

# Inversions – a radical idea: Information from ambient noise

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## ABSTRACT

Ambient noise, generated by natural and anthropogenic sound sources, is a ubiquitous feature of the undersea environment. The noise is a stochastic process that, traditionally, has had negative connotations, since it is often the factor that limits the performance of passive sonar systems. For many years, the fact that ambient noise contains information about the ocean and its boundaries remained largely unrecognized and unexploited. It was not until the mid 1980s that interest in extracting information from ambient noise began to develop.

One of the first attempts to use the noise involved a free-floating vertical line array of hydrophones to measure the vertical directional density function (defined as the noise power per increment of polar angle), which yielded the critical angle of the bottom boundary and thus the sound speed of the sediment<sup>1</sup>. The critical angle was identified from two discontinuities in the directional density function, appearing asymmetrically on either side of the horizontal. These discontinuities depict the angular boundary between shallow noise rays, with grazing angles less than the critical, that are totally reflected by the sea bed, and steeper rays which penetrate and hence are lost to the water column. Although the noise is a random process, this angular technique illustrates that certain statistical measures (in this case, the directional density function) exhibit robust features from which information about the environment may be extracted. When these early “inversion” experiments were being planned, it was not clear that anything at all could be gleaned from the noise, so the determination of minimal information on the surficial properties of the sea bed was deemed to be a considerable success. Today, of course, it is almost taken for granted that information can be extracted from ambient noise. Indeed, inversions of the vertical directionality (or coherence) of ambient noise in shallow water have been developed to the point where they return, not just the geo-acoustic properties of the surficial sediment, but also the sub-bottom structure with a clarity that rivals more conventional echo-sounding techniques<sup>2</sup>.

Much like natural light in the atmosphere, ambient noise in the ocean consists of a random superposition of plane waves propagating in all directions. As such, it “illuminates” objects located in the water column and on the sea bed. In the 1990s, this observation spawned the idea of “acoustic daylight imaging” in which ambient noise is used to create images of objects in the ocean. The first experiments to investigate ambient noise imaging (ANI) were conducted with a single hydrophone mounted at the focus of a parabolic reflector, which was directed at planar wooden targets faced with a closed-cell neoprene rubber. The noise level was found to increase by about 3 dB when a target was placed in the beam of the receiver<sup>3</sup>. This result spurred the development of a multi-element acoustic lens (ADONIS) consisting of a spherical reflector with an array of 132 hydrophones in the focal surface. The intensity of the noise registered by each sensor was plotted as a pixel on a computer screen, to create a 132-pixel image of the object space. Color was used to provide spectral information over the acoustic frequency band from 8 to 80 kHz, and moving images were created by refreshing the frame 25 times per second<sup>4</sup>. Through ambient noise, the acoustic daylight technique returns recognizable images, which contain useful information about the ocean and its contents. Since no dedicated sound sources are involved, ANI has the advantage of being entirely covert.

Looking to the future, a deep-diving, broad-band (0.05 - 60 kHz) acoustic monitoring system is being developed, which will descend to and ascend from the deepest regions of the ocean to provide profiles of the ambient noise as a function of depth and frequency. In addition, it is anticipated that the deep-diving system will be capable of recovering the acoustic signatures of, for example, hydrothermal vents. An inversion of its characteristic sounds may provide insight into the physical processes deep in the sea bed that are responsible for the formation of a vent.

## REFERENCES

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