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Scientific Letter

Comments on proposed low frequency boundary models for ODIN

Background

ODIN is an underwater warfare software simulation suite, developed by Atlas Elektronik Group, used by the Maritime Simulation Cell MSC) at the Canadian Forces Maritime Warfare Centre (CFMWC) for operational research and tactical development. The suite is being enhanced with low frequency and multistatic capabilities, and an addition of a low-frequency parabolic equation propagation model (SPUR) to the existing high-frequency Gaussian beam model Bellhop. As part of this, a set of boundary models for acoustic propagation calculations is being added to ODIN. The following low frequency boundary models have been proposed:

- Surface reflection loss: angle–independent Beckmann-Spizzichino;
- Bottom reflection loss: three-layer model with depth-dependent sediment sound speed;
- Surface scattering strength: Chapman-Harris;
- Bottom scattering strength: Ellis and Crowe.

DRDC was contacted by the MSC to provide input into the validity of these models.

Proposed models

Surface reflection loss: The existing surface loss in ODIN being used with Bellhop is a bubble attenuation model developed by APL-UW for high-frequency loss (broadly speaking above 10 kHz, but applicable down to a few kHz). The proposed model for low frequency surface loss is the Beckmann-Spizzichino angle-independent model. This model is based the theory of electromagnetic waves scattering from a rough surface (Beckmann and Spizzichino, 1963), and neglecting the term:

$$\sqrt{1-\left(\sin\theta-\frac{\sin\theta}{\theta}\frac{e^{-s\theta^2/4}}{\sqrt{s\pi}}\right)}$$

Bottom reflection loss: The existing bottom reflection loss model used in ODIN is an APL-UW forward loss high frequency model, for a single bottom type. The proposed low frequency loss model is a thin-layer geoacoustic model. Based on the description provided by Atlas, the SPUR

PE model would use this as a three fluid layer (two layer plus basement) model, while a bottom reflection loss for Bellhop would be computed based on the McCammon (1988) reference (it is assumed that Bellhop would not be altered to split bottom-bounce rays into reflected and refracted components at the sediment-water interface). This model assumes fluid layers, i.e., no shear waves.

Surface scattering strength: The low frequency scattering strength model proposed is the Chapman-Harris model (Chapman and Harris, 1962). This would only be used for low frequency scattering for the Bellhop model in ODIN, as it is not applicable to SPUR. The current scattering model is the APL-UW model, which is valid for high frequencies.

Bottom scattering strength: As with the surface scattering strength, the bottom scattering strength model is only applicable to Bellhop. The current high-frequency model is the APL-UW model, which requires geoacoustic parameters for the sediment as well as roughness spectra constants. The proposed Ellis-Crowe (Ellis and Crowe, 1991) model is a bistatic semi-empirical model that includes facet scattering as well as a Lambert or Mackenzie Law term.

Discussion

Surface reflection loss model: The 1984 report from the NORDA (Naval Ocean Research and Development Activity) working group on surface loss (Eller, 1984) recommended that a modified version of the Eckart model (Eckart, 1953) be used rather than any of the Beckmann-Spizzichino based models or the Schulkin-Marsh model used in AMOS, which is based on measurements of loss per bounce for surface-ducted propagation. However, the report also states that comparisons with experimental data suggest that the modified Eckart model likely underestimates the small grazing angle losses. Other low-frequency loss models exist (e.g., Ainslie (2010) based on measurements by Weston and Ching (1989), Brekhovskikh and Lysanov (1991), and Marsh et al. (1961)). Of note, all three of these include a 3/2-power dependency on frequency. Nevertheless, as all disagree with each other, it is not clear that they would provide a significant advantage over the Beckmann-Spizzichino model. Therefore, the Beckmann-Spizzichino model is a reasonable compromise, with some caveats.

Recent work (Williams et al., 2004) involving comparisons of parabolic equation models with a Gaussian ray-based model (GRAB) has shown that the Beckmann-Spizzichino model (as implemented in GRAB, i.e., similar to that proposed here but with angle-dependence) does not give accurate predictions of coherent loss at long ranges, as compared to a rough-surface parabolic equation (PE) code using a small slope approximation. As well, for very low frequencies, the Beckmann-Spizzichino model may overestimate loss, particularly at steeper grazing angles when the grazing angle dependence is neglected, as proposed. However, for long-range propagation, surface loss is important primarily in surface ducts, where trapped rays have grazing angles below 3° in almost all cases (Hodges, 2011). Therefore, the neglect of angle dependence is justified in most cases of long-range propagation. The angle-dependent term could certainly however be included for use with Bellhop, for higher grazing angle, shorter-range situations. An angle-dependent reflection loss can also be incorporated into a parabolic equation model (Moore-Head et al., 1989), but this would require modification of the core propagation code if it were not already incorporated. Similarly, a very accurate rough surface PE extension could potentially be implemented within the context of SPUR, but again this would require extensive changes in the core model.

Bottom reflection loss model: In low frequency cases (< 200 Hz or so) where the sediment layers are thin, the assumption of a fluid rather than an elastic or poro-elastic sediment can lead to an underestimate of the reflection loss (Vidmar, 1980) as energy should be lost in shear

waves. However, neither the SPUR model nor Bellhop supports elastic or poro-elastic layers, so in this situation it is not relevant.

Surface scattering strength model: The Chapman-Harris model is an empirical model derived from measurements taken in the range of 400–6400 Hz, with wind speeds up to 15 m/s (Jensen et al., 2011). It includes frequency and wind speed dependence. A semi-empirical model that incorporates a more complete set of scattering mechanisms was developed by Gauss et al. (2002) for the NRL. This provides a better match to measured data, in particular for higher grazing angles. It is also a bistatic scattering strength model. Although the full model uses additional parameters (two surface wave spectrum parameters and a parameter characterizing the depth of the bubble layer), it has been further simplified to dependence only on the wind speed and frequency. It was designed to be valid over a broad range of frequencies (100 Hz to tens of kHz).

Bottom scattering strength model: The main weakness of the Ellis-Crowe model is that as a semi-empirical model, it requires an input of ad hoc parameters, and that it does not necessarily extend to areas where the underlying sediment geophysics changes. Similarly to the surface scattering case, a physics-based bistatic bottom scattering strength model was developed by Gauss et al. (2002) at NRL. Given good environmental inputs, it has been shown to fit experimental data well. It uses the same geoacoustic and roughness constants as the APL-UW model, although it generally assumes elastic sediments.

Conclusions and recommendations

The four models proposed by Atlas Elektronik for inclusion in ODIN are all standard models that are well understood and have been used as part of other systems, such as the US Navy Comprehensive Acoustic Simulation System. The Beckmann-Spizzichino model is a good choice for a model that can be used with SPUR and Bellhop, and has been shown to have reasonable validity in the low- and mid-frequency range. If better short-range loss estimates are desired when using Bellhop, or for comparison to the existing APL-UW model, the angle dependence could be included for Bellhop trivially. The Beckmann-Spizzichino model will probably overestimate coherent loss at long ranges, which may affect propagation modeling in surface-ducted environments, but in most cases this will not be a large effect.

The proposed bottom-reflection loss model should function well in all frequency regimes, although for frequencies of tens of Hz, there are limitations on the propagation models in dealing with poro-elastic media.

For the boundary scattering models, the physics-based NRL surface and bottom scattering strength models would be preferred. They are valid over a very broad range of frequencies, are more rigorous and typically provide a better match to experimental data, especially for higher grazing angles for the surface; however, the bottom scattering strength data-theory improvements depend in some cases on fluid-elastic interfaces, which are not used as part of the core models. An additional point in favour of the NRL bottom-scattering model otherwise is that it used the same parameters as the APL-UW model, whereas the Ellis-Crowe one uses different ones.

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