Cluster of Sound Speed Fields by an Integral Measure

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Abstract— A technique to cluster large area oceanic predictions of sound speed into quasi-range independent areas is presented. Oceanic models produce high fidelity predictions of the oceanic sound speed fields that enable large-scale simulation of acoustic propagation with reasonable accuracy. Unfortunately, the oceanic models can produce sound speed fields quicker than can be digested by current technologies in underwater acoustic performance prediction systems. The speed bottleneck can be broken in two ways, a long term improvement in prediction technologies, and a interim process that allows similar acoustic areas to be aggregated into range dependent regions while maintaining a high degree of fidelity with the performance prediction resulting from using the complete oceanic model output. The interim process created must be capable of reflecting changes in sound speed field that control water born energy, and the changes in the field that effect the interaction with the oceanic bottom.

This study uses vertically integrated gradient of the sound speed field as a basis for creating quasi-range dependent areas. The integrated gradient, when applied over a restricted latitudinal extent, gives an estimate of the mean ray curvature in the wave-guide. Since the field is integrated over depth, the effects of water depth are included in the calculation. The nature of the interaction with the oceanic bottom is not included in this calculation. The variations in bottom loss over the region of interest will be integrated into the analysis at a latter stage. The quantity cannot be used to predict transmission loss, but indicates where similar propagation conditions occur. The method is shown to be sensitive to the characteristics of the deep sound channel, and changes in the near surface structure of the sound speed field. The method is sensitive to the vertical integration weighting, which needs to be investigated further.

The method is applied to an oceanic region where variations in bottom effects are simple and relatively well understood. Incoherent acoustic transmission loss predictions are made from a single receiver depth to a single target depth for each of the longitude-latitude mesh points in the computational domain of the oceanic prediction model where the initial water depth is greater than both the receiver depth and the target depth to a maximum range of 100km. The transmission loss predictions are fitted to a two-parameter family of curves. The two-parameter family of curves accomplish two closely related goals: (1) the number of parameters that must be compared is minimized, and (2) the slight differences in range of maximum and minimum that so often cloud prediction comparisons are eliminated. The relationships between transmission loss parameters, and integrated gradient of the sound speed field are relatively well constrained. The relationships cluster into groups that are characterized by bottom type. The relationships between the two-parameter family of curves and the vertically integrated index are thus far diagnostic, the variations in parameter coefficient are large enough such that a prognostic relationship does not appear to be supported.

I. INTRODUCTION

Accurate performance prediction requires accurate environmental input, and accurate acoustical models. The current technology in oceanic prediction models can predict large area high fidelity predictions that can be used for acoustic performance prediction. The current state of technology in acoustic performance prediction does not allow for high fidelity predictions on a schedule comparable with the oceanic prediction models.

Integral parameterization of the oceanic environment have been made for range dependent situations - for example surface duct propagation, and depth excess. In particular consider depth excess, it is related to the integral of the gradient of the sound speed in a range independent environment. In this paper two parameters will be introduced that are of particular value in spherical coordinates.

A. Scope of the Problem

Before considering this problem a number of simplifying assumptions will be made. First assume each acoustic calculation can be made at 1 or more frequencies at the same cost in time. The increasing the number of sensor depths does not cause execution time to increase. And finally assume that the time required to input the data, and extract the data from the acoustic model is zero.

Consider the set of acoustic calculations that are required to predict sonar performance in an area that is N degrees in latitude by M degrees in longitude. Assume that an acoustic environment is predicted at L points per degree of longitude and latitude. There are then $(LN+1)*(LM+1)$ locations in which acoustic predictions must be made to estimate performance. For a relatively small area, say 5 degrees latitude by 5 degrees longitude, with an environment resolution of 2 minutes there are 22801 locations in which acoustic models must be exercised. Unless each environment is identical acoustic predictions will have to made along a number of bearings. A minimum number would be the cardinal and intercardinal points, or a total of 8 radials per locations, thus giving a grand total of 182408 radials to characterize the area. On a single

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14. ABSTRACT
A technique to cluster large area oceanic predictions of sound speed into quasi-range independent areas is presented. Oceanic models produce high fidelity predictions of the oceanic sound speed fields that enable large-scale simulation of acoustic propagation with reasonable accuracy. Unfortunately, the oceanic models can produce sound speed fields quicker than can be digested by current technologies in underwater acoustic performance prediction systems. The speed bottleneck can be broken in two ways, a long term improvement in prediction technologies, and a interim process that allows similar acoustic areas to be aggregated into range dependent regions while maintaining a high degree of fidelity with the performance prediction resulting from using the complete oceanic model output. The interim process created must be capable of reflecting changes in sound speed field that control water born energy, and the changes in the field that effect the interaction with the oceanic bottom. This study uses vertically integrated gradient of the sound speed field as a basis for creating quasi-range dependent areas. The integrated gradient, when applied over a restricted latitudinal extent, gives an estimate of the mean ray curvature in the wave-guide. Since the field is integrated over depth, the effects of water depth are included in the calculation. The nature of the interaction with the oceanic bottom is not included in this calculation. The variations in bottom loss over the region of interest will be integrated into the analysis at a latter stage. The quantity cannot be used to predict transmission loss, but indicates where similar propagation conditions occur. The method is shown to be sensitive to the characteristics of the deep sound channel, and changes in the near surface structure of the sound speed field. The method is sensitive to the vertical integration weighting, which needs to be investigated further.

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processor, with each radial requiring 1-second total clock time, the calculation would require more than 50 hours.

If the required elapsed times between acoustic performance predictions are less than can be performed, there are three options. The processor throughput can be increased, the acoustic model can be optimized, or the number of runs can be reduced through similarity of conditions to a number than can be executed using existing hardware, and software.

Assuming that the hardware/software solution lies in the future it is necessary to consider some methods to characterize local environments into nearly range dependent areas as a stop-gap solution.

B. Scope of the Paper

In this paper the two parameters developed in this study are presented. A study using a simple but realistic case for a depth limited environment will be presented. The mean relationships between the parameters under consideration will be discussed.

II. HEURISTICS

In this section two parameters will be defined. One parameter will highlight vertical changes in the sound speed structure, and the second will highlight horizontal changes. In general the choice of the coordinate system depends on the form of the solution that is desired. In this case a coordinate system will be selected to cause one parameter to vertically dominate, and the other horizontally dominate.

Define the parameter Z to be

$$Z = \int_b^0 \nabla C(\rho,\theta,\lambda) \cdot \nabla C(\rho,\theta,\lambda) d\rho \qquad (1)$$

and parameter P to be

$$P = Z - \int_b^0 \frac{\partial C(\rho,\theta,\lambda)}{\partial \rho} \frac{\partial C(\rho,\theta,\lambda)}{\partial \rho} d\rho \qquad (2)$$

where (ρ,θ,λ) are the usual geocentric spherical coordinates, and the limits of integration are the sea surface, and sea bottom. The second term of the right hand side of the equation is the square of the sound speed difference between the surface and the sea bottom. In spherical coordinates the Z parameter is dominated the vertical gradients. Normally the vertical gradients are much larger, but using spherical coordinates requires that the horizontal (θ, λ) terms be normalized by the radius. In the case of geocentric coordinates this term is on the order of 6.4 million meters. The Z parameter will then overemphasize changes in the bottom grazing angle, while the P parameter will highlight subtle changes in the horizontal gradients.

The scaling effects of the coordinate system forces the two parameters to be largely independent. The Z parameter gives insight into the integrated gradients of the sound speed field, and by way of ray theory into the total curvature of the ray fields. The P parameter gives insight into the mean squared horizontal slope of the sound speed field, thus the first order range dependency.
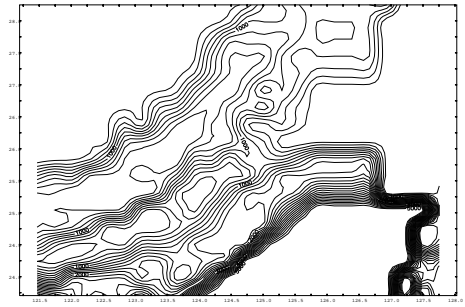

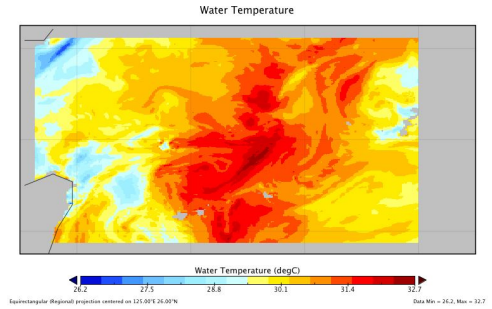Fig. 1. Plot of bathymetry in the modeling area.

Fig. 2. Plot of water surface temperature in the modeling area.

III. SAMPLE CALCULATION

The parameters are now applied to a depth limited region of the western pacific. A contour plot of the bathymetry is shown in figure 1, and the sea surface temperature for the run is shown in figure 2. The analysis will be in the area from 122 E to 127 E, and 25 N to 28 N, thus the water depths are typically less than 2200 m. The oceanic data is from a summer prediction. The water temperatures, and salinities are converted to sound speed using the Chen-Millero [2] relationship. The bottom sediments are modeled using a Hamilton [3] model consisting of uniform silty-clay in the water depths greater than 200m, and very fine sand in water depths less than 200 m. Transmission loss to a receiver located at depth of 8m, from a source located at a depth of 60 m at a nominal frequency of 3 kHz is calculated using ray based transmission loss model[4]. The transmission loss predictions are then fitted to logarithmic curve to smooth the prediction. A mean coverage range is calculated by assuming a figure of merit of 80 dB, and taking the arithmetic mean of the ranges associated with the eight cardinal and intercardinal directions.

Figure 3 shows the Z parameter calculated from the oceanic model input fields. In general there is very little correspondence to the bathymetry plot (figure 1) or the sea-surface temperature (figure 2). Figure 4 shows the P parameter calculated from the oceanic model input fields. The P parameter shows relationship to both the bathymetry, and the sea surface temperature. The P parameter is only sensitive to horizontal gradients in the temperature and salinity fields. The current ,salinity and temperature fields are all influenced by the bathymetry. The Z parameter is dominated by the squared of

the vertical gradients in the sound speed, it is very much a local value related to the depth excess.

Figure 5 shows a contour plot of the ratio of the mean coverage range to depth for the modeling area. Figure 6 shows a contour plot of the ratio of the mean coverage range to Z parameter. Figure 7 shows a contour plot of the ratio of the mean coverage range to P parameter. All three figures display some similar characteristics. First the strongest variability is in the shallow (less than 200 m water depth) region. However, the variability in the ratio of the mean coverage range to Z parameter is much larger in the central trough region running from 122.5 E 25 N to 126.5 E 27 N than those of the other two ratios shown. The Z parameter ratio is showing the effect of integrated squared vertical gradient of the sound speed. As the water depth changes the sound speed ratio between the surface water and bottom water changes which would change the grazing angles at the bottom. But since the bottom is characterized by a silty-clay the changes in bottom grazing angle will have little effect on the bottom loss. The P parameter will be sensitive to square of the horizontal gradients in the sound speed. Thus only the oceanic effects which change either temperature or salinity will be reflected in the P parameter. So the P parameter shows the changes induced by the shelf break, and the island chain to the south-east of the trough axis. Second the trend of all three ratios follows the trend of the bathymetry. And third, the ratio between the largest value of any ratio and the mean value of the ratio is about 2. One difference between the plots is related to the clarity of the island chain - most clear in the water depth ratio plot, least clear in the P parameter plot. A second difference is the apparent sift of features in the P parameter plot - this is largely an artifact of the differencing scheme used to calculate the parameter.

The qualitative agreement visible in the ratio plots are reflected in quantitative measures. The linear correlation coefficient between the mean coverage range and the local water depth, Z parameter, and P parameter are 0.77, 0.47, and 0.59 respectively. The water depth, and P parameter are well correlated to the mean coverage range, and the Z parameter is weakly correlated. For water depths greater than 500 m the linear correlation coefficients between the mean coverage range and the local water depth, Z parameter, and P parameter are 0.83, 0.46, and 0.65 respectively. The shallow water correlations are similar for all three parameters, around 0.5.

Figure 8 shows the relationship between the mean coverage range divided by the P parameter and the P parameter. At low values of the P parameter the ratio between the mean coverage range and P parameter is poorly constrained. At higher values of P parameter the relationship is better constrained.

IV. SUMMARY AND CONCLUSION

The P parameter is well correlated mean coverage range in this depth limited environment. The correlation between the P parameter and the mean coverage range is not good as the correlation as the relationship between water depth and mean
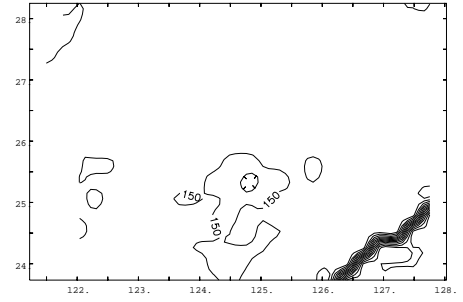

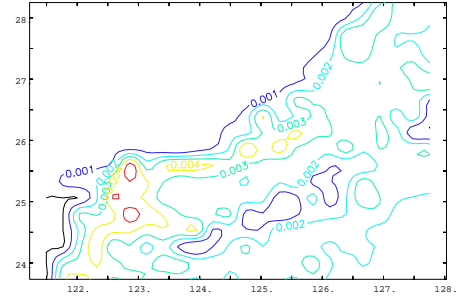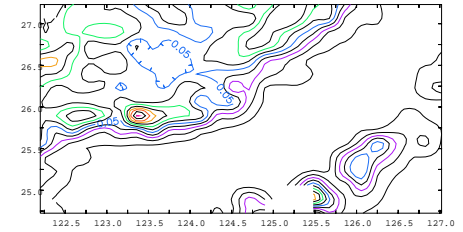Fig. 3. Plot of Z parameter in the modeling area.

Fig. 4. Plot of P parameter in the modeling area.

Fig. 5. Plot of ratio of the mean coverage range to water depth in the modeling area.

Fig. 6. Plot of ratio of the mean coverage range to Z parameter in the modeling area.

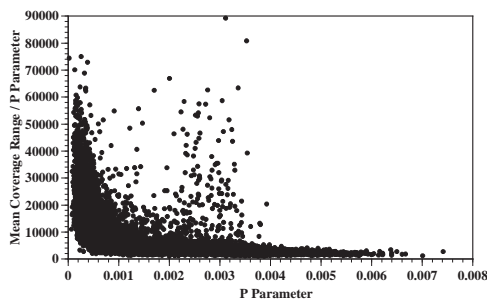Fig. 7. Plot of ratio of the mean coverage range to P parameter in the modeling area.

Fig. 8. Plot of ratio of the mean coverage range divided by the P parameter as function of the P parameter.

coverage range. In shallow water these two correlations are approximately the same,as is the Z parameter correlation.

In the central trough region the P parameter suggests that a mean sound speed is sufficient to model the propagation. The correlation in mean coverage range and P parameter is extremely good. In the shallow regions the correlation is poor. It appears that P must be of some critical size before it is useful as a tool.

The predictive ability of the P parameter is limited. Figure 8 shows that there is a relationship between the mean coverage range and the P parameter. The definition of the measure implies that for small range sound speed range dependencies the value of P is small, thus it may be useful as ancillary measure to more traditional range independent measure (surface duct measure and depth excess for example) but as the sole measure if is of limited utility in environments characterized by small range dependencies.

REFERENCES

[1] Boyles, Allan C. *Acoustic Waveguides*, Applications to Oceanic Science, John Wiley and Sons Inc, New York ,NY, 1984.
[2] Chen, C.T. and F. J. Millero, Speed of sound in seawater at high pressures, J. Acoust. Soc. of Amer., vol. 62, no. 5, 1977, pp. 1129-1135.
[3] Hamilton, Edwin L, and Richard T. Bachman, "Sound velocity and related properties of marine sediments," J. Acoust. Soc. of Amer., vol 72, no. 6, 1982, pp. 1891-1904.
[4] Fulford, J. K., "A Simple Gaussian-Beam-Based Reverberation Model," in Environmental Acoustics International Conference on Theoretical and Computational Acoustics Volume 2, Ding Lee and Martin H Schultz (eds), World Scientific, Singapore, 1994, pp 991-998.