximum peak (see Figure 2). The algorithm allowed for two zero-crossings to occur where the local peak is not within 9 dB of the maximum before stopping the search. This defined the time window of the detected click.
5. The following classification parameters were extracted: The number of zero crossings within the click, the median time separation between zero crossings, and the slope of the change in time separation between zero crossings. The slope parameter helped to identify beaked whale clicks, as beaked whale clicks increased in frequency (upsweep).
6. The Mahalanobis distances between the extracted classification parameters and the templates of known click types were computed. The covariance matrices for the known click types, computed from manually identified clicks for each species, were stored in an external file. Each click was classified as a type with the minimum Mahalanobis distance, unless none of them were less than the specified distance threshold.

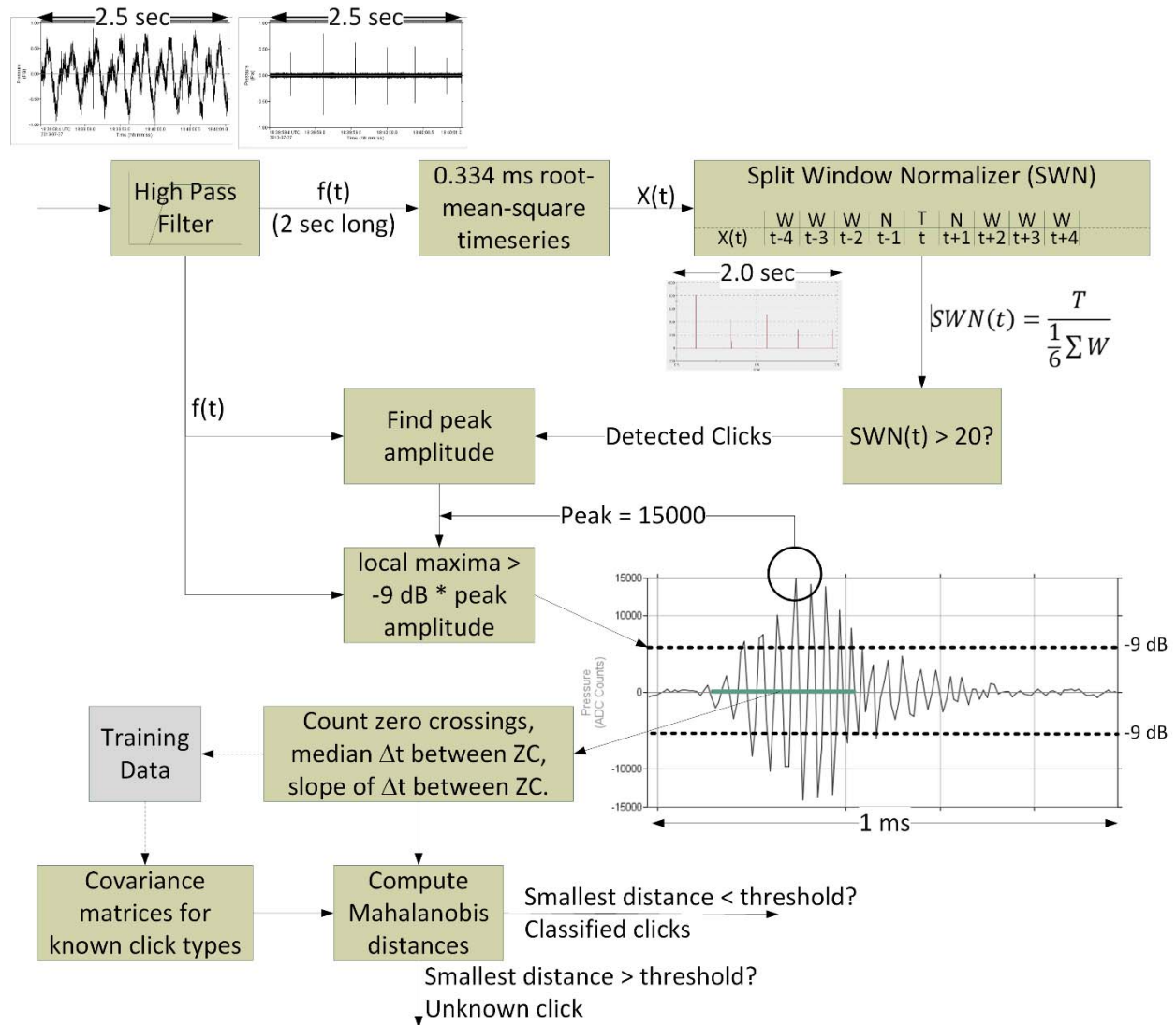


Figure 2. The click detector/classifier block diagram.

2.1.2.1.2. Tonal Call Detection

The tonal call detector identified data likely to contain marine mammal moans, songs, and whistles. Tonal calls were detected by the following steps (Martin et al. 2014):

1. Spectrograms at a resolution appropriate for the detection of each mammal call type were computed over a detection window of 5-120 seconds (see Table 3). For each frequency in the spectrogram, the median amplitude was computed over the detection window which was then used to normalize the spectrogram. A binary-spectrogram was created by setting the value of all time-frequency bins that exceeded a detector threshold (see Table 3) to '1' and all other time-frequency bins to '0'.
2. Contours were created within the binary spectrogram by stepping over the spectrogram using a search mask (Figure 3) and joining adjacent bins that were '1's.
3. Contour features were extracted: these were:

- a. minimum frequency;
 - b. maximum frequency;
 - c. duration;
 - d. maximum bandwidth in any of the time bins that are part of the contour;
 - e. the sweep rate: (maximum-minimum frequency)/duration.
4. A call -sorting algorithm determined if the properties of the contours matched the definition of a mammal call type (See Table 4).

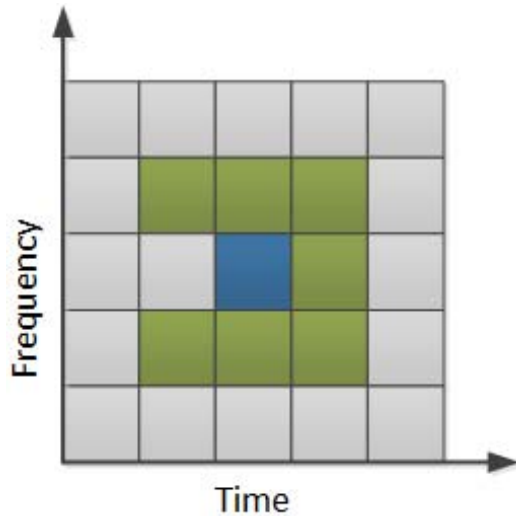


Figure 3. Illustration of the search area used to connect binary spectrogram bins. The blue square represents a detected bin in the binary spectrogram and the green squares represent the potential bins it could be connected to. The algorithm advances from left to right so gray cells left of the test cell need not be checked.

Table 3. Fast Fourier transform and detection window settings used to detect tonal calls of marine mammal species expected in the data. Values are based on JASCO’s experience and empirical evaluation on a variety of datasets. Updated settings, if any were used, will be contained in the processed file descriptions delivered with each dataset.

Possible species	Call type	FFT			Detection window (s)	Normalized Spectrogram Detector threshold
		Resolution (Hz)	Frame length (s)	Timestep (s)		
Pilot whales	Whistle	16	0.03	0.015	5	3
Dolphin	Whistle	64	0.015	0.005	5	3
Humpback whales	Moan	4	0.2	0.05	5	3
Blue whales	Infrasonic moan	0.125	2	0.5	120	4
Fin whales	20-Hz note	1	0.2	0.05	5	4
Sei whales	Downsweep	3.25	0.2	0.035	5	3.5

Table 4. Call sorter definitions for the tonal calls of cetacean species expected in the area. Updated settings, if any were used, will be contained in the processed file descriptions delivered with each dataset.

Possible species	Call type	Frequency (Hz)	Duration (s)	Bandwidth (Hz)	Other detection parameters
Pilot whales	Whistle	1,000–10,000	0.5–5	> 300	Minimum frequency < 5,000 Hz
Dolphin	Whistle	4,000–20,000	0.3–3	> 700	Maximum instantaneous bandwidth = 5,000 Hz
Humpback whales	Moan	100–700	0.5–5	> 50	Maximum instantaneous bandwidth = 200 Hz
Blue whales	Infrasonic moan	15–22	8–30	1–5	Minimum frequency < 18 Hz
Sei whales	Downsweep	20–150	0.5–1.7	19–120	Maximum instantaneous bandwidth = 100 Hz Sweep rate = -100 to -6 Hz/s
Fin whales	20 Hz downsweep	8–40	0.3–3	> 6	Minimum frequency < 17 Hz Sweep rate = -100 to 0 Hz/s

2.1.2.1.3. Validation of Automated Detectors

Automated detectors are often developed and tested with example data files that contain a range of vocalisation types and representative background noise conditions. However, test files normally cannot cover the full range of possible conditions. Therefore, a selection of files must be manually validated to check the detector performance in the specific conditions of each recorder. For each recorder and for each species or call type, a sample of files containing low, medium, and high numbers of detections was reviewed. Files that contained early or late automated detections were primarily selected to help bound the period of occurrence of a species/call type. The automated detector results were checked to evaluate the true presence or absence of each species, as well as vessels and other anthropogenic signals. These validated results were fed to a maximum likelihood estimation (grid search) algorithm that maximized the probability of detection and minimized the number of false alarms using the ‘F-score’:

$$F = \frac{(1 + \beta^2)PR}{(\beta^2)P + R}; P = \frac{N_{TP}}{N_{TP} + N_{FP}}; R = \frac{N_{TP}}{N_{TP} + N_{FN}}$$

where N_{TP} (true positive) is the number of correctly detected files, N_{FP} (false positive) is the number of files that are false detections, and N_{FN} (false negatives) is the number of files with missed detections. P is the classifier’s precision, representing the proportion of detected calls that are true positives. A P value of 0.9 means that 90 % of the detections are correctly classified, but says nothing about whether all calls in the dataset were identified. R is the classifier’s recall, representing the proportion of calls in the dataset that are detected by the detector. An R value of 0.8 means that 80 % of all calls in the dataset were detected but says nothing about how many classifications were wrong. Thus, a perfect detector/classifier would have P and R values equal to 1. An F-score is a combined measure of P and R where an F-score of 1 indicates perfect performance—all events are detected with no false alarms. The algorithm determines a classification threshold for each species that maximizes the F-score. Table 5 shows the dependence of the classification threshold on the β -parameter and its effect on the precision and recall of the detector and classifier system. β is the relative weight between the recall and precision. Here, we have made precision more important than recall as a β of 0.5 means the recall has half the weight of the precision.

Table 5. Effects of changing the F-score β -parameter on the classification threshold, precision, and recall for the odontocete clicks.

β	Classification threshold	Precision $P = \frac{TP}{TP + FP}$	Recall $R = \frac{TP}{TP + FN}$	F-score
2	25	0.87	0.95	0.93
0.5	50	0.91	0.91	0.91

Detection time series based on the restrictions above were plotted and critically reviewed. Questionable detections based on time of year and location or overlap with the detection period of other species were manually reviewed and removed from the plots if they were found to be false. The detector performance metrics presented in data analysis reports are based on the fully revised and edited results as shown in the detection time series. Detections were also presented as spatial plots showing the number of detections at each station over selected periods.

2.1.2.2. Manmade sources

Manmade sources were detected in two stage processes where distinctive features were first identified in each .wav file and then a second stage process looked at the evolution of the features across longer time periods to make the final detections and accumulate the daily SEL from the sources. The results of the per .wav file analysis were stored in the file's corresponding .xml file. The results of the second stage analysis were stored in .csv files containing the per-minute detector results.

2.1.2.2.1. Vessel Detection

Vessels were detected in two steps (Martin 2013):

1. Detected constant, narrowband tones produced by a vessel's propulsion system and other rotating machinery (Arveson and Vendittis 2000). These sounds were also referred to as tonals. We detected the tonals as lines in a 0.125 Hz resolution spectrogram of the data (8 seconds of data, Hann window, 2 second advance).
2. Assessed the SPL for each minute in the 40–315 Hz shipping frequency band which commonly contains most sound energy produced by mid-sized to large vessels. Background estimates of the shipping band SPL and system-weighted SPL were then compared to their mean values over a 12 h window, centered on the current time.

Vessel detections were defined by the following criterion (Figure 4):

- The SPL in the shipping band (40-315 Hz) was at least 3 dB above the 12-hour mean for the shipping band for at least 5 minutes
- AND at least three shipping tonals (0.125 Hz bandwidth) were present for at least one minute per 5-minute window (tonals were difficult to detect during turns and near the closest points of approach due to Lloyds' mirror and Doppler effects).
- AND The SPL in the shipping band was within 12 dB of the system weighted SPL.

The time period where these constraints are valid was identified as a period with shipping present. A 10 -minute shoulder period before and after the detection period was also included in

the shipping period. The shipping period was searched for the highest 1-minute SPL in the vessel detection band, which was then identified as the closest point of approach (CPA) time.

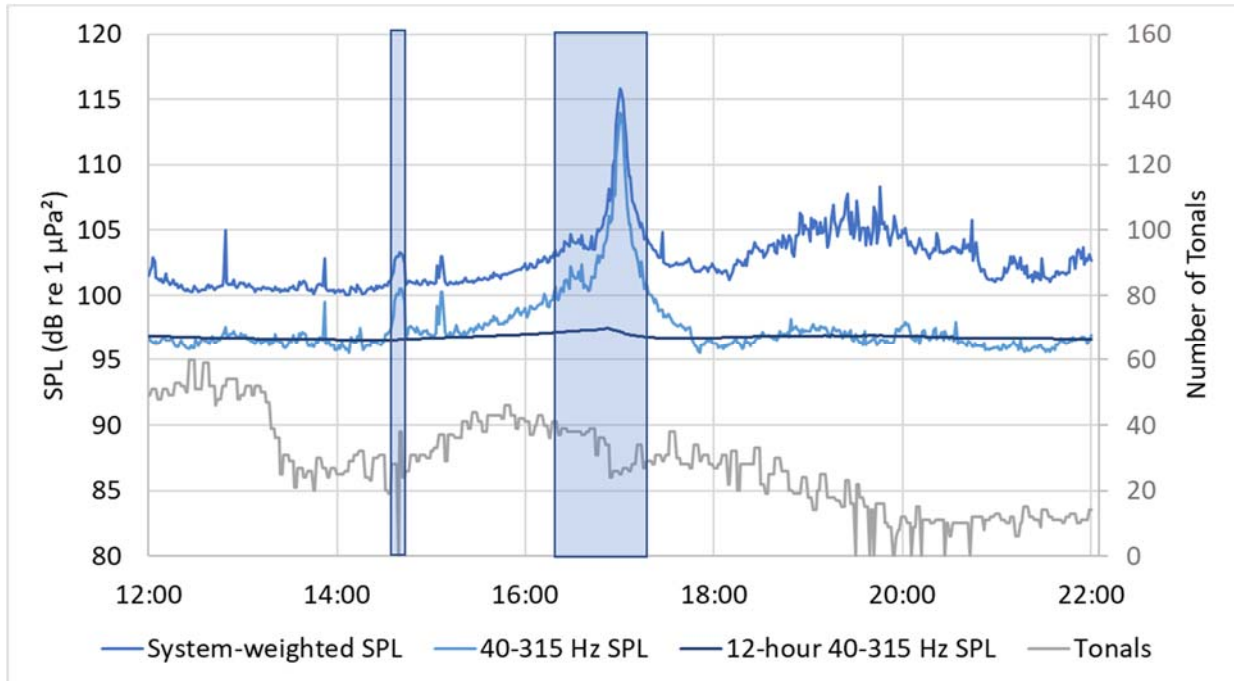


Figure 4. Example of system-weighted and 40–315 Hz band SPL, as well as the number of tonals detected per minute as a ship approached a recorder, passed nearby, and then departed. The shaded area is the period of shipping detection. Fewer tonals are detected at the ship’s closest point of approach (CPA) at 17:00 because of masking by broadband cavitation noise and due to Doppler shift that affects the tone frequencies.

This algorithm was designed to find *detectable* shipping, that is, situations where the vessel noise could be distinguished from the background. It did not identify cases of two vessels moving together, or cases of continuous noise from stationary platforms, such as oil and gas drilling and dynamic positioning operations. Those situations were identified from tools such as the daily SEL and long-term spectral average figures.

2.1.2.2.2. Airgun Pulse Event Detection

Airgun pulse sequences were detected using correlated spectrogram contours. We calculated spectrograms using a 300 s long window with 4 Hz frequency resolution and a 0.05 s time resolution (Hann window). Similar to the mammal contour detector, all spectrogram frequency bins were normalized by their median values over the 300 s window. A binary spectrogram was created using a detector threshold of 3 times the median value at each frequency. Contours were created by joining the time-frequency bins above threshold in the 7–1000 Hz band using the same 3×3 bin kernel as the mammal contour detector (Figure 3). Contours 0.2–6 s in duration with a bandwidth of at least 60 Hz were retained for further analysis.

An “event” time series was created by summing the normalized value of the frequency bins in each time step that contained detected contours. The event time series was auto-correlated to look for repeated events. The correlated data space was normalized by its median and a detector threshold of 3 was applied. Peaks larger than their two nearest neighbours were

identified, and the peaks list was searched for peaks with a spacing between 4.8 to 65 s, which captured the normal range of airgun pulse periods. When at least six regularly-spaced peaks occurred, the original event time series was searched for all peaks that matched the repetition period within a tolerance of 0.25 s to create a seismic pulse train. For each peak in the pulse-train, the 90 % energy duration of each peak was determined and those pulses more than 3 s long were removed. The pulse train and each individual pulse were stored in the output XML file.

This detector was effective for identifying periods with airgun pulses from single platforms, or multiple platforms at different ranges with similar pulse repetition intervals that rarely overlap. Some wide-area azimuth surveys may also be detected by this algorithm, however, the irregular pulse periods in these surveys were generally rejected. For these types of surveys the impulse detector should be employed instead.

2.1.2.2.3. *Impulse Detector*

Occurrence of detectable impulses, from pile-driving, airgun impulses, ice cracking, sonar pulses, and thunder, were automatically detected using a Teager-Kaiser energy detector. Similar to the click-detector, the impulse detector's first stage was computing the energy over a period of time that depends on the type of impulse to be detected. For instance, pile-driving and airgun pulses were well detected using a 50 ms integration time and no high pass filters. Naval sonar pulses were best identified by employing a suitable bandpass filter and a longer integration window. Impulses were detected in the time-series the Teager-Kaiser operator:

$$TK = \frac{E(t)^2}{E(t-1)E(t+1)}$$

where $E(t)$ is the energy time series. For each identified impulse $L_{p,\delta t}$, $L_{pk,\delta t}$, $L_{p,ddec,\delta t}$, $L_{E,\delta t}$, and $L_{E,ddec,\delta t}$ were computed and stored, where δt is either a fixed duration window or the 90 % energy duration window of the pulse.

2.1.2.3. *Geophysical sources*

The geophysical source detections were performed using the per-minute decidecade sound levels during post processing of the .xml files. The source flags were stored in the same file that contained the man-made source identifications.

The one-minute spectra were compared to template spectra for different wind speeds and rain conditions (Ma et al. 2005) to identify when these sources were present. This algorithm was also being extended to estimate when vessels or fin whales were present.

2.1.2.4. *Source Directionality*

The ADEON lander included four hydrophones in a right-angle array, which were intended for measuring the direction of arrival of detected sound sources. Two methods of directional analysis were employed.

The direction of arrival for the hydrophone arrays depended on the frequencies of interest. For frequencies below the 750 Hz cut-off, analysis was performed by forming equally spaced beams in azimuth and elevation, then selecting the beam with the highest received signal level for each frequency and time. This method provided the Cramer-Rao lower bound estimate on the direction of arrival for a compact array (Urazghildiiev and Hannay 2017). This method did not

rely on having a particular geometry for the compact array; the relative positions of each sensor must be known. For ADEON, we employed a radial resolution of 10 degrees (36 beams). Vertical beams were important if the azimuthal direction for sources within ~3 water depths was desired; seven vertical beams were recommended when processing the deep water recordings for ADEON.

For frequencies above the 750 Hz cut-off, broadband direction of arrivals became ambiguous when applying a beamformer. Instead, the time delay of arrival of a transient signal on each of the hydrophones may be used to determine the direction. For sounds that have a signal-to-noise ratio level of at least 6 dB, the direction of arrival was computed using the time delay of arrival (TDOA) between the center hydrophone and each of the hydrophones on the X, Y, and Z arms of the array. To find the TDOA we:

1. Detected the signal on the center hydrophone, and measured the bandwidth and duration of the signal.
2. Selected the time window corresponding to the detection on each of the hydrophones.
3. Band-pass filtered the data using a cosine-tapered window on each of the hydrophone channels to remove energy that was not from the identified signal.
4. Cross-correlated the X, Y, and Z hydrophones with the center hydrophone to measure the TDOA.
5. Used the time delays and speed of sound to estimate the direction of arrival.

The conductivity and temperature sensors allowed us to compute the speed of sound at the sensor location to improve the accuracy of the bearing estimates.

The source direction was stored in each .wav files corresponding to an .xml data analysis output file.

2.1.3. Passive Data Recorder Analysis Implementation Overview and Outputs

2.1.4. Passive Data Recorder Analysis Implementation

The passive data recorder analysis was performed using custom JAVA and MATLAB software written by JASCO Applied Sciences (Figure 5). The raw acoustic data (.wav files), meta-data files (deploymentInfo.csv), first level analysis output files (.xml), summary output files (.csv), and post-processed summary output files (.csv & .tiff) were all sent to the University of New Hampshire Research Computing Center for distribution and archiving. The key file formats are described in Appendix A.

The passive data analysis was performed on the 'Grid', which is the JASCO high-performance computing cluster that included 120 computer cores and 400 TB of backed-up disk space, all interconnected using a FiberChannel network fabric. JASCO has created an efficient suite of tools for documenting, queuing, and post-processing grid-runs so that we could track what analysis was performed on each data set. A full processing run on the ADEON data took ~6 hours per recorder and was repeated as necessary when new algorithms or configurations were warranted.

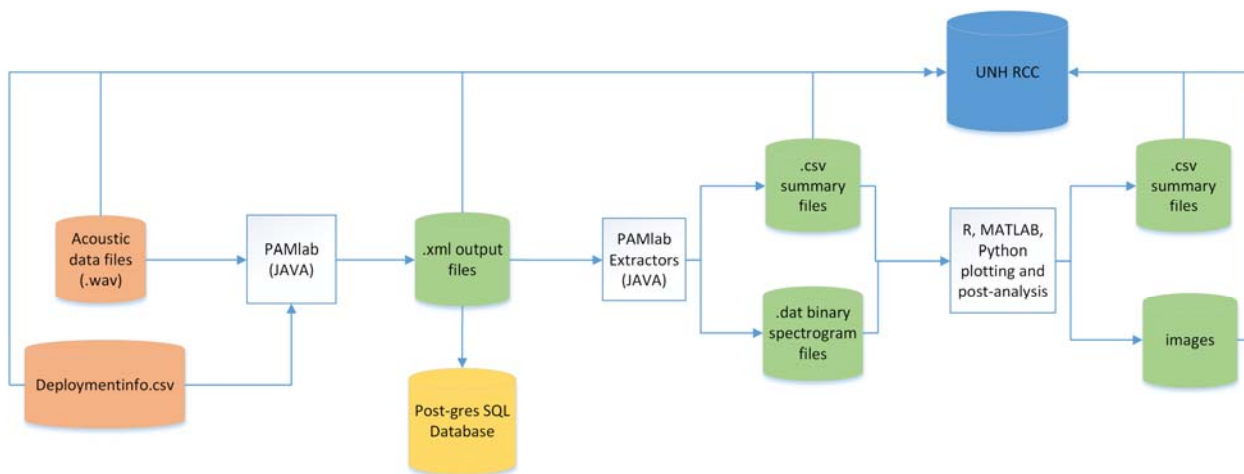


Figure 5. Overview of the data files, data analysis software, and output files associated with the passive acoustic data recorder analysis

2.1.5. Level 0 Data Products

The raw passive acoustic monitoring data were stored in .wav files that were organized by the vessel cruise on which the data were retrieved. For each data set there was an associated 'deploymentInfo.csv' file that contained the recording meta-data and calibration information. The Level 0 data were available from NCEI via their online data browser https://maps.ngdc.noaa.gov/viewers/passive_acoustic/

2.1.6. Level 1 Data Products

There were no Level 1 data products.

2.1.7. Level 2 Data Products

The quantitative soundscape metrics were referred to as the Level 2 results computed from the ADEON passive acoustic monitoring data. Level 2 results were sound pressure levels (SPL), sound exposure levels (SEL) computed over different snapshot durations, and SPL/SEL statistics computed over different temporal analysis windows, as described in the ADEON Soundscape and Modelling Metadata Standard.

The results were organized by deployment and recording location. The deployments were named after the cruise during which the recorder was retrieved:

- AR 25 includes a single 'test' data set two weeks long from Nov 2017.
- EN 615 retrieved the recordings from Nov 2017 – Jun 2018.
- EN 626 retrieved the recordings from Jun 2018 – Nov 2018.
- AR 40 retrieved the recordings from Nov 2018 – Nov 2019.
- A final cruise will retrieve the recordings for Nov 2019 – Nov 2020.

The results were provided for hydrophone 1 (or the omnidirectional hydrophone of the M20). Within each folder there were three subfolders (Figure 6): a data folder for each sample rate (8000 and 375000 Hz) and a data folder for the daily sound exposure levels (dailySELS).

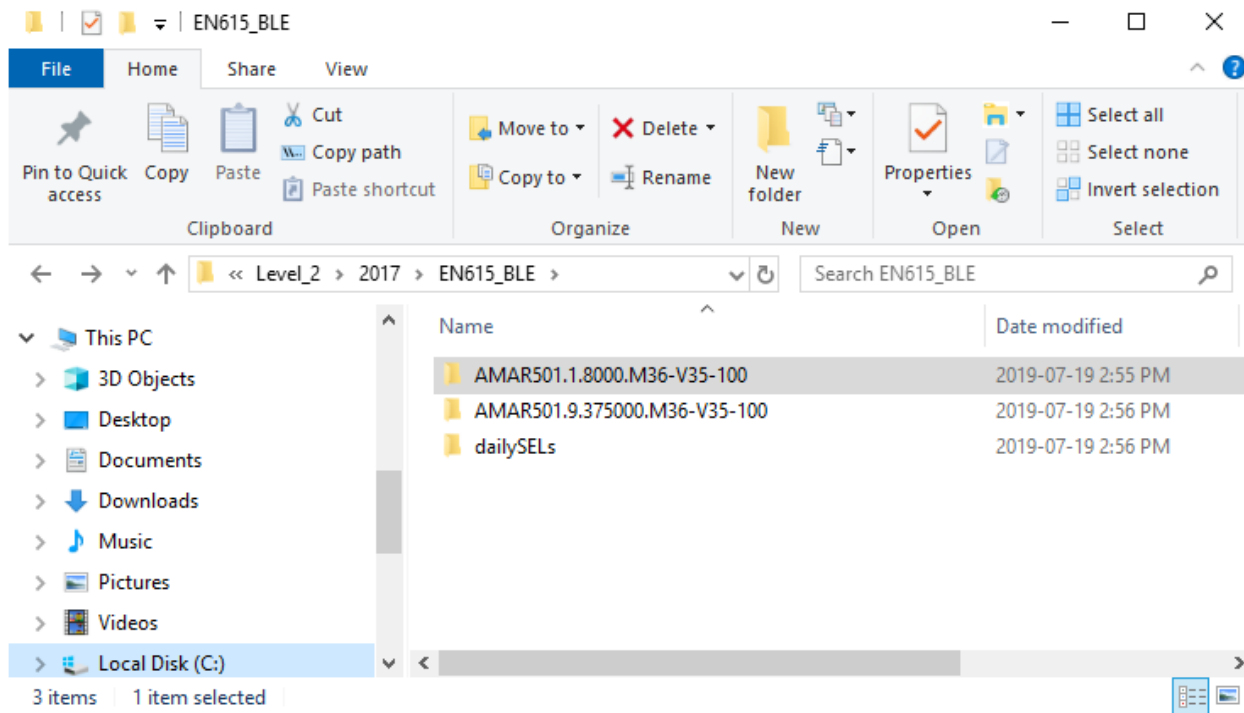


Figure 6. Per-recorder subfolders

The two sample rate data folders contained two image files, four ‘.csv’ data files, and a folder (Figure 7). The contents of these files are:

- *_bandSpec.png: summary of the recording sound levels shown as hourly decade band sound pressure levels and the long-term spectral average.
- *_percDecidecade.png: a summary of the recording sound levels shown as the distribution of the power spectral densities and box-and-whisker plots of the decidecade sound pressure levels.
- *_decidecadeHourlyMeans.csv: the hourly mean decidecade levels. The format for this file is contained in ‘decidecadeHourlyMeans_readMe.docx’.
- *_hourlyMeanPSDs.csv’: this a large file that has the mean power spectral densities per hour. The format of this file is described in ‘hourlyMeanPSD_readMe.docx’.
- *_decidecade_means_1.0_seconds.csv and *_decidecade_means_60.0_seconds.csv: These files contain the decidecade sound pressure levels averaged over the time duration shown in the file name. The format of these files is described in
- decidecade_means_1.0_60.0_seconds_readMe.docx’

The subfolder ‘DailyDecidecadePercs’ has one file per day that contains the 1st, 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 99th percentiles of the decidecades computed for each day. The format for these files are described in ‘DailyDecidecadePercs_readMe.docx’.

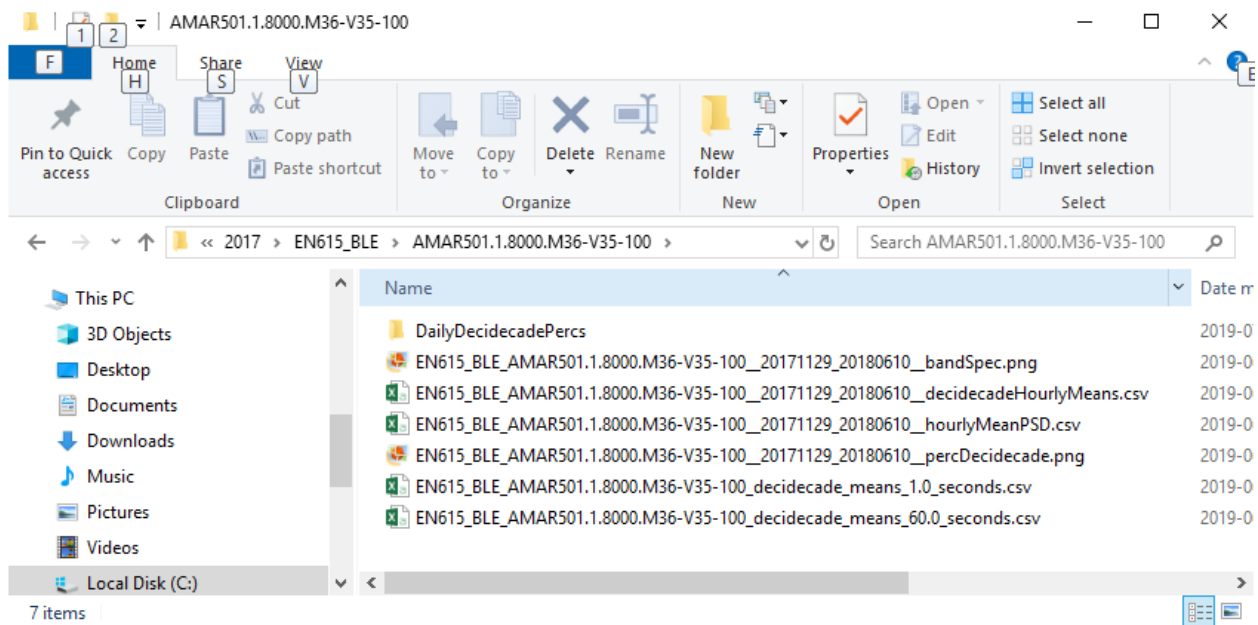


Figure 7. Per-sampling rate results directory contents.

The 'dailySELS' folder contains two files, a figure and a .csv with the unweighted and NMFS 2018 weighted daily sound exposure levels. The .csv file format is described in 'dailySEL_readMe.docx'.

2.1.8. Level 3 Data Products

The qualitative soundscape results are Level 3 results, which consist of automated detections of identifiable sound sources for each minute of data. Those sources are narrowband frequencies (tonals) from vessels, the closest point of approach of vessels, seismic airgun pulses, and marine mammal vocalizations. All identified sounds were indications that the sound source may have been present as determined by automated algorithms. Validation of their presence by manual analysis is recommended before reporting on the distribution of sound sources in time and space.

There is one results file per sampling rate per recording location. All analysis was performed on hydrophone 1 (or the omni channel for the M20 sensor). The results files have '_detections_levels.csv' in their names. These files also include broadband sound pressure levels as well as decidecade and decade sound pressure levels for context. The format of the files is described in 'detection_levels_readme.docx'.

2.2. Towed Array Passive Acoustic Data Recorders

In addition to the long-duration acoustic observations taken from the bottom-mounted landers, there were 4 separate cruises with a towed array passive acoustic system. A horizontal line array (HLA) was deployed from a sailboat with a drogue weight to maintain depth and the sound field was measured. The purpose of this portion of the test was to measure the horizontal directionality of the sound field and to connect the soundscape from one mooring to an adjacent mooring and to take data to help define the spatial correlation distance of the sound field. A sailboat was chosen to minimize the contamination of the recording from self-noise, in the form of sound radiated by the towing vessel. The first cruise employing the HLA was in the spring of 2018, followed by a mooring recovery and replacement cruise in June. The April cruise was conducted aboard a United States Coast Guard (USCG) sailing ship, staffed by cadets from the USCG Academy in New London, as well as ADEON scientists from OASIS Inc. The USCG Academy volunteered ship time and personnel in order to gain the experience of participating in an acoustics trial.

In 2018 and 2019, Applied Ocean Sciences (AOS) performed two sea tests in support of the ADEON project. One of the goals of the sea tests was to provide the project with directional horizontal sound measurements near the ADEON deployed lander sites. The tests both used sailboats to tow a hydrophone array. Sailboats are much quieter than a motorized vessel.

The array towed in both tests was the OASIS Towed Array #3 (OTA3). The array had 16 elements spaced 0.75 m apart, giving a total array length of 11.25 m. Each element in the array had a sampling rate of 3125 Hz, though there is a low pass filter starting to roll off at 1 kHz. The useable band for the beamformer is 50 Hz to 1 kHz. During the tow, the array's estimated depth was approximately 5 m.

A processor was run in real time on the boat to directly compute and store the conventional beamformer (CBF) response of the array. This section outlines the processing and defines the data that will be delivered to the ADEON researchers for Phase IV, archived and made publicly available. The raw acoustic time series (L0 products) will not be made available to the public. This is to prevent subsequent reprocessing of the data for purposes other than soundscape monitoring. The L0 raw acoustic data were stored as a backup in case there are issues with the broadband CBF processing. The data were also provided to the USCG for use by the students in various research projects.

2.2.1. Processing Steps

The array digitized the samples into a 16-bit word. The broadband sensitivities of the ADC and the hydrophone were

$$M_{\text{ADC},V} = \frac{32768}{4.5} \text{ V}^{-1} \approx 7282 \text{ V}^{-1}$$
$$M_{\text{hp},V} = \frac{1}{37.5837} \text{ V Pa}^{-1} \approx 0.26607 \text{ V Pa}^{-1}$$

The sensitivity was mostly flat (less than 0.5 dB change) in the frequency domain of interest (50 Hz to 1 kHz) and a single value was applied uniformly across the band. The time series data were collected and stored in 1-minute files. Each 1-minute file has 16 channels and 187500 points.

The processing steps performed on the raw acoustic data files were:

1. **Spectral decomposition:** The processor assembled the incoming stream of samples into 50 % overlapped chunks, applied a Hann window to each chunk, and performed a fast Fourier transform (FFT). The FFT length was 1 second. Because the Hann window reduced the amplitude of approximately one-half of the data window, two successive buffers of data were averaged to obtain the 1 s power spectral densities. The input buffer had a 50% overlap so that there was one output every second from this analysis stage. The modern FFTs used in this processing do not require a number equal to a power of 2.

Considerations for ensuring a unity gain of a signal during this processing:

- a. The Hann window amplitude was scaled so that its average power is 1. This was done so that the application of the Hann window did not change the total power in the signal.
- b. The Fast Fourier Transform using the West library (FFTW) was applied and was normalized such that the data satisfy Parseval's theorem (the total integrated power in the time series was equal to the total integrated power in the frequency domain).

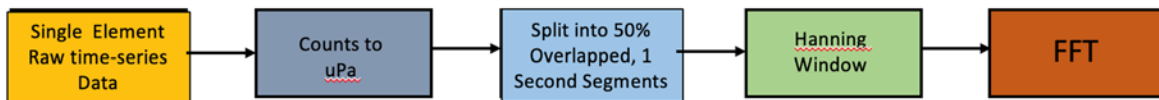


Figure 8. Processing steps for computing frequency domain power from the element time series. The L0 input is $x(t)$. The L2 output is $P(f)$.

The conversion from pressure time series $p(t)$ to power spectral density $P_f(f)$ is below (following Ainslie et al. 2018c):

$$x(t_n) = \sqrt{\frac{8}{3}} \cos^2 \frac{\pi t}{T} p(t_n)$$

$$X_m = \frac{T}{N} \sum_{n=1}^N x(t_n) \exp \frac{-2 \pi i n m}{N}$$

where $p(t_n)$ is the sound pressure, X_m is the sound pressure spectrum, N is the number of time samples and T is the duration of the temporal observation window (TOW), equal to N times the sampling interval.

$$E_f(f_m) = 2|X_m|^2$$

$$P_f(f_m) = \frac{E_f(f_m)}{\Delta t}$$

$E_f(f_m)$ is the energy spectral density and $P_f(f_m)$ is the power spectral density of the sound pressure, whose dimensions are (pressure squared)/(frequency).

The PSD $P_f(f_m)$ may be expressed as a level (the power spectral density level) in the form

$$L_{p,f}(f_m) = 10 \lg \frac{P_f(f_m)}{1 \mu\text{Pa}^2/\text{Hz}} \text{ dB}$$

- Plane wave beamforming:** A Hann shaded frequency domain conventional beamformer (CBF) was applied to each frequency component of the acoustic signal. The set of beams was uniformly spaced in 1° beams from forward endfire. The number of beams formed was twice the number of half wavelengths spanned by the array at the highest frequency of interest.

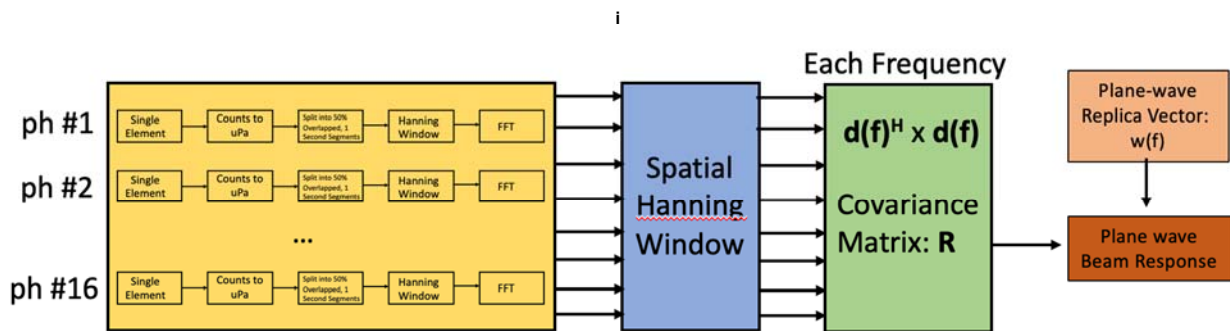


Figure 9. Processing steps for the frequency domain plane wave beamformer mapping the element complex pressure in a frequency bin to the beam power (vs. angle) of that frequency bin.

The conversion from the element pressure $p(t)$ to beam power begins with the output of Step 1, the sound pressure spectrum $X(f)$ resulting from the FFT, henceforth abbreviated “complex pressure”. The array was weighted using a spatial Hann window according to:

$$Y_m = Y(f_m) = \sqrt{\frac{8}{3}} \cos^2 \frac{\pi l}{L} X_m$$

Where L is the array length and l is the distance from the center of the array. In order to provide some degree of smoothing, the data covariance matrix was computed over Λ TOWs by adding the outer product of the data vectors:

$$\mathbf{R}(f) = \delta f \sum_{\lambda=1}^{\Lambda} \mathbf{Y}(f, \lambda) \cdot \hat{\mathbf{Y}}(f, \lambda)$$

Where λ is the time index of TOWs, \mathbf{Y} is the data vector made up of the frequency domain complex pressure for each element. The covariance matrix has the same dimensions as the power spectral

density (pressure squared frequency⁻¹). For plane wave beamforming, the replica \mathbf{w} , is a plane wave coming across the array from an angle θ :

$$w_j = \frac{1}{\sqrt{N}} e^{-ik \cdot j \Delta x \cos \theta}$$

Where Δx is the array spacing ($l = j \Delta x$), N is the number of elements and k is the wavenumber ($k=2\pi f / c$). The beamforming replica was normalized in such a way that the beam response of a unit power plane wave is 1 in the arrival direction of the wave.

To perform the beamforming the windowed replica was applied to the data covariance matrix:

$$B_f(f) = \mathbf{w}'(f) \mathbf{R}(f) \mathbf{w}(f) = \delta f \sum_{t=0}^T |(\mathbf{h} \cdot \mathbf{w}(f))' \cdot \mathbf{X}(f)|^2$$

Where the ' is the Hermitian conjugate (transpose, complex conjugate). The in-beam power spectral density level (Ainslie, 2010) is

$$L_{B,f}(f_m) = 10 \lg \frac{B_f(f)}{1 \mu\text{Pa}^2/\text{Hz}} \text{ dB}$$

- Band averaging:** Frequency band metrics were all computed based on 1 second buffers of the time series data converted to ~1 Hz resolution spectral data. The resulting data were ~1 Hz power spectral densities (PSD) that could be directly summed between the band start and stop frequencies (see ADEON Soundscape Specification tables 5 and 6) to obtain the 1 s band-limited sound power. Since the ~1 Hz bands did not align exactly with the decidecade band start and stop frequencies the PSDs in the bins that straddle two decidecade bands were divided according to the percentage overlap with the stop and start frequency of the adjacent bands.

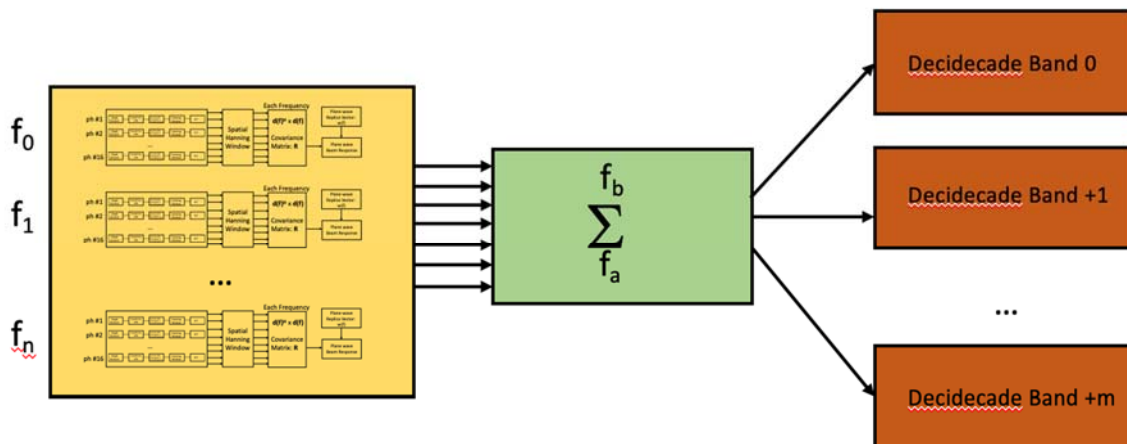


Figure 10. Processing steps computing the decidecade sound exposure level (integrated power) for each beam across the band.

The output of the beamformer (highlighted in amber in Figure 10) was then summed across the decidecade band to produce the decidecade in-beam power

$$B_{\text{ddec}}(f_{\text{ddec}}) = \delta f \sum_{f_{\text{min}}}^{f_{\text{max}}} B_f(f)$$

Where δf is the frequency resolution of the DFT (1 Hz). The decidecade bands are defined by index numbers as:

$$f_{\text{center}} = (1000 \text{ Hz}) 10^{\frac{n}{10}}$$

With the bounding bands:

$$f_{\text{max}} = f_{\text{center}} 10^{\frac{1}{20}}$$
$$f_{\text{min}} = f_{\text{center}} 10^{-\frac{1}{20}}$$

The decidecade in-beam power spectral density level are reported in dB which is computed using the following:

$$L_{B,\text{ddec}}(f_m) = 10 \lg \frac{B_{\text{ddec}}(f_{\text{ddec}})}{1 \mu\text{Pa}^2} \text{ dB}$$

The complete table of decidecade band indices, bounds and center frequencies are shown below.

Table 5. Decidecade limits and center frequencies for index n from -10 to 0.

Decidecade Index	Lower Bound	Center Frequency	Upper Bound	(Nominal Center Frequency)
-10	89.125 Hz	100 Hz	112.20 Hz	(100 Hz)
-9	112.2 Hz	125.89 Hz	141.25 Hz	(125 Hz)
-8	141.25 Hz	158.49 Hz	177.83 Hz	(160 Hz)
-7	177.83 Hz	199.53 Hz	223.87 Hz	(200 Hz)
-6	223.87 Hz	251.19 Hz	281.84 Hz	(250 Hz)
-5	281.84 Hz	316.23 Hz	354.81 Hz	(320 Hz)
-4	354.81 Hz	398.11 Hz	446.68 Hz	(400 Hz)
-3	446.68 Hz	501.19 Hz	562.34 Hz	(500 Hz)
-2	562.34 Hz	630.96 Hz	707.95 Hz	(630 Hz)
-1	707.95 Hz	794.33 Hz	891.25 Hz	(800 Hz)
0	891.25 Hz	1000 Hz	1122 Hz	(1 kHz)

2.2.2. Examples

A set of examples presenting the above towed array signal processing procedure mapping the data from element level time series $p(t)$ through the Fourier transform, the beamformer and the band integrator to get to the decidecade in-beam power.

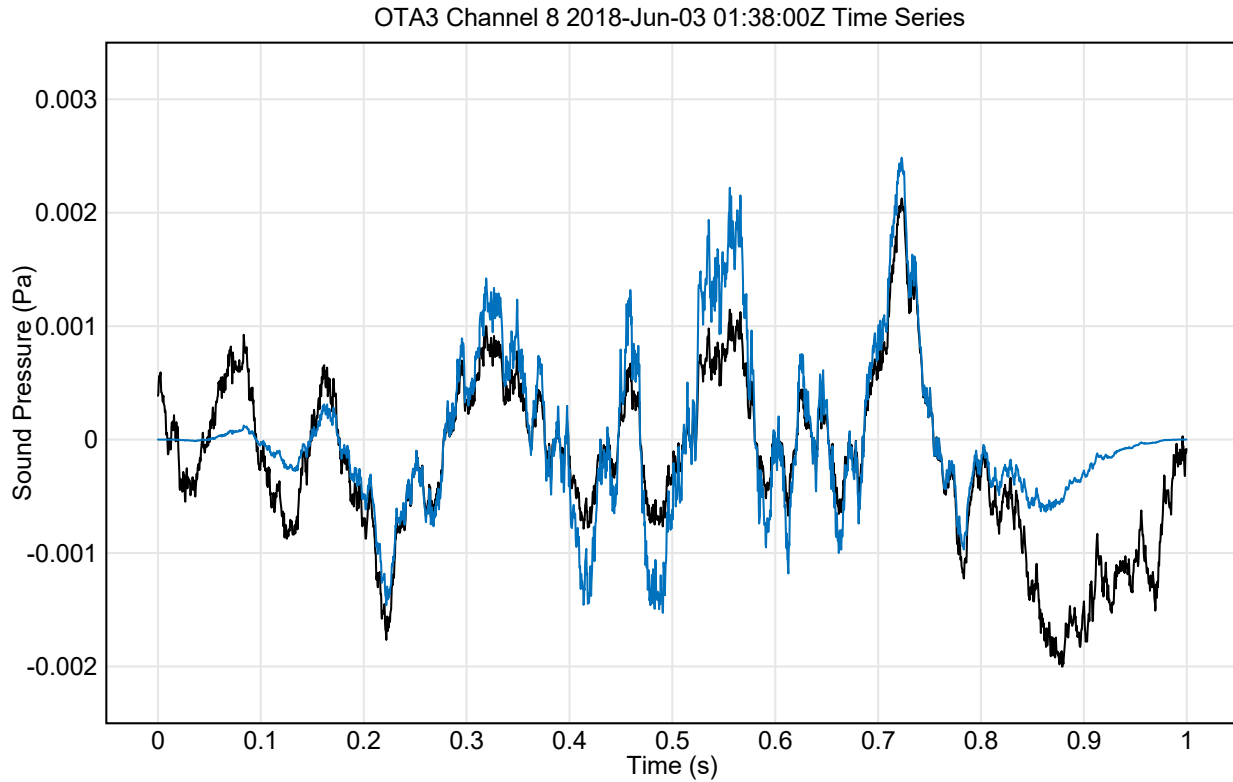


Figure 11. The system-weighted time series $p(t)$ for 1 second of data from Channel 8 on Jun 2, 2018, in pascals. The Hann weighted system-weighted $h(t)p(t)$ is plotted in blue.

Following the processing step 1 outlined above, the data were fast Fourier transformed (FFT) using 1-second lengths, 50 % overlapped and with a Hann window applied. The array has a lowpass filter that allows 0 Hz to 1000 Hz to pass.

Applying the FFT to the Hann weighted signal produced the power spectral density P_f of the above time series is plotted below in Figure 12.

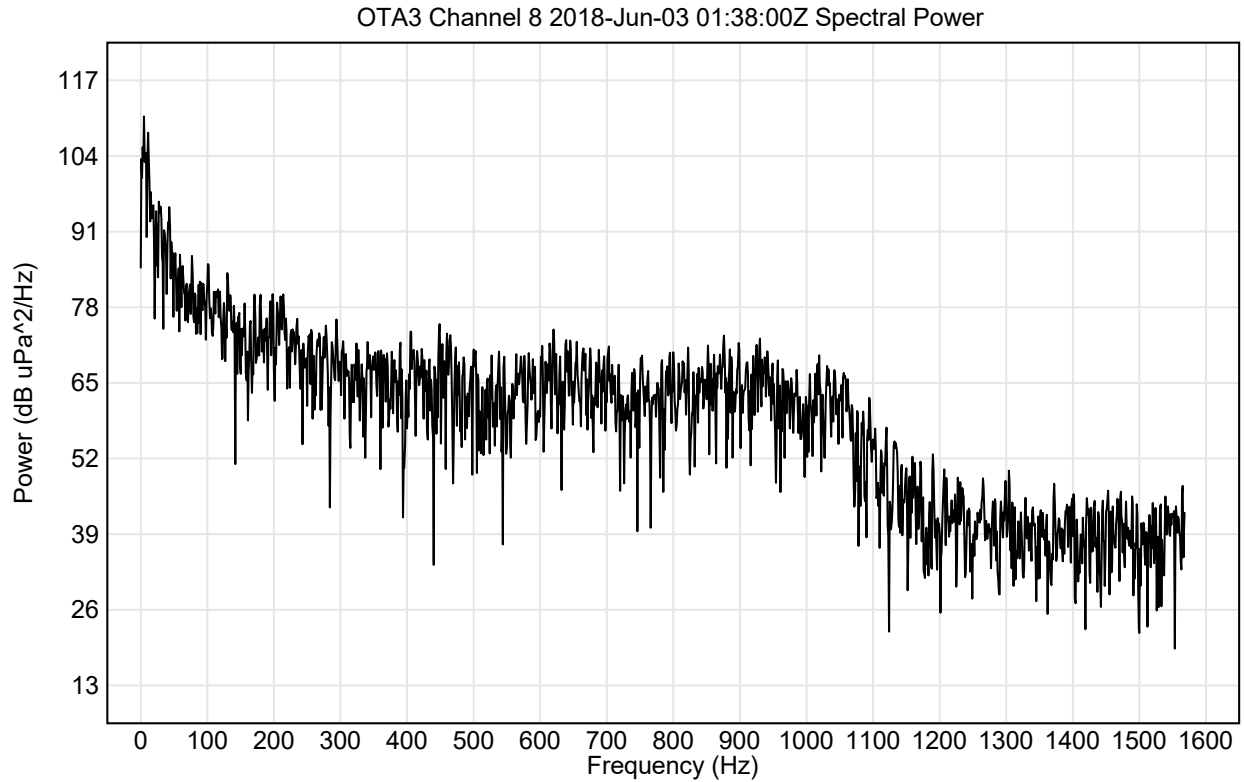


Figure 12. Power spectral density level $L_{p,f}(f)$ re $1 \mu\text{Pa}^2/\text{Hz}$, in decibels, for 1 Hz frequency resolution and 1 s time duration.

Applying the 50 % overlap to 1 s windows, the Hann window and FFT, produced a spectrogram of power spectral density as a function of frequency and time. The resulting spectrogram plot of $P_f(f,t)$ is shown below in Figure 13.

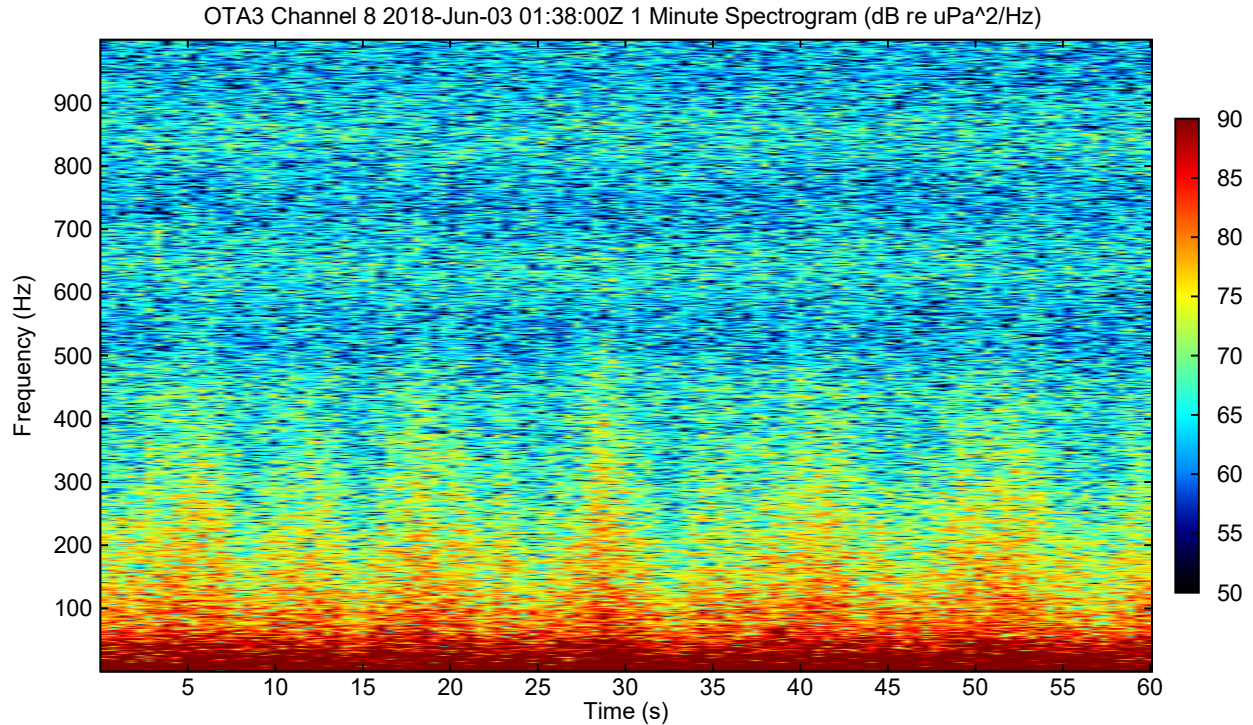


Figure 13. A 1-minute spectrogram showing power spectral density level $L_{p,f}(f)$ L_{PSD} vs time and frequency (re $1 \mu\text{Pa}^2/\text{Hz}$), in decibels, generated by stacking 60 one-second FFTs for a single channel.

Following the data processing step 2 procedure outlined above, each frequency bin was spatially Hann windowed and the conventional beamformer was applied. The resulting conventional beam former (CBF) response as a function of frequency is shown in Figure 14 below. Note the linear effect of frequency on beamwidth. At the low frequencies the array was comparatively short (small numbers of wavelengths) and the beamwidth could be quite large.

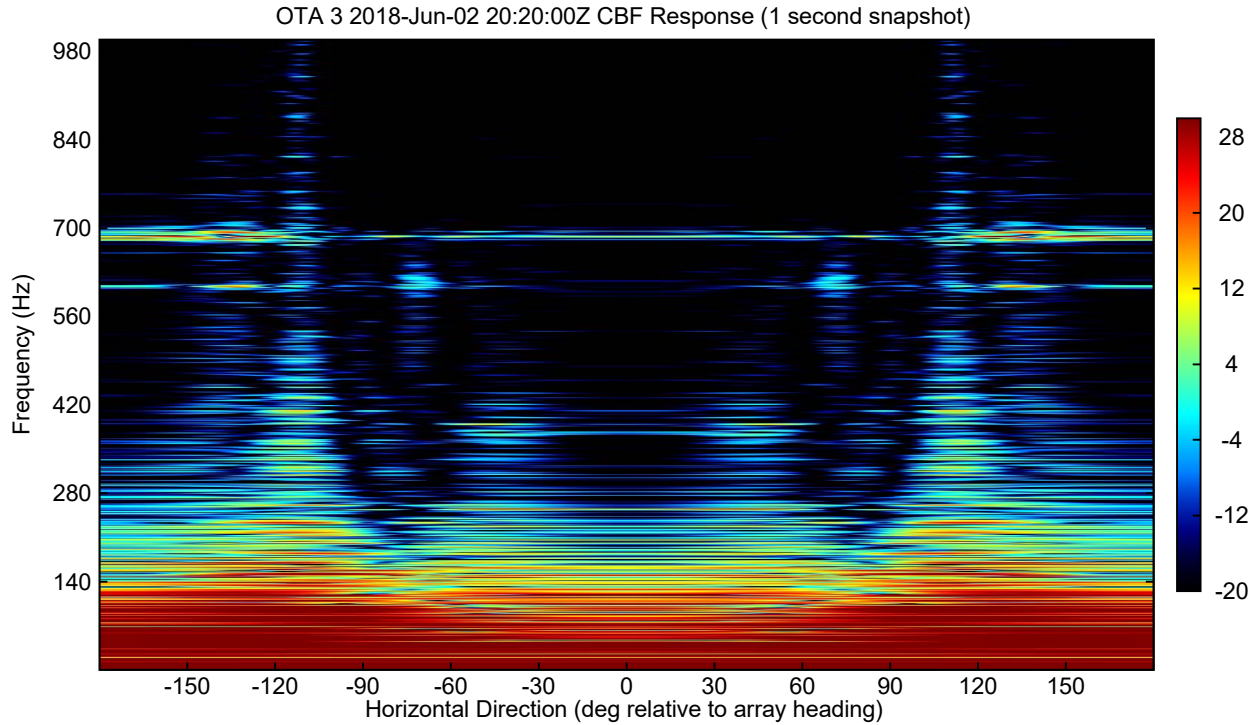


Figure 14. Conventional Beam Former (CBF) response, showing in-beam power spectral density level $L_{B,f}(f)$ (re $1 \mu\text{Pa}^2/\text{Hz}$), in decibels, vs beam steering angle ('horizontal direction'), in degrees, and frequency, in hertz, for a 1-s TOW.

2.2.3. Level 0 Data Products

The L0 data (raw passive acoustic for the sailboat towed horizontal line arrays) were recorded on binary files while at sea. These data were not approved for public release by the Office of Naval Research, and therefore have not been included in the data products made available by ADEON.

2.2.4. Level 1 Data Products

Level 1 data are those with ancillary data beyond the electronic measurements of bits. For the towed array data this would include time-stamps and calibration values. These data were not stored and the timing and calibration were applied during processing to produce Level 2 data. No L1 data were released to the public.

2.2.5. Level 2 Data Products

Application of the broadband calibration to the data, a time-stamp, along with spectral processing (FFT) and beamforming produced the Level 2 data for the towed horizontal line array. Level 2 results are a bearing time record (power per beam at a set of times), integrated over decade bands of the conventional beamformer output (this is $L_{B,\text{dec}}(f, \theta, t)$ in units of dB/re $1 \mu\text{Pa}^2$).

The data delivered and available to the public included the cruise reports, the L2 Conventional Beamforming decidecade BeamGrams, along with readme files, a MATLAB reader (**obb_read.m**), as well as the GPS data for the sail cruise were all stored on the NCEI server, according to the directory structure outlined shown below in Figure 15.

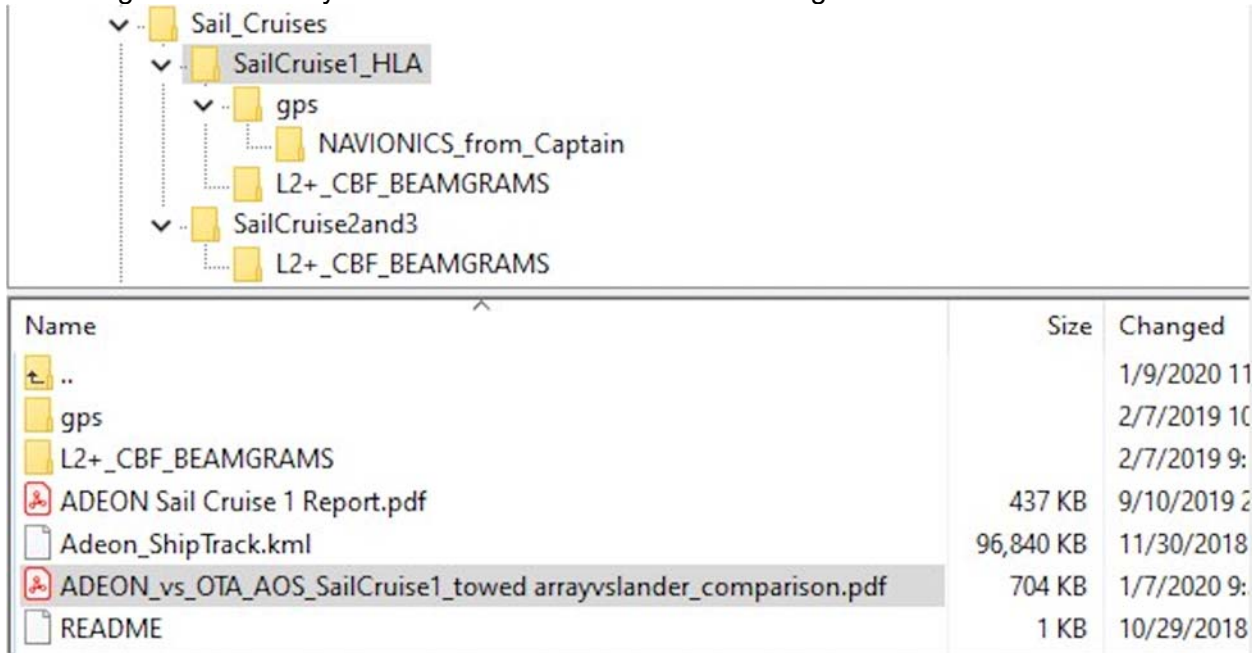


Figure 15. Directory structure of Sail Cruise data for Cruises 1, 2 and 3 from the NCEI website.

The file naming conventions, as illustrated by a directory listing of Sail_Cruises/SailCruise1_HLA/L2+CBF_BEAMGRAMS below in Figure 16 is date, time and decidecade band index {n} according to the nomenclature:

YYYYMMDDTHHMMSSZ_CBF_band_{n}.obb

3. Active Acoustic Recorders

The objective of this specification is to describe the processing of ADEON echosounder data that were essential for accurately characterizing acoustic backscatter in the water column. This section contains two sections:

- 3.1 Processing of data from remotely deployed echosounder systems
- 3.2 Processing of data from vessel-mounted echosounder systems

3.1. Processing of data from remotely deployed echosounder systems

3.1.1. Level 0 Data Products

Level 0 data products are the raw binary AZFP files recorded by the AZFP sensor. The Level 0 data are available from NCEI via their online data browser.

3.1.2. Level 1 Data Products: Importing binary files directly into Echoview

ADEON integrated a 4-frequency echosounder system (38 kHz, 125 kHz, 200 kHz, and 455 kHz) into three of the seven constructed bottom lander platforms. The transducers were mounted at an approximate 15° angle off vertical to eliminate interference from the lander sensors and were floatation-mounted slightly above the transducers. The AZFP (ASL Environmental Sciences) system was a self-contained instrument designed to measure and record acoustic returns from the water column. The AZFP stored acquired data on a 32 GB Compact Flash memory card, and downloading of data can occur via 1) an RS-232 interface through a bulkhead connector on the pressure housing or 2) by removing the instrument from its pressure housing and using a USB card reader to transfer the data from the CF card to a PC. It is recommended that the deployment data be downloaded to a PC for ease and speed of further processing.

Echoview Version 9 software directly read AZFP binary files and automatically input the calibration information for each frequency and unit directly into Echoview resulting in a calibrated time series. All the individual transducer calibration coefficients (contained in the configuration (.cfg) file for each instrument; ADEON Calibration and Deployment Good Practice Guide, 2017) were integrated as part of the instrument firmware and were applied to the binary data during the Echoview import process to produce fully calibrated values of S_v in Echoview. However, the AZFP binary files did not contain a TVG correction factor or frequency-dependent absorption. TVG correction and frequency-dependent absorption were applied to each dataset with a .ecs calibration file specifying STANDARD TVG and the following absorption coefficients: 0.009 dB/m at 38 kHz, 0.041 dB/m at 125 kHz, 0.056 dB/m at 200 kHz,⁴ and 0.11 dB/m at 455 kHz for the ADEON region bottom conditions.

For AZFP temperature data time series, binary data were exported in A/D (counts) ASL CSV format from the AZFPLink software on the Export tab (the AzfpLink Users Guide (Version 1.0.16)).

⁴ <http://resource.npl.co.uk/acoustics/techguides/seaabsorption/>

3.1.3. Level 2 Data Products: Processing Echoview files

AZFP binary files were loaded into Echoview software and compiled to create monthly Echoview (.EV) files for processing. Each monthly .EV file was constructed to include all 4 frequency S_v time series. The .EV files were saved with the designated format: SITE_YEAR_MON.EV. An example for ADEON data would be VAC_2017_DEC.EV. The initial processing of the .EV files included 1) background removal via techniques outlined in De Robertis & Higginbottom (2007), and 2) a median 3 x 3 filter applied to smooth the data and remove noise interference generated either by our own ship in the region or by other passing ships. Both of these steps were accomplished within the Echoview software using the Background Noise Removal and Median Filter 3x3 operators, respectively. The parameters of the Background Noise Removal operator applied to the averaging and thresholding of ADEON AZFP data were (in the language of Echoview):

Averaging:

Vertical extent (samples) = 5

Vertical overlap (%) = 0

Thresholds:

Maximum noise (dB) = -125

Minimum SNR (dB): 5

The reference value for 'Maximum noise' was not stated in the Echoview software.

Each monthly .EV file was then also manually scanned to 1) identify "bad data" regions (regions of prolonged interference visible even after the noise removal operators were applied, transducer ringdown, etc.) which were marked and excluded from further processing, and 2) designated an appropriate surface line for referencing depth consistently with the fine-scale acoustic survey data. Because of the 15° tilt from vertical of the AZFP transducers on the bottom landers, the true air-sea interface was offset slightly from the surface identification viewed in Echoview. The offset was a function of the transducer beamwidth (38 kHz: 12°; 125 kHz: 8°; 200 kHz: 8°; 455 kHz: 7°). The true air-sea interface was calculated with the following offsets from the visible surface line on the Echoview display: 38 kHz = 4.5 m, 125 kHz = 3.14 m, 200 kHz = 3.14 m, and 455 kHz = 3.04 m. This processed and conditioned data were then used to export information for classification into designated animal groups.

Conditioned data were exported from the .EV files to .csv files for classification with MATLAB software. Conditioned data were exported in four separate data packages (Table 6) to capture the long-term variability at selected temporal and spatial scales. The set-up and execution of export grid averaging in Echoview was described in detail in Appendix B. The naming convention for exported data from Echoview is Site_SerialNumber_Frequency_Year_Month_ExportType.csv (Table 7).

Table 6. Selected data export packages from conditioned Echoview data

	Depth Averaging	Time Averaging
Full Depth	200-500 m	24 h
Daily Partition	5 m	24 h
60 min Partition	5 m	60 min
60 min Full Depth	200-500 m	60 min

Table 7. Naming convention key for exported .csv files from Echoview

Site	VAC, WIL, HAT, etc
SerialNumber	Four digit serial number (i.e. 5041)
Frequency	Three digit frequency (038, 200, 455, 775)
Year	Four digit year
Month	Two digit month
Export Type	FullDepth, Partition, 60minPartition, 60minFullDepth

For direct, short-term comparison to the focused survey data obtained from vessel-mounted echosounder systems, export packages of AZFP data during the period of vessel measurements reflect higher temporal resolution (shorter averaging windows) over daylong durations.

3.1.4. AZFP Temperature Processing

The temperature time series measured by the AZFP is contained in the files exported by AzfpLink software in the A/D (counts) ASL CSV Format. The .csv files are titled as follows:

SerialNumber_C1_FREKHZ_YYMMDD_dig.csv

For example, *55018_C1_200KHZ_20130501_dig.csv* contains 200 kHz data from instrument 5018 on May 1, 2013.

Note that the .csv files needed to calculate temperature are separate from the .sv.csv files that are used by Echoview.

The MATLAB code **AWCP_csvExp_avgTemp_v3.m** was run to extract temperature information from the .csv files and calculate the daily average temperature.

3.2. Processing of data from vessel-mounted echosounder systems

3.2.1. Level 0 Data Products

Level 0 data products were the binary (.raw) files recorded by the EK60, ES60, or EK80 Simrad Scientific Echosounder software. The Level 0 data were available from NCEI via their water column sonar data archive:

https://www.ngdc.noaa.gov/maps/water_column_sonar/index.html

3.2.2. Level 1 Data Products: Importing binary files directly into Echoview

The Level 1 Data Products for the vessel-mounted echosounder system were Echoview (.ev) files that reference the Level 0 (.raw) files and incorporate system environmental and calibration information.

This document assumes that the user will be using software provided by the echosounder manufacturer or Echoview (software from Myriax) to process the data. The order of the following

steps may vary depending on software used, but are provided as a general guide. Processing guides were written by Cornell University (<http://www.acousticsunpacked.org/SuggestedSOP.html>) and Dr. Kevin Boswell (http://www.gulfspillrestoration.noaa.gov/sites/default/files/wp-content/uploads/2013_03_28_WATER_Biological-Acoustics-Processing-Plan-LA-signature1_Redacted-v3.pdf). ADEON_Data Processing_Specification.V0.1.DRAFT.docx was utilized as a resource for this processing guide.

This document assumes that you have successfully transferred the data files from the instrument recording the echosounder data to the computer that will be used to analyze the data. It also assumes that you have backed up your raw data files before beginning any processing.

3.2.2.1. *Environmental parameters*

Temperature and salinity profiles of the water column can be used to calculate sound speed profiles and other important acoustic parameters such as absorption coefficients. Hydrographic sampling should be done to properly characterize the study environment. In some situations, mean profiles may be used throughout a survey, but in regions where hydrography is more variable, then these parameters may need to be varied within the data processing software.

3.2.2.2. *System and calibration settings*

Usually the system settings of the program used to record the echosounder data are included as metadata within the raw data files and will be transferred automatically into the data processing software. However, any calibrations that were conducted during the survey will provide data that must be entered into the data processing software so that calibrated survey data can be output. See individual echosounder manufacturer instructions for specifics on how to do this.

3.2.2.3. *Transducer geometry settings*

The physical locations (depth, relative distances) of the transducers should be entered into the software as this information is necessary to properly synchronize and georeference insonified regions.

3.2.2.4. *Time settings*

Ensure that if different recording devices were used for different instruments, the time offsets are entered so that data can be synchronized for analysis.

3.2.3. Level 2 Data Products: Processing Echoview files

The Level 2 Data Products from the vessel-mounted echosounders were exported grids (.csv) of integrated and gridded (typically 100 m horizontal, 5 m vertical) single frequency NASC backscatter data. The steps to generate these Level 2 data products are detailed in this section.

3.2.3.1. *Construct a Surface Exclusion Line*

Near-surface backscatter data were excluded from analysis for a variety of reasons including: being within the nearfield of the echosounder/transducer, being contaminated by bubble sweepdown or flow along the hull of the vessel, or being contaminated by bubbles injected into the water column by waves or other vessels. It is rare to have a constant depth surface exclusion line throughout a survey due to dynamic weather conditions, however if a single value was used, it must be deep enough that contaminated data were not included at any point in the survey.

3.2.3.2. *Detect the bottom and construct a bottom exclusion line*

Some software programs can automatically detect the seafloor, although it is unlikely that these automatic detectors will work perfectly. Therefore any bottom-detection automatically done should be visually scrutinized for errors and corrected. In many cases, an offset of 1-10 m was used relative to the seafloor to eliminate the chance of data contamination due to the bottom dead zone or sidelobe reflections off of nearby bathymetry changes. This problem was more prevalent in areas of dynamic bathymetry such as canyons or the shelf break. In some situations (i.e. very deep water), bottom detections were far below the region of interest so this may not be necessary and a constant-depth exclusion line can be used.

3.2.3.3. *Removal of bad data regions*

There are many sources of noise or contamination in acoustic survey data. These regions should be identified, categorized (as to the source if known), and either removed or marked such that they can be excluded from further analysis processes. Common sources of noise or contamination include: false bottoms (due to incorrect ping interval settings or changes in bathymetry), engine noise, or environmental noise.

3.2.3.4. *Remove ambient noise*

Using data collected with the echosounder in passive mode during typical survey conditions, the ambient or background noise of the system can be subtracted from the data during analysis. Users should be careful with the selection and implementation of this, especially when conditions during the survey are variable (i.e. differing engine speeds throughout the survey, changes in equipment mid-survey, etc). A more detailed discussion of this method can be found in De Robertis and Higginbottom (2007).

3.2.3.5. *Remove self-noise*

Noise spikes or non-constant noise also need to be removed or marked as such before further processing is done. A common source of this noise is cross-talk from other acoustic systems (e.g. ADCP, depth-sounders) on the vessel or elsewhere. Visual inspection of the echograms is often necessary to find these regions. However, there are several techniques that can be used to identify and remove these noise sources, such as implementing a median 3 or 5 ping filter, looking for rapid increases and decreases in backscatter values from ping-to-ping that are short in duration and strong in amplitude (e.g. > 10 dB).

3.2.3.6. *Set a Sv or TS threshold*

In many cases, the data of interest are where biological scatterers are most abundant. Therefore, it can be useful to establish a threshold Sv (or less commonly target strength (TS)) where only data exceeding those values is included in later analysis. Data compared between different surveys or regions should use the same thresholding.

3.2.3.7. *Set the size of the analysis cell*

Acoustic survey data are often binned both vertically and horizontally to avoid creating exceptionally large data files and to examine broad-scale processes. Smaller bin sizes allow for the study of smaller spatial or temporal processes, but at the expense of file size and analysis time. It is common for analysis cells to include echoes from 10-50 targets in most cells, although this is not true in all cases. It should be noted that the selection of horizontal bin size may include different numbers of echoes in analysis cells if ship speed is not constant. Horizontal bins are often 100, 200, 500, or 1000 m in distance, but again this depends on the survey scale. Vertical bins are usually smaller than horizontal bins with 1 m, 10 m, and 100 m bins used. It is possible (although complicated) to use different bin sizes in a single survey, but this should only be done under special circumstances where care is taken to ensure that artifacts of bin size do not contaminate later analysis.

3.2.3.8. *[Optional] Identification of specific scatterers (species or other groups)*

If multiple frequency acoustic data, a priori information about community composition, or other information is available, it is possible to apportion the acoustic backscatter data to specific organisms or groups of organisms. This process is challenging (or impossible) in many environments, but in regions where only a few species are present or the species present have different scattering characteristics, it can provide great insights into the ecosystem. Users who have not done this type of analysis before should consult the literature or experts for guidance in this process as it is very easy for this process to go awry.

3.2.3.9. *Export integrated backscatter and TS data*

Single-beam echosounders only produce Sv data so there is no TS data to analyze, whereas split-beam systems provide both Sv and TS information. Make sure that bad data or noise regions are excluded from the integration and not included as 0 (zero) values, as that can cause erroneous results.

Note: All of the above steps need to be done for each acoustic frequency that is used in the survey. Some steps (calibration, calculation of absorption coefficient) must be done independently for each frequency, while others (analysis cell size) should be consistent (if possible) across all frequencies.

3.2.3.10. *Examine data outputs*

It can be useful to examine the output products at this point and examine any outlier values. It is quite common for visual inspection to miss some contamination (either bottom regions above the bottom exclusion line or small but strong noise spikes) so re-examining the echograms to confirm that very strong regions of integrated backscatter correspond to aggregations of scatterers and not noise is necessary.

3.2.3.11. *Analyze the data*

Data analysis depends on the questions being asked. In this project, we examined the spatial variability in backscatter within and among the different study regions. So mean integrated backscatter values were used to compare and contrast the different habitats.

3.2.3.12. *Estimate uncertainty*

This step is rarely done in many surveys, but having some idea of the uncertainty (or possible error) in the echosounder data analysis is very useful. Uncertainty estimates can be done based on noise levels, environmental variability, diel or seasonal changes, or many other processes. At a minimum, a list of potential sources of uncertainty in the survey or analysis can be made.

3.2.3.13. *Cross-calibration with remotely deployed echosounder systems*

An additional export of the vessel-mounted system was done with analysis cell sizes selected to best match the data from the bottom-located, remotely-deployed AZFP systems. Comparisons were made between the two different systems with data collected in the same geographic region (e.g. within 1 km of the bottom-deployed system) and at the same time (e.g. within 1 day). For this comparison, vessel-mounted acoustic data were binned temporally (e.g. 1 min or 1 h bins) and vertically to match the analysis cells from the bottom-deployed systems.

4. Conductivity, Temperature, Dissolved Oxygen (CT-DO) Loggers

The SBE-37 CT-DO loggers store their Level 0 data as '.hex' files. These were converted to Level 1 data using SBE Data Processing's Data Conversion module (Version 7.26.7.114) and the manufacturer's calibration values. The Data Conversion module outputs and units are:

1. Time, Elapsed [hours]
2. Dissolved Oxygen [mL/L] from the SBE 63 optical dissolved oxygen sensor
3. Conductivity [S/m]
4. Temperature [ITS-90, deg C]
5. Practical salinity [-]; derived from the temperature and conductivity using TEOS-10 equations.

The Data Conversion module outputs results as a '.cnv' ASCII text file that was opened with Microsoft Excel and converted a '.csv' format for delivery to users.

5. VEMCO VR2-W Fish Tag Loggers

The VEMCO VR2-W fish tag loggers provide Level 0 data as '.vri' data. These files were converted to human-readable Level 0 tag Detection Records in '.csv' using Fathom Software (Version 2.4.0-20190610-bb13aa). The '.csv' files were further edited to removed empty columns and convert the time records to yyyy-mm-dd hh:mm:ss format.

The Detection Records log the times that VEMCO 69 kHz fish tags were detected. Further information is needed from the researchers who inserted the tags to identify the species, sex, and tagging location. Ocean Tracking Network maintains a database of publicly available information on tagged fish.

6. ADEON Satellite Data Set Processing

Satellite and modeled ocean datasets collected for the ADEON project study area (Table 8) were obtained from public websites, and covered a variety of spatial and temporal scales. All global data were processed to Level 3 or 4. The global data were gridded from 1 to 25 km² resolution, ranging from daily to weekly time scales. There was also a near real-time Level 2 data stream originating from NASA at higher spatial resolution (1 km²) over the ADEON area for Chlorophyll *a* and SST. Real-Time Ocean Forecasting Systems (RTOFS) model data for the Atlantic Ocean were also being streamed and collected daily. Details of each dataset, naming convention, and file structure are given in the following sections.

Table 8. Global gridded satellite/model product characteristics for ADEON

Parameter	Source	Sensor/Model	Spatial Resolution (pixel size)	Temporal Range
Sea Surface Temperature	NASA JPL	GHRSSST	1 km ²	Daily
Chlorophyll <i>a</i>	NASA Goddard	VIIRS	4.6 km ²	8-day mean
Net Primary Productivity	Oregon State University	VGPM	12.5 km ²	8-day mean
Photosynthetically Available Radiation	NASA Goddard	VIIRS	4.6 km ²	8-day mean
Precipitation	NASA Goddard	GPM		Daily
Mixed Layer Depth	Oregon State University	HYCOM	12.5 km ²	8-day mean
Surface Wind Speed & Stress	IFREMER (France)	ASCAT	0.25°	Daily
Surface Currents	JPL	OSCAR	0.25°	5-Day
Sea Surface Altimetry FSLE	AVISO	Finite Size Lyapunov Exponent	4 km ²	Daily

6.1. Global gridded data sets

Global ocean data (Table 9) are in a gridded, mapped format at Level 3 or Level 4. Level 3 data are derived geophysical variables from Level 2 that have been aggregated/projected onto a defined spatial grid over a defined time period. Level 2 data consist of derived geophysical variables at the same resolution as the source Level 1 data (unprocessed satellite data). Level 4 data are model outputs or results from analyses of lower level data (e.g., variables derived from multiple measurements). Ocean net primary productivity is an example of a Level 4 product.

Table 9. Satellite product names and units for ADEON

Parameter	Processing level	Description	Units	Notes
CHL	Level 3 (NASA) ⁵	Chlorophyll a concentration	mg /m ³	
PAR	Level 3 (NASA)	Photosynthetically available radiation	mol /(m ² d)	NASA use the unit einstein/(m ² d) for this quantity. One einstein is defined loosely as the energy in a mole of photons, but ultimately PAR is the number of moles of photons per square metre of Earth's surface per day – hence our choice of unit. A PAR of 1 mol/(m ² d) corresponds to a light energy flux spectral density of approximately 1 mW/(cm ² μm) (Kirk, 1994; Frouin et al., 2003)
WSPD	Level 3 (IFREMER) ⁶	Wind speed	m/s	
PRECIP	Level 3 (NASA)	Daily precipitation	Mm	
SST	Level 4 (NASA) ⁷	Sea surface temperature	°C	
NPP	Level 4 (NASA)	Net primary productivity (C) ⁸	mg / (m ² d)	
MLD	Level 4	Mixed layer depth	m	HYCOM model (Oregon State University)
CURRENTS	Level 4 (NASA)	u,v surface currents vectors	m/s	See Sec. 6.1.7
FSLE	Level 4 (IFREMER) ⁹	Finite-size Lyapunov exponents	degrees, 1/d	See Sec. 6.1.5

6.1.1. NASA JPL Sea Surface Temperature

ADEON used a high resolution, global blended SST product obtained from the Jet Propulsion Laboratory (JPL). The global product is from the Group for High Resolution Sea Surface Temperature (GHRSSST) Level 4 sea surface temperature analysis produced as a retrospective dataset (four day latency) and near-real-time dataset (one day latency) at the JPL Physical Oceanography DAAC using wavelets as basis functions in an optimal interpolation approach on a global 0.01 degree grid. The version 4 Multiscale Ultrahigh Resolution (MUR) L4 analysis was based upon nighttime GHRSSST L2P skin and subskin SST observations from several instruments including the NASA Advanced Microwave Scanning Radiometer-EOS (AMSR-E), the JAXA Advanced Microwave Scanning Radiometer 2 on GCOM-W1, the Moderate

⁵ Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.

⁶ Level 3 data are presented in relation to identical and standardized space-time reference scales. The data can thereby be easily compared and aggregated, including between different measurement programmes

⁷ Model output or results from analyses of lower-level data (e.g., variables derived from multiple measurements).

⁸ carbon

⁹ This level consists of interpolated data, resulting from data analysis. (FSLE is referred to as a “Level 4+” product by AVISO).

Resolution Imaging Spectroradiometers (MODIS) on the NASA Aqua and Terra platforms, the US Navy microwave WindSat radiometer, the Advanced Very High Resolution Radiometer (AVHRR) on several NOAA satellites, and in situ SST observations from the NOAA iQuam project.

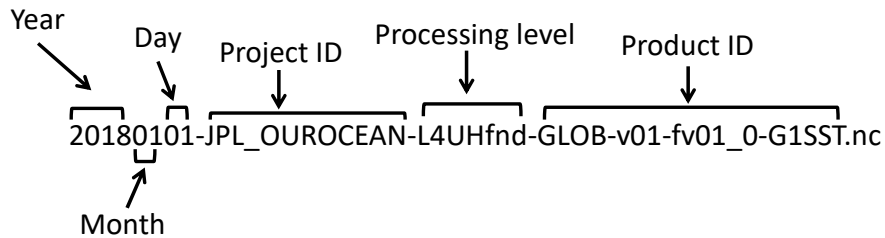


Figure 15. Filename convention for the JPL global 1 km SST product produced by the GHRSSST project.

The filename convention is shown in Figure 15. All files are in netCDF format. Each file comprises a single day and contains a set of variables related to sea surface temperature gridded at 1km resolution, and contains the SST field along with a mask array for ice/land/ocean/lake designation, and an estimated error (standard deviation) for each grid cell or pixel. Latitude and longitude fields are included in each file.

NASA Ocean Level-3 Standard Mapped Image (SMI) Products

The NASA SMI products were generated from binned (spatially or temporally aggregated) data products and represent data binned over the period covered by the parent product. These products include CHL and PAR for ADEON. The arithmetic mean was used in each case to obtain the values for the SMI grid points from the binned data products.

Each SMI product contains one image of a geophysical parameter and is stored in one physical file. The Level 3 files for CHL and PAR are in netCDF format, and utilize a variety of international standards and conventions for metadata and file structure.

The NASA Level 3 filenames contain the date period (i.e., temporal resolution), product type: CHL or PAR, and spatial resolution. The ADEON project used the 8-day averaged fields at 4.6 km² pixel resolution for CHL and PAR. The NASA-NOAA Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (SNPP) satellite was the source sensor for both CHL and PAR.

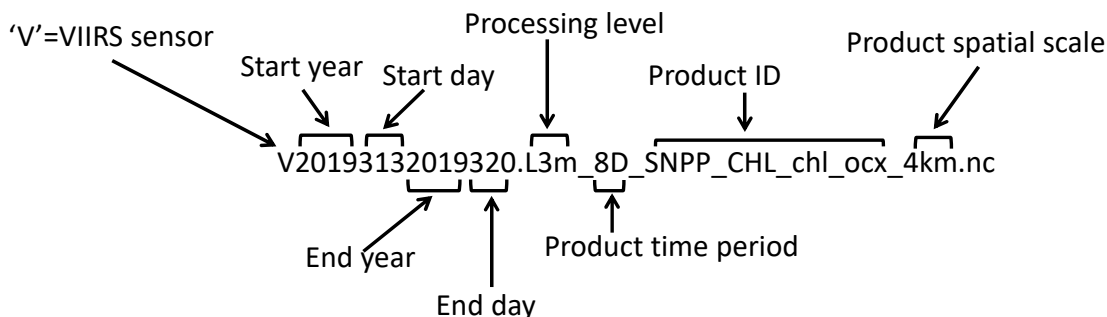


Figure 16. Filename convention for NASA 8-day chlorophyll product from SNPP- GHRSSST project.

The file name description for CHL is shown in Figure 16, and is similar for PAR. Inside the netCDF files, the data object, 'l3m_data', in each SMI product represented a mean at each grid point of the parameter specified by the global attribute Parameter. This object is a two-dimensional array of an Equidistant Cylindrical (also known as Plate Carrée) projection of the globe at approximately 4.6 x 4.6 km². Latitude and longitude fields are included in each file. More detailed information on the Level 3 Standard Mapped Image data product format specifications can be found in the NASA Ocean Level 3 SMI Data Products document (https://oceancolor.gsfc.nasa.gov/docs/format/Ocean_Level-3_SMI_Products.pdf).

6.1.2. Net Primary Productivity

Net primary productivity (NPP) is a Level 4 product, derived from other Level 3 and Level 4 data. The NPP product chosen for the ADEON project was the Vertically Generalized Production Model (VGPM) by Behrenfeld and Falkowski (1997), and is a commonly used algorithm for estimating oceanic NPP. The VGPM algorithm used chlorophyll concentration (CHL) and other parameters as input fields governed by the general equation:

$$\text{NPP} = \text{CHL} * \text{Pb_opt} * \text{Day Length}$$

where *Day Length* is the number of hours of day light and *Pb_opt* is the maximum daily NPP found within a given water column. The latter is a rate term that represents the chlorophyll-specific assimilation efficiency for carbon fixation. The NPP quantity is *water column integrated productivity* per unit of ocean area, and the unit is milligrams of carbon fixed per day per unit volume. *Note*: NPP is a rate term and differs fundamentally from CHL (which is the standing stock of biomass). A more detailed description of the VGPM and model code can be found here: <http://www.science.oregonstate.edu/ocean.productivity/vgpm.model.php>.

These files are in an Equidistant Cylindrical projection and HDF format. The filename contains the time stamp of the data set:

vgpm.yyyyddd.hdf

vgpm = NPP model rate of flux (C) (units of mg / (m² d))
 yyyy = year

ddd= yearday (day of year from 001-358) of the start of each 8-day file
hdf = file type

The NPP data object inside the HDF file is accessed as 'vgpm'. Latitude and longitude fields are not included as data objects with the NPP HDF files, but can be calculated for any grid point using the dimensions of the grid with the latitude/longitude boundary configuration (i.e., the coordinates of the northwest corner).

To calculate a latitude and longitude grid for the NPP (and HYCOM MLD) products:

For 2160 x 4320 data, the grid spacing is 1/12 of a degree in both latitude and longitude.

- 2160 rows * 1/12 degree per row = 180 degrees of latitude (+90 to -90).
- 4320 columns * 1/12 degree per column = 360 degrees of longitude (-180 to +180). The northwest corner of the start of the gridded products is at +90 Lat, -180 Lon.

To obtain the location of the center of any pixel:

- Take the number of rows and columns you are away from the NW corner,
- Multiply by the grid spacing to get the change in latitude and longitude,
- Subtract the change in latitude from +90 lat,
- Add the change in longitude to -180 lon;
- Shift the latitude down (subtract) by 1/2 of a grid spacing
- And shift the longitude over (add) by 1/2 of a grid spacing.

The original VGPM paper by Behrenfeld and Falkowski (1997) as well as the [Ocean Productivity site](#) should be referenced for the data.

6.1.3. Mixed Layer Depth

The mixed layer depth (MLD) product for ADEON was derived from the HYbrid Coordinate Ocean Model (HYCOM). Simplified and renamed versions of the original data files (available at <https://hycom.org/>) were obtained from ftp servers at OSU, served alongside with their NPP products. The OSU versions were averaged to 8-day time intervals at 4.6 km² resolution and based on 0.125 density contrast.

These files are in an Equidistant Cylindrical projection and HDF format. The filename contains the time stamp of the data set:

mld.yyyyddd.hdf

mld = mixed layer depth (units of m)
yyyy = year
ddd= yearday (day of year from 001-358) of the start of each 8 day file
hdf = file type

The MLD data object inside the HDF file is accessed as 'mld'. Latitude and longitude fields are not included as data objects with the MLD HDF files, and are determined in the same manner as the NPP data in the previous section.

6.1.4. Precipitation Data

Daily precipitation data were obtained from NASA as a level-3 product from the Global Precipitation Measurement (GPM) mission. ADEON used products from the Integrated Multi-satellite Retrievals for GPM (IMERG) product, which is the unified U.S. algorithm that provides the multi-satellite precipitation product. This dataset is the GPM Level 3 IMERG *Final* Daily 10 x 10 km (GPM_3IMERGDF) derived from the half-hourly GPM_3IMERGHH. The derived result represents the final estimate of the Daily accumulated precipitation. The dataset were produced at the NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC) by simply summing the valid precipitation retrievals for the day in GPM_3IMERGHH and giving the result in (mm).

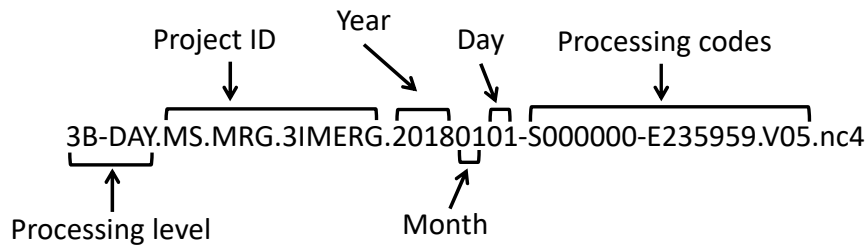


Figure 17. Filename convention for daily global GPM precipitation data from NASA.

Files are in netCDF format, with each file corresponding to one day's precipitation totals (in units of mm). The grid size is $0.1^\circ \times 0.1^\circ$ (roughly 10 km x 10 km) and covers the full globe. There are several products within each file, including precipitation, error and count fields. For general use, it is recommended the 'precipitationCal' data be used. Latitude and longitude fields are included in each file. Filename convention is shown in Figure 17.

6.1.5. Altimetry Data

Altimetry 'value-added' products – the Finite-Size Lyapunov Exponents or FSLE - were obtained from the AVISO web portal. These products provided the exponential rate of separation of particle trajectories initialized nearby and advected by altimetry velocities. FSLEs highlighted the transport barriers that controlled the horizontal exchange of water in and out of eddy cores, multimission altimetry-derived gridded backward-in-time Finite Size Lyapunov Exponents, and Orientations of associated eigenvectors. These products have been computed in collaboration between CLS, LOcean, CTOH and Cnes.

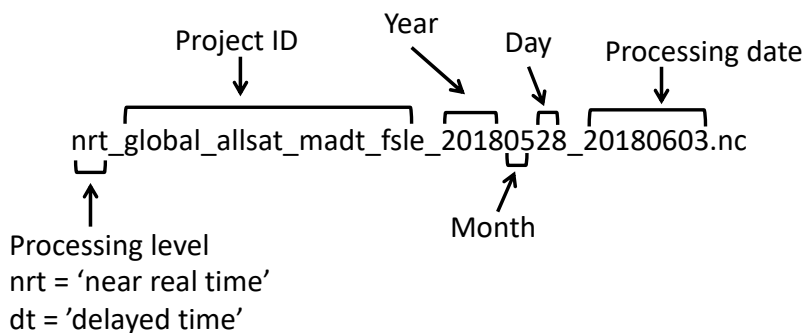


Figure 18. Filename convention for daily global FSLE altimetry data from AVISO.

As a snapshot, each map represents the sea state for a given day. One spatial resolution is available: $1/25^\circ \times 1/25^\circ$ on a cartesian grid. Each file is a gridded product, provided in delayed time and routine production of 20-day latency. ADEON is receiving both streams. File formats are netCDF, and contain 2 FSLE parameters – 'fse_max' (unit 1/day) and 'theta_max' (unit in degrees), as well as latitude and longitude information. Filename convention is shown in Figure 18.

6.1.6. Wind Speed and Stress

The Advanced SCATterometer (ASCAT) is a real aperture sensor onboard the meteorological operational (MetOp) platforms and maintained by the European Space Agency (ESA). The prime objective of ASCAT is to measure wind speed and direction over the oceans. It is a real aperture radar (one with a physical array of sensors), operating at 5.255 GHz (C-band) and using vertically polarized antennas. With the rapid global coverage, day or night and all-weather operation, ASCAT offered a unique tool for long-term climate studies.

New gridded daily-averaged wind and wind stress fields (DASCAT) have been estimated over global oceans from ASCAT retrievals using objective methods. The analyses used standard products ASCAT L2b during the period April 2007 - March 2009, and ASCAT L2b 12.5 from April 2009 to present (http://www.osisaf.org/biblio/docs/ss3_pm_ascat_1_8.pdf). The requested atmospheric and oceanic variables such as sea surface temperature, air temperature, and specific air humidity were derived from ECMWF 6-hourly analysis. According to the ASCAT sampling scheme, the objective method allowing the determination of regular in-space and surface wind fields used ASCAT observations as well as ECMWF analyses. The latter were considered as the temporal interpolation basis of ASCAT retrievals. The resulting fields have spatial resolutions of 0.25° in longitude and latitude. The calculation of daily estimates used ascending as well as descending available and valid retrievals. The objective method aimed to provide daily-averaged gridded wind speed, a zonal component, a meridional component, wind stress, and the corresponding components at global scale. The error associated with each parameter, related to the sampling impact and wind space and time variability, was provided too.

Daily ASCAT wind analysis data files are available in standard netCDF format.
Daily ASCAT wind data are available in separate daily files. They are named as follows:

YYYYMMDD00_YYYYMMDD00_daily-ifremer-L3-MWF-GLO-yyyydddmmhmn-01.0.nc

where YYYY, MM, DD indicate year, month, and day respectively of daily analysis.
yyyymmddhmmss indicates production date.

The main variables of each netCDF file are listed in Table 10. They are provided with attributes and units.

Table 10 Data file variables for daily ASCAT Wind netCDF files from IFREMER
These data were obtained from the Centre de Recherche et d'Exploitation Satellitaire (CERSAT), at IFREMER, Plouzané (France).

Parameter	Description	Units
Time	Daily analysis date (since January 1, 1990)	h
Latitude	Grid point latitude	°
Longitude	Grid point longitude	°
Wind speed	10 m reference height wind speed in neutral condition (24 hour average)	m/s
Zonal wind component	Eastward wind component	m/s
Meridional wind component	Northward wind component	m/s
Wind Stress	Amplitude of wind stress	Pa
Zonal wind stress component	Surface downward eastward wind stress	Pa
Meridional stress wind component	Surface downward northward wind stress	Pa
Wind speed error	Standard deviation of wind speed error derived from the objective method	m/s
Zonal wind error	Standard deviation of zonal wind error derived from the objective method	m/s
Meridional wind error	Standard deviation of meridional wind error derived from the objective method	m/s

6.1.7. Surface Currents

ADEON utilized upper ocean surface current products from the Ocean Surface Current Analysis Real-time (OSCAR) project at JPL. OSCAR contains near-surface ocean current estimates, derived using quasi-linear and steady flow momentum equations. The horizontal velocity was directly estimated from sea surface height, surface vector wind and sea surface temperature. These data were collected from the various satellites and in situ instruments. The model formulation combines geostrophic, Ekman, and Stommel shear dynamics, and a complementary term from the surface buoyancy gradient. Data are on a 1/3 degree grid with a 5 day resolution.

The data files are in netCDF format, with one file per year. Each file contains the entire year of global data products at 5-day time step intervals. These include the average zonal ('u') and meridional ('v') surface currents and associated maximum values during each 5-day interval.

6.1.8. Local Real-time NASA satellite data

High-resolution satellite Level 2 imagery for the ADEON region is now available for CHL and SST products. Both products were derived from processing data from Level 1 to Level 2 using

climatological ancillary datasets, thus the Level 2 products were not refined. Level 2 data were processed by NASA from the NASA-NOAA NPP VIIRS platform and NASA's MODIS-Aqua platform. Both datasets had an approximate 1 km-pixel resolution mapped to a region that spanned the U.S. East Coast and covered the entire ADEON region (Figure 17). Image files were automatically uploaded daily from NASA ftp sites to ADEON data servers whenever there was 30 % or more satellite coverage of the defined region. This can result in multiple files per day per product, depending on the swath coverage and satellite view.

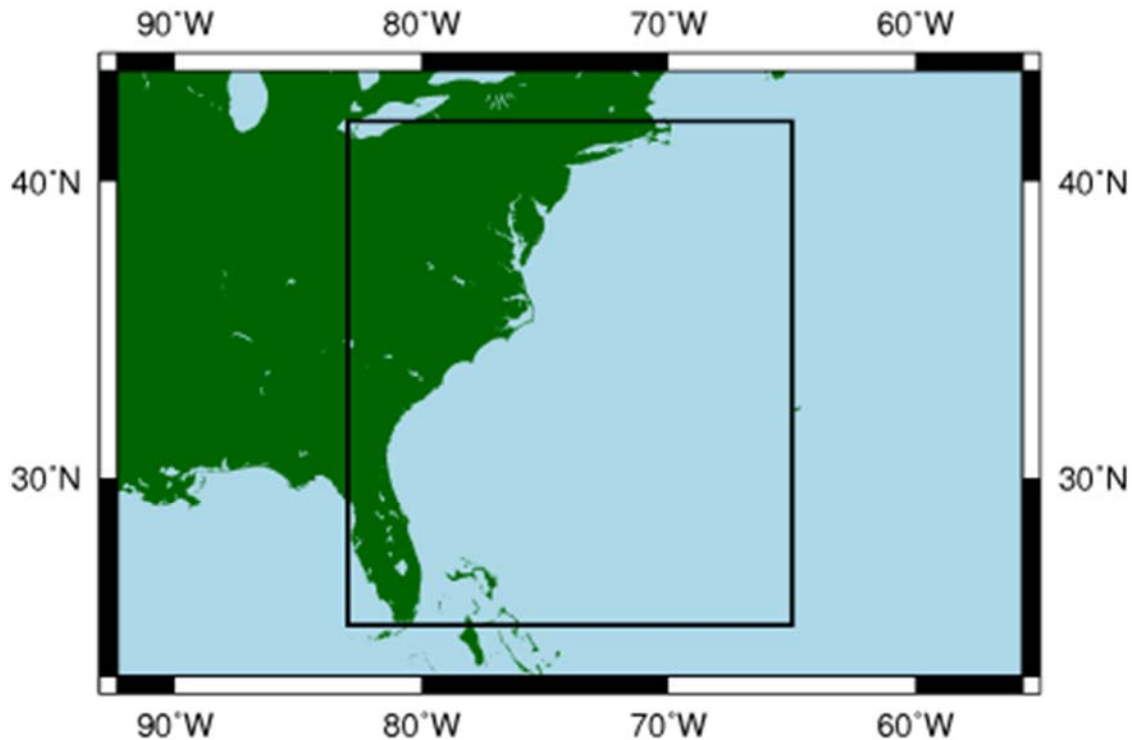


Figure 17. Defined region (black lines) for acquiring real-time NASA CHL and SST data

The real-time Level 2 files are in netCDF format, and follow a common filename convention with the satellite source and time stamp in the filename:

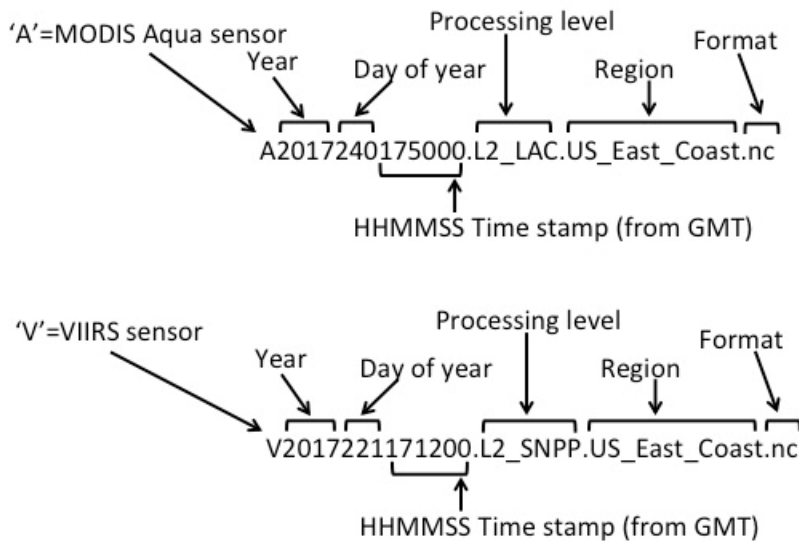


Figure 20. Filename convention for daily NASA real-time daily Level 2 data.

Each Level 2 file contains a number of data objects, including SST, CHL, Level 2 flags and spectral remote sensing reflectance. The CHL product can be accessed as a netCDF data object in both source files as 'chlor_a', and SST as 'sst'. Due to current sensor degradation, we favored the CHL data from the VIIRS sensor, while SST was valid from either. Navigation data were accessible as data objects in both file sources as 'lat' and 'lon'. Filename convention is shown in Figure 20.

6.1.9. RTOFS data

Modeled ocean data (RTOFS) from NOAA for the Atlantic Ocean were received daily. The RTOFS is a series of ocean forecast systems based on HYCOM. Part of the development of this system was done under a multi-national HYCOM Consortium funded by NOPP. HYCOM is the result of collaborative efforts among the University of Miami, the Naval Research Laboratory (NRL), and the Los Alamos National Laboratory (LANL), as part of the multi-institutional HYCOM Consortium for Data-Assimilative Ocean Modeling funded by the National Ocean Partnership Program (NOPP) to develop and evaluate a data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate ocean model.

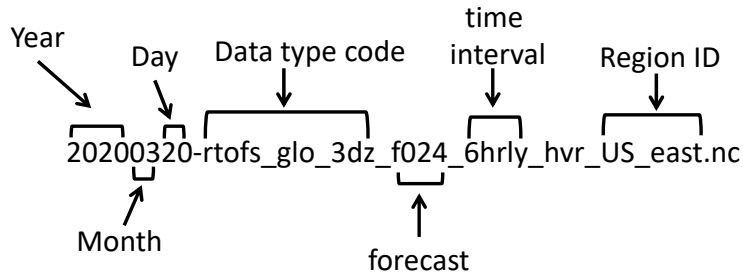


Figure 21. Filename convention for daily RTOFS real-time 6-hourly data.

Each file is a 6-hour snapshot of the state of temperature, salinity and current velocity fields at 40 depths in 3-dimensional arrays as data objects). File format is netCDF. Depth, Latitude and longitude are included fields. Filename convention is shown in Figure 21. The grid box corner coordinates are (NW) 80N, 105W and (SE) 0N, 40W.

6.2. File Formats and navigations for ADEON satellite data sets

Table 11. Products and data objects for Level 3 and 4 global files

Product	File format	Data Object	Lat/lon data object	Northwest corner coordinate (lat, lon)	Pixel Resolution	Grid Dimension
SST	netCDF4	'sst4'	'lat', 'lon'	+90, -180	1 km ²	18000x36000
CHL	netCDF4	'chlor_a'	'lat', 'lon'	+90, -180	4.6 km ²	4320x8640
PAR	netCDF	'par'	'lat', 'lon'	+90, -180	4.6 km ²	4320x8640
NPP	HDF	'npp'	Equidistant	+90, -180	12.5 km ²	2160x4320
MLD	HDF	'mld'	Equidistant	+90, -180	12.5 km ²	2160x4320
GPM Precipitation	netCDF	'precipitation Cal'	'lat', 'lon'	+90, -180	10 km ²	1800x3600
Wind speed, Wind stress	netCDF	'wind_speed', 'wind_stress'	'latitude', 'longitude'	80, -180	0.25 degree (~25 km ²)	1440x640
Eularian Surface Currents	netCDF	'u', 'v'	'lat', 'lon'	80, -180	0.33 degree (~33 km ²)	481x1201
FLSE components	netCDF	'fsle_max', 'theta_max'	'lat', 'lon'	90, 0	4 km ²	4500x9000

6.3. Additional resources

<https://oceancolor.gsfc.nasa.gov/docs/format/l2nc/>

https://oceancolor.gsfc.nasa.gov/docs/format/Ocean_Level-3_SMI_Products.pdf

<https://www.science.oregonstate.edu/ocean.productivity/>

<ftp://ftp.ifremer.fr/ifremer/cersat/products/gridded/MWF/L3/ASCAT/Daily/Doc/DailyAscatWind-Doc.pdf>

<http://www.globcurrent.org/>

<https://hycom.org/hycom/overview>

https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/FSLE_handbook.pdf

https://podaac.jpl.nasa.gov/dataset/OSCAR_L4_OC_third-deg

<https://www.aviso.altimetry.fr/en/data/products/value-added-products/fsle-finite-size-lyapunov-exponents/fsle-description.html>

https://polar.ncep.noaa.gov/ofs/about_aofs.shtml?

Acronyms

AAF	anti-alias filter
AC	alternating current
ACI	acoustic complexity index
ADC	analog to digital converter
ADCP	Acoustic Doppler current profiler
ADEON	Atlantic Deepwater Ecosystem Observatory Network
AM	arithmetic means
AMAPPS	Atlantic Marine Assessment Program for Protected Species
AMAR	autonomous multichannel acoustic recorder
AOS	Applied Ocean Sciences, LLC
ASCAT	Advanced SCATterometer
AVISO	Archiving, Validation and Interpretation of Satellite Oceanographic data
AZFP	Acoustic Zooplankton Fish Profiler
BOEM	Bureau of Ocean Energy Management
BTR	Bearing time record
CBF	Conventional beamformer
CERSAT	Centre de Recherche et d'Exploitation Satellitaire
CF	CompactFlash
CHL	Chlorophyll <i>a</i>
CMRR	common mode rejection ratio
CPA	closest point of approach
CSAC	chip-scale atomic clock
CSV	comma-separated values
CTD	conductivity, temperature, depth
DASCAT	Daily ASCAT
DPS	Data Processing Specification
DR	dynamic range
DV	digital values
ECMWF	European Centre for Medium-range Weather Forecasts
EEZ	exclusive economic zone
ENOB	effective number of bits
ESA	Endangered Species Act
ESA	European Space Agency
EU	European Union
FFT	fast Fourier transform

FFTW	Fastest Fourier Transform in the West
FIR	Finite Impulse Response
FLSE	Finite-Size Lyapunov Exponents
FS	full scale
FTP	file transfer protocol
GHRSSST	Group for High Resolution Sea Surface Temperature
GPM	global precipitation measurement
HARP	High-frequency Acoustic Recording Package
HDF	hierarchal data format
HLA	horizontal line array
HYCOM	HYbrid Coordinate Ocean Model
IEEE	Institute of Electrical and Electronics Engineers
IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer
ISO	International Organization for Standardization
JASCO	Joseph A. Scrimger Co.
JPL	Jet Propulsion Laboratory
LSB	least significant bit
MATLAB	matrix laboratory
MLD	mixed layer depth
MMPA	Marine Mammal Protection Act
MODIS	Moderate Resolution Imaging Spectroradiometer
MSFD	Marine Strategy Framework Directive
NASA	National Aeronautics and Space Administration
NBDC	National Data Buoy Center
netCDF	Network Common Data Form
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPP	Net primary productivity
NRS	Noise Recording Station
OASIS	Ocean Acoustics Services and Instrumentation Systems
OCS	Outer Continental Shelf
ONR	Office of Naval Research
OSC	ocean surface currents
OSU	Oregon State University
PAR	photosynthetically available radiation (or photosynthetically active radiation)
PC	personal computer
PSD	power spectral density

PSRR	power supply rejection ratio
pH	potential hydrogen
RF	radio frequency
rms	root mean square
RTOFS	Real-Time Ocean Forecast System
S-AIS	satellite-based Automatic Identification System
SAR	synthetic-aperture radar
SD	secure digital
SEL	sound exposure level
SFA	Sustainable Fisheries Act
SFDR	spurious free dynamic range
SiNAD	signal to noise and distortion
SMI	standard mapped image
SNR	signal to noise ratio
SPL	sound pressure level
SST	sea surface temperature
TCXO	temperature controlled crystal oscillator
TDOA	time delay of arrival
THD	total harmonic distortion
TNO	The Netherlands Organisation for Applied Scientific Research
TS	target strength
UDP	unit data packet
UNH	University of New Hampshire
USCG	United States Coast Guard
VGPM	Vertically Generated Production Model
VIIRS	Visible Infrared Imaging Radiometer Suite
VMS	vessel monitoring system
WAV	waveform audio file
WSPD	wind speed
xsd	extendible schema definition

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Appendix A. Data Analysis and Output File Formats

A.1. DeploymentInfo.csv

The purpose of any Deployment Info File (`deploymentInfo.csv`) is to record metadata about acoustic and non-acoustic data acquired during instrument deployment. This well-defined, structured metadata can then be used by display, processing, and analysis software.

The Deployment Info File contains the following information about acoustic data, which is often not captured in WAV files (or similar):

- Identification of the recording instrument(s)
- When the instrument deployment occurred
- Where the deployment occurred
- The type and identity of instruments used to capture the data
- The type(s) of hydrophone/sensor and its sensitivity/frequency response

When you display/process WAV files with the *PAMlab* application, *PAMlab* looks for a Deployment Info File within the directory and parent directories of the WAV files. If it can't find a file, then it uses default deployment metadata or warns the user and exits, depending on the runtime parameter settings.

A.1.1. Format and Example

The Deployment Info File consists of lines of comma-separated values; it is a `.csv` file. A `.csv` file is a simple text file that you can open and edit with a text editor, with Microsoft Excel, or similar spreadsheet applications.

CAUTION Be careful that Excel doesn't remove leading zeroes from entries, say from serial numbers or folder names. A simple solution is to use Excel or similar programs only for viewing and use a text editor for creation and modification.

The Deployment Info File has three (3) types of lines:

- Comment lines—start with a `#` character and a comma
- Header lines—a specific type of comment line, so they also start with a `#` character and a comma
- Data entry lines—start with a specific keyword:
 - Deployment Summary Line—starts with the keyword `deployment`
 - Frequency Points Line—starts with the keyword `frequencyPoints`
 - Recorder Lines—start with the keyword `recorder`

Other than comment lines, **do not use spaces** in the deployment file; instead use dashes, periods, or colons as per the instructions below. Use commas only to separate fields.

A sample Deployment Info File is shown in Figures A1 and A2, viewed in Microsoft Notepad and Excel, respectively.

```

1 #,"""This file contains recorder deployment information. Each row contains a set of data concer
2 #,clientId,region,period
3 deployment,jasco,earth,2016-10
4 #,The frequency points that has the calibration value
5 frequencyPoints,1.600000,3.200000,6.400000,12.800000,25.600000,51.200000,100.000000,200.000000,
6 #,recorderId,recorderMake,recorderVersion,stationId,hydrophoneId,hydrophoneMake,sampleRate,chan
7 recorder,AMAR421.1.64000.M36-V35-100,AMAR,G3-4.3,stn4,B002490,M36-V35-100,64000,1,24,AMAR421.1.
8 recorder,AMAR421.9.375000.M36-V35-100,AMAR,G3-4.3,stn4,B002490,M36-V35-100,375000,1,16,AMAR421.
9 recorder,AMAR424.1.64000.M36-V35-100,AMAR,G3-4.3,stn6,B002481,M36-V35-100,64000,1,24,AMAR424.1.
10 recorder,AMAR424.9.375000.M36-V35-100,AMAR,G3-4.3,stn6,B002481,M36-V35-100,375000,1,16,AMAR424.
11

```

Figure A1. A sample Deployment Info File from the fictitious 2016-10 deployment (described in Section A.1.2), viewed in Notepad++ without word wrap

A	B	C	D	E	F	G	H	I	J	
#	"This file contains recorder deployment information. Each row contains a set of data concerning the deployment, frequencies, or the recorders. The first field in each row is the deployment name, followed by the client name, region, and period. The next field is the frequency points, followed by the recorder ID, recorder make, recorder version, station ID, hydrophone ID, hydrophone make, sample rate, channels, bits per sample, and file structure."									
#	clientId	region	period							
deployment	jasco	earth	Oct-16							
#	The frequency points that has the calibration value									
frequencyPoints	1.6	3.2	6.4	12.8	25.6	51.2	100	200	300	
#	recorderId	recorderMake	recorderVersion	stationId	hydrophoneId	hydrophoneMake	sampleRate	channels	bitsPerSample	fileStructure
recorder	AMAR421.1.64000.M36-V35-100	AMAR	G3-4.3	stn4	B002490	M36-V35-100	64000	1	24	AMAR421.1.
recorder	AMAR421.9.375000.M36-V35-100	AMAR	G3-4.3	stn4	B002490	M36-V35-100	375000	1	16	AMAR421.9.
recorder	AMAR424.1.64000.M36-V35-100	AMAR	G3-4.3	stn6	B002481	M36-V35-100	64000	1	24	AMAR424.1.
recorder	AMAR424.9.375000.M36-V35-100	AMAR	G3-4.3	stn6	B002481	M36-V35-100	375000	1	16	AMAR424.9.

Figure A2. A sample Deployment Info File from the fictitious 2016-10 deployment (described in Section A.1.2), viewed in Excel

A.1.2. Data file locations and folder structures

All acoustic and non-acoustic data files are arranged within a master deployment folder. This deployment folder contains a folder for each station, and each station folder has a folder for each recorder-channel-sample rate combination.

Each recorder-channel-sample rate folder (simply referred to as the *recorder folder* from now on) contains the WAV files.

The Deployment Info File should reside within the master deployment folder and it should contain one Recorder Line for each recorder folder of acoustic data. The names of the station folder and recorder folder are entered in the *stationId* and *recorderId* fields within the Recorder Line.

Figure A3 shows example folder structures for the following two deployments:

1. 2016-10 deployment: Recorder AMAR421 was deployed, configured to record on one 24-bit channel (Channel 1), and the 16-bit high sample rate channel (Channel 9).
2. 2016-10 deployment: Recorders AMAR421 and AMAR424 were deployed at stations stn4 and stn6, respectively. Each recorder was configured to record on two (2) acoustic channels (Channels 1 and 9).

NOTE The two 2016-10 recorders happened to be deployed at different stations, but you can have more than one recorder per station.

The format for folder names, and thus the `stationId` and `recorderId` fields, is as follows:

- Station folder name/`stationId`—a string naming the deployment station. No spaces allowed, but hyphens and periods are acceptable (e.g., `stn1`, `rocky-point`, `cooks.mount`).
- Recorder folder name/`recorderId`—`<recorder-id>.<cc>.<rate>.<sensor>`, a string that identifies the recorder, where:
 - `Recorder-id` is a string that identifies the recorder. Typically the recorder serial number.
 - `cc` is the channel number. A one or multi-character number.
 - `rate` is the sample rate in Hertz. A multi-character number.
 - `sensor` is the sensor type/model. A multi-character string.

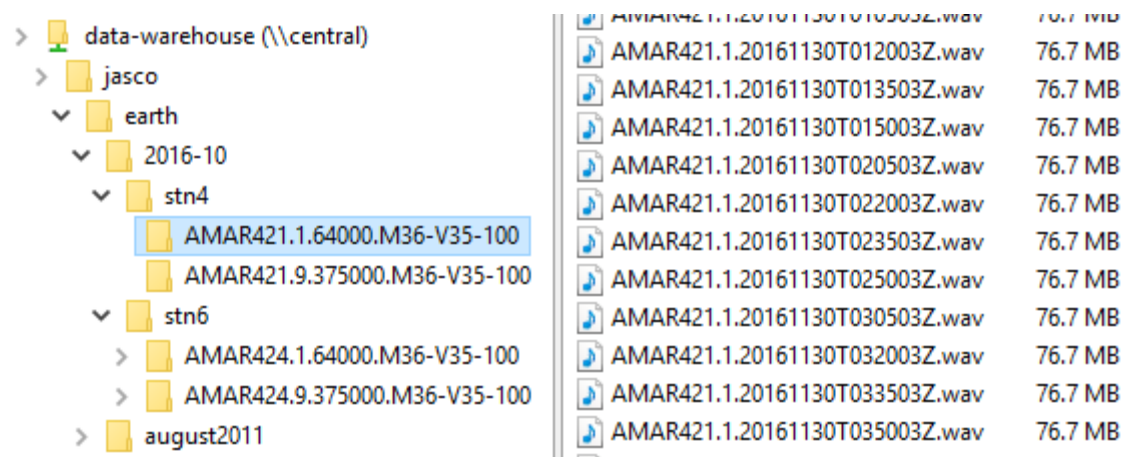


Figure A3. Data folder structures for two example deployments – 2016-10 and august2011

A.1.3. Comment lines

Comment lines consist of free-form text that follows the `#` character and comma. Comments serve two purposes: (1) they provide additional detail about the other lines in the file, and (2) they apply descriptive headers to the file when it is viewed in a spreadsheet. The processing software ignores all comment lines. You can put as many comment lines as you need in the file, and in any place you require them.

The `#` character will populate the first column of the spreadsheet, and the rest of the comment line will populate subsequent columns. If your comment text contains commas and you want the whole line to appear in one column (rather than split at each comma), place three (3) double quotation marks (`"""`) at the start and end of the comment text (as shown for Line 1 below). The quotes tell Excel to ignore the commas within the comment. For example:

```
#, """"This is some comment text. It's enclosed within three (3) sets of
double quotes so that Excel ignores any commas that are within the
comment text.""""
```

A.1.4. Header and data entry lines

Header lines are comment lines that contain a series of comma-separated *labels*. The *labels* correspond to the fields of the data entry lines below. The labels are separated by commas in the same order as their associated fields in the line(s) below. The labels become column headers when the CSV file is opened in a spreadsheet application like Excel. For example, the Deployment Summary Line and its header look like this:

```
#,clientId,location,period
deployment,Shell,nileRiver,2012-summer
```

A.1.5. Calculating ADC voltage conversion factor

Figure A4 shows the sampling of an acoustic signal.

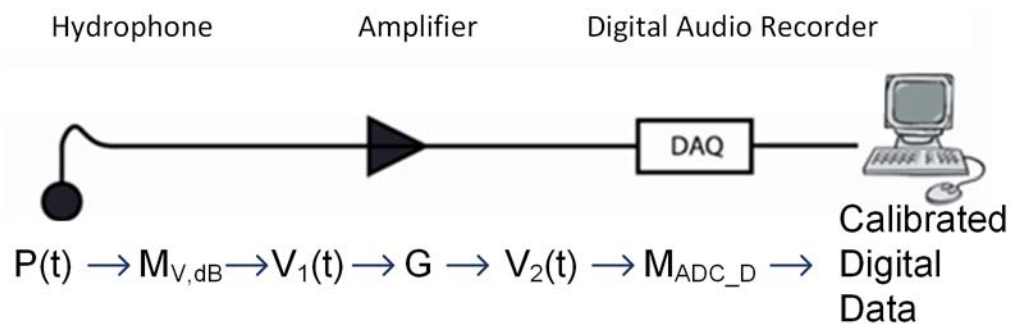


Figure A4. Signal data acquisition

The WAV file recordings consist of integer samples of n bits. To determine the sensing device's voltage output when the sample was taken, you must know the ADC voltage conversion factor, which depends on:

- The full-scale voltage of the ADC (v_{\max}) measured in volts (V)
- The number of bits in a sample (n)
- The AAF voltage gain ($G_{AAF,V}$)
- The pre-amplifier voltage gain ($G_{pA,V}$)

The ADC voltage conversion factor (reciprocal of ADC sensitivity) is calculated as follows:

$$\mu_V = \frac{v_{\max}/2^n}{G_{pA,V} G_{AAF,V}}$$

where:

- v_{\max} —Depends on the recorder make and model, e.g., the AMAR-G3R4 has an FS of 5 V on the 24-bit channels.
- n —Depends on the input channel, which is selected by the user when they configure the recorder, e.g., the AMAR High Resolution channels have a 24-bit resolution ($n = 24$) and the High Speed channel has a 16-bit resolution ($n = 16$).

- G —Depends on the configuration; the user sets the analog gain when they configure the recorder.

A.1.6. Determining hydrophone sensitivity

The effect of hydrophone sensitivity is shown in Figure A4. The sensor converts a real-world signal (an underwater acoustic signal in the case of a hydrophone) into a voltage signal. Hydrophone sensitivity can be determined two ways:

1. Obtain the sensitivity from the manufacturer's documentation for that make and model, or
2. Measure the sensitivity using a calibrated sound source like a pistonphone.

From the sensitivity and the frequency (f_s) at which it was measured, you can create the hydrophone's sensitivity curve from the nominal curve for that make and model.

1. Calculate the difference (Δ) between the measured sensitivity at f_s and the hydrophone's nominal sensitivity at f_s from the nominal curve.
2. Apply Δ to each of the frequency points of the nominal curve to create the sensitivity curve specific to the hydrophone for that deployment.

A.1.7. The Deployment Info File, line by line

A.1.7.1. Line 1: Comment describing the file

Line 1 is a comment that describes the contents of the file itself. This line should usually read:

```
#, ""This file contains recorder deployment information. Each row
contains a set of metadata concerning the deployment, frequencies, or
the recorders. The first field in each row is the keyword to the rest
of the line. If the keyword is a '#', the line is a comment. Each set
of rows is provided with a header comment row to indicate the purpose
of each field in the row. The fields in each row are position-
dependent.""
```

A.1.7.2. Line 2: Header for the Deployment Summary Line

Line 2 contains the labels of the fields in the Deployment Summary Line. This line should always read:

```
#,clientId,location,period
```

A.1.7.3. Line 3: Deployment Summary Line

The deployment summary line gives information about who made the deployment, and where and when it happened. The line has four (4) comma-separated text fields, the first one being the deployment keyword; order is important (example below). Table A1 instructs on how to fill in these fields.

```
deployment,companyX,nileRiver,2012-summer
```


Table A1. Fields of the deployment summary line

Field	Label	Format	Explanation	Example
1	–	Deployment	Enter exactly as shown	
2	clientId	String, no spaces	The client or purpose of the deployment.	company <i>or</i> bigBirdUniversity
3	Location	String, no spaces	Where the deployment occurred.	nileRiver <i>or</i> myBathtub
4	Period	String, no spaces (recommend yyyy-dd)	When the deployment occurred/started	2012-06 <i>or</i> 2012-summer

A.1.7.4. Line 4: Header for the Frequency Points Line

Line 4 signals that the next line contains all of the frequency points for which there are sensor calibration data. This line usually reads:

```
#,The frequency points that have calibration values
```

The actual calibration/sensitivity data for each of these points is at the end of each Recorder Line.

A.1.7.5. Line 5: Frequency Points Line

The Frequency Points Line lists the frequencies for which sensitivity values are provided in each Recorder Line. It starts with the `frequencyPoints` keyword followed by the list of frequencies for which there are calibrated sensitivities defined. The frequencies are float values in hertz (Hz). There must be exactly the same number of entries at the end of each recorder line to represent the calibrated sensitivity values at these frequency points.

This example Frequency Points Line shows 35 frequencies starting at 1.6 Hz and ending at 32000 Hz:

```
frequencyPoints,1.6,3.2,6.4,12.8,25.6,51.2,100,200,300,400,500,600,700,
800,900,1000,1200,1300,1400,1500,2000,2500,3000,3500,4000,4500,5000,550
0,6000,6500,7000,7500,8000,16000,32000
```

A.1.7.6. Line 6: Header for the Recorder Line(s)

Line 6 contains the 24 labels of the fields in the Recorder Line(s). This line should always read:

```
#,recorderId,recorderMake,recorderVersion,stationId,hydrophoneId,hydroph
oneMake,sampleRate,channels,bitsPerSample,fileStructure,startDate,star
tTime,driveNo,latitude,longitude,meters,dropDate,dropTime,recoveryDate,
recoveryTime,vPerBit,sensitivity,sensitivityFrequencyPoint,Calibrations
for Frequency Points
```

A.1.7.7. Lines 7+: Recorder Line(s)

The Recorder Lines contain the metadata of the recorded acoustic data. Create one (1) Recorder Line for each recorder-channel-sample rate combination; see Section A.1.2. The values entered in the fields of a Recorder Line(s) have a critical impact on the results of the acoustic display, processing, and analysis applications.

There are 24 comma-separated fields in a Recorder Line, the first of which is the recorder keyword; order is important. Table A2 lists each field's label and instructs on how to fill in these fields.

The last, 24th, field of the line, labelled **Calibrations for Frequency Points**, consists of comma-separated hydrophone sensitivities. The sensitivities are float values in dB re 1V/ μ Pa. These sensitivities correspond, in order, to the frequencies listed in the Frequency Points Line.

Table A2. Fields of the recorder line(s)

Field	Label	Format	Unit	Explanation	Example
1	–	Recorder	–	Type as shown	recorder
2	recorderId	String, id.ch.rate.sensor	–	The recorder-channel-sample rate	AMAR421.1.6400 0.M36-V35-100
3	recorderMake	String, no spaces	–	The recorder make and model	AMAR <i>or</i> AMAR-G3R3
4	recorderVersion	String: <i>major.minor</i>	–	The recorder firmware version	1.4
5	stationId	String, no spaces	–	The recorder station. StationId and recorderId combine to create a unique “key” for each recorder line.	stn1 <i>or</i> B35 <i>or</i> cape-horn
6	hydrophoneId	String, no spaces	–	Hydrophone/sensor serial number	00195
7	hydrophoneMake	String, no spaces	–	Hydrophone/sensor make and model	M8E
8	sampleRate	Float	Hz	The sample rate	16000
9	Channels	Integer	–	The number of channels in a WAV file (typically 1)	1
10	bitsPerSample	Integer	–	The number of bits per sample	16 <i>or</i> 24
11	fileStructure	String, no spaces	–	A deployment wav file name <i>[optional]</i>	<i>blank or</i> example.wav
12	startDate	dd-mmm-yy	–	When the recording began	21-Jul-11
13	startTime	hh:mm:ss	–	When the recording began	13:20:00
14	driveNo	0	–	DEPRECATED/RESERVED	0
15	latitude	d.ddddd	°	Latitude of the deployed recorder	44.6589
16	longitude	d.ddddd	°	Longitude of the deployed recorder	-63.6339
17	Meters	Integer	M	Depth of the deployed recorder	33
18	dropDate	dd-mmm-yy	–	Date the recorder was deployed	22-Jul-11
19	dropTime	hh:mm:ss	–	Time the recorder was deployed	05:20:30
20	endDate	dd-mmm-yy	–	Date the recorder was retrieved	03-Sep-11
21	endTime	hh:mm:ss	–	Time the recorder was retrieved	17:05:50
22	vPerBit	Float	V	The ADC voltage conversion factor of the recorder (see Sec. 1.1.1.1.A.1.5)	0.00000485 <i>or</i> 7.63E-05

Field	Label	Format	Unit	Explanation	Example
23	sensitivity	Float	dB	The logarithmic sensitivity at one specific frequency of the hydrophone. Based on a pistonphone calibration or the manufacturer's documentation $10 \lg \left(\frac{M_{hr,V}}{1 \mu\text{Pa}} \right)^2 \text{ dB}$	-164.041
24	sensitivityFrequency	Integer	Hz	The frequency at which the calculated or manufacturer's sensitivity applies	250
25	Calibrations for Frequency Points	comma-separated floats	dB	The calculated logarithmic hydrophone sensitivities at the frequencies listed in the Frequency Points Line (see Sec. 1.1.1.1.1.A.1.6) $10 \lg \left(\frac{M_{hr,V}}{1 \mu\text{Pa}} \right)^2 \text{ dB}$	-164.1, -164.2,...

A.2. .xml File Format: Extendible Schema Definition File

The .xml files output by PAMlab are described using an extendible schema definition file (.xsd). The .xsd defines the data types generated by PAMlab and is used both for creating the output files and reading them as formatted data structures. The contents of this file are:

```
<?xml version="1.0" encoding="UTF-8"?>
<schema xmlns="http://www.w3.org/2001/XMLSchema"
xmlns:tns="http://www.example.org/obhProcessingOutput/"
targetNamespace="http://www.example.org/obhProcessingOutput/"
xmlns:Q1="http://www.example.org/whaleVocalization/">
  <import schemaLocation="contourAnalysisXML.xsd"
namespace="http://www.example.org/whaleVocalization/" />
  <element name="obhOutput" type="tns:obhProcessingOutput" />

  <complexType name="obhProcessingOutput">
    <sequence>
      <element type="string" minOccurs="0" maxOccurs="1" name="comment" />
      <element name="filename" type="string" maxOccurs="1" minOccurs="1" />
      <element name="auralID" type="string" maxOccurs="1"
minOccurs="1" />
      <element name="fileStartTime" type="string" maxOccurs="1"
minOccurs="1" />
      <element name="temperature" type="double" maxOccurs="1"
minOccurs="0" />
      <element name="spectrogramRealSamples" type="int" maxOccurs="1"
minOccurs="0" />
      <element name="spectrogramFFTSIZE" type="int" maxOccurs="1"
minOccurs="0" />
      <element name="spectrogramAdvance" type="int" maxOccurs="1"
minOccurs="0" />
      <element name="auralLatitude" type="double" maxOccurs="1"
minOccurs="1" />
    </sequence>
  </complexType>
</schema>
```

```

        <annotation>
            <documentation>decimal degrees, negative for
south</documentation>
        </annotation>
    </element>
    <element name="auralLongitude" type="double" maxOccurs="1" minOccurs="1">
        <annotation>
            <documentation>decimal degrees, - for West</documentation>
        </annotation>
    </element>

    <element name="calibration" type="tns:CalibrationInfoType" maxOccurs="1"
minOccurs="0"/> <!-- minOccurs is 0 so we can read in older files -->

    <element name="shipping" type="tns:ShippingDetectionType" maxOccurs="1"
minOccurs="0"/>
    <element name="seismic" type="tns:SeismicDetectionType"
maxOccurs="1" minOccurs="0"/>
    <element name="ambient" type="tns:AmbientType"
maxOccurs="unbounded" minOccurs="0"/>
    <element name="mammals" type="tns:mammalsType" maxOccurs="1"
minOccurs="0"/>
    <element name="mammalEvents" type="tns:mammalEventsType" maxOccurs="1"
minOccurs="0"/>
    <element name="spectrogram" type="tns:spectrogramType"
maxOccurs="unbounded" minOccurs="0"/>
    <element name="seismicParams" type="tns:SeismicParameters" maxOccurs="1"
minOccurs="0"/>
    <element name="broadband" type="tns:BroadBandType"
maxOccurs="unbounded" minOccurs="0"/>
    <element name="timeSeriesInfo" type="tns:timeSeriesPropertiesType"
maxOccurs="unbounded" minOccurs="0"/>
    <element name="impulseEvents" type="tns:impulseEventsType" maxOccurs="1"
minOccurs="0"/>
    <element name="ACI" type="tns:ACITypeDefinition"
maxOccurs="unbounded" minOccurs="0"/>
    <element name="ThirdOctaveHistograms"
type="tns:ThirdOctaveHistogramsTypeDefinition" maxOccurs="1" minOccurs="0"/>
</sequence>
</complexType>

<complexType name="ShippingDetectionType">
    <sequence>
        <element name="parameters" type="tns:ShippingProcessingParametersType"/>
        <element name="shipDet" type="tns:shippingDetection" maxOccurs="unbounded"
minOccurs="0"/>
    </sequence>
</complexType>

<complexType name="shippingDetection">
    <sequence>
        <element name="time" type="double" maxOccurs="1" minOccurs="1">
            <annotation>
                <documentation>seconds since epoch</documentation>
            </annotation>
        </element>
        <element name="duration" type="double" maxOccurs="1" minOccurs="0"/>
        <element name="freq" type="tns:FrequencyType" maxOccurs="unbounded"
minOccurs="1"/>
        <element name="id" type="string" maxOccurs="1" minOccurs="0"/>
    </sequence>
</complexType>

```

```

<complexType name="FrequencyType">
  <sequence>
    <element name="harm" type="string" maxOccurs="unbounded" minOccurs="0"/>
    <element name="BBSPL" type="double" maxOccurs="1" minOccurs="0"/>
  </sequence>
  <attribute name="freq" type="double"/>
  <attribute name="SNR" type="double"/>
</complexType>

<complexType name="SeismicDetectionType">
  <sequence>
    <element name="fileWithProbableOrHigherDetection" type="int"
maxOccurs="1" minOccurs="0"/>
    <element name="time" type="double" maxOccurs="1" minOccurs="0"/>
    <element name="seismicSequences" type="tns:seismicSequence"
maxOccurs="unbounded" minOccurs="0"/>
    <element name="NewElement" type="tns:SeismicParameters" maxOccurs="1"
minOccurs="0"/>
  </sequence>
</complexType>

<complexType name="SeismicDetection">
  <sequence>
    <element name="time" type="double" maxOccurs="1" minOccurs="1">
      <annotation>
        <documentation>seconds since epoch</documentation>
      </annotation>
    </element>
    <element name="SPL" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="SEL" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="pk" type="double" maxOccurs="1" minOccurs="0"/>
    <element name="pkpk" type="double" maxOccurs="1" minOccurs="0"/>
    <element name="start" type="double" maxOccurs="1" minOccurs="0"/>
    <element name="end" type="double" maxOccurs="1" minOccurs="0"/>
    <element name="fileTime" type="double" maxOccurs="1" minOccurs="0"/>
    <element name="thirdOctaves" type="tns:BroadBandType"
maxOccurs="unbounded" minOccurs="0"/>
  </sequence>
</complexType>

<complexType name="AmbientType">
  <sequence>
    <element name="time" type="double" maxOccurs="1" minOccurs="1">
      <annotation>
        <documentation>epoch time of start of file</documentation>
      </annotation>
    </element>
    <element name="comment" type="string" maxOccurs="1" minOccurs="0"/>
    <element name="fileNoiseTime" type="double" maxOccurs="1" minOccurs="1">
      <annotation>
        <documentation>amount of time in the file that was used to calculate
ambient noise</documentation>
      </annotation>
    </element>
    <element name="v" type="tns:sv" maxOccurs="unbounded" minOccurs="0"/>
  </sequence>
</complexType>

<complexType name="ShippingProcessingParametersType">
  <sequence>
    <element name="threshold" type="double"/>
    <element name="FFTlength" type="int"/>
    <element name="FFTOverlap" type="int"/>
  </sequence>
</complexType>

```

```

        <element name="normalizerWidth" type="int"/>
        <element name="normalizerNotch" type="int"/>
        <element name="detectorM" type="int"/>
        <element name="detectorN" type="int"/>
        <element name="FFTAverages" type="int"/>
    </sequence>
</complexType>

<complexType name="sv">
    <annotation><documentation>Spectral Value type</documentation></annotation>
    <attribute name="f" type="double"><annotation><documentation>frequency of data
point</documentation></annotation></attribute>
    <attribute name="spl" type="double"><annotation><documentation>absolute SPL of
data point, uPa / root(Hz)</documentation></annotation></attribute>
</complexType>

<complexType name="mammalsType">
    <sequence>
        <element name="detection" type="tns:mammalDetectionType"
maxOccurs="unbounded" minOccurs="0"/>
    </sequence>
</complexType>

<complexType name="MammalClassType">
    <annotation>
        <documentation>Only complete elements that have values >
1%</documentation>
    </annotation>
    <sequence>
        <element name="probGray" type="double"/>
        <element name="probBowhead" type="double"/>
        <element name="probBeluga" type="double"/>
        <element name="probWalrus" type="double"/>
        <element name="probHumpback" type="double"/>
        <element name="probFin" type="double"/>
        <element name="probFish" type="double"/>
        <element name="probSeal" type="double"/>
        <element name="probUnknown" type="double"/>
    </sequence>
</complexType>

<complexType name="mammalDetectionType">
    <sequence>
        <element name="species" type="string" maxOccurs="1" minOccurs="1"/>
        <element name="numberOfPossibleCallsDetected" type="int" maxOccurs="1"
minOccurs="1"/>
        <element name="totalDurationOfCalls" type="double" maxOccurs="1"
minOccurs="1"/>
        <element name="totalProbabilityOfCalls" type="double" maxOccurs="1"
minOccurs="1"/>
        <element name="probabilityPerCall" type="double" maxOccurs="1"
minOccurs="1"/>
        <element name="callDescription" type="Q1:VocalizationDefinition"
maxOccurs="1" minOccurs="1"/>
        <element name="time" type="double" maxOccurs="1" minOccurs="0"/>
        <element name="fileWithProbableOrHigherDetection" type="int" maxOccurs="1"
minOccurs="0"/>
    </sequence>
</complexType>

<complexType name="mammalEventsType">
    <sequence>

```

```

        <element name="mamEv" type="tns:mamEv" maxOccurs="unbounded"
minOccurs="0" />
    </sequence>
</complexType>

<complexType name="localizationType">
    <sequence>
        <element name="ambiguousBearing" type="double" maxOccurs="unbounded"
minOccurs="1" />
    </sequence>
</complexType>

<complexType name="mamEv">
    <sequence>
        <element name="spc" type="string" maxOccurs="1" minOccurs="1" />
        <element name="rep" type="string" maxOccurs="1" minOccurs="0" />
        <element name="dur" type="double" maxOccurs="1" minOccurs="1" />
        <element name="prob" type="double" maxOccurs="1" minOccurs="0" />
        <element name="time" type="double" maxOccurs="1" minOccurs="1" />
        <element name="sel" type="double" maxOccurs="1" minOccurs="0" />
        <element name="spl" type="double" maxOccurs="1" minOccurs="0" />
        <element name="fmin" type="double" maxOccurs="1" minOccurs="0" />
        <element name="bw" type="double" maxOccurs="1" minOccurs="0" />
        <element name="localizations" type="tns:localizationType"
maxOccurs="unbounded" minOccurs="0" />
    </sequence>
</complexType>

<complexType name="spectrogramType">
    <sequence>
        <element name="SpectrogramLine" type="tns:SpectrogramLineType"
maxOccurs="unbounded" minOccurs="0" />
        <element name="broadband" type="tns:BroadBandType" maxOccurs="unbounded"
minOccurs="0" />
    </sequence>
    <attribute name="baseFreq" type="double" />
    <attribute name="freqSpace" type="double" />
    <attribute name="NFreqs" type="int" />
    <attribute name="ambientFFTDuration" type="double" />
</complexType>

<complexType name="SpectrogramLineType">
    <sequence>
        <element name="broadband" type="tns:BroadBandType" maxOccurs="unbounded"
minOccurs="0" />
    </sequence>
    <attribute name="time" type="double" />
    <attribute name="values" type="string" />
    <attribute name="bbStartFreq" type="double" />
    <attribute name="bbEndFreq" type="double" />
    <attribute name="bbSPL" type="double" />
</complexType>

<complexType name="seismicSequence">
    <sequence>
        <element name="repRate" type="double" />
        <element name="avgSPL" type="double" />
        <element name="avgSEL" type="double" />
        <element name="numberPulses" type="int" />
        <element name="seismicDet" type="tns:SeismicDetection"
maxOccurs="unbounded" minOccurs="0" />
    </sequence>

```

```

</complexType>

<complexType name="SeismicParameters">
  <sequence>
    <element name="detectionWindow" type="double" maxOccurs="1"
minOccurs="1"/>
    <element name="minSpacing" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="maxSpacing" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="timeTol" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="contourThreshold" type="double" maxOccurs="1"
minOccurs="1"/>
    <element name="minNumPeaks" type="double" maxOccurs="1" minOccurs="1"/>
  </sequence>
</complexType>

<complexType name="BroadBandType">
  <sequence>
    <element name="time" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="averagingDuration" type="double"
minOccurs="1"/>
    <element name="Fnominal" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="Flo" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="Fhi" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="SPL" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="SPLAtFnominal" type="double" maxOccurs="1" minOccurs="0"/>
    <element name="name" type="string" maxOccurs="1" minOccurs="0"/>
    <element name="bearing" type="double" maxOccurs="1" minOccurs="0"/>
  </sequence>
</complexType>

<complexType name="timeSeriesPropertiesType">
  <sequence>
    <element name="label" type="string" maxOccurs="1" minOccurs="0"/>
    <element name="time" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="avgDuration" type="double" maxOccurs="1"
minOccurs="1"/>
    <element name="pk" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="pkpk" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="rms" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="mean" type="double" maxOccurs="1" minOccurs="0"/>
    <element name="ANSIFastTimeRMS" type="string" maxOccurs="1"
minOccurs="0"/>
    <element name="IECFastTimeRMS" type="string" maxOccurs="1"
minOccurs="0"/>
    <element name="OneSecRMS" type="string" maxOccurs="1" minOccurs="0"/>
    <element name="SEL" type="double" maxOccurs="1" minOccurs="0"/>
  </sequence>
</complexType>

<complexType name="impulseEventsType">
  <sequence>
    <element name="impulseEv" type="tns:impulseEvType" maxOccurs="unbounded"
minOccurs="0"/>
  </sequence>

  <attribute name="maxSlidingWindowDuration" type="double"/>
</complexType>

<complexType name="impulseEvType">
  <sequence>
    <element name="time" type="double" maxOccurs="1" minOccurs="1"/>
    <element name="duration" type="double" maxOccurs="1" minOccurs="1"/>
  </sequence>

```



```

        <element name="maxSlidingWindowStats"
type="tns:WindowStatsTypeDefinition" minOccurs="0" maxOccurs="1"/>
    </sequence>
</complexType>

<complexType name="WindowStatsTypeDefinition">
    <attribute name="PeakSPL" type="double"/>
    <attribute name="RMS SPL" type="double"/>
    <attribute name="thirdOctaveSEs" type="string"/>
</complexType>

<complexType name="CalibrationFactorType">
    <attribute name="Hz" type="double"/>
    <attribute name="dB" type="double"/>
</complexType>

<complexType name="CalibrationInfoType">
    <sequence>
        <element name="Sensitivity" type="tns:CalibrationFactorType"
maxOccurs="1" minOccurs="1"/>
        <element name="CalibrationFactor" type="tns:CalibrationFactorType"
maxOccurs="unbounded" minOccurs="0"/>
    </sequence>
    <attribute name="ADCToV" type="double"/>
</complexType>

<complexType name="ACITypeDefinition">
    <sequence>
        <element name="ACIPeriod" type="tns:ACIPeriodTypeDefinition"
maxOccurs="unbounded" minOccurs="0"/>
    </sequence>

    <attribute name="LowFreq" type="double"/>
    <attribute name="HighFreq" type="double"/>
    <attribute name="BinPeriod" type="double"/>
    <attribute name="IntegrationPeriod" type="double"/>
    <attribute name="TotalACI" type="double"/>
</complexType>

<complexType name="ACIPeriodTypeDefinition">
    <attribute name="time" type="double"/>
    <attribute name="ACI" type="double"/>
</complexType>

<complexType name="ThirdOctaveHistogramsTypeDefinition">
    <sequence>
        <element name="ThirdOctaveHistogram"
type="tns:ThirdOctaveHistogramTypeDefinition" maxOccurs="unbounded" minOccurs="0"/>
    </sequence>

    <attribute name="LowerBound" type="double"/>
    <attribute name="UpperBound" type="double"/>
    <attribute name="CellCount" type="int"/>
</complexType>

<complexType name="ThirdOctaveHistogramTypeDefinition">
    <attribute name="NominalCenterFreq" type="double"/>
    <attribute name="Cells" type="string"/>
    <attribute name="NumBelowLowerBound" type="int"/>
    <attribute name="NumAboveUpperBound" type="int"/>
</complexType>

```

Appendix B. Exporting of AZFP Data in Echoview

After the surface line and bad data regions have been created for all frequencies in a deployment, exporting and classifying the data are performed. All of the data should be exported before classification begins. Data are exported in four packages for further interpretation and application. Each package is defined by its bin depth and time window averaging.

Table B1. Bin depths and time averages of exported data

	Depth Averaging	Time Averaging
Full Depth	200-500 m	24 h
Daily Partition	5 m	24 h
60 min Partition	5 m	60 min
60 min Full Depth	200-500 m	60 min

Step 1 is to create averaging grids within the echogram for each export package. This must be done for all frequencies in each .EV file.

Right click on the echogram, and select “Variable Properties”

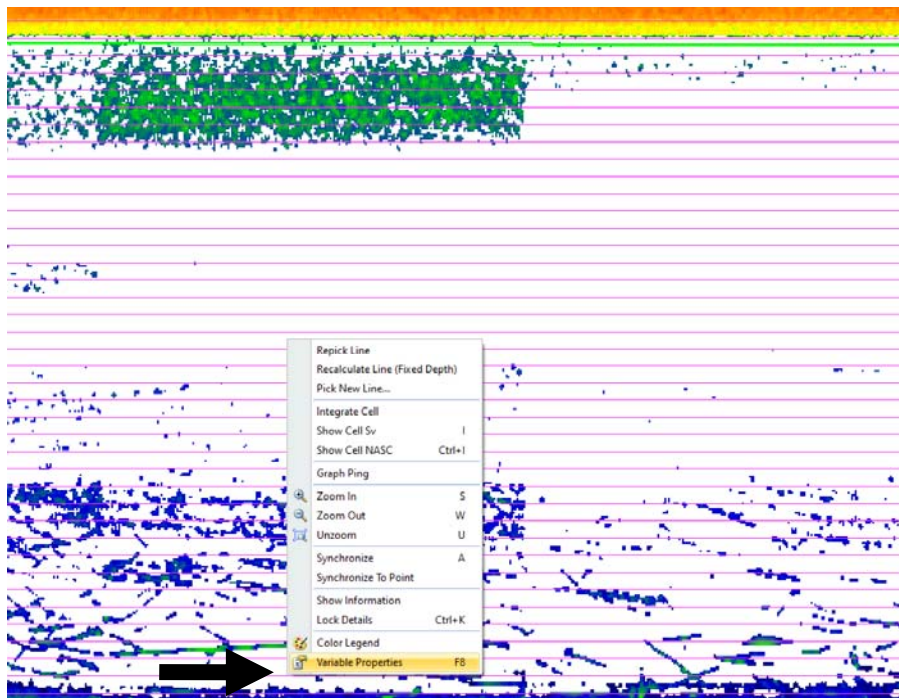


Figure B1. “Variable Properties” option within the echogram

From the left column of options, select “Grid”

The screenshot shows the 'Grid' dialog box in the Echoview software. The dialog is titled 'Grid' and has a subtitle 'Display and analysis grid'. It contains several settings:

- 'Show time/distance grid:' with a dropdown menu set to 'Time' (indicated by a black arrow).
- 'Time between grid lines (minutes):' with a text box containing '1440.00'.
- An unchecked checkbox labeled 'Start interval numbering from the first ping in the echogram'.
- 'Show depth/range/line-referenced grid:' with a dropdown menu set to 'Water surface (depth of zero)'.
- 'Separation (m):' with a text box containing '5.0'.

At the bottom of the dialog are four buttons: 'OK', 'Cancel', 'Apply', and 'Help'. On the left side of the main window, a sidebar menu is visible with 'Grid' highlighted in orange.

Figure B2. Time/distance grid in Echoview

For the “Show time/distance grid:” make sure “Time” is selected.

Set the “Time between grid lines (minutes):” to the value for the current export package. This will either be 1440 min (24 hours) or 60 min.

The check box should be unchecked.

For the “Show depth/range/line-referenced grid:” select “Water Surface (depth of zero)”. **Make sure you do NOT select “Surface Line”**. By selecting the Water Surface (depth of zero) all water column depths are referenced to the true air-water interface.

For “Separation (m)”, select the value that corresponds to the current export package (either 5 m or max water depth of deployment).

Click the “Apply” button on the bottom of the window.

Now go to “Analysis” on the left column of options

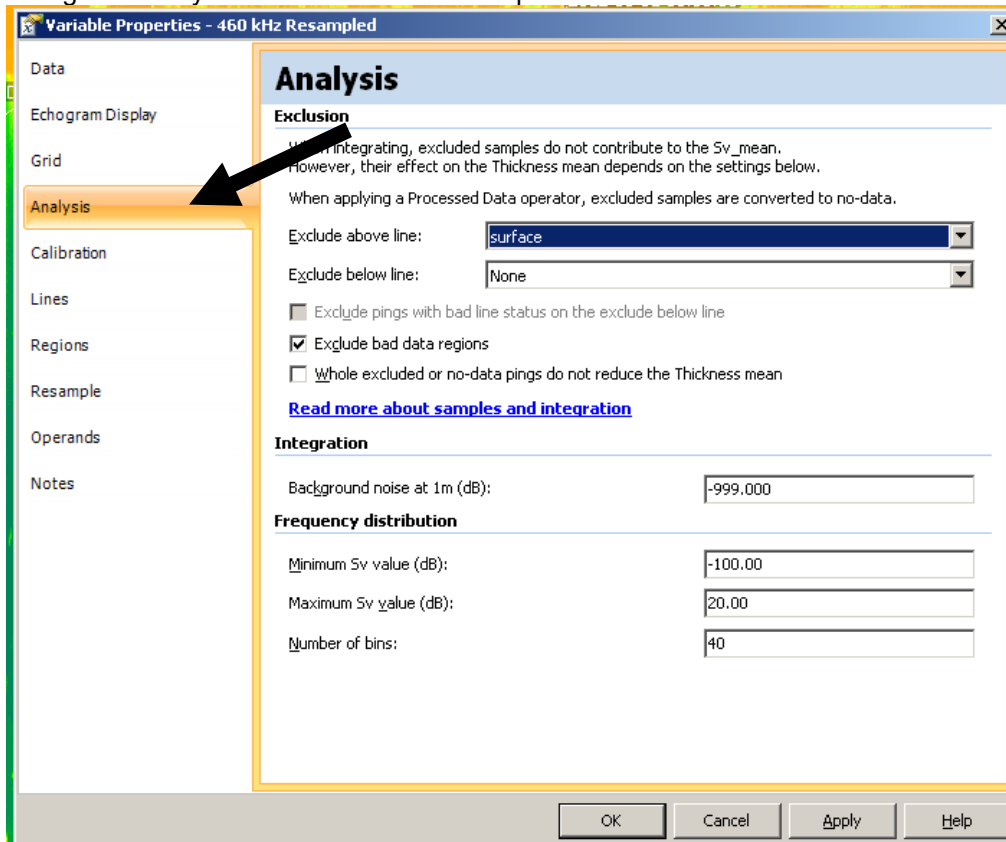


Figure B3. Analysis Menu in Echoview

Make sure the top drop down box, “Exclude above line:” has the name of your surface reference line selected. Most likely this name will be “Surface”.

Click “OK” at the bottom of the pop-up window.

Magenta lines for the grids will now be drawn vertically at the time interval specified, and horizontally, following the surface line. If you are doing the full depth export you will not be able to see the horizontal line.

Here is an example of a 60 minute, 5 meter gridded echogram

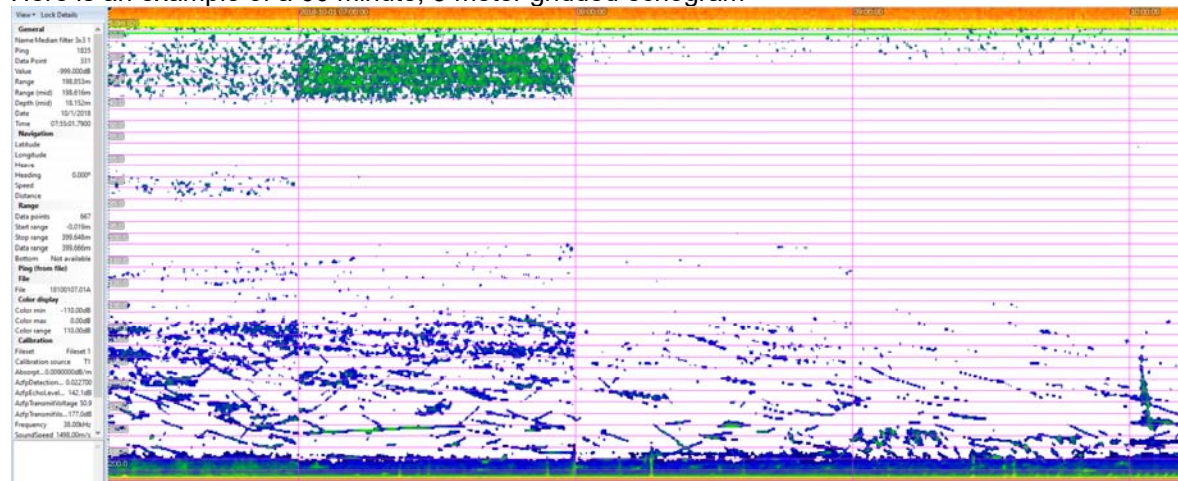


Figure B4. A 60 minute, 5 meter gridded echogram

You are now ready, to export the data for the frequency you just gridded. From the dropdown menu at the top, select:
Echogram→**Export**→**Analysis By Cells**→**Integration**

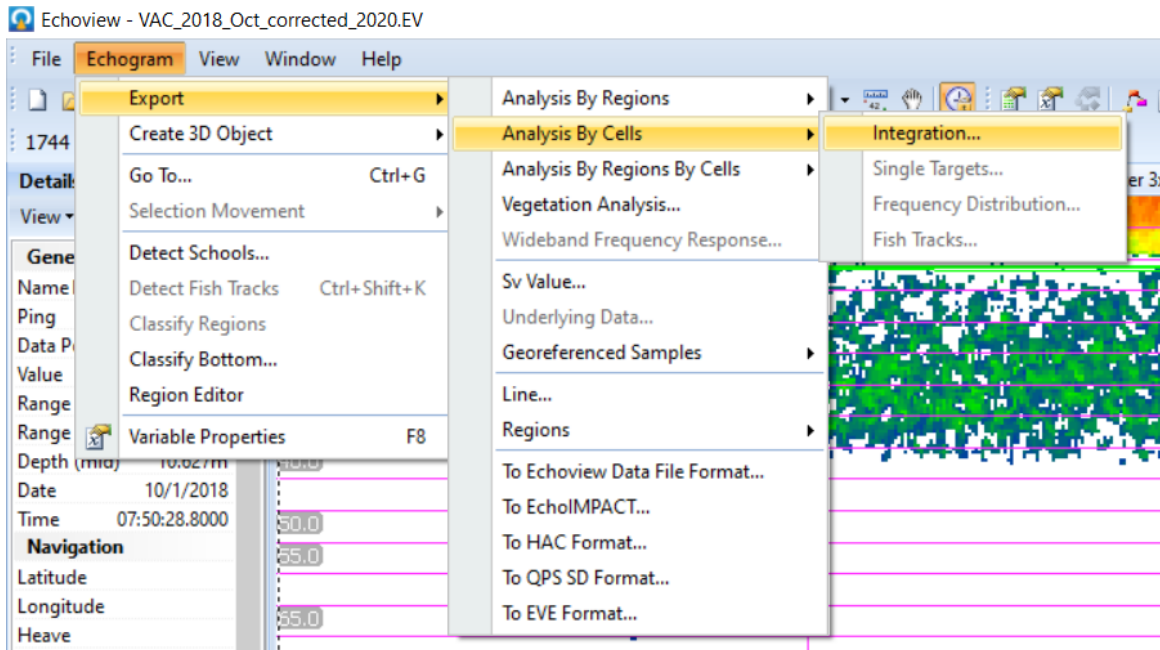


Figure B5. Screenshot of integration option in Echoview

Navigate to the folder for the deployment you are analyzing (i.e., “AWCP_M5_FA12”). Depending on the export package you are doing, select or create a folder to hold the exported file. Exported files are .CSV formatted files with the naming convention used below:

GLO_Site_SerialNumber_Frequency_Year_Month_ExportType.csv

GLO	Geographical Location
Site	29D, 30S, HAT, etc
SerialNumber	Four digit serial number (i.e. 5041)
Frequency	Three digit frequency (038, 200, 455, 775)
Year	Two digit year
Month	Two digit month
Export Type	FullDepth, Partition, 60minPartition

Click “Save”

Echoview will now export the data. Repeat for all of the frequencies and all of the export package types for each monthly Echoview file in the deployment.

Appendix C. Millidecade Definition and Band Parsing Algorithm

One of the soundscape metrics recommended by ADEON is the 1 Hz resolution hourly mean power spectral density. To compute this metric from the 375 kHz or 512 kHz sampling rate data requires very large intermediate data files since up to 256,000 frequency bins must be retained. However, there is very little useful information in most of the high frequency bins since ocean sounds in the 10's of kHz all have wider bandwidths than 1 Hz. Millidecade frequency resolution is proposed as a solution that reduces the size of the spectral data by a factor of 40:1 (at 512 kHz) without compromising use of the data for identification of the presence of many species of marine life, anthropogenic sound sources, and natural sources like wind, rain and ice. Similar to decidecades (third-octave bands (base 10)), millidecades are logarithmically spaced frequency bands with a bandwidth equal to one thousandth of a decade (0.001 dec). The proposed approach is to store 1 Hz frequency bins up to 456 Hz, then store bins that are 0.001 dec wide.

This Appendix contains source code for two MATLAB functions that compute 1) the band limits for any sort of octave or decadal frequency bands; and 2) use the band definitions to divide data from an evenly spaced spectrum into the frequency bands.

A.1. Get Band Table

```
function [ bands ] = getBandTable(fftBinSize, bin1CenterFrequency, fs, base, ...
    bandsPerDivision, firstOutputBandCenterFrequency, useFFTResAtBottom)
% getBandTable(): This is generic software that returns a three column array:
%   with the start, center, stop frequencies for logarithmically spaced
%   frequency bands such as milli-decades, decidecades (third octaves base 10)
%   or third octaves base 2. These tables are passed to
%   'getBandSquaredSoundPressure' to convert square spectra to band
%   levels. The squared pressure can be converted to power spectral
%   density by dividing by the bandwidths.
% Inputs:
%   fftBinSize - the size of the FFT bins in Hz that subsequent processing of
%   data will use.
%   bin1CenterFrequency - this is the center frequency in Hz of the FFT
%   spectra that will be passed to subsequent processing, normally this
%   should be zero.
%   fs - data sampling frequency in Hz
%   base - base for the band levels, generally 10 or 2.
%   bandsPerDivision - the number of bands to divide the spectrum into
%   per increase by a factor of 'base'. A base of 2 and
%   bandsPerDivision of 3 results in third octaves base 2. Base 10
%   and bandsPerDivision of 1000 results in milliDecades.
%   firstOutputBandCenterFrequency: this is the frequency where the output bands will start.
%   useFFTResAtBottom: In some cases, like milliDecades, we do not want
%   to have logarithmically spaced frequency bands across the full
%   spectrum, instead we have the option to have bands that are equal
%   FFTBinSize. The switch to log spacing is made at the band that has a
%   bandwidth greater than FFTBinSize and such that the
%   frequency space between band center frequencies is at least FFTBinSize.
% Outputs:
%   Three column array where column 1 is the lowest frequency of the
%   band, column 2 is the center frequency, and 3 is the highest
%   frequency
% Author: Bruce Martin, JASCO Applied Sciences, Feb 2020.
```

```

%   bruce.martin@jasco.com.

bandCount = 0;

maxFreq = fs/2;

lowSideMultiplier = power(base, -1/(2*bandsPerDivision));
highSideMultiplier = power(base, 1/(2*bandsPerDivision));

% count the number of bands:
linearBinCount = 0;
logBinCount = 0;

if (useFFTResAtBottom)
    binWidth = 0;
    while (binWidth < fftBinSize)
        bandCount = bandCount + 1;
        centerFreq = firstOutputBandCenterFrequency * power(base, bandCount / bandsPerDivision);
        binWidth = highSideMultiplier*centerFreq - lowSideMultiplier*centerFreq;
    end
    % now keep counting until the difference between the log spaced
    % center frequency and new frequency is greater than .025
    centerFreq = firstOutputBandCenterFrequency * power(base, bandCount / bandsPerDivision);
    linearBinCount = ceil(centerFreq / fftBinSize);
    while (linearBinCount * fftBinSize - centerFreq > 0.0)
        bandCount = bandCount + 1;
        linearBinCount = linearBinCount + 1;
        centerFreq = firstOutputBandCenterFrequency * power(base, bandCount / bandsPerDivision);
    end
else
    linearBinCount = 0;
end

logBand1 = bandCount;

% count the log space frequencies
centerFreq = firstOutputBandCenterFrequency;
while (maxFreq > centerFreq)
    bandCount = bandCount + 1;
    logBinCount = logBinCount + 1;
    centerFreq = firstOutputBandCenterFrequency * power(base, bandCount / bandsPerDivision);
end

bands = zeros((linearBinCount + logBinCount), 3);

% generate the linear frequencies
for i = 1:linearBinCount
    bands(i, 2) = bin1CenterFrequency + (i-1)*fftBinSize;
    bands(i, 1) = bands(i, 2) - fftBinSize/2;
    bands(i, 3) = bands(i, 2) + fftBinSize/2;
end

% generate the log spaced bands
for i = 1:logBinCount
    outBandNumber = linearBinCount + i;
    mDecNumber = logBand1 + i;

```



```

bands(outBandNumber, 2) = firstOutputBandCenterFrequency * power(base, (mDecNumber-1) / bandsPerDivision);
bands(outBandNumber, 1) = bands(outBandNumber, 2) * lowSideMultiplier;
bands(outBandNumber, 3) = bands(outBandNumber, 2) * highSideMultiplier;
end

```

```
bands(outBandNumber, 3) = maxFreq;
```

```
end
```

A.2. Get Band Squared Sound Pressure

```
function bandsOut = getBandSquaredSoundPressure(linLevel, fftBinSize, bin1CenterFrequency, ...
    firstBand, lastBand, freqTable )
```

```
% getBandSquaredSoundPressure - this function sums squared sound pressures
% to determine the in-band totals. The band edges are normally obtained
% from a call to 'getBandTable.m'
```

```
%
```

```
% inputs: linLevel - array of squared pressures from an FFT with a frequency step size
```

```
%   fftBinSize - the size of the FFT bins in Hz.
```

```
%   bin1CenterFrequency: the freq in Hz of the first element of the FFT array -
%   normally this is frequency zero.
```

```
%   firstBand: the index in 'freqTable' of the first band to compute and output
```

```
%   lastBand: the index in 'freqTable' of the last band to compute and
```

```
%   output
```

```
%   freqTable - the list of band edges - Nx3 array where column 1 is the
```

```
%   lowest band frequency, column 2 is the center frequency and 3 is the maximum.
```

```
%
```

```
% Outputs: band squared sound pressure vector with one entry per band.
```

```
% Author: Bruce Martin, JASCO Applied Sciences, Feb 2020.
```

```
%   bruce.martin@jasco.com.
```

```
bandsOut = zeros(1, lastBand-firstBand+1);
```

```
step = fftBinSize / 2;
```

```
nFFTBins = size(linLevel, 2);
```

```
startOffset = floor(bin1CenterFrequency / fftBinSize);
```

```
for j = firstBand:lastBand
```

```
    minFFTBin = floor((freqTable(j,1) / fftBinSize) + step) + 1 - startOffset;
```

```
    maxFFTBin = floor((freqTable(j,3) / fftBinSize) + step) + 1 - startOffset;
```

```
    if (maxFFTBin > nFFTBins)
```

```
        maxFFTBin = nFFTBins;
```

```
    end
```

```
    if (minFFTBin < 1)
```

```
        minFFTBin = 1;
```

```
    end
```

```
    % disp(['min Freq ' num2str(minFreq) ' freqTable(j, 1) ' num2str(freqTable(j, 1)) ...
```

```
    %   ' max Freq ' num2str(maxFreq) ' freqTable(j, 3) ' num2str(freqTable(j, 3))]);
```

```
    if (minFFTBin == maxFFTBin)
```

```
        bandsOut(j) = linLevel(1, minFFTBin) * ((freqTable(j, 3) - freqTable(j, 1)) / fftBinSize);
```

```
else
  % Add the first partial FFT bin - take the top of the bin and
  % subtract the lower freq to get the amount we will use:
  % the top freq of a bin is bin# * step size - binSize/2 since bin
  %
  lowerFactor = ((minFFTBin - step) * fftBinSize - freqTable(j, 1));
  bandsOut(j) = linLevel(1, minFFTBin) * lowerFactor;

  % Add the last partial FFT bin.
  upperFactor = freqTable(j, 3) - (maxFFTBin - 1.5*fftBinSize)* fftBinSize;
  bandsOut(j) = bandsOut(j) + linLevel(1, maxFFTBin) * upperFactor;
  %
  % Add any FFT bins in between min and max.
  if (maxFFTBin - minFFTBin) > 1
    bandsOut(j) = bandsOut(j) + sum( linLevel(1,minFFTBin+1:maxFFTBin-1) );
  end
end
end
end
```

