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Statistics of broadband transmissions through a range-dependent fluctuating ocean waveguide

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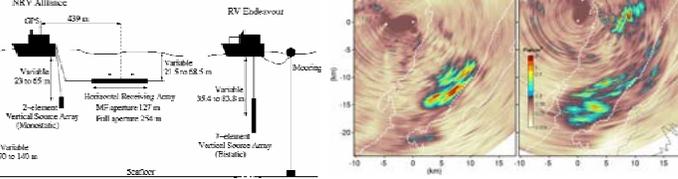
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Abstract

Acoustic signals transmitted through an ocean waveguide are temporally and spatially varying due to multimodal interference and effects such as internal waves. Estimating parameters of sonar, the environment and scatterers requires a statistical approach that incorporates medium uncertainties into the signal analysis. Short duration broadband pulses were transmitted from a moored source array and measured by a towed horizontal receiving array at varying ranges from the source. The ping-to-ping fluctuations in the measured acoustic data are a result of changes in the waveguide modal interference structure due to both motion of the array and presence of time dependent random internal waves. Our analysis shows that the Parseval sum and match filter outputs of the broadband transmissions for the direct arrival have significantly smaller standard deviations compared to the instantaneous single frequency transmission. We account for these observations by modeling the broadband acoustic field intensity in both a static waveguide and with Monte Carlo simulations in a fluctuating waveguide. A maximum likelihood estimator is implemented to provide a global inversion of the data for source level and a range-dependent expected intensity, as well as quantifying the match filter degradation in the multi-modal ocean waveguide.

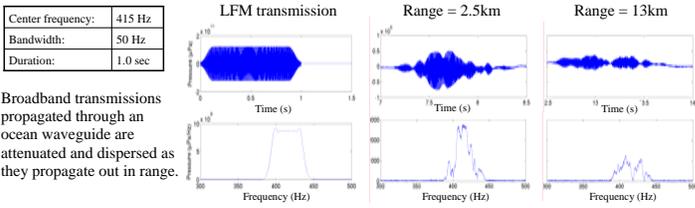
ONR Main Acoustic Clutter Experiment (2003), Geoclutter Program

Bistatic experimental setup used for Ocean Acoustic Wave Remote Sensing (OAWRS)



• Long range SONAR such as OAWRS can be used to instantaneously image schools of fish or other targets.
• Propagation and statistics of broadband signals must be thoroughly understood to invert for scattering strength

Broadband Transmissions



Broadband Processing

Received Signal: $\Psi(t) = \int_{-\infty}^{\infty} Q(f)G(r|r_s, f) \exp(j2\pi ft) df$

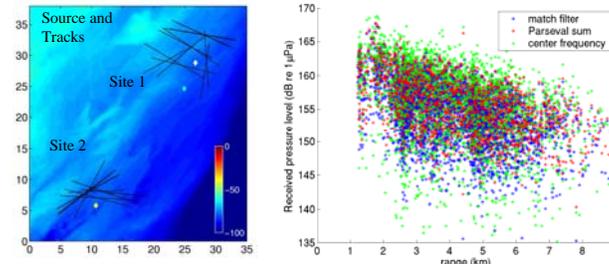
Single Frequency Field: $\Phi(f) = \int_{-\infty}^{\infty} \Psi(t) \exp(-j2\pi ft) dt = Q(f)G(r|r_s, f)$

Single Frequency Intensity: $|\Phi(f)|^2 = |Q(f)G(r|r_s, f)|^2$

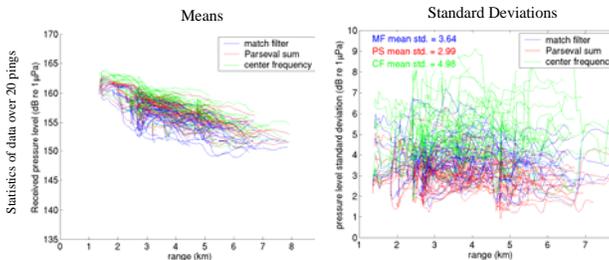
Parseval Sum: $E_s = \int_{f_1}^{f_2} |\Psi(t)|^2 dt = \int_{f_1}^{f_2} |\Phi(f)|^2 df = \int_{f_1}^{f_2} |Q(f)G(r|r_s, f)|^2 df$
Parseval Sum is the sum of all of the energy in the bandwidth of the signal

Match Filter: $h(t) = Kq^*(t_M - t)$ $H(f) = \int_{-\infty}^{\infty} h(t) \exp(j2\pi ft) dt = KQ^*(f) \exp(-j2\pi ft_M)$
Match Filter Field: $MF(t) = \int_{f_1}^{f_2} \Phi(f)H(f) \exp(j2\pi ft) df = K \int_{f_1}^{f_2} |Q(f)|^2 G(r|r_s, f) \exp[j2\pi f(t - t_M)] df$
Match Filter Intensity: $|MF(t)|^2 = \left| \int_{f_1}^{f_2} |Q(f)|^2 G(r|r_s, f) \exp[j2\pi f(t - t_M)] df \right|^2$ $K = \left(\int_{f_1}^{f_2} |Q(f)|^2 df \right)^{-1}$
Match filter extracts the energy that "matches" the original signal Q(f)

One Way Propagation Data



Broadband signals transmitted directly from the source to receiver traveling along a straight track were collected and processed using a Parseval sum intensity, match filter intensity, and compared to the intensity at the center frequency. The statistics using a running window over each track is shown below.



Calibrating for Source Level and Expected Intensity from one-way Data

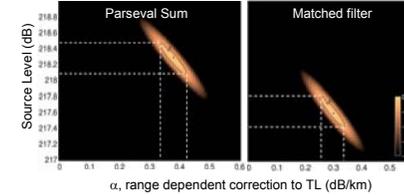
Range-dependent Expected intensity: $\bar{I} = A_s \left\langle |G(r|r_s)|^2 \right\rangle \exp(2\alpha r)$
Expected transmission loss using RAM model: α range-dependent correction coefficient

Source Level: $SL = 10 \log_{10} A_s$

Likelihood Function: $P(W) = \prod_{i=1}^N \frac{(\mu/\bar{I})^\mu W_i^{\mu-1} \exp(-\mu W_i/\bar{I})}{\Gamma(\mu)}$
 W_i = Intensity measurement
 μ = time bandwidth product (see below)

The statistics of the one-way propagated data is used to calibrate for the expected intensity versus range by calibrating both the Source level, as well as a range dependent correction, α , to the expected transmission loss. This is accomplished using a maximum likelihood estimator, which incorporates all of the one-way data and the expected transmission loss using a depth average of the RAM model.

Normalized Likelihood Functions $10 \log |P(W)|$

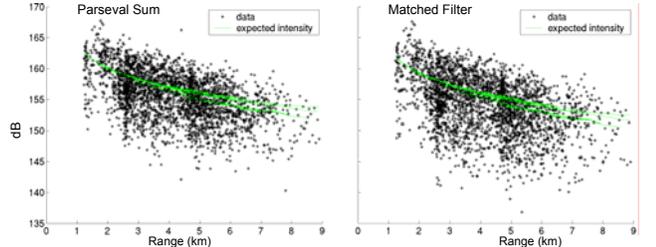


Calibration Results:

	Parseval Sum	Matched Filter
SL (dB)	218.3	217.6
α (dB/km)	0.38	0.30

MF degradation = 0.7dB
Range-dependent deg = 0.08dB/km

Expected intensities and Data



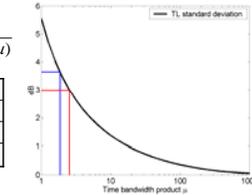
Time Bandwidth Product

Intensity standard deviation relates to time-bandwidth product:

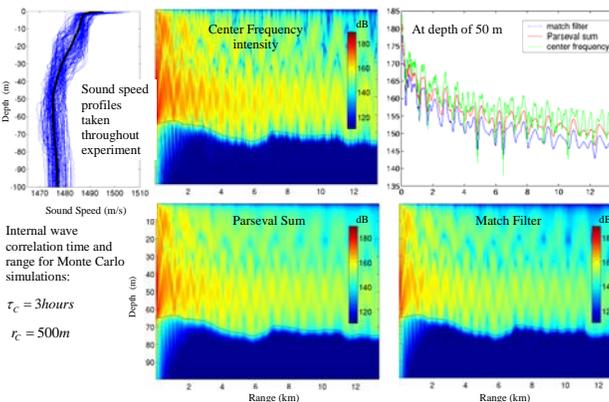
$$\sigma_I = (10 \log e) \sqrt{\zeta(2, \mu)}$$

The time bandwidth product, μ , is a measurement of the number of independent measurement samples.

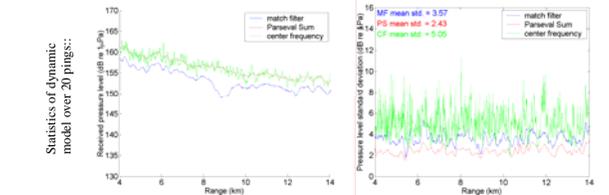
	σ (dB)	μ
Center frequency	4.98	1.18
Parseval Sum	2.99	2.56
Match Filter	3.64	1.88



Ocean Waveguide Computational Modeling



The Range Dependent Acoustic Model (RAM) accounts for the environmental parameters of the ocean, such as the sea floor geoaoustic parameters, the sound speed profile, and the changing bathymetry over range (above). It is applied here to investigate the statistics of the processed signal intensity in both space and time, using Monte Carlo simulations. (below)



Conclusions

- An approach is demonstrated to calibrate for the source level as well as the range-dependent expected intensity using a maximum likelihood estimator.
- Statistical spatial and temporal fluctuations of the broadband intensities, as well as match filter degradation are accounted for using a range-dependent computational model.
- It is demonstrated that modal interference and modal dispersion are primary causes of these effects.

References

- N. C. Makris, "The effect of saturated transmission scintillation on ocean acoustic intensity measurements," J. Acoust. Soc. Am. 100(2), 769-783 (1996).
Goodman, Joseph W., *Statistical Optics*, Wiley, New York, (1985)

Acknowledgements

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