The Complex Relationship between Seismic Velocity and Volcanic, Tectonic, and Environmental Forcings at Mt. St. Helens

Peter Makus[1,2], Marine Denolle[3], Christoph Sens-Schönfelder[1], Manuela Köpfli[3], Frederik Tilmann[1,2]

[1]Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Potsdam, Germany
[2]Institute for Geological Sciences, Freie Universität Berlin, Berlin, Germany
[3]Institute for Earth and Space Sciences, University of Washington, Seattle, United States of America

GFZ Helmholtz Centre Potsdam

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UNIVERSITY of WASHINGTON

Contact:
Peter Makus
makus@gfz-potsdam.de

Introduction

Passive Image Interferometry (PII)[4] relies on the ubiquitous ambient seismic noise to quantify changes in the seismic propagation velocity (*dv/v*). Despite being a relatively novel tool, it has shown promising results in volcano monitoring (e.g., [1]). Here, we apply it to a very long continuous dataset recorded at Mount St. Helens (MSH). We show that *dv/v* relates to various physical properties of the medium.

Methods

- We exploit energy of the ambient field in octave-wide windows from 0.25 to 2 Hz
- Preprocessing: taper, instrument response removal, one-bit-normalisation, spectral whitening
- Interstation cross-correlation in the frequency domain of all available components
- *dv/v* is retrieved using the stretching technique[4]
- Automatic QC of *dv/v* time-series based on a coherence threshold
- We derive *dv/v* in the time-domain, apply a spatial inversion[2], and integrate along the time-domain on the spatial grid to obtain our final estimate

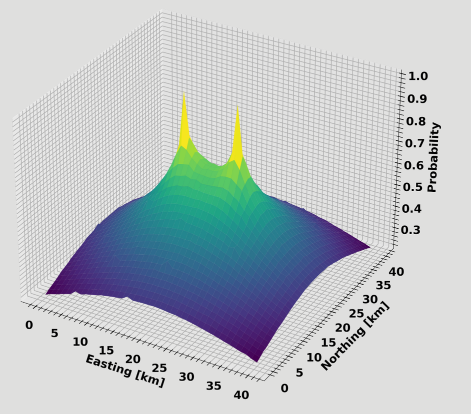

Fig.4: Illustration of a spatial sensitivity kernel between two seismic stations. We employ such kernels to estimate a spatial dv/v time series.

Long Term Trends

- Until 2004: *dv/v* remains relatively steady
- 2004-2008 (during MSH eruption): fluctutations in *dv/v* - probably related to (a) changes in the wavefield and (b) changes in the medium associated to the eruption
- After 2008: Strong velocity increase of locally up to 12% (see Fig. 2) probably due to a deflation of the feeding magma chamber located below the maximum increase[6]
- GPS data shows a downwards motion coinciding with the velocity increase

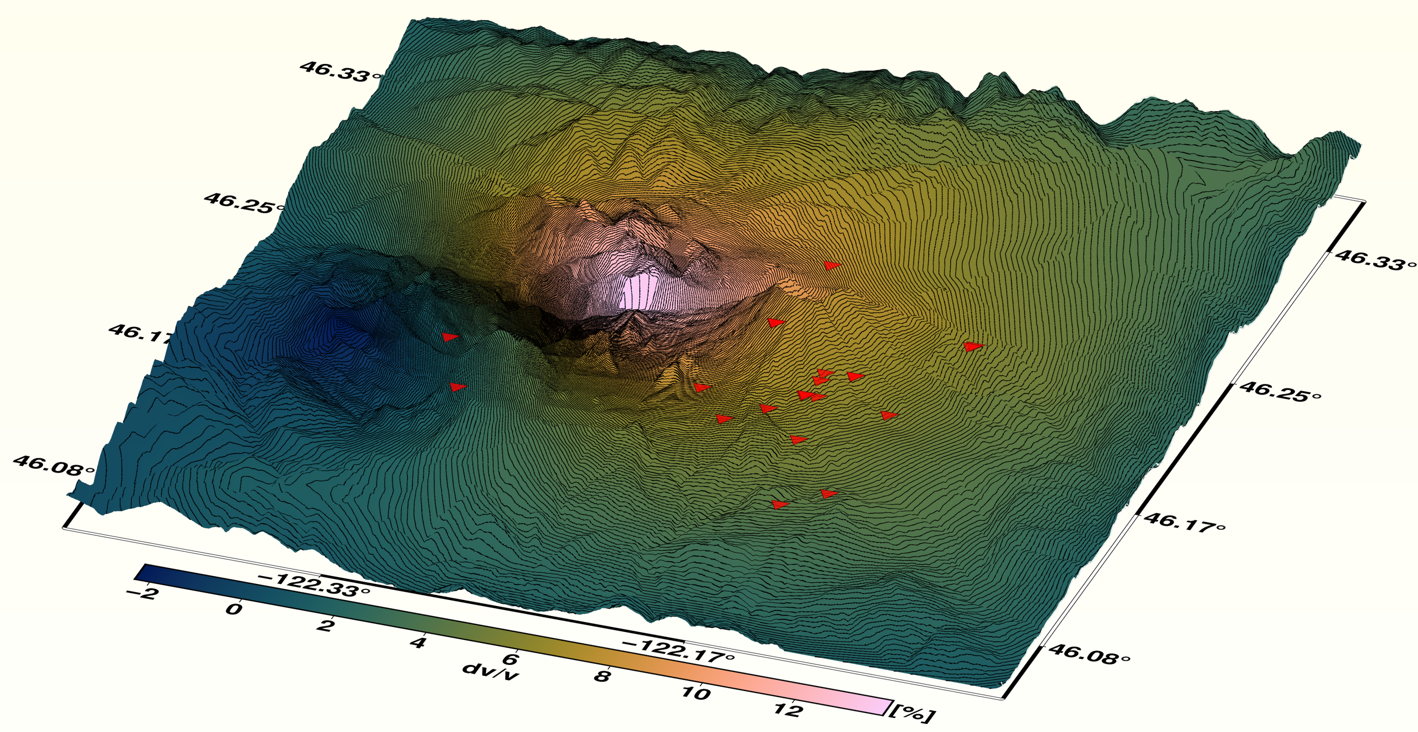

Fig. 2: The total dv/v over 25 years (1997-2022) inverted onto a spatial grid. We plot dv/v as a coloured mask on top of the regional topography. dv/v increases dominate the grid. The location of the highest increase coincides with the location of the magma chamber[6]. For the spatial inversion, we use a modified variation of the solution proposed by Obermann et al., 2013[2] (see methdos panel for details). The locations of the seismic stations are indicated by red inverted triangles.

Conclusions & Outlook

- **Long term velocity changes correlate to a topographic downward motion and are probably related to the volcanic deflation**
- **The maximum of the deflation signal is located above MSH's magma chamber**
- **On first order, seasonal velocity variations correlate to confining pressure changes induced by snowload and hydrological influx**
- **We speculate that modulations in the seasonal cycle's phase and amplitude after MSH's eruption are due to a changed diffusivity of the medium**

processed using SeisMIC

Seasonal Cycles

- We highpass-filter *dv/v* to focus on higher-frequent variations
- *dv/v* exhibits clear seasonal variations most likely due to variations in the pore pressure and surface load
- We attempt to model pressure-induced velocity changes using snow load, snow melt, and precipitation data with an approach similar to [3] & [5]
- After MSH's eruption the medium's response to pressure changes is strongly altered - expressed as changes in amplitude and phase of the *dv/v* time series
- Hypothesis: The damage induced by MSH's eruption increases the medium's permeability/diffusivity α

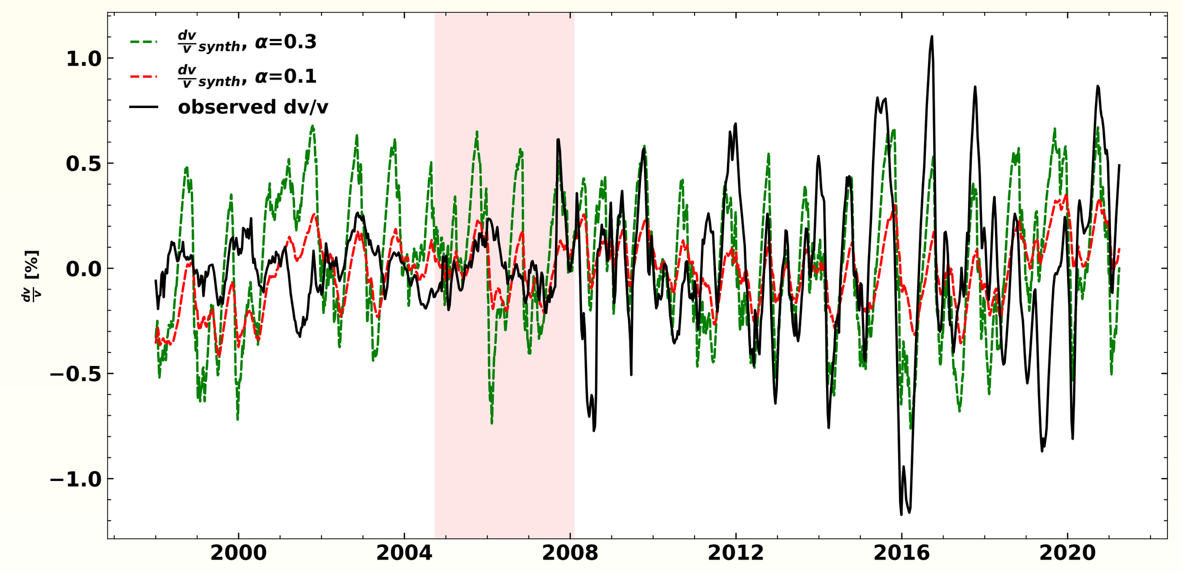

Fig. 3: Seasonal variability of the seismic velocity. In black, we plot the highpass-filtered dv/v from a central gridpoint located around MSH's summit. The dashed lines show two possible models purely derived from hydrological input (i.e., precipitation and meltwater) and snowload. We indicate the diffusivity α used for the two models. The red background indicates MSH's 2004-2008 eruptive crisis.

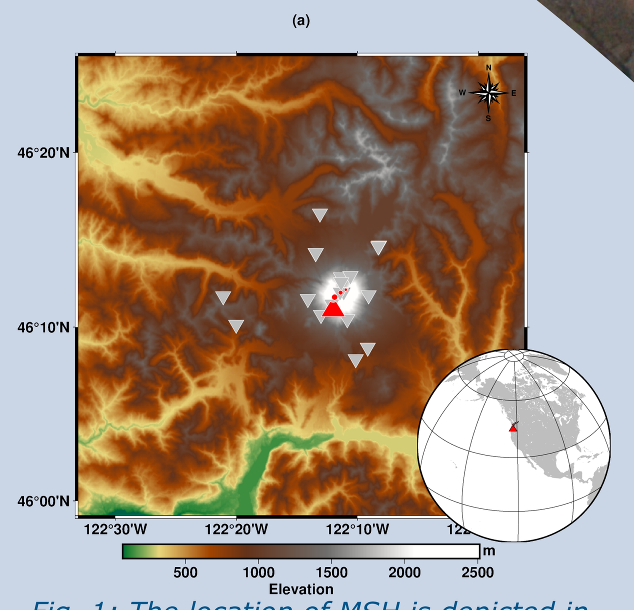

Fig. 1: The location of MSH is depicted in red. We plotted the seismic stations used for this study as grey inverted triangles. All stations are mantained by the Pacific Northwest Seismic Network.

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Image Courtesy

Photograph of Mt St. Helens (upper right): USGS

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