Seismic velocity changes in the epicentral area of the Mw 7.8 Pedernales (Ecuador) earthquake from cross-correlation of ambient seismic noise

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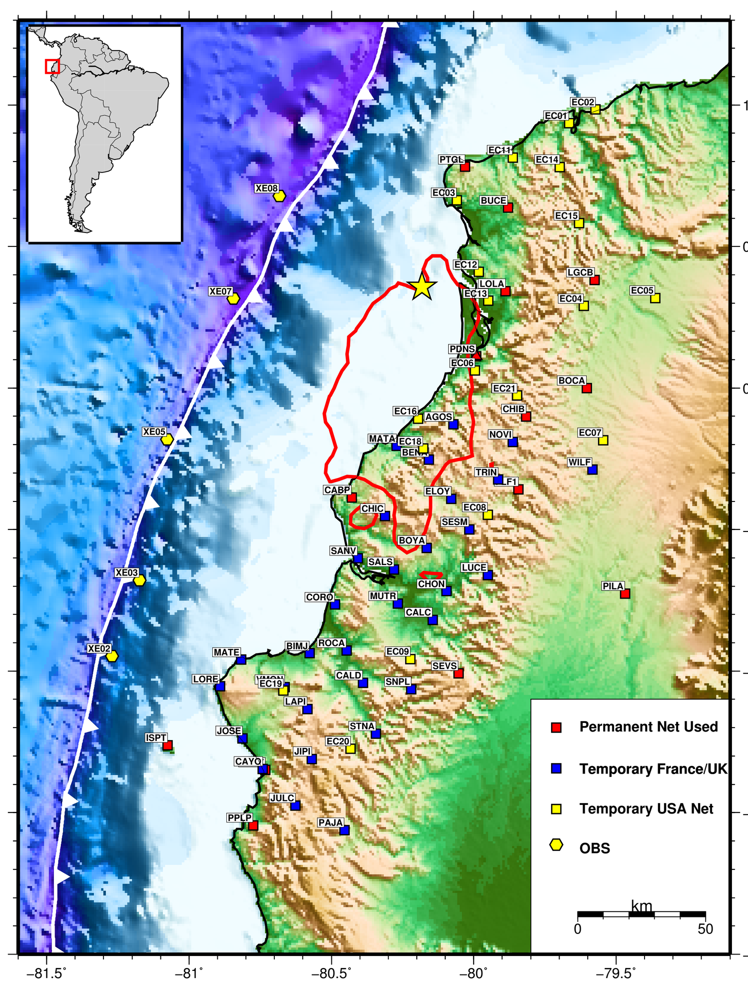
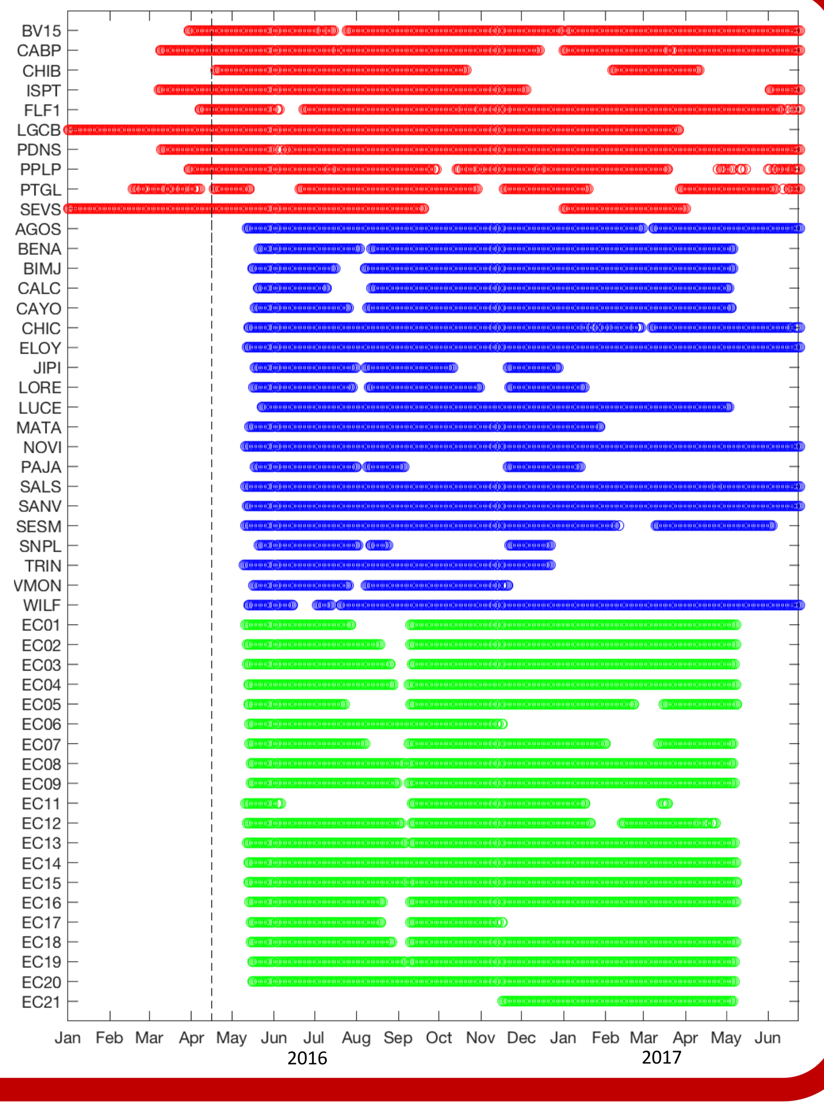
Introduction

- Temporal variations in the elastic behavior of the Earth's crust can be monitored through the analysis of the Earth's seismic response throughout time.
- Seismic noise allow us to retrieve seismic Green's functions from the cross-correlation of records of a random seismic wave-field.
- Noise is recorded continuously and does not depend on earthquake sources.
- CC functions are analogous to records from continuously repeating doublet sources placed at each station, and can be similarly used to extract observations of variations in seismic velocities.
- On 16 April 2016, a Mw 7.8 megathrust earthquake affected the central-north Ecuadorian margin.
- Our goal is to explore the crust's response to the mainshock by analysing CC functions of ambient seismic noise.



Data

- Raw waveforms from Permanent Ecuadorian Network [1] and from Pedernales Aftershock Deployment [2].
- Instruments correspond to a mix of broad-band and intermediate-period sensors. Short-period marine and land stations were not considered.
- Data availability from Permanent Network is scarce, whilst the Temporary Deployment recorded quasi-continuously between mid-May 2016 to May 2017.



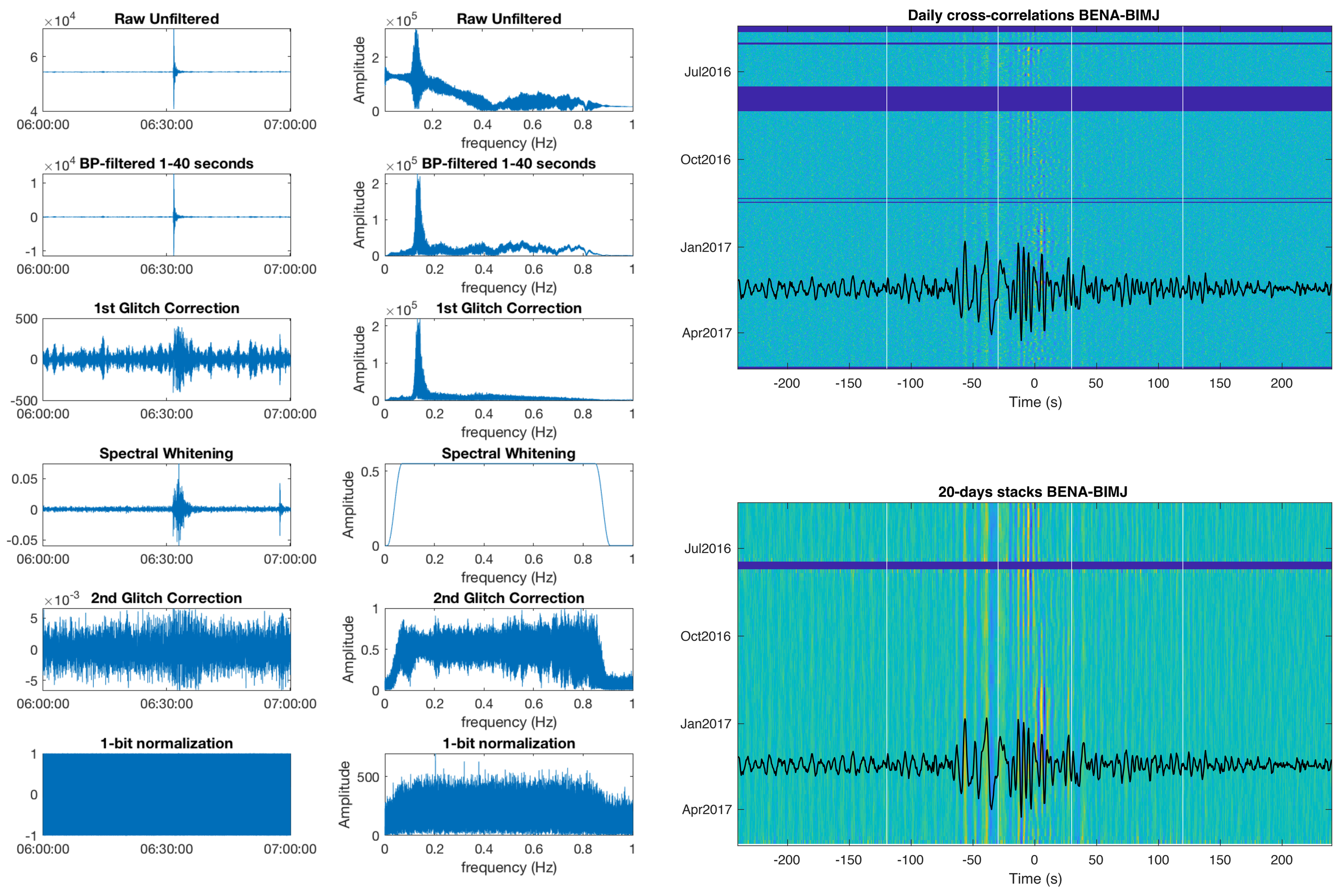
Methods

1. Pre-processing

- Daily mseed traces (Z component)
- We use code package Whisper [3]
- Resample daily records to 2 Hz.
- BP-filter 1-40 s (0.025 – 1 Hz)
- Glitch correction (6/3/0)
- Spectral whitening
- Glitch seismicity (3/1/1)
- 1-bit normalization

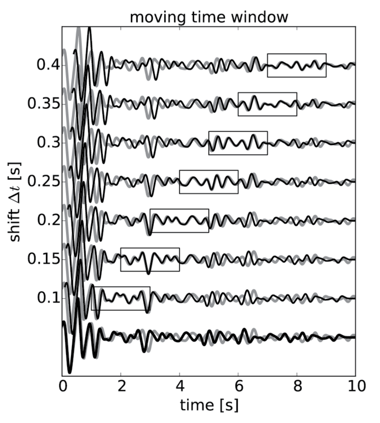
2. Cross-correlations

- Daily cross-correlation windows of 240 s.
- Stacking of periods of 20 days with overlapping of 80%



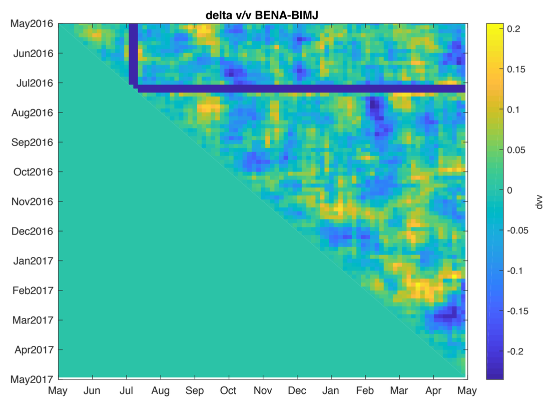
3. Calculation of relative velocity variations

We use Moving-Window Cross Spectral Analysis (MWCS; [4]), in turn based on the Doublets method [5]. The goal is to determine transient changes in travel-times between a reference cross-correlation function CC_{REF} and a current cross-correlation function CC_{CUR}. These changes are proportional to those in the velocity field such as that $\frac{\Delta v}{v} = -\frac{\Delta t}{t}$. Errors are estimated following [6].



← Left Application of a moving time-window for the estimation of time-shifts between a CC_{REF} (grey) and a CC_{CUR} (black).

Right → Example of a data matrix containing dv/v values for station pair BENA-BIMJ

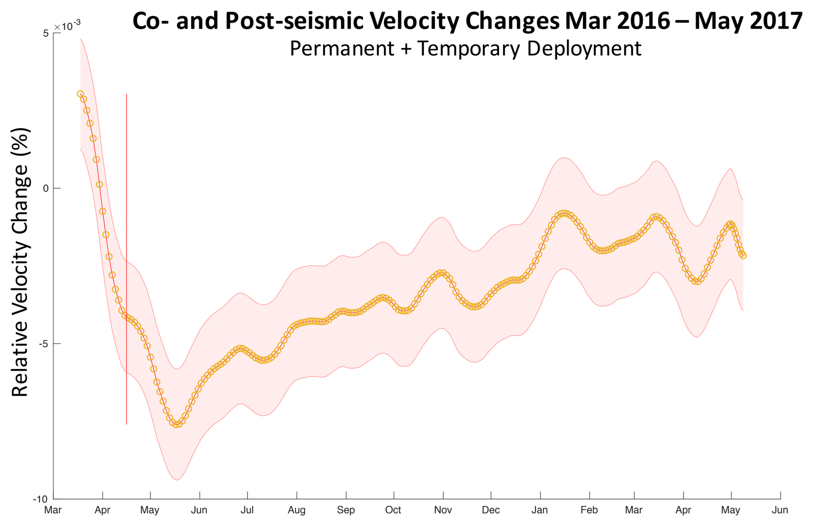


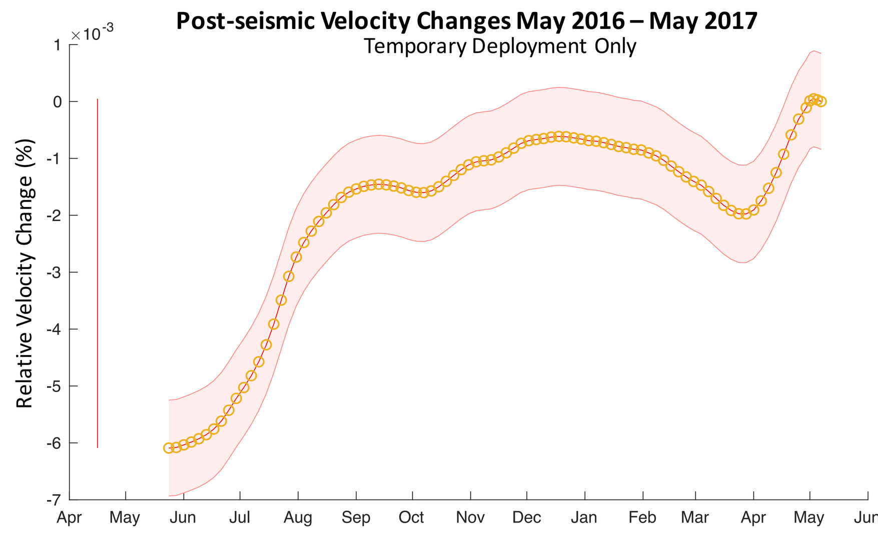
4. Inversion of relative velocity variations

We performed a Bayesian least-squared matrix inversion following [7], avoiding the use of an arbitrary reference function and thus improving the robustness of our results.

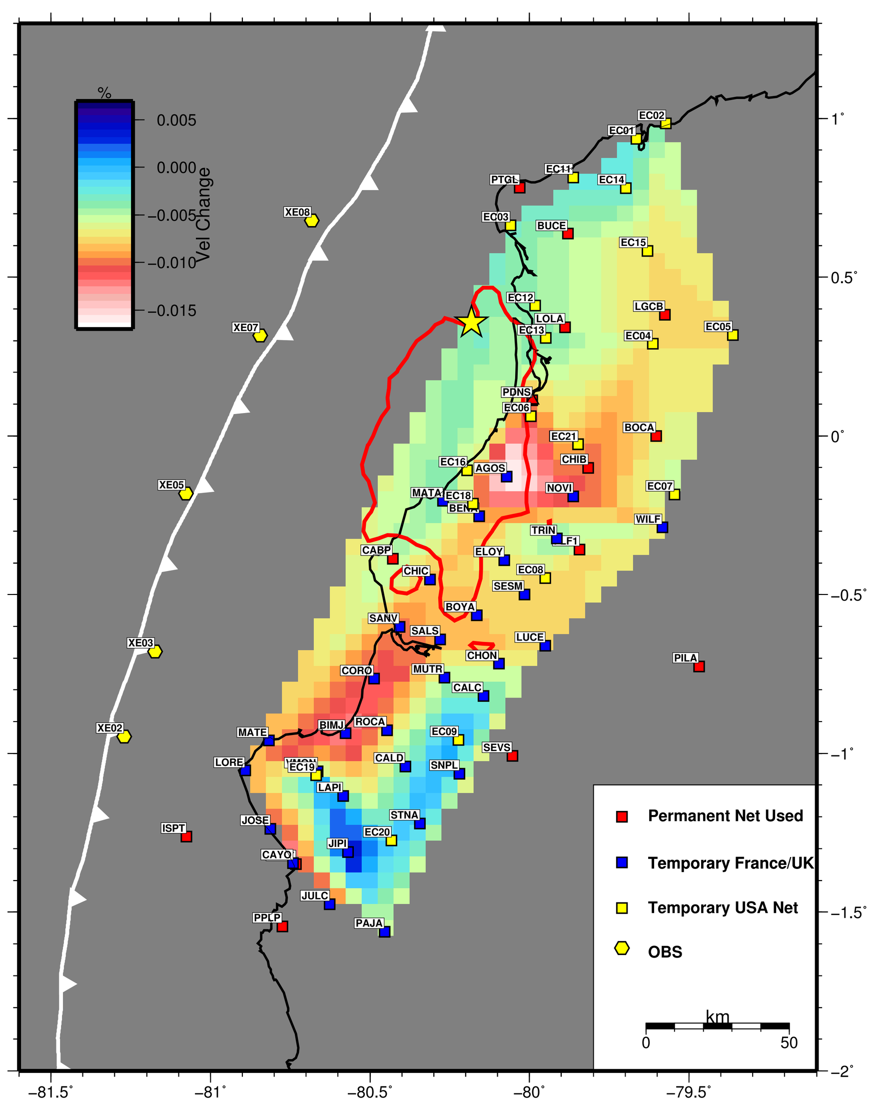
$$\delta v_{ij} = \frac{v_j - v_i}{v_i} = mwcs(ccf_i, ccf_j) \qquad d = \begin{bmatrix} \delta v_{12} \\ \delta v_{13} \\ \delta v_{14} \\ \vdots \\ \delta v_{n-1n} \end{bmatrix} \qquad m = \begin{bmatrix} \delta v_1 \\ \delta v_2 \\ \delta v_3 \\ \vdots \\ \delta v_n \end{bmatrix} \qquad G = \begin{bmatrix} -1 & 1 & 0 & 0 & 0\ldots\ldots \\ -1 & 0 & 1 & 0 & 0\ldots\ldots \\ -1 & 0 & 0 & 1 & 0\ldots\ldots \\ . & & & & \\ . & & & & \\ 0 & 0 & 0 & 0 & 0\ldots -1 \quad 1 \end{bmatrix} \qquad m = \left(G^t C_d^{-1} G + \alpha . C_m^{-1}\right)^{-1} G^t C_d^{-1} d$$

Results and Discussion

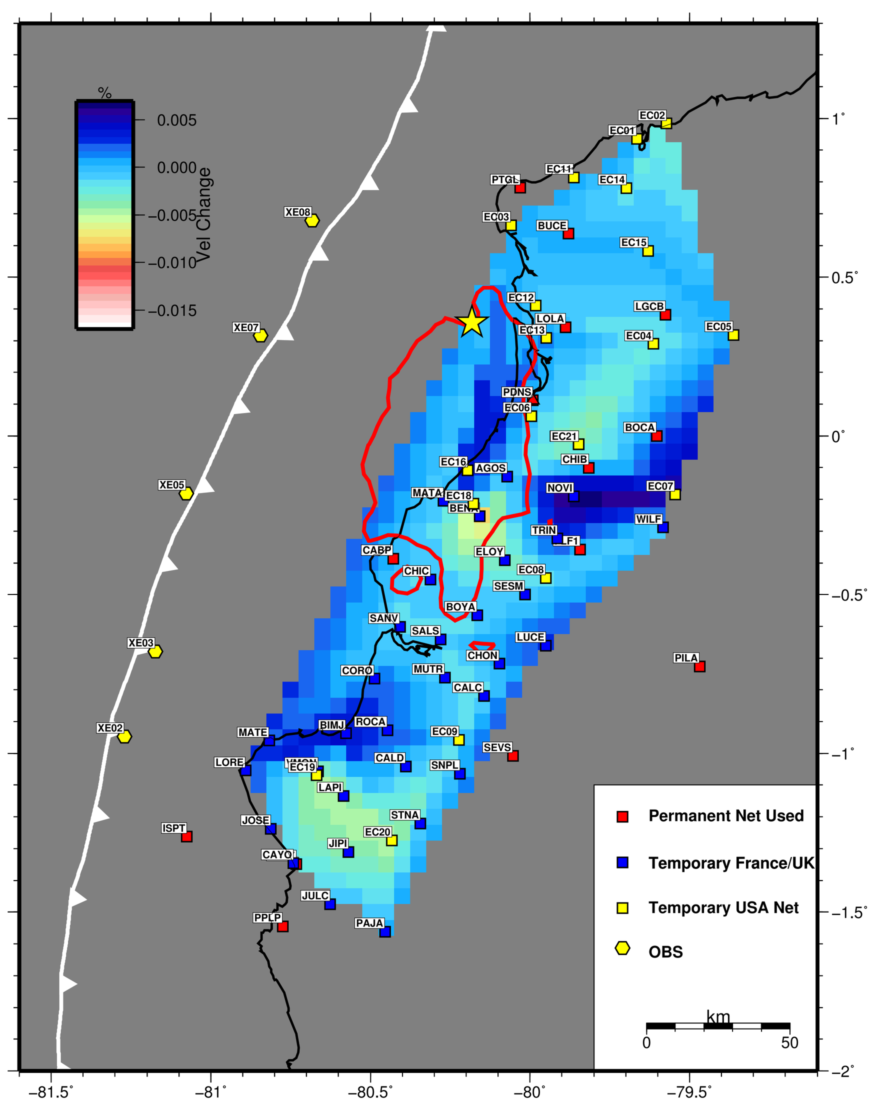




Relative Velocity Changes (May 2016)

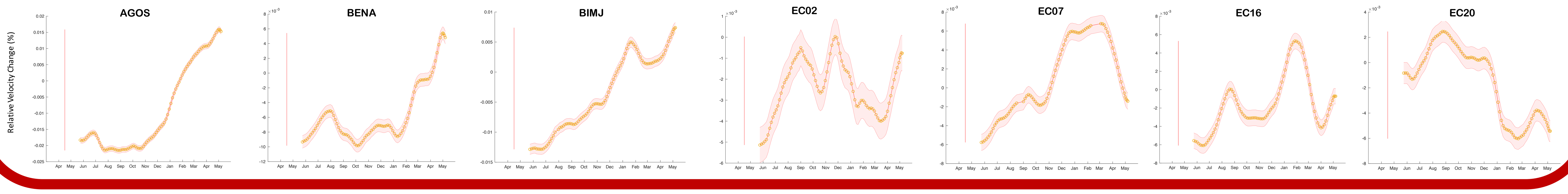


Relative Velocity Changes (Jan 2017)



- Steep decrease of velocities from the beginning of the studied period (mid-March 2016) to mid-May
- Steady increase of velocities (recovery) from mid-May 2016 until ~December 2016
- Increase flattens out from December 2016 onwards ➔ end of recovery
- Geographical distribution from single-station inversions shows larger amplitudes of velocity decrease in front of the rupture area and towards the south along the coastline
- Velocity changes interpreted as the crust's response to the dynamic/static stress changes induced by the Pedernales earthquake
- Velocity variations could be due to the mainshock fracture damage and presence of pressurised pore fluids and/or the action of the ensuing afterslip.

Examples of single-station inversions



Acknowledgments

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