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Spatio-temporal Evolution of Seismicity in the Northern Apennines: Insights from a High-Resolution Earthquake Catalog

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1. Introduction

The analysis of microseismicity has a fundamental role in understanding earthquakes driving processes such as seismic sequences evolution and preparatory phase.

Recent advances in machine learning (ML)-based detection and location techniques, coupled with dense seismic networks have led to the development of a new generation of earthquakes catalogs illuminating fault systems in unprecedented detail.

We use the high-resolution catalog of Poggiali et al. (2025) to analyze the seismicity of the area monitored by the Alto Tiberina Near Fault Observatory (TABOO-NFO) from 2010 to 2023, which accounts for more than 400,000 events (Fig. 1).

The study area is located in an extending sector of the Northern Apennines of Italy characterized by a **very high rate of microseismic release**, the presence of a **complex fault systems** (including a low-angle normal fault at depth: the Altotiberina Fault, ATF) evolving in a shallow crust surrounded by **deep fluids circulation**. Fluids presence is testified both by the high CO_2 emissions at the surface and by overpressure (85% of lithostatic load) measured in boreholes at ~ 4 km depth (Chiaraluce et al., 2007).

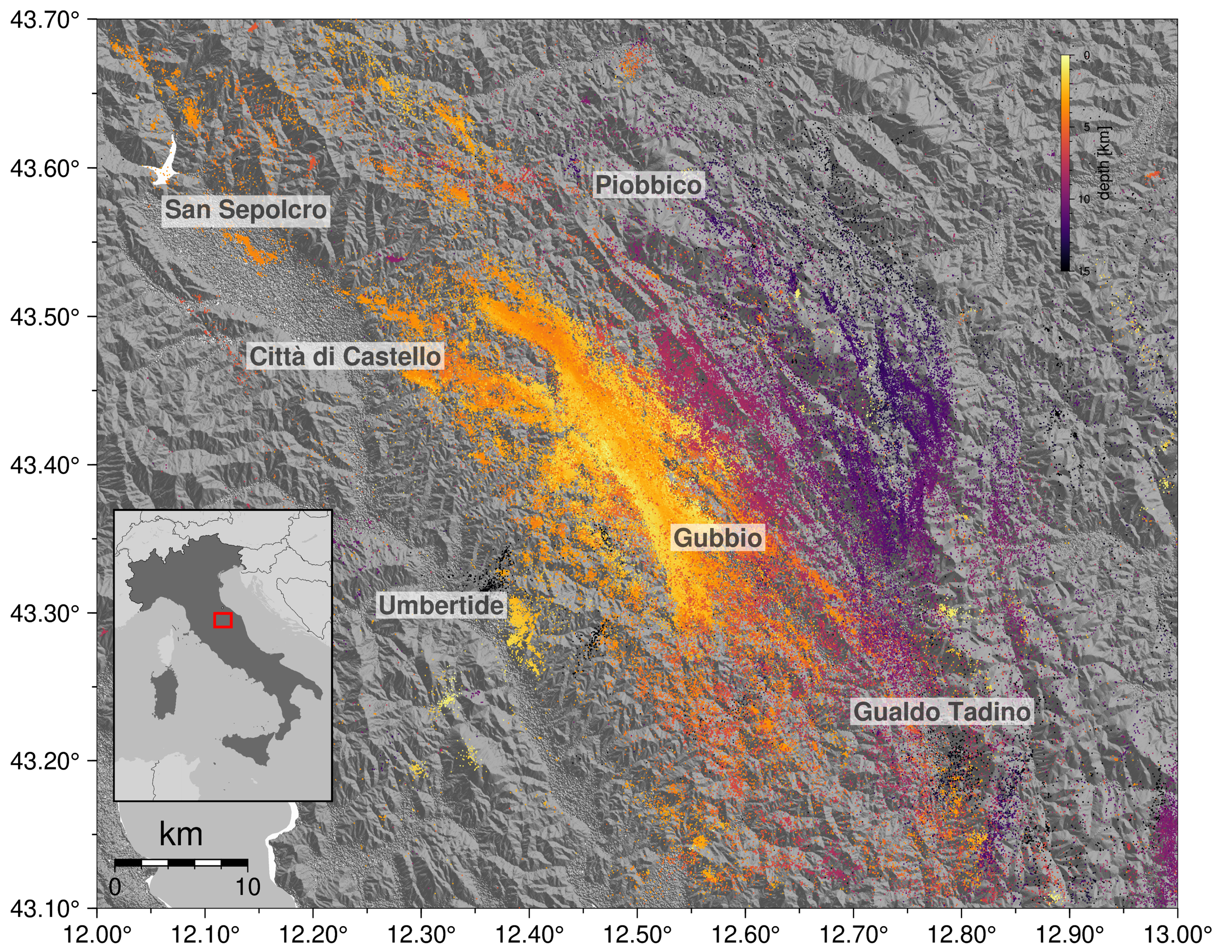


Figure 1. Map of the seismicity of the area from the catalog of Poggiali et al. (2025).

2. Clusters Identification

The clusters are extracted with DBSCAN using spatial (x, y, z) and temporal dimensions (eps=500m and 10 days, minobs=100). All clusters are located in the hangingwall of the ATF, at depths < 5 km (see cross sections in Fig 2).

We perform an additional clustering to check for the presence of small clusters on the ATF by decreasing minobs to 10 (yellow in Fig 2 and Fig 3).

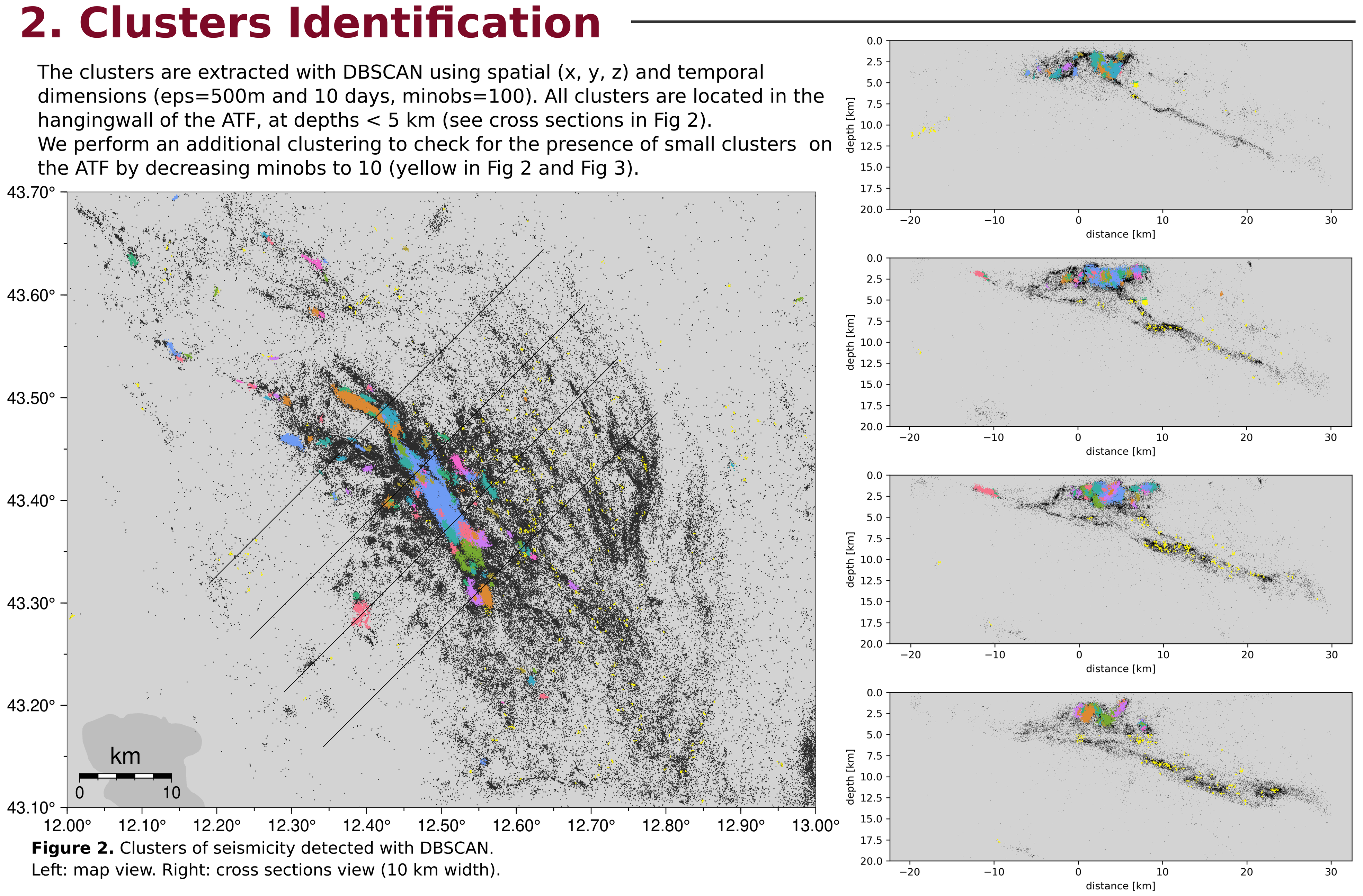


Figure 2. Clusters of seismicity detected with DBSCAN.
Left: map view. Right: cross sections view (10 km width).

3. Migration of seismicity

Many clusters show a **clear along strike migration** (Fig 3). To perform a systematic analysis we fit each cluster (time vs hypocentral distance) with a power law in order to identify those compatible with a migrating seismic front of any shape. We then **fit both a linear migration and a diffusion-like front to each cluster** (Fig 4) to estimate diffusivities and migration speeds. In this process, the first 10% of events are iteratively tested for the source of migration. Each fit is repeated 100 times with a random subset of each cluster to check the stability of the retrieved parameters.

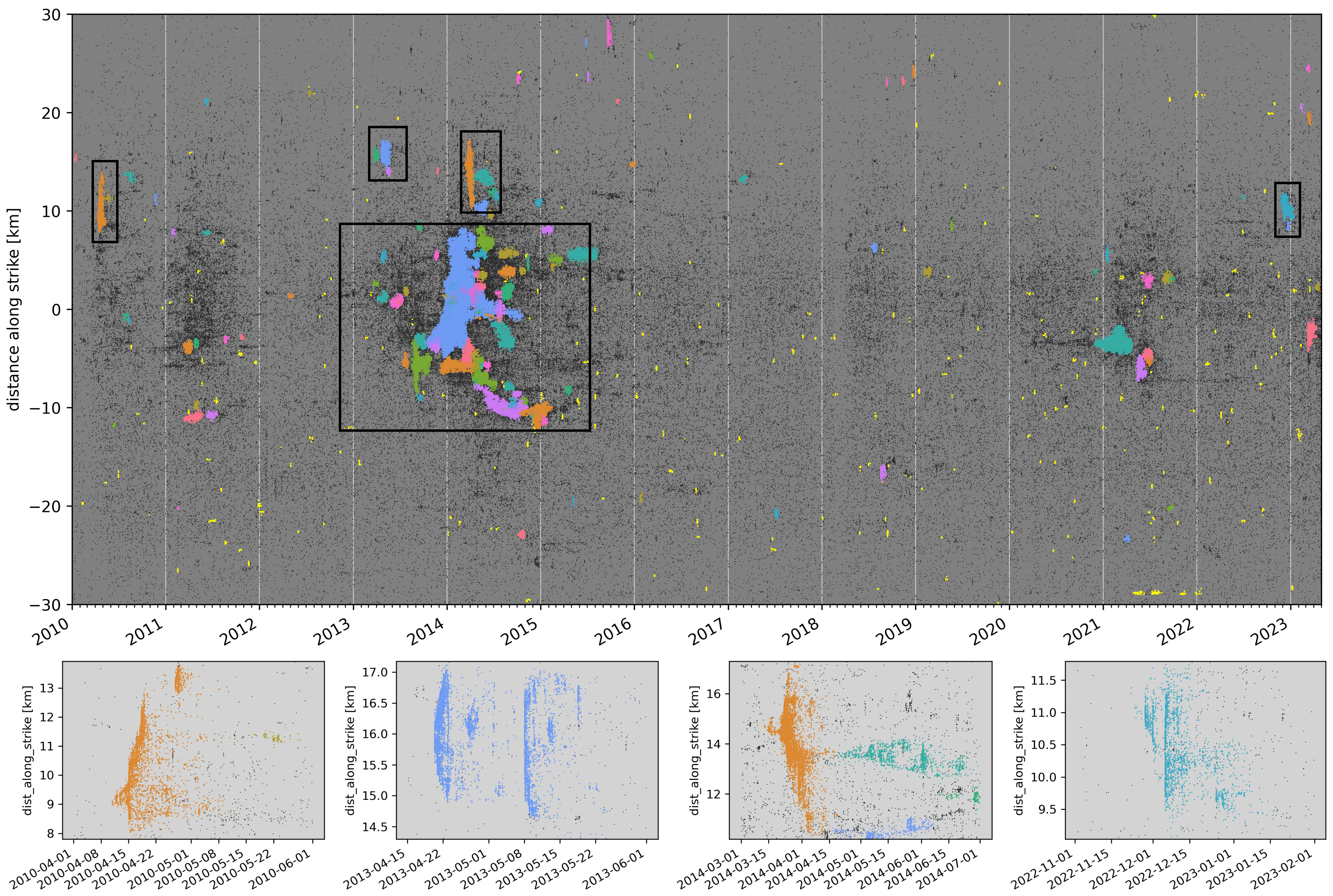


Figure 3. Top: Along strike distance vs time of the seismicity with clusters highlighted. Bottom: zoom on selected clusters.

4. A multiscale process?

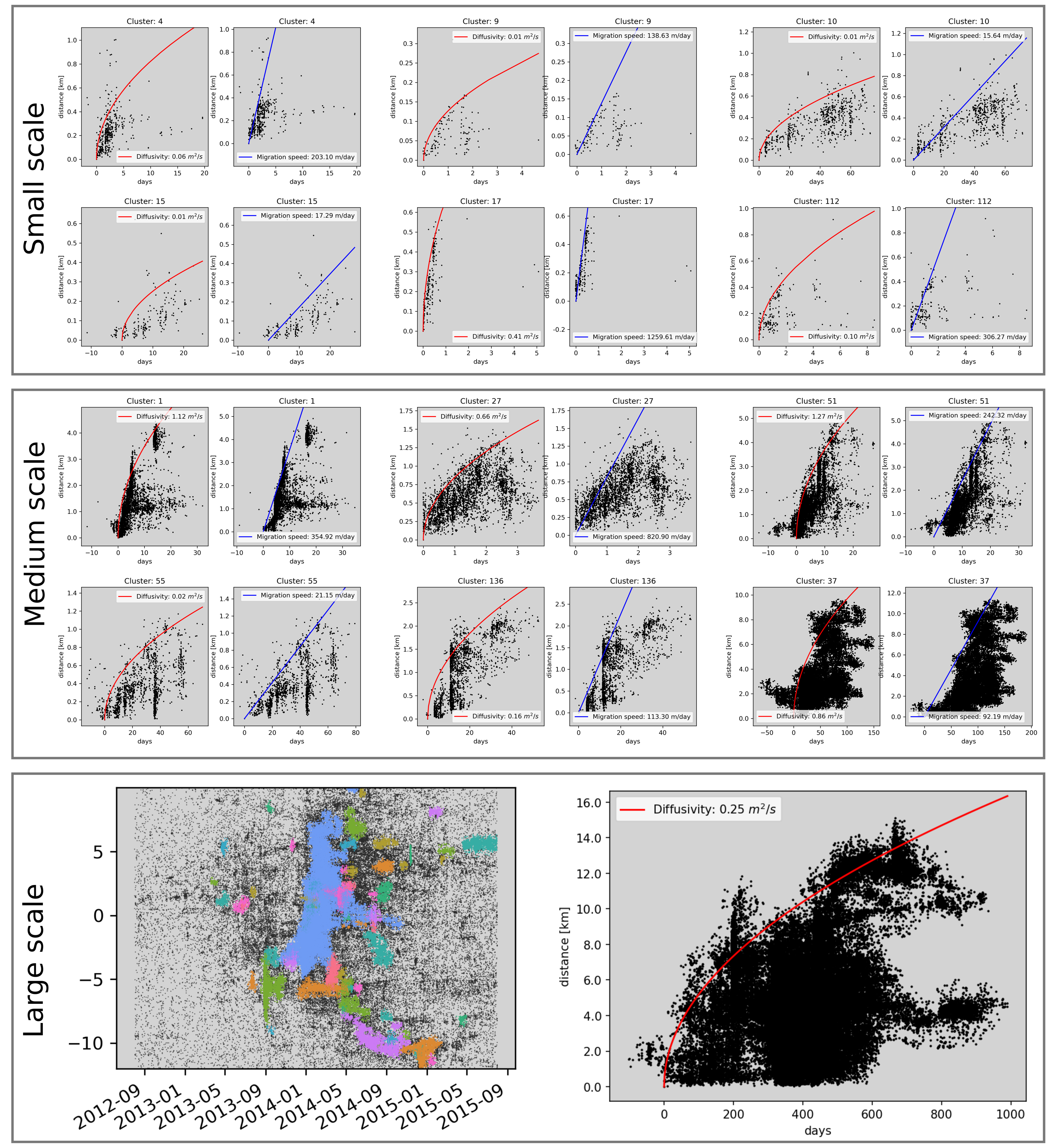


Figure 4. Examples of clusters fitted with diffusion-like and linear migration.
Small scale: small clusters lasting only a few days and extending for less than 1 km.
Medium scale: main sequences of the area, lasting weeks to months and including mainshocks with magnitudes 3<M<4.
Large scale: considering all the "Gubbio swarm" (Gualandi et al., 2017) as a single cluster, a migrating front is still visible.

5. Clusters characterization

Diffusivity vs magnitude

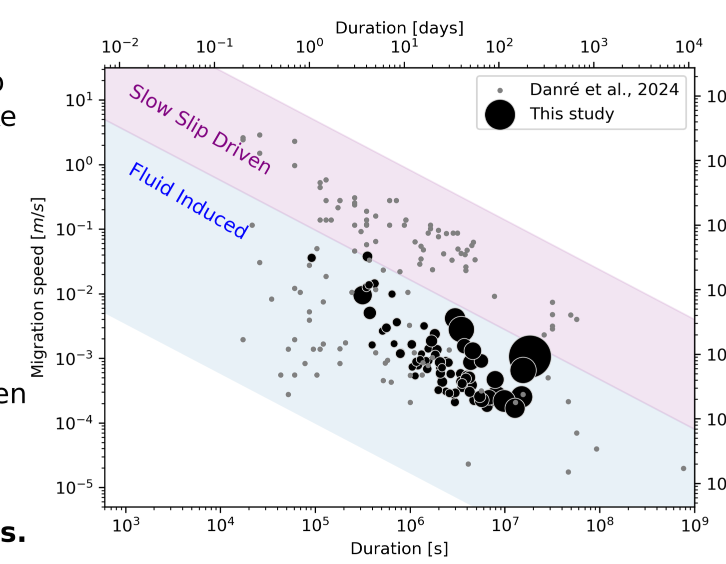
We integrate our diffusivity values (from 10^{-2} to 10^{1}) with those estimated for natural earthquake swarms from the literature (Fig. 5, below).

A trend appears to emerge between maximum magnitude and diffusivity (and coseismic permeability).

Migration speed vs duration and moment

Migration speeds are compared with the values from Danré et al. (2024), to discriminate between Fluid Induced and Slow Slip Driven swarms (Fig. 5, right).

Our values suggest fluid induced processes.



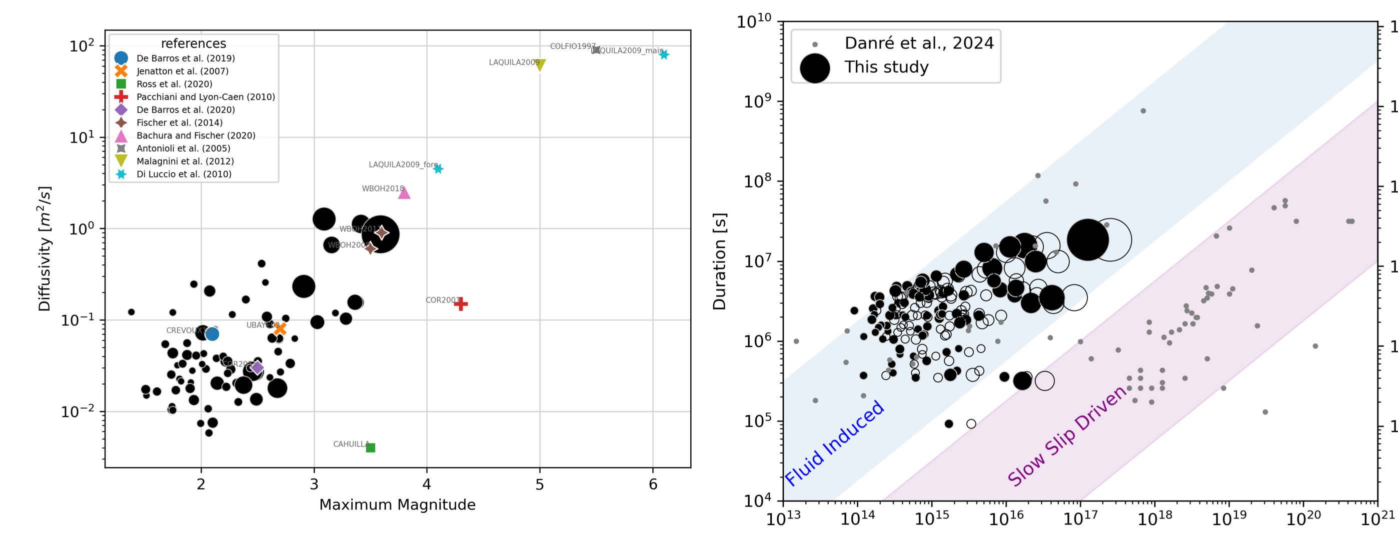
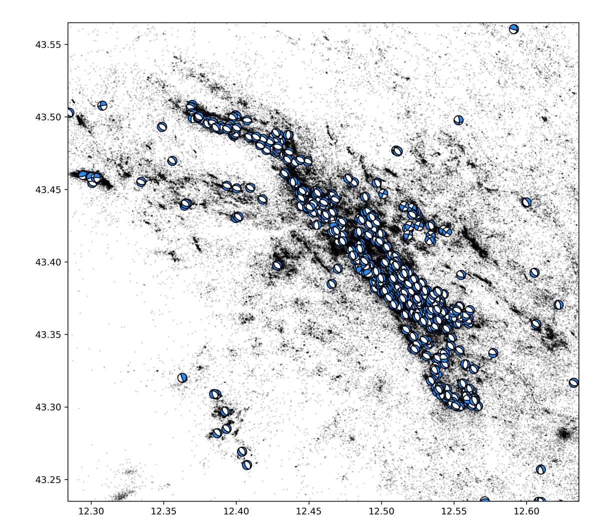
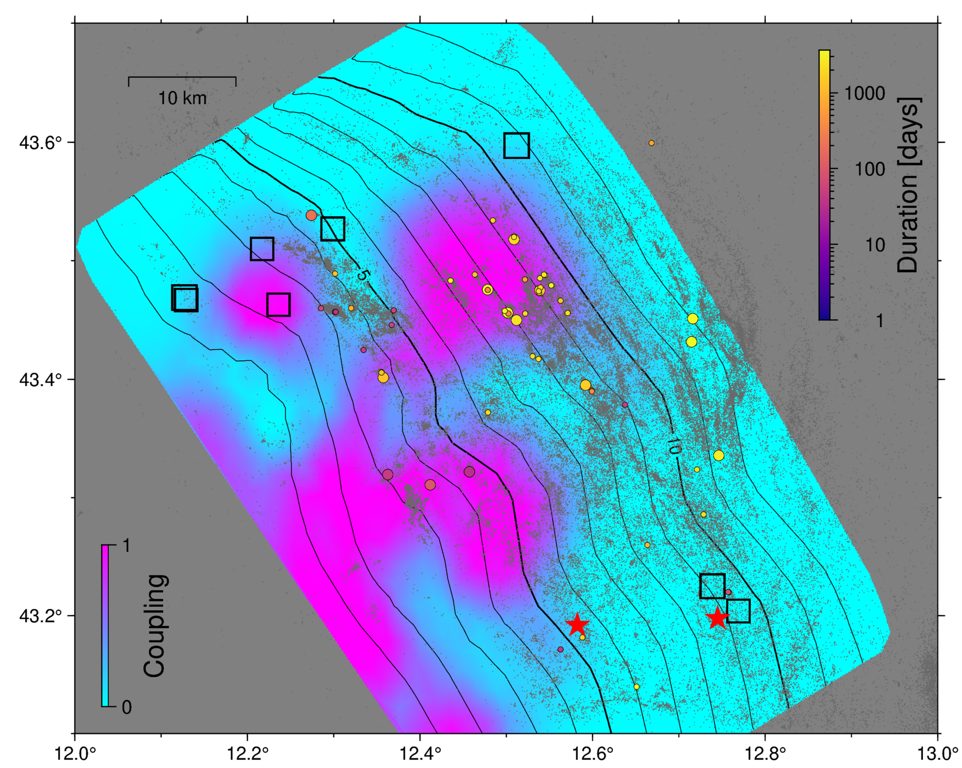


Figure 5. Statistical analysis of diffusivities and migration speeds.
In the duration versus moment plot, the seismic moment is represented by filled black circles, while empty circles indicate double the seismic moment, which accounts for equal parts of seismic and aseismic moment. This adjustment allows for better comparison with the total moment used in Danré et al. (2024).

Ongoing and Future Work

We are conducting analyses on repeating earthquakes on the Altotiberina Fault and improving our focal mechanisms and moment tensors solutions to better characterize the behaviour of the fault at depth.





Refereneces

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