MONITORING AND LOCATING WEAK CHANGE WITH DIFFUSE WAVES

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ABSTRACT. We present an imaging technique to locate a weak perturbation in a multiple scattering environment. We study the change using both the decorrelation of the seismic coda (with the LOCADIFF technique) and the relative velocity change (with the Coda Wave Interferometry technique). We derive a formula to predict the spatio-temporal variation of the diffuse coda waves induced by an extra scatterer or a local velocity change. We present numerical simulations that confirms the theoretical models, and application to real experiments in concrete and on a volcano.

INTRODUCTION: In very heterogeneous media constituted by a myriad of scatterers, the incident wave is scattered many many times before reaching the receiver, such that the wave enters the multiple scattering regime. Imagine now that, among the myriad of heterogeneities, a local change occurs, either due to a local smooth velocity change or to a local change of structure (position/size of the scatterer for instance). To detect and locate the change, we propagate a wave before and after the change while keeping sources and receivers fixed. This yields to two set of coda: $\varphi_A(t)$ (before) and $\varphi_B(t)$ (after). We will take advantage of the very high sensitivity of late arrivals constituting the seismic or acoustic coda, in a two steps process:

1) The detection is performed quantitatively by measuring the decorrelation (LOCADIFF) and/or the relative velocity change (CWI) in different time windows in the coda [1-3].
2) The location of the change is performed using a sensitivity kernel based on the probability of transport of the wave intensity.

DATA PROCESSING: In order to retrieve the dV/V in real data, the coda can be processed as a whole or in different time windows with the stretching technique [4]: the final waveform $\varphi_B(t)$ is interpolated at times $t(1+\varepsilon)$ and the correlation coefficient with the initial waveform $\varphi_A(t)$ is evaluated:

$$CC(\varepsilon,t)=\frac{\int_{t-T/2}^{t+T/2}\varphi_A(u)\varphi_B\big(u(1+\varepsilon)\big)du}{\sqrt{\int_{t-T/2}^{t+T/2}\varphi_A{}^2(u)du\int_{t-T/2}^{t+T/2}\varphi_B{}^2(u)du}}$$

where T is the length of the time-window centered at time t. This calculation is performed for various stretching factors. The stretching factor $\varepsilon_{\max}$ that corresponds to the apparent relative velocity change maximizes the correlation coefficient. In the case of a homogeneous change, the apparent change is: $\varepsilon_{\max}=dV/V$. We also measure the decorrelation coefficient $K^d(S,R,t)=1-CC(\varepsilon_{\max},t)$ in different time windows [3-4].

Imagine now that the change is not global, but located at a given position x (see figure 1). If the modification is a (smooth, small and weak) velocity change, the wavepackets going through this area will be slightly delayed; if the modification is a change of a scatterer, the waves going through this defect will be decorrelated. In both cases, only wavepaths propagating in the region of the change will be affected, other trajectories will remain the same.

Let's now consider what happens in the time domain: at early times, the diffusive halo has not reach the location of the change and the waves remain the same (left part of figure 1). Later on, some of the waves have interacted with the change and the coda starts to be slightly modified.

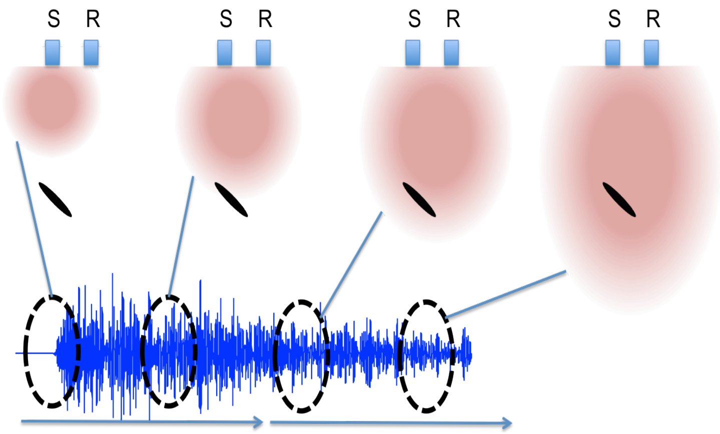

FIGURE 1. Schematic view of the spatio-temporal sensitivity of coda waves to a local change. The diffusive halo is represented in pink. At early times (first two snapshots on the left), the waves propagating from the source *S* to the receiver *R* have hardly felt the change and the waveforms remain the same. Later on (two snapshots on the right), some waves have hit the defect: the coda is decorrelated in the case of a scatterer change, or delayed in the case of a local velocity change.

THEORY: In the case of a local (weak) velocity change, the apparent relative velocity change observed in the coda will be [5]:

$\varepsilon^{\text{app}}(S,R,x,t) = \dfrac{dv}{v}\dfrac{\Delta \text{V}}{t}\dfrac{\int_0^t g(S,x,u)g(x,R,t-u)du}{g(S,R,t)}$, with t the time in the coda, and ΔV the volume of the change. In the case of a change of scatterer, the decorrelation in the coda will be [3,6-7]: $\text{K}_\text{d}(\text{S,R,x,t}) = 1 - \dfrac{c\sigma}{2}\dfrac{\int_0^t g(S,x,u)g(x,R,t-u)du}{g(S,R,t)}$, where σ is the scattering cross-section of the change, and c the average velocity. In both cases, the main quantity to study is the sensitivity kernel (right fraction) expressed as the ratio between the amount of waves passing through the change (top) and the total amount of waves propagating from the source to the receiver (bottom). *g(S,R,t)* is the probability of transport of the wave from the source *S* to the point *R* over a time *t*. In most cases *g* is unknown, but can be for instance approximated by the solution of the diffusion equation or by the radiative transfer equation. The sensitivity kernel depends on the position of the source and receiver, and on the time, which are known parameters. It also depends on the amplitude and location of the change, which are unknowns. By using a large amount of independent data (several sources, receivers and/or time windows) it is possible to recover these unknowns [3,8].

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