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4aAB3. Global ocean soundscapes

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There has been increasing interest in understanding the effects of human-induced noise on the marine environment. Under a variety of programs around the world, researchers are modeling "soundscapes" that depict the undersea sound fields in localized areas such as national EEZs. In this work we develop techniques for modeling soundscapes on a global scale and present as an example world maps of ship noise. The resulting soundscapes compose a database for global shipping noise. The noise due such shipping can travel very long distances producing sort of a background haze for localized modeling in the EEZs.

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INTRODUCTION

In 2010 the National Oceanic and Atmospheric Administration created an Underwater Sound Field Mapping Working group (USF Working Group, 2012) to demonstrate a preliminary capability to produce “soundscapes” that would enable marine conservationists to better understand these effects. The U.S. EEZ was the area of interest and a variety of sound sources were considered including pile driving for a proposed wind farm installation, a Navy sonar exercise, air-gun surveys for seismic explorations, and ship traffic. It was recognized at the outset that although the initial effort was focused on the U.S. EEZ, the noise from global shipping would provide a background level that needed to be included. In parallel to the NOAA effort a separate effort was begun to plan an International Quiet Ocean Experiment with a particular interest in global soundscapes. Some of the early modeling results were presented there (Porter and Henderson, 2011).

The basic techniques for ocean noise modeling are well developed (Carey and Evans, 2011). However, modeling the soundscape due to global shipping is a fairly challenging task. As in any underwater acoustic simulation the first problem is to get the important environmental information such as the bathymetry, ocean sound speed, and bottom type. This is always difficult and particularly on a global scale. Secondly, the modeling requires an enormous number of field calculations. Normal mode, ray/beam, parabolic equation, and heuristic models are all possible approaches with varying advantages and disadvantages. Here we demonstrate a 3D normal mode approach that provides a full wave solution with modest computation time.

ENVIRONMENTAL DATA

A mentioned above, a key issue in this sort of calculation is to find the environmental data needed for the entire globe. For the ocean sound speed, we used the World Ocean Atlas (WOA) annual average, already on a 1-degree grid. The World Ocean Atlas is a climatology that provides monthly, seasonal, and annual averages and will provide the basis for a similar noise climatology.

For bathymetry, we converted the SRTM-30 bathymetry (http://topex.ucsd.edu/WWW_html/srtm30_plus.html) to a 1-degree lat/lon grid. For bottom properties, we combined the NOAA sediment thickness database, the public-distribution version of the Navy’s BST (Bottom Sediment Type), and dbSeabed instaar.colorado.edu/~jenkinsc/dbseabed/). Examples of some of these environmental inputs are shown in Fig. 1.

SOURCE LEVEL DENSITY FOR SHIPS

The next key ingredient is the source level data. For shipping, we used the global merchant shipping based on the VOS (Volunteer Observation System) from Halpern et al. (2009). Approximately 10% of the global fleet provides their ship positions to VOS. To agree with the source levels of the modern global fleet, the VOS ships were calculated to consist of about 82% ANDES type “Merchant Vessel” and 18% “Large Tanker”. The global shipping data was provided in terms of km of track per 10x10 km square. This information was then reprocessed into SL density (ρ_{SL}) maps by assuming a fixed speed to calculate a dwell or residence time for a ship in each cell.

Figure 2 shows the resulting SL density maps for 200 Hz. The VOS database we used does not give fractional ships in a cell (kilometers of ship tracks per km^2) causing a jump from zero to a lower limit on the SL density calculated from 1.0 ships. For instance, the minimum SL density is 79 dB for “Merchant Vessels” at 50 Hz.

GLOBAL SOUNDSCAPES

Regardless of the model type, we first pre-calculate the transmission loss (TL) for a grid of hypothetical sources covering the globe. We then compute the noise level (NL) by convolving this TL data with a source level density (ρ_{SL}). This two-stage approach allows us to rapidly produce updated soundscapes as the SL density changes due to different source types or to temporal variations. One can imagine, for instance, ocean soundscapes that are updated daily based on the changing shipping and winds but using the same TL calculations.

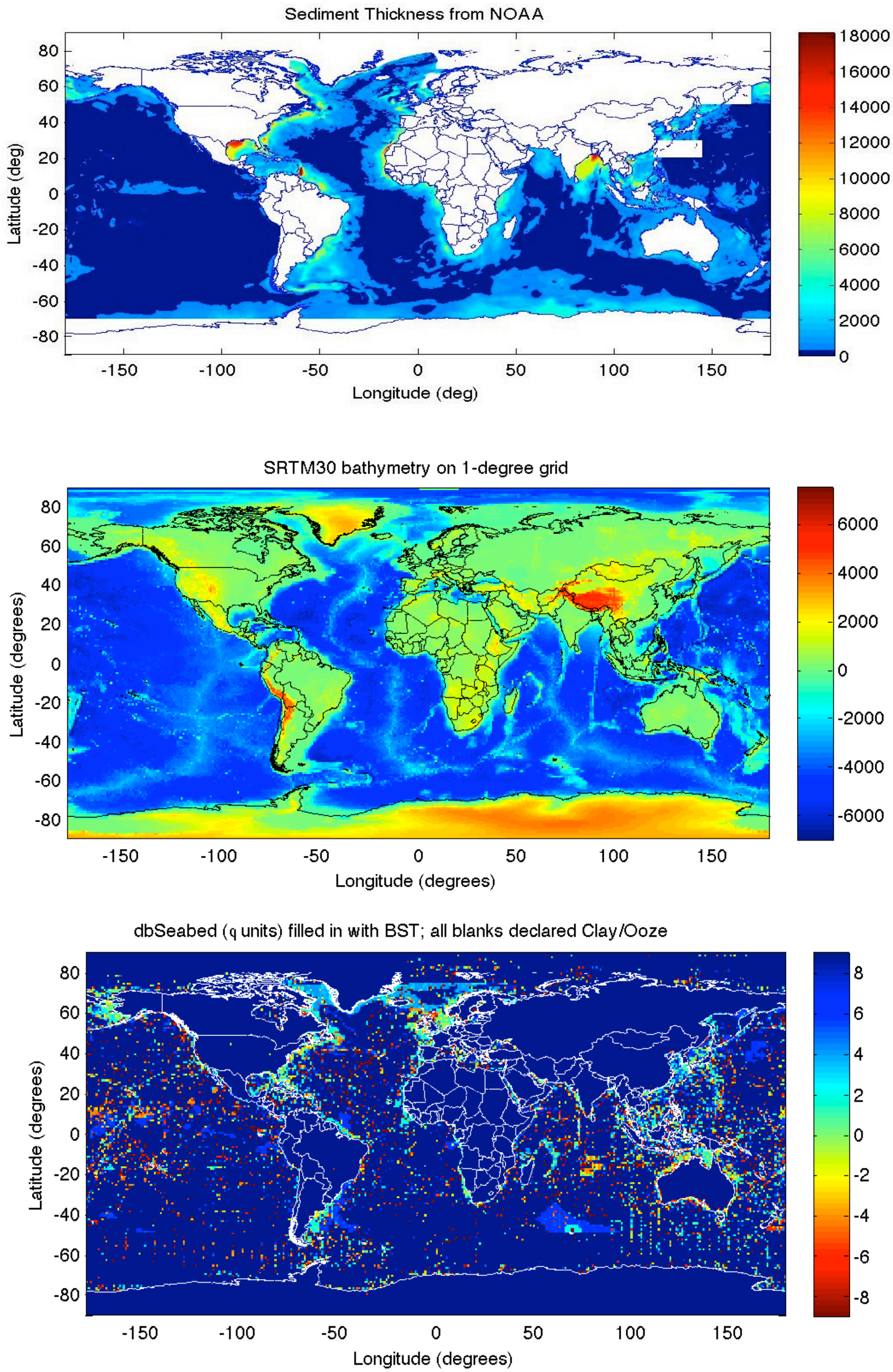

FIGURE 1. NOAA sediment thickness (upper), SRTM bathymetry (middle), and global sediment grain-size in phi units (combined from dbSeabed and BST databases) (lower).

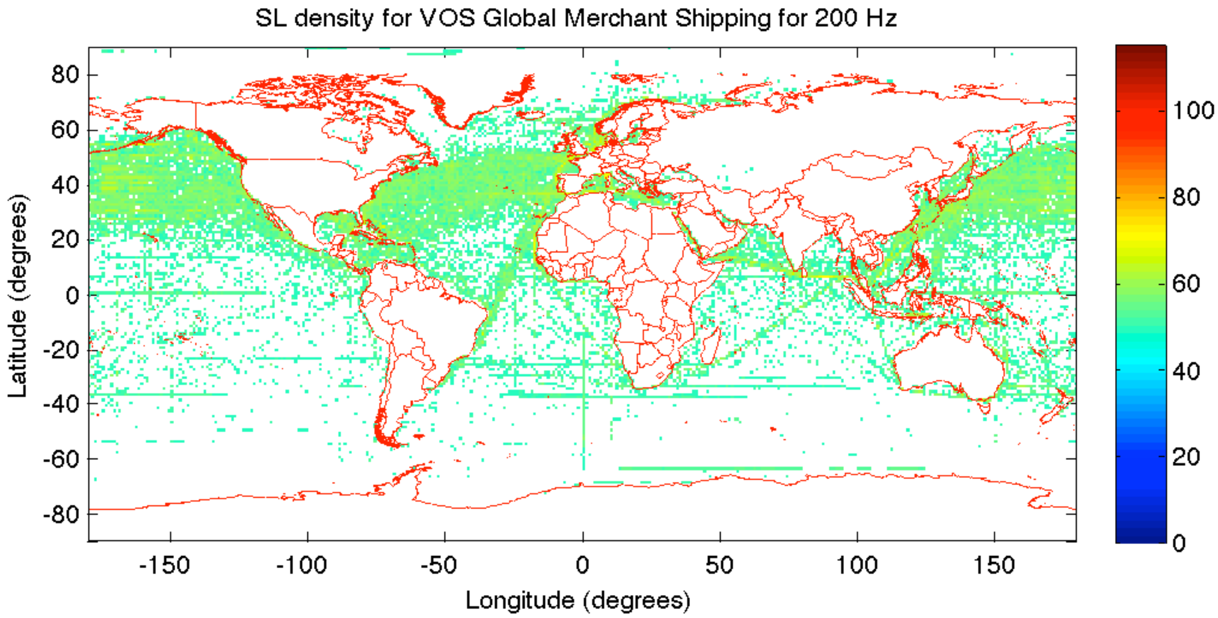

FIGURE 2. Source level density (dB re (1 microPascal)^2 / Hz @ 1 m/m^2)) at 200 Hz due to merchant shipping for the year 2006.

For the global TL calculations we place virtual sources at a 1-degree spacing over the entire globe. Thus there are 360 x 180 source coordinates. At each source location we calculate the acoustic field along a fan of radials with a 10-degree angular spacing and a 500 km radius. Thus we are calculating the transmission loss along 360 x 180 x 36 slices. This has been done for frequencies of 50, 100, 200, 400, and 800 Hz, and depths 5, 15, 30, 200, 500 and 1000 m. The normal mode method provides all the receiver depths in a single TL run so the total number of runs is about 10 million. (Land areas are omitted.)

Clearly attention must be paid to the propagation model to enable 10 million runs to be done reliably and in a reasonable amount of time. Our initial approach uses the KRAKEN program (Porter and Reiss, 1984) to calculate the normal modes of the ocean at each of the lat/lon points. The field is rapidly calculated by doing an adiabatic mode calculation along each radial using the FIELD3D code. The combined packaged is referred to as KRAKEN3D and became the basis of the Navy's Wide-Area Rapid Acoustic Prediction System (WRAP) (Kuperman, et al., 1991). This approach has many advantages; however, it is likely that mode coupling will need to be included in some parts of the world, depending also on the source frequency.

The total run time for these 10 million TL slices covering the entire globe is several days on an iMac computer and is therefore quite manageable. The calculations are 'trivially parallelizable' since the modes at each lat/lon coordinate and each frequency are completely independent. Thus using multiple processors it is very practical to update the global soundscapes several times per day as new oceanographic forecasts are provided. Run time is proportional to the square of the frequency.

This sort of calculation involves quite a few steps, particularly when we include different sources such as multiple ship-types, air-gun arrays, pile drivers, and sonar. As a means of ensuring the calculations are correct, we have structured the algorithms so that all source types are first mapped into a SL density. This SL density represents the power spectral density in a 1-Hz band for a nominal 1-m source depth and per unit area (dB re (1 microPascal)^2 / Hz @ 1 m/m^2). These SL density maps are very informative in themselves to get a general sense of the energy the source is putting into the water column. As mentioned above, the final stage is then to convolve that SL distribution with the channel response to bring in the propagation effects.

Finally we convolve the SL density map with the transmission loss data to obtain the global soundscapes. This has been done for 1-Hz bands at 50, 100, 200, 400, and 800 Hz, and depths 5, 15, 30, 200, 500 and 1000 m. Figure 3 shows an example global soundscape for a 200 Hz frequency. Soundscapes for other frequencies and depths are provided on http://oalib.hlsresearch.com/ as KMZ files that can be viewed in Google Earth.

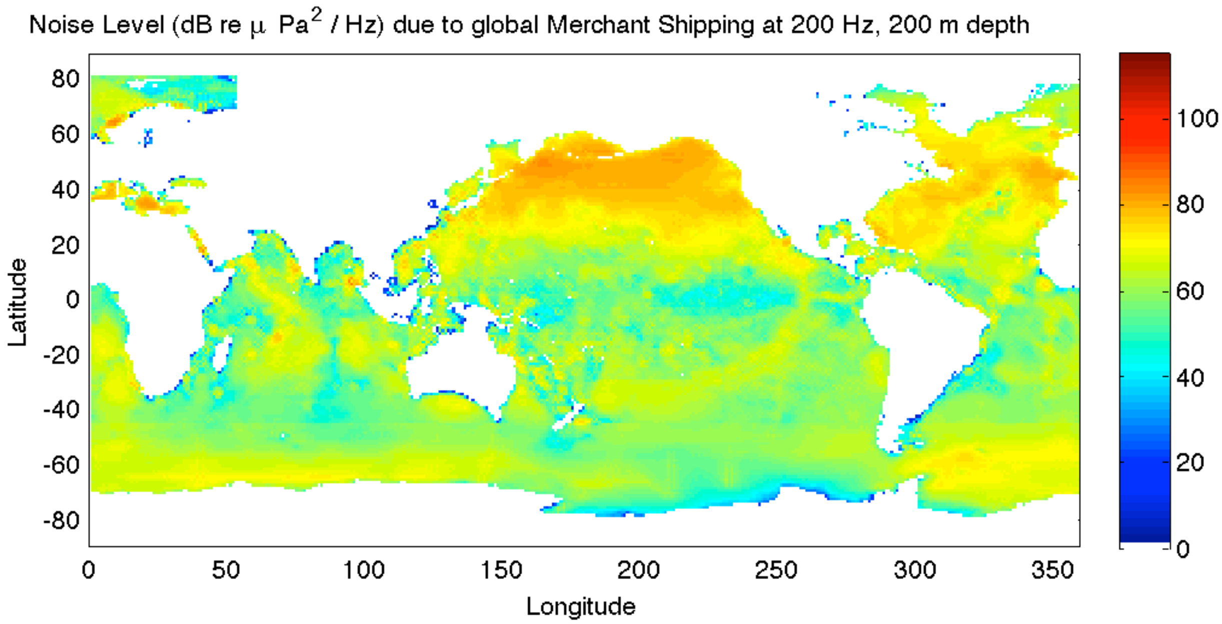

FIGURE 3. Modeled noise spectrum level at 200 Hz and 200 m depth due to merchant shipping for the year 2006.

CONCLUSIONS

The global ship-noise database presented here provides soundscapes that can be useful for marine spatial planning. In the process of producing them, we have demonstrated that full-wave acoustic models can be readily used (i.e., with reasonable run times) for such calculations. We emphasize that these are preliminary model results that undoubtedly will be refined over time. We anticipate further improvements in the environmental databases that feed the noise simulator, further improvements in the acoustic modeling, and inclusion of many different natural and human-induced noise sources.

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