Characterizing the range-dependent accuracy of a near real-time baleen whale monitoring system

Hansen Johnson[1,2*], Mark Baumgartner[2], Ying-Tsong Lin[2], Arthur Newhall[2], Christopher Taggart[1]

Dalhousie University, Halifax NS, Canada[1]; Woods Hole Oceanographic Institution, Woods Hole MA, USA[2]
*corresponding author: hansen.johnson@dal.ca

Background

Whale monitoring

Nearly all baleen whale conservation strategies rely on efficient monitoring. WHOI has developed the digital acoustic monitoring (DMON) instrument and low-frequency detection and classification system (LFDCS) to detect and classify baleen whales in near real-time from autonomous platforms (e.g., buoys and gliders)[1,2]. The DMON-LFDCS automatically draws 'pitch tracks' through tonal calls (Fig 1), classifies them according to species, and relays the information back to shore for manual review (Fig 2).

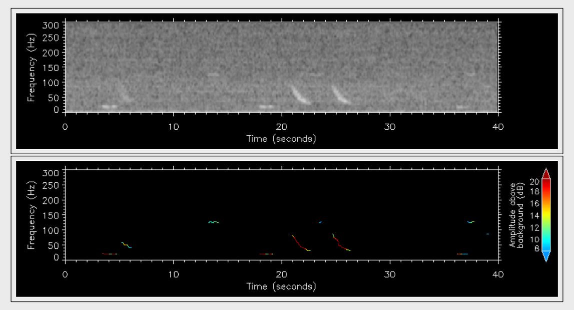

Figure 1: Spectrogram (top) versus pitch tracks (bottom) of sei whale calls generated by the DMON-LFDCS

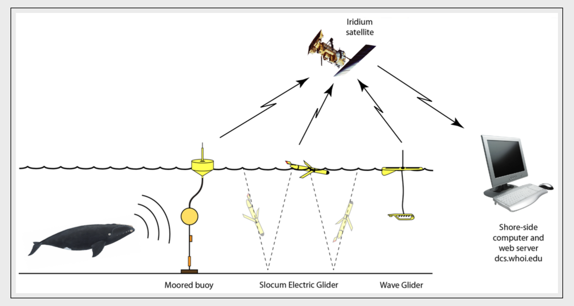

Figure 2: DMON-LFDCS platforms send pitch tracks and classification information back to shore for review

Acoustic localization

Conventional methods for acoustic localization of baleen whale calls rely on a widely spaced array of synchronized receivers. The normal mode back-propagation technique[3] (NMBP) exploits the dispersive nature of normal modes in shallow water (Fig 3 and 4) to localize low frequency calls from a vertical line array (VLA) and horizontal line array (HLA) deployed at the same station. The general steps are to:

1. **Beamform** with the HLA to determine call bearing
2. **Model** mode shapes and velocities along arrival path[4]
3. **Mode filter** with the VLA to determine amplitudes and timing of modal arrivals
4. **Back-propagate** the modes along the arrival path until they converge at the estimated source range and depth

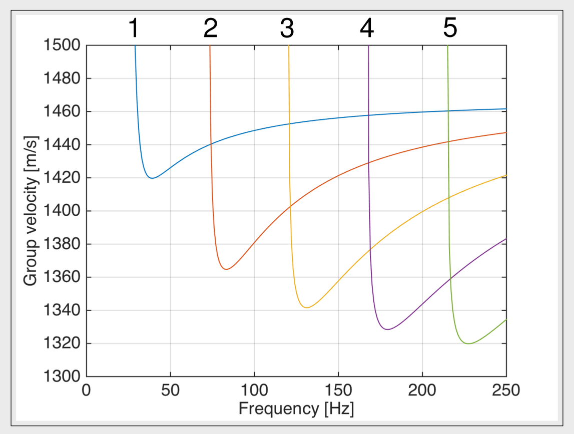

Figure 3: Velocities of each mode as a function of frequency in 30m water depth, with each color representing a different mode. The frequency-dependence of group speed causes modes to spread out, or disperse, as a signal propagates.

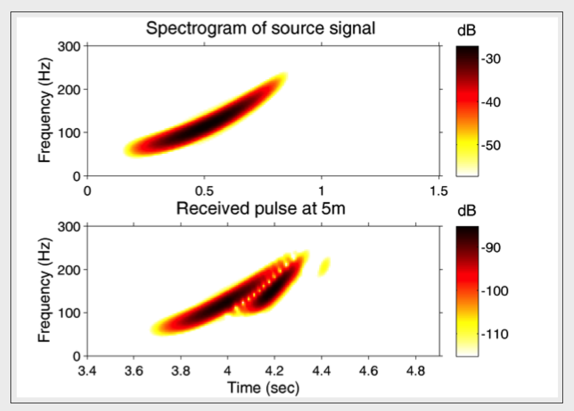

Figure 4: Theoretical modal dispersion of a right whale upcall in an idealized 30m water column. The upper panel shows the original signal, while the lower panel shows the separation between modes after propagating 5 km.

Goal

To effectively use passive acoustics to monitor marine mammals, an understanding of the area over which the monitoring system can detect each species of interest is absolutely critical. **The goal of this study is to determine the range-dependent accuracy of the DMON-LFDCS real-time whale monitoring system on mobile and fixed platforms.**

Experimental Design

This experiment can be generally summarized in four steps:

1. Deploy an 8-channel HLA, 4-channel VLA and DMON-LFDCS Slocum glider in close proximity to an extant DMON-LFDCS moored buoy.
2. Identify all calls received on the HLA/VLA, then localize using the NMBP technique
3. Conduct a call-by-call comparison between calls detected on the HLA/VLA and those pitch tracked by the glider or buoy DMON-LFDCS to determine the probability of detection for each platform
4. Quantify the probability of detection for each platform as function of range to the call

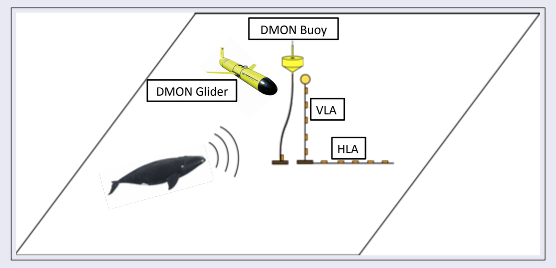

Figure 5: Concurrent deployment of acoustic array and DMON-LFDCS buoy and Slocum glider allows for direct comparison and performance evaluation

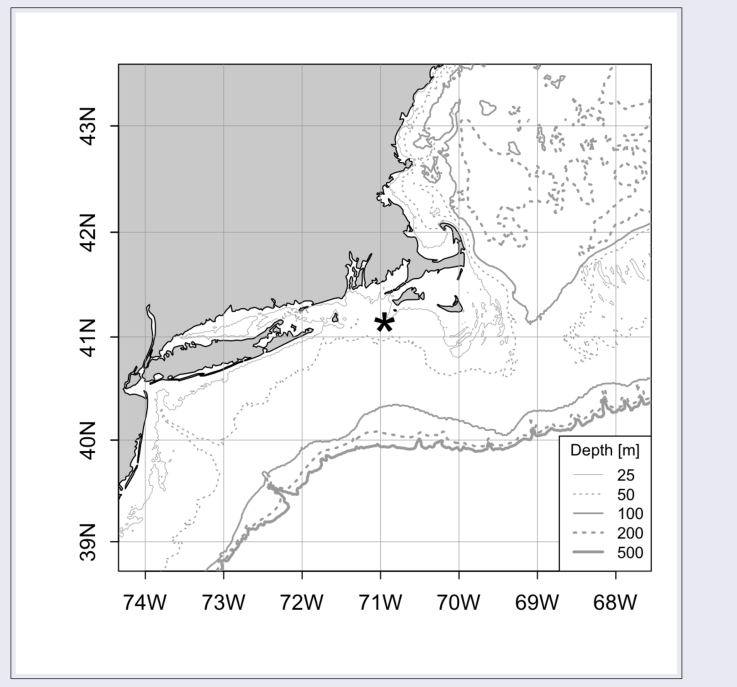

Figure 6: Study site in 30m water depth ~15 km SW of Nomans Island, MA, USA

Results I: Localization

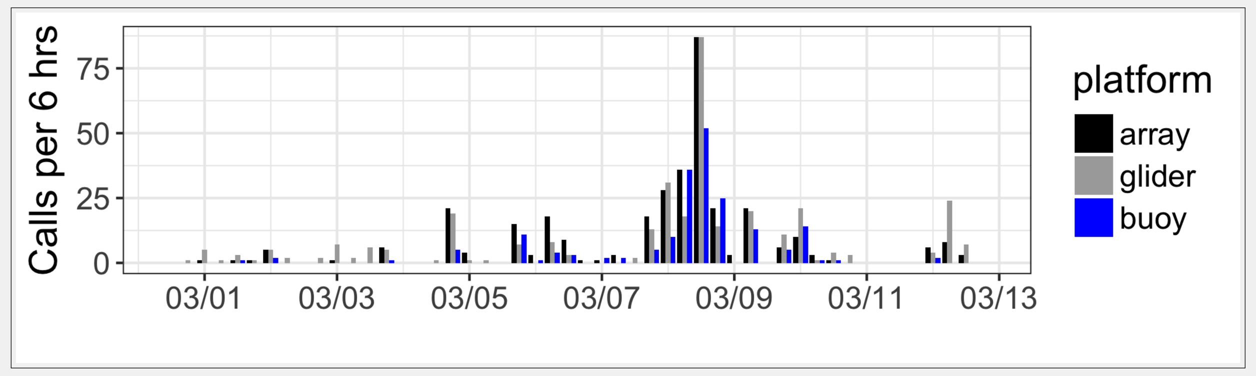

Figure 7: Detections of right whale upcalls from the WHOI array acoustic record (n=341) and the pitch track records from the DMON-LFDCS glider (n=340) and buoy (n=196)

North Atlantic right whale upcalls were detected on all three platforms during the study period from 28 Feb to 13 Mar 2017 (Fig 7). A total of 341 calls were extracted from the HLA/VLA acoustic record. The signal quality of many of these calls was degraded by storm-induced noise. At present, only 75 calls could be confidently localized, but more may be possible using advanced signal processing. Figure 8 shows an example of the localization for a single call, while figures 9 and 10 show the spatial and range distributions of the 75 localized calls, respectively. Initial results suggest the 50% detection range is ~6.5km for the buoy and ~10.5km for the glider, though the latter is not statistically significant (Fig 11).

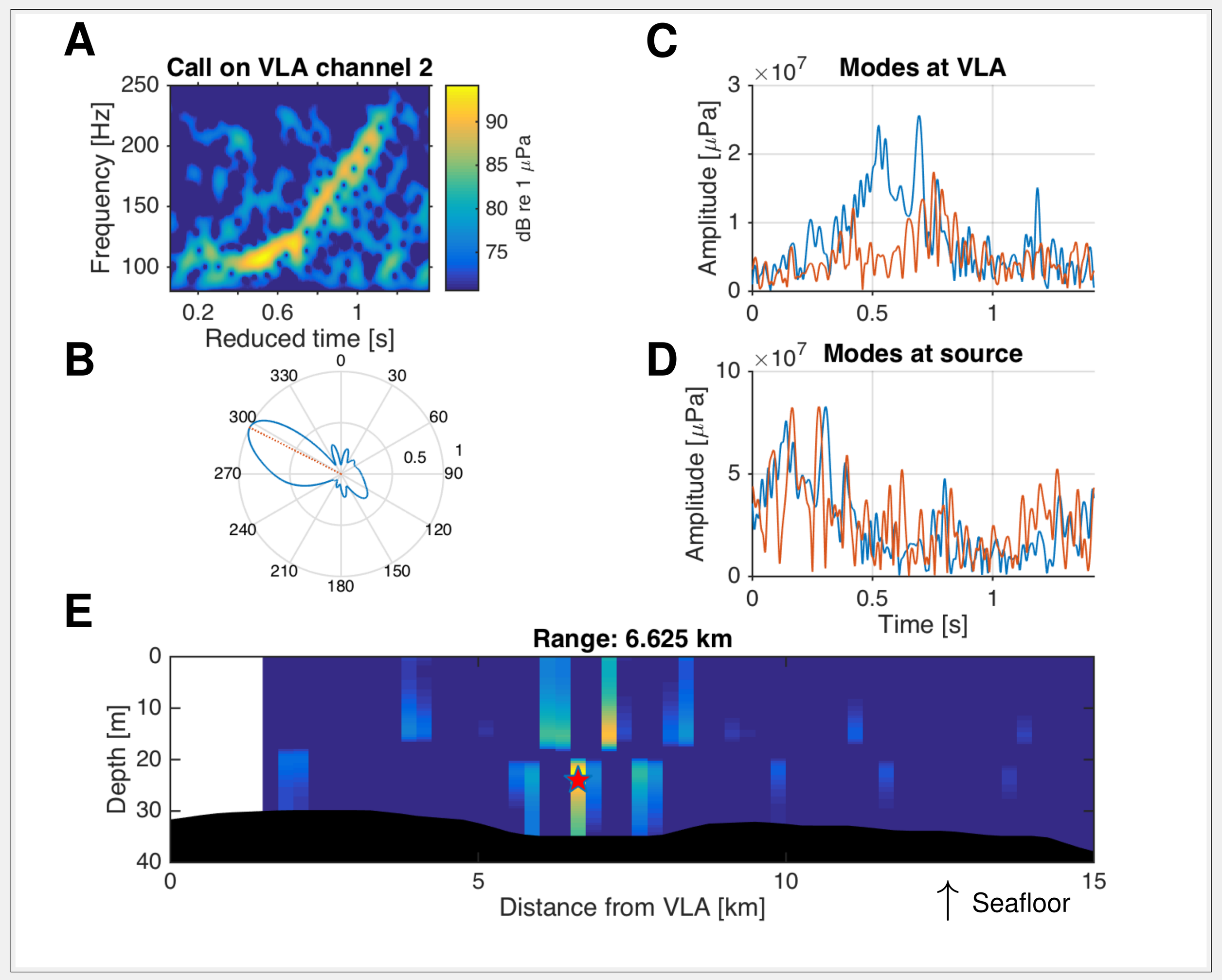

Figure 8: Example localization workflow for a single call showing the call spectrogram [A], beam pattern (blue) and arrival angle (red line) [B], received amplitudes of mode 1 (blue) and 2 (red) [C], back-propagated amplitudes of the same modes [D], and a normalized probability map of the back-propagation results [E]

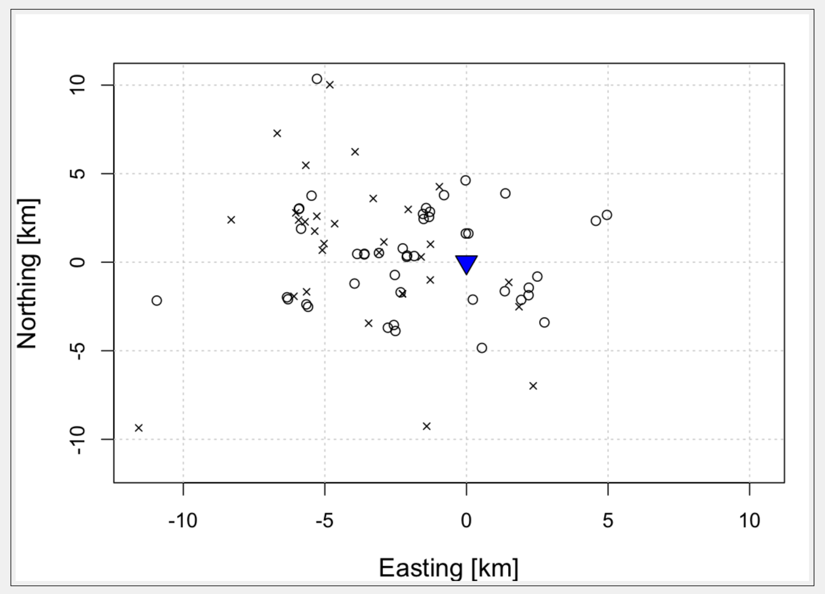

Figure 9: The spatial distribution of localized calls (n=75), with open circles and crosses indicating calls detected and not detected by the DMON-LFDCS buoy [blue triangle], respectively

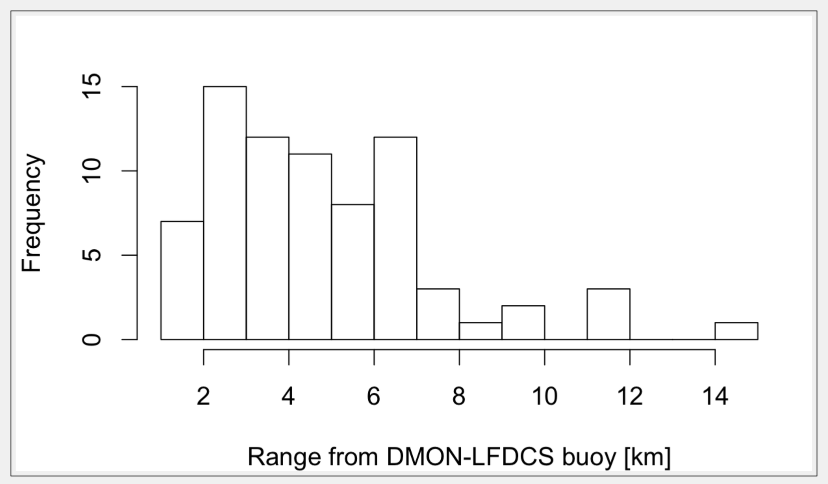

Figure 10: Distribution of ranges from the DMON-LFDCS buoy to localized calls (n=75)

Results II: Probability of Detection

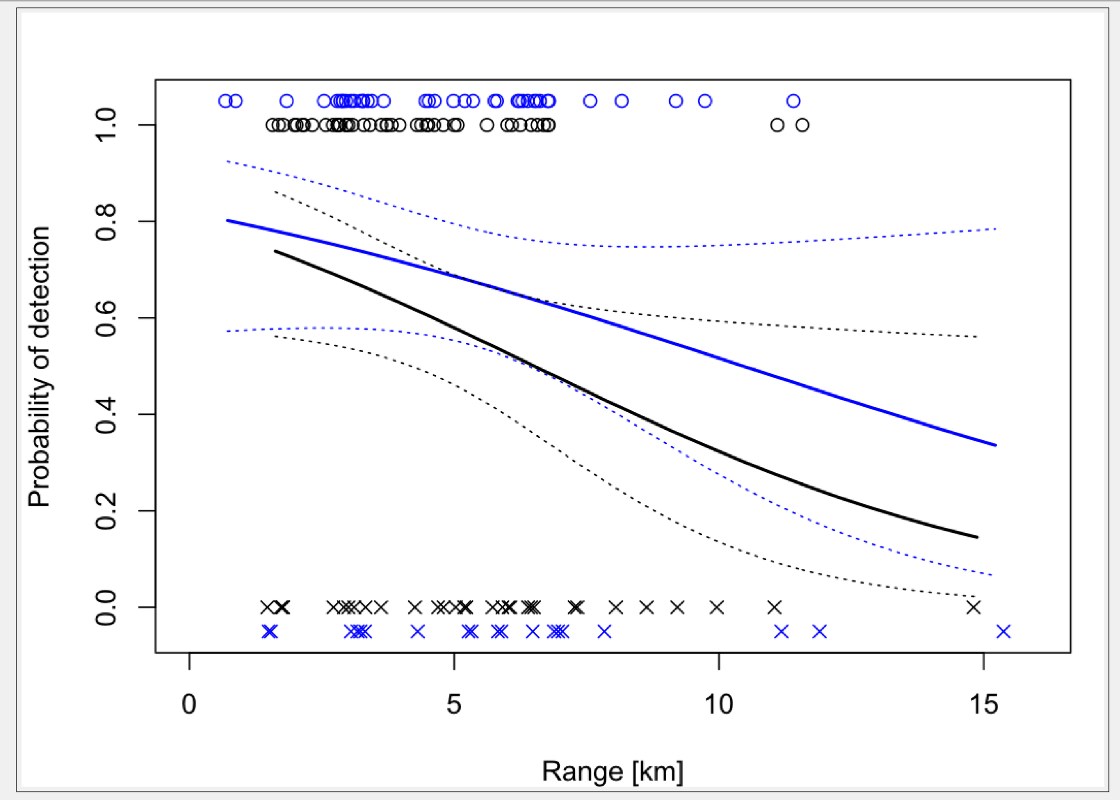

Figure 11: Probability of detection of right whale upcalls by the DMON-LFDCS as a function of range to the buoy (black; n=75) and glider (blue; n=58). The open circles and crosses indicate calls detected or undetected on either platform, respectively. Logistic regression analysis suggests detection probability for the buoy declines significantly with range (p = 0.033), but the relationship is not significant for the glider (p = 0.152). The regression model predictions are shown as solid lines, with 95% prediction intervals shown as dotted lines.

Next steps

- Implement additional signal processing techniques (e.g. Gauss-Markov mode filter) to facilitate localization of calls received during periods of storm-induced noise
- Expand analysis to include deployments from summer 2017
- Attempt to use localization results to quantify aspects of right whale ecology, including movement patterns, individual calling rates, source levels, calling depths, etc.

Citations

1. Baumgartner, M. F., Fratantoni, D. M., Hurst, T. P., Brown, M. W., Cole, T. V. N., Van Parijs, S. M., & Johnson, M. P. (2013). Real-time reporting of baleen whale passive acoustic detections from ocean gliders. The Journal of the Acoustical Society of America, 134(3)
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