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SOFTWARE FOR THE LOCALISATION OF BALEEN WHALE CALLS USING DIFAR SONOBUOYS: AN UPDATE ON REAL-TIME USE OF PAMGUARD DIFAR SOFTWARE

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ABSTRACT

As a component of the 2015 New Zealand-Australia Antarctic Ecosystems Voyage, acoustic real-time localisation and tracking of Antarctic blue whales was carried out using DIFAR sonobuoys and open-source PAMGuard software. A module in this software was specifically developed to facilitate analysis of the signals from DIFAR sonobuoys. This voyage was the first time the DIFAR capability of this software had been used in the field. The software performed well, and allowed over 40,000 Antarctic blue whale calls to be processed during more than 520 hours of operation. The software constitutes a key advance in the accessibility of DIFAR methodology to locate baleen whales. We present an update on the functionality of the software, and demonstrate how effective it was for real-time tracking of Antarctic blue whales.

BACKGROUND

In 2013, the Antarctic Blue Whale Project (ABWP) of the Southern Ocean Research Partnership (SORP) conducted a research voyage using new passive acoustic techniques to facilitate the study of Antarctic blue whales. These techniques involved using DIFAR sonobuoys to detect blue whale vocalisations, and to track and locate them for further study, including close approaches for photo-identification and biopsy sampling (Milller et al., 2015). Unlike standard sonobuoys, DIFAR sonobuoys can estimate bearings to received sounds based on amplitude and phase differences between the output of a pressure transducer (i.e. a normal hydrophone) and crossed particle motion sensors. The signals from the three sensors are transmitted to a nearby vessel or aircraft using a single multiplexed VHF channel. The 2013 SORP Antarctic Blue Whale Voyage demonstrated the viability and efficiency of these techniques, and their suitability for increasing encounter rates of these sparsely-distributed whales. However, whilst the functionality of the hardware and software on the 2013 voyage was sound, the availability and accessibility of appropriate software for demultiplexing and processing the DIFAR signal was identified as a potential impediment to the wider uptake and use of these techniques.

Whilst DIFAR sonobuoys have been in use in whale research programs for the past two decades, the software to process and analyse data collected from sonobuoys has remained scarce (Miller et al, 2014). Miller (2012) and Miller et al. (2013) used a combination of disparate tools available for working with DIFAR data including the beamforming software from WhaleAcoustics http://whaleacoustics.com/, and the demultiplexing software by Greeneridge Sciences Inc. http://www.greeneridge.com/software.html. However, the necessity of using several discrete software programs to carry out each step of the process made the system complicated, fragile, and was a potential barrier to wider uptake of the technique.

DIFAR LOCALISATION MODULE DEVELOPMENT

The DIFAR localisation software developed by the Australian Marine Mammal Centre (AMMC) and the University of St. Andrews in response to this need is within the open-source framework of PAMGuard (Gillespie et al. 2008; www.pamguard.org), the industry standard software for cetacean passive acoustic monitoring, with flexible, modular architecture. The development of the DIFAR module to process signals from directional DIFAR sonobuoys in order to obtain bearings to vocalisations from whales within the PAMGuard structure is described in Miller et al., 2014. In brief, the module has been built within the structure of PAMGuard to work in conjunction with existing modules which include features such as the acquisition, filtration and display of acoustic data, the acquisition and mapping of positional/spatial data, management of hydrophone deployment metadata, automated detection of vocalisations, measurement of signals and noise, and data storage.

The DIFAR module includes functionality to facilitate collection of metadata during sonobuoy deployment, manually and/or automatically select, inspect, and classify sound clips for further analysis, demodulate DIFAR signals, correct for the non-flat frequency response of DIFAR acoustic sensors to make calibrated measurements of received levels, and to compute the bearing to a sound using the signals from all three of the acoustic and magnetic sensors within the DIFAR sonobuoy.

The PAMGuard DIFAR module was initially developed and tested with the widely-used Greeneridge Science demultiplexing software. However, Greeneridge Science's Demultiplexer must be purchased and therefore cannot be included with the freely distributable version of PAMGuard. To provide full functionality to the freely distributable version of PAMGuard, the DIFAR module includes an alternative open-source demultiplexer, created by the AMMC.

Since the earliest versions, the PAMGuard array manager has included a single parameter for the sensitivity of each hydrophone (i.e. dB V/μPa), and could therefore compute received levels with respect to 1 μPa for hydrophones that had a flat frequency response. However, DIFAR sonobuoys have a non-flat frequency response (Greene et al., 2004), which when making measurements of received level must be corrected along with any non-flat frequency response of the receiving hardware. The latest version of the DIFAR module allows for the correction of a non-flat frequency response in the recording chain so that calibrated received levels may be calculated (i.e. received levels reported in dB re 1 μPa).

REAL-TIME USE OF SOFTWARE

On the 2015 voyage, 320 DIFAR sonobuoys were deployed between 29 January and 10 March. Signals were received from the sonobuoys using an almost-identical hardware configuration to that used by Miller et al. (2015). An aerial mounted at a height of 16 metres gave typical maximum radio reception distances of around 22 km at which bearing information from signals could be processed reliably. Whale vocalisations and other sounds were displayed on spectrograms, from whence they were either identified and clipped automatically by PAMGuard's Whistle and Moan Detector (Gillespie et al., 2013), or through manual selection. Sounds were then manually classified for further processing. These classifications included categories for Antarctic blue whale 26Hz tones, Z calls and FM calls, as well as for other baleen whale species (fin whales 20Hz pulse, humpback whales and sei whales), and more generic categories such as unidentified whale calls, and possible ice noise.

Classifications for self-vessel noise were also included to enable sonobuoy compass correction/calibration in order to account for local magnetic anomaly and the magnetic deviation inherent in the compass within the sonobuoy. Calibrating the compass (see Miller et al., 2015) involves measuring several magnetic bearings to the known positions of the research vessel as it moves away from a sonobuoy after deployment. The software provided options for largely automating this calibration process. The flexible functionality of the module also allowed further classification categories with user-definable lengths/bandwidths to be added during the voyage.

Initially on the voyage, the classified signals were demultiplexed using the Greenridge Science software. However, following stability problems with the PAMGuard interface to the Greeneridge demultiplexer, the AMMC demultiplexer was used for the rest of the voyage. Although the AMMC demultiplexer had not received extensive use or testing prior to the 2015 voyage, it functioned well, providing consistent and reliable results while remaining stable throughout the duration of the voyage. This is encouraging, as it indicates that a wholly open-source system may be used in the module's operation.

After the signals (both vessel, for calibration, and whale vocalisations) were demultiplexed, beamforming algorithms were used to obtain an estimate of the signal power as a function of tonal frequency and magnetic bearing. For a given detection, the bearing and frequency with the highest power will usually represent the direction of the vocalisation. The DIFAR module can automatically suggest the bearing and frequency with the highest power in order to provide a bearing. Whilst there is also the option to allow the user to select a different bearing and frequency from that which has been automatically suggested (important if a portion of the spectrum contains noise), in practice, the automatically-generated bearings were almost invariably the ones chosen. It did however prove valuable for the operator to be able to quickly judge from the graphical displays whether a bearing was likely to be unreliable due to noise. Accepted bearings to the sound source were displayed on the PAMGuard map. Throughout the process from sounds being clipped to being classified and then plotted as bearings, there was a choice as to whether to allow PAMGuard to perform the action automatically, or to carry it out manually.

From over 520 hours of whale recordings made during the voyage, over 40,000 whale calls were clipped with their bearings plotted and displayed on the map. A large proportion of this monitoring time used only one sonobuoy, yet there was often a need to compare a set of bearings from different buoys received several hours apart in order to estimate the direction and proximity to vocal aggregations of whales. The mapping facilities within PAMGuard were important for allowing such comparisons. Bearing lines were colour-coded according to their classification and also the length of the bearing line was adjusted based on received level.

Two simple models of acoustic propagation loss are included in the DIFAR module in order to determine the length of plotted bearings: geometric inverse spreading, and a surface duct (Urick, 1983). During the voyage, geometric spreading was used to scale bearing lines in temperate waters, while the surface duct model was used in Antarctic waters. Parameters for each model were adjusted in-situ so that the endpoints of bearing lines broadly agreed with visual sightings of Antarctic blue whales.

PAMGuard Viewer, the offline mode of PAMGuard, also proved effective for enabling the viewing of all data collected since the start of the voyage. The ability to load, select and view large (e.g. week-long) segments of data enabled visualisation of longer-term trends within the voyage (Figure 1), facilitating planning. In particular the Viewer mode allowed an integrated view of bearings from multiple single-buoy deployments in order to obtain the best estimates of the locations of vocalising groups of whales (Figure 2).

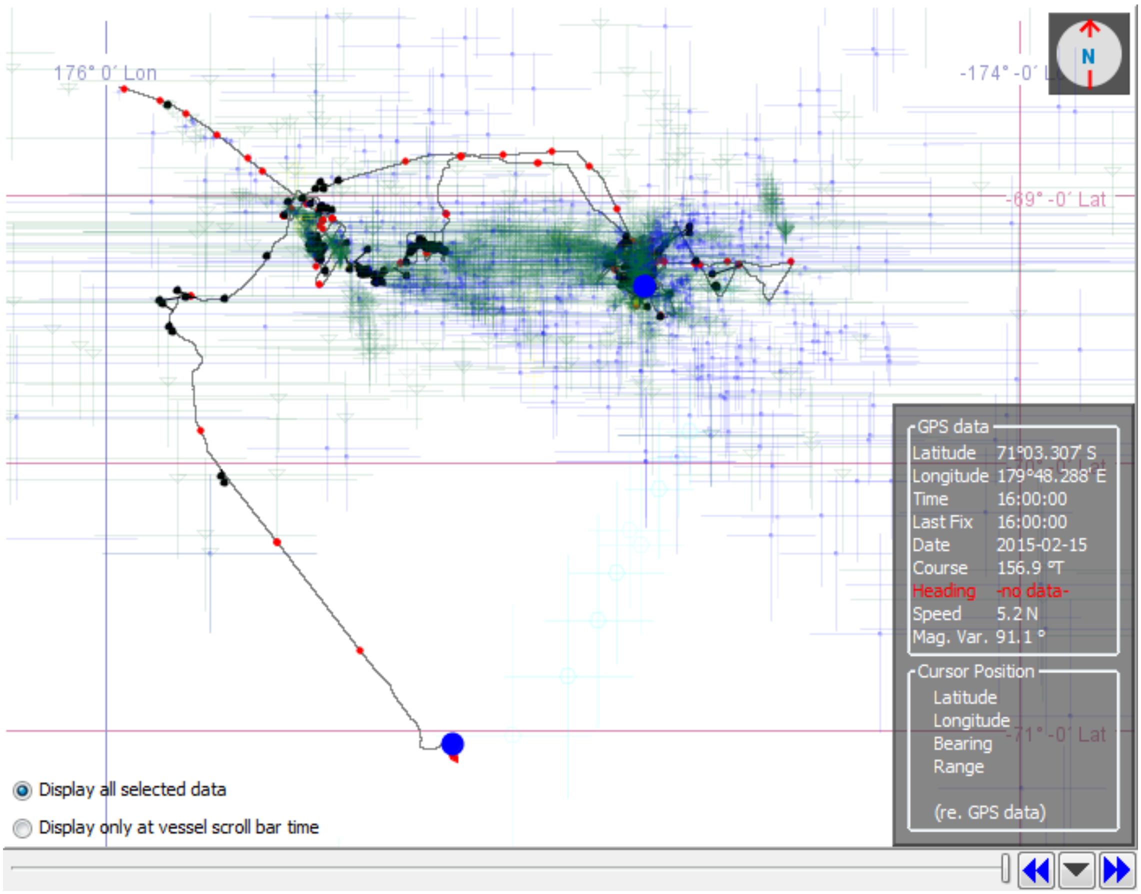

Figure 1 - PAMGuard Map in Viewer Mode showing seven days of data from the 2015 voyage. Blue circles show the deployment location of the most recently active sonobuoys while red dots show the deployment location of previous sonobuoys. Blue and green crosses show acoustically triangulated locations of Antarctic blue whale calls. Newer calls are more opaque, while the oldest calls are nearly transparent. Plotting all of the crossbearings for seven days reveals a widely spread vocalising aggregation of Antarctic blue whales around 69° S between 176° E and 176° W. The black line shows the ship's track (GPS) from 8-15 February.

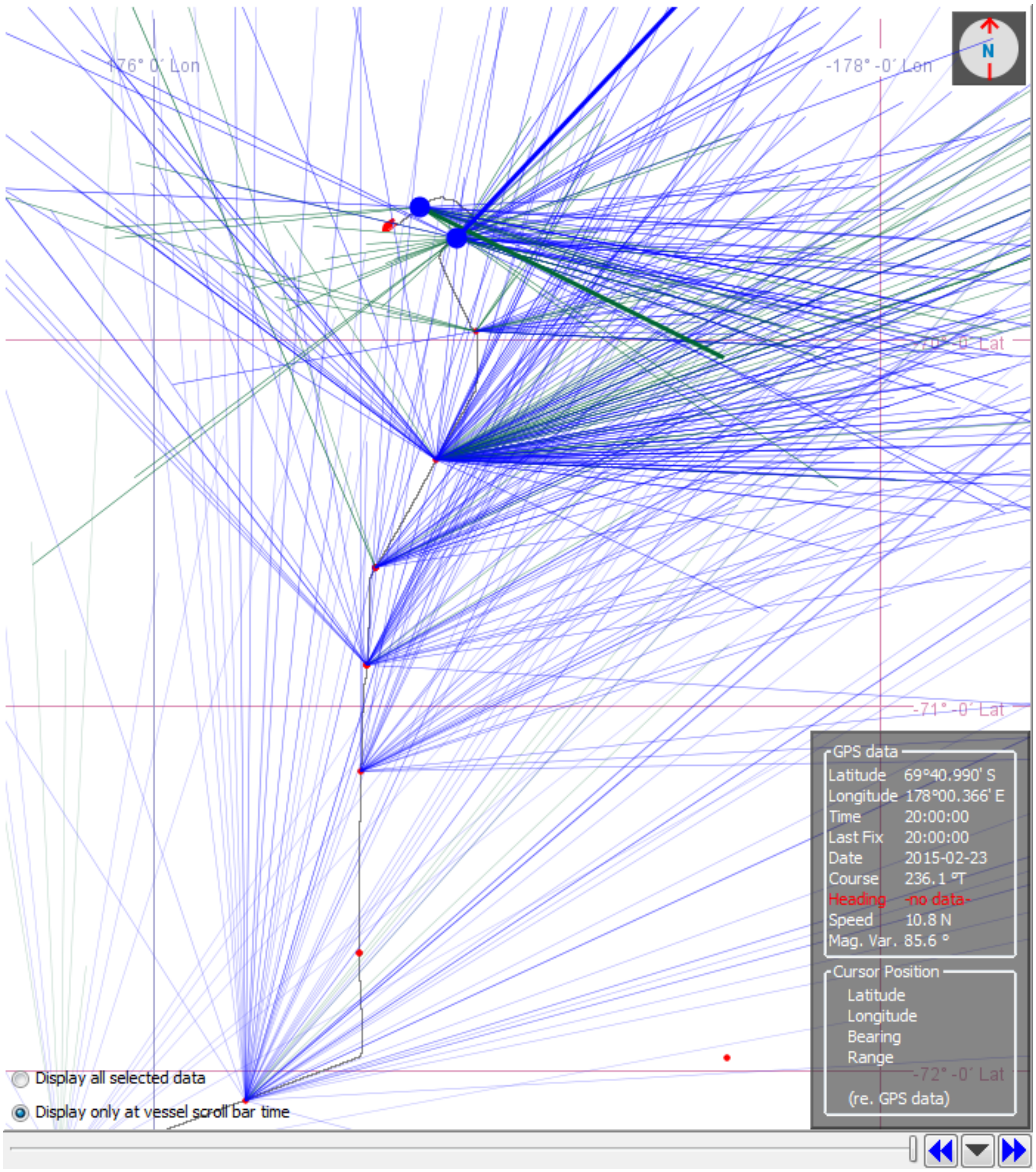

Figure 2 - PAMGuard Map in Viewer Mode showing 24 hours of DIFAR bearings from the 2015 voyage. Blue circles show the deployment location of active sonobuoys while red dots show the deployment location of previous sonobuoys. Blue lines show bearings to 26 Hz tones of Antarctic blue whales, while green lines show bearings to FM calls. Older bearings are drawn with more transparency so that they appear to fade and eventually disappear over a user defined time-period. Length of bearing lines was calculated assuming source level of 182 dB re 1 uPa, and a surface duct with a transition range of 2000 m. The black line indicates the ship's track (GPS) for 23 February.

TRIANGULATION

The PAMGuard DIFAR module allows for the simultaneous deployment of two (or more) sonobuoys, enabling triangulation of the bearings to calculate a two-dimensional location. The DIFAR module automatically determines whether bearings could have originated from the same source based on time of arrival and type of classification, and if so the intersection point of these bearings is automatically calculated and displayed. Whilst the DIFAR module can theoretically handle acoustic data from multiple sonobuoys, only pairs of sonobuoys were used successfully on the 2015 voyage. Of the

40,000 bearings to calls of Antarctic blue whales, 8,000 could be paired as calls that were received simultaneously on two sonobuoys. These were used to obtain 4,000 triangulated positions of calling whales. The placement and spacing of pairs of sonobuoys is key to successful triangulation of bearings to enable calling individuals, and aggregations of calling whales, to be located. A maximum likelihood approach is used to determine the intersection point and estimate the error bounds of the triangulated position. Triangulated positions and error-bars are displayed on the PAMGuard Map, and use identical colour-coding as that of the bearings (Figure 3). Both tonal and FM calls of Antarctic blue whales were detected within and around vocal aggregations. 26 Hz tones could be heard at great distances from the vocal aggregations, while FM and Z calls were only detected much closer to vocal aggregations.

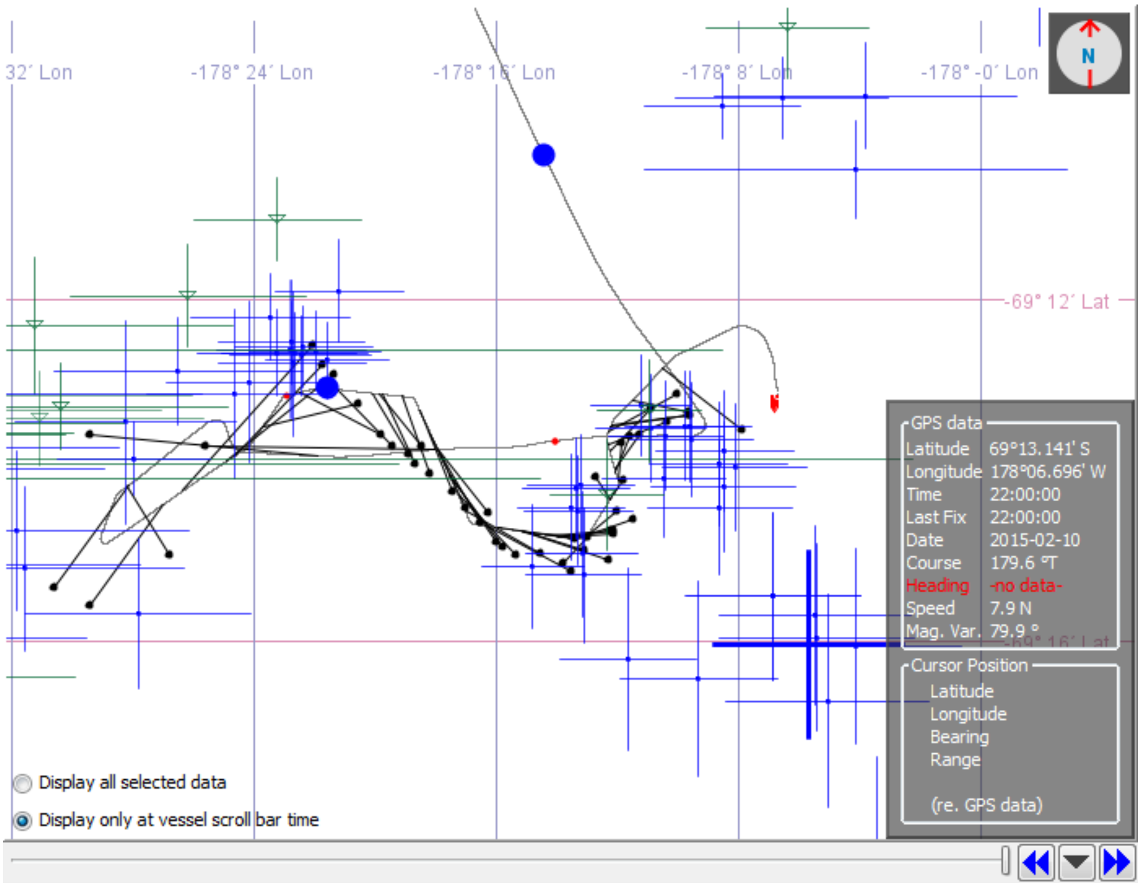

Figure 3 - PAMGuard Map in Viewer Mode showing six hours of data from the 2015 voyage. Large blue circles show the deployment location of active sonobuoys while red dots show the deployment location of previous sonobuoys. Black line shows the ship's track (GPS) on 10 February. Crosses show the error bounds of each acoustic triangulation (blue crosses indicate tonal calls of Antarctic blue whales, while green crosses indicate FM calls). Black dots with lines originating from the ship's track indicate the location of visual observations of an Antarctic blue whale during a focal-follow. NB: Only triangulated positions are shown via a user-selectable option in the DIFAR module configuration.

CONCLUSION

PAMGuard was the sole software program used to acquire, process and analyse the DIFAR sonobuoy data received. The PAMGuard DIFAR module not only performed better than systems that were used during the 2013 Antarctic Blue Whale Voyage (Miller et al. 2015), it was also more stable and accessible. It was reliable over long tracking periods which usually lasted several days.

As much of the functionality was automated, it allowed more time for planning subsequent deployments and tracking strategy. This is an important aspect of the software if it is being used for real-time tracking to enable close approaches to whales for biopsy, photo-identification or other studies. In poor viewing conditions, the operator needs to be able to process often sporadic calls quickly in order to direct the vessel towards the vocalising whale. For studies related to feeding ecology there was a need to process a number of whale locations in a short space of time in order to allow the design of appropriate survey tracks for sampling prey distributions using active acoustics. On the 2015 voyage there was a team of four specialist acousticians. The continued development of user-friendly software may in the future allow detection and localisation of whales by non-specialists. Whilst it is still beneficial to have someone monitoring the received signals whenever sonobuoys are deployed, there may now be less need for specialists, and thus more scope to integrate visual and acoustic teams.

Through its use on the 2015 New Zealand-Australia Antarctic Ecosystems Voyage, the PAMGuard DIFAR localisation module has moved from a concept to a working solution. We are confident that the module, which integrates elegantly with existing PAMGuard modules, provides a stable, accessible framework with a simple workflow. It is hoped that these improvements will also facilitate standardised protocols for acoustic localisation of low-frequency tonal calls of baleen whales. Furthermore, the DIFAR module's ability to make calibrated intensity measurements and locate low-frequency tonal sounds in real-time may greatly facilitate in-situ validation of models of anthropogenic noises such as sonar, pile-driving, seismic airguns, and shipping that are increasingly used in management of marine developments. The DIFAR module is available in the current and future PAMGuard releases (http://www.pamguard.org/).

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REFERENCES

Gillespie, D., Gordon, J.C.D., Mchugh, R., Mclaren, D., Mellinger, D., Redmond, P., Thode, A., Trinder, P., Deng X.Y. (2008) PAMGUARD: Semiautomated, open source software for real-time acoustic detection and localisation of cetaceans. In: Proceedings of the Institute of Acoustics. Conference on Underwater Noise Measurement, Impact and Mitigation 2008., Southhampton, UK, p 54–62

Gillespie, D., Caillat, M., Gordon, J., and White, P. (2013) Automatic detection and classification of odontocete whistles J. Acoust. Soc. Am., 134, 2427–2437

Greene, C.R.J., McLennan, M.W., Norman, R.G., McDonald, T.L., Jakubczak ,R.S., Richardson, W.J. (2004) Directional frequency and recording (DIFAR) sensors in seafloor recorders to locate calling bowhead whales during their fall migration. J. Acoust. Soc. Am. 116:799–813

Miller, B.S. (2012) Real-time tracking of blue whales using DIFAR sonobuoys. In: Proceedings of Acoustics 2012. Australian Acoustical Society, Fremantle, p 7

Miller, B.S., Barlow, J., Calderan, S., Collins, K., Leaper, R., Kelly, N., Peel, D., Olson, P., Ensor, P. and Double, M.C. Long-range acoustic tracking of Antarctic blue whales. Paper SC/65a/SH18 presented to the IWC Scientific Committee, June 2013, Jeju Island, Republic of Korea

Miller,B.S.,Gillespie, D.,Weatherup, G.,Calderan, S.and Double,M.C. Software for the localisation of baleen whale calls using DIFAR sonobouys: PAMGuard DIFAR. Paper SC/65b/SH06 presented to the IWC Scientific Committee, May 2014, Bled, Slovenia

Miller, B., Barlow, J., Calderan, S., Collins, K., Leaper, R., Olson, P., Ensor, P., Peel, D, Donnelly, D., Andrews-Goff, V., Olavarria, C., Owen, K., Rekdahl, M., Schmitt, N., Wadley, V., Gedamk,e J., Gales, N., Double, M. (2015) Validating the reliability of passive acoustic localisation: a novel method for encountering rare and remote Antarctic blue whales. Endangered Species Research 26(3)

Urick, R.J. (1983) Principles of Underwater sound, 3rd ed. McGraw-Hill, New York, 423p