BACKGROUND ACOUSTIC NOISE MODELS FOR THE IMS HYDROACOUSTIC STATIONS

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ABSTRACT

Background acoustic noise levels in the ocean have been increasing for the past several decades (McDonald, 2006) yet many of our hydroacoustic detection assessment tools use noise models based on data from the 60's and 70's (Urick, 1983). In some ocean basins, noise levels in the monitoring band (1-100 Hz) have risen 15 dB since the 1960's. To address this issue and provide accurate noise models at each of the six International Monitoring System (IMS) hydroacoustic stations, noise models are constructed using historical data from the stations, many now in operation for over 5 years. The analysis procedure consists of computing a power spectral density (PSD) curve for each 2-hour time period and for each hydrophone sensor (28 in all) over the entire archived data history of the stations. There are nearly 20,000 2-hour spectra for some stations. The PSD's are instrument corrected, converted to units of dB relative to 1 micropascal, and accumulated in 1 dB wide bins at each 0.1 Hz increment for each individual hydrophone. This results in a "noise model" matrix for each sensor that can be viewed as hydrophone noise histograms for each 0.1 Hz increment from 1 to 100 Hz. The noise model becomes a probability density model by simply dividing the matrix by the total spectra count. The noise model is used to create maximum probability curves and 90% confidence curves for each sensor that can then be utilized as background noise levels in network capability assessments. The noise models do not support or refute that acoustic noise levels have risen significantly since the stations do not have a long history of measurements to compare with. They do show that noise variation between stations is significant and complex. The noise models document the existence of persistent noise sources at most stations as well as some notable differences in sensor noise within triads. Besides serving as input to network assessment codes, these noise models can also help track and assess the system health of individual sensors over time as well as changes in the ambient background noise.

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OBJECTIVES

Accurate assessment of the detection capability (and to a lesser extent location capability) of the IMS hydroacoustic network is necessary in understanding and communicating the strengths and weaknesses of the monitoring network. Assessment tools that model the long-range propagation of acoustic signals, such as HydroCAM (Farrell, 1996), are utilized for this purpose but are only as accurate as the source signal levels and background noise levels provided and the propagation physics implemented. The objective of this work is to improve the accuracy of hydroacoustic network assessments by providing data-driven noise models at each hydroacoustic station based on the archived data history of the station. The noise models will improve the accuracy of assessments by providing background noise levels based on the noise level history of each station rather than using composite ocean noise models that are sweeping averages and, for older models given in textbooks (Urich, 1983), out-of-date due to the anthropogenic changing acoustic noise levels in the ocean.

A secondary objective of this work is to provide a procedure for computing a data-driven probability density noise model for each sensor that can be used to assess the specific noise environment of the sensor and state of health of the sensor and acquisition system. Comparing noise models over a period of time may be used to identify changes in the ambient noise environment and/or the sensor. The methodology can easily be applied to seismic monitoring as well.

RESEARCH ACCOMPLISHED

Background acoustic noise levels in the ocean have been increasing for the past several decades (McDonald, 2006) and this is primarily the result of modern cargo ships that have increased dramatically in number and tonnage, radiating much of their acoustic energy in the 1-100 Hz monitoring band (Arveson, 2000). The increase in acoustic noise levels can be 15 dB higher in some areas than they were in the 1960’s (see Figure 1 for the nominal global deep-ocean background noise levels taken from data collected in the 1960’s). In addition, a recent study (Hester, 2008) suggests that the acidification of the oceans caused by CO_2 emissions will significantly reduce acoustic attenuation in the ocean, making the oceans acoustically noisier. It is not clear if this will be deleterious for hydroacoustic monitoring since signals will be less attenuated also. The changing acoustic noise field means current noise models are needed in monitoring assessments.

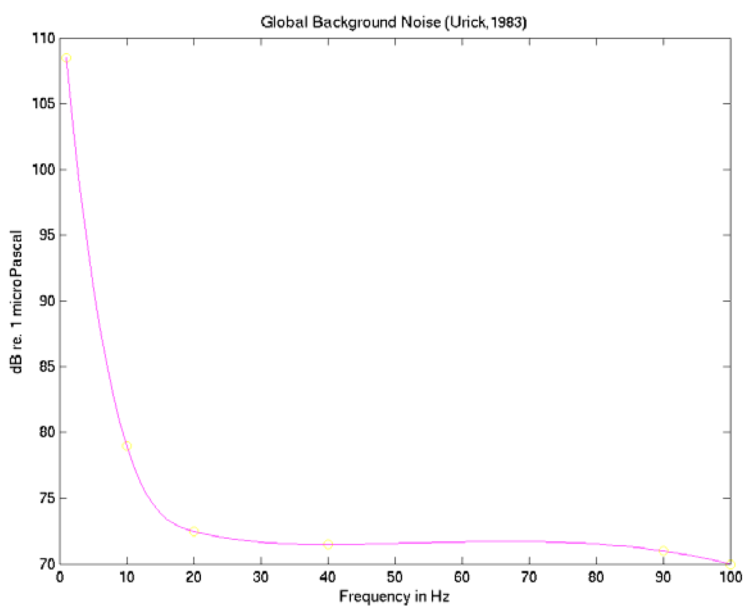

Figure 1. The global background acoustic noise in the deep ocean primarily from data taken in the 1960’s. The background noise composite is shown over the full monitoring band (1-100 Hz). Adapted from Urick, 1983.

To address this issue and provide accurate noise models at each of the six IMS hydroacoustic stations, noise models are constructed using historical data from the stations, many now in operation for over 5 years. Due to the large amount of data analyzed, an automated process was developed that utilizes the 2-hour file length records that are typically archived. Sometimes, in an apparently random manner, files were broken up into smaller, unpredictable sizes upstream in the acquisition process. When this occurred the data for that period was rejected from the analysis. Consequently, the data used is less than the full historical archive though it is the vast majority of the archive. It should be noted that the Crozet Island station had a short period of useful operational data and consequently the statistics of the noise models for Crozet are less robust. Table 1 shows the number of spectra calculated and percentage of the historical data used.

Table 1. The number of 2-hour spectra used for the noise models for each sensor are given by year. The final column gives the percent of available data used for each noise model.

SENSOR	2004	2005	2006	2007	2008	2009	TOTAL	POSSIBLE	% of data
ASN1		1340	3060	3036	3744	3336	14516	18816	77
ASN2		1608	3036	3036	3744	3336	14760	18816	78
ASN3		1608	3036	3036	3744	3336	14760	18816	78
ASS1		1596	3012	3036	3648	3264	14556	18816	77
ASS2		1596	3012	3036	3648	3264	14556	18816	77
ASS3		1596	3012	3036	3648	3264	14556	18816	77
DGN1		3228	4200	4212	4116	3756	19512	20820	94
DGN2		3228	4200	4212	4116	3756	19512	20820	94
DGN3		3228	4200	4212	4116	3756	19512	20820	94
DGS1		3204	4164	4152	4044	3744	19308	20820	93
DGS2		3204	4164	4152	4044	3744	19308	20820	93
DGS3		3204	4164	4152	4044	3744	19308	20820	93
WKN1				2232	1392	3828	7452	7884	95
WKN2				2232	1392	3828	7452	7884	95
WKN3				2232	1392	3828	7452	7884	95
WKS1				2196	1380	3792	7368	7884	93
WKS2				2196	1344	3792	7332	7884	93
WKS3				2196	1332	3792	7320	7884	93
CLW1	384	2484	2520	2268	2232	2640	12528	21648	58
CLW2	384	2484	2520	2268	2232	2640	12528	21648	58
CLW3	384	2484	2520	2268	2232	2640	12528	21648	58
JFN1		1308	0	3576	3456	2832	11172	14688	76
JFN2		1308	0	3564	3456	2832	11160	14688	76
JFN3		1308	0	3552	3456	2832	11148	14688	76
CZN1	0	0	0	0	0	0	0	0	N/A
CZN2	443	2550	0	0	0	0	2993	4236	71
CZN3	443	2550	0	0	0	0	2993	4236	71
CZS1	419	1627	444	0	0	0	2490	3256	76
CZS2	0	0	0	0	0	0	0	0	N/A
CZS3	419	1615	444	0	0	0	2478	3256	76

The analysis procedure consists of computing a PSD curve for each 2-hour time period and for each hydrophone sensor (28 in all) over the entire archived data history of the stations. This results in nearly 10,000-20,000 2-hour spectra for some stations. Three hundred 30-sec windows are used to compute the correlation function for each 2-hour time period and the resulting correlation function is used to compute the power density spectra. The spectra are corrected for instrument response, decimated, and converted to units of dB relative to one micro-Pascal, a standard unit of comparison in acoustics. Uncorrected and corrected spectra are saved. The instrument corrections are given as fap (frequency-amplitude-phase) curves with the conversion factor to pressure given at 10 Hz (20 Hz for the Crozet Island station). Each hydrophone sensor was corrected using the specific calibration curve for that sensor but all curves were very similar. Representative amplitude fap curves from each station are shown in Figure 2. It should be noted that although the noise models were constructed for the full monitoring band (1-100 Hz), all data presented here, with the exception of one plot, is in the frequency band 5-95 Hz. This is because, as can be seen in the fap curve plots, the instrument response falls off at the high frequency and, particularly, low frequency extremes where instrument response correction accuracy may be more subject to question.

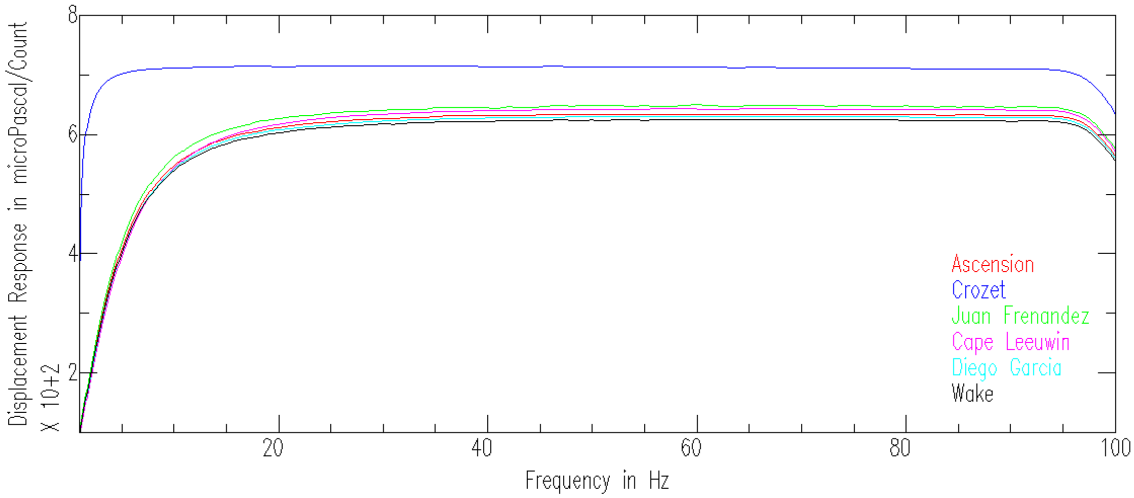

Figure 2. Output amplitude of the hydrophone is shown as a function of frequency for a representative sensor at each station. Excepting Crozet, the instrument responses are nearly identical.

To make noise models from the PSD's we loosely follow an approach used for the U.S. National Seismograph Network (McNamara, 2004). Noise models are created for each spectral frequency between 1 and 100 Hz, in increments of 0.1 Hz. (991 in all) and this is done for every hydrophone in the network. A noise model is the binning of all the PSD's for a particular hydrophone and frequency in 1 dB wide bins by rounding the amplitude in dB to the nearest integer. This results in hydrophone histograms for each 0.1 Hz increment from 1 to 100 Hz. A view of such a frequency slice can be seen in Figure 3. The noise model is simply a 200 X 991 matrix, the row index is the dB bin (1 to 200), the column index is the frequency to the nearest 0.1 Hz (e.g. index 571 is 58 Hz) and the matrix value at the ith row and jth column is the number of spectra at the jth frequency with the ith dB value. Dividing the noise model matrix by the total number of spectra used results in a probability density model.

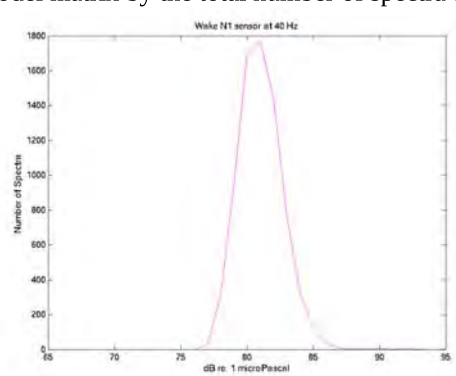

Figure 3. A slice of the noise model for the 1st sensor of the north arm of Wake Station at 40 Hz. Dividing by the total number of spectra would convert to a probability density.

The noise models are shown in the panel of contour plots in Figure 4. The third element of each sensor triad for each station and station arm results in the ten noise models displayed. All plots are to the same scale but the seven contour levels chosen are specific to each model based on the data range of that model.

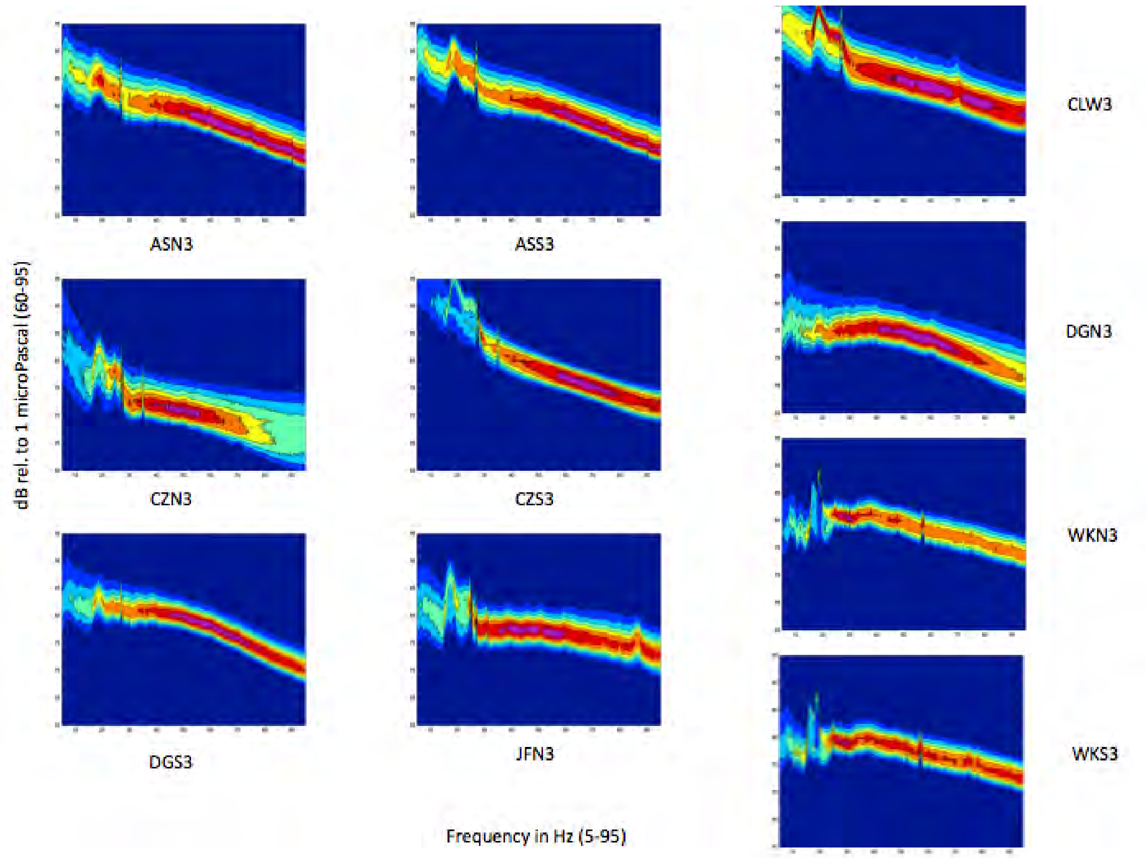

Figure 4. The probability density noise models are displayed here for the 3rd element of each arm as contour plots of probability between 5 and 95 Hz and between 60 and 95 dB. The naming convention uses a two letter identifier and a two character arm/sensor identifier (e.g., CZS3 is the third element of the Crozet Island south arm).

The noise models show some interesting persistent features at many stations. Observe the narrow band 27 Hz peak that is clearly shown on stations CL, AS north and south, CZ north and south, JF north, and DG south but absent from DG north, and WK north and south. Although the blue whale is known to produce strong narrow band calls at 27 Hz (Sirovic, 2007), the persistence and global distribution implied by the noise models would have to be shown to be consistent with blue whale population distribution and calling habits for this to be a viable explanation.

The low-frequency behavior of the stations can be seen in Figure 5. In this figure, the smoothed maximum probability density is plotted for the N1 element of each station. From 1 Hz to 3.5 Hz or so there is relatively little difference in noise levels for the six stations that span most of the world's oceans.

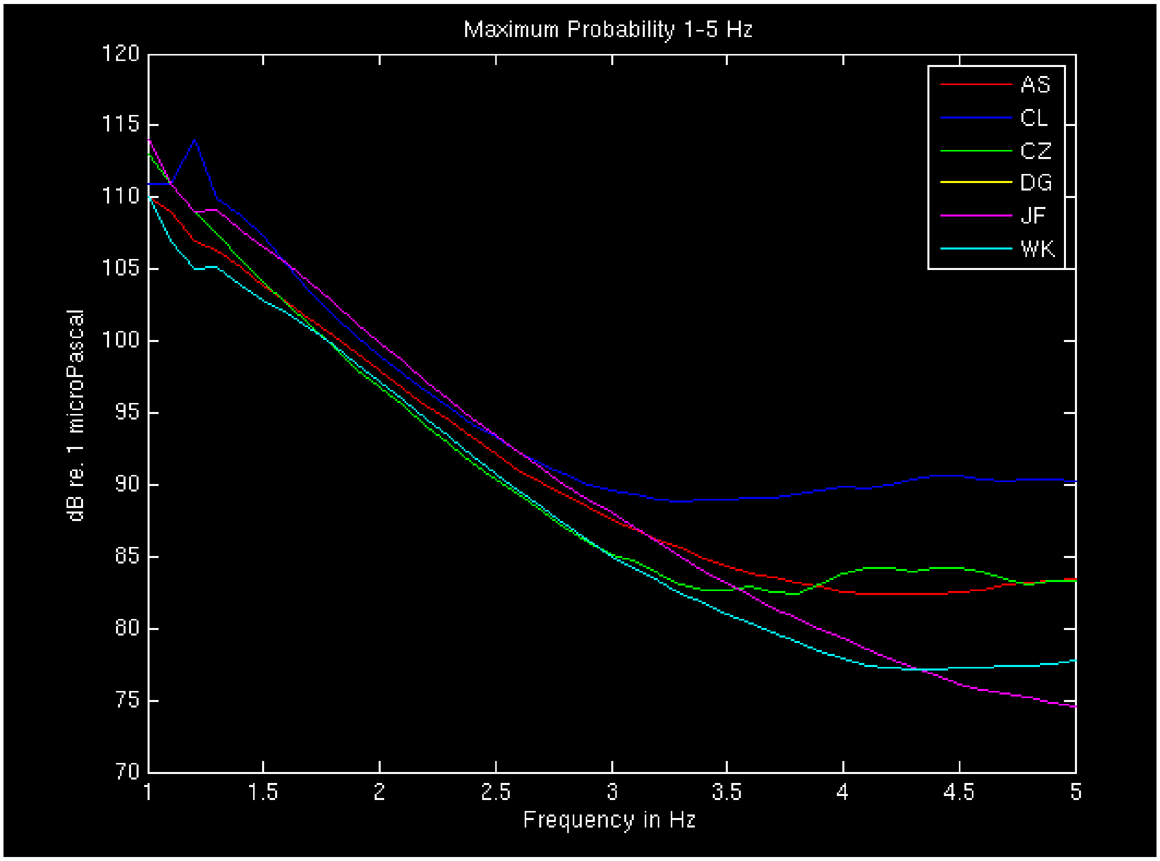

Figure 5. Low-frequency comparison of the N1 (north arm number 1) sensor from each of the six hydroacoustic station.

Since individual sensors composing the triads are separated by less than 2 kilometers, one expects that the noise models for the triads are very similar. Where they are not, installation or sensor/system problems would be likely. The panel of plots in Figure 6 shows each triad with the smoothed maximum probability density plotted for each sensor in the triad. In general, individual sensors within triads do have very similar noise models but there are some small anomalies. The S1 sensor in the Diego Garcia south arm is about 2 dB below the other two sensors over most of the monitoring band. Similarly, the S2 sensor of the Wake south arm is consistently below the other sensors of the south arm. The Ascension north arm shows relatively higher variability among sensors, particularly at low frequencies. Most striking are the differences between arms of the same station, particularly Crozet Island, with the north arm among the lowest broadband noise levels of all stations and the south arm among the highest.

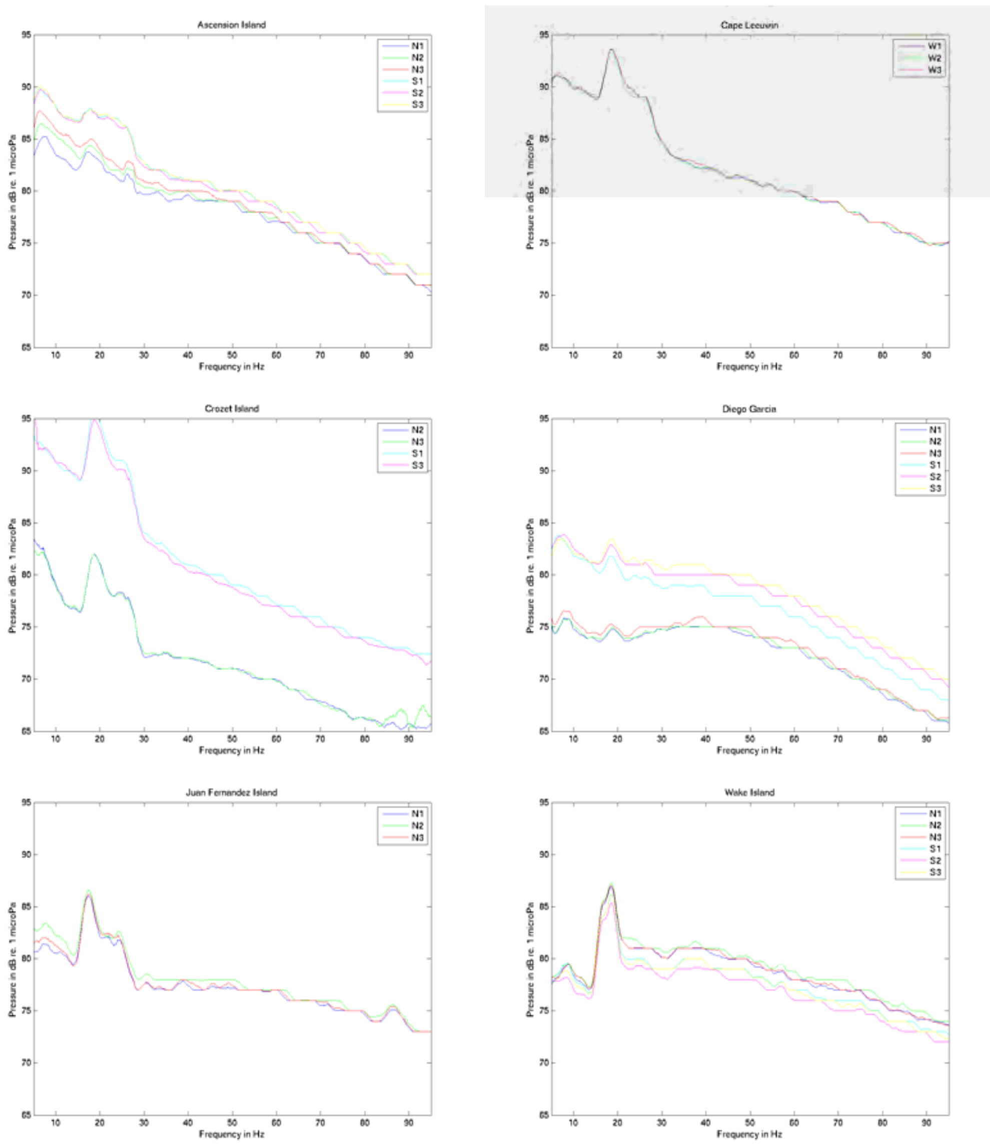

Figure 6. The plot shows the smoothed maximum noise probability for all hydrophones composing that station. We expect noise models of triad sensors to be nearly identical while north and south arms can have different background noise environments, Crozet providing an extreme example.

To use the noise models in an assessment, they must be condensed as in the last figure that uses maximum probability, which is one of many criteria that can be used. In general, the nature and purpose of the assessment will favor different criteria. Figure 7 shows how the criteria selection affects the noise levels. Maximum probability, 10% confidence (i.e., 10% of spectra were lower), and 90% confidence (i.e., 90% of spectra were lower) background noise curves are shown for Diego Garcia South (S3). The maximum probability and 10% confidence curve are coincident at some points and this is due to granularity, the binning into 1 dB increments. It does show that the maximum probability is near the low noise extreme of the model. It also suggests that using a 90% confidence results in a background noise about 5 dB higher than the maximum probability for frequencies above about 20 Hz and up to 15 dB higher at the lowest frequencies.

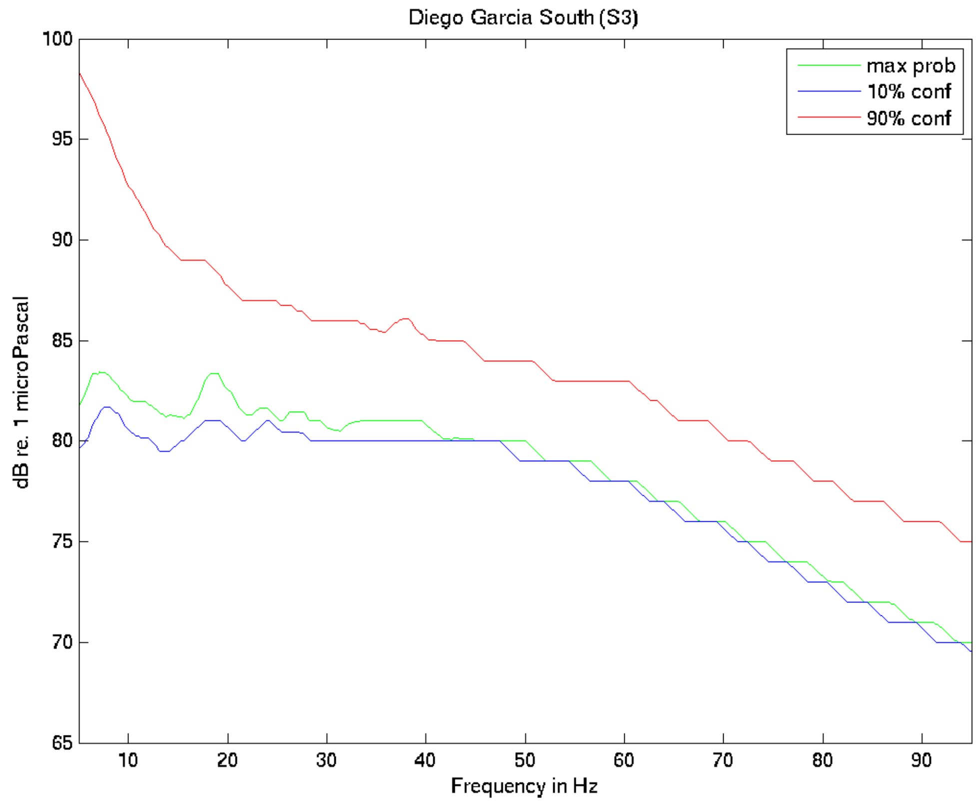

Figure 7. Maximum probability, 90% confidence, and 10% confidence smoothed noise model for Diego Garcia south (S3).

The noise models can easily be constructed for smaller time periods such as yearly or seasonal. Using periods of a month or less would result in only 350 or less spectra for the noise model with consequent poor statistics.

In Figure 8, yearly noise models were calculated for the Ascension Island north N1 sensor, the smoothed maximum probability shown plotted by year. Over the 5 years, no obvious pattern emerges with the exception that 2007 is an anomalously high background noise year.

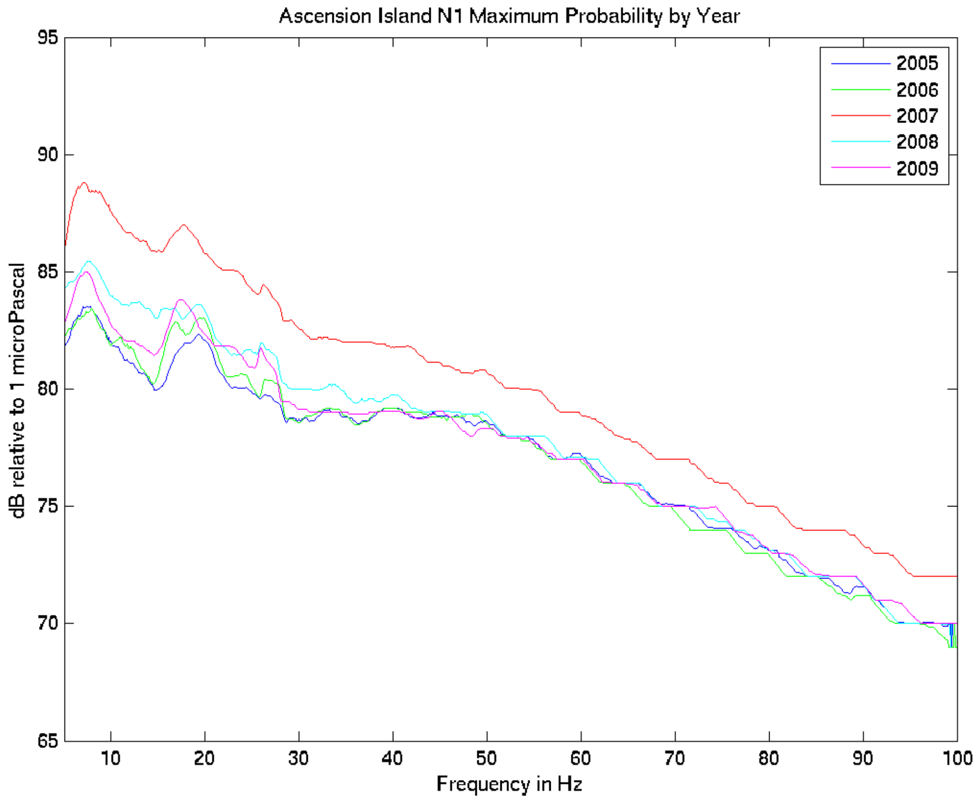

Figure 8. Smoothed maximum probability of yearly noise models for the Ascension Island north hydrophone (N1).

CONCLUSIONS AND RECOMMENDATIONS

Noise models for the IMS hydroacoustic monitoring stations have been developed based on the historical archived data. These models can serve as input to monitoring network assessment codes such as HydroCAM and should improve assessment accuracy by providing more accurate and reliable background noise data. Which noise levels to use (most probable, mean, median, mode, 90^{th} percentile, 10^{th} percentile, etc.) in a network assessment depends on the purpose of the assessment and the underlying question the assessment is trying to answer. The noise models can also be used to quantify temporal changes in the ambient noise environment and to identify persistent narrow band noise features that may be indicative of hydrophone sensor/system malfunction or a continuous noise source in the region of the sensor. Given that ambient background acoustic noise is increasing, it makes good sense to update the noise models periodically. In addition to maintaining accurate values for input to assessment models, the acoustic noise model at each IMS station over time can help in documenting the changing noise field in the world's oceans.

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