Modeling ocean noise on the global scale

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ABSTRACT

In recent years there has been a much greater interest in understanding noise in the ocean. In Europe this interest is tied to the Marine Strategy Framework Directive, which seeks to maintain 'good environmental status' with specific attention to sound. In the U.S. a similar commitment was made to evaluate and improve tools for assessing the impacts of human-induced noise in the ocean. In earlier work we did extensive modeling of soundscapes in the U.S. EEZ to understand the various layers of sound. Pile driving, seismic surveys, shipping, and sonar exercises were all considered. In this work, we are extending this modeling to the global scale. The global scale presents unique and interesting challenges in terms of the computational modeling. We discuss the approach and present preliminary results characterizing the global soundscape.

Keywords: Ocean, Soundscape, Global, I-INCE Classification of Subjects Number(s): 23

1. INTRODUCTION

There is currently much concern about sound in the ocean, viewed as a sort of pollutant that might harm marine mammals or more broadly marine life. It is clear from marine mammal strandings, for instance, that sound can be harmful. However, the scope of the problem is not well understood. Our goal in this work is not to take a position on how great the impact is, but rather to develop maps of the sound level throughout the ocean that can be used to inform conservationists, program managers, and other parties interested in marine spatial planning. These sound maps can be compared to similar maps of population densities for various species to understand the overlap of sound with affected species.

Both the sound maps and the population maps are really multilayered. For instance one may produce sound maps for noise due to shipping, winds, air gun exploration, pile driving, etc. Such maps also allow one to get a sense of which of these various sources contributes most to the overall sound field. Here we will consider just shipping noise. Examples of sound maps for other sources may be found in reference (6).

The general procedure for modeling noise fields in the oceans is literally textbook material, see for example references (1, 2). One calculates the field due to each sound source and sums up the contributions to get the total noise map. This is analogous to calculating the brightness of a room by summing up the contributions of individual light sources. The calculation of the sound field due to a single source typically involves sophisticated propagation models that take into account the reflectivity of the ocean surface and seafloor, as well as refraction within the ocean. However, the propagation modeling also leverages a well-developed literature with many open-source models available (see for instance http://oalib.hlsresearch.com).

That glib description is a good high-level view of the process; however, it makes things sound much easier than they are. Here is a partial list of some of the challenges: 1) the propagation models require accurate global databases for the oceanography, the bathymetry, the sediment thickness, the bottom type, and the boundary roughness, 2) noise sources from very far away can contribute significantly; they get quieter with distance, but the annulus of contribution sources increases in area, 3) one needs to know how loud the sources are and where they are located; different ships, for

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instance, have different noise levels and the same ship may be louder when traveling faster, 4) a global noise field as a function of depth, latitude, and longitude, and frequency involves tens of millions or propagation runs.

We envision that it will be possible to produce global noise maps that are updated like a weather forecast or nowcast. However, there are formidable challenges and this is what makes interesting research problems. In previous work we presented some of those first global noise maps that were generated using the so-called adiabatic mode approximation for global sound propagation. We have also developed a shortcut called the 'locally flat' approximation. It provides similar results with greater ease, as well as some useful diagnostics. However, it is not applicable in certain situations. Generally, the locally flat approximation assumes that the noise field at any point in the ocean can be estimated as if the field were due to an infinite sheet of noise sources at that point and in a flat (stratified) ocean environment. Thus in areas where the 'illumination' due to the noise sources changes rapidly with location, the approximation will break down. Similarly, if the environment varies rapidly (e.g. canyons) the approximation will break down.

2. THE GLOBAL NOISE FIELD DUE TO SHIPPING

2.1 Margin Settings

As discussed above, we begin the process by assembling environmental information. Figure 1 shows a slice of the ocean sound speed derived from the World Ocean Atlas. (We have also used GDEM for this purpose.) This particular slice is taken at the ocean surface, but information throughout the water column is used in the propagation modeling. Sound propagation occurs not just in the ocean volume but also within the sediment so additional databases are required to characterize that. For instance the sediment thickness derived from a NOAA database is shown in Figure 2. For brevity we skip displaying results of the other databases that are used; however, bathymetry and sediment grain size is also included, and the sediment is typically terminated with basalt.

Propagation modeling must then be done for a grid of sources covering the globe. The sources are positioned at a depth of 6 m below the ocean surface representing a nominal depth of the propeller of a ship. The propeller is typically the dominant noise source. In the introduction we simplified the description by assuming the actual source level is included in the propagation calculation. In practice we do the calculations for a noise of unit strength and then weight the results after the fact using the distribution of noise sources that is of interest. By splitting the process in these two stages, we can reuse the noise fields with different noise sources, e.g. different classes of ships, and produce noise maps for a variety of sources within minimal additional effort.

Figure 3 shows how we grid up the ocean using nodes spaced roughly every 100 km apart. This particular plot is actually just a subset of the North Pacific. Details of the process may be found in references (1, 4), but normal modes of the ocean are calculated at each node and the sound field is calculated along a fan of radials using adiabatic mode theory. The modes are interpolated using bilinear interpolation within each triangular tile of the grid. The fan in the lower left corner is just one example of the roughly 65,000 source points that are used to cover the globe.

In Figure 4 you can see how each node of the grid is used to calculate a noise field (approximately every 10^{th} node in latitude and longitude from Figure 3 is shown). We are actually displaying transmission loss plots here, so the noise field is obtained by forming SL – TL where SL is the source level and TL is the transmission loss in dB using consistent units. This particular plot is schematic in the sense that the real calculation is done with a finer grid of 1 degree or very roughly 100 km around the world. Many of the terms in this process are frequency dependent such as the source level, the attenuation in the sediment, and therefore the transmission loss. A calculation is done for each frequency of interest.

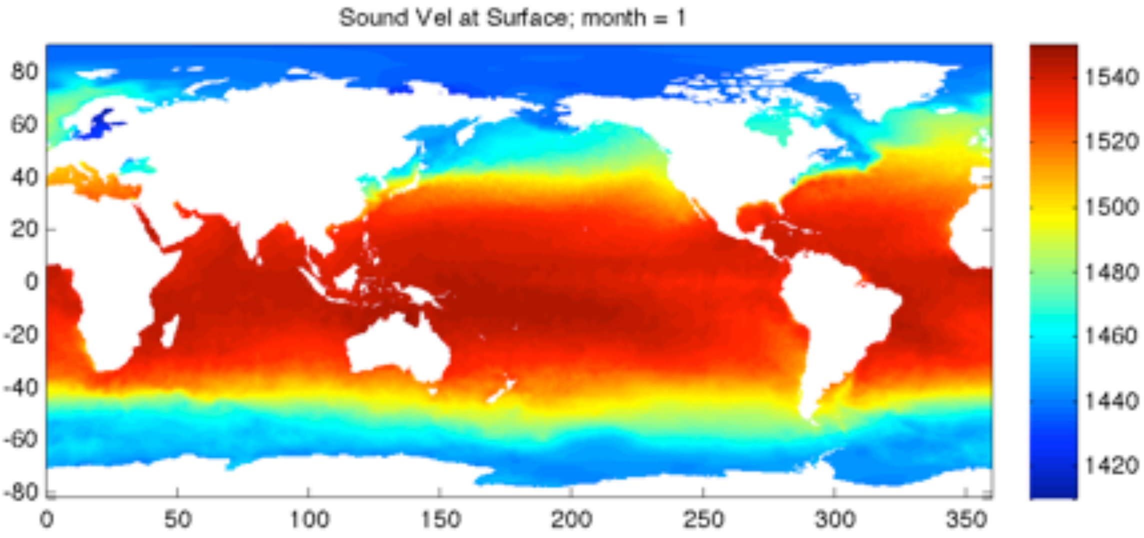

Figure 1 – Ocean sound speed at the surface derived from the World Ocean Atlas.

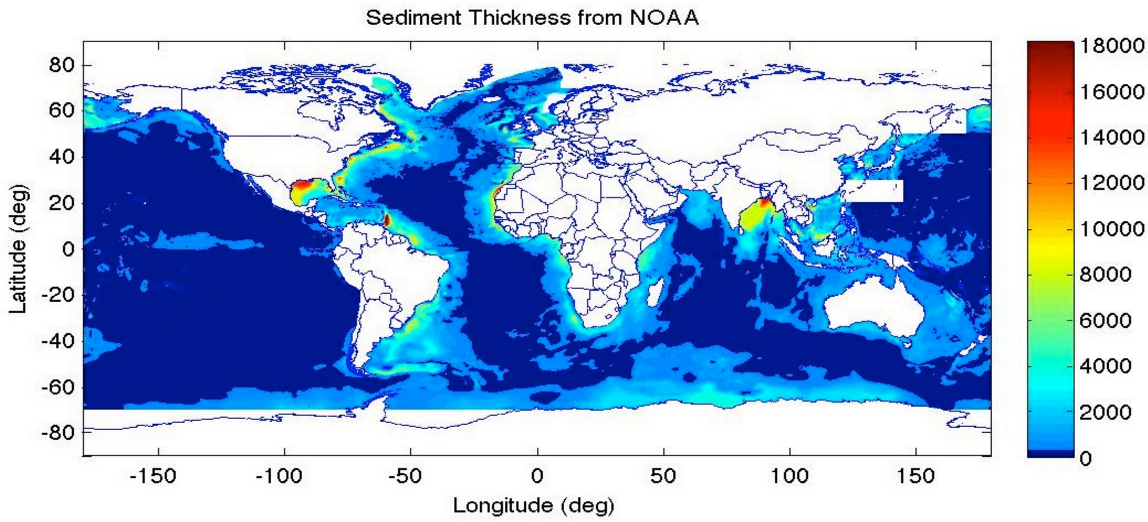

Figure 2 – Sediment thickness in meters from the NOAA database.

The next step is to weight the sound fields associated with the virtual sources using the actual source levels. The key database here is from the Voluntary Observing Ship program (VOS), which provides information on the waypoints of ships. Approximately 12% of the global fleet participates in the program. A map of the shipping traffic is shown in Figure 5. We convert this data to a shipping density (ships per km^2). Then we convert that to a source level density based on published data in reference (1) for the source level of ships. That becomes the 'illumination' used to weight the virtual sources.

Finally, in Figure 5 we show the final soundscape or noise map for 100 Hz due to merchant shipping. The color scale shows the noise level in dB relative to a standard reference of 1 micropascal^2/Hz. This is really just a slice of a multi-dimensional matrix representing the field as a function of frequency and the spatial coordinate. The receiver depth here is 200 m.

The resulting soundscape is really a combination of many influences. Most obviously we see the effect of ships with the traces of major shipping lines clearly visible. However, if the noise level were directly derivable from that we would not require the propagation models. The propagation model brings in the quality of the ocean in each part of the world in terms of how effectively it propagates noise. On this scale it is hard to see but we find that the mid-Atlantic ridge can strip out noise energy, for example. On the other hand, one can see a general increase in noise level towards the poles. This is attributed to the change in the sound speed profile, which tends to produce cooler water near the surface at the poles. This in turn leads to a more effective channel in terms of acoustic propagation.

3. CONCLUSIONS

The noise maps due to shipping presented here are preliminary—our focus at this stage is mainly on developing the processes. Their accuracy is limited principally by the quality of the environmental information, especial sub-bottom properties. In addition, the broader community is conducting on-going work to understand better the sources levels. However, we believe these maps can serve an important role in illustrating what may be possible on a global scale, and hopefully motivating further research.

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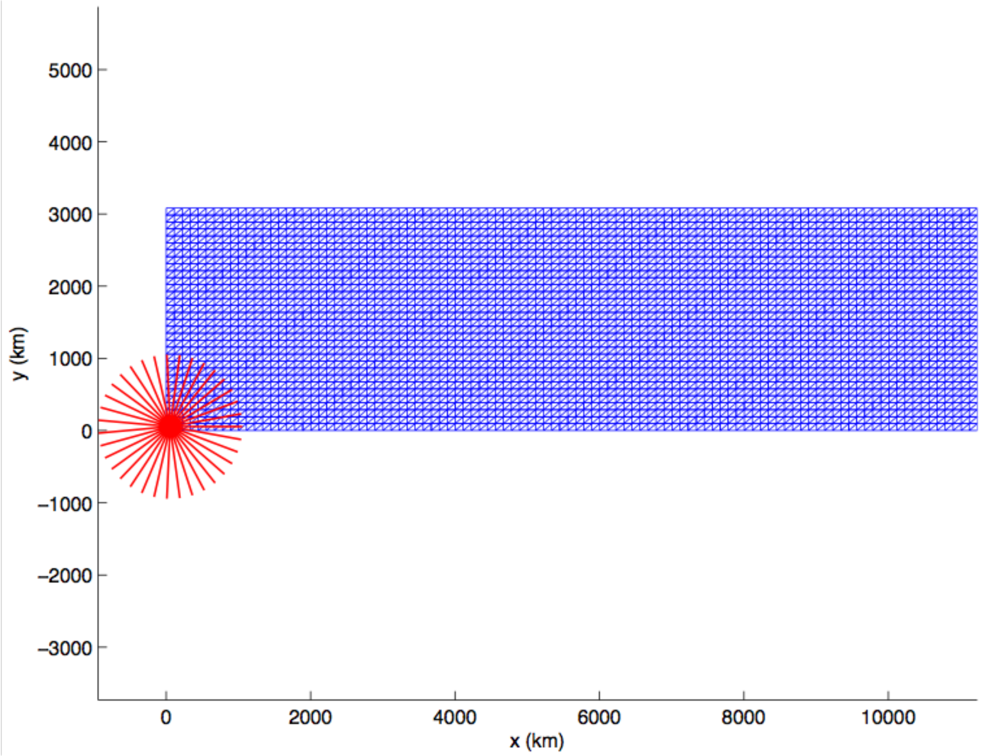

Figure 3 – Sound propagation calculations are done for a fan of radials and for a grid of noise sources spaced roughly every degree around the globe. There are about 65,000 (360x180) such virtual noise sources for the entire globe and a fan of radials is generated for each.

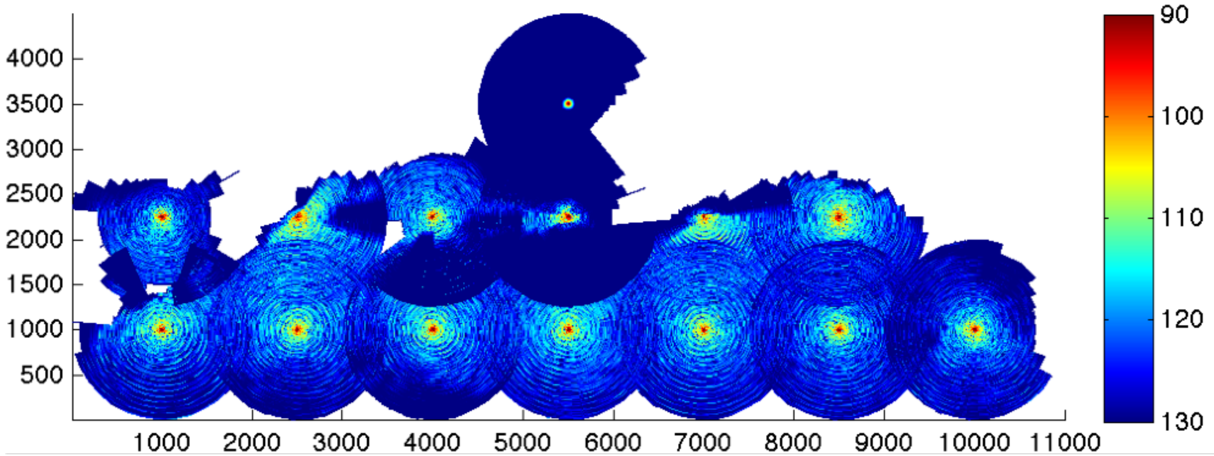

Figure 4 – Sample transmission loss plots in dB for each virtual noise source. The fine rings in each disc are convergence zone patterns caused by refraction in the water column. The example here shows virtual source spaced every 1000 km. In the actually calculation they were done every 100 km.

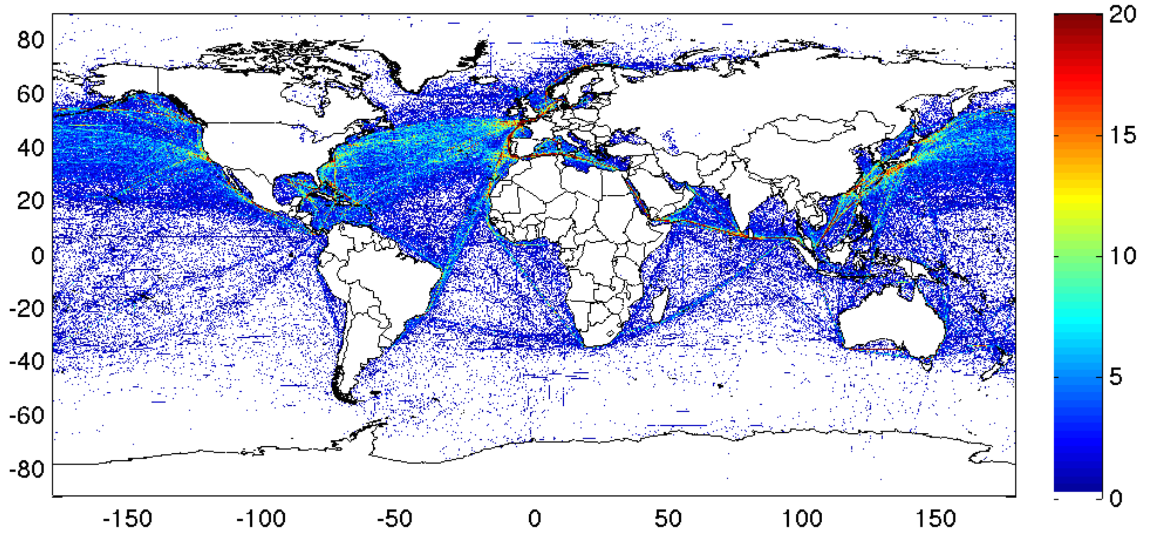

Figure 5 – Global shipping in units of km of track per unit area.

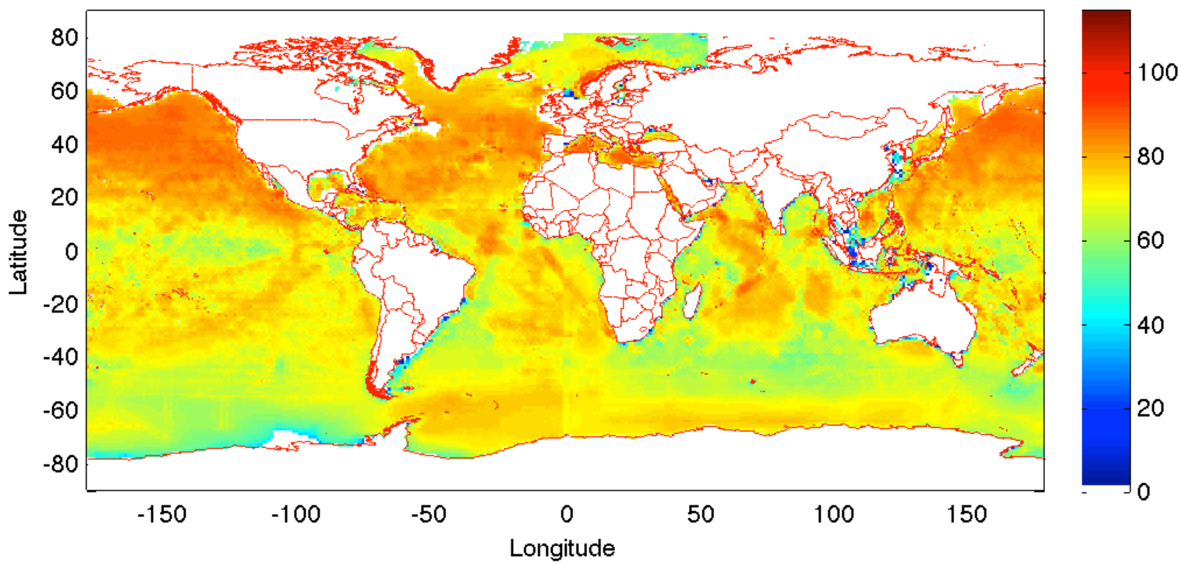

Figure 6 – A final soundscape or noise map for the entire globe for one frequency and one receiver depth. The noise levels are presented in dB using the standard reference of 1 micro Pascal and for a 1-Hz band.

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