A quantitative comparison of sound levels of compact marine sources

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Summary

We present a quantitative comparison of the sound emission for a range of compact marine source arrays geared towards different applications. Compact marine sources with adapted bandwidth provide geophysical and operational advantages, and tend to be quieter and less disturbing for the hydrosphere's fauna. We discuss how their sound output and bandwidth can be adapted towards geophysical objectives while minimizing environmental impact.

Introduction

Marine seismic sources are traditionally realized by combining many individual airguns of different volumes into arrays for the purpose of maximizing the primary pressure peak and minimizing the unwanted bubble reverberations. This paradigm is gradually shifting towards smaller and more compact sources consisting of fewer elements. On the one hand, improved methods for source signature deconvolution, enabled by broadband acquisition, reduce the need to minimize bubble reverberations (e.g., Kristiansen et al., 2015). On the other hand, the now routine application of blended acquisition facilitates denser inline sampling to achieve comparable amplitude density with smaller sources. More compact source arrays can improve resolution (Dhelie et al., 2017) and provide a comparable signal-to-noise ratio (SNR) if coupled with broadband multi-component receivers (Kragh et al., 2012). Operationally, compact sources are realized by combining subarray floats to arrays differently with only one or two subarrays per source array. This provides the flexibility to increase the number of sources towed by one vessel which greatly increases efficiency (Hager et al., 2015). It also facilitates the distribution of multiple sources over a wider spread which reduces the near-offset gap in streamer acquisition without compromising on acquisition efficiency (Widmaier et al., 2019). Smaller sources are desirable not only for the stated geophysical and operational reasons, but also because they reduce sound exposure to marine mammals. The environmental impact of seismic sources is strongly frequency dependent: most species have significantly reduced hearing sensitivity below 100 Hz, the band most relevant for seismic wave propagation through the highly attenuating Earth for deep-seated targets. High-resolution seismic for shallow targets (e.g., wind farm site characterization) requires higher frequencies, but much lower source strength is acceptable for these proximal targets. The goal is therefore to ensure sufficient source strength at mid-to-low seismic frequencies (3-100 Hz) and limiting output to acceptable levels at higher frequencies. Low-frequencies can be emphasized to some extent by adapting source- or receiver depth, enabled by multi-sensor broadband acquisition. If long-range propagation is required for FWI purposes, a low-frequency source system such as the Gemini (Brittan et al., 2020) might be worth considering. While not exactly small in terms of volume, it consists basically of one gun cluster, and therefore qualifies as a compact source with the stated operational advantages and geophysical similarity to a point source.

This paper quantitatively compares the sound output for different compact source arrays. We use a standard metric for environmental impact assessment in the form of sound pressure- and sound exposure level (SPL and SEL). The comparison also includes standard ultra-high resolution seismic sources such as sparkers and boomers, which naturally have an emphasis on the very high frequencies, but typically exhibit a lower sound level. The quantitative comparison provides a pathway to adapt source design to the respective geophysical needs while ensuring minimal sound output.

Example Results

As an example, we show in Figure 1 a comparison of SEL as a function of horizontal distance (range) from the source. We consider the SEL at a constant depth of 1 m below the source, moving away under the assumption of a semi-cylindrical (15 log(R)) spreading term. Due to the ghost reflection (Lloyd's mirror effect), the horizontal amplitude decay is much larger than the assumed spreading term. Horizontal propagation is most relevant for sound emission into the water column. When applying the mildest low-frequency cetacean filter (Finneran, 2016), the SEL of the 8000 cu.in low-frequency source is in principle the same as for the 400 cu.in. array, despite a factor 20 difference in volume. Both sources are significantly lower in output than the standard 3280 cu.in. array. This perhaps counterintuitive result shows that careful adaptation of the source output and bandwidth to the imaging problem can be more effective than pure size considerations. Due to their much larger overlap with the mammal hearing range, sparker and boomer change insignificantly with the hearing filter applied but are generally lower.

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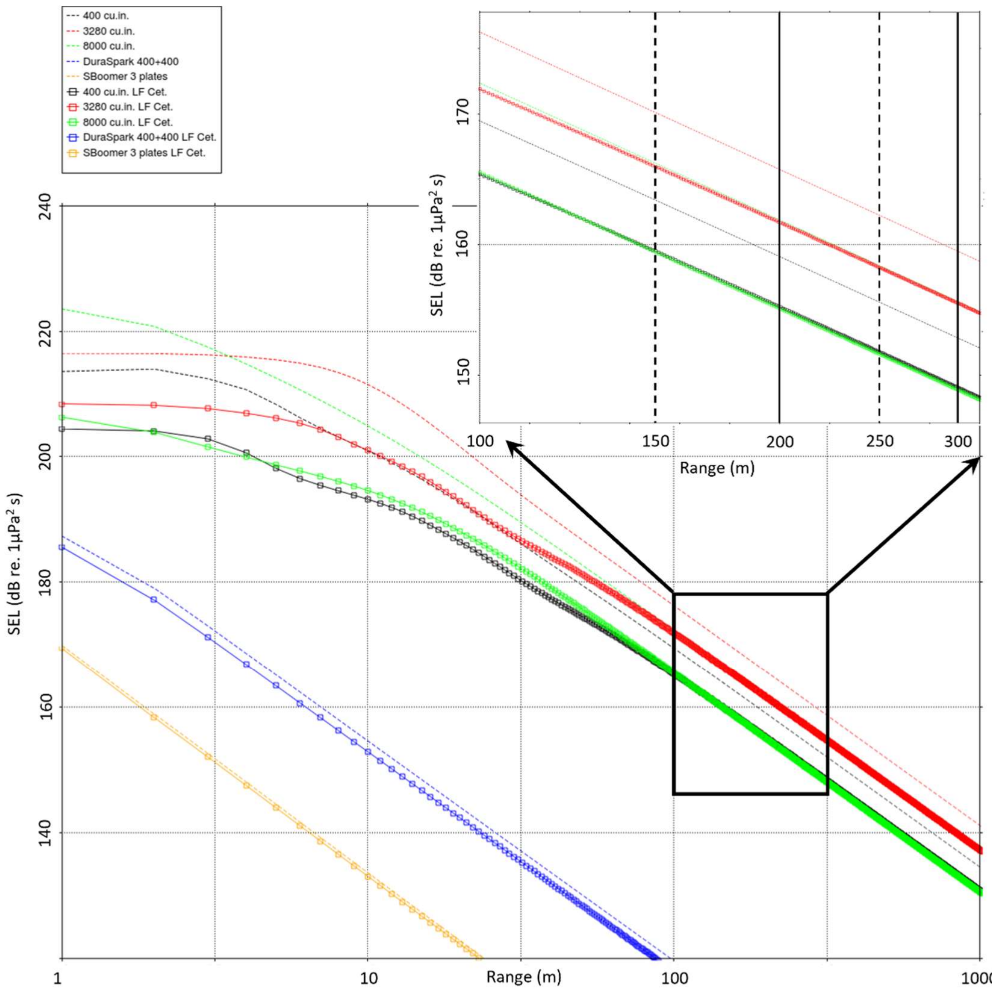

Figure 1 *SEL vs. distance for several marine sources including a standard airgun array (red), a compact 400 cu.in. array (black), the 8000 cu.in. Gemini low-frequency source (green), an 800-tip dual-level sparker (blue), and a three-plate boomer (orange). Dashed lines are unfiltered, and solid lines with squares are filtered with a low-frequency cetacean filter. Inset zooms to the 100-300 m range.*

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