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Geoacoustic Parameter Sensitivity and Interaction Study

Summary of Work and Results

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Contract Number: W7707-063411
Contract Scientific Authority: Sean P. Pecknold, 902-426-3100 x222

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Abstract

This report presents a summary of the most important results of the Geoacoustic Parameter Sensitivity and Interaction Study performed by GD Canada and a team of consultants for DRDC Atlantic. Detailed results are presented in four separate Contractor Reports.

Résumé

Le présent rapport contient un résumé des principaux résultats de l'Étude de sensibilité et d'interaction de paramètres géoacoustiques réalisée pour RDDC Atlantique par *General Dynamics Canada* et par une équipe de consultants. Les résultats détaillés sont présentés dans quatre rapports d'entrepreneurs distincts.

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Executive Summary

Introduction/Background

This work was undertaken as part of the Geoacoustic Parameter Sensitivity and Interaction Study. The objective of the Study was to examine the sensitivity of acoustic propagation to variability and uncertainty in the underwater environment.

Results

This document presents a high-level overview of the results of the Study. The results include the development of new measures of sensitivity; an examination of the spatial shifts that arise in the acoustic field due to environmental perturbations; an examination of the interaction between geoacoustic parameters; the effect of sampling resolution on the modeled field in range-dependent environments; the identification of an important error in the Bellhop acoustic prediction model and other ray-based models; and a summary of current literature related to interaction with the sea surface. Detailed results are presented in four separate reports to follow.

Significance

Building on previous work, this study has developed more useful measures of sensitivity to environmental variability, and applied them in more and more realistic underwater environments. As an additional benefit the study has identified some weaknesses in acoustic models currently in wide use at DRDC Atlantic and elsewhere.

Future Plans

The level of realism in the modeled environments has reached the point where it should be possible to apply the techniques developed in this work to real environments, for comparison to data collected at sea. Some of the results could also be used to guide future investigations into potential improvements to acoustic models.

G.H. Brooke; D.F. McCammon; P.M. Giles; S.E. Dosso; M. Morley. 2007. Geoacoustic Parameter Sensitivity and Interaction Study: Summary of Work and Results.
DRDC Atlantic CR 2007-101. Defence R&D Canada - Atlantic.

Sommaire

Introduction et contexte

Ces travaux ont été entrepris dans le cadre de l'Étude de sensibilité et d'interaction de paramètres géoacoustiques. L'objectif de l'étude était d'examiner la sensibilité des modèles d'ondes acoustiques, à la variabilité et aux incertitudes du milieu marin.

Résultats

Le présent document contient un aperçu de haut niveau des résultats de l'étude. Les résultats comprennent l'élaboration de nouveaux types de mesures de sensibilité, un examen du déplacement spatial du champ acoustique causé par des perturbations environnementales, un examen des interactions entre les paramètres géoacoustiques, les effets de la résolution de l'échantillonnage sur le champ modélisé dans des milieux définis par la portée, l'identification d'une importante erreur dans le modèle de prévision acoustique Bellhop et d'autres modèles basés sur le trajet de l'onde, ainsi qu'un sommaire des publications récentes liées aux interactions avec la surface de la mer. Des résultats détaillés sont présentés dans quatre rapports distincts à venir.

Portée

Réalisée à partir de travaux antérieurs, cette étude a permis d'élaborer des types de mesures plus utiles de la sensibilité à la variabilité environnementale et les a appliquées à un plus grand nombre d'environnements et à des environnements sous-marins plus réalistes. Un avantage additionnel de cette étude est la découverte de certaines lacunes dans les modèles acoustiques utilisés actuellement à RDDC Atlantique et ailleurs.

Recherches futures

Le degré de réalisme dans les environnements modélisés a atteint un niveau où il serait possible d'appliquer les techniques mises au point dans le cadre des travaux à des environnements réels, pour les comparer avec les données recueillies en mer. Certains résultats pourraient également être utilisés en vue d'orienter les études à venir, de manière à apporter éventuellement des améliorations aux modèles acoustiques.

Brooke, G.H.; D.F. McCammon, P.M. Giles, S.E. Dosso, M. Morley. 2007. Étude de sensibilité et d'interaction de paramètres géoacoustiques : Résumé des travaux et résultats. RDDC Atlantique CR 2007-101. RDDC Atlantique.

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1 Introduction

This report is submitted to DRDC Atlantic as a deliverable of the Geoacoustic Parameter Sensitivity and Interaction Study. The purpose of this document is to provide a high-level overview of the project and to summarize the results of the investigation carried out by the General Dynamics (GD) Canada team. Detailed descriptions of the project results are included in four companion reports.

1.1 Project Background

Sonar can be used to remotely investigate the underwater environment and to detect and track vessels therein, either by their own acoustic emissions or through scattering from active transmission. The acoustic signals available to an observer, using either active or passive sonar, are a function of the transmitter's relative position, course, and signature, and the local environment. By making use of prior knowledge of the environment as well as some of the relevant sources and targets, the potential exists for an observer to determine the position, velocity and classification of local targets.

In order to make most effective use of the received acoustic signals, an observer requires a thorough understanding of the propagation and scattering characteristics of the overall underwater environment as well as the implications of those characteristics on the analysis techniques applied to the received signals.

Underwater acoustic propagation depends strongly on the environment, in particular on the properties of the water column and the seabed. The sensitivity of acoustic propagation to the variability of these environmental parameters is an important question for determining how well the propagation can be modeled and to what extent in situ environmental measurements can improve modeling capabilities.

The Geoacoustic Sensitivity Study [1] carried out by GD Canada and its consultants in collaboration with DRDC Atlantic examined the sensitivity of the acoustic pressure field to variations in various seabed and water column properties. The study incorporated a variety of acoustic models and mathematical techniques in that analysis. The Geoacoustic Parameter Sensitivity and Interaction Study is an extension of that previous work that aims to add to our understanding of the sensitivity to the environment.

The work described in [1], and the follow-on Geoacoustic Parameter Sensitivity and Interaction Study, are intended to support DRDC Atlantic's Rapid Environmental Assessment project. Rapid Environmental Assessment is a technique that aims to enhance underwater warfare mission planning by allowing real-time or near-real-time assessment of the underwater environment.

An accurate model of the underwater environment is critical to sonar performance modeling and therefore to mission planning and execution. In practice, this means collecting information about various geophysical and oceanographic parameters. To ensure an effective and timely environmental assessment capability, it is necessary to identify specifically what type of information needs to be gathered.

In [1], the General Dynamics team determined a relative ranking of the sensitivity of the acoustic field to geoacoustic parameters. The sensitivity was determined for two different nominal environments, based on the Emerald Basin and the Malta Plateau (further described in [1]). The investigation also considered two

different frequencies (1200 and 6500 Hz). A major thrust of the investigation was to assess the linearity of the sensitivity; an important conclusion was that the pressure perturbation as defined in that work showed a linear dependence on the magnitude of most typical geoacoustic perturbations. The project also measured the range and depth dependence of the sensitivity for the two environments considered.

The study also included experiments on the sensitivity to range-independent and range-dependent water column properties, specifically depth and sound speed profile. The sound speed profile perturbations were selected to mimic typical oceanographic variability. The resulting pressure perturbations were large compared to the sensitivities of geoacoustic parameters, and were nonlinear functions of the size of the environmental perturbations.

The Geoacoustic Sensitivity Study also described several possible avenues for future work, including some that have been identified as objectives of the Geoacoustic Parameter Sensitivity and Interaction Study. The work described in this proposal extends the scope of the Geoacoustic Sensitivity Study, and will allow for a broader and a deeper understanding of sensitivity in realistic operational scenarios.

1.2 Project Objectives

The objective of the work described in this report and its companion documents is to examine the sensitivity of acoustic propagation on variable and uncertain geophysical and oceanographic quantities. The RFP Statement of Work for the Geoacoustic Parameter Sensitivity and Interaction Study defined five component objectives:

- Examine the dependence of acoustic propagation, using transmission loss as a proxy, on the water column properties, such as sound speed profile and surface roughness.
- Extend the seabed properties study to consider other environments, or slight modifications of the nominal environments (from the Geoacoustic Sensitivity Study), with the goal of drawing some more general conclusions about the sensitivity to bottom properties.
- Examine the dependence of transmission loss on the interaction of two or more parameters, such as the sound speed at the bottom of the water column compared to the compressional sound speed of the first sediment layer.
- Extend the seabed properties study to include range-dependent bottom properties. This should also provide comparisons of the dependence of transmission loss on uncertain (or mismeasured) bathymetry vs. seabed properties.
- Compare model results to measured transmission loss and environmental data.

This document summarizes the work done during the Geoacoustic Parameter Sensitivity and Interaction Study. The detailed results of the study are provided in four separate reports. This document gives a high-level overview of the results. The contents of the companion reports are described briefly in the following section.

1.3 Project Deliverables and Document Organization

In addition to this report, there are four companion reports to be delivered to DRDC Atlantic at the conclusion of the Geoacoustic Parameter Interaction and Sensitivity Study:

1. *Effects of Spatial Shifts in Sensitivity Measures* – This report is summarized in Section 2.

2. *The Sensitivity of Transmission Loss Modeling to Environmental Resolution: Emerald Basin Bathymetry and Sediment Composition* – This report is summarized in Section 3.

3. *Comparison Between Bellhop and PECan for Range-Dependent Bathymetry: Errors Arising in Bellhop* – This report is summarized in Section 4.

4. *Acoustic Propagation and the Sea Surface: Literature Review* – This report is summarized in section 5.

Section 6 presents a very brief summary of the results of the project.

In addition to the four reports noted above, GD Canada will deliver all source codes created during the Geoacoustic Parameter Sensitivity and Interaction Study.

2 Spatial Shifts and Sensitivity

In [1] the GD Canada team defined several different measures of sensitivity and quantitatively assessed the sensitivity to variations in various water column and sea sediment properties. In all cases the sensitivity was defined in terms of the acoustic pressure change at a fixed point in space.

One of the deliverables of the Geoacoustic Parameter Sensitivity and Interaction Study is a report titled *Effects of Spatial Field Shifts in Sensitivity Measures*. This report, which was principally written by Dr. Stan Dosso and Mike Morley, extends the work of [1] in several ways. First, the measure of sensitivity is extended by recognizing that some environmental perturbations cause the acoustic field to shift in range and/or depth, and this can lead to a misleading assessment of sensitivity. The document develops a practical approach to account for the effects of spatial field-shifting in acoustic sensitivity analysis, thereby producing more meaningful measures of sensitivity.

This approach is examined for a realistic environmental model based on the Malta Plateau. The study indicates that for low frequencies and/or small perturbations to bathymetry, the field-shift component of sensitivity dominates, and field-shift correction substantially reduces the sensitivity. The effectiveness of field-shift corrections decreases with frequency, perturbation size, and overall complexity of the bathymetry. There appears to be little or no advantage to field-shift correction for sensitivities to seabed geoacoustic parameters, with the possible exception of sediment-layer thickness. Interaction between geoacoustic parameters is also considered and quantitatively assessed for a few examples using a multidimensional Monte Carlo technique.

DRDC Atlantic has a practical interest in understanding the sensitivity of acoustic data to uncertainty in bathymetry and other environmental parameters in operational areas. The field-shifting method developed and tested here produces a more meaningful sensitivity measure for such applications. The field-shifted sensitivity measure can now be applied to various environments of interest. Furthermore, the project developed the ability to assess sensitivity in fully range-dependent environments using PECan. This means that similar experiments can be conducted in quite realistic environments. It should not be difficult to adapt the results to other environments of interest, particularly environments where DRDC Atlantic has collected field trial measurements.

3 Sensitivity to Resolution

In [1] sensitivity was assessed mainly in terms of range-independent perturbations to range-independent environments, although a few very simple range-dependent cases were included. When more complicated range dependence is introduced, it raises the issue of environmental resolution: how finely do we need to sample the environment in range to make an accurate acoustic prediction?

One of the deliverables of the Geoacoustic Parameter Sensitivity and Interaction Study is a report titled *The Sensitivity of Transmission Loss Modeling to Environmental Resolution: Emerald Basin Bathymetry and Sediment Type*. This report, principally written by Dr. Diana McCammon with contributions from Dr. Stan Dosso and Mike Morley, extends the work of [1] in several ways. First, a realistic range-dependent bathymetry is introduced to the nominal Emerald Basin environment. The report documents an assessment of the error introduced in the transmission loss when the true bathymetry is subsampled at increasingly large intervals. The results show that the overall transmission loss error is roughly constant at about 7-10 dB for range sampling intervals between 40 and 200 m. Second, the report assesses the impact of range-dependent variations in bottom sediment type, considering a number of different types of environmental uncertainty that might be present in a realistic scenario. The results show, again, a roughly constant transmission loss error of 7-10 dB for sampling intervals between 2000 and 9000 m. Finally, the report considers combined effects of simple range-dependent bathymetry and range-dependent sediment type. The results show that different effects will dominate depending on the sediment type.

In order to predict sonar performance in a given environment, the environment must first be characterized. The results presented in this report will be useful in defining the resolution with which the environment should be characterized, and the penalty (TL error) for using a low-resolution assessment.

This study has extended the work of [1] to the point where sensitivity to environmental variability can now be assessed in much more realistic scenarios, including range-dependent bathymetry and sediment type. Although the examples used in this report are meant to be representative of the Emerald Basin, it should not be difficult to extend these techniques to other environments. In particular, it would be interesting to extend the experiments to environments where DRDC Atlantic has collected field trial measurements of transmission loss.

4 Issues Arising With Bellhop

Like many other projects at DRDC Atlantic, the Geoacoustic Sensitivity Study [1] and the Geoacoustic Parameter Sensitivity and Interaction Study have made extensive use of the acoustic model Bellhop. Bellhop is a ray-based acoustic model that uses Gaussian beams to model the acoustic field.

One of the deliverables of the Geoacoustic Parameter Sensitivity and Interaction Study is a report entitled *Comparison Between Bellhop and PECan for Range-Dependent Bathymetry: Errors Arising in Bellhop*. The report, which was primarily written by Dr. Gary Brooke and Dr. Diana McCammon, describes the results of an investigation into Bellhop's performance in an environment where the water depth (bathymetry) is range-dependent. It is noted that Bellhop appears to be extremely sensitive to changes in the bathymetry specification. By comparison to other acoustic models, it is shown that a number of ray-based models show the same sensitivity, but a parabolic equation model known as PECan does not. In particular, the ray-based models are inaccurate in scenarios where there is a change in the bottom slope. The document also provides evidence that suggests a possible explanation for the inaccuracies in the ray models.

DRDC Atlantic has made a considerable investment in Bellhop and the model is currently being used to provide acoustic predictions in a number of different projects. For many applications a ray-based model like Bellhop is the only practical approach to acoustic modeling. The error identified in this report will not be important in all situations; however, it does impact the accuracy of the results produced by Bellhop whenever there is significant acoustic interaction with the sea floor and the sea floor has changes in slope.

A complete solution to the problem and a repair of the Bellhop model are beyond the scope of this project. However, future work should include a full investigation of the cause of the problem, and a subsequent repair of the Bellhop model.

5 Surface Interaction Literature Review

The study described in [1] did not include a detailed consideration of the influence of the sea surface. While assessing sensitivity of the acoustic field to water depth, sound speed profile, and sediment properties, the report did not assess sensitivity to surface properties such as wave height or wind speed.

One of the deliverables of the Geoacoustic Parameter Sensitivity and Interaction Study is a report entitled *Acoustic Propagation and the Sea Surface: Literature Review*. The report, which was primarily written by Dr. Peter Giles, presents a brief summary of current scientific research into the interaction of underwater sound with the ocean surface. There are two primary methods by which the sea surface influences acoustic propagation: through reflection and scattering from the rough water-air boundary; and through scattering, absorption, and refraction by entrained air bubbles in the near-surface part of the water column. The relative importance of these mechanisms varies with frequency and wind speed. It is also noted that most commonly used acoustic models do not include sophisticated models of wind-driven waves or bubbles, and so cannot produce high-fidelity predictions for environments where surface interactions are important.

The literature review presents the state of current knowledge, highlighting those areas that are of particular relevance for the environments and frequencies that have been the focus of [1] and the Geoacoustic Parameter Sensitivity and Interaction Study. The report also points out a potential weakness in acoustic models that are in wide use at DRDC Atlantic and elsewhere.

It will be difficult to extend the current work on geoacoustic sensitivity to include a quantitative assessment of sensitivity to surface properties unless the fidelity of surface models can be improved. We propose that this literature review could be used as a starting point for a more detailed investigation into potential improvements to Bellhop and/or PECan.

6 Conclusions and Future Work

The results of the Geoacoustic Parameter Sensitivity and Interaction Study have been summarized in the previous sections. Two of the deliverable reports, *Effects of Spatial Shifts in Sensitivity Measures* and *The Sensitivity of Transmission Loss Modeling to Environmental Resolution: Emerald Basin Bathymetry and Sediment Type* contain the main original scientific results. The two reports consider two quite different base environments, and use different measures of sensitivity, as described in section 1 and 2 respectively. A common outcome, however, is that both documents extend the investigations begun in [1] to more and more realistic environments. Those environments now may include realistic bathymetry profiles, and variations in sediment type with range.

We expect that this realism has now reached the point where we could perform meaningful experiments for areas where DRDC Atlantic has collected field measurements of transmission loss. This would allow the techniques developed to date to be evaluated against real data.

There are two other reports to be delivered as by-products of this investigation. The first describes an error that has been identified in the way that Bellhop and other ray-based models behave in an environment where the sea floor changes slope. Since DRDC Atlantic has made a considerable investment in Bellhop, we expect that the special sensitivity of Bellhop to range-dependent bathymetry variations will be of general interest.

Although the error was discovered accidentally, some effort was spent investigating the root cause. The results should help guide future work to improve and correct Bellhop and potentially other acoustic models in wide use.

The second auxiliary report presents a literature review on the topic of the interaction of underwater sound with the ocean surface. To date our investigations into geoacoustic sensitivity have not considered the properties of the ocean surface in any detail. The literature review identifies those domains where different sea surface interactions may be important, which can help to guide future studies. The report also notes that few current acoustic models provide a high-fidelity model of the interaction with the sea surface. This identification of a potential deficiency might lead to future improvements or extensions.

References

[1] P.M. Giles, S. Dosso and D. McCammon, *Geoacoustic Sensitivity Study Phase II and Phase III: Final Report*, Defence R&D Canada – Atlantic (2006), DRDC Atlantic CR 2006-066.

List of Symbols/Abbreviations/Acronyms/Initialisms

DND	Department of National Defence
OPI	Office of Primary Interest
R&D	Research & Development

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