SITE AND FREQUENCY DEPENDENCE OF AMBIENT NOISE IN THE NORTHEASTERN PACIFIC OCEAN

by

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ABSTRACT

One-hour averages of omnidirectional ambient noise measurements at 60 Hz and 165 Hz are analyzed for two nearby, deep ocean sites in the Northeastern Pacific during February and March 1981. Site A is a high noise site and is located near major east-west shipping lanes and near major Pacific storm paths. Site B is a lower noise site and is located approximately 450 n.m. from Site A away from major shipping lanes and Pacific storm paths. The site and frequency dependence of ambient noise is found to be highly variable with shippiing noise being totally dominant at 60 Hz at Site A and storm noise being totally dominant at 165 Hz at Site B. Both shipping and storm noise can dominate the 165 Hz Site A or 60 Hz Site B noise levels depending on weather conditions.

Storm noise has a possible indirect effect on shipping noise, since very low noise periods occur in between storms, especially when the storm passes nearby the site. A limited number of WMO ships sampled indicate that ships slow down or stay in port during storms. Average omnidirectional noise levels at 60 Hz at both sites and at 165 Hz at Site A were 3 to 4 dB lower during a stormy week than they were during a relatively calm week.

Array noise gain measurements at Site B indicate that the coherence of noise during stormy periods is much less than it is during calm periods. Generally, this implies that the increase in beam level at 165 Hz, caused by storm noise, will be significantly less than corresponding increase in omnidirectional noise levels. At 60 Hz at Site B, this implies that beam levels will decrease, in general, during storms, especially if the storm system is nearby.

1.0 INTRODUCTION

There are many sources of ambient noise[1] in the ocean and it is shown in this paper that different noise sources (shipping and storms in this case) can dominate the noise characteristics of two nearby sites. For the analysis presented here- it is important to differentiate between short term (minutes) noise fluctuations and changes in the long term (hours) noise intensity level. The two major factors affecting long term noise intensity levels are the distribution of noise sources relative to the measurement site and transmission loss from each noise source to the measurement site. The data analyzed in this paper illustrate the measurement site dependence and frequency dependence of long term averaged ambient noise. Bottom mounted hydrophone data were collected from two sites and two frequencies in deep water in the Northeastern Pacific Ocean during February and March 1981. The data used in this analysis are averaged over 1 hour at 60 Hz and 165 Hz. Short term noise fluctuations will not be addressed in this paper.

Two dominant sources of noise in the Northeastern Pacific Ocean during the winter are shipping and storms. Site A is located near major Pacific shipping lanes and is in the path of many large Pacific storms. Site B is located approximately 450 miles from Site A and is located well south of major shipping lanes and Pacific storms. Consequently, Site A is much noisier than Site B and the 60 Hz noise levels at Site A were totally dominated by shipping noise. On the other extreme, the 165 Hz levels at Site B were totally dominated by storm noise. The objective of this paper is to show that low frequency ambient noise can be extremely site and frequency dependent and to show the large changes in array noise gain that can occur in a period of 1 day.

To differentiate between storm and nearby shipping events in the ambient noise time series, the following criteria were used: Storm events were defined as increases in noise level lasting from 2 to 7 days at 10 Hz and 165 Hz with little or no change in noise level at 60 Hz. Nearby shipping events, on the other hand, are defined as increases in ambient noise level at all frequencies from 10 Hz to 165 Hz lasting 1 or 2 hours. Distant shipping noise background has a maximum near 60 Hz, and since the shipping spectra is relatively flat, storm events have a greater effect on 10 Hz and 165 Hz noise levels than on 60 Hz levels. The 10 Hz noise levels were used only to define storm events and no analyses of these data are presented in this paper. Every storm event defined in the manner described above was accompanied by a major Pacific storm and it is unlikely, in the author's opinion, that shipping can produce the storm noise characteristics defined above (and vice versa).

A subsequent paper will cover the subjects of distant versus local storm noise and modeling ambient noise based on Wilson's wind source level curves[2-4] and historical shipping densities. This paper covers ambient noise characteristics of Sites A and B, emphasizing the frequency and site dependence of ambient noise.

2.0 AMBIENT NOISE CHARACTERISTICS

The data base for this analysis is 60 Hz and 165 Hz omnidirectional data from two deep water, Northeastern Pacific, bottom mounted hydrophones. A 1-hour (dB) averaging time was used in order to analyze long term changes in ambient noise time series at each site. Wind speed information was taken from the Fleet Numerical Oceanographic Center (FNOC) surface wind analyses performed every 6 hours (Zulu time). The accuracy of the FNOC surface wind analyses for the mid-latitudes was evaluated in the NORPAC Pole Experiment[5].

2.1 Site A - The High Noise Site

Figures 1 and 2 show the 60 Hz and 165 Hz omnidirectional ambient noise data at Site A for the month of February 1981. Data points were plotted every 12 hours (Zulu time) except on 12/13 February 1981, when no data were available. Four major Pacific storms passed to the north of Site A during 6 to 8 February, 16 February, 18 to 20 February and 21 to 27 February 1981, while a small local squall passed overhead Site A on 10 February 1981.

Except for the high levels on 10, 18-19 and 24 February 1981, Figure 1 shows little effect of the passage of the Pacific storms at 60 Hz. It can be concluded that the ambient noise at Site A is dominated by shipping the vast majority of the time. The 60 Hz levels of 85 dB/μPa//Hz$^{1/2}$, shown in Figure 1, are high enough (relative to the 165 Hz levels at Sites A and B) to limit storm effects to 2 to 4 dB increases lasting periods of 1 day or less.

The 5 to 7 dB level increases at 165 Hz shown in Figure 2 during storm periods are much more pronounced with the high levels lasting up to 5 days in duration. The fact that these high levels correlate very well with the presence of large Pacific storms is a direct result of noise produced by storms. The indirect effect of storms is also potentially significant. Figure 2 suggests that very low levels (e.g., 9, 11-12 and 21-22 February 1981) can occur at 165 Hz between storms. Figure 1 shows the same effect at 60 Hz, but to a much lesser extent. The question that arises is "Does the presence of storms reduce shipping noise by causing ships to slow down or change course?"

The author has not done an extensive study of ship course or speed changes during storm periods, but several WMO ships were tracked that were in the Northeastern Pacific during storm periods on 6 to 8 and 10 February 1981. The source of WMO ship position, course and speed data are the WMO ship reports received by FNOC, Montery. Figure 3 shows the tracks of five WMO ships (with reported speed time series shown in the insert) from 5 to 11 February 1981. These ships were selected because they reported frequently and were located in the east-west shipping lane that crossed the storm center. Although the WMO ship list does not include all ships at sea, several characteristics of WMO ship operations observed during or after storms may be typical of most ships. In examining the WMO ship locations, courses and speeds, the following observations are made:

- o All WMO ships during this time period slowed down within (e.g., JBSP) or near (e.g. H8DE) the major storm system.
- o Not all WMO ships slowed down at the same time, since location relative to storm systems was the major factor in speed changes.
- o WMO ships that did not cross the storm system (e.g., D5HD) tended to maintain constant course and speed.

- o Significant long term changes in WMO ship course were not observed. The preferred method of getting around a storm seems to be slowing down and "waiting" for calm weather.

- o The vast majority of WMO ships during this time period were on easterly courses with very few WMO ships leaving west coast ports on westerly trans-Pacific routes.

The above observations were made on a very limited time period for WMO ships only and, therefore, a much more extensive analysis is needed to say these are typical of ship course and speed changes. However, all the observations imply less ship noise during and between storms. This could be a possible explanation for the low noise levels observed in Figure 2. After a storm has passed, it could take approximately a day for shipping densities and speeds to increase to normal levels.

The week from 5 to 11 February 1981 was a typical storm period for the Northeastern Pacific, with one normal and one small storm during the week. The period from 20 to 27 March 1981 was an extended, unusually calm weather period for the Northeastern Pacific during winter, with one storm beginning on the last day of the week. The period from 20 to 26 March 1981 was shipping-dominated and a comparison of the 1-hour averaged noise statistics between the 2 weeks (5 to 11 February 1981/20 to 27 March 1981) is shown in Figure 4. On the average, noise levels during the calm March week are 3 dB and 4 dB higher at 65 Hz and 165 Hz, respectively, than corresponding noise levels during the stormy February week. Again, the possibility of storms lowering the average noise level between 60 Hz and 165 Hz is suggested for high noise sites like Site A. Certainly, Figure 4 shows there are many more very low noise periods during the stormy week. It is interesting to note the bimodal distribution of noise levels at 165 Hz during the stormy week shown in Figure 4. Physically, this occurs because the noise levels during stormy and calm periods are typically 6 dB apart and there is relatively little time in transition between calm and stormy periods.

Although more intensive analysis of the effect of storms on shipping noise is needed, the data presented here suggests the possibility that, for high noise areas like Site A, storms may produce lower overall noise levels between 60 Hz and 165 Hz by reducing ship noise.

2.2 Site B - The Low Noise Site

As discussed previously, Site B is located approximately 450 n.m. from Site A and is well south of the major east-west shipping lanes and major Pacifc storms. Consequently, noise levels at 60 Hz and 165 Hz at Site B are, on the average, approximately 11 dB and 14 dB quieter during calm weather periods than corresponding levels at Site A. Figures 5 and 6 show the omnidirectional levels for Site B during February 1981 at 60 Hz and 165 Hz, respectively. The data are 1-hour averages plotted every 12 hours Zulu time.

In comparing the data in Figures 5 and 6 with the data in Figures 1 and 2, some differences between Sites A and B (other than average level) are evident. The 165 Hz levels at Site B are totally dominated by storm noise with level increases from 9 dB to 13 dB during every February 1981 storm period described previously. During the calm period between storms, the 165 Hz levels at Site B are very low, approaching 59 to 60 dB/μPa//Hz$^{1/2}$ as a "noise floor." At these very low noise levels, shipping noise is not a factor since a 10 or 15 knot local wind[2,3] is sufficient to dominate these noise floor levels. A large distant storm can raise the noise level above 70 dB/μPa//Hz$^{1/2}$ and Figure 6 shows that the omnidirectional 165 Hz levels at Site B act as a "weather barometer" for Pacific storms. Figure 7 shows the time series at 165 Hz at Site B for the week of 13 to 21 February 1981, which illustrates the major noise sources (local shipping, local storm, distant storm and calm or distant shipping background).

The 60 Hz levels at Site B shown in Figure 5 vary much less (2 to 4 dB) with storm events than the 165 Hz levels. This indicates that the 60 Hz levels are dominated more by shipping noise than storm noise most of the time. However, the 60 Hz levels at Site B have more variability than the 60 Hz levels at Site A (Figure 1) which were totally dominated by shipping.

It appears that the 60 Hz levels at Site B are dominated by relatively nearby ships, since the lowest levels in February 1981 occurred on 11 Febrary 1981, just after the small local storm on 10 February 1981. The other more distant storms in February 1981 did not result in low levels between storms.

Figure 8 shows a comparison of the 1-hour averaged statistics at Site B for the same stormy week (5 to 11 February 1981) and the same calm week (20 to 27 March 1981) used in Figure 4 for Site A. The average 60 Hz levels at Site B increased by approximately 3 dB during the calm week, possibly because shipping densities and speeds increased to normal levels when no storms were present. However, the average 165 Hz levels at Site B decreased by 5 to 6 dB during the calm week due to decreased wind noise. The high noise levels in the bimodal distribution shown in Figure 8 for 165 Hz at Site B during the calm week are due to a storm the last day of that week.

3.0 ARRAY GAIN

Analysis of the omnidirectional data in the previous section illustrated site and frequency variability of ambient noise. However, the coherence of the noise field is an extremely important factor in assessing array performance and omnidirectional data is not impacted by noise coherence. Array noise gain (ANG) measurements were collected for a near broadside beam for both Sites A and B during part of the February/March 1981 data collection period. To eliminate measurement system effects, theoretical array noise gain, ANG_{theo}, was subtracted from measured array noise gain ANG_{meas} as follows:

$$\overline{ANG} = ANG_{meas} - ANG_{theo} \qquad (1)$$

The objective of this section is to illustrate the highly variable noise source dependence of $\overline{ANG}$ by eliminating system gain against an ideal noise field. The results discussed for $\overline{ANG}$ depend on the coherence of the dominant noise source only and apply to any array system.

If the noise field were isotropic and totally incoherent, $\overline{ANG}$ would be zero for all beams and array gain would be constant and equal the theoretical array gain value. For Site A, and especially Site B, $\overline{ANG}$ was highly variable and dependent on the noise source. Physically, $\overline{ANG}$ is expected to be nearly euqal to ANG_{theo} when the dominant noise source is a large, distant Pacific storm. Since a typical Pacific storm has a fetch (greater than 20 knot winds) on the order of 2000 n.m. (2/3 the size of the Contintental United States), it should appear more incoherent and isotropic than a noise field dominated by nearby surface ships. Figure 9 shows $\overline{ANG}$ at Site B plotted for several weeks in February/March 1981 with the 165 Hz omnidirectional levels at Site B used as an index or "storm barometer." $\overline{ANG}$ at 165 Hz is anticorrelated with the 165 Hz levels probably because distant storm noise is uncorrelated. The noise field during calm periods may be dominated by a relatively few nearby ships and, consequently would be more highly correlated. Since Site B is a low noise site, it is probably not impacted greatly by distant shipping noise. The 60 Hz $\overline{ANG}$ shipping values shown in Figure 9 support this supposition. The storm on 16 to 18 March 1981 passed very close to Site B and the 60 Hz $\overline{ANG}$ values were also anticorrelated with the 165 Hz levels. Other more distant storms did not result in as great a decrease in $\overline{ANG}$. For example, the 60 Hz $\overline{ANG}$ values did not decrease as much during the distant storm on 1 to 3 April 1981 as it did during the more local storm of 16 to 18 March 1981.

The $\overline{ANG}$ values at 60 Hz and 165 Hz may have different performance implications for an array of elements when the changes in $\overline{ANG}$ plus the omnidirectional level are considered. At 165 Hz, the results imply that beam level increases during storm periods will not be nearly as large as the increases in omnidirectional noise levels. In other words, the coherence of storm noise relative to the coherence of the noise field during calm weather periods results in beam level increases that are much less than the omnidirectional level increases. At 60 Hz, however, the situation is different since the 60 Hz omnidirectional noise levels at Site B remain constant or increase very little during storm periods. Since $\overline{ANG}$ generally decreased more than the omnidirectional level increase, the storm indirectly resulted in lower beam levels at 60 Hz at Site B. Changes in ship speeds and densities are possible explanations for lower beam levels.

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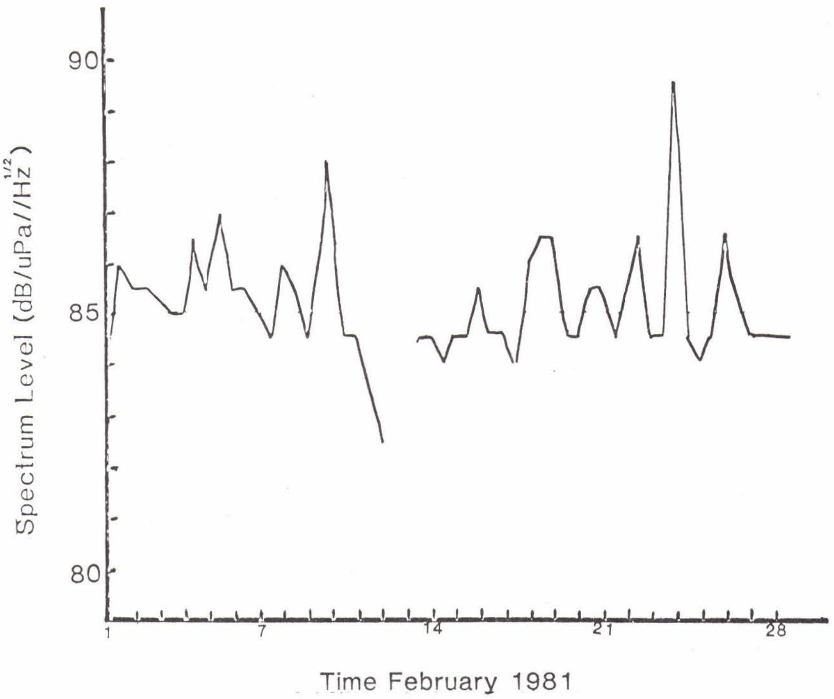

FIG. 1 SITE A — 60 Hz

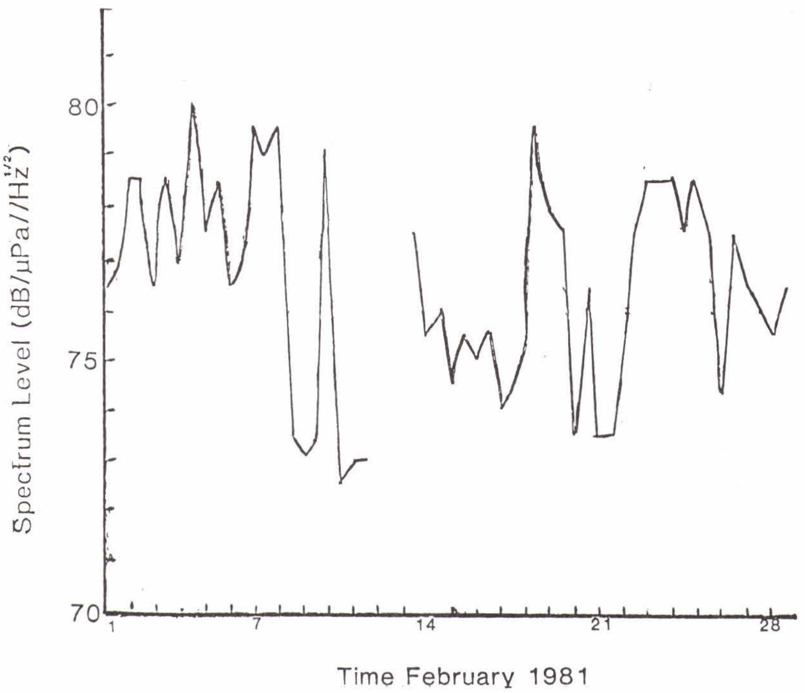

FIG. 2 SITE A — 165 Hz

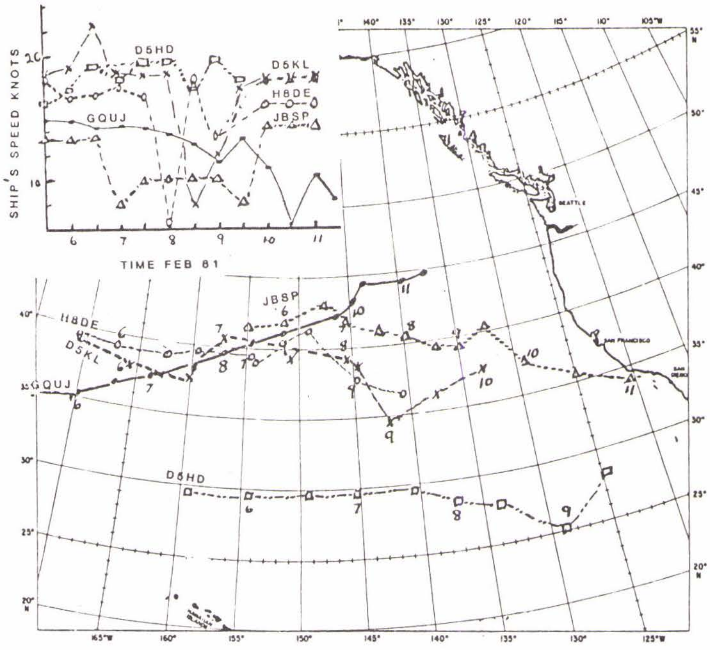

FIG. 3 SELECTED WMO SHIP TRACKS

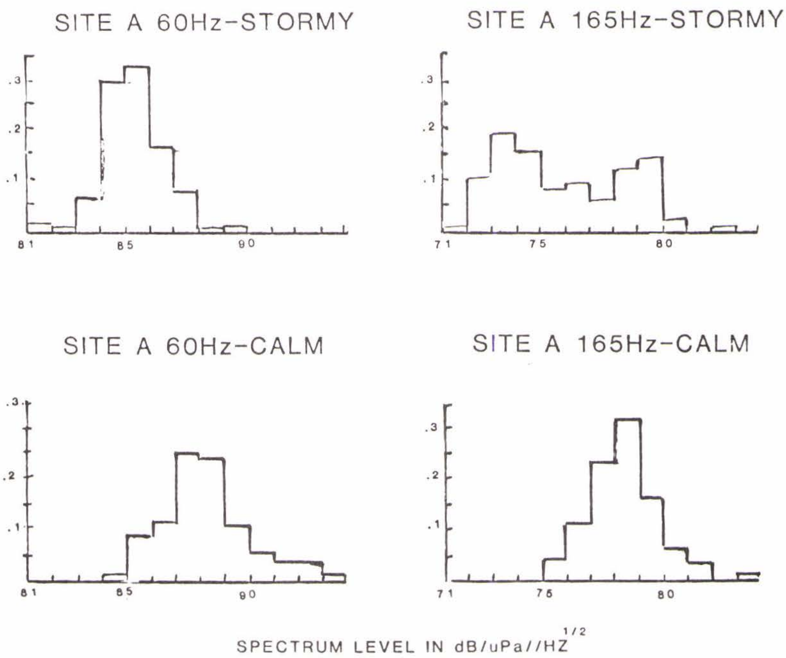

FIG. 4 ONE-HOUR AVERAGE NOISE STATISTICS FOR SITE A FOR A CALM AND STORMY WEEK

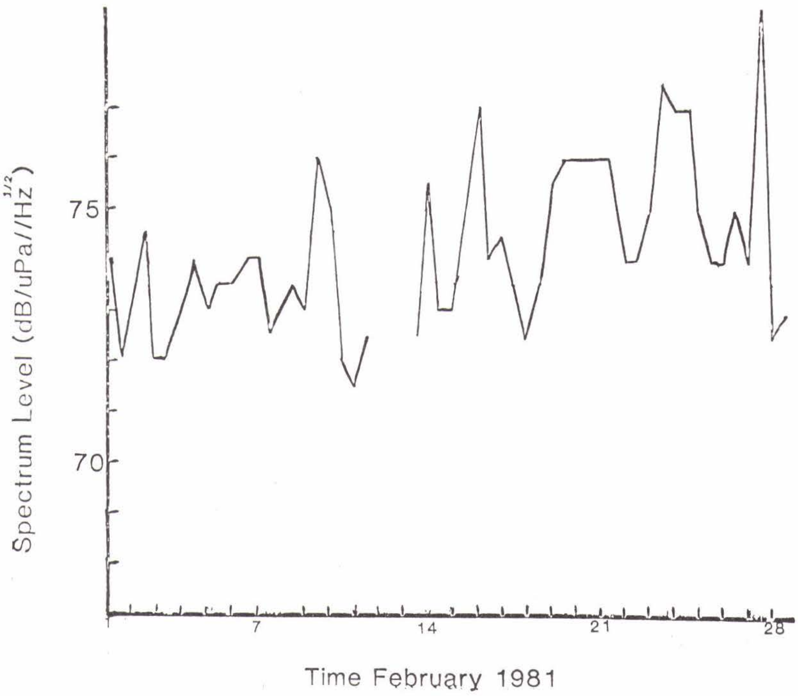

FIG. 5 SITE B — 60 Hz

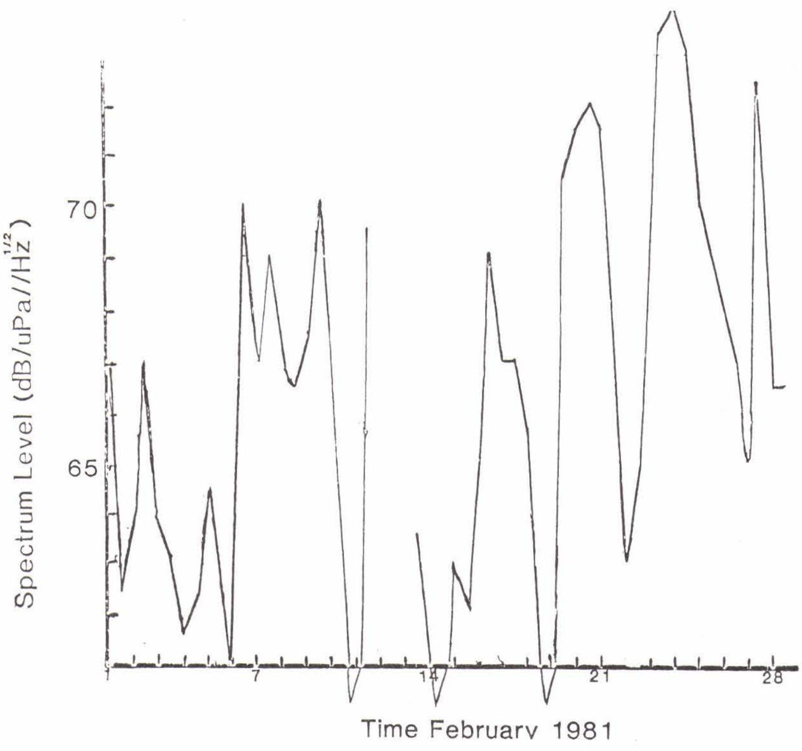

FIG. 6 SITE B — 165 Hz

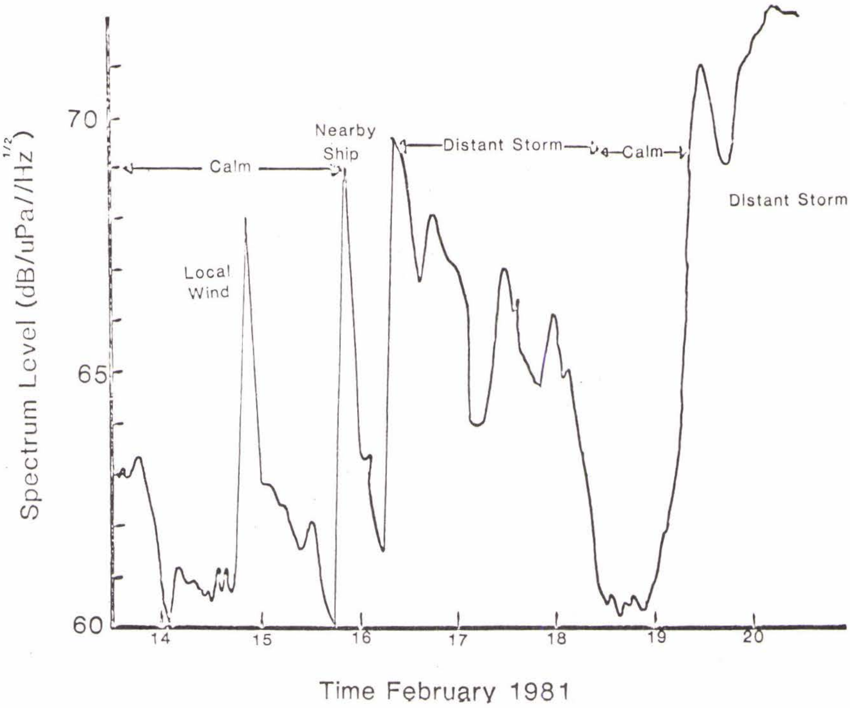

FIG. 7 SITE B — 165 Hz TIME SERIES

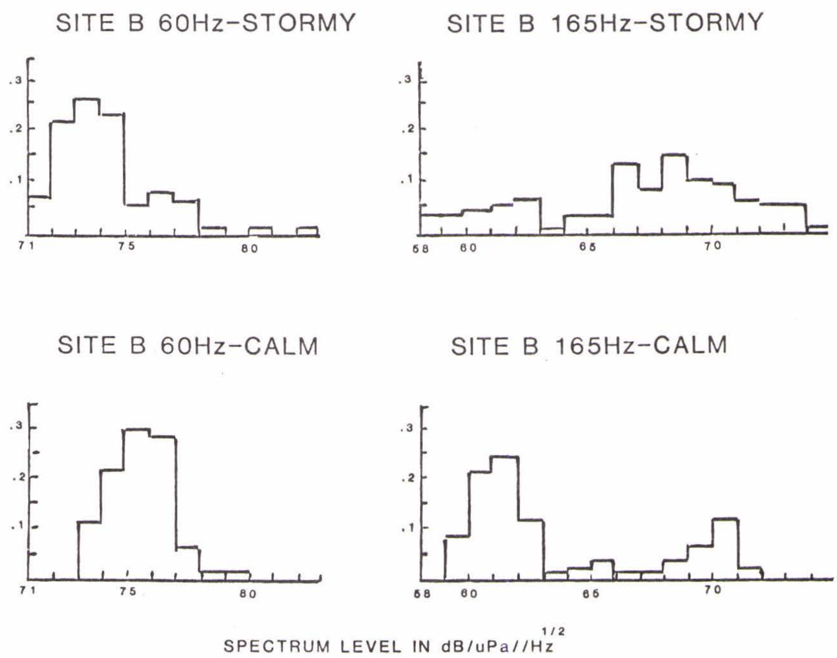

FIG. 8 ONE-HOUR AVERAGE NOISE STATISTICS FOR SITE B FOR A CALM AND STORMY WEEK

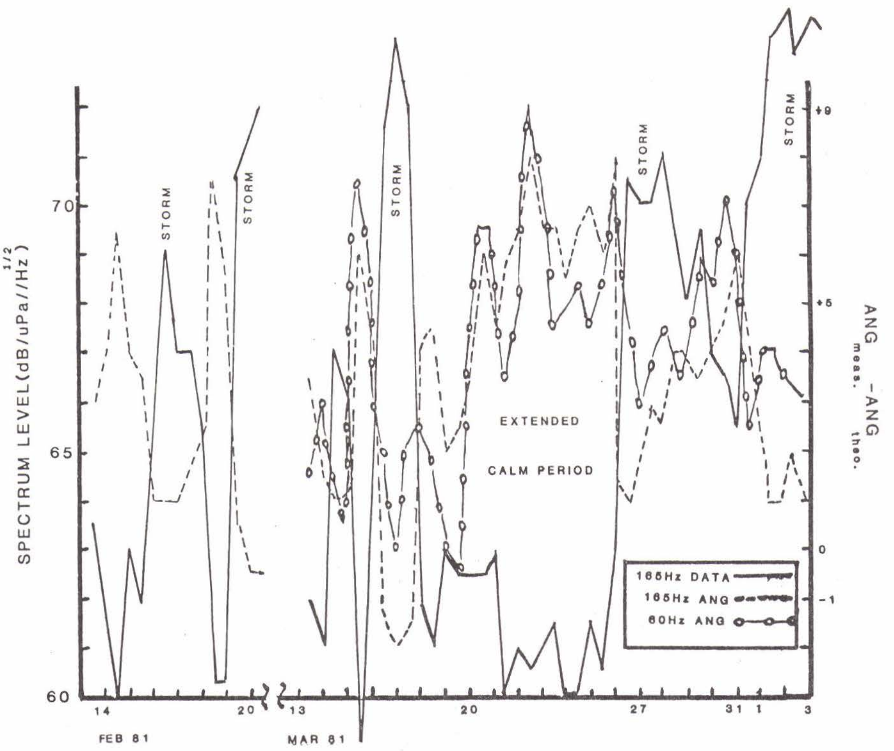

FIG. 9 ARRAY NOISE GAIN AT SITE B AT 60 Hz AND 165 Hz