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A Jupyter Notebook devoted to a multiparametric investigation of the Amatrice-Norcia Italian seismic sequence 2016-2017

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Abstract

Central Italy experienced a catastrophic seismic sequence that suddenly started on 24 August 2016 at 1:36:32 UTC with an Mw = 6.0 earthquake. Buildings damaged by the shaking of this event caused about 300 fatalities, and several towns (e.g., Amatrice, Accumuli, Arquata del Tronto) were destroyed entirely. A seismic sequence started from this event, and the largest event occurred more than two months later on 30 October 2016 at 6:40:17 UTC with magnitude Mw = 6.5. On 18 January 2017, a resurgent of the seismic sequence occurred with four events of magnitude equal to or greater than 5.0 in a Southern sector of the interested region (close to Capitignano/Montereale/Campotosto Lake). Then, the sequence followed a typical multi-year decay. The impact was huge, and from an energetic point of view, the event of 30 October 2016 was one of the largest recorded in the last 40 years in Italy.

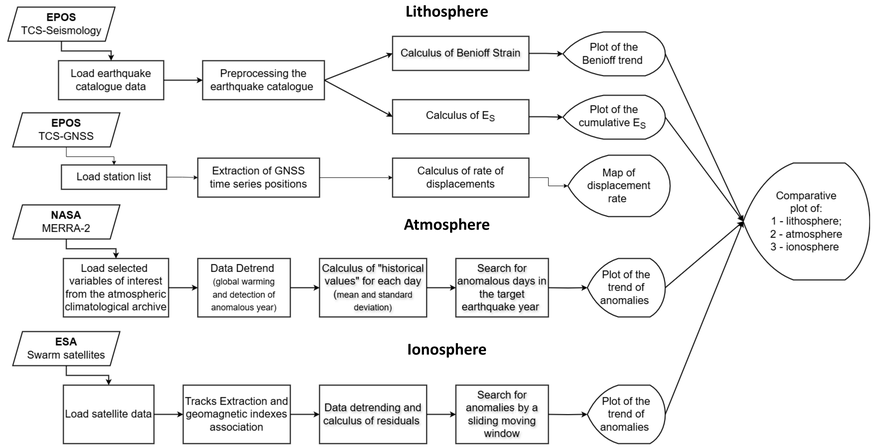
Considering this particular case study, we developed a multidisciplinary and multiparametric Jupyter Notebook which can be run, e.g. in a Virtual Research Environment (VRE). The Open Source Code and friendly environment of Jupyter Notebook permit future users to adopt the same VRE to study other earthquakes.

The Jupyter Notebooks retrieves data mainly from the European Plate Observing System (EPOS) platform (Bailo et al., 2023, https://doi.org/10.1038/s41597-023-02697-9), integrating with other sources such as climatological archives and *Swarm* magnetic satellites of European Space Agency (ESA). EPOS is a European research infrastructure devoted to understanding plate tectonics through multidisciplinary and multiparametric studies. EPOS has already implemented a portal (https://www.epos-eu.org/dataportal, last accessed 10 January 2024) where users can retrieve data grouped into 10 disciplines (Thematic Core Services – TCS).

The Italian seismic sequence interests the extensional plate typical of the Central Apennine Mount Chain, and multiparametric data can help to understand the physical and chemical processes that could occur before and during the earthquake. The VRE relies on the results published by (Marchetti et al., 2019) but using updated algorithms such as the one used to study the Arabian Plate earthquake doublets (Ghamry et al., 2024, https://doi.org/10.3390/atmos15111318). We will also include other atmospheric investigations of specific parameters (e.g., Piscini et al., 2017, https://doi.org/10.1007/s00024-017-1597-8). Such previous studies propose evidence for anomalies in the organised chain of lithosphere, atmosphere, and ionosphere that were identified before the Italian seismic sequence 2016-2017.

These preliminary studies contribute to investigating the relations between geo-layers in our Earth's system and the influence of seismic activity on them. Furthermore, this VRE adds a tool to the EPOS platform with potentially several applications, such as investigations of other significant earthquakes or other natural hazards, such as volcano eruptions

Workflow



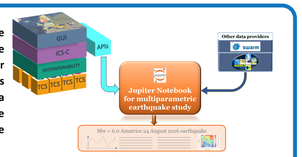


Fig. 1—Sketch of the VRE. The core of the VRE is the Jupyter Notebook. It retrieves most of the data (e.g., the earthquake catalogue) from the EPOS platform via APIS and integrates it with other external data sources, such as Swarm satellite geomagnetic data. It provides an output report with information on the Italian Seismic sequence 2016, graphs, and analyses of the retrieved data.

The case study

The Italian seismic sequence started on 24 August 2016 in the Central Apennine was used as a reference case study. The main two events were the Mw = 6.0 Amatrice earthquake, which occurred on 24 August 2016 at 1:33 UT, and the Mw = 6.5 Norcia earthquake, which occurred on 30 October 2016 at 6:40 UT. Epicentre locations, together with a foreshock that occurred on 26 October 2016 close to Visso town, are represented in Figure 2.

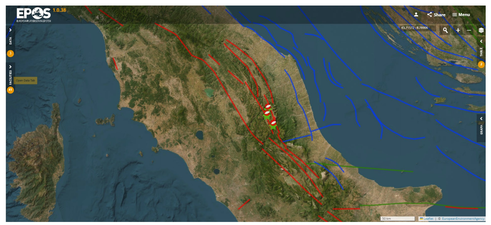


Fig. 2 – Localization of the earthquakes (green stars) with magnitude equal to or greater than 6.0 using EPOS Platform. The focal mechanisms of the same events were overplotted using the EPOS Service "Moment tensor data for modern earthquakes (2013-present)" provided by TCS Seismology. The active faults were shown on the same map, and their colour indicates the tectonic mechanism (red = extensional, blu = compressional, green = transcurrent).

The main active faults are overlaid on the same map, taking advantage of the integrated visualisations of the EPOS Data Portal (https://www.epos-eu.org/dataportal, last access 18 Dec 2024).

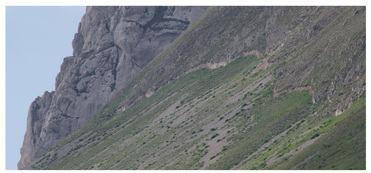
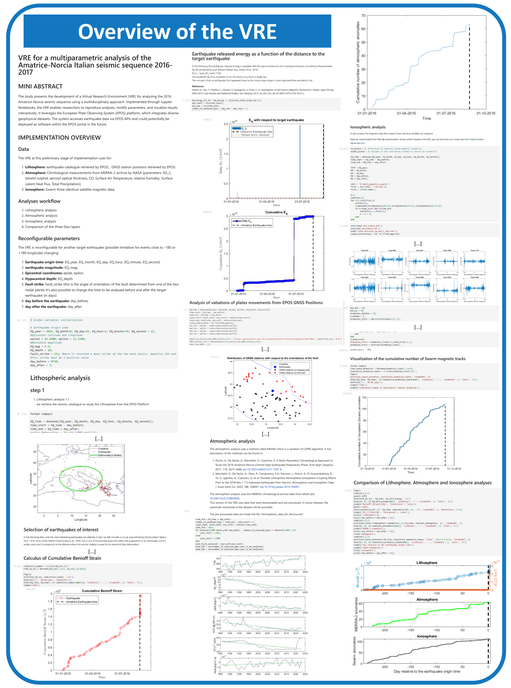


Fig. 3 – Photo on the Vettore Mount of the displacement in correspondence with the surface emersion of Bove-Vettore Fault, responsible for the 30 October 2016 earthquake.

One can see that the earthquakes occurred in a very dense region of faults dominated by extensional tectonic stress. The focal mechanisms of these events are in agreement with a normal focal mechanism solution. A multiparametric study of this seismic sequence was provided by (Marchetti et al., 2019). The paper also involved previous investigations of specific parameters (e.g., Piscini et al., 2017). Collecting analyses from the lithosphere, atmosphere and ionosphere, it was possible to detect a chain of phenomena that preceded the start of the seismic sequence of Amatrice-Norcia 2016.

Overview of the VRE



GNSS data analysis

In the present version of the VRE, we integrated the GNSS position data retrieved by EPOS portal. The analysis of the variations of the permanent GNSS positions may help to understand possible tectonic movements in the preparation of the earthquake as identified by Panza et al., 2018. However, here we don't want to necessary repeat the work of Panza et al. Here we plotted the time series (Fig. 4) of the upward component along the transects of the fault and after we mapped the three-components rate of variations every two weeks before the Amatrice-Norcia 2016 earthquakes (Fig. 5).

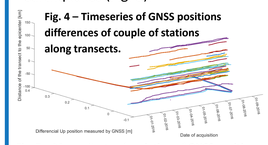


Fig. 4 – Timeseries of GNSS positions differences of couple of stations along transects.

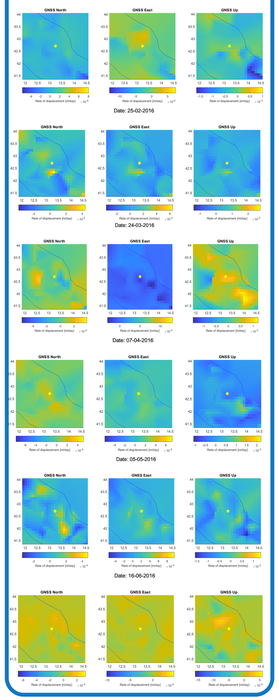


Fig. 5 – Maps of rate of variation of GNSS positions.

Discussion and future perspectives

We developed a preliminary version of the VRE that can already analyse parameters from the lithosphere, atmosphere, and ionosphere and compare them in a summary graph.

It's worth noting a particular trend in the lithosphere in the 8 months before the start (on 24 August 2016) of the Italian Central Apennine 2016 Seismic sequence with two moments of higher seismic activity in the Dobrovolskys's area:

1.About 225 days before the start of the seismic sequence

2.About 60 days before the start of the seismic sequence

However, the E_S parameter shows a very much higher value for the second event. This is due to the closeness to the target event. It was an earthquake of magnitude Mw = 4.4 that occurred on the North side of Bolsena Lake in Central Italy on 30 May 2016 (see Fig. 6). This seismic event was about 104 km far from 24-08-2016 Amatrice earthquake and 95 km far from the 30-10-2016 Norcia earthquake. Nevertheless, the involved faults are very far and not directly connected.

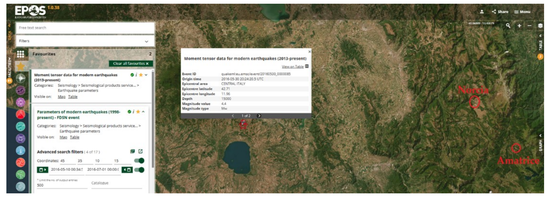


Fig. 6 – Localization of the Mw = 4.4 earthquake occurred on 30 May 2016. Positions of the towns of Amatrice and Norcia are marked.

From the analysis of GNSS positions recorded in Central Italy in the 8 months before the seismic sequence it was possible to identify an interesting trend in the North timeseries (see Fig. 7). However, from the detailed plot taking into account the distance of each transect from the epicenter the interesting profile is far from the epicenter and so it's probably not connected with the preparation of the earthquake.

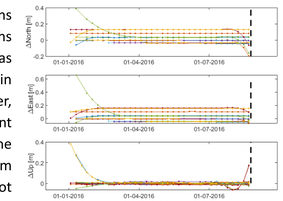


Fig. 7 – Timeseries of GNSS positions differences of couple of stations along transects..

Finally, from the comparison of the three geo-layers some synchronous trend can be depicted, suggesting a possible coupling between the lithosphere, atmosphere and ionosphere. Future perspectives include adding other parameters from the EPOS data platform and other data providers to better understand the geodynamics of our planet.

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Repository

https://github.com/dedalomarchetti/VRE_Amatrice