

Fault system anatomy and preparatory phase of the 2009 Mw6.1 L'Aquila earthquake imaged by 64k high-precision foreshock and aftershock locations

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Outline: the M_w 6.1 2009 L'Aquila seismic sequence

Basing on about **64k high-precision foreshocks and aftershocks locations**, we will describe:

- ✧ The **foreshocks and aftershocks seismicity pattern** of the 2009 M_w 6.1 L'Aquila earthquake.
- ✧ The **geometry and mechanics** of the fault system.

While we investigate...

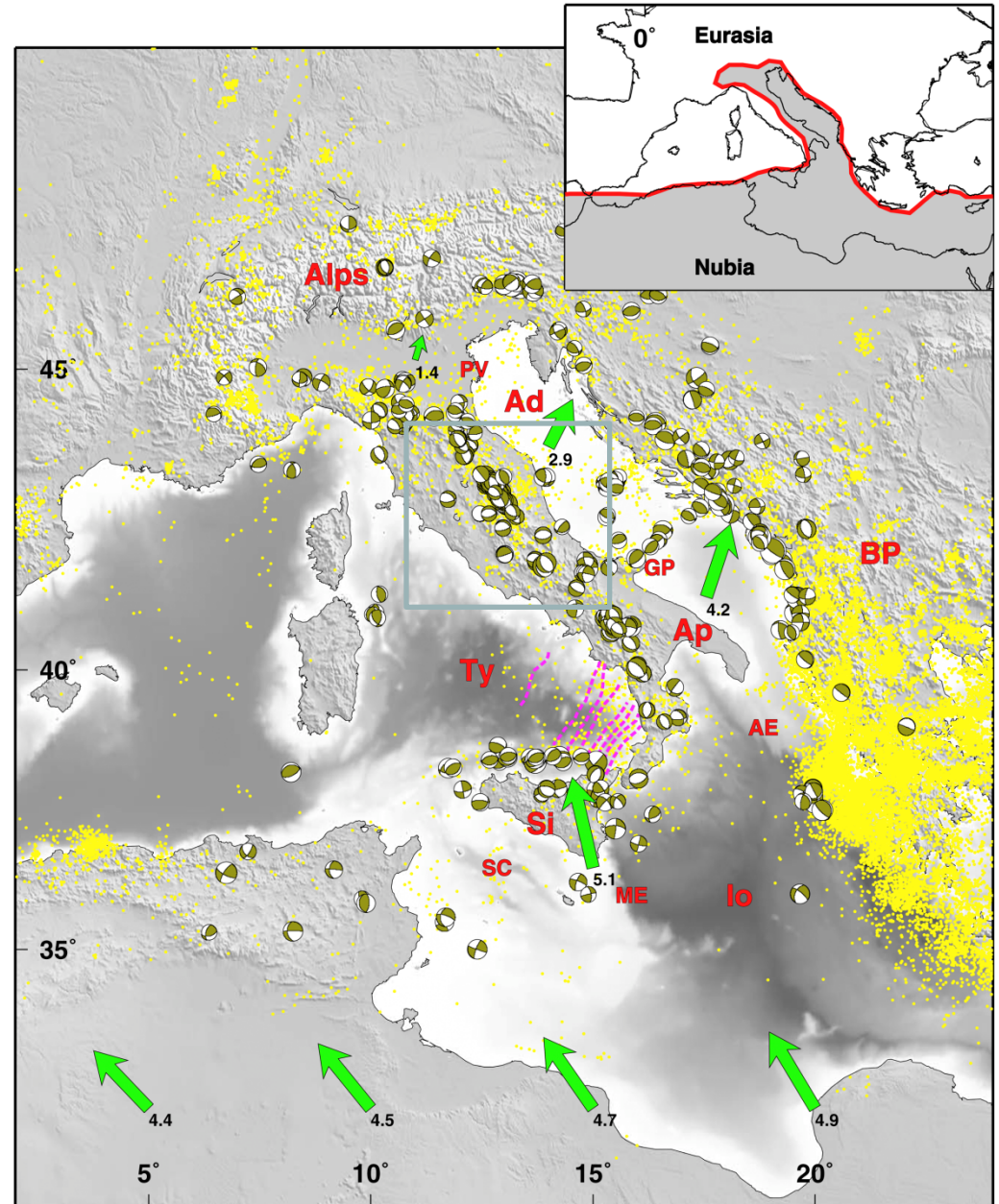
- The role of **fluid diffusion** processes in controlling the seismicity pattern.
- How normal faults may terminate at depth.
- The Fault Zone Internal structure.
- Mainshock preparatory processes.

Seismotectonic settings of the region

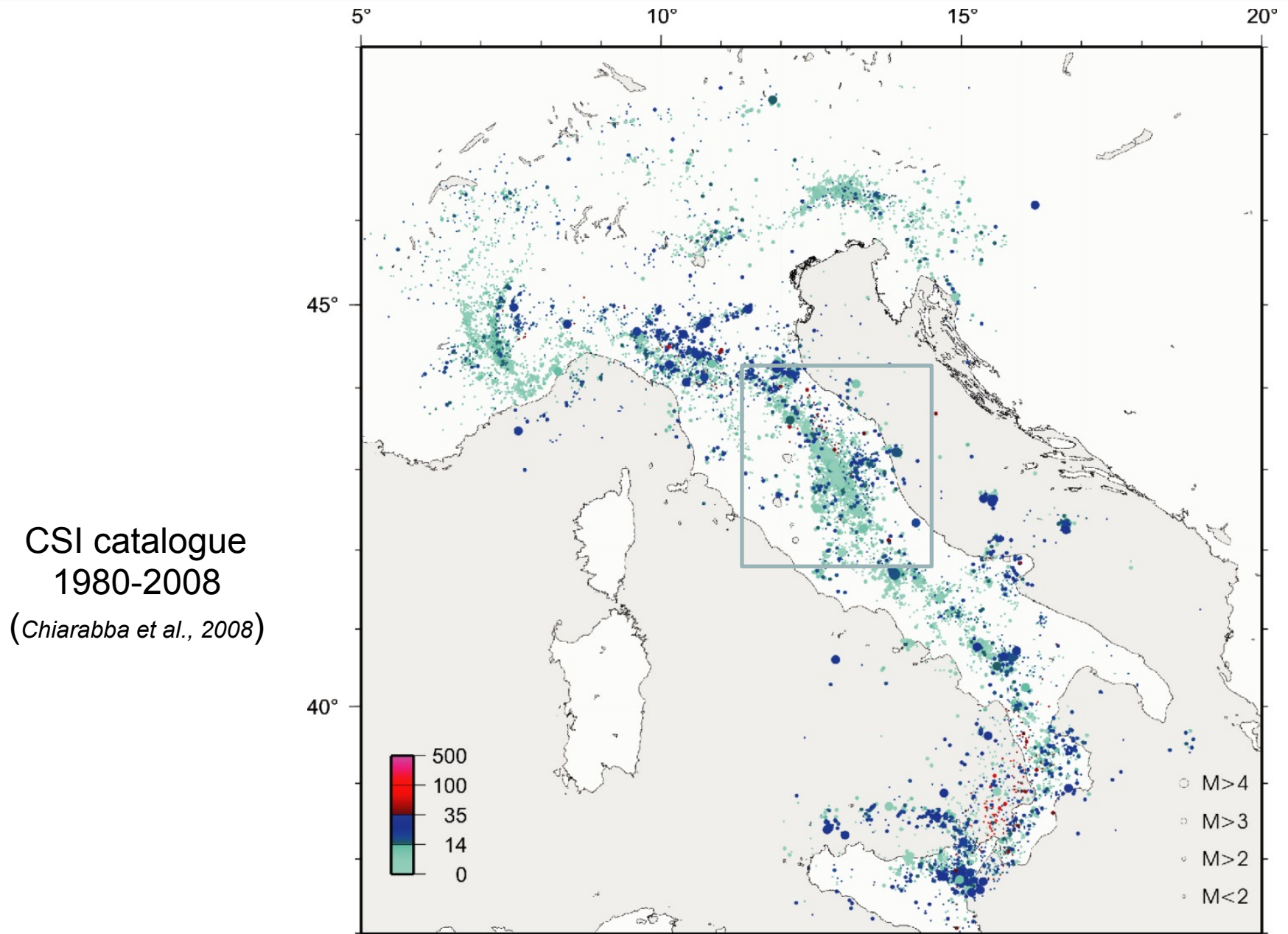
Velocities in mm/a relative
to Eurasia from the GPS
(D'Agostino et al., 2008)

M>3.5 eqks 1973-2006
(INGV - N.E.C.)

Regional Centroid
Moment Tensor
(Pondrelli et al. 2006)

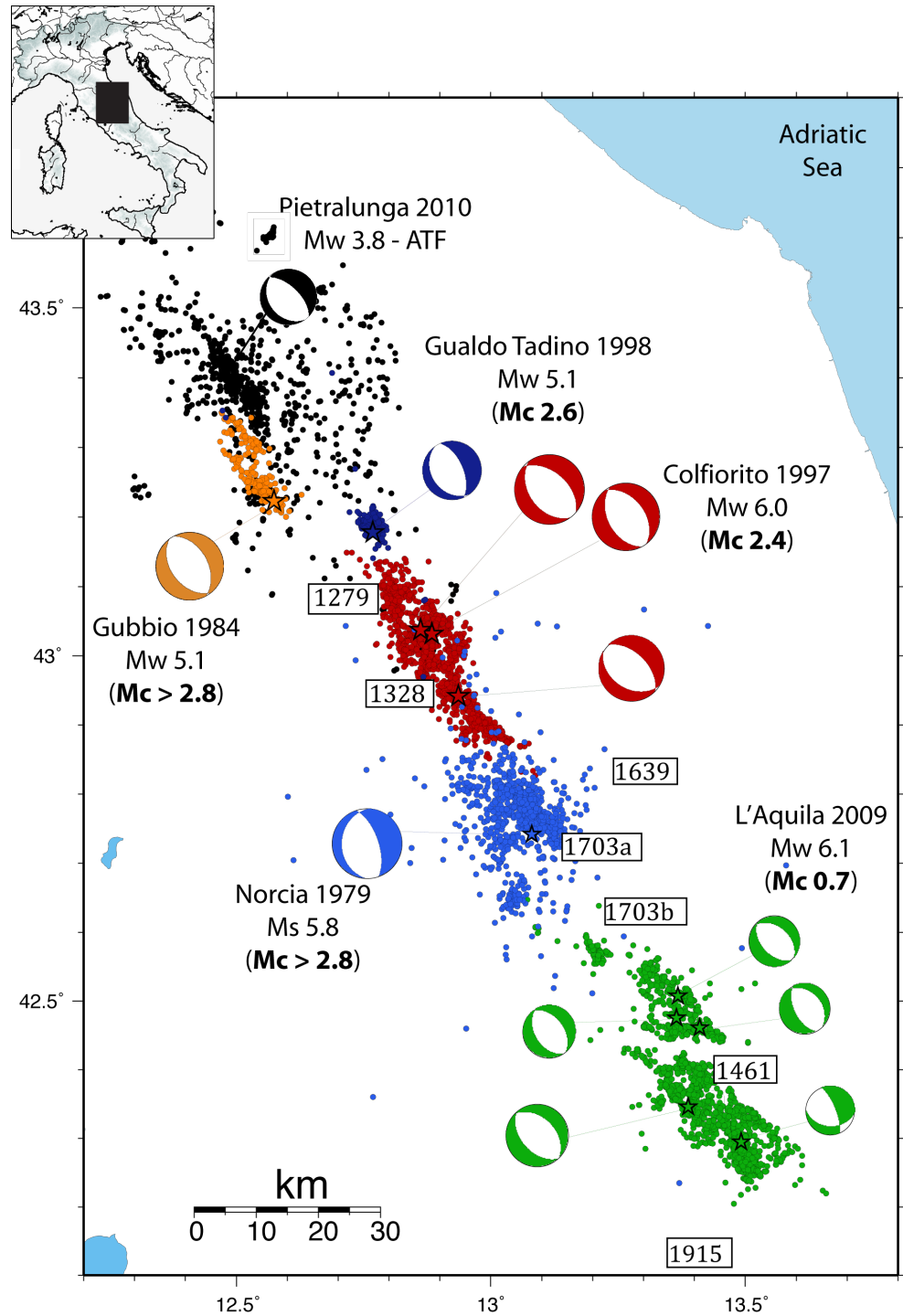


Background seismicity

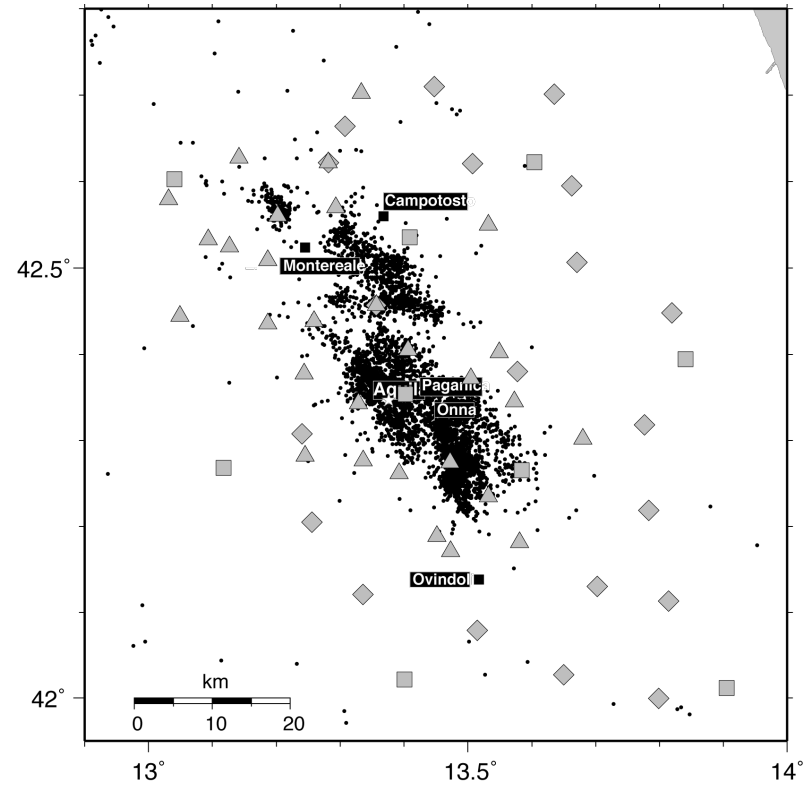
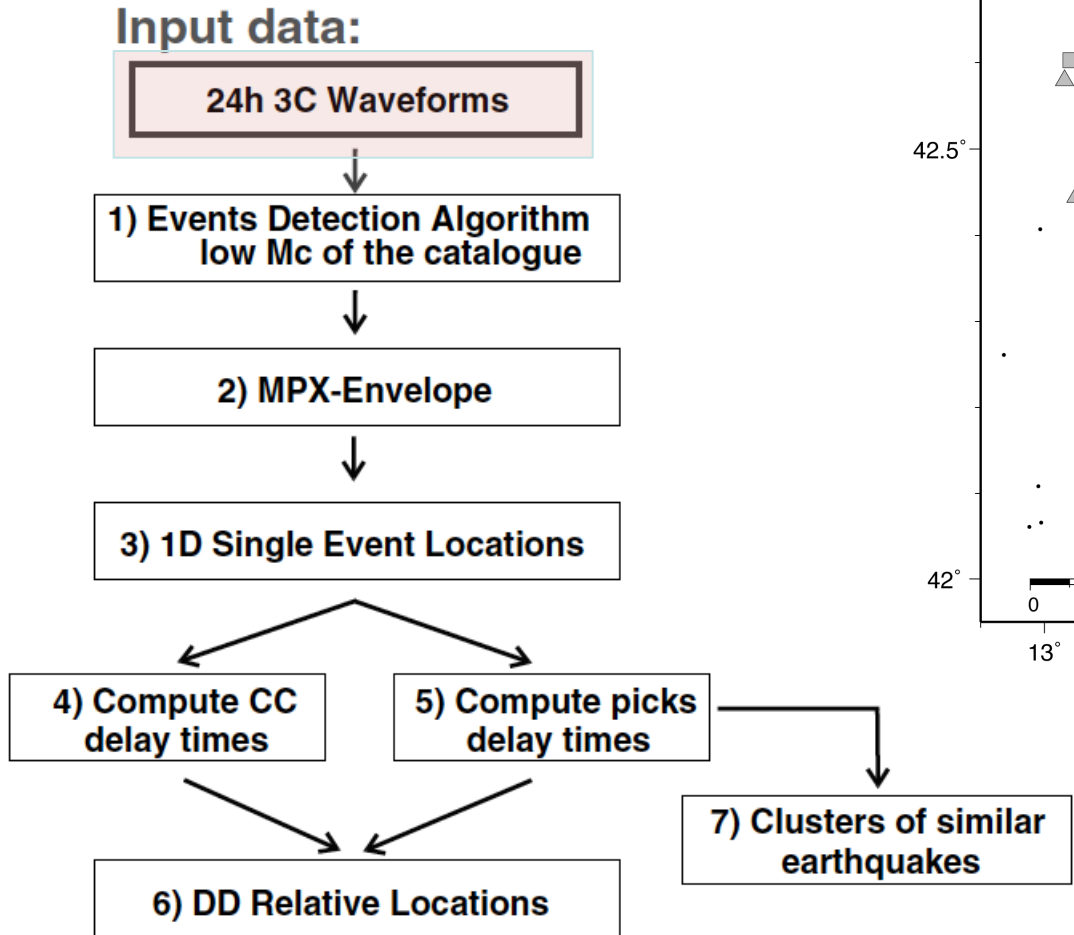


seismic sequences

Catalogue of the most recent seismic sequences
1979-2009
(*Chiaraluce, 2012 - JSG*)



work flow



work flow

Input data:

24h 3C Waveforms

1) Events Detection Algorithm
low Mc of the catalogue

2) MPX-Envelope

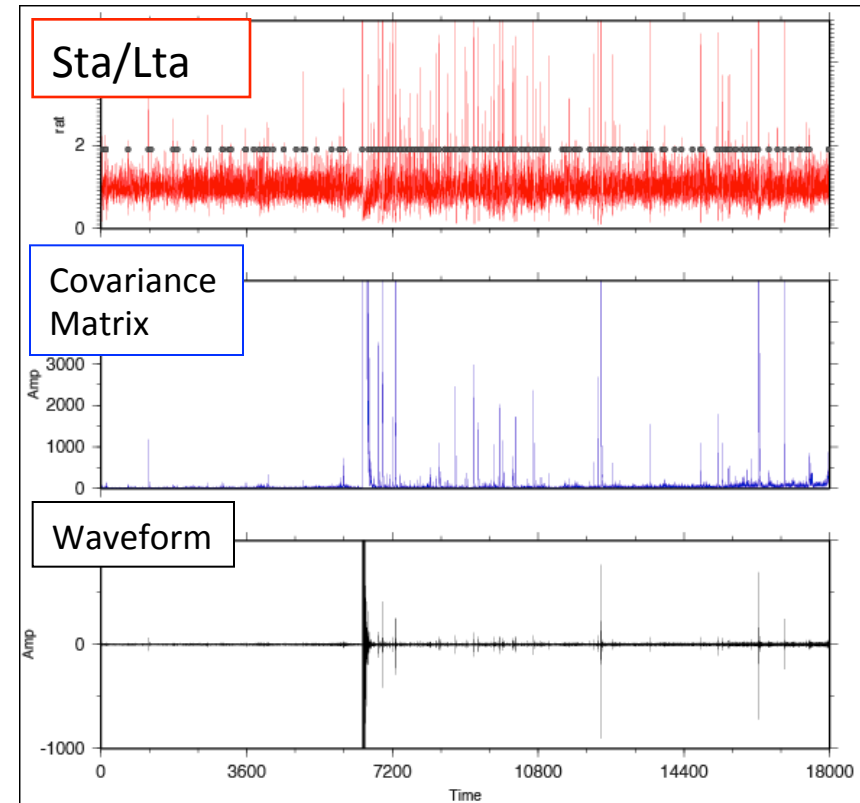
3) 1D Single Event Locations

4) Compute CC
delay times

5) Compute picks
delay times

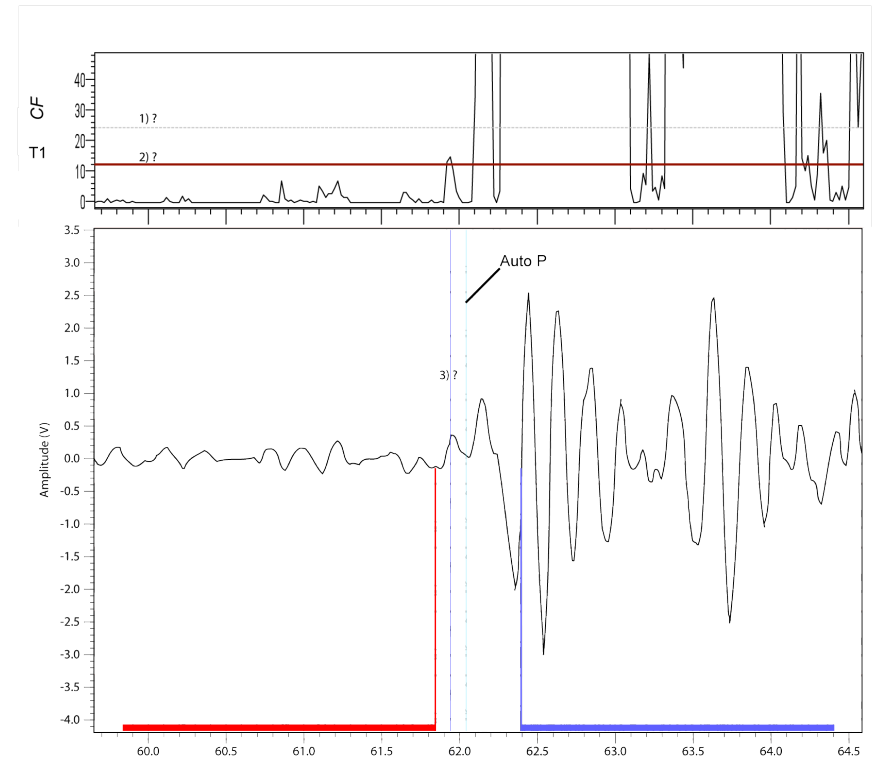
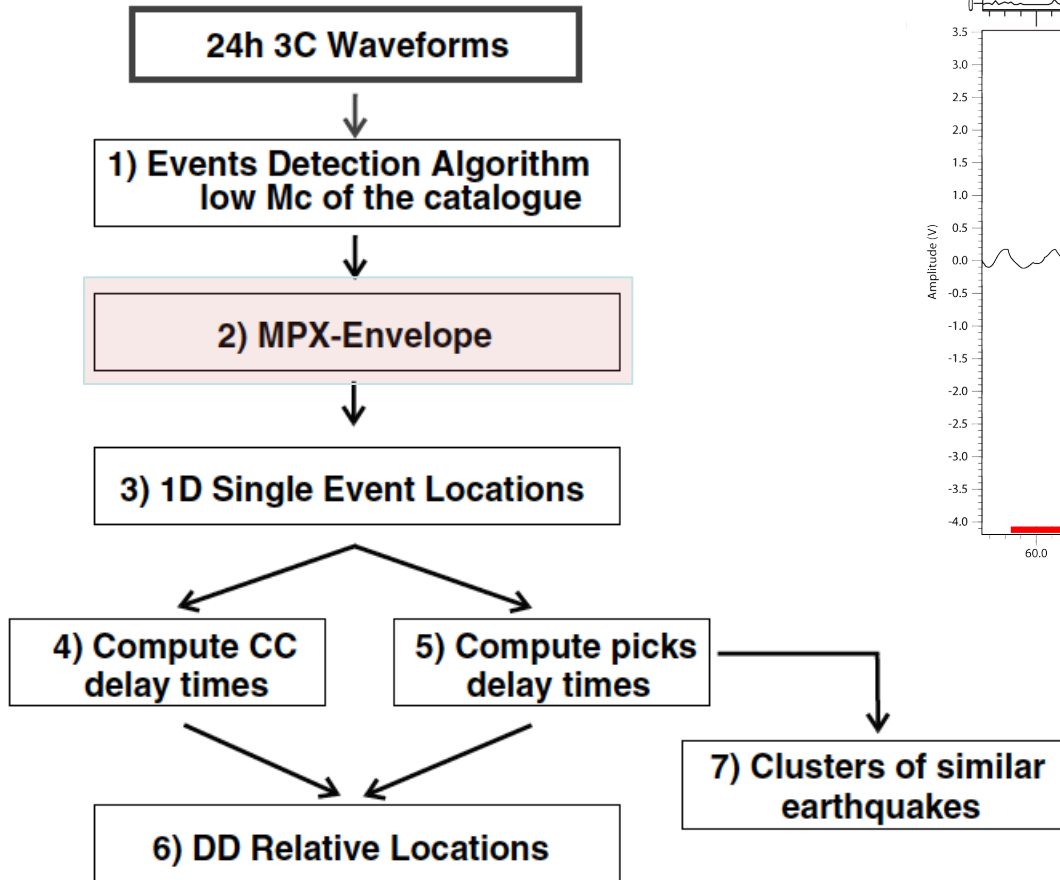
6) DD Relative Locations

7) Clusters of similar
earthquakes



work flow

Input data:



MPX-automatic picking:

- Very precise and accurately weighted P- and S-wave arrival times
- Magnitude determination
- First motion polarity (focal mechanisms)

work flow

Input data:

24h 3C Waveforms

1) Events Detection Algorithm
low M_c of the catalogue

2) MPX-Envelope

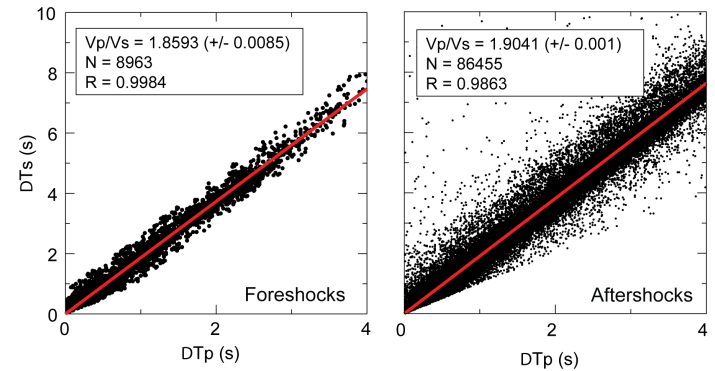
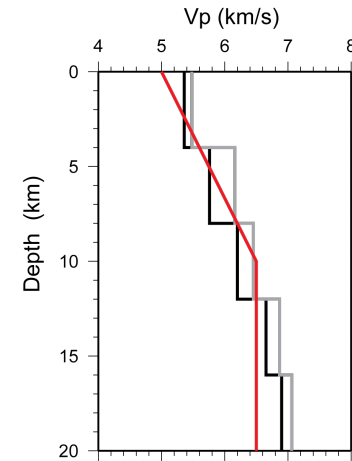
3) 1D Single Event Locations

4) Compute CC
delay times

5) Compute picks
delay times

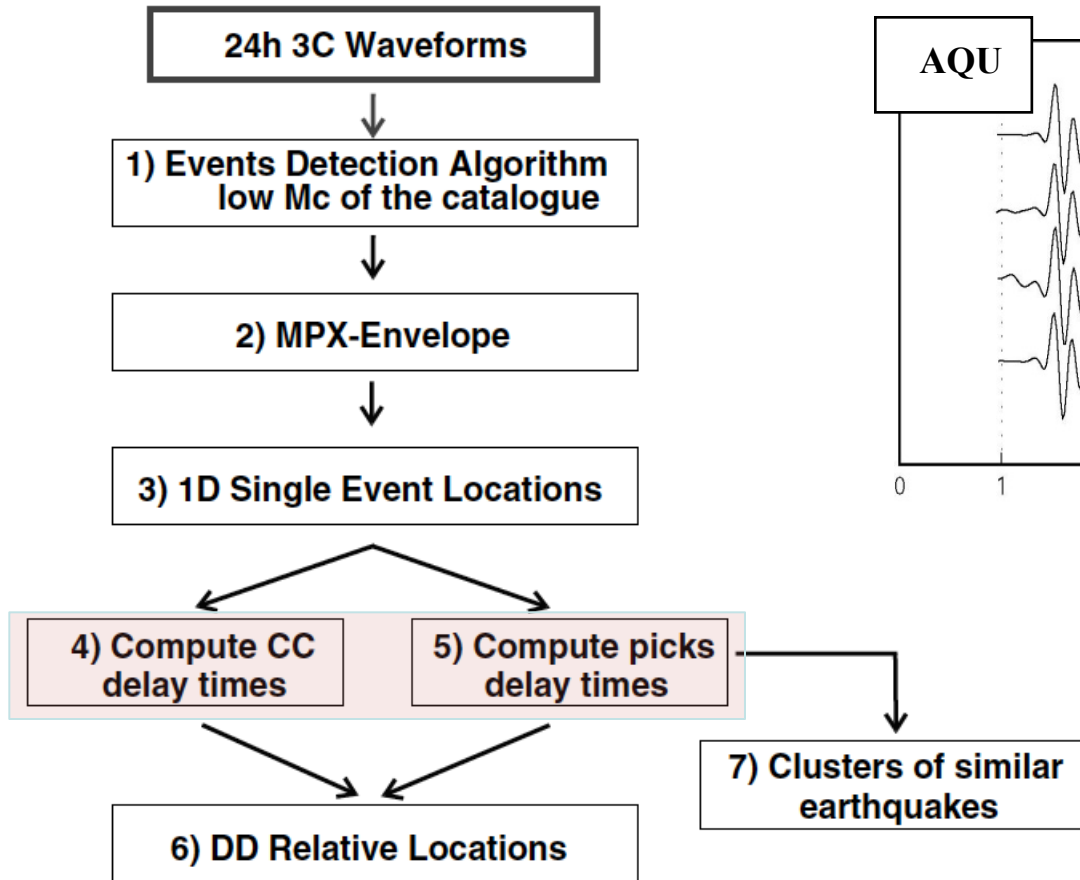
6) DD Relative Locations

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earthquakes

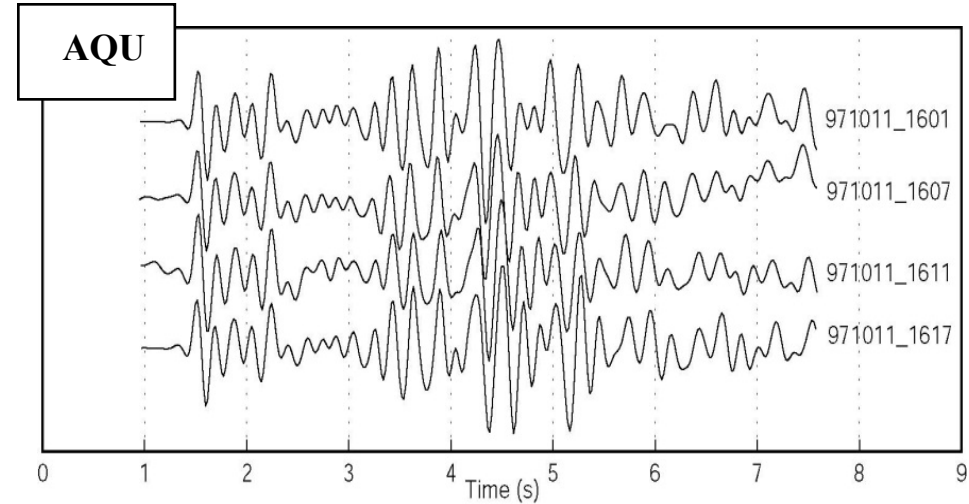


work flow

Input data:

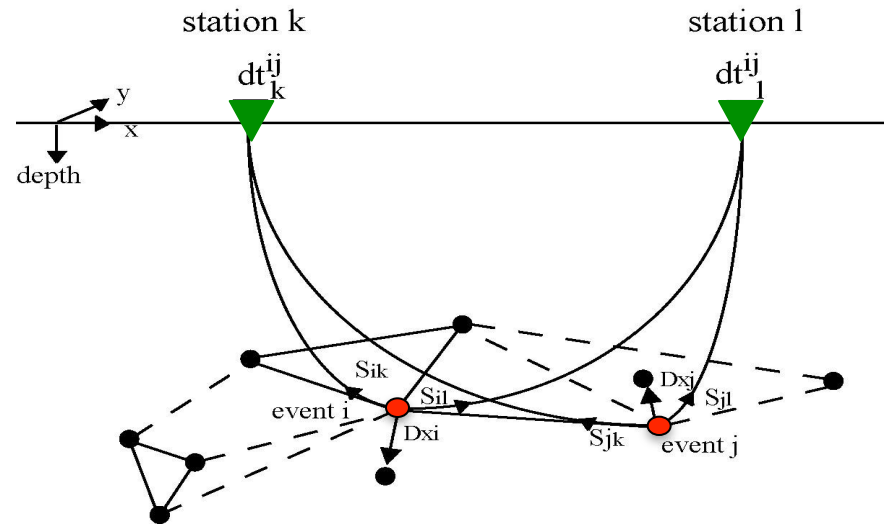
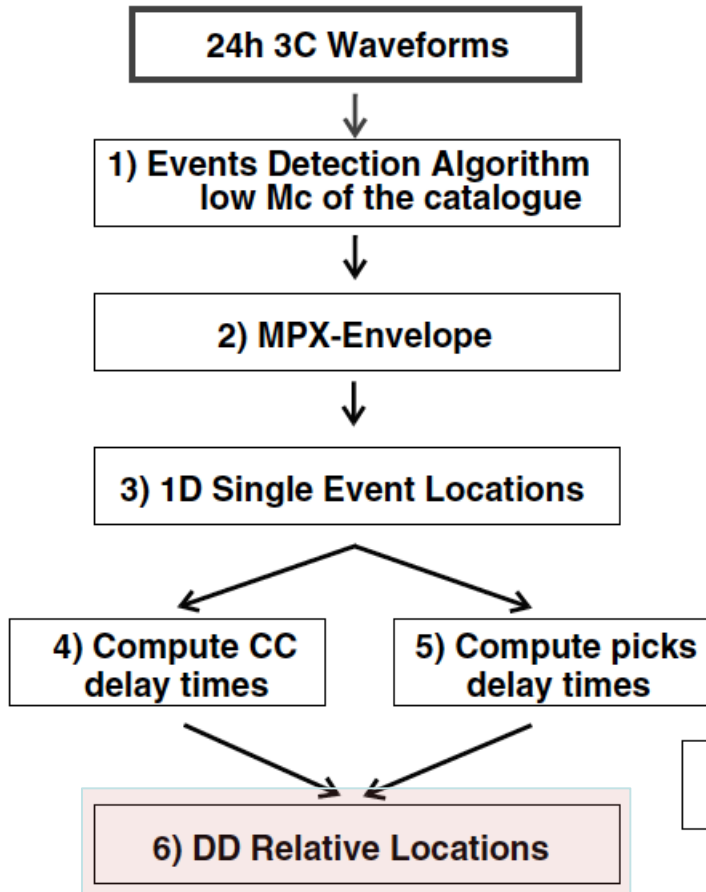


Cross-correlation performed in the time domain within a 1.6 s tapered window



work flow

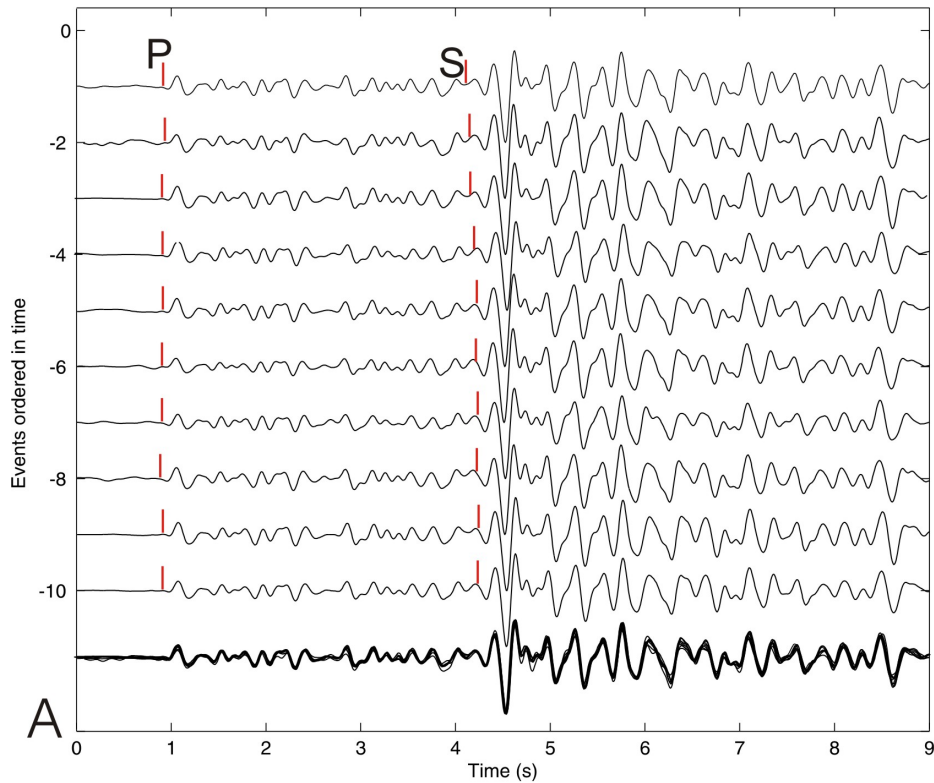
Input data:



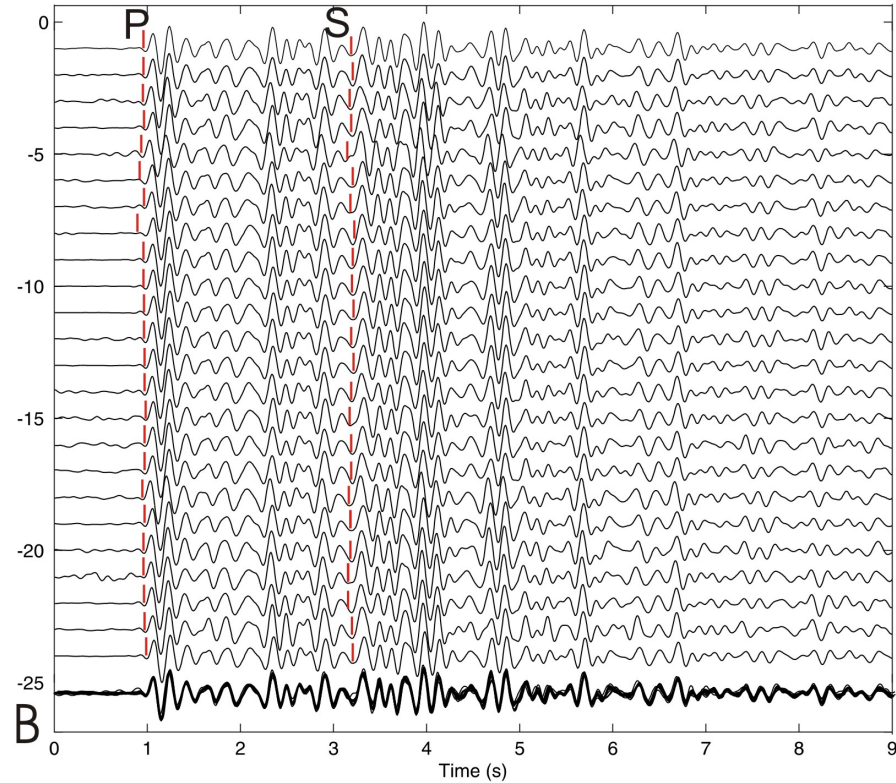
Double-Difference algorithm
[Waldhauser and Ellsworth, 2000]

Workflow: Clusters of similar earthquakes

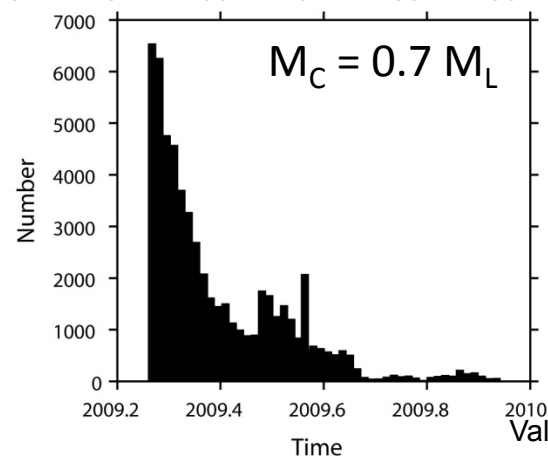
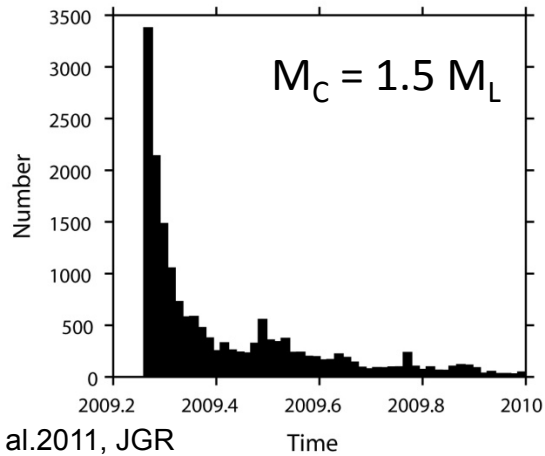
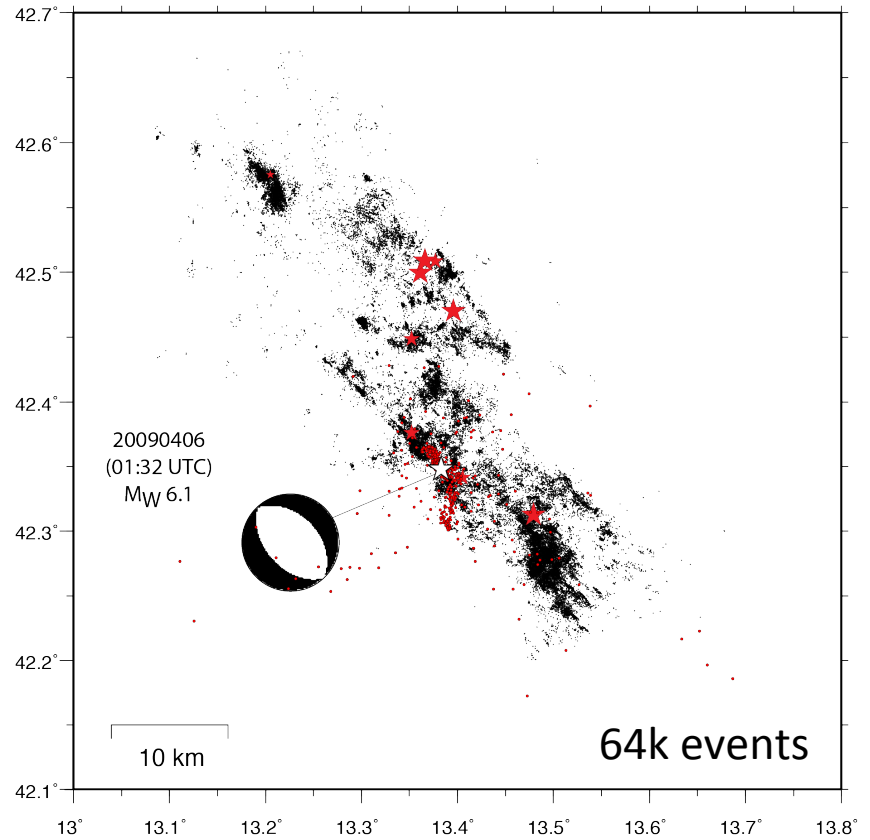
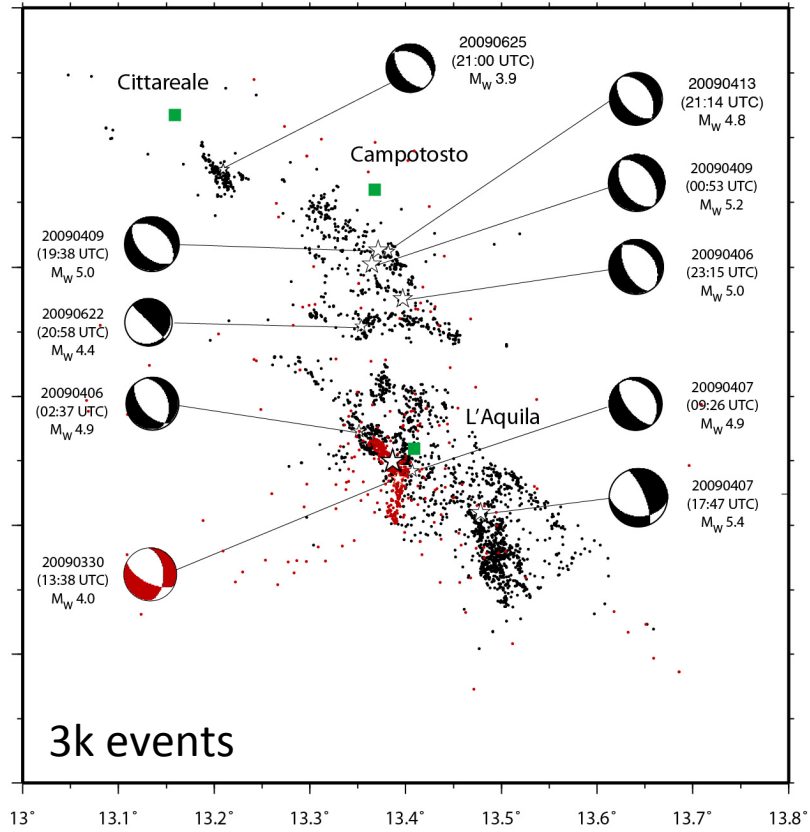
Station name: FIAM



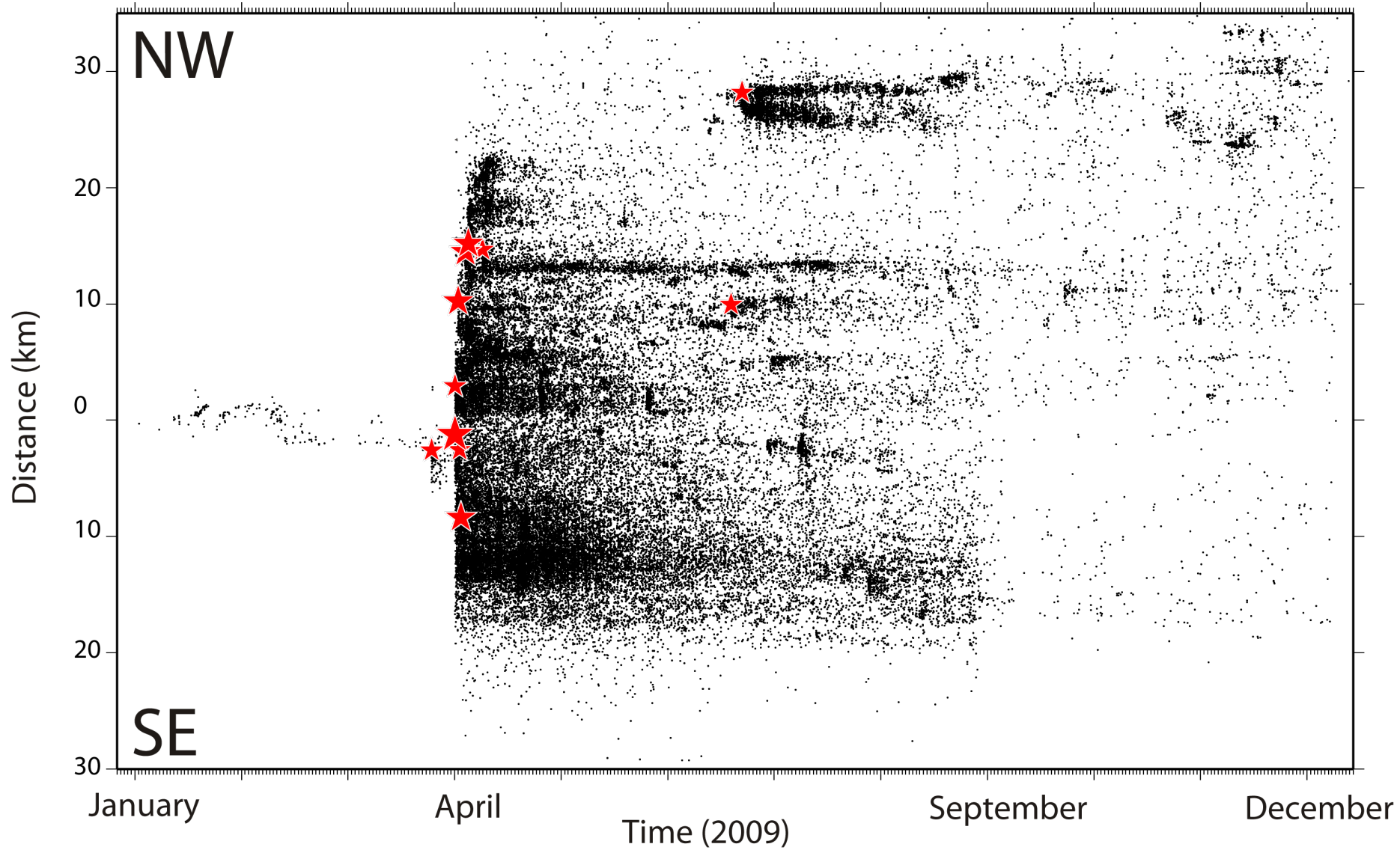
Station name: Rm06



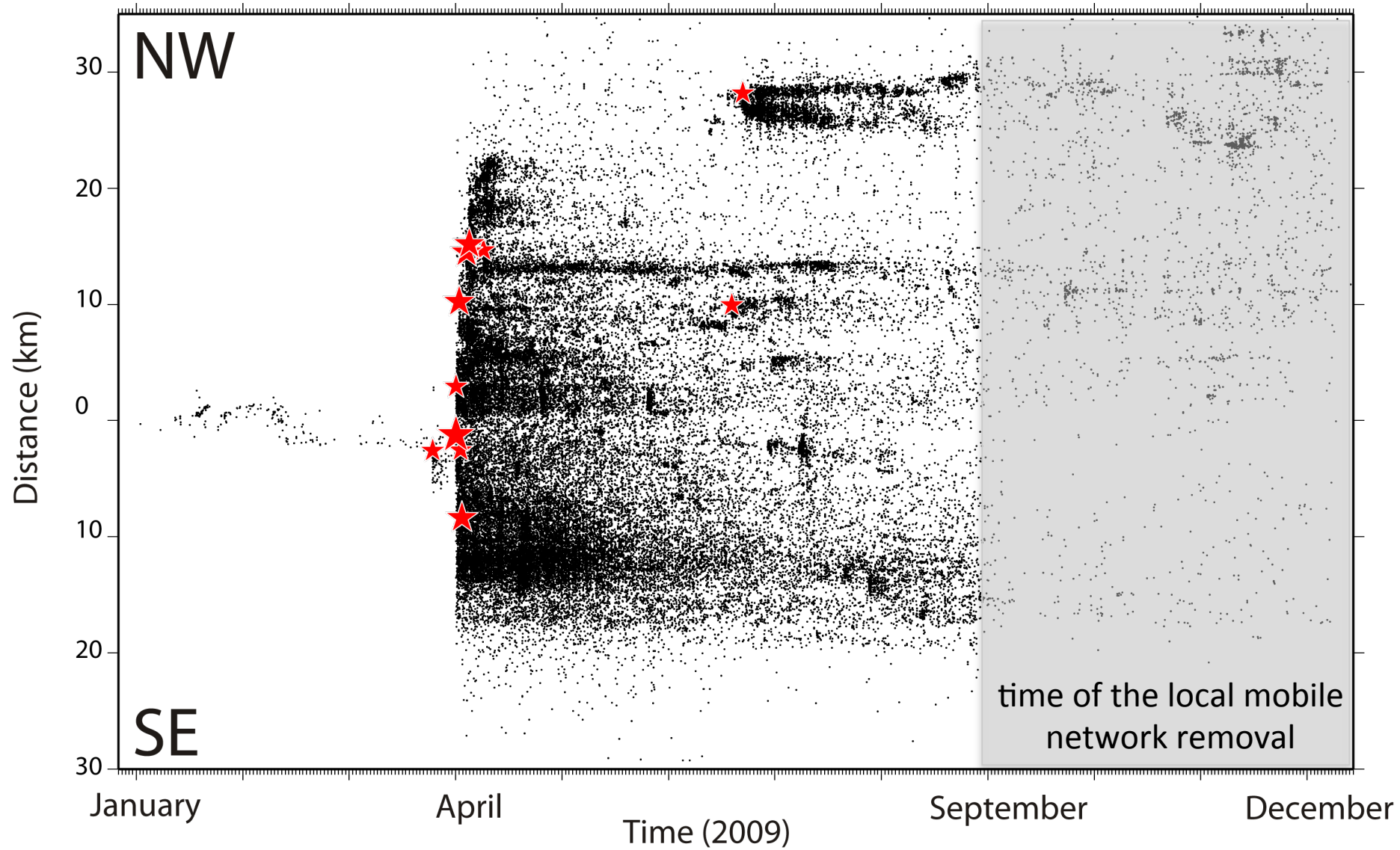
hand VS automatic picker



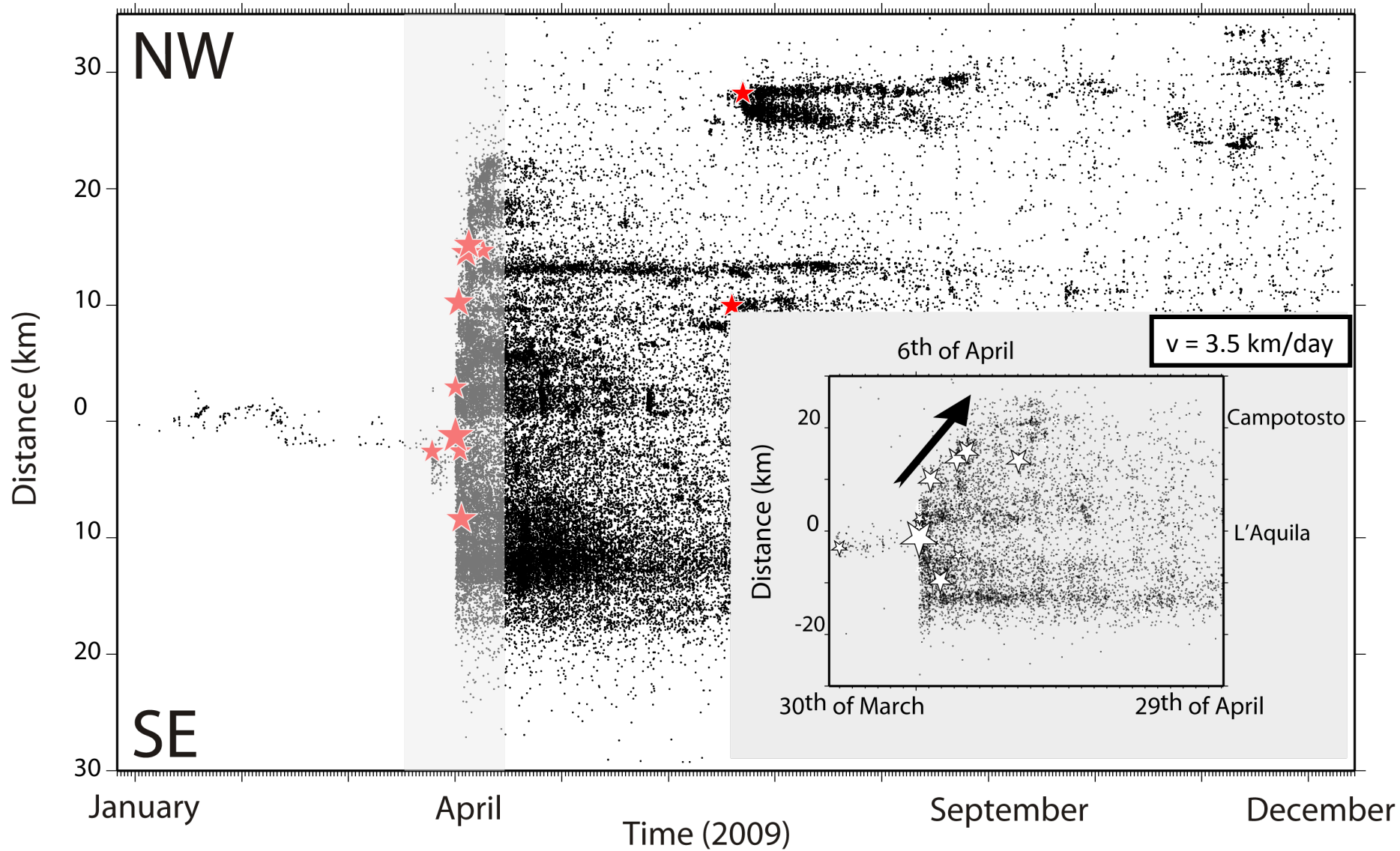
space VS time



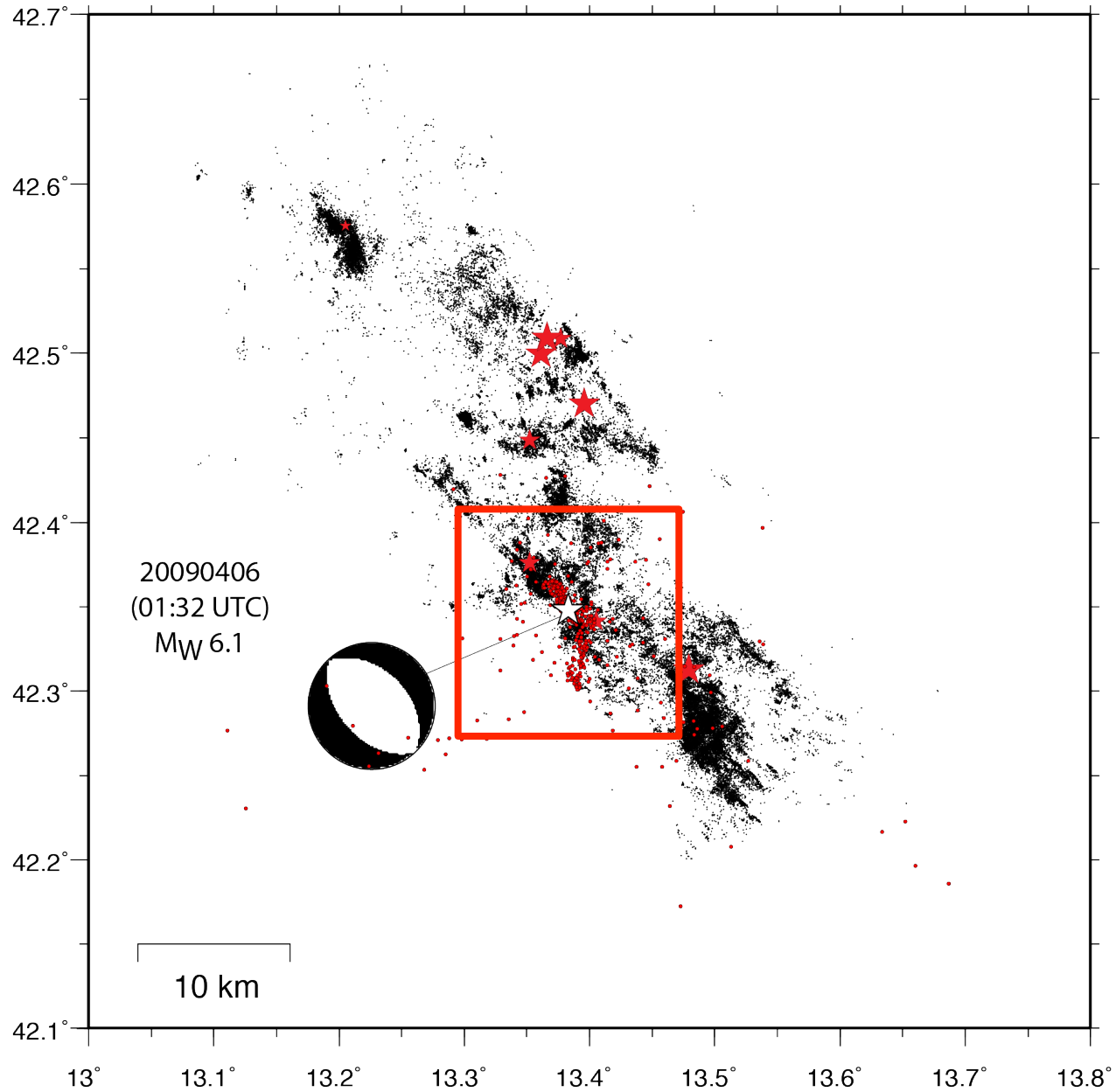
space VS time



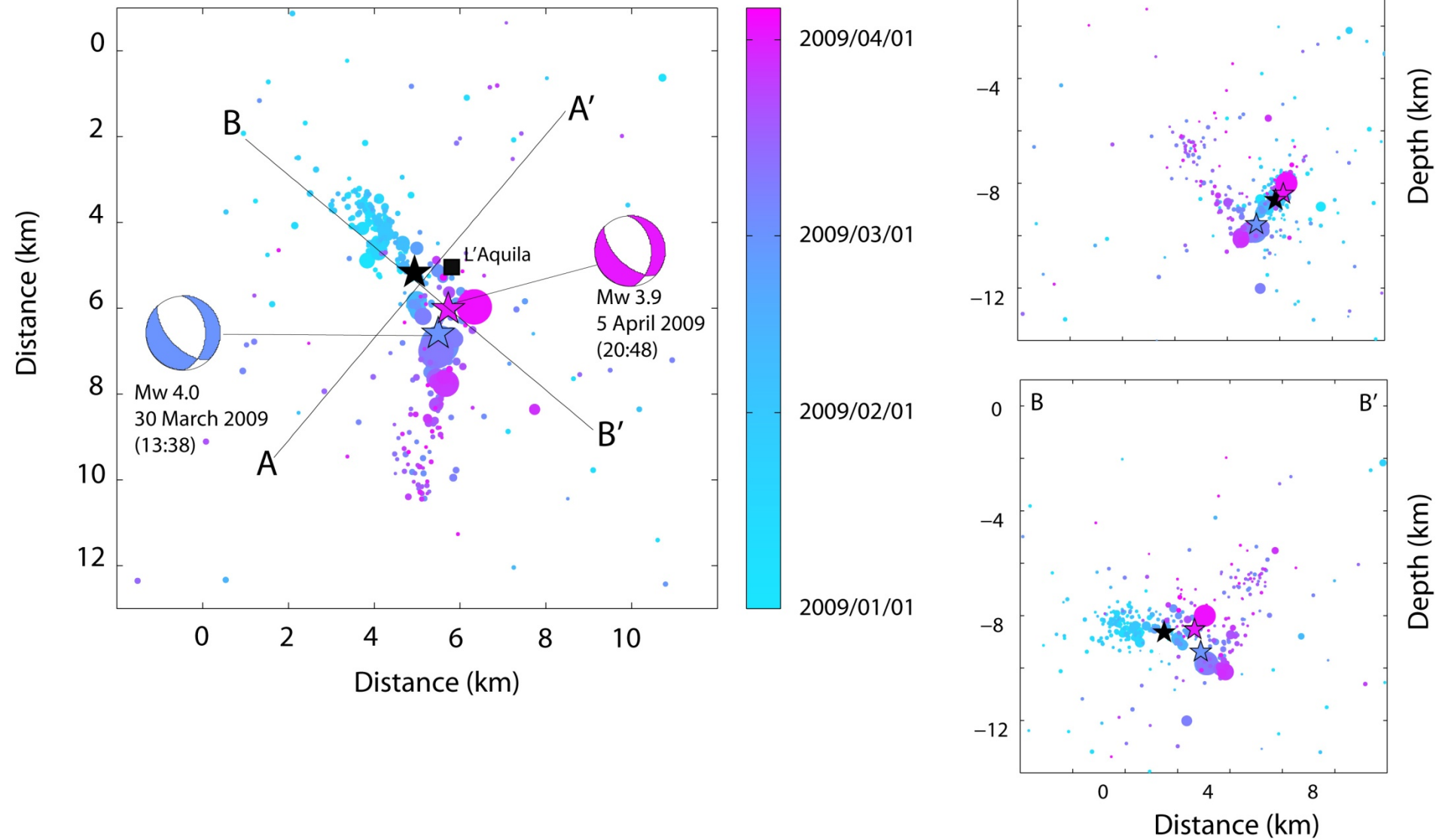
space VS time



map view and foreshocks

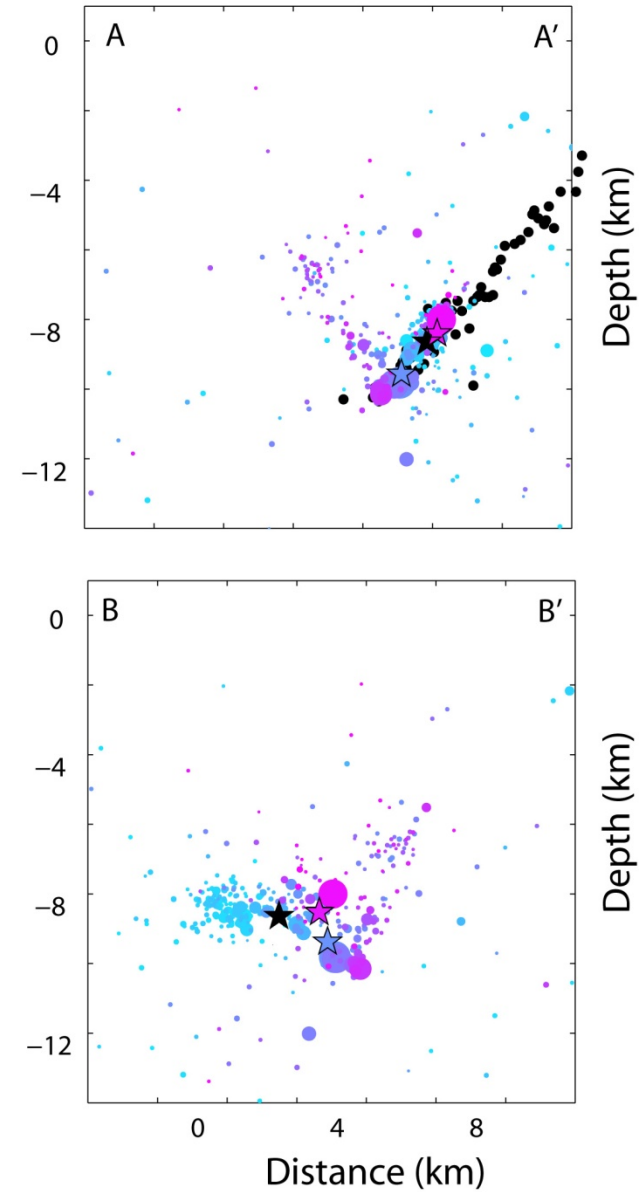
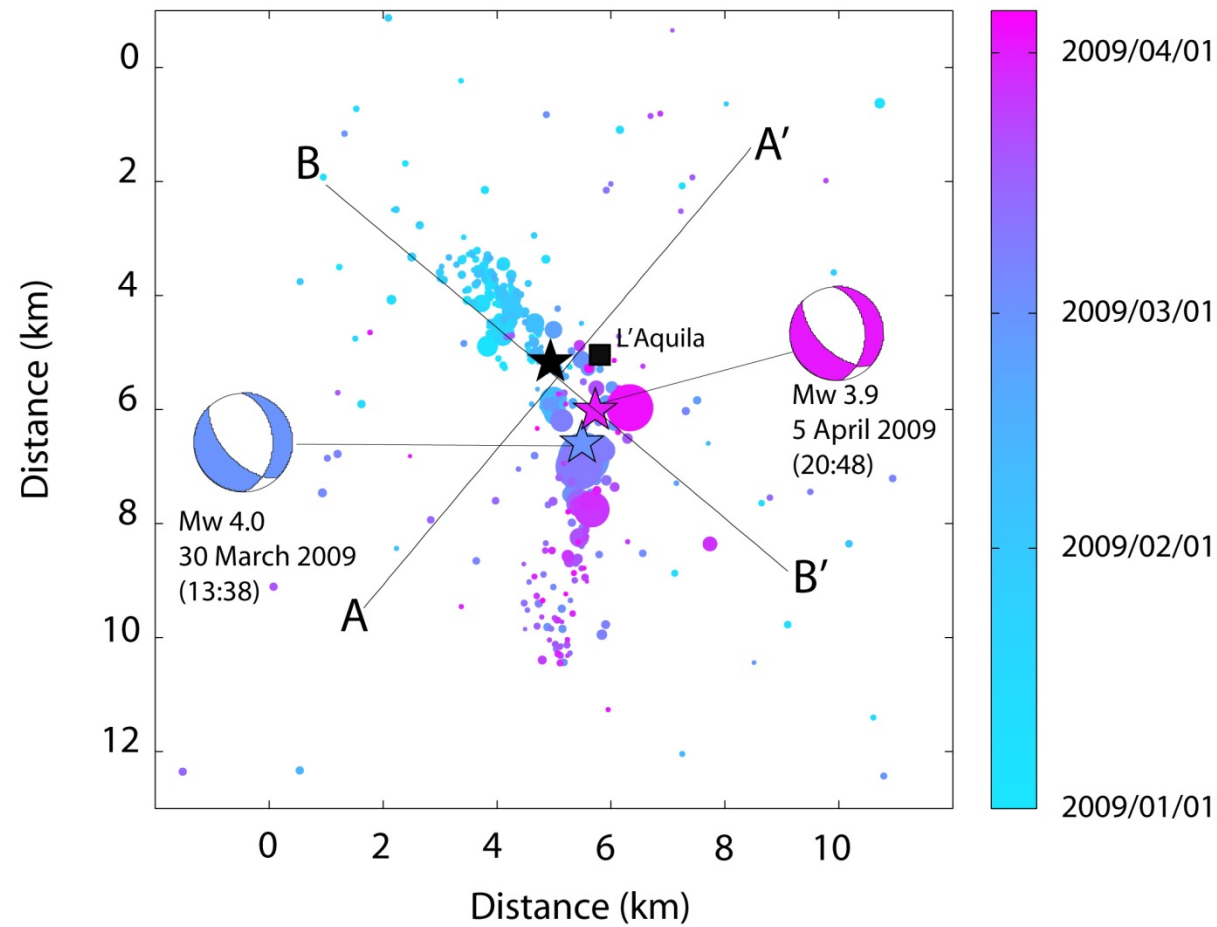


foreshocks



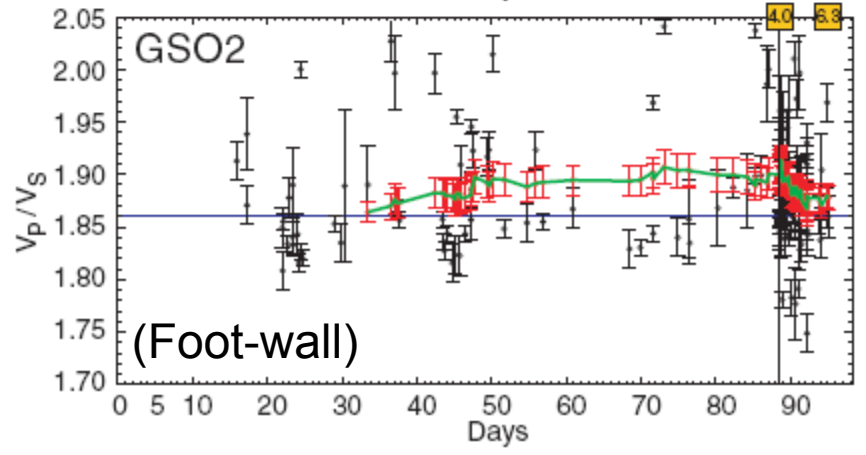
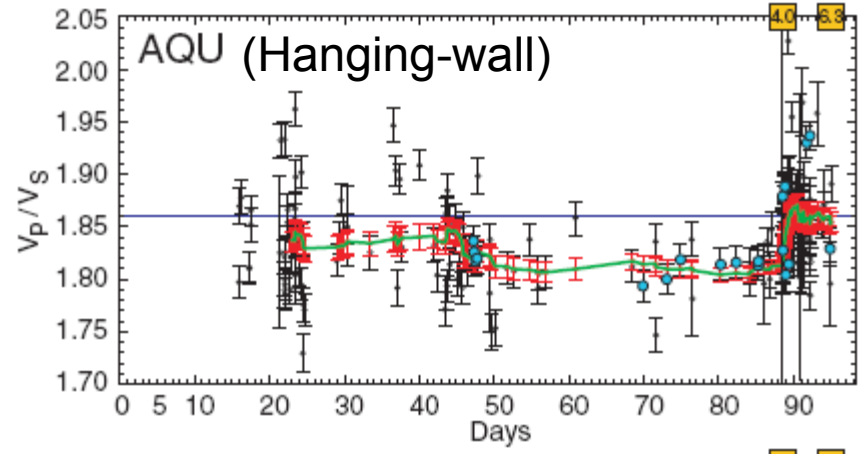
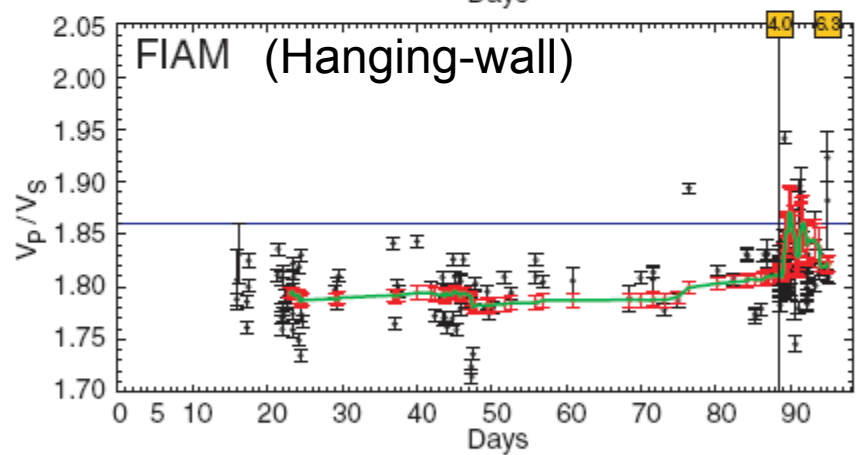
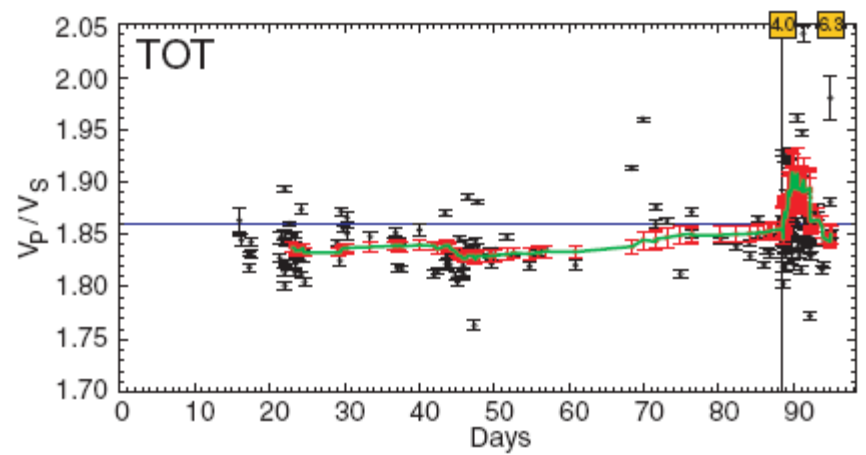
(Chiaraluce et al., 2011 JGR)

foreshocks



(Chiaraluce et al., 2011 JGR)

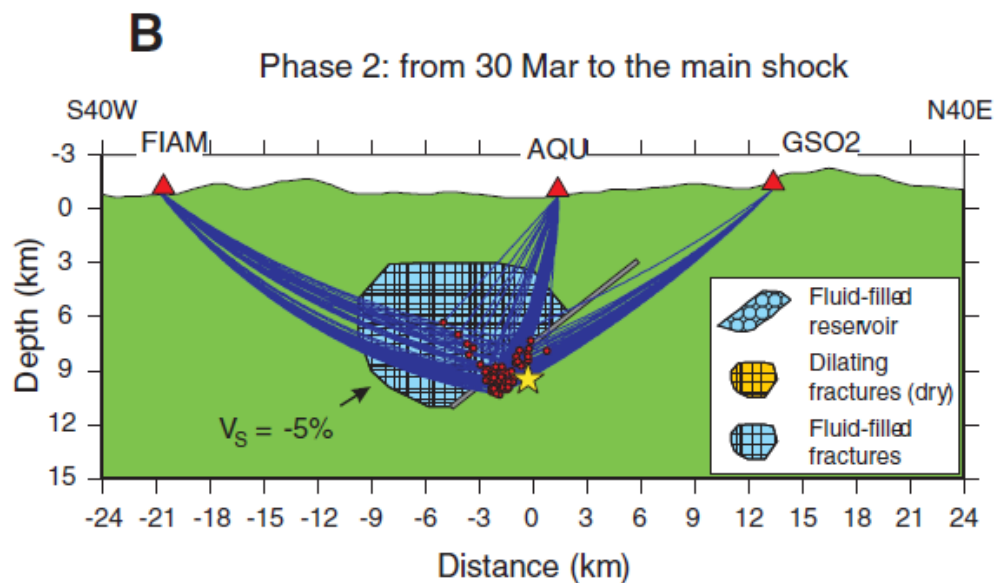
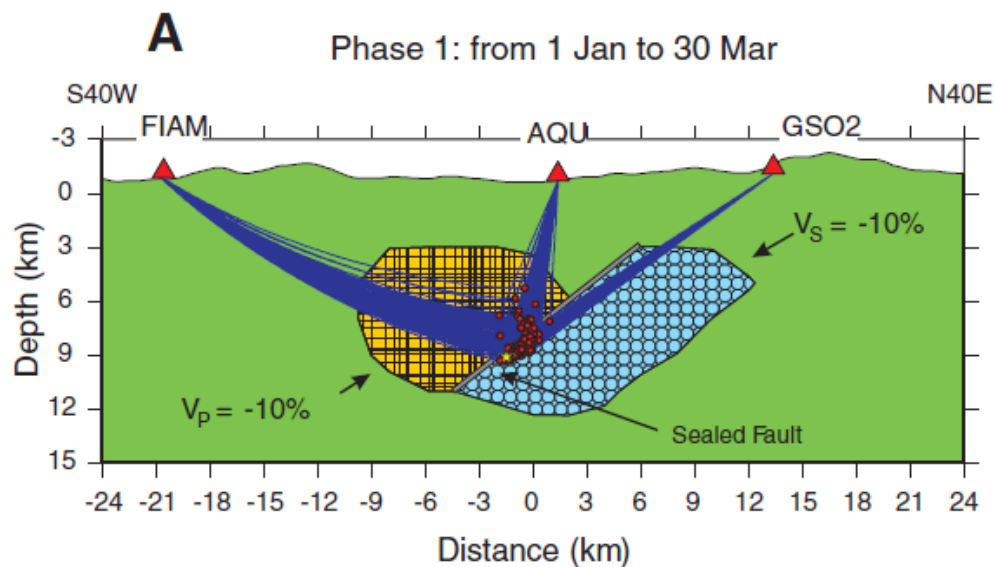
Foreshock sequence: V_p/V_s vs time



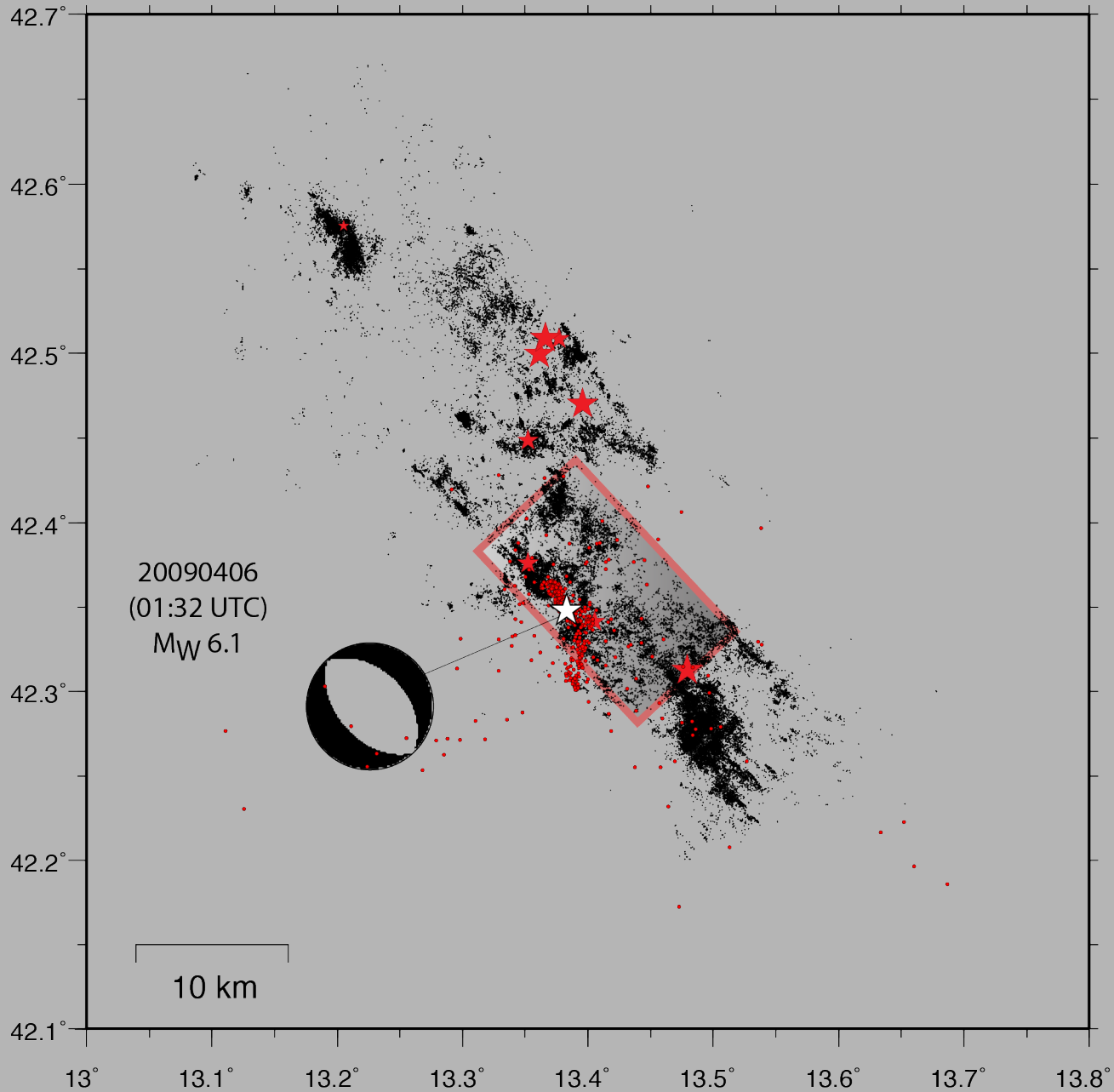
The observed behaviour suggests the occurrence of a dilatancy diffusion process.

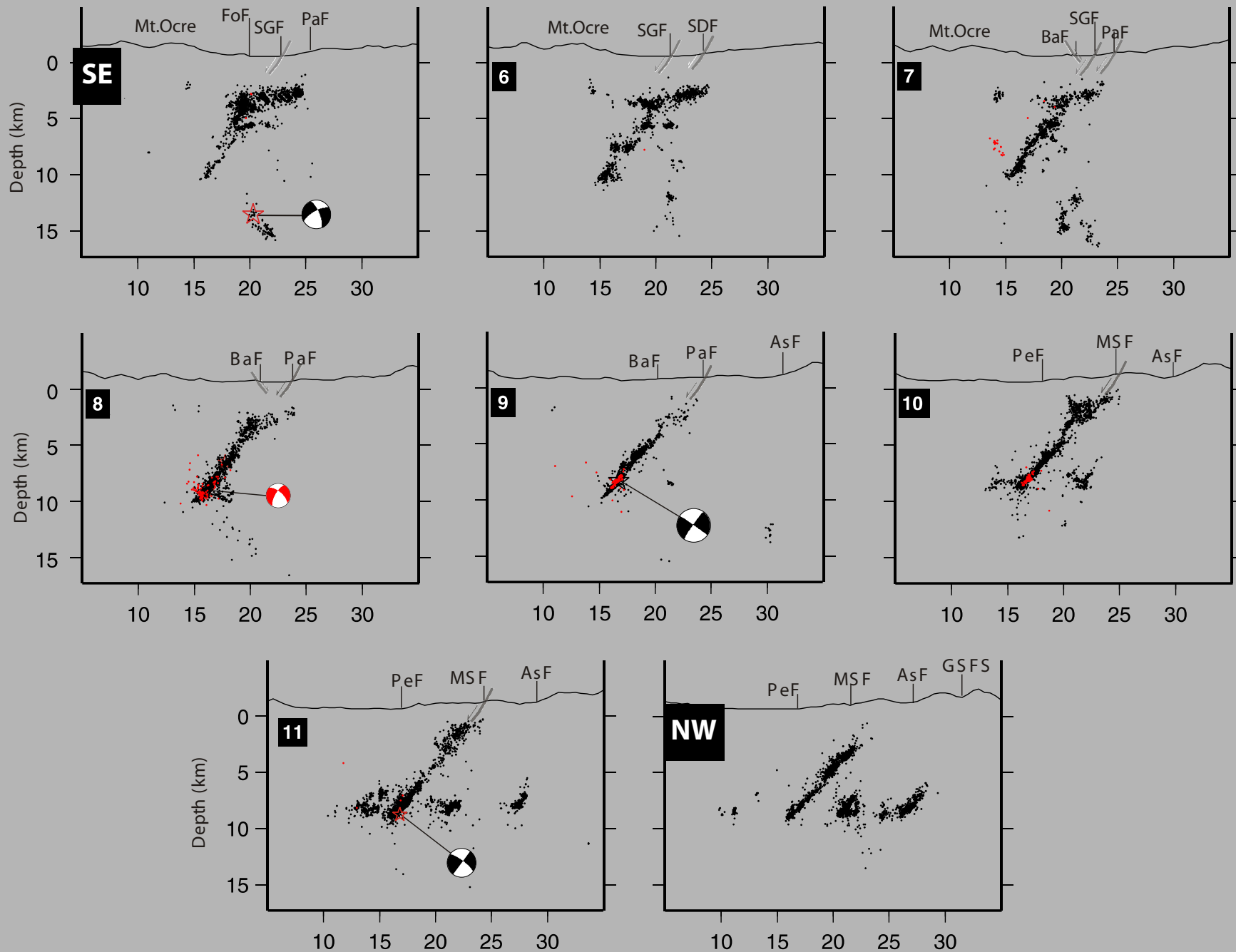
(Lucente et al., 2010 Geology)

Foreshock sequence: a possible model



L'Aquila fault



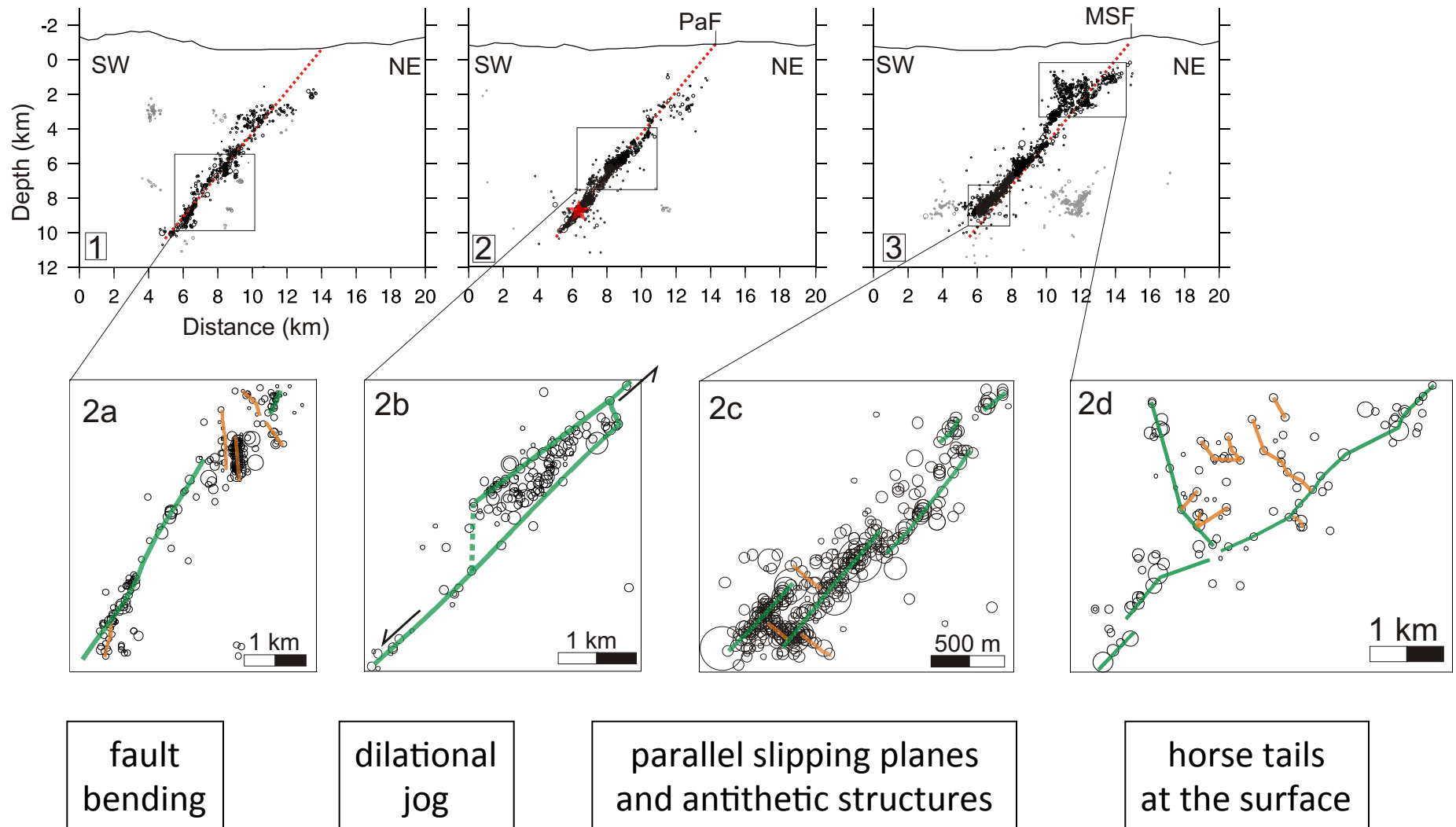


Cross sections thickness 2 km

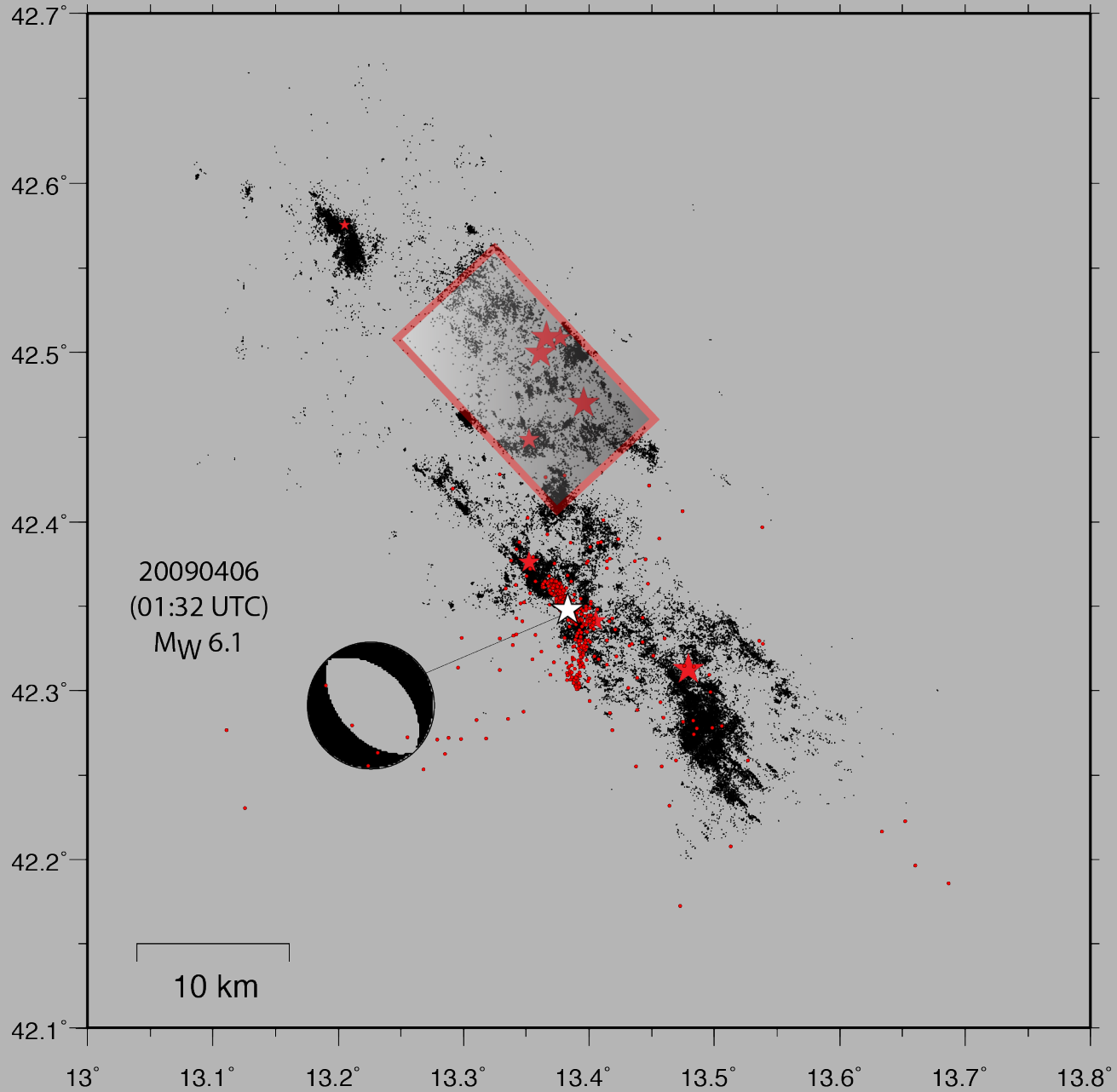
Distance (km)

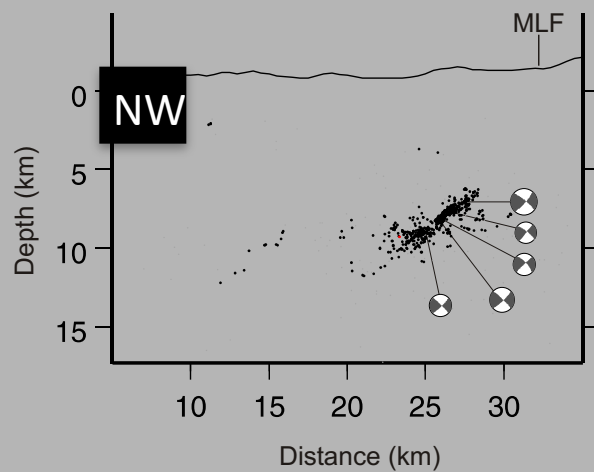
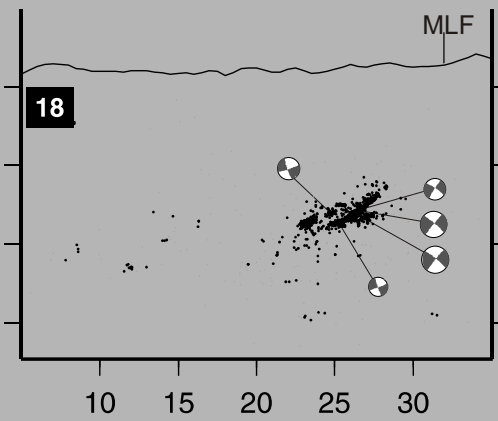
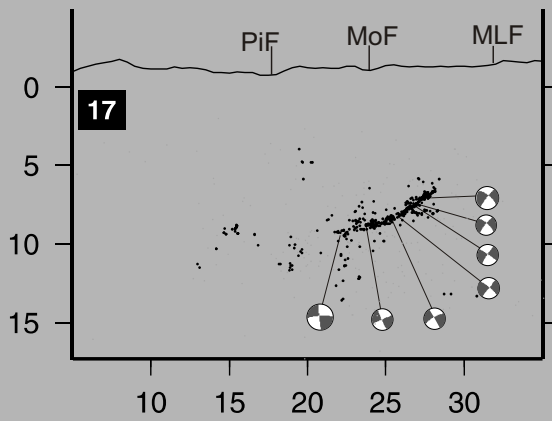
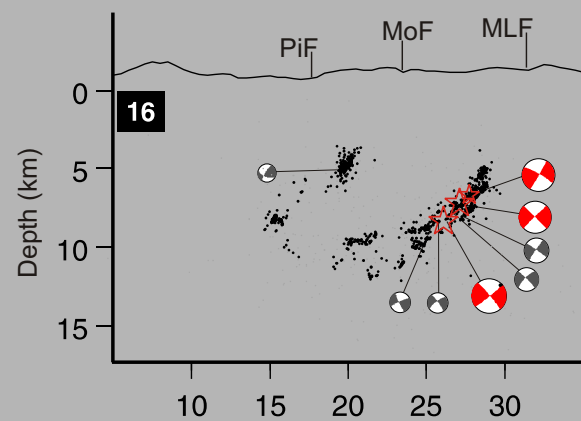
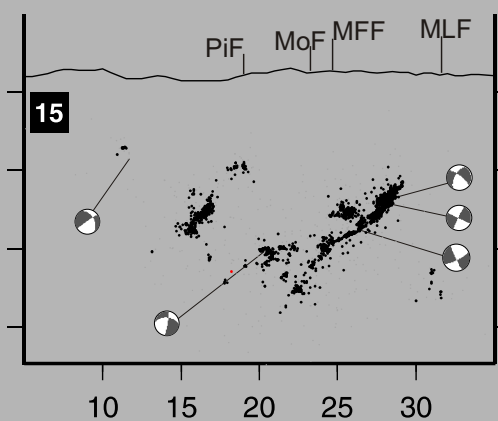
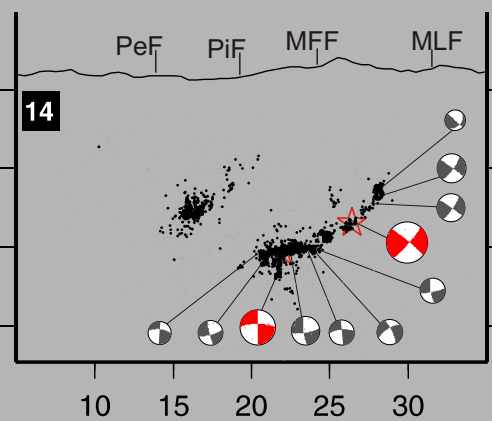
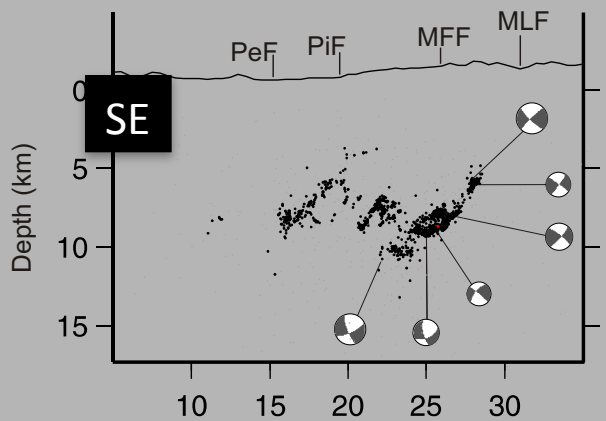
Distance (km)

zoom in



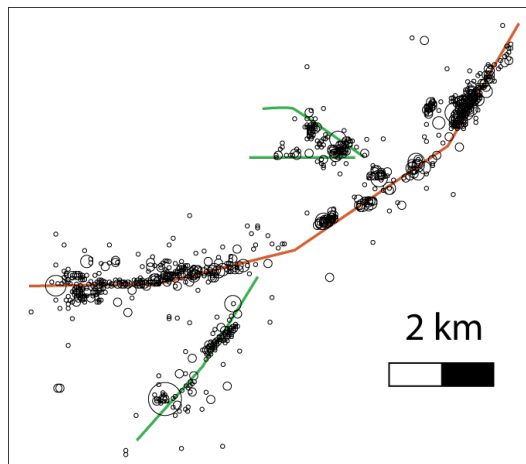
Campotosto fault



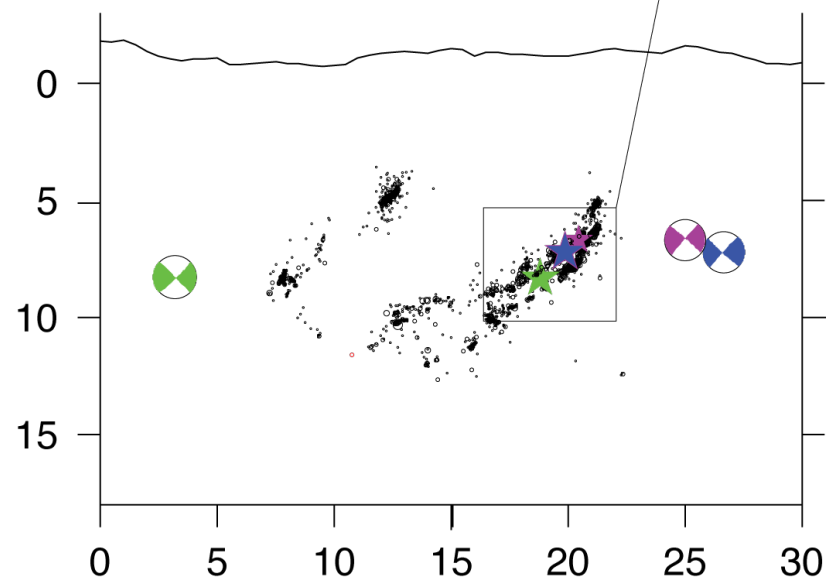
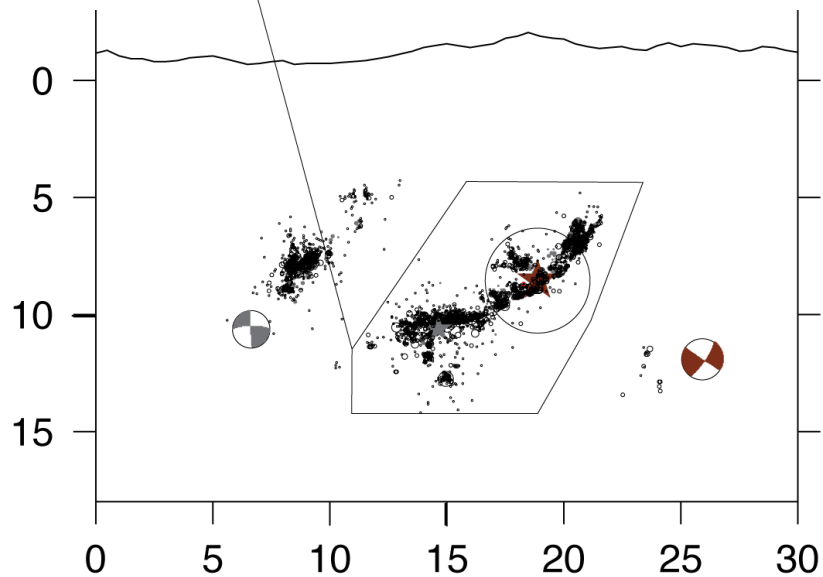
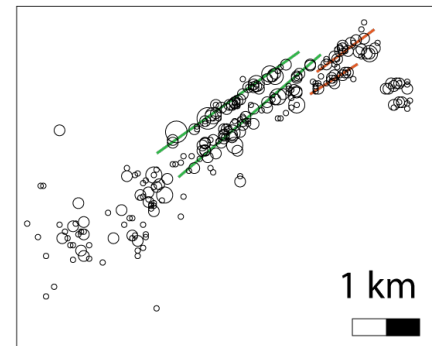


zoom in

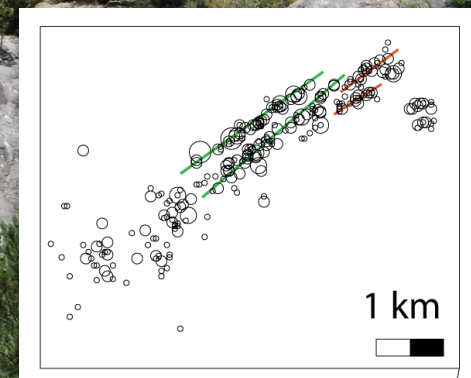
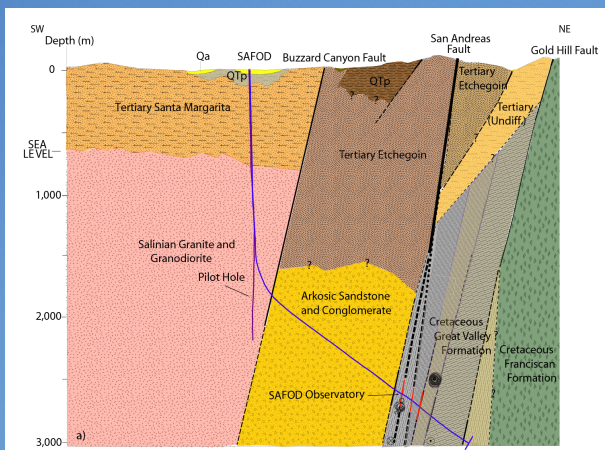
ramp-flat structures



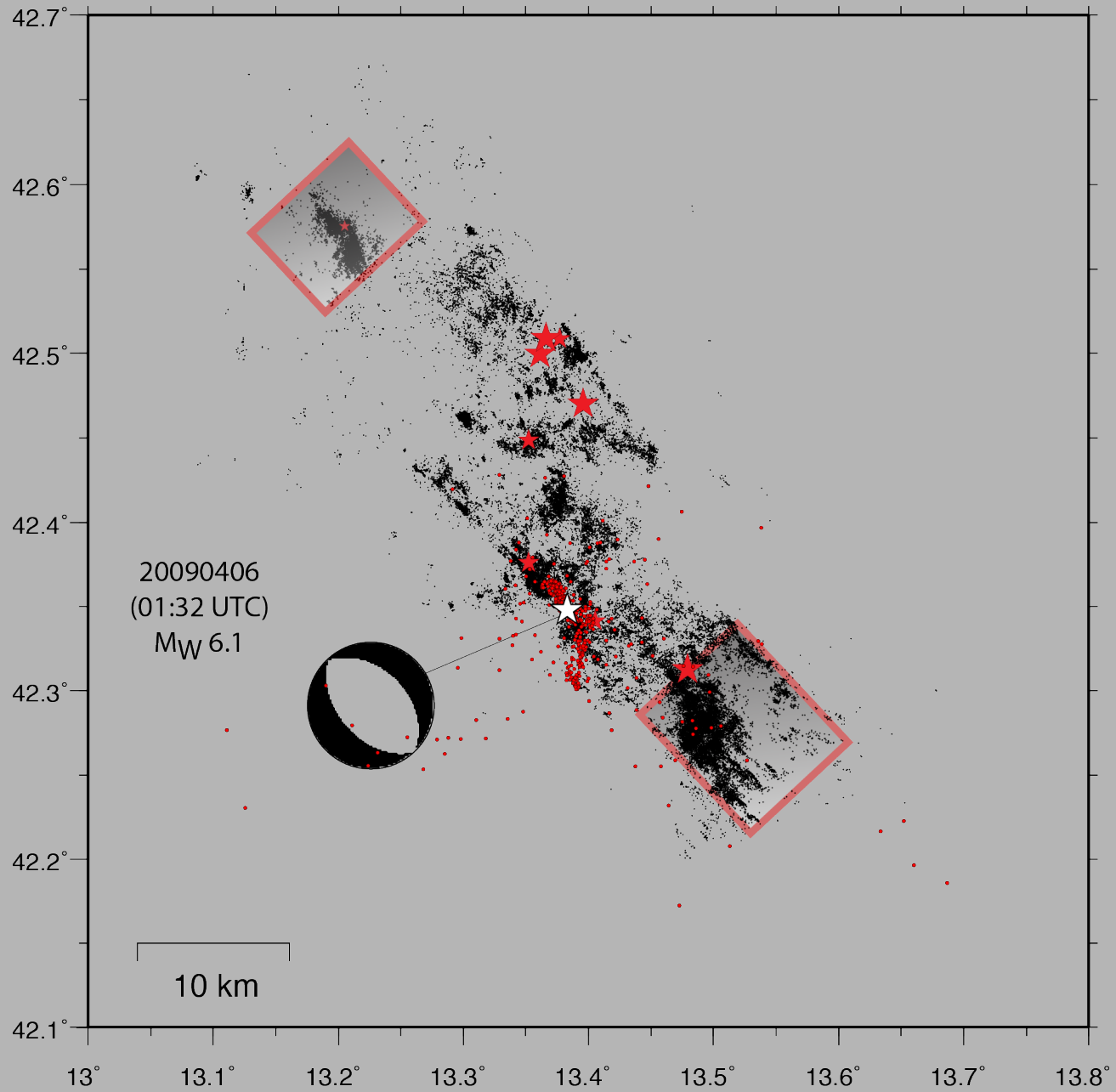
sub-parallel slipping planes

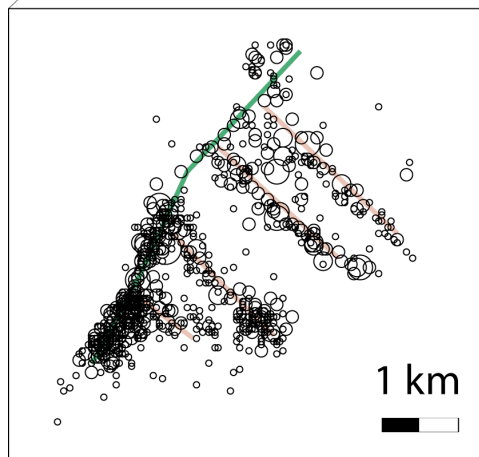
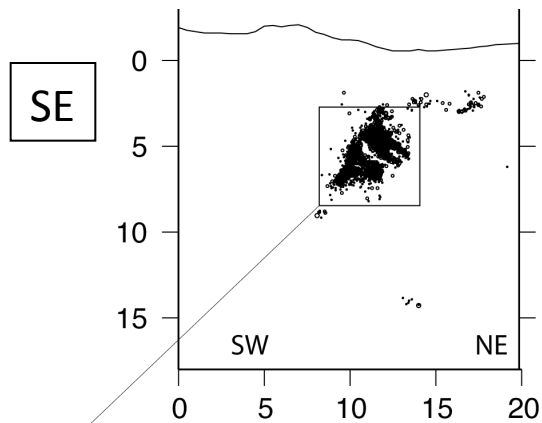


parallel fault planes

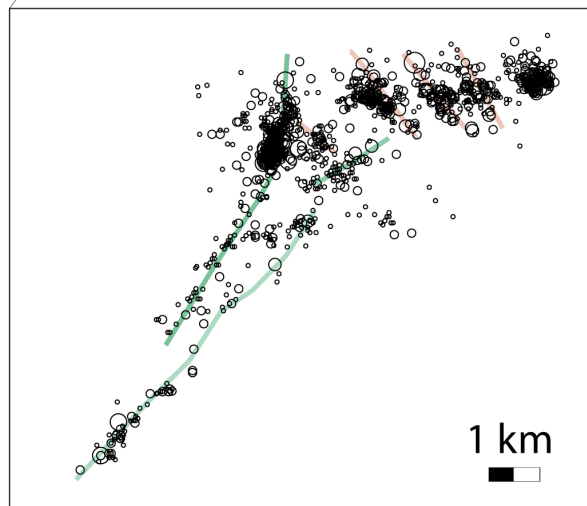
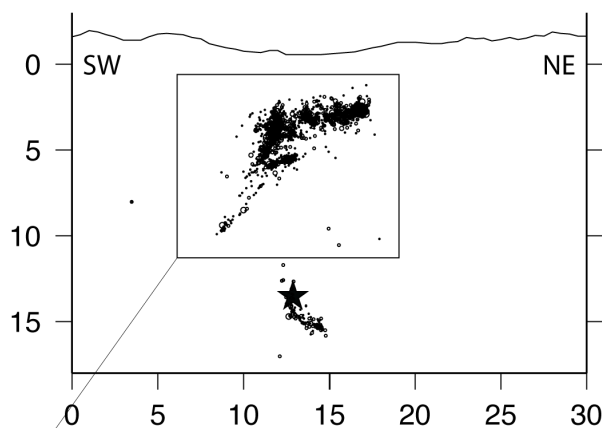


fault termination-s

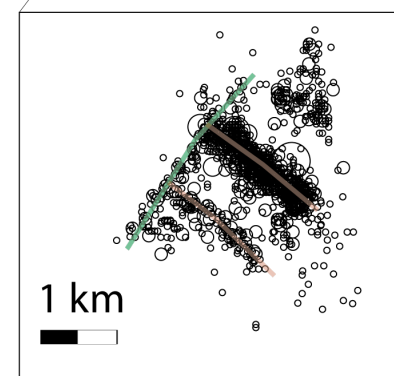
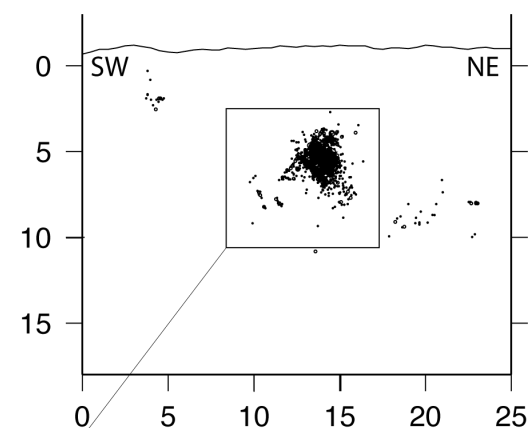




antithetic
structures
in the f-footwall



splitting of the main L' Aquila plane into sub-parallel planes
plus a set of minor antithetic structures



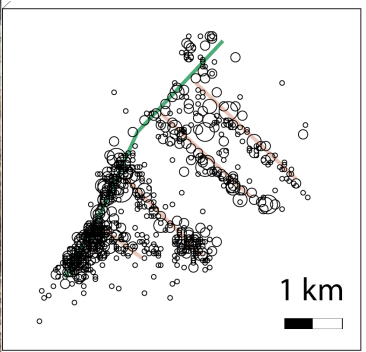
NW

antithetic
structures
in the f-footwall



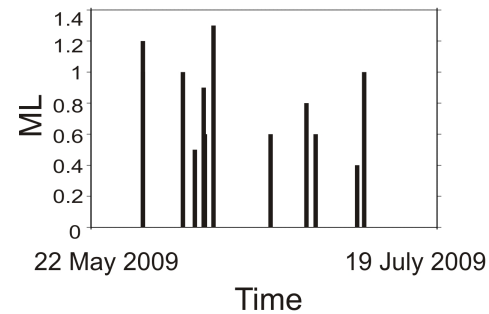
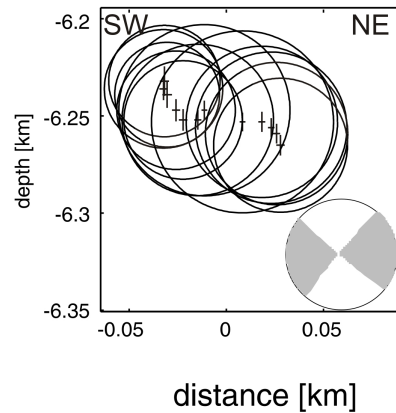
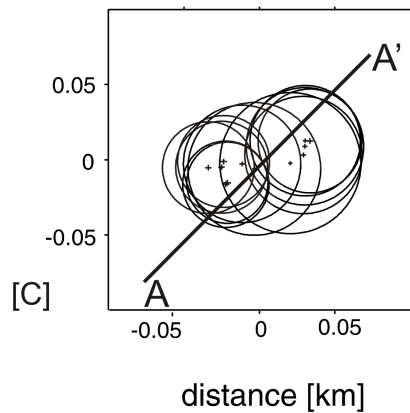
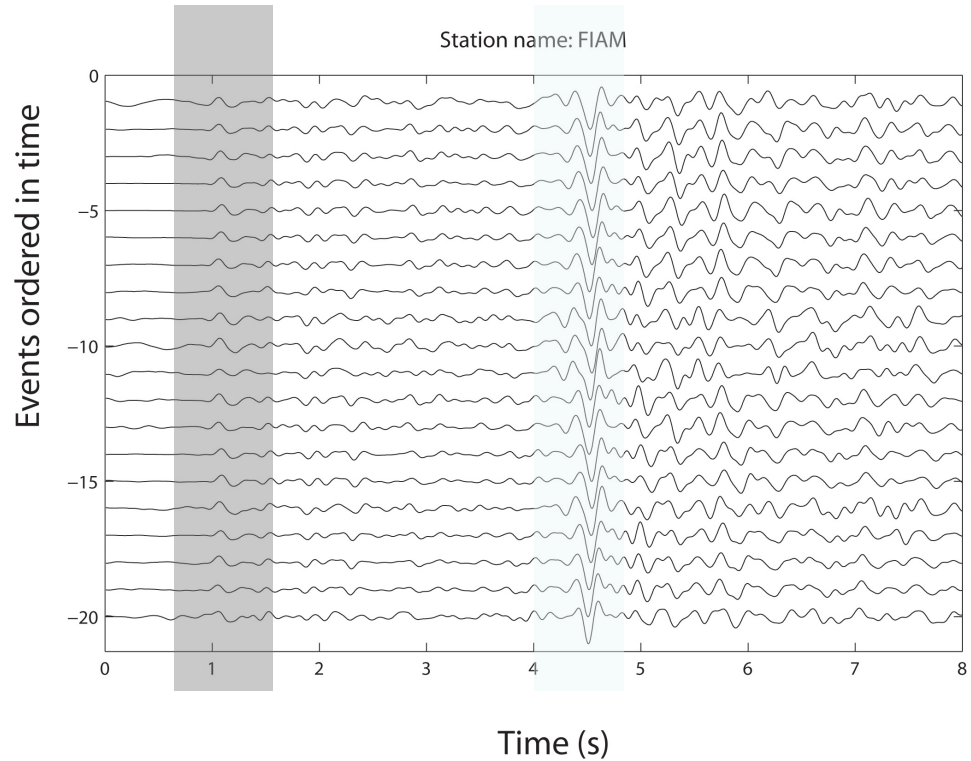
minor anti-thetic faults

major fault plane

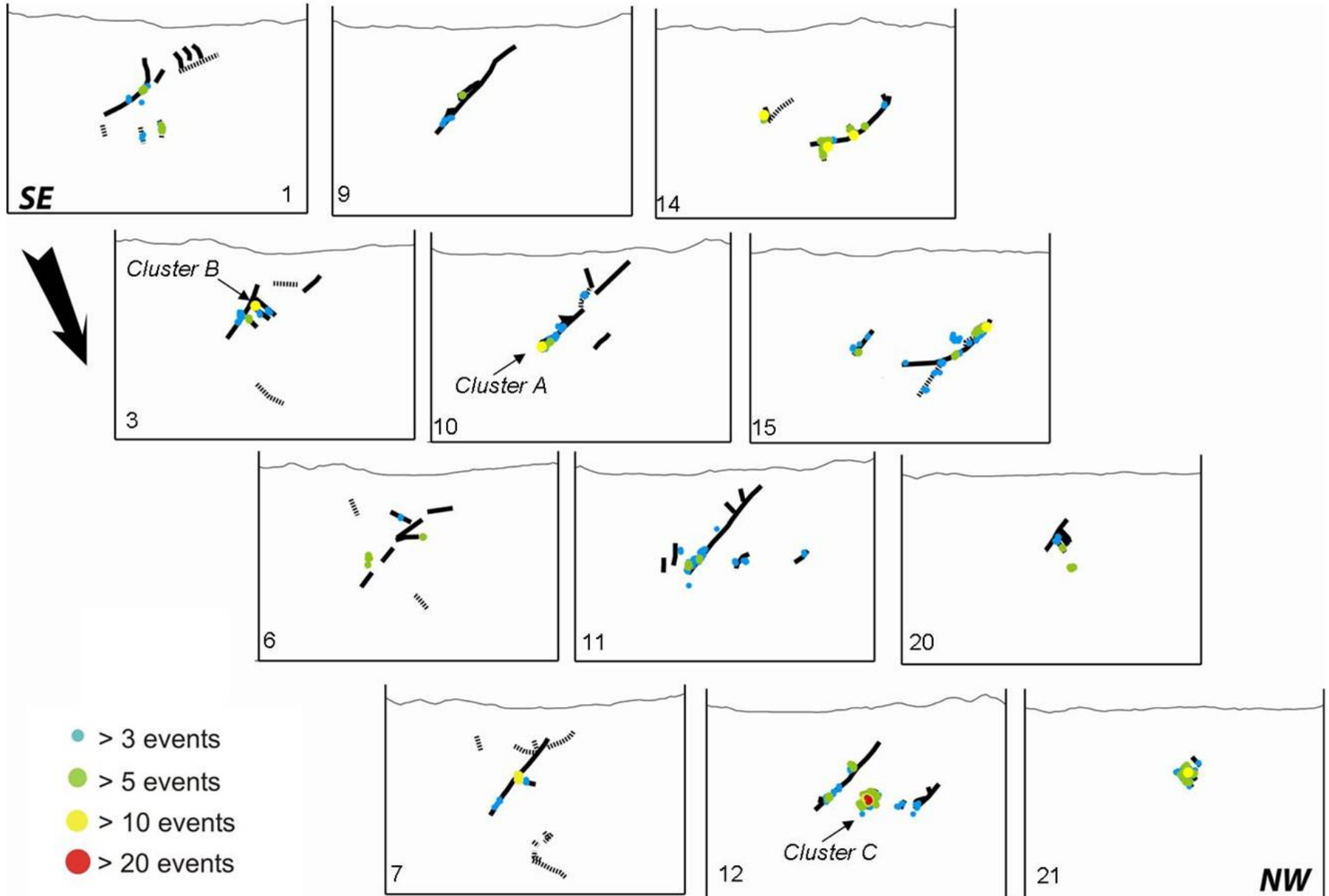


similar waveforms similar earthquakes

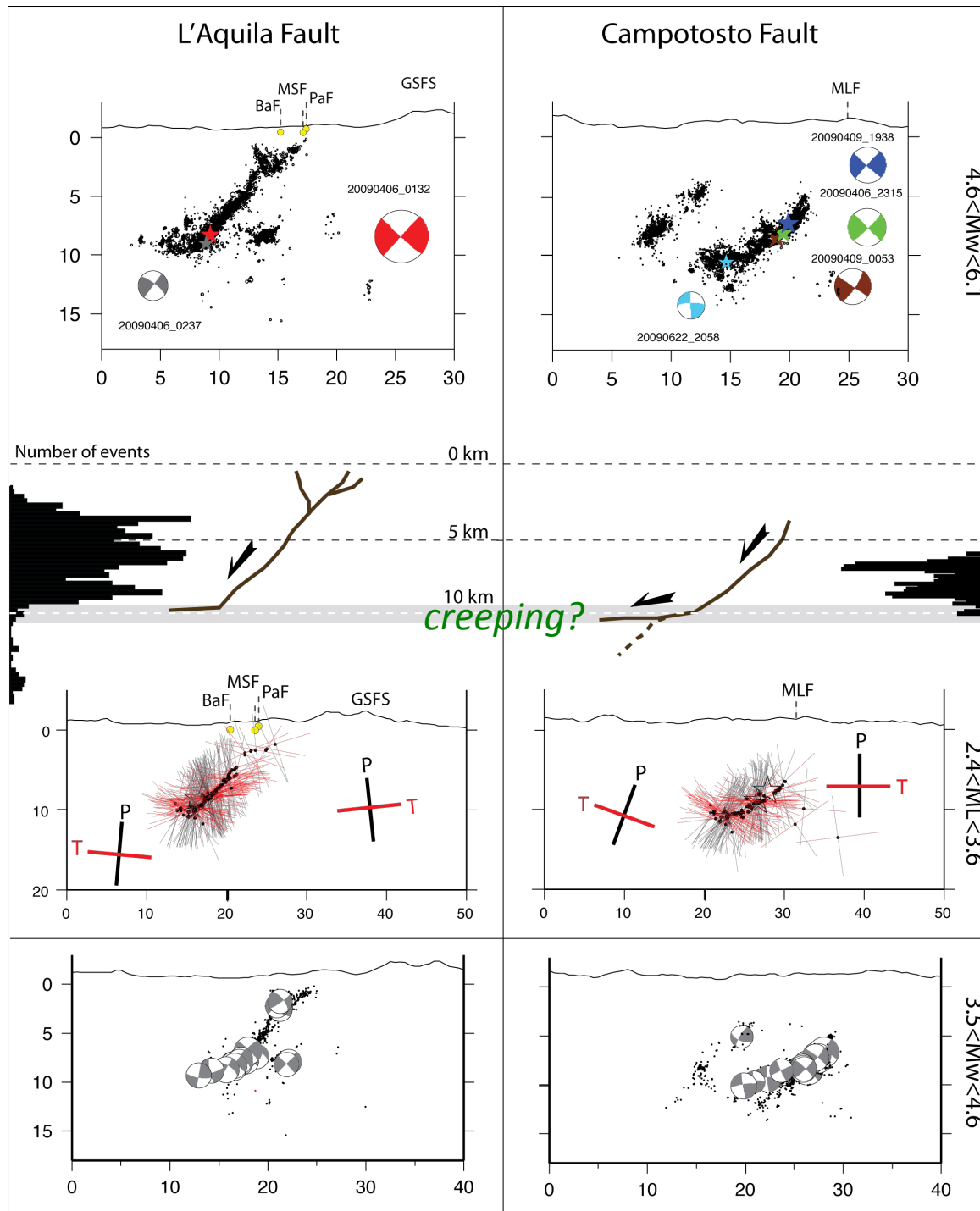
Repeating earthquakes are events rupturing with time a fixed patch of a fault in accordance with simple stick slip models.



where in the fault system



how faults terminate at depth



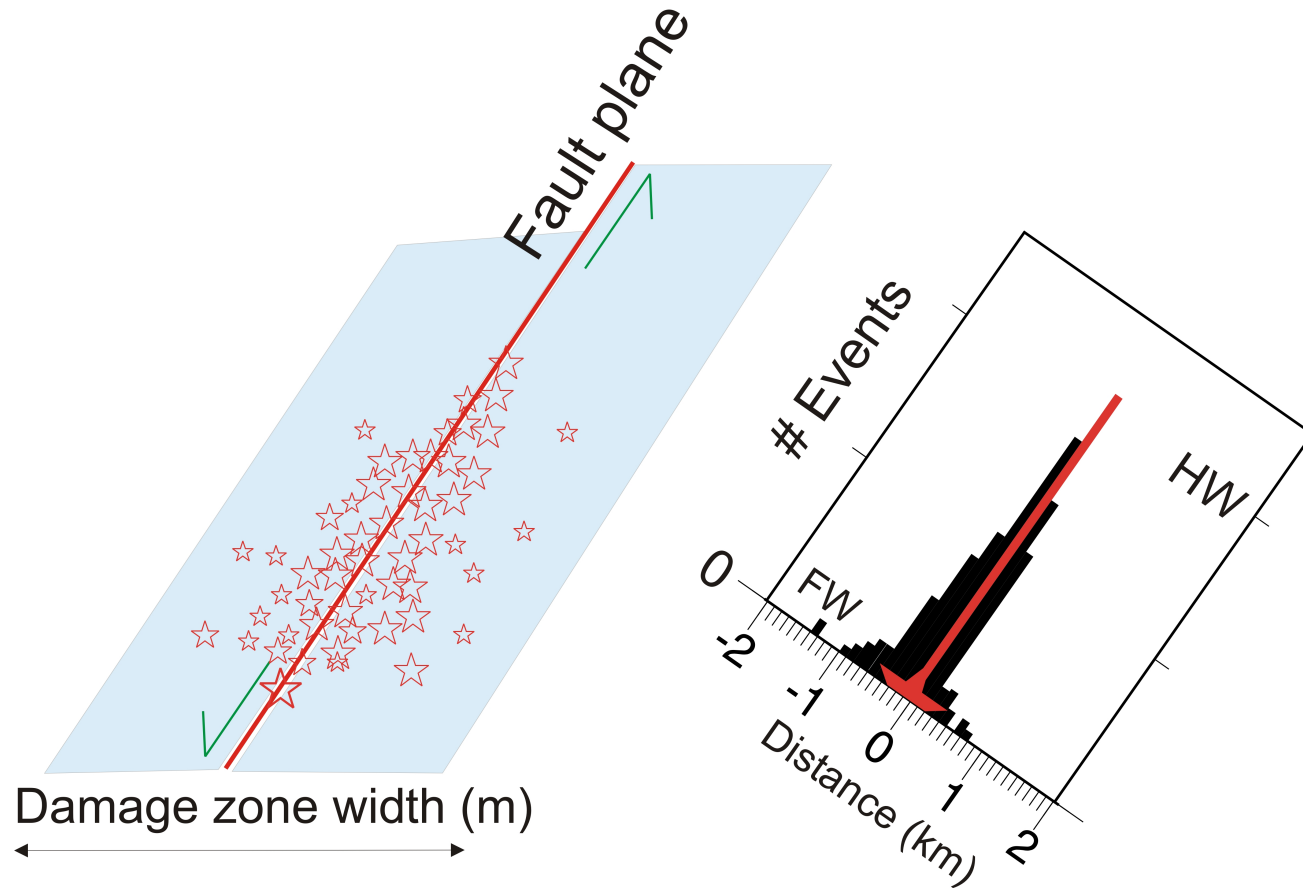
Outcomes on Fault Geometry

- **L'AQUILA FAULT** breaks the entire upper crust showing geometric and kinematic complexities both along strike and depth;
- **CMP FAULT** is **LISTRIC** with the largest earthquakes occurring in correspondence of major dip changes;
- **SECONDARY FAULTS** (i.e., tens of meters) are located in the overlapping areas in both FW and HW;
- the two major faults **DETACH** at the same depth with eqks showing low-angle extensional planes, suggesting a change in the **rheology** with depth.
- the seismological fault architecture (in carbonate bearing rocks) shows high-degree of complexity and strong similarities with field studies.

Just a little bit more...

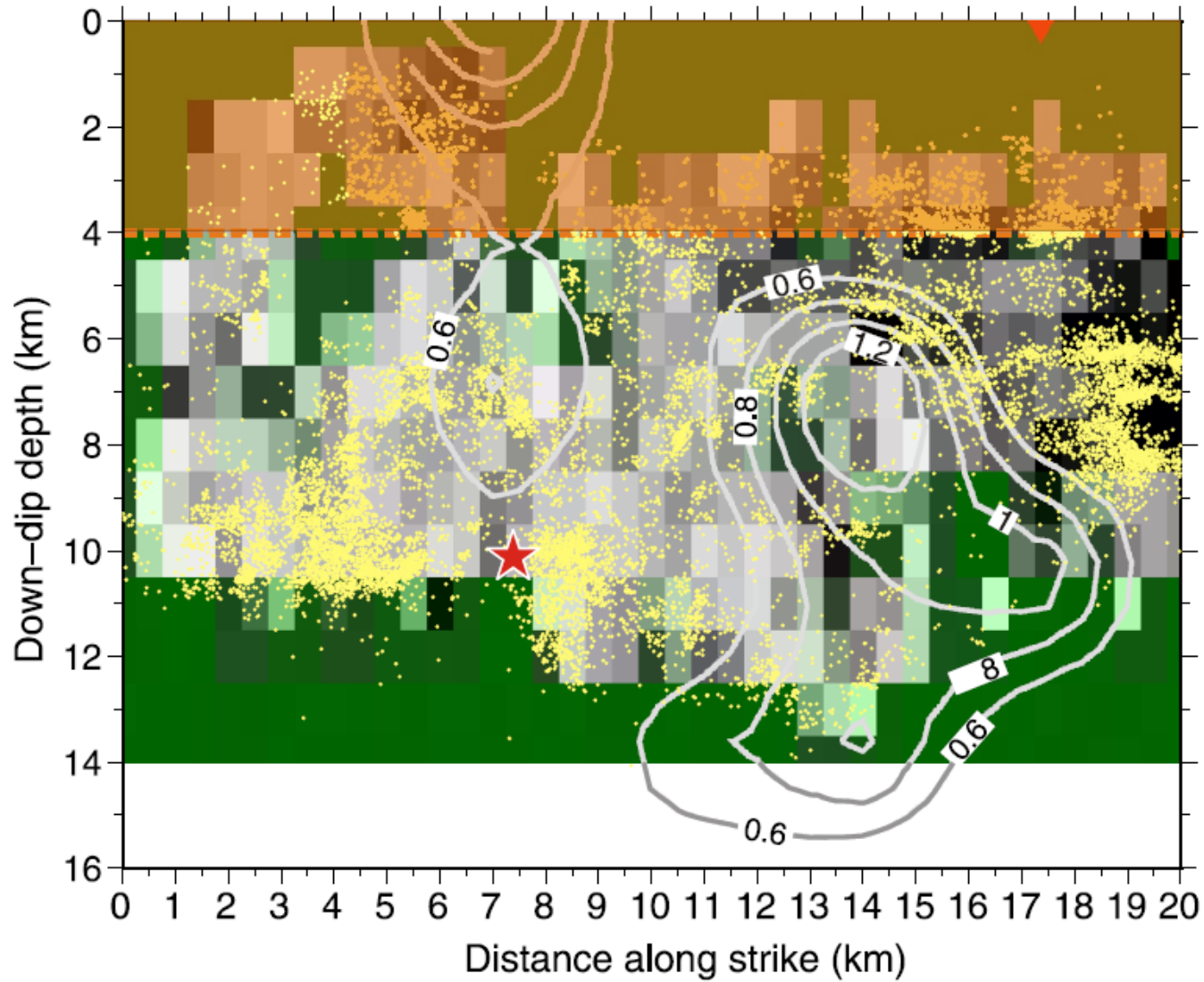
The **fault zone internal structure** (i.e., *fault geometry*) and its related properties (e.g., *lithology and/or fluid contents*) play a **key role in controlling the earthquake mechanics** (i.e., nucleation, propagation and arrest of an earthquake rupture).

Seismological Damage Zone (SDZ)



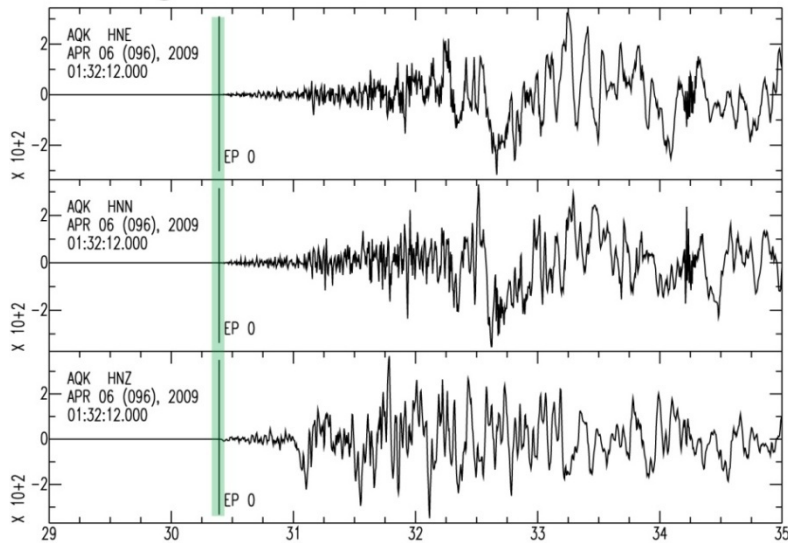
We investigate the structure of the damaged zone by quantifying earthquakes distribution in the main fault hanging- and foot-wall block.

SDZ along the fault plane

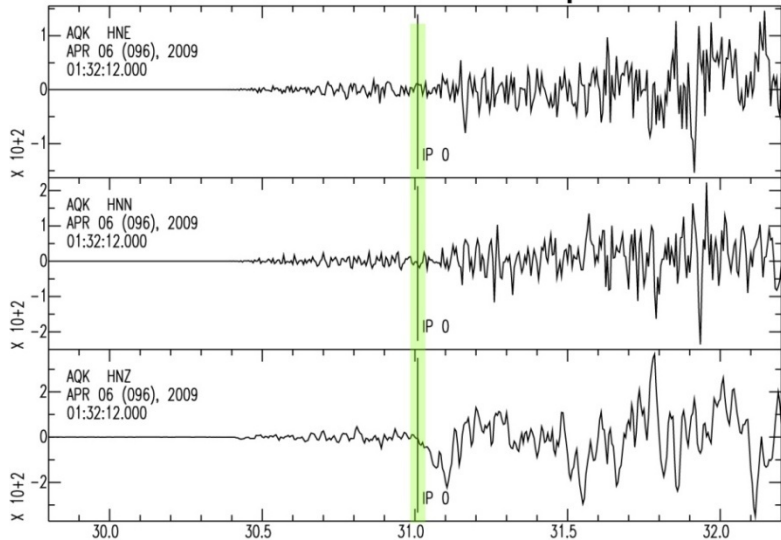


mainshock rupture

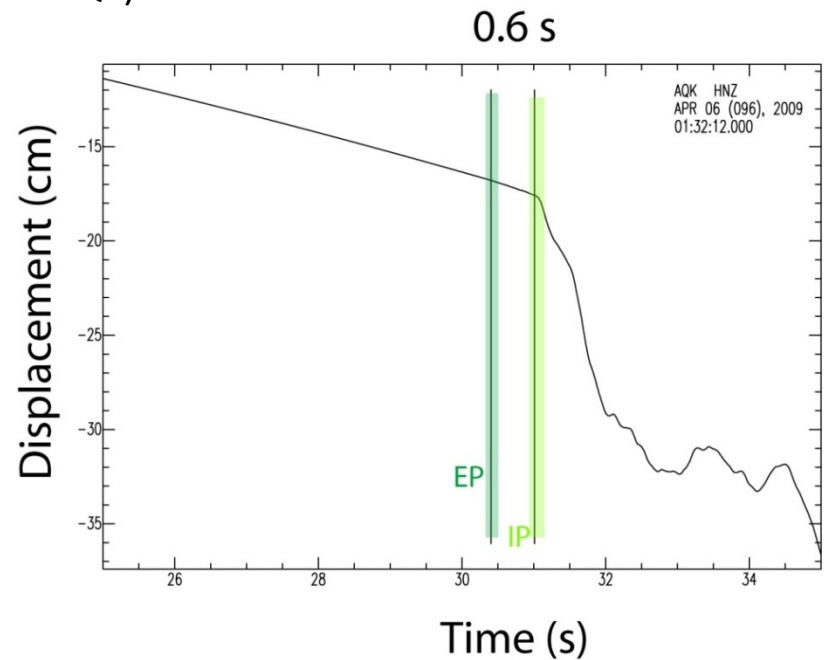
Emergent onset



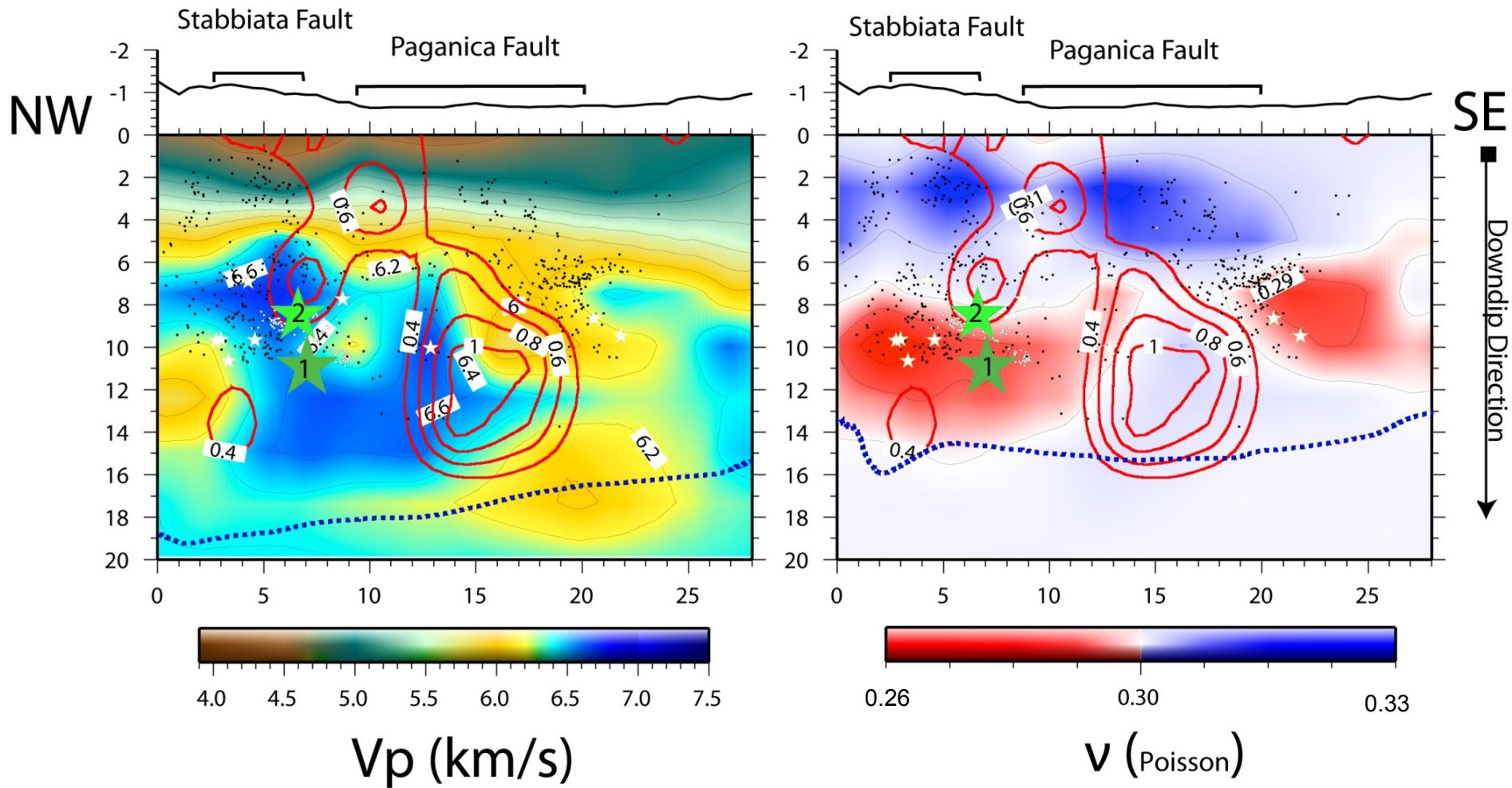
Main rupture



The 6th of April 2009 mainshock waveform shows evidence for source complexity: the figure highlights the *emergent (EP)* onset before a *impulsive (IP)* arrival (near field station AQK).



V_p , Poisson and coseismic slip



Outcomes on Earthquake Mechanics

- Strong spatial variations of **fault geometry** and **material properties** along faults **control the rupture** propagation during moderate-to-large magnitude earthquakes.
- Clear is the **fluid involvement** both in the preparatory/nucleation phase of the mainshock and in the early stage of the seismicity migration.

Grazie!