A MATLAB GUI for Ocean Acoustic Propagation

Chris Eggen, Bruce Howe, and Brian Dushaw

Applied Physics Laboratory
University of Washington
1013 NE 40th Street
Seattle, WA 98105

Abstract–**A MATLAB-based MAP Graphical User Interface (GUI) is described for accessing bathymetry and sound speed databases and using them to predict ocean acoustic transmission and to display the results. MATLAB scripts have been developed to estimate a field of view from a single transducer and to compute transmission losses between a source and receiver using one of several standard propagation codes. The GUI called MAP is described and several test cases are presented.**

The MAP GUI supports three simple functions that display database information; an image of bathymetry for a user-specified area may be plotted, a sound speed profile (SSP) at a user-selected location may be plotted, and bathymetry and SSP along a geodesic between a transmitter and receiver may be plotted.

The MAP GUI supports two types of algorithms modeling acoustic transmission loss. The first is computation of the acoustic field between two points. External propagation codes written by other agencies are used to do the basic simulation. MATLAB accesses database information, writes input files for the simulations, runs them, and plots results. Currently five external simulations are supported; (1) EIGENRAY written by Brian Dushaw of the Applied Physics Laboratory at the University of Washington, (3) RAY, written by Jim Bowlin of Woods Hole Oceanographic Institution, (3) CASS, written by Henry Weinberg of the Naval Underwater System Center, (4) UMPE, written by Fred Tappert of the University of Miami, and (5) RAM, written by Mike Collins at the Navy Research Laboratory. The First three simulations are ray-based models, and the last two are parabolic expansion models.

The second type of algorithm is mapping a "field of view" for a transducer (a "shadow" plot). Horizontal rays are propagated from the instruments and the range at which acoustic propagation fails is displayed. Two algorithms are supported. One accesses a database of sound channel depths along with bathymetry information and uses heuristics to estimate propagation along the horizontal rays. The other accesses the Levitis SSP database and uses Weston's Ray Invariant to identify ray elevations 'interrupted' by bathymetry or (if specified by the user) by the surface.

I. INTRODUCTION

The MAP GUI was originally constructed in 1999 to support acoustic computations of the EIGENRAY program [1], which was designed for use in several tomography programs. It was written as a MATLAB script on a PC running Linux, with calls to external programs to access some of the databases and to run EIGENRAY. Given the ubiquity of MATLAB and the availability of several "Unix style" Fortran and C compilers on Windows, this construction is inherently portable to almost any but Apple Systems.

The MAP GUI was modified to support other prediction programs, and to incorporate a simple shadowing algorithm for mapping a transducer's field of view. In 2001, the Comprehensive Test Ban Treaty Organization (CBTO), Hydroacoustics Branch, requested improvement and upgrades, including a revised shadowing computation and a revision in the MAP GUI to start moving toward a windows-based software

paradigm, where the GUI is resident in pull-down menus at the start of the Bathymetry plot.

This paper describes the present state of and illustrates some of its capabilities. We will discuss the MAP software structure, databases, the acoustic propagation simulations supported by MAP, and the shadowing algorithms in MAP and present some results for propagation in the Sea of Japan.

II. SOFTWARE STRUCTURE

A main MATLAB script, mkMap, is envoked from the MATLAB command window. This brings up the main MAP GUI, which is populated by text windows and submenus, i.e., edit windows, pushbuttons, and pull-down/pop-up menus. The submenus provide the capability to specify databases for bathymetry and sound speed profile (SSP), to specify instruments (transmitters and receivers), to display bathymetry images, bathymetry sections, and SSPs, to set some high-level simulation parameters, and to call the acoustic propagation and shadowing functions. Note that the submenus are arranged in seven rows. The main MAP GUI also contains an area at the bottom where error and progress messages can be displayed in text boxes.

A. Database Selection

The main MAP GUI is shown in Fig. 1. The top (1st) row of submenus, containing three edit windows and three pushbuttons, each labeled "Select", allows the user to define directories to use for databases, for intermediate computations, and for data written in prior runs for reuse. The definition is done either by explicitly entering a new directory in the edit window or by clicking on the "Select" pushbutton, which envokes the MATLAB command "uigetfile" and brings up a file select window. The directory is selected by selecting any file within the directory.

The next two (2nd and 3rd) rows of submenus define the area of interest and the bathymetry. The top of these two rows contains a popup menu with a list of files whos name contains latitude-longitude intervals. These files contain bathymetry for previously defined subareas. Next to this is a pushbutton menu labeled "Select Lat-Lon from File Name". Clicking on this pushbutton will select the file currently selected in the pull-down menu and read bathymetry from it.

In the bottom of these two rows there are four edit boxes for the latitude and longitude limits and a pushbutton labeled "Enter". If values for the limits are entered and the pushbutton is clicked, the main bathymetry database is accessed, the desired bathymetry is cut from the worldwide database, and a new file containing bathymetry within the latitude-longitude limits is

stored. After the latitude-longitude box is selected, an image of bathymetry is plotted. The second process takes much longer than the first, which is why it is worth saving sections of the bathymetry database once extracted.
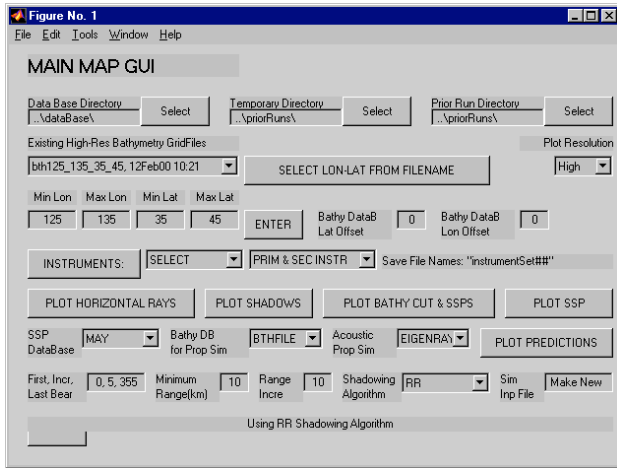

Fig. 1. The Main MAP GUI

The next (4th) row of submenus allows the instrument(s) to be defined. There is a pushbutton labeled 'Instruments:", and two pull-down menus. An instrument consists of a name, a type (transmitter, receiver, or transducer), latitude, a longitude, a depth, and a list of connections to other instruments. (If two instruments are not connected, it is assumed that they cannot sense one another.)

The first pull-down menu can be set to "Add", "Edit", "Delete", "Display", "Save", or "Select". The contents of the second pull-down menu depend on the selection in the first. By selecting "Add" in this menu and making the appropriate selection in the second pull-down menu, previously entered file of instruments can be selected, or instruments can be added individually, or a new connection between instruments specified. A new interactive window is brought up which supports either explicit changes in edit windows or allows changes to be made by point-and-click on the bathymetry chart. Once defined, instruments can be edited or deleted in similar fashion. Once an instrument or sets of instruments is defined, the save filename can be edited and the instrument(s) can be saved to a file for future use.

Once a set of instruments is defined, instruments, connections, and distances between instruments can be displayed. Additionally, a primary and secondary instrument can be selected. The first is the origin in point-to-point acoustic propagation predictions and the origin in field of view computations. The second is the second point in point-to-point acoustic propagation predictions.

The "Instruments" submenu was designed to be easily implemented as the upper menu of a window. The intent is to eventually implement the MAP functions at the top of the bathymetry menu.

The SSP database is selected in the first pull-down menu of the 6th row of submenus on the main MAP MENU. The most commonly used options are an "Annual", "Seasonal" or "Monthly" mean. Additionally, names of specific files containing measured sound speed profiles can be selected for point-to-point acoustic propagation computations.

Using the second pull-down menu of the 6th row, the name of a specific file containing a measured bathymetry profile can be selected for point-to-point acoustic propagation computations. This bathymetry is used in place of area bathymetry defined earlier.

B. Acoustic Propagation Function Selection

The 5th row, the latter half of the 6th row, and the last (7th) row of submenus on the main MAP MENU provide for implementation of the mapping functions. The simplest function is to plot an SSP at a location on the bathymetry image. This is selected by clicking the fourth pushbutton in the 5th row. The bathymetry image is brought to the fore, the user is instructed to point and click at the location of the SSP, and a new figure is brought up with the plot of SSP. The location of the SSP plot is marked on the bathymetry image.

The point-to-point functions are implemented by clicking on the third pushbutton in the 5th row or the last pushbutton in the 6th row. (These are interchangeable.) Point-to-Point Functions use the information in two edit menus on the 7th row. The "Range Increment" edit box controls the interval at which bathymetry and sound speed is read from the databases. The "Sim Input File" contains the name of an input file for an acoustic propagation simulation. If a file name is present, that is used instead of the file that is normally generated.

All point-to-point functions include a plot of bathymetry and the SSPs between two points. If the third pull-down menu on the 6th row is set to "None", that is all that is done. However, if a simulation is specified on the third pull-down menu on the 6th row, then a simulation-input file is written using bathymetry, SSPs, and instruments specified previously. The display varies for each simulation and will be discussed later.

The shadowing functions are implemented by clicking on the first or second pushbutton in the 4th row. The first pushbutton makes a new bathymetry image in a new figure plots lines on geodesics out from the primary instrument until they no longer propagate (according to the heuristic-shadowing algorithm). The azimuths (at the primary instrument) at which geodesics are plotted is read from the first edit box in the 7th row. Bathymetry and sound speed is sampled along each line starting a distance specified in the second edit box in the 7th row, at intervals specified third in the edit box in the 7^h row.

The second pushbutton plots where sound cannot propagate. The form of the plot and the algorithm is specified in pull-down menu box in the 7th row. If the heuristic algorithm is specified, the display is basically the inverse of that described in the previous paragraph, with lines on geodesics out from the primary instrument where there is no acoustic propagation.

If the RSR or RR algorithm is selected, the algorithm based on Weston's ray invariant is used. Lines on geodesics out from the primary instrument are plotted and color changes as the amount of shadowing increases. The initial range is set as above, but both angle and range intervals are determined from the range resolution in the second edit box in the 7th row. As range

increases, new geodesics are initiated between the old to maintain the desired range interval. After the algorithm is completed, a new bathymetry plot is made with a checkerboard pattern over areas where more than one-half of the acoustic energy has been lost.

III. DATABASES

The two main databases necessary for acoustic propagation prediction are bathymetry and sound speed profiles.

A. Bathymetry

We are currently using the version 6.2 of the bathymetry database David Sandwell constructed from satellite altimetry and in-situ data. This database covers the world except the areas near the poles, i.e., from –72° to 72° latitude, with resolution of 0.033°. The accuracy of the bathymetry from the database is a minor issue in shallow water. Depths from Sandwell have been observed to disagree with local charts in the East China Sea and Sea of Japan by as much as 50 m.

The database is supplied in the form of a GMT ".grd" file. This implies that database manipulation, e.g., transects, cutouts and pastes, must be done using the GMT program suite. This is not an issue in terms of software portability, but is an issue in terms of simplicity of the installation.

We are considering including other databases as an option. Sandwell has two other bathymetry databases extracted from satellite data in alternate ways, versions 7.2 and 8.2. Both should give improved accuracy in shallow water. Neither is GMT based. Sandwell provides software to read the new databases and provide MATLAB arrays. Depending on the speed of this software, this capability could greatly simplify manipulation of bathymetry data.

A second source for a worldwide database is the U.S. Navy's DBDBV database, which is much improved in shallow water. It would require significant effort to bring DBDBV into MAP, and might also require further limitations on distribution. However, this would seem to be a useful addition for MAP users within the U.S. Navy research community.

B. Sound Speed Profiles

SSPs are obtained from the 1999 Levitus World Wide Temperature and Salinity Databases using the Chen-Millero-Li [2] conversion equations. There is a separate file containing annual averages, four seasonal averages, and twelve monthly averages. The resolution is every degree.

Simpler databases of sound speed channel axis depth and extent were extracted from the Levitus SSPs for use in the heuristic shadowing algorithm.

IV. POINT-TO-POINT ACOUSTIC PROPAGATION

Five point-to-point acoustic propagation models can be set up and run from MAP. Whenever any entry other than "None" is set in the "Acoustic Propagation Simulation" pull-down menu on the 6th row, another menu is brought up to define simulation inputs which are not used in other MAP functions. These are elevation intervals, test ray elevation increment and max number of reflections for ray–based simulations, acoustic frequency, files containing reflection loss for RAY and CASS, wind speed or bottom type for CASS, or bottom sediment and basement properties for UMPE or RAM.

The general paradigm for running point-to-point acoustic models is to use database information and specified simulation inputs to construct a simulation input file and then to run the simulation from MATLAB using the input file. After the run is complete, MATLAB reads the output files and plots the simulation results. An alternative is to specify a preexisting input file for the run, and then to display the outputs from the MAP program. This allows the user to specify capabilities not provided for in MAP, such as multiple layers in the bottom for UMPE and RAM. After use, the input files created by MAP may themselves be modified for use in other runs. For example, a CASS input file could be modified to compute reverberation.

A. EIGENRAY

The EIGENRAY program [1] was written by Brian Dushaw of the Applied Physics Laboratory at the University of Washington. It is a ray-based acoustic prediction program designed to find eigenrays at long ranges accurately and efficiently using sophisticated logic in addition to exhaustive search. Because of the sophisticated logic and because it is written in FORTRAN with a view toward parallel processing, the EIGENRAY program can potentially process difficult cases quickly.

The ray increment from the simulation input menu is not used in EIGENRAY, which controls its own search parameters. In addition, because EIGENRAY does not attempt to model transmission loss, boundary parameters from the simulation-input submenu are not used.

Plotting of EIGENRAY predictions results in a three-panel plot. The bottom panel contains the same plot of bathymetry and SSPs along the line from source to receiver (primary to secondary instrument) which is produced when plotting bathymetry and SSPs along a cut on the bathymetry area. The middle panel contains bathymetry and a plot of eigenrays between source and receiver found by EIGENRAY. The top panel contains a plot of number of turning points of each eigenray vs. travel time.

EIGENRAY executables are distributed with MAP, but the source code is not because it includes code from "Numerical Recipes in FORTRAN". The source code is available from Brian Dushaw (2066854198, dushaw@apl.washington.edu) after obtaining a site license for numerical recipes.

B. RAY

The RAY program [3] was written by Jim Bowlin of Woods Hole Oceanographic Institution. Like EIGENRAY, RAY is also a ray-based acoustic prediction program. It is also designed to find eigenrays at long ranges accurately, but it tends to take a more brute-force approach to searching than EIGENRAY. Ray does have the advantage over EIGENRAY in that it does try to estimate transmission loss (TL) on individual rays. Anecdotal

comments indicate that the accuracy of the TL estimates is somewhat questionable.

Like EIGENRAY, plotting of RAY predictions results in a three-panel plot, but the contents of each panel are different. The bottom panel contains a plot of test rays emitted from the source (primary instrument) with eigenrays between the source and receiver (primary and secondary instrument) found by RAY superimposed in a lighter color. The middle panel contains a plot of number of turning points of each eigenray vs. travel time. The top panel contains a plot of transmission loss (TL) for each eigenray vs. travel time. TL is plotted as vertical lines between 0 in units of power ($10^{((TL \text{ in dB}) / 10)}$). This gives a rough prediction of the expected appearance of a plot of envelope squared of a high-resolution signal emitted from the source arriving at the receiver.

For very long-range predictions, the ray output files, junk.out and junk.mat, in the temporary directory may become very large. If ray fails to run, determine if the disk partition on which the temporary directory resides has been filled. If so, reset the temporary directory to a disk partition with adequate space and try to rerun.

B. Comprehensive Acoustic Sonar Simulation (CASS)

The CASS program [4] was written by Henry Weinberg of the Navel Underwater Systems Center. It is designed for general purpose propagation predictions, and thus less effort has been expended than for either EIGENRAY or RAY for finding long range eigenrays or estimating their travel time. However, it has many supporting acoustic models for reflection loss and attenuation built in and probably computes TL more accurately than the RAY model.

Like EIGENRAY and RAY, plotting of CASS predictions results in a three-panel plot. The contents of each panel are very similar to the graphical output for RAY. The only difference is that the bottom panel contains a plot of test rays emitted from the source, but a geometrical representation of eigenrays between the source and receiver are not output by CASS and thus are not plotted.

Although MAP supports the CASS model, that model is restricted and cannot be distributed with MAP. The point of contact for requesting CASS is Emily Childs McCarthy, Naval Undersea Warfare Center, Newport, RI, 02841-1708, (401) 832-8713, mccarthyeh@npt.nuwc.navy.mil.

C. University of Miami Parabolic Equation Simulation (UMPE)

The UMPE program [5] was written by Fred Tappert of the University of Miami. Unlike the three acoustic prediction programs described previously, it is not ray-based. Rather it is a wideband parabolic equation (PE) model supporting multiple bottom layers containing both longitudinal and shear waves.

UMPE also supports random surface waves. However, our implementation assumes a smooth surface and a single sediment layer above a half space (basement). (In the future, we intend to implement models of surface reflection loss for UMPE, and have put boxes in the GUI to support these models. However, MAP does not currently support modeling of surface conditions for UMPE.)

Plotting of UMPE predictions results in a two-panel plot. The bottom panel contains the same plot of bathymetry and SSPs along the line from source to receiver (primary to secondary instrument). The top panel contains bathymetry and an image of TL vs. range. The TL estimate is narrow band only. Because of this, there is no detailed plot of estimated time structure at the receiver from a high-resolution signal emitted from the source.

D. Range-Dependent Acoustic Model (RAM)

The RAM program [6] was written by Mike Collins at the Navy Research Laboratory. Like UMPE, RAM is a PE rather than a ray-based model. However, it is not wideband. If time resolution is desired, the model must be run at a number of frequencies and the results recombined after the runs. There are many versions of RAM with different capabilities. RAM.f is restricted to a smooth surface and compression waves in the bottom, although it will support many bottom layers. RAMS.f allows shear waves in the bottom. RAMSURF.f allows a rough surface.

The MAP implementation assumes a smooth surface and a single sediment layer above a half space (basement). The sediment or basement may support shear. If not, the "RAM" executable is used. If shear is specified the "RAMS" executable is used.

Plotting of RAM predictions results in a three-panel plot. The bottom panel contains the same plot of bathymetry and SSPs along the line from source to receiver (primary to secondary instrument). The top panel contains bathymetry and an image of TL vs. range. The TL estimate is narrow band only. The user can specify the top plot. After RAM is run, a grid of amplitude and phase is produced and read into MATLAB. A submenu is brought up that allows the user to plot:

    (1) Transmission loss vs. depth at a specified range
    (2) Transmission loss vs. range at a specified depth
    (3) Phase vs. depth at a specified range
    (4) Phase vs. range at a specified depth

The submenu can be changed and the top panel replotted until the user is satisfied with the display. When finished, the user can close the submenu.

Multiple RAM runs could be done to support computation of travel time but this has not been implemented in the current version of MAP. It would be a very long computation for a widely separated transmitter and receiver.

V. SHADOWING

A. Heuristic Algorithm

The heuristic shadowing algorithm focuses on estimating whether the bathymetry blocks the channel or whether the channel disappears. No attempt is made to estimate loss due to narrowing of the channel, except if the channel totally disappears. The algorithm uses a database of channel depth and channel depth limits computed from the Levitus database.

Bathymetry along geodesics is computed from the primary instrument to the edges of the bathymetry image, launched at azimuths specified in the main MAP GUI. Then starting at the minimum range specified, and stepping out in intervals equal to the range increment, the algorithm estimates whether the bathymetry intrudes into the channel above the channel axis. If the source is in shallow water, it is assumed that the sound will find some way to get to the deeper water, i.e., it allows propagation from shallow to deep water, but not from deep to shallow.

Using the heuristic algorithm, areas to which acoustic signals can be transmitted or from which acoustic signals can be heard are shown by plotting geodesics for ranges before propagation is blocked. To do this, click the "PLOT HORIZONTAL RAYS' pushbutton on the 5th row of submenus on the main MAP GUI.

Areas to which acoustic signals cannot be transmitted or from which acoustic signals cannot be heard are shown by plotting geodesics for ranges after propagation is blocked. To do this, select the "HEURISTIC" shadowing algorithm in the pull-down menu on the 7th click the "PLOT SHADOWS" pushbutton on the 5th row of submenus on the main MAP GUI

B. Shadowing Algorithm Based on Weston's Ray Invariant

Shadows may also be plotted using an algorithm based on Weston's Ray Invariant [7]. The ray invariant is the time it takes for a ray trapped in a duct to travel from its deepest to its shallowest depth. Mathematically, the ray invariant is

$$RI = \int_{zLower}^{zUpper} (\sin(rayElev(z))/c(z))dz$$

where *zUpper* is the shallowest depth and *zLower* is the deepest depth to which the ray goes. For slow changes in the SSP the value of the ray invariant does not change as a ray travels. The maximum ray invariant for a channel is the ray invariant for the ray going between the upper and lower depths of the channel.

There are two separate versions of the algorithm which differ in that one (RSR) allows propagation in channels involving both refraction and surface reflections, whereas the second (RR) only allows propagation via refraction, i.e., upper and lower vertices. Thus for the RSR algorithm the maximum sound speed in the channel is given by the maximum sound speed below the channel axis and above the bottom. The lower depth of the channel is the depth of the maximum sound speed. The upper depth is the surface or the depth above the channel axis at which sound speed equals the channel sound speed maximum, if such a depth occurs.

For the RR algorithm the maximum sound speed in the channel is given by the minimum of 1) the maximum sound speed above the channel axis and below the surface and 2) the maximum sound speed below the channel axis and above the bottom. The lower depth of the channel is the depth of the maximum sound speed. The upper depth is the depth above the channel axis at which sound speed equals the channel sound speed maximum, if such a depth occurs. Aside from the difference in computation of channel extent, both versions of the algorithm operate the same.

Fig. 2 illustrates an SSP that has both an RR channel and an RSR channel. The RR channel has a maximum sound speed of about 1483 m/s, and goes from *zUpper* = 10 m to *zLower* = 2068 m. The RSR Channel has a maximum sound speed of about 1494 m/s and goes from the surface to the bottom.
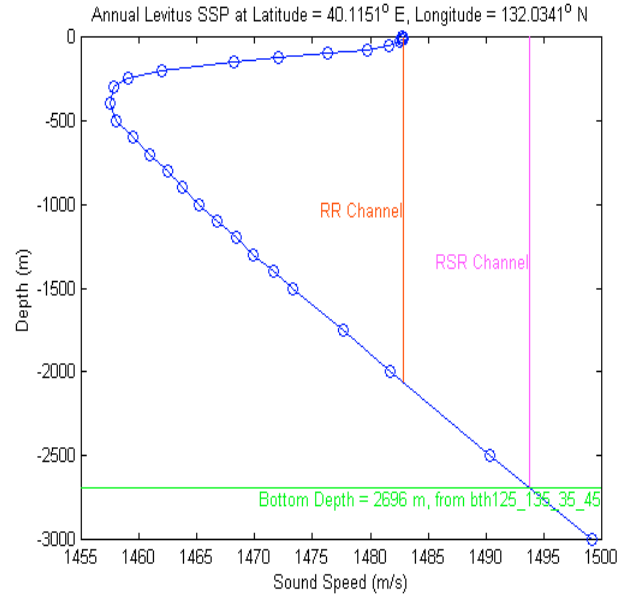

Fig 2. Illustration of RR and RSR Channels

Geodesics are computed going outward from the source to the edge of the bathymetry image. The maximum ray invariant is computed at range intervals equal to the range increment and used to compute a shadowing statistic. The shadowing statistic starts at one. Let:

RI(R,φ) = Ray Invariant at Range R for ray with on-axis elevation = φ.

maxRI(R) = Maximum Ray Invariant at range R.

If max (*maxRI(r)* for *r < R*) *< maxRI(R),* then compute *shadStat(R)* using the following algorithm

(1) Compute $\varphi 0$ *(R)* such that *RI(0, $\varphi 0$ (R)) = maxRI(R).*

(2) φ *(zSrc, R) = acos (cos($\varphi 0$ (R)) * c(zSrc,0) / c(axis,0)* where *c(zSrc,0)* is the sound speed at the source *and c(axis, 0)* is the sound speed on the channel axis at the source.

(3) *shadStat(R) = φ (zSrc, R) / φ (zSrc, 0),* where φ *(zSrc, 0)* is the maximum elevation for rays at the source that are trapped in the channel.

The geodesics are computed between the azimuth limits defined on the main MAP GUI. The shadowing statistic is set to 1 at the minimum range and decreased from there. The initial

bearing increment is set so that the range between initial points on the geodesics is about one-half the range increment. As range on geodesic increase, the separation between contiguous geodesics may become large enough that bathymetry pixels between the geodesics are separated from both of the geodesics by more than the ray increment. If this occurs, a new geodesic between the two is generated starting at this range, with the shadowing statistic initiated to a value equal to the mean of that on the two original geodesics at the range where the new geodesic is generated. This recruitment process is continued until there are no pixels more separated from the nearest range increment by more than a range increment.

When the algorithm is started, a new bathymetry image is plotted and as geodesics are generated, they are plotted with a color that varies from white to black as the shadowing statistic decreases from 1 to 0.

After the computation is completed, the shadowing statistic at each bathymetry pixel is computed by interpolated nearby values on the geodesics. A second new bathymetry image is plotted and the areas for which the shadowing statistic is less than 0.5 are indicated by a grid overlaid on the bathymetry.

V. CASE STUDY

Fig. 3 shows bathymetry from the MAP GUI for the Sea of Japan. Two instruments are shown, a source on the North edge of the Sea, and a receiver on the north side of an island at about 37.5 N Latitude and 131 E Longitude. A geodesic connecting the two instruments is shown as a black line. A point-to-point acoustic prediction was made from source to receiver with the EIGENRAY program. The results are shown in Fig. 4. The lower panel shows a plot of bathymetry along the geodesic and five SSPs along the track for the month of August. Although it is not easy to discern, the SSPs change slightly along the path.
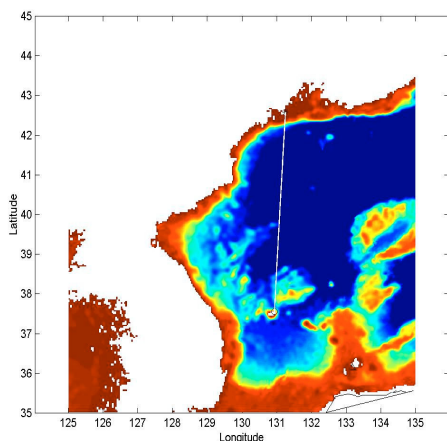

Fig 3. Bathymetry for the Sea of Japan

The middle panel shows eigenrays from source to receiver found by program EIGENRAY, launched from the source at elevations between $-12.5°$ to $12.5°$. The source is in a shallow continental shelf area. All the eigenrays propagate via multiple bottom reflections and either surface reflection or upper vertices on the shelf, then spill down the slope into the deeper portion of

the sea and propagate within an RR channel until they reach the receiver, which is at a depth of 450 m on the upslope to an island.

The top panel shows a scatter plot of number of turning points (vertices or boundary reflections) vs. travel time. Eighty-one eigenrays were generated with arrival times spanning about 0.5 s.
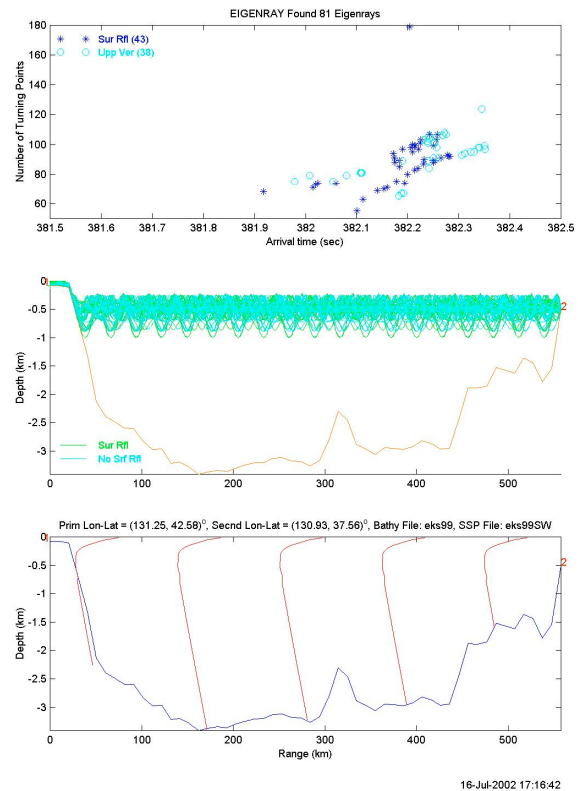

Fig 4. EIGENRAY Results for the Sea of Japan

Fig. 5 shows geodesics used in a Weston Ray Invariant Shadowing Computation using the receiver as the primary instrument. The geodesics are shown in white in the Sea of Japan except where the bottom intrudes significantly into the channel. This occurs immediately south of the receiver because of the island and then in several other shallow areas of the sea. As would be expected, in the land areas the geodesics are all black indicating no acoustic propagation. The azimuth increment of geodesics is greater when bottom is encountered at short range because recruitment of intermediate rays stops.

Fig. 6 shows the same geodesics as Fig. 5, except zoomed around the receiver. The receiver to the north of an island (shown as 4 white pixels) is seen easily at this resolution, as is the shadowing of the island. The island does not shadow one geodesic (at azimuth 180° from true North) because the initial range for computing shadowing is on the other side of the island. Also note that some of the geodesics start at longer ranges. These are the geodesics that are recruited to fill in between geodesics after they have separated by more than twice the required range resolution for the shadowing computation.

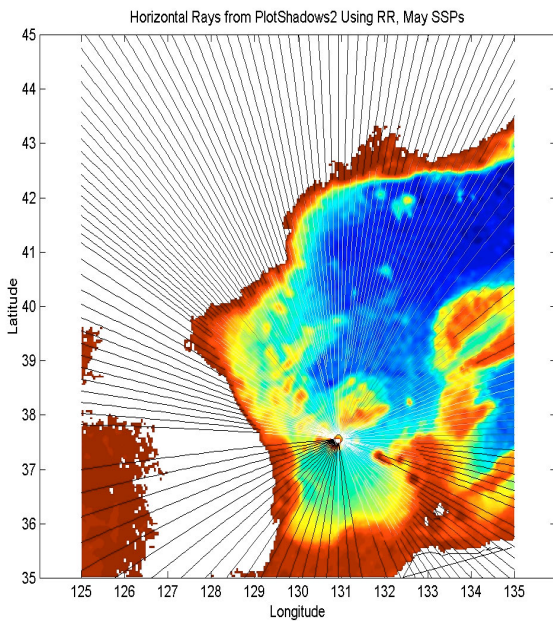Fig. 7 shows the final output plot for the scattering algorithm based on the Weston Invariant.

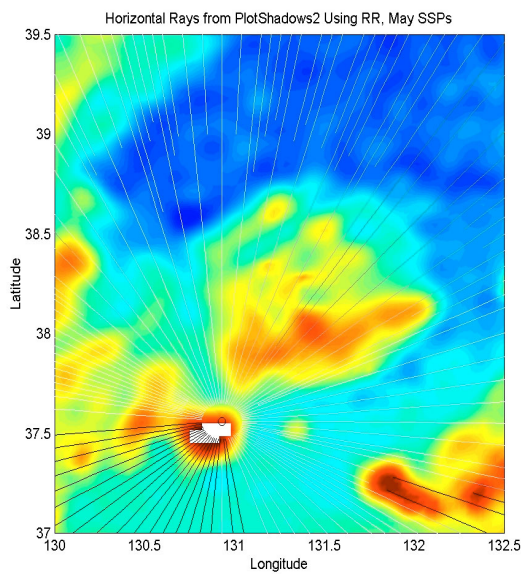Fig 5. Shadowing for the Sea of Japan

Fig 6. Shadowing for the Sea of Japan

V. CONCLUDING REMARKS

The MAP GUI brings together bathymetry and SSP databases and acoustic propagation predictions. Selection of instruments, setup of simple prediction computations and display of results are easy and convenient. Files written by MAP also provide a convenient basis for more detailed prediction computations.
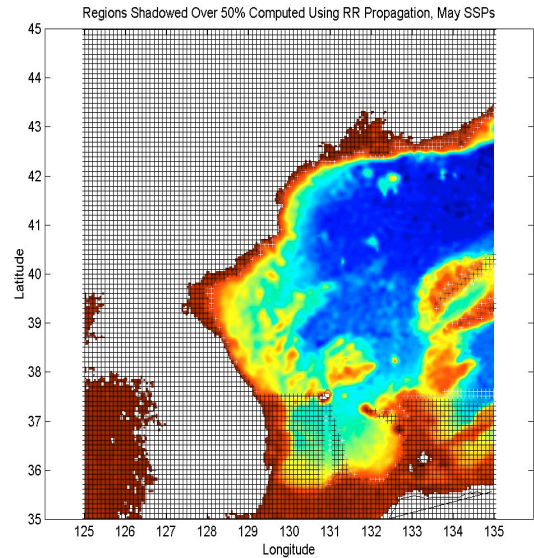

Fig 7. Areas Shadowed by over 50% for the Sea of Japan

References

[1] B. Dushaw, and J. A. Colosi, *Ray Tracing for Acoustic Tomography* APL-UW TM 3-98, Applied Physics Laboratory, University of Washington, Seattle, Dec 1998.

[2] *APL-UW High Frequency Ocean Environmental Acoustic Models Handbook*, APL-UW TR 9407, Applied Physics Laboratory, University of Washington, Seattle, 1994.

[3] J. B. Bowlin, J. L. Spiesberger, T. F. Duda, and L. F. Freitag, *Ocean Acoustical Ray-Tracing Software RAY*, Tech Rep WHOI-93-10, Woods Hole Oceanographic Institution, Woods Hole, MA., 1992.

[4] H. Weinberg and R.E. Kennan, "Gaussian ray bundles for modeling high-frequency propagation loss under shallow-water conditions," *J. Acoust. Soc. Am.* 100 (3), pp. 1421 – 1431, Sep 1996

[5] K. B. Smith and F. E. Tappert, *The University of Miami Parabolic Equation Model, Version 1.1,* MPL TM 432, Marine Physical Laboratory, University of California, San Diego, CA, May 1993

[6] Collins, M.D., "A split-step Pade' solution for the parabolic equation method," J. Acoust. Soc. Am., Proc 93, pp. 1736-1742, 1993.

[7] D.E. Weston, "Guided propagation in a slowly varying medium," *J. Acoust. Soc. Am., Proc Phys. Soc. London* 73, pp. 365-384, 1959.