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Dynamic Ambient Noise Model (DANM) Evaluation Using Port Everglades Data

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14. ABSTRACT
Measured omnidirectional noise at a shallow water site near Port Everglades and radar tracks for local ships were used to evaluate a new ambient noise model, the Dynamic Ambient Noise Model (DANM), developed for use on board Navy systems. For four consecutive days of data, the daily means of the modeled noise levels were higher than the data. The most likely cause of mismatch was two factors associated with the ship sources. The first was the relative assignments of ship classes to the radar track vessels for input to the model. The vessels were assigned classes by speed with no means to discriminate between large vessels traveling at low speeds and recreational vessels that do not contribute significantly to the noise field. The second factor was the source level model within DANM, which is implemented with no speed dependence. A dependence was introduced into the model through the ships class assignments, but would be more properly implemented within the model itself, and may be necessary for accurate predictions near a port. The lack of speed-dependent source levels and the source level curves themselves may be the causes of the frequency dependence seen in the model/measurement mismatch. Model predictions with all radar vessels assigned to the minimum source level resulted in lower but better model/measurement agreement. This spread of about 10 dB in daily means with different source level assignments confirms that source level assignments for dynamic shipping are critical to accurate model predictions. There was frequency dependence to the mismatch, with the model matching better at higher frequencies. Shear propagation is unaccounted for in the propagation models used by DANM and is a likely source of error for this environment at the lower frequencies.

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CONTENTS

DYNAMIC AMBIENT NOISE MODEL (DANM) EVALUATION USING PORT EVERGLADES DATA

1. INTRODUCTION

The Dynamic Ambient Noise Model (DANM) developed by Planning Systems, Inc. under sponsorship of PEO(C41 and Space), PMW 155 (MetOC Systems) was submitted for inclusion in the Oceanographic Master Library (OAML) during 2002. This model/measurement study was conducted to evaluate the performance of DANM, Version 1.0, for a dynamic coastal environment, and to help guide the development of later versions of the model.

The evaluation consists of a comparison between measured data and DANM simulated data. The measured data provides omnidirectional noise levels and radar ship tracks for a week, with four days being used in this study. In the absence of any measured ship information, only statistical similarities can be expected between the model and measured noise levels. Since radar tracks are provided for this data set, the model is also being evaluated for predicting short time trends related to discrete ship numbers and locations. For the *statistical* evaluation, daily noise averages are computed. For the short-time *trend* comparisons, hourly noise averages are computed.

In Section 2, a description of the fundamental mechanics of DANM is provided. Section 3 describes the measured data set, including information on both radar track data and acoustic data. Section 4 presents the methodology and results for the model/measurement comparison. A detailed discussion of the study and resulting implications are given in Section 5. Finally, Section 6 presents conclusions.

2. NOISE MODEL (DANM)

DANM Version 1.0 produces an estimate of the ship-induced ambient noise at a specified receive location. The model must be provided with the transmission loss (TL) over a radial grid covering the area and a file containing either ship densities and/or discrete ship locations within a maximum range from the receive location. From this, DANM generates an average horizontal directionality, a time series of omnidirectional noise levels, and relevant statistics of the noise time series. DANM also calculates omnidirectional wind noise using either historical wind speeds or user-input values. More detail on the DANM model can be found in Hall (2001).

The radial TL grid provided to the model is used to estimate an individual receive level for each ship. To generate the radial grid of TL, azimuth is divided into evenly spaced angles, and the TL model is run from the receive point to a user-defined maximum range along each radial. The TL is interpolated and saved at evenly spaced range points along the radials (the default is 380 points per radial) and is assumed to represent adjacent areas centered on the points within the radial slice. Assuming that the requirements for reciprocity hold, each TL point represents the propagation from that point toward the receive location, and is used to calculate the receive level from a ship. TL for each ship between radials is found by interpolating in range along the nearest azimuth. DANM is currently configured to use either the

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ASTRAL model (Version 5.0) or the Parabolic Equation (PE Version 5.1) model for calculating the TL grid. PE 5.1 is configured to use the Range-Dependent Acoustic Model (RAMGEO 1.5). DANM automatically extracts bathymetry, sound speed, and geoacoustic parameters from Navy standard databases to build TL input files. The output from other TL models can be used in DANM by supplying it with a formatted TL file or linking the standalone executable code directly to DANM.

DANM calculates ship noise from both ship densities and discrete ships. Densities are appropriate representations for distant shipping and generally come from the Historical Interim Temporal Shipping (HITS) database, which has recently been revised and is available as the Historical Temporal Shipping Density Database (HITS 4.0) (Emery et al. 2001). Discrete ships are used to represent the dynamic local component of the ship noise, and are provided to DANM in the form of a file containing ship positions and classes. Discrete ships can be generated by the HITS Vessel Motion Simulation Model (HVMS 1.0) (Bradley and Emery 2001), which uses the HITS densities to populate and move ships along lanes and between ports. It can also be supplied through a properly formatted file containing radar or satellite data.

Each ship is assigned to one of five classes of vessels and each class is associated with a frequency-dependent source level function. The source level algorithm in DANM 1.0 is derived from the 1986 version of the Ambient Noise Directionality Estimation System (ANDES) model (Renner 1986). The source level functions for each class in the ANDES model have the same shape, differing only by scalar amounts. They represent source levels for a point source located at a depth of 6 m. An updated source level model is planned for DANM Version 2.0 (Wales and Heitmeyer 2002).

3. EARS DATA

The noise measurements used to evaluate the model were taken at 26° 01.55' N, 79° 59.08' W, a location 3 nmi east of the shore, just south of the Port Everglades Harbor. The data set was taken during September 2000 to support the Acoustic Observatory system of acoustic and environmental sensors planned for deployment in the area. The measurement location shown in Fig. 1 has a bottom depth of 258 m. Measured times for the acoustic and radar data are in Zulu, with local time being Zulu time minus 4 hours.

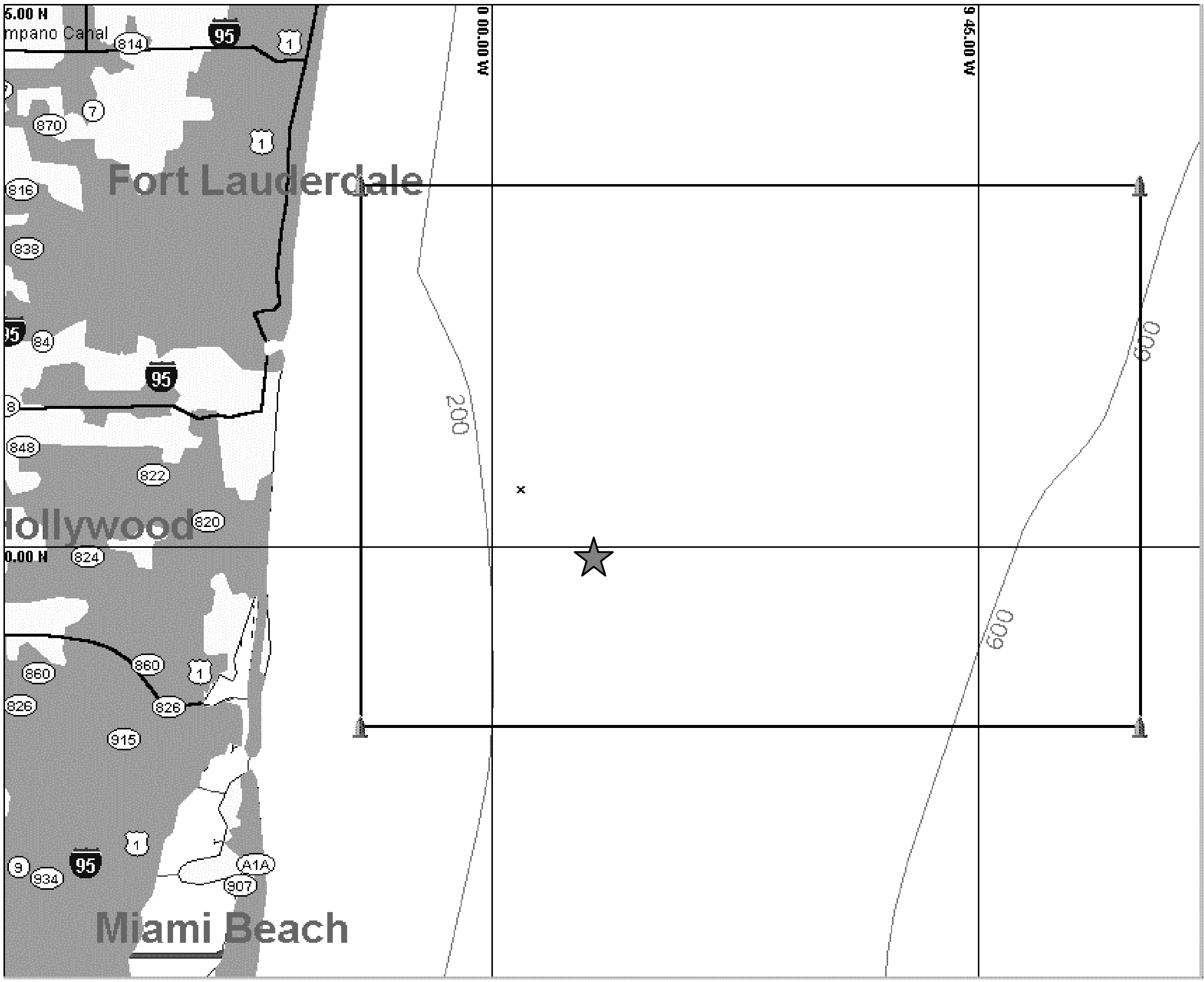


Fig. 1 — Measurement site and radar box

3.1 Environment

The measurement site is an oceanographically complex region characterized by proximity to the Florida current and occasional southward flowing fresh water current. The interaction creates meandering eddies and the strongly downward-refracting sound speed profile has a mixed layer from 20 to 100 m deep.

A low-frequency (0.5 to 12 kHz) chirp sonar track crossing the array location from west to east and bottom sediment samples were used to estimate the geoacoustics of the area. The bottom in the area was determined to have a thin 20 cm sandy sediment layer overlying bare rock and bare rock exposed in much of the area (Fulford 2002). The area east of the measurement location is primarily bare rock, while the area west of the array (inshore) is primarily sediment over rock.

3.2 Vessel Traffic

A vessel traffic survey was conducted using a Litton Marine Systems BridgeMaster E 250 radar interfaced with a Transas Marine Ltd. Navi-Harbor 3000 Vessel Traffic Monitoring System (VTMS). The radar was installed on top of the 31-story Points of America II building located on the north side of the

Port Everglades inlet. The survey began on September 18 at 0800 hours and ended on September 25 at 0800 hours. Radar contacts in a box defined by latitudes 25° 55'N and 26° 10'N and longitudes 79° 40'W and 80° 04'W were recorded. Each vessel that entered the radar box was assigned an identification number, and the vessel was tracked until it moved out of range even when outside the radar box. Information on tracked vessels included position, course, speed, and a tracking number, all stored at approximately 10-s intervals. The radar was manned at all times during the survey, and when possible, vessels were identified by name or classified according to type and length.

Traffic was heavier during the weekend, but Tuesday, September 18 also had very heavy traffic. The survey revealed the presence of three distinct transit routes: 1) an inshore North-South route, 2) an offshore North-South route, and 3) an East-West route. The inshore North-South route was approximately 6 to 8 nmi offshore and used by vessels to enter and exit the Port Everglades harbor. Vessels using the harbor included coastal freighters of approximately 300 to 500 ft, shallow draft tugs and barges, Coast Guard cutters, and numerous private craft. The offshore North-South route was approximately 16 to 20 nmi offshore and used almost exclusively by large commercial vessels (600 to 800 ft) such as freighters, tankers, bulk carriers, and deep draft tugs and barges. Most traffic along this route did not use the Port Everglades harbor; rather, they were seen using the Port of Miami as an origin or destination. The East-West route consisted of vessels traveling to and from the Bahamas. Traffic included small island freighters (180 to 250 ft), large motor yachts (80 to 200 ft) and medium size cruise ships (400 to 600 ft) that conduct daily transits to the islands. Commercial vessels tended to use one of the transit routes, whereas the smaller craft (fishing boats, sport fishing boasts, small motor yachts, sailboats, speedboats, and dive boats) did not. The fishing boats tended to congregate in several nontransit route locations, presumably searching for particular types of fish and generally not leaving sight of the shoreline.

A study of vessel locations revealed that the ship nearest to the measurement site was on average 1.5 nmi from the hydrophone. It was rare to have an hour where there was not a ship within 4 nmi.

Figure 2 shows daily traffic contacts for Thursday, Sept. 20 through Sunday, Sept. 23 in 100-m^2 cells. The radar box is also marked. A single contact is a radar-recorded ship location for a 10-s period. The maximum number of contacts shown in a cell is limited to 100 although thousands may have been present. The traffic is heavier on the weekend days (Days 22 and 23), and is particularly heavy on Saturday (Day 22), especially near the buoy location.

A statistical analysis vessel survey can be found in Thompson et al. (2002).

3.3 Acoustic Data

Acoustic data were recorded on an Environmental Acoustic Recording System (EARS) buoy with an omnidirectional hydrophone. The water depth at the measurement site was 258 m and the buoy was moored 20 m above the bottom. Noise between 10 Hz and 1010 Hz was recorded and sampled at a rate of 2246 Hz. For the model evaluation, sequential 512-point fast Fourier transforms were calculated and averaged to provide a 3-s average power spectrum estimate at 10-s intervals.

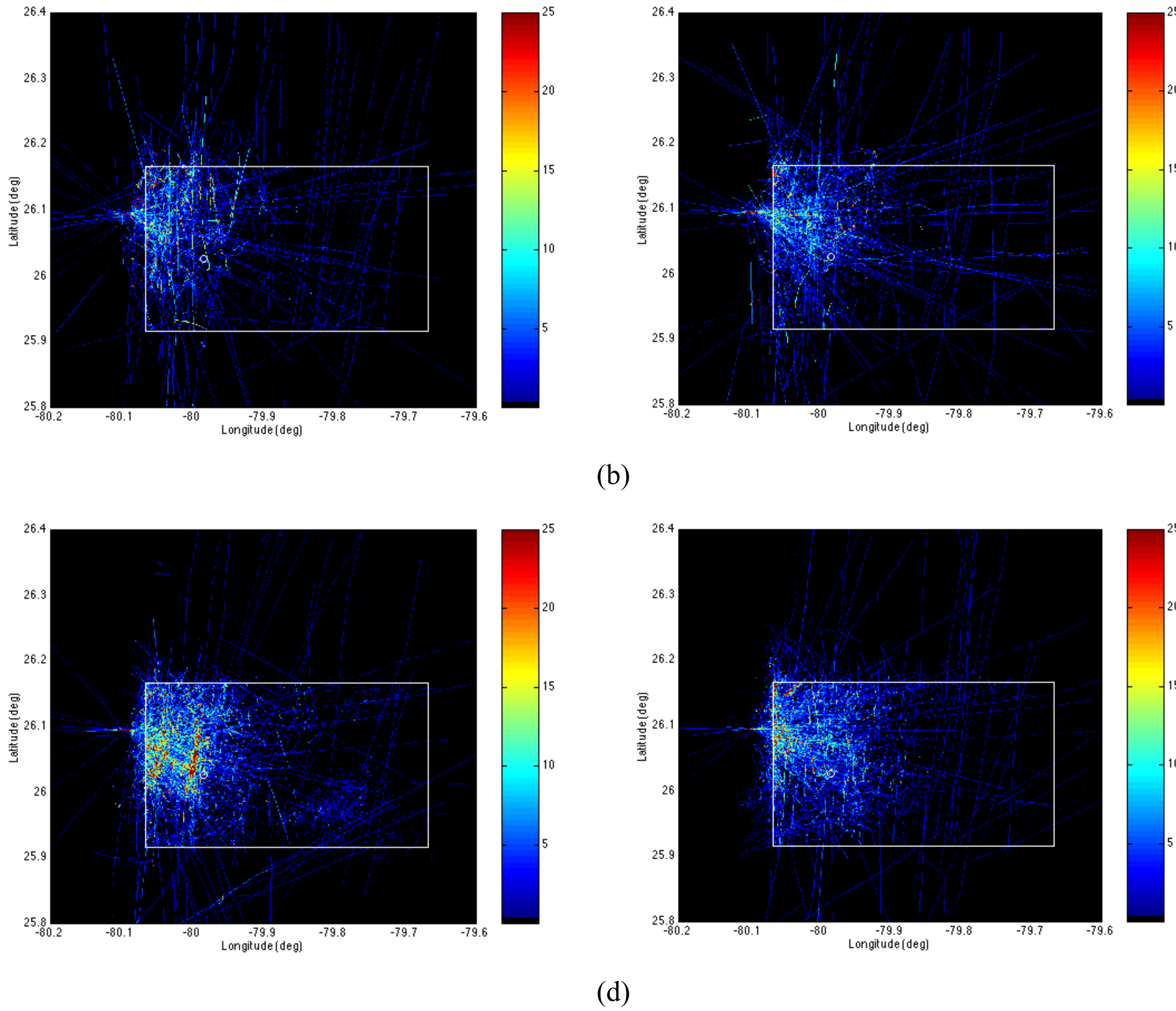


Fig. 2 — Radar contacts in 100-m^2 cells for four days of the survey: (a) Thursday, Day 20, (b) Friday, Day 21, (c) Saturday, Day 22, and (d) Sunday, Day 23

4. MODEL/MEASUREMENT COMPARISON

The primary goal of the model/measurement comparison was to evaluate the DANM capability for predicting the mean omnidirectional noise level over a period of hours or days. The EARS data provided DANM with an especially challenging situation. DANM is designed to provide statistical estimates of the noise, which result from the statistical distribution of the ships, ship source levels, and the propagation environment. In many deep-water locations, the statistical distribution of the ships is a primary determinant of noise prediction accuracy. The large number of ships, wide range of ship speeds within each ship class, and distant locations warrant use of a mean source level model. In shallow-water locations, the ship source levels are more important since nearby discrete ships can easily dominate the noise. The distribution of ships at the EARS site is known, but the source levels are not known. The variable sound speed at the measurement location was not measured, but is probably less important than the shipping information (Section 5).

The radar data provided ground truth for the ship distribution and tracks with some important caveats. First, the radar box did not extend all the way into the port so ships leaving the port were not tracked until they entered the box. Ships entering the port were tracked since they would have already been inside the radar box while approaching.

For simulations to compare to the measured data, the maximum range in DANM was set to 20 nmi, and the TL was calculated at a range resolution of about 0.5 nmi. The PE propagation model was used.

4.1 Ship Class Assignments

The radar was manned during the measurement, and ships were identified when possible. When identifications were noted, the ships were assigned a DANM class using Table 1. The five DANM source classes are

1 = supertanker
2 = large tanker
3 = merchant
4 = tanker
5 = fishing.

Table 1 — Source Level Classifications for Identified Radar Ships

RADAR TAG	SHIP TYPE	CLASS
BC	Bulk Cargo	4
BG	Barge	0
CC	Coast Guard Cutter	3
CF	Coastal Freighter	3
CN	Container Ship	3
CS	Cruise Ship	3
DB	Dive Boat	5
DG	Dredge	5
FB	Fishing Boat	5
FR	Freighter	3
MC	Merchant Ship	3
MY	Motor Yacht	5
PB	Power Boat/Speedboat	0
PL	Port Pilot	5
RIB	Rigid Inflatable Boat	0
RO	Roll-on/Roll-off	3
SB	Sailboat	0
SF	Sport Fishing Boat	5
TG	Tug Boat	5
TK	Tanker	2
TP	Tug Pushing Barge	5
TT	Tug and Tow	5

Assignments in the table were based on recommendations by an expert in the area for ships at cruising speed. Ships are also assumed to be at cruising speed in the DANM source level model (Wales 2002). Powerboats, speedboats, and sailboats under motor were assigned a zero source level since they sit high in the water and the noise they produce undergoes considerable surface interaction. When no identification of a vessel was noted, the current speed was used to assign a class based on a simplification of the algorithm used in the RANDI model and Ross source level model with assignments shown in Table 2 (Breeding et al. 1996; Ross 1987). The source level model in DANM is independent of speed, although varying the source level class introduced a minor speed dependence. Although occasional supertankers are expected in the area, no ships were assigned that classification since a supertanker would likely have been identified as such, and unidentified high-speed vessels were more likely to be powerboats than supertankers.

Table 2 — Source Level Classifications by Speed

Class	**Speed**
Supertanker	18 - 22
Large Tanker	15 – 18
Merchant	12 – 16
Tanker	10 – 15
Fishing	7 - 10

4.2 Model Predictions Using Ship Densities

As a baseline, the HITS densities alone are used in the DANM simulation and compared to the four-day average noise level of the EARS data. HITS densities for the area are shown in Fig. 3. Note that this version of HITS does not contain shipping for the Port Everglades harbor.

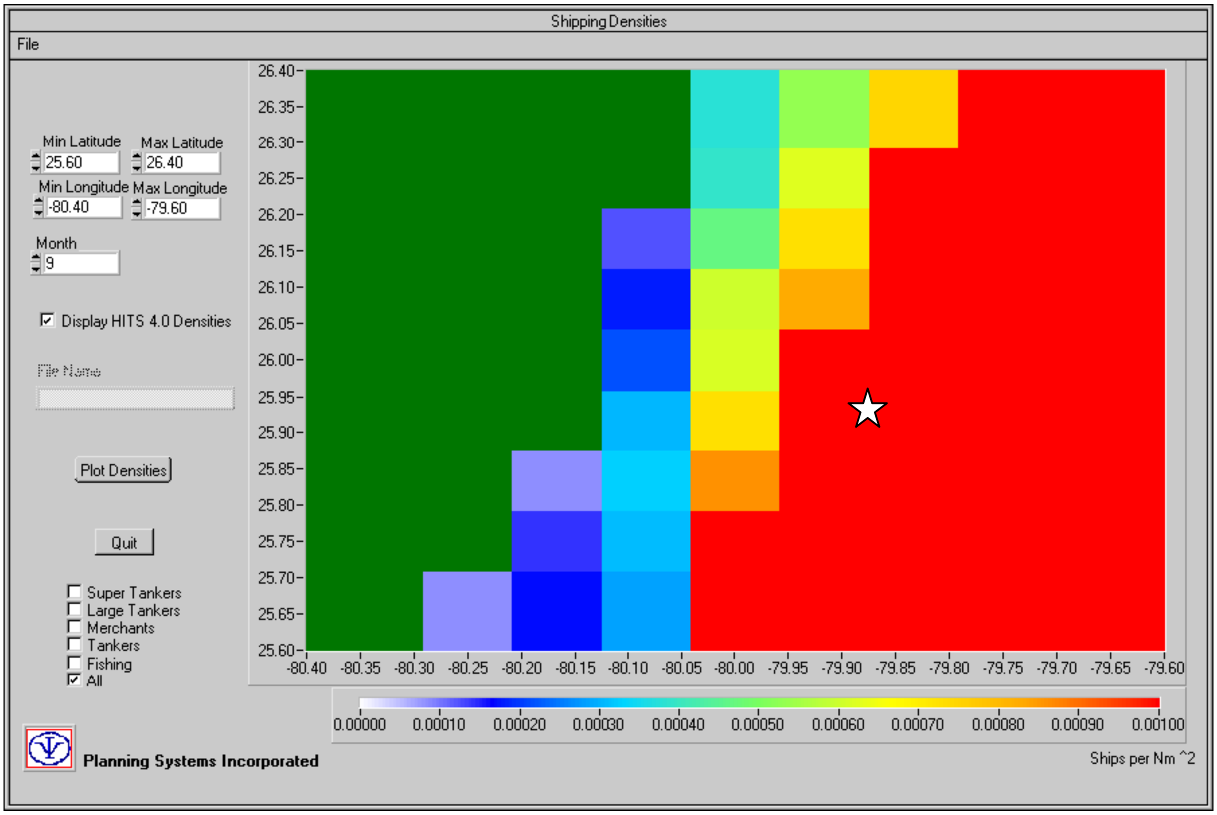


Fig. 3 — HITS densities for the measurement area. The star denotes the buoy location.

Table 3 shows the results of the model measurement comparison along with the DANM noise level for a historical wind speed of 11.3 kn. For this calculation, the HITS densities to a range of 1200 nmi were included, and the range resolution for the TL model (PE) was 1 to 3 nmi. The DANM results are too high at lower frequencies, with the mismatch decreasing at higher frequencies. The HITS shipping density contains far fewer ships than are actually present at the measurement site, and the model should be producing levels that are lower than the measurements. The number of ships derived from the HITS database at any instant in the 0 to 20 nmi radius are 0.01, 0.91, 1.5, 0.31, and 0.17 for supertankers, large tankers, merchants, tankers, and fishing vessels, respectively. The radar data showed that the number of ships actually present was rarely that low, even during the quietest times.

Table 3 — Omnidirectional Source Levels Predicted by DANM for HITS Shipping and Wind

Freq (Hz)	DANM/HITS Noise Level (dB) 0-1200 nmi	DANM/HITS Noise Level (dB) 20-1200 nmi	EARS Noise Level (dB)	DANM Wind Noise Level (dB)
50	87.4	80.8	80.5	59.5
100	79.5	70.4	74.7	60.6
150	76.0	65.7	72.1	61.1
250	69.3	62.4	69.9	61.8
400	64.7	62.2	67.9	62.2

A second calculation excluding HITS ships within the 0 to 20 nmi radius about the buoy produced levels that were small compared to the discrete ship generated levels for most frequencies (see Table 3).

Since numerous ships were always present within the discrete limit during the measurement, the HITS-generated noise levels from shipping was not included in the DANM results beyond here.

4.3 Model Predictions Using Dynamic Ships

For comparison of the measured noise and model using dynamic ships from radar data, daily noise averages were calculated. The results are presented in Table 4. As expected for ship noise, both the EARS and DANM daily noise levels decrease with increasing frequency. Table 5 shows the corresponding dB differences between the measured and modeled averages, with positive differences indicating that the model noise level is higher than the measured level.

Table 4 — Measured (EARS) and Modeled (DANM) Daily Noise Levels in dB

Frequency (Hz)	**Day 20**		**Day 21**		**Day 22**		**Day 23**	
	EARS	**DANM**	**EARS**	**DANM**	**EARS**	**DANM**	**EARS**	**DANM**
50	82.5	89.1	84.0	92.3	78.3	83.0	77.0	81.7
100	76.9	84.7	77.9	87.3	72.4	78.5	71.9	77.6
150	73.8	81.0	75.0	82.9	70.2	75.1	69.2	74.3
250	71.9	76.1	72.3	77.4	68.6	70.3	66.9	69.8
400	70.1	70.5	70.6	71.3	66.1	65.1	64.8	64.9

Table 5 — Differences Between DANM and EARS Daily Noise Levels in dB

Frequency (Hz)	**Day 20**	**Day 21**	**Day 22**	**Day 23**
50	6.6	8.3	4.6	4.7
100	7.8	9.4	6.1	5.8
150	7.2	7.9	4.9	5.1
250	4.2	5.0	1.7	2.9
400	0.4	0.7	-1.0	0.1

There is a definite trend of the model noise levels being higher on average than the measured noise levels, and the discrepancy between the model and measured results are larger at lower frequencies. The discrepancy is also larger on the weekdays than on the weekend. Figure 4 depicts the results displayed in Table 4.

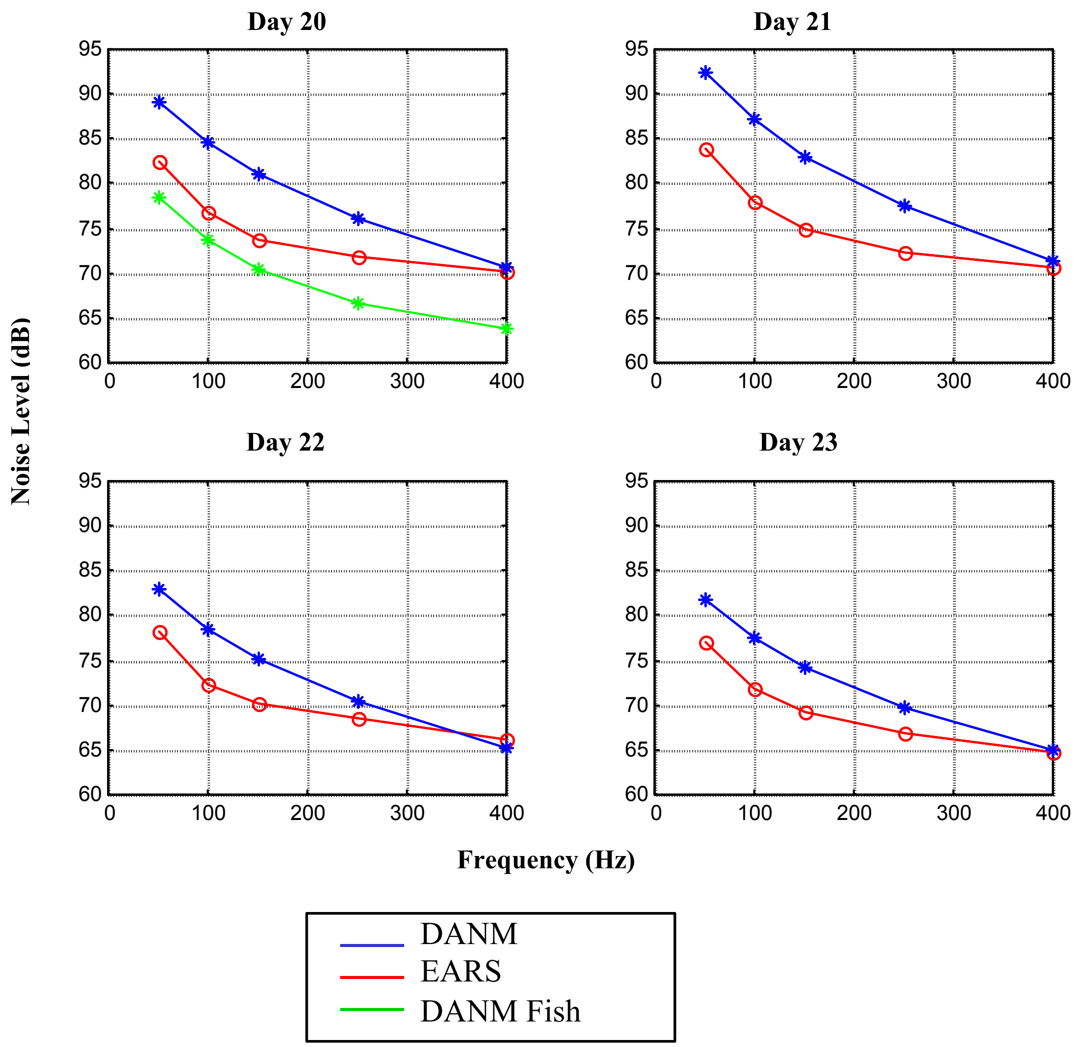


Fig. 4 — Mean omnidirectional levels for the model and measurements

Appendix A provides graphs of the daily measured and modeled noise levels for each of the 24-h periods and for each frequency. On the two weekdays, there are more quiet periods than on the two weekend days, which have much higher vessel activity. During the hours of from 700 to 1230 (Zulu time) on the weekdays, the noise is at its highest average level, with few, if any, lulls. On the weekend days, this peak extends until about 1700. On the weekdays, the model and data noise levels match best over this time period of sustained high noise (see Appendix A, Figs. A1 and A2). On the weekends, the model and data match well for about the first 2.5 h of this period, but then the model rises well above the data corresponding to a large increase of active vessels in the area, as shown in Fig. 5. The mismatch between model and data during the period from 1030 to 1700 is fairly constant, at about 5 dB for 400 Hz, and growing as frequency decreases to about 20 dB at 50 Hz. The number of ships increases on the weekdays after 1230 and the model and data diverge here as well. The model noise level rises with the number of ships, but there are likely a large number of recreational vessels during these times that are not actually contributing to the noise. This indicates that misclassification of ships and their corresponding source levels may be a significant contributor to the discrepancy between model and measured noise.

Even though there is less model/measurement discrepancy during midday on the weekdays, the differences between the daily means are higher on those days than on the weekend (Table 5). The reason is seen in the hourly means plotted in Appendix B, which show the model producing consistently higher levels than the data before and after midday on the weekdays. On the weekends, the model is closer to the data for more time periods.

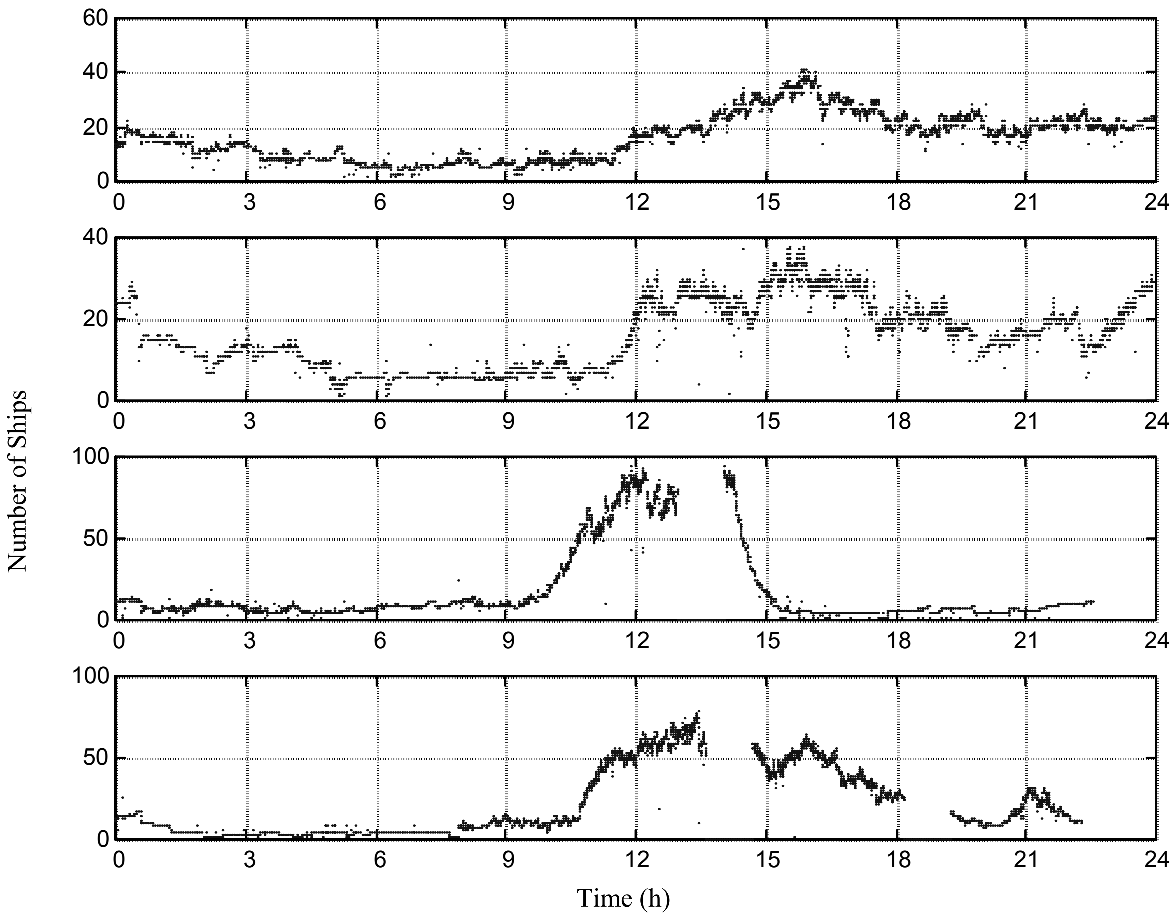
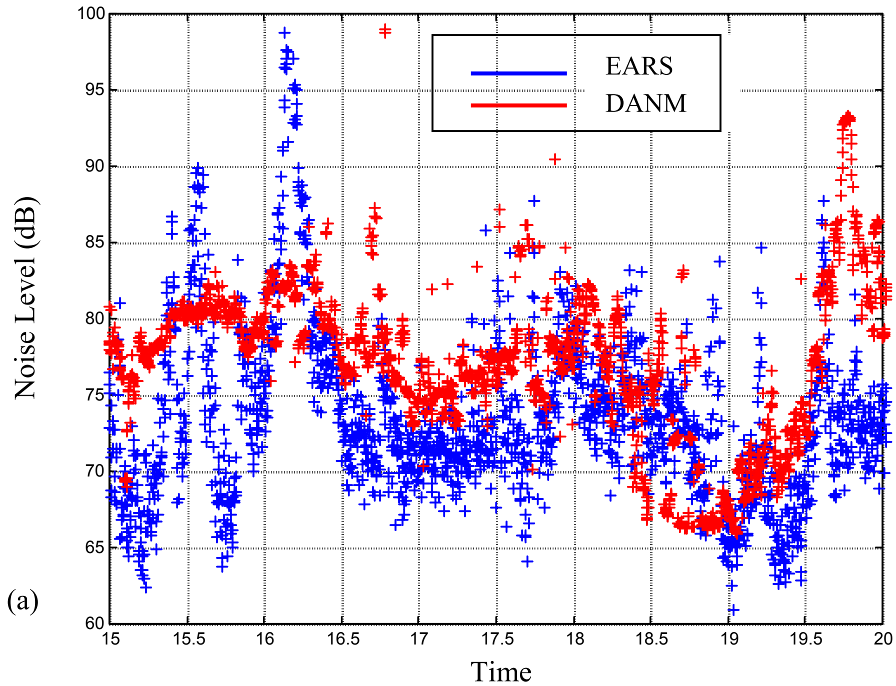


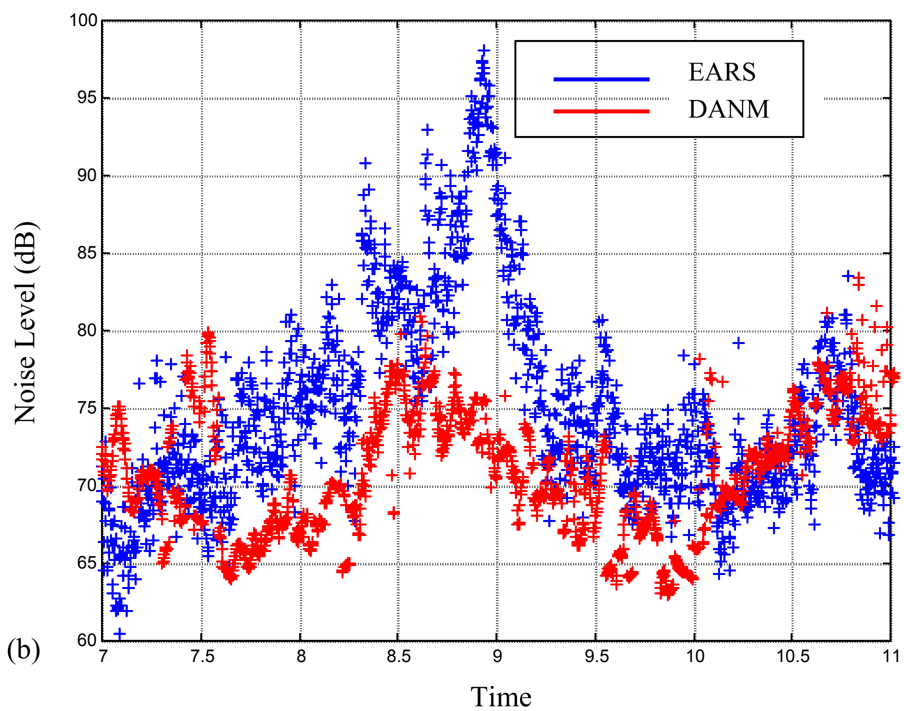
Fig. 5 — Number of ships included in the DANM noise predictions for each day

From the figures in Appendix A, one can see that the peaks and troughs in the model and data do not generally match, although there are some time periods when the model and measurement trends compare well. These usually are when the model noise levels are not much higher than the EARS levels. For example, Fig. 6(a) contains a close-up of the model and measured data for Day 21, Hours 15 to 20 at 250 Hz. Here, the model tracks the measurement as it dips twice, but misses the peaks at 15.5 and 16.2. Then for Day 22, Hours 7 to 11 at 400 Hz (Fig. 6(b)), the model level tracks the measured level as it rises over Hours 8 and 9, drops to a minimum near Hour 10, and rises again over the next hour. Again, the model misses the strong peak in the data times 8.5 to 9.0.

The third example in Fig. 6(c) shows the model and data agreeing well for the first three hours except for a data peak between times 1.0 and 1.5. Between times 3.5 and 4.0, the model produces excessively high noise levels related to a ship that begins and ends moving only during that time and obviously has been assigned a source level that is too high (class 3). The model misses the data peak near time 5.3, but matches the 95 dB and 85 dB peaks just before and after quite well. The 95 dB peak appears suddenly in the model when an additional radar ship is added to the calculation. In this time period, there are only three or four ships on the radar that are being used in the model calculations. The numbers of ships increase to over 10 ships in Hour 7 and continue increasing to over 60 during the 10- to 20-h period when the modeled noise is consistently higher than the data.



(a)



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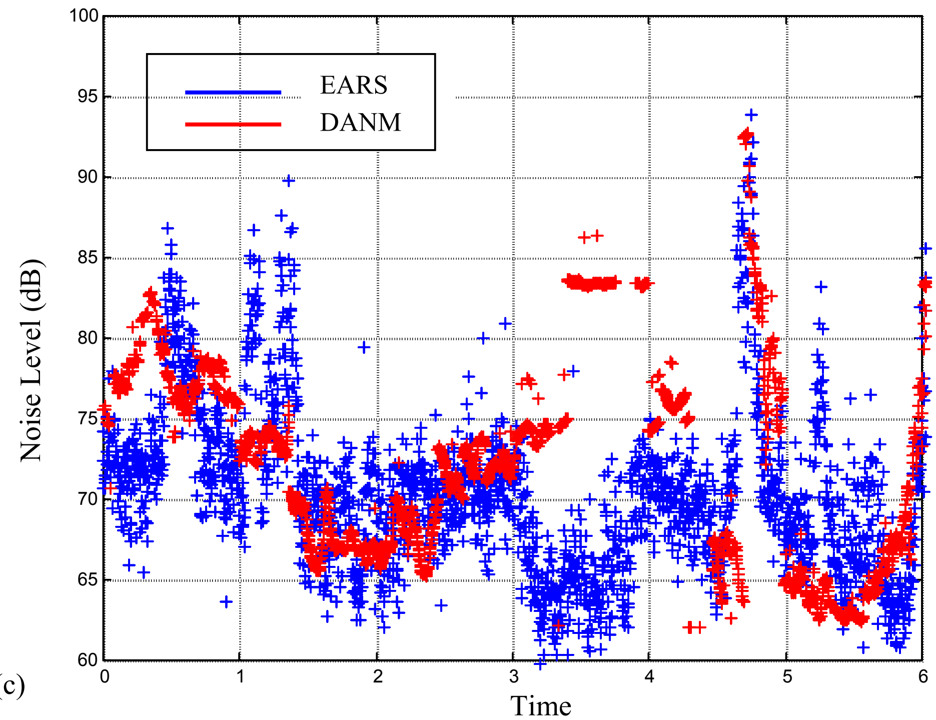

(c)

Fig. 6 — DANM and EARS noise levels for (a) Day 21, Hours 15 to 20 at 250 Hz, (b) Day 22, Hours 7 to 11 at 400 Hz, and (c) Day 23, Hours 0 to 6 at 250 Hz

4.4 Noise Level Variability

Variation in the measured noise levels over time come from both ships and the environment, but in the model only from the ships. The variation in ship location is the primary source of variability in DANM simulations of noise, with minimal source level changes related to speed introduced through ship classification in this study. Since the model cannot include all the variability in a real environment, one expects the standard deviation to be less than that of the measured data. For Days 20, 21, and 22 that is the case, as shown by the standard deviations of daily noise levels for both the EARS data and the DANM simulations presented in Table 6. For Days 20 and 21, the model did not often reproduce the significant rises seen in the data and the model standard deviation is more than 2 dB lower than that of the data. They are closer for Day 22. In contrast, the DANM standard deviations are higher than those of the data for Day 23. On this day, the measured noise level varied less than on other days, and the model varied more than on other days, possibly due to inaccurate or inconsistent source classifications, a problem discussed in the following section.

Table 6 — Standard Deviation of DANM and EARS Daily Noise Levels in dB

Frequency (Hz)	**Day 20**		**Day 21**		**Day 22**		**Day 23**	
	EARS	**DANM**	**EARS**	**DANM**	**EARS**	**DANM**	**EARS**	**DANM**
50	7.3	5.1	7.7	5.0	8.6	6.8	6.8	8.4
100	7.9	5.1	7.5	5.1	7.9	6.9	6.4	8.3
150	7.5	5.3	7.3	4.8	7.9	6.8	6.5	7.8
250	7.3	5.4	7.0	5.0	7.4	7.3	6.3	7.7
400	6.8	4.8	7.2	4.4	6.7	6.1	6.1	6.5

For completeness, probability distribution functions (PDFs) for the EARS data and DANM model are shown in Appendix C (Figs. C1 through C4) for each of the four days. The PDFs are calculated for deviations from the mean omnidirectional level. The skewness and kurtosis are also given in Appendix C (Tables C1 and C2).

At the higher frequencies, the EARs levels occasionally fall below the simulated wind noise level. The wind noise basement was not included in the standard deviation or PDF calculation of the model levels since a few of the higher frequency model statistics are artificially skewed by the single wind-generated level, and it is unlikely that the data is ever limited by the wind noise. In general, the DANM PDFs are more symmetric than the data PDFs, having smaller skewness. The DANM PDFs also have smaller absolute values of kurtosis, being more consistent with a Gaussian distribution than the data.

5. DISCUSSION

In an effort to discover why the model noise levels tend to be higher than the measured levels, several components of DANM and its inputs were investigated. In-depth studies were performed for two hours of low ship traffic, Day 90, Hours 10 and 12. Hour 10 was of particular interest since the ship traffic had two notable features. A port pilot very near the array started moving about 35 minutes into the hour and corresponded to an increase in the measured noise level at that time. Also, a Coast Guard cutter, the Mohawk, moving steadily south toward the buoy, stopped for several minutes during the later part of the hour. A corresponding drop in the noise was visible in the acoustic data (see Fig. 7 for a depiction of the nearby ships and Fig. 8 for the measured data). Conclusions for Hour 12 were the same as for Hour 10, so only Hour 10 results are shown.

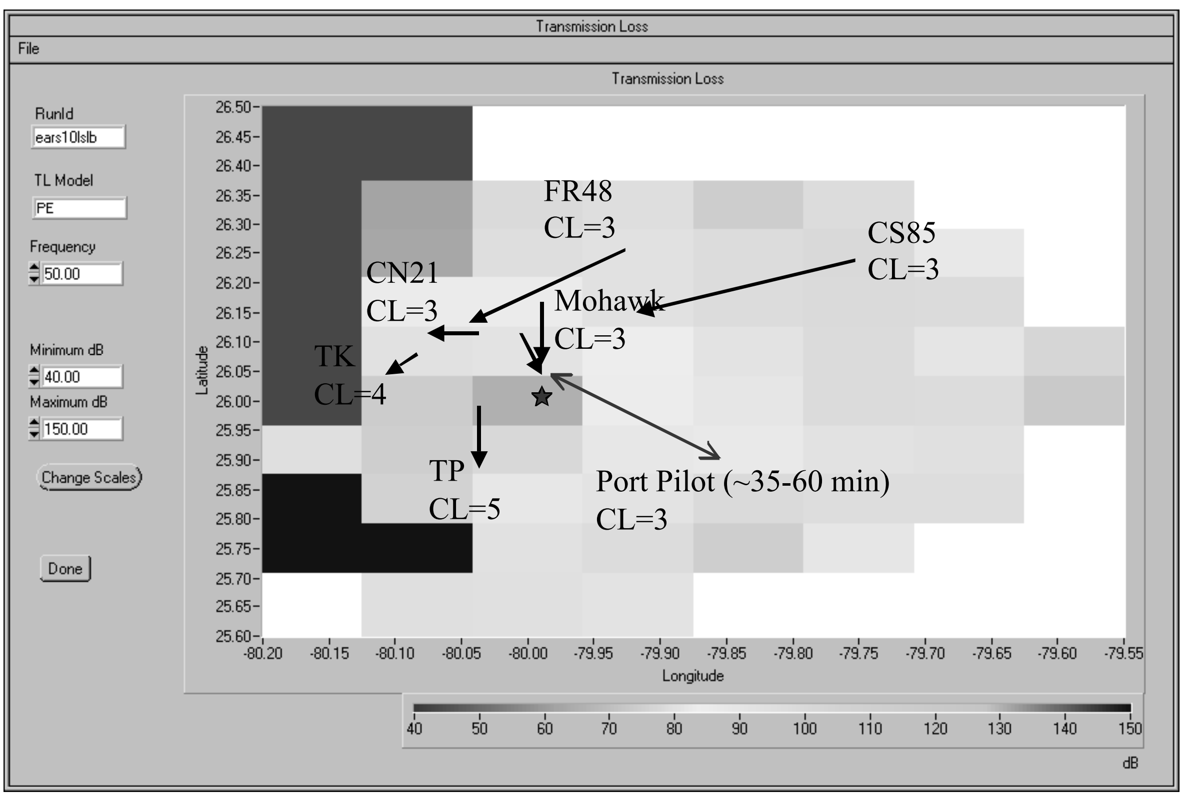

Fig. 7 — Day 20, Hour 10 radar ships on DANM TL plot for 50 Hz (plotting resolution for the TL is 5 min). CL is the original vessel class assignment for the ships.

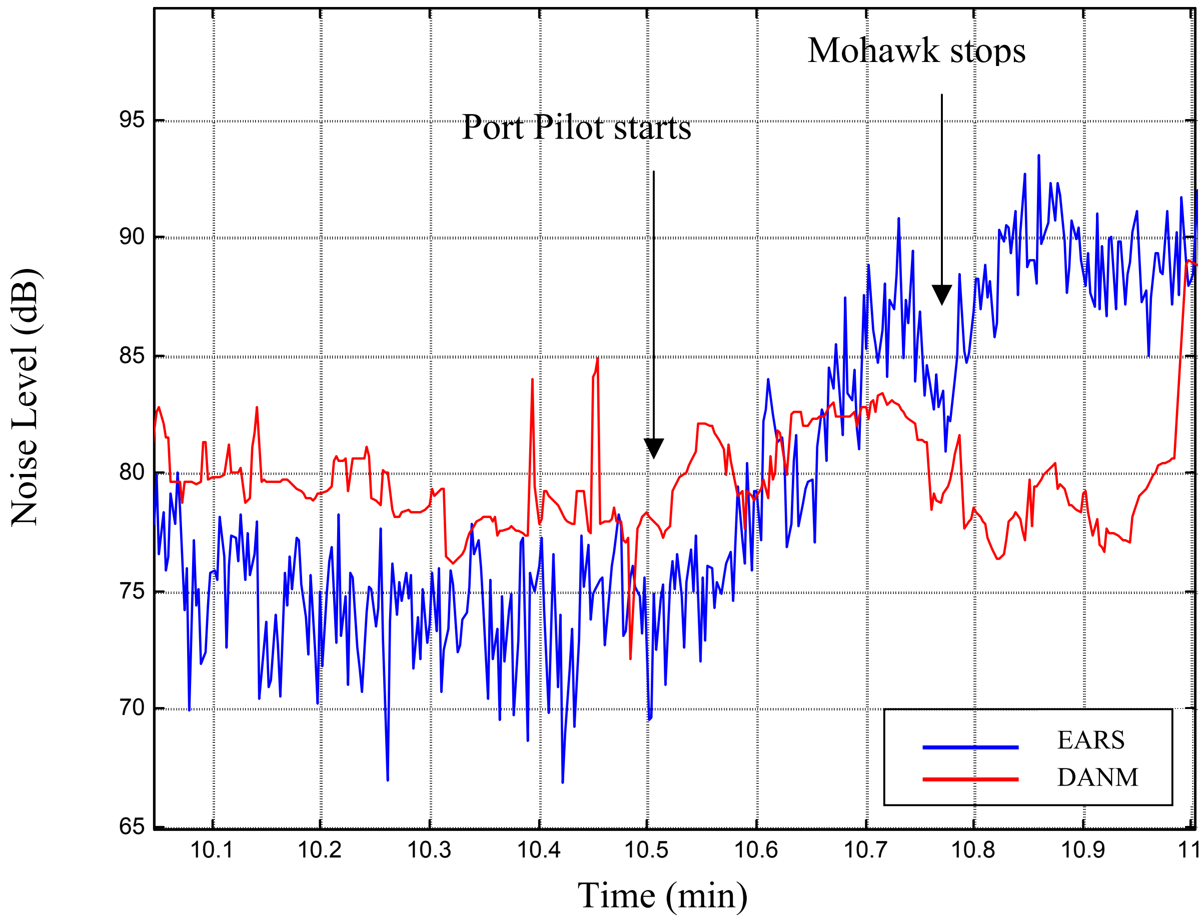

Fig. 8 — Measured data for Day 20, Hour 10, frequency 150 Hz

5.1 Propagation Models/Parameters

DANM automatically sets the TL resolution in range to the maximum range of the radial divided by 398. For the HITS density calculation of distant shipping, the resolution was approximately 1 to 3 nmi. Initially this same TL calculation was used for the local discrete shipping. A separate TL calculation was done with a maximum range of 20 nmi and range resolution of approximately 0.1 nmi. For Day 20, Hour 10, the noise level results did not change significantly on average over the hour (less than 0.76 dB for all frequencies; see Table 7).

The PE model is expected to be more accurate (but slower) than ASTRAL for highly variable environments and was used for all the simulations in this study. A comparison of noise levels for Hour 10 using the two propagation models showed less than 2 dB difference on average except for 100 Hz, which had an average difference of 3.29 dB for Hour 10 (the differences were larger, but all less than 2.7 dB for Hour 12).

The speed dial setting is a feature of the propagation model PE 5.1. It controls the depth and range steps used by RAMGEO and thus determines the how fast the PE will run. The PE has a default setting of 5 for the speed dial parameter. This corresponds to the recommended range step of

$$\Delta r \;=\; 17\lambda \;=\; 17C_o / f$$

and depth step of

$$\Delta z \;=\; \lambda / 4.5 \;=\; C_o / (4.5 f)$$

for balancing accuracy requirements with speed. Although not an option in DANM, the speed dial setting was set to 1 to determine if the range and depth settings in PE were sufficiently small to give accurate results in this environment. The speed dial setting of 1 corresponds to $\Delta r = 1.25\lambda$ and $\Delta z = \lambda / 3$. There were differences of 1.61 to 3.47 dB for the various frequencies with the noise levels being higher for 50, 250, and 400 Hz and lower for 100 and 150 Hz in Hour 10. The lack of a pattern was also seen in Hour 12, so changing the speed dial was not expected to account for the consistent trend of higher model than measured noise levels seen throughout the four-day study.

As a side note, the differences using the PE speed dial settings are related to the particular bottom parameters in the database for this location. The high angle settings in PE are inconsistent with the method used to derive the bottom parameters from data (loss vs angle), confirmed by comparison of results using two bottom database interpretation algorithms in PE 5.1.

Table 7 — Absolute Average dB Differences Between EARS and DANM Noise Levels for Hour 10 Using Various Propagation Configurations

Frequency (Hz)	PE Large vs Small Range Resolution	PE vs ASTRAL	PE Speed Dial 7 vs 1
50	0.41	1.14	3.47
100	0.22	3.29	2.79
150	0.76	1.55	1.61
250	0.74	1.86	3.30
400	0.35	1.74	1.86

5.2 Environment Mismatch

The measurement area is one where the sound speed varies considerably over time and space due to meandering eddies generated by local currents. The profile during September is strongly downward refracting with significant changes occurring in the sound speed minimum and the depth of the mixed layer. Measured sound speed profiles were not available, but historical data from the Master Oceanographic Database (MOODS) shown in Fig. 9 are probably a fair representative. There are 23 profiles bounded by latitudes 25° 31.8'N and 25° 45.0'N, and longitudes 80° 3.0'W and –79° 40.2'W. Range-independent propagation simulations for the EARS buoy site and a selection of MOODS profiles spanning the set in Fig. 9 produced only a few dB difference out to 20 nmi with variation in the depth of the mixed layer for the profile used in the DANM calculations (shown by the bold curve in the figure). Strengthening the downward-refracting nature of the sound speed profile to the extreme shown in Fig. 9 produced a decrease in TL of 7 dB at 10 nmi and 10 dB at 20 nmi. Thus, the sound speed used in the DANM calculations could be a source of error; however, the tendency would be to push the DANM noise levels even higher.

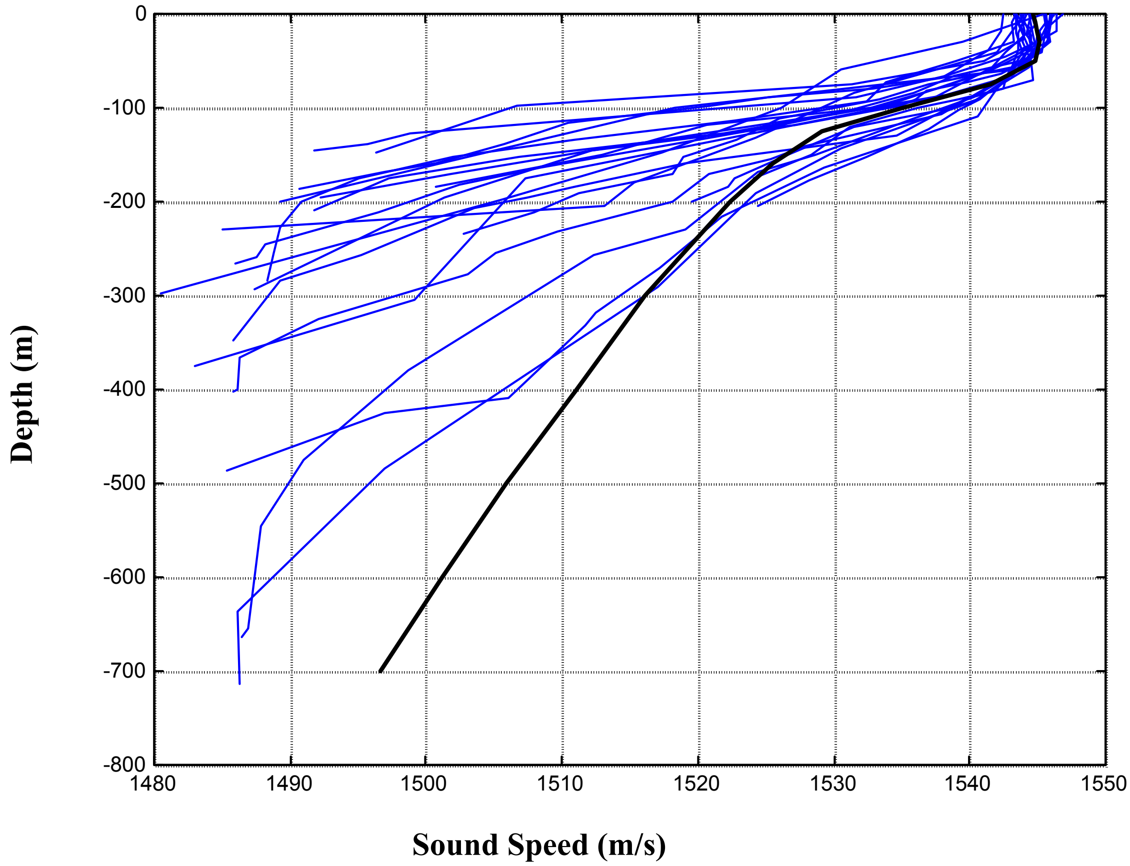

Fig. 9 — MOODS historical sound speed profiles and DANM database sound speed profile (bold curve) for the EARS buoy site

With the downward-refracting sound speed profile, much energy is directed to the bottom, making the geoacoustic parameters important for this site. Comparisons between the database parameters used in DANM and the chirp-sonar estimates for the range-independent TL calculations are shown in Fig. 10. The propagation was calculated for four frequencies. Results using both the bare rock bottom (which occurs mostly east of the site) and the sediment over bare rock (which occurs mostly west of the site) are compared to those using the DANM bottom. Significant differences are seen between the two chirp-sonar determined bottoms for all but the 400 Hz case with the sediment layer over rock causing more loss than the bare rock model. The DANM bottom gives results very similar to the sediment over rock bottom except for the 400 Hz case. Since the majority of ships are located near and inshore of the buoy, the DANM bottom is probably a good representation for 50 to 250 Hz in this area. In the 400 Hz case, changing the DANM bottom to the measured bottom would decrease the loss and make the DANM noise levels higher and further from the measured levels.

Calculations using the RAMGEO model with shear indicate that at the lower frequencies (< 150 Hz), the TL over the sediment areas should be higher. This may account for discrepancies between the model and measurements at these frequencies. Unfortunately, the RAMGEO shear model is not well suited to automated calculation as required by DANM, due to potential numerical instabilities.

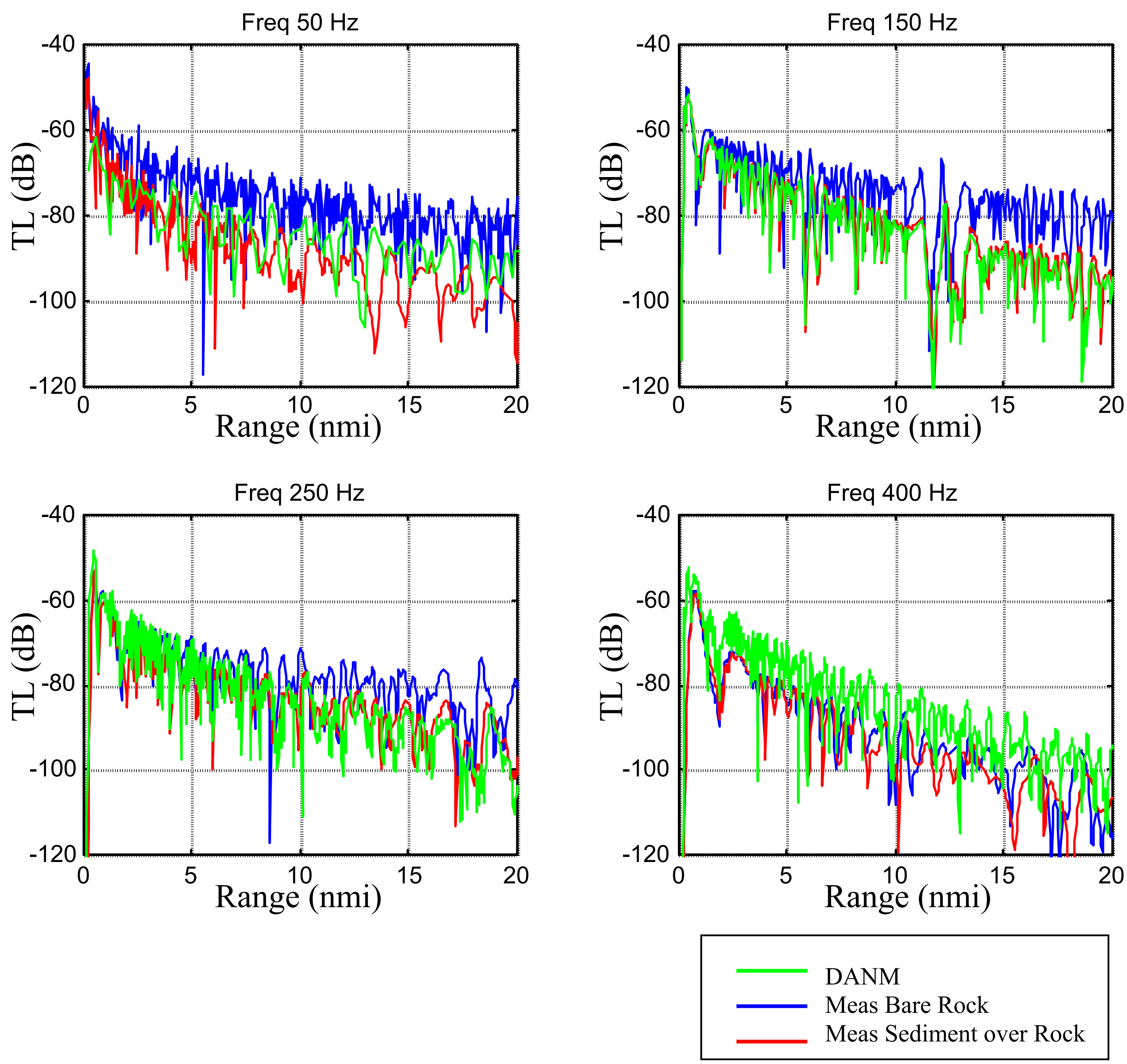

Fig. 10 — TL for a range-independent environment at the EARS buoy location using geoacoustic parameters from the DANM database and the two chirp-sonar derived parameters sets

5.3 Source Parameters

The most likely source of mismatch between the model and measured noise levels is the source level of the ships. There are two sources of error: the first is the assignment of vessel classes to the radar ships, and the second is the actual source level model for the five classes.

In-depth modeling for Day 20, Hour 10 illustrated the difficulty of assigning relative source levels to nearby ships. Based on the acoustic and radar data, it seemed that the Port Pilot and Mohawk were the dominant ship sources for 35 to 60 minutes. The original source level assignments to the other nearby ships, shown in Fig. 10, had both ships classified as merchants (class 3), which would make them not only the closest ships but two of the loudest ships. With these settings, however, the DANM model failed to generate the approximate 10-dB rise seen in the measured data. A variety of simulations with various source level combinations for the nearby ships were performed, but none came close to matching the rising trend in the measurement. Assigning the Port Pilot and Mohawk vessel classifications of merchants (class 3) and reducing the source levels of the remaining ships to fishing (class 5) produced a minor rise near the 35-min point, but far from the 10-dB change in the data. Although propagation may play a role in the problems with modeling this hour of data, the relative source level assignments and source levels themselves are certainly major contributors.

One issue in assigning source levels that may influence the predictions is speed dependence for individual ships. DANM 1.0 assigns a mean source speed to each ship. Near a harbor, not all ships are traveling at cruising speed, and in fact, many change speed. Speed dependence was introduced into the simulations done here to include speed in that each unidentified ship was assigned one of the five source classes based on its current speed. That is, a single ship could change its classification as it sped up or slowed down. Adding speed dependence to the DANM source level for the discrete ship calculations may improve its performance.

An additional model simulation was done for Day 20 in which all ships were assigned a fishing vessel source level. The modeled and measured data for this case are shown in Fig. A5, and the mean daily noise levels are in Table 8. The mean levels are also shown in Fig. 4. The model levels are much reduced from those using the original source classifications (Table 5) and in fact, are on average lower than the measured data. This illustrates the large impact source level classification has on the noise at this site. Of particular interest is that the trends in the model match those in the data better for the first 7 h when the source level classes are all fishing. In contrast, a correctly modeled peaked near the 20-h point with the original source level assignments is no longer present with the fishing-only source level assignments. This exercise indicates that improper source level assignments are a significant cause of incorrect model predictions.

Table 8 — DANM Noise Level and Mismatch Between DANM and EARS Noise Levels in dB for Day 20 and Minimum Source Levels

Frequency (Hz)	DANM Noise Level	EARS/DANM Mismatch
50	78.5	-4.0
100	73.8	-3.1
150	70.5	-3.3
250	66.7	-5.2
400	63.8	-6.3

Figures 11 and 12 further illustrate the strong influence of ship classification on the model results. The figures contain two different model results for Day 21, Hour 4. Figure 11 compares the measured data with model results using the original speed-based ship classifications described in Section 4.1, and also with a model result with all ship classifications set to that of fishing vessels. Whereas the original model result is much too high at all but the measured peak near 0.65 to 0.70 h, the all-fishing model result is about 15 dB lower and near or below the measured levels. Figure 12 shows the same results except the all-fishing result is replaced by a model result where particular ships were designated as merchants. The model now matches the measurement quite well over most of the hour, tracking the shape and magnitude of peaks in the measured data at 0.30 and 0.62 h. It is impossible to know if all the ship classifications have been set correctly, but certainly this exercise illustrates that a suitable classification exists and accounts for trends and levels in the measured noise levels.

Also, the source models currently in DANM are for source depths of 6 m. The source depth was chosen to produce correct source levels for ships at a distance. For smaller vessels and vessels near the receiver, a more appropriate shallower source depth would produce lower source levels, and perhaps give more accurate model predictions.

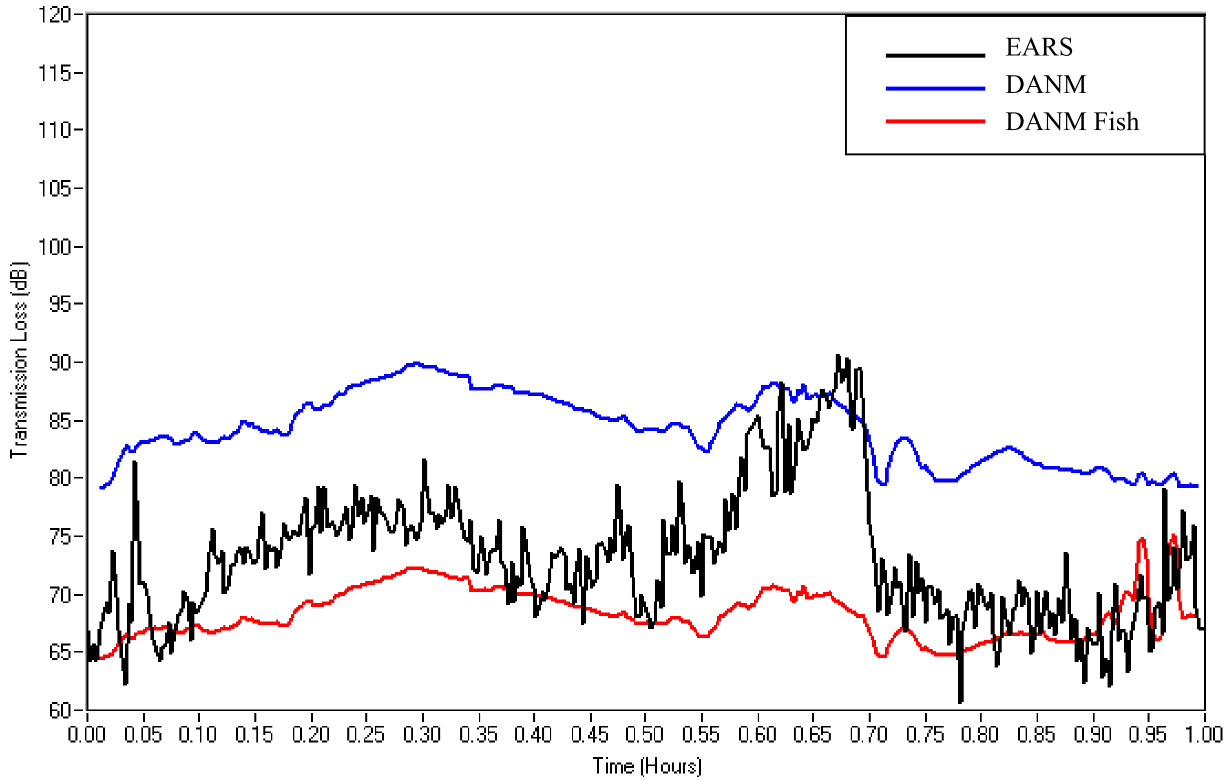

Fig. 11 — Model and measured omnidirectional levels for Day 21, Hour 4 at 250 Hz. The blue curve represents the model results for the original radar ship classifications. The red curve represents the model results with all ships classified as fishing vessels.

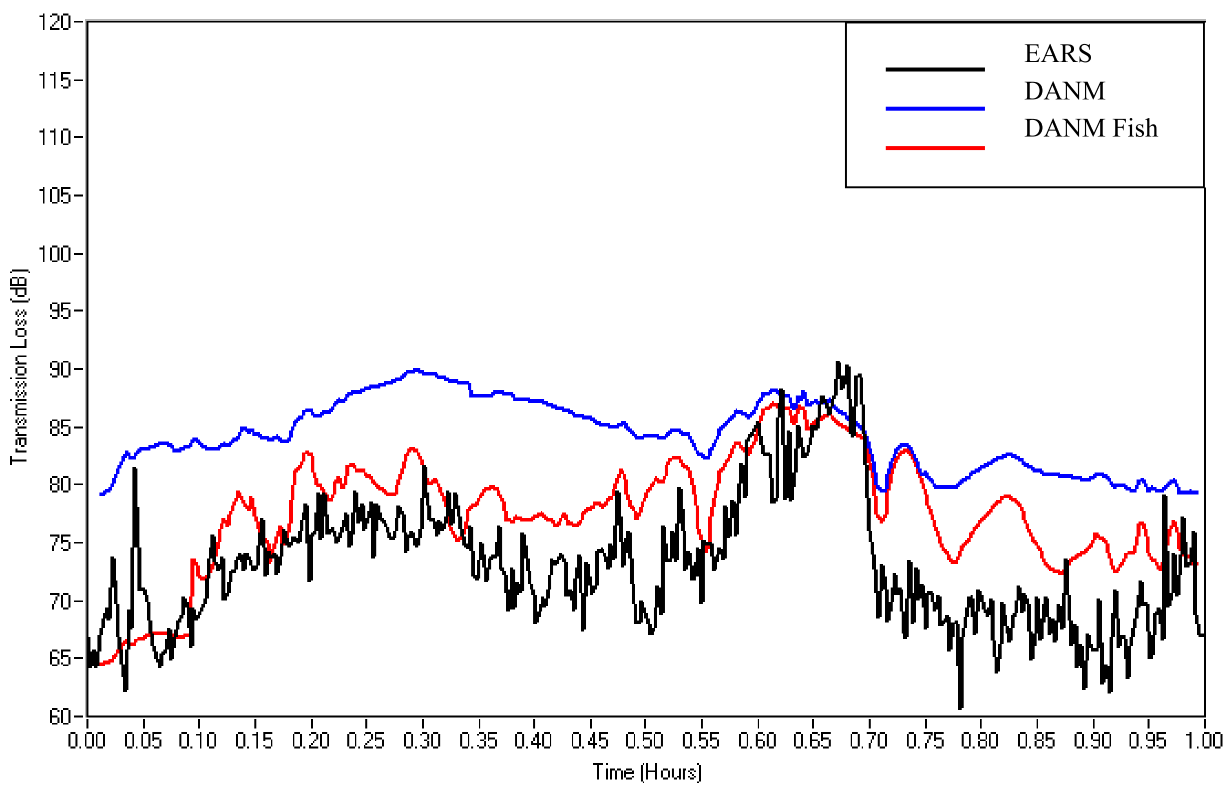

Fig. 12 — Same as Fig. 11 except that the red curve here represents the model result with the ships classified as a selected combination of fishing and merchant vessels

The frequency-dependent mismatch between model and data is maintained when the minimum source levels are used (see Fig. 4). Although the source level curves for the different ship classes have various frequency-dependencies, it appears that class assignments to the radar data are not a cause of the frequency-dependent mismatch.

A final calculation illustrates that the frequency dependent mismatch in the local ship model-measurement comparison is also present in the distant ship component. Noise levels at the 10th percentile in the cumulative distribution of all values for each day are chosen as an estimate of the distant shipping component. The noise levels obtained are likely to be in error on the high side, since a few local ships contributed to the noise during the quiet times. These levels are shown in Fig. 13 along with the DANM results using HITS densities in the 20 to 1200 nmi range (from Table 3). The model results match reasonably well for the 100 to 400 Hz range, but are clearly too high at 50 Hz, and there is obviously a stronger frequency dependence in the model results compared to the measurements. The frequency dependence in the data holds for the 15th and 20th percentiles as well.

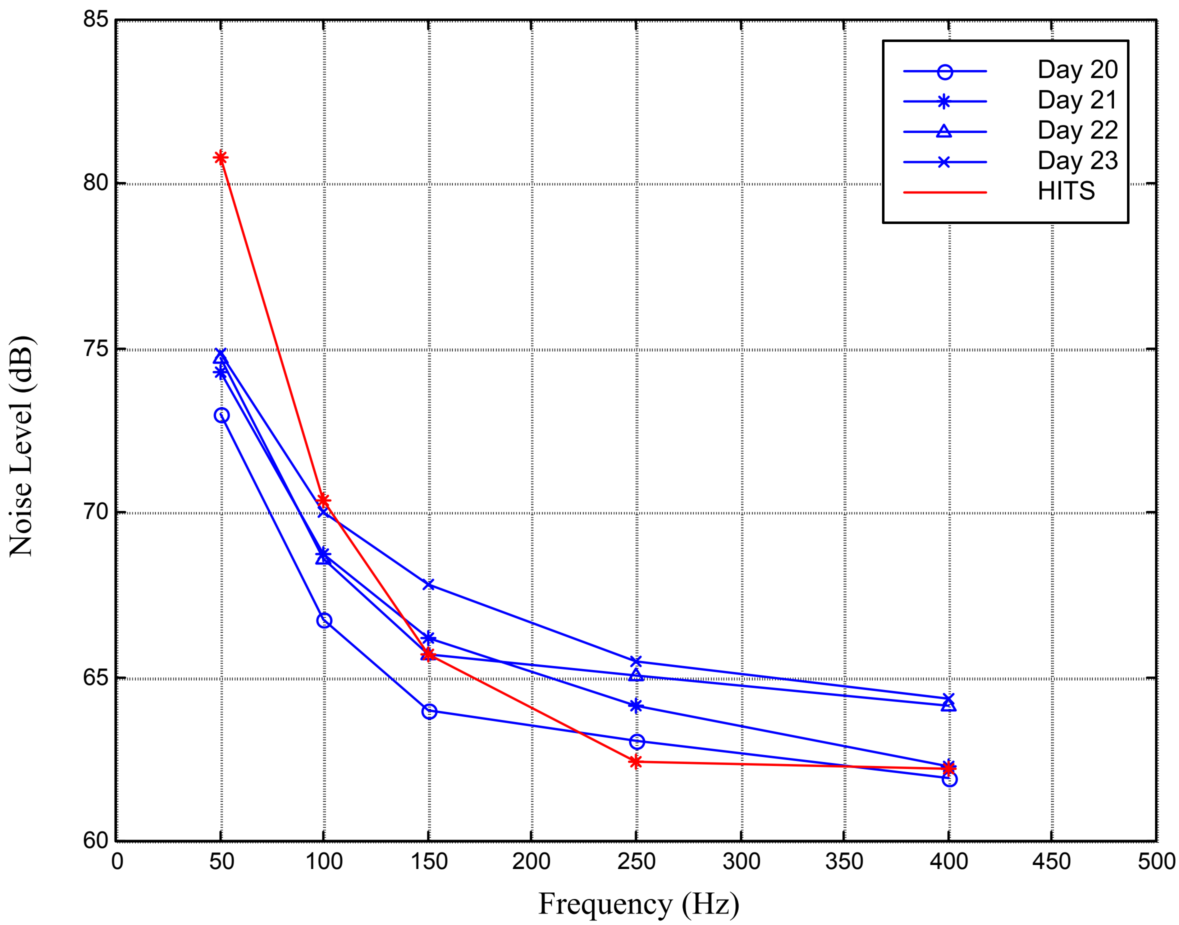

Fig. 13 — Tenth percentile noise levels for the measured data compared to DANM level using distant ships from HITS

6. CONCLUSIONS

Measured omnidirectional noise at a shallow water site near Port Everglades and radar tracks for local ships were used to evaluate a new ambient noise model (DANM) designed for the Navy Fleet. For four consecutive days of data, the daily means of modeled noise levels were higher than the data.

In general, the model predictions tended to be higher than the measured levels. A variety of environmental and propagation parameters were investigated, but the discrepancy appeared to be due to two factors associated with the ship sources. The first was the relative assignments of ship classes to the radar track vessels for input to the model. The unidentified vessels were assigned classes by speed. There was no means to discriminate between large vessels traveling at low speeds and recreational vessels that did not contribute significantly to the noise field. The second factor was the source level model within DANM, which is implemented with no speed dependence within the various ship classes. A slight speed dependence was introduced into the model through the speed-dependent ships class assignments, but would be more properly implemented within the model itself, and may be necessary for accurate predictions near a port where ships are not at cruising speed.

Model predictions with all radar vessels assigned to the minimum source level resulted in a better model/measurement comparison than the predictions with the speed-dependent class assignments. In this case, the daily model means were lower than the measured levels. The spread of about 10 dB in daily means with different source level assignments confirms that this function is critical to accurate model predictions for dynamic shipping.

There was a frequency dependence to the mismatch, with the model tending to be too high at lower frequencies. This mismatch occurred in both the original measured noise levels and derived estimates of the distant noise component. Shear propagation is unaccounted for in the propagation models used by DANM and is a likely source of error for this environment at the lower frequencies.

7. ACKNOWLEDGMENTS

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REFERENCES

Bradley, M. and L. Emery, 2001. "Software Design Description (SDD) for the HITS Vessel Motion Simulation (HVMS)," Planning Systems Incorporated, Slidell, LA, TRS-299.

Breeding, J.E., Jr., L.A. Pflug, M. Bradley, M.H. Walrod, and W. McBride, 1996. "RANDI 3.1 Physics Description," NRL/FR/7176--95-9628, Naval Research Laboratory, Stennis Space Center, MS.

Emery, L., M. Bradley, and T. Hall, 2001. "Data Base Description (DBD) for the Historical Temporal Shipping Data Base (HITS), Version 4.0," Planning Systems Incorporated, Slidell, LA, TRS-301.

Fulford, J.K., 2002. Personal communication.

Hall, T., 2001. "Software Test Description for the Dynamic Ambient Noise Model (DANM)," Planning Systems Incorporated, Slidell, LA, TR-308.

Renner, W.W., 1986. "Ambient Noise Directionality Estimation System (ANDES) Technical Description," Science Applications International Corporation, McLean, VA, SAIC-86/1645.

Ross, D., 1987. *Mechanics of Underwater Noise* (Peninsula Publishing, Los Altos, CA) pp. 253-287.

Thompson, C., B. Gomes, N. Williams, H. DeFerrari, H. Ngueyen, and K. Corregan, 2002. "Comparison of Surface Radar Traffic Density Contact Records to Receive Levels from Separate Acoustic Data Sets," 36th ASILOMAR Conf. on Signals, Systems, and Computers, Pacific Grove, CA, pp. 411-414.

Wales, S.C., and R.M. Heitmeyer, 2002, "An Ensemble Source Spectra Model for Merchant Ship-Radiated Noise," *J. Acoust. Soc. Am*. **111**, 1211-1231.

Wales, S.C., 2002. Personal communication.

Appendix A

EARS AND DANM NOISE LEVELS

Figures A1 through A5 contain the measured EARS buoy noise levels in blue and the DANM model noise levels in red. Each figure contains the results for five frequencies: 50, 100, 150, 250, and 400 Hz. Day 21, Hour 23, Day 22, Hour 14, and Day 23, Hours 15 and 20 were missing radar or acoustic data.

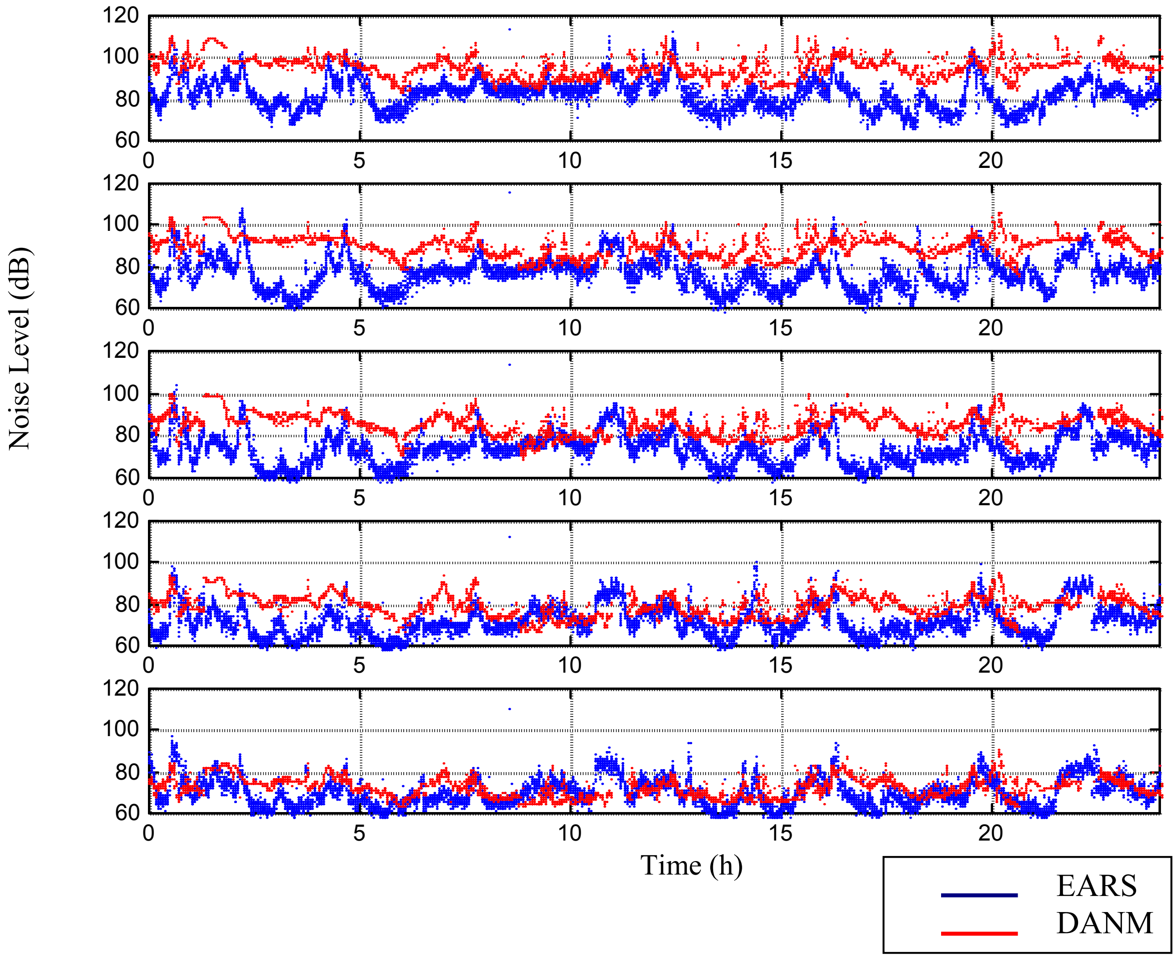

Fig. A1 — EARS and DANM omnidirectional levels for Day 20

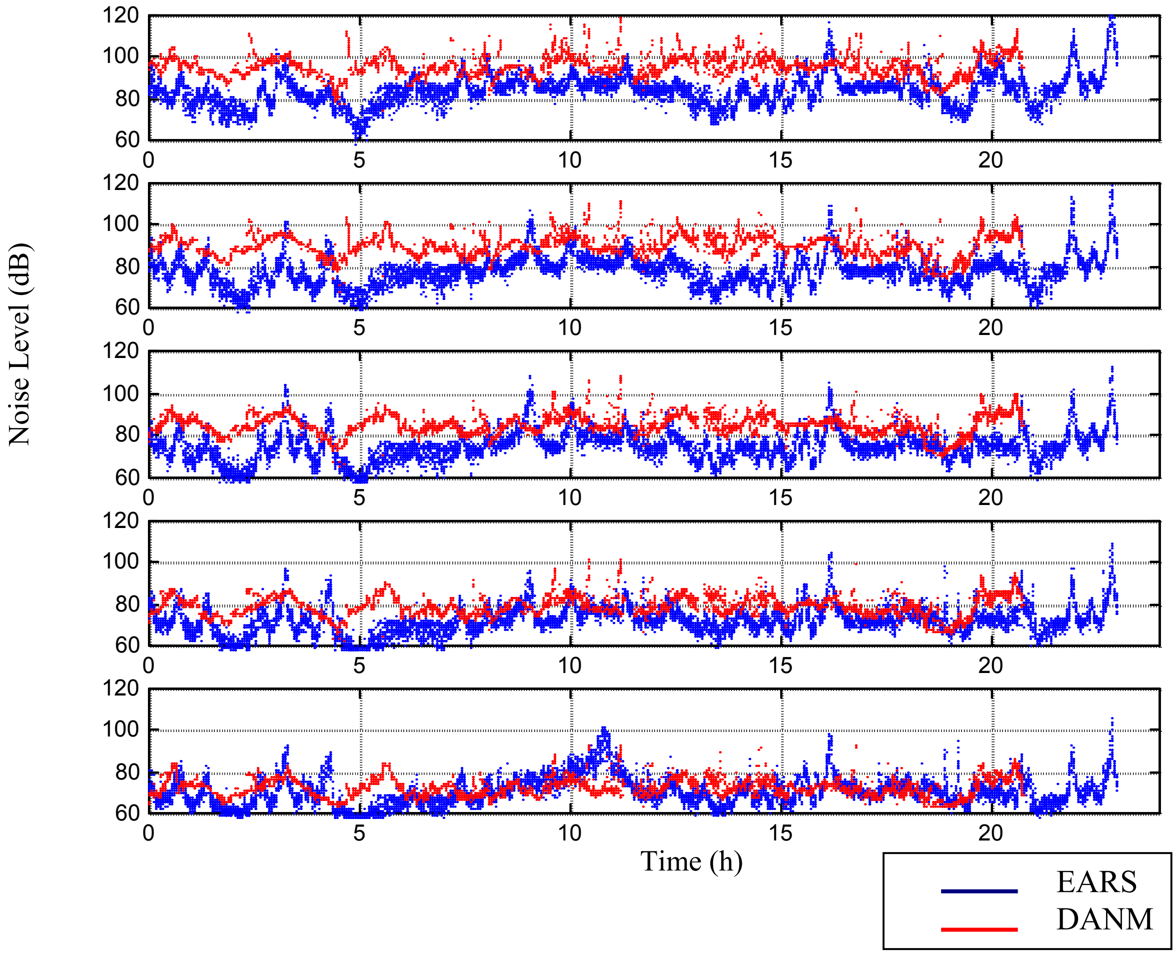

Fig. A2 — EARS and DANM omnidirectional levels for Day 21

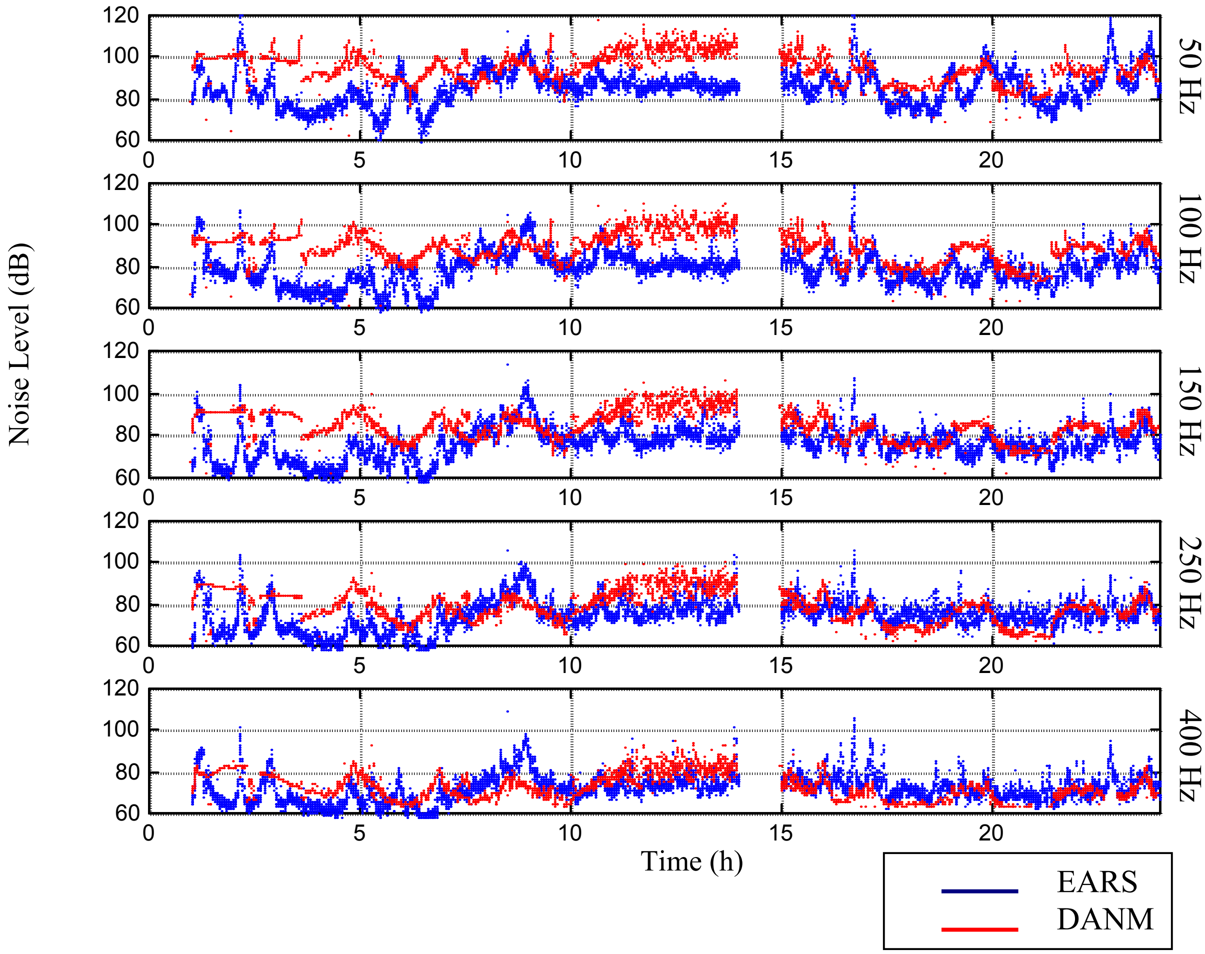

Fig. A3 — EARS and DANM omnidirectional levels for Day 22

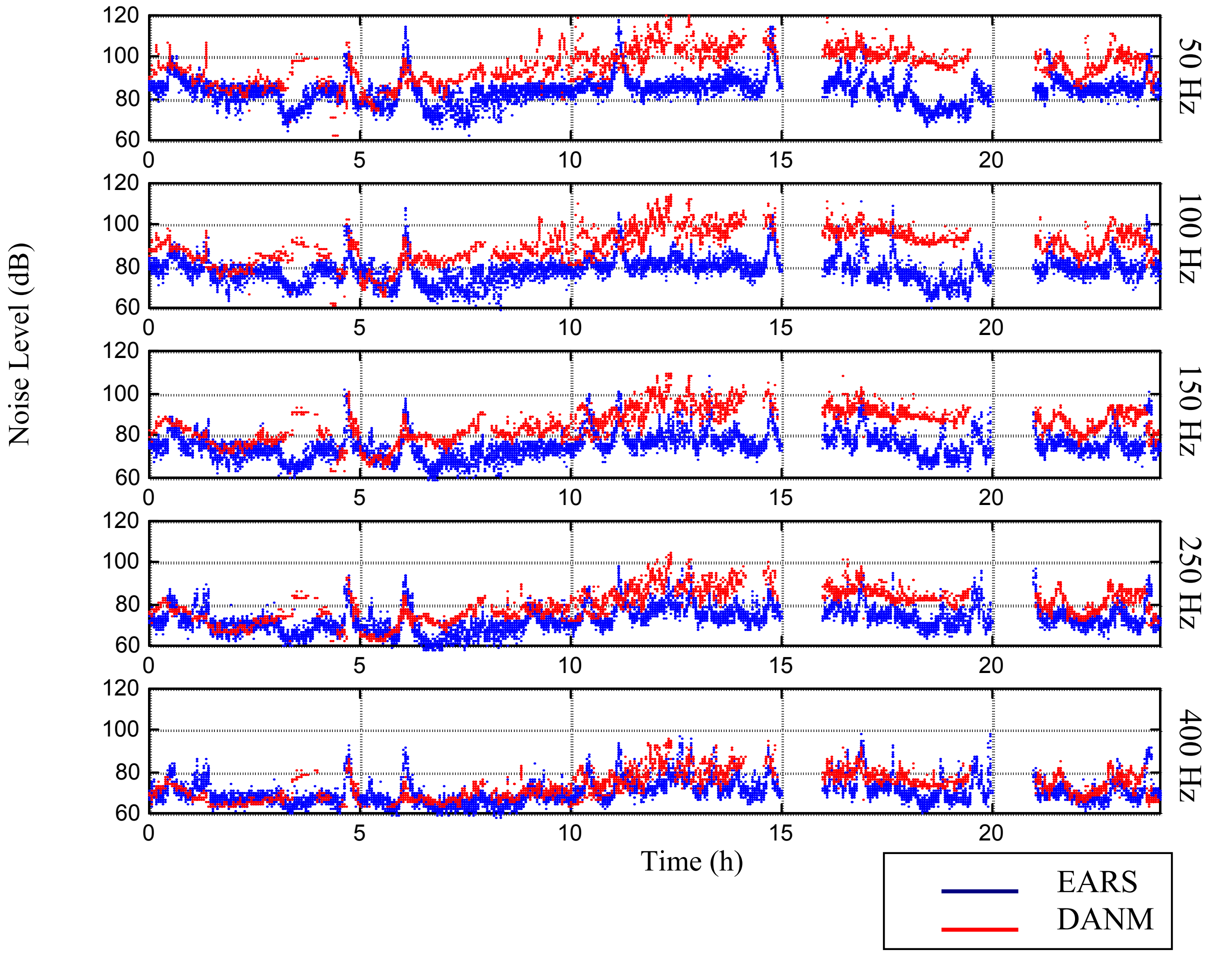

Fig. A4 — EARS and DANM omnidirectional levels for Day 23

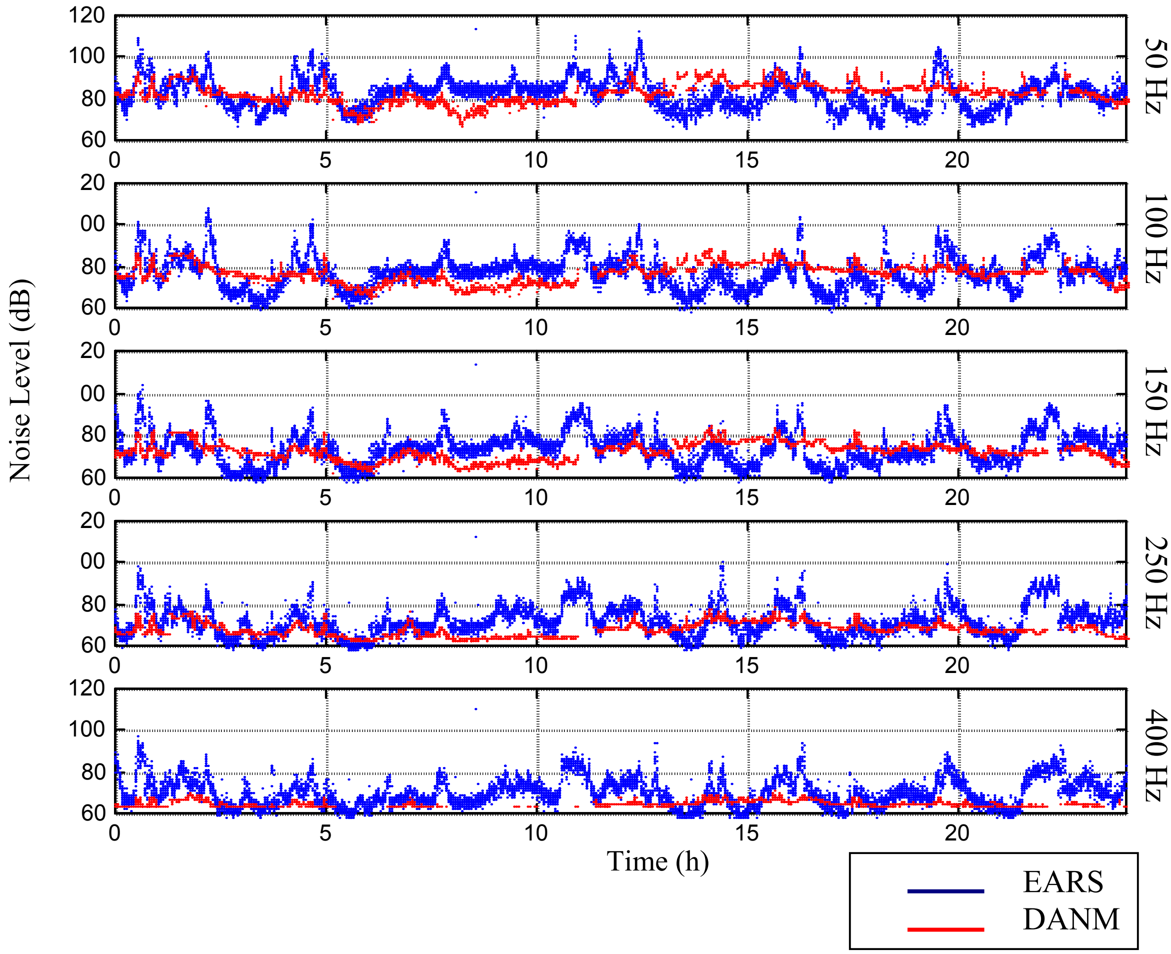

Fig. A5 — EARS and DANM omnidirectional levels for Day 20 with all fishing sources

Appendix B

EARS AND DANM NOISE LEVEL DIFFERENCES

Using the measured and modeled data in Appendix A, the figures here show the dB difference between them on a per hour basis. Positive differences indicate that the modeled noise is higher than the measured noise.

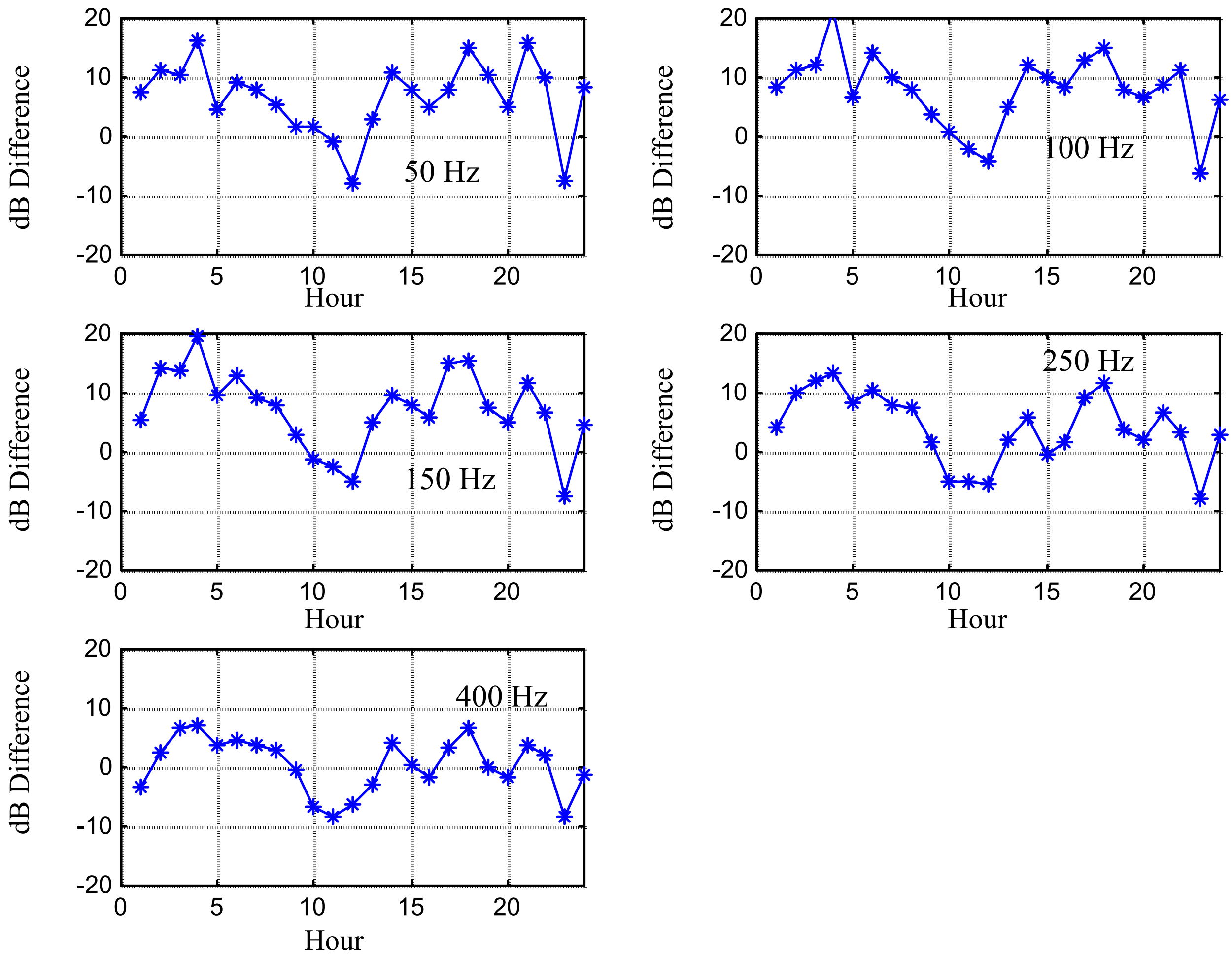

Fig. B1 — Per hour differences between DANM and EARS noise levels for Day 20

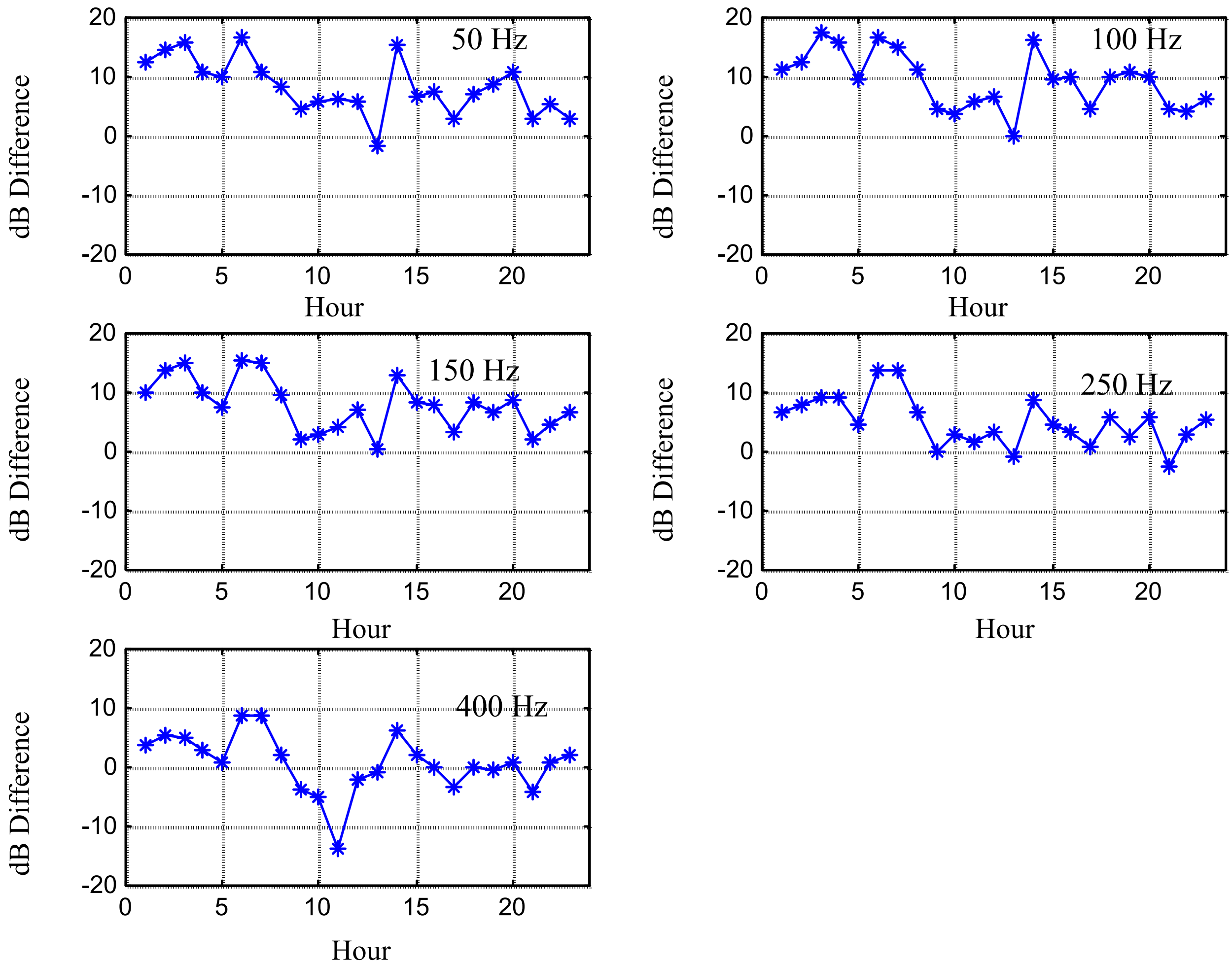

Fig. B2 — Per hour differences between DANM and EARS noise levels for Day 21

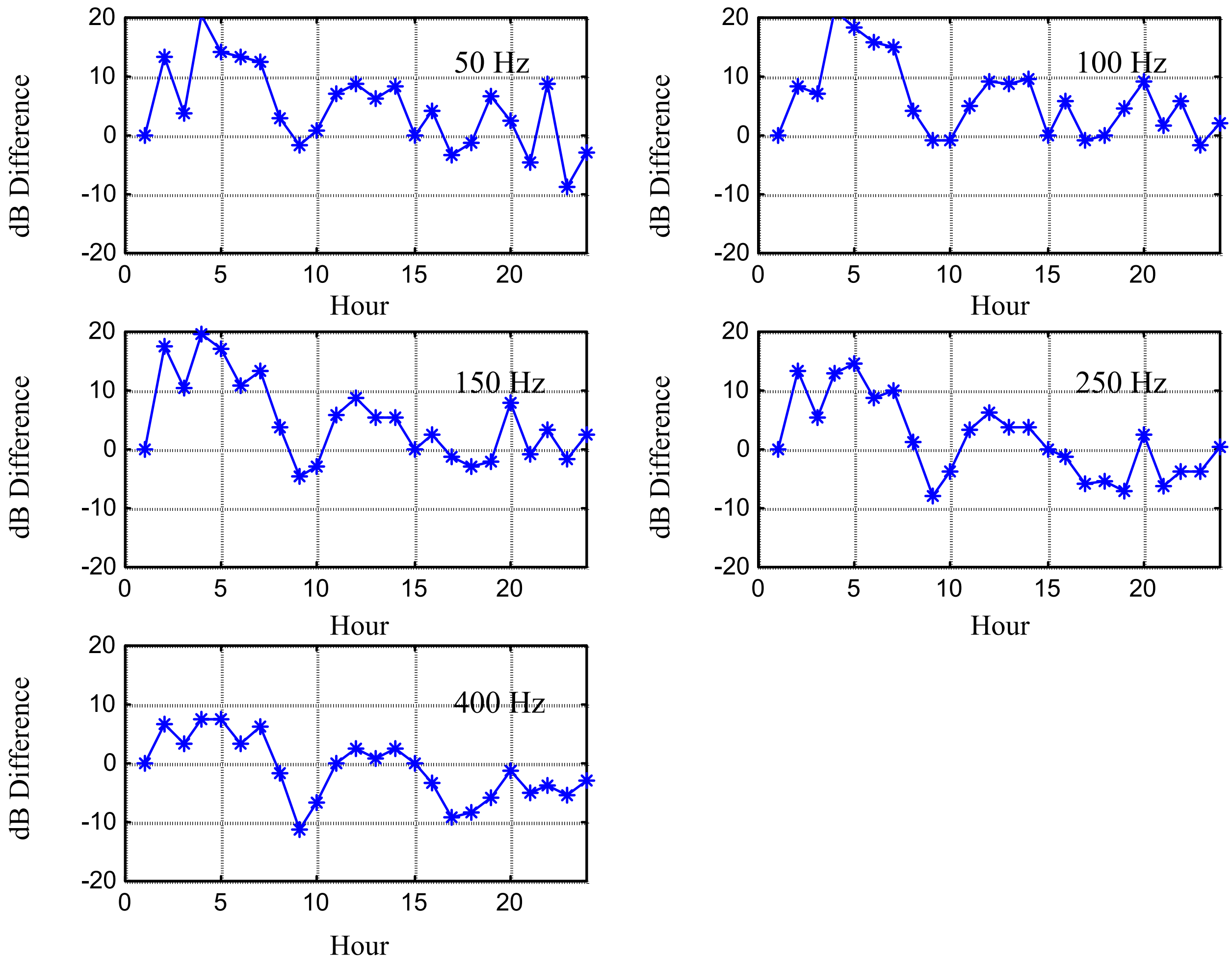

Fig. B3 — Per hour differences between DANM and EARS noise levels for Day 22

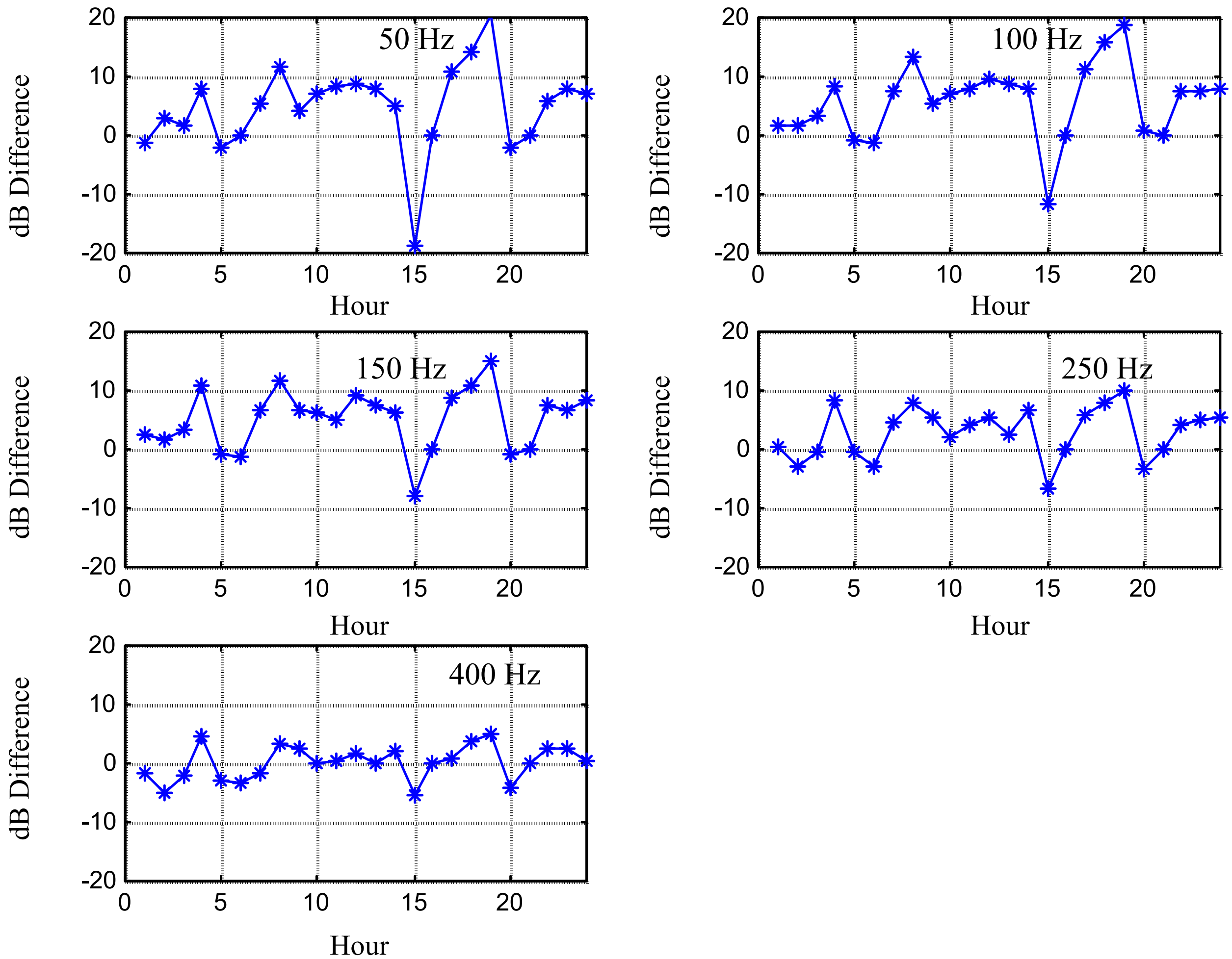

Fig. B4 — Per hour differences between DANM and EARS noise levels for Day 23

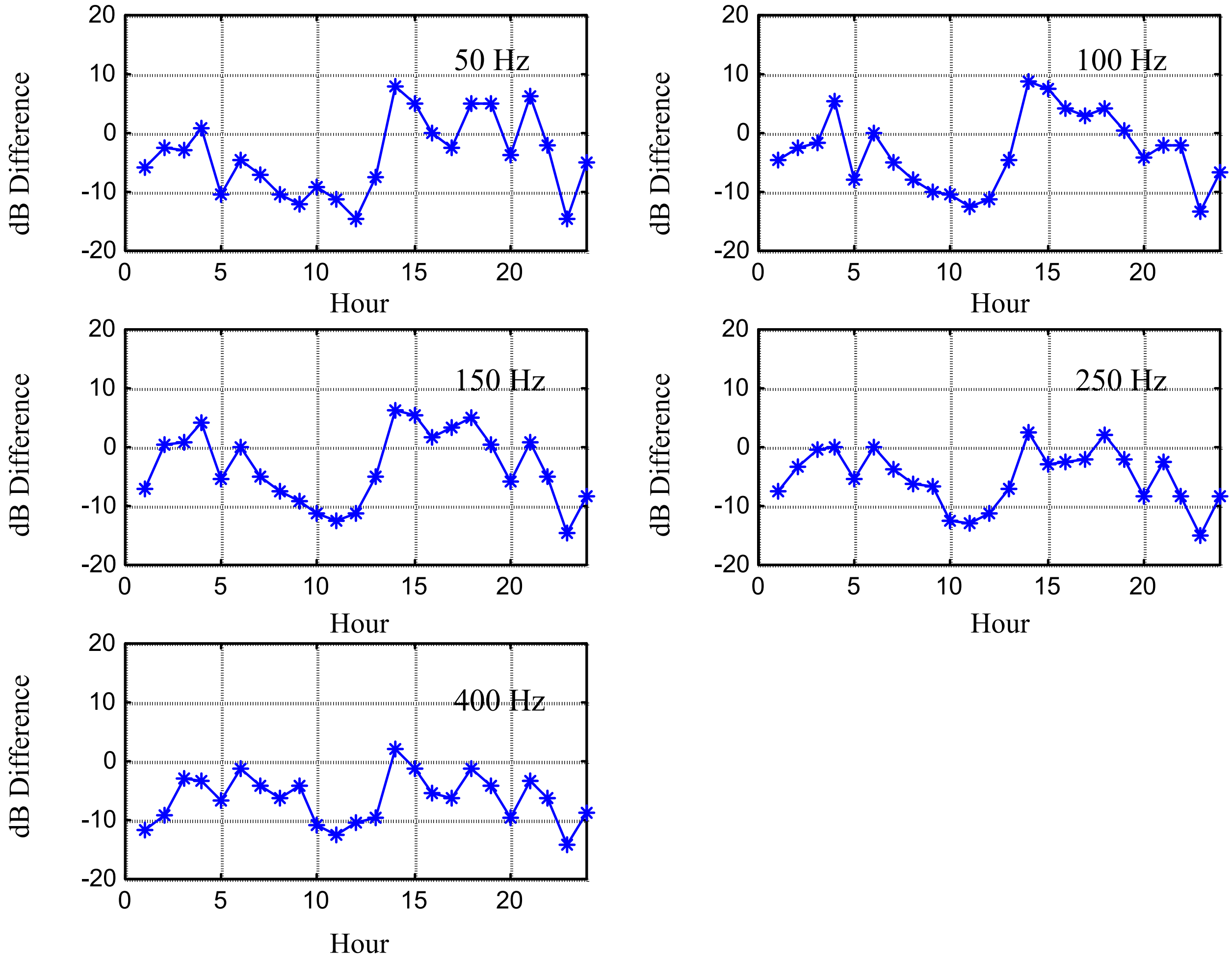

Fig. B5 — Per hour differences between DANM and EARS noise levels for Day 20 with all fishing sources

Appendix C

PROBABILITY DISTRIBUTION FUNCTIONS

Probability distribution functions (PDFs) for the EARS data and DANM simulated noise levels for each day are shown in Figs. C1 through C4. Some of the 250 and 400 Hz DANM PDFs have left tails missing due to a wind noise basement in the model calculations. The wind noise basement was not included in the PDFs since it is unlikely that the data are ever bottom-limited by the wind noise. Tables C1 and C2 contain the skewness and kurtosis for the distributions.

Table C1 — Skewness of DANM and EARS Daily Noise Levels

Freq (Hz)	Day 0920 (dB)		Day 0921 (dB)		Day 0922 (dB)		Day 0923 (dB)	
	EARS	DANM	EARS	DANM	EARS	DANM	EARS	DANM
50	0.37	0.30	0.80	0.34	0.49	-0.04	0.80	0.34
100	0.50	0.18	0.76	-0.07	0.35	-0.20	076	-0.074
150	0.41	0.10	0.69	-0.07	0.23	-0.0027	0.69	-0.069
250	0.68	0.19	0.60	0.17	0.27	0.0078	0.59	0.17
400	0.58	0.37	0.90	0.62	0.70	0.46	0.90	0.62

Table C2 — Kurtosis of DANM and EARS Daily Noise Levels

Freq (Hz)	Day 0920 (dB)		Day 0921 (dB)		Day 0922 (dB)		Day 0923 (dB)	
	EARS	DANM	EARS	DANM	EARS	DANM	EARS	DANM
50	0.18	0.15	3.45	0.96	1.32	-0.21	3.45	0.96
100	0.21	0.12	2.16	0.75	0.78	-0.13	2.16	0.75
150	0.03	0.05	1.73	0.94	0.36	-059	1.73	0.94
250	0.33	-0.28	1.63	0.53	0.60	-0.68	1.63	0.53
400	0.11	-0.44	1.40	0.91	1.24	-0.55	1.40	0.91

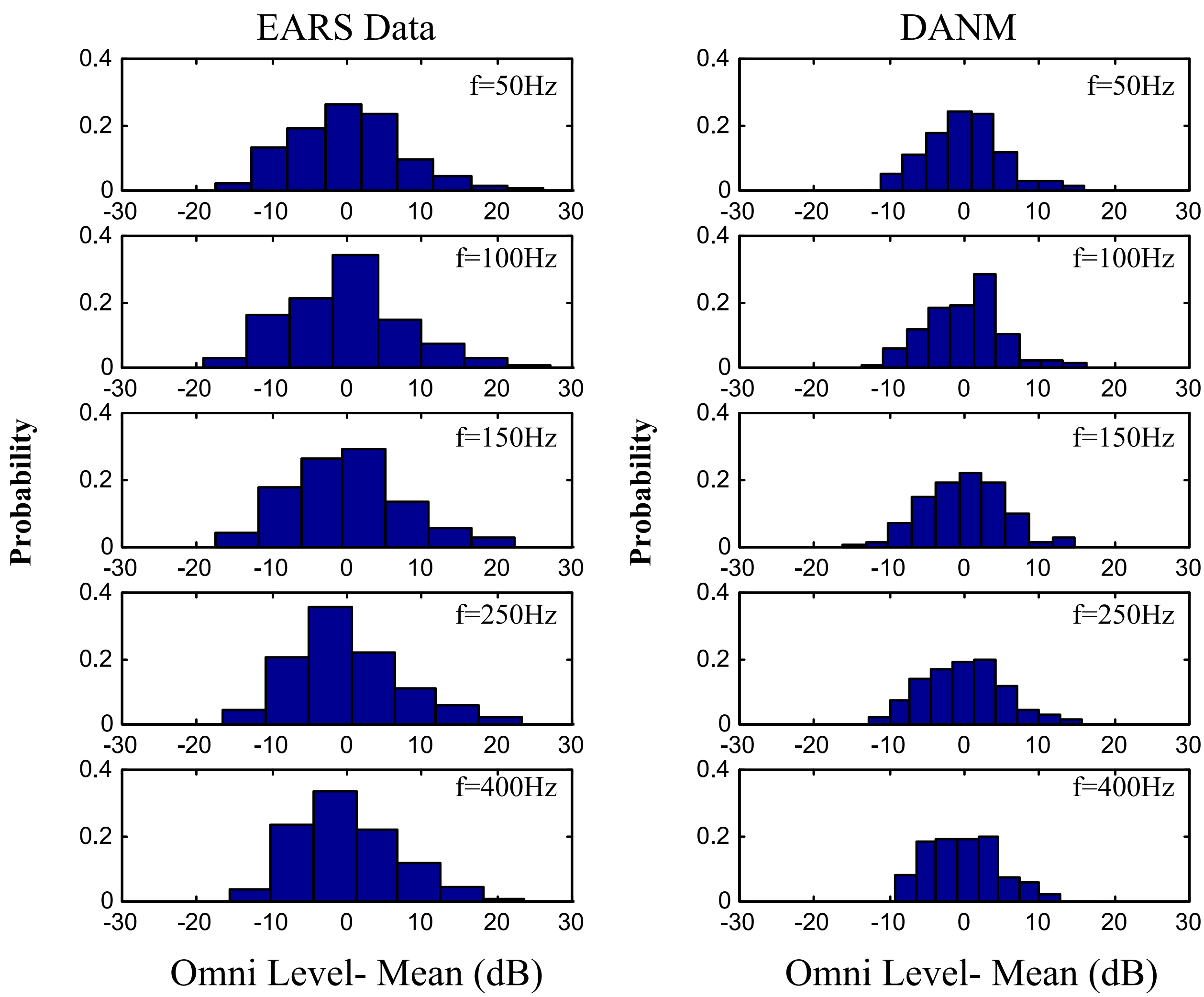

Fig. C1 — Probability distribution function for EARS and DANM noise levels for Day 20

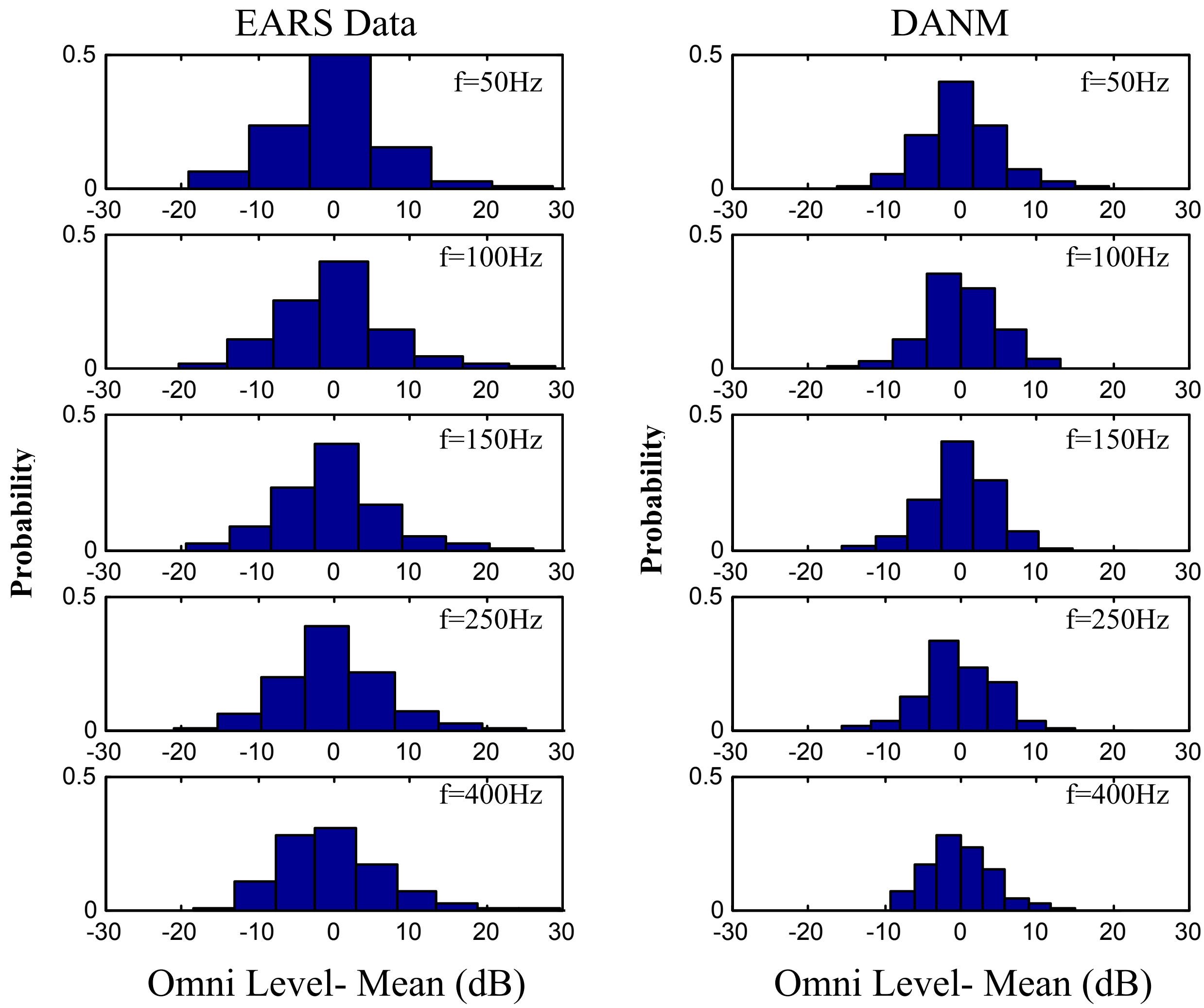

Fig. C2 — Probability distribution function for EARS and DANM noise levels for Day 21

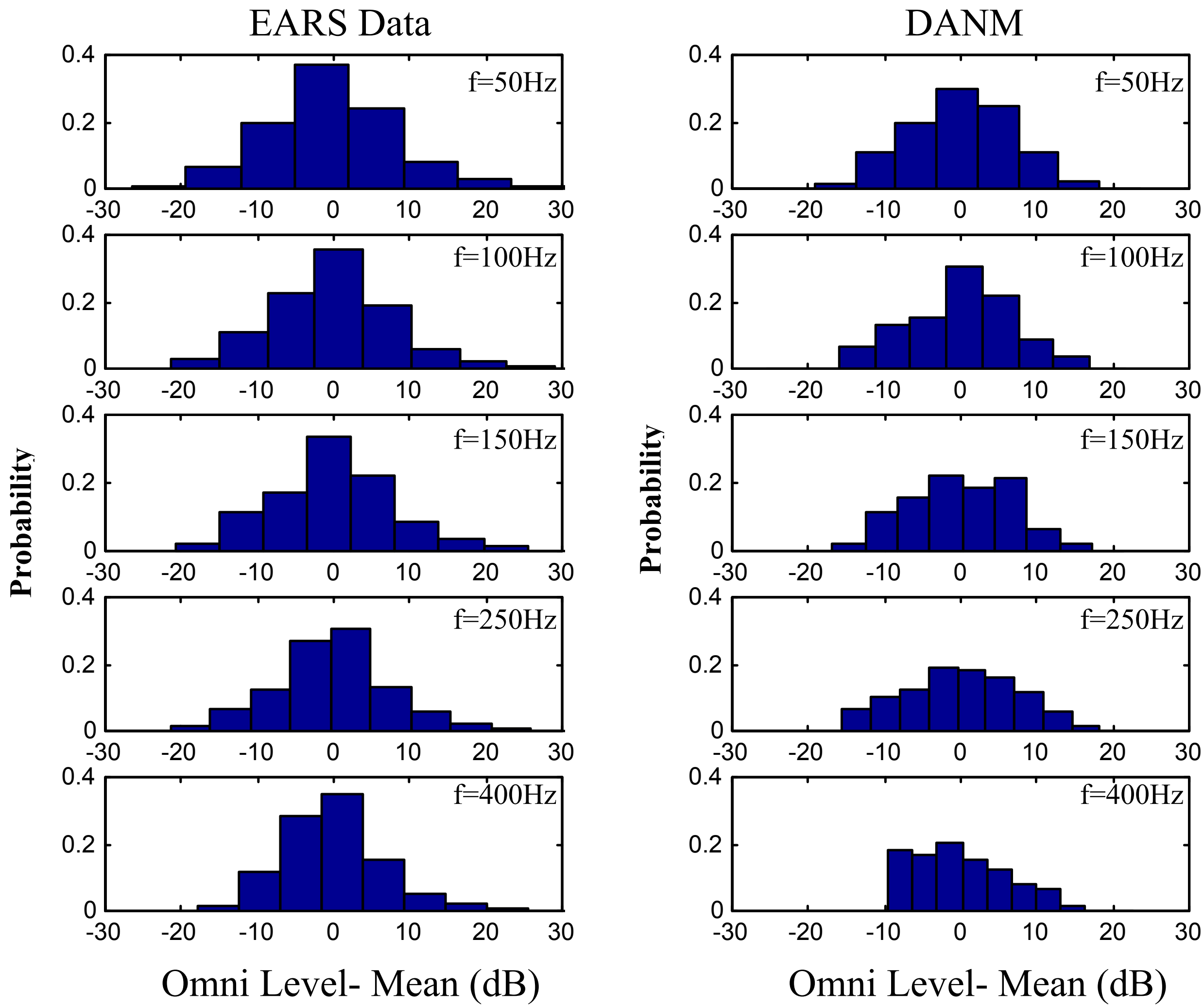

Fig. C3 — Probability distribution function for EARS and DANM noise levels for Day 22

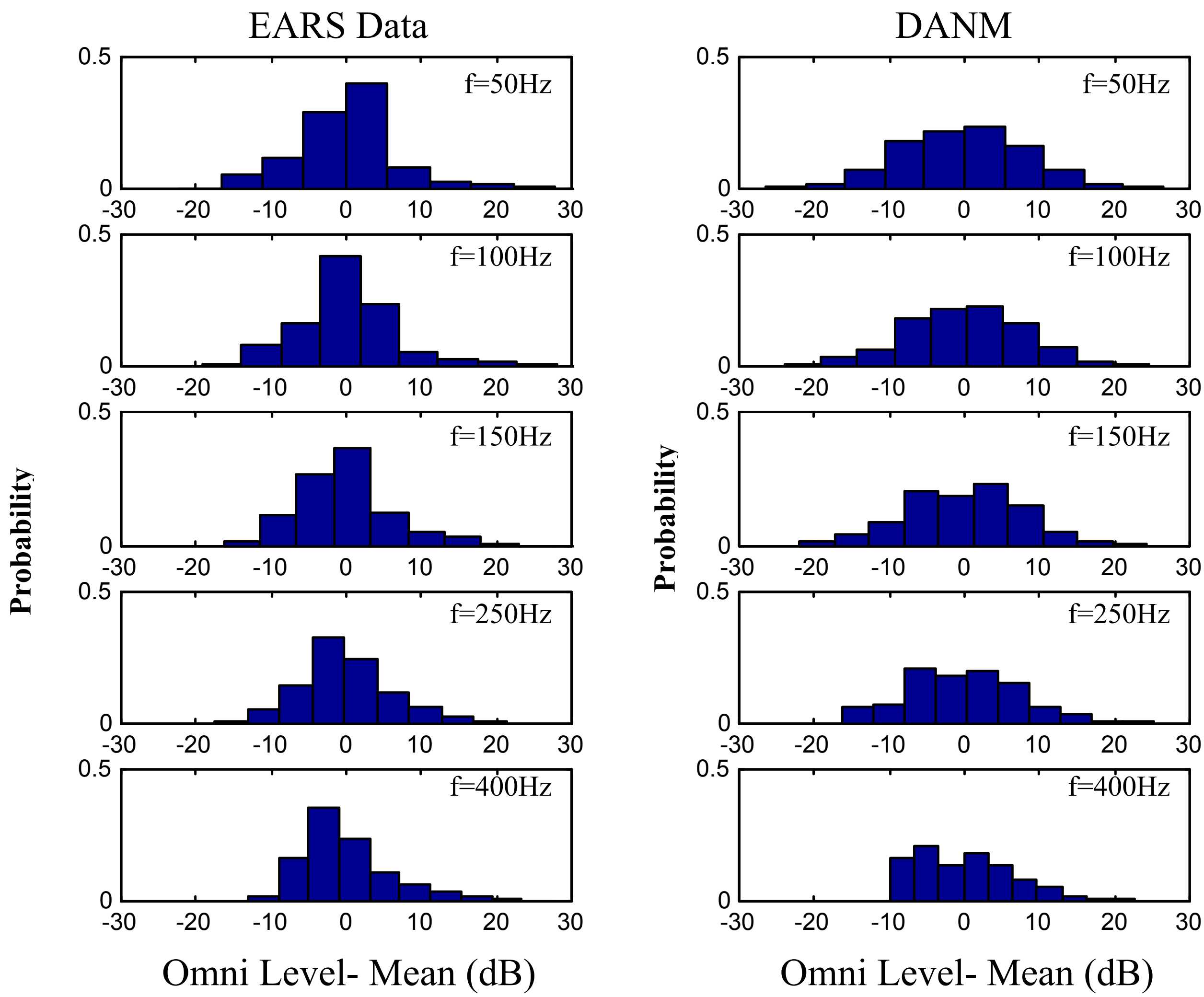

Fig. C4 — Probability distribution function for EARS and DANM noise levels for Day 23