Underwater Ambient Noise and Sperm Whale Click Detection during Extreme Wind Speed Conditions

Joal J. Newcomb*, Andrew J. Wright**, Stan Kuczaj***, Rachel Thames***, Wesley R. Hillstrom****, and Ralph Goodman*****

**Naval Research Laboratory, Code 7180, Stennis Space Center, MS 39529*
***Previously at the University of Wales, Bangor, UK*
****University of Southern Mississippi, Psychology Dept, Box 5025, Hattiesburg, MS 39406*
*****Naval Oceanographic Office, Stennis Space Center, MS 39522*
****** University of Southern Mississippi, Dept of Marine Sciences, Stennis Space Center, MS 39529*

Abstract. The Littoral Acoustic Demonstration Center (LADC) deployed three Environmental Acoustic Recording System (EARS) buoys in the northern Gulf of Mexico during the summers of 2001 (LADC 01) and 2002 (LADC 02). The hydrophone of each buoy was approximately 50m from the bottom in water depths of 645m to 1034m. During LADC 01 Tropical Storm Barry passed within 93nmi east of the EARS buoys. During LADC 02 Tropical Storm Isidore and Hurricane Lili passed within approximately 73nmi and 116nmi, respectively, west of the EARS buoys. The proximity of these storm systems to the EARS buoys, in conjunction with wind speed data from three nearby NDBC weather buoys, allows for the direct comparison of underwater ambient noise levels with high wind speeds. These results are compared to the G. M. Wenz spectra at frequencies from 1kHz to 5.5kHz. In addition, the impact of storm conditions on sperm whale clicks was assessed. In particular, although the time period during the closest approach of TS Barry tended to produce lower click rates, this time period did not have the greatest incidence of non-detection at all the EARS buoys. It follows that storm-related masking noise could not have been responsible for all the observed trends. The data suggest that sperm whales may have left the vicinity of the deepest EARS buoy (nearest TS Barry's storm track) during the storm and possibly moved into the shallower waters around the other EARS buoys. It also appears that sperm whales may not have returned to the deepest EARS area, or did not resume normal behavior immediately after the storm, as the click rate did not recover to pre-storm levels during the period after TS Barry had dissipated. Results of these analyses and the ambient noise analysis will be presented. (Research supported by ONR).

INTRODUCTION

The Littoral Acoustic Demonstration Center (LADC) is an Office of Naval Research funded consortium consisting of the University of New Orleans, the University of Southern Mississippi, the Naval Research Laboratory, and the University of Louisiana at Lafayette. LADC deployed three Environmental Acoustic Recording System (EARS) buoys in the northern Gulf of Mexico (GoM) during the summers of 2001 (LADC 01) and 2002 (LADC 02) to study ambient noise and marine mammals. The LADC EARS buoy (developed by the Naval Oceanographic Office) is an autonomous, self-recording buoy capable of more than 66 days continuous recording of a single channel at a 11.7kHz sampling rate. The hydrophone of each buoy was approximately 50m from the bottom in water depths of 1034m to 645m along an upslope track. The buoys were labeled EARS 1 (deepest), EARS 2, and EARS 3 (shallowest). Oceanographic data (CTD and XBT data) were obtained during each deployment along a longer upslope track and along a cross slope track centered at EARS 1. Bottom information for these tracks was obtained during LADC 01 from side-scan sonar data.

During LADC 01, Tropical Storm Barry passed within 93nmi east of the EARS buoys. During LADC 02 Tropical Storm Isidore and Hurricane Lili passed within approximately 73nmi and 116nmi, respectively, west of the EARS buoys. The proximity of these storm systems to the EARS buoys, in conjunction with wind speed data from three nearby National Data Buoy Center (NDBC) weather buoys (Fig. 1), allows for the direct comparison of underwater ambient noise levels with high wind speeds.

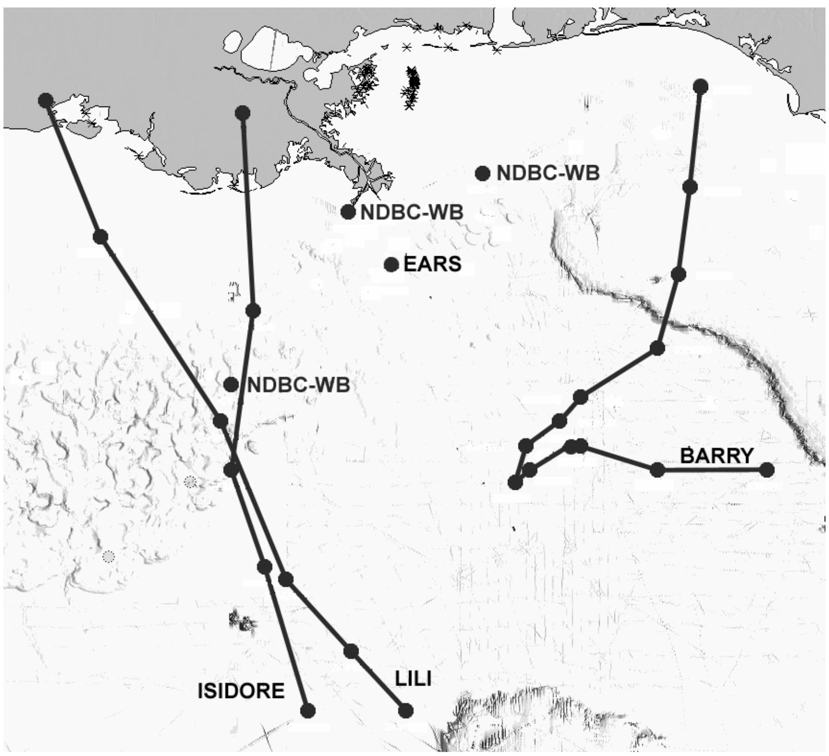

FIGURE 1. Chart of storm system tracks during the summer of 2001 and 2002 relative to the EARS deployment site and the NDBC weather buoys. The storm systems' tracks were obtained from positional data published by the National Hurricane Center (NHC) indicated by the solid circles connected with straight lines.

AMBIENT NOISE RESULTS

The storm systems' tracks were obtained from positional data published by the National Hurricane Center (NHC). Wind speed estimates at the EARS location were obtained from an examination of wind speed and wave height measurement data obtained from the NDBC weather buoys. Ambient noise results were obtained from a spectral analysis of the EARS raw acoustic data.

Hurricane Lili (October 2002)

Hurricane Lili at closest approach passed about 116nmi west of the EARS buoys. All three NDBC buoys were used to estimate wind speed for each time period except for the time period where Hurricane Lili passed very close to NDBC buoy 42041.

Figure 2 illustrates the ambient noise results for Hurricane Lili for EARS 1 from 1kHz to 5.5kHz. The closely grouped spectra are the noise levels for the time periods corresponding to published positions of Hurricane Lili and represent estimated wind speeds of 20 to 47kts. The much lower level spectrum represents the results for a time period during which there were no storm systems in the GoM and is presented only for comparison. As expected, when Hurricane Lili approached EARS 1, the wind speeds increased and the corresponding noise levels increased. Superimposed upon these results are the Wenz curves [1] for Beaufort Wind Forces (BWF) of 5 and 8 (solid black lines) and the projected upper limit of prevailing noise. As can be seen from Fig. 1, the measured spectra agree well with the slope and levels of the BWF 8 curve for wind speeds of 34kt to 40kt. Results from the EARS 3 buoy have overall higher spectral levels, but otherwise are very similar.

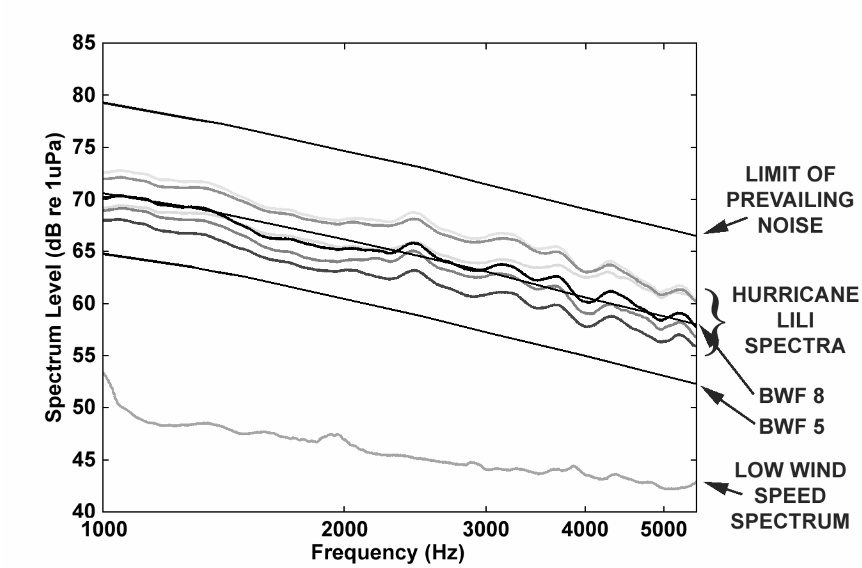

FIGURE 2 Illustration of the ambient noise results for EARS3 during Tropical Storm Isidore superimposed upon the results from Wenz [1] for Beaufort Wind Force 5 and 8. Also shown are the upper limit of the prevailing noise from Wenz [1] and a low wind speed spectrum for comparison.

Tropical Storm Isidore (September 2002)

Tropical Storm Isidore was less organized and weaker than Hurricane Lili. She was also a very large storm geographically. As can be seen from Fig. 1, TS Isidore passed approximately 43nmi closer to the EARS buoys than Hurricane Lili at closest approach (73nmi west of EARS buoys). Consequently, the spectrum levels for TS

Isidore are about the same as the spectrum levels for Hurricane Lili. All three NDBC buoys were used to estimate wind speed for each time period except for the time period where TS Isidore passed very close to NDBC buoy 42041.

Figure 3 illustrates the ambient noise results for TS Isidore from 1kHz to 5.5kHz for EARS 3. The closely grouped spectra correspond to the published positions of TS Isidore and represent estimated wind speeds of 21 to 55kt. The much lower level spectrum represents the results for a time period during which there were no storm systems in the GoM and is for comparison only. As expected, and similarly to the results for Hurricane Lili, when TS Isidore approached EARS 3, the wind speeds increased and the corresponding noise levels increased.

Superimposed upon the results for TS Isidore are the Wenz curves for Beaufort Wind Forces (BWF) of 5 and 8 (solid black lines) and the projected upper limit of prevailing noise. As can be seen from Fig. 3, the measured spectra agree well with the slope and levels of the BWF 8 curve for wind speeds of 34kt to 40kt. Results from the EARS 1 buoy have overall lower spectral levels (except for the EARS 1 anomalous time period), but otherwise are very similar.

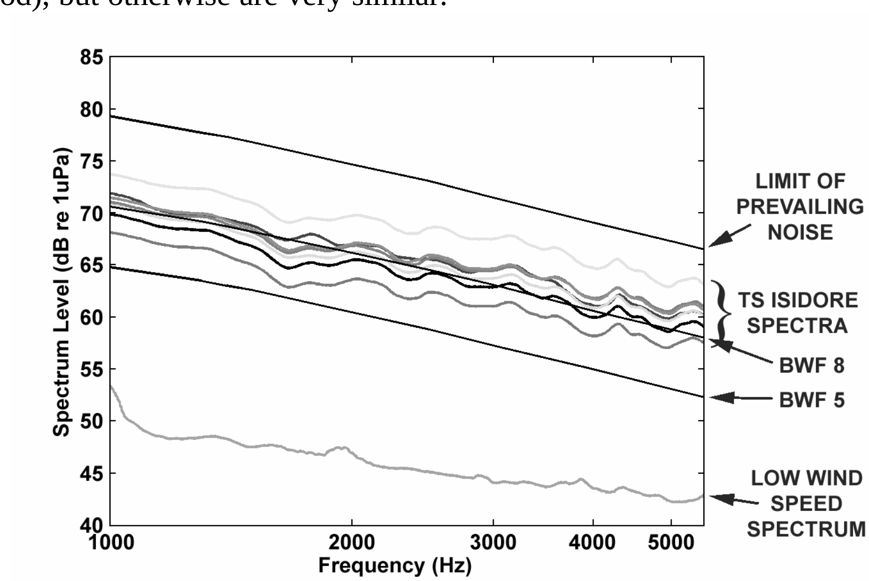

FIGURE 3 Illustration of the ambient noise results for EARS3 during Tropical Storm Isidore superimposed upon the results from Wenz [1] for Beaufort Wind Force 5 and 8. Also shown are the upper limit of the prevailing noise from Wenz [1] and a low wind speed spectrum for comparison.

There were some anomalous time periods during TS Isidore where the noise levels were much higher than those expected from the wind speed estimates. In those cases, acoustic data from 30 minutes before or after the original time period yielded results in line with wind speed estimates. It is postulated that these anomalies might be due to the banding nature of tropical storm systems. In these bands localized severe weather conditions are possible (e.g., rain squalls, high wind speeds, tornadoes, etc.). If these anomalies were due to banding effects, it would be expected that they occur periodically throughout the passage of the storm. This is currently being explored.

Tropical Storm Barry (August 2001)

Tropical Storm Barry passed about 93nmi east of the EARS buoys at closest approach. An acoustic noise analysis of the data and wind speed estimates, similar to the analysis for the 2002 storm systems, is currently underway. A generic spectral analysis of the acoustic data has been performed. Figure 4 illustrates the results of that analysis for a 24-hour period before TS Barry and a 24-hour period during the passage of TS Barry. The broadband lines seen on both spectrograms have been identified as shipping traffic. As can be seen from Fig. 4, the period before TS Barry has more shipping than the period during TS Barry. Also evident is the increase of noise levels in the frequency band from 1kHz to 4kHz during TS Barry. A close examination of the results during TS Barry indicates that the increase of levels is periodic, perhaps due to banding effects.

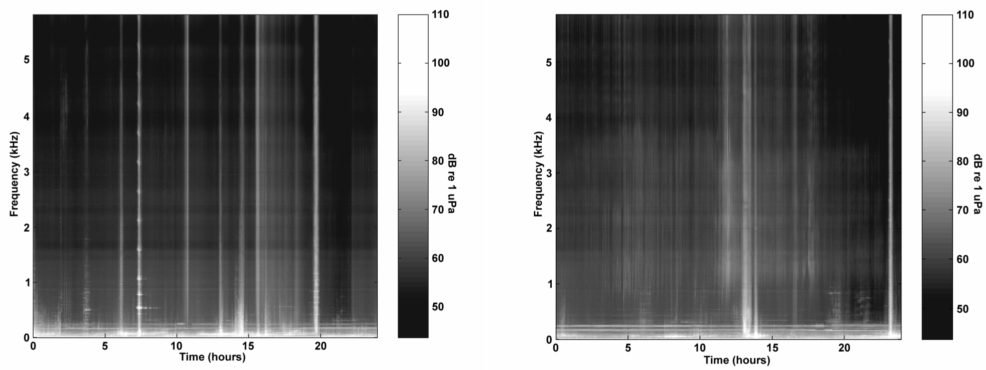

FIGURE 4. Spectrograms of the ambient noise before (left) and during (right) Tropical Storm Barry.

CLICK PRODUCTION

Ishmael [2] version 1.0 was employed to detect clicks automatically in the acoustic data. Ishmael generates noise-equalized spectrograms and calculates an average spectral energy. It then records detections after applying energy threshold criteria for frequencies over 2kHz. The Ishmael output, combined with the use of Raven [3] version 1.0, allowed anomalous sounds to be identified in the data, including pulse noises (e.g., those generated by seismic airguns) and more consistent noise (e.g., shipping noise). Furthermore, the unique multi-pulsed structure [4] of the clicks was periodically confirmed in order to verify that a sperm whale had produced them. Data containing detection events generated predominantly by non-sperm whale sounds were removed from subsequent analyses, as were those containing considerable consistent noise.

The whole study period was broken down into three major sections (Table 1) based on the 2001 NHC advisories for TS Barry. The storm period was defined by the time of the first and last advisories (1 and 17). Statistical significance was determined using Kruskal-Wallis tests to test the null hypothesis that storm activity had no impact on sperm whale vocal behavior.

TABLE 1. Definition of the time periods used in the analyses. Times determined by the NHC advisories for Tropical Storm Barry.

Time Period	NHC Advisory Number(s)	Start of Period			End of Period		
		Date	Julian Day	Time (GMT)	Date	Julian Day	Time (GMT)
Pre-storm	Pre-1	26-Jul	207	00:00	2-Aug	214	18:00
During	1,17	2-Aug	214	19:00	6-Aug	218	08:00
Post-storm	Post-17	6-Aug	218	09:00	13-Aug	225	23:00

Results

The mean click rate was highest during the pre-storm period at all EARS buoys either with or without the zero-files analyzed; zero-files are acoustic data files in which Ishmael detected no clicks. Additionally, the click rate was lowest during the storm period for all analyses with the exception of the EARS 2 data with the zero-files still included (i.e., the unadjusted click rate).

Although patterns also can be seen in the proportion of zero-files for each period at all three EARS buoys (Fig. 5), the variation was not quite significant (p=0.026, p=0.004 and p=0.006 at EARS 1, 2 and 3 respectively). EARS 1 displayed the highest incidence of zero-files during TS Barry, while EARS 2 and EARS 3 had their lowest proportion of zero-files during the storm confirming that the results do not simply reflect the impact of increased levels of masking noise. Further evidence for this is provided by the fact that the mean adjusted click rate for hours 4-8 at EARS 2 was higher during the storm than at any other time (Fig. 6). It is worth noting that this may also suggest that the whales are increasing the strength of their clicks in response to higher levels of ambient noise, since sperm whales are known to be capable of regulating the sound pressure of their clicks independently of their environment [5].

Produced pneumatically [6], it is possible that louder clicks requires the use of more air which may, in turn, reduce the number of clicks that can be produced before some air recycling must take place [7]. Alternatively, greater pressures might be required placing more physical strain on the tissues involved in production [6]. However, the full repercussions of a potential increase in signal strength, physiological or energetic, can not be determined from this data, although any such compensatory efforts would have implications for regions of heavy vessel activity.

The diurnal distributions at EARS 1 before and after the storm were very similar, although the absolute values after the storm were significantly lower (Fig. 6). Sperm whales are known to live in very stable groups [8], which have been found to extend to foraging behavior at depth and not just surface activities [9]. Consequently, this result, together with the different pattern observed during the storm, suggests that the whales from this area may have moved away during TS Barry and were slowly returning to the site after the storm had passed.

EARS 2 and 3 displayed visibly different diurnal patterns in adjusted click rate during each period (Fig. 6), although the post-storm and during-storm periods were possibly most similar, especially at EARS 2. It is likely that the very different daily peaks were created by the presence of whales that were not recorded in the area before the storm. Storm-related mixing could be expected to simply reduce any diurnal trends in diving behavior rather than producing an alternative trend since prey would be more

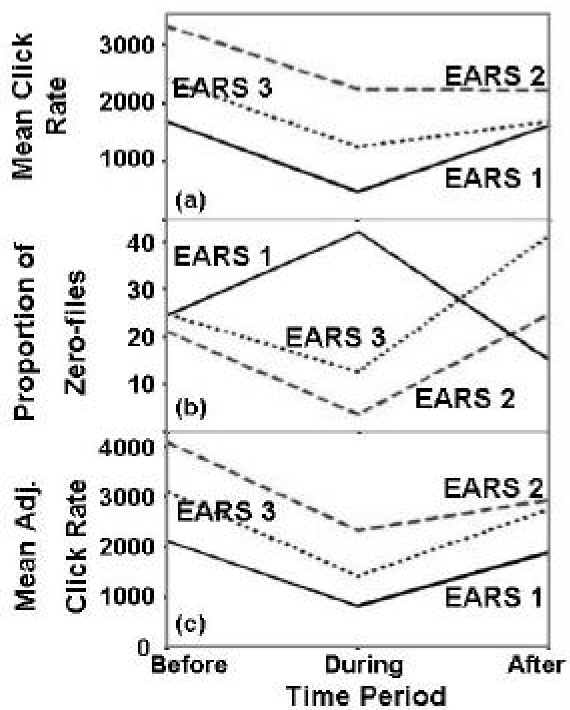

FIGURE 5. (a) Mean click rate, (b) mean proportion of zero-files and (c) adjusted click rate for the three time periods and each EARS buoy.

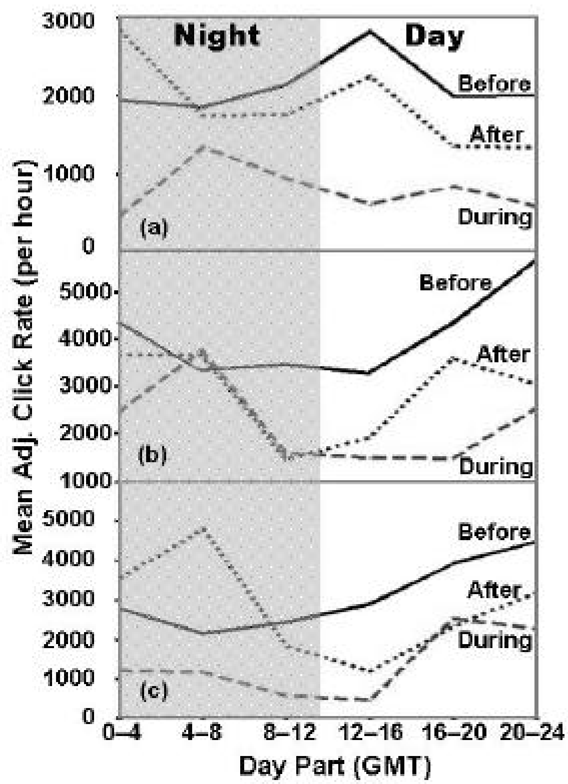

FIGURE 6. Mean adjusted click rate over the parts of the day at (a) EARS 1, (b) EARS 2 and (c) EARS 3 for the three time periods.

evenly distributed throughout the water column. Furthermore, the original trends were not revived after the storm suggesting that the migrations observed were more permanent than the remaining time included in this study (approximately one week).

It is not known whether these movements were due to an avoidance of deep water during the storm or more simply of the storm itself. Neither is it possible to determine if all the observed responses were due to increased ambient noise levels or changes in the Sea State. However, this preliminary study clearly shows that the distribution and behavior of the whales are affected by the presence of near-by tropical storms.

SUMMARY

Ambient noise results in the frequency range of 1kHz to 5kHz from the LADC 2002 experiment during Hurricane Lili and TS Isidore are in good agreement with expected wind trends. They also agree well with the Wenz curves. A similar analysis is planned for the TS Barry acoustic data from LADC 2001. A separate analysis of the data from the LADC 2001 experiment, showed that TS Barry had a definite impact upon the detected sperm whale click rates. A similar analysis of the LADC 2002 data for Hurricane Lili and TS Isidore is planned.

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