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EGU26 GENERAL ASSEMBLY

Seismicity-Driven Insights into the Extensional Architecture of the Northern Apennines, Italy

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Scientific question

WHAT DO WE KNOW? Some Apennine sectors are well studied — usually those affected by major sequences (e.g. Amatrice–Visso–Norcia, L'Aquila). Others, tectonically active and equally populated, receive less attention

WHAT'S STILL HIDDEN? Routine catalogs often fail to capture much of the microseismicity that delineates active structures, particularly in areas with low station density or where faults lack surface expression

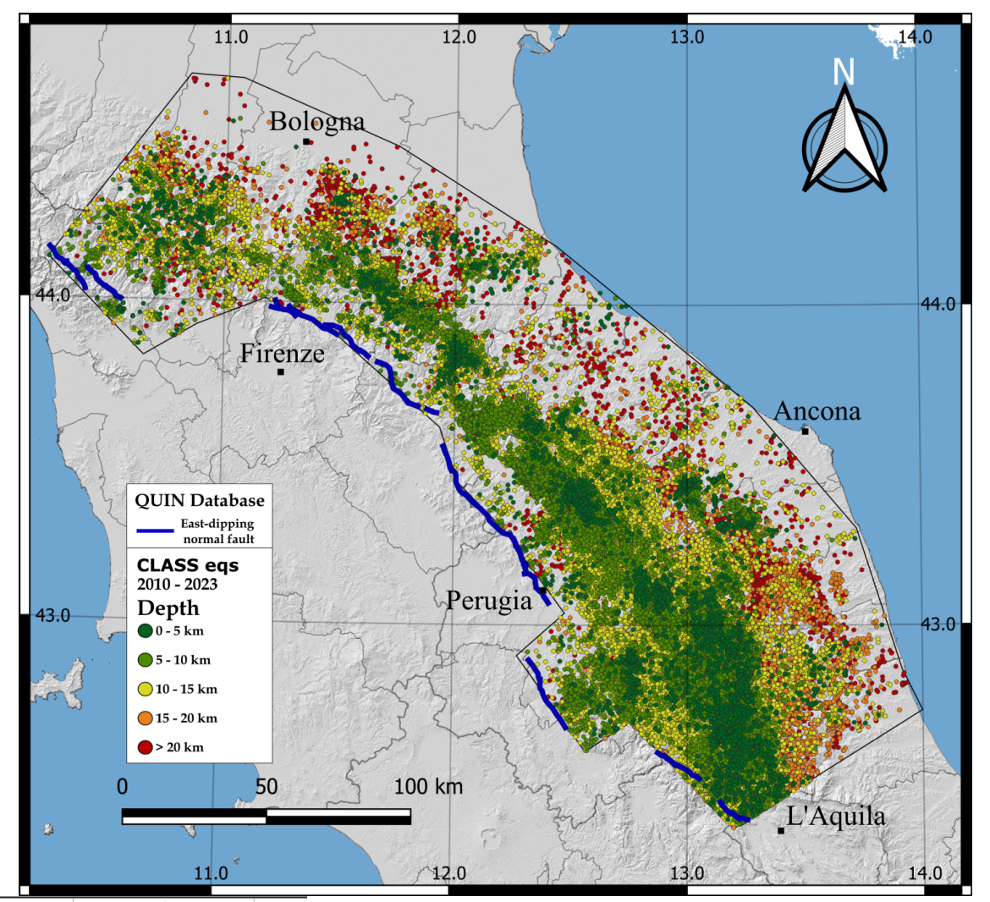
WHAT THIS WORK DOES Multi-scale and multi-disciplinary approach:
1) HDBSCAN + KDE to identify spatio-temporal clusters
2) Template Matching on selected clusters
3) Focal mechanisms + Stress inversion + PCA + Geodesy

METHODS

Dataset

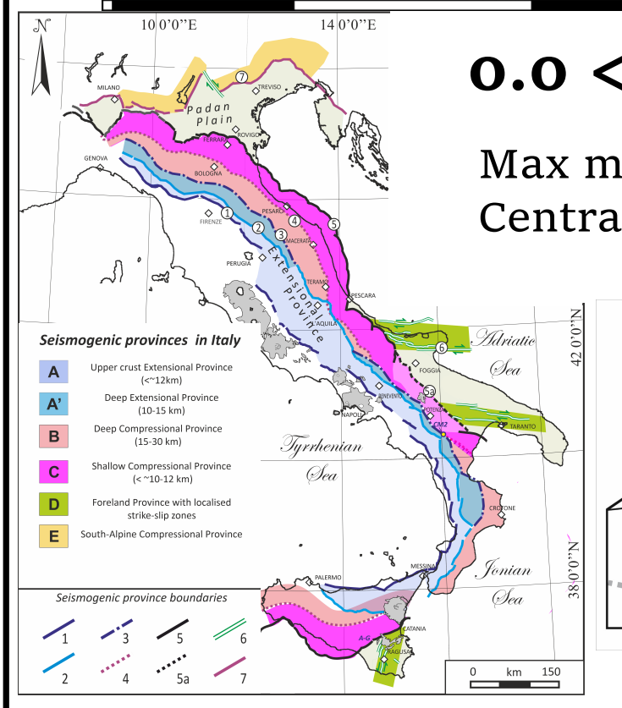
CLASS catalog
Latorre et al., 2023

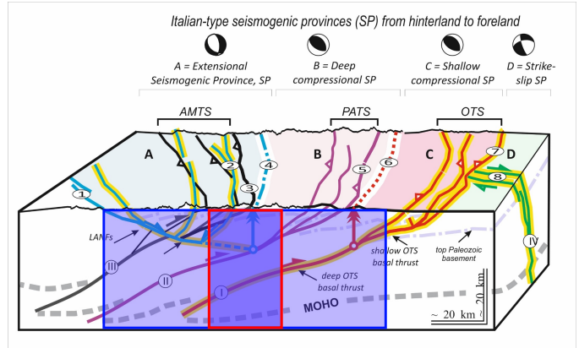
More than 230.000 events in the shown area of the Central-Northern Apennines in the 2010-2023 timespan



0.0 < Mag < 6.5

Max magnitude 2016 Central Italy earthquake



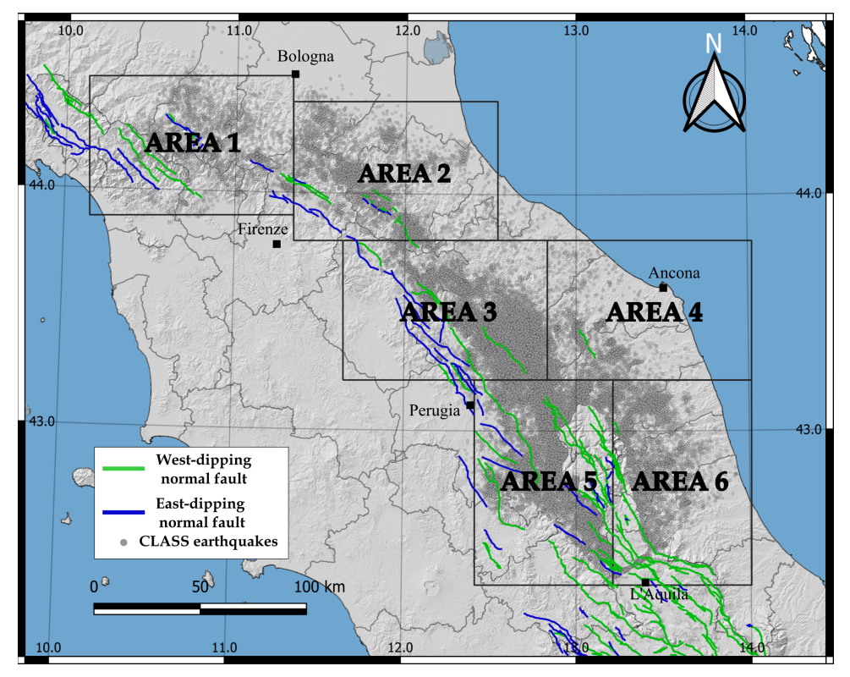


Lavecchia et al., 2021

Clustering

HDBSCAN
(Campello et al., 2013)

- Hierarchical Density Based clustering algorithm
- Single input parameter (Minimum Cluster Size)
- Best MCS found by Sensitive analysis
- Interevent time normalized with the three spatial dimensions for a direct spatio-temporal analysis

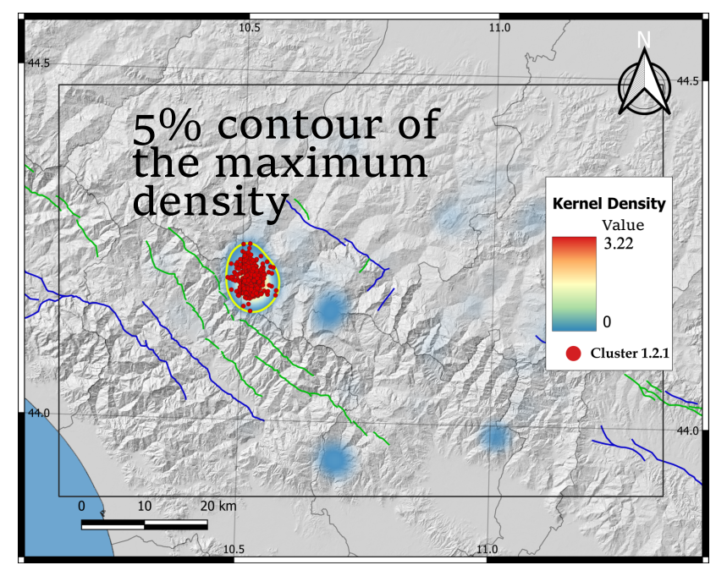


Applied on

6 EQUAL-AREA SUB-REGIONS

7 TWO-YEAR TIME WINDOWNS

3D KERNEL to refine clusters

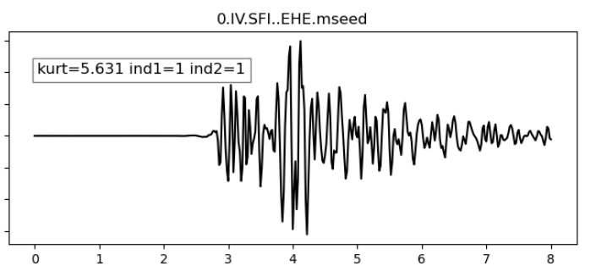


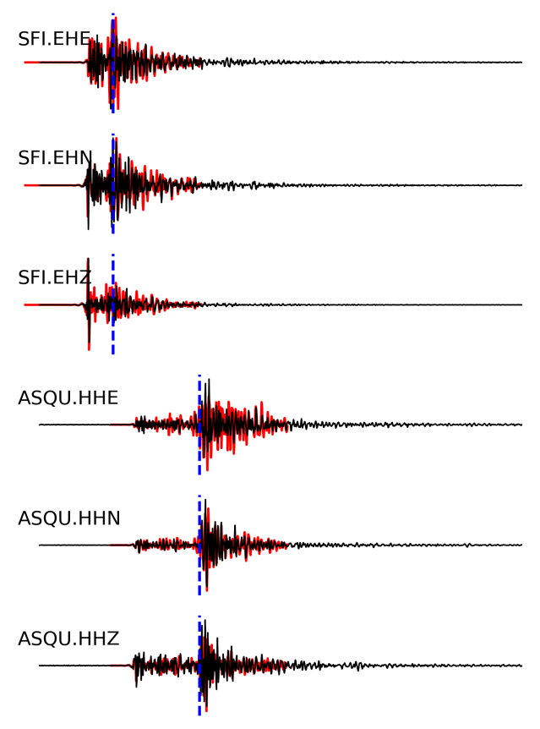
Processing

Template Matching
PyMPA Method
(Python Matching Phase Algorithm)
(Vuan et al., 2018)

Template Matching helps to find earthquakes which are not identified by standard detection techniques (hidden earthquakes), using waveforms of known earthquakes **(templates)**

Template
Ml 1.8





New event detected

Ml 0.5

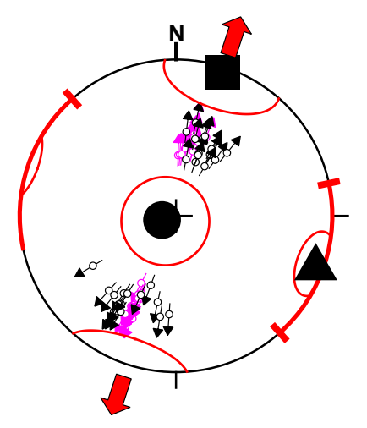
av. CC = 0.56

→ Use of Cross-Correlation functions
→ Analyze only the band frequencies of interest
→ Adaptive detection threshold based on MAD
→ Align and sum (stack) the CC functions across multiple stations
→ Magnitude estimation of detected events

Analysis

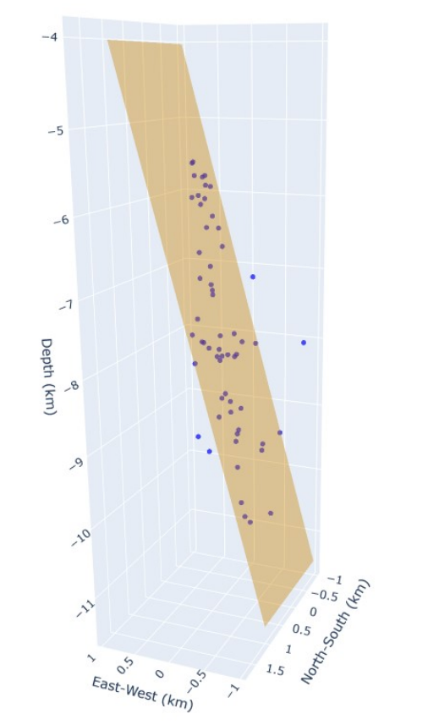
1) Focal Mechanisms

- Analyzed 33 focal mechanisms
17 newly computed in this study
16 from the TDMT catalog
(Scognamiglio et al., 2006)
- Mean focal mechanisms computed for each cluster



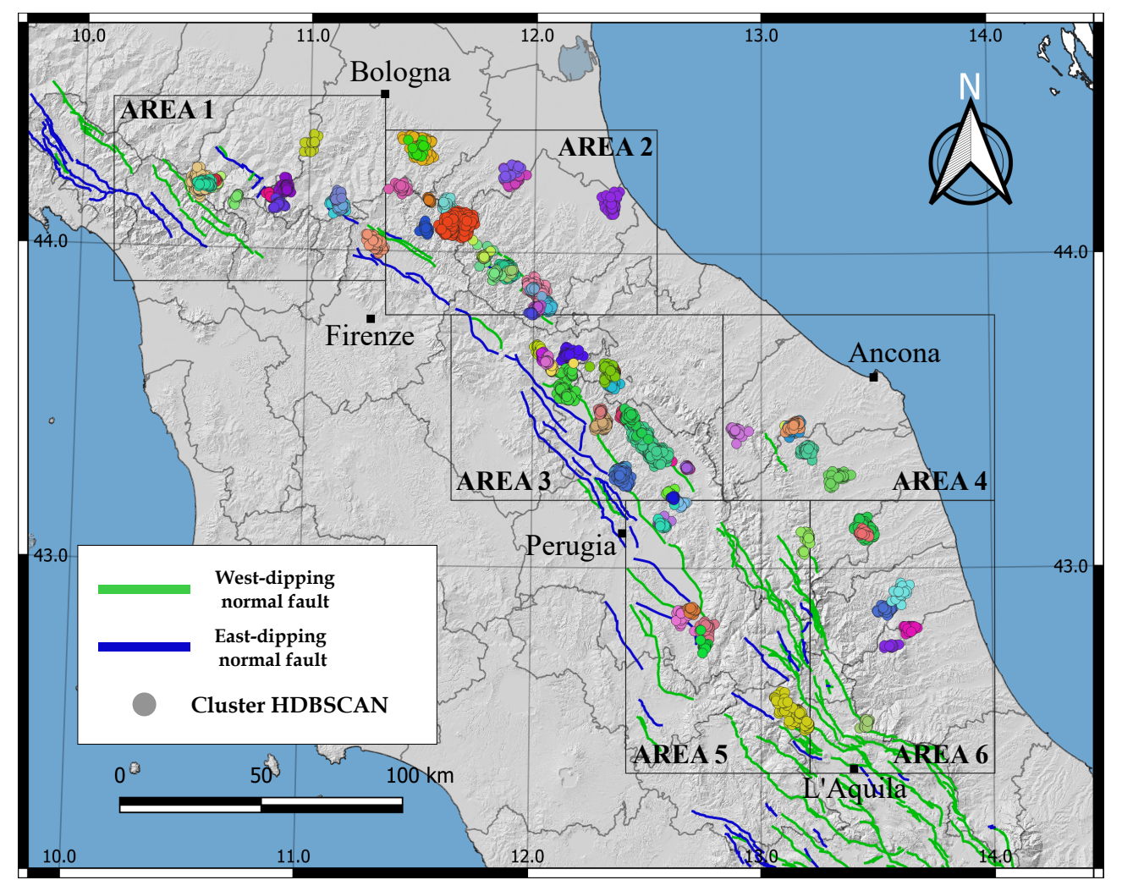
2) Stress inversion

3) Principal Component Analysis (PCA)



RESULTS

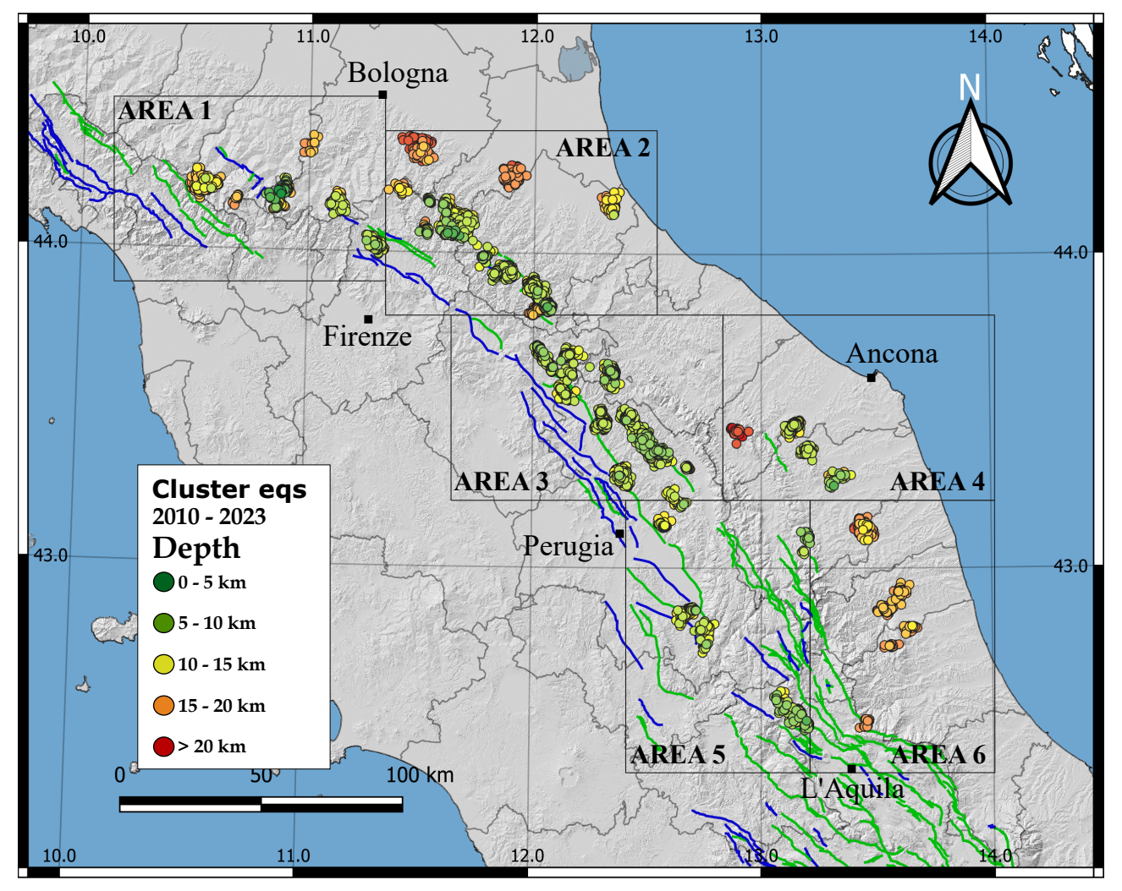
Clustering Results



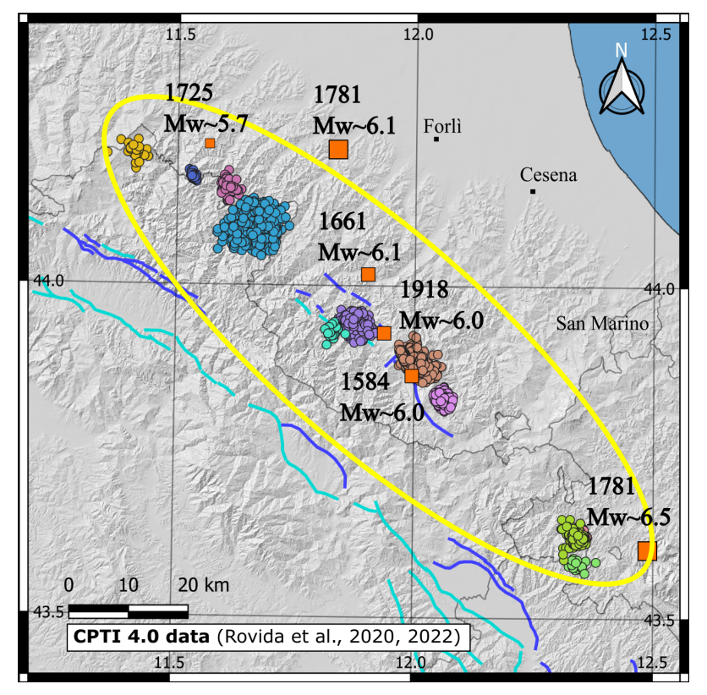
78 spatio-temporal clusters

41 SWARMS

37 SEQUENCES
30 with foreshocks
(Ogata & Katsura, 2012)

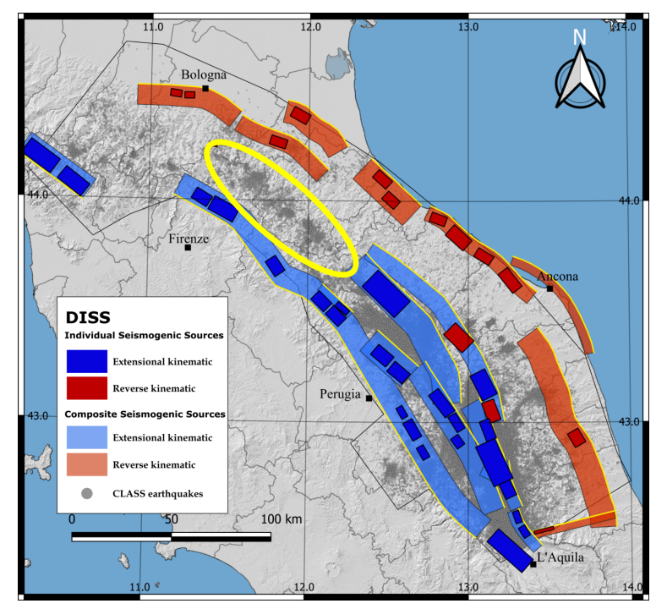


Identification of an area of interest in the Northern Apennines

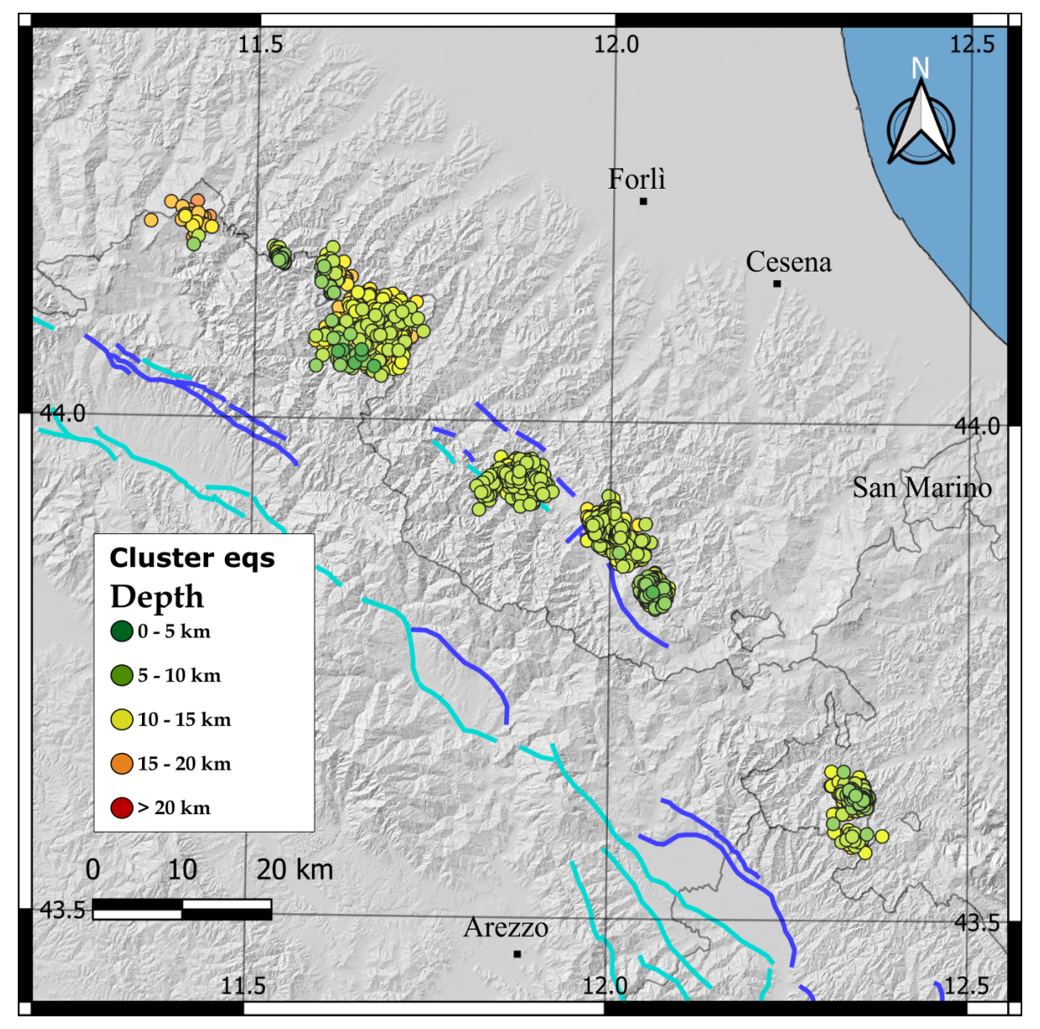


This area of the Northern Apennines shows **17** clusters and several historical damaging earthquakes, but lacks known active structures

The average hypocentral depths are shallow (all < 10 km except one), locating the seismicity within the upper crust

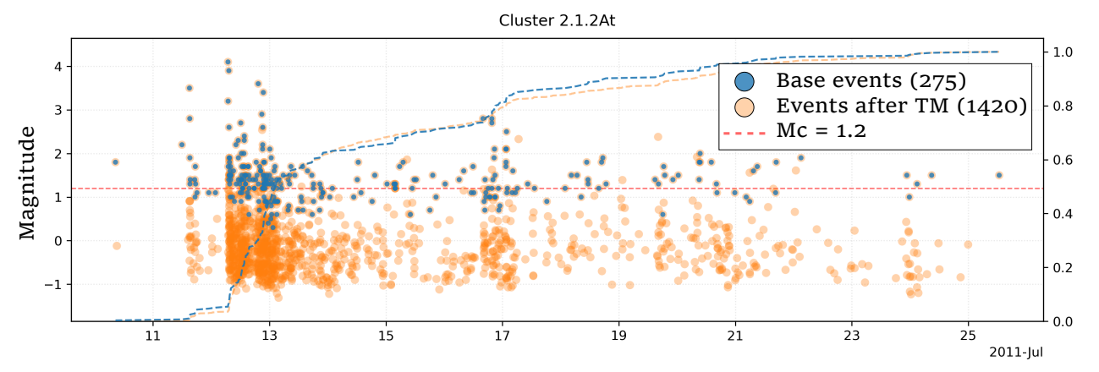


DISS working group, 2025



Template Matching Results

→ Applied to 12 clusters, each containing at least 15 events of high location quality
→ **Average 450% increase in the number of events**, with a maximum of 800%
→ Magnitudes of the new events (down to Ml -1.5) are often lower than the magnitude of completeness (Mc = 1.2) of the CLASS catalog for the area
→ Conservative detection: only events with an average value of CC > 0.5 have been retained



ID Cluster	Base events	Events after TM	Increase %	Events/ day	Max Mag
2.1.2At	275	1420	**416**	94	4.1
2.1.3	1172	4897	**318**	135	3.9
2.2.1e2	217	1636	**654**	264	4
2.3.3A	38	340	**795**	113	3.7
2.5.2	64	488	**663**	55	3.5
2.6.1	152	749	**393**	158	2.7
2.7.2	78	369	**373**	133	2.3
2.7.3	482	1523	**216**	86	4.8
3.3.1B.At	43	179	**316**	17	3.4
3.3.1B.Bt	65	403	**520**	139	1.6
3.3.1B.Ct	247	864	**250**	61	3.7
Average	258	1170	**447**	114	

Analysis of the enhanced catalogs

5 SWARMS

4 show diffusivity pattern

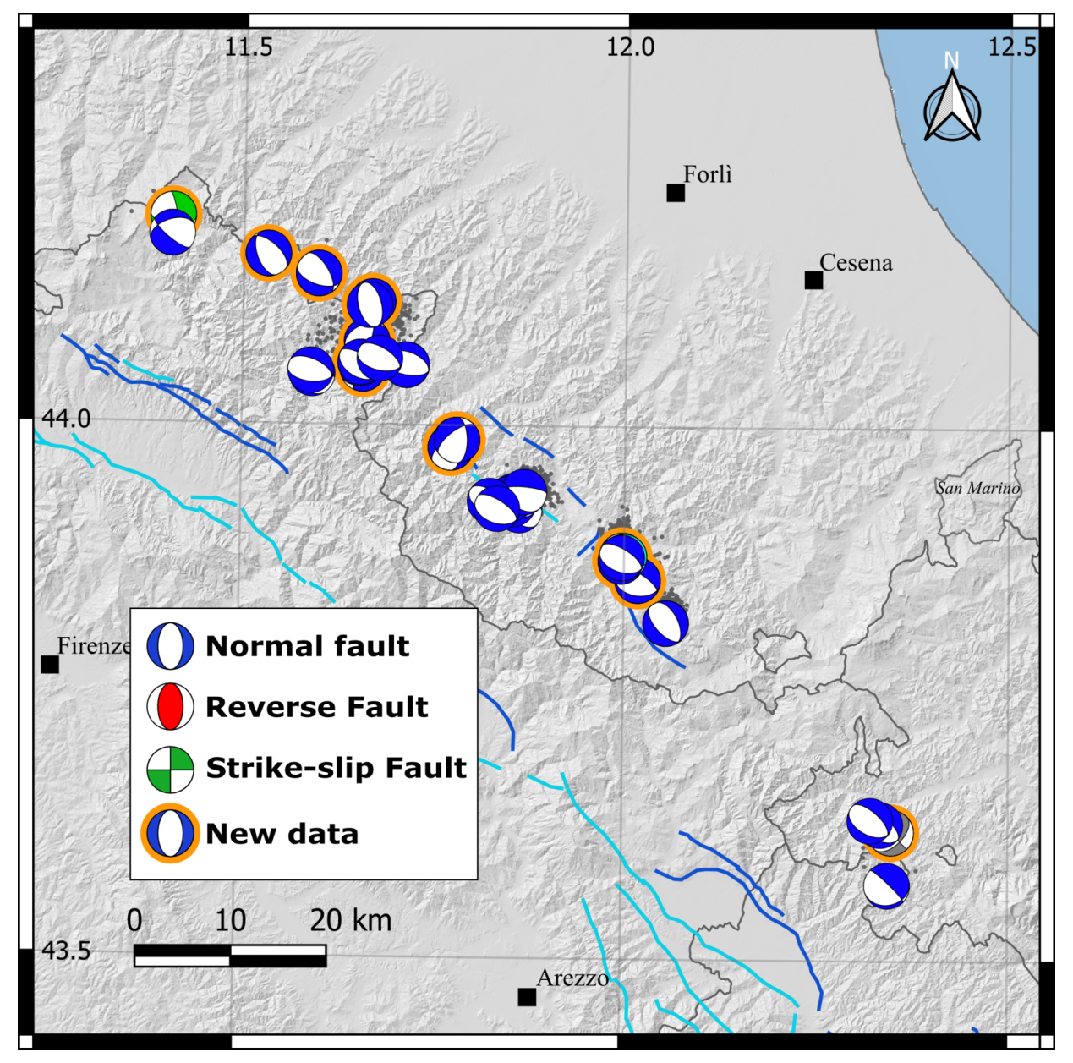
7 SEQUENCES
5 with foreshocks

2 show diffusivity pattern

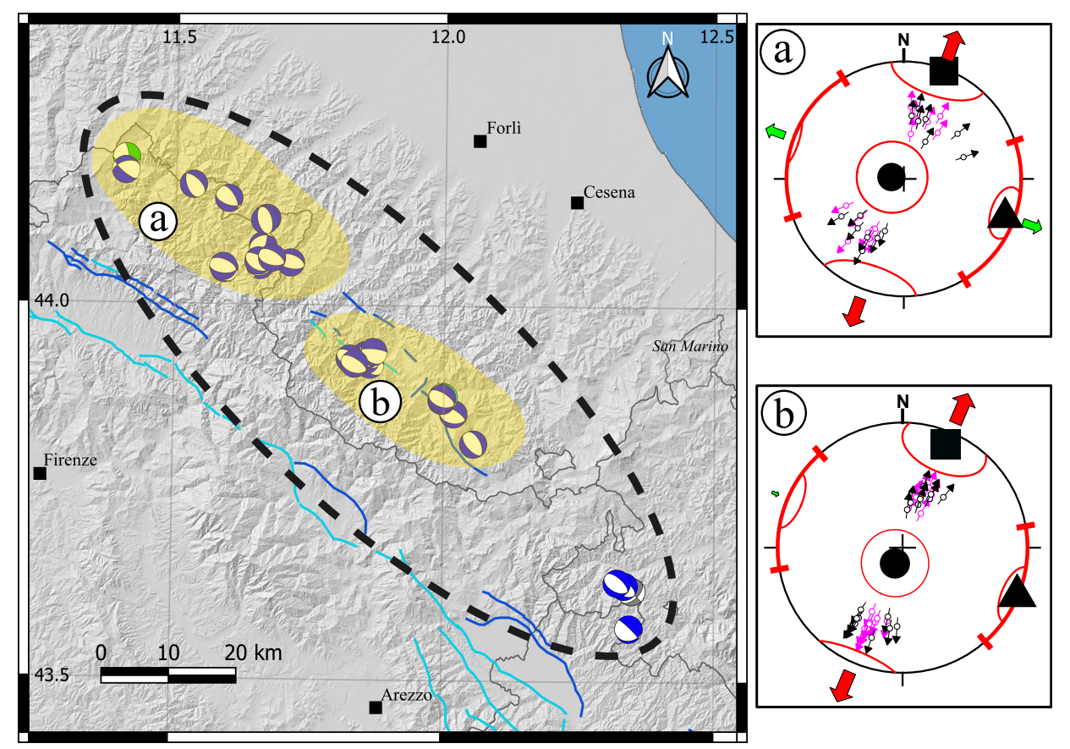
Diffusivity = probably caused by pressurized fluids
(Shapiro et al., 2002)

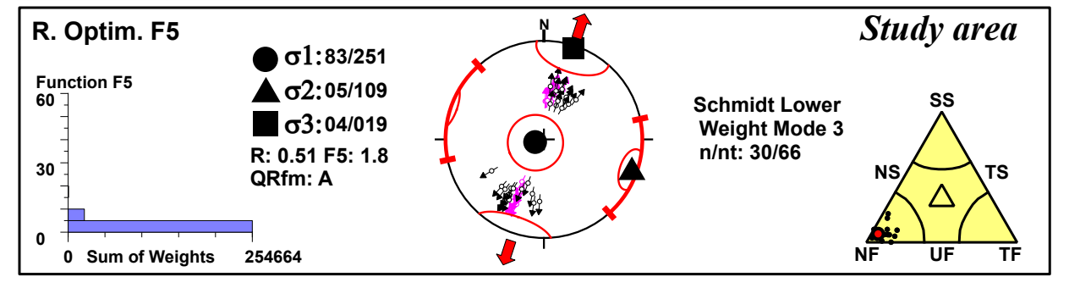
Analysis Results

Focal Mechanisms



Stress inversion: All events, a, b

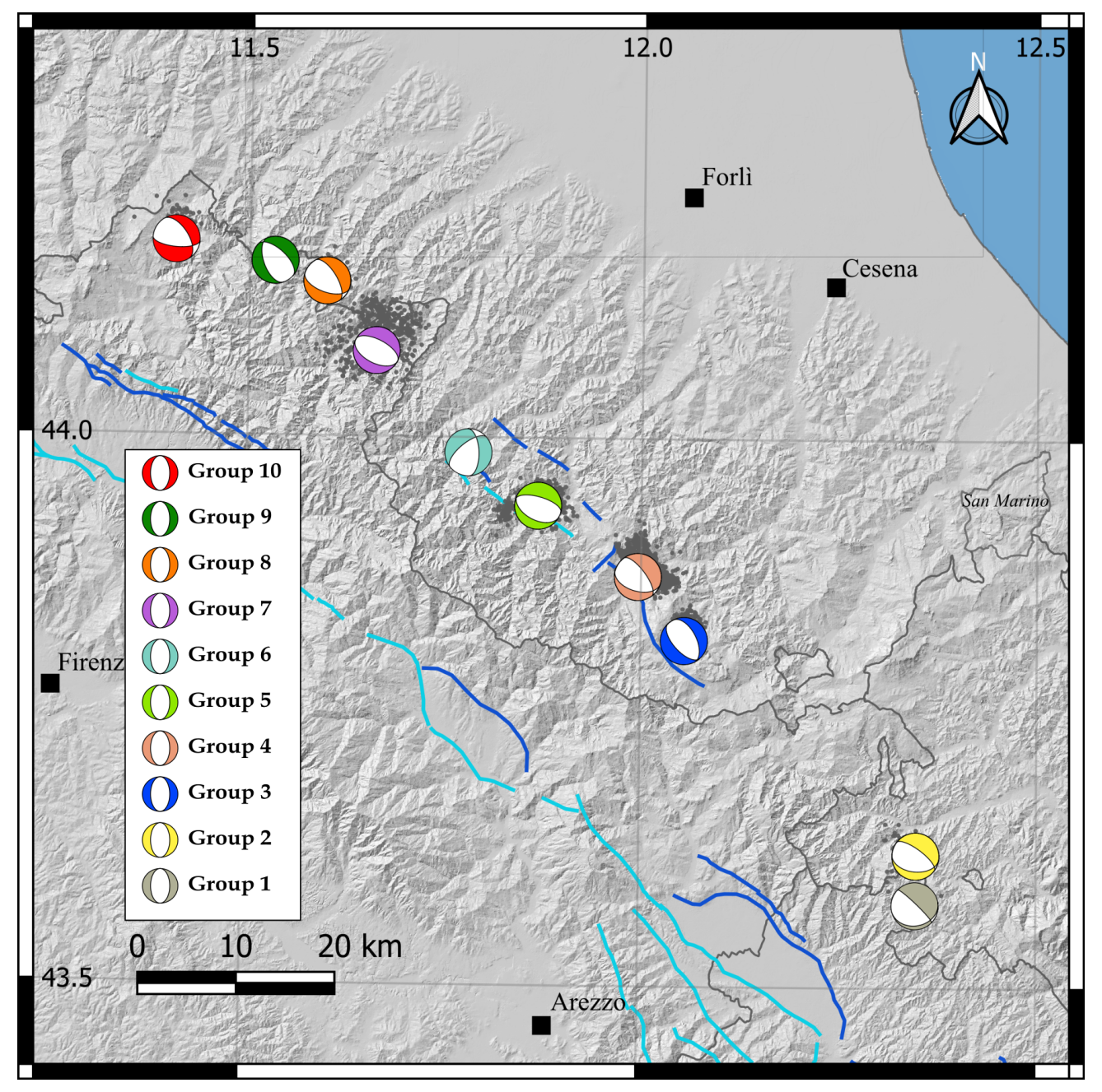




	ALL	a	b
Stress Ratio (R)	0.51	0.17	0.73

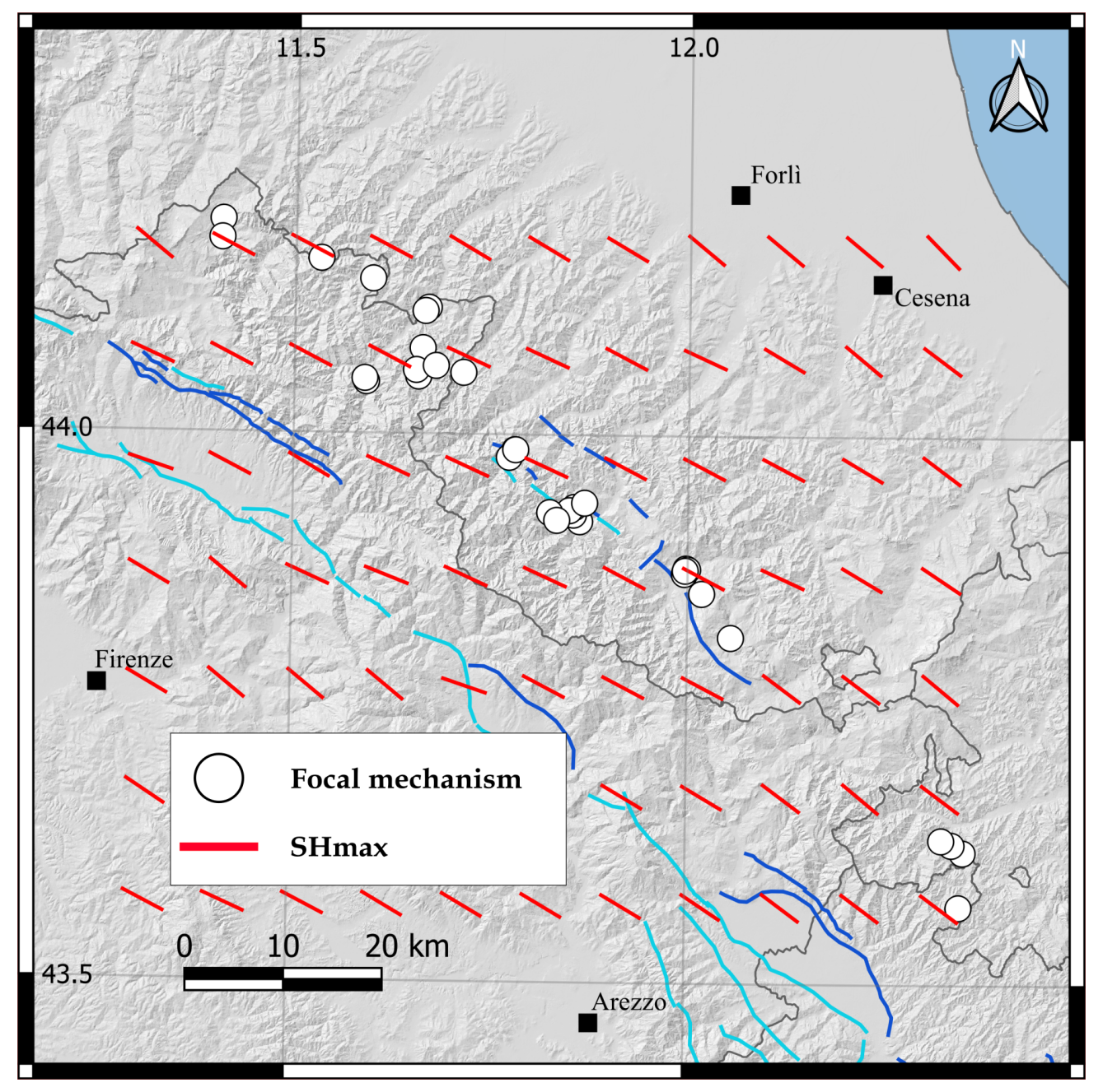
COMPARISONS

Kinematic Analysis



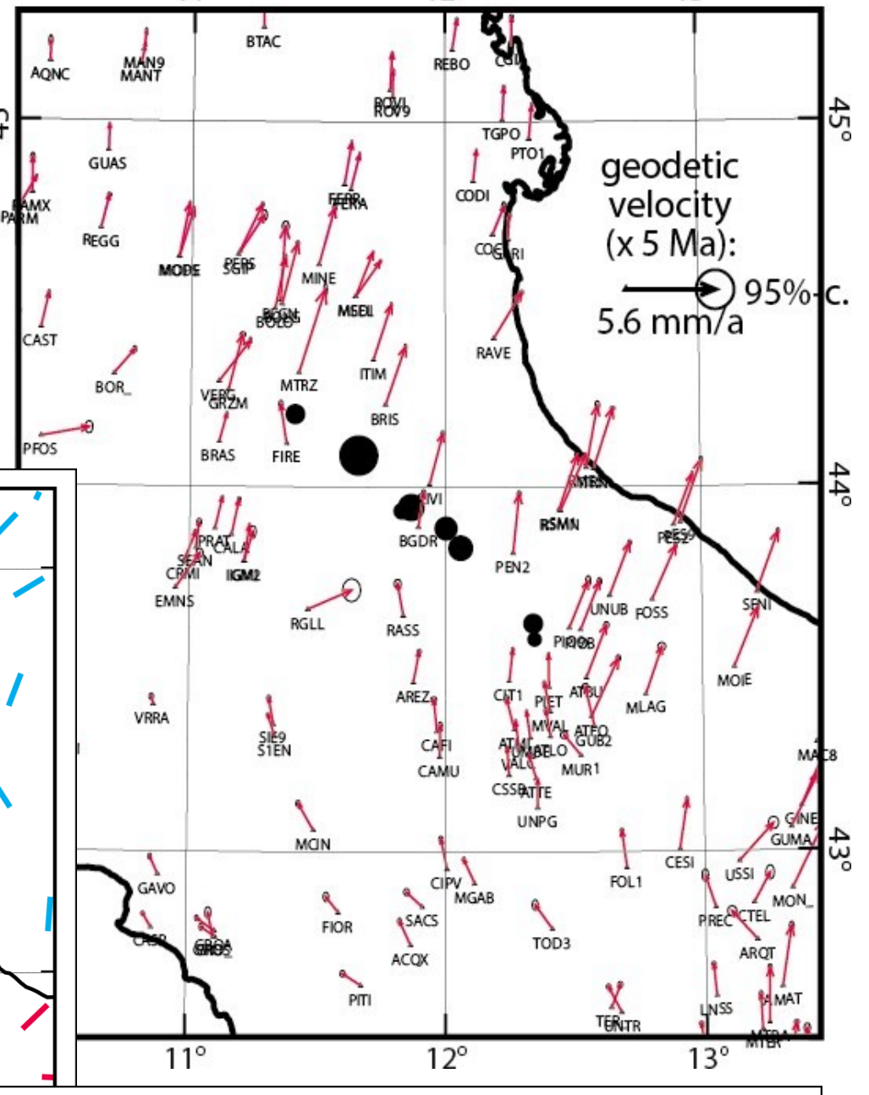
Mean focal mechanisms indicate primarily normal faulting with NW-SE trend.
The only exception is Group 6, which shows an anti-Apenninic trend, where QUIN faults terminate

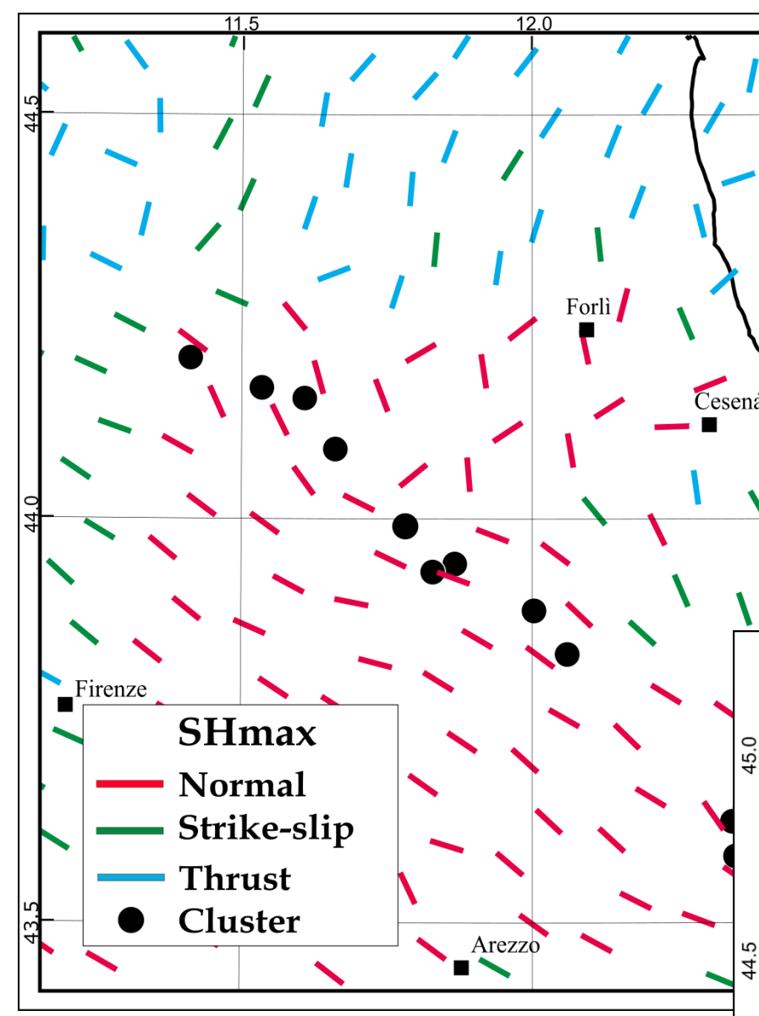
The SHmax spatial map, derived from focal mechanisms, shows a consistent pattern



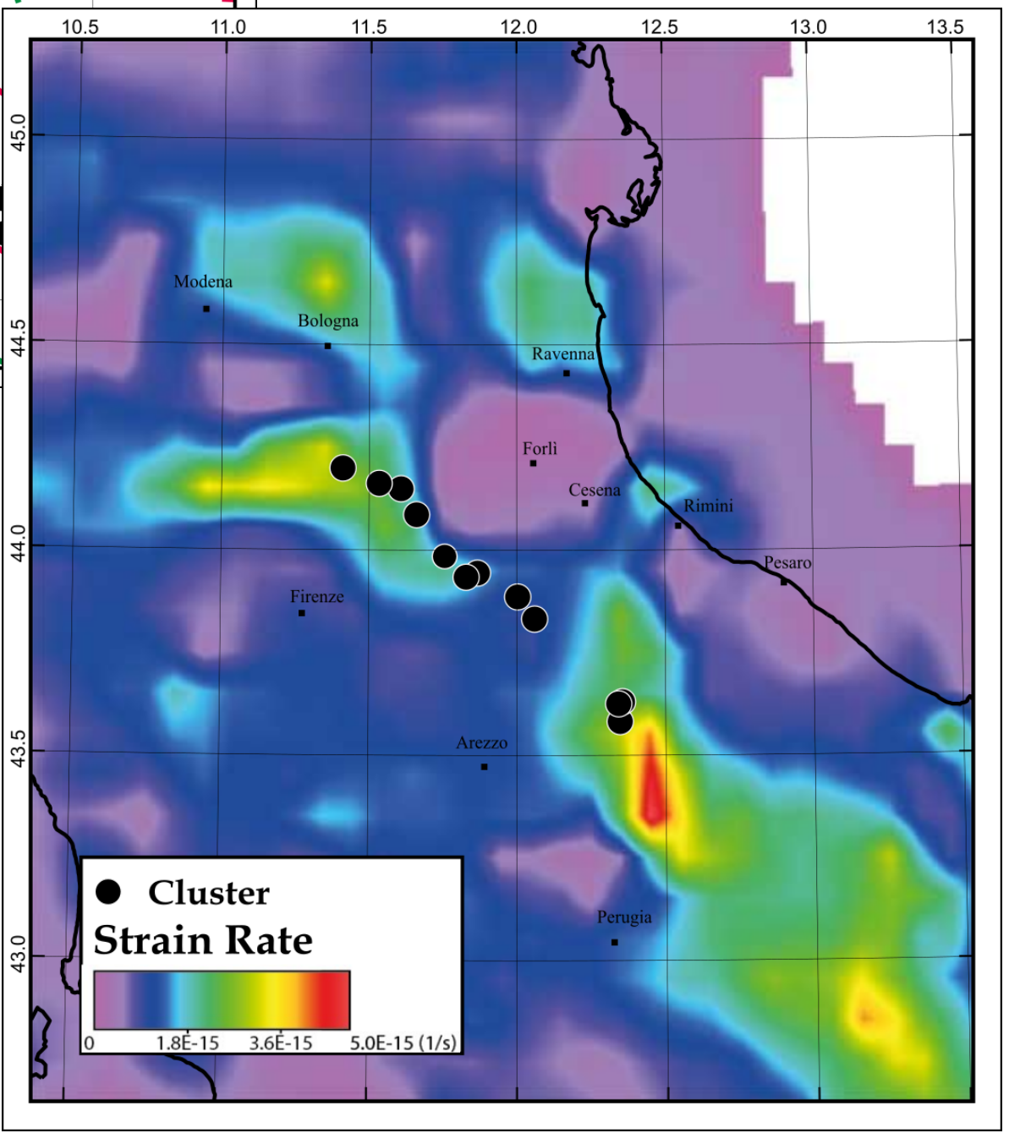
Geodetic Analysis

The clusters are located within the extensional domain, but in its easternmost part. SHmax trends NW-SE, with a variation NE-SW west of Cesena



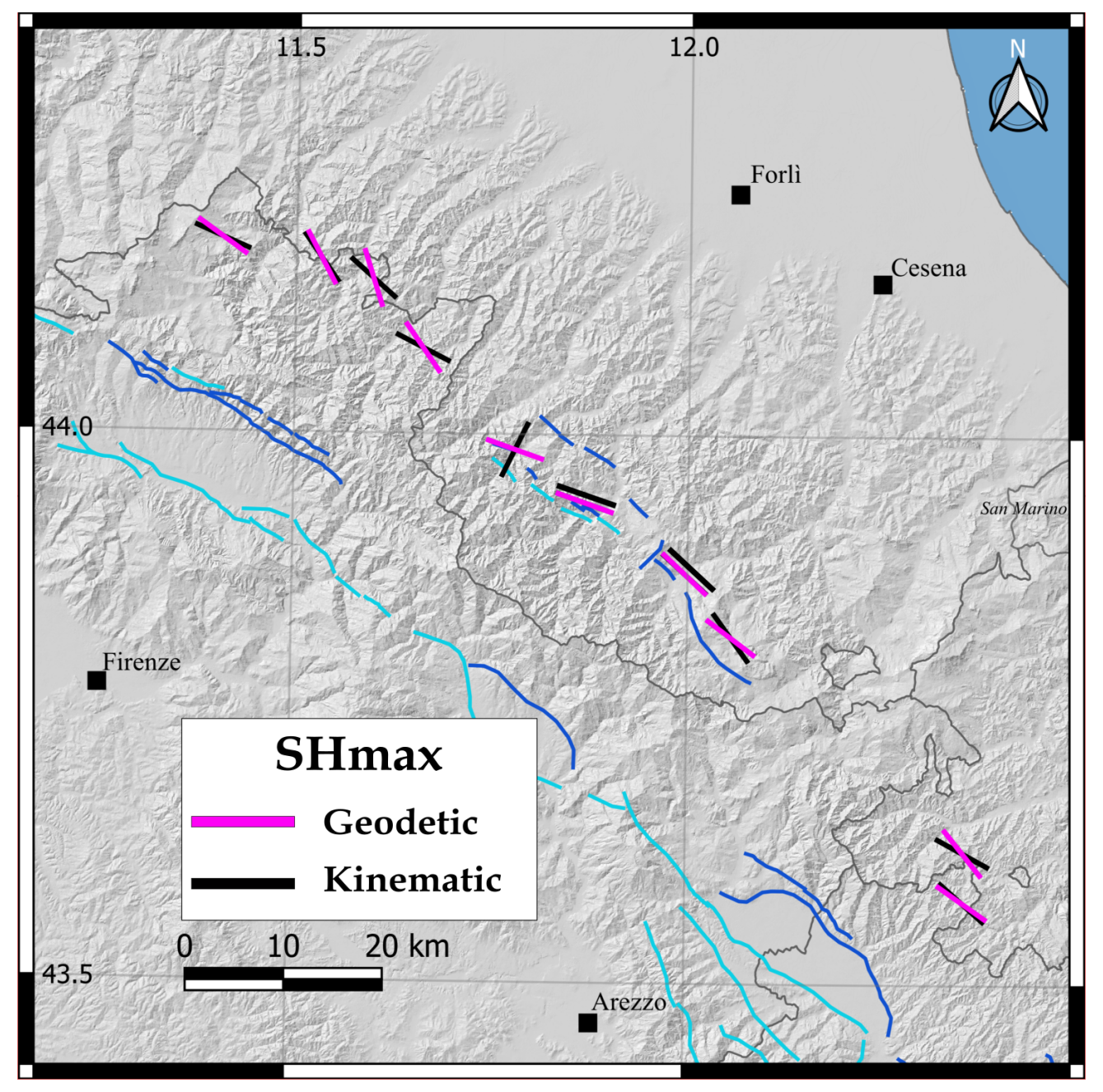


The Strain Rate map shows that clusters coincide with maximum values in the Apennine area. However, some are located in a local minimum, potentially representing a locked area



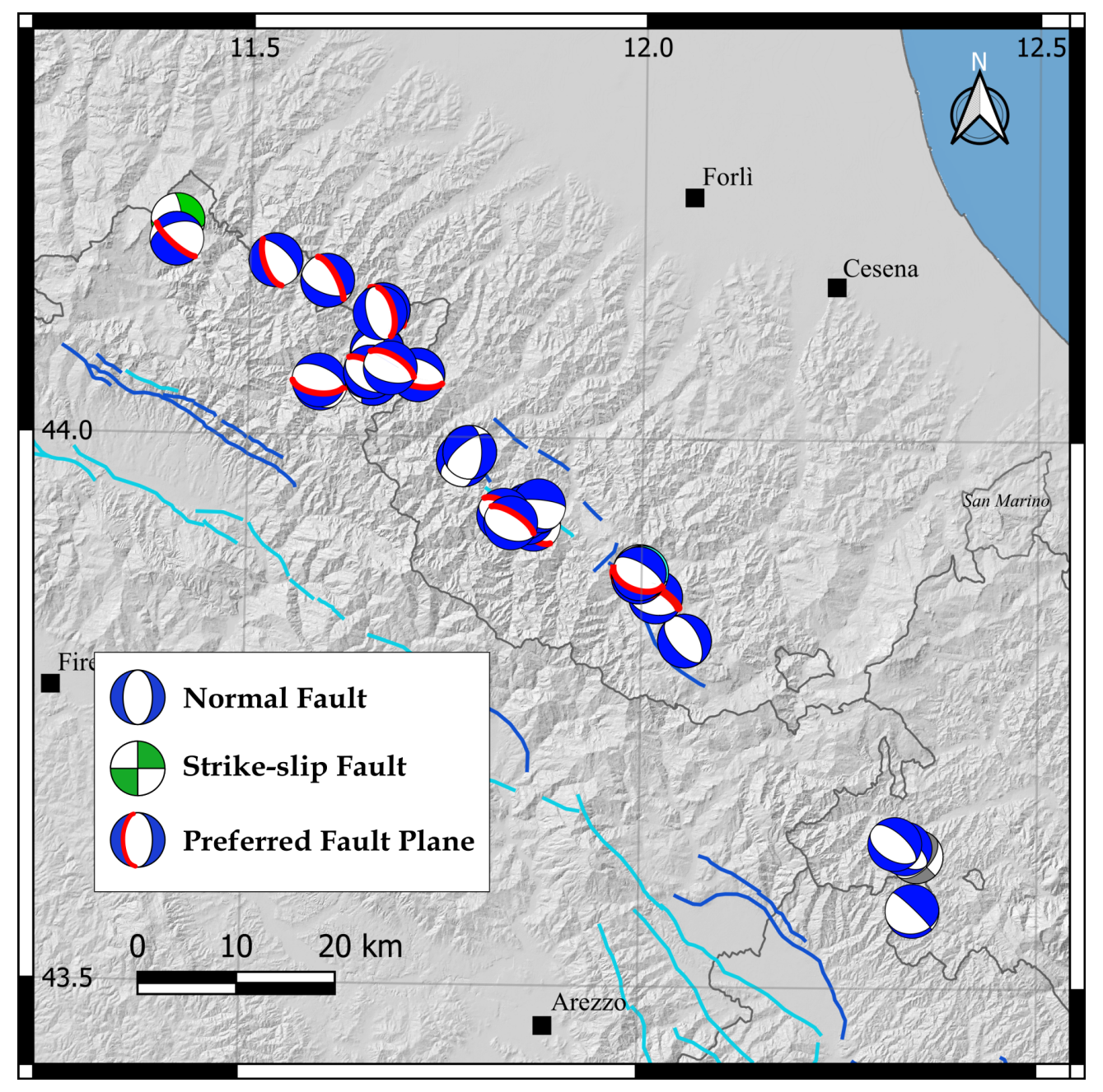
Bird & Carafa, 2016

Kinematic vs Geodetic

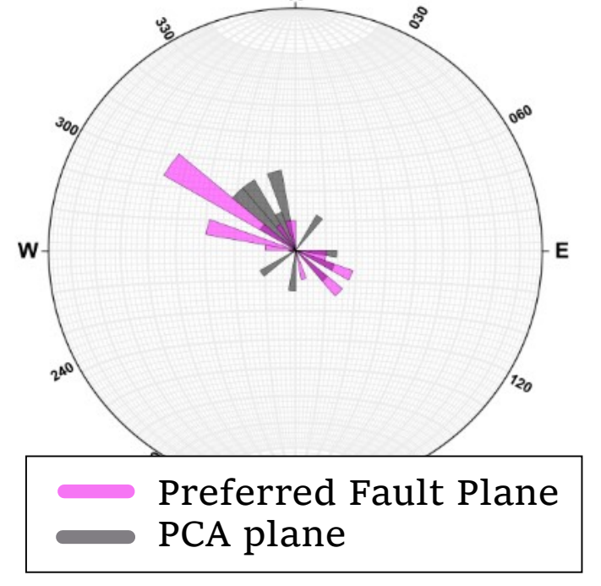


Kinematic and geodetic SHmax, calculated at clusters centroids, are very similar. The only discrepancy is in Group 6, where the geodetic data does not capture the anti-Apenninic rotation, which is visible on the spatial map

Kinematic vs PCA



Preferred Fault Planes and PCA planes show NW-SE trends, dipping both NE and SW. This is a common feature in the Apennines



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