Measurements of Ambient Noise during Extreme Wind Conditions in the Gulf of Mexico

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***Abstract*-The Littoral Acoustic Demonstration Center (LADC) deployed three Environmental Acoustic Recording System (EARS) buoys in the northern Gulf of Mexico during the summer of 2002 (LADC 02). The hydrophone of each buoy was approximately 50 m from the bottom in water depths of 645 m to 1034 m. During LADC 02 Tropical Storm Isidore and Hurricane Lili passed within approximately 73 nmi and 116 nmi, 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 weather (NDBC) 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 1 kHz to 5.5 kHz. Anomalously high levels of ambient noise may be due to banding effects of the storms. Results of the ambient noise analysis will be presented. (Research supported by ONR PE62435N).**

I. 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 during the summer of 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 an 11.7 kHz sampling rate. The hydrophone of each buoy was approximately 50 m from the bottom in water depths of 1034 m to 645 m 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 (summer of 2001) from side-scan sonar data.

During LADC 02 Tropical Storm Isidore and Hurricane Lili passed within approximately 73 nmi and 116 nmi, 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 (see Fig. 1), allows for the direct comparison of underwater ambient noise levels with high wind speeds.

II. Ambient Noise Results

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 in Fig. 1. 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 at closest approach passed about 116 nmi 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.

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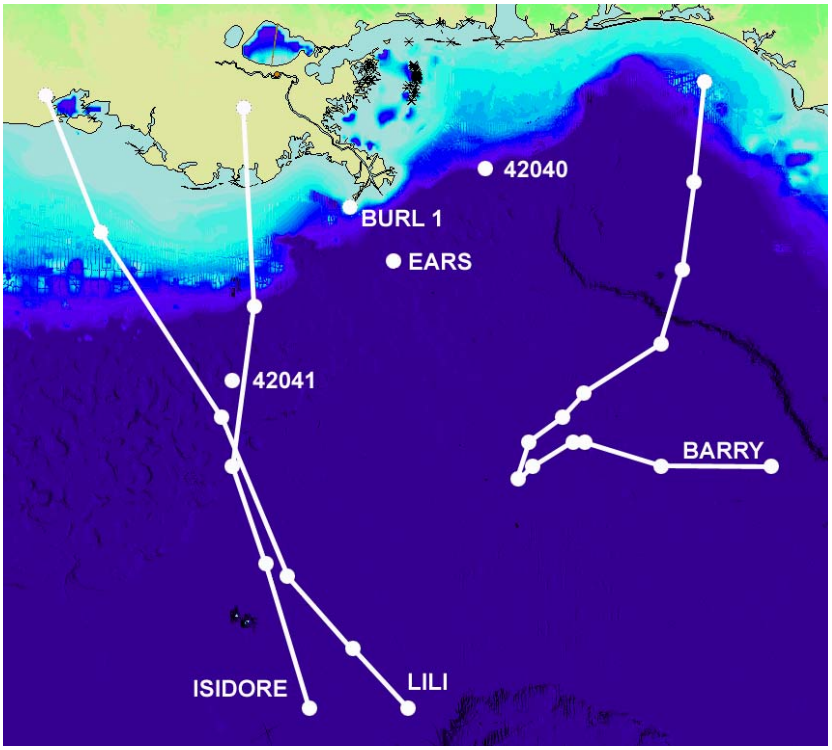

Fig. 1 Chart of storm system tracks during the summer of 2001 and 2002 relative to the EARS deployment site and the NDBC weather buoys.

Fig. 2 illustrates the ambient noise results for Hurricane Lili for EARS 1 from 1 kHz to 5.5 kHz. 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 47 kt. The much lower level spectrum represents the results for a time period during which there were no storm systems in the Gulf of Mexico and is presented only for comparison. As expected, when Hurricane Lili approached EARS 1, the

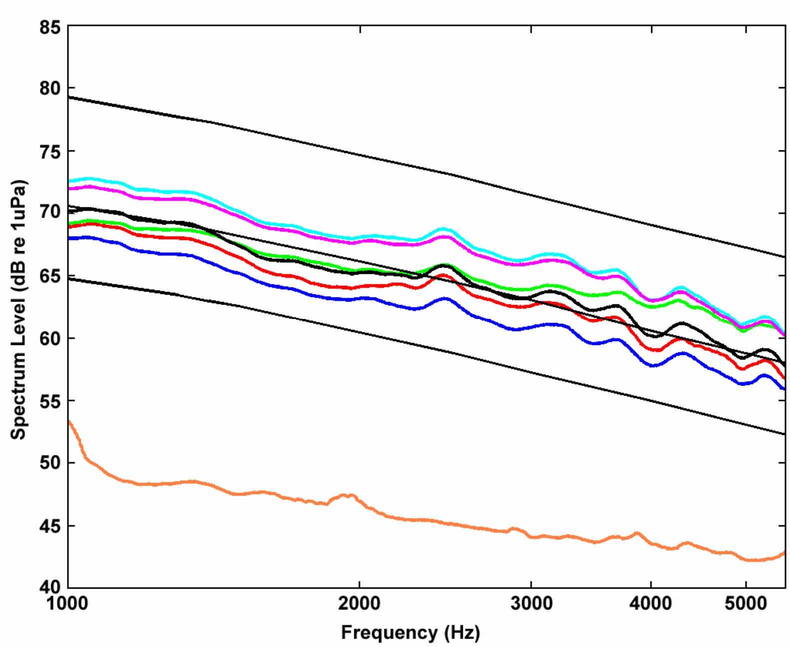

Fig. 2 Illustration of the ambient noise results for EARS 1 during Hurricane Lili.

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 34 kt to 40 kt. Results from the EARS 3 buoy have overall higher spectral levels, but otherwise are very similar.

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, Tropical Storm Isidore passed approximately 43 nmi closer to the EARS buoys than Hurricane Lili at closest approach (73 nmi west of EARS buoys). Consequently, the spectrum levels for Tropical Storm 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 Tropical Storm Isidore passed very close to NDBC buoy 42041.

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

There were some anomalous time periods during Tropical Storm Isidore where the noise levels were much higher than those expected from the wind speed estimates (e.g., upper red curve in Fig. 3). In those cases, acoustic data from 30 minutes before or after the original time period yielded results in line with wind speed estimates.

Superimposed upon the results for Tropical Storm 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 34 kt to 40 kt. The sole exception being the anomaly noted previously.

It is postulated that these anomalies might be due to the banding nature of tropical storm systems. Fig. 4 is a composite satellite photograph of Tropical Storm Isidore clearly illustrating two major bands of the storm. In these bands localized severe weather conditions are common (e.g., rain squalls, high wind speeds, tornadoes, etc.).

If the anomalously high ambient noise levels were due to banding effects, it would be expected that they occur periodically throughout the passage of the storm. Fig. 5 is a spectrogram of the ambient noise for a 24-hour period during Tropical Storm Isidore. There are four broadband regions of high level ambient noise starting near hour 12. Examined closely these four bands do not have the characteristic scalloping associated with shipping noise. Further, they lack the low frequency content and have more high frequency content than the noise from a passing ship (e.g., high level noise seen near hour 3, Fig. 5). An aural examination of the four broadband regions reveals no indication of shipping noise.

Fig. 6 is an illustration of a six minute average of the ambient noise during the first of the four bands of high level noise near

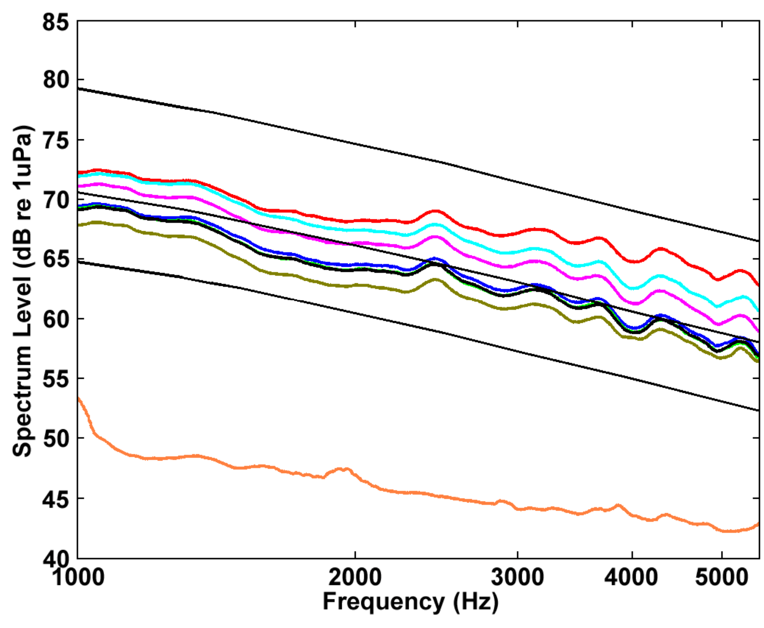

Fig. 3 Illustration of the ambient noise results for EARS 1 during Tropical Storm Isidore.

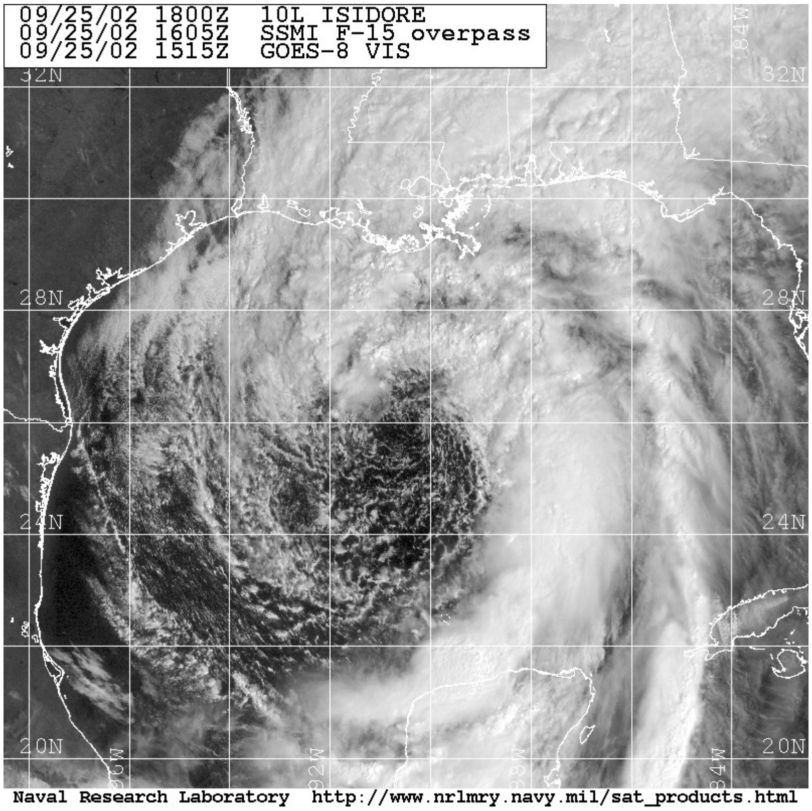

Fig. 4. Satellite image of Tropical Storm Isidore illustrating banding.

hour 12 (upper data curve) and during a time period that does not contain a band (lower data curve). The ambient noise levels are superimposed upon the Wenz curves for BWF 5 and 8 and the upper limit of prevailing wind noise. As can be seen from Fig. 6,

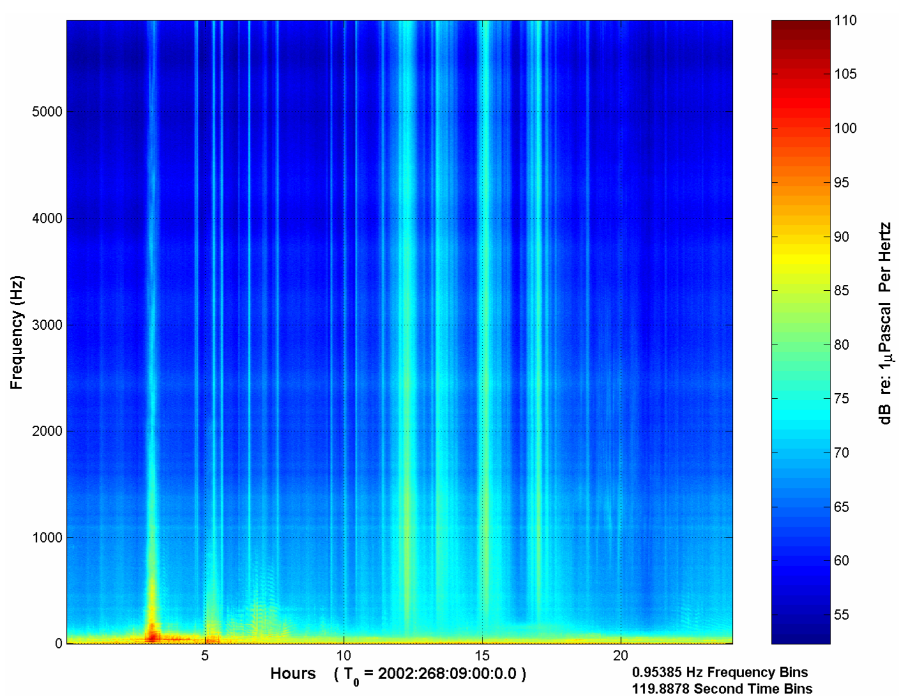

Fig. 5. Spectrogram of the ambient noise results for EARS 1 during Tropical Storm Isidore illustrating effects of banding.

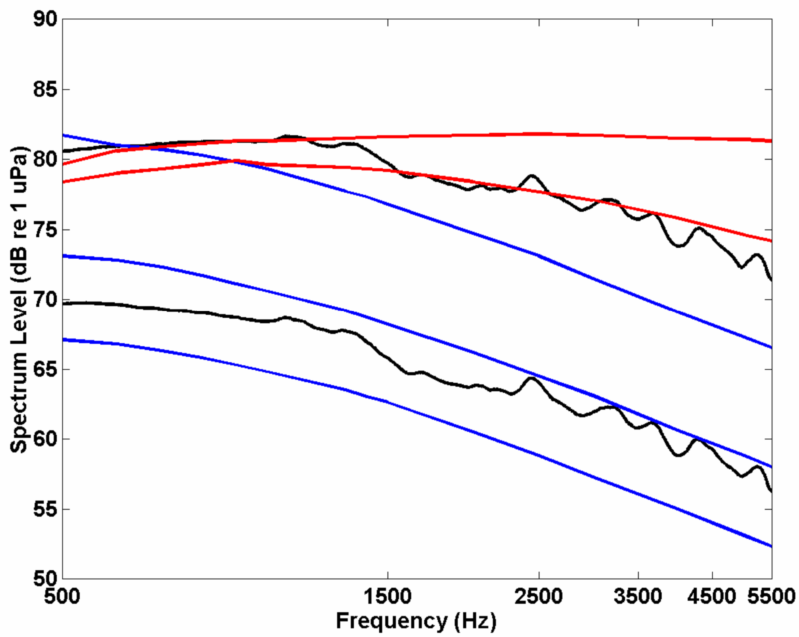

Fig. 6. Illustration of the ambient noise results for EARS 1 during Tropical Storm Isidore (black) compared to Wenz curves (blue) and rain curves (red).

the measured spectrum for the lower data curve agrees well with the slope and levels of the BWF 5 and 8 Wenz curves. The higher level data is well above the BWF 8 Wenz curve and in fact is above the upper limit of prevailing wind noise.

Also in Fig. 6 are the curves representing the noise levels expected from heavy [1] and moderately heavy precipitation [2]. The high level data clearly agree well with the Wenz curve for heavy precipitation for frequencies below about 1500 Hz. Above 1500 Hz the data diverge from the heavy precipitation curve and fall off in a manner similar to the Wenz wind curves although at highly elevated levels. This would seem to indicate that the noise is some combination of noise due to wind and rain.

Jeffrey Nystuen at the Applied Physics Laboratory University of Washington has developed a mathematical relationship between rainfall amounts and recorded noise levels [3, 4]. Table I displays the calculated rainfall amounts for the four bands based on the average noise levels of the bands. Rainfall amounts are displayed in mm/hour and in in/hour.

III. Summary

Ambient noise results in the frequency range of 1 kHz to 5 kHz from the LADC 2002 experiment during Hurricane Lili and Tropical Storm Isidore, with notable exceptions, are in good agreement with expected wind trends. They also agree well with the Wenz curves. The exceptions can be attributed to banding effects of the storms and are at least partially due to heavy precipitation.

Acknowledgment

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TABLE I
AVERAGE NOISE LEVELS FOR BANDS OF TROPICAL STORM ISIDORE COMPARED TO CALCULATED RAINFALL AMOUNTS.

Band	Average Noise SPL (dB)	Rain Rate (mm/hour)	Rain Rate (in/hour)
1	70.7	68.8	2.71
2	69.6	58.4	2.30
3	72.8	94.2	3.71
4	71.4	76.4	3.01

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