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4aAB1. Computing cumulative sound exposure levels from anthropogenic sources in large data sets
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The goal of many underwater acoustic environmental assessments is to characterize the soundscape in an area before, during or after an anthropogenic activity. The assessment determines the range of baseline noise levels from natural and anthropogenic sources and the contribution of the new anthropogenic activity. The noise levels are considered in aggregate for possible effects on the environment. It is accepted that the effects of anthropogenic noise on marine life depend on the intensity and duration of exposure, the frequency content of the sound relative to the hearing abilities of the species, and the behaviour context of the species exposed to the sounds. A growing body of scientific evidence is being analyzed to establish threshold sound levels and dose-response curves for injury or behavioural disturbance effects to marine life. Recent research is also raising new questions about the most appropriate ways to compute ambient sound levels and exposure metrics. In this paper we present our methods for quantifying ambient sound levels and anthropogenic sound levels from shipping and seismic survey activities in large data sets. We also make recommendations on how to estimate background sound levels in the presence of these sound sources.

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INTRODUCTION

The large body of literature on underwater ambient noise shows that anthropogenic sources, especially commercial shipping, dominate ocean sound in the region of approximately 40–200 Hz (e.g., Wenz 1962, MacDonald et al. 2008, Andrew 2011, Erbe et al. 2012, Merchant 2012b). The literature also shows that the amount of sound generated by human activity is increasing as we make greater use of the ocean for transportation of goods, renewable energy generation, and exploration and extraction of hydrocarbons. Seismic exploration of oil and gas reserves is a particularly intense sound source, which can be detected hundreds of kilometers away (Nieukirk et al. 2012). Research has shown that the natural ocean ambient noise from 200 to 50 000 Hz is affected mainly by wind and precipitation. Wind noise typically peaks at 500 Hz and decays by about 20 dB/decade. Underwater noise from precipitation is generated by the impact on the water surface and by the oscillation and collapse of entrained bubbles. Precipitation noise spans up to 1–30 kHz in frequency and often dominates the wind noise (Wenz 1962, Scrimger 1985, Vagle et al. 1990, Ma et al. 2005).

The effects of anthropogenic underwater noise on marine life are complex and still largely unknown. They depend on the level, frequency band, and duration of the sound; the hearing range or vocalization range of the animals; and the behavioral context of the animal encountering the sound—be it feeding, migrating, caring for young, resting, mating, etc. (e.g., NRC 2005, Ellison et al. 2012). Anthropogenic sounds can disturb animals, cause temporary or permanent injury to the animal’s hearing, or even cause injury to non-auditory organs and tissues. Southall et al. (2007) provide an excellent review of these effects. Smaller animals, especially fish with swim bladders, can suffer barotrauma from exposure to high sound levels that can even lead to death (e.g., Popper and Hastings 2009, Halvorsen et al. 2012).

Government regulators are evolving frameworks for measuring marine noise based on the emerging science. Southall et al. (2007) proposed criteria for measuring and predicting the effects of noise on marine life. The peak sound pressure level (SPL) is related to injury (the onset of temporary or permanent threshold shifts in hearing) by impulsive and nonimpulsive sounds. The root-mean-square (rms) SPL is related to disturbance by continuous and impulsive sources. The sound exposure level (SEL) metric quantifies the effects of exposure over time (and over multiple sound events) and is related to disturbance by single pulses as well as injury.

Proponents of new marine-industrial projects must characterize the acoustic effects of their activities as part of environmental impact assessments. These assessments can include studies of the acoustic soundscape before, during, and after the projects. Long-term acoustic assessments produce large amounts of data for analysis and interpretation, and efficient analysis of these data sets is essential.

This paper proposes methods to automate detecting and quantifying underwater noise from anthropogenic activities (seismic and shipping) and for estimating the background sound levels if the anthropogenic sounds were absent. Three methods of estimating the background are evaluated. Method 1 attempts to detect all of the energy from anthropogenic sources and subtract it from the total to obtain the background estimate. Method 2 predicts the sound levels from the wind speed. Method 3 measures histograms of the ambient sound distribution as a function of the sound level in the 6300 Hz 1/3-octave band, and then predicts the sound levels when anthropogenic activity is present based on the measured level in the 6300 Hz 1/3 octave band.

The terms ‘ambient sound’ and ‘background sound estimate’ are used in this paper. In this context ambient sound refers to the sound that is left-over after detecting identifiable anthropogenic sounds, specifically shipping and seismic survey pulses, whereas background estimates are the result of applying an algorithm to determine what the sound levels may have been without the detected anthropogenic sounds.

METHODS

This study focuses on 6 weeks of data collected from 29 July to 10 September 2010 in the Chukchi Sea with an Autonomous Multichannel Acoustic Recorder (AMAR, JASC O Applied Sciences Ltd.) sampling at 16 ksps. Before deployment the AMAR and its M8E hydrophone (GeoSpectrum Technologies Inc., –164 dB re 1 V/µPa sensitivity) were calibrated with a Pistonphone Type 42AA (G.R.A.S. Sound & Vibration A/S). The combined frequency response of the hydrophone and AMAR rolled off below 16 Hz at a combined rate of 12 dB/octave. The first 24 days of recording contain primarily ambient sounds, while the last 20 days are dominated by seismic survey sounds. We examined a total of 62,995 continuous minutes of data (i.e., 1050 h), in which the dominant sound source was manually classified as seismic, shipping, or ambient/natural in origin (FIGURE 1).

The AMAR data were stored in 15 minute long WAV files. Custom software quantified the ambient sound levels in each minute of data, detected the number of shipping tonals in each minute of data, and detected seismic survey pulse sequences. The results from each file were combined into a single dataset for further analysis. The
ambient sound level metrics include the rms, peak, peak-to-peak, and 1/3-octave band rms SPLs as well as 1 Hz spectral density levels (120 averages of a 16 384-point fast Fourier transform (FFT) with 16 000 real data points, 8 000-point advance, and Hamming window). For each seismic pulse detected, the rms SPL and SEL were computed.

Throughout this paper the rms SPL is used as the primary measure of sound level (Southall et al. 2007, Merchant 2012b). While this metric can be biased upward by high intensity outliers, its relationship to SEL makes it especially useful. For detection thresholds the median SPL distribution acts as the reference level. It is more stable than the averaged values and leads to more predictable detections. The relative energies of ambient, shipping, and seismic sounds are presented as the cumulative sound exposure levels (cSEL) per day or per hour.

The time base of our analysis is 1-minute values. A 1-minute time scale is sufficient to sample changes in sound levels due to rain (minutes), wind (hours), shipping vessels (5–600 minutes), and seismic survey activity, which can be stable for long periods of time and then change abruptly, such as changing from a single mitigation airgun (intended to act as a deterrent between line acquisitions) to a full airgun array.

**FIGURE 1.** Summary of the study dataset: (a) Cumulative sound exposure level (cSEL) per day per source as identified by manual analysis; and (b) box-and-whisker plot of the range of sound pressure levels (SPLs) measured per day. The vertical line denotes the start of the seismic survey.

**Shipping Detection**

Ships produce narrowband sinusoidal tones from the propulsion and other rotating machinery, as well as broadband energy from propeller cavitation (Avreson and Vendittis 2000). JASCO implemented a shipping detector based on overlapped FFTs. The number of seconds of data input to the FFT determines its spectral resolution. Avreson and Vendittis used both 0.5 and 0.125 Hz resolutions. **FIGURE 2** shows how FFTs of different lengths resolve the shipping tones. We recommend 0.125 Hz resolution by using 8 s of real data with a 2 s advance. This frequency resolution separates the tones from each other for easy detection, and the 2 s advance provides suitable temporal resolution. Higher frequency resolutions can reduce detectability of shipping tones, which are often unstable within 1/16 Hz for long periods.

Tonal detection is performed on the 15-minute WAV files. A 120 s-long spectrogram is created with 0.125 Hz frequency resolution and 2 s time resolution (131 072-point FFTs, 128 000 real data points, 32 000-point advance, Hamming window). A split-window normalizer (Struzinski 1984) selects the tonal peaks from the background (16-point window, 6-point notch, and detection threshold of 4 times the median). The peaks are joined with a 7×7 kernel to create contours. Associations in frequency are then made if contours occur at the same time. The event time and number of tones for any event at least 20 s long and 40 Hz in bandwidth are recorded for further analysis.
FIGURE 2. Effect of FFT resolution on shipping tonal detection. Tones appear as distinct vertical spikes in these spectra. (a) 16 Hz resolution typically used for marine mammal whistle detection; (b) 2 Hz resolution typically used for marine mammal moan detection; (c) 0.5 Hz resolution; (d) 0.125 Hz resolution. 0.125 Hz is the recommended resolution since individual tones are separated and detectable. All FFTs used a Hamming window, 50% overlap, and 16 averages.

The shipping detection is performed on the combined results from each WAV file. We define a ‘shipping band’ of 40–315 Hz and obtain an rms SPL for the band once per minute. Background estimates of the shipping band rms SPL and the total rms SPL are compared to their median values over the 12-hour window centered on the current time. Shipping is detected when the rms SPL in the shipping band is at least 3 dB above the median, at least 5 shipping tonals are present, and the rms SPL in the shipping band is within 8 dB of the total rms SPL (FIGURE 3). When these conditions are true, the total per-minute rms SPL is attributed to shipping. The shipping post-processor also performs a search for broadband shipping sound. If the rms SPL in the shipping band is greater than 105 dB, the 1/3-octave band SPL at 630 Hz exceeds the SPL at 6300 Hz by at least 10 dB, and there were tonals detected within ½ hour of the current time, then broadband shipping is detected. The 10 dB constraint between 1/3-octave bands separated by a decade in frequency is equivalent to the 20 dB/decade slope discussed in Wenz (1962).

FIGURE 3. Broadband and in-band rms sound pressure level (SPL) and the number of 0.125 Hz wide tonals detected per minute as a ship approached the recorder, stopped to perform a task, and departed (6–7 August 2010 UTC). The shaded area is the time period of shipping detection. All tonals are from the same vessel. Fewer tonals are detected at the ship’s closest points of approach (CPA, at 23:00 for example) because of the broadband cavitation noise at CPA and the Doppler shift of the tonals.

Detection of Seismic Survey Pulse Sequences

Seismic pulse sequences are detected using correlation detection on spectrogram contours. A 300 s long spectrogram is created with 4 Hz frequency resolution and 0.05 s time resolution (4096-point FFT, 3200 real data points, 800-point advance, Reisz window). Each frequency bin is normalized to the median bin value over the 300 s window. The detection threshold is 3 times the median value. Contours are created by joining the detected
time/frequency bins in the frequency range of 7–1000 Hz using a 7×7 kernel. Any contour between 0.2 and 6 s long with a bandwidth of at least 60 Hz is kept for further analysis. An ‘event’ time series is created by summing the normalized value of the frequency bins at each time bin that contains detected contours. The event time series is auto-correlated to look for repeated events. The correlated data space is normalized to its median and a detection threshold of 3 is applied. Peaks larger than their two nearest neighbors on each side are identified and the peaks list is searched for entries with a set repetition interval. The minimum and maximum time spacing of the peaks are appropriately set, typically at 4.8 s and 65 s, to allow for the normal range of seismic pulse periods of 5–60 s. If at least 6 peaks occur with a regular spacing, the original event time series is searched for all peaks that match the repetition period within a tolerance of 0.25 s. The duration of the 90% rms SPL window of each peak is determined from the originally sampled time series, and pulses more than 3 s long are rejected. To minimize false alarms, especially from biological sources, sequences with a duration standard deviation greater than 0.2+(number of pulses)/30 seconds are rejected. Finally the 100% SEL is computed by adding 0.46 dB to the SEL computed over the 90% rms SPL window, and the pulse time, duration, 90% rms SPL, and SEL are stored for later use. The detected peaks are removed from the event time series and the process is repeated to look for weaker sequences or changes in sequence timing.

Some situations are not well handled by this detector. If the pulse period is unstable by more than 0.25 s, the detector cannot ‘lock-on’. Also, if fewer than six pulses occur at the beginning or end of a WAV file at a particular repetition rate, they are missed. Post-processing is applied to address these issues and smooth the results. If at least 8 out of 20 minutes have seismic detections, and the rms SPL during that period is stable within 3 dB and is greater than 125 dB, then seismic is declared missing for the minutes that meet the criteria. The missing minutes are filled in using the 1-minute rms SPL and SEL from the ambient computations.

A variation of the seismic detector was run to investigate the effects of detector/classifier performance on the cSEL and background estimates, and is referred to as Classifier 2. Classifier 2 used a spectrogram with an 8 Hz frequency resolution and 0.05 second time resolution (2048 point FFT, 1600 points of data, 800 point advance). It did not bound the maximum seismic frequency, it limited the duration of possible seismic pulses to 4 seconds, required 8 pulses to create a sequence, and placed an additional constraint on pulses that the duration of the 20%--25% energy transition must be shorter than the 90%–95% transition. Both classifiers used the same post-processor.

Three Methods of Background Estimation

Our objective is to detect when shipping or seismic survey noise dominates the background sound levels, predict what the background levels would have been without the anthropogenic activity, and determine the time-frequency bands that were affected by the anthropogenic sound. We evaluate three methods and discuss their merits. Method 1 involves detecting and quantifying all anthropogenic activity and removing it from the total sound levels to obtain the background. Methods 2 and 3 build upon the results of Vagle et al. (1990) and Ma and Nystuen (2005), which show a linear relationship between the long term wind speed and ambient noise levels in the frequency range of 500–30 000 Hz. Rain, biological calls, anthropogenic activity, and changes in wind speed or direction perturb the linear relationship. The slope of the linear relationship depends on the geography of the recording location, including fetch and water depth. Methods 2 and 3 do not explicitly predict the linear relationship; instead we develop histograms of background sound levels for different background noise states and use their median values to estimate the natural background noise when anthropogenic noise is detected.

In Method 2 the background sound levels are predicted from the wind speed. The efficacy of this technique was tested by first correlating the rms SPLs with wind measurements. Wind speed measured in Barrow, Alaska, 275 km east-southeast of the recorder, correlated well at a lag of 11 hours (FIGURE 4). Twenty wind-speed bins were defined, evenly spaced between the maximum and minimum wind speeds (0-12.4 m/s). For each minute of data without anthropogenic noise detection within 1 hour, the data were sorted based on the 11-hour delayed wind-speed and 1/3-octave band background noise histograms were created. For the 1-minute time bins with anthropogenic detections, the 1/3-octave band background sound distributions are determined from the delayed wind speed and the median value is used as the background estimate.
Method 3 is similar to the wind speed method, except the SPL in the 6300 Hz 1/3-octave band acts as a reference value for sorting each minute of data without detected anthropogenic activity within 1 hour. Twenty reference bins were defined, evenly spaced between the maximum and minimum of the reference 1/3-octave band SPL. 6300 Hz was chosen as the reference 1/3-octave band because it is the highest band contained in the data set. For data sets with higher sampling rates, a higher 1/3 octave band, up to 25000 Hz, should be used. Higher frequency bands contain lower levels of anthropogenic energy making them a better choice for the reference band. Above 25000 Hz there is minimal contribution of wind and rain to the sound levels, making them inappropriate for the reference band. It is also important to consider the noise floor of the recorder compared to the expected range of sound levels in the reference band.

**Plotting the Cumulative SEL**

The results are presented as cumulative sound exposure level (cSEL) plots. The cSEls are computed for the total received sound energy, the detected seismic survey energy, the detected shipping energy, the background estimate from Method 1 when the shipping and seismic energy is subtracted from the total, and finally for the background estimates from Methods 2 and 3. The cSEL is the linear sum of the 1-minute SELs. For ambient, background estimates, and shipping, the 1-minute cSEL is the linear 1-minute squared rms levels multiplied by the duration, 60 s. For seismic survey pulses the 1-minute SEL is the linear sum of the per-pulse SELs. Hourly cSEls and daily cSEls are compared.

**RESULTS**

**Method 1: Background Estimation by Subtraction of Shipping and Seismic Energy**

For the background estimation by subtraction to work, the detectors must detect and sum all of the anthropogenic sound. The data set had five shipping events between 29 July and 21 Aug, and nearly continuous seismic detections after 21 Aug (FIGURE 1). The shipping detector found all of the shipping events, and accumulated the sound energy very well (TABLE 1). On the 19th and 20th of Aug the detectors missed 1.2 dB and 1.0 dB of cSEL, respectively, this increased the background estimate by 3.1 and 8.8 dB.

**TABLE 1.** Comparison of manually annotated versus detected shipping daily cSEls and manually annotated ambient daily cSEls to daily background cSEL estimated by subtracting the daily shipping cSEL from the total daily cSEL.

<table>
<thead>
<tr>
<th>Date</th>
<th>Manual Shipping cSEL, dB re 1 µPa²/s</th>
<th>Detected Shipping cSEL, dB re 1 µPa²/s</th>
<th>Manual Ambient cSEL, dB re 1 µPa²/s</th>
<th>Background cSEL Estimate, dB re 1 µPa²/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Aug</td>
<td>159.2</td>
<td>159.2</td>
<td>141.6</td>
<td>141.6</td>
</tr>
<tr>
<td>13 Aug</td>
<td>151.1</td>
<td>150.7</td>
<td>149.8</td>
<td>150.2</td>
</tr>
<tr>
<td>16 Aug</td>
<td>152.9</td>
<td>153.0</td>
<td>149.3</td>
<td>149.0</td>
</tr>
<tr>
<td>19 Aug</td>
<td>160.4</td>
<td>159.2</td>
<td>154.3</td>
<td>157.4</td>
</tr>
<tr>
<td>20 Aug</td>
<td>157.1</td>
<td>156.1</td>
<td>141.6</td>
<td>150.4</td>
</tr>
</tbody>
</table>

150701 seismic pulses were manually identified in the data set. The precision, recall and F1-score metrics of each seismic detector/classifier with and without post-processing smoothing are shown in **TABLE 2**. **FIGURE 5** and **TABLE 3** show that all of the detector/classifiers produce estimates of the daily seismic cSEL that are within 1.65 dB of the manually obtained value. However, small changes in the seismic cSEL estimate (0.07 dB) produces much more significant differences in the background estimate (1.4 dB).

**TABLE 2.** Performance scores for the seismic classifiers, with and without post-processing.

<table>
<thead>
<tr>
<th>Seismic Classifier</th>
<th>True Positives, TP</th>
<th>False Positives, FP</th>
<th>False Negatives, FN</th>
<th>Precision</th>
<th>Recall</th>
<th>F-Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>126020</td>
<td>32</td>
<td>24861</td>
<td>0.9995</td>
<td>0.8347</td>
<td>0.9097</td>
</tr>
<tr>
<td>2 with Post-Processing</td>
<td>139199</td>
<td>0</td>
<td>11502</td>
<td>1.0</td>
<td>0.9237</td>
<td>0.9603</td>
</tr>
<tr>
<td>1</td>
<td>147913</td>
<td>240</td>
<td>2788</td>
<td>0.9984</td>
<td>0.9815</td>
<td>0.9898</td>
</tr>
<tr>
<td>1 with Post-Processing</td>
<td>149937</td>
<td>40</td>
<td>764</td>
<td>0.9997</td>
<td>0.9949</td>
<td>0.9973</td>
</tr>
</tbody>
</table>

**FIGURE 6** shows the background sound estimate using the Classifier 2 with post-processing. The peak of the ambient cSEls before the seismic survey started was 165 dB re 1 µPa²/s due to a rain storm. Only three days during
the seismic survey have background estimates below this peak value (Aug 25, 26 and 29). This suggests that the background estimate by subtraction is significantly above the actual sound levels without the anthropogenic activity.

**FIGURE 5.** Effect of seismic classifier performance (indicated by the ‘F-Score’, see Error! Reference source not found.) on (a) daily cumulative sound exposure level estimates and (b) background sound level estimates calculated by subtracting the seismic SEL from the total SEL. Good estimates of the seismic SEL are obtained by all of the classifiers (a). Small changes in the seismic estimate (eg, 0.07 dB) make large changes in the background estimate (1.4 dB)(see TABLE 3).

**TABLE 3.** Mean (±standard deviation) of the measured seismic SEL compared to the total SEL and the estimated ambient SEL (see Figure 5).

<table>
<thead>
<tr>
<th>Seismic Classifier</th>
<th>Difference between Actual Seismic daily cSEL and Detected Seismic cSEL (dB)</th>
<th>Difference between Background cSEL Estimate and [Total SEL] (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.65 ± 0.50</td>
<td>5.2 ± 1.1</td>
</tr>
<tr>
<td>2 with Post-Processing</td>
<td>1.03 ± 0.23</td>
<td>6.9 ± 0.8</td>
</tr>
<tr>
<td>1</td>
<td>0.25 ± 0.16</td>
<td>13.4 ± 2.6</td>
</tr>
<tr>
<td>1 with Post-Processing</td>
<td>0.18 ± 0.10</td>
<td>14.8 ± 2.1</td>
</tr>
</tbody>
</table>

**FIGURE 6.** Estimate of background sound levels (blue) by Method 1: subtraction of the detected daily anthropogenic cSEL (seismic and shipping) from the total daily cSEL.

**Methods 2 and 3: Background Estimation by Substitution**

Method 2 and Method 3 both produced background estimates that appear to be better than Method 1 (FIGURE 7). As an evaluation of the accuracy the background estimate was applied to the period before the seismic survey began. The mean difference between the daily ambient cSEL and the Method 2 daily background cSEL estimate was 4.2 +/- 2.5 dB. The hourly cSEL difference was 3.9 +/- 3.0 dB. The mean difference between the ambient value and the Method 3 daily background cSEL estimate was 2.7 +/- 2.4 dB. The hourly cSEL difference as 3.3 +/- 2.6 dB. The standard deviation of the hourly Method 2 background estimate during the period.
with seismic survey pulses was 3.0 dB. The standard deviation of the hourly Method 3 background estimate during the period of seismic survey pulses was 4.6 dB.

**FIGURE 7.** Comparison of Methods 2 and 3 for estimating cumulative sound exposure level (cSEL) from seismic, shipping, and ambient sources for 6 weeks of data using hourly cSEls. (a) Method 2: Ambient sound levels predicted from the wind speed at Barrow, AK. (b) Method 3: Estimate of ambient sound levels using the 6300 Hz 1/3-octave band sound level as a key to predict ambient sound levels. Each blue curve is the background noise estimated by subtracting the detected shipping and seismic cSEls from the total cSEL (Method 1).

**DISCUSSION**

The cSEls calculated from the shipping and seismic detections are within 1.65 dB of the manually computed cSEls even for the relatively poor seismic ‘Classifier 2’. However, the resulting background estimate was very poor, only 5.2 dB below the total SEL, when the expected value was 30 – 35 dB below the total. Seismic classifier 1, with post-processing, had an F-score of 0.997, however, the background estimate calculated using this classifier’s cSEL was still 14.8 dB below the total SEL, and 15 – 20 dB above the expected ambient level. The higher the anthropogenic sound levels are above the expected ambient sound, the more a small error in accumulating the anthropogenic cSEL will impact the background estimate. If the anthropogenic sound energy is 40 dB above ambient, then missing 1% (F-score of 0.995) of the anthropogenic energy will increase the background estimate by 20 dB. This leads to the conclusion that it is unrealistic to expect any automated detector / classifiers to adequately detect enough anthropogenic energy for use in background estimation. Further, it is concluded that improving anthropogenic classifiers beyond an F-score of 0.96 is of limited value since it will only improve the anthropogenic cSEL estimates by less than 1 dB (**TABLE 2**) when the anthropogenic energy exceeds the ambient by 30 – 35 dB.

The results show that both Method 2, using wind speed to develop histograms of the background sound levels, and Method 3, using the sound level in a reference 1/3-octave band, have different strengths and weaknesses. Background estimates using Method 3 were significantly better correlated with the manually computed ambient levels for the period before the seismic survey began (**TABLE 4**). However, it appears that the reference 1/3-octave band of 6300 Hz included energy from the seismic survey pulses at some times, so that the background estimates were increased during those periods (**FIGURE 7**). This resulted in a much higher standard deviation compared to Method 2 during the seismic survey period.

The effect of correlation between the wind speed and sound levels was investigated by using different delays between the wind speed and data time (**TABLE 4**). These results suggest that if a better wind speed record were available, the results of Method 2 may be as good as or better than Method 3.

In general Method 3 is recommended for computing background estimates in the presence of anthropogenic sound sources. It is independent of other environmental measurements such as wind speed and a priori knowledge.
of the wind speed to ambient noise relationship. It automatically adapts to the diverse recording scenarios since it accounts for frequency dependent hydrophone sensitivity, the recorder depth, wind fetch and mooring design.

It is recommended that the cSEL be accumulated hourly. Comparing FIGURE 6 and FIGURE 7 the hourly results provide higher detail and can easily be integrated to obtain daily results if those are required.

**TABLE 4.** Mean (+standard deviation) and correlation coefficients of the hourly ambient SEL compared to the background estimate SELs using Method 2 with four wind-to-noise time offsets and Method 3.

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean (+standard deviation) difference between hourly ambient SPL and background estimate</th>
<th>Correlation Coefficient between hourly ambient SPL and background estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>2; -11 Hr wind lag</td>
<td>3.9 ± 3.0</td>
<td>0.53</td>
</tr>
<tr>
<td>2; 0 Hr wind lag</td>
<td>3.9 ± 3.1</td>
<td>0.55</td>
</tr>
<tr>
<td>2; 12 hr wind lead</td>
<td>4.0 ± 3.7</td>
<td>0.48</td>
</tr>
<tr>
<td>2; 24 hr wind lead</td>
<td>4.1 ± 3.6</td>
<td>0.41</td>
</tr>
<tr>
<td>3</td>
<td>3.3 ± 2.6</td>
<td>0.88</td>
</tr>
</tbody>
</table>

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