A modelling approach to spatial extrapolation of ocean ambient noise measurements

Kevin D. HEANEY[1]

[1] OASIS Inc, Fairfax Station USA

ABSTRACT

With the growing understanding that anthropogenic ocean noise can have potential harmful impacts on the ocean ecosystem, many national environmental agencies are beginning to grapple with the task of assessing the levels of ambient noise in their regional waters and an understanding of these impacts. The challenge facing national regulatory agencies, in particular European Union Member States, which are now required to come up with a plan for assessing the environmental health of their waters, is to use limited resources intelligently to estimate the overall impact of man-made sounds. In this paper, we present an efficient modeling approach for low-frequency sound and a way forward for incorporating measurements into an environmental assessment framework.

Keywords: Ocean Ambient Noise, Propagation Modeling, and Measurements I-INCE Classification of Subjects Number(s): *13.5.2*

1. INTRODUCTION

With increased ocean acoustic observational capabilities, particularly provided by remote recording equipment, there has been a growing understanding of both the level of acoustic energy put into the ocean and regional seas and the sensitivity of the marine environment to ambient noise levels. The challenge is to develop a methodology for estimating the current state of the regional national seas and to extend this to the large basins, which are considered “international water”. The European Union has moved towards classifying man made ocean ambient noise as a pollutant and has instructed Member States to devise a methodology for demonstrating that their national waters are in a state of Good Environmental Status (GES). Although a precise definition of GES is a profoundly difficult biological question, it can be summarized by a demonstration that the man-made sounds are having no adverse affects. This approach requires both an estimate of the current state of the ambient noise field and an understanding of the natural ocean ambient noise features.

Any methodology for quantifying the current state of the ocean noise environment must be an intelligent combination of modelling and measurements. Regional seas, in particular, are diverse acoustically and source density distributions are complex. The ambient noise statistics in these regions are expected to be non-stationary and an approach based entirely upon measurements would require a sampling of each region with stationary statistics. A model only approach is equally tenuous because of the combined lack of environmental knowledge suitable for confidence in propagation models and the limited understanding of source spectral levels for surface ships and other man-made sources.

In this paper the beginnings of an approach to combine measurements and models to map out the ambient noise (and it’s associated statistics) in a complex propagation environment is presented. In Section 2, we begin with the presentation of a new instantiation (re-coding in C with an environmental front end) of the popular RAM Parabolic Equation(1) model. This model is applied to range-dependent ambient noise prediction in the shallow water Skaggerak in northern European waters and then to the deep-water ambient noise problem off of the Azores. Section 3 addresses the use of models to determine the acoustic horizontal isotropy of the ocean. In this section, a basin-scale methodology for determining how far measurements can be suitably extrapolated. In Section 4, an iterative methodology for modeling and measuring is outlined for the initial

[1] Oceansound04@yahoo.com

development of a comprehensive understanding of the ambient noise environment.

2. AMBIENT NOISE MODELLING

2.1 The PEREGRINE Model

OASIS has developed a version of the Parabolic Equation (Peregrine), which easily incorporates the 4D (lon, lat, depth, time) environmental field for computation of the 3D (either with Nx2D or full 3D propagation) acoustic field for regional or global scale problems. Peregrine is based on Michael Collins' split-step Padé PE marcher (RAM), a widely used acoustic model for low to mid frequency undersea sound propagation modelling. Starting from Collins' RAMGEO 1.5 Fortran code, Peregrine has been ported to C, refactored for performance on modern computers, optimized for fully range-dependent problems, and is able to interpolate directly from geographically defined ocean field and bathymetry inputs. Sound speed profiles were obtained from The World Ocean Atlas. It includes an optional 3D azimuthal coupling operator, integrated time-domain output, range and depth antialiasing, volume attenuation, and two-parameter sediment specification (thickness and grain size) among other improvements. For broadband, Nx2D, and 3D problems, Peregrine will automatically use all available CPUs in parallel.

Peregrine has two specific developments that are relevant to the ambient noise prediction problem. The first is the inclusion of the full 4D environmental field as a netcdf, which is mapped to memory for direct access. This means individual range/depth input files are never calculated and the intensive process of writing these to disk and reading them for computation of radials (followed by a writing of the field and then an interpolation to a display) is by-passed. The second innovation is that Peregrine determines the radials required for the particular source/receiver combination and can easily be set up to do the source (specified lon, lat, depth) to everywhere – fixed grid of lon, lat depths.

2.2 Instantaneous Ambient Noise Field

The source-to-everywhere, particularly with a gridded receiver output, permits the computation of the acoustic power received at every point in the ocean (within the output grid) for each interferer. These can easily be summed incoherently in power, with the inclusion of a source term, to develop a map of the predicted instantaneous ambient noise field. These maps have come into vogue lately and are commonly referred to as noise maps, or (less commonly) as soundscapes. An example of a noise-map is shown in Figure 1, where an AIS display of surface shipping locations in the Skaggerak (from marine-traffic.com) is digitized to provide shipping locations at a particular instant in time. The acoustic field for each ship is then run from the source position to each output grid cell. Note that the PE step size is generally smaller than the output grid size and is defined (internally to Peregrine) to provide adequate vertical angle resolution. The World Ocean Atlas volume cube defines the ocean environment. The bathymetry is from ETOPO01. A medium-sand sediment with a 40 m sediment thickness is used for this environment. The source levels were set using a nominal model for source levels at 60 Hz based upon the ship types within the AIS information stream.

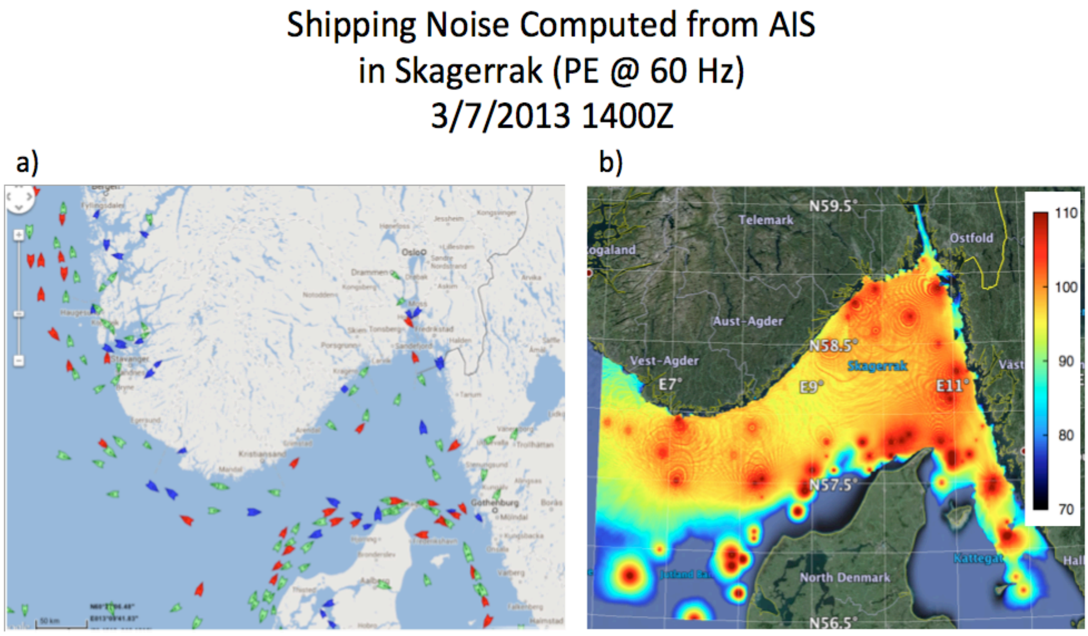

Figure 1 – Instantaneous Shipping Noise Model Computation for the Skaggerak.

The resulting field in Figure 1 b demonstrates several issues relevant to the challenge of measuring the ambient noise. The first observable is the difference in propagation regimes between very shallow water (~ 15m) in the central Baltic where propagation interference patterns don't exist and propagation is very poor. In these regions a local ambient noise is likely to be driven entirely by the nearest ship. This situation is quite different in deeper water, such as in the central Skaggerak – where many, many ships can add to the total received level. In the open ocean environment, as will be displayed below, this is even more pronounced.

2.3 Seasonal Average Modelling

In this section a seasonal average of the deep-water ambient noise model depicting the spatial dependence of the average ambient noise at 60 Hz (surface shipping) in the region of Madeira and the Canary Islands is presented. Rather than modeling each individual ship, a shipping surface density is used. This surface density, in this case, is taken from the US NAVY HITS model, which is not publically available. An average of land-based AIS could easily generate such a map and there are other publically available surface ship density models. For this computation, the surface shipping density was discretized into a 32 x 32 grid. Each position was then used as a source position to the Parabolic Equation Model Peregrine. The output acoustic field was range averaged (smoothed) to the resolution of the input field (every 15 km). This averaging process takes into account the spatial distribution of sources. These were then summed over all source positions to yield the output plot.

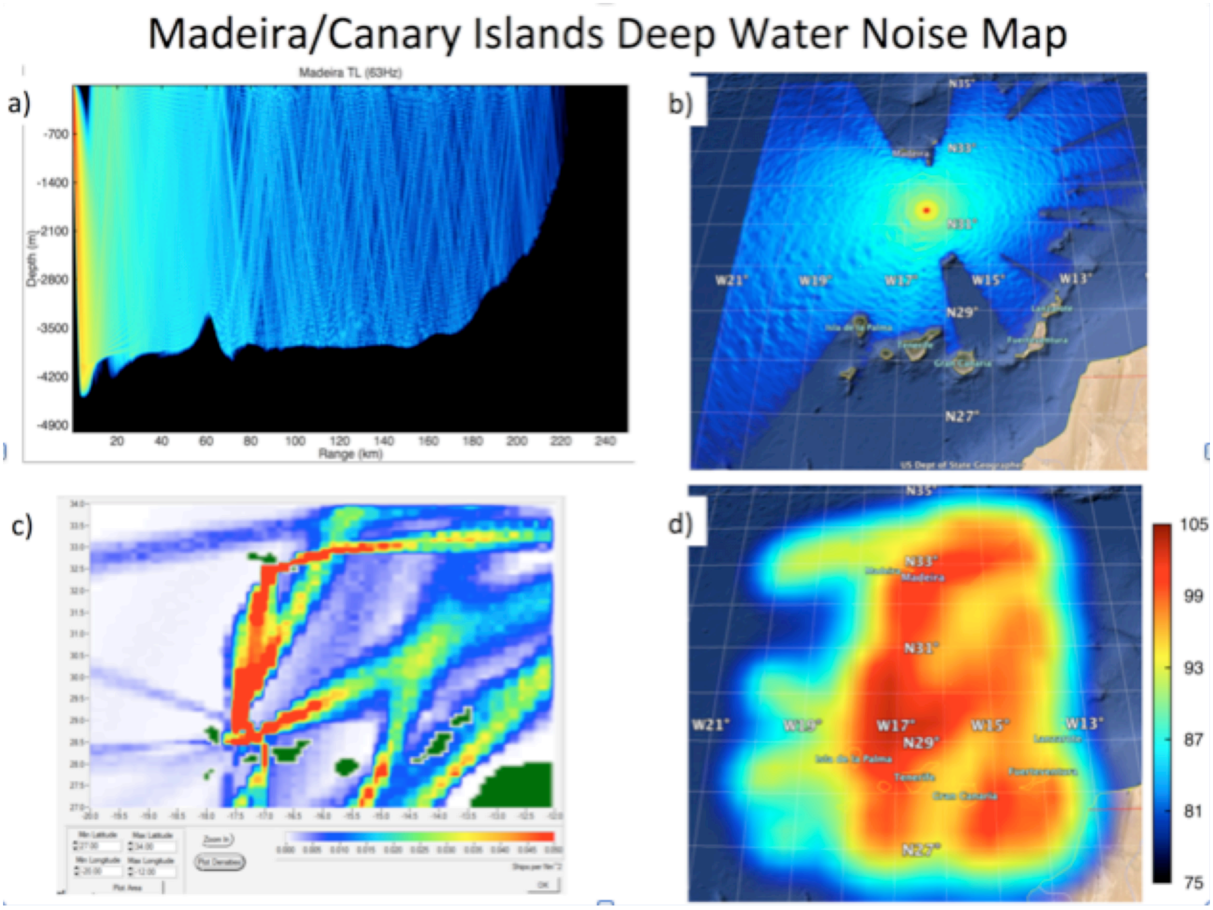

Figure 2 – Peregrine Computation of Seasonal Ambient Noise Average in Madeira and the Canary Islands. 2a) TL Slice for a surface shipping source. 2b) Planview run showing ~ 200 radials and interference patterns in high-resolution output range 2c) HITS surface shipping source distribution 2d) cumulative field for all source positions.

Figure 2a and 2b illustrate the acoustic field output of Peregrine, showing bottom limited deep water propagation, with coherent interference patterns. The surface shipping distribution, computed from HITS is shown in 2c. To generate a range-averaged output – which is equivalent to the prediction of the seasonal ambient noise level, the Peregrine output model range is set to 10 km (the output and input range resolution) and the power average within this range window is stored to disk. Each source position is then summed over (as in Figure 1) and the average output power is computed. Note that the range averaging accounts for the smoothing of the complex interference pattern and the source level distribution. One of the take-away messages from this particular modelling exercise is that within the canary islands, there is predicted to be a significant (~20 dB) average sound level difference, primarily driven by the spatial distribution of the sources.

3. ACOUSTIC HORIZONTAL ISOTROPY

3.1 Intellectual Property

Authors must obtain permission from the intellectual property holders before publishing or reproducing figures, images or other intellectual property in their manuscript. An acknowledgement that such permission has been obtained from the intellectual property holders must be included in the manuscript.

3.2 Submission of Papers

All papers shall be submitted on-line as unprotected PDF files (Adobe Portable Document Format) via the Conference website http://www.internoise2014.org . Use the username and password given in the e-mail sent after the submission of your abstract. The size of a PDF file shall not exceed 10-megabytes. Given the large numbers of papers expected for this conference, the Secretariat does not have the resources to typeset or to proofread the individual papers. Please review your paper carefully for format, spelling, grammar, punctuation, and technical content. Your paper will be placed into the Proceedings just as received. Any paper that varies from the format presented in this template will be returned to the author(s) for re-formatting using the guidance of this template. Only papers conforming to the template guidelines will be included on the USB memory stick.

The deadline for submission of the complete manuscript is 25 July 2014. Your paper can only be accepted if the PDF file is uploaded via the Conference Website. The corresponding author (who submitted the abstract) will be notified of receipt of the paper by e-mail. If you do not receive an e-mail notifying you of the receipt of your paper within 24 hours of your paper submission, please notify the editor of this fact by e-mail to inoise14techprog@gmail.com .

3.3 Mandatory Registration of Authors

An invited or contributed paper may be part of the Conference program and proceedings only if a registration fee (Regular Participant or Student) has been paid by the deadline for the paper submission for the Proceedings. One registration fee is valid only for one paper. If the same author submits more than one paper, the "Additional paper" fee shall be paid for each additional paper submitted.

4. CONVERSION TO PORTABLE DOCUMENT FORMAT (PDF)

4.1 Embedding Fonts

One of the most common problems related to conversion to PDF format is failure to embed fonts in the document created by a word processor program. If fonts are not embedded, the PDF conversion program does its best to select fonts that match the original document, but the appearance of the PDF file may not be what is intended.

To embed fonts in a Microsoft Word file, go to "Word Options." Then click on "Save" and check the box "Embed fonts in file." You can reduce the size of the MS Word file by also checking "Embed only the characters used in the document (best for reducing file size)" and "Do not embed common system fonts". Other word processing programs may have similar options.

If using Adobe Acrobat to convert the document to PDF format, go into Properties in the print dialogue box and untick "Rely on system fonts only: do not use document fonts".

4.2 Inspecting Your PDF File

Carefully inspect your PDF file before submission to be sure that the PDF conversion was done properly and that there are no error messages when you open the PDF file. Common problems are: missing or incorrectly converted symbols especially mathematical symbols, failure of figures to reproduce, and incomplete legends in figures. Identification and correction of these problems is the responsibility of the authors.

5. PRESENTATION TIMES

For Plenary and Keynote papers, the presentation time is 60 minutes (50 minutes plus 10 minutes for questions, comments and room changes).

For Invited and Contributed papers, presentation time is 20 minutes (15 minutes plus 3 minutes for questions, and 2 minutes for room changes). The Session Chair will enforce the time limits.

All papers at INTER-NOISE 2014 will be presented in English.

6. CONCLUSIONS

The section before the references is normally called CONCLUSIONS, SUMMARY, or FINAL REMARKS, where the authors describe the most-relevant findings of the work.

ACKNOWLEDGEMENTS

The Authors would like to acknowledge the support of the Office of Naval Research – Ocean Acoustics for this work. This work has come out of extensive conversations and research with

Michael Ainsle (TNO) and Jen Miksis-Olds (ARL-PSU). The Peregrine Model was written primarily by Richard Campbell (OASIS).

REFERENCES

1. Collins M. A split-step Pade solution for the parabolic equation method. Journal of the Acoustical Society of America. 1993;93(4):1736-42.