DRAFT Soundscape and Modeling Metadata Standard
Version 2

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

Contract: M16PC00003

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Contents

Abbreviations

Non-acoustical abbreviations are listed in Table 1. For acoustical abbreviations see Appendix 1 (Table 15).

Table 1 – Non-acoustical abbreviations

Abbreviation	**Meaning**
ADEON	Atlantic Deepwater Ecosystem Observatory Network
AIS	Automatic Identification System (for shipping)
ANSI	American National Standards Institute
BIPM	International Bureau of Weights and Measures
BOEM	Bureau of Ocean Energy Management
EC	European Commission
ESA	Endangered Species Act
EU	European Union
GES	(MSFD) Good Environmental Status
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IQOE	International Quiet Ocean Experiment
ISO	International Organization for Standardization
ISQ	International System of Quantities
IWC	International Whaling Commission
JASCO	JASCO Applied Sciences
MMPA	Marine Mammal Protection Act
MS	(EU) Member State
MSFD	(EU) Marine Strategy Framework Directive
NA	not applicable
NMFS	NOAA National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OASIS	Ocean Acoustical Services and Instrumentation Systems, Inc.
OCS	outer continental shelf
ONR	Office of Naval Research
ONR-G	ONR Global
SBU	Stony Brook University
SFA	Sustainable Fisheries Act
SI	International System of Units
SWFSC	NOAA Southwest Fisheries Science Center
TNO	Netherlands Organisation for Applied Scientific Research
TSG Noise	(EU expert group) Technical Sub-Group Noise
UNH	University of New Hampshire
UTC	Coordinated Universal Time

1. Introduction

ADEON project

The Atlantic Deepwater Ecosystem Observatory Network (ADEON) for the U.S. Mid- and South Atlantic Outer Continental Shelf (OCS) is currently being developed and is anticipated to be deployed in the summer of 2017. 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 SWFSC.

This observatory network will generate long-term measurements of both the natural and human factors active in this region, thus informing the ecology and soundscape of the OCS. Long-term observations of living marine resources and marine sound will assist Federal agencies, including BOEM, ONR, and NOAA, in complying with mandates in the Endangered Species Act (ESA), Marine Mammal Protection Act (MMPA), and Sustainable Fisheries Act (SFA).

Objectives

ADEON project objectives

The ADEON project objectives are to:

- Establish an ecosystem observation network that provides baseline monitoring and supports predictive modeling of the soundscape and its relationship to marine life and the environment of the Mid- and South Atlantic Planning Areas.
- *Develop standardized measurement and processing methods and 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 analyses 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 for consideration in 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 mooring locations.
    - What are the environmental factors that define and constrain the horizontal range of appropriate extrapolation of observations measured at the stationary mooring sites?
- Develop and apply new methods for the effective visualization of 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.

ADEON Standardization objectives

The objectives of ADEON’s Standardization task are to:

- Ensure compatibility within ADEON between soundscapes based on measurements and those based on models;
- ensure compatibility between measurements made by different researchers or institutes within ADEON;
- facilitate compatibility between ADEON soundscapes, whether based on measurement or model 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 *Soundscape and Modeling Metadata Standard*, is the first of five Standardization reports, which together meet the above four objectives.

Report structure and terminology

The remainder of this report is structured as follows. In Sec. 2, the meaning of "soundscape" is discussed, and a specific meaning selected for the ADEON project. Quantitative and qualitative soundscape metrics are listed in Secs. 3 and 4, respectively, followed by requirements for reporting soundscape products in Sec. 5. The main report is followed by the following three appendices:

- Appendix 1 – Acoustical terminology;
- Appendix 2 – Non-acoustical terminology;
- Appendix 3 – Galway Statement on Atlantic Ocean Cooperation.

The terminology standard ISO 18405:2017 Underwater Acoustics – Terminology has been adopted by the ADEON project and is followed throughout this report. The main reasons for preferring ISO 18405 over other available terminology standards (e.g., ANSI S1.1-2013 Acoustical Terminology) are that it has international consensus and was developed specifically for underwater acoustics. For example, sound exposure level (SEL) is by default an unweighted quantity according to ISO 18405, consistent with the way this term is normally used by practitioners of underwater acoustics, whereas ANSI S1.1-2013 defines SEL as a weighted quantity, and by default A-weighted, making this ANSI standard unsuitable for underwater acoustics applications.

2. What is a soundscape?

Formal definition

For airborne acoustics, in the context of human hearing, the term "soundscape" usually implies an element of perception of the sound. For example, entry 2.3 of ISO 12913-1:2014 defines this term as "acoustic environment as perceived or experienced and/or understood by a person or people, in context". However, the same term is used without this implication in contexts other than human hearing, both in air (Pijanowski et al., 2011; Farina and Pieretti, 2012; Gage and Axel, 2014) and in water (Fay, 2009; Dugan et al., 2013; Hastings and Širović, 2015). For this reason, the definition of "soundscape" according to the international underwater acoustical terminology standard ISO 18405 also excludes a perception element. Following ISO 18405, therefore ADEON defines the terms 'soundscape' and 'ambient sound' as shown in Figure 1 and Figure 2, respectively. The related terms "auditory scene" and "auditory stream" are in use to describe the perception of a soundscape by a listener (Hulse, 2002; Shamma et al., 2011).

3.1.1.3
soundscape
<underwater acoustics> characterization of the *ambient sound* (3.1.1.2) in terms of its spatial, temporal and frequency attributes, and the types of sources contributing to the sound field

Figure 1 – Definition of “soundscape” from ISO 18405:2017.

3.1.1.2
ambient sound
sound (3.1.1.1) that would be present in the absence of a specified activity

Note 1 to entry: Ambient sound is location-specific and time-specific.

Note 2 to entry: In the absence of a specified activity, all sound is ambient sound.

Note 3 to entry: Ambient sound includes *ambient noise* (3.1.5.11).

Note 4 to entry: Examples of specified activity include the act of measuring the underwater sound and the radiation of sound by specified sound sources.

Note 5 to entry: Ambient sound can be anthropogenic (e.g. shipping) or natural (e.g. wind, biota).

Figure 2 – Definition of “ambient sound” from ISO 18405:2017.

Remarks on formal definition

The definition of soundscape excludes non-acoustic self-noise, such as flow noise. It also excludes acoustic self-noise such as the sounds from our ship or equipment, and sounds made by animals within the immediate proximity to the transducer attracted by our presence. Examples of acoustic self-noise include sound produced from biofouling organisms, sound produced by fish attracted as to a fish aggregation device, and sound made by inquisitive cetaceans “interrogating” our equipment. We therefore need to identify and remove self-noise from our recordings.

It is also possible that animals that would normally have vocalized are deterred from doing so by the deployment, use, maintenance or recovery of an active or passive acoustic sensor. While such vocalizations are by definition part of the soundscape, they would be absent from our recordings, making for an incomplete representation of the soundscape.

The risk of soundscape contamination, whether by omission of wanted sounds or by addition of self-noise, will be addressed by the ADEON deployment guidelines (Warren et al., 2017).

Requirements

In principle there are an infinite number of ways to quantify a sound field or soundscape. In practice we must select between these and the purpose of this report is to make this choice, guided by inputs from our sponsors (BOEM, ONR, and NOAA), the EU’s Marine Strategy Framework Directive (MSFD) and an international soundscapes workshop held in 2014.

Sponsor guidance

The project sponsors have indicated their interest in the following characteristics of a soundscape:

- Sound pressure time series;
- root-mean-square (rms) sound pressure and peak sound pressure, including statistics of the rms sound pressure;
- a measure of the anthropogenic addition to the natural background;

- metrics of relevance to signal excess at a resolution of not less than diurnal scale;
- metrics of relevance to masking or disturbance.

MSFD guidance

The project objective “Develop standardized measurement and processing methods and visualization metrics for comparing ADEON observations with data from other monitoring networks” requires international co-operation because underwater sound does not respect national boundaries. In addition, the Galway Statement (Appendix 3) announces a cooperation of EU, Canada and USA intended to advance a shared vision of a “healthy, resilient, safe, productive, understood and treasured” Atlantic Ocean.

To ensure international cooperation with Canada and the EU, it is important to seek international agreement on appropriate acoustical metrics. Compared with sound in air, for which 202 ISO standards have been published since the inception of the ISO Technical Committee TC43 Acoustics in 1947, there exist at the time of writing only three ISO standards relevant to underwater acoustics. Of these three, only one (the terminology standard, ISO 18405) is of direct relevance to soundscapes. In the absence of suitable international standards it makes sense to seek agreement on common metrics with international projects generally and with Canada and EU, to the extent that suitable acoustical metrics have been specified, or are being specified, by these parties.

The EU’s MSFD (EC, 2008) requires its Member States (MS) to achieve or maintain Good Environmental Status (GES) by the year 2020, which implies a requirement for the MS to monitor underwater sound. The MSFD specifies eleven descriptors of GES, one of which (Descriptor 11) specifically addresses underwater noise. GES Descriptor 11[1] is

Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment

The European Commission (EC) has defined two indicators for Descriptor 11, one (11.1.1) requiring MS to register use of impulsive sound sources, the other (11.2.1) requiring them to monitor underwater sound. Indicator 11.2.1, for “Continuous low frequency sound” reads (EC, 2010)

Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate

The EU expert group set up to advise MS on interpretation (TSG Noise) offers the following interpretation of Indicator 11.2.1 (Dekeling et al., 2014 – Part I):

Trends in the annual average of the squared sound pressure associated with ambient noise in each of two third octave bands, one centred at 63 Hz and the other at 125 Hz, expressed as a level in decibels, in units of dB re 1 µPa, either measured directly at observation stations, or inferred from a model used to interpolate between or extrapolate from measurements at observation stations

[1] see http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-11/index_en.htm

For the annual average, TSG Noise proposed processing by which the mean square sound pressure is determined in successive time intervals ("snapshots") of duration *T*. A distribution of snapshots with fixed *T* is then obtained by collecting them over one or more consecutive years. TSG Noise considered the mode, median, arithmetic mean (AM) and geometric mean (GM) of this distribution. Of these, all except the AM were found to depend on the choice of snapshot duration *T*. Because of the need for a robust measure and because there was no consensus on appropriate snapshot duration, the AM was therefore recommended for calculating trends based on the annual average. However, recognizing that the snapshot duration relevant to impact was likely to be less than a year, TSG Noise further recommended to retain not only a histogram in 1 dB level bins, but also the full time history of the root-mean-square sound pressure level (SPL[2]) with a snapshot duration not greater than one minute. The full TSG Noise recommendation (Dekeling et al., 2014 – Part II) reads

> *The advantages and disadvantages of different averaging methods (arithmetic mean, geometric mean, median and mode) are reviewed, and TSG Noise* ***recommends that Member States adopt the arithmetic mean****.*
>
> *In order to establish the statistical significance of the trend, additional statistical information about the distribution is necessary. TSG Noise recommends that* ***complete distribution be retained in the form of sound pressure levels as a function of time, along with a specified averaging time****. TSG Noise advises the retention of the amplitude distribution for this purpose in bins of 1 dB, and the associated snapshot duration. TSG Noise advises MS that the snapshot duration should not exceed one minute.*

IWC guidance

The international workshop 'Predicting sound fields – Global soundscape modelling to inform management of cetaceans and anthropogenic noise', sponsored by IWC, IQOE, NOAA, ONR-G, TNO, and Netherlands Ministry of Infrastructure and the Environment, was held in Leiden (the Netherlands) on 15-16 April 2014. The purpose of the workshop was to discuss sound modeling and mapping methodologies, to assess data needs, and to make recommendations for further development of existing techniques. The workshop report (IWC, 2014) makes the following recommendations

- *Record for 1 minute at least once per hour*
- *Compute daily sound level statistics*
- *Compute the arithmetic mean … in each 1/3 octave band from 10-1000 Hz for every 24h period*
- *Compute percentile power spectrum density levels (10th , 25th , 50th , 75th , 90th) in each 1/3 octave band from 10-1000 Hz, in 1-minute windows, for every 24-hour period.*

3. Quantitative soundscape metrics

In this section we specify the quantitative characteristics (metrics) that make up a soundscape. Practical considerations mean that what is measured is not identical to what is modeled. For example, measurements typically have high temporal resolution and low spatial resolution.

[2] SPL is also referred to as Lrms to distinguish this quantity from peak sound pressure level (Lpk)

Conversely, model predictions are capable of high spatial resolution, while their temporal resolution is limited.

Metrics derived from the sound pressure are used to describe a soundscape. Sound pressure is widely quantified in terms of its mean-square or peak values, often as a level in decibels, and less frequently in terms of its kurtosis. Specific metrics selected are the mean-square sound pressure level, Lrms, zero-to-peak sound pressure level, Lpk, and sound pressure kurtosis, β (ISO 18405):

$$L_{p,\mathrm{rms}} = 10\,\mathrm{lg}\frac{p_{\mathrm{rms}}^2}{p_0^2}\ \mathrm{dB}$$

$$L_{p,\mathrm{pk}} = 10\,\mathrm{lg}\frac{p_{\mathrm{pk}}^2}{p_0^2}\ \mathrm{dB},$$

where $p_0 = 1\ \mu\mathrm{Pa}$ is the reference sound pressure

$$\beta = \frac{\mu_4}{\mu_2^2}.$$

Here μ_2 and μ_4 are the second and fourth moments of the sound pressure

$$\mu_2 = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} [p(t) - \bar{p}]^2\,\mathrm{d}t$$

$$\mu_4 = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} [p(t) - \bar{p}]^4\,\mathrm{d}t,$$

where $p(t)$ is the sound pressure and $\bar{p}$ is the mean sound pressure between t_1 and t_2. If $\bar{p}$ is small, the second moment is approximately equal to the mean-square sound pressure, p_{rms}^2.

Particle motion is also relevant, especially for sensing of sound by fish and invertebrates, and for this reason the ADEON project plans to deploy receivers sensitive to particle motion. However, the study of particle motion is considered not yet sufficiently advanced for formal standardization, and is therefore excluded from the scope of this report.

Unlike for air acoustics, which has undergone widespread standardization since the late 1940s, the process of international standardization in underwater acoustics started in the early 2010s. As a result, standards for measurement, modeling or data processing for underwater acoustics are virtually non-existent. In particular, no widely accepted value for snapshot duration exists for underwater sound (nor for airborne sound applied to non-human animals). Therefore, the time window (snapshot duration) over which the various statistics are calculated needs to be specified.

Statistics

Arithmetic mean (AM)

Consider a snapshot i, during which the mean-square sound pressure, averaged over the snapshot duration T_i is Q_i ($Q_i = \overline{p^2}$)

$$Q_i = \frac{1}{T_i}\sum_j p_{i,j}^2,$$

where p_{ij} is the jth sample of the ith snapshot.

The sound pressure level is the level of the arithmetic mean of squared sound pressure samples

$$L_{p,\mathrm{a}} = 10 \lg \frac{Q_\mathrm{a}}{Q_0} \mathrm{dB},$$

where Q_0 = 1 μPa² and

$$Q_\mathrm{a} = \frac{\sum_{i=1}^{N} w_i Q_i}{\sum_{i=1}^{N} w_i}.$$

The individual mean-square sound pressures Q_i are weighted by w_i. This weighting factor is normally equal to 1. One exception is for combining contributions from unequal duration months to form an annual average. A non-unity weighting would also be appropriate to compensate for planned or unplanned downtime. For the case $w_i = 1$ the weighted mean simplifies to the unweighted arithmetic mean, i.e.,

$$Q_\mathrm{a} = \frac{1}{N} \sum_{1}^{N} Q_i.$$

Geometric mean (GM)

In the same way that Q_a is the AM of the individual Q_i values, we introduce Q_g as the GM of the Q_i. The weighted geometric mean (GM) of the snapshot Q_i values, Q_g , is related to the individual Q_i by

$$\log \frac{Q_\mathrm{g}}{Q_0} = \frac{\sum_{i=1}^{N} w_i \log \frac{Q_i}{Q_0}}{\sum_{i=1}^{N} w_i}.$$

For the case $w = 1$ the expression for $\log\left(Q_\mathrm{g} / Q_0\right)$ simplifies to the unweighted geometric mean

$$\log \frac{Q_\mathrm{g}}{Q_0} = \frac{1}{N} \sum_{1}^{N} \log \frac{Q_i}{Q_0}$$

The logarithm can be any base, but it simplifies conversion to decibels if base 10 is chosen. Specifically:

$$L_{p,\mathrm{g}} = 10 \lg \frac{Q_\mathrm{g}}{Q_0} \mathrm{dB}$$

$$\therefore L_{p,\mathrm{g}} = \frac{10\ \mathrm{dB}}{N} \sum_{1}^{N} \lg \frac{Q_i}{Q_0} = \frac{1}{N} \sum_{1}^{N} 10 \lg \frac{Q_i}{Q_0} \mathrm{dB}.$$

The GM is defined for completeness, primarily to clarify the difference between AM and GM. It is not used further in this standard.

Cumulative distribution function

The cumulative probability distribution function (cdf) provides temporal level percentiles. It is a cumulative histogram of the individual L_i values:

$$L_{p,i} = 10 \lg \frac{Q_i}{Q_0} \mathrm{dB}.$$

The cdf resolution shall be sufficient to extract at least the 10th, 25th, 50th, 75th and 90th temporal level percentiles (see also Section 5 (page 23) for reporting requirement). TSG Noise (Dekeling et al., 2014; Part II) advises a bin size no larger than 1 dB.

In the following, soundscape products are considered first for measurements, then for predictions.

Measurements

Metrics

Measured soundscape metrics are listed in Table 2 . Where 'AM' is stated, the arithmetic mean (AM) of the snapshot mean-square sound pressure values is calculated, and expressed as a level, in decibels ($L_{p,\mathrm{ddec}}$). The AM is expected to vary horizontally along each row, whereas its value in any one column should be a constant. The purpose in including the AM in every row is to provide a consistency check. Where 'cdf' is stated in a cell, it is calculated for all variables listed in the leading diagonal of that cell's row. A cdf is not required for distributions containing fewer than 100 samples.

Table 2 – Analysis/snapshot truth table: soundscape measurement products. Pale blue shading indicates optional metrics.

	Analysis window duration							
Snapshot duration	δt_{H}	**1 s**	**60 s**	**200 s**	**1 h**	**24 h**	**1 mo**	**1 a**
$\delta t_{\mathrm{H}} < 1$ s (optional)	$L_{p,\mathrm{ddec},\delta t_{\mathrm{H}}}$ $L_{p,\mathrm{pk},\delta t_{\mathrm{H}}}$ $\beta_{\delta t_{\mathrm{H}}}$	AM	AM, cdf		AM, cdf	AM, cdf	AM, cdf	AM, cdf
1 s		$L_{p,\mathrm{ddec,1s}}$ $L_{p,\mathrm{pk,1s}}$ β_{1s}	AM		AM, cdf	AM, cdf	AM, cdf	AM, cdf
60 s			$L_{p,\mathrm{ddec,60s}}$ $L_{p,\mathrm{pk,60s}}$ β_{60s}		AM	AM, cdf	AM, cdf	AM, cdf
200 s				$L_{p,\mathrm{ddec,200s}}$ $L_{p,\mathrm{pk,200s}}$ β_{200s}	AM	AM, cdf	AM, cdf	AM, cdf
1 h					$L_{p,\mathrm{ddec,1h}}$	AM	AM, cdf	AM, cdf
24 h						$L_{p,\mathrm{ddec,24h}}$ $L_{E,\mathrm{ddec,24h}}$ $L_{E,\mathrm{w,24h}}$	AM	AM, cdf
1 mo							$L_{p,\mathrm{ddec,1mo}}$	AM
1 a								$L_{p,\mathrm{ddec,1a}}$

For snapshot durations of 60 s or longer, the full time series of each variable shall be stored.

For snapshot durations of 1 s or longer, the full time series of each variable should be stored.

Soundscape products shall incorporate snapshot durations of one second (1 s), one minute (60 s), one hour (1 h = 3600 s), one day (24 h), one month (1 mo), and one year (1 a) and are chosen because of their correspondence with the way humans experience and report time. Where there is interest in the perception of sound, whether with regard to audibility, masking or loudness, a snapshot duration, δt_{H}, should be chosen to be of relevance to the form of perception of interest.

Possible values of δt_{H} range from a few hundred microseconds in connection with the detection of echolocation clicks (Vel'min and Dubrovskii, 1976; Moore et al., 1984; see also Branstetter et al., 2007) to a few hundred milliseconds for detection of other signals in noise (see Madsen et al, 2005, Kastelein et al., 2010a and references therein). For this purpose it is desirable to select simple sub-multiples of one second such as (say) 500 μs, 20 ms or 100 ms, such that an integer number of samples could be combined to recreate the statistics of a 1-s snapshot. While we consider it premature to recommend a value in this draft report, based on audibility measurements on two harbor seals (Kastelein et al., 2010b) and a beluga whale (Johnson, 1991), possible choices include values in the range 10 to 50 ms.

Finally, a duration of 200 s is included in order to facilitate comparisons with the historical records resulting from pioneering measurements by G. Wenz in the 1960s, for example at Point Sur (see Andrew et al., 2002), at San Nicolas Island (see McDonald et al., 2006), and at San Clemente Island (see McDonald et al., 2008).

Monthly and annual statistics of 1 d snapshots

The daily snapshots place special emphasis on the weighted sound exposure level (SELw) because of the 24-hour integration time recommended by Southall et al. (2007) and NOAA (2016).

The choice of weighting shall be flexible and permit the user to select between (for example) M weighting (Southall et al., 2007), current National Marine Fisheries Service (NMFS) weighting (NOAA, 2016) and flat weighting in specified standard frequency bands. Further, the weighting should be flexible enough to incorporate improved knowledge as it becomes available – see Houser et al. (2017) for a thorough review of frequency weighting functions.

Individual (unweighted) decidecade levels shall be stored in such a way as to permit appropriate frequency weighting in the future as understanding of animal hearing improves.

The selected weighting function(s) shall be specified for this study whenever derived products are provided.

Daily, monthly and annual statistics of 1 min snapshots

The one minute snapshots are used to construct a cdf of temporal level percentiles.

Broadband quantities

Peak sound pressure level (Lpk) and sound pressure kurtosis are broadband quantities and shall be reported in one or more of the decade or multi-decade frequency bands specified below. Broadband Lrms, SEL and SELw shall be reported in the same frequency band (or bands). The band (or bands) shall be specified.

Spectral and temporal correlation functions

Characterization of spectral and temporal correlations will be specified in the data processing standard (Heaney et al., 2017).

Summary of measurement products

The main soundscape measurement products are:

- Monthly and annual statistics of 24 h snapshots (e.g., SELw);
- hourly, daily, monthly and annual statistics of 60 s snapshots (e.g., Lrms);
- hourly, daily statistics of 1 s snapshots (e.g., Lrms).

Predictions

Metrics

Predictions are used to improve spatial resolution, permitting the creation of soundscapes, albeit at a lower temporal resolution than is available from measurements. There is therefore more emphasis on spatial statistics.

For predictions the short time scales (variability at scales less than a minute) are excluded because these are considered unpredictable. Similarly, kurtosis and Lpk are excluded as they too are considered unpredictable. The predictions therefore focus on Lrms and its statistics for snapshot durations of 1 min and longer, and SEL and its statistics for a snapshot duration of 24 h. Modeled soundscape products are listed in Table 3.

Table 3 – Temporal analysis/snapshot truth table: prediction products

	Temporal analysis window					
Snapshot duration	**60 s**	**200 s**	**1 h**	**24 h**	**1 mo**	**1 a**
60 s	$L_{p,\mathrm{ddec,60s}}$		AM	AM, cdf	AM, cdf	AM, cdf
200 s		$L_{p,\mathrm{ddec,200s}}$	AM	AM, cdf	AM, cdf	AM, cdf
1 h			$L_{p,\mathrm{ddec,1h}}$	AM	AM, cdf	AM, cdf
24 h				$L_{p,\mathrm{ddec,24h}}$ $L_{E,\mathrm{ddec,24h}}$ $L_{E,\mathrm{w,24h}}$	AM	AM, cdf
1 mo					$L_{p,\mathrm{ddec,1mo}}$	AM
1 a						$L_{p,\mathrm{ddec,1a}}$

For snapshot durations of 60 s or longer, the full time series of each variable shall be stored.

Spatial percentiles

Measurements at a fixed location provide high temporal resolution but no information about spatial variation evaluation of spatial percentiles.

Spatial statistics shall be predicted according to Table 4 for analysis footprints of area 1000 km^2, 10 000 km^2 and 100 000 km^2. Footprints smaller than 1000 km^2 and larger than 100 000 km^2 are optional. The analysis will be carried out in a volume given by the specified area and a range of depths to be determined.

These spatial statistics shall be calculated for a fixed snapshot duration, δt_{F}, to be specified. This snapshot duration shall be one of the durations from Table 3, i.e., one of 60 s, 200 s, 1 h, 24 h, 1 mo and 1 a.

Table 4 – Spatial analysis/footprint truth table: prediction products (for a fixed snapshot duration to be specified). Pale blue shading indicates optional metrics. The integer index refers to the power of 10 corresponding to the footprint area in square kilometers. The stated values are applicable to basin or OCS-scale predictions; finer scale (up to 1 km^2 resolution) are to be provided around the mooring positions.

	Spatial analysis window					
footprint area/ km^2	**10 km^2**	**100 km^2**	**1000 km^2**	**10 000 km^2**	**100 000 km^2**	**1000 000 km^2**
10	$L_{p,\mathrm{ddec},1}$	AM	AM, cdf	AM, cdf	AM, cdf	AM, cdf
100		$L_{p,\mathrm{ddec},2}$	AM	AM, cdf	AM, cdf	AM, cdf
1000			$L_{p,\mathrm{ddec},3}$	AM	AM, cdf	AM, cdf
10 000				$L_{p,\mathrm{ddec},4}$	AM	AM, cdf
100 000					$L_{p,\mathrm{ddec},5}$	AM
1000 000						$L_{p,\mathrm{ddec},6}$

Temporal correlation functions

Characterization of temporal correlations will be specified in the data processing standard (Heaney et al., 2017).

Spatial correlation functions

Characterization of spatial correlations will be specified in the data processing standard (Heaney et al., 2017).

Summary of prediction products

The main soundscape prediction products are:

- Monthly and annual statistics of 24 h snapshots (e.g., SELw);
- hourly, daily, monthly and annual statistics of 60 s snapshots.

Practical choices

Decidecade bands

Decidecade bands shall be used. A decidecade is defined as one tenth of a decade (ISO 18405). Its value is approximately equal to that of one third of an octave, and for this reason is sometimes referred to as a “one-third octave”.

More specifically frequency bands of IEC 61260-1:2014 are used, consistent also with ANSI S1.6-2016. According to IEC 61260-1 the center frequencies f_c are

$$f_{\mathrm{c},n} = (1\ \mathrm{kHz})\ 10^{\frac{n}{10}}.$$

Upper and lower frequencies are respectively 0.5 ddec above and below the center frequency, namely

$$f_{\mathrm{max},n} = f_{\mathrm{c},n}\ 10^{\frac{n}{20}}$$

$$f_{\mathrm{min},n} = f_{\mathrm{c},n}\ 10^{-\frac{n}{20}}.$$

Table 5 shows nominal “one-third octave” bands according to IEC 61260-1 for decidecade frequency bands with center frequencies 1 Hz ($n = -30$) Hz to 1 MHz ($n = +30$). Their precise bandwidth is one tenth of a decade (one decidecade), which is close to one third of an octave. Center frequencies of nominal octave bands (the precise bandwidth of these frequency bands is 3 ddec) are **bold.**

Table 5: Decidecade frequency bands, as defined by IEC 61260-1:2014, with center frequencies between 1 Hz ($n = -30$) and 1 MHz ($n = +30$). Alternate light and dark shading shows decade bands A to F specified in Table 6.

band index	**Lower bound**	**center frequency**	**Upper bound**	**(nominal center frequency)**
n	f_{min} /Hz	f_{c} /Hz	f_{max} /Hz	$f_{\mathrm{c,nom}}$
-30	0.891251	1	1.122018	(1 Hz)
-29	1.122018	1.258925	1.412538	(1.25 Hz)
-28	1.412538	1.584893	1.778279	(1.6 Hz)
-27	1.778279	1.995262	2.238721	(2 Hz)
-26	2.238721	2.511886	2.818383	(2.5 Hz)
-25	2.818383	3.162278	3.548134	(3.2 Hz)
-24	3.548134	3.981072	4.466836	(4 Hz)
-23	4.466836	5.011872	5.623413	(5 Hz)
-22	5.623413	6.309573	7.079458	(6.3 Hz)
-21	7.079458	7.943282	8.912509	(8 Hz)
-20	8.912509	10	11.22018	(10 Hz)
-19	11.22018	12.58925	14.12538	(12.5 Hz)
-18	14.12538	15.84893	17.78279	(16 Hz)
-17	17.78279	19.95262	22.38721	(20 Hz)
-16	22.38721	25.11886	28.18383	(25 Hz)
-15	28.18383	31.62278	35.48134	(32 Hz)
-14	35.48134	39.81072	44.66836	(40 Hz)
-13	44.66836	50.11872	56.23413	(50 Hz)
-12	56.23413	63.09573	70.79458	(63 Hz)
-11	70.79458	79.43282	89.12509	(80 Hz)
-10	89.12509	100	112.2018	(100 Hz)
-9	112.2018	125.8925	141.2538	(125 Hz)
-8	141.2538	158.4893	177.8279	(160 Hz)
-7	177.8279	199.5262	223.8721	(200 Hz)
-6	223.8721	251.1886	281.8383	(250 Hz)
-5	281.8383	316.2278	354.8134	(320 Hz)
-4	354.8134	398.1072	446.6836	(400 Hz)
-3	446.6836	501.1872	562.3413	(500 Hz)
-2	562.3413	630.9573	707.9458	(630 Hz)
-1	707.9458	794.3282	891.2509	(800 Hz)
0	891.2509	1000	1122.018	(1 kHz)
1	1122.018	1258.925	1412.538	(1.25 kHz)
2	1412.538	1584.893	1778.279	(1.6 kHz)
3	1778.279	1995.262	2238.721	(2 kHz)
4	2238.721	2511.886	2818.383	(2.5 kHz)
5	2818.383	3162.278	3548.134	(3.2 kHz)
6	3548.134	3981.072	4466.836	(4 kHz)
7	4466.836	5011.872	5623.413	(5 kHz)
8	5623.413	6309.573	7079.458	(6.3 kHz)
9	7079.458	7943.282	8912.509	(8 kHz)

10	8912.509	10000	11220.18	(10 kHz)
11	11220.18	12589.25	14125.38	(12.5 kHz)
12	14125.38	15848.93	17782.79	(16 kHz)
13	17782.79	19952.62	22387.21	(20 kHz)
14	22387.21	25118.86	28183.83	(25 kHz)
15	28183.83	31622.78	35481.34	(32 kHz)
16	35481.34	39810.72	44668.36	(40 kHz)
17	44668.36	50118.72	56234.13	(50 kHz)
18	56234.13	63095.73	70794.58	(63 kHz)
19	70794.58	79432.82	89125.09	(80 kHz)
20	89125.09	100000	112201.8	(100 kHz)
21	112201.8	125892.5	141253.8	(125 kHz)
22	141253.8	158489.3	177827.9	(160 kHz)
23	177827.9	199526.2	223872.1	(200 kHz)
24	223872.1	251188.6	281838.3	(250 kHz)
25	281838.3	316227.8	354813.4	(320 kHz)
26	354813.4	398107.2	446683.6	(400 kHz)
27	446683.6	501187.2	562341.3	(500 kHz)
28	562341.3	630957.3	707945.8	(630 kHz)
29	707945.8	794328.2	891250.9	(800 kHz)
30	891250.9	1000000	1122018	(1 MHz)

Decade and multi-decade bands

One of the ADEON project objectives is to develop “standardized measurement and processing methods and visualization metrics for comparing ADEON observations with data from other monitoring networks.” To meet this objective we need to be able to compare like with like not just within ADEON but also with other projects outside our control. This implies a need to specify precise frequency bands that are both useful and achievable. The decidecade is used as a basic building block for broadband quantities because decidecade bands are well defined (IEC 61260-1) and are being adopted by EU MS in connection with the MSFD.

For a decidecade band it suffices to specify the index of that band (**Table 5**) and snapshot duration. For other quantities we need to specify upper and lower frequency limits, but on its own that does not meet our objective, because if another projects chooses a different band (or averaging time), a like comparison is no longer possible. At some stage we therefore need to be prescribe the frequency band. Requirements for this frequency band must be:

- broad enough such that properties like peak sound pressure and kurtosis provide meaningful correlates with potential effects on aquatic life;
- narrow enough to be achievable by another present or future project (e.g., US or EU) with comparable but not identical resources, such that it would be reasonable for a regulator to require it of others.

We suggest that a one decade band (comprising 10 contiguous decidecade bands) meets both requirements, while accepting that there needs to be some flexibility in the precise choice of decade. Our proposal is to specify (see Table 6) a selection of decade and multi-decade bands from which to choose, according to local requirements and equipment availability.

Table 6 – Proposed decade and multi-decade frequency bands. For precise frequencies see Table 5.

name of frequency band	index n_{min} of lowest decidecade	lower frequency limit (3 sig. figs.)	index n_{max} of highest decidecade	upper frequency limit (3 sig. figs.)	# decades
band A	-30	0.891 Hz	-21	8.91 Hz	1
band B	-20	8.91 Hz	-11	89.1 Hz	1
band C	-10	89.1 Hz	-1	891 Hz	1
band D	0	891 Hz	+9	8.91 kHz	1
band E	+10	8.91 kHz	+19	89.1 kHz	1
band F	+20	89.1 kHz	+29	891 kHz	1
band AB	-30	0.891 Hz	-11	89.1 Hz	2
band BC	-20	8.91 Hz	-1	891 Hz	2
band CD	-10	89.1 Hz	+9	8.91 kHz	2
band DE	0	891 Hz	+19	89.1 kHz	2
band EF	+10	8.91 kHz	+29	891 kHz	2
band AC	-30	0.891 Hz	-1	891 Hz	3
band BD	-20	8.91 Hz	+9	8.91 kHz	3
band CE	-10	89.1 Hz	+19	89.1 kHz	3
band DF	0	891 Hz	+29	891 kHz	3
band AD	-30	0.891 Hz	+9	8.91 kHz	4
band BE	-20	8.91 Hz	+19	89.1 kHz	4
band CF	-10	89.1 Hz	+29	891 kHz	4
band AE	-30	0.891 Hz	+19	89.1 kHz	5
band BF	-20	8.91 Hz	+29	891 kHz	5
band AF	-30	0.891 Hz	+29	891 kHz	6

On its own the existence of this table is not enough to ensure compatibility. If one project chooses to report broadband quantities in decade band CD (89.1 Hz to 8.91 kHz) while another selects band DE (891 Hz to 89.1 kHz), a like-with-like inter-project comparison of such broadband quantities would not be possible. Therefore there remains a need to encourage cross-project co-ordination to ensure compatibility.

Broadband quantities such as peak sound pressure level and kurtosis shall be reported in one or more of the standard frequency bands specified in Table 6. Each band spans an integer number (between 1 and 6) of contiguous decades. The selected band shall be specified. Frequencies outside the specified reporting band shall be removed, using appropriate filters. The choice of band should take into consideration both local conditions and the need for compatibility with other projects.

Remark on ISO, IEC and ANSI terminology for fractional octave bands

Both IEC 61260-1:2014 and ANSI S1.6-2016 use the term "one-third octave" to mean one tenth of a decade, while ISO 18405:2017 uses the term "decidecade" for the same quantity. We follow ISO 18405, which defines "one-third octave" as one third of an octave and "decidecade" as one tenth of a decade. An alternative term for decidecade is "one-third octave (base 10)".

For standard decidecade bands (IEC 61260-1:2014) see Table 5. For proposed standard decade and multi-decade bands (this report) see Table 6.

For decidecade bands whose index is less than -20, the acoustic period is comparable with (and in some cases greater than) 1 s, making the choice of a 1-second snapshot duration questionable. For this reason, the 1-second snapshot duration is optional for frequency bands comprising decidecade bands with $n < -20$.

Duration of snapshots and analysis windows

Second, minute and hour

Short durations of up to one day (1 d) shall be expressed in units of seconds, minutes or hours. The second is the SI unit of time (BIPM, 2014), while the minute, hour and day are defined in terms of the second (Table 7). Longer durations may be expressed either in these SI-compatible units or in units of days, months or years. Ambiguities in these longer units are discussed in turn below.

Table 7 – Units of time used to report ADEON statistics (ISO 80000-3:2006)

unit	symbol	definition	duration	notes
second	s	duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom	1 s	SI base unit (BIPM, 2014)
minute	min	60 s	60 s	exact (BIPM, 2014)
hour	h	60 min	60 min	exact (BIPM, 2014) 60 min = 3600 s
day	d	24 h	24 h	exact (BIPM, 2014) 24 h = 86 400 s
UTC month	mo	one calendar month	28 d to 31 d	the use of unequal month durations introduces a risk that selected statistics might be distorted (for example, the number of extreme events will be larger on average in long months than in short ones)
UTC year	a	one calendar year	365 d or 366 d	

Day

The day is defined by BIPM as 24 hours (86 400 s), almost identical to the UTC calendar day, which can differ from 86 400 s because of occasional leap second adjustments to UTC. This variation is considered negligible by the present authors, and no further distinction is made in this report between the UTC day and the BIPM day.

Month

The UTC calendar month varies between 28 and 31 days, a variation of up to about 10 % (Table 8). Specifically, the maximum departures from a mean Julian month of 730.5 h are -8 % (28 d = 672 h) and +2 % (31 d = 744 h). Such a variation in snapshot duration or analysis window can lead to statistical artefacts caused only by the difference in this duration.[3] To avoid this risk one could instead construct statistics of equal sized (Julian) months by combining either 14,610 two hundred-second snapshots or 730.5 one-hour snapshots. Compliance with this ADEON standard requires reporting statistics in UTC calendar months.

Table 8 – Variations in the duration of a "month", including UTC calendar months and mean Julian month.

duration / days	**duration / hours**	**notes**
28	672	February (non-leap years)
29	696	February (leap year)
30	720	even months, except February
365.25/12 = 30.4375	730.5	mean Julian month
31	744	odd months

Year

The UTC calendar year is either 365 or 366 days. This one day variation amounts to less than 0.3 %, which is considered unlikely by the present authors to lead to statistically significant artefacts.

Conversion to local time

Conversion from UTC to local time is optional, and sometimes desirable, with the time relative to dawn or dusk being of particular relevance. Nautical definitions of dawn and dusk shall be used.

Nautical dawn occurs when the sun is 12° below the horizon to sunrise. Nautical dusk occurs when the sun is 12° below the horizon to sunset (Leroy et al., 2016). Precise times of sunrise and sunset can be found at US Naval Observatory Astronomical Applications Department website (USNO, 2011).[4]

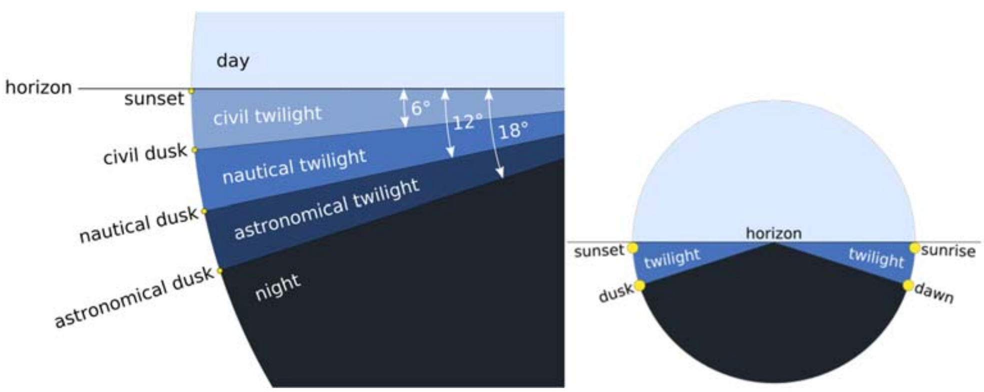

Figure 3 – Definition of dusk and dawn (source: https://en.wikipedia.org/wiki/Dawn[5]). The nautical definitions of dusk and dawn shall be used.

[3] For identical weather conditions, the probability of a storm occurring in January is greater than that of a storm in February. Therefore, on average one can expect a higher value for the 99th percentile waveheight in January than in February. For the same reason, on average one would expect to encounter a higher value for the 99th percentile sound pressure level in January than in February, even for statistically identical acoustical conditions.
[4] see also http://www.gaisma.com/en/
[5] left: By TWCarlson - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=21159109; right: By TWCarlson - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=21157096

Duty cycle

For sampling rates up to 2 kHz (corresponding to a system with a Nyquist frequency less than 1 kHz), the recording duty cycle shall be continuous.

For sampling rates up to 100 kHz (Nyquist frequency below 50 kHz), the recording duty cycle shall be not less than three minutes in every hour.

Duty cycle (proportion of planned recording time, e.g., 1 minute every hour) shall be specified.

Downtime (e.g., lost time due to maintenance or equipment failure) shall be specified.

Receiver depths

Receiver depths for measurements shall be chosen according to Warren et al. (2017).

Receiver depths for predictions shall comply with IWC guidelines (IWC, 2014):

> *In order to characterize the heterogeneity of the sound field in any one modelled geographic location, and allow assessment of the predicted sound fields to which marine life living at or diving to different depths might be exposed, modelling should be conducted with outputs spanning the near surface to full ocean depth. The receiver depths modelled should offer higher resolution in surface waters but include depths at well-defined intervals to the ocean bottom. To accomplish this, it is recommended that sound levels be computed at the following depth intervals where applicable: every 5 m depth interval to 30 m (5, 10, 15...), every 10 m in depth to 100 m (i.e. 30, 40, 50….), every 100 m to 1,000 m depth (200, 300, 400, 500…), at 2,000 m, 3,000 m, 4,000 m, 5,000 m, and at a contour following the bottom depth directly (i.e. 1 m) above the seabed*

Combination of measurement and prediction products

The combination of measurements and predictions will be addressed in Phase IV of the ADEON project.

4. Qualitative soundscape metrics

By definition a soundscape includes qualitative information concerning “the types of sources contributing to the sound field”. At the very least we can report what sources are known or expected to be present, based on sources of information about activities in the area such as AIS, shipping radar, and permits for offshore activities.

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 measure this proportion. What can be measure instead is the proportion of time for which the contribution from a specified source dominates, for a specified snapshot duration (e.g., 1 min).

Regardless of their generic nature, the present study will explore ways of characterizing measured sounds from sources of unknown or uncertain origin.

Geophysical sources

For a snapshot duration of 1 min, snapshots dominated by wind shall be identified.

For a snapshot duration of 1 min, snapshots dominated by rain should be identified.

For a snapshot duration of 1 min, snapshots dominated by one or more lightning strikes should be identified.

For a snapshot duration of 1 min, identification of snapshots dominated by resuspension should be considered.

The above statements apply to measurements. For modeled soundscapes, the contribution from wind shall be quantified.

Biological sources

Mysticete detectors for fin, blue, sei, humpback, right and minke whales should be considered.

Whistle detectors for pilot whales and the rest of the delphinid group should be considered.

Click detectors for sperm whales, delphinids and pilot whales, beaked whales (e.g., Sowerby's, Cuvier's, Blainville's), porpoise, Kogia sp. should be considered.

The detector algorithms, manual validation methods, and detector performance results shall be clearly reported.

Man-made sources

For a snapshot duration of 1 min, snapshots dominated by vessel sounds shall be identified.

For a snapshot duration of 1 min, snapshots dominated by one or more airgun pulses should be identified.

The detector algorithms, manual validation methods, and detector performance results shall be clearly reported.

5. Reporting soundscape products

International Systems of Quantities (ISQ)

All quantities and their units are reported following ISQ as specified by ISO/IEC 80000 Quantities and Units. The only exceptions are where overruled by the precedence rule of the acoustical (see Appendix 1) or non-acoustical (Appendix 2) terminology.

Coordinated Universal Time

All times shall be reported in UTC, following ISO 8601. Where local time is of particular relevance, for example in connection with dawn or dusk choruses, conversion to local time should be considered.

Reporting levels in decibels

Levels shall be reported in one of the following permitted forms

$$L_Q = \langle x \rangle \text{ dB re } \langle Q_0 \rangle$$

$$L_Q = \langle x \rangle \text{ dB (re } \langle Q_0 \rangle)$$

$$L_Q(\text{re } \langle Q_0 \rangle) = \langle x \rangle \text{ dB}$$

$$L_{Q/Q_0} = \langle x \rangle \text{ dB} \,,$$

where L_Q is the level of a quantity Q, the numerical value in decibels is x. The nature of the physical quantity shall be specified. The reference value Q_0 for reporting the levels shall be specified (a history of reference values used in underwater acoustics is provided by Ainslie, 2015). For quantities listed in Table 9 the reference values shall be those of the right-hand column of that table. Once adopted, the same form shall be followed throughout any single report.

Table 9 – The reference values in this table shall be used. All are compliant with ISO 18405.

Term (**Table 14**)	**Abbr.**	**symbol**	**unit**	**reference value**
rms sound pressure level	Lrms or SPL	$L_{p,\mathrm{rms}}$	dB	$1\ \mu\mathrm{Pa}$
peak sound pressure level	Lpk	$L_{p,\mathrm{pk}}$	dB	$1\ \mu\mathrm{Pa}$
sound exposure level	SEL	L_E	dB	$1\ \mu\mathrm{Pa}^2\ \mathrm{s}$
source level	SL	L_S	dB	$1\ \mu\mathrm{Pa\ m}$
propagation loss	PL	N_{PL}	dB	$1\ \mathrm{m}$
transmission loss	TL	ΔL_{TL}	dB	NA
mean-square sound pressure spectral density level	PSDL	$L_{p,f}$	dB	$1\ \mu\mathrm{Pa}^2/\mathrm{Hz}$
sound exposure spectral density level	ESDL	$L_{E,f}$	dB	$1\ \mu\mathrm{Pa}^2\ \mathrm{s/Hz}$

Compliant examples include:
sound pressure level: $L_p = 80\ \mathrm{dB\ re\ 1\ \mu Pa}$

sound exposure level: $L_E = 170\ \mathrm{dB\ (re\ 1\ \mu Pa^2 s)}$

source level: $L_S(\mathrm{re\ 1\ \mu Pa\ m}) = 210\ \mathrm{dB}$

sound power level: $L_{W/(1\ \mathrm{pW})} = 100\ \mathrm{dB}$

Non-compliant examples include:
sound pressure level: $L_p = 80\ \mathrm{dB_{rms}\ re\ 1\ \mu Pa}$

sound pressure level: $L_p = 100\ \mathrm{dB\ SPL}$

mean-square sound pressure spectral density level: $L_{p,f} = 170\ \mathrm{dB}\ \left(\mathrm{re\ 1\ \mu Pa/Hz^{\frac{1}{2}}}\right)$

source level: $L_S = 210\ \mathrm{dB\ re\ 1\ \mu Pa\ @\ 1\ m}$

Reporting level percentiles

The 10th, 25th, 50th, 75th, 90th temporal level percentiles shall be reported. In addition, the 1st, 5th, 95th and 99th temporal level percentiles should be reported where justified by the number of samples available.

For predictions, the 10th, 50th, 90th spatial level percentiles shall be reported.

For applications related to human hearing, exceedance levels are used to characterize noise levels in air (ISO 1996-1). Conversion of level percentiles to exceedance levels is optional.

6. Appendix 1 – Acoustical terminology (normative)

This section will be incorporated into the Project Dictionary (acoustical terminology standard).

Every attempt has been made by the ADEON project to follow relevant international standards. Nevertheless where there is a project-specific need to depart from an international standard, this is achieved by giving the ADEON standard precedence over all others. For acoustical terminology, the following standards are followed, in order of decreasing precedence

- ADEON acoustical terminology standard (this appendix)
- ISO 18405:2017 Underwater Acoustics – Terminology
- ISO 80000-8:2007 Quantities and Units – Acoustics
- ISO 80000-3:2006 Quantities and Units – Space and Time
- ISO 80000-1:2009 Quantities and Units – General

General acoustical concepts and quantities

Qualitative descriptions of concepts like "sound" and "soundscape" are needed (see Table 10) before the physical characteristics of these concepts can be quantified (Table 11).

Table 10 – General acoustical terminology: concepts

term	**Definition**	**notes**
sound	alteration in pressure, stress or material displacement propagated via the action of elastic stresses in an elastic medium and that involves local compression and expansion of the medium, or the superposition of such propagated alterations	source: ISO 18405, entry 3.1.1.1
ambient sound	*sound* (3.1.1.1) that would be present in the absence of a specified activity	see Figure 2 source: ISO 18405, entry 3.1.1.2
soundscape	<underwater acoustics> characterization of the *ambient sound* (3.1.1.2) in terms of its spatial, temporal and frequency attributes, and the types of sources contributing to the sound field	see Figure 1 source: ISO 18405, entry 3.1.1.3
material element	smallest element of the medium that represents the medium's mean density	source: ISO 18405, entry 3.1.1.5
signal	specified time-varying electric current, voltage, *sound pressure* (3.1.2.1), *sound particle displacement* (3.1.2.9), or other field quantity of interest	source: ISO 18405, entry 3.1.5.8
acoustic self-noise	*sound* (3.1.1.1) at a receiver caused by the deployment, operation, or recovery of a specified receiver, and its associated platform	source: ISO 18405, entry 3.1.5.10
ambient noise	*sound* (3.1.1.1) except *acoustic self-noise* (3.1.5.10) and except *sound* associated with a *specified signal* (3.1.5.8)	source: ISO 18405, entry 3.1.5.11

term	Definition	notes
snapshot	time interval within which a statistic of the sound pressure is calculated or estimated	examples of statistic include rms sound pressure, peak sound pressure, and sound pressure kurtosis
temporal analysis window	time interval during which statistics are calculated over multiple snapshots	
footprint	volume of space within which the spatially averaged mean-square sound pressure is calculated or estimated, for a specified snapshot duration	The size of an averaging footprint is specified by means of an area (e.g., 1000 km^2) and a range of depths (e.g., 50 m to 200 m)
spatial analysis window	volume of space within which statistics are calculated over multiple averaging footprints	The size of an analysis window is specified by means of an area (e.g., 100 000 km^2) and a range of depths (e.g., 50 m to 200 m)

Table 11 – General acoustical terminology: quantities

preferred term	synonym	unit	Symbol	Definition	notes
sound pressure		Pa	$p(t)$	contribution to total pressure caused by the action of *sound* (3.1.1.1)	from ISO 18405, entry 3.1.2.1
sound pressure spectrum		Pa/Hz	$P(f)$	Fourier transform of the *sound pressure* (3.1.2.1)	from ISO 18405, entry 3.1.2.2
zero-to-peak sound pressure	peak sound pressure	Pa	$p_{0-\mathrm{pk}}$ p_{pk}	greatest magnitude of the *sound pressure* (3.1.2.1) during a specified time interval, for a specified frequency range	from ISO 18405, entry 3.1.2.3
sound particle displacement				displacement of a *material element* (3.1.1.5) caused by the action of *sound* (3.1.1.1)	source: ISO 18405, entry 3.1.2.9
mean-square sound pressure		Pa^2	$\overline{p^2}$	integral over a specified time interval of squared *sound pressure* (3.1.2.1), divided by the duration of the time interval, for a specified frequency range	from ISO 18405, entry 3.1.3.1

preferred term	synonym	unit	Symbol	Definition	notes
time-integrated squared sound pressure	sound pressure exposure	Pa^2 s	$E_{p,T}$	<underwater acoustics> integral of the square of the *sound pressure* (3.1.2.1), p, over a specified time interval or event, for a specified frequency range	from ISO 18405, entry 3.1.3.5
sound pressure exposure spectral density	sound exposure spectral density	Pa^2 s/Hz	E_f	<underwater acoustics> distribution as a function of non-negative frequency of the time-integrated squared *sound pressure* (3.1.3.5) per unit bandwidth of a sound having a continuous spectrum	from ISO 18405, entry 3.1.3.9
Mean-square sound pressure spectral density		Pa^2/Hz	$\left(\overline{p^2}\right)_f$	distribution as a function of non-negative frequency of the *mean-square sound pressure* (3.1.3.1) per unit bandwidth of a sound having a continuous spectrum	from ISO 18405, entry 3.1.3.13
one-third octave	one-third octave (base 2)	oct		one third of an octave	from ISO 18405, entry 3.1.4.1 An octave is the logarithmic frequency ratio corresponding to a factor 2 increase in frequency (ISO 80000-8:2007). cf *decidecade*
decidecade	one-third octave (base 10)	oct	ddec	one tenth of a decade	from ISO 18405, entry 3.1.4.2 A decade is the logarithmic frequency ratio corresponding to a factor 10 increase in frequency (ISO 80000-8:2007). A decidecade is approximately equal to a one-

preferred term	synonym	unit	Symbol	Definition	notes
					third octave and may be referred to as a “one-third octave (base 10)”. cf *one-third octave*
Sound pressure kurtosis		1	β	kurtosis of the sound pressure, $p(t)$, over a specified time interval, t_1 to t_2, for a specified frequency range	from ISO 18405, entry 3.1.5.5
source waveform		Pa m	s	product of distance in a specified direction, r, from the *acoustic centre* (3.3.1.3) of a sound source and the delayed *far-field sound pressure* (3.3.1.2), $p(t - t_0 + r/c)$, for a specified time origin, t_0, if placed in a hypothetical infinite uniform lossless medium of the same density and sound speed, c, as the actual medium at the location of the source, with identical motion of all acoustically active surfaces as the actual source in the actual medium	from ISO 18405, entry 3.3.1.4
source factor		$Pa^2\ m^2$	F_S	product of the square of the distance from the *acoustic centre* (3.3.1.3) of a source, in a specified direction, r^2 , and *mean-square sound pressure* (3.1.3.1) in the acoustic far field (3.3.1.1) at that distance, $\overline{p^2}$, of a sound source, if placed in a hypothetical infinite uniform lossless medium of the same density and sound speed as the real medium at the location of the source, with identical motion of all acoustically active surfaces as the true source in the true medium	from ISO 18405, entry 3.3.1.6

preferred term	synonym	unit	Symbol	Definition	notes
source spectrum			S	Fourier transform of the *source waveform* (3.3.1.4)	from ISO 18405, entry 3.3.1.8
average mean-square sound pressure		Pa^2		spatially averaged mean-square sound pressure, for a specified averaging time, specified frequency band, and specified averaging volume	Needed for spatial statistics
snapshot duration		s		duration of a snapshot	
source factor spectral density		$Pa^2\ m^2/Hz$		ratio of source factor in a specified frequency band to the width of that frequency band	
surface-affected source factor		$Pa^2\ m^2$		product of the square of the distance from the *acoustic centre* (3.3.1.3) of a sound source and its sea surface-reflected image, in a specified direction, r^2, and *mean-square sound pressure* (3.1.3.1) in the *acoustic far field* (3.3.1.1) at that distance, $\overline{p^2}$, of a sound source, if placed in a hypothetical semi-infinite uniform lossless medium of the same density and sound speed as the real medium at the location of the source, with identical motion of all acoustically active surfaces as the true source in the true medium	needed for the wind source level
surface-affected source factor spectral density		$Pa^2\ m^2/Hz$		ratio of surface-affected source factor in a specified frequency band to the width of that frequency band	
areic surface-affected source factor spectral density		$Pa^2m^2Hz^{-1}/m^2$		ratio of surface-affected source factor spectral density from a specified region of the surface, evaluated in the vertical direction, to the area of that specified region	

Spectra (Fourier transform pairs)

As a general rule a lower case symbol is used for a time domain quantity such as sound pressure, $p(t)$, or source waveform, $s(t)$, with the upper case symbols $P(f)$ and $S(f)$ for the corresponding Fourier transforms (ISO 80000-2). Specifically, if $x(t)$ and $X(f)$ form a Fourier transform pair, they are related by

$$X(f) = \int_{-\infty}^{+\infty} x(t) \exp(-2\pi i f t) \, dt$$

$$x(t) = \int_{-\infty}^{+\infty} X(f) \exp(+2\pi i f t) \, dt.$$

Levels and other logarithmic quantities usually expressed in decibels

Level of a power quantity

In general, a level is a logarithm of a ratio of two like quantities. A widely used level in acoustics is the level of a power quantity (ISO 80000-3:2006; IEC 60027-3:2002). A power quantity is one that is proportional to power. The level of a power quantity, P, is the logarithm of that power quantity to a reference value of the same quantity, P_0 , defined such that

$$L_P = 10 \log_{10} \frac{P}{P_0} \text{ dB}.$$

When expressing the value of a level of a power quantity in decibels, it is imperative to also specify the reference value, P_0. Some common examples, with standard reference values, are listed in Table 12.

Table 12 – Examples of level of a power quantity, and associated reference values for sound in water (ISO 1683:2015; ISO 18405:2017). For comparison, the final column lists corresponding reference values for sound in air (ISO 1683).

level, L_P	**power quantity, P**	**reference value (sound in water), P_0**	**reference value (sound in air), P_0**
sound exposure level (SEL)	sound exposure	$1\ \mu\text{Pa}^2\ \text{s}$	$400\ \mu\text{Pa}^2\ \text{s}$
mean-square sound pressure spectral density level (PSDL)	mean-square sound pressure spectral density	$1\ \mu\text{Pa}^2/\text{Hz}$	$400\ \mu\text{Pa}^2/\text{Hz}$
sound power level (SWL)	sound power	$1\ \text{pW}$	$1\ \text{pW}$
sound pressure level (Lrms or SPL)	mean-square sound pressure	$1\ \mu\text{Pa}^2$	$400\ \mu\text{Pa}^2$
source level (SL)	source factor	$1\ \mu\text{Pa}^2\ \text{m}^2$	NA

Level of a field quantity

Also widely used in acoustics is the level of a field quantity (ISO 80000-3:2006; IEC 60027-3:2002). A field quantity is one whose square is proportional to power. The level of a field quantity, F, is the logarithm of that field quantity to a reference value of the same quantity, F_0 , defined such that

$$L_F = 20 \log_{10} \frac{F}{F_0} \text{ dB}.$$

When expressing the value of a level of a field quantity in decibels, it is imperative to also specify the reference value, F_0. Some examples, with standard reference values, are listed in Table 13. The levels (of the listed field quantities) defined in Table 13 have identical values to the levels of the corresponding power quantities listed in Table 12. The reason for providing both definitions is to clarify that the choice between P_0 (say 1 μPa^2/Hz) and F_0 (1 μPa/Hz$^{1/2}$) for the reference quantity makes no difference to the value of the level. The level of a power quantity is identical to the level of the corresponding field quantity, defined as the square root of the power quantity (also known as a 'root-power quantity' (ISO 80000-1:2009; Ainslie 2015)).

Table 13 – Examples of level of a field quantity, and associated reference values for sound in water (ISO 1683:2015; ISO 18405:2017). For comparison, the final column lists corresponding reference values for sound in air (ISO 1683).

level, L_F	**field quantity, F**	**reference value (sound in water), F_0**	**reference value (sound in air), F_0**
sound exposure level (SEL)	root-sound exposure	$1\ \mu\text{Pa s}^{\frac{1}{2}}$	$20\ \mu\text{Pa s}^{\frac{1}{2}}$
mean-square sound pressure spectral density level (PSDL)	square root of the mean-square sound pressure spectral density	$1\ \mu\text{Pa/Hz}^{\frac{1}{2}}$	$20\ \mu\text{Pa/Hz}^{\frac{1}{2}}$
sound power level (SWL)	root-sound power	$1\ \text{pW}^{\frac{1}{2}}$	$1\ \text{pW}^{\frac{1}{2}}$
sound pressure level (Lrms or SPL)	root-mean-square sound pressure	$1\ \mu\text{Pa}$	$20\ \mu\text{Pa}$
source level (SL)	root-source factor	$1\ \mu\text{Pa m}$	NA

Table 14 – Levels and other logarithmic quantities usually expressed in decibels

Quantity (preferred name)	**synonym**	**Abbr.**	**Symbol**	**definition**	**notes**
mean-square sound pressure level	root-mean-square sound pressure level Sound pressure level	SPL, Lrms	L_p $L_{p,\text{rms}}$	level of the *mean-square sound pressure*	based on ISO 18405, entry 3.2.1.1 *Mean-square sound pressure* is a power quantity whose reference value is 1 μPa^2. SPL is also equal to the level of the field quantity *root-mean-square sound pressure*.

Quantity (preferred name)	**synonym**	**Abbr.**	**Symbol**	**definition**	**notes**
time-integrated squared sound pressure level	sound exposure level sound pressure exposure level	SEL	$L_{E,p}$	level of the *time-integrated squared sound pressure*	based on ISO 18405, entry 3.2.1.5 *Time-integrated squared sound pressure* is a power quantity whose reference value is 1 μPa^2 s.
sound exposure spectral density level		ESDL	$L_{E,f}$	level of the *sound exposure spectral density*	based on ISO 18405, entry 3.2.1.9 *Sound exposure spectral density* is a power quantity whose reference value is 1 μPa^2 s/Hz.
mean-square sound pressure spectral density level		PSDL	$L_{p,f}$	level of the *mean-square sound pressure spectral density*	based on ISO 18405, entry 3.2.1.10 *Mean-square sound pressure spectral density* is a power quantity whose reference value is 1 μPa^2/Hz.
zero-to-peak sound pressure level	peak sound pressure level	Lpk	$L_{p,0-\mathrm{pk}}$ $L_{p,\mathrm{pk}}$	level of the *zero-to-peak sound pressure*	based on ISO 18405, entry 3.2.2.1 *Zero-to-peak sound pressure* is a field quantity whose reference value is 1 μPa.
source level		SL	L_S	level of the *source factor*	based on ISO 18405, entry 3.3.2.1 *Source factor* is a power quantity whose reference value is 1 μPa^2 m^2.

Quantity (preferred name)	synonym	Abbr.	Symbol	definition	notes
transmission loss		TL	N_{TL}	reduction in a specified level between two specified points x_1, x_2 that are within an underwater acoustic field	from ISO 18405, entry 3.4.1.3 TL is difference between like quantities; it has no reference value Cf propagation loss
propagation loss		PL	N_{PL}	difference between *source level* (3.3.2.1) in a specified direction, L_{S}, and *mean-square sound pressure level* (3.2.1.1), $L_p(x)$, at a specified position, x	from ISO 18405, entry 3.4.1.4 PL is the difference between SL and SPL, such that SPL = SL – PL. Cf transmission loss
source factor spectral density level			$L_{\mathrm{S},f}$	level of the source factor spectral density	source factor spectral density is a power quantity This level is needed for correct interpretation of the source level associated with ships (Wales and Heitmeyer, 2002)
areic surface-affected source factor spectral density level			$L_{\mathrm{S'},f}$	level of the areic surface-affected source factor spectral density	areic surface-affected source factor spectral density is a power quantity This level is needed for correct interpretation of the source level associated with wind (Kuperman and Ferla, 1985)
N percent temporal exceedance level			$L_{t,N\%}$	*mean-square sound pressure level* that is exceeded for N % of the time in a specified analysis window	snapshot duration, frequency band, and position in space are specified

Quantity (preferred name)	synonym	Abbr.	Symbol	definition	notes
					Based on entry 3.1.3 of ISO 1996-1:2003
Nth temporal level percentile				value of *mean-square sound pressure level* below which *N* % of observations fall, in a specified analysis window	Based on ISO 11064-4: "value of a variable below which a certain percentage of observations fall"
N percent spatial exceedance level			$L_{x,N\%}$	*mean-square sound pressure level* that is exceeded for *N* % of the space in a specified analysis footprint	snapshot duration, frequency band, and UTC time are specified
Nth spatial level percentile				value of *mean-square sound pressure level* below which *N* % of observations fall, in a specified analysis footprint	

Abbreviations

This section contains acoustical and mathematical abbreviations used in this report.

Table 15 – Acoustical and mathematical abbreviations

Abbreviation	Meaning
AM	arithmetic mean
cdf	cumulative probability distribution function
GM	geometric mean
Lrms	root-mean-square sound pressure level (synonym of sound pressure level and mean-square sound pressure level – see also SPL)
Lpk	zero-to-peak sound pressure level (synonym of peak sound pressure level)
PL	propagation loss
rms	root-mean-square
ROC	receiver operating characteristic (curve)
SEL	sound exposure level
SELw	weighted sound exposure level
ESDL	sound exposure spectral density level
SL	source level
SPL	sound pressure level (synonym of root-mean-square sound pressure level – see also Lrms)
PSDL	mean-square sound pressure spectral density level
SWL	sound power level
TL	transmission loss

7. Appendix 2 – Non-acoustical terminology (normative)

In general the International System of Quantities (ISQ), as described in ISO/IEC 80000, shall be followed. If by exception a need arises to use a unit outside the ISQ, IEEE Std 260.1 (eg, for a conversion from liters to cubic inches to characterize the volume of an airgun array) shall be followed. Apart from this exception, for non-acoustical terminology, the following standards are followed, in order of decreasing precedence

- non-acoustical ADEON terminology (this appendix)
- The International System of Units (SI): 8th edition (BIPM, 2014)
- ISO 80000-1:2009 Quantities and Units – General
- ISO 80000-2:2009 Quantities and Units – Mathematical signs and symbols to be used in the natural sciences and technology
- IEC 80000-13:2008 Quantities and Units – Information science and technology

Units of distance, speed and angle are listed in (Table 16). Units of data storage are listed in Table 17. Symbols for natural, base 2 and base 10 logarithms are listed in Table 18.

Table 16 – Units of distance, speed and angle (from ISO 80000-3:2006)

name of unit	Symbol	definition
nautical mile	nmi	1852 m
knot	kn	1 nmi/h
degree (angle)	°	(2π/360) rad
minute (angle)	′	(1/60)°
second (angle)	″	(1/60)′

Table 17 – Units of data storage (IEC 80000-13:2008)

name of unit	Symbol	definition	notes
kilobyte	kB	1000 B	not 1024 B
megabyte	MB	1000 kB	not 1024 kB
gigabyte	GB	1000 MB	not 1024 MB
terabyte	TB	1000 GB	not 1024 GB
petabyte	PB	1000 TB	not 1024 TB
exabyte	EB	1000 PB	not 1024 PB
zettabyte	ZB	1000 EB	not 1024 EB
yottabyte	YB	1000 ZB	not 1024 ZB

Table 18 – Standard symbols for logarithms (ISO 80000-2:2009)

type of logarithm	symbol	alternative symbol	notes
base 2	$\log_2 x$	$\mathrm{lb}\, x$	
base e	$\log_e x$	$\ln x$	also known as natural logarithm
base 10	$\log_{10} x$	$\lg x$	

8. Appendix 3 – Galway Statement on Atlantic Ocean Cooperation (informative)

The Galway Statement is an announcement of cooperation between the EU, Canada and the USA to advance a shared vision of a "healthy, resilient, safe, productive, understood and treasured" Atlantic Ocean and to promote the "well-being, prosperity, and security of present and future generations". The full text of the announcement, signed on 24 May 2013, follows:

Galway Statement on Atlantic Ocean Cooperation

Launching a European Union - Canada - United States of America Research Alliance

The Signatories of this Statement meeting on the occasion of the high level event

The Atlantic – a Shared Resource, held on

23 and 24 May 2013

***at the* Marine Institute, Galway, Ireland**

Recognizing the importance of the Atlantic Ocean to our citizens, prosperity, human health and well-being, adaptation to climate and other environmental change, and security,

Cognizant of our reliance upon the best available science and knowledge to inform decisions affecting the Atlantic Ocean,

Realizing that our countries face similar challenges in promoting a healthy and well-understood Atlantic Ocean,

Acknowledging the critical interlink between the Atlantic Ocean and the portion of the Arctic region that borders the Atlantic,

Appreciating the value of our ongoing cooperation on ocean science and observation in the Atlantic Ocean, and

Valuing the essential role of international partnership to achieve our shared objectives and the potential of greater cooperation to advance our knowledge of the Atlantic Ocean,

Intend to advance our shared vision of an Atlantic Ocean that is healthy, resilient, safe, productive, understood and treasured so as to promote the well-being, prosperity, and security of present and future generations.

This cooperation is intended to increase our knowledge of the Atlantic Ocean and its dynamic systems - including interlinks with the portion of the Arctic region that borders the Atlantic - by aligning our ocean observation efforts to improve ocean health and stewardship and promote the sustainable management of its resources. Observation is fundamental to understanding the ocean and forecasting its future. Activities may include efforts to better coordinate data sharing, interoperability and coordination of observing infrastructures and seabed and benthic habitat mapping.

This cooperation may result in mutual benefits including better ecosystem assessments and forecasts and deeper understanding of vulnerabilities and risk, including those relating to the global climate system and climate change impacts. It can also help to generate new tools to increase resilience, conserve rich biodiversity, manage risk and determine social, environmental and economic priorities.

We further intend to promote our citizens' understanding of the value of the Atlantic by promoting oceans literacy. We intend to show how results of ocean science and observation address pressing issues facing our citizens, the environment and the world and to foster public understanding of the value of the Atlantic Ocean.

We intend to advance this agenda by

- taking stock of and utilizing existing bilateral science and technology cooperation (e.g. the U.S. - European Union Science and Technology Joint Consultative Group and the Canada - European Union Science and Technology Joint Coordinating Committee) and multilateral cooperation frameworks including those related to ocean observation, and ocean literacy initiatives;
- recommending priorities for future cooperation and, where possible,
- coordinating the planning and programming of relevant activities in these areas, including promoting researcher mobility.

This cooperation could potentially involve national partners and European Commission representatives, the private sector, and the scientific community to further our efforts by harnessing the value of public-private partnerships.

This initiative is also expected to reinforce existing international efforts to advance our knowledge of the ocean, including the World Ocean Assessment.

Signed in Galway on 24 May 2013 in three originals in the English language.

For the European Union	**For the Government of Canada**	**For the Government of the United States of America**
Máire GEOGHEGAN-QUINN **Commissioner for Research, Innovation and Science**	**Edward FAST** **Minister of International Trade and Minister for the Asia-Pacific Gateway**	**Dr Kerri-Ann JONES** **Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs**
Maria DAMANAKI **Commissioner for Maritime Affairs and Fisheries**		

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