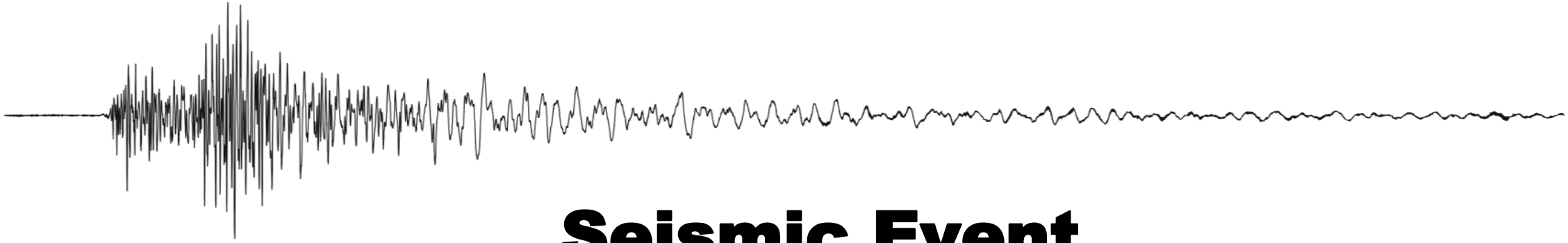

Seismic Event
M_L 3.5 Laviano (SA)
26/07/2023

Open File Report
The RISSC-Lab Team

F. Carotenuto, S. Colombelli, G. De Landro, L. Elia, G. Festa, A.G. Iaccarino, V. Longobardi, T. Muzellec, S. Nazeri, M. Palo, M. Picozzi, R. Rea, G. Russo, A. Scala, F. Scotto di Uccio, C. Strumia, S. Tarantino, M. Adil, A. Zollo

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RISSC-Lab: Laboratorio di
RIcerca in Sismologia Sperimentale e
Computazionale

INFO
Irpinia Near-Fault
Observatory

OUTLINE

- ❑Seismotectonic setting
- ❑Waveforms, location and mechanism
- ❑Seismic Moment, Rupture radius and stress drop
- ❑Strong Ground Shaking prediction – Shake Maps
- ❑Earthquake Early Warning testing

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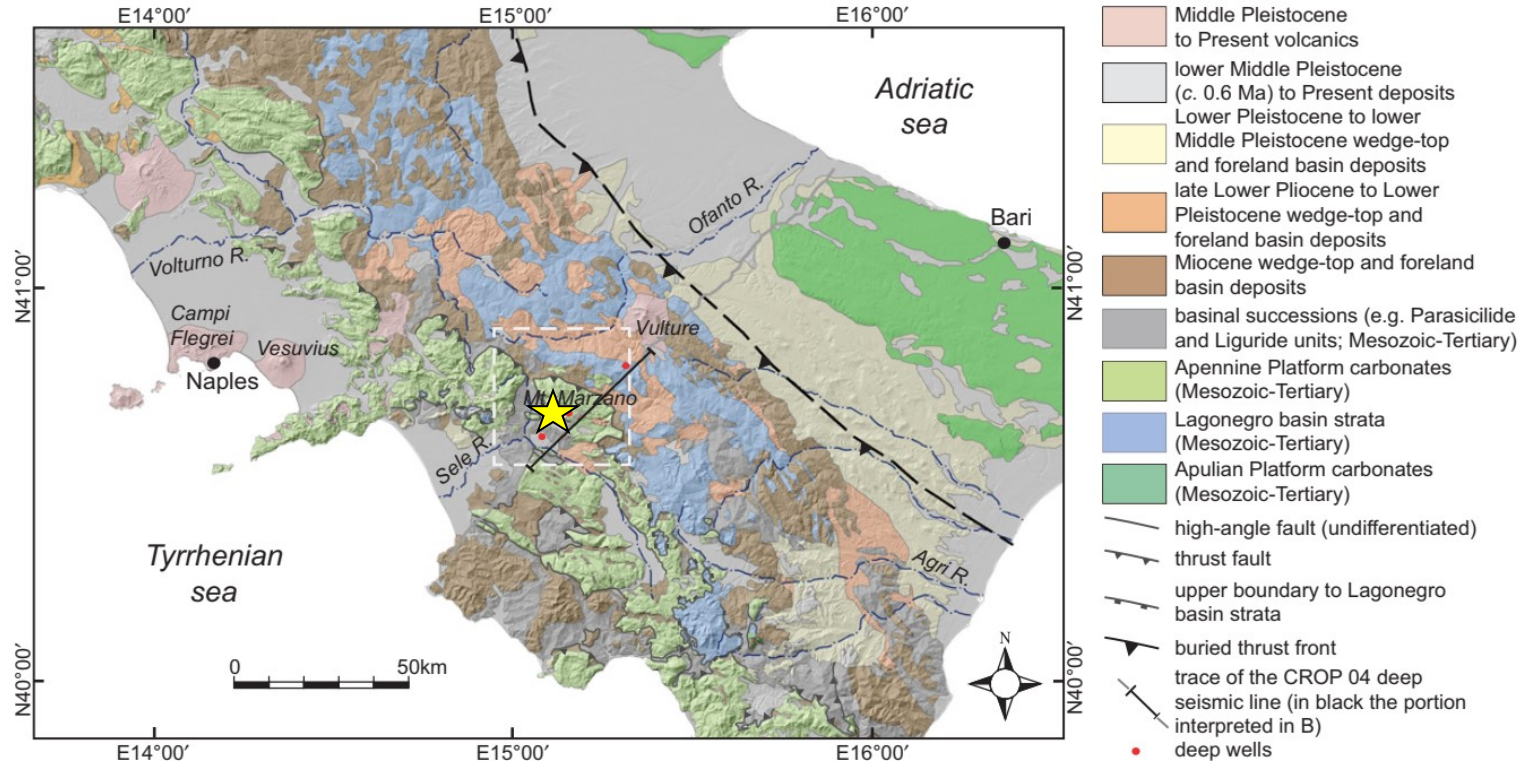
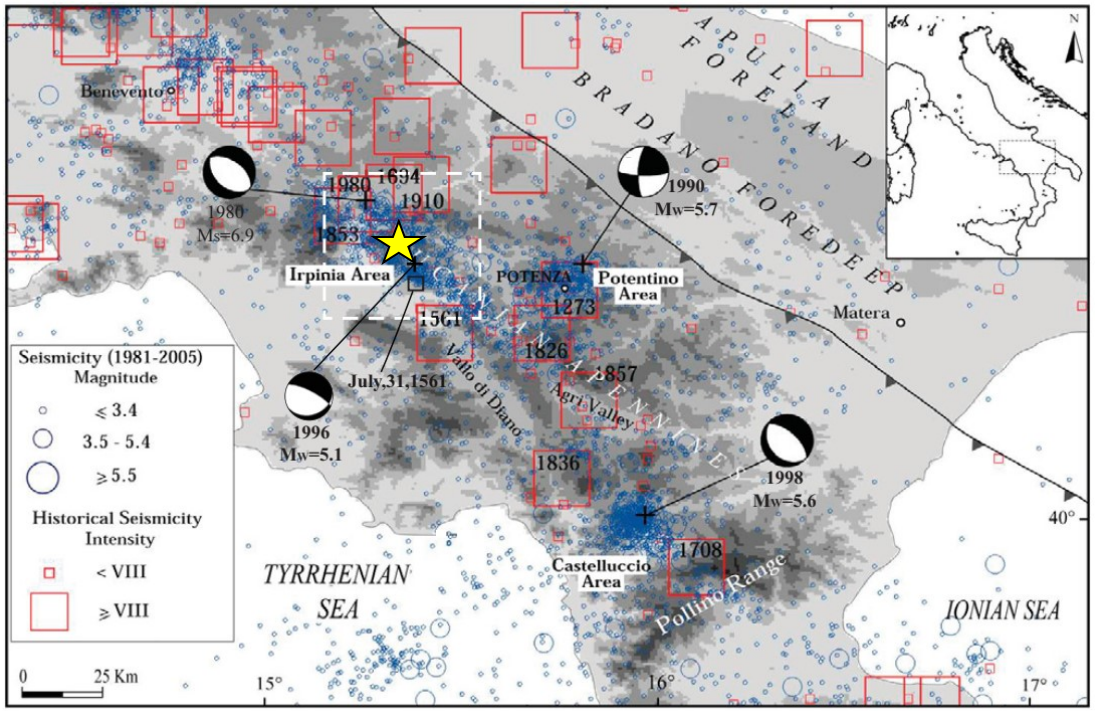
Seismotectonic Setting

Geological Setting



The ML 3.5 earthquake occurred along the Southern Apennines chain, a **fold and thrust belt** characterized by ENE-verging duplexes geometries and out-of-sequence thrusting due to orogenic contraction. It has been active since upper Eocene-Oligocene Miocene till late Pliocene. During the Quaternary the Southern Apennines thrust belt was dissected by NW-SE oriented normal faults that accommodated an **extensional tectonic phase**, according to a stress field with the axis of maximum extension coaxial to the axis of maximum compression of Apennines belt (*Doglioni 1995; Patacca et Scandone, 2007a, Ascione, 2013*). The figure shows the geological sketch map of Southern Apennines derived from A*scione et al.* (*2013*).

Historical and Instrumental Seismicity



Several historical earthquakes struck the Irpinia region with MCS intensity I ≥ X, occurred in A.D. 989, 1694, 1930, and 1962 (*CPTI Working Group, 2019; Ascione et al., 2013*). **The Ms 6.9, 1980 Irpinia earthquake** was the most destructive, instrumental earthquake of Southern Apennines **occurred along a system of NW-SE trending normal faults**. This event is described by a complex rupture process involving multiple fault segments according to (at least) three different nucleation episodes at 0 s, 20 s and 40 s times (e.g. *Bernard and Zollo, 1989*). In 1996 a seismic sequence with a mainshock of Mw 5.1 took place (*Cocco et al., 1999*) inside the epicentral area of 1980 earthquake.
In the figure the (historical and instrumental) seismicity and the focal mechanisms of the main last decade earthquakes are reported. The location of the July,26,2023 , ML 3.5 Laviano earthquake is indicated by the yellow star.

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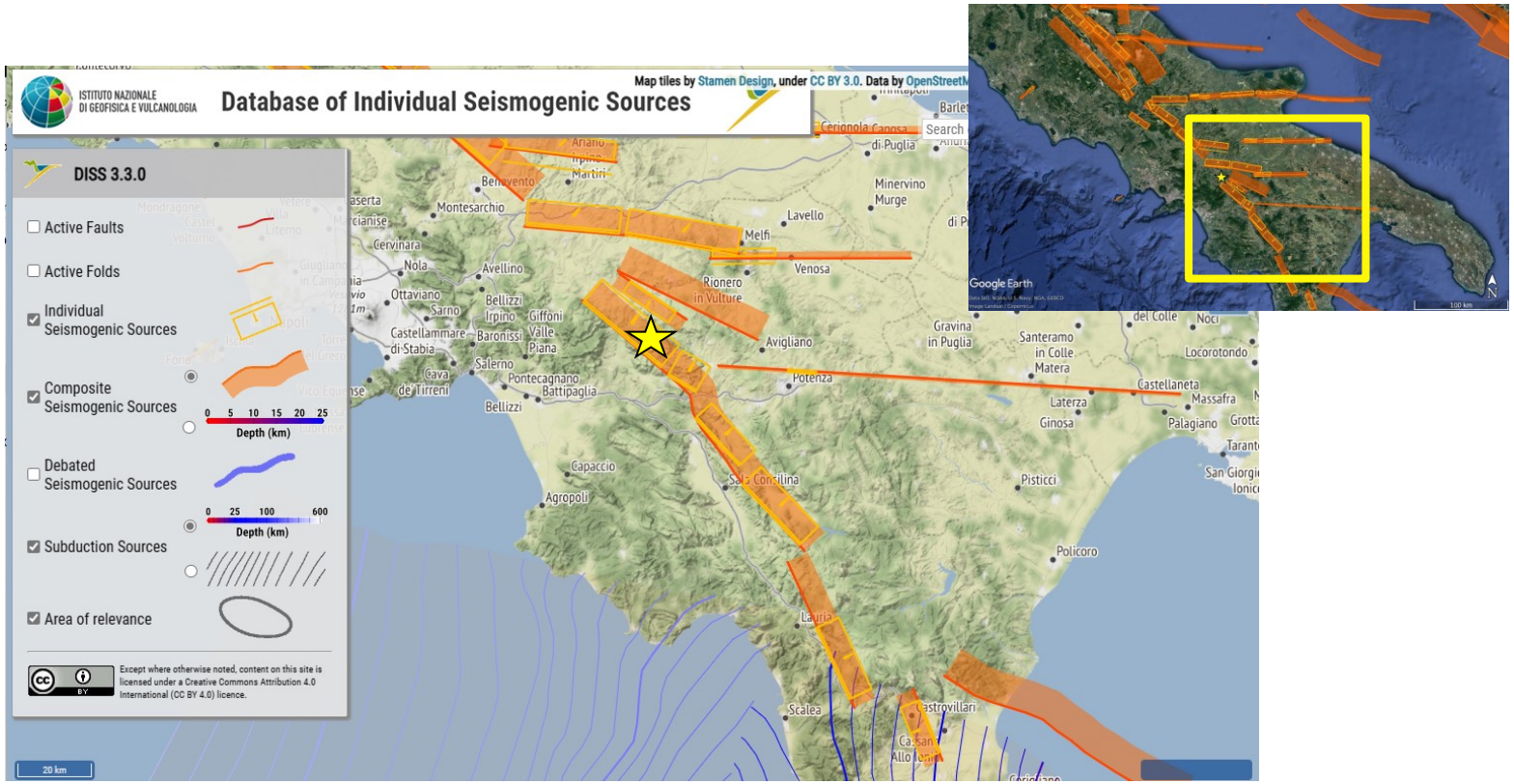
Seismotectonic Context



Historical earthquakes up to X-XI MCS intensities and instrumental seismicity with moderate to large events depict the Southern Apennines as a region with one of the **highest seismic hazard** of the Mediterranean area, with segmented, seismogenic structures (lateral extent of few tens of kilometers) capable of **generating up to M 7 earthquakes** (*Chiarabba et al, 2005; Improta et al., 2014*). The **ML 3.5, 2023, Laviano Earthquake occurred near the southern tip** of the NE-dipping fault segment activated during **the Ms 6.9, 1980 Irpinia earthquake**. In the figure the sources of earthquakes larger than ML 5.5 in Southern Apennines are reported (*DISS Working Group, 2018*). The location of the Laviano earthquake is indicated by a yellow star.

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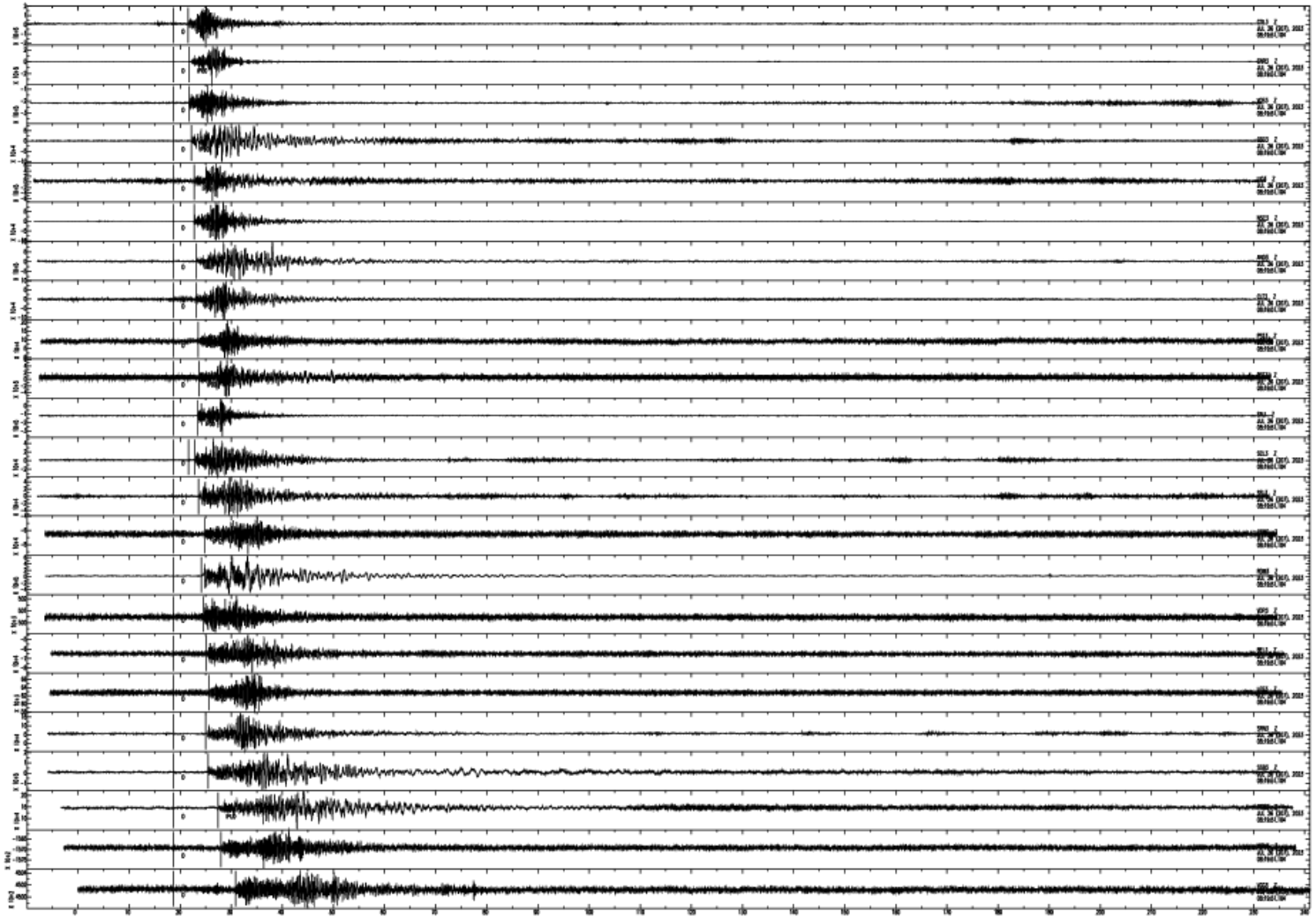
Seismic waveforms, Earthquake location & mechanism

Seismic records @ ISNet



Example of **seismic waveforms (vertical component)** recorded at the stations of ISNet, for the ML 3.5 event (26/07/2023 08:20:09 UTC) in the epicentral distance **range 11- 94 km.**

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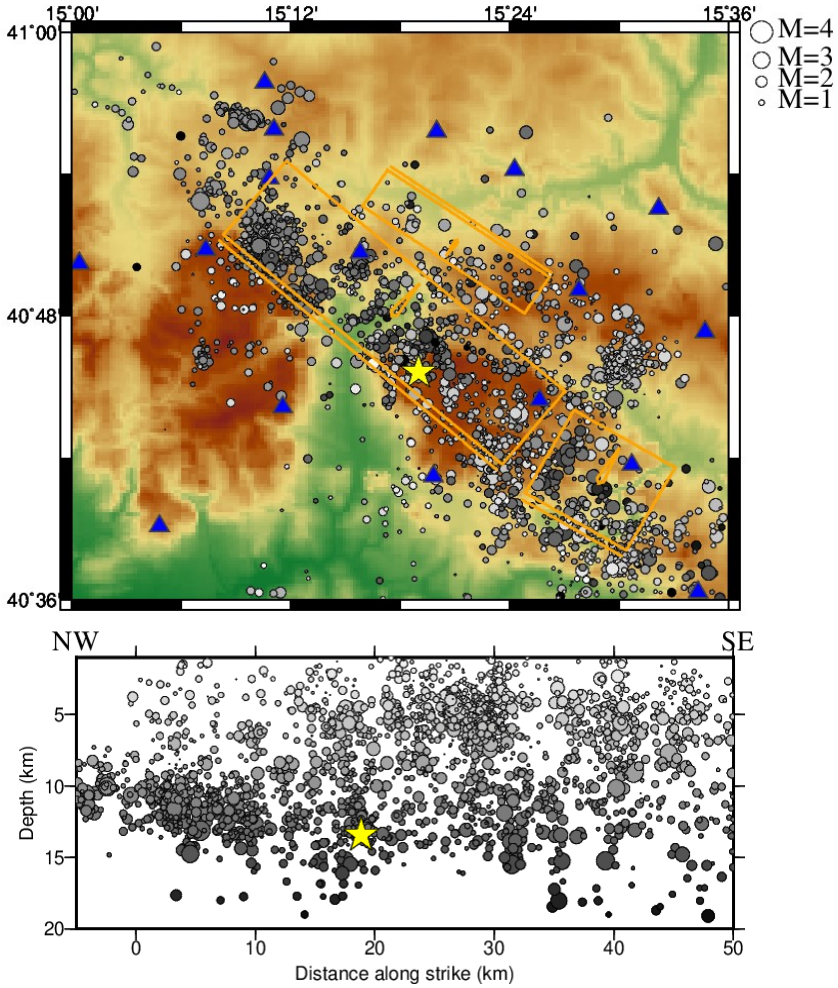
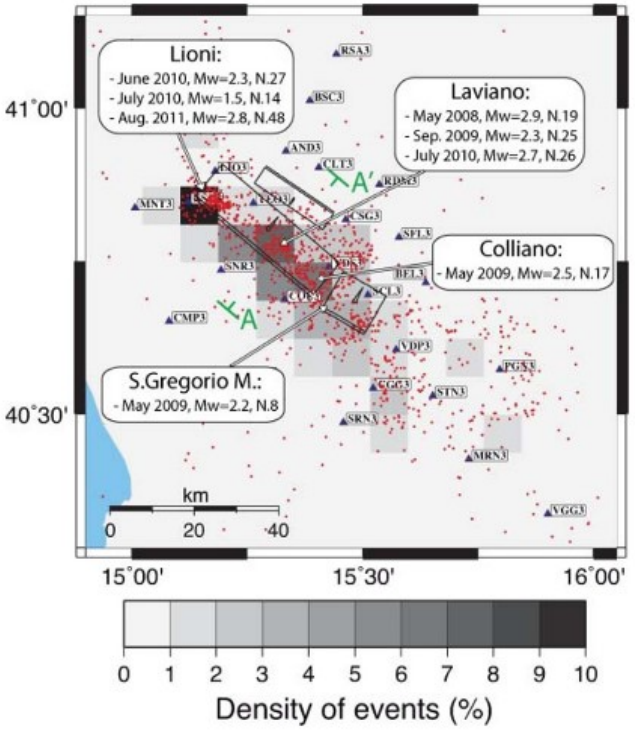
3D Absolute location



DATE & TIME: 2023-07-26 08:20:09.83
LAT: 40.7606 LON: 15.3167 DEPTH: 13.5

We performed the absolute location of Laviano event with NLLoc (Lomax, 2009) and the 3D P- and S-wave models optimized for the area (De Landro et al. 2022). The yellow star represent the event location. The location is well constrained with 48 arrival times (23 P and 15 S), GAP 59 degree, RMS 0.12 s and horizontal and vertical location errors of 200 m.
The grey dots represent the events occurred from 2008 within ISNet (-0.4<ML<3.7), coloured by depth. The orange boxes represent the 80 Irpinia eqk fault segments (DISS, 2023). The bottom panel shows the distribution of seismicity along strike (NW-SE) versus depth.
The event occurred in a volume with a high density of seismicity, especially seismic sequences, as in Stabile et al. 2012.



Stabile et al., 2012. SR

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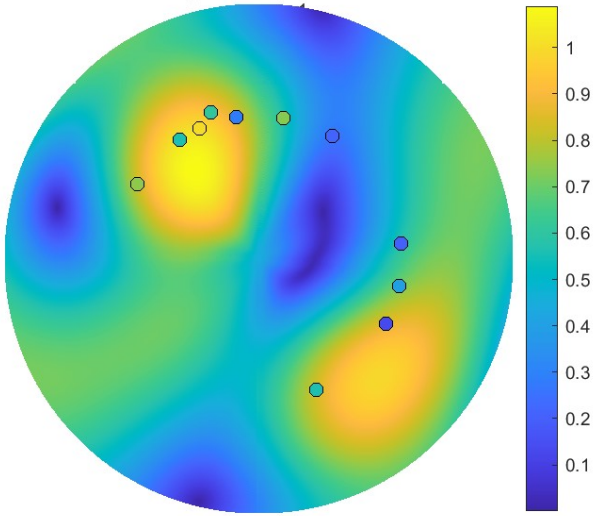
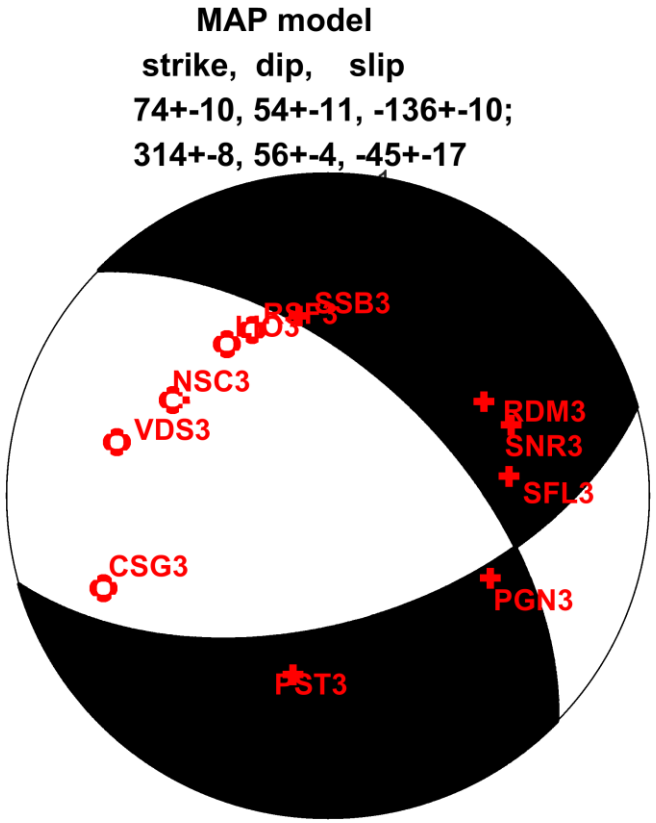
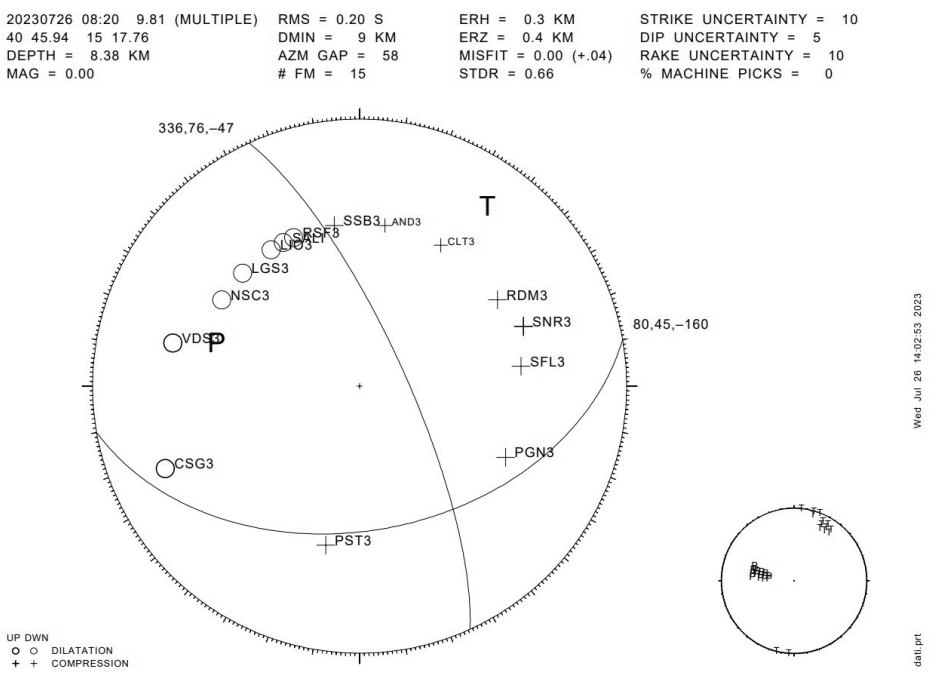
(c)



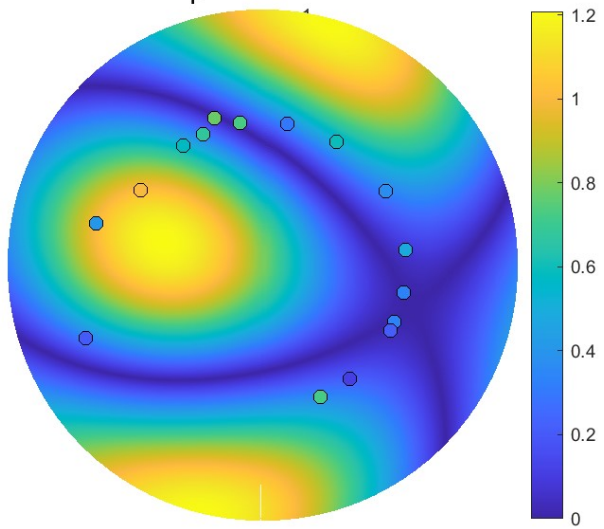
(b)



(a)



(d)



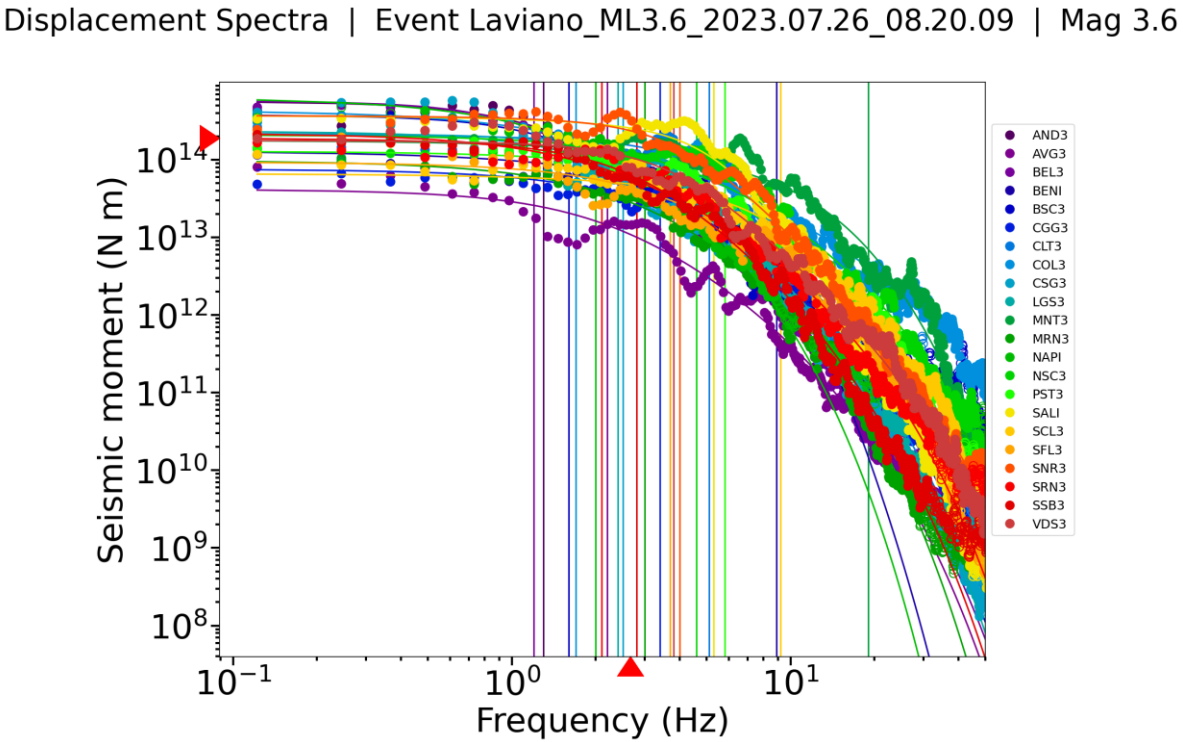
Focal mechanism solution shows a normal fault mechanism with a strike-slip component. Inversions performed using only polarities (a) and P and S amplitudes together with polarities (b-d) provide slightly different focal planes. The Kagan Angle between the two solutions is equal to 30°.

Seismic Moment, Moment Magnitude, Ruture radius and Stress Drop

Frequency Domain source parameters

- Data have been preprocessed to remove the instrumental response, then a time window of $8s$ has been selected around the S-pick, starting $1.5s$ before the arrival.
- Local attenuation in the spectral modeling is corrected using a regional quality factor Q=230.

Mw	ΔM_w	$f_c(Hz)$	$\Delta f_c(Hz)$	γ	$\Delta\gamma$	$\sigma(MPa)$	$\Delta\sigma(MPa)$	$r(\mathrm{m})$	$\Delta r(m)$
3. 44	0.01	2.7	0.1	2.33	0.03	3.2	0.3	295	10



Source parameter are resolved at 22 stations of the network.

Moment magnitude estimations between $M_w 3.22$ and $M_w 3.81$, with an averaged value $(M_w 3.44 \pm 0.01)$ that is coherent with ISNet $(M_w 3.3 \pm 0.2)$ and INGV $(M_L 3.6)$.

Most of corner frequencies estimates range in the bandwith $1Hz$ to $4Hz$; outliers may be ascribed to poor resolution of local attenuation properties.

Final estimate leads to a stress drop of $(3.2 \pm 0.3)MPa$ using the law from Kaneko & Shearer (2014).

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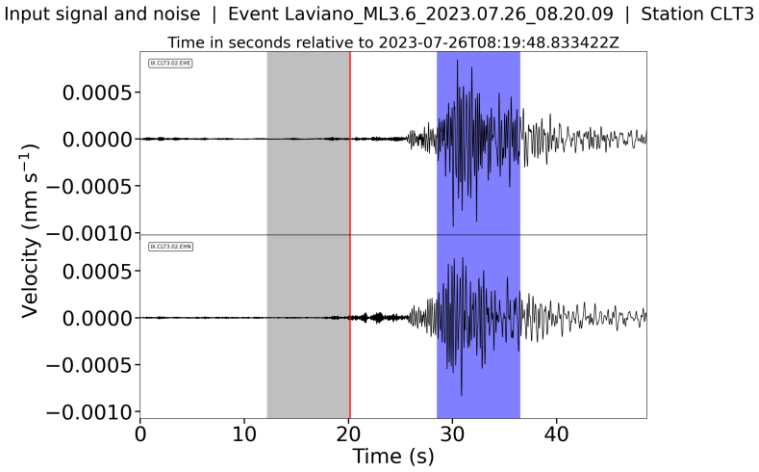
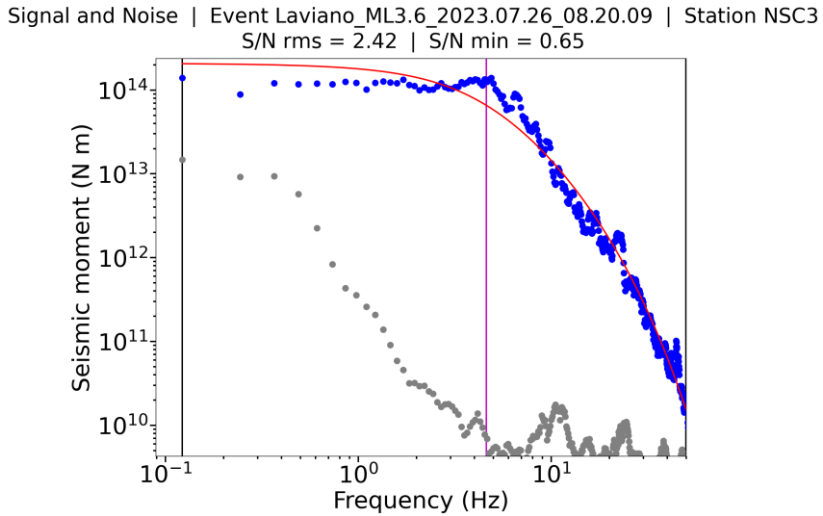
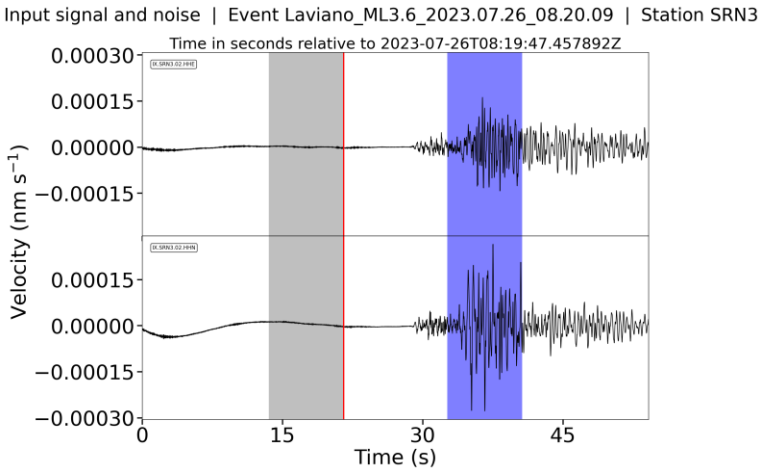
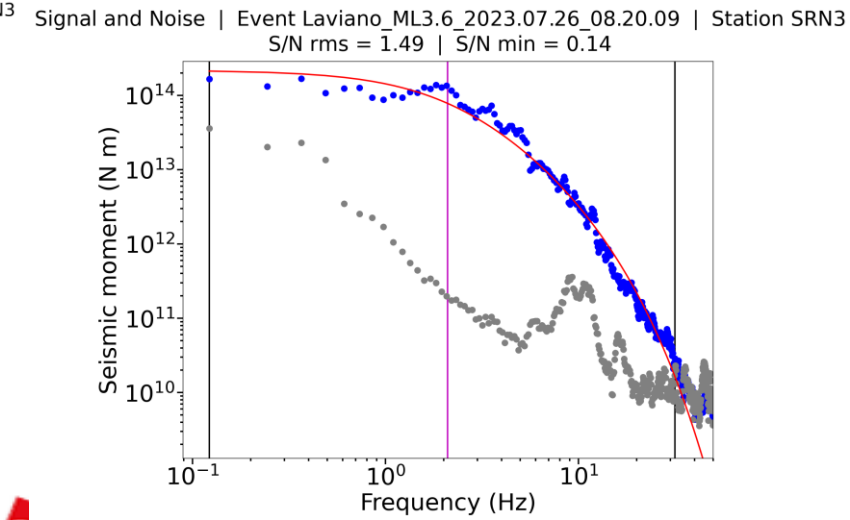
Frequency Domain source parameters: examples of records and displacement spectra









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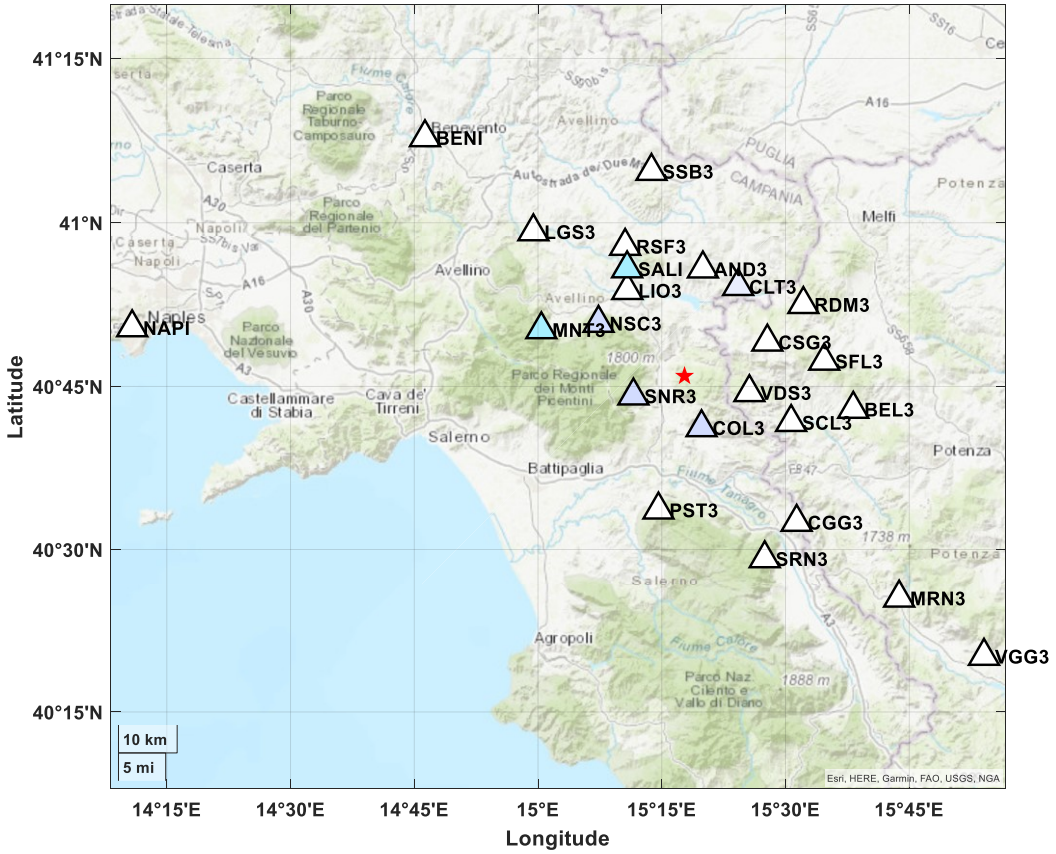
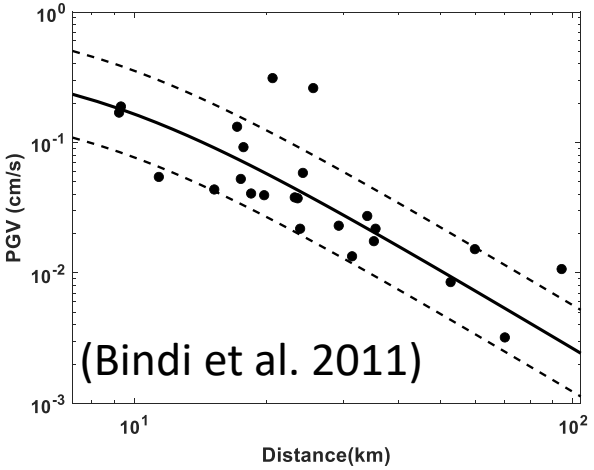
Strong Ground Shaking Prediction – Shake Maps

Strong Ground motion (PGV)



- Average epicentral distance $\sim 30.7\ km$
  - Min distances IX.COL3 $-9.2\ km$
  - Max distance IX.NAPI $-94.5\ km$
- PGV observed on velocimeters (where available) and integrated from accelerometers
- PGV range
  - $PGV_{min} = 3.2 \cdot 10^{-3}\ cm/s$ (IX.VGG3)
  - $PGV_{max} = 0.31\ cm/s$(IX.SALI)



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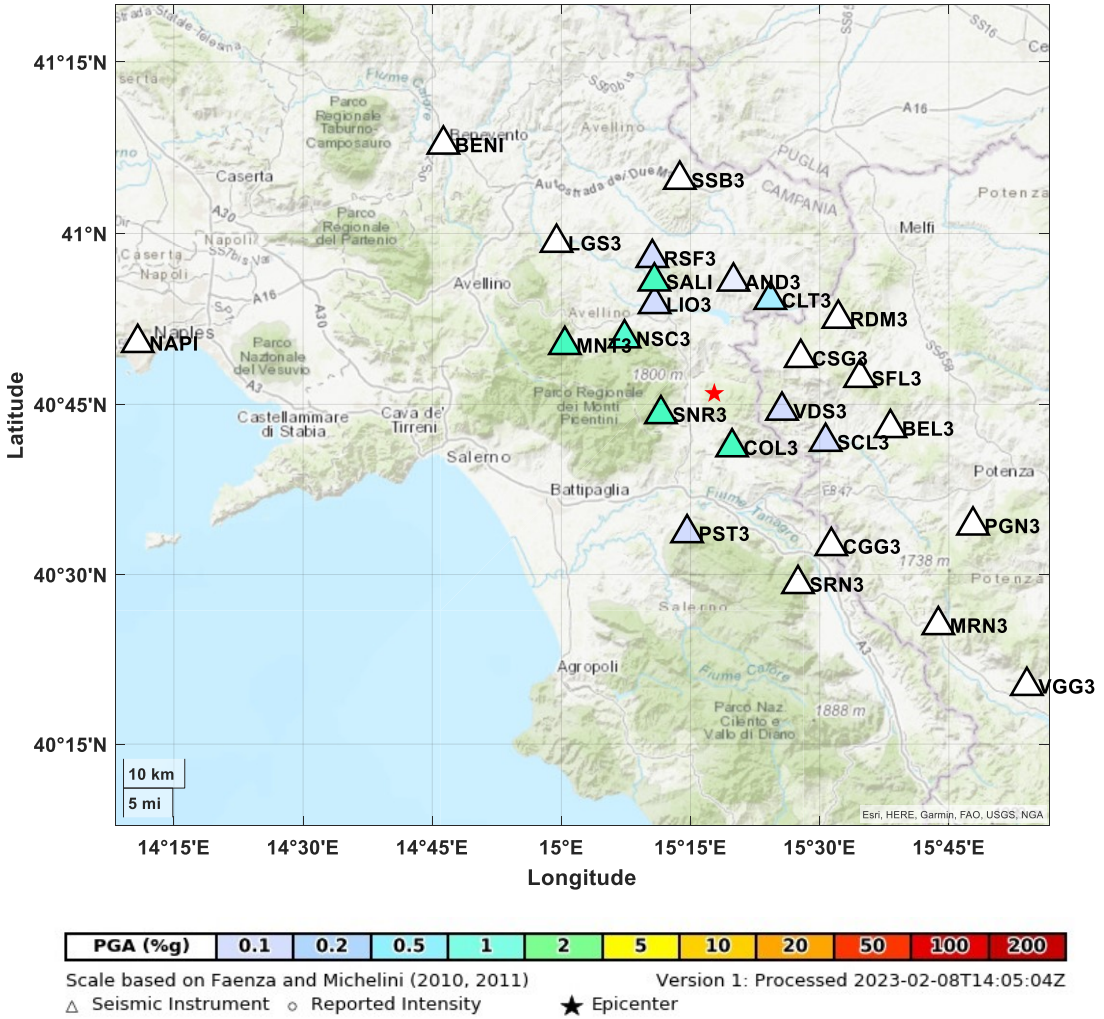
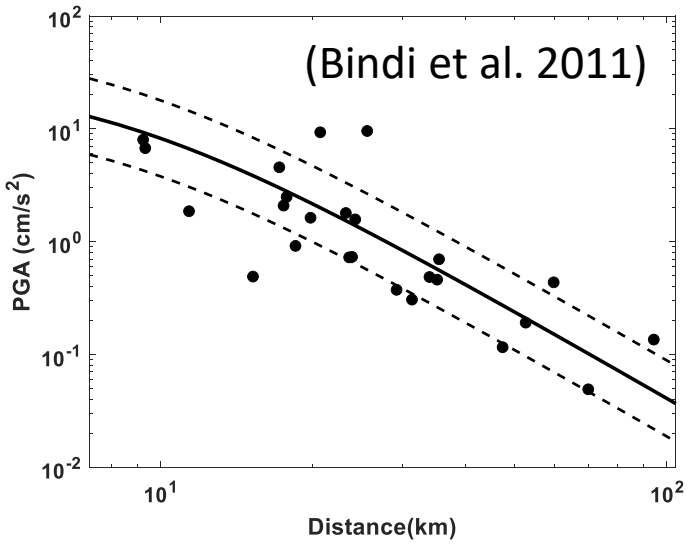
Irpinia Near-Fault Observatory

Strong Ground Motion (PGA)



- PGA range
  - $PGA_{min} = 5.0 \cdot 10^{-3}\%g$ (IX.VGG3)
  - $PGA_{max} = 0.98\%g$ (IX.MNT3)



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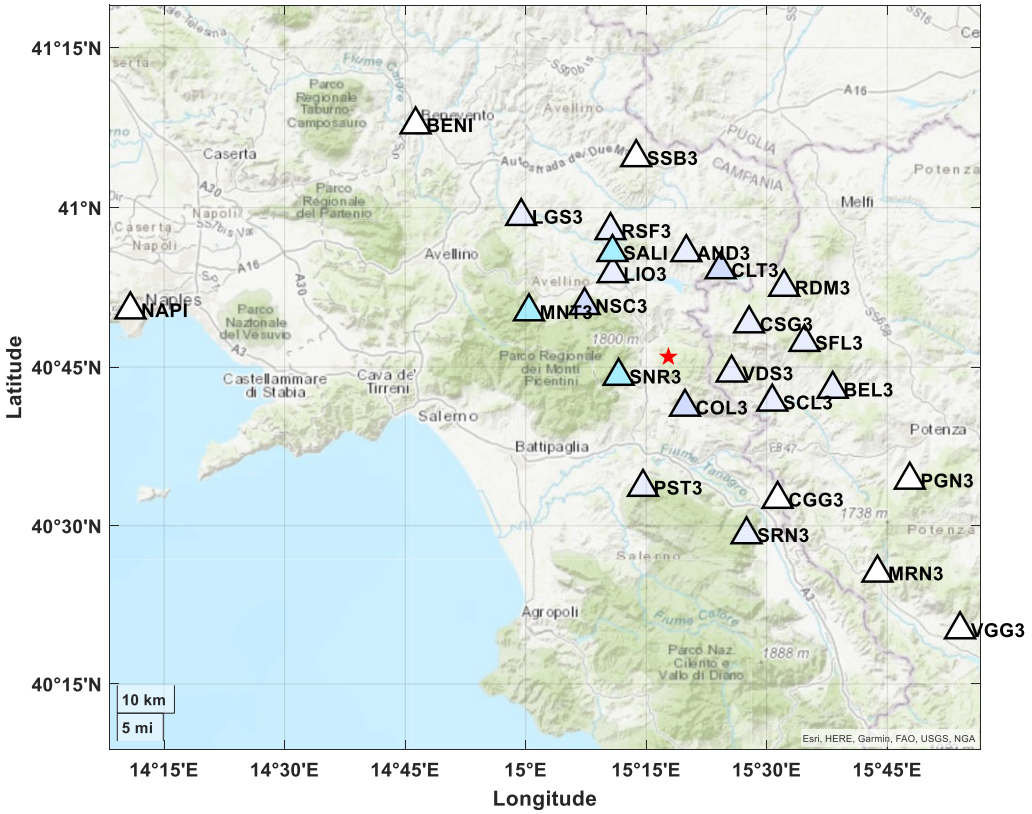
Irpinia Near-Fault Observatory

Strong Ground motion (IMM)



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0556	0.212	0.808	1.97	4.82	11.8	28.7	70.1	>171
PGV(cm/s)	<0.0178	0.0775	0.337	0.898	2.39	6.37	17	45.2	>120
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Faenza and Michelini (2010, 2011) Version 1: Processed 2023-02-08T14:05:04Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter

- Average epicentral distance $\sim 30.7\ km$
  - Min distances IX.COL3 $-9.2\ km$
  - Max distance IX.NAPI $-94.5\ km$
- IMM range
  - $IMM_{max} = IV$ (3.9 - IV.SALI)

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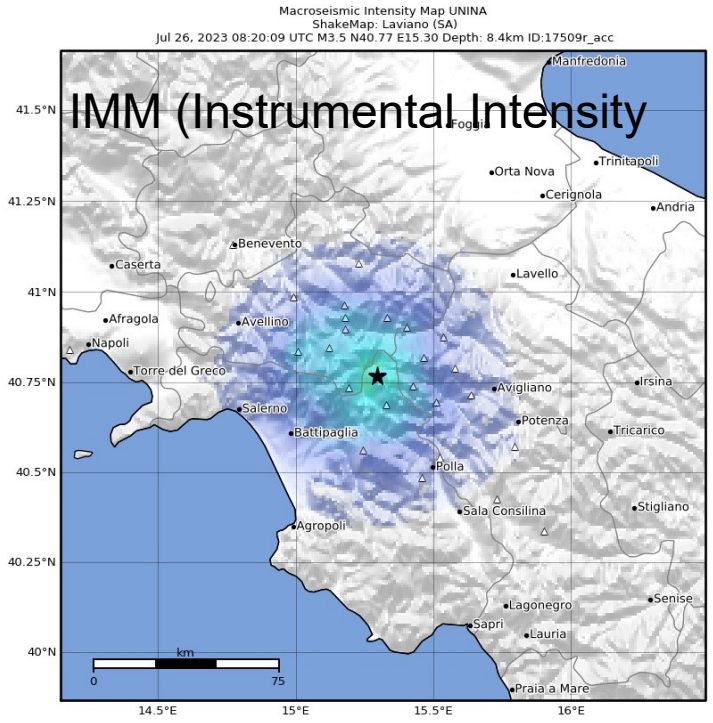
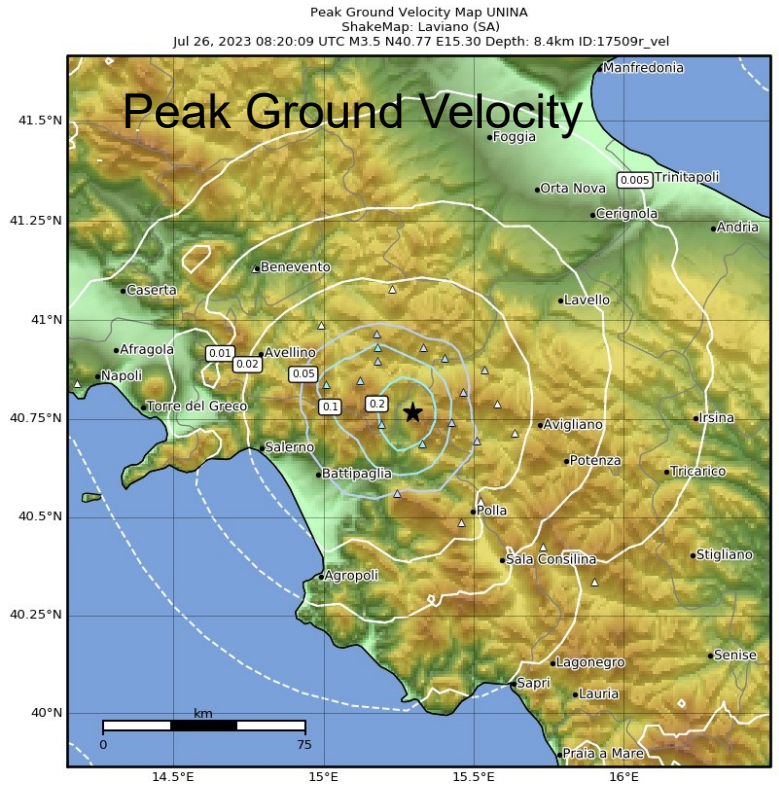
Irpinia Near-Fault Observatory

Strong Ground motion (ShakeMaps)



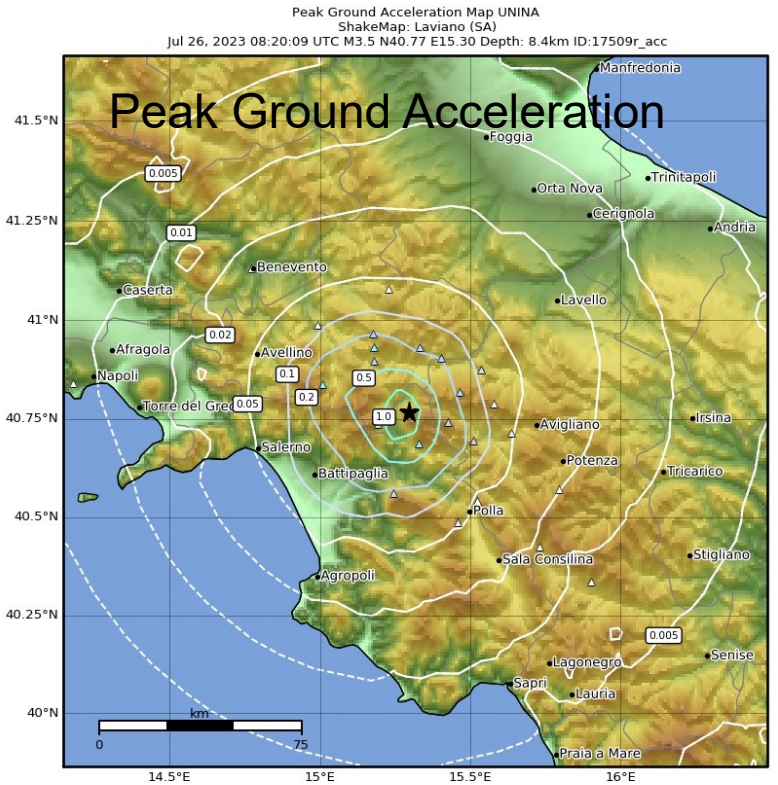
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.055	0.212	0.808	1.97	4.82	11.8	28.7	70.1	>171
PGV(cm/s)	<0.0178	0.0775	0.337	0.898	2.39	6.37	17	45.2	>120
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Faenza and Michelini (2010, 2011) Version 1: Processed 2023-07-26T13:51:13Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter



PGV (cm/s)	0.1	0.2	0.5	1	2	5	10	20	50	100	200

Scale based on Faenza and Michelini (2010, 2011) Version 1: Processed 2023-07-26T13:53:53Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter



PGA (%g)	0.1	0.2	0.5	1	2	5	10	20	50	100	200

Scale based on Faenza and Michelini (2010, 2011) Version 1: Processed 2023-07-26T13:51:13Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter

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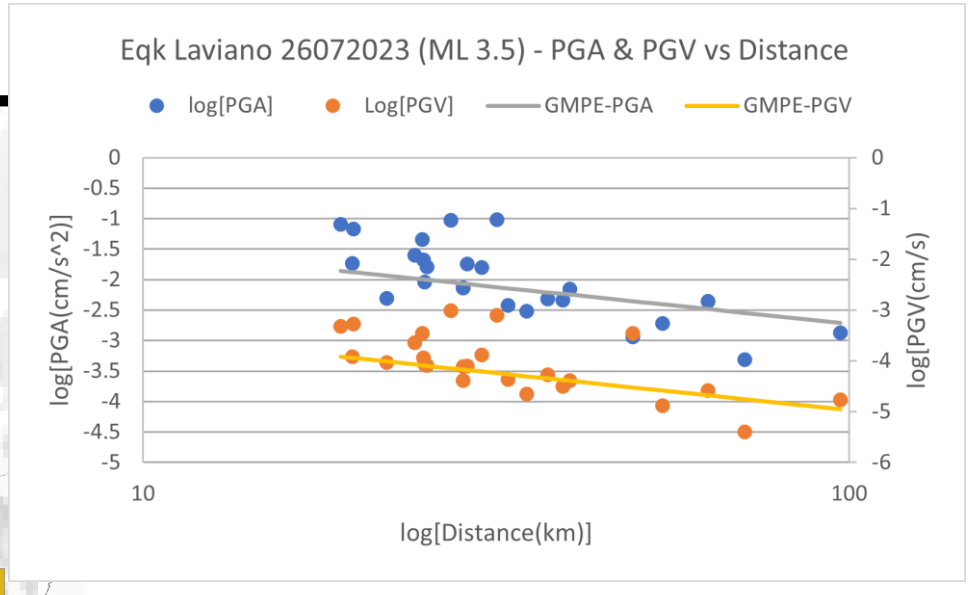
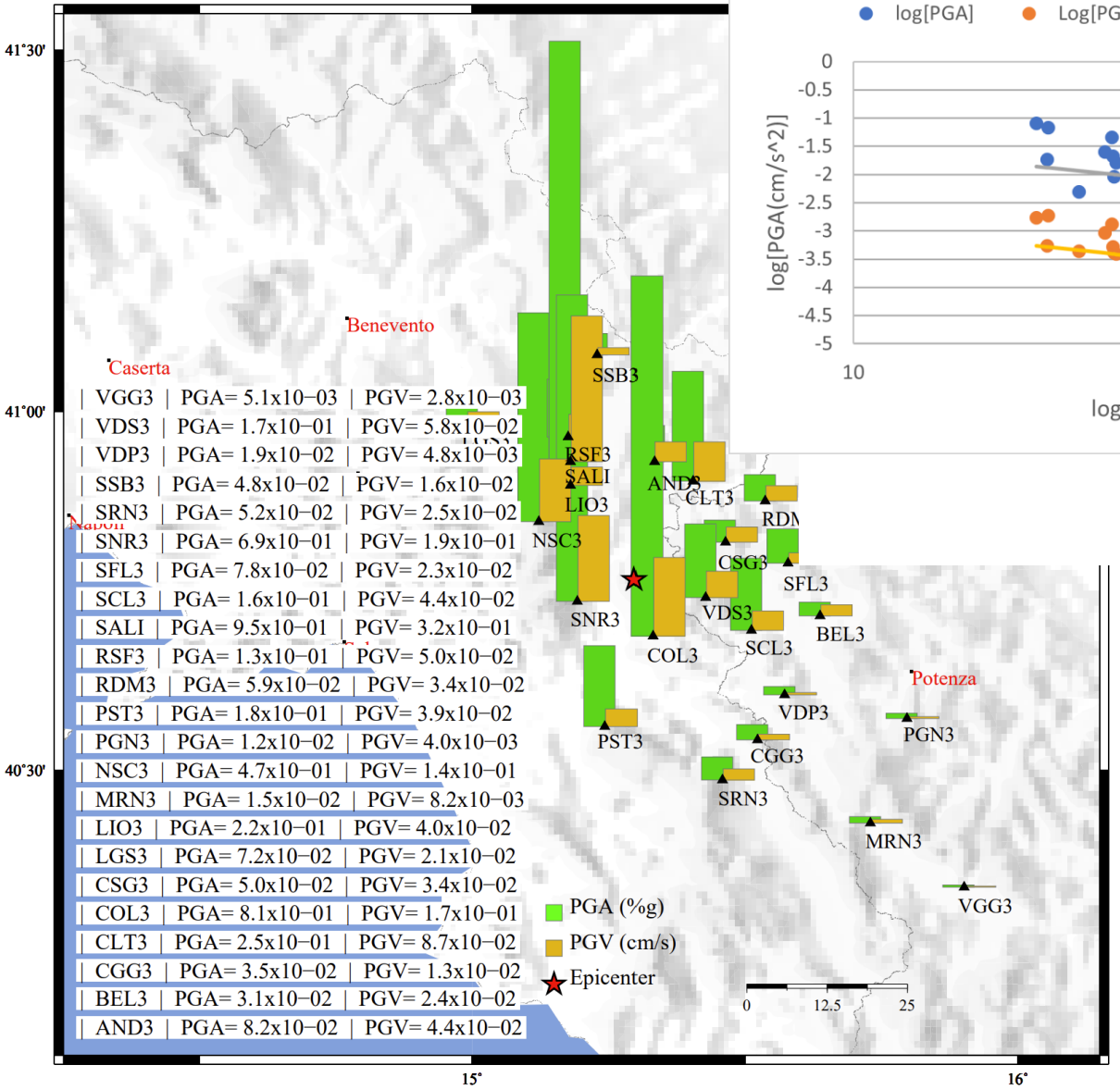
GROUND MOTION





VGG3	PGA= 5.1x10−03	PGV= 2.8x10−03
VDS3	PGA= 1.7x10−01	PGV= 5.8x10−02
VDP3	PGA= 1.9x10−02	PGV= 4.8x10−03
SSB3	PGA= 4.8x10−02	PGV= 1.6x10−02
SRN3	PGA= 5.2x10−02	PGV= 2.5x10−02
SNR3	PGA= 6.9x10−01	PGV= 1.9x10−01
SFL3	PGA= 7.8x10−02	PGV= 2.3x10−02
SCL3	PGA= 1.6x10−01	PGV= 4.4x10−02
SALI	PGA= 9.5x10−01	PGV= 3.2x10−01
RSF3	PGA= 1.3x10−01	PGV= 5.0x10−02
RDM3	PGA= 5.9x10−02	PGV= 3.4x10−02
PST3	PGA= 1.8x10−01	PGV= 3.9x10−02
PGN3	PGA= 1.2x10−02	PGV= 4.0x10−03
NSC3	PGA= 4.7x10−01	PGV= 1.4x10−01
MRN3	PGA= 1.5x10−02	PGV= 8.2x10−03
LIO3	PGA= 2.2x10−01	PGV= 4.0x10−02
LGS3	PGA= 7.2x10−02	PGV= 2.1x10−02
CSG3	PGA= 5.0x10−02	PGV= 3.4x10−02
COL3	PGA= 8.1x10−01	PGV= 1.7x10−01
CLT3	PGA= 2.5x10−01	PGV= 8.7x10−02
CGG3	PGA= 3.5x10−02	PGV= 1.3x10−02
BEL3	PGA= 3.1x10−02	PGV= 2.4x10−02
AND3	PGA= 8.2x10−02	PGV= 4.4x10−02

PGA – PGV observations

Here we represent the peak amplitudes (**PGA and PGV**) observed at ISNet stations. We observe the maximum peak amplitudes for stations nearby the epicenter. However, along the Apennine direction, in the NO direction, the peak amplitudes are larger than those observed in the SW direction.

On average **peak amplitudes match the GMPEs** (blu/orange curves) retrieved for the area (*Emolo et al., 2011*).

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Irpinia Near-Fault Observatory

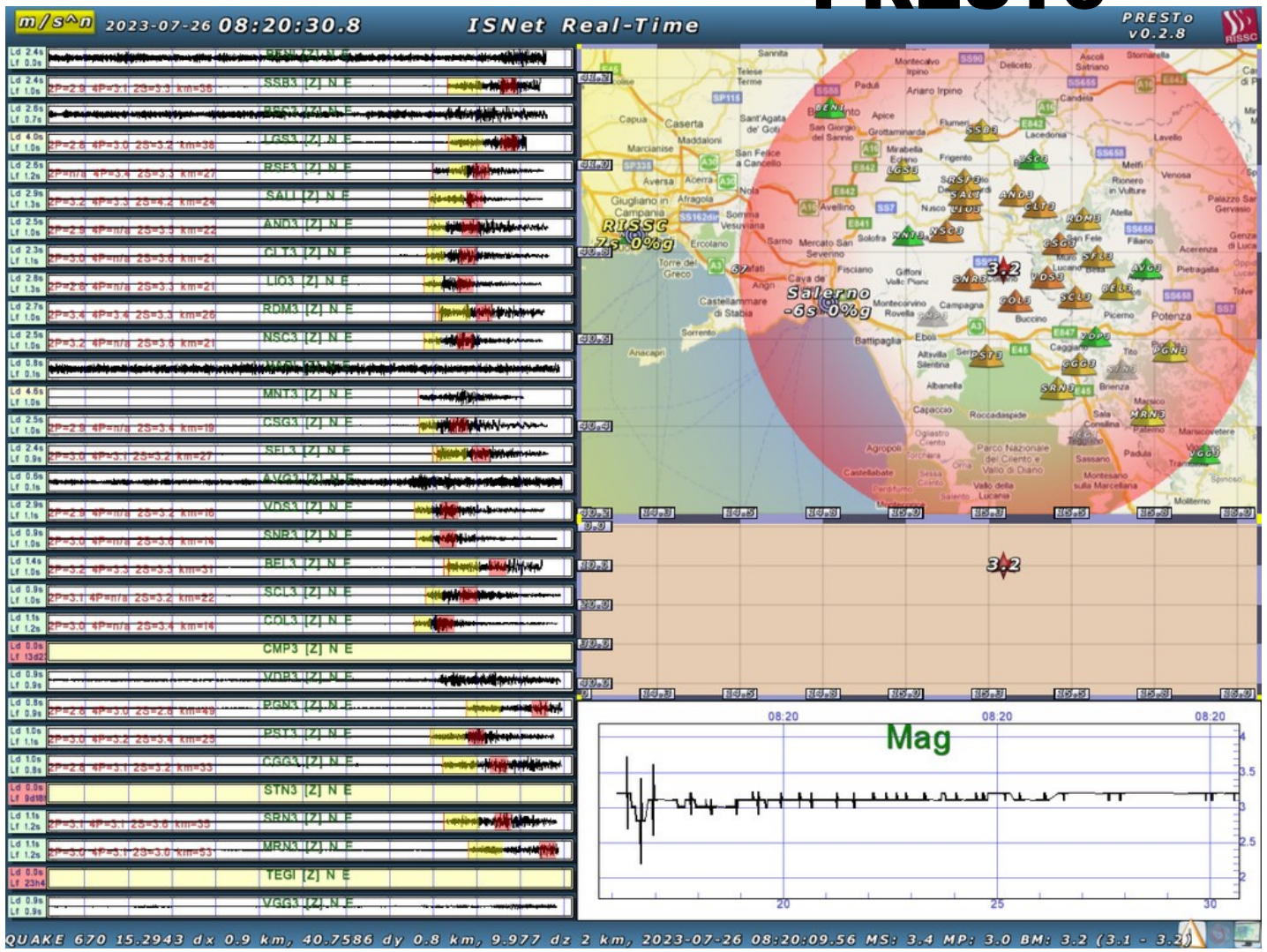
Earthquake Early Warning Testing

PRESTo – Probabilistic and Evolutionary Early Warning System

QuakeUP – Shaking-Forecast Based Earthquake Early Warning System

SAVE – Onsite Alert Level warning system

Early Warning System (network-Based)
PRESTo



ML 3.2, Laviano (SA)
40.7633, 15.3091, 13.094 km
2023-07-26 08:20:09.24 (UTC)

FIRST ALERT AFTER: 6.9 sec from the Origin Time
(4.5 sec from 1st pick, 8 stations)

MAG error: -0.3

LOC_epi error : 4.8 km
LOC_dep_error: 10 km

LAST ALERT AFTER 21.3 sec from T0
(17,85 sec from 1st pick, 21 stations)
MAG error: -0.3
LOC_epi error : 1 km
LOC_dep_error: 1.8 km

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Final Message from PRESTo

Il sistema di Early Warning **PRESTo**, in fase di sperimentazione presso il RISSC-Lab,
ha rilevato automaticamente un evento:

ML: **3.2**
Data: **2023-07-26 08:20:09.56 (UTC)**
Località: **Laviano (SA)**
Google Map

utilizzando **21 stazioni** della rete **ISNet - Irpinia Seismic Network.**

La prima informazione su magnitudo e localizzazione dell'evento è stata disponibile al tempo:

2023-07-26 08:20:16.21 (UTC)

Cioè circa **3.5** secondi dopo il primo arrivo P rilevato alla stazione COL3 al tempo:

2023-07-26 08:20:12.71 (UTC)

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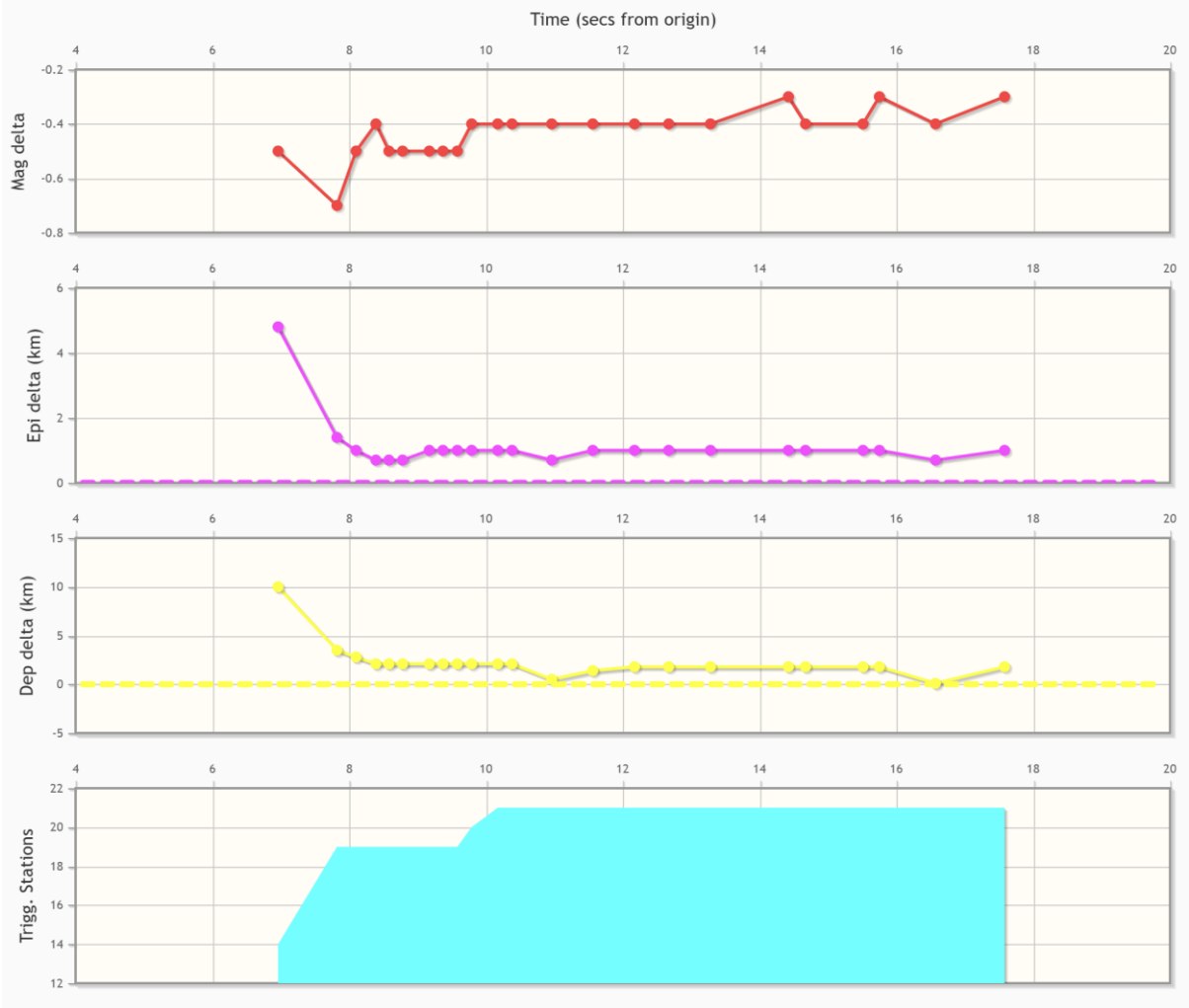
Real Time evolution PRESTO

Magnitude

Epicenter

Depth

Stations



Comparison of PRESTo estimates with ISNet bulletin values (dashed lines).

These analyses are automatically performed by the platform CREW

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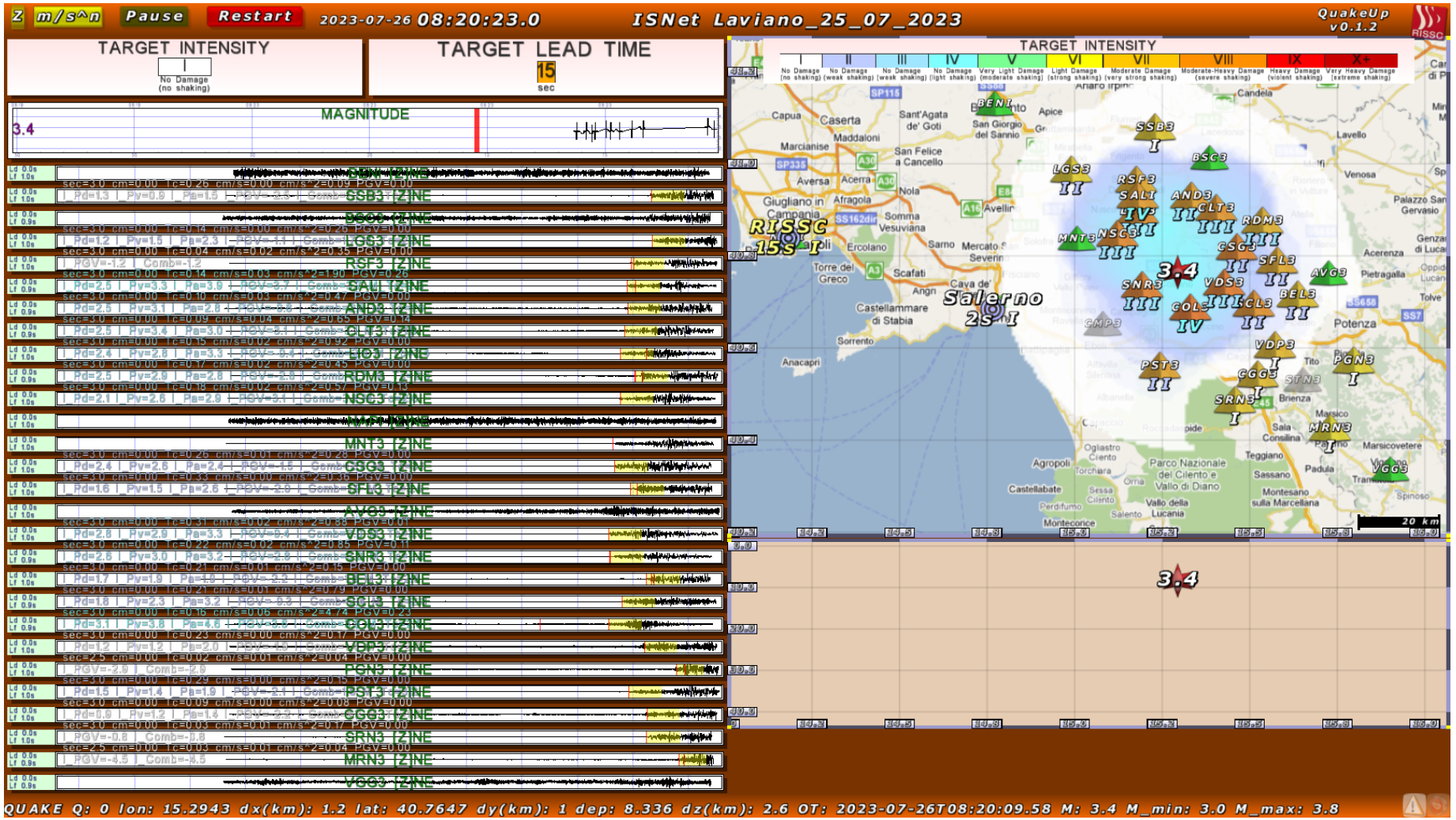
EARLY WARNING

Shaking-Forecast-Based Early Warning System
QUAKE-UP



About 6 sec after the Origin time of the earthquake the system is able to predict and map the extent of the Potential Damage Zone (here represented by the IMM 3-4) using the information from early P-wave amplitudes combined with predictions from the GMPE through the real-time earthquake location and magnitude. The predicted PDZ shows a primary elongation toward NW, which is an indication for dominant rupture directivity to N-NW.

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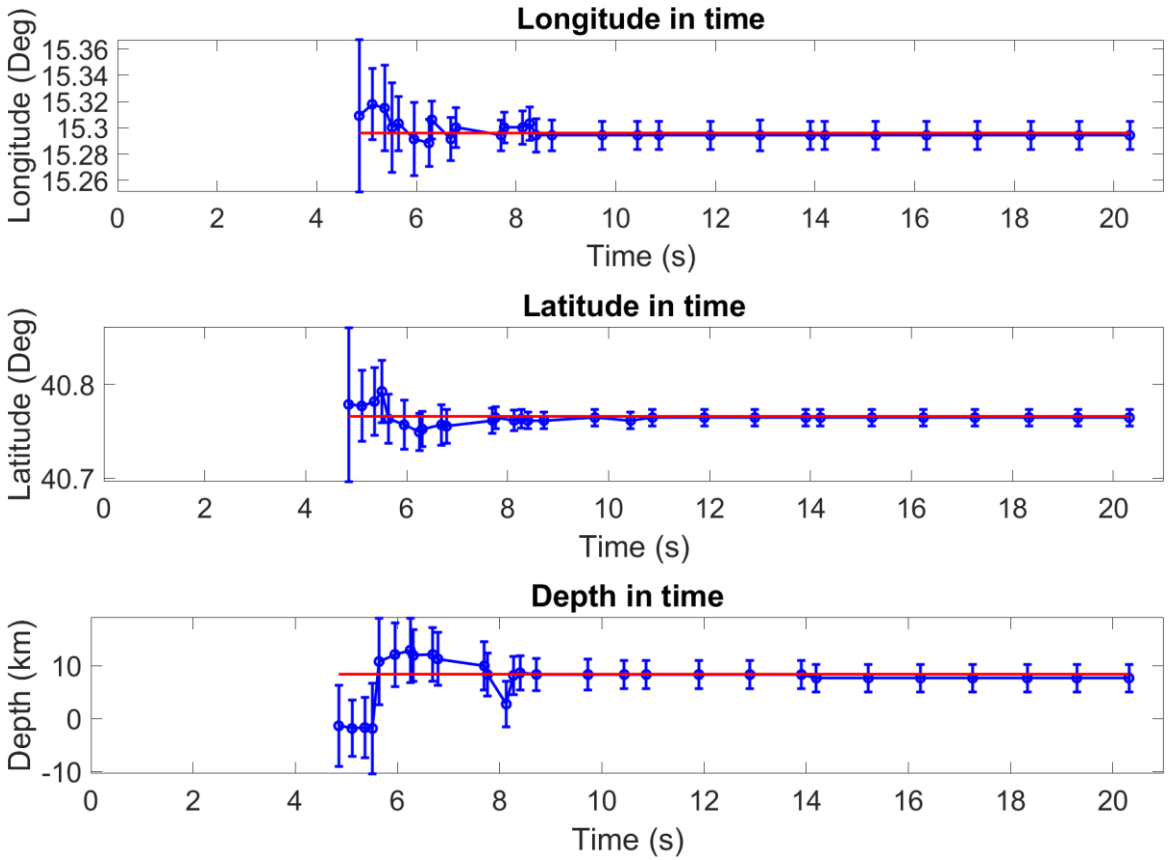
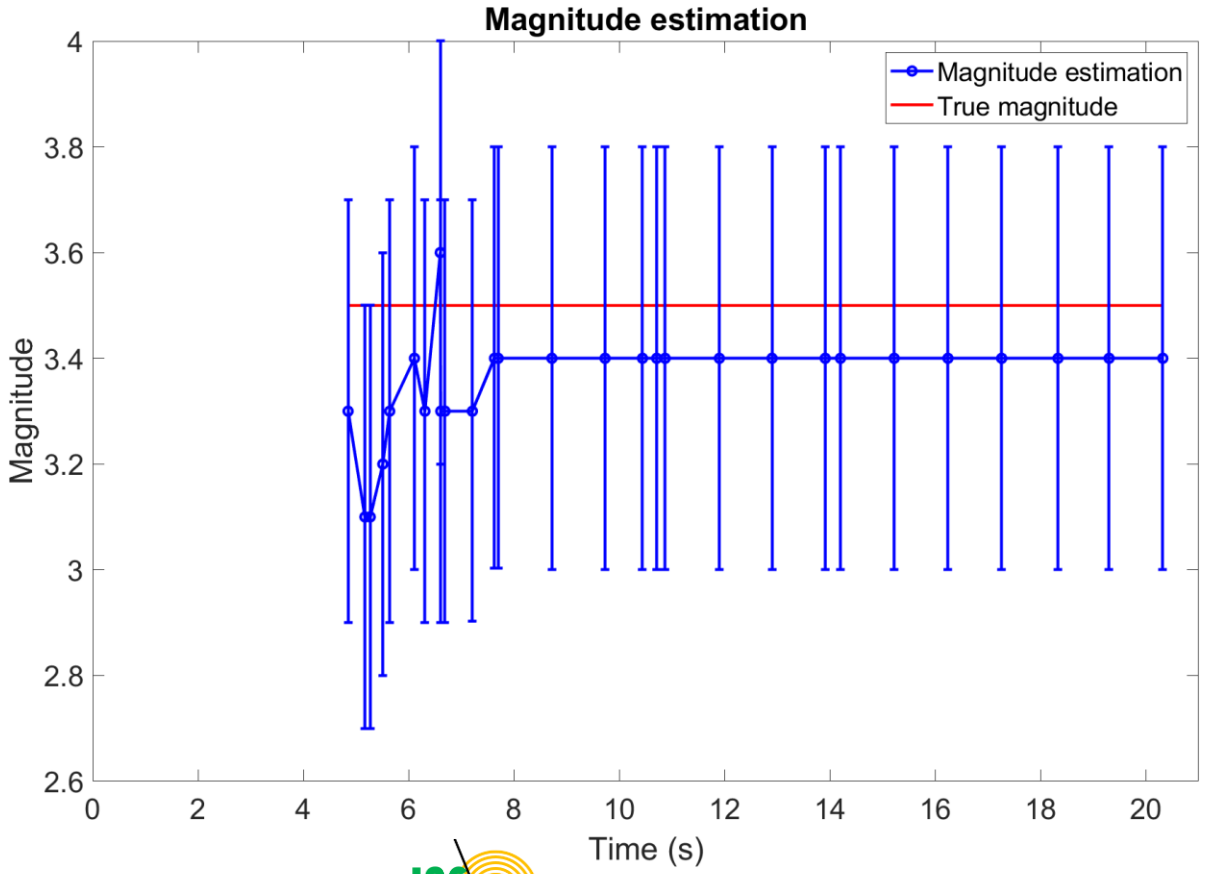
QUAKE-UP Performances

The first location estimation is available in 4.85 s after the O.T. We have a stable magnitude estimation in 8 s after the O.T., while the stable estimation in location is obtained after 9 s.





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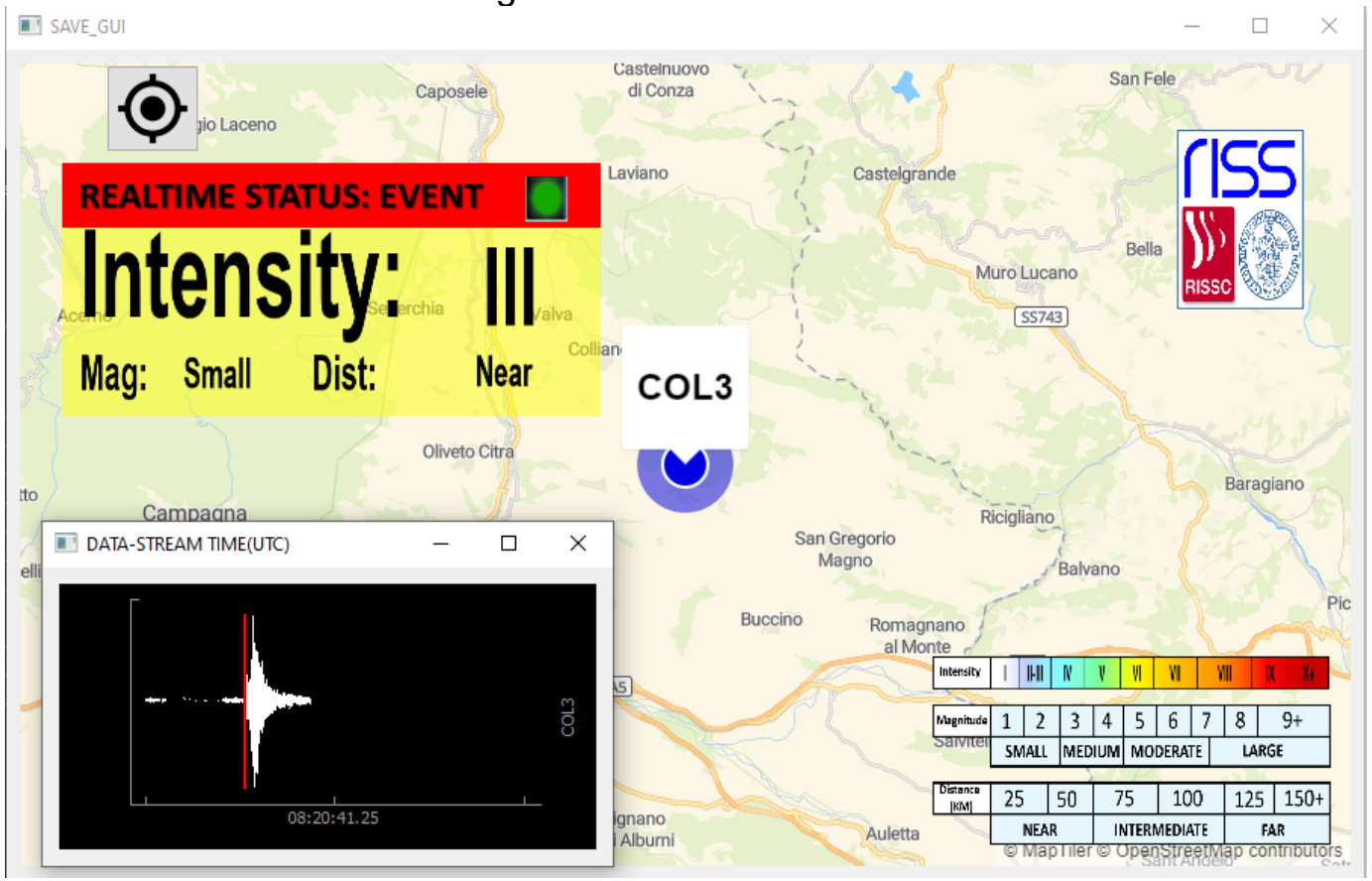
Offline Performances of the onsite early warning system SAVE installed at the station of Colliano (COL)

On-Site estimates of Intensity, Alert Level, Magnitude and Distance as provides by SAVE@COL station (epicentral distance 9.23 km), through the playback of recorded waveforms. All the estimates are obtained using the vertical component of acceleration waveforms and using the first 3 seconds of recorded P-wave signal.



The system was able to compute both the Pd amplitude and the Tauc parameter, and was able to provide estimates of magnitude, distance and intensity ranges.

The **estimated intensity (through the Pd) was III**, which is consistent with the observed value.

The event was correctly classified as a **small magnitude** event **nearby** the station.

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ISNet EW-APP

ISNET EWApp received the folllowing alert from PRESTo:

- Mag: 3.1, Time: 2023-07-26 08:20:09

The pictures show the screenshot of the app, on a smartphone located at Naples (epicentral distance of 56 km), during the events.

5 smartphones received the alerts for this event.
The smartphones were located between Naples, Sorrento and Palomonte.
The smartphones received the warning within an average time ranging between 0.3 and 0.9 s, with an average value of 0.6s.

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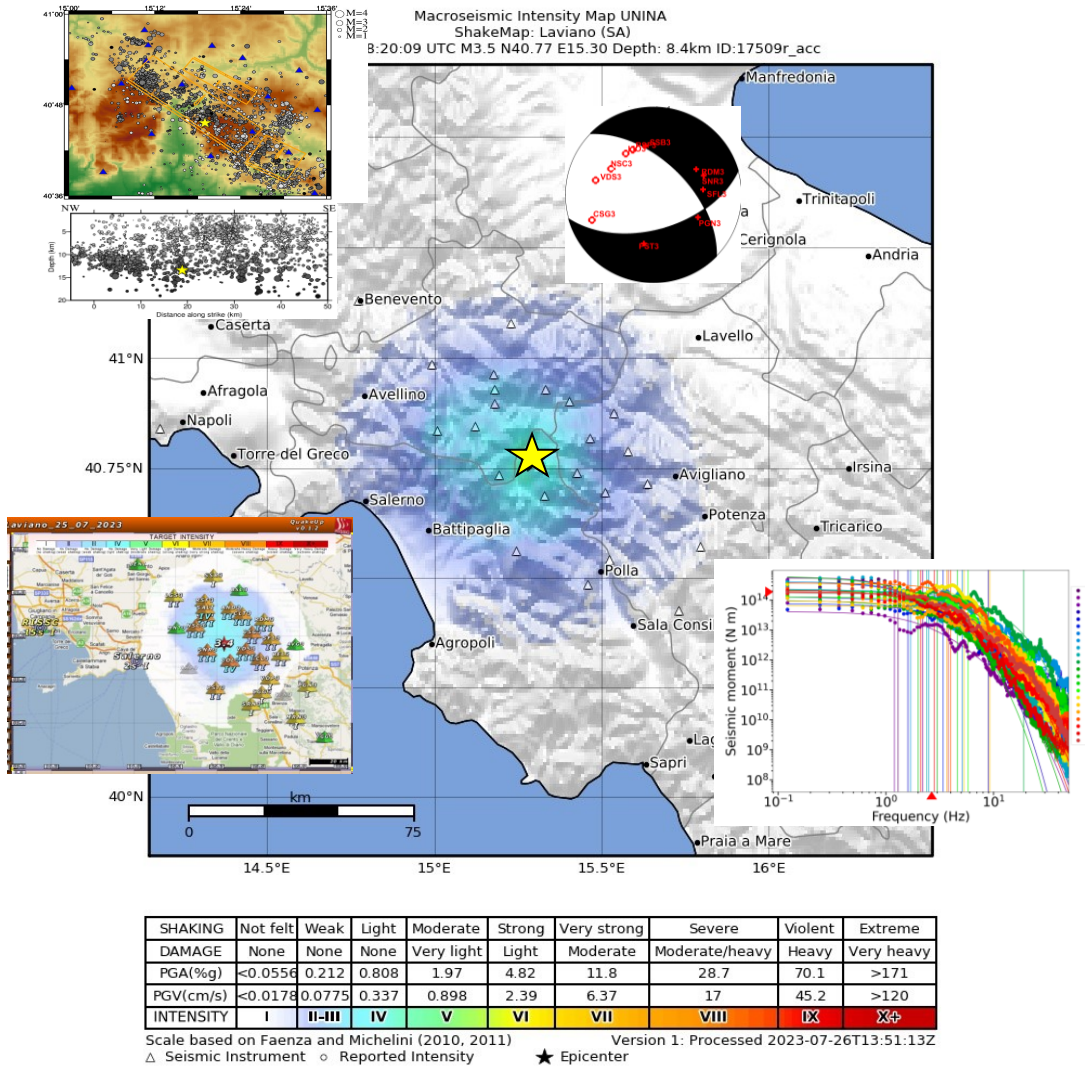
Summary

- The 2023, July 27 (ML 3.5, Mw 3.3) Laviano earthquake occurred at the southern tip of the northern segment of the 1980, MS 6.9 earthquake.
- The event occurred at 08:20:09.83 (UTC), 40.7606 lat. and 15.3167 long. at a depth of 13.5 km. The well constrained location (rms of 0.12 s and 200 m of location errors) is in a volume of high density of events, already interested in the past by seismic sequences
- The focal mechanism solution shows a normal faulting with a minor strike-slip component. The nodal planes and the source mechanism are consistent with the regional tectonic stress field and the past seismicity.
- Moment magnitude $M_w(3.44 \pm 0.01)$ and corner frequency $(2.7 \pm 0.1)\mathrm{Hz}$ suggest for an involved rupture area around $0.3km^2$, with a relevant stress drop of $(3.2 \pm 0.3)MPa$.
- A maximum Instrumental intensity of III-IV has been recorded over an area of about 50 km radius around the epicenter with max recorded PGA : $= 1\%g$ and max PGV$= 0.31\ cm/s$. Areal distribution of PGA/PGV values and the epicenter location indicate a rupture directivity to the NW direction
- Earthquake early warning testing: the 3 used methods (PRESTo, QuakeUP and SAVE) showed a good performance in terms of first alert (about 6-8 sec after the OT) and impact prediction. QuakeUp is able to estimate the IMM III-IV perceived shaking zone using P-wave after only 8 seconds from the OT.



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0556	0.212	0.808	1.97	4.82	11.8	28.7	70.1	>171
PGV(cm/s)	<0.0178	0.0775	0.337	0.898	2.39	6.37	17	45.2	>120
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Faenza and Michelini (2010, 2011) Version 1: Processed 2023-07-26T13:51:13Z
△ Seismic Instrument ○ Reported Intensity ★ Epicenter

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Sperimentale
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Useful Links:

ISNet http://isnet.unina.it/

ISNet Bulletin http://isnet-bulletin.fisica.unina.it/cgi-bin/isnet-events/isnet.cgi

CREW: https://lccepos.fisica.unina.it/

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