University of
New Hampshire

DRAFT ADEON Data Processing Specification

Version 2

Atlantic Deepwater Ecosystem Observatory Network (ADEON): An Integrated System

Contract: M16PC00003

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1. Introduction

1.1. ADEON Project

The Atlantic Deepwater Ecosystem Observatory Network (ADEON) is a five-year study of the US Mid- and South Atlantic Outer Continental Shelf (OCS). The lead P.I. 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 UNH, OASIS, TNO, JASCO, Stony Brook University, and NOAA.

This observatory network will generate multi-year measurements of the natural and human factors that describe the ecology and soundscape of the OCS. Ocean processes, marine life dynamics, and human ocean use are each inherently three-dimensional and time-dependent, and each occur at many spatial and temporal scales. No single measurement system (*in situ* or remote) is sufficient for describing any of the ocean state variables, and a “multi-platform, multi-variable” observational approach integrated with models is required (Seim et al. 2009). ADEON combines acoustic information with contextual data from space-based remote sensing, hydrographic sensors, and mobile platforms to fully comprehend how human and natural (biotic and abiotic) components create the soundscape and influence ecosystem dynamics of the OCS. Measurements made within this research program serve as a baseline for pattern and trend analyzes of ambient sound and the ecosystem components contributing to the OCS soundscapes.

The outputs of this study will be standardized tools for comparing soundscapes across regions and predictive models for the soundscape and overall ecology of the southeast OCS in water depths between 100–1000 m. The data and models will allow the public to estimate short-term and cumulative effects on the soundscape from changes in human activity as well as ecosystem changes driven by seasonal variability, or other environmental factors. The project’s public data management interface will be used by interested parties to create value-added products so that the information is used as widely as possible.

Conceptually, the ADEON network consists of stationary bottom landers, glider missions, and vessel-based measurements supplemented with space-based remote sensing It also leverages data from established ocean observation systems and databases.

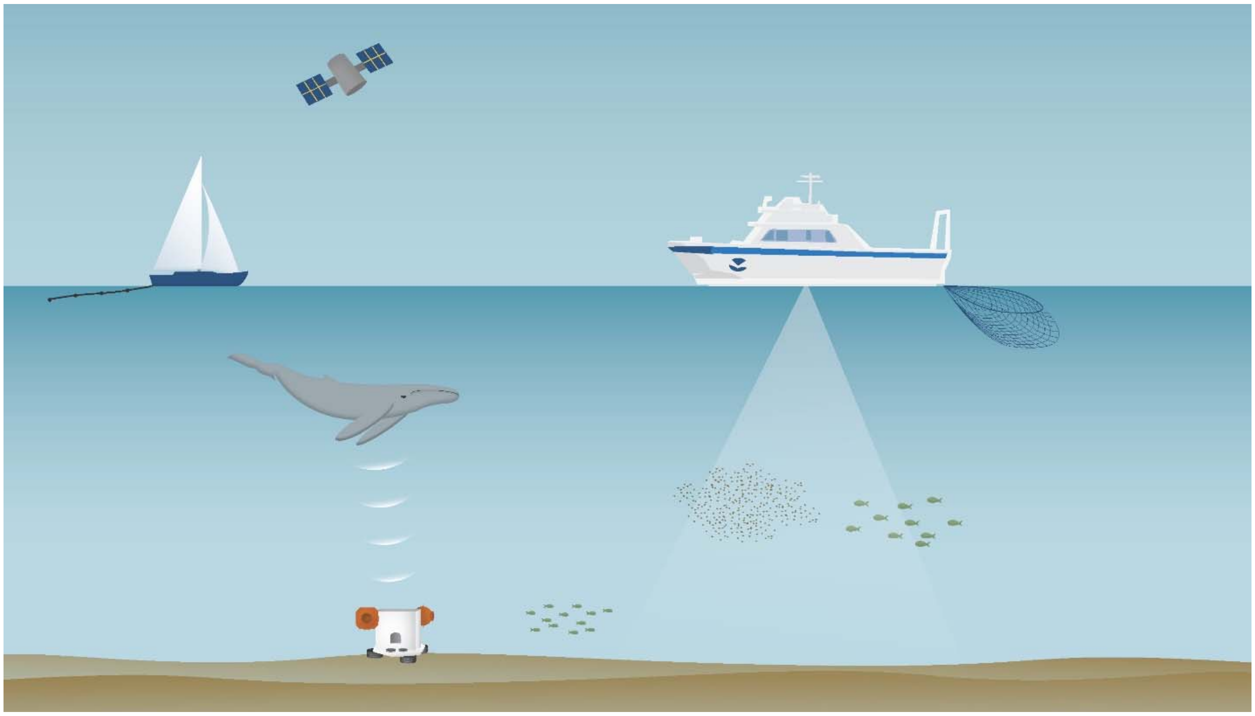

Figure 1. ADEON design including stationary bottom landers, mobile platforms, and remote sensing satellites for data collection.

The seven stationary bottom landers provided a continuous time-series of passive acoustic data, active acoustic backscatter measurements of the prey field, physico-chemical measurements of the local physical environment, and detections of passing tagged fish. Two types of bottom landers were deployed—four bottom landers without active acoustic backscatter measurements and three bottom landers with active acoustics and fish tag loggers. The passive acoustic data from the ADEON bottom landers complement measurements performed by the Duke / USN Living Marine Resources Program being conducted until mid-2020, NOAA's AMAPPS program through summer 2019, and the long-term Noise Reference Station program.

The time-series measurements from the bottom landers were supplemented with targeted measurements from a towed array support vessel, the bottom lander service vessel, and remote sensing. During the bottom lander service cruise, the service vessel:

- Made detailed water column measurements with conductivity, temperature and depth (CTD) loggers, collected water samples, and performed active sonar transects,
- Conducted net tows to sample the zooplankton community structure, and
- Had visual observers document the presence of marine life including sunfish, turtles, sharks, birds, and marine mammals.

Separate towed array cruises deployed a horizontal line array (HLA) with 32 hydrophones channels spaced for effective beamforming at 800 Hz, which provided bearing-time-response (BTR) curves of the ambient sound field. The arrays estimated ambient noise directionality from 50 Hz to 1 kHz, albeit with poor bearing resolution at the lower frequencies. The tow vessel also regularly collected CTD measurements.

Table 1. ADEON sensor platforms, types, and sampling periods.

Platform	**Sampling protocol**	**Omni acoustics**	**Directional acoustics**	**Horizontal line array**	**Active acoustics**	**CTD/SST**	**Chlorophyll a**	**Dissolved oxygen**	**Fish tracking**	**Visual observations**	**Vessel tracking**	**Wind, wave, and surface features**
Standard bottom landers (4)	Continuous on duty cycle	✓	✓			✓		✓				
Active acoustic bottom landers (3)	Continuous on duty cycle	✓	✓		✓	✓		✓	✓			
Towed array	During cruises	✓	✓	✓		✓						
Vessel measurements	Continuous: Active acoustics, SST, and Chl a Station sample: CTD, net tow Day hours: Visual observations				✓	✓	✓	✓		✓		
Remote sensing	As available					✓	✓				✓	✓
Accessible databases (such as Chl-a)	As available					✓					✓	✓

Space-based remote sensing is an excellent resource that provided a continuous data set of chlorophyll-a concentration; net primary productivity (NPP); sea surface temperature (SST); wind and wave fields; large vessel traffic (S-AIS); fishing traffic (VMS); and weather and wave history (National Data Buoy Center (NDBC)). These data were supplemented with accessible databases such as the Argo program (which measures oxygen, carbon dioxide, and pH), Global Real-Time Ocean Forecast system (RTOFS) program, and the Pioneer Coastal Ocean Observatory north of the project area. The satellite data were also supplemented by data from oceanographic buoys within the project area, specifically NDBC buoys NDBC41010, NDBC41002, NDBC41004, NDBC41025, and NDBC44014.

1.1.1. ADEON Deployment Locations

The ADEON mandate requires measurements of the soundscape and ecosystem between 100–1000 m water depth in the Mid and South Atlantic OCS (Virginia to mid-Florida). Considerations for the ADEON site selection include:

- Providing good north-south and east-west coverage of the project area.
- Providing an even distribution of ranges between long-term acoustic recorders (AMAPPS and ADEON) for evaluation of the portability of soundscapes.
- Locating at least two bottom landers north of Cape Hatteras, which has significantly more biologic activity than south of Hatteras.
- Locating two recorders within deep-water coral areas to assess if these areas have complex soundscapes like coral reefs within the photic zone.

The selected locations, approved by BOEM, NOAA NMFS, NOAA Office of Protected Resources and the US Navy, are shown in **Error! Reference source not found.**Figure 2.

ecisions on final locations were approved by all sponsoring agencies. These locations provided a distribution of distances between ADEON and additional recorders, which should allow for assessing the soundscape portability distance. The Wilmington and Savannah Deep bottom landers are in proximity of known deep-water coral sites (lophelia at Wilmington and other corals at Savannah Deep).

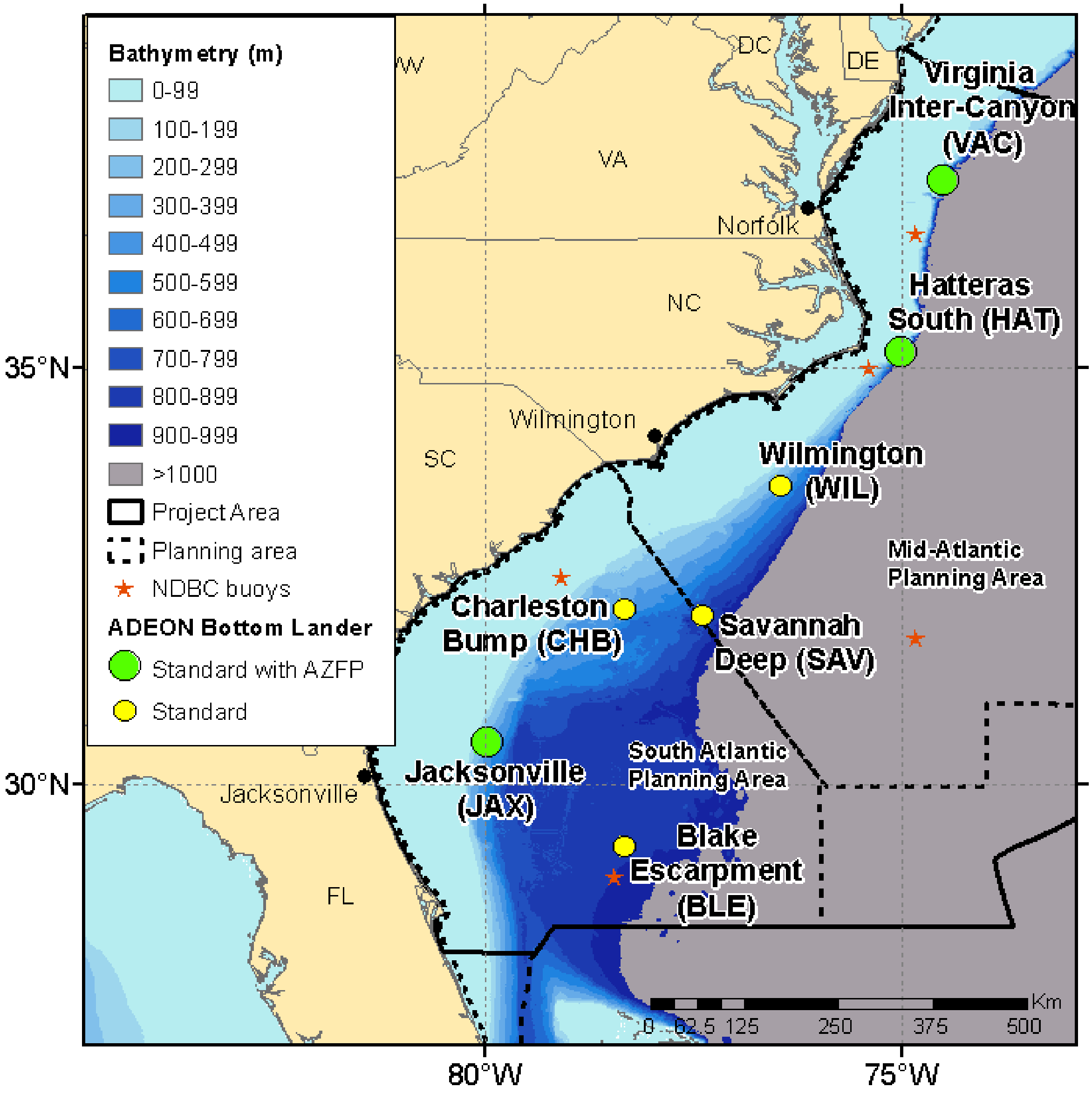

Figure 2. ADEON bottom lander and NDBC buoy locations.

Table 2. ADEON bottom lander locations and water depths. Locations shallower than 400 m have the acoustic fish and zooplankton profilers.

Location	Latitude (°)	Longitude(°)	Depth (m)
Wilmington	33.57295	−76.4614	461
Virginia Inter-Canyon	37.24616	−74.5142	239
Savannah Deep	32.01604	−77.401	802
Charleston Bump	32.1	−78.35	410
Hatteras South	35.2	−75.02	281
Blake Escarpment	29.25	−78.35	874
Jacksonville	30.5	−80	343

Table 3. Additional acoustic recording locations. (NOAA Packages: HARP – High Frequency Acoustic Recording Package, NRS – Noise Recording Station)

Location	Latitude (°)	Longitude (°)	Depth (m)	Programme	Recorder type
HARP Cape Hatteras A	35.5791	−74.757	1176	LMR	HARP
HARP Norfolk Canyon A	37.1652	−74.4666	1116	LMR	HARP
HARP 06	33.6656	−76.0013	961	AMAPPS	HARP
HARP 07	32.10603	−77.0943	974	AMAPPS	HARP
HARP08	30.58378	−77.3907	1010	AMAPPS	HARP
NRS07	29.3336	−77.9999	873	NRS	PMEL

1.2. Objectives

1.2.1. ADEON Project Objectives

The ADEON project objectives are:

- 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.

This report, the draft *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 selected hardware and the characteristics of bottom landers and equipment required to meet the project objectives.

1.3. Data Processing Specification Overview

In Section 2 we present a list of the ADEON Hardware (taken directly from the *Hardware Specification Guide*) in order to provide background material on the specifics of the sensors used and a description of the ADEON array as it spans the Atlantic Outer Continental Shelf.

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 take the raw data and map it into a form which is 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 records machine readable raw data (Level 0) that must, in many cases, be processed. This procedure usually includes some form of error checking or filtering, some form of statistical or spectral processing and some form of averaging. The resulting files (Level 1) are then useful to the wider community. Depending upon the level of aggregation, some of the products can reach a maturity of Level 2 and beyond.

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 is the raw Level 0 data. This is then band-passed (outlier rejection) and a filtered time-series is generated. The data is then processed for quantitative soundscape metrics (Level 1) such as the level in decidecade bands or the peak sound pressure level. Event detection and classification of signals as marine mammals and ships is presented, below but this is considered Level 2 data. The work of Phase IV may include longer-term averages, or 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 Tim Moore and the team at University of New Hampshire is included in the DPS for completeness, although it does not involve data processing as outlined above. There is significant effort put forward by the global remote sensing (satellite) community to generate products. These products are generally received in either Level 3 or Level 4. Their description in this document is suitable because this 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., 2017a). This second objective is met by Section 3, which for this reason 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 will lead to an extensive set of data products for analysis. These include:

1. Passive acoustic data from bottom lander moorings (Section 3.1)
2. Passive acoustic data from the towed array sensor (Section 3.2)
3. Active acoustic data from remotely deployed echo sounder systems (Section 4.1)
4. Active Acoustic data from mounted echo sounder systems (Section 4.2)
5. Satellite Data Set Processing (Section 5)
6. Traditional hydrographic and physio-chemical measurements

1.4. Supporting Documentation and Standards

There are several existing Standards, Good Practice Guides, and publications concerning acoustic data terminology and metrics, passive acoustic data recorders and measurements that this section endeavors to clarify and amplify. The order of precedence is:

1. This Data Processing Specification Guide.
2. Ainslie, de Jong, Prior, TNO 2017 R10022 (DRAFT). Standard Procedures for Underwater Noise Measurements for Activities Related to Offshore Oil and Gas Exploration and Production. Phase I: Processing and Reporting Procedures: Data processing, draft TNO report, January 2017).
3. IEEE. STD-1057-2007. IEEE Standard for Digitizing Waveform Recorders.

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 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 the 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 defines the Snapshot Durations (duration over which data is integrated) and Data Analysis Durations (duration over which data is 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 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 (National Marine Fisheries Service, 2016) or selected marine mammal audiograms.

The Snapshot and Data Analysis Durations are 1, 60 or 200 s, 1 h, 1 d, 1 mo, and 1 a (Ainslie et al, 2017a). 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, these durations are limited to 1, 60 and 200 s. For the kurtosis, these durations are limited to 1, 60 and 200 s. For the sound exposure levels the snapshot duration is always 1 d and are reported per month and year. For combinations of Snapshot and Data Analysis durations where the Data Analysis duration is longer than the Snapshot duration, the arithmetic mean is reported. When there are at least 100 Snapshot windows in the Data Analysis window the cumulative distribution function is also reported. The decidecade, decade, and multidecade metrics are computed for frequency bands to be selected from bands BC, BD, CE, DF, BE, and CF (see Soundscape Specification tables 5 and 6).

Filtering into decidecades is carried out in the frequency domain. The block diagram for the implementation of the quantitative metrics analysis is shown in Figure 3. The processing is divided into two sections. The first section (shown in gray) follows Ainslie et al. (2017b) and computes metrics on the ‘raw’ acoustic data recordings and stores the results in an individual ‘.xml’ file for each acoustic data file. The “raw time series” comprises calibrated sound pressure samples vs time. The length and sampling rate of the raw acoustic data depends on the recorder duty cycle. The second section (shown in light blue) combines processed data from sequential acoustic recordings to generate the Snapshot and Data Analysis durations that are longer than one raw acoustic data file.

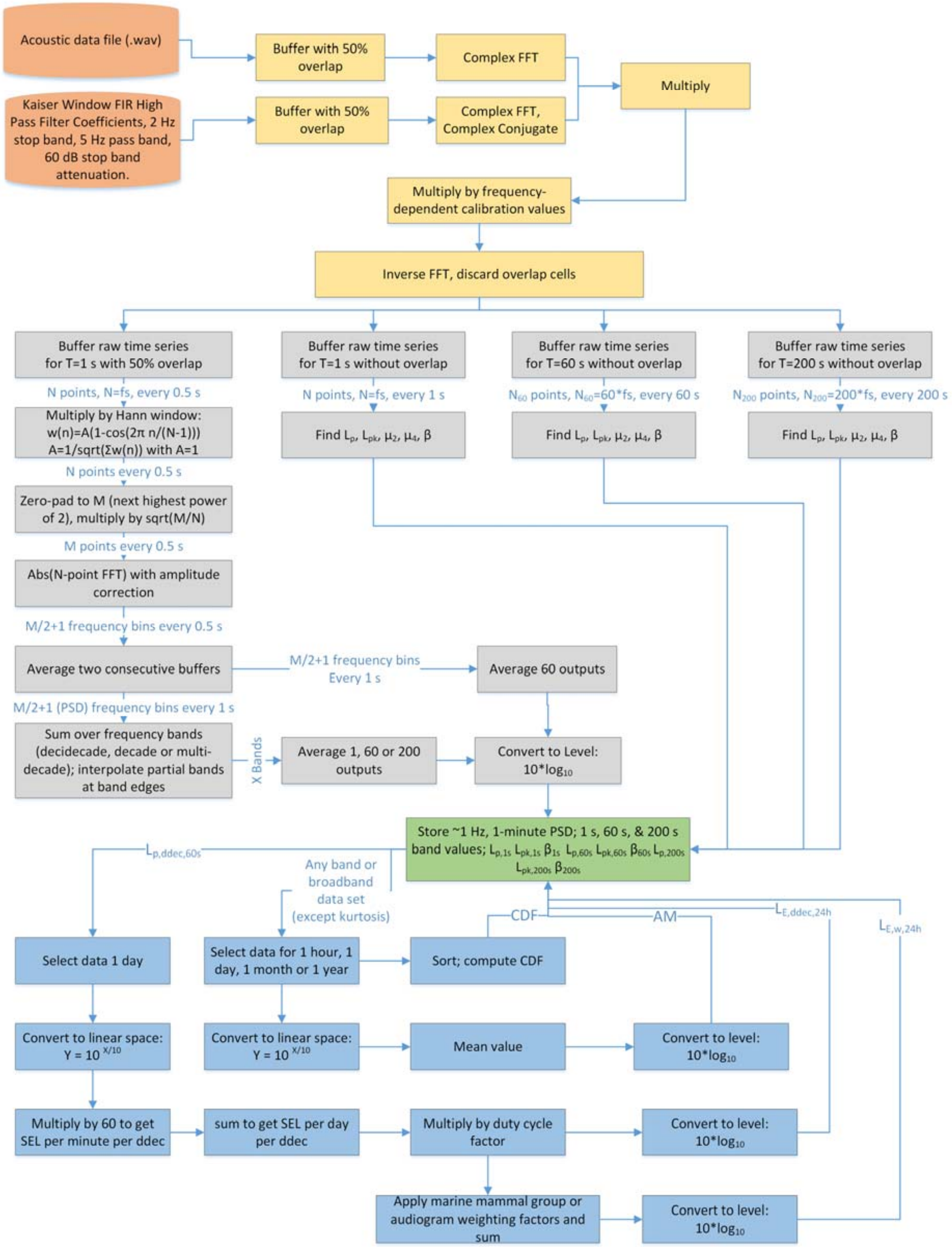

Figure 3. ADEON Quantitative soundscape metrics processing block diagram.

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

1. CALIBRATION Pre-processing (Yellow boxes): The raw data are pre-processed using a high-pass Finite Impulse Response (FIR) filter to remove any DC offsets from the analog-to-digital conversion process and the hydrophone and frequency dependent system calibration values are applied. The filtering process is implemented in the frequency domain (i.e. multiply the complex conjugate of the complex fast-Fourier transform (FFT) of the filter coefficients and complex FFT of the raw data, both with 50 % zero padding then take the inverse-FFT to obtain the filtered time series). The filters coefficients are generated using the MATLAB filter design toolbox with the following parameters:

    a. Stop band cut-off frequency: 2 Hz

    b. Pass-band frequency: 5 Hz

    c. Stop band attenuation: 60 dB

    d. Design method: Kaiser window (Harris, 1978).

    See the Hardware Specification, Appendix A, for information on how to compute and apply the calibration values.

    The output of Step #1 is the calibrated broadband sound pressure time series p(t)

2. CALCULATE SPECTRA Decidecade, decade, and multidecade frequency band metrics ($L_{p,ddec,\Delta t}$) (Left hand gray boxes in Figure 3): Frequency band metrics are all computed based on 1 second buffers of the time series data converted to ~1 Hz resolution spectral data. A Hann window is applied to the data prior to performing the FFT. Because the data may not be sampled at an even power of two, the windowed data is zero-padded to an even power of two, which results in frequency bin sizes that are smaller than 1 Hz. Because the Hann window reduces the amplitude of approximately one-half of the data window, two successive buffers of data are averaged to obtain the 1 s power spectral densities. The input buffer has a 50 % overlap so that there is one output every second from this analysis stage. The resulting data are ~1 Hz power spectral densities (PSD) that can be directly 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 band-limited levels are then averaged over 1, 60, and 200 s and converted to sound pressure levels to obtain those data analysis duration metrics. The PSDs are also averaged over 60 s, converted to levels and stored.

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

    a. The FFT data input buffer must be scaled by the square-root of the ratio of the 1 s buffer size and FFT buffer size.

    b. The Hann window amplitude must be scaled so that it's total weight is 1.

    c. The FFT must be scaled for a unity gain, which normally means dividing by 1/sqrt(2M), where M is the number of points. However this may depend on the FFT implementation selected. The implementation selected for the ADEON passive acoustic recorder data employs the Fastest Fourier Transform in the West library (FFTW).

    The output of Step #2 is calibrated sound pressure spectra P(f) and calibrated sub-band sound pressure time series.

CALCULATE METRICS $L_{p,\Delta t}$, $L_{pk,\Delta t}$ and $\beta_{\Delta t}$ (right-hand three columns in Figure 3): These metrics are computed directly from the filtered and calibrated time series. There is no overlap or scaling required. The output of Step #3 is the required set of soundscape metrics.

3.

The metrics generated by the first stage of analysis are stored for later use by plotting and reporting software. The metrics are also used to compute the soundscape metrics for the longer Data Analysis Durations:

1. Arithmetic Means (AM): the arithmetic means are computed by converting level values (L) back to the linear domain ($10^{L/(10\text{ dB})}$), computing the mean, and taking the $10*\log_{10}$(mean) to obtain the level of the mean value.
2. Cumulative Distribution Functions: the level data is sorted from smallest to largest values, which are then used to generate a cumulative distribution function for the measurements.
3. $L_{E,ddec,24h}$: This metric is computed from the one-minute decidecade SPL values ($L_{p,ddec,60s}$) by converting the values back to linear space, 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 are made on a duty cycle, then the sum is multiplied by a correction factor of total duty cycle duration divided by duty cycle on time. For example, if the recorder is on for 10 minutes out of every 15, then the sound exposure is multiplied by 15/10. The values are stored as levels.
4. $L_{E,w,24h}$: The weighted daily SELs are computed from the daily decidecade values in linear space. The sound exposure values are multiplied by the auditory frequency weighting functions (ISO 18405), for example from (e.g.[NMFS] National Marine Fisheries Service 2016) at the center of each decidecade and then all of the decidecades are summed. The metric is 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 375 kHz will be made one minute out of X(TBD), and this data will be used to compute the frequency weighted $L_{E,w,24h}$ metrics (and detect odontocetes). Therefore, we assume a stationary noise field for the other X-1 minutes. Similarly, we will record for X-1 minutes at the lower sampling rate (8 or 16 kHz, TBD) and for those periods we have to assume that the dominant energy source is in the recorded frequency band. Two common cases where the assumptions fall apart are when there are naval sonars or echosounders above the low sampling rate Nyquist frequency, 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”. 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), 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.

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 apply automated analysis techniques to detect sounds from odontocetes and mysticetes in the acoustic data (pinnipeds are not expected in the ADEON project area). Targeted signals for odontocetes are echolocation clicks and tonal whistles. Echolocation clicks are high-frequency with 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).

Biologic sources are detected in each .wav file, and the detections are stored in the files corresponding .xml file (see Section 2.1.1). The number of detections per species may be summarized per minute, per recording file, and per day.

2.1.2.1.1. Click Detection

We apply an automated click detector/classifier to the high-frequency data to detect clicks from sperm whales, beaked whales, porpoise, and delphinids (Figure 4). This detector/classifier is 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 4). Clicks are detected by the following steps (Figure 4):

1. The raw data are high-pass filtered to remove all energy below 8 kHz. This removes most energy from other sources such as shrimp, vessels, wind, and cetacean tonal calls, while allowing the energy from all high frequency marine mammal click types to pass.
2. The filtered samples are summed to create a 0.5 ms rms time series. Most high frequency marine mammal clicks have a 0.1–1 ms duration.
3. Possible click events are identified with a Teager-Kaiser energy detector (Kaiser, 1990).
4. The maximum peak signal within 1 ms of the detected peak is found in the high-pass filtered data.
5. The high-pass filtered data is searched backwards and forwards to find the time span where the local data maxima are within 9 dB of the maximum peak. The algorithm allows for two zero-crossings to occur where the local peak is not within 9 dB of the maximum before stopping the search. This defines the time window of the detected click.
6. The classification parameters are 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 are computed. The slope parameter helps to identify beaked whale clicks, as beaked whale clicks increase in frequency (upsweep).
7. The Mahalanobis distance between the extracted classification parameters and the templates of known click types is computed. The covariance matrices for the known click types, computed from thousands of manually identified clicks for each species, are stored in

an external file. Each click is classified as a type with the minimum Mahalanobis distance, unless none of them are less than the specified distance threshold.

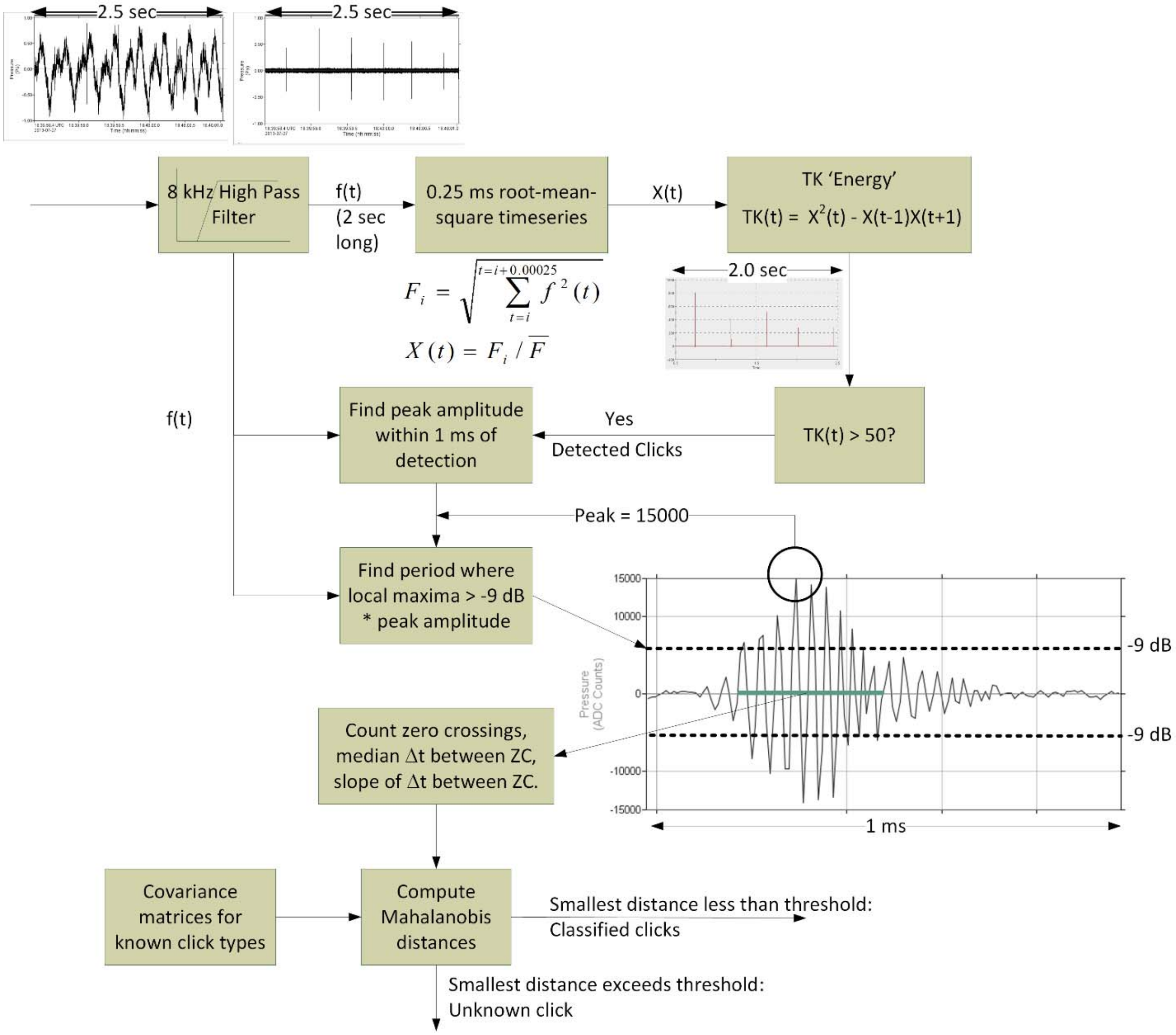

Figure 4. The click detector/classifier and a 1-ms time-series of four click types.

2.1.2.1.2. Tonal Call Detection

The tonal call detector identifies data likely to contain marine mammal moans, songs, and whistles. Tonal calls are detected by the following steps:

1. Spectrograms of the appropriate resolution for each mammal call type that are normalized by the median value in each frequency bin for each detection window (Table 4) are created.
2. Adjacent bins are joined and contours are created via a contour-following algorithm (Figure 5).
3. A call sorting algorithm determines if the contours match the definition of a mammal call type (See Table 5).

Methods of separating minke whale pulse trains from humpback pulse trains are still under development.

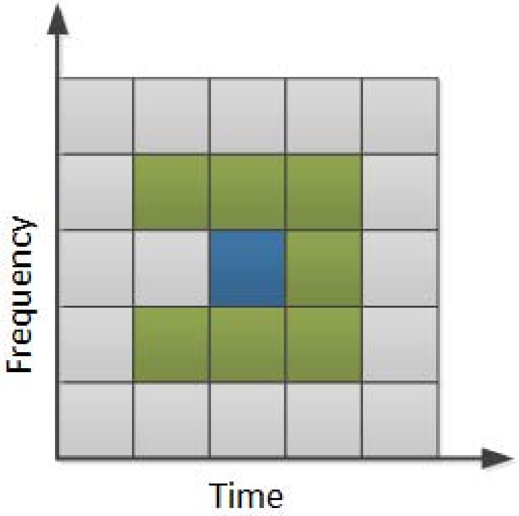

Figure 5. Illustration of the search area used to connect spectrogram bins. The blue square represents a bin of the binary spectrogram equalling 1 and the green squares represent the potential bins it could be connected to. The algorithm advances from left to right so grey cells left of the test cell need not be checked.

Table 4. 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 data sets.

Possible species	**Call type**	**FFT**			**Detection window (s)**	**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 5. Call sorter definitions for the tonal calls of cetacean species expected in the area.

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

Possible species	Call type	Frequency (Hz)	Duration (s)	Bandwidth (Hz)	Other detection parameters
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 maximised the probability of detection and minimised the number of false alarms using the 'F-score':

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

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 6 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 6. 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 are plotted and critically reviewed. Questionable detections based on time of year and location or overlap with the detection period of other species are manually reviewed and removed from the plots if they are 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 are also presented as spatial plots showing the number of detections at each station over selected periods.

2.1.2.2. Man-made sources

Man-made sources are detected in two stage processes where distinctive features are first identified in each .wav file and then a second stage process looks 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 are stored in the file’s corresponding .xml file. The results of the second stage analysis are stored in .csv files containing the per-minute detector results.

2.1.2.2.1. Vessel Detection

Vessels are detected in two steps:

4. Detect constant, narrowband tones produced by a vessel’s propulsion system and other rotating machinery (Arveson and Vendittis 2000). These sounds are also referred to as tonals. We detect the tonals as lines in a 0.125 Hz resolution spectrogram of the data.
5. Assess the SPL for each minute in the 40–315 Hz frequency band. Figure 6 shows an example with a bandwidth of 40–315 Hz, which commonly contains most sound energy produced by mid-sized to large vessels. In cases where airgun is present the lower cut-off frequency is adjusted to 100 Hz. Background estimates of the shipping band SPL and broadband SPL are then compared to their median values over the 12 h window, centred on the current time.

Vessel detections are defined by the following criterion

- The SPL in the shipping band is at least 3 dB above the median.
- AND At least three shipping tonals (0.125 Hz bandwidth) are present for at least one minute per 5 minute window (tonals are 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 is within 12 dB of the broadband SPL (Figure 6).

The time period where these constraints are valid is identified as a period with shipping present. A 10 minute shoulder period before and after the detection period is also included in the shipping period. The shipping period is searched for the highest 1 minute SPL in the vessel detection band which is then identified as the closest point of approach (CPA) time.

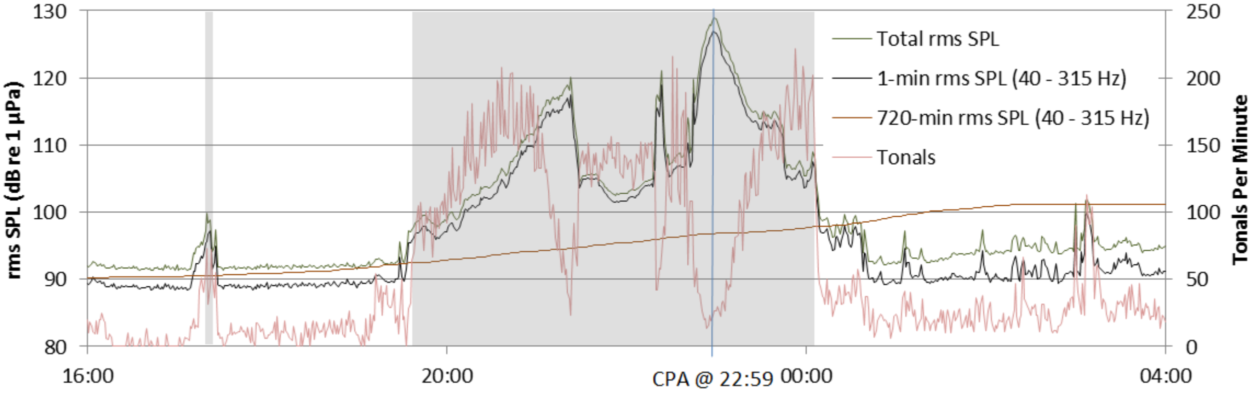

Figure 6. Example of broadband and 40–315 Hz band SPL, as well as the number of tonals detected per minute as a ship approached a recorder, stopped, and then departed. The shaded area is the period of shipping detection. Fewer tonals are detected at the ship's closest point of approach (CPA) at 22:59 because of masking by broadband cavitation noise and due to Doppler shift that affects the tone frequencies.

This algorithm is designed to find *detectable* shipping, that is, situations where the vessel noise can be distinguished from the background. It does 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 are easily 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 are detected using correlated spectrogram contours. We calculate spectrograms using a 300 s long window with 4 Hz frequency resolution and a 0.05 s time resolution (Hann window). All frequency bins are normalized by their medians over window the 300 s window. The detector threshold is three times the median value at each frequency. Contours are created by joining the time-frequency bins above threshold in the 7–1000 Hz band using a 3 × 3 bin kernel (Figure 6). Contours 0.2–6 s in duration with a bandwidth of at least 60 Hz are retained for further analysis.

An "event" time series is created by summing the normalized value of the frequency bins in each time step that contained detected contours. The event time series is auto-correlated to look for repeated events. The correlated data space is normalized by its median and a detector threshold of 3 is applied. Peaks larger than their two nearest neighbours are identified, and the peaks list is searched for entries with a set repetition interval. The allowed spacing between the minimum and maximum time peaks is 4.8 to 65 s, which captures the normal range of airgun pulse periods. When at least six regularly spaced peaks occur, the original event time series is searched for all peaks that match the repetition period within a tolerance of 0.25 s. The duration of the 90% energy duration of each peak is determined from the originally sampled time series, and pulses more than 3 s long are rejected.

This detector is 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 are generally rejected. For these types of surveys the impulse detector should be employed instead.

2.1.2.2.3. Impulse Detector

Sound levels for each detectable impulses such as pile-driving, airgun impulses, ice cracking, sonar pulses and thunder are automatically detected using a Teager-Kaiser energy detector. This is the same algorithm used to identify possible odontocete clicks (see the first row of boxes in Figure 4). The algorithm to the type of impulse to be detected. For instance, pile-driving and airgun pulses are well detected using a 50 ms integration time and no high pass filters. Naval sonar pulses are best identified by employing a suitable bandpass filter and a longer integration window. For each identified impulse $L_{p,\delta t}$, $L_{pk,\delta t}$, $L_{p,ddec,\delta t}$, $L_{E,\delta t}$ and $L_{E,ddec,\delta t}$ are 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 are performed using the per-minute decidecade sound levels during post processing of the .xml files. The source flags are stored in the same file that contain the man-made source identifications.

Periods dominated by rain are identified based on the spectrum in the 8-15 kHz band having higher energy than both the 4-8 kHz and 15-20 kHz bands. It is also essential that no delphinid whistles are detected in the 8-15 kHz band.

Periods dominated by wind are identified as any period where the frequency band of 300-1000 Hz has higher energy than the 30-300 Hz band or 1000-10000 Hz band and no marine mammal, fish, crustacean or anthropogenic sources were identified in that one-minute period.

Periods that may contain thunder will be identified with the impulse detector (using a 50 ms integration time and threshold of 100, see Section 2.1.2.2.3 and Figure 5), and requiring the detection of rain within 5 minutes of the possible thunder event. All candidate thunder detections will be manually validated.

2.1.2.4. Source Directionality

The ADEON lander includes four hydrophones in right-angle array that are intended for measuring the direction of arrival of detected sound sources. For sounds that have a signal to noise ratio level of at least 6 dB, the direction of arrival will be 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 will:

1. Detect the signal on the center hydrophone, and measure the bandwidth and duration of the signal.
2. Select the time window corresponding to the detection on each of the hydrophone
3. Band-pass filter the data using a cosine-tapered window on each of the hydrophone channels to remove energy that is not from the identified signal.
4. Cross-correlate the X, Y, and Z hydrophones with the center hydrophone to measure the TDOA.
5. Use the time delays and speed of sound to estimate the direction of arrival.

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

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

2.1.3. Extended Soundscape Metrics

We will develop and evaluate ways to measure soundscape metrics, then present them in our analysis reports for discussion with the project sponsors.

Development of metrics that summarize a soundscape, or the possible effects of man-made sound on animals is an area of active investigation by many teams, including ADEON's. As the project progresses promising new metrics will be added to our processing suite and their values included in the Phase 4 analysis to see if they are useful predictor or response values for the soundscape. Metrics to be considered include:

- Acoustic complexity index (Pieretti et al. 2011);
- Acoustic diversity index (Towsey et al. 2014);
- Acoustic evenness index (Towsey et al. 2014);
- Spectral and temporal entropy (Erbe and King 2008, Towsey et al. 2014)
- A comodulation index as a proxy for potential masking of marine mammal calls by man-made noise (Branstetter et al. 2013)

2.1.4. Passive Data Recorder Analysis Implementation Overview

The passive data recorder analysis will be performed using custom JAVA and MATLAB software written by JASCO Applied Sciences (Figure 7). 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) will all be 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 is performed on the 'Grid', which is the JASCO high performance computing cluster that includes 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 can track what analysis was performed on each data set. A full processing run on the ADEON data takes ~6 hours per recorder and will be repeated as necessary when new algorithms or configurations are warranted.

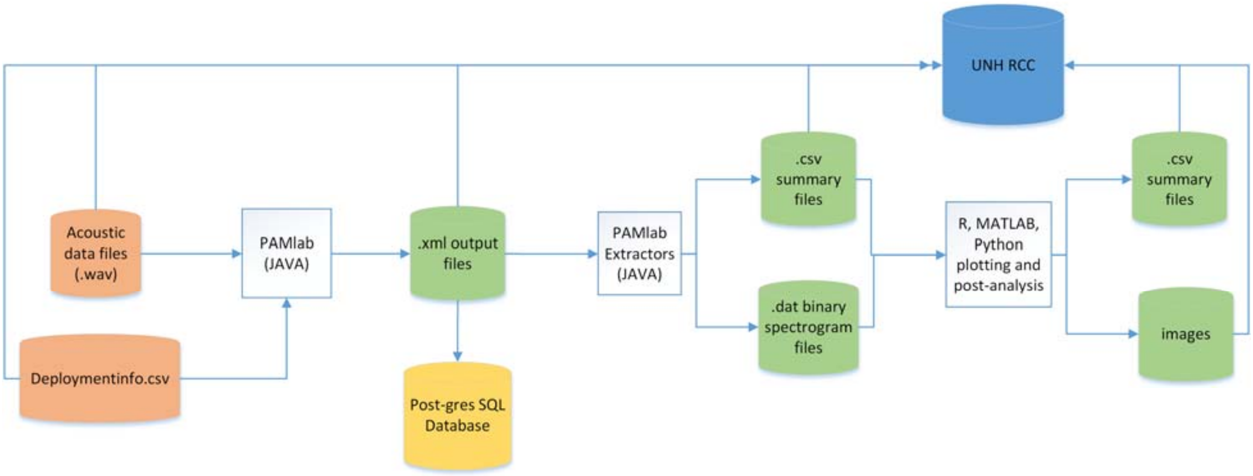

Figure 7. Overview of the data files, data analysis software, and output files associated with the passive acoustic data recorder analysis.

2.2. Towed Array Passive Acoustic Data Recorders

In addition to the long-duration acoustic observations taken from the bottom-mounted landers, there will be 4 separate cruises with a towed array passive acoustic system. A horizontal line array (HLA) will be deployed from a sailboat with a drogue weight to maintain depth and the acoustic noise field will be measured. The purpose of this portion of the test is to measure the horizontal directionality of the noise 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 soundscape field. A sailboat was chosen to minimize the contamination of the recording from the towing vessel. The first cruise employing the HLA will be in the Spring of 2018, prior to mooring recovery and replacement cruise in June. The April cruise will be 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 is volunteering ship time and personnel in order to gain the experience of participating in an acoustics trial.

A processor will be 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 publically available. Note that the raw acoustic time series will not be made available to the public. This is to prevent subsequent reprocessing of the data for purposes other than soundscape monitoring. The raw acoustic data will be stored as a backup in case there are issues with the broadband CBF processing. The data will also be provided to the USCG for use by the students in various research projects.

The raw acoustic files are generated by ingesting acoustic voltage values from each hydrophone from the sensor UDP packets coming up from the array via an Ethernet port. The data is then stored as raw (Level 0) data and processed in real-time to produce bearing time records (BTRs) of the sound field directionality (Level 1). The output product will be the incoherent power average of the beam response for each decidecade band, sampled at 1s.

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

1. **Spectral decomposition:** The processor assembles the incoming stream of samples into 50% overlapped chunks, applies a Hann window to each chunk, and performs a fast Fourier transform (FFT). It is expected that the FFT length will be 1 second. Because the Hann window reduces the amplitude of approximately one-half of the data window, two successive buffers of data are averaged to obtain the 1 s power spectral densities. The input buffer has a 50% overlap so that there is one output every second from this analysis stage. Note that the modern FFTs used in this processing do not require a number strictly defined as a power of 2.

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

   a. The Hann window amplitude must be scaled so that it's total weight is 1.
   b. The FFT must be scaled for a unity gain, which normally means dividing by 1/sqrt(2M), however this may depend on the FFT implementation selected. The implementation selected for the ADEON passive acoustic recorder data employs the Fastest Fourier Transform in the West library (FFTW).

2. **Plane wave beamforming:** A simple Hann shaded frequency domain conventional beamformer (CBF) beamformer is applied to each frequency component of the acoustic signal. The set of beams is uniformly spaced in cosine of angle from forward endfire. The number of beams formed is twice the number of half wavelengths spanned by the array at the highest frequency of interest.
3. **Band averaging:** Frequency band metrics are all computed based on 1 second buffers of the time series data converted to ~1 Hz resolution spectral data. The resulting data are ~1 Hz power spectral densities (PSD) that can be directly summed between to 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.
4. **Soundscape metrics computation:** Given the broadband BTR output many metrics can be computed to evaluate the soundscape. For the array data, this is considered a research project and is part of the Phase IV Data Analysis phase.

3. Active Acoustic Recorders

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

3.1 Processing of data from remotely deployed echo sounder systems
3.2 Processing of data from vessel mounted echo sounder systems

3.1. Processing of data from remotely deployed echo sounder systems

3.1.1. Converting raw binary files into EchoView formatted .csv files

ADEON is integrating a 4-frequency echo sounder system (38 kHz, 125 kHz, 200 kHz, and 455 kHz) into three of the seven constructed bottom lander platforms. The transducers are mounted at an approximate 15° angle off vertical to eliminate interference from the lander sensors and floatation mounted slightly above the transducers. The AZFP (ASL Environmental Sciences) system is a self-contained instrument designed to measure and record acoustic returns from the water column. The AZFP stores 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 case and using USB card reader to transfer the data from the CF card to a PC. It is recommended that the raw data be downloaded to a PC for ease and speed of further processing.

Initial processing occurs with the AzfpLink software. Detailed instructions on exporting raw AZFP files to .csv files readable by EchoView is provided in the AzfpLink Users Guide (Version 1.0.16) Part V Section 10. In summary, raw files for export are selected under the AzfpLink software Export Tab. For ADEON data, raw data is exported in two formats: 1) A/D (counts) ASL CSV format, and 2) Sv (Backscatter Strength in dB) EchoView CSV format. The ASL CSV format data is used to generate the temperature time series. The EchoView CSV format is generated for direct import into EchoView for further processing. All the individual transducer calibration coefficients (contained in the configuration (.cfg) file for each instrument)(ADEON Calibration and Deployment Good Practice Guide, 2017), which are integrated as part of the instrument firmware and able to be manually specified in the Export Tab, are applied to the raw data during the export process for fully calibrated values of S_v in the EchoView CSV format files. The equations used to relate the AZFP raw data to calibrated measures of S_v is described in Appendix G of the AZFP Operator’s Manual (AZFP Operator’s Manual GU-100-AZFP-01-R27).

Daily files are exported from the AzfpLink software in .sv.csv format and are referred to as the Level 1 raw data described in the ADEON Data Dictionary in terms of data management. These are daily S_v matrix files as a function of time and depth with the format: 550SN_C1_FREKHZ_YYYYMMDD.sv.csv where SN is instrument serial number, C# is the cycle number in the data collection phase, and FRE is unit frequency. An example file is: 55017_C1_125KHZ_20160426.sv.csv.

3.1.2. Processing EchoView files

Daily files exported from the AzfpLink software are loaded into EchoView software, and compiled to create monthly EchoView (.EV) files for processing. Each monthly .EV file is constructed to include all 4 frequency S_v time series. The .EV files are saved with the designated format: GLO_YEAR_MON.EV. An example for ADEON data would be 30N_2017_DEC.EV. Each monthly .EV file is manually scanned to 1) identify “bad data” regions (regions of interference, transducer ringdown, etc) which are marked and excluded from further processing, and 2) designate an appropriate surface line for referencing depth. This processed and conditioned data is then used to export information for classification into designated animal groups.

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Conditioned data is exported from the .EV files to .CSV files for classification with Matlab software. Conditioned data is exported in three separate data packages (Table 7) to capture the long term variability at selected temporal and spatial scales. The set-up and execution of export grid averaging in EchoView is described in detail in Appendix A. The naming convention for exported data from EchoView is GLO_Site_SerialNumber_Frequency_Year_Month_ExportType.csv (Table 8).

	Depth Averaging	Time Averaging
Full Depth	200-1000 m	24 h
Daily Partition	5 m	24 h
30 m Partition	5 m	30 min

Table 7. Selected data export packages from conditioned EchoView data.

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, 30minPartition

Table 8. Naming convention key for exported .csv files from EchoView.

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 will reflect higher temporal resolution (shorter averaging windows) over day long durations. Exact depth bin and time window averaging will be specified in the FINAL document after data is retrieved and processed from the first deployment.

3.1.3. Classification of EchoView exported Sv

Custom Matlab scripts have been written to classify the acoustic backscatter as to the likely source of the scattering based on differences in scattering amplitude between the four frequencies. Analyses using this dB-difference approach and comparing to theoretical scattering curves (Watkins and Brierley, 2002; Reiss et al., 2008; De Robertis et al., 2010) are typically groundtruthed with information from net tows or video observations. Theoretical scattering curves for at least four different types of individual scatterers will be generated and dB-differences at the four acoustic frequencies used in this study will be calculated. Scattering amplitudes (and the subsequent dB differences at 38 kHz, 125 kHz, 200 kHz, and 455 kHz) will be generated using a Stochastic Distorted Wave Born Approximation model (Demer and Conti, 2003) for the following scatterers: 1) small scatterers such as copepods (lengths of 1 – 5 mm), 2) medium scatterers (lengths of 5 – 15 mm) which includes juvenile krill, chaetognaths, and amphipods, 3) large scatterers such as adult euphausiids (lengths of 15 - 30 mm), 4) resonant scatterers, and 5) unknown.

The Matlab scripts first reorganizes the exported mean S_V data into a two dimensional table with depth increasing along the columns, and time/date increasing with rows. Three scripts are run in the following order:

1. OrganizeAWCPExport_30min_Grids.m
2. OrganizeAWCPExport_30minForClass.m
3. percentComp_24hr.m

The output of running the Matlab script sequence is a .CSV daily time series file of Percent Community Composition broken down by the 5 scattering groups described above.

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 will be titled as follows:

SerialNumber_C1_FREKHZ_YYYMMDD_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** is 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

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 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) were utilized as resources 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. And that you have backed up your raw data files before beginning any processing.

3.2.1. 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. 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.

3.2.3. 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.

3.2.4. Time settings

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

3.2.5. Construct a Surface Exclusion Line

Near surface backscatter data are excluded from analysis for a variety of reasons including: within the nearfield of the echosounder/transducer, contaminated by bubble sweepdown or flow along the hull of the vessel, 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 is used it must be deep enough that contaminated data are not included at any point in the survey.

3.2.6. 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 is 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 is more prevalent in areas of dynamic bathymetry such as canyons or the shelfbreak. In some situations (i.e. very deep water), bottom detections are far below the region of interest so this may not be necessary and a constant-depth exclusion line can be used.

3.2.7. 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.

3.2.8. 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. engine speeds different during part of the survey, changes in equipment mid-survey, etc). A more detailed discussion of this method can be found in DeRobertis and Higginbottom (2007).

3.2.9. Remove self-noise

Noise spikes or non-constant noise also needs 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 is often necessary of the echograms 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).

3.2.10. 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 TS) threshold where only data exceeding those values is included in later analysis. Data compared between different surveys or regions should use the same thresholding.

3.2.11. 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 broadscale 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 was 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.

3.2.12. [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.

3.2.13. 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.

3.2.14. 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.

3.2.15. Analyze the data

This section depends on the questions being asked. In this project, we will be examining the spatial variability in backscatter within and among the different study regions. So mean integrated backscatter values will be used to compare and contrast the different habitats.

3.2.16. Estimate uncertainty

This step is rarely done in many surveys, but having some idea of the uncertainty (or possibly 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.

3.2.17. Cross-calibration with remotely deployed echosounder systems

An additional export of the vessel-mounted system will be done with analysis cell-sizes selected to best match the data from the bottom-located, remotely-deployed AZFP systems. Comparisons will be 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 will be binned temporally (e.g. 1 min or 1 h bins) and vertically to match the analysis cells from the bottom-deployed systems.

4. ADEON Satellite Data Set Processing

Satellite and modeled ocean data sets collected for the ADEON project study area (Table 9) are obtained from public websites, covering a variety of spatial and temporal scales. All global data are processed to Level 3 or 4 (defined in 1.1). The global data are gridded at 4 – 25km^2 resolution, ranging from daily to weekly time scales. There is also a near real-time Level 2 data stream originating from NASA at higher spatial resolution (1km^2) over the ADEON area for chlorophyll-a and SST. Details of each data set, naming convention, and file structure are given in the following sections.

Table 9. Global gridded satellite product characteristics for ADEON

Parameter	Source	Sensor/Model	Spatial Resolution (pixel size)	Temporal Range
Sea Surface Temperature	NASA Goddard	MODIS-Aqua	4.6 km^2	8-day mean
Chlorophyll-a	NASA Goddard	VIIRS	4.6 km^2	8-day mean
Net Primary Productivity	Oregon State University	VGPM	12.5km^2	8-day mean
Mixed Layer Depth	Oregon State University	HYCOM	12.5km^2	8-day mean
Surface Wind Speed & Stress	IFREMER (France)	ASCOT	0.25degree	Daily
Surface Currents	Globcurrent (ESA)	Merged	0.25degree	3-hourly

4.1.1. Global gridded data sets

Global ocean data (Table 10) are in gridded, mapped format at Level 3 or Level 4 processing level. 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 output 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 10. Satellite product names and units for ADEON

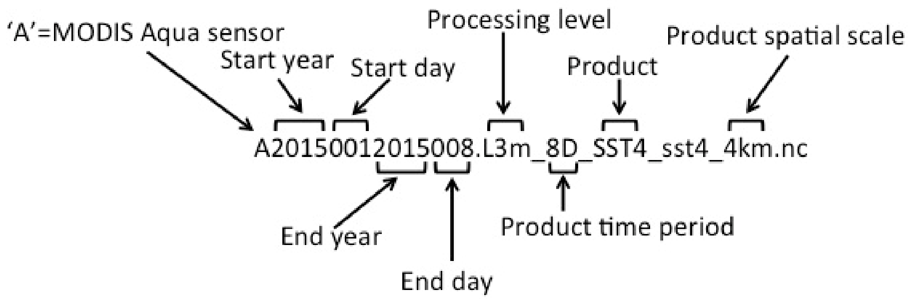
Parameter	Description	Units
SST (Level 3)	Sea Surface Temperature	° C
CHL (Level 3)	Chlorophyll-a concentration	mg /m^3
NPP (Level 4)	Net Primary Productivity (C)	mg / (m^2 d)
MLD (Level 4)	Mixed Layer Depth	m
WSPD (Level 3)	Wind speed	m/s
Eularian (Level 4)	Surface Currents	m/s

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

The NASA SMI products are 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 SST for ADEON. The arithmetic mean is 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 SST are in netCDF4 format, and will utilize a variety of international standards and conventions for meta-data and file structure.

The NASA Level 3 filenames contain the date period (i.e., temporal resolution, product type: either SST or CHL), and spatial resolution. The ADEON project is using 8-day averages at 4.6km^2 pixel resolution for CHL and SST. For SST, MODIS-Aqua is the source sensor, and the NASA-NOAA Visible Infrared Imaging Radiometer Suite (VIIRS) is the source sensor for CHL. An example filename for an 8-day composite for SST from MODIS-Aqua is shown below:



The CHL product from VIIRS has a similar file naming convention. The file name extensions (after the first '.') are of the form L3m_tt_pppp_r, where 'tt' represents the binning period length, pppp is a code for the geophysical parameter of the product (repeated again), and r is the resolution. *Note*: the code for SST is SST4 (indicating the night time 4 micron channel algorithm).

Inside the netCDF files, the data object, 'l3m_data', in each SMI product represents 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 4.6x4.6 km^2. 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).

4.1.1.2. 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 is the Vertically Generalized Production Model (VGPM) by Behrenfeld and Falkowski (1997), and is a commonly used algorithm for estimating oceanic NPP. The VGPM algorithm uses chlorophyll concentration (CHL) and other parameters as input fields governed by the general equation:

NPP = CHL * Pb_opt * 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 a *water column integrated productivity* per unit of ocean area, and the unit is milligrams of carbon fixed per day per unit volume. *Note*: it 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 (units of mg C / m^2 / day)
yyyy = year
ddd= day of year 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 by 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

Citation: "Please reference the original VGPM paper by *Behrenfeld and Falkowski, 1997a* as well as the *Ocean Productivity site* for the data.

4.1.1.3. Mixed Layer Depth

The mixed layer depth (MLD) product for ADEON is derived from the HYbrid Coordinate Ocean Model (HYCOM). Simplified and renamed versions of the original data files (available at https://hycom.org/) are being obtained from ftp servers at OSU, served alongside with their NPP products. The OSU versions are averaged to 8-day time intervals at 4.6km^2 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= day of year of the start of each 8day 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 section 1.1.2.

4.1.1.4. Wind Speed and Stress

The Advanced SCATterometer (ASCAT) is a real aperture on board 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 operating at 5.255 GHz (C-band) and using vertically polarised antennas. With the rapid global coverage, day or night and all-weather operation, ASCAT offers 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 method. The analyses use standard products ASCAT L2b during the period April 2007 through 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 are 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 uses ASCAT observations as well as ECMWF analyses. The latter are 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 uses ascending as well as descending available and valid retrievals. The objective method aims to provide daily-averaged gridded wind speed, zonal component, meridional component, wind stress and the corresponding components at global scale. The error associated to each parameter, related to the sampling impact and wind space and time variability, is 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-yyyyddddmmhhmn-01.0.nc

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

The main variables of each netCDF file are listed in Table 11. They are provided with attributes and units.

Table 11. Data file variables for daily ASCAT Wind netCDF files from IFREMER.
Citation: ***"These data were obtained from the Centre de Recherche et d'Exploitation Satellitaire (CERSAT), at IFREMER, Plouzané (France)"***

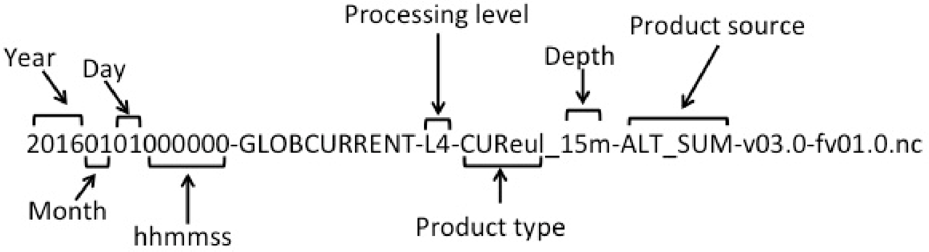
Time	Daily analysis date (since January 1st, 1990)	Hours
Latitude	Grid point latitude	Degree
Longitude	Grid point longitude	Degree
Wind speed	10m wind speed in neutral condition	m/s
Zonal wind component	Eastward wind component	m/s
Meridional wind component	Northward wind component	m/s
Wind Stress	Amplitude of wind stress	Pa
Zonal wind stress component	Surface downward eastward wind stress	Pa
Meridional stess 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

4.1.1.5. Surface Currents

ADEON is utilizing upper ocean surface current products at quarter-degree scale from ESA's **Globcurrent** project. Ocean surface currents (OSC) are defined as the coherent horizontal and vertical movement of surface ocean water (over a specific depth regime) with a given velocity and an upper boundary in contact with the atmosphere that persist over a geographical region and time period. Direct and indirect estimates of OSC and higher level derived quantities can be derived using a variety of satellite sensors including altimetry, gravimetry, SAR, scatterometry, optical and passive microwaves. **Globcurrent** project integrates satellite observations with a variety of in situ measurements - from drifting and moored buoys, coastal HF-radar installations, Argo floats, gliders and ship observations – to produce estimates of OSC with systematic data merging and sensor synergy combined with advanced processing tools and simulation models.

A variety of surface current data products are available from **Globcurrent.** For ADEON, we are obtaining an average surface current over the top 15 m. This data product is referred as **eulerian_total_current_velocity** defined as the total velocity of the current as measured at a fixed point (by means of a current meter for instance). This is typically estimated by combination of infrared (SST) and hyperspectral (ocean colour) imagers, or combination of altimeters with other sources (weather model).

The data files are in netCDF format. Each file data products for a given 3-hour time step. The filename contains the time stamp, processing version, file type, and other information:



Inside each file, there are a number of data objects, including northward (‘northward_eulerian_current_velocity’) and eastward (‘eastward_eulerian_current_velocity’) components of the eularian surface drift, latitude and longitude, and estimated error fields. The full list of file data objects is shown in Table 12.

Table 12. Data file variables for daily Globcurrent 3-hourly Eularian current netCDF files from IFREMER.

time	Daily analysis date (since January 1st, 1950)	Hours
lat	Grid point latitude	Degree
lon	Grid point longitude	Degree
eastward_eulerian_current_velocity	Zonal component of the combined current at 15 m calculated as the sum of the geostrophic current and the Ekman current at 15 m depth	m/s
northward_eulerian_current_velocity	Meridional component of the combined current at 15 m calculated as the sum of the geostrophic current and the Ekman current at 15 m depth	m/s
eastward_eulerian_current_velocity_error	Error estimate based on the Root Mean Square differences between the unfiltered drifting buoy zonal velocities (with drog attached at 15 m) and the GlobCurrent zonal eulerian velocities at 15 m, calculated into 20° by 20° boxes and by month.	m/s
northward_eulerian_current_velocity_error	Error estimate based on the Root Mean Square differences between the unfiltered drifting buoy meridional velocities (with drog attached at 15 m) and the GlobCurrent meridional eulerian velocities at 15 m, calculated into 20° by 20° boxes and by month.	m/s

Citation: ***"These data were obtained from the Centre de Recherche et d'Exploitation Satellitaire (CERSAT), at IFREMER, Plouzané (France)"***

4.1.1.6. 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 processed data from level-1 to level-2 using climatological ancillary data sets, and thus the level-2 products are not refined. Level 2 data are processed by NASA from the NASA-NOAA NPP VIIRS platform and NASA’s MODIS-Aqua platform. Both data sets have an approximate 1km-pixel resolution mapped to a region that spans the U.S. east coast and covers the entire ADEON region (Figure 8). Image files are automatically uploaded daily from NASA ftp sites to ADEON data servers whenever there is 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.

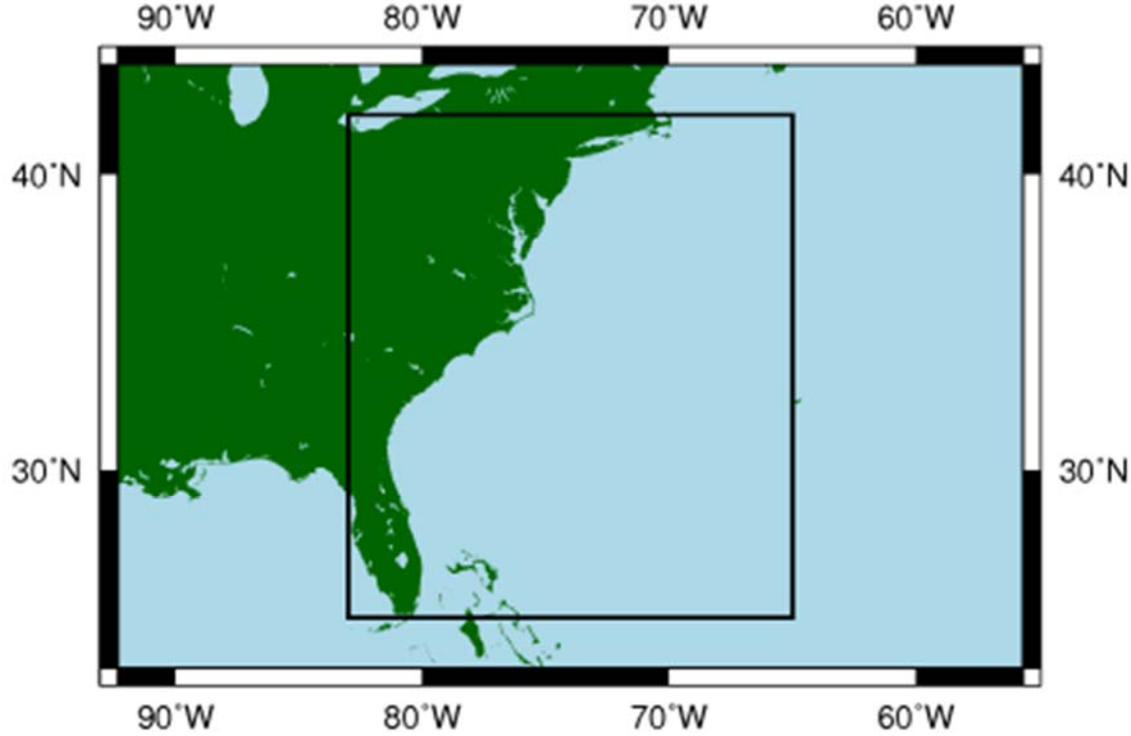
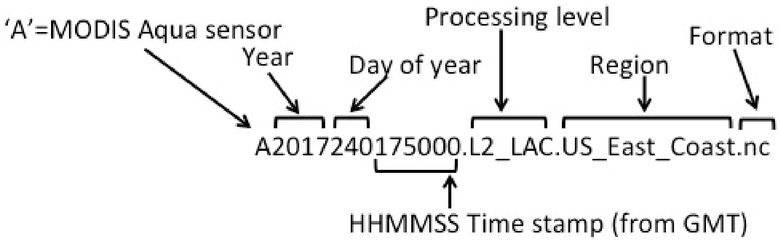
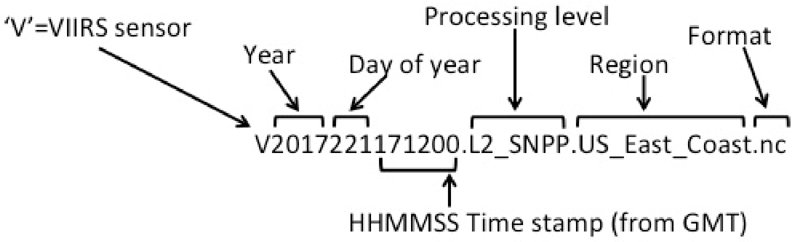


Figure 8. Defined region (black lines) for acquiring real-time NASA CHL and SST data.

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:





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 favor the CHL data from the VIIRS sensor, and SST is valid from either. Navigation data is accessible as data objects in both file sources as ‘lat’ and ‘lon’.

4.1.2. File Formats and navigations for ADEON satellite data sets

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	4.6 km^2	4320x8640
CHL	netCDF4	‘chlor_a’	‘lat’, ’lon’	+90, -180	4.6 km^2	4320x8640
NPP	HDF	‘npp’	Equidistant	+90, -180	12.5 km^2	2160x4320
MLD	HDF	‘mld’	Equidistant		12.5 km^2	2160x4320
Wind speed, Wind stress	netCDF	‘wind_speed’, ‘wind_stress’	‘latitude’, ‘longitude’	-80,-180	0.25 degree (~25 km^2)	1440x640
Eularian Surface Currents	netCDF	‘eastward_eularian_current_velocity’, ‘northward_eularian_current_velocity’	‘lat’, ’lon’	-80,-180	0.25 degree (~25 km^2)	1440x720

4.1.3. 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

Acronyms

AAF	anti-alias filter
AC	alternating current
ACI	acoustic complexity index
ADC	analog to digital converter
ADEON	Atlantic Deepwater Ecosystem Observatory Network
BTR	Bearing time record
CBF	Conventional beamformer
CMRR	common mode rejection ratio
CPA	closest point of approach
CSAC	chip-scale atomic clock
DR	dynamic range
DV	digital values
ENOB	effective number of bits
ESA	Endangered Species Act
FFT	fast Fourier transform
FIR	Finite Impulse Response
FS	full scale
HARP	High Frequency Acoustic Recording Package
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
LSB	least significant bit
MMPA	Marine Mammal Protection Act
NDBC	National Data Buoy Center
NRS	Noise Recording Station
OCS	Outer Continental Shelf
ONR	Office of Naval Research
PSRR	power supply rejection ratio
RF	radio frequency
rms	root mean square
SD	secure digital
SFA	Sustainable Fisheries Act
SFDR	spurious free dynamic range
SiNAD	signal to noise and distortion
SNR	signal to noise ratio
SPL	sound pressure level

TCXO	temperature controlled crystal oscillator
THD	total harmonic distortion
UDP	Unit Data Packet
UNH	University of New Hampshire
USCG	United States Coast Guard

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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 meta-data 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 or with *Microsoft Excel* or similar spreadsheet applications.

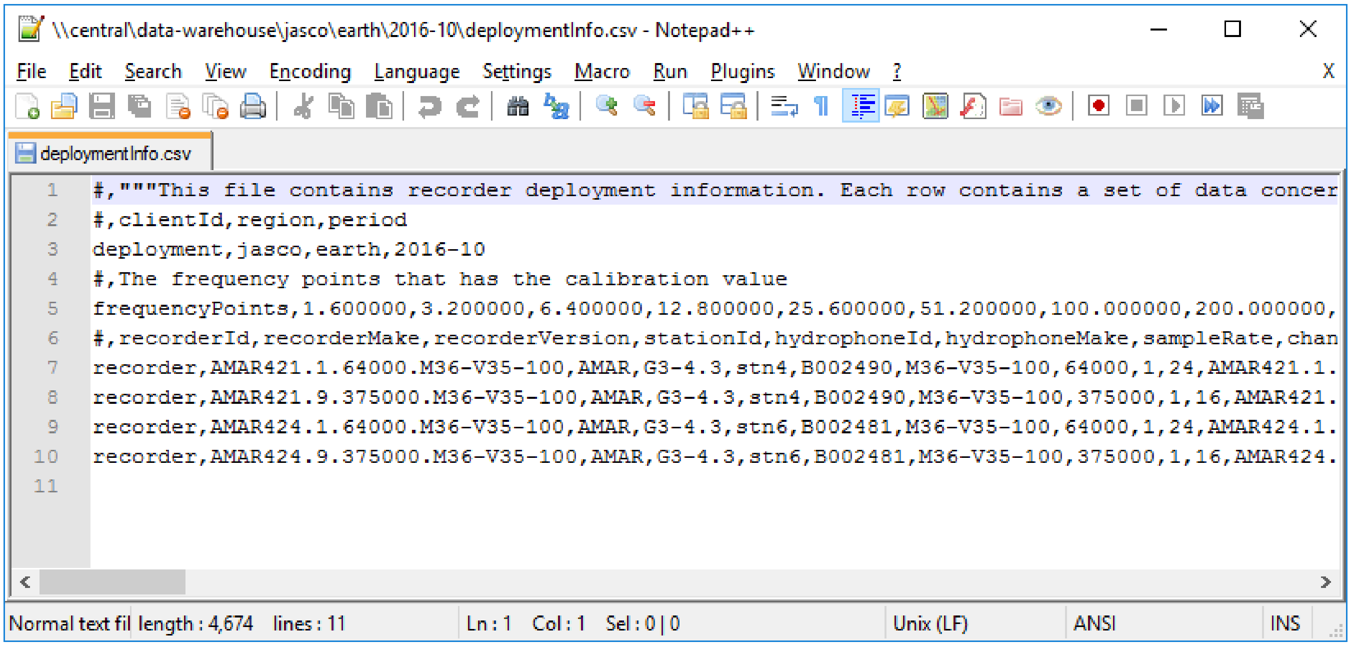
CAUTION Be careful that *Excel* doesn't remove leading zeroes from entries, say from serial numbers or folder names. A simple solution is to use *Excel* or similar only for viewing and use a text editor for creation and modification.

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

- Comment lines—start with a `#` character
- Header lines—a specific type of comment line, so they also start with a `#` character
- 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`

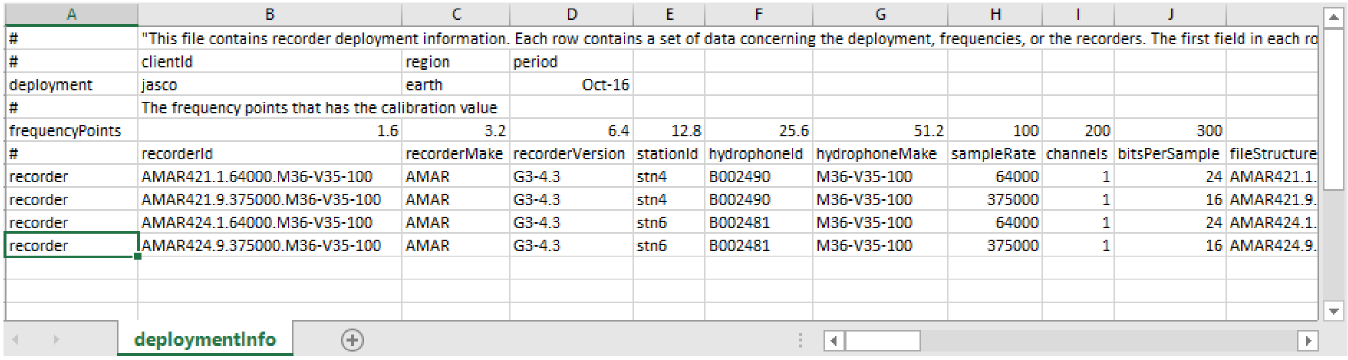
Other than comment lines, **do not use spaces** in the deployment file; instead use dashes, periods, or colons as per the instructions below. Use commas only to separate fields.

A sample Deployment Info File is shown in Figures 3 and 4, viewed in *Notepad* and *Excel*, respectively.



```
#,"""This file contains recorder deployment information. Each row contains a set of data concer
#,clientId,region,period
deployment,jasco,earth,2016-10
#,The frequency points that has the calibration value
frequencyPoints,1.600000,3.200000,6.400000,12.800000,25.600000,51.200000,100.000000,200.000000,
#,recorderId,recorderMake,recorderVersion,stationId,hydrophoneId,hydrophoneMake,sampleRate,chan
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.
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.
```

Figure 3. 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 ro									
#	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 4. 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 5 shows example folder structures for the following two deployments:

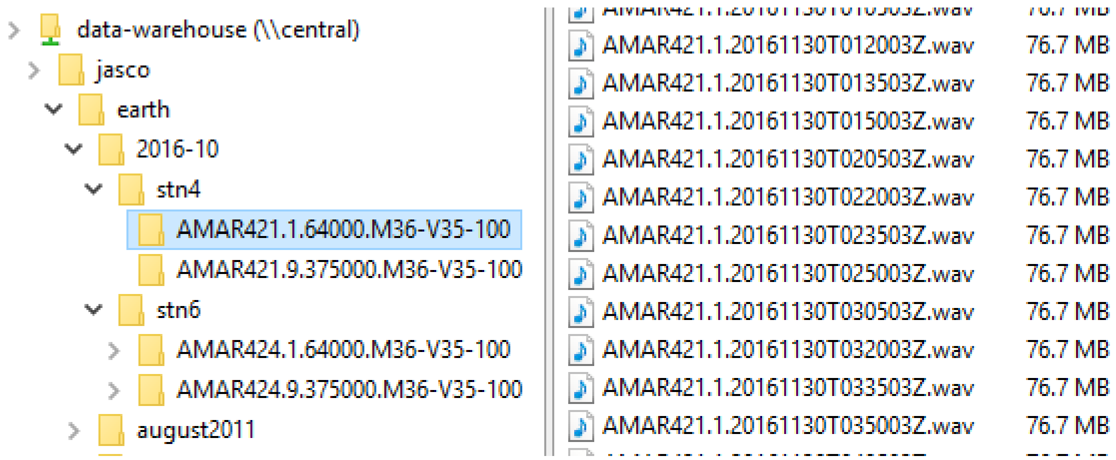
1. `2016-10` deployment: Recorder AMAR421 was deployed configured to record two (2) acoustic channels (Channels 1 and 9).

2. `2016-10` deployment: Recorders AMAR421 and AMAR424 were deployed at stations `stn4` and `stn6`, respectively. Each recorder configured to record on one 24-bit channel (Channel 1), and the 16-bit high sample rate channel (Channel 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, hyphens and periods are okay, 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.



data-warehouse (\\central)
  jasco
  earth
    2016-10
      stn4
        AMAR421.1.64000.M36-V35-100
        AMAR421.9.375000.M36-V35-100
      stn6
        AMAR424.1.64000.M36-V35-100
        AMAR424.9.375000.M36-V35-100
    august2011

AMAR421.1.20161130T012003Z.wav	76.7 MB
AMAR421.1.20161130T013503Z.wav	76.7 MB
AMAR421.1.20161130T015003Z.wav	76.7 MB
AMAR421.1.20161130T020503Z.wav	76.7 MB
AMAR421.1.20161130T022003Z.wav	76.7 MB
AMAR421.1.20161130T023503Z.wav	76.7 MB
AMAR421.1.20161130T025003Z.wav	76.7 MB
AMAR421.1.20161130T030503Z.wav	76.7 MB
AMAR421.1.20161130T032003Z.wav	76.7 MB
AMAR421.1.20161130T033503Z.wav	76.7 MB
AMAR421.1.20161130T035003Z.wav	76.7 MB

Figure 5. 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 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 6 shows the sampling of an acoustic signal.

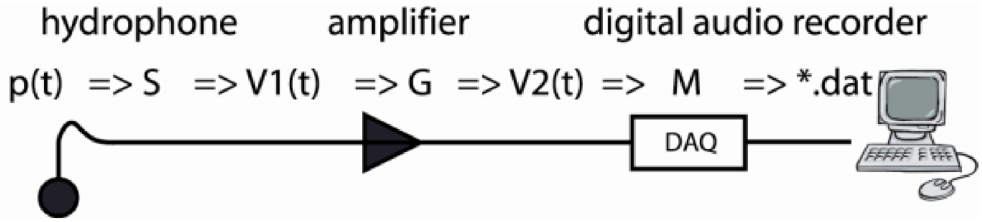


Figure 6. Signal data acquisition.

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 ($G_{\mathrm{AAF},V}$)
- The pre-amplifier voltage gain ($G_{\mathrm{pA},V}$)

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

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

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 6. 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 the 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. Table 7 instructs on how to fill in these fields.

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

Table 7. 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 *or* bigBirdUniversity
3	location	String, no spaces	Where the deployment occurred.	nileRiver *or* myBathtub
4	period	String, no spaces (recommend yyyy-dd)	When the deployment occurred/started	2012-06 *or* 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,hydrop
honeMake,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 8 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/µPa. These sensitivities correspond, in order, to the frequencies listed in the Frequency Points Line.

Table 8. 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	AMAR421.1.64000.M36-V35-100
3	`recorderMake`	String, no spaces	–	The recorder make and model	AMAR *or* AMAR-G3R3
4	`recorderVersion`	String: *major.minor*	–	The recorder firmware version	1.4

Field	Label	Format	Unit	Explanation	Example
5	`stationId`	String, no spaces	–	The recorder station. StationId and recorderId combine to create a unique “key” for each `recorder` line.	stn1 *or* B35 *or* 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`	Integer	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 *or* 24
11	`fileStructure`	String, no spaces	–	A deployment wav file name *[optional]*	*blank or* 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. 1.1.1.1.1.A.1.5)	0.00000485 *or* 7.63E-05
23	`sensitivity`	Float	dB	The logarithmic sensitivity at one specific frequency of the hydrophone. Based on a pistonphone calibration or the manufacturer’s documentation $10\,\mathrm{lg}\frac{M_{\mathrm{hp,V}}}{1\ \mathrm{V}/\mu\mathrm{Pa}}\ \mathrm{dB}$	-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) $10\,\mathrm{lg}\frac{M_{\mathrm{hp,V}}}{1\ \mathrm{V}/\mu\mathrm{Pa}}\ \mathrm{dB}$	-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/whaleVocalizaton/">
    <import schemaLocation="contourAnalysisXML.xsd"
namespace="http://www.example.org/whaleVocalizaton/"/>
    <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">
               <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 calclulate
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"/>
            <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"      maxOccurs="1"
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"/>
             <element name="maxSlidingWindowStats"
type="tns:WindowStatsTypeDefinition" minOccurs="0" maxOccurs="1"/>
       </sequence>
    </complexType>

    <complexType name="WindowStatsTypeDefinition">
      <attribute name="PeakSPL" type="double"/>
      <attribute name="RMSSPL" type="double"/>
      <attribute name="thirdOctaveSELs" 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>
```

A.3. **_ oneMinuteAmbientBBSPLsAndDetects_AOutput.csv

One ‘AOutput.csv file is generated for each recorder deployment. This file merges the $L_{p,60s,}$ $L_{pk,60s}$, $L_{p,ddec,60s}$, per-minute detector outputs and the across-file detector outputs into a single .csv file that is subsequently used for many plotting functions and soundscape analysis in Phase 4. The format for this file is describe below.

The ordering of the columns is defined by this Appendix. This is implemented by the order in which strings are present in the *oneMinuteAmbientBBSPLsAndDetects.csv file, and by the order in which the MatLab post-processing code appends columns during post-processing. The .CSV column ordering is determined by the order in which they are written to the object `StringBuffer minBuf` in `extractDetectionResults.java`. The MatLab post-processing column ordering is determined by the order in which columns are added to the `header` and `data` variables used in `ProcessCSVFile.m` and the various functions called from within.

The CSV columns are generally divided into five groups, always occurring in this order: time, SPL values, anthropogenic detector results, mammal detections, SPL values and Acoustic Complexity Indices (ACIs). The post-processing columns are always to the right of the CSV columns, and are generally divided into five groups, always occurring in this order: 10 Hz and Up SPL, weighted SPL values, airgun classifier output, shipping classifier output, and anthropogenic classifier output. The file format will be extended to include new processing outputs as needed during the ADEON project.

A.3.1. Time

The Time column is the time for each line in the CSV file, presented as a string in the format dd-mmm-yy hh:mm:ss. The time is always UTC, and the yy is the last two digits of the year with 20- omitted.

A.3.2. Broadband Sound Levels and Airgun

The broadband SPL values and airgun detection columns are always present and in the following order:

- Peak sound pressure level (Lpk,60s; dB re 1 µPa)
- Dummy value
- Root-mean square sound pressure level (Lrms,60s; dB re 1 µPa)

A.3.3. Anthropogenic Detector Results

This section contains the results of the shipping, airgun and impulse detectors for anthropogenic sound energy:

- Shipping Tonals – the number of constant frequency tones detected in this minute of data
- Airgun Pulses (count)
- Max Airgun SPL – maximum per-pulse SPL (dB re 1 µPa) using a 90 % energy window.
- One Minute Airgun SEL (dB re 1 µPa^2)
- MSFD – impulse SEL
- Number of Impulses detected from the configured Teager-Kaiser detector. The default settings detect events on the order of 50 – 500 ms long where the energy in the first 50 ms window is more than 50 times the energy on either side of the window.

A.3.4. Mammal Detections

The mammal detection columns have variable number and order. They are determined by the mammal detectors selected during data analysis. There is presently no comprehensive list of column names.

A.3.5. Band-limited SPL values (Lp,ddec,60s)

The band-limited SPL columns are always present but the number of columns is determined by the sample rate. The first column is the broadband SPL, followed by a variable number of decidecade SPL columns, followed by a variable number of decade-band SPL columns. All columns contain the one minute SPL in dB re 1 µPa.

A.3.5.1. Broadband SPL

The first column is always the broadband SPL, but the lower frequency limit is determined at the time the data is first processed by AcousticAnalysis. It could be 0.0, 1.0 Hz or 10.0 Hz. The upper frequency limit is typically half the sample rate. The list of allowed column header names is given in Appendix A.

A.3.5.2. Decidecade SPL

The next set of columns is the decidecade band SPL values (dB re 1 µPa). The column header is given as “x.x Hz”, where x.x is the nominal center frequency of the decidecade band (see Soundscape Specification Table 5). The first column may be “1.0 Hz” or “10.0 Hz”. The last column will be the last band center frequency which is below one-half of the sample rate. For example, data sampled at 16 kHz will have a “6300.0 Hz” band, but no “8000.0 Hz” band, since 8 kHz is exactly half (not below one half) of the sample rate. Note that it may to have an “incomplete” band even if the band center is below the Nyquist frequency. For example, 128 kHz data will have a “63000.0 Hz” column, but that column will not include data up to 71200 Hz that would ideally be included in a 63 kHz decidecade band, since only data up to at most 64 kHz are actually present in the data.

A.3.5.3. Decade Band SPL

The last set of columns is the decade band SPL values (dB re 1 µPa). The column header is given as "x.x Hz", where x.x is near the nominal center frequency of the decade band. The column names are not exactly the same as the nominal center frequency, to avoid duplication of column names from one-third octave columns. The possible columns are:

Column Name	Decade Band Range (Hz – Hz)	Present when fs greater than
31.6 Hz	10 – 100	Always present
316.0 Hz	100 – 1000	1000 Hz
3160.0 Hz	1000 – 10000	10000 Hz
31600.0 Hz	10000 – 100000	100000 Hz

A.3.6. ACIs

ACIs may be present, and will depend on the ACI configuration specified when AA was originally run. Each ACI header is in the format:

ACI[*lf-hf*|*bp*|*ip*]

Where

lf	Lower frequency bound of the ACI calculation (Hz)
hf	Upper frequency bound of the ACI calculation (Hz)
bp	The period of the FFT bins used in the ACI (seconds)
ip	The integration period of the ACI (seconds)

All columns values are ACIs according to the parameters as indicated in the corresponding header.

A.3.7. 10 Hz and Up SPL

This one column is always present and computed from the CSV one-third octave columns beginning with the 10.0 Hz column and ending with the highest band present.

A.3.8. Custom Bands SPL

If AAPA is configured to analyze custom frequency bands, then a variable number of columns will appear in this position. Each column header will be passed through unmodified from the AAPA configuration file loadParameters.m

A.3.9. Weighted SPL values

These six columns are always present in the following order:

- lfMWeighted SPL
- mfMWeighted SPL
- hfMWeighted SPL
- phocid MWeighted SPL
- otariid MWeighted SPL
- unWeighted SPL

Each of these is computed from the one-third octave columns. If the startMWeightsat1Hz Boolean is set then the SPL values start from the 1.0 Hz band, otherwise the default is to start from the 10.0 Hz band.

A.3.10. Airgun Classifier

There is one column titled “smoothed airgun SEL” which is always present.

A.3.11. Shipping Classifier

The shipping classifier columns are always present in the following order:

- 40 - 315 Hz
- lowest of the left and right sided minute mean for ll.l Hz-hhh.h Hz
    - where X is a function of the `backgroundWindowLength` parameter (but may be less than `backgroundWindowLength/2` for duty cycled data, to account for the actual amount of data available relative to the window length, which is treated as real time).
    - Where ll.l is the lowest and hhh.h is the highest frequency band included in the mean, either 63.0 – 1000.0, 40.0 – 2000.0, or 40.0 315.0 Hz depending on the `shippingDetectorShallow` parameter
- XX min moving avg number of tonals
    - XX is the length of the moving average in minutes, computed as `2*minShippingDuration+1`
- shipping detection flag
    - If this is duty cycled data with `continuousMinutes < 2`, then this is equal to the Shipping Tonals column produced by AA.
    - Otherwise the shipping tonals column is further processed to exclude ice condition times (as set by loadParameters), exclude tonals detected when airgun is present, exclude shipping when mammal detections exceed shipping detections, and limit shipping detections to continuous detections subject to minimum and maximum lengths (defined in loadParameters.m)
- vesselCPAFlag
    - This flag is set for the row that has the peak sound pressure level for a given time period bounding each shipping detection (after the filtering applied to shipping detection flag, above)
- ambient smoothed flag
    - This flag is set for any time which does not have any shipping, airgun, or biophony detections within a window of time either before or after the current time slice. This window size is set by either `loadParameters.fixedAnthropogenicShoulder`, or `loadParameters. anthropogenicExclusionForAmbientWindowStart`
- Ambient raw flag
    - This flag is set for any time which does not have any shipping, airgun, or biophony detections in the same time slice.

Appendix B. Terminology

B.1. New definitions

the following terms need to be defined:

term	definition	notes
high frequency marine mammal click	TBD	
raw data	calibrated sound pressure time series	
broadband SPL	TBD	
shipping tonal	TBD	
shipping band	frequency band between 40 Hz and 315 Hz	
rms time series	TBD	
maximum peak signal	TBD	
peak amplitude	zero-to-peak sound pressure	
minimum frequency	TBD	see Table 5
maximum instantaneous bandwidth	TBD	see Table 5
sweep rate	TBD	see Table 5
logarithmic sensitivity	TBD	see Table 9
calculated logarithmic hydrophone sensitivity	TBD	see Table 9
scattering amplitude	TBD	
low sampling rate Nyquist frequency	TBD	