Radiative transfer and Bayesian inversion: application to modelling and imaging using stochastic seismic wavefields.

De Siena L., Geosciences
Bachmayr M., Mathematics
Hartung L., Mathematics
Baumann T., Geosciences

Seismology offers the most straightforward tools to image the inner structure of the Earth. Seismic waves, such as primary (P) or shear (S) waves as in Fig. 1, are deterministic elastic waves whose propagation is governed by equations of motion that are well known, at least under the assumption that the medium controlling phase and amplitude variations changes gradually in space. This approximation is invalid when both frequency and heterogeneity increase, as in volcanic media. In these cases, late wave-packets (t_c) can be modelled using simple diffusion approximations; however, the remaining coherency, complex multiple-scattering effects and boundary conditions affect the intermediate-time wavefield (red line, Fig.1).

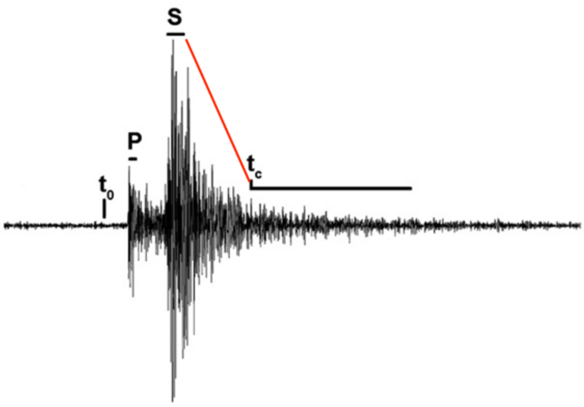

Fig.1: *A high-frequency seismogram recorded at Mount St. Helens volcano (US). The origin time (t_0) and P- and S-wave ample volcano-tectonic seismogram. The symbols show the time windows used to compute the P- and the S- "coherent" wavepackets, generally used in seismic tomography. The diffusive coda-amplitudes (t_c) can be modelled using the diffusion equation. No analytical solution exists to model the multiple-scattered waves in between (red line).*

While disregarding phases, Radiative Transfer Theory has shown the potential to model seismic amplitudes (intensities) of the stochastic (coda) waves arriving after coherent arrivals (Fig. 2, *De Siena et a. 2013*). An open-access imaging framework for modelling the Earth's attenuation properties and separate its attenuation mechanisms (scattering and absorption) is today available (*De Siena et al. 2014a*). While this framework has been applied to image 10s of volcanoes around the world (e.g. *Prudencio et al. 2015; De Siena et al. 2017*), it still uses diffusive approximations, restricting the amount of data, sensitivity and reliability of the derived inverse models. The improvement in seismic imaging we could achieve by embedding more complex interactions in the multiple-scattering theory and implementing these interactions computationally will go well beyond our ability to reconstruct seismic amplitudes produced by earthquakes, e.g. influencing new techniques that use ambient noise in the reconstruction of Earth structures and processes (*Garnier & Papanicolau 2016; De Siena et al. 2018*).

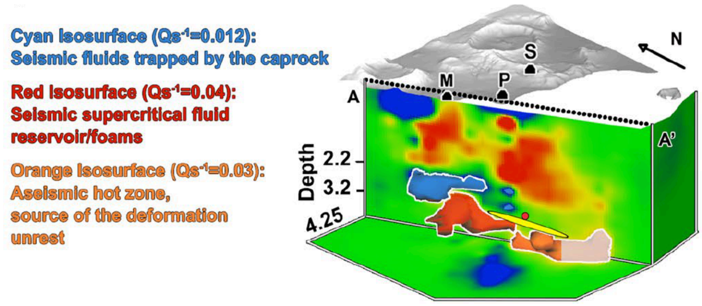

Fig.2: *3D inverse model of the shear-wave attenuation structure of Campi Flegrei caldera (Italy). The method combines the imaging potential of ray-base (coherent) waves and coda (diffusive) wave fields to image the geothermal reservoir and magmatic sills under the volcano (isosurfaces).*

In order to improve the modelling of the intermediate coda amplitudes in highly heterogeneous environments and use them as an imaging tool, this project aims at:

(1) improving the forward model by:

   a. including absorption and previous anisotropic scattering interactions into the stochastic description of the multiple scattering processes;
   b. describing each interaction as well as the probability of recording the scattered energy by a stochastic process.

(2) Improving the inverse tomographic model by:

   a. applying state-of-the-art numerical methods for deterministic regularization (e.g. Tikhonov regularization and variants);
   b. implementing novel Bayesian inversion strategies (e.g. Markov Chain Monte Carlo algorithms) that can give a better assessment of uncertainties in seismic attenuation imaging (*Stuart 2010*, *Fichtner & Simutė 2018*);
   c. exploring the application of Bayesian methods to test the reliability of dynamic (4D) tomography, an essential tool for eruption forecasting whose uncertainties are often disregarded.

The PhD student will be based at the Institute of Geosciences. He/she will have a strong physics/geophysics/computational background. The project will allow the candidate to acquire unique skills in mathematical and computational modelling, becoming an expert in theoretical seismology and volcano-geodynamical modelling. These skills can pave the way to a career in either academia or applied/industrial research.

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