# Geomorphological controls on seismic recordings in volcanic areas

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# Aim and Methods

- This study aims to find a link between coda-wave attenuation imaging and geomorphological evidence at Mount St Helens, by discriminating scattering and absorption characteristics in the volcano and forward modelling the coda envelope

- Mount St Helens (Fig. 1) is a stratovolcano of the Cascadia volcanic arc, and the present morphology is mainly due to the destructive eruption of 18 May 1980. The largest product of this eruption are **debris avalanche** and **mudflows**

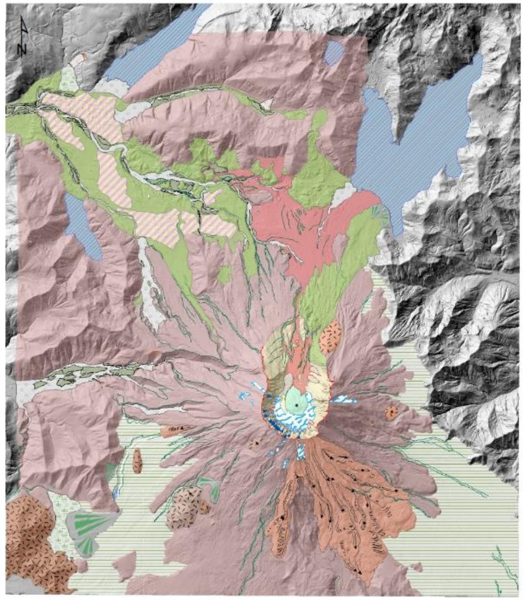

*Fig. 1: Mt St Helens geomorphological map (Gabrielli et al., in preparation)*

- The dataset (Fig. 2) is composed by 64 earthquakes (between 2000-2003), with a magnitude between 1.5 and 2.7. The depth ranges between ~1 km and ~20 km → **Under-Determined System**

- We inverted the dataset for coda attenuation imaging using the Energy Transport Equation (ETE) kernels – implemented with MLTWA results – testing its resolution and stability against analytical diffusive (AD) kernels.

- In this framework, we want to discriminate between scattering and absorption characteristics in the volcano

- Radiative Transfer Theory was applied to forward model the coda-envelopes with a simulation of the diffusive transport of the elastic energy

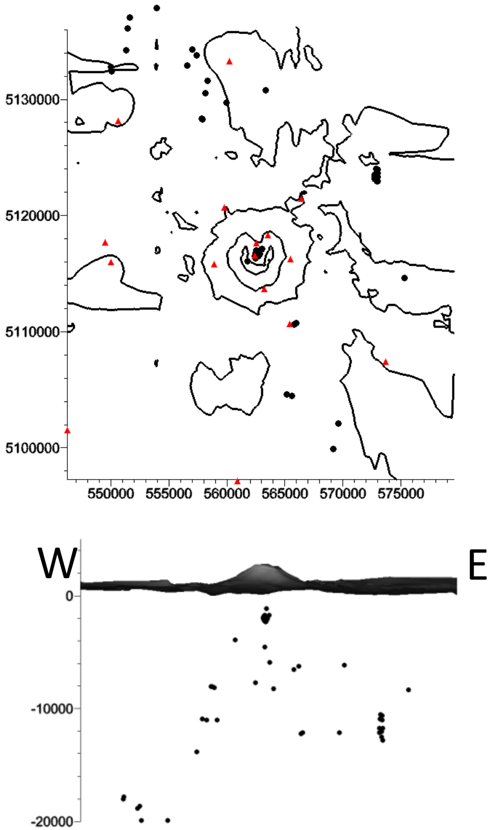


*Fig. 2: Dataset of 2000-2003, XY plane and WE cross-section. Events in black dots, stations in red triangles*

# Coda Waves - MLTWA

Coda waves are the wave train of the tail portion of seismograms after body waves (S arrival), contain information about scattering. They are used in standard procedure like the Multi Lapse Time Windows Analysis (MLTWA).

**Attenuation** is the most important variation in coda waves - The decay rate of the coda envelope with increasing lapse time can be quantified by the inverse coda quality factor $\mathbf{Q_c^{-1}}$

**MLTWA** (Fig. 3) is a method to discern the intrinsic attenuation $\mathbf{Q_i^{-1}}$ from the scattering $\mathbf{Q_s^{-1}}$. It gives a characterisation of the medium (scattering – fractures; intrinsic attenuation – fluids).

The waveform is divided into 4 windows (here, Δt = 10s). The time integrals of the energies of the first 3 windows are corrected for the fourth window (Coda Normalisation Window) and the geometrical spreading, then plotted vs. source-receiver distance among with the best fit calculated with the solution of the transport equation in the uniform half-space assumption (Fig. 4)

We obtain **Extinction Length Le**, reciprocal of the total attenuation and the **Seismic Albedo $B_0$**, ratio of the scattering attenuation to total attenuation

**$B_0$ > 0.5** → scattering attenuation is prevailing
**$B_0$ < 0.5** → intrinsic attenuation is dominant

| Frequency(Hz) | $B_0$ |
|---|---|
| 3 | 0.95 ± 5% |
| 6 | 0.50 ± 20% |
| 12 | 0.35 ± 10% |
| 18 | 0.25 ± 60% |

*Mount st Helens MLTWA results*

**ANOMALOUSLY HIGH!**

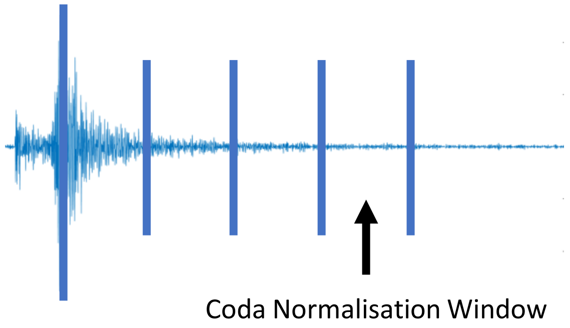


*Fig. 3: Application of MLTWA on a waveform*

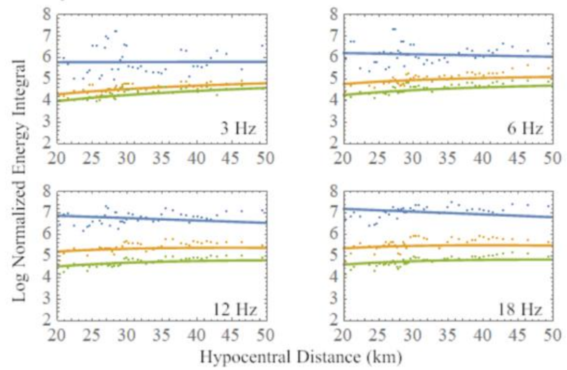


*Fig. 4: Energy integrals plotted versus the hypocentral distance range of 20-50 km: blue, orange and green dots represent first, second and third window of the seismogram, respectively,. The continuous lines are the best fit*

# Radiative Transfer Theory

- Radiative Transfer Theory model the propagation of the elastic wave energy describing scattering behaviour in the crust. To forward model the envelopes, the code RADITATIVE3D is used

- The vertical earthquake recordings for two earthquakes and two stations (Fig. 5a) and for the 3 Hz and 12 Hz frequency bands were simulated for far (F) and near (N – next slide) fields

- High scattering is necessary to reproduce the envelope at YEL in far field (Fig. 5b). In near-field (Fig. 5c) the anomalous phases (scattered surface waves) are visible at both stations. The shallow plumbing system, the crater, and the debris avalanche of the 1980 eruption act as near-station scatterers

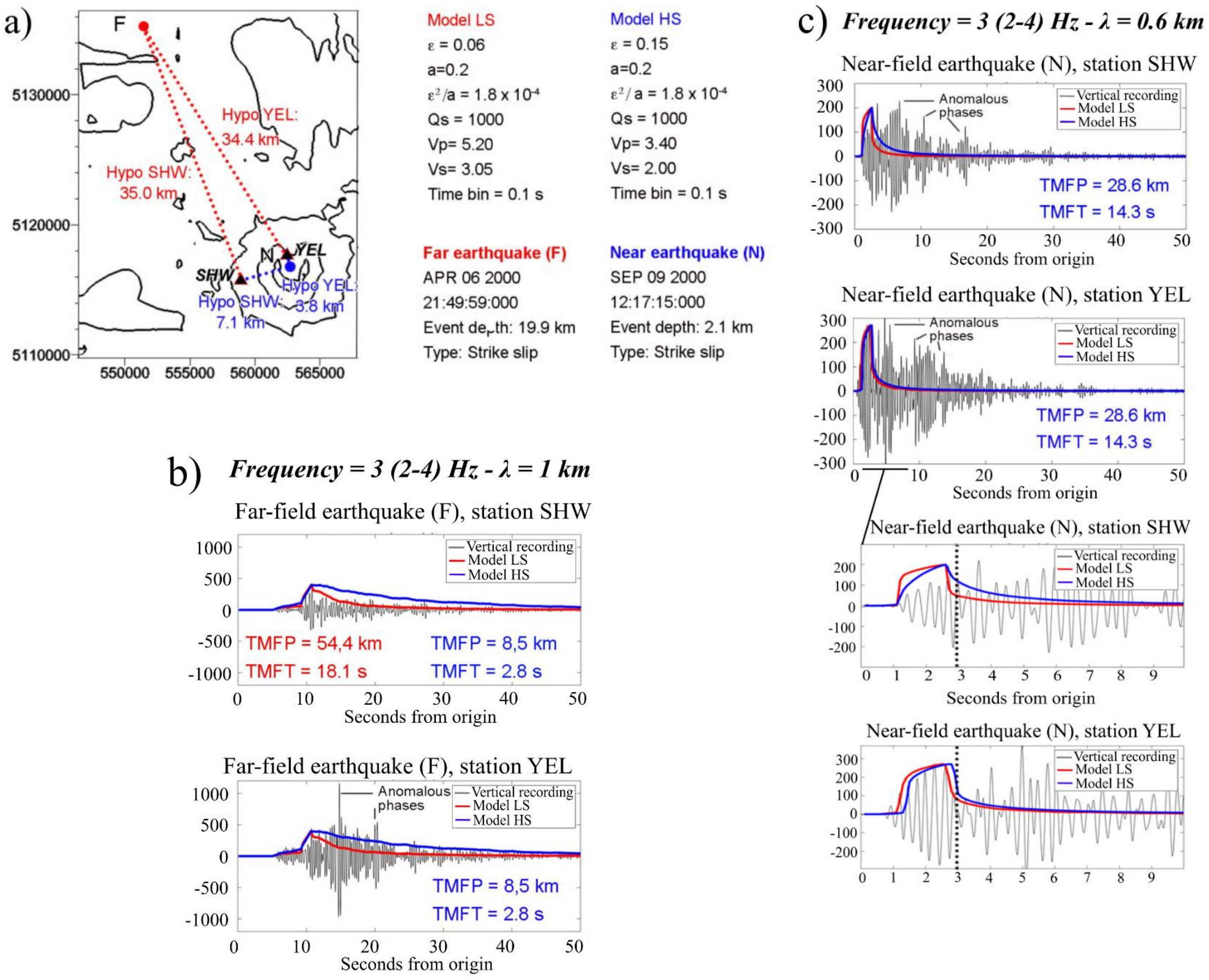


*Fig. 5: Radiative Transfer model of far (F) and near (N) fields recordings at stations SHW and YEL at 3 Hz*

# Kernel analysis

- Sensitivity Kernels have been applied at regional scales and in volcanoes. They can be used to invert the spatial distribution of Qc
- Here, we applied the 2D analytic kernel obtained assuming a diffusive coda envelope (AD) (Del Pezzo et al., 2016) and the 2D frequency-dependent bulk sensitivity kernels in the multiple-scattering (using the Energy Transport Equations – ETE, Del Pezzo et al. 2018)
- MLTWA parameters provide inputs to build frequency-dependent ETE kernels. There are no differences in sensitivity between different frequencies for the ETE, even with the different inputs from MLTWA (Fig. 6, left)
- The AD and ETE are compared: they have the same contribution at source and receiver, but only AD can cover the space between them, providing a larger illumination, over-estimating the sensitivity of coda measurements (Fig. 6)
- The MLTWA results and the RTT models are both highlighting the instability of the 3 Hz frequency band
- Both tomographic models show the progressive shift of a high attenuation anomaly at 12 Hz consistent with the shift of the deep plumbing materials towards the east

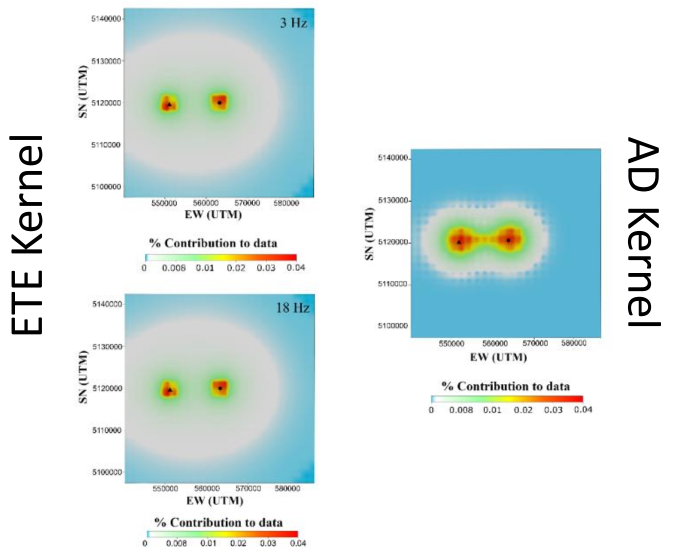


*Fig. 6 ETE Kernels (left) and AD kernels*

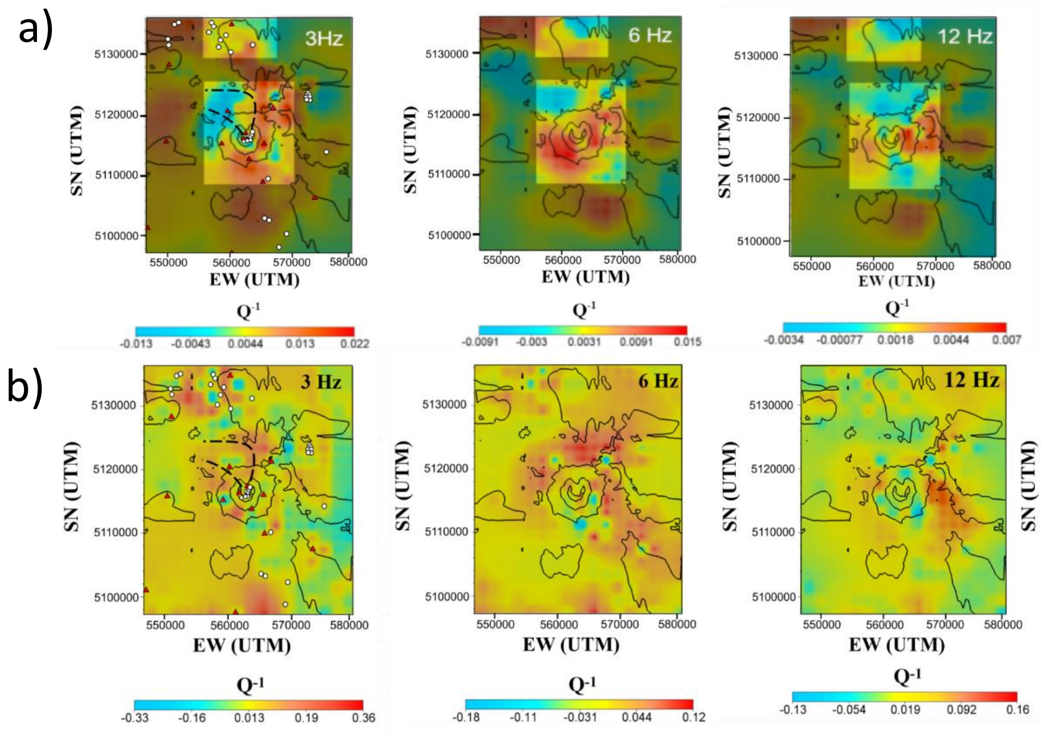


*Fig. 7 Coda attenuation mapping using AD (a) and ETE (b) kernels*

# Can we link Coda Attenuation Imaging and Geomorphology?

- The MLTWA results and the RTT models are both highlighting the **instability** of the **3 Hz** frequency band

- The low attenuation anomalies of AD inversion at 3 Hz are spatially fitting with the deposits of the debris avalanche of 1980

- The hummocky structures (Fig. 8) can reach a maximum length of 600 m, a height between 10 and 73 m, and a width spanning from a few meters to 400 m. This feature can have the size of the wavelength to enhance the scattered surface waves

- At low frequencies (3 Hz) the **shallow unconsolidated materials** (e.g. debris avalanche) are the cause of the **anomalous seismic albedo** and they don't allow to model bulk-wave envelopes without including **scattered surface waves** (like in the volcanic cone) and create a bias in AD and ETE kernels-dependent imaging

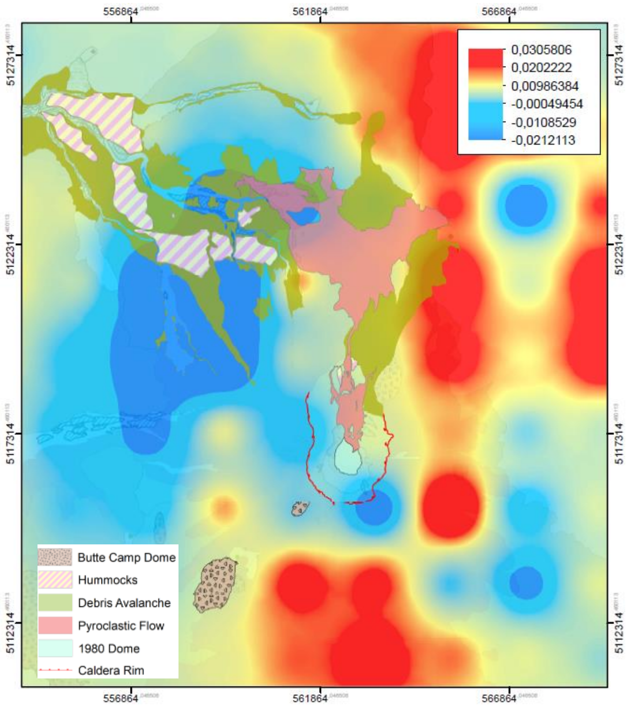


*Fig. 8 Overlap of the 3 Hz AD attenuation imaging and some features of the geomorphological map of Mount St Helens*

- The bias due to shallow unconsolidated materials can produce anomalies and cause a **misinterpretation** of seismic imaging based on amplitude modelling, covering deeper structures in the volcano

- Next Step: forward model of seismic waves using wave-equation in an anisotropic anelastic medium, adding geomorphological and geological observations (e.g. domes, faults) to constrain the model