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LOW-FREQUENCY AMBIENT NOISE IN THE DEEP SOUND CHANNEL - THE MISSING COMPONENT

by

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Low-frequency ambient noise in the deep sound channel—The missing component

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There is an important component of the undersea ambient noise which has generally been overlooked or ignored. It is the noise which arrives at a sensor, located in a deep sound channel, by way of ducted sound propagation. It is generated at the surface and becomes channeled as a result of a gradually sloping sound channel axis and through repeated reflections from a sloping bottom. It can be of sufficient level to dominate the local measurement. Examples are given in which neglecting it leads to incorrect interpretation of results and erroneous conclusions, including agreement between modeling and measurement.

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INTRODUCTION

Ambient noise in the ocean is a complex phenomenon. To begin to understand it, one must have a knowledge of acoustic propagation and noise-source distributions and characteristics. Further, to understand measured noise data requires knowledge of the influence of the measurement system on the data. For practical reasons, past investigations of the noise have concentrated on some aspects that are considered interesting or important, while limiting consideration of the others. This being the case, it is not surprising that a major component of the noise can remain unrecognized while the general appearance is that only relatively minor effects remain to be investigated.

This paper discusses a major component of the noise which has either been overlooked or ignored by the bulk of the scientific community investigating the undersea ambient noise environment. The component being referred to is the noise from distant sources which arrives at a sensor, located within a deep sound channel, by way of ducted sound propagation. The discovery of this component is not the result of new theory, nor can it be attributed to one individual. The "germ of the idea" originated more than 20 years ago when it was observed that the signal level received from a source at a considerable distance could be more than if the source was much closer in range. The application of this principle to establish the existence of noise which travels throughout the oceans by way of the deep sound channel had not been made until recently. Its omission in the interpretation of noise measurement results, and the lack of documented evidence of its theoretical or experimental investigation, indicates it is not presently recognized nor understood by the scientific community as a whole. On a limited basis, this paper attempts to change this.

I. BACKGROUND

When one considers how specialized our theoretical and experimental investigations of the undersea ambient-noise environment have become, since the classic paper by Wenz in 1962,[1] he cannot help being impressed. The investigations include the horizontal[2] and vertical directionality of the noise,[3,4] depth dependence,[5] coherence characteristics,[6] attenuation coefficients,[7] wind[8] and shipping[9] noise source characteristics, processing techniques,[10,11] and various forms of noise models[12-15] to name but a few. In some cases, the investigations are attempting to account for just a few decibels.[7] It tends to imbue a feeling of confidence, that the scientific community understands the first-order effects and simply needs to "chip away" on the second-order effects to achieve a complete understanding of the ambient-noise field. (In this context, second-order effects are those which, if omitted, would affect the noise by only a few decibels.)

There has, unfortunately, been one first-order component of the noise which has generally been overlooked or ignored. It is the noise which arrives at a sensor, located in a deep sound channel, by way of continuously refracted (RRR) ray paths. This noise is usually generated a considerable distance from the measurement location.[4] It can be of sufficient level to dominate the local measurement. There is evidence that some experimentalists understood the importance of this component.[4,16] The modelers, however, being among the major recipients of new knowledge and their models, the barometers with which to measure the total accumulation and utilization of that knowledge, have generally ignored it. The only exception which comes to mind is Ref. 12, in which it is explicitly treated as a separate component.

At frequencies below a few hundred hertz, where shipping is the major source, the noise can be dominated by the noise which travels from afar by way of SOFAR channel (deep sound channel) propagation. The noise from nearby and less distant sources may contribute only a fraction of a decibel to the total noise level. This situation could well exist in most areas of the oceans in the northern hemisphere. Neglecting it can be a serious error, leading to misguided experiment design and incorrect interpretation of the noise environment.

There are several reasons why the "SOFAR channel noise" has been overlooked or ignored. Among them are the following:

(1) All areas do not possess a SOFAR channel.
(2) It is not a significant contribution above a few hundred hertz where attenuation is severe.

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(3) It is masked by high density local shipping.
(4) The most significant noise sources are generally believed to be within a few hundred miles of the sensor.
(5) Consideration of distant noise sources and range dependent acoustic propagation are required.
(6) Low-frequency vertical directionality measurements, which give a direct measure of it, are relatively recent.

II. MECHANISMS

There are several mechanisms by which sound can become trapped within the deep sound channel, including diffraction and scattering of sound originating near the surface and the source being physically located within the channel. The contributions from these mechanisms, however, can probably be considered second- or third-order effects when compared to the total amount of noise which is trapped in the channel.

There are at least two first-order effects which, together can account for the levels that are measured. The first is the axis of the deep sound channel approaching the surface with increasing latitude where large concentrations of shipping exist. This happens in the North Pacific and the North Atlantic. Figure 2 of Ref. 7 illustrates this characteristic in the northeast Pacific. Ships at high latitudes (about 45°–50°N) would radiate sound to the south which could become trapped after only a few surface reflections, as a result of the gradually changing sound speed profile. Once the noise is confined to the channel, a cylindrical spreading law would apply. The importance of this mechanism can be appreciated when one realizes that for economic reasons, ships tend to follow great circle paths across the ocean basins. During the summer this puts large concentrations of ships at high latitudes. During the winter the ships tend to be farther south to avoid the more extreme sea and weather conditions. The surface water is also cooler. This may change the location of the region for good sound coupling into the channel with a corresponding effect on the amount of noise coupled. The relative magnitude of the contribution of this component of the noise to the total SOFAR channel noise is difficult to visualize mentally. However, it involves a "straightforward" range-dependent propagation calculation, which can be handled by current propagation models.[17-19]

The second mechanism, which is important for the introduction of noise into the deep sound channel is the "downslope conversion phenomenon." This refers to the conversion of bottom reflected/surface reflected (BR/SR) raypaths into continuously refracted (RRR) raypaths, when a sloping bottom is encountered at depths within a deep sound channel. Upon reflection, the angle of the reflected ray is less than the angle of the incident ray by twice the slope angle. After repeated reflections, the incident ray angle can become sufficiently reduced to eliminate additional boundary interactions. By this mechanism, sound generated in shallow water, by the usual sources (ships, winds, waves, surf, biologics, etc.), can enter the deep sound channel and become trapped. Once in the channel, it travels with relatively low loss through cylindrical spreading. Northrop *et al.*,[20] give just such an example for noise (explosive sources) originated in shallow water off Point Arena, California, being recorded by hydrophones at SOFAR depths near Eniwetok and Midway. The maximum levels received correspond to shots over the edge of the continental shelf, with levels decreasing by about 10 dB seaward and about 5 dB shoreward. The shoreward reduction was attributed to the increased number of reflections necessary to get the sound into the channel. A seaward reduction was attributed to the bottom becoming deeper than channel depth. For sound generated over the slope, they state "... the first bottom reflection is from the continental slope, where the effect of the steeper bottom slope ($3\frac{1}{2}°$) becomes important in channeling BR/SR ("bottom-reflected/surface-reflected") rays into RRR ("continuously refracted") rays. For example, for a surface shot in 300 m of water a ray that is initially the 0° ray steepens to 11° before it strikes the bottom at a depth of 475 m. and the ray becomes continuously refracted. Steeper rays become RRR after one or more bottom reflections on the lower continental slope." An enhancement in level (less propagation loss) is gained as a result of the RRR propagation having a more favorable geometric spreading law than either RSR (reflected-surface refracted) or BR/SR with no boundary interactions and corresponding losses. Similar experimental results, for noise due to shipping, were reported by Morris.[16] Officer[21] also discusses this mechanism from a theoretical "point of view." A range-dependent propagation model, which can handle a variable bottom profile[17-19] could calculate the propagation loss for such a case.

Gaining an understanding of the importance of the down-slope conversion mechanism for introducing noise into the deep sound channel is straightforward. Assuming an average continental slope of 5°,[22] extending 1000 m into the channel, there exists an offshore surface band which surrounds the continents and extends to about 11.4 km beyond the continental shelf, Fig. 1(a). A similar, probably thinner, band surrounds all islands. Sound from any generator operating within these bands would be expected to eventually find its way into the deep sound channel (assuming favorable conditions). The received level would depend on the distance to the source, the number of reflections, and the bottom loss characteristics of the slope and shelf. In the case of seamounts or guyots (an isolated submarine peak with a flat top), a similar ring or annulus would be expected [Fig. 1(b)] such that, the sound from any surface source within the annulus would be reflected into the deep sound channel. However, since an averaged slope for the upper part of a seamount or guyot is about 15°,[23] only the steeper rays (about 30° on a direct intersection and somewhat less on an oblique intersection) will enter the sound channel after reflection. Assuming 1000 m of height within the channel gives a thickness of the annulus equal to about 4 km and radius somewhat less than that of the guyot or seamount at channel depth. With the large number of seamounts, guyots, and islands within an ocean, the extensive

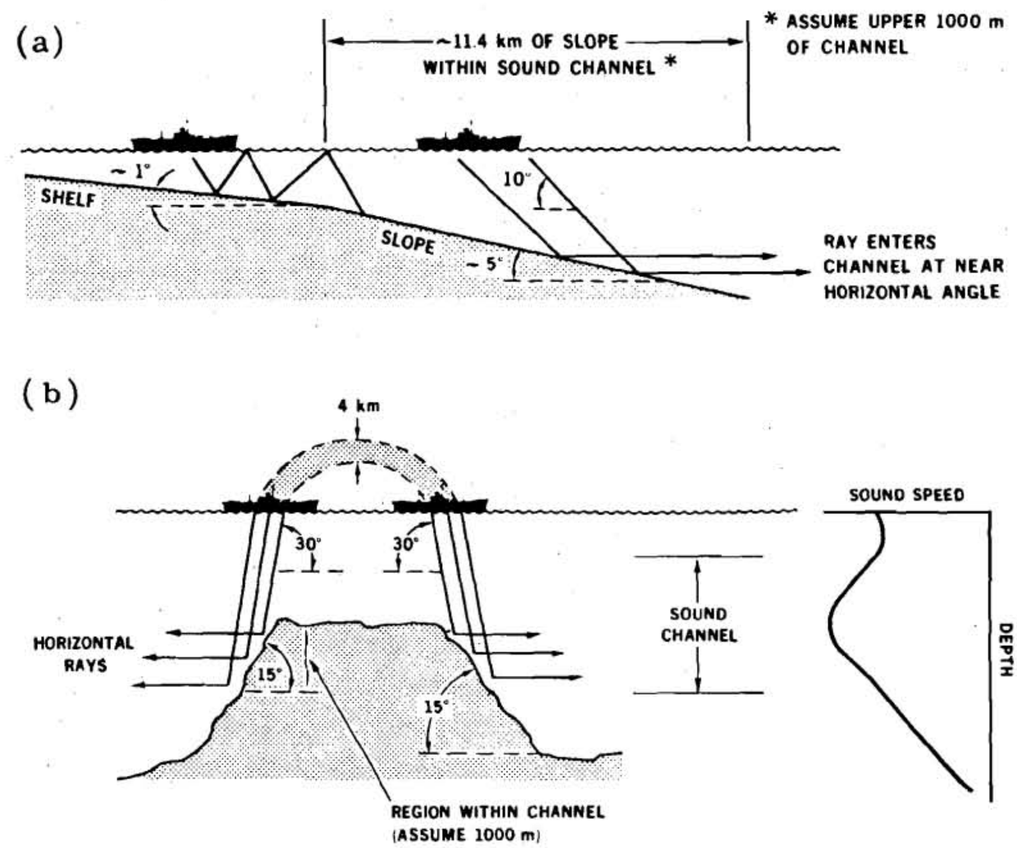

FIG. 1. Conversion of high-angle raypaths to nearby horizontal by reflection off a sloping bottom.

above-shelf surface belt surrounding the ocean, and the large number of ships transiting at high latitudes, it is evident that the amount of noise that could get trapped in the deep sound channels could be considerable.

One need not rely entirely on the establishment of mechanisms for channeling the noise to suggest the possible existence of a major component. Its existence has been established by direct measurement, at least in the case of the Northeast Pacific Ocean. This was accomplished by measuring the vertical directionality of the noise with an array having beamwidths small compared to the channel-limiting ray-angles (less than about 15° or 20° on channel axis). These measurements, reported by Anderson[4] were for four depths within the channel and one below critical depth. These measurements indicate that the low-frequency (100 Hz and below) noise at channel depths was dominated by the component which arrived from angles more horizontal than the SOFAR channel limiting ray angle. In other words, if all other noise contributions were neglected (i.e., from RSR and SR/BR components), the remaining noise (SOFAR component) generally would not differ from the total level by more than a fraction of a decibel. Neglecting the SOFAR component, on the other hand, could cause an error of 7 dB or more and give the incorrect noise versus depth profile. These results are clear evidence of the existence and the significance of the SOFAR noise component.

III. APPLICATION

Theoretical and experimental evidences are available which attest to the existence of mechanisms for introducing noise into the deep sound channel and to the presence of "channeled" noise of sufficient level to dominate the measurement. What remains to be established is that this component is important to the understanding of the noise field, and neglecting it could be a serious error. This can best be done by example.

First, consider what can happen when it is neglected. Weston, for example, presents a model for noise depth dependence in Ref. 15. He compared results from his model with data measured in the Northeast Pacific.[5] By a convenient "trick"[15] he manufactured one below-axis datum from another datum that was above the channel axis. This improved the agreement between modeling and measurement which was then pronounced "acceptable." Utilizing the model results to aid in understanding the measured noise field, Weston suggested that a maximum in the depth profile of the noise had been missed by Morris slightly above critical depth.[15] He further suggested that the region below critical depth may not deserve any particular concentration of measurements. Believing Weston's model, one would likely agree.

Unfortunately, Weston made the mistake of comparing his model results to noise data from a noise field to which the model does not apply. The Northeast Pacific has a significant amount of low-frequency noise trapped within the deep sound channel.[4] Weston's model, on the other hand, has no mechanism for introducing noise into the channel or even acknowledging its existence. Hence he is led to erroneous conclusions by neglecting it. For example, one of Anderson's[4] measurement depths, 3781 m, was approximately where Weston's model predicted the maximum, between 3000 and 4000 m. (Note: FLIP was the measurement platform in September 1973 for the measurements reported by both Anderson[4] and Morris.[5]) The measured result, unlike the modeled result, showed a monotonic decrease with depth.

Now consider a case in which the SOFAR component of the noise is included by the noise model. The location for this example is the Northeast Pacific in the vicinity of the measurements reported by Anderson[4] and Morris.[5] The average distribution for all ships in the Northeast Pacific ocean given in Ref. 24 was used as an estimate of the shipping during the measurement time period. The ocean was then divided into several "pie slice" sectors about the modeled location. This permitted adequate representation of the variations in range to the continental shelves surrounding the basin and in the shipping density above them. The RANDI model[12] was then used to calculate the noise level at several frequencies and depths. This was done two different ways. The first excluded all noise which arrived by way of the deep sound channel (RRR component). The second calculation included it. In addition, since RANDI calculates the noise as a function of vertical arrival angle, the response of a vertical array, having the same hydrophone spacing and aperture as that used by Anderson,[4] was calculated. The ambient-noise calculations were then compared to measured data.

Figure 2 presents the omnidirectional noise level results obtained for 100 Hz. These results are typical of similar comparisons at other frequencies. The solid circles correspond to the modeled 100-Hz levels without the contribution from the noise which is generated at a distance (chiefly above the continental shelves) and eventually becomes trapped within the channel The open circles are for calculations which include the channeled noise. The solid and dashed horizontal lines indicate measured levels with error bounds. The dashed lines correspond to the FLIP data reported in Ref. 5. The solid lines correspond to data measured by an Acoustic Data Capsule (ACODAC) in the same general area but to the north of the FLIP location. The profile at the FLIP location, as well as bottom and critical depths at both measurement locations, are also given.

Figure 2 illustrates that when the SOFAR channel noise is not included, the shape of the noise versus depth profile is similar to that obtained by Weston[15] but not in agreement with measured data. Including the SOFAR component, on the other hand, brings the profile in line with the measured data. The maximum differences between the two modeled results in Fig. 2 is about 7 dB at the channel axis. Below critical depth, the two modeled results were identical as a result of RRR propagation being confined to the channel.

The vertical array responses to the modeled field for 100 Hz are compared in Fig. 3 to the "averaged" data of Anderson.[4] The solid lines are the modeled results for five different depths. The erratic behavior of these responses for angles greater than 20° from the horizontal (0 declination/elevation angle) is due to grating lobes caused by being above the half-wavelength design frequency of the array. The dashed curves are the corresponding averaged measured results.[4] Because of the grating lobe problem, the measured results were

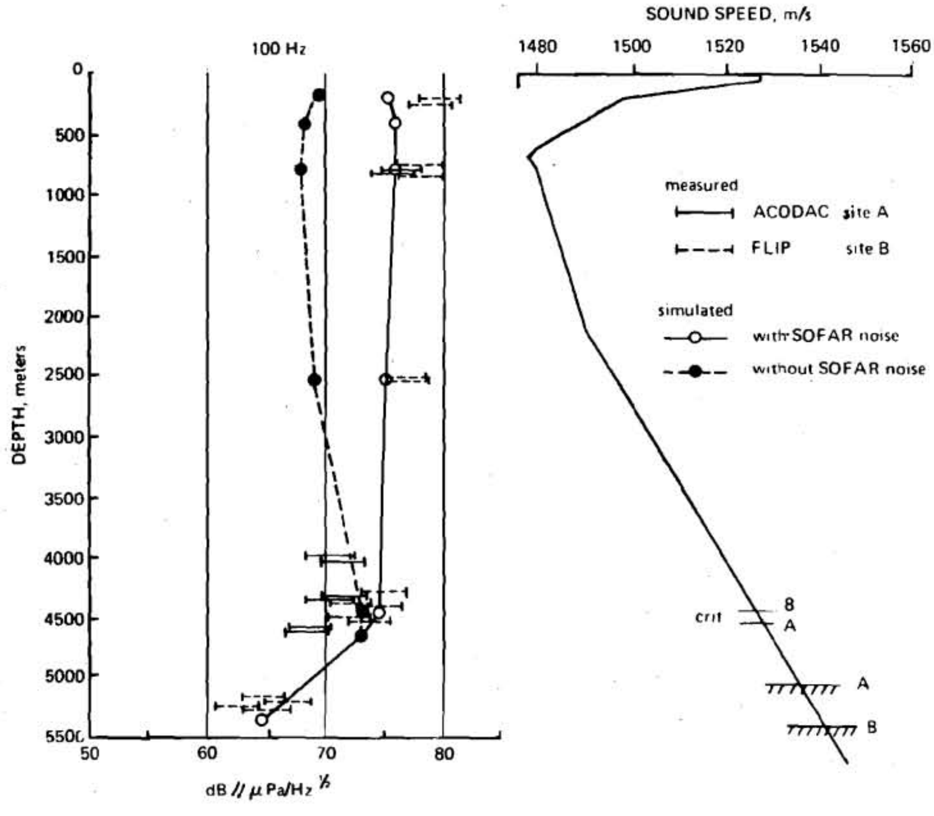

FIG. 2. Comparison of modeled ambient-noise depth-dependence results at 100 Hz for two cases (with and without SOFAR channel noise) with data measured in the Northeastern Pacific Ocean.

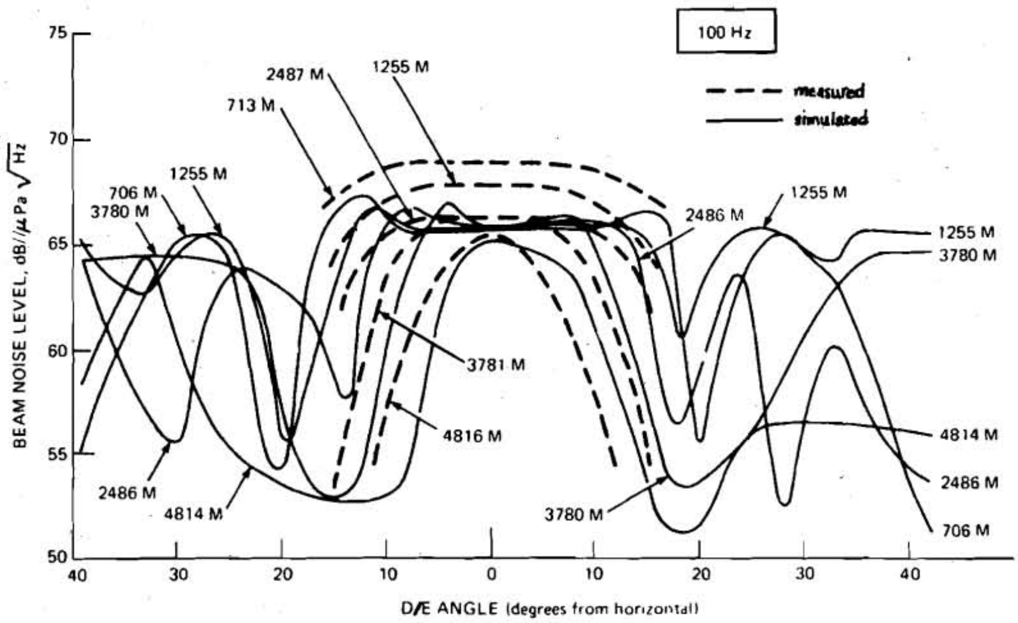

FIG. 3. Comparison of stimulated vertical array response to the modeled 100-Hz ambient noise, at five depths, with the corresponding measured results.[4]

reported only for angles less than about 20° from the horizontal. The agreement between the measured and modeled results is generally good, within two or three decibels. Without the near horizontal arrivals from the deep sound channel, the modeled and measured responses would have deep notches near horizontal at all channel depths. Even if the noise source levels were increased in the model results to compensate for the lack of the SOFAR component near the horizontal, the vertical directionality results could not agree. It is also obvious from Fig. 2 that the depth dependence results, as well, could not agree. An increase in source level merely shifts the depth profile in level; it does not change the shape.

IV. CONCLUSIONS

A simplistic concept of the noise field may be adequate for some cases, but it is not when the noise field is complex. Unfortunately, unless one has a basic understanding of noise fields which are complex, he cannot distinguish one from the other. Considering range-variable acoustic propagation to the basin boundaries coupled with distributions of distant-noise sources is a complexity which accounts for low-frequency noise in the deep sound channel. This component of the noise has been generally overlooked or ignored. This can result in misguided experiment design and incorrect interpretation of the results.

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