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How to Make the Best Use of Three-Dimensional Hamiltonian Acoustic Ray Tracing by Avoiding Modeling Artifacts

R. Michael Jones
Cooperative Institute for Research in Enviornmental Sciences (CIRES)
University of Colorado/NOAA
Boulder, Colorado 80309-0216, USA

Abstract

Methods for improving acoustic propagation simulation by Hamiltonian ray tracing are discussed. As with any ray tracing method, effective modeling of the sound-speed, current, and bathymetry represents the greatest challenge. Using models without extraneous structure at small scales avoids extraneous propagation effects (such as false caustics) and shortens integration time. Although Hamiltonian ray tracing does not require extraneous structure in sound-speed models (as do some ray tracing methods), it accepts models with some extraneous structure. For example, it is difficult to avoid extraneous structure on the scale of the grid size with models based on interpolation. Methods are discussed for detecting and eliminating extraneous small-scale structure in models.

1 Introduction

Because raypath calculations by a correctly working ray tracing program correctly represent the sound-speed model, all significant raypath errors can be attributed to modeling errors. A modeling error in sound speed is any difference between the model and the true sound speed for the case we want to simulate. Sound speed is an example. The same results apply as well to ocean currents, atmospheric winds, or bathymetry.

The true sound speed has structure at all scales. The sound-speed model may also have structure at all scales. Any differences in sound speed between the two at any scale is an error at that scale. Thus, error is a function of scale size.

Some of the structure in the model may be an artifact of the model having nothing to do with the true sound-speed structure at that scale. For example, models based on interpolation may introduce extraneous structure on the scale of the grid size.

Any error at any scale will result in errors in the ray tracing simulation. However, errors due to artifacts of the model represent particularly troublesome errors that are often avoidable. The troubles caused by such artifacts in the model fall into two categories:

1. The ray tracing calculation can be more difficult, more costly, or can take longer.
2. The ray tracing calculation will be in error.

Errors in the ray tracing calculation due to model artifacts can lead to further problems:

1. False caustics (*e.g.*, Pedersen, 1961)
2. Difficulty determining eigenrays
3. Extraneous or missing eigenrays
4. Significant signal strength errors (*e.g.*, Pedersen, 1961)

2 Recognizing artifacts in models

An easy way to recognize artifacts in models is through profile plots, contour plots, or spectral plots of sound speed, ocean current, or bathymetry. There are computer programs for making profile and contour plots for the environmental models for the HARPA and HARPO (Jones et al, 1986a,b) ray

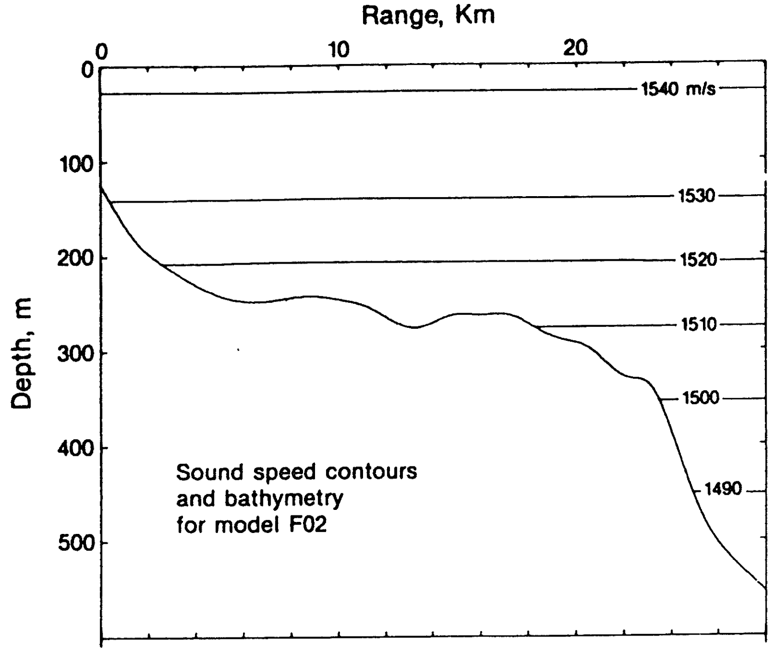

Figure 1: This ocean-bottom profile is a model of the first 30 km across the Florida Straits. It is construced from linear segments smoothed where they join. The smoothing is over 1 km, giving a relatively smooth bottom profile. The sound-speed contours are also shown. (Figure from Jones et al., 1984.)

tracing programs. These programs will display profiles or contours of sound speed, current/wind speed, current/wind velocity (each component), or terrain (the ground, for HARPA, the ocean bottom, for HARPO). Specifically, these programs will make:

1. Profile plots at any longitude and latitude
2. Contour plots through any vertical plane
3. Contour plots through any horizontal plane
4. Profile plots of terrain in any vertical plane
5. Contour plots of terrain in any region

Figs. 1 and 2 show examples of some of these kinds of plots. The programs that produce these plots are described by Harlan et al (1991a, 1991b, 1992).

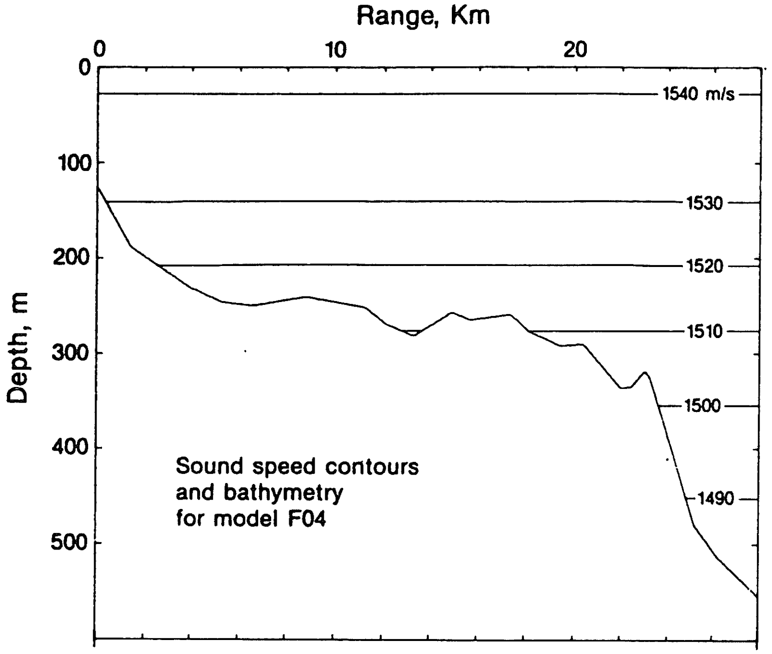

Figure 2: Ocean-bottom profile modeling the first 30 km across the Florida Straits. It is construced from linear segments smoothed where they join, as in Fig. 1, except that the smoothing is over 0.01 km, giving a profile with nearly sharp "corners." The sound-speed contours are also shown. (Figure from Jones et al., 1984.)

Each of these reports includes a floppy disk that contains the program. In addition, these programs are available on anonymous ftp from pooh.etl.noaa.gov in the directory /pub/etl/raytracing, and in subdirectories below that.

Artifacts can often be recognized in such profile and contour plots. For example, Fig. 2 shows sharp corners in the terrain profile.

3 Recognizing possible extraneous structure in ray tracing results

When extraneous structure in models is too subtle to be recognized from profile and contour plots of the models directly, it can sometimes be recognized from the ray tracing results. Weickmann et al (1989) describe a program to plot range versus elevation angle of transmission or range versus travel time from the output of the HARPA or HARPO programs. The report includes the program on a floppy disk. The range versus launch angle plot is particularly useful for showing propagation behavior that may indicate extraneous structure in the models. Fig. 3 shows raypaths typical of the region of the Florida Straits modeled in Figs. 1 and 2. Range as a function of launch angle can be plotted for a specified number of bounces on the bottom. Figs. 4 and 5 show examples of these plots of range versus launch angle. The apparent discontinuities in Fig. 5 are caused by the near discontinuities in terrain slope in Fig. 2.

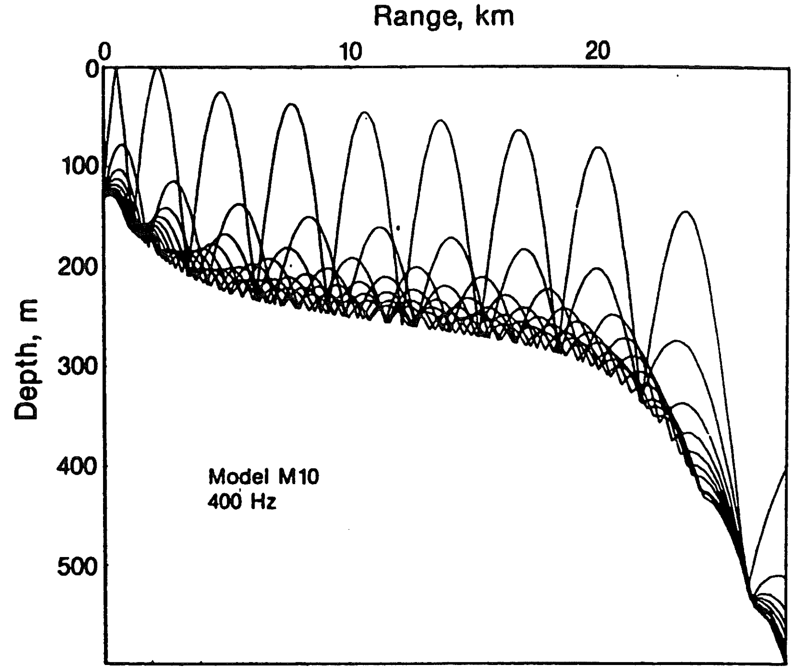

Figure 3: These raypaths show typical behavior of sound propagation in this region of the Florida Straits, where decreasing sound speed with depth causes rays to be refracted downward. (Figure from Jones et al., 1984.)

This program is also available on anonymous ftp at pooh.etl.noaa.gov in the pub/etl/raytracing/eigen subdirectory.

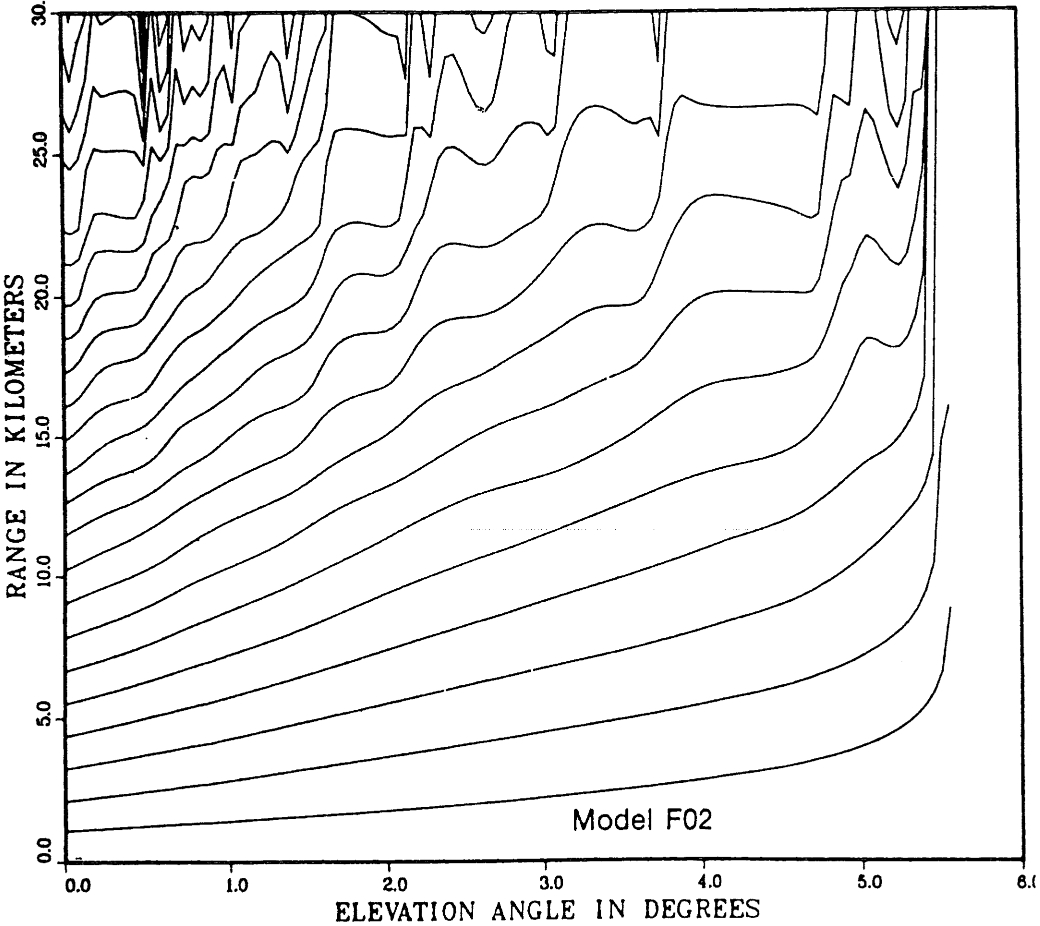

Figure 4: These range-versus-launch-angle plots were constructed from rays traced from a source on the bottom, using the bottom model in Fig. 1. The lowest curve shows the range to the first bounce on the bottom, the next curve for the second bounce, etc. Eigenrays can easily be found as intersections with a horizontal line drawn at the receiver range. (Figure from Jones et al., 1984.)

4 Avoiding artifacts in models

Extraneous structure in sound-speed models can be avoided with Hamiltonian ray tracing programs because Hamiltonian ray tracing programs put no restrictions on the models other than continuity and continuity of gradients. There are several methods for avoiding extraneous structure in sound-speed models:

1. Base the model on formulas that depend on the physics of the medium, such as ocean dynamic modes.

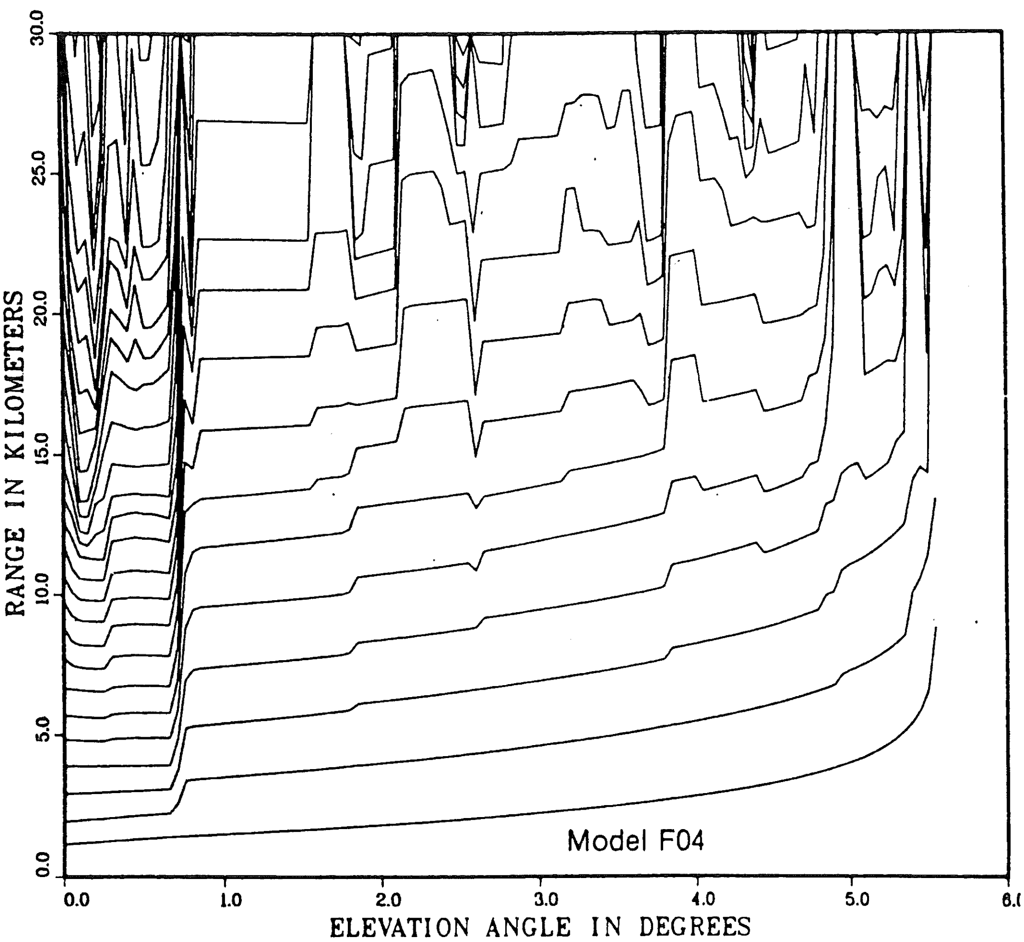

Figure 5: Range-versus-launch-angle plots as in Fig. 4, but using the bottom model in Fig. 2. These curves show that bottom profiles having sharp corners produce sharp jumps in range, which may not be realistic. Such jumps make it hard to interpolate for eigenrays and hard to estimate acoustic intensity from the slope. (Figure from Jones et al., 1984.)

2. Express the sound speed in terms of a general set of orthogonal functions.

3. Express the sound speed in terms of empirical orthogonal functions (EOF's).

4. Model specific known features in the sound speed, starting with large scales and add smaller scale features.

5. Avoid models based on interpolation.

5 Acknowledgment

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