IQOE Workshop Report:
"Guidelines for Observation of Ocean Sound"

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Park Hotel, Den Haag, Netherlands

Workshop Sponsors

Directorate-General for Public Works and Water Management (Rijkswaterstaat)
International Quiet Ocean Experiment (IQOE)
US Office of Naval Research - Global (ONR-G)
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TNO

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Overview

A one-day workshop was convened to develop International Quiet Ocean Experiment (IQOE) program guidelines for measuring, processing, and reporting of ocean sound levels. Fifteen international experts came together from eight countries to discuss current practices for measuring, processing, and reporting ocean sound levels from existing long-term monitoring projects and to recommend key consensus parameters for ocean sound level measurements designed to facilitate cross-project comparisons. The workshop product is a meeting report that includes recommendations directed to ocean sound research programs, sponsoring international organizations, and/or their science advisory groups to support the development and implementation of ocean sound processing reporting guidelines needed to make meaningful soundscape comparisons across time, space, and monitoring programs.

The workshop recommendations are summarized in Table 4 at page 10 of this document.

Steering Group

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Rationale

The ocean community is challenged on how to best monitor and compare soundscapes over time and space to appropriately interpret change and impact when there are no standards or accepted guidelines on how to collect, process, and report ocean sound levels. Many ocean sound observation projects world-wide have started or are being planned (Table 1); harmonization and standardization of approaches will facilitate inter-comparison of the results. A lack of data processing, modeling and reporting standards can lead to the misinterpretation of analyses, creation of policy that may be either too conservative or liberal, and create obstacles for collaboration across past, current, and future monitoring studies. This is a time-critical topic, as ocean sound has recently been accepted as an Essential Ocean Variable (EOV) by the Global Ocean Observing System (GOOS) (Miksis-Olds et al., 2018), and a large influx of ocean sound data are expected in the near future as new acoustic sensors are integrated into GOOS. Multiple national and international entities have recognized the significance in addressing this need by convening cross-sector workshops of ocean stakeholders over the past five years to develop protocols and guidelines towards standardizing ocean sound analysis and reporting (IWC (2014); COL (2018)). These workshops resulted in the identification of consensus items and recommendations to enable meaningful soundscape comparisons, but lack of funding and leadership has led to systemic inaction in moving from recommendation to implementation. This IQOE Standards workshop was designed to evolve from recommendations to the development of guidelines for measuring, processing, modeling and reporting of ocean sound levels with application to characterization of soundscapes, ambient sound and ambient noise.

Table 1 – Subset of long-term acoustic monitoring projects from the recent past, present, and foreseeable future.

Project	Location	Country/Countries
ADEON (Atlantic Deepwater Ecosystem Observatory Network)	SE US Outer Continental Shelf	USA
BIAS (Baltic Sea Information on the Acoustic Soundscape)	Baltic Sea	Sweden, Denmark, Germany, Poland, Estonia, Finland
ECHO (Enhancing Cetacean Habitat and Observation) Program	British Columbia, Vancouver Port waters	Canada
ESRF (Acoustic Monitoring of Canada's East Coast)	Canadian Atlantic coast waters	Canada
IMOS (Integrated Marine Observing System)	Australian coastal waters	Australia
JOMOPANS (Joint Monitoring Programme for Ambient Noise North Sea)	North Sea	Netherlands, UK, Denmark, Sweden Belgium, Norway, Germany
JONAS (Joint Framework for Ocean Noise in the Atlantic Seas)	NE Atlantic waters	Ireland, Spain, Portugal, France, UK
NOAA CetSound Project	US coastal waters	USA
NOAA Noise Reference Station Program	NE Pacific, Hawaii, NW Atlantic and Caribbean waters	USA
QuietMed	Mediterranean Sea	Spain, Greece, Malta, Italy, France, Slovenia, Croatia
QuietMed II	Mediterranean Sea	Spain, Italy, Malta, Greece, Cyprus, Croatia, Slovenia and Denmark
SeaWays	Gulf of St. Lawrence	Canada
SOUNDSCAPE	North Adriatic Sea	Italy, Croatia

For a list of participants see Appendix 1.

Terminology

In underwater acoustics many different terms are used, often using the same term with different meanings. To facilitate effective communication, we follow ISO 18405:2017. In addition, some specialized terms are defined in Appendix 2. Symbols and abbreviations used in this report are listed in Appendix 3.

Workshop Preparation

Prior to the 1-day workshop, the workshop organizers distributed a brief questionnaire to various acoustic monitoring projects (Table 1) soliciting project-specific information about data collection, analysis, and reporting. Information returned from the questionnaires was compiled for discussion (Table 2) during the workshop and integrated into the workshop agenda. Information was also compiled prior to the workshop summarizing the recommendations from previous workshop discussions related to soundscapes, observation of ocean sound, and soundscape modeling. Effort invested by the workshop organizers prior to convening the present workshop provided a clear starting point to work from without wasting time or effort in duplicating past efforts and discussions.

Table 2 – Summary of responses from pre-workshop questionnaire reflecting project specific data processing parameters.

Temporal observation window[1]	**Temporal analysis window**[2]	**SPL percentiles**	**Total frequency band**
1 s: 5 projects 20 s: 1 project 30 s: 2 projects 60 s: 5 projects 1 h: 2 projects 1 d: 3 projects 1 mo: 2 projects 1 a: 3 projects	1 hour (h): 2 projects 1 day (d): 6 projects 1 month (mo): 6 projects 1 year (a): 5 projects	25, 50, 75: all projects 10, 25, 50, 75, 90: 5 projects 5, 25, 50,75, 95: 3 projects 1, 10, 25, 50, 75, 90, 99: 1 project	Lower limit: between 1-63 Hz, majority 10 Hz Upper limit: between 1-100 kHz

Responses related to duty cycle and hydrophone depth were widely varying with no clear specifications.

The following five questions were also included in the pre-workshop questionnaire upon which recommendations were made based on questionnaire responses and workshop discussion:

1. Is there a standard, guideline, or recommendation consulted in directing your choice of measurement, processing, or modeling parameters?
2. Is SPL sufficient?
3. Should we consider other metrics such as peak sound pressure, sound exposure, or kurtosis?
4. Should we consider frequency-weighted metrics?
5. Should we consider particle motion or other vector metrics?

Upon workshop consensus, modeling parameters were not discussed, as those with modeling expertise were not represented among the workshop participants. Consequently, discussion was focused on ocean sound data acquisition, processing, and reporting.

[1] averaging window for SPL percentiles
[2] unit for SPL statistics

Workshop Agenda

PART 1:	PART 2:
Why we are here?	Questionnaire feedback
Introductions	Open discussion
Workshop objective	Conclusions
Workshop scope	Where we agree, summarize consensus
Questionnaire overview	Where we disagree, summarize the stumbling blocks

Preceding the discussion identifying consensus items for recommended guideline, the topic of data levels was addressed. The Global Ocean Observing System data levels were suggested as a model for structuring the standards for ocean acoustics:

- Level 0 – raw uncalibrated data time series
- Level 1 – calibrated data time series
- Level 2 – data products (SPL, SEL, percentile levels, etc.)

Ocean acoustic guidelines being recommended in this workshop pertain largely to Level 2 data with a few recommended guidelines associated with data acquisition related to Level 0 and Level 1. It was noted that guidelines for measurement parameters should be completely aligned for processing and analysis, while recognizing that hardware may not match.

Workshop Summary

Main recommendations for data acquisition and processing

Technical guideline recommendations for data acquisition and processing are summarized in Table 3 for both temporal and spectral parameters, as well as for appropriate acoustical metrics. Recommendations from 2014 (IWC, Leiden) and 2018 (COL, Washington) workshops are shown for comparison.

Table 3 – Recommendations from three international workshops focused on soundscapes and long term trends in ocean sound. The table content reflects essential and desirable sampling and processing parameters where workshop consensus was achieved, recognizing that individual projects/programs would likely exceed the minimum recommendations.

Workshop	Temporal parameters			Spectral parameters		Metrics
	Duty cycle	**Temporal observation window (averaging window for SPL percentiles**	**Temporal analysis window (unit for SPL statistics)**	**Frequency analysis bandwidth**	**Total frequency bandwidth**	**SPL statistics**
IWC, 2014 Joint IWC/IQOE/ NOAA/ONR/TNO Workshop	1 min/h	1 min	1 d (see footnote[3])	Decidecade (i.e., one-third octave (base 10)) bands	10 Hz – 1 kHz decidecade bands	Arithmetic mean and specified percentiles (10, 25, 50, 75, 90th).
COL, 2018 COL Ocean Sound Workshop	2 min/h with minimum 30 s contiguous recording time	30 s	1 d (see footnote[4])	Decidecade (i.e., one-third octave (base 10)) bands	1 Hz bands at 1 s resolution over full frequency of recordings **Optional**: 10 Hz bands at 0.1 s resolution and 100 Hz bands at 0.01 s resolution	Arithmetic mean and specified percentiles (10, 25, 50, 75, 90th).
2019 IQOE Standards Workshop (this workshop)	**Essential**: Sufficient data to calculate percentiles with minimum 60 s contiguous recording time **Desirable**: ≥ 5 min/h, spread evenly over the hour	**Essential**: 1 min **Desirable**: 1 s	**Essential**: 1 mo **Desirable**: 1 h, 1 d, 1 a	**Essential**: Decidecade (i.e., one-third octave (base 10)) bands **Desirable**: 1 Hz **Desirable**: Broadband calculated from decidecade bands (ADEON, 2018b)	**Essential**: 10 Hz – 1 kHz decidecade bands, i.e., the 21 decidecade bands with index -20 to 0 inclusive (ADEON, 2018b) **Desirable**: 10 Hz - 1 kHz in 1 Hz bands, 10 Hz-20 kHz in decidecade bands, optional up to maximum recording frequency	**Essential**: Arithmetic mean and specified percentiles (10, 25, 50, 75, 90th) in the temporal analysis window. **Desirable**: Include 5 and 95th percentiles in the temporal analysis window **Desirable**: Full CDF in 1 % steps in the temporal analysis window

[3] IWC (2014) further remarks that based on the data recorded using a temporal analysis window of 1 d, "monthly, seasonal and annual statistics (arithmetic means and percentiles) can be computed."
[4] COL (2018) further requires processing of data in decidecade bands on hourly intervals.

Temporal parameters

The terms ‘temporal observation window’ and ‘temporal analysis window’ are defined in Appendix 2. Considerations for the choices of 1 s and 1 min for the temporal observation window include:

- Relevance for animal hearing (integration time)
- Compatibility with earlier work
- Robustness (sensitivity to impulsive sounds)
- Data characteristics for modeling
- Averaging time for wind speed (≈ 10 min)
- Averaging time for ship source level measurements
- Effects of sound travel time

Spectral parameters

It is recommended that projects should monitor the 21 decidecade bands with center frequencies between 10 Hz and 1 kHz. In making this recommendation the value of CTBTO recordings is recognized because of its global coverage and continuous long-term recordings. CTBTO data are therefore exempted from covering the full frequency band, and should instead cover the 11 decidecade bands with center frequencies between 10 Hz and 100 Hz.

Acoustical metrics

Metrics are percentiles and the arithmetic mean (AM) of the squared sound pressure samples. There was consensus for including the AM in all three workshops (IWC, 2014; COL, 2018; this report). The AM is needed to facilitate inter-project comparability, regardless of the size of the temporal observation window. The corresponding sound pressure level, L_{AM}, is

$$L_{\mathrm{AM}} = 10 \log_{10} \frac{1}{N} \frac{\sum_{i=1}^{N} p_i^2}{1\ \mu\mathrm{Pa}^2}\ \mathrm{dB},$$

Equation 1

where p_i is the sound pressure of the ith sample and N is the number of samples.

Responses to itemized questions, and associated recommendations

Recommendations related to the five itemized questions in the pre-workshop survey are summarized below:

1. *Is there a standard, guideline, or recommendation consulted in directing your choice of measurement, processing, or modeling parameters?*
   The questionnaire responses indicated that there was no single standard or guideline that all projects were using. ADEON and JOMOPANS are documenting their own project standards based on available ISO standards related to terminology, frequency parameters, and time standards.

Recommendation:

- Follow the following existing standards for a) terminology described in ISO 18405, b) frequency bands specified by IEC 61260-1, and 3) time stamps relative to UTC time outlined in ISO 8601.
- Use time intervals of calendar months (not Julian months) and calendar years (not Julian years).
- All processing and reporting of ocean sound should be from calibrated data, following the IEC hydrophone calibration standard. (IEC 60565)

2. *Is SPL sufficient?*
   The majority of respondents indicated that SPL is not sufficient to convey ocean sound dynamics. Source contribution, kurtosis, sounds exposure, and peak sound pressure were all aspects suggested for consideration in addition to SPL.

   Recommendation:

   - Record sound pressure time series for subsequent processing as other standards and guidelines become available.

3. *Should we consider other metrics such as peak sound pressure, sound exposure, or kurtosis?*
   All but one of the responses were yes to this question. Suggestions for other metrics were SEL, averaged power spectrum, kurtosis, and peak sound pressure.

   Recommendation:

   - Standardize frequency bands for broadband quantities.

4. *Should we consider frequency-weighted metrics?*
   Responses to this question on the questionnaire ranged from yes to no. Discussion related to the topic yielded interest from all parties about the value of weighted levels, but it was also recognized that unweighted data are required in cases where weighting details may change in the future. If the averaged power spectrum is provided, then the data can be weighted at a later date.

   Recommendation:

   - Store the unweighted SPL spectrum in standard decidecade bands so that these can be weighted at a later date.

5. *Should we consider particle motion or other vector metrics?*
   Responses and discussion related to particle motion was polarized. Many recognized the value of particle motion and measurement of the metric, but there was also general agreement that the current technology is not adequate to support mainstream monitoring of this quantity.

Recommendation:

- Particle motion is valuable and measurements should be acquired as technology matures. At this point, the discussion related to standards for measuring, processing, and reporting particle motion can be revisited.

Guidelines for modeling

Participants recognized a need for providing recommendations for modeling. Few of those present had experience in modeling, and therefore no firm recommendations are made. However, some discussion took place and the following guidelines for modeling are suggested:

- In shallow water (water depth H<200 m), calculate the arithmetic mean and variance over full depth of the mean-square sound pressure.
- In deep water (H>200 m), calculate the arithmetic mean and variance over the top 200 m of the mean-square sound pressure. Further consideration is needed for receiver depths exceeding 200 m.
- Input parameters used in modeling should correspond where possible to the physical situation (deployment geometry, source geometry, propagation conditions) and to the type of processing (e.g., frequency band, averaging time).
- Uncertainties in input parameters should be taken into account.
- Output should include an estimate of uncertainty.
- Frequency bands should include the nominal 63 Hz and 125 Hz decidecade bands for consistency with the recommendation of the EU's expert group advising EU Member States on Descriptor 11 of Good Environmental Status (underwater noise) (TG Noise, 2014).

Summary of IQOE Recommendations

The workshop recommendations are summarized in Table 4.

Table 4 – Summary of recommendations

Recommendations for	Essential	Desirable	Notes
Standards:			
acoustical terminology	follow ISO 18405		
frequency bands	follow ISO 61260-1		The decidecade bands specified by ISO 61260-1:2014 are referred to in that standard as "one-third octave" bands. See Appendix 2.
Timestamps	follow ISO 8601		Use time intervals of calendar months (not Julian months) and calendar years (not Julian years
Calibration		follow IEC 60565	
Temporal parameters:			
duty cycle	Sufficient data to calculate percentiles with minimum 60 s contiguous recording time	≥ 5 min/h, spread evenly over the hour	
Temporal observation window	1 min	1 s	
Temporal analysis window	1 mo	1 h, 1 d, 1 a	
Spectral parameters:			
Frequency analysis bandwidth	Decidecade (i.e., one-third octave (base 10)) bands	1 Hz Broadband calculated from decidecade bands	Follow IEC 61260-1 for international standard decidecade frequency bands.

Total frequency bandwidth	10 Hz – 1 kHz decidecade bands, i.e., the 21 decidecade bands with index -20 to 0 inclusive	10 Hz- 1 kHz in 1 Hz bands, 10 Hz-20 kHz in decidecade bands, optional up to maximum recording frequency	Although CTBTO recordings do not meet the letter of this requirement, the exceptional value of CTBTO data is recognized despite this limitation.
Acoustical Metrics:			
Percentiles	10th, 25th, 50th, 75th, and 90th percentiles in the temporal analysis window	5th and 95th percentiles in the temporal analysis window Full CDF in 1 % steps	for temporal averaging window of 60 s and temporary analysis window of 1 mo
other metrics	arithmetic mean (AM) in the temporal analysis window		The AM is evaluated using Equation 1.
General:			
	Record calibrated sound pressure time series for subsequent processing as other standards and guidelines become available.		All processing and reporting of ocean sound should be from calibrated data, following the hydrophone calibration standard IEC 60565.
	Store the unweighted SPL spectrum in standard decidecade bands so that these can be weighted at a later date.		
	report hydrophone depth		It is good practice to report measurement conditions generally.

Areas where agreement was not reached

In some cases proposals were made for which no consensus was reached. There were also items planned for discussion, but were ultimately not discussed at the meeting because of time limitations. Such items are itemized below for future discussion.

Proposals made and no consensus reached:

- For Fourier transform operations from the time domain to frequency, a number of projects use a Hann window with 50 % overlap. While no specific objections were raised to this choice, it was considered too detailed at this early stage.
- A minimum measurement depth of 5 m was proposed. It was considered too soon to standardize measurement depth.
- Standardization of frequency weighting was discussed. While considered an important topic, this is outside the scope of the meeting. It is recommended that standardization of frequency weighting instead be considered by IQOE's Marine Bioacoustics Working Group.

Items not discussed, or not discussed in detail:

- Standardization of modeling generally;
- Spatial coverage and spatial averaging;
- The need to quantify uncertainty in measurements;
- The need for data processing benchmarks.

Future directions

The following priorities for future standardization were agreed:

- Standardize frequency bands for broadband quantities.
- Particle motion is valuable and measurements should be acquired as technology matures. At this point, the discussion related to standards for measuring, processing, and reporting particle motion can be revisited.
- The workshop participants considered the study diurnal patterns to be important, but the start and end times of diurnal variations are dependent on the local sun/moon rise/set times. The authors of this report suggest that data analysis be based on the UTC day (00:00-23:59 UTC) for the analysis window. This choice would ensure that there are no discontinuities in moving between time zones nor when adjusting for Daylight Saving Time.

Finally, it is recommended that IQOE continues to support future standardization efforts such as workshops and standards-related publications in underwater acoustics and underwater bioacoustics.

References

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ADEON soundscape standard (ADEON, 2018b)

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IEC (2006) IEC 60565:2006

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Appendix 1 - Participant Information

Table 5 – List of participants

Participant Name	Email	Projects
Michael Ainslie*	michael.ainslie@jasco.com	IQOE, ADEON
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*Indicates workshop co-organizer

Appendix 2 - Terms and Definitions

A list of terms used in this report and their definitions is provided in Table 6.

Table 6 – Terms and definitions

Term	Definition	Ref
ambient noise	sound except acoustic self-noise and except sound associated with a specified signal	ISO 2017
ambient sound	sound that would be present in the absence of a specified activity	ISO 2017
day **symbol**: d	86 400 s	ISO 2006
decade **symbol**: dec	logarithmic frequency interval between f1 and f2 when f2/f1 = 10	ISO 2007
decidecade **synonym**: one-third octave (base 10) **symbol**: ddec	one tenth of a decade (1/10 dec)	ISO 2017
octave **symbol**: oct	logarithmic frequency interval between f1 and f2 when f2/f1 = 2	ISO 2007
one-third octave **synonym**: one-third octave (base 2)	one third of an octave (1/3 oct)	ISO 2017
temporal analysis window	interval of time during which statistics are calculated over multiple temporal observation windows	ADEON 2018a
temporal observation window	interval of time within which a statistic of the sound pressure is calculated or estimated	ADEON 2018a
UTC month **synonym**: month **symbol**: mo	one calendar month (28 d to 31 d)	ADEON 2018b
UTC year **synonym**: year **symbol**: a	one calendar year (365 d or 366 d)	ADEON 2018b

Appendix 3 - Symbols and abbreviations

Lists of symbols and abbreviations used in this report are provided in Table 7 and Table 8.

Table 7 –abbreviations

Abbreviation	Meaning
AM	arithmetic mean (of squared sound pressure samples)
CDF	cumulative distribution function
COL	Consortium for Ocean Leadership
EU	European Union
IEC	International Electrotechnical Commission
IQOE	International Quiet Ocean Experiment
ISO	International Organization for Standardization
IWC	International Whaling Commission
SEL	sound exposure level
SPL	sound pressure level
UTC	Coordinated Universal Time

Table 8 – Symbols

Symbol	Meaning
a	year (annum)
d	day
dB	decibel
h	hour
L_{AM}	sound pressure based on AM
min	minute
mo	month
N	number of sound pressure samples used in the calculation of L_{AM}
p_i	sound pressure of ith sample