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Initial Implementation of an Active Prediction Capability in Bellhop

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Defence R&D Canada – Atlantic

Contract Report
DRDC Atlantic CR 2010-120
October 2010

Canada

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Abstract

This report discusses the BellhopDRDC active program which is designed to produce reverberation and signal excess from bistatic scenarios using the Bellhop propagation engine. The discussion will primarily focus on the operational implementation issues of the present program and suggestions for its improvement.

Résumé

Le présent rapport traite du programme actif Bellhop de RDDC, conçu pour produire la réverbération et l'excédent de signaux d'après des scénarios bistatiques en utilisant le moteur de propagation Bellhop. Le rapport portera principalement sur des questions de mise en œuvre opérationnelle du programme actuel et sur des suggestions pour l'améliorer.

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Executive summary

Initial Implementation of an Active Prediction Capability in Bellhop

McCammon, D.F.; DRDC Atlantic CR 2010-120; Defence R&D Canada – Atlantic; October 2010.

Introduction: Bellhop is an acoustic prediction engine that generates estimates of the transmission loss of sound in the ocean, and is a key component of the tactical oceanography system called the Environment Modeling Manager. This report provides recommendations to enhance the Bellhop software package to better predict the effect of the ocean environment on the transmission of active sonar pulses.

Results: DRDC Atlantic's *BellhopDRDC_active_v4* is the version of Bellhop specifically designed to provide an active capability. This model is currently configured to accept multiple sensors and a transmitter, each with vertically angle-dependent beam patterns, but with no azimuthal dependence. It has been enhanced to include range dependent bottom losses along each of the bearing radials chosen by the user. A study was undertaken to provide recommendations to mitigate current implementation issues and to improve the active sonar capability, including improved scattering strength calculations, adding a clutter model, and more realistic towed array beam patterns.

Significance: The Environment Modeling Manager is a sophisticated tactical oceanography system being developed to aid naval planning and operations. It provides tactical decision aids with accurate and consistent predictions of acoustic conditions and target detectability. This report provides recommendations to improve those predictions associated with acoustic propagation from active sonars, mainly the effect from reverberation resulting from the use of subsurface projectors.

Future plans: Recommendations from this report will be considered and those with the greatest impact incorporated into the Bellhop software package.

Sommaire

Initial Implementation of an Active Prediction Capability in Bellhop

McCammon, D.F.; DRDC Atlantic CR 2010-120; R & D pour la défense Canada – Atlantique; Octobre 2010.

Introduction : Bellhop est un moteur de prévision de champs sonores qui produit des estimations de l'affaiblissement acoustique dans l'océan, et représente une composante essentielle du système d'océanographie tactique appelé *Environment Modeling Manager*. Le présent rapport énonce des recommandations en vue d'améliorer le progiciel Bellhop, afin de mieux prévoir l'effet du milieu océanique sur l'émission d'impulsions de sonar actif.

Résultats : La version *BellhopDRDC_active_v4* de RDDC Atlantique est la version du Bellhop spécifiquement conçue pour offrir une capacité active. Le modèle est présentement configuré pour accepter des capteurs multiples et un émetteur, chacun comportant des diagrammes de faisceau qui dépendent de l'angle à la verticale, mais sans dépendance azimutale. Des améliorations ont été apportées pour inclure les pertes au fond associées à la distance le long de chaque radial choisi par l'utilisateur. Une étude a été entreprise afin d'énoncer des recommandations en vue d'atténuer les problèmes actuels de mise en œuvre et d'améliorer la capacité du sonar actif, notamment pour l'amélioration des calculs de l'indice de réverbération, l'ajout d'un modèle de fouillis et des diagrammes de faisceaux de réseaux remorqués plus réalistes.

Importance : L'*Environment Modeling Manager*, un système perfectionné dans le domaine de l'océanographie tactique, est en cours d'élaboration afin de soutenir la planification et les opérations navales. Il représente un outil d'aide à la décision tactique offrant des prévisions exactes et cohérentes sur les conditions acoustiques et la détectabilité des cibles. Le présent rapport renferme des recommandations en vue d'améliorer les prévisions associées à la propagation acoustique provenant de sonars actifs, et principalement l'effet de réverbération résultant de l'utilisation de projecteurs immergés.

Perspectives : Les recommandations contenues dans le présent rapport seront étudiées et celles qui auront le plus d'impact seront intégrées au progiciel Bellhop.

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Acknowledgements

The helpful advice and timely data transfer from Dr. Dale Ellis are greatly appreciated and hereby acknowledged.

1. Introduction

1.1 Scope of implementation discussion

This report discusses the version of the Bellhop acoustic prediction program called BellhopDRDC, which concentrates on active transmissions that produce reverberation and signal excess from bistatic scenarios. The discussion will primarily focus on the implementation issues of the present program and suggestions for its improvement.

1.2 Present program capabilities

The current version of Bellhop, called BellhopDRDC_active_v4, has been customized for DRDC Atlantic to provide an active sonar capability. This model is configured to accept multiple sensors and a transmitter, each with vertically angle-dependent beam patterns but no azimuthal dependence. The model uses the May 2008 version of Bellhop for the propagation engine which accepts range dependent sound speed and bathymetry. BellhopDRDC_active_v4 is currently enhanced to include range dependent bottom losses along each of the bearing radials chosen by the user. The outputs include:

1. transmission loss from the sensors and the transmitter to each assigned target depth and bearing,
2. surface and bottom reverberation time series,
3. target echo time series,
4. signal excess as a function of range for each target depth, target bearing and sensor.

The source code, executable, and User's Guide to BellhopDRDC_V4 were provided to the Scientific Authority as part of the deliverables.

2. Suggested Improvements to the Active Program

2.1 Upgrade to Bellhop February 2010 web version

The February 2010 upgrade to the web version of Bellhop includes code that the author, Dr. Michael Porter, thinks will fix the algorithm bug that was documented in 2009 during the Curvilinear Bottom study. If the upgrade is successful, BellhopDRDC would be able to handle rough bottoms in a more efficient and more accurate manner in coherent calculations by using the curvilinear bathymetry interpolation option.

Dr. Porter also mentions that the newest web version of Bellhop is capable of computing the field from backward traveling rays. This added capability should be examined to determine if it will be of use to the present applications of BellhopDRDC.

2.2 Enable towed array beam patterns

Presently the active implementation does not handle azimuthally dependent beams such as the conical beams formed by a towed array. The most logical approach to obtain this capability would be to provide an intermediate output of the reverberation time series in a table as a function of bearing and D/E angle and then perform the beamforming for all towed array beams using this table. With external beamforming, the user would not have to rerun Bellhop for each towed array beam desired, so it would be a more flexible and more efficient calculation.

2.3 Reduce number of scattering strength models

The current surface scattering strength algorithms (choice of Ogden-Erskine or Chapman-Harris) could potentially be replaced by the newer NRL model described by Gauss et al. [1] This could remove the necessity for carrying two models and remove the uncertainty of choice.

The current bottom scattering strength algorithms (choice of Ellis-Crowe, Lambert or omni) do not have any newer alternatives. It seems clear from Harrison [2] and Ainslie [3] that the angle dependence of bottom backscattering is not known exactly and, in fact, may vary from $\sin\theta$ to $\sin^2\theta$ or somewhere in between. This certainly presents a complication for an operational model because databases of scattering strength dependences and coefficients do not exist. In Section 3 Figure 5, a comparison of the two different angle dependences shows about a 7 dB difference in the reverberation levels before the noise floor, with the omni rule being more pessimistic (higher reverberation level). To remove the necessity for user choice of model, a database of scattering strength coefficients and angle dependences would have to be constructed.

2.4 Add LFBL (BLUG) Bottom loss

In 2008, McCammon [4] performed an assessment of AESS bottom loss in model-data transmission loss comparisons in Sable Bank and the Emerald Basin environments. As part of this assessment it was necessary to use the LFBL (BLUG) model of bottom loss to provide tables of loss for BellhopDRDC. While the LFBL database of parameters is classified, the model algorithm is not. Therefore, using the techniques employed in the assessment, BellhopDRDC can be augmented by attaching the BLUG model. Alternatively, the BLUG model can reside within the EMM and provide the bottom loss table to BellhopDRDC.

2.5 Enable use of clutter model

The clutter model designed by Ellis, Preston, Hines and Young [4] is a method of injecting selected high reverberation segments in the bottom topography that would model known clutter sources. This method defines the Lambert coefficient of back scattering strength to have a smaller value (less negative gives stronger returns) in specific area-dependent locations. This method is suitable for implementation within BellhopDRDC_active_v4 with only minor modifications of the existing code. Specifically the Lambert coefficient will have to be input and accessed as a bearing and range dependent value.

3. Data Comparison

Data supplied by Ellis and Preston [6] was used for a simple comparison with BellhopDRDC_active_v4's reverberation. The measurements were made in the Strataform area of the New Jersey Shelf in May 2001. The area was flat, uniform and featureless with a depth of 118 m. The data were matched with reverberation generated by the Generic Sonar Model (GSM) in which the Lambert coefficient was varied to achieve the best fit in level to the data.

For this comparison, the critical inputs to BellhopDRDC_active_v4 were the same as those used in GSM in figure 10 of reference [6] for the 630 Hz data at Site P2. The 30m depth towed array broadside beam of 3.6º beamwidth was simulated by shifting the omni-directional beam by -17dB (i.e., 10*log(2*3.6/360)). The bottom was modeled as a uniform half-space with speed 1650m/s, relative density 1.7, and attenuation 0.5dB/m/kHz. The surface loss model, Eckart, and the surface scattering strength model, Chapman-Harris, were used at 15 kts wind speed, although the surface reverberation was not as strong as the bottom reverberation, so these inputs were secondary. The bottom scattering strength model was the Ellis-Crowe model with a Lambert coefficient of -32dB, facet strength of 10dB and facet width of 5º. Graphs of these losses are shown in Figure 1 and Figure 2. The 90m SUS charge source level was 203.3 dB and the pulse length was modeled as 0.17sec. The sound speed was basically a downward refracting profile below a surface duct of 20m depth. The data/model comparison is shown in Figure 3.

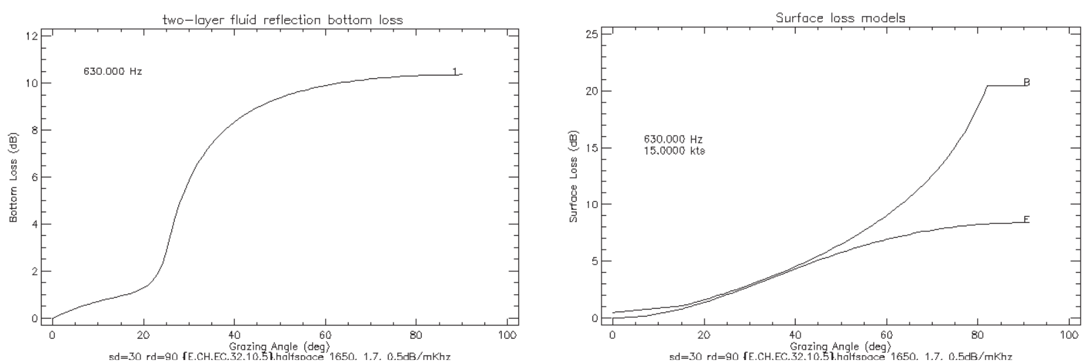


Figure 1. Left: Bottom loss for 630 Hz. Right: Surface loss model choices- E was used.

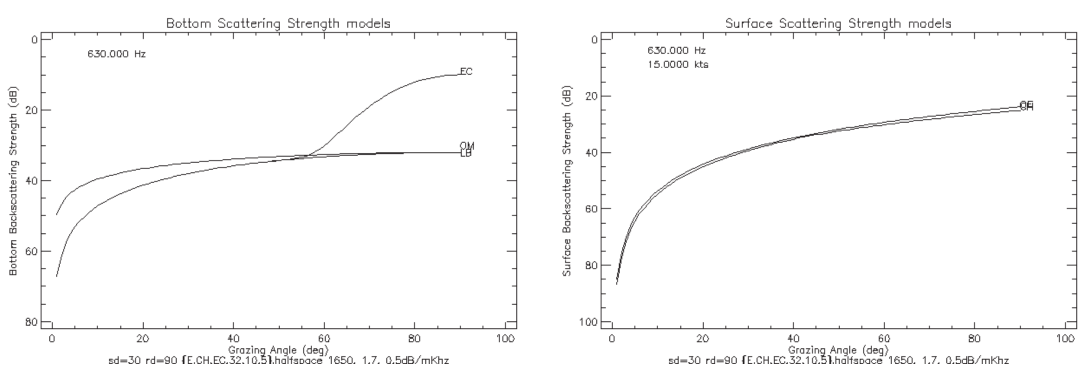


Figure 2. Left: Bottom Scattering strength model choices- EC was used. Right: Surface scattering strength model choices – CH was used.

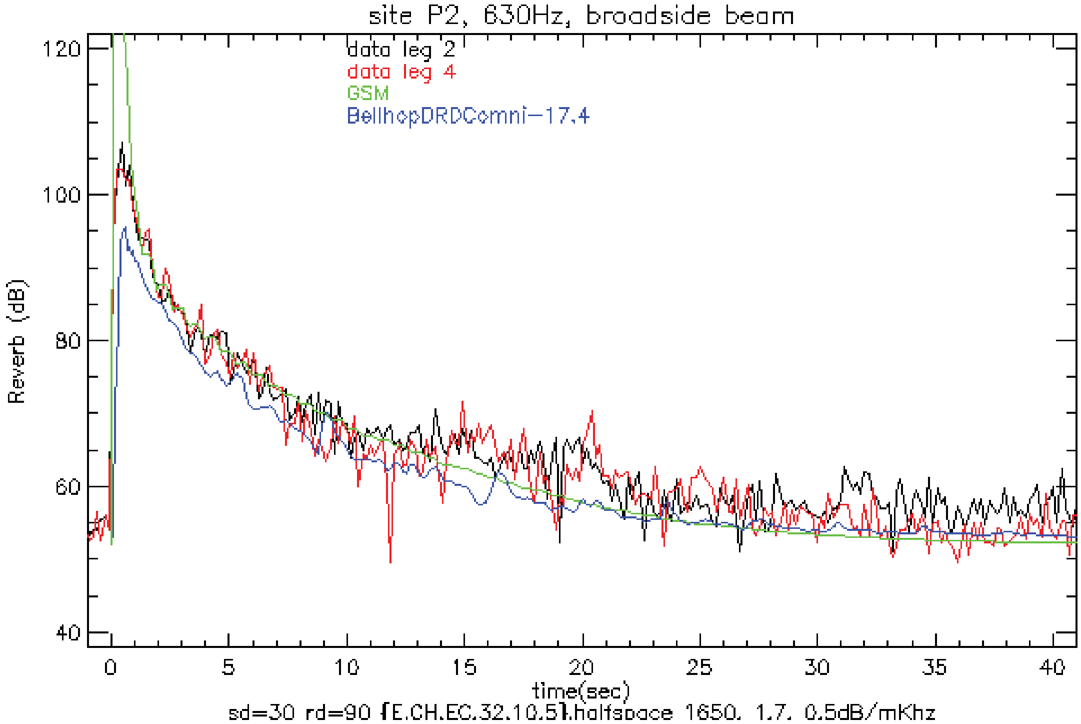
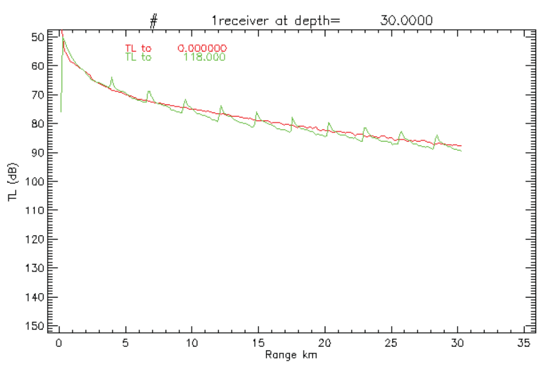


Figure 3. Reverberation time series. Data (red and black), GSM (green), BellhopDRDC (blue). Noise floor 53dB, Lambert coefficient -32dB.

The transmission loss from the towed array to the surface and bottom and from the transmitter to the surface and bottom is shown in Figure 4. The surface contribution is smaller than the bottom because the surface duct refracts sound away from the surface for the 90m source.



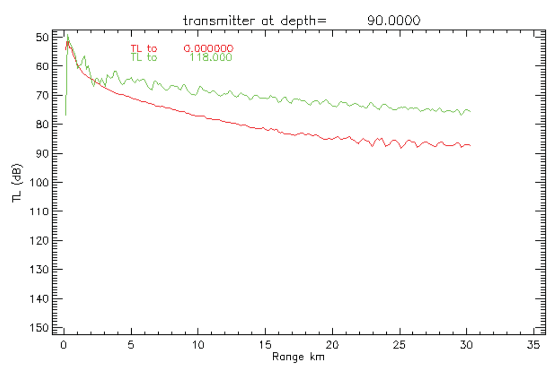


Figure 4. Left: TL from receiver to surface(red) and bottom(green). Right: TL from source to surface(red) and bottom(green).

It is useful to examine the sensitivity of the reverberation to the choice of backscattering model. In Figure 5, the reverberation is shown as computed with the Omni and Lambert models. The differences of about 7dB are entirely due to the sinθ versus $\sin^2\theta$ grazing angle dependence in the backscattering strength.

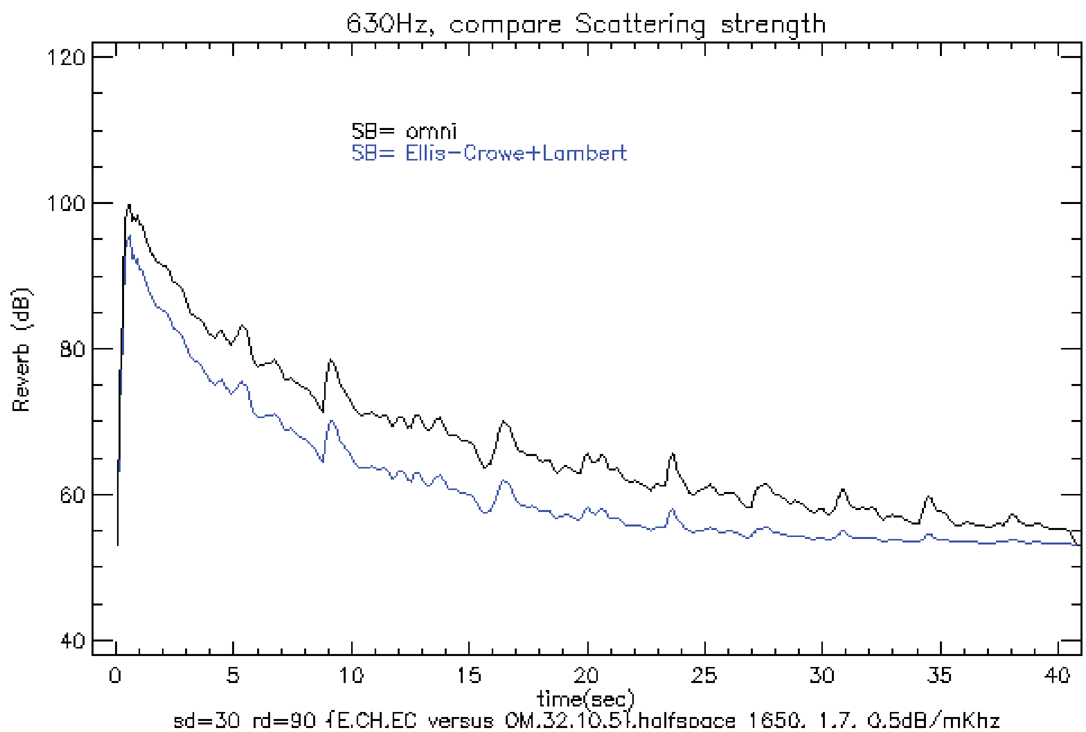


Figure 5. Comparison between Omni and Lambert angle dependences in backscattering strength, both using the same coefficient.

4. Future Implementation Direction

4.1 Goal of Operational Models

The goal for an operational model is to make the computations as foolproof as possible for the inexperienced user. That means removing confusing choices and simplifying the inputs required. It also means using models that are not overly sensitive to the inputs. To that end, the use of the BellhopDRDC model as an operational model presents a few problems.

4.2 Implementation Issues with Bellhop

The BellhopDRDC propagation program is not optimized for operational use. It was created from a research program and originally it offered no environmental loss models. To prepare the program for use at DRDC, several changes were made. The inputs were broken into files of one parameter such as SSP, Bathymetry, Bottom loss, etc. Several loss and scattering models were included as choices for the user. Finally, runtime parameters such as the number of rays and the trace step size were taken directly from the research program and not optimized for operational use.

The following list contains implementation issues that should be considered when preparing BellhopDRDC for operational use.

1. The structure of the input files should be coordinated with the EMM capabilities to make sure that input files are easily constructed, particularly for complicated scenarios with multiple sensors in range dependent and azimuthally changing environments. The input structure could be rearranged to have one file per sensor which contains all its environmental descriptors. It may also be advantageous to reduce the input complexity of BellhopDRDC_active_v4 by performing the calculations for just one sensor/transmitter combination along one bearing only. The table of partial reverberation output needed for towed array beamforming could be employed more generally for all sensors.

2. The present range of choices for scattering strengths is not to be recommended for operational use because the user may not be able to make intelligent choices. Indeed, in the case of bottom scattering strength, no one knows exactly when to employ Lambert and what the coefficient should be. Serious thought should be given to reducing the model choice dilemma, perhaps by deciding to assume worst case scenarios or by investigating the construction of a scattering strength database.

3. The speed of the calculation using BellhopDRDC in a complicated environment with multiple bearings and sensors may be an issue operationally. A few things can be done to reduce the runtime of the model.

    a. Simplify the sound speed profile as much as possible because runtime is directly affected by the number of points in the SSP. The penalty for this is to lose some of the details which would affect the coherent output.

b. Reduce the size of the angle fan used by Bellhop because the number of rays being traced is directly related to the width of the angle fan. Present defaults are ± 25º. Reducing this will speed the program at the cost of losing the high angle contributions to reverberation at short ranges. The exact extent of the trade off could be determined by a sensitivity study.

c. Reduce the maximum range of the requested calculation because the square root of the range is also used to determine the number of rays being traced. A back-of-the-envelope calculation may help determine where in time (range) the noise floor will be met, and the reverberation calculation could stop there.

4. Internally computed parameters relating directly to accuracy and run time are the number of rays to trace and the ray trace step size. Currently these parameters are defaulted to the values used in the research code. An effort should be made to gauge their effect on accuracy of prediction and determine if they can safely be changed to reduce the runtime.

5. Implementation of a LFBL (BLUG) bottom loss would remove the necessity of determining bottom properties. The penalty for this is that the bottom losses may be too inaccurate. Possibly the EMM could inject a correction to overcome errors, at least for those areas with a known bottom loss.)

References

[1] Roger Gauss, Joseph Fialkowski, Daniel Wurmser, and Redwood Nero, “New broadband models for predicting bistatic surface and volume scattering strengths”, *ONR Environmentally Adaptive Sonar Technology (EAST) Peer Review*, (8-11 February 2000).

[2] C.H. Harrison, “Closed-form expressions for ocean reverberation and signal excess with mode stripping and Lambert’s law”, J. Acoust. Soc. Am., **114**(5), 2744-2756, (2003).

[3] Michael A. Ainslie, “Observable parameters from multipath bottom reverberation in shallow water”, J. Acoust. Soc. Am., 121(6), 3363-3376, (2007).

[4] Diana McCammon, “Assessment of AESS bottom loss in model-data transmission loss comparisons”, DRDC Atlantic, CR 2008-036, Defence R&D Canada – Atlantic (2009)

[5] Dale D. Ellis, John R. Preston, Paul C. Hines, and Victor W. Young, “Bistatic signal excess calculations over variable bottom topography using adiabatic normal modes” in *International Symposium on Underwater Reverberation and Clutter*, P.L. Nielsen, C.H. Harrison and J.C. LeGac, eds., NATO Undersea Research Center, La Spezia, Italy, pp. 97-104, (2008).

[6] Dale D. Ellis and John R. Preston, “Extracting bottom information from towed-array reverberation data Part II: Extraction procedure and modeling methodology”, J. Marine Systems, **78**, S372-S381, (2009).

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Annex A BellhopDRDC_Active_v4 Flow Chart

For implementation of a reverberation and signal excess calculation using BellhopDRDC, the general steps are to read inputs, compute salt tables (sound angle, level, and time), assemble reverberation from surface and bottom, assemble target echo, then form the signal excess ratio. The steps are:

1. Read in the environmental descriptions for each sensor and the transmitter (assets) along the bearings desired. Choose scattering strength models, target depths-of-interest, and bearing-of-interest.

2. Compute salt tables for all sensors and the transmitter. Loop over assets and bearings. Transfer environmental data from storage arrays into Bellhop arrays for each asset at each bearing. Call BellhopDRDC to compute salt table containing # arrivals, intensity, launch angle, arrival angle, and travel time.

3. Compute surface and bottom reverberation, target echo and then form the signal-to-reverberation ratio and signal excess. Transmission loss along the target bearing from each asset can also be output.

Table 1 shows the subroutine names that perform each of these functions.

Table 1: Listing of BellhopDRDC_active_v4 subroutines

Subroutine	Called by	Function
Frontend_active_v4.f90	BellhopDRDC_active_v4.exe	Main program: read inputs, call for salt tables, call reverb, target echo and SE, write output
Readinput_active.f90	Frontend_active_v4.f90	Inputs all environmental and asset information. Requires: active_general.inp radial_bathy.inp radial_svp.inp radial_bottomloss.inp and asset_beampattern.inp.
Envstore_v4.f90	Frontend_active_v4.f90 within first loop over each asset and bearing	Transfer each individual asset information for each bearing into arrays for Bellhop
Salt_v4.f90	Frontend_active_v4.f90 within first loop over each asset and	Calls BellhopDRDC to compute salt tables: # arrivals, intensity, launch angle, arrival

	bearing	angle, travel time
Reverb.f90	Frontend_active_v4.f90 within second loop over each sensor along target bearing	Computes surface and bottom reverberation as a function of time
Targetecho.f90	Frontend_active_v4.f90 within second loop over each sensor along target bearing	Computes target echo in time using 0dB target strength and source level. Also computes TL from transmitter to target and from sensor to target.
SE_active.f90	Frontend_active_v4.f90 within second loop over each sensor along target bearing	Computes SNR and SE for input target strength, source level, and noise level.
Writeoutput_active.f90	Frontend_active_v4.f90 within second loop over each sensor along target bearing	Contains all subroutines for writing output files of arrival tables, reverberation, target echo, TL, and SE

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