# Blurring the line between intrinsic/extrinsic attenuation via the Shannon entropy

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## Introduction

We compute a version of the Shannon entropy $S$ of snapshots of a seismic wave field. $S$ is argued to be a measure of the degree of either multiple scattering, or attenuation, or both, experienced by the wave.

Invoking it forces us to reject the distinction between intrinsic and extrinsic attenuation, and allows us to place thin-bed reverberations, Q, and multiples, on an equal footing should we decide to do so.

$S$ is easily computable, as is shown with synthetics and a field VSP example. It relies on stable estimates of the histograms of wave amplitude values.

## Wave field disorder

We seek a way to quantify the relative disorder of a field (see Fig. 1), which increases whether a wave is reverberating or attenuating.

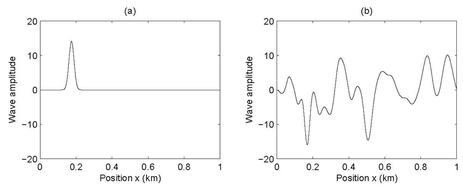


Figure: 1. Qualitatively, the wave field in (a) seems to be "more disordered" than (b).

## Wave field histograms

The disorder is reflected in histograms of the wave field amplitude values (Fig. 2):

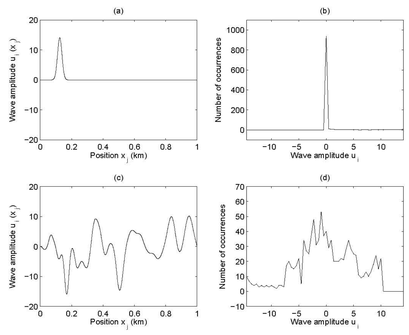


Figure: 2. (a)-(c) Wave field snapshots; (b)-(d) their respective histograms.

## Shannon entropy $S$: heterogeneous acoustic media

Nonattenuating, 3-interface case: from histograms of amplitudes $u_x$ we calculate PDFs $p(u_x)$ and thereafter $S = -\sum_x p(u_x) \log p(u_x)$:

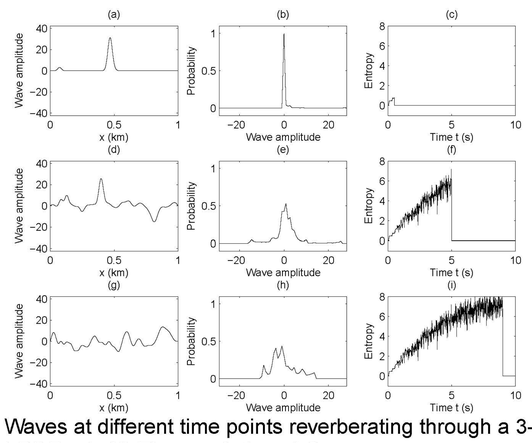


Figure: (a,d,g) Waves at different time points reverberating through a 3-interface medium. (b,e,h) PDFs. (c,f,i) Time evolution of $S$.

## Shannon entropy $S$: homogeneous attenuating media

Attenuating, homogeneous medium case: again from histograms of amplitudes $u_x$ we calculate PDFs $p(u_x)$ and thereafter $S = -\sum_x p(u_x) \log p(u_x)$:

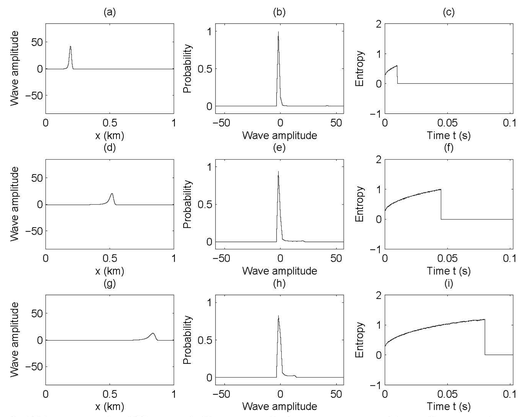


Figure: 4. (a,d,g) Waves at different time points propagating through a constant attenuating medium. (b,e,h) PDFs. (c,f,i) Time evolution of $S$.

## Comparisons

We compare the consequences to $S$ of propagation in the heterogeneous vs. attenuating media. Increasingly thin and numerous layers (Fig. 5), and increasing attenuation (Fig. 6) have essentially the same effect on $S$.

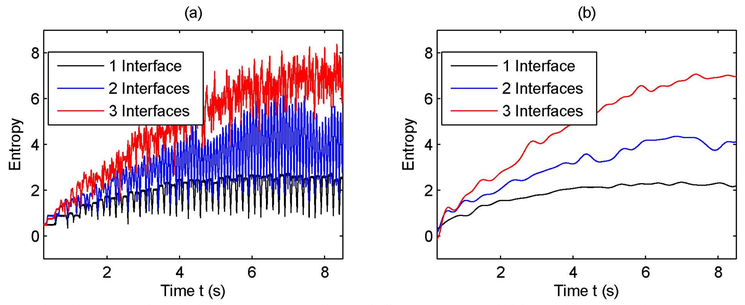


Figure: 5. Unsmoothed (a) and smoothed (b) versions of $S$ vs. time for increasing numbers of thin layers.

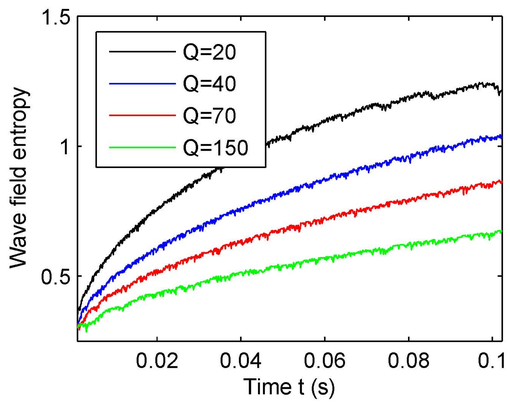


Figure: 6. $S$ vs. time for increasing attenuation (i.e., decreasing $Q$ values).

We tentatively conclude that a version of the Shannon entropy calculated on wave snapshots puts extrinsic and intrinsic $Q$ on an even footing, and measures this continuously as resolved multiples transition to unresolved thin layering effects.

## The Ross Lake VSP data set

Is $S(t)$ a computable quantity for real, measured seismic data? It appears to be well-suited to VSP experiments, wherein the depth and time variations in wave fields are detected in roughly the direction of propagation.

We consider the near offset source part of the Ross Lake VSP data set, wherein there is known to be significant attenuation, though an unknown degree of thin-bed reverberation.

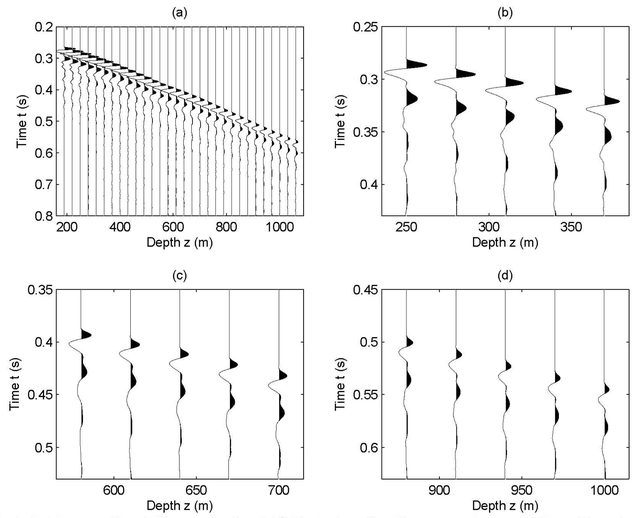


Figure: 7. (a) Near offset Ross Lake VSP data; (b-d) zoom-ins on the direct wave at increasing depths.

## Shannon entropy at Ross Lake

Testing bin sizes and examining the $S(t)$ of the Ross Lake VSP data. A rate of increase qualitatively in agreement with the numerical examples is found.

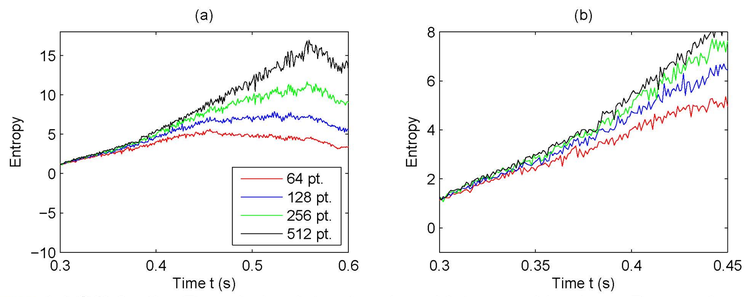


Figure: (a) S(t) for the Ross Lake data at various histogram bin sizes. Decreasing curves are an artifact.

## Discussion

Consider a wave propagating past a set interfaces, repeated with a decreasing central frequency. At first, the interfaces would be felt as fully-resolved multiples, which gradually cease to be resolved, finally appearing as amplitude-phase changes within the wavelet.

We have developed a means of discussing this progression in terms of a continuous quantity $S(t)$. It, in fact, provides as a limiting case a working definition of "truly" intrinsic attenuation: disordered motion occurring on spatial scales small enough that they are observed as an increase in the temperature of the medium.

## Bibliography

Please see the corresponding CREWES report for a full bibliography.