

# Extracting Coherent Structure from Ocean Noise

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## LONG-TERM GOALS

The central effort of this research will be to develop the appropriate theoretical structure and subsequent processing tools and then to experimentally demonstrate utility of extracting the deterministic acoustical properties of the environment from random noise originating in the ocean.

## OBJECTIVES

Using theory and experiment, we will study the space-time wavefront coherence properties of surface noise not previously explored. We seek the underlying physics and signal processing methods that ultimately will allow for the extraction of wavefronts representing the time-domain Green's function (TDGF) between noise observation points. An important potential use of the latter results is for inversion.

## Report Documentation Page

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## **APPROACH**

We have shown in recent work that the two-point acoustic TDGF can be obtained passively in the ocean using natural surface noise or analogously shipping noise [1]. Further, we have shown that the random ocean noise can be used for array element localization and array synchronization [2]. Our latest research involves developing the formal theory of how the TDGF emerges from the random noise field [3,4]. Further, in order to confirm the theory we have gone to studying ocean noise from data taken on land seismic sensor networks [5,6]. We have studied ocean wave generated microseisms to confirm the theory.

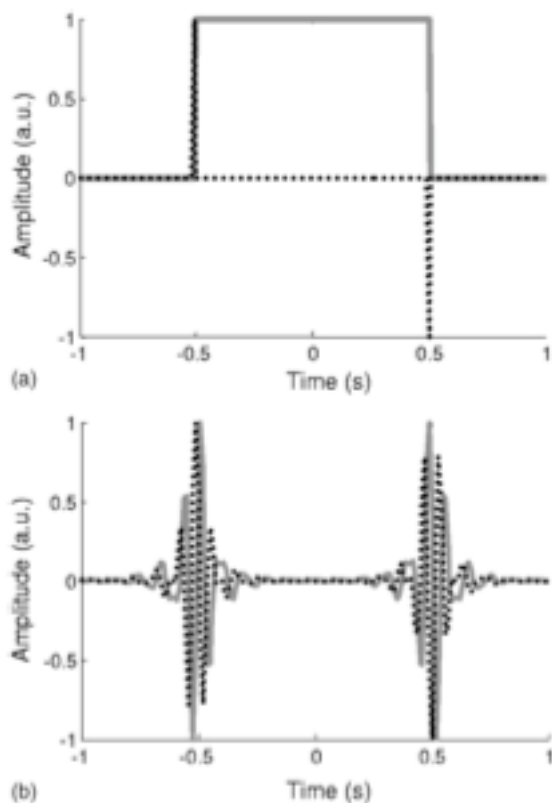
## **WORK COMPLETED**

It turns out from a formal derivation, that is actually from the time derivative of the noise correlation function that the TDGF emerges. The free space noise problem is the most fundamental to the physics of the phenomenon, and in particular, free space with attenuation [3]. We have also shown that the time derivative of the noise correlation function in a waveguide can be derived from image theory combined with the stationary phase evaluation of the resulting integrals [4]. In order to further test some of the theory of noise correlations as related to Green's functions we analyzed some seismic data in the ocean microseism regime. Employing the ideas developed in our noise correlation research, we were able to obtain seismic properties previously obtained by elaborate, passive and active experiments.

## **RESULTS**

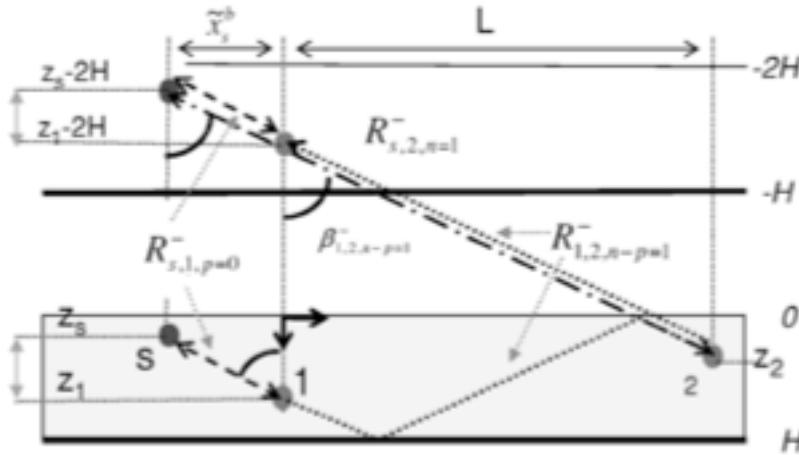
### *Theory*

Our formal derivation of the relation between the noise correlation and TDGF was recently completed for free space with attenuation. The results show that it is the time derivative of the correlation function that is actually the TDGF. It is then important to understand the tradeoffs between using the correlation and its time derivative. For finite bandwidth, the two approaches yield approximately the same results; However, as we go towards infinite bandwidth, the two approaches differ. For tomography, where accurate time of arrival structure is important, it is the derivative approach that should be utilized (see example in Figure 1 taken from [3]).



**Figure 1. Representation of noise correlation function (gray line) and its time derivative (black dotted line). (a) in an infinite bandwidth case, (b) in a limited bandwidth case (see Ref 3.)**

Our next theoretical development was to show that the waveguide theory of the noise correlation as related to the TDGF can be derived, derivative properties and all, from an image based solution. There are two classes of image/stationary phase components in which the set of images for the first case are shown Fig. 2 as an example from [4]. This paper also discusses the relevance of the depth of the noise sources and their rate of generation.

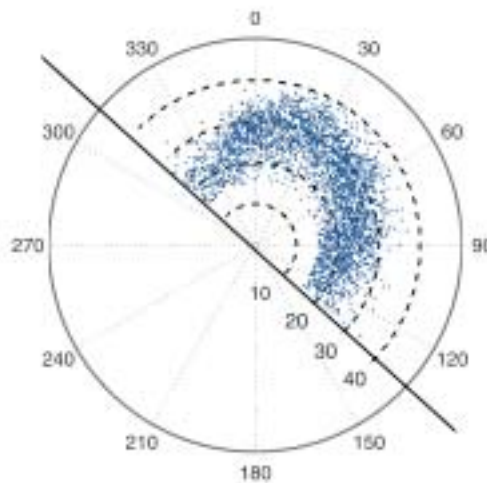


**Figure 2.** An example of the set of images making up one of the stationary phase evaluations of the noise correlation function. The noise sources are located in the plane  $z=z_s$

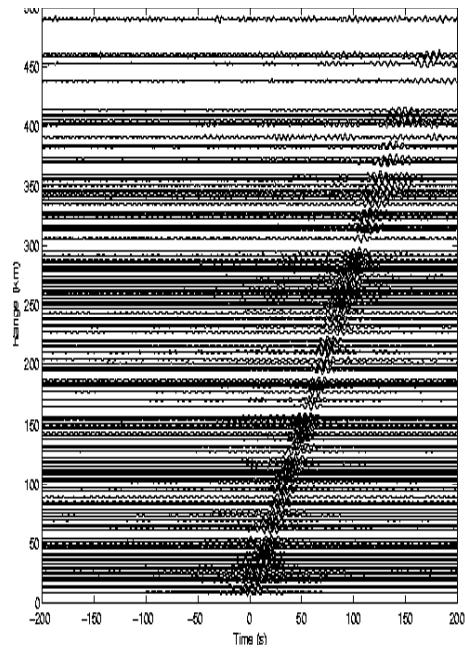
*Data Analysis and inversions from noise*

Our first attempt to do inversions has been with Southern California seismic data in which temporal medium fluctuations are not important [5,6]. We used data from a set of seismic stations pairs (see +’s in Figure 5) approximately end-fire oriented toward the direction of the dominating ocean as shown in Figure 3 where North is upward. This distribution of the time derivative of the noise correlation function for SNR > 15 dB shows that it is ocean microseisms coming from the southwest (again see Fig. 5).

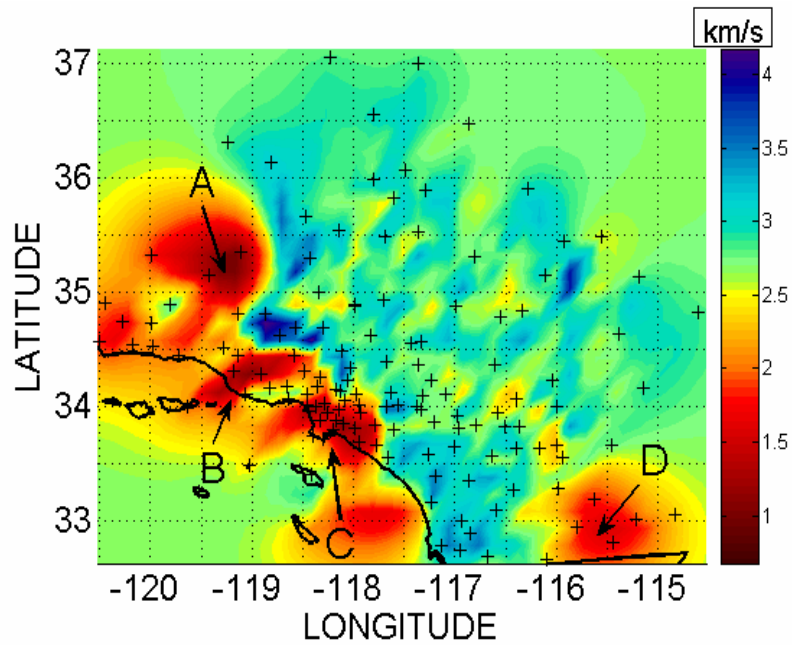
Figure 4 is the time derivative of the NCF (measured over 30 days) of the seismic vertical components ordered in terms of pair separation. We also computed the NCF for the other polarizations indicating we were measuring Rayleigh waves. This data was then inverted by a simple tomographic procedure for the surface shear speed in this region; a map of the results is shown in Fig. 5 in agreement with known results obtained over many years of seismic research.



**Figure 3.** Distribution of the SNR (above 15 dB) of the time derivative of noise correlation function. The line indicates the approximate orientation of the coastline.



*Figure 4. The NCF time derivatives for station pair separations of up the 500 km.*



*Figure 5. Velocity map corresponding to the maximum a posteriori solution for the tomographic inversion scheme. The main regions with slow surface-wave velocity (below 1.5 km/s) are related to large sedimentary basins, as indicated by the arrows (A: San Joaquin Valley, B: Ventura, C: Los Angeles, D: Salton Trough)*

## **IMPACT/APPLICATIONS**

The underlying physics of what has been presented here has now been experimentally confirmed from ultrasonics to seismic scales—over 7 orders of magnitude in wavelength. This is truly a robust process, The two aspects of our work have direct application to passive coherent signal processing from ocean ambient noise. Further, this research demonstrates that noise can be used for inversions.

## **PUBLICATIONS**

[1] P. Roux and W.A. Kuperman, “Time Reversal from ambient noise”, submitted to J. Acoust. Soc. Am, 2004. (cited for background)

[2] K.G. Sabra, P. Roux, A.M. Thode, G.L. D’Spain, W.S. Hodgkiss and W.A. Kuperman, “Using ambient noise for array self-localization and self-synchronization”, submitted to IEEE J. Ocean. Eng, 2004(cited for background)

[3] P. Roux, K.G. Sabra, W. A. Kuperman and A. Roux, “Ambient noise cross correlation in free space: Theoretical approach,” J. Acoust. Soc. Am, 117,1 79-84, 2005.

[4] K. G. Sabra, P. Roux and W. A. Kuperman, “Arrival-time structure of the time-averaged ambient noise cross-correlation function in an oceanic waveguide,” J. Acoust. Soc. Am, 117,1 164-174, 2005.

[5] K.G. Sabra, P. Gerstoft, P. Roux, W. A. Kuperman and M. C. Fehler, “Extracting time-domain Green’s function estimates from ambient seismic noise,” Geophys. Res. Letters, 32, L03310, 2005.

[6] K.G. Sabra, P. Gerstoft, P. Roux, W. A. Kuperman and M. C. Fehler, “Surface wave tomography from microseisms in Southern California,” Geophys. Res. Letters, 32, L14311, 2005.