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A method of measuring the degree of inhomogeneities in media with a complex structure
(following E. Larose et al, Phys. Rev. Lett. 93 048501 (2005))

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Let $s_i(t)$ be N time signals, and let

$$R = \sqrt{\frac{\langle [\sum_i s_i(t)]^2 \rangle}{N \sum_i \langle s_i^2(t) \rangle}} \tag{1}$$

be the ratio signal to noise, where the angular brackets $\langle\rangle$ denote the average over a characteristic time. If $s_i(t)$ are waves, then $\langle s_i s_j \rangle \sim \delta_{ij}$, *i.e.* the signals are uncorrelated, and the ratio $R \sim 1/\sqrt{N}$ vanishes in the limit $N \rightarrow \infty$. On the contrary, if $\langle s_i s_j \rangle \sim \langle s_i^2 \rangle$, then the signals are correlated and the ratio R approaches unity.

Such a contrast can be seen in waves propagating in heterogeneous media. Indeed, if the wavelength is much longer, or much shorter, than the characteristic length of disorder, then the waves do propagate, and their signals in various points of the medium are uncorrelated. On the contrary, if their wavelength is comparable with the characteristic length of the disorder, then the waves get localized around their point-sources, over a wavelength, the signals become correlated, and the ratio R approaches unity. This is the weak localization of the waves (near-field regime), well-documented in mesoscopic physics for instance (electronic magnetoresistance at low temperatures),[1]-[3] the energy getting double on the localized spot, as a consequence of the superposition of the emergent wave and the reflected wave. It is assumed that inhomogeneities are weak, *i.e.* they do not affect the wave velocity (or frequency), in contrast with Anderson localization. The effect is also known as coherent backscattering in optics[4, 5] and in acoustics.[6, 7] The mean-free path (or lifetime), or diffusion constant, can be measured this way, as a result of multiple scattering,[8]-[10] in contrast with the old belief that multiple scattering of waves in disordered media reduces the transport to radiative transfer.

The weak localization of seismic waves has also been documented recently.[11]

Signals were produced by a sledgehammer strike at time $t = 0$ on a 20cm$\times$20cm aluminum plate repeated 50 times for each location. Locations are defined by an array of 23 geophones separated by 2.5m. Repetition rate is in the range 15- 30Hz, producing waves (both surface waves, Rayleigh-type, and bulk waves) with wavelength from 9m (30Hz, Rayleigh) to 40m (15Hz, compressional).

The records at the source location exhibits a characteristics coda, *i.e.* small oscillations in a delay time. The delay time is practically the lifetime of the wave, untill it becomes localized. The ratio R is practically 1 for this coda, vanishing outside the coda time range (where noise is present). Seismic coda could be processed this way, with the purpose of assessing the soil inhomogeneities.[12, 13]

The localized energy originates in the average of the scattered wave

$$\int rdrd\varphi \cdot e^{-ikr\cos\varphi} \sim r\Delta r \cdot J_0(kr) \tag{2}$$

which yields the energy amplification ratio

$$E_{loc}/E_{em} = 1 + J_0^2(kr) \ , \tag{3}$$

where $J_0$is the Bessel function. It si worth noting that the localization spot is independent of time (near-field regime) in contrast with the far-field regime (propagating regime). Similarly, the energy ratio becomes 2 in the limit of $r \to 0$ ($J_0(0) = 1$).[14]-[17]

It is found this energy enhancement in a spot of width of the order of the wavelength. The characteristic length of the inhomogeneities for experiments reported in Ref. 11 is about 200m, corresponding to Rayleigh waves of frequency 20Hz, velocity $c \sim 300$m/s, recorded in a time lapse of cca 0.7s. It is a measure of the mean-free path of seismic waves.

Earthquakes codas in seismograms can be analyzed the same way, for different locations on a microarray of detectors, for assessing the degree of the inhomogeneities, and their characteristic length.

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