Spatio-temporal variation of Anelastic and Scattering Seismic Attenuation during the 2016-2017 Central Italy Seismic Sequence

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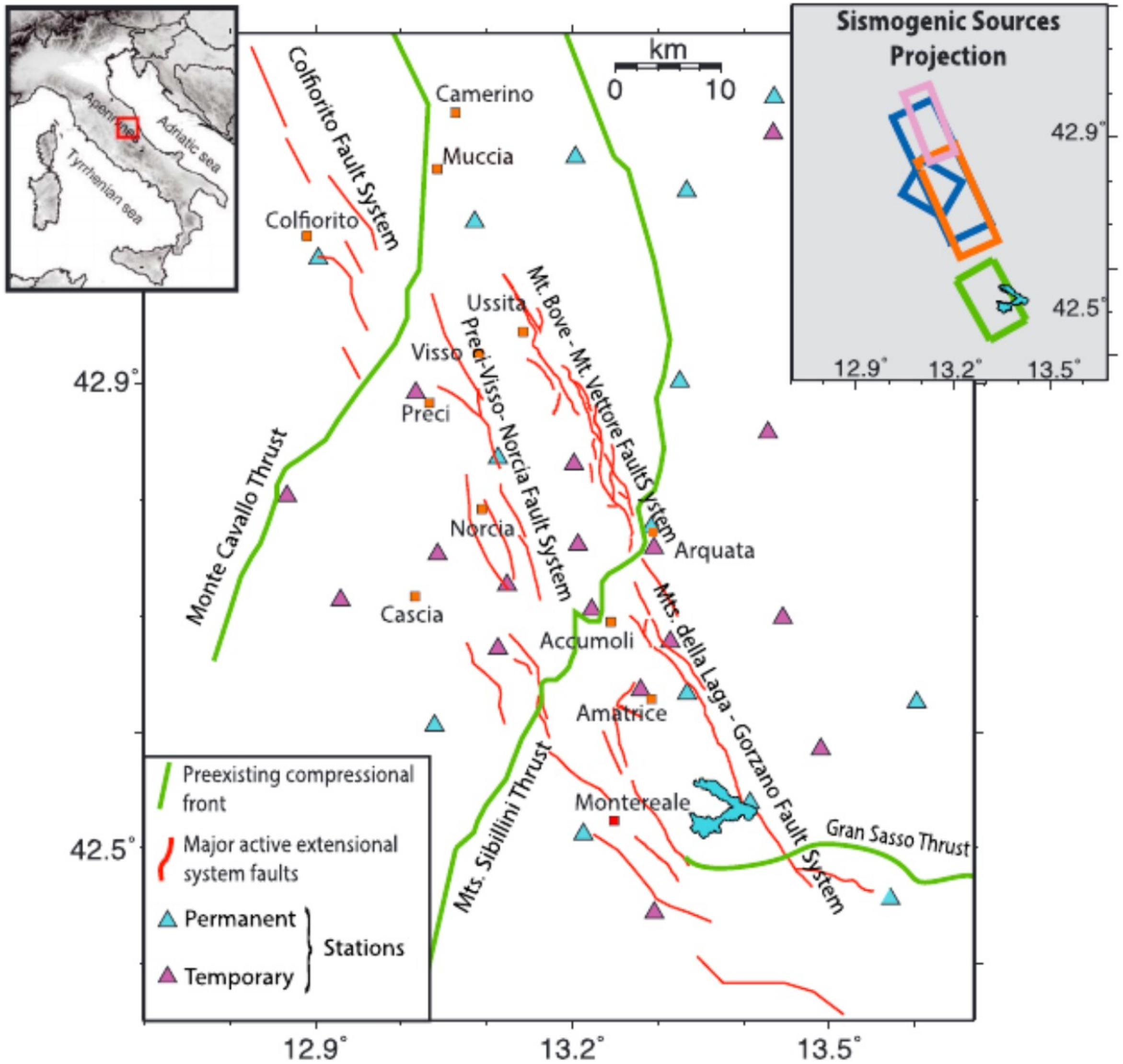
Objectives

- Study focused on the sequence of **large earthquakes** occurred in the Central Apennines in 6–7 months during 2016–2017
- Defined as **cascading earthquake sequence** associated with **fluid movements** through a network of cracks around the active faults (Walters et al., 2018; Malagnini and Munafò, 2018)

- Spatial and temporal evolution of the **attenuation contributions** during the 2016-2017 Amatrice (M_w 6.0) - Visso (M_w 5.9) - Norcia (M_w 6.5) sequence and a pre-sequence (2013-2016) dataset
- **Coda attenuation tomography** together with the **peak delay time** to quantify the intrinsic and scattering attenuation
- Discrimination of their spatial variation and interpretation of the fluid migration and the development of the 2016-2017 seismic sequence

Geological Background

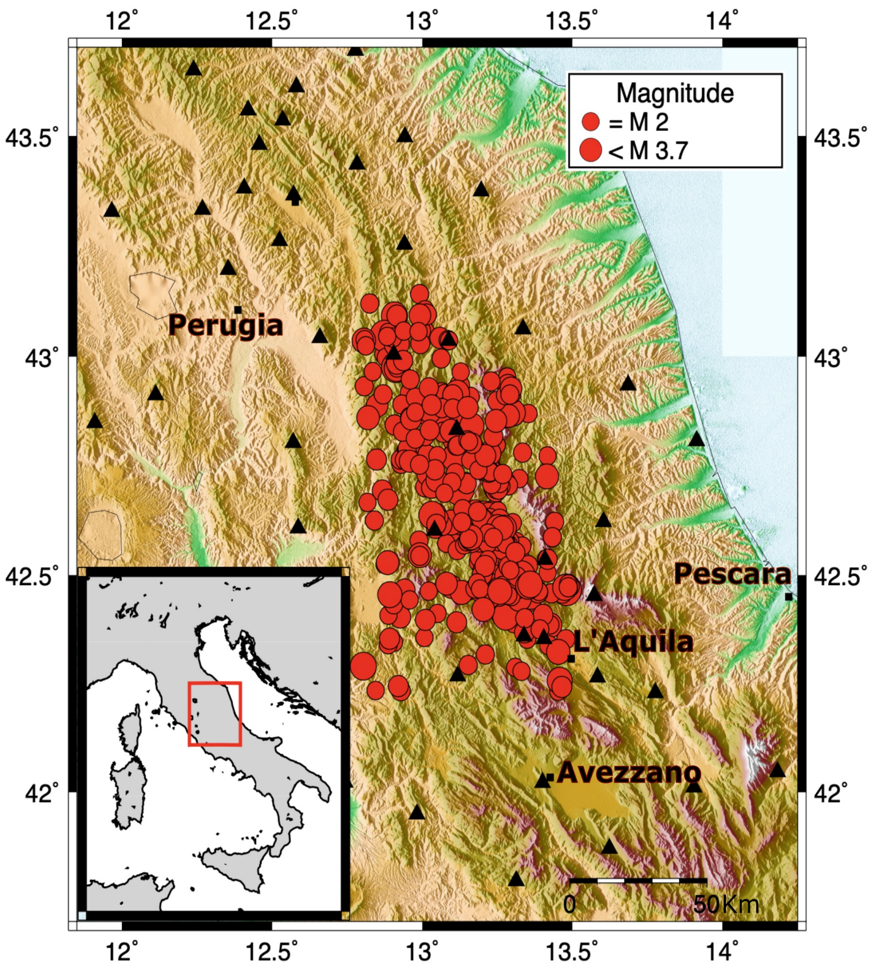
- Mainly composed by thrust sheets imbricated towards the Adriatic Sea
- Having a NW-SE trend and creating a contact between the Meso-Cenozoic succession and the Miocenic flysch
- Extension started in Late Pliocene
- Network of normal faults controlling the generation of intermontane basins



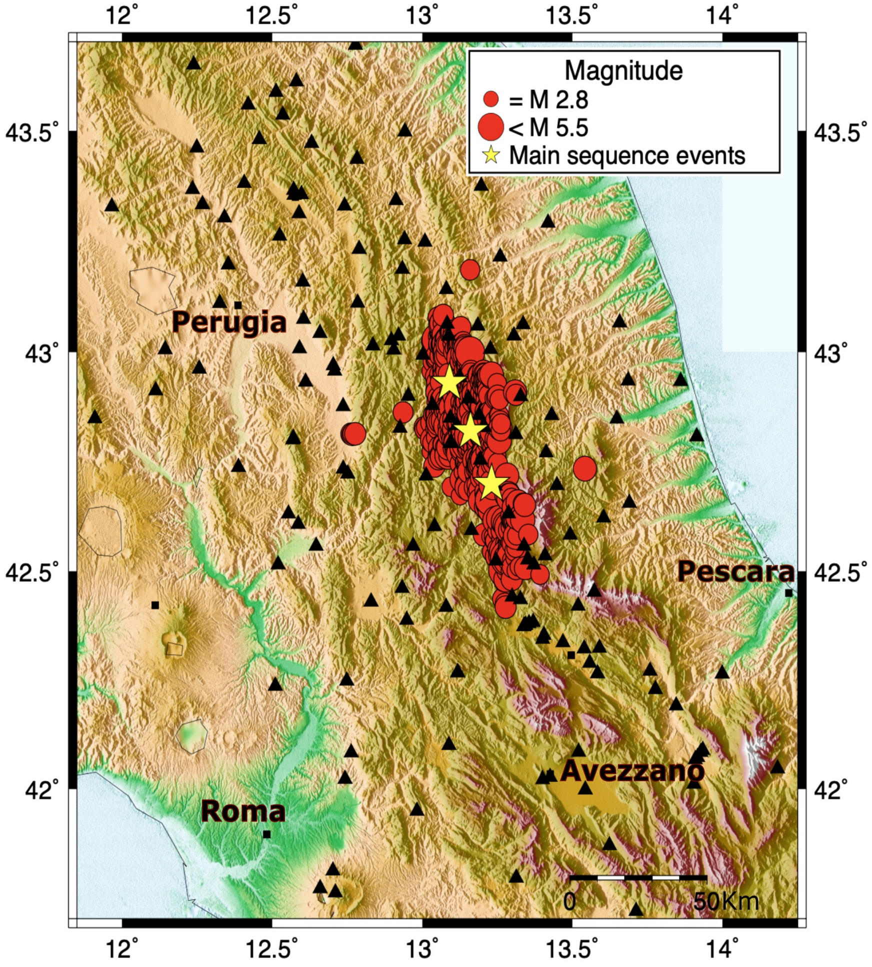
From Pastori et al., 2019

Data

PRE-SEQUENCE (2013-2016)

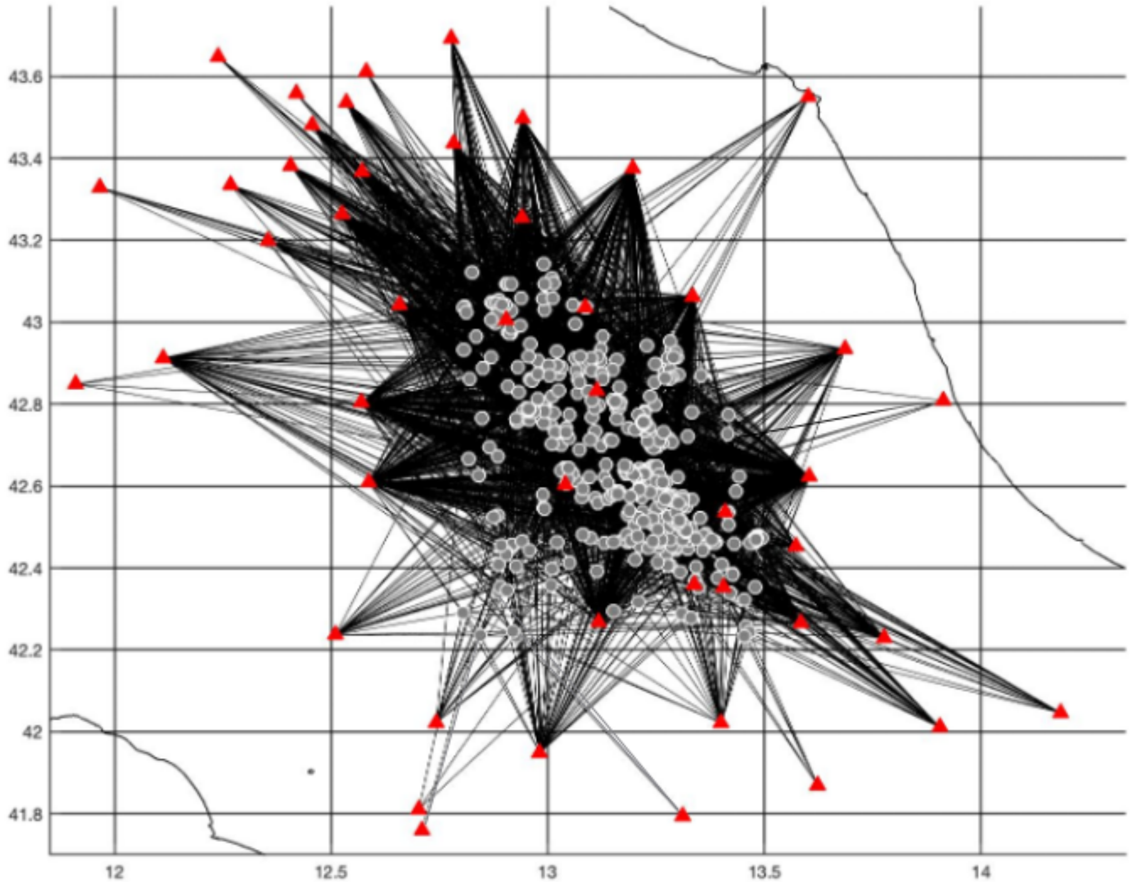


SEQUENCE (2016-2017): AMATRICE (M_W 6), VISSO (M_W 5.9), NORCIA (M_W 6.5)



Data

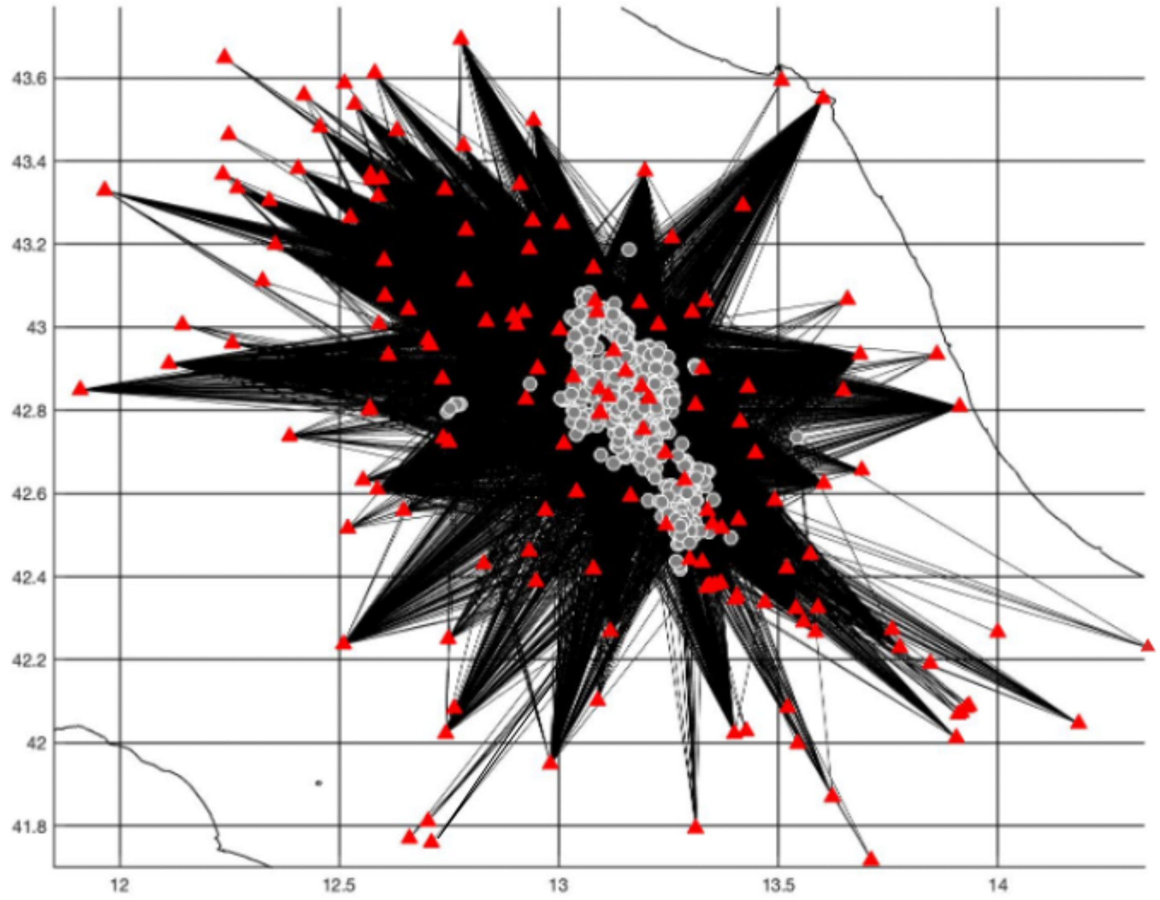
PRE – SEQUENCE (~6000 WAVEFORM PER EACH COMPONENT)



SEQUENCE (~14000 WAVEFORM PER EACH COMPONENT)

$2.8 \leq M \leq 6.3$

Maximum depth: 20 km



Attenuation of seismic waves

- The study of attenuation parameters (frequency and amplitude dependant) gives information about the material properties (pressure, temperature, fractures)

- The **overall quality factor** is given by:

$$Q_{tot}^{-1} = Q_i^{-1} + Q_s^{-1}$$

where Q_i^{-1} and Q_s^{-1} are the quality factors due to the **intrinsic attenuation** and the **scattering loss**.

Intrinsic Attenuation → Anelastic processes and internal friction, resulting in heat dissipation (depends on temperature, chemical composition and fluids)

Scattering → Energy loss and amplitude attenuation due to the presence of small-scale heterogeneities (e.g., fractures)

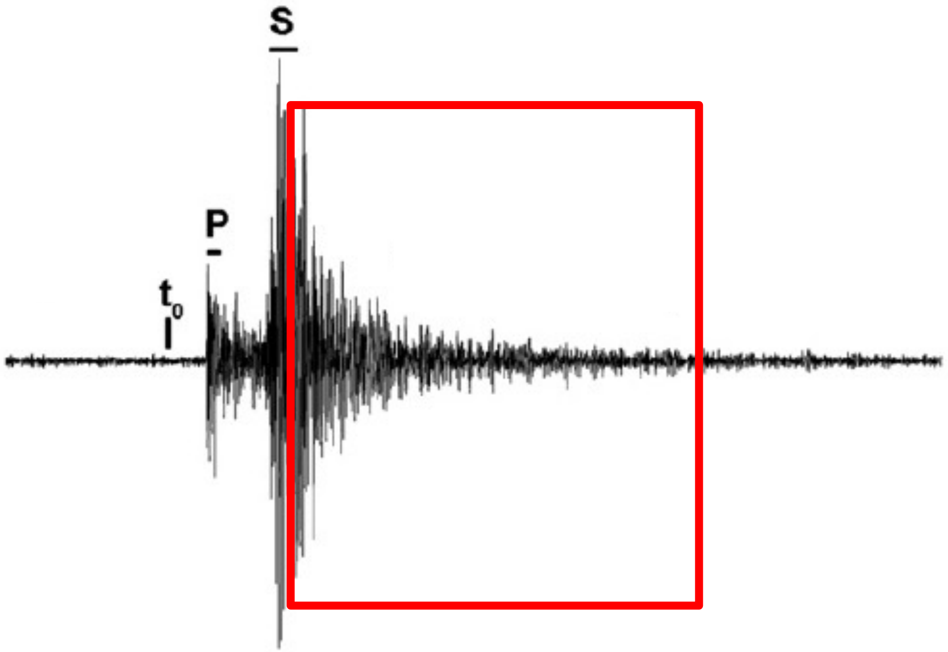
Attenuation of Coda Waves

- Coda waves are after body waves (S arrival), contain information about scattering. Backscattering waves from the heterogeneities encountered from the seismic waves during their path in the earth's crust

- The parameter to quantify the shape of the decay curve is the coda attenuation Qc^{-1}

$$E(t,f) = S(f)t^{-1.5} exp - \left(\frac{2\pi f t}{Q_c}\right)$$

- We inverted the dataset for coda attenuation imaging using kernel function



From De Siena et al. (2014)

Qc Inversion Using Kernel Functions

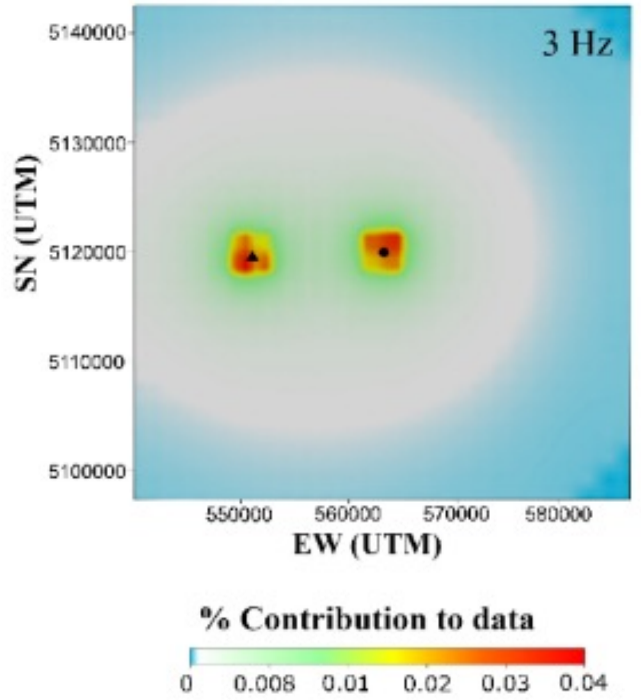
- Kernels have been applied at regional scales and in volcanoes. They can be used to invert the spatial distribution of Qc
- 2D frequency-dependent bulk sensitivity kernels in the multiple-scattering (using the Energy Transport Equations, Del Pezzo et al. 2018)

$$K_{i,j}^{3D}[\rho,t,B_0,Le^{-1},v] = \int_0^T E^{3D}[r_{s\rho},\tau,B_0,Le^{-1},v]E^{3D}[r_{\rho r},T-\tau,B_0,Le^{-1},v]d\tau$$

- They are implemented with the B0 and Le^{-1} obtained by Akinci et al. (2020) for the area

Frequency	B0	Le^{-1}
1.5 Hz	0.65	0.05
3 Hz	0.5	0.05
6 Hz	0.3	0.04
12 Hz	0.25	0.03

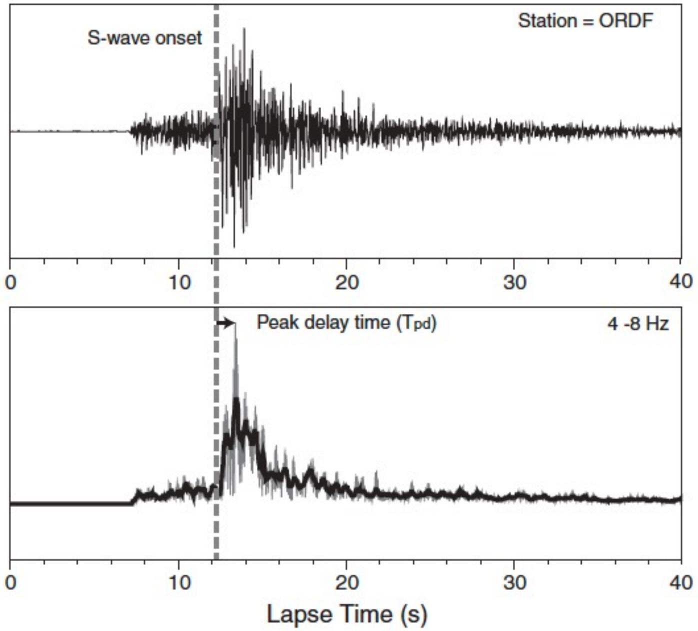
Results MLTWA (Sequence), Akinci et al., 2020

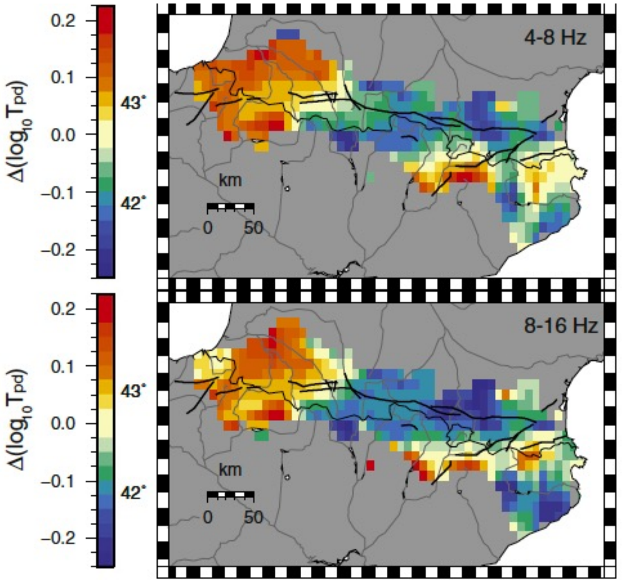


Map view of a sensitivity kernel. From Gabrielli et al., 2020

Peak Delay

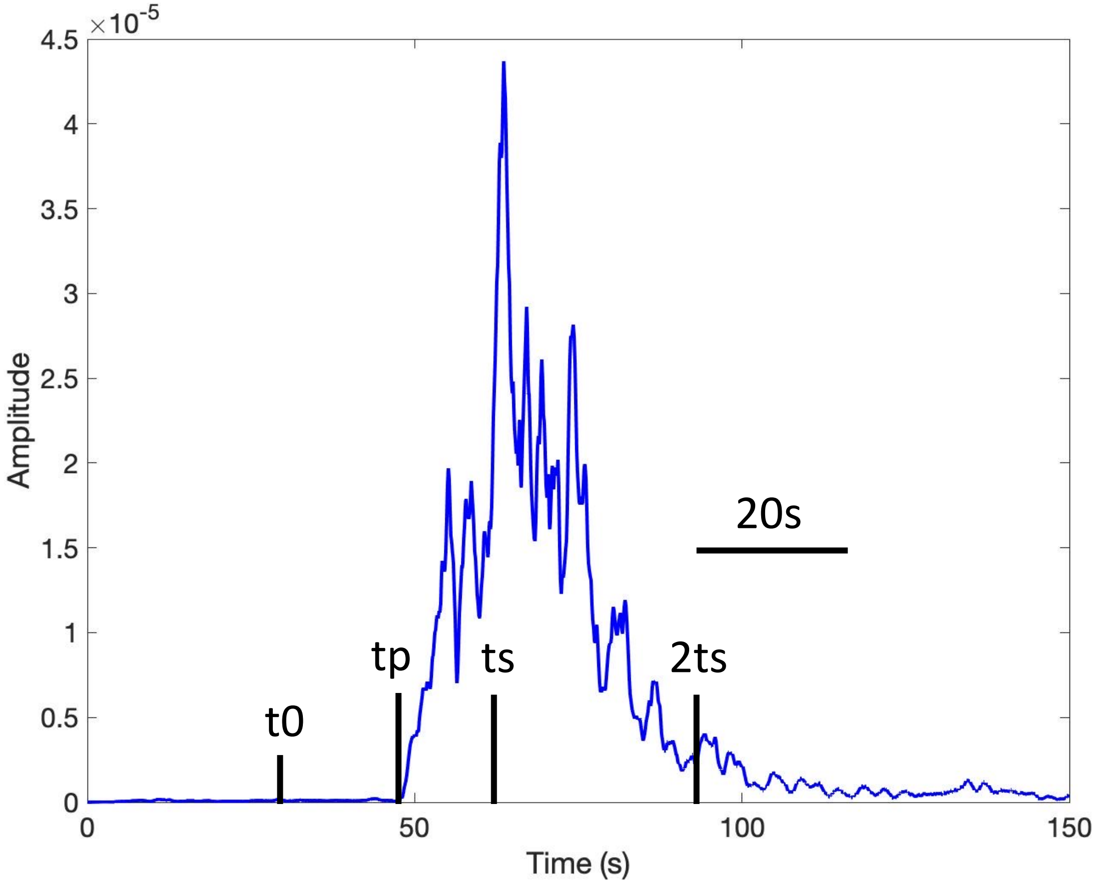
- Direct measurement of multiple forward scattering, applied already at volcanic and regional scale (De Siena et al., 2016; Calvet et al., 2013)
- Defined as the time lag between the S-wave arrival and the maximum amplitude of the arrival (Takahashi et al., 2007; Saito et al., 2002); **higher lag – higher scattering; lower lag – lower scattering**





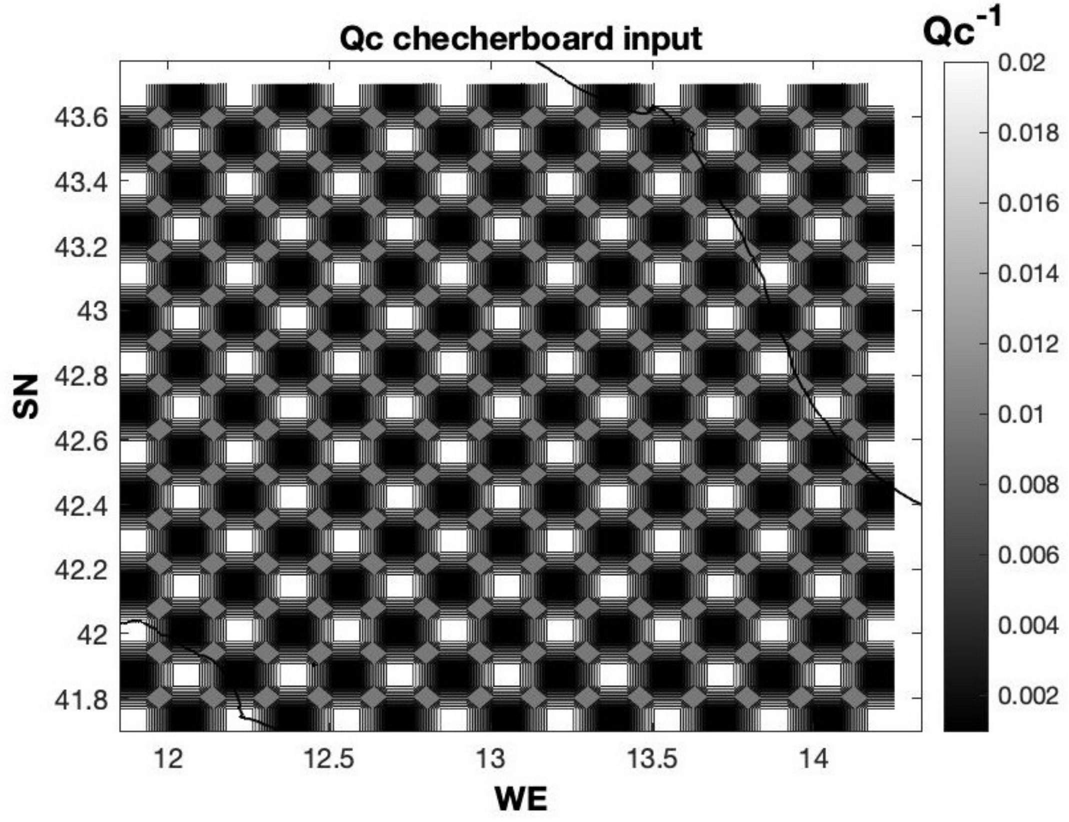
Example of the definition of peak delay time (left) and its spatial variation in a regional setting (right). From Calvet et al., 2013

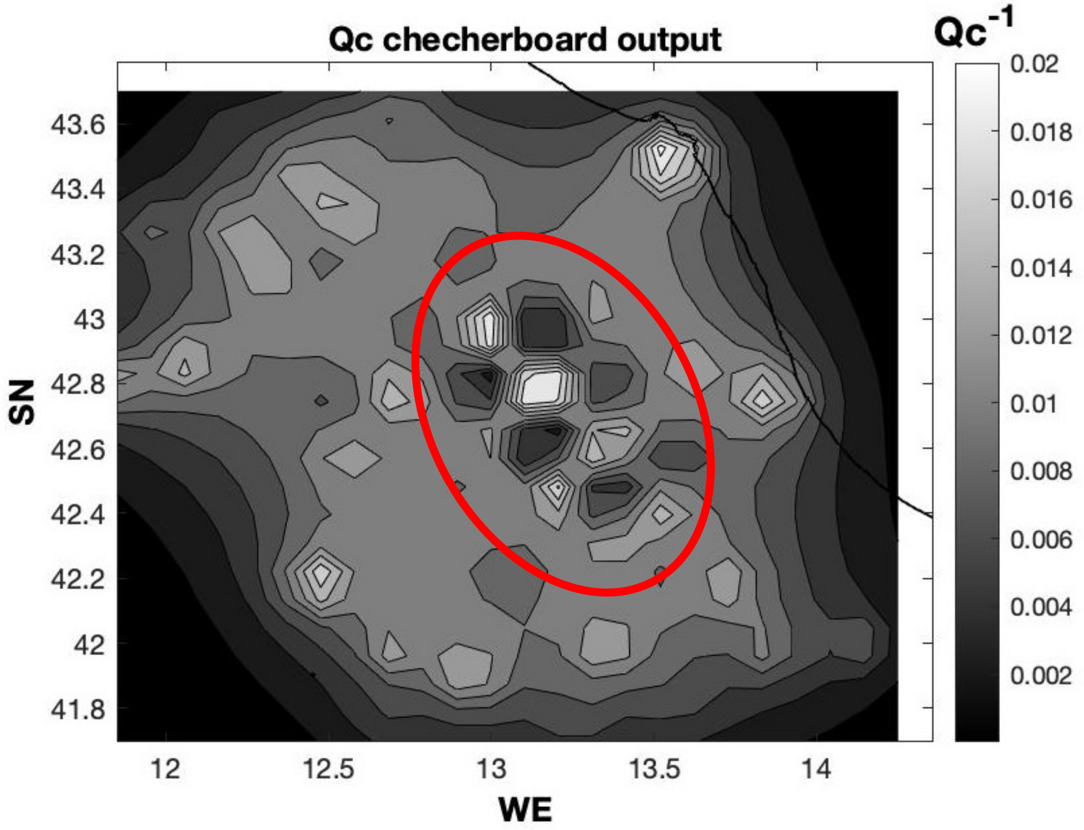
Application to Central Apennines Dataset



- Frequency band: 1.5 – 3 – 6 – 12 Hz
- Filter Butterworth (4th order)
- Peak Delay window: 10 s
- Lapse Time: 2ts
- Coda window: 20 s
- P waves velocity: 6 km/s
- S waves velocity: 3.5 km/s

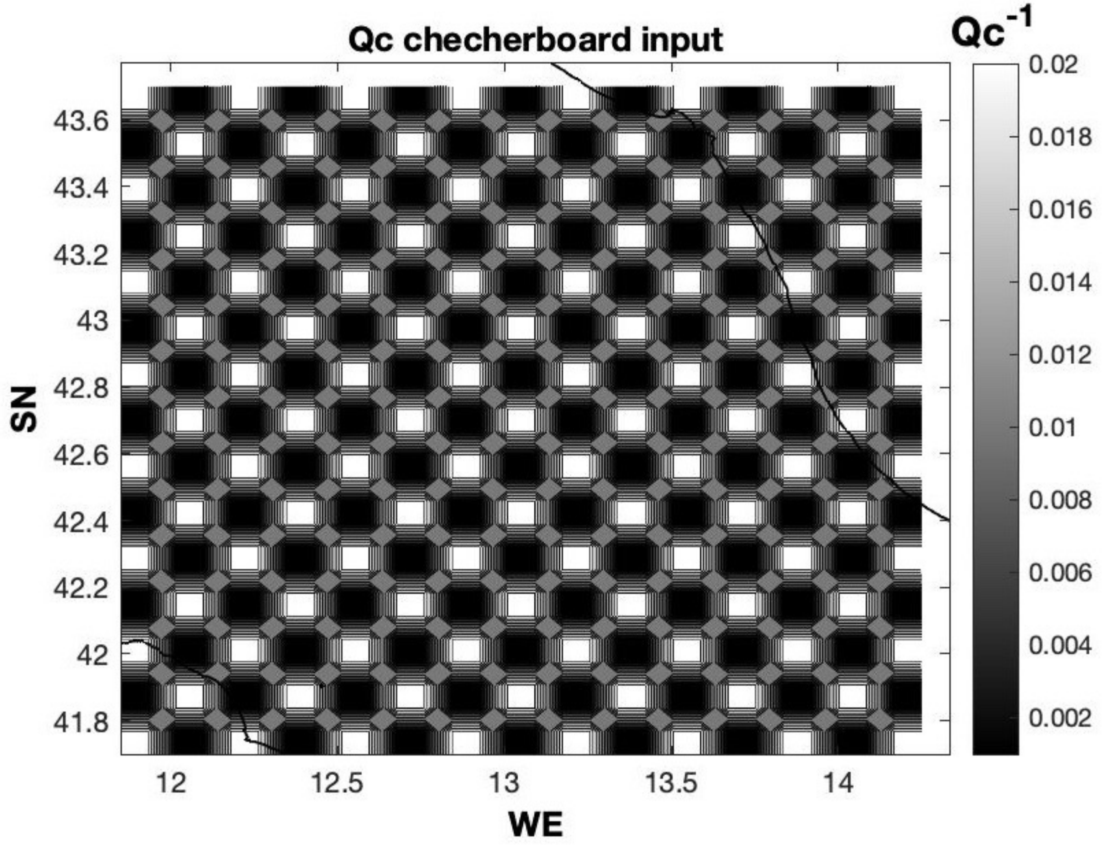
Resolution Map for Qc – Pre-Sequence

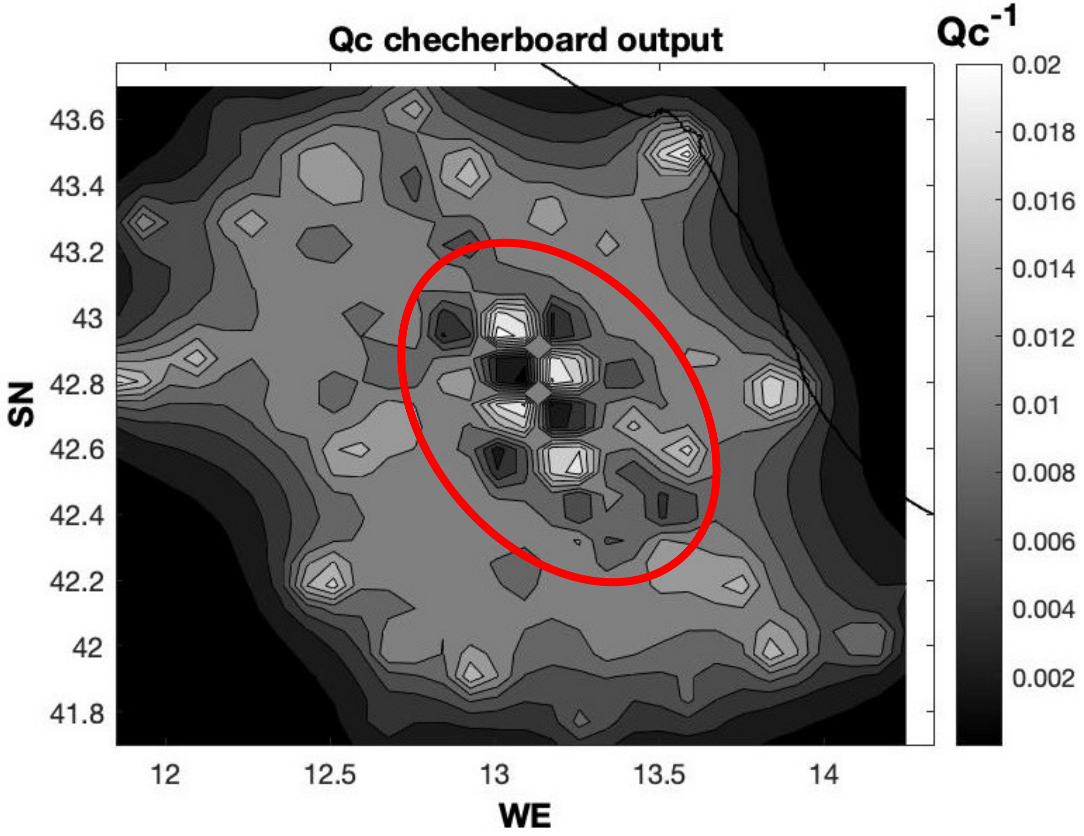




Red circle highlights the resolved area

Resolution Map for Qc – Sequence



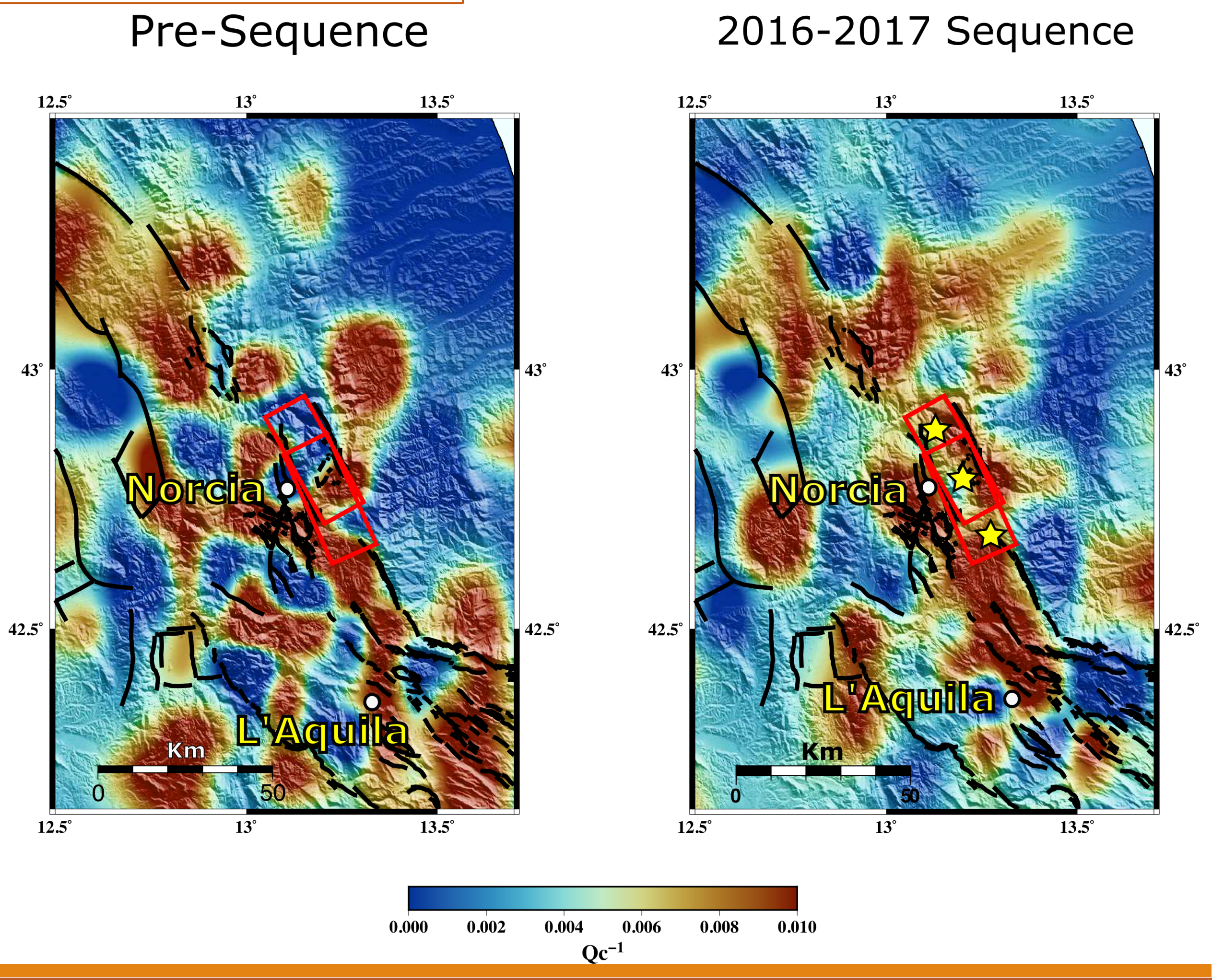


Red circle highlights the resolved area

Spatial Variation of Coda Attenuation (1.5 Hz)

Hot colour indicates high attenuation areas
Cold colour indicates low attenuation areas

- High Intrinsic Attenuation (Qc^{-1}) is spread in the pre-sequence
- L'Aquila-Gran Sasso sector changes from high attenuated in the pre-sequence to a strong decrease during the sequence
- During the sequence, high attenuation is focused in the highly fractured/faulted areas and in the seismogenic fault planes (red boxes)
- This is probably due to fluid circulations in the fault network before the 2016-2017 seismic sequence

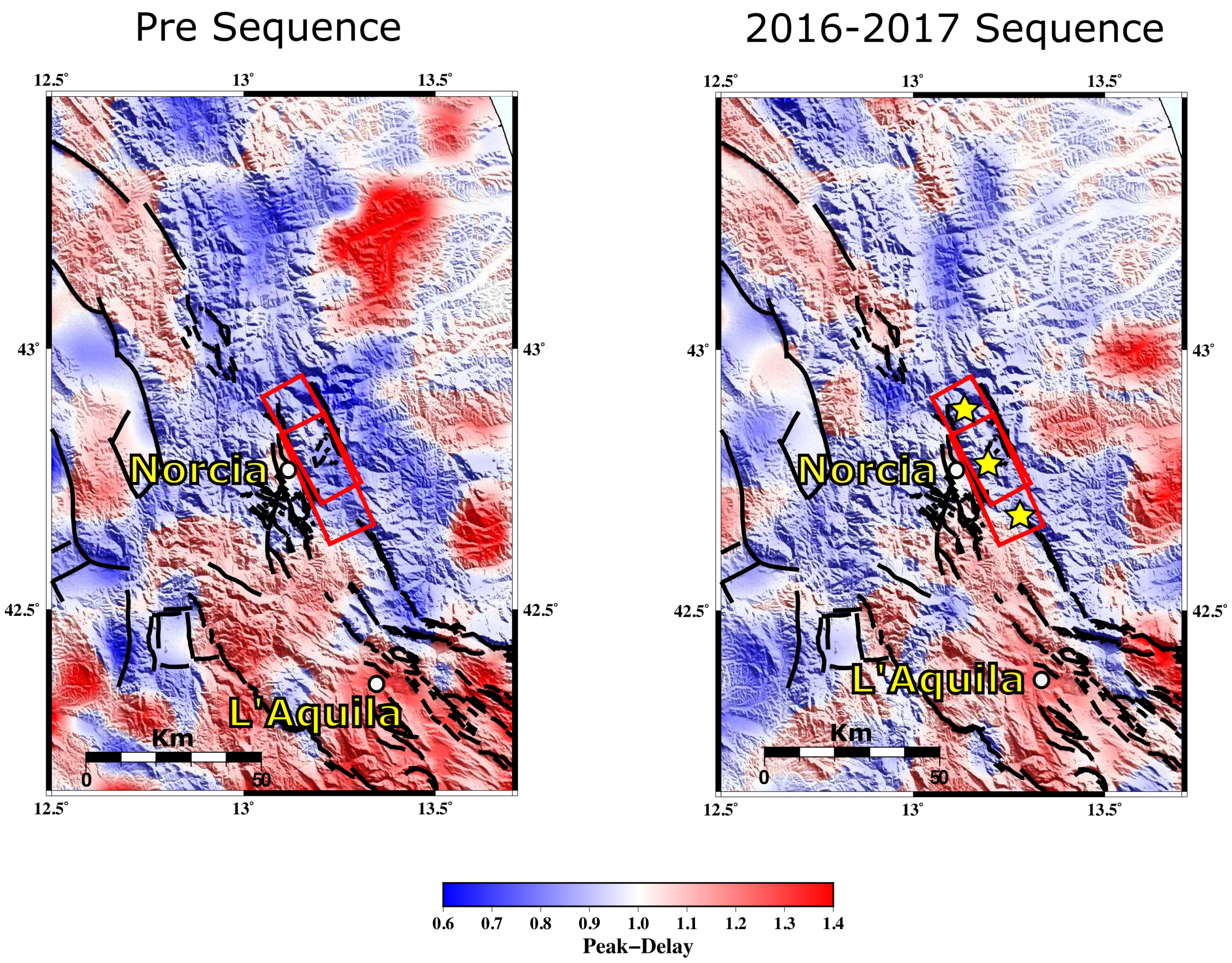


Fault from: *DISS Working Group (2018). Database of Individual Seismogenic Source (http://diss.rm.ingv.it/diss/)*
And from ITHACA catalogue (*http://sgi1.isprambiente.it/geoportal/catalog/content/project/ithaca.page*)

Spatial Variation of Peak Delay (1.5 Hz)

Hot colour indicates high scattering areas
Cold colour indicates low scattering areas

- Peak Delay mapping show a spatial agreement with the tectonic setting (e.g., Mt. Sibillini Thrust – blue anomaly with a NE-SW direction)
- The high scattering area in the peak delay on the south of Amatrice can be connected to the Lazio-Abruzzi fractured carbonates and the L'Aquila seismogenic basin (red anomaly)
- The **fault network** west of Norcia changes from low scattering to **high scattering** during the sequence (high density of fractures/cracks)



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Conclusion

- Peak Delay and Coda Attenuation mapping show a spatial agreement with the tectonic setting (Mt. Sibillini Thrust)

- The high scattering area in the peak delay on the south of Amatrice can be connected to the Gran Sasso Carbonate aquifer

- The change from low to high scattering in the fault network west of Norcia can indicate an increased fracturing due to the intense seismic activity

- The change in space and time of the intrinsic attenuation anomalies can be associated to fluid circulation in the fault network