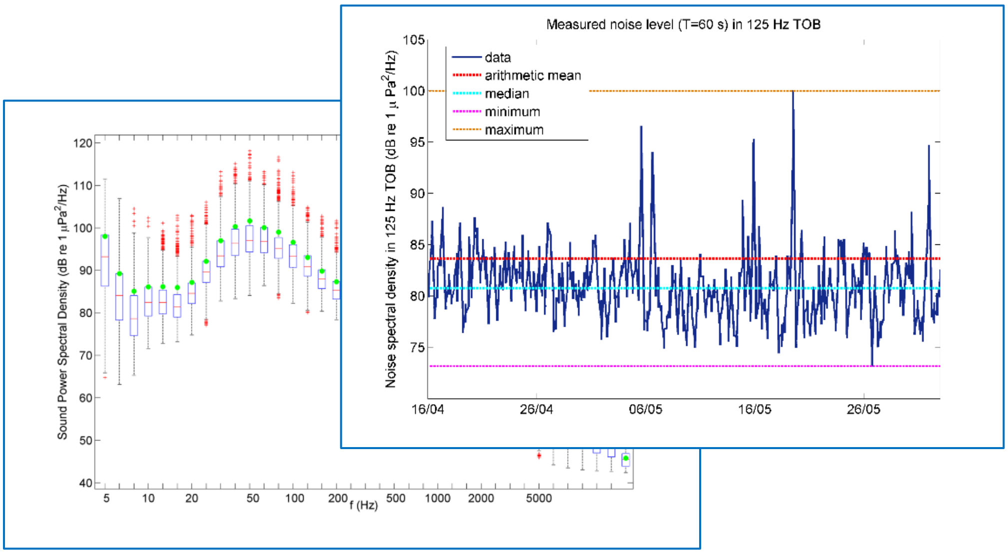
Joint Monitoring Programme for Ambient Noise North Sea

2018 – 2020

Standard for Terminology

WP 3

Deliverable/Task: 3.1



Authors: L. Wang, S Robinson

Affiliations: NPL

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Colophon	
Name	Niels Kinneging (Project Manager)
Organization Name	Rijkswaterstaat
Email	niels.kinneging@rws.nl
Phone	+31 6 5321 5242

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JOMOPANS standard: Terminology for ambient ocean noise monitoring

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Summary

The aim of this project is to develop a framework for a fully operational joint monitoring programme for ambient noise in the North Sea. Output will be the tools necessary for managers, planners and other stakeholders to incorporate the effects of ambient noise in their assessment of the environmental status of the North Sea, and to evaluate measures to improve the environment.

Sounds are omnipresent in the underwater environment and can be produced by natural (waves, weather, animals) and anthropogenic (shipping, construction) sources. International concern increasingly focusses on the potential negative effects of anthropogenic underwater noise on sensitive marine fauna. Sound sources, sound transmission, and the distributions of vulnerable species in the North Sea are all transnational questions which must be tackled transnationally, as specifically required by the Marine Strategy Framework Directive.

The project will deliver an innovative combination of modelling and high quality measurements at sea for an operational joint monitoring programme for ambient noise in the North Sea. The use of consistent measurement standards and interpretation tools will enable marine managers, planners and other stakeholders internationally to identify, for the first time, where noise may adversely affect the North Sea. Next, we will explore the effectiveness of various options for reducing these environmental impacts through coordinated management measures across the North Sea basin.

This report is a Deliverable 3.1 of Work Package 3 of project JOMOPANS. The aim of WP3 is to develop underwater noise monitoring standards suitable for monitoring MSFD Indicator 11.2.1 in the North Sea Region as part of "JOMOPANS" joint monitoring project

At this moment, there are no international standards for monitoring and predicting ambient noise in the ocean. Such standards would require consensus on a number of topics:

- (i) terminology for describing the monitoring of underwater ambient noise;
- (ii) specification, performance requirements, calibration and deployment of the measurement equipment;
- (iii) analysis of the measured data obtained from monitoring;
- (iv) acoustic modelling of underwater sound field.

Within the project, there is a need to standardize these activities so that all partners use a common approach in order that data obtained within the project are comparable. Task 3.1 is concerned with developing a standard for terminology (item (i) above).

The aim of this task is to obtain consensus on terminology to be used in the project, and meaning of all key terms. The work began by reviewing other sources of definitions of acoustic terminology as the basis for discussion of the project standard, including standards under development in other projects, good practice guides and international standards developed by international standards bodies. These included:

- ISO 18405:2017 [1]
- ADEON project: Underwater Soundscape and Modeling Metadata Standard, v 1 [2]
- ADEON Project Dictionary (Terminology Standard, v 2) [3]
- NPL Good Practice Guide for Underwater Noise Measurement [4],
- IEC60050:1994 [5],
- IEC 1260-1:2014 [6],
- Dictionary of Acoustics (Morfey 2001) [7],
- ISO1996-1 2006 [8],
- ISO 80000-8 2020 [9],
- ISO/TR25417 2007 [10]
- ISO/IEC 25010:2011 [16]
- ISO 18406:2017 [19]

Note that for completeness, a wide range of metrics have been defined, many of which will **not** be used in the JOMPANS project. Where a specific metric has been chosen for JOMOPANS, this is made clear in the text.

1 General acoustic terms

1.1 Definitions of basic quantities and metrics

There are a number of different metrics that may be used as measures of the sound pressure. These are listed below, and some of them are illustrated graphically in Figure 1. Tables 1-5 shows some general terms.

See ISO 18405 2017 [1], ADEON project "Underwater Soundscape and Modeling Metadata Standard v 1" [2], ADEON Project "Dictionary (Terminology Standard, v 2)" [3], NPL Good Practice Guide for Underwater Noise Measurement [4], IEC60050 1994 [5], IEC 1260-1:2014 [6], Morfey 2001 [7], ISO1996-1 2006 [8], ISO 80000-8 2020 [9], ISO/TR25417 2007 [10].

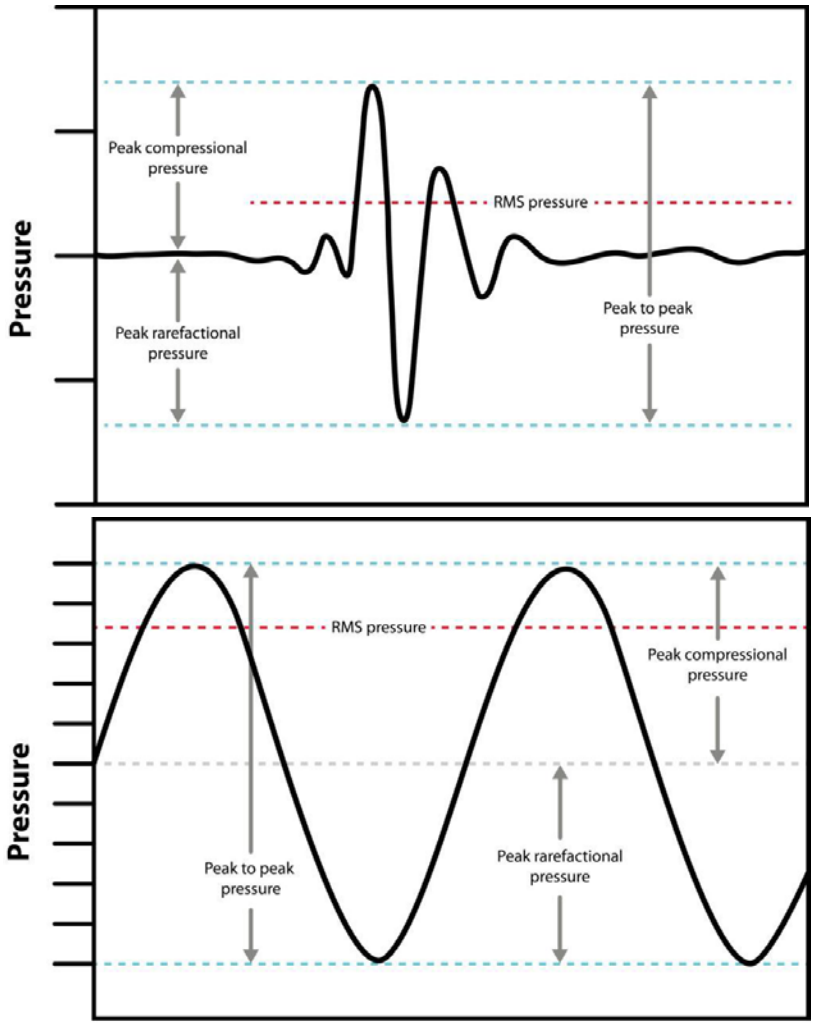

Fig 1: Some of the metrics for sound pressure illustrated for a sound pulse (upper plot) and for a periodic waveform (lower plot). Note that in the figures above, "pressure" should be taken to mean "sound pressure" in all cases.

The following tables contain specific examples of definitions which were mostly sourced from ISO 18405 [1], following the choices of content made by ADEON [3].

Table 1 General acoustical terminology
[ISO 18405 [1], and ADEON Terminology Standard v2 Table 4 [3]]

Term	Definition
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 NOTE: Source: ISO 18405, entry 3.1.1.1 If only acoustic pressure fluctuations are present (implying the absence of mean flow and turbulence), the total pressure at a location is the background hydrostatic pressure plus the sound pressure.
signal	specified time-varying electric current, voltage, sound pressure, sound particle displacement, or other field quantity of interest NOTE: Source: ISO 18405, entry 3.1.5.8
ambient noise	all sound except sound associated with a specified signal and except self-noise NOTE Source: ISO 18405, entry 3.1.5.11 In the absence of a specified signal of interest, ambient noise is all sound except acoustic self-noise.
acoustic self-noise	sound at a receiver caused by the deployment, operation, or recovery of a specified receiver, and its associated platform NOTE: Source: ISO 18405, entry 3.1.5.10 Sometimes called “platform noise” or “deployment noise”, acoustic self-noise comprises a number of parasitic sources of sound which only exist because of the deployment of the acoustic sensor and platform (eg, noise from moorings and fixtures, flow noise, etc).
non-acoustic self-noise (electronic self-noise)	fluctuations in output of a receiver system in the absence of any sound pressure input NOTE The most common example of non-acoustic self-noise is electrical noise in the hydrophone and receiver electronics. In a digital receiver system, the output might be a digital representation of the original voltage.
self-noise	fluctuations in output of a receiver system caused by the combination of acoustic self-noise and non-acoustic self-noise NOTE In a digital receiver system, the output might be a digital representation of the original voltage.
ambient sound	sound that is present in the absence of sound from a specified activity NOTE: source: ISO 18405, entry 3.1.1.2
soundscape	<underwater acoustics> characterization of the ambient sound in terms of its spatial, temporal and frequency attributes, and the types of sources contributing to the sound field NOTE: Source: ISO 18405, entry 3.1.1.3
material element	Smallest element of the medium that represents the medium’s mean density NOTE: Source: ISO 18405, entry 3.1.1.5

Note that in the JOMOPANS project, the physical quantity being estimated is considered to be the **ambient noise** in the ocean; that is, all sound *except* sound associated with a specified signal and *except* self-noise. Note that *all* sound is to be measured and considered to be of interest, and there is no specific signal which is interest (all sounds in the ocean are considered to be “signal”). Note that in some other ocean monitoring projects, the quantity being estimated is given the name ambient sound.

Table 2 Frequency bands
[ISO 18405 [1], and ADEON Terminology Standard v2 Table 5 [3]]

Term	Definition
octave	logarithmic frequency interval between frequencies f_1 and f_2 when $f_2/f_1 = 2$ NOTE: See clause 8.1 of ISO 80000-8:2020.
decade	logarithmic frequency interval between frequencies f_1 and f_2 when $f_2/f_1 = 10$ NOTE 1: See clause 8.1 of ISO 80000-8:2020. NOTE 2: The formal definition of this unit is “1 dec :=lb 10 = (lb 10) oct”. Note that 1 dec ≈ 3.322 oct
one-third octave (base 10)	one tenth of a decade NOTE: From IEC 61260:1-2014, entry 5.2 and 5.4. Also in ANSI S1.11:2014. Note that use of one-third octave (base 10) is *mandated* by IEC 61260:1-2014 and ANSI S1.11:2014. In these standards (and in all air acoustics), all calculations of one-third octaves are performed as base 10 calculations (and so are really one tenth decades). In ISO 18405, entry 3.1.4.2 (where alternative names are specified as either one-third octave (base 10) or decidecade). Note that one-third octave (base 10) is approximately equal to one-third octave (base 2): 1 one tenth of a decade ≈ 0.3322 oct. The frequencies of the one tenth of octave bands are listed in Annex A.
one-third octave (base 2)	one third of an octave NOTE: From ISO 18405, entry 3.1.4.1. Note that use of one-third octave (base 2) is *deprecated* by IEC 61260:1-2014 and ANSI S1.11:2014. In these standards (and in all air acoustics), all calculations of one-third octaves are performed as base 10 calculations (and so are really one tenth decades). One one-third octave (base 2) is approximately equal to a one-third octave (base 10); 1 one third of an octave ≈ 1.003 one tenth of a decade

Note that in the JOMOPANS project, the base 10 calculation of one-third octave frequencies and bands (equivalent to one tenth decades) is the chosen definition and nomenclature. The base 10 designation is stated when the term is first introduced in a document. If on subsequent occurrences, the term is named as “one-third octave”, it *always* means the base 10 calculation and *never* the base 2 calculation. This is in accord with IEC 61260:1-2014 (and ANSI S1.11:2014) and with the most common usage adopted throughout the field of acoustics.

Note that in some other ocean monitoring projects, the name “decidecade” is used to describe the same frequency band [1, 2].

Table 3 Basic sound field properties
[ISO 18405 [1], and ADEON Terminology Standard v2 Table 6 [3]]

Term	Symbol	Unit	Definition
sound pressure	$p(t)$	Pa	contribution to total pressure caused by the action of sound NOTE: Source: ISO 18405, entry 3.1.2.1
sound pressure spectrum	$P(f)$	Pa/Hz	Fourier transform of the sound pressure NOTE: Source: ISO 18405, entry 3.1.2.2
sound particle displacement	$\delta(t)$	m	displacement of a material element caused by the action of sound NOTE: Source: ISO 18405, entry 3.1.2.9
sound particle velocity	$u(t)$	m/s	contribution to velocity of a material element caused by the action of sound NOTE: Source: ISO 18405, entry 3.1.2.10
sound particle acceleration	$a(t)$	m/s^2	contribution to acceleration of a material element caused by the action of sound NOTE: Source: ISO 18405, entry 3.1.2.11

In the JOMOPANS project, the property of the sound field chosen for measurement is the **sound pressure**. This choice does not imply that the other field properties are not valuable or important in other contexts.

Table 4 Sound field metrics

[ISO 18405 [1], and ADEON Terminology Standard v2 Table 7 [3]]

Term	Symbol	Unit	Definition
mean-square sound pressure	$\overline{p^2}$	Pa^2	integral over a specified time interval (from t=t_1 to t=t_2)of squared sound pressure, divided by the duration of the time interval, for a specified frequency range $$\overline{p^2} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} p(t)^2 \mathrm{d}t$$ NOTE: Source: ISO 18405, entry 3.1.3.1 Note that the time interval must be specified.
root mean-square sound pressure	p_{rms}	Pa	The square root of the mean-square sound pressure NOTE: Source: ISO 18405 Note that the time interval must be specified.
zero-to-peak sound pressure	p_{pk}	Pa	greatest magnitude of the sound pressure during a specified time interval, for a specified frequency range NOTE: Source: ISO 18405, entry 3.1.2.3
time-integrated squared sound pressure	$E_{p,T}$	Pa^2 s	<underwater acoustics> integral of the square of the sound pressure, *p*, over a specified time interval or event, for a specified frequency range NOTE: Source: ISO 18405, entry 3.1.3.5
sound pressure exposure spectral density	E_f	Pa^2s/Hz	<underwater acoustics> distribution as a function of non-negative frequency of the time-integrated squared sound pressure per unit bandwidth of a sound having a continuous spectrum NOTE: Source: ISO 18405, entry 3.1.3.9
mean-square sound pressure spectral density	$(p^2)_f$	Pa^2/Hz	distribution as a function of non-negative frequency of the mean square sound pressure per unit bandwidth of a sound having a continuous spectrum NOTE: Source: ISO 18405, entry 3.1.3.13
average mean-square sound pressure	$\langle p^2 \rangle$	Pa^2	spatially averaged mean-square sound pressure, for a specified averaging time, specified frequency band, and specified averaging volume NOTE: The average mean-square sound pressure is needed for spatial statistics. Source: ADEON [3] (Table 7)

In the JOMOPANS project, the sound field metric chosen for measurement is the **mean-square sound pressure**. This choice does not imply that the other sound field metrics are not valuable or important in other contexts.

Table 5 Source properties
[ISO 18405 [1], and ADEON Terminology Standard v2 [3] Table 8]

Term	Symbol	Unit	Definition
source waveform	*s*	Pa m	product of distance in a specified direction, r, from the acoustic centre of a sound source and the delayed far-field sound pressure, for a specified time origin, if placed in a hypothetical infinite uniform lossless medium of the same density and sound speed, 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. Based on ISO 18405, entry 3.3.1.4 & ADEON [3] Table 8
source spectrum	*S*	Pa m/Hz	Fourier transform of the source waveform NOTE: Source: ISO 18405, entry 3.3.1.8
source factor	$F_{s,mp}$	Pa^2 m^2	product of the square of the distance from the acoustic centre of a sound source, in a specified direction, and mean-square sound pressure in the acoustic far field at that distance, 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 NOTE: Based on ISO 18405, entry 3.3.1.6 & ADEON [3] Table 8
source factor spectral density	$F_{s,f,mp}$	Pa^2 m^2/Hz	ratio of source factor in a specified frequency band to the width of that frequency band
surface-affected source waveform	*s'*	Pa m	product of distance in a specified direction, r, from the acoustic centre of a sound source and its sea surface-reflected image and the delayed far-field sound pressure, for a specified time origin, if placed in a hypothetical semi-infinite uniform lossless medium of the same density and sound speed, 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. Source: ISO 18405, entry 3.3.1.7
surface-affected source spectrum	*S'*	Pa m/Hz	Fourier transform of the surface-affected source waveform NOTE: Source: ISO 18405, entry 3.3.1.9
surface-affected source factor	$F_{s,dp}$	Pa^2 m^2	product of the square of the distance from the acoustic centre of a sound source and its sea surface-reflected image, in a specified direction, and mean-square sound pressure in the acoustic far field at that distance, 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 NOTE: needed for the specification of wind source level Source: ADEON [3] Table 8
surface-affected source factor spectral density	$F_{s,f,dp}$	Pa^2 m^2/Hz	ratio of surface-affected source factor in a specified frequency band to the width of that frequency band Source: ADEON [3] Table 8
areic source factor spectral density	$F_{s,f,a,mp}$	$Pa^2m^2Hz^{-1}/m^2$	ratio of source factor spectral density from a specified region of the surface to the area of that specified region Source: ADEON [3] Table 8

areic surface-affected source factor spectral density	$F_{s,f,a,dp}$	Pa^{2}m^{2}Hz^{-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 NOTE: An alternative way of writing the unit is Pa^2 Hz^{-1}. However, the full form Pa^{2}m^{2}Hz^{-1}/m^2 is preferred to avoid the risk of confusion with the unit for mean-square sound pressure spectral density. Source: ADEON [3] Table 8

1.2 Levels used in underwater acoustics

1.2.1 Use of decibels

In acoustics, it is common to express certain of the above quantities as levels using decibels (dB). A level is a method of expressing the magnitude of a quantity as a logarithmic ratio to a reference value. The decibel uses logarithms to base 10. The decibel is itself not an S.I. unit, but it has been accepted by the Committee International des Poids et Measures for use with the S.I.

All absolute levels expressed in decibels are expressed relative to a reference value of that quantity. The basic convention for calculating levels in decibels is as follows:

$$Level\ of\ quantity\ A = 10\ \log_{10}\left[\frac{A}{A_0}\right]\ \mathrm{dB}$$

where A is the value of the quantity and A_0 is the reference value of that quantity (both the values are expressed in the same units, thus rendering the ratio dimensionless). Note that the use of 10 as the multiplier makes the units into decibels, or one-tenth of a bel (the bel being an inconveniently large unit for many applications).

The convention for the use of decibels is that the above ratio is taken of quantities that relate to power (or energy) of a signal. When using decibels for quantities which depend on the square root of the signal power or energy (sometimes called “field quantities”), it is common to make use of the following mathematical relationship in the expression of the level in decibels:

$$Level\ of\ quantity\ B = 10\ \log_{10}\left[\frac{B^2}{B_0^2}\right]\mathrm{dB}\ = 20\ \log_{10}\left[\frac{B}{B_0}\right]\ \mathrm{dB}$$

where B is the **root mean square** (RMS) value of the field quantity and B_0 is the reference value of that quantity. Examples of field quantities where the above mathematical identity is commonly used are *sound pressure*, and *electrical voltage*.

When reporting absolute values of acoustic levels in decibels, it is strongly recommended that the following principles be adopted:

- State the physical parameter clearly
- State the reference value clearly, preferably in S.I. units
- State any averaging time clearly
- State any applicable frequency bandwidth clearly
- State any frequency weighting clearly

Tables 6 and 7 show sound field metrics and source metrics in decibels.

1.2.2 Quantities in decibels

Table 6 Sound field metrics

Quantity	Symbol	Expression	Reference value
sound pressure level (SPL) (mean-square sound pressure level)	$L_{p,rms}$	$L_{p,rms} =$ $10\ \log_{10}\left[\frac{\overline{p^2}}{p_0^2}\right]\mathrm{dB} =$	p_0^2 =1µPa^2 p_0 =1µPa

NOTE: based on ISO 18405, entry 3.2.1.1		$20\ \log_{10}\left[\frac{p_{rms}}{p_0}\right]$ dB	
sound exposure level NOTE: based on ISO 18405, entry 3.2.1.5	$L_{E,p}$	$L_{E,p} =$ $10\ \log_{10}\left[\frac{E}{E_0}\right]$dB	$E_0 = 1\mu\text{Pa}^2\text{s}$ $E_0^{1/2} = 1\mu\text{Pa s}$
sound exposure spectral density level NOTE: based on ISO 18405, entry 3.2.1.9	$L_{E,f}$	$L_{E,f} =$ $10\ \log_{10}\left[\frac{E_f}{E_{f,0}}\right]$dB	$E_{f,0} = 1\mu\text{Pa}^2 s/\text{Hz}$ $E_{f,0}^{1/2} = 1\mu\text{Pa}s^{1/2}$ /Hz
mean-square sound pressure spectral density level NOTE: based on ISO 18405, entry 3.2.1.10	$L_{p,f}$	$L_{p,f} = 10\ \log_{10}\left[\frac{\overline{(p^2)}_0}{\overline{(p^2)}_{f,0}}\right]$ dB	$\overline{(p^2)}_{f,0} = 1\mu\text{Pa}^2/\text{Hz}$ $\sqrt{\overline{(p^2)}_{f,0}} = 1\mu\text{Pa}$ /Hz$^{1/2}$
zero-to-peak sound pressure level NOTE: based on ISO 18405, entry 3.2.2.1	$L_{p,0-pk}$	$L_{p,0-pk} =$ $10\ \log_{10}\left[\frac{p_{p,0-pk}^2}{p_0^2}\right]$dB	p_0^2 =1μPa^2 p_0 =1μPa

In the JOMOPANS project, the level of the sound field metric chosen for estimation of the sound field is the **sound pressure level**. This choice does not imply that the other levels of sound field metrics are not valuable or important in other contexts.

Table 7 Source metrics

Quantity	Symbol	Expression	Reference value
source level NOTE: based on ISO 18405, entry 3.3.2.1	$L_{s,mp}$	$L_{s,mp} =$ $10\ \log_{10}\left[\frac{F_{s,mp}}{F_{s,mp,0}}\right]$dB	$F_{s,mp,0} = 1\mu\text{Pa}^2 m^2$ $F_{s,mp,0}^{1/2} = 1\mu\text{Pam}$
Source factor spectral density level NOTE: based on ADEON [15]	$L_{s,f,mp}$	$L_{s,f,mp} =$ $10\ \log_{10}\left[\frac{F_{s,a,f,mp}}{F_{s,a,f,mp,0}}\right]$dB	$F_{s,a,f,mp,0} = 1\mu\text{Pa}^2 m^2/\text{Hz}$ $F_{s,a,f,mp,0}^{1/2} = 1\mu\text{Pam}/\text{Hz}^{1/2}$
Areic surface-affected source factor spectral density level NOTE: based on ADEON [15]	$L_{s,a,f,dp}$	$L_{s,a,f,dp} =$ $10\ \log_{10}\left[\frac{F_{s,a,f,dp}}{F_{s,a,f,dp,0}}\right]$dB	$F_{s,a,f,mp,0} =$ $1\mu\text{Pa}^2 m^2/(m^2\text{Hz})$ $F_{s,a,f,mp,0}^{1/2}$ $= 1\mu\text{Pam}/(\text{mHz}^{1/2})$

Table 8 Statistical metrics

Term	Definition
percentile	a statistical measure indicating the value below which a given percentage of observations in a group of observations fall NOTE: The Nth percentile is the value of an estimated parameter below which N % of observations fall, in a specified analysis window. For example, the 20th percentile is the value (or score) below which 20% of the observations may be found.
cumulative distribution function (CDF)	The empirical cumulative probability distribution function is a cumulative histogram of the individual observed values NOTE 1: The CDF provides a method for estimating the temporal level percentiles. NOTE 2: The CDF resolution needs to be sufficient to extract at least the 10th, 25th, 50th, 75th and 90th temporal level percentiles. NOTE 3: Where the number of samples is sufficiently high, the 1st, 5th, 95th and 99th temporal level percentiles may be calculated. Reference [13] advises

	a bin size no larger than 1 dB.
temporal observation window	interval of time within which a statistic of the sound pressure is calculated or estimated NOTE 1: Examples of a statistic that may be calculated include RMS sound pressure and sound pressure level. NOTE 2: Source: ADEON [3] Table 8
temporal analysis window	interval of time during which statistics are calculated over multiple temporal observation windows NOTE 1: The temporal analysis window is generally formed by aggregating the information from multiple successive temporal observation windows. NOTE 2: Source: ADEON [3] Table 8
spatial observation window	region of space within which the spatially averaged mean-square sound pressure is calculated or estimated, for a specified duration of the temporal observation window NOTE 1: The size of a spatial observation window is specified by means of a surface area (e.g., 1000 km^2) and a depth range (e.g., 50 m to 200 m). NOTE 2: Source: ADEON [3] Table 8
spatial analysis window	region of space within which statistics are calculated over multiple spatial observation windows NOTE 1: The size of a spatial analysis window is specified by means of an area (e.g., 100 000 km^2) and a depth range (e.g., 50 m to 200 m). NOTE 2: Source: ADEON [3] Table 8

Note that in JOMOPANS the temporal observation window and the temporal analysis window are both defined as being equal to 1 second. Thus the statistics of the ambient noise are calculated from the 1 second windows, and these windows are not aggregated into longer analysis periods.

2 Metrics for ambient noise monitoring in JOMOPANS

2.1 Metrics for use in JOMOPANS

In the JOMOPANS project, the sound field metric chosen for estimation of the sound field is the **sound pressure level** (SPL) described in Table 6. The SPL is calculated from the **mean-square sound pressure** described in Table 4.

The temporal observation window and the temporal analysis window are both defined as being equal to 1 second. The windows are not aggregated into longer analysis periods and the statistics of the ambient noise are calculated from the 1 second windows alone.

In JOMOPANS, the measured SPL values are filtered into 34 one-third octave bands (base 10) with centre frequencies in the range 10 Hz to 20 kHz. These bands are listed in Annex A.

Note that in the JOMOPANS project, the base 10 calculation of one-third octave frequencies and bands (equivalent to one tenth decades) is the chosen definition and nomenclature. This is in accord with IEC 61260:1-2014 (and ANSI S1.11:2014) and with the most common usage adopted throughout the field of acoustics.

An examination is made of the distribution of estimated SPL values averaged over 1 second and evaluated in the one-third octave bands described above. The statistical percentiles (described in Table 8) are calculated based on the above distribution of values.

Note that in the JOMOPANS project, the physical quantity being estimated is considered to be the **ambient noise** in the ocean; that is, all sound *except* sound associated with a specified signal and *except* acoustic self-noise.

2.2 Other common metrics not used in JOMOPANS

The following metrics have been used in other ocean noise monitoring projects and may occur in discussions, but are not being used in the JOMOPANS project. (The text in this section follows that in the ADEON project [2]).

Arithmetic mean (AM)

Consider a temporal observation window i, during which the mean-square sound pressure, averaged over the temporal observation window duration T_i is Q_i,

$Q_i = \frac{1}{T_i}\sum_j p_{i,j}^2$, where $p_{i,j}$ is the jth sample of the ith temporal observation window.

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

Samples $L_{p,a} = 10log_{10}\frac{Q_a}{Q_0}$dB where $Q_0 = 1\mu$Pa^2 and $Q_a = \frac{\sum_{i=1}^{N} w_i Q_i}{\sum_{i=1}^{N} w_i}$

The individual mean-square sound pressures Q_i are weighted by w_i.

A feature of the AM is that its value is independent of the choice of temporal observation window duration. See ADEON Underwater Soundscape and Modeling Metadata Standard, v 1.0 [2].

Geometric mean (GM)

In comparison with the arithmetic mean, the sound pressure level is the level of the geometric mean of squared sound pressure as described by $L_{p,g} = 10log_{10}\frac{Q_g}{Q_0} = \frac{1}{N}\sum_1^N 10log_{10}\frac{Q_i}{Q_0}$dB

See ADEON Underwater Soundscape and Modeling Metadata Standard, v 1.0 [2].

3 Terminology used in acoustic modelling

3.1 General terms

Transmission loss (TL) is the reduction in a specified level between two specified points x_1, x_2 that are within an underwater acoustic field, for example, $\Delta L_{TL} = L_{p,rms}(x_1) - L_{p,rms}(x_2)$ (Source: ISO 18405, entry 3.4.1.3).

Propagation loss (PL) is the difference between source level in a specified direction, L_s, and mean-square sound pressure level, at a specified position, x, $N_{pl}(x) = L_s - L_{p,rms}$ (ISO 18405 entry 3.4.1.4).

Propagation models

- **Normal mode** – normal mode solutions including all variations such as adiabatic, coupled mode.
- **Ray** – ray method including all variations such as geometric beam
- **Parabolic equation** – parabolic equation models including all variations such as RAM and others
- **Wave number integration** – wave number integration including range dependent treatment such as RDOAST

Source models for ships

- **Wales and Heitmeyer** [11] – empirical ship noise model,
- **RANDI III** [12]

Acoustic properties of media

- **Sound speed** – compressional wave speed in bulk medium in unit of m/s
- **Density** – mass of bulk medium in a unit volume in kg/m^3
- **Attenuation** – logarithm amplitude decay of acoustic pressure over a distance in wave propagation direction in unit of dB/wavelength, or Np/m

3.2 Model calibration, validation and verification

3.2.1 ISO 25010 Terminology

There is an international standard covering the above process: ISO/IEC 25010:2011 “Systems and software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — System and software quality models”.

ISO 25010 defines validation and verification as follows:

Validation (entry 4.1.13)
confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled

> NOTE 1 “Validated” is used to designate the corresponding status.
> NOTE 2 In design and development, validation concerns the process of examining a product to determine conformity with user needs.
> NOTE 3 Validation is normally performed on the final product under defined operating conditions. It can be necessary in earlier stages.
> NOTE 4 Multiple validations might be necessary if there are different intended uses.

Verification (entry 4.1.14)
confirmation, through the provision of objective evidence, that specified requirements have

been fulfilled

NOTE 1 “Verified” is used to designate the corresponding status.

NOTE 2 In design and development, verification concerns the process of examining the result of a given activity to determine conformity with the stated requirement for that activity.

Note that the above strictly apply to software engineering, but are often interpreted to cover theoretical modelling in general.

The concept of **verification** is essentially a demonstration (based on evidence) that the model developed “does its task correctly”, in that it correctly calculates the outputs for specified inputs, but not that the model itself correctly represents physical reality. So the model may be verified if it calculates the correct outputs for specified inputs even if the assumptions made in establishing the model are incorrect (if the model does not accurately reflect the underlying physical reality).

The concept of **validation** is essentially a demonstration (based on evidence) that the model “does the correct task”, in that it calculates the correct outputs for specified inputs and that the outputs reflect an adequate representation of physical reality. This evidence of adequate representation of reality comes from comparison to physical measurements. Occasionally, it may also come from comparison with the results of specific problems where there exists an exact analytic solution (and where that solution is regarded as a good representation of the underlying physics),

benchmarking
The concept of model **benchmarking** by comparison is a useful tool and sits between verification and validation. Here a series of scenarios are set up to allow comparison of different model types, each of which is exercised using the scenarios. Good agreement between the outputs of different models provides extra confidence in the individual models, and is a strong indicator of likely validation, especially if the different models adopt different modelling approaches. Benchmarking demonstrates agreement between models but does not does not prove that the models represent physical reality accurately (unless some of the scenarios have analytic solutions which may be regarded as essentially accurate). And, disagreement between models may represent an error or “bug” in one or other model, or that the models are attempting to solve different problems (so that the problem could be one of poor verification or poor validation).

model calibration
The concept of calibration of models is not explicitly covered by ISO 25010. However, the concept essentially consists of adjustments made to parameters within the model that govern its execution in order that the model outputs provide an accurate representation of reality (as determined from a comparison with physical measurements). This is useful in cases where the model parameters are subject to considerable uncertainty (for example, environmental parameters such as seabed properties, sea surface roughness, sound speed profiles, etc), and where adjustments of the values of these parameters are used to obtain closer agreement to physical data (measurements). In some modelling methods (eg neural networks) this is sometimes called “training” the model.

model sensitivity analysis
Here, the model inputs may be varied in a systematic manner (or using a Monte Carlo method) and the changes in model outputs are calculated to determine the output “sensitivity” to changes in each input parameter.

3.2.2 Modelling in JOMOPANS

In JOMOPANS, the modelling strategy is outlined in several reports produced in WP4, namely the JOMOPANS Model and Data Inventory [17] and in Binnerts et al [18].

4 Terms for technology and hardware

The terms below are derived from a number of sources including IEC 60500:2017, IEC 60050:1995, ISO 18406:2017, IEC 60565-2:2019, IEC 60565-1:2020 and ADEON Terminology Standard v2 Table 9 [3].

Table 9. Acoustical terminology for hardware specification: Concepts.

Term	Definition
hydrophone	electroacoustic transducer that produces electrical signals in response to water borne pressure signals NOTE: A hydrophone is designed to respond principally to underwater sound pressure. In general, a hydrophone may also produce a signal in response to non-acoustic pressure fluctuations (for example, those existing in a turbulent boundary layer during high water flow). [IEC 60500:2017]
hydrophone input	pressure fluctuation in the water at the position of the element of the hydrophone NOTE: Adapted from ADEON standard [3] and IEC 60500:2017.
hydrophone output	voltage appearing at the electrical terminals of a hydrophone in response to the water-borne pressure fluctuation NOTE: Adapted from ADEON standard [3] and IEC 60500:2017.
pre-amplifier	amplifier located immediately after the sensing element to increase the amplitude of the voltage (or current) NOTE: A preamplifier often takes the form of a low-noise amplifier located as near as possible to the sensing element or another signal source. Other amplifiers may be placed later in the measurement chain. Adapted from IEC 60050-713-10-45 and ISO 18406:2017.
anti-alias filter (AAF)	low-pass filter designed to restrict the frequency content of the signal before digitization to below the Nyquist frequency of the acquisition system NOTE: This avoids under-sampling of an analogue signal during digitization. Adapted from ISO 18406:2017 and ADEON standard [3].
analogue-to-digital converter (ADC)	electronic component that converts an analogue input signal to a digital output signal NOTE: The input signal is typically an analogue electric voltage and the output is a digitized representation of the input sampled at finite time intervals. Adapted from ISO 18406:2017, IEC 60050-723-10-04.
acquisition system	sequence of electronic components which may be considered together as whole, with a single overall performance NOTE: An underwater acoustic acquisition typically comprises a hydrophone, a pre-amplifier, an AAF, and an ADC.
ADC input	an analogue input signal to an ADC input such as electric voltage NOTE: Adapted from ADEON standard [3].
ADC output	a digital representation of the ADC input sampled at finite time intervals NOTE: An ADC output is suitable for storage in a digital storage medium or processing on a digital computer. Adapted from ADEON standard [3].

crosstalk	undesired energy appearing in a signal channel as a result of coupling from signals in other channels NOTE: Typically caused by induction, conduction, radiative pick-up or non-linearity. Adapted from IEC 60050-722-15-03.
digital autonomous acoustic recorder	acoustic acquisition system with storage to record acoustic signals in a digital format NOTE: Typically, these may be programmed to operate autonomously and sample over a range of duty cycles. Adapted from ISO 18406:2017.

Table 10. Quantities used to characterize a hydrophone

Term	Symbol	Unit	Definition
free-field voltage sensitivity	$M_{h,V}$	V Pa^{-1}	quotient of the hydrophone open-circuit output voltage to the sound pressure for specified frequency and specified direction of plane wave sound incident on the position of the reference centre of the hydrophone in the undisturbed free field if the hydrophone was removed NOTE: Source: IEC 60500:2017, IEC 60565-2:2019. The above assumes that the hydrophone has zero phase response. The hydrophone free-field sensitivity is really a complex-valued parameter. The modulus of the free-field sensitivity of a hydrophone is expressed in units of volt per pascal, $V \cdot Pa^{-1}$. The phase angle of the sensitivity is expressed in units of degrees, and represents the phase difference between the electrical voltage and the sound pressure. To express the complex-valued sensitivity, a definition is typically provided in the frequency domain.
equivalent rms hydrophone self-noise sound pressure	p_w	Pa	ratio of the root-mean-square noise voltage *in the relevant frequency band* present at the electrical terminals of the hydrophone, in the absence of sound pressure or pressure fluctuations at the hydrophone input, to its sensitivity *in the specified frequency band* NOTE: Adapted from IEC 60500:2017 (3.10 *equivalent bandwidth noise pressure*). Also termed *hydrophone non-acoustic self-noise voltage* (ADEON [3]).
equivalent rms hydrophone noise sound pressure	$P_{N,eq}$	Pa	ratio of the rms open-circuit output voltage to the free-field voltage sensitivity NOTE: Adapted from ISO 18405 (3.6.1.15)
hydrophone mean-square non-acoustic self-noise voltage spectral density		V^2/Hz	ratio of mean-square hydrophone non-acoustic self-noise voltage in a specified frequency band to the width of the frequency band NOTE: From ADEON standard [3].
equivalent hydrophone mean-square non-acoustic self-noise sound pressure spectral density		Pa^2/Hz	ratio of hydrophone mean-square non-acoustic self-noise voltage spectral density to the squared free-field voltage sensitivity NOTE: Adapted from ADEON standard [3] and from IEC 60500:2017, 3.11 equivalent noise pressure spectral density.

Table 11. Quantities used to characterize a digital sampling system, including pre-amplifier and anti-alias filter (AAF).

The terms in Table 11 follow the definitions established in the ADEON Terminology Standard v2 Table 11 [3] unless otherwise stated.

Term	Symbol	Unit	Definition
integer ADC output	N	1	integer representation of ADC output, defined such that a unit change in integer ADC output corresponds to a change in the lowest significant bit from 0 to 1, or 1 to 0
maximum integer ADC output	N_{max}	1	largest possible value of the integer ADC output
minimum integer ADC	N_{min}	1	smallest possible value of the integer ADC output
full-scale ADC output	N_{FS}	1	difference between maximum integer ADC output and minimum integer ADC output
bit depth	N_{bit}	bit	amount of digital memory available at ADC output to digitize one value of ADC input
ADC sensitivity to voltage	$M_{ADC,V}$	V^{-1}	ratio of rms integer ADC output to rms ADC input voltage
ADC voltage conversion factor	µV	V	reciprocal of ADC sensitivity to voltage
maximum unsaturated voltage	V_{max}	V	maximum ADC input voltage for which the ADC sensitivity to voltage is independent of ADC input
Minimum unsaturated voltage	V_{min}	V	minimum ADC input voltage for which the ADC sensitivity to voltage is independent of ADC input
full-scale input range			difference between maximum unsaturated voltage and minimum unsaturated voltage
Ideal code bin width	Q		full-scale input range divided by Nfs+1, where Nfs is the full-scale ADC output
equivalent mean-square ADC self-noise voltage	$V_{N,eq}^2$	V	ratio of mean-square integer ADC output to the squared ADC sensitivity to voltage
pre-amplifier voltage gain	$G_{pA,V}$	1	ratio of rms pre-amplifier output voltage to rms pre-amplifier input voltage
AAF voltage gain	$G_{AAF,V}$	1	ratio of rms AAF output voltage to rms AAF input voltage
full-scale signal			signal whose peak-to-peak value spans the entire range of input values recordable by an ADC, from minimum unsaturated voltage to maximum unsaturated voltage
non-acoustic self-noise			fluctuations in voltage in an acoustic receiver in the absence of sound pressure input NOTE: Based on ISO 18405:2017 and ADEON standard [3].
signal-to-noise-and-distortion ratio			square root of the signal to noise power ratio at the ADC output

Table 12. Quantities used to characterize the passive data recorder acquisition system.

term	symbol	unit	definition
system sensitivity	M_{tot}	Pa^{-1}	quotient of the root-mean-square open-circuit voltage at a specified point in the measurement system (usually the electrical output terminals) to the incident root-mean-square sound pressure that would be present at the position of the reference centre of the hydrophone in the undisturbed free field if the hydrophone was removed for specified frequency and specified direction of plane wave sound NOTE 1: From ISO 18406:2017 NOTE 2: The system sensitivity is defined here as a free-field sensitivity for an acoustic measurement system designed to measure sound pressure signals in water. The measurement system will typically consist of hydrophone(s) connected to amplifier(s) and filter(s), and will feed an output voltage into a digital acquisition and storage system. Note that the response of the system will in general vary with acoustic frequency. NOTE 3: The analogue system sensitivity is described in terms of the electrical voltage developed per pascal of acoustic pressure, and is stated in units of V/Pa. The sensitivity level is sometimes expressed in decibels as dB re 1 V/μPa. For digital systems, the calibration of the ADC is typically incorporated into the overall sensitivity of the whole system, which is the number of digital counts per unit change in sound pressure (unit Pa^{-1}). NOTE 4: If the hydrophone is physically attached to the body of an acoustic recorder (rather than deployed on an extension cable), diffraction and scattering of sound by the recorder body may affect the free-field sensitivity at kilohertz frequencies, causing enhanced directivity compared to the response of the free hydrophone. NOTE 5: In general, the measuring system may introduce a phase delay into the measured signal. This may be accounted for by representing the system sensitivity as a complex valued quantity, the modulus of which represents the magnitude-only response (and is described by the definition above), and the phase of which describes the phase response of the system. Note that the complex-valued system sensitivity will in general vary with acoustic frequency.
system non-acoustic self-noise output		1	system digital output in the absence of sound pressure at the hydrophone input NOTE 1: Adapted from ADEON standard [3].
system mean-square non-acoustic self-noise output spectral density		Hz^{-1}	ratio of mean-square ADC non-acoustic self-noise output in a specified frequency band to the width of the frequency band NOTE 1: From ADEON standard [3].
equivalent system mean-square non-acoustic self-noise sound pressure spectral density			ratio of system mean-square non-acoustic self-noise output spectral density to the squared total system sensitivity NOTE 1: From ADEON standard [3].
electrical noise power		W	time-averaged product of noise current and noise voltage NOTE 1: Adapted from ADEON standard [3].
electrical signal power	W_s	W	time-averaged product of signal current and signal voltage NOTE 1: Adapted from ADEON standard [3].

signal to noise power ratio	R_{SN}	1	the ratio of the power of the signal to that of the coexistent noise at the system output, under specified conditions NOTE: Sometimes expressed as a level in decibels. From IEC 60050-713-11-19 and ADEON standard [3].
intermodulation distortion			distortion resulting from the combination within the system of two independent input signals NOTE 1: Adapted from IEC 60050-561-02-23 and IEC 60050-161-06-20 and ADEON standard [3]. NOTE 2: This occurs due to interaction in a system between the spectral components of the input signal or signals producing new output spectral components having frequencies equal to linear combinations of the inputs with integral coefficients of the frequencies of the input spectral components. Intermodulation can result from a single non-sinusoidal input signal or from several sinusoidal or non-sinusoidal input signals applied to the same or to different inputs. An input signal containing multiple tones may generate output distortion containing the sums and differences of the input tones.
system self-noise spectral density		Pa^2/Hz	mean-square self-noise voltage spectral density at the system output divided by the squared system voltage sensitivity NOTE 1: From ADEON standard [3].

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Annex A One-third-octave band (base 10) frequencies

This Annex closely follows the guidance text provided in ADEON Underwater Soundscape and Modelling Metadata Standard v1 [2], and is based on the frequency bands described in IEC (2014) (consistent also with ANSI, 2016a).

In JOMOPANS, one-third-octave bands (base 10) shall be used. The centre frequencies f_c are:

$$f_c = (1\ kHz)\ 10^{\frac{n}{10}}$$

Upper and lower frequencies are respectively 0.5 one tenth of decade above and below the centre frequency, namely:

$$f_{min} = f_c\ 10^{\frac{-1}{20}} \qquad f_{max} = f_c\ 10^{\frac{1}{20}}$$

Table 13 shows the bands according to IEC (2014),5 for one-third-octave frequency bands with centre frequencies from 10 Hz (n = -20) Hz to 20 kHz (n = +13).

Table 13 One third of octave band frequencies

Band index	Lower bound	Centre frequency	Upper bound	Nominal centre frequency
n	f_{min}/Hz	f_c/Hz	f_{max}/Hz	f_c, nom/Hz
-20	8.9125	10	11.22	10
-19	11.22	12.589	14.125	12.5
-18	14.125	15.849	17.783	16
-17	17.783	19.953	22.387	20
-16	22.387	25.119	28.184	25
-15	28.184	31.623	35.481	31.5
-14	35.481	39.811	44.668	40
-13	44.668	50.119	56.234	50
-12	56.234	63.096	70.795	63
-11	70.795	79.433	89.125	80
-10	89.125	100	112.2	100
-9	112.2	125.89	141.25	125
-8	141.25	158.49	177.83	160
-7	177.83	199.53	223.87	200
-6	223.87	251.19	281.84	250
-5	281.84	316.23	354.81	315
-4	354.81	398.11	446.68	400
-3	446.68	501.19	562.34	500
-2	562.34	630.96	707.95	630
-1	707.95	794.33	891.25	800
0	891.25	1000	1122	1000
1	1122	1258.9	1412.5	1250
2	1412.5	1584.9	1778.3	1600
3	1778.3	1995.3	2238.7	2000
4	2238.7	2511.9	2818.4	2500
5	2818.4	3162.3	3548.1	3150
6	3548.1	3981.1	4466.8	4000
7	4466.8	5011.9	5623.4	5000
8	5623.4	6309.6	7079.5	6300
9	7079.5	7943.3	8912.5	8000
10	8912.5	10000	11220	10000
11	11220	12589	14125	12500
12	14125	15849	17783	15000
13	17783	19953	22387	20000