Blind Deconvolution in Underwater Multipath Environments and Extensions to Whale Localization

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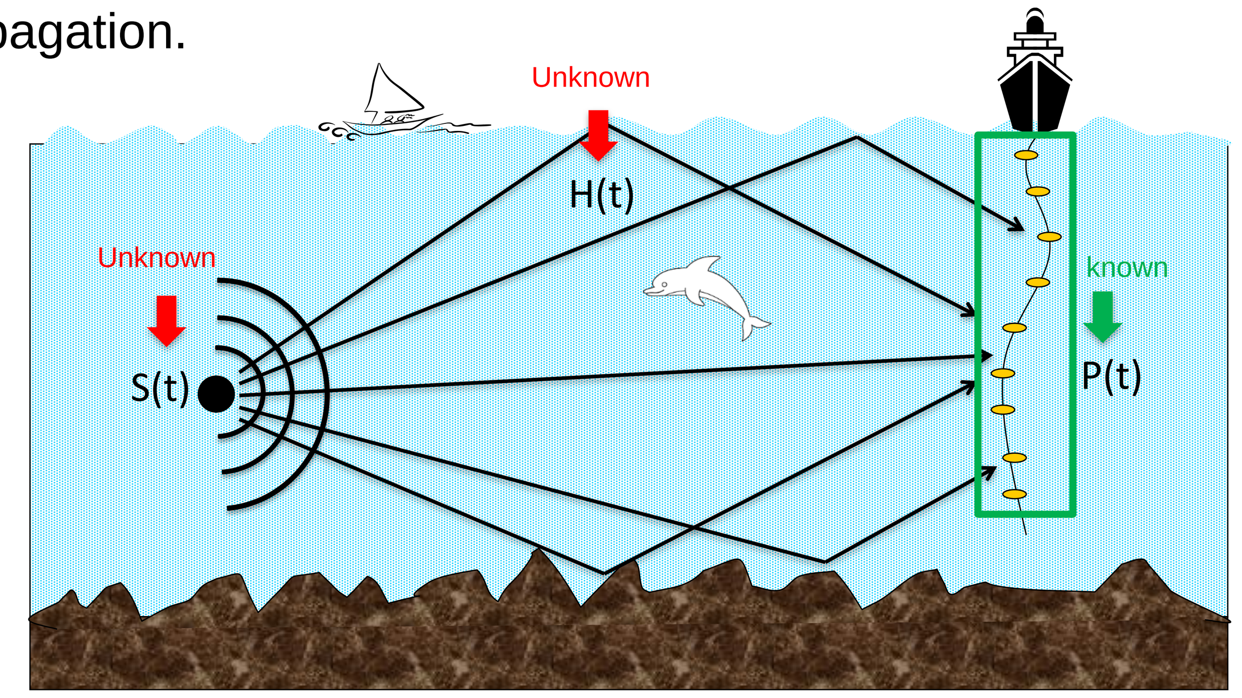
Introduction

The acoustic signal from a remote source recorded by an underwater hydrophone array is commonly distorted by multipath propagation.



The robust means for determining the location of an unknown remote source (source localization) and estimating its original broadcast waveform (blind deconvolution) in a poorly-known or unknown environment are enduring underwater remote sensing priorities.

Blind Deconvolution Technique

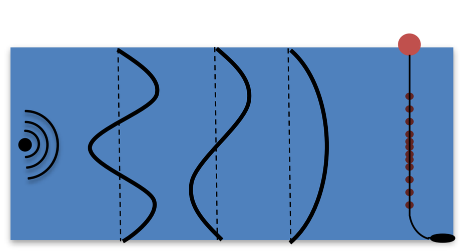
Blind deconvolution is the task of determining the source signal and the impulse response from array-recorded sounds when the source signal and the environment's impulse response are both unknown. Synthetic time reversal (STR) is a passive blind deconvolution technique that relies on generic features (rays or modes) of multipath sound propagation to estimate the original source signal and the source-to-array impulse responses.

$$P_j(t)=\int_{-\infty}^{+\infty} G(r_j,r_s,t-t_s)S(t_s)\,dt_s \quad \xrightarrow{\text{FFT}} \quad \tilde{P}_j(\omega)=\tilde{G}(r_j,r_s,\omega)\tilde{S}(\omega)$$

$$\frac{\tilde{P}_j(\omega)}{\sqrt{\sum_{j=1}^{N}|\tilde{P}_j(\omega)|^2}}=\frac{\tilde{G}(r_j,r_s,\omega)}{\sqrt{\sum_{j=1}^{N}|\tilde{G}(r_j,r_s,\omega)|^2}}\exp\{i\varphi_s(\omega)\}$$

Develop a correction phase:

$$\alpha(\omega)=\arg\left(\sum_{j=1}^{N}\Psi_m(z_j)\tilde{P}_j(\omega)\right)=\varphi_s(\omega)+\frac{R}{c}\omega$$



Recovering the Green's function:

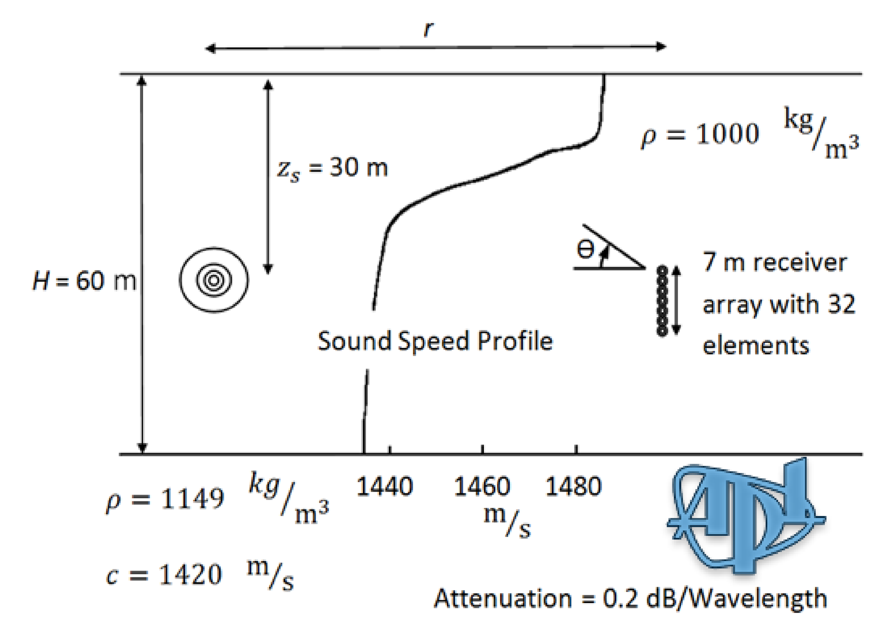
$$\hat{\tilde{G}}(r_j,r_s,\omega)=\frac{\tilde{P}_j(\omega)}{\sqrt{\sum_{j=1}^{N}|\tilde{P}_j(\omega)|^2}}\exp\{-i\alpha(\omega)\}=\frac{\tilde{G}(r_j,r_s,\omega)}{\sqrt{\sum_{j=1}^{N}|\tilde{G}(r_j,r_s,\omega)|^2}}\exp\left\{-i\frac{R}{c}\omega\right\}$$

Recovering the source signal:

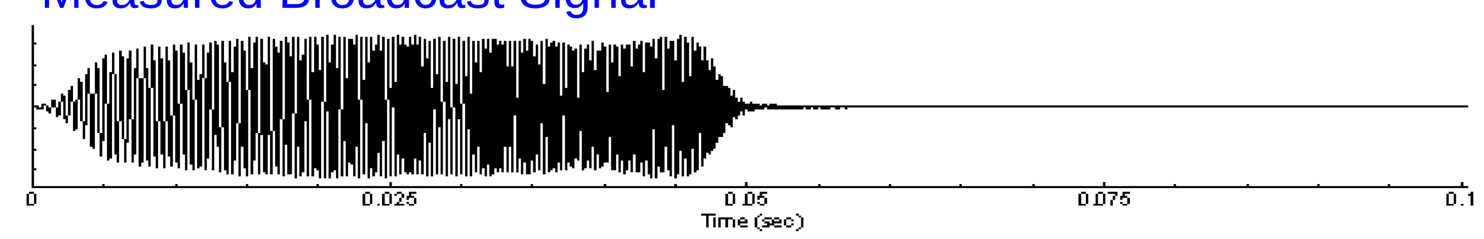
$$\hat{\tilde{S}}(\omega)=\sum_{j=1}^{N}\hat{\tilde{G}}^*(r_j,r_s,\omega)\tilde{P}_j(\omega)=\frac{1}{N}\sum_{j=1}^{N}\tilde{P}_j(\omega)\Big/\hat{\tilde{G}}(r_j,r_s,\omega)$$

Results

- Lake Washington (CAPEX09)
- Source signal: 50 ms chirp
- Bandwidth: 1500-4000 Hz
- Source to array range: 100 m
- Number of receivers: 32
- Element distance: 0.22 m
- Bottom of lake: muddy

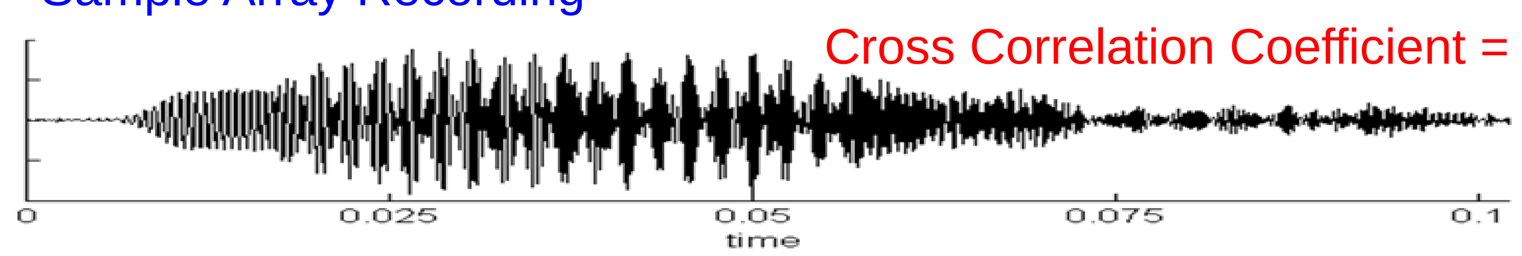


Measured Broadcast Signal



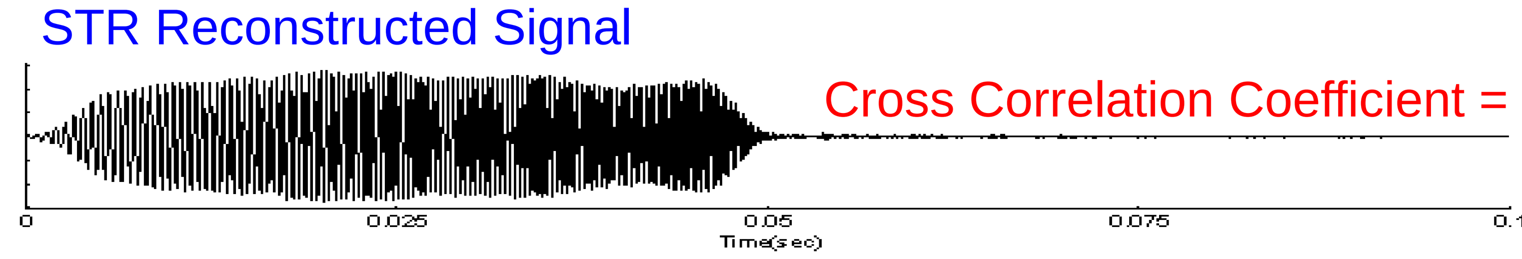
Sample Array Recording

Cross Correlation Coefficient = 57%

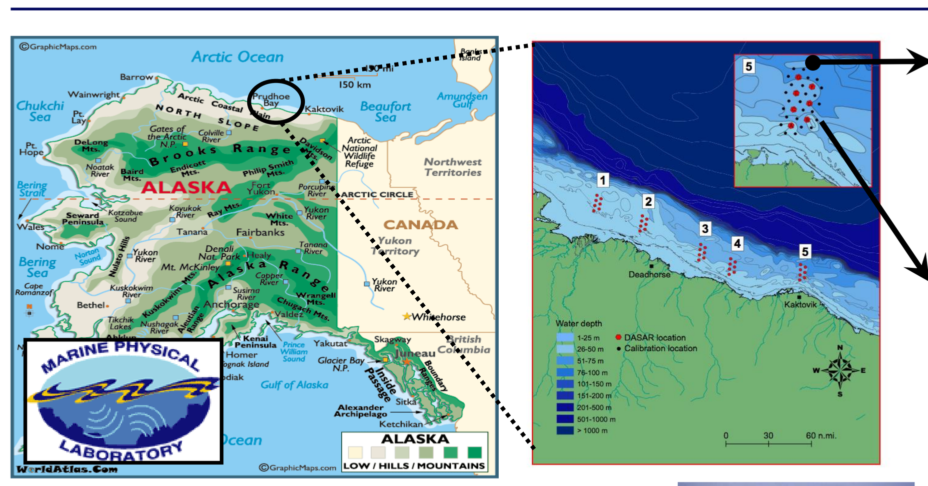


STR Reconstructed Signal

Cross Correlation Coefficient = 99%



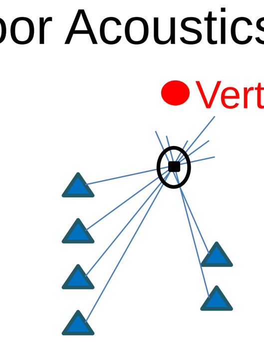
Whale Localization



Vertical Array:
12 elements, Spanning the middle %60 of the water column

DASARs:
(Directional Autonomous Seafloor Acoustics Recorders)

Bowhead whale: 50-500 Hz



Applying STR:

$$\hat{S}_1(\omega)\leftrightarrow\exp(\hat{\varphi}_s(\omega)+ik_1R)$$
$$\hat{S}_2(\omega)\leftrightarrow\exp(\hat{\varphi}_s(\omega)+ik_2R)$$

Correlation:

$$\hat{S}_1^*(\omega)\hat{S}_2(\omega)\leftrightarrow\exp(\hat{\varphi}_s(\omega)-\hat{\varphi}_s(\omega)+i(k_2-k_1)R)$$

$$(k_2-k_1)\approx\frac{2\pi.const}{\omega}$$

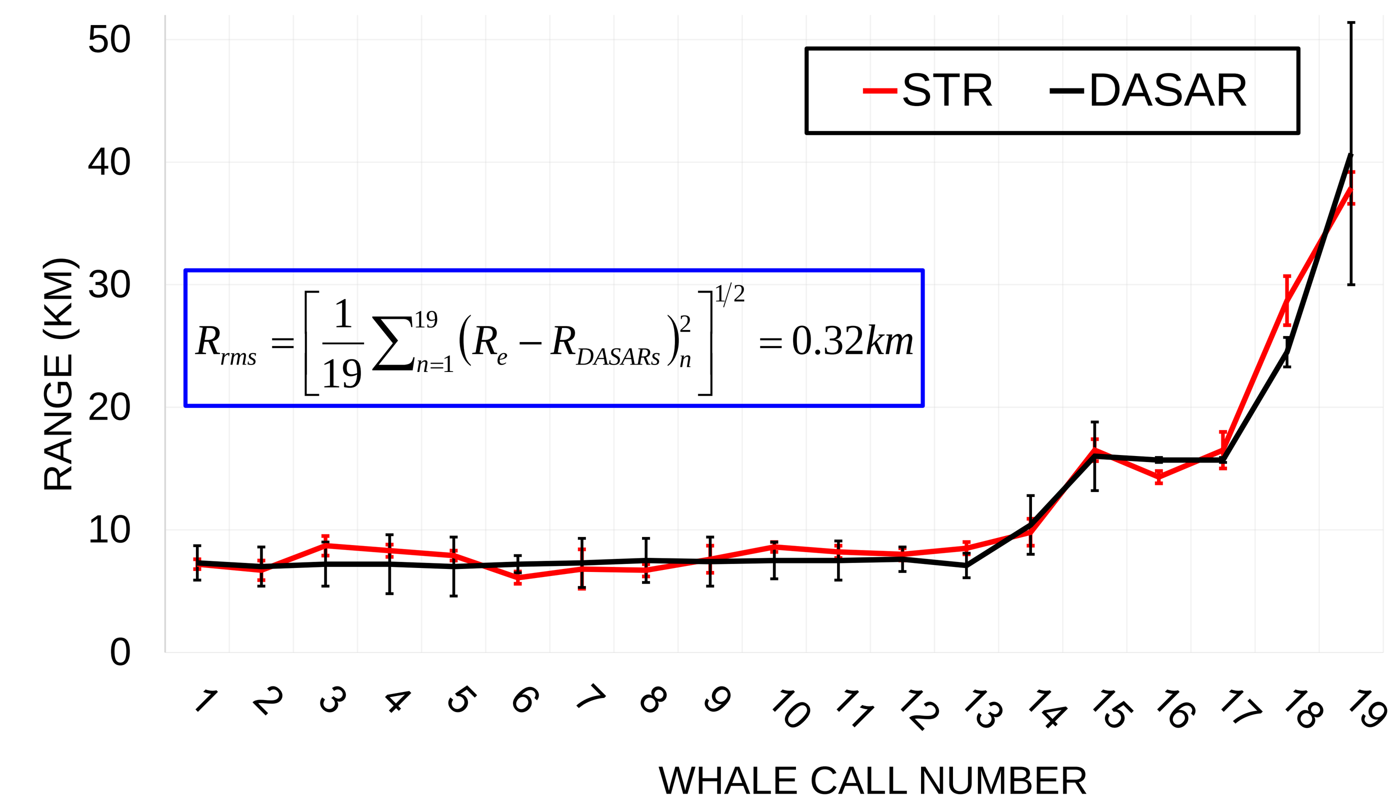
Grachev, 1993

Mean Square Error:

$$Error(R_e)=\sum_{\omega=\omega_1}^{\omega_2}\left[\{k_2(\omega)-k_1(\omega)\}R_e-\frac{2\pi.\Delta}{\omega}\right]^2$$

Propagation Model

Whale Ranging Result



Conclusions

The vertical array ranging results are generally within ±10% of the DASAR results. The results suggest that numerous precisely time-synchronized instrument packages across a wide region (several deployments) can be replaced by a vertical array (single deployment).

Current Work

My current research focuses on passive acoustic detection and localization of whale calls in vicinity of seismic survey. This research focuses on the analysis of baleen whale calls recorded before, during, and after periods of active seismic activity to look for any changes in calling patterns or frequencies as well as animal locations where possible.

Acknowledgements

This research effort was supported by the Office of Naval Research under award number N00014-11-1-0047.

References

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