Time-Reversing Array Focusing in Shallow Ocean Waters

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LONG-TERM GOAL

The long term goals of this project are: i) to predict and understand time reversing array (TRA) retrofocus size and longevity in a shallow water acoustic environment based on acoustic, geometrical, and environmental parameters, and ii) to deduce the effectiveness of using a TRA for monitoring and/or determining the acoustic properties of unknown environments.

OBJECTIVES

This project seeks to determine TRA retrofocus size and longevity in the presence of a linear superposition of dynamic random shallow-water internal-waves, noise, and three dimensional effects typical of the shallow ocean. In particular, the influence of acoustic frequency, source array range, and propagation in a dynamic mulitpath sound-channel on time-reversing array retrofocusing is not completely understood. The challenge here is to separate the various influences and impacts of propagation complexities (bottom losses, water-column dynamics, noise, three-dimensional scattering, etc.) so that the phenomena primarily responsible for TRA retrofocusing persistence and limitations can be identified. While our past work dealt with simple dynamic environments [1], the current effort incorporates realistic oceanic sound propagation to a much greater degree.

APPROACH

This project exploits the established narrowband formulation of a time-reversing array, and analytic and computational propagation models. To predict array performance in a ocean sound channel, the parabolic equation code RAM (by Mike Collins of NRL) is used for the necessary two-way propagation calculations. We are using a custom version of RAM that allows us to recover the amplitude and phase of the field. Analytic propagation models are used for more idealized efforts involving only one or two acoustic paths between the source and array.

Since TRA performance is limited in dynamic environments, a serious effort has been undertaken to develop a computationally tractable shallow water environment that mimics the dynamics of the real ocean. Here we have constructed a linear superposition of internal waves whose dynamics match the spectral measurements made during the SWARM '95 experiment. The internal wave modes are calculated from a measured (and smoothed) buoyancy frequency profile. These internal waves and a Garrett-Munk spectral weighting are then used to convect a measured (and smoothed) sound speed profile to obtain a shallow water sound channel having realistic acoustic scattering from internal-wave scattering dynamics. The SWARM measurements were provided to us by Steve Finette of NRL. The matching of the compuational internal wave model with the SWARM measurements was achieved by

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setting the internal wave energy level (E), the mode scaling number (j*), and the wavenumber decay exponent (p). While it is our intent to eventually extend these efforts to include three-dimensional scattering effects, we will first exhaust the possibilities with the current model and simulations, including an extension to soliton-type internal waves. The graduate student working on this part of the project is Michael Dungan.

For the investigations of noise on TRA retrofocusing performance, a unbounded free space environment and a shallow water sound channel have been investigated. The main effect of noise is to rob the array of the ability to retransmit signal by forcing it to retransmit received noise. The main focus of this effort has been two fold. First, we sought the proper formulation of a self-consistent rule governing how the array would function in a noisy environment when its transducers can only deliver a finite power level. Second, we simulate the performance of the array in a noisy environment using a Monte-Carlo approach. To date, we have only addressed spatially white noise fields but hope to advance to more realistic noise models in the near future. Here, we assess the performance of the array based on its probability of producing a retrofocus within a half wavelength of the intended retrofocus location. The graduate student working on this part of the project is Sunny Khosla.

WORK COMPLETED

Given our interest in the details of the TRA retrofocus field, our initial work with RAM involved learning how choose range and depth step sizes to obtain consistent results. Although this may seem unnecessary, our use of RAM to determine field properties on spatial scales of order wavelengths is essentially unique, and we had to be sure that our utilization of RAM was appropriate.

For the dynamic sound channel work, the internal wave model has been constructed and successfully implemented within RAM.

For the noise investigations, an array amplification rule based on a power limitation for a individual hydrophone was formulated. Using this rule, the first round of free space and sound channel simulations were completed.

RESULTS

For the dynamic internal wave studies, simulations have been performed at frequencies of 100, 250, and 500 Hz, for four internal wave energy levels. 0.01, 0.1, 1, and 10 times the internal wave activity level found during SWARM '95 when solitions were not present. The final internal wave strength is unrealistic, but serves as a clear upper bound for the oceanic possibilities. Sample results at 500 Hz and a source array range of 10 km are shown on Figure 1 where the relative amplitude at the focus is plotted versus the time delay between forward (source to array) and backward (array to source) propagation. Overall, the four curves show that the amplitude at the retrofocus point is degraded more quickly in the more dynamic environments. However, the "1 times" SWARM curve shows a temporary increase in focal amplitude. This phenomena of temporary retrofocusing improvement was also seen in the time-reversal experiments conducted in the Mediterrainian sea by the team headed by Dr. William Kuperman.

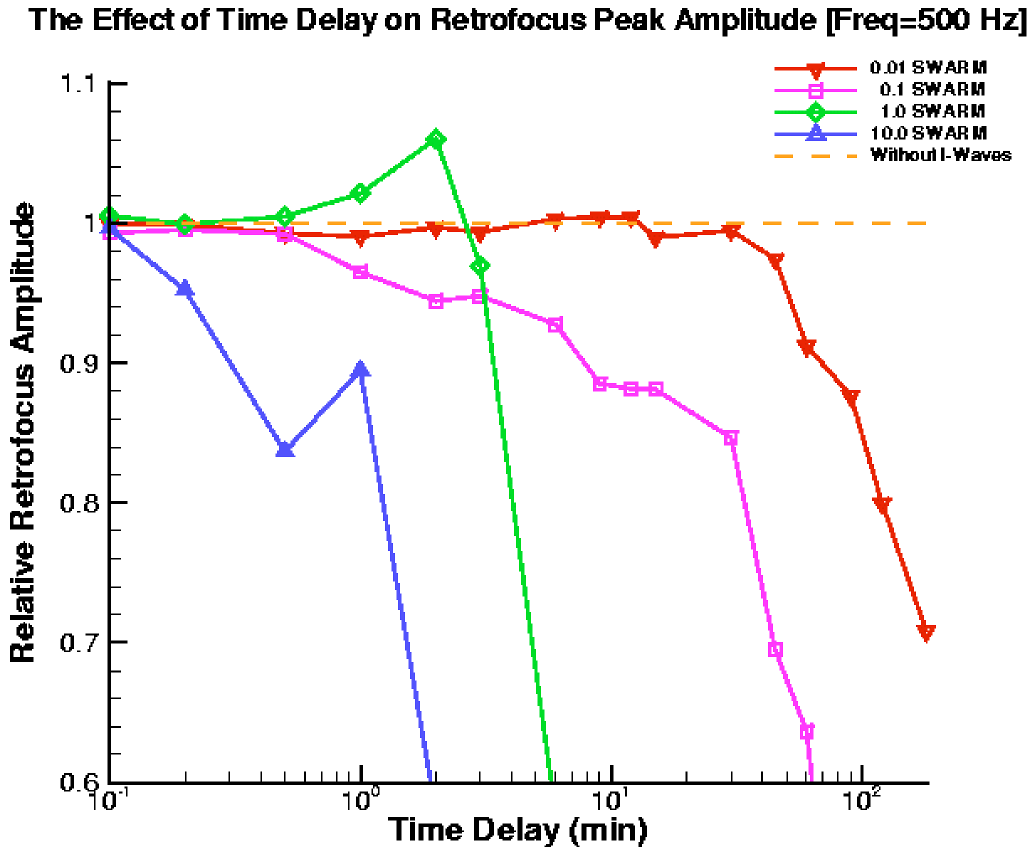

Figure 1.

Our studies on the impact of noise have shown two important phenomena. First (as expected) noise received by a TRA is rebroadcast to the noise source(s). So, when an omni-directional noise field is used, the TRA is able to retrofocus well even at negative dB SNR because the rebroadcast noise is widely dispersed and does retrofocus as the signal does. In free space, a 40 element array is easily able to combat a received SNR of –5 dB. The second major finding of this investigation, concerns retrofocusing in a sound channel. Here, it has been found that the sound channel improves TRA performance compared to free-space propagation.

IMPACT/APPLICATION

These results show that time reversing arrays may be able to function well in shallow ocean waters because the phase structure of the mulitpath propagation is not entirely destroyed by shallow water internal waves for time periods of several minutes to tens of minutes. On the contrary, dynamic internal wave activity may sometimes actually improve TRA retrofocusing. The results of the noise studies are promising as well because they suggest that a TRA benefits by being deployed in the sound channel compared to an unbounded environment. The frequency and range dependencies of these results, which are now under investigation, will predict the performance limitiations of active sonar, underwater communication, and ocean monitoring applications of time reversing arrays.

TRANSITIONS

The results of this project should aid in the design of further experiments, and eventually, TRA sonar hardware. To this end exploratory discussions with personnel from the MIT Lincoln laboratory are now under way.

RELATED PROJECTS

1 - This project runs parallel to the on-going nonlinear acoustic retrofocusing studies under the direction of Dr. Ronald Roy at Boston University and Dr. Steve Kargl at APL-UW.

2 - This research project runs parallel to the retrofocusing experiments and analysis of the international research team headed by Drs. William Kuperman and William Hodgkiss of SIO. Planned collaborations with this team to further investigated the effect of noise on TRA performance should begin soon.

REFERENCES & PUBLICATIONS

[1] S. Khosla and D.R. Dowling, "Time reversing arrary retrofocusing in simple dynamic underwater environments," J. Acoust. Soc. Am, in press 1998.