Software for the localisation of baleen whale calls using DIFAR sonobuoys: PAMGuard DIFAR

BRIAN S. MILLER[1], DOUGLAS GILLESPIE[2], GRAHAM WEATHERUP[3], SUSANNAH CALDERAN[1], AND MICHAEL C. DOUBLE[1]

1 - Australian Marine Mammal Centre, Australian Antarctic Division. Kingston, Tasmania Australia

2 -Sea Mammal Research Unit, Scottish Oceans Institute, University of St. Andrews, St. Andrews, Scotland.

3 – St Andrews instrumentation Ltd, St Andrews, Scotland.

ABSTRACT

Over the past two decades DIFAR sonobuoys have been increasingly used to locate the low-frequency vocalisations of baleen whales. Here we introduce a software module that facilitates analysis of the signals from DIFAR sonobuoys. This DIFAR module integrates into the open-source software program for passive acoustic localisation, PAMGuard. We present an overview of the functionality of the software and validate the functions with a case study in which the DIFAR module is used to localize an Antarctic blue whale. Finally, we discuss the current limitations of the software and offer suggestions for future developments.

KEYWORDS: ACOUSTIC LOCALISATION, SOFTWARE, BALEEN WHALES, SONOBUOY

BACKGROUND

The Antarctic Blue Whale Project (ABWP) of the Southern Ocean Research Partnership (SORP) is the primary (and only extant) scientific research program on endangered Antarctic blue whales. This program has identified that real-time passive acoustic tracking of blue whales may be an efficient means of increasing encounter rates (Peel et al. 2014) and can thus facilitate monitoring of these rare and somewhat inaccessible whales during their putative recovery after industrial whaling. In three recent studies conducted by the ABWP, DIFAR (directional) sonobuoys were used to locate pygmy blue whales off the southern coast of Australia (Miller 2012), blue whales around New Zealand (Miller, Collins, et al. 2014), and Antarctic blue whales in the Southern Ocean (Miller et al. 2013). The results of these surveys indicated that locating blue whales using DIFAR sonobuoys was not only theoretically possible, but also a viable and efficient practice (Miller et al. 2013, Miller, Collins, et al. 2014, Peel et al. 2014). Thus the Steering Committee of the ABWP has encouraged the use of DIFAR sonobuoys more widely within the ABWP. However, a key element in the wider uptake of the methodology is the availability and accessibility of appropriate hardware and software.

Over the past two decades DIFAR (directional) sonobuoys have seen increased use in whale research programs worldwide (Rivers 1997, McDonald & Fox 1999, Thode et al. 2000, McDonald et al. 2001, 2005, Swartz et al. 2003, Greene et al. 2004, McDonald 2004, Rankin et al. 2005, Wade et al. 2006, 2011, Oleson, Calambokidis, Burgess, et al. 2007, Rankin & Barlow 2007, Oleson, Calambokidis, Barlow, et al. 2007, Gedamke & Robinson 2010, Širović & Hildebrand 2011, Miller et al. 2013, Miller, Collins, et al. 2014, Miller 2012, Miller et al. 2012, Blackwell et al. 2012, 2013). Furthermore, DIFAR sonobuoys were used at many hundreds of the acoustic monitoring stations conducted during the IWC Southern Ocean Whale and Ecosystem Research (SOWER) surveys from 1996 to 2009 (Clark & Fowler 2001, Rankin et al. 2005, Ensor et al. 2006, 2007, 2008).

Increased usage of DIFAR sonobuoys is in accord with the increasing trend towards use of passive acoustics to detect and locate marine mammals (eg. Mellinger et al. 2007, Van Parijs et al. 2009). The broad adoption of these techniques is due in part to the high vocalisation rate of many species, the development of affordable data acquisition systems (eg. Wiggins & Hildebrand 2007, Rankin & Barlow 2011), and the development of efficient software for automated analysis (eg. Mellinger 2001, Gillespie et al. 2008). However, to date, most passive acoustic software focuses on the analysis of data from towed arrays of hydrophones (eg. Rainbow Click, Ishmael, PAMGuard), or on data from long-term autonomous acoustic recorders (XBAT, Triton, PAMGuard), rather than on data collected from DIFAR sonobuoys.

DIFAR sonobuoys contain a single omnidirectional pressure sensor, two directional particle-velocity sensors, and a magnetic compass. By comparing the amplitude and phase of signals on each of the three acoustic sensors it is possible to calculate the direction that a sound is coming from relative to magnetic north (Greene et al. 2004, McDonald 2004). Additionally, most DIFAR sonobuoys send data via VHF radio link back to an aircraft or nearby vessel. Consequently, the acoustic data from the three sensors are multiplexed (modulated) into a single signal prior to transmission. An important part of the processing is therefore the de-multiplexing (demodulation) of the signal back into the three separate acoustic components (Delagrange 1992). While there are some general purpose tools available for working with DIFAR data such as the beamforming software from WhaleAcoustics http://whaleacoustics.com/, and the demultiplexing software by Greeneridge Sciences Inc http://www.greeneridge.com/software.html, thorough and integrated spatial analysis of signals from DIFAR sonobuoys has remained the province of a limited number of bespoke systems.

Miller (2012) and Miller et al. (2013) used such a bespoke system during research voyages on blue whales, and while these systems functioned well throughout both voyages, the setup and maintenance of these systems proved to be cumbersome due to the use of several discrete software programs. These software programs essentially served to analyze, integrate, and/or display the position of the ship, the deployment location of the sonobuoys, the incoming acoustic data, and the localisations of whale calls. However, some of the software programs comprising this system were old, fragile, suffered from compatibility issues, and/or required expensive licences to operate.

Thus in order to encourage wider uptake of the ABWP's DIFAR-whale-tracking methodology, there was a need to develop a more integrated, nimble, and accessible software system. Here we present the initial version of such software, the PAMGuard DIFAR module. We first introduce the features and operation of this PAMGuard DIFAR module, and then consider a case study in which we use the PAMGuard DIFAR module to re-analyse a small portion of the data from the 2013 Antarctic Blue Whale Voyage.

FEATURES AND OPERATION

Infrastructure

In order to leverage existing software infrastructure for passive acoustic monitoring, the DIFAR localisation software is built upon the open-source framework, PAMGuard (Gillespie et al. 2008). PAMGuard has three modes of operation allowing for real-time monitoring and analysis, post-processing of data, and viewing and re-processing of data, and the DIFAR module can operate in all three of these modes.

Existing features of PAMGuard used by the DIFAR module include modules for: the acquisition of acoustic data, the acquisition of the ship's track (ie. GPS and NMEA data), manipulating and displaying acoustic data, automated detection of sounds from marine mammals, and mapping spatial data. In addition to the pre-existing modules, the DIFAR subsystem also includes new modules for the demodulation of DIFAR signals, and a module to compute the directionality of sound using the signals from all three of the acoustic and magnetic sensors within the DIFAR sonobuoy.

Signal processing

The main purpose of the DIFAR Localisation module is to process signals from directional DIFAR sonobuoys in order to obtain bearings to vocalisations from whales. The detection of whale vocalisations may take place automatically via PAMGuard's automated whistle and moan detector, or can take place via manual selection of calls on the spectrogram. Regardless of the method of detection, the DIFAR module then requires the classification of sounds for further processing. Classifications may include categories, species designations, or descriptions such as "Antarctic blue whale song", "downswept baleen whale call", or "vessel noise", and the classification will determine the parameters used for further analysis of the detection.

Upon classification, the acoustic data must be demodulated before further processing can occur. The DIFAR module presently uses a proprietary software library for the demodulation of DIFAR signals. It therefore requires purchase of a license to use the Greeneridge Sciences DIFAR Demodulator software (http://www.greeneridge.com/technology.html).

After de-multiplexing of the signals, the PAMGuard DIFAR module uses the beamforming algorithms as described by (D'Spain 1994, McDonald 2004) to obtain an estimate of the signal power as a function of tonal frequency and magnetic bearing. We refer to the display of signal power as a function of frequency and bearing as the DIFARGram. For a given detection, the bearing and frequency with the highest power can usually be said to represent the direction of the vocalisation. The DIFAR module can automatically suggest the bearing and frequency with the highest power, but can optionally allow the user to select a different bearing and frequency from the DIFARGram. Manual selection of the best-bearing is important if a portion of the spectrum contains noise, a situation that commonly occurs. Bearings to the sound source are displayed on the PAMGuard map.

Compass correction

In addition to providing a magnetic bearing to the source of acoustic detections, the DIFAR module provides a means to "calibrate" the compass of the sonobuoy in order to account for local magnetic anomaly and the magnetic deviation inherent in the compass within the sonobuoy. After "calibration" the DIFAR module will report all bearings referenced to true north. The procedure for "calibrating" the compass is the same as that presented in detail by (Miller 2012, Miller et al. 2013, Miller, Collins, et al. 2014), and basically involves measuring several magnetic bearings to the known positions of the research vessel as it moves away from a sonobuoy after deployment. This "calibration" procedure is simpler, and perhaps slightly less accurate than that described by (Greene et al. 2004), as it requires the assumption of continued reliability of the sonobuoy compass and it does not include an explicit model for bias that may occur as a function of bearing (eg. "gain imbalance").

Distance estimation and triangulation

The DIFAR module can optionally incorporate a simple model of acoustic propagation loss which allows for very basic estimation of distances to sounds that have a known source level. The acoustic propagation loss is modelled using geometric spreading (ie. $PL = SL - a \log_{10} r$; where *PL* is the propagation loss, *SL* is the source level, *a* is the geometric spreading coefficient, and *r* is the distance from the sonobuoy to the source). An additional option for cylindrical propagation loss is also under development.

When multiple sonobuoys are used simultaneously, the DIFAR module will automatically determine whether bearings could have originated from the same source (based on time of arrival), and if so the intersection point of these bearings will be automatically calculated and the two-dimensional geo-location (ie. latitude and longitude) will be stored in the PAMGuard database and displayed on the map in addition to the bearings. The DIFAR module can theoretically handle acoustic data from as many as 32 sonobuoys (limited only by the maximum number of acoustic channels that can currently be handled by PAMGuard), but has so far only been tested with data from one and two sonobuoys.

LOCALISATION OF AN ANTARCTIC BLUE WHALE: A CASE-STUDY

In order to validate the function of the DIFAR module, a small set of data collected during the 2013 Antarctic Blue Whale Voyage (Double et al. 2013) was re-analysed using PAMGuard's Mixed-Mode operation in which archived acoustic data re-played in synchrony with archived GPS data. The data set corresponded to an encounter with an Antarctic blue whale on 07 February 2013 during which acoustic data from two DIFAR sonobuoys were acquired simultaneously. The original results from this data set are presented in several other papers submitted to SC/65b (Miller, Leaper, et al. 2014; Miller et al. 2014). The resulting acoustic localisations from the DIFAR module compared favourably with acoustic localisations obtained in real-time during the 2013 voyage as well as surfacing locations determined concurrently via photogrammetric video tracking (Miller, Wotherspoon, et al. 2014). Furthermore, this case-study fully utilised all of the current features of the DIFAR module, thus validating the module for these purposes.

LIMITATIONS AND ROADMAP FOR FUTURE DEVELOPMENT

While the PAMGuard DIFAR module has demonstrated feature parity with the systems that were used during the 2013 Antarctic Blue Whale Voyage (Miller et al. 2013), the module has so far only been tested on a small subset of the data corresponding to an encounter with an Antarctic blue whale. Further testing is needed to ensure that the PAMGuard DIFAR module can also operate reliably during periods of long-distance tracking and targeting which can last for days at a time (Miller et al. 2013).

A current limitation of the PAMGuard DIFAR module is that there are only two sets of analysis parameters for calculating the DIFARGram: those used for "calibration" and those used for "whales." This limitation results in difficulties when attempting to analyse calls that contain substantially different bandwidths and/or durations. Future developments should allow for parameters for the DIFARGram to be set for each user defined classification, rather than simply as "whale" or "vessel," and this should facilitate concurrent analysis of calls with different durations and/or bandwidth.

Another limitation of the system is that the DIFAR module does not presently make use of the shaped (ie. non-flat), frequency response of the omnidirectional acoustic sensor in all DIFAR sonobuoys. New modules allowing acoustic filters with an arbitrary frequency response will be introduced in the next version of PAMGuard, and these filters should allow this issue to be resolved. Until then, the DIFAR module will only output "calibrated" sound pressure levels for a subset of the omnidirectional bandwidth. Further publicly available information on the frequency response of sonobuoys can be found in (Greene et al. 2004), and further information on intensity calibration of DIFAR sonobuoys can be found in (Maranda 2001).

Finally, future enhancements to the functionality of the DIFAR module should include modelling of drift of sonobuoys (Miller, Wotherspoon, et al. 2014). The addition of such a feature should be relatively straightforward, but would require further modification to the "Array Manager." The Array Manager is an important core module of PAMGuard upon which all other acoustic modules depend, so modifications to this module must be made with care.

CONCLUSION

We have presented a new and improved software program for the analysis of acoustic and directional data from DIFAR sonobuoys. The PAMGuard DIFAR module represents a substantial improvement in over prior systems, especially in terms of integration, ease-of-use and display of data. The improved integration and ease-of-use should ultimately result in a simpler workflow and make the software accessible to a wider audience. It is hoped that these improvements will also facilitate standardized protocols for acoustic localisation of Antarctic blue whales as for use by the ABWP. The DIFAR module will be available in PAMGuard version 1.13 (released in 2014; http://www.pamguard.org/).

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