YIP Expansion: Ocean Basin Impact of Ambient Noise on Marine Mammal Detectability, Distribution, and Acoustic Communication

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LONG-TERM GOALS

Results from the original award effort revealed that ocean sound levels have increased in the Indian Ocean, but have not uniformly increased across the globe over the past decade. Ambient sound levels decreased over the past decade in the Equatorial Pacific and South Atlantic Oceans. This expanded research effort extends the trend analyses of decadal ocean sound levels completed under the original award to an analysis of trends and shifts in characteristics of specific sources contributing to the soundscape over time. The primary sources of interest are baleen whales, as it is critical to identify any shift in vocalization characteristics over time to ensure optimal performance of automatic detectors used in passive acoustic monitoring, mitigation and density estimation applications. Secondary sources of interest are seismic airgun signals, shipping, and geophysical contributions from wind and ice because contributions from these sources have the potential to mask biological signals targeted in monitoring and mitigation efforts and to impact animal behavior.

OBJECTIVES

The major goal of the proposed work is to relate observed ocean sound trends to changes in source patterns and acoustic characteristics over the past decade in the Indian, Pacific, and Atlantic Oceans.

1. To assess temporal pattern, acoustic frequency, and geospatial distribution shifts of low frequency whale vocalizations over the past decade.
2. To assess temporal pattern, acoustic frequency, and geospatial distribution shifts of relevant anthropogenic and geophysical sources over the past decade.
3. To relate any observed shift in source category parameters to regional sound level trends

APPROACH

The study will use over a decade of historical acoustic data from the Comprehensive Nuclear Test-Ban Treaty Organization (CTBTO) International Monitoring System locations in the Indian, Equatorial, and South Atlantic Oceans that were acquired during the original YIP effort (Table 1; Figure 1).

Sources of investigation include low frequency sounds produced by baleen whales, seismic airgun signals, commercial shipping, and geophysical contributions from wind, natural seismic events, and ice. Parabolic equation modelling will be used to identify the range over which each class of sources is contributing to the regional soundscape. Many of the target acoustic signal categories have been well characterized allowing for development of automated spectrogram correlation detectors that can be run on long batches of recorded data to detect the presence of sounds produced by particular species or sources (i.e. Mellinger & Clark, 2006). Detectors developed and characterized under the original YIP effort and ONR Award N00014-14-1-0397 (Large Scale Density Estimation of Blue and Fin Whales (LSD)) will be further refined and applied to the more detailed source analyses in the current research.

Long-term trends in the frequency of each source class of interest (e.g. Sri Lankan blue whales, fin whales, ships, etc.) will be estimated using weekly average Power Spectrum Density (PSD) consistent with the methods in Gavrilov et al. (2012). This approach reduces the effect of short term variations due to the difference in signal production rate of different whales, human activity, or other natural source mechanisms. A sub-set of individual calls or signals from each source category will be examined for further analysis of bearing location and temporal signal characteristics. Automatic detectors will be applied to the dataset to identify individual source signals and calculate signal-to-noise ratios (SNR) of each signal. Appropriate SNR thresholds will be determined for each source category to identify signals suitable for further consideration.

Geospatial distribution of the sources detected in each source category will be assessed through an analysis of bearing estimations, as previous work with blue whale data from CTBTO arrays at Diego Garcia and the Crozet Islands has shown that only signals from the closest sources can be localized due to the instrument spacing (Samaran et al., 2010; Harris 2012). Bearings will be estimated using a custom MATLAB script being developed in support of current density estimation work under ONR Award N00014-14-1-0397. A script to find bearings of a sound source for CTBTO data using time-difference-of arrival techniques has been previously developed by Stephen Nichols at ARL under ONR Ocean Acoustics Award N000141110039 to David Bradley (ARL), and it will be modified for each source category in the proposed study. In addition, more robust methods of calculating the cross-correlation and the sound speed will be developed, assessed, and implemented, if appropriate.

The first step in linking any observed source class parameter shifts to low-frequency ocean sound level trends is to determine the extent and range over which each class of sources contributes to the regional soundscape. Estimates of signal detection range will be determined from source level, regional noise level, and propagation loss information. The transmission loss for each source class at each location will be modelled along 360 bearings at 1^{o} resolution using the OASIS Peregrine parabolic equation model for a receiver in the deep sound channel and a source position appropriate for each source class. The extent to which each source class contributes to the regional soundscape will be assessed through a soundscape budget analysis of the dominant sources identified in each time unit of analysis.

The exact formulation of the statistical models utilized during this research will largely be determined by which source parameters reveal shifts over time. However, because it is anticipated that the data will violate assumptions of traditional least squares regression approaches, namely a violation of homogeneity, demonstrate nonlinearities, and be characterized by a lack of spatial and temporal independence, models that provide more flexibility in model structure (e.g. additive models) and more complex error structures (e.g. temporal and spatial correlation) will be investigated. Models to be investigated fall within the class of models described as generalized least squares, generalized additive modeling, generalized linear mixed modeling, and generalized additive mixed modeling. These classes of models will provide a flexible framework for accommodating the complex spatial and temporal dynamics that are anticipated during this research.

The partnerships necessary to complete the expanded work scope bring together expertise in bioacoustics, acoustical oceanography, signal processing, marine mammal biology, propagation modelling, and statistics. Familiarity and previously established access and ability to process CTBTO data through the original YIP Award provides a solid basis for a productive and successful expansion study. Investigator Miksis-Olds (ARL PSU) has a strong background in methodologies for recording, analyzing, and interpreting ocean soundscapes. This knowledge is being coupled with expertise in automatic detection methodologies from Sharon Nieukirk (OSU) and propagation modelling from Kevin Heaney (OASIS).

WORK COMPLETED

The expansion study kicked off in August 2015 with the arrival of award funds. The research team is currently in the process of establishing subcontracts between the collaborating institutions.

The first phase of the project is concentrated on quantifying the shift in Sri Lankan blue whale vocalizations in support of Objective 1; a continual decrease in frequency was visually observed in long-term spectral averages created in support of the original work scope (Figure 2). Weekly Power Spectrum Density (PSD) averages were created over the decadal time series at Diego Garcia H08 N1 in the Indian Ocean. This method was selected to be consistent with the methods in Gavrilov et al. (2012). The level and frequency of tonal peaks in the 100-107 Hz range from Sri Lankan blue whale calls were identified from the PSD plots for each week of the time series from 2002-2012 (Figure 3).

PSD of ambient sound was also averaged weekly over 3 different frequency bands as part of Objective 3 to determine if there is any relationship between the observed frequency decrease in whale vocalizations and the background sound levels. Weekly average PSD and peak level were computed in the frequency band of 100-107 Hz to capture the full band of whale calls as they decreased over years. Weekly average PSD was also computed in the adjacent 93-100 Hz and 107-114 Hz bands. A linear fit between the average level in the 93-100 Hz and 107-114 Hz bands was computed because the noise level was not flat across the frequency range. The average noise level at the peak frequency in the 100-107 Hz frequency band was interpolated to correct for the contribution of background acoustic energy in the peak PSD levels of the whale frequency band, assuming that the average sound level between 93 and 114 Hz decreases linearly. The full spectrum sound levels (5-115 Hz) were also computed.

RESULTS

The frequency of Sri Lankan blue whale vocalizations was observed to decrease at approximately 0.5 Hz per year over the 2002-2012 time period from approximately 107 Hz to 100 Hz (Figure 4). This is a 6.5% decrease in frequency over a decade. Over the same time period, weekly average sound levels did not show any trend within the 100-107 Hz frequency band for either the background sound level compensation or uncompensated sound levels (Figure 5).

IMPACT/APPLICATIONS

Identifying and quantifying the shift in source characteristics contributing to the overall soundscape is critical in monitoring and mitigation efforts. Real-time monitoring and mitigation acitvites often rely on the use of automatic detectors to process large amounts of data quickly. Work involving developing, characterizing and implementing automatic detectors has been underway for a number of years and a wide variety of methods have been used (Mellinger & Clark, 2000; Munger et al. 2005; Morrissey et al. 2006; Mellinger et al., 2007; Gavrilov & McCauley, 2013). The method most suitable for a given species is dependent on the type of and variability in the vocalization to be detected. For large baleen whales with relatively stereotyped calls, commonly considered types of automatic detection include spectrogram correlation and matched filtering. Spectrogram correlation involves cross-correlating a synthetic kernel a known signal with the spectral data of interest (Mellinger & Clark 2000). Matched filter detectors are designed to maximize the ratio of signal level to noise level at a particular time by condensing the signal into a very small time interval. The filter is then cross correlated with the time domain signal (Van Trees 1968). In both methods, an accurate model vocalization is used in the detector. If shifting source characteristics are now accounted for in the detector model, the detector will not perform at an optimal level. Automatic detector outputs are also used in processing long time series in support of regional animal denisty estimations vital to Navy risk assessment. Utilizing the most effective detectors will produce the most accurate denisty estimates.

These results will also contribute to the ongoing debate on the effect of noise on marine mammals. Application of the most optimal automatic detectors to density estimation efforts over time, examined in conjuntion with sound levels and source contirbutions, will provide valuable information about long-term impacts or effects of the changing soundscape and/or specific sources on marine mammal populations. A better understanding of the effects of sound at the population level is vital to ultimately detemining any overarching biological significance of changing ambient sound levels or source activities and extends our knowledge of individual responses obtained from targeted behavioral response or observational studies.

TRANSITIONS

Successful execution of this program will provide the Navy with an improved understanding of the source mechanisms of low frequency ambient noise and the relative magnitude of the mechanisms that drive the noise field. Understanding the ocean sound components will contribute to predictive modelling of signal detection in the marine environment, as both noise statistics and source characteristics are critical parameters when describing soundscapes and are fundamental to reducing the uncertainty of signal detection when applying the passive sonar equation. Improvements to both the Ambient Noise Data Base (ANDB) and the SAFE (shipping and fishing) noise model are also possible transitions.

RELATED PROJECTS

The propagation modeling included in this study in collaboration with Kevin Heaney (OASIS) is directly related to ONR Ocean Acoustics Award N00014-14-C-0172 to Kevin Heaney titled "Deep Water Acoustics".

The current project is also directly related to and collaborative with ONR Ocean Acoustics Award N00014-11-1-0039 to David Bradley titled "Ambient Noise Analysis from Selected CTBTO

Hydroacoustic Sites". Patterns and trends of ocean sound observed in this study will also be directly applicable to the International Quiet Ocean Experiment being developed by the Scientific Committee on Oceanic Research (SCOR) and the Sloan Foundation (www.iqoe-2011.org).

Results and efforts related to this award will directly benefit the follow-on work under ONR Award N000141410397 titled "Large scale density estimation of blue and fin whales." The project is collaborative with Len Thomas and Danielle Harris of CREEM, University of St. Andrews.

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PUBLICATIONS

None under the first two months of the Expansion effort.

PRESENTATIONS

Haver, SM, Klinck, H, Miksis-Olds, JL, Nieukirk, SL, Matsumoto, H, Dziak, RP (2015). The not-so silent world: Measuring Arctic, Equatorial, and Antarctic soundscapes in the Atlantic Ocean. Society of Marine Mammalogy Society Meeting. San Francisco, CA. Dec. 13-18.

HONORS/AWARDS/PRIZES

Office of Naval Research Young Investigator Program (YIP) Award – 2011
Presidential Early Career Award in Science and Engineering (PECASE) - Nominated 2013

Table 1. Data successfully downloaded and available to ARL Penn State.

Site/Location	Start Day	Most Recent Download	# Missing Days	Total Days	Total Years
HA08/Diego Garcia	01/21/2002	07/29/2015	41	4897	13.5
HA10/Ascension Island	11/04/2004	07/29/2015	5	3915	10.8
HA11/Wake Island	04/25/2007	07/29/2015	15	3002	8.2

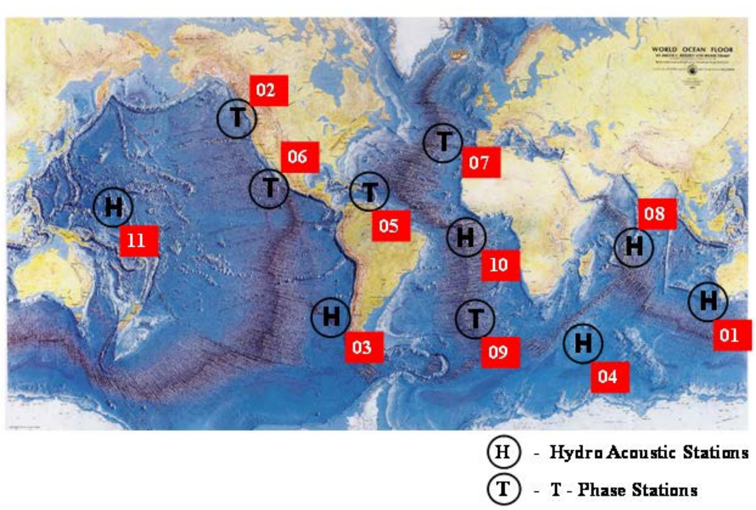

Figure 1. Location of CTBTO Hydroacoustic Sites. H sites denote hydrophone sites, moored in the water column at sound channel depths. T sites denote seismic "T-phase" sensors. This project will use data from H08, H10, and H11.

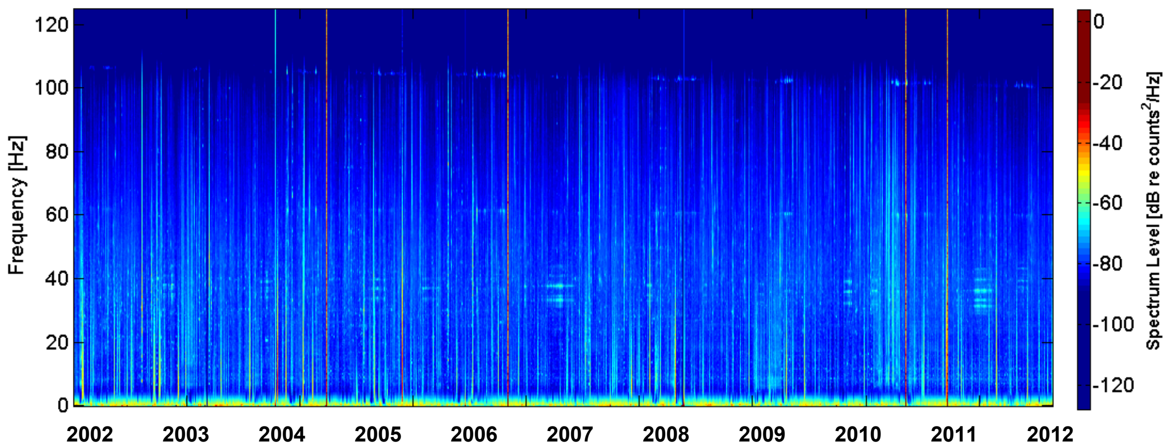

Figure 2. Long term spectral average from the Diego Garcia H08 N1 location in the Indian Ocean. The decadal spectral image was constructed using a 1-hour window and 0.25 Hz resolution. A decrease in the Sri Lankan blue whale call is observed over time in the 110-100 Hz range.

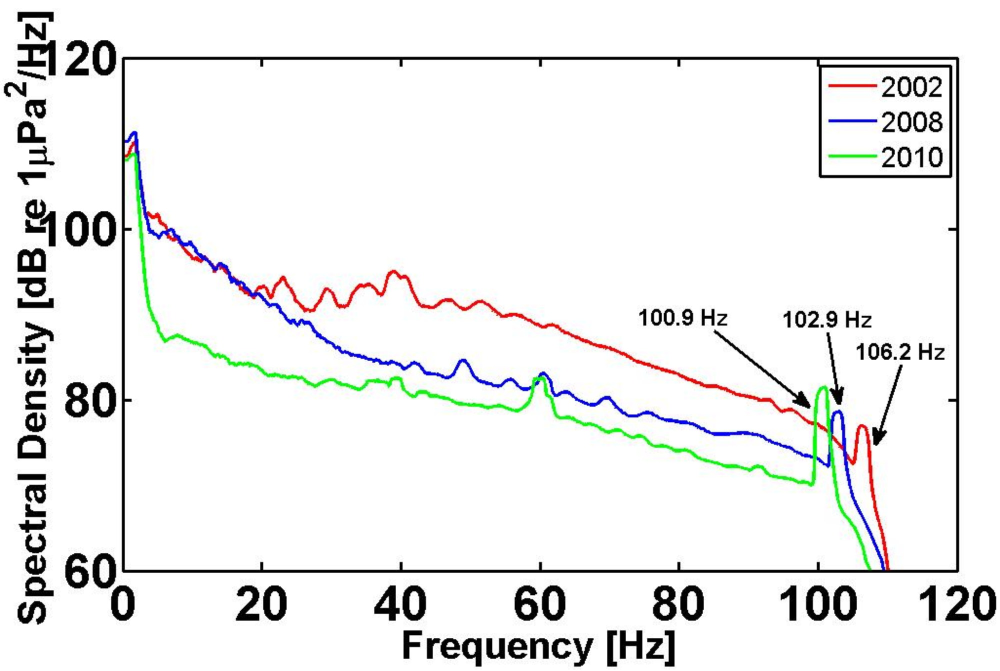

Figure 3. Power spectral density of ambient ocean sound averaged over week 22 (28 May – 3 June) in 2002, 2008, and 2012. The indicated peaks reflect the tonal peak of Sri Lankan blue whale calls.

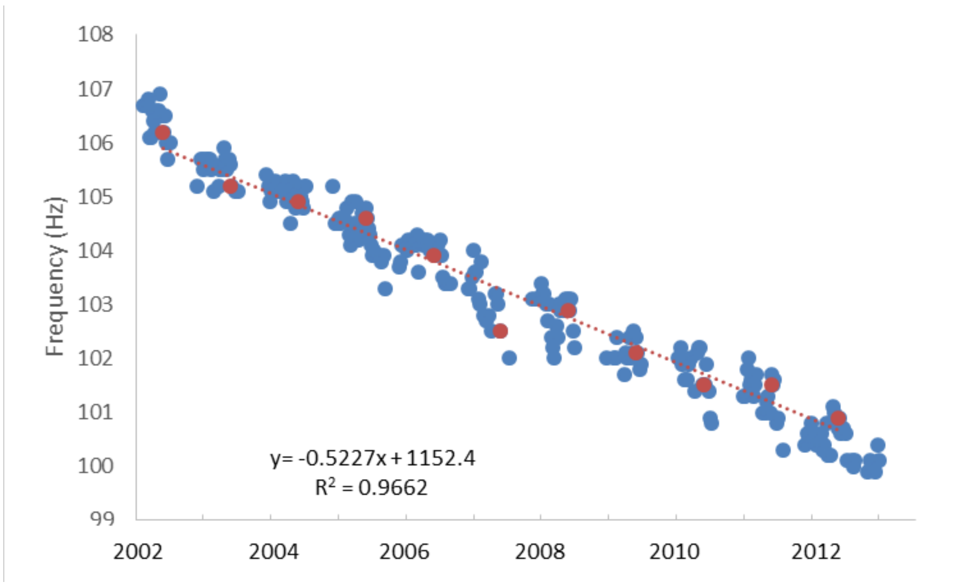

Figure 4. Peak Sri Lankan whale vocalization frequency determined from weekly PSD sound level averages. The blue circles are the weekly peaks measured each week throughout the season when whales were present. The red dots are the peak frequencies from week 22 of each year related to the trend line.

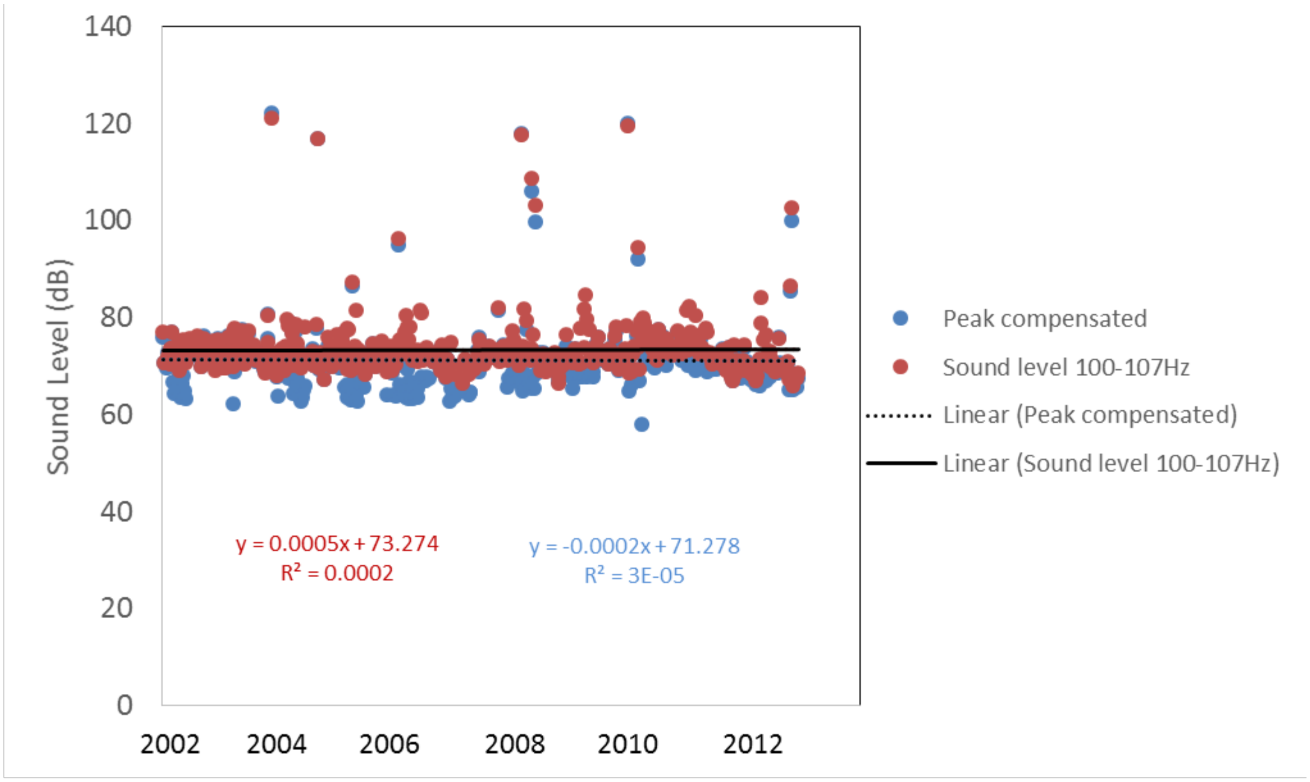

Figure 5. Sound levels for the peak compensated and uncompensated average weekly PSD levels from 2002-2012. Linear trends, equations, and R^2 values are shown.