



SECURE

REGIONAL-SCALE EARTHQUAKE **GROUND MOTION PREDICTIONS**
THROUGH PHYSICS-BASED AND EMPIRICAL APPROACHES:
A CASE STUDY CENTRAL ITALY

SECURE KICKOFF MEETING

19-20 JUNE 2025

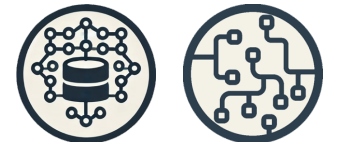
Application of Machine Learning Techniques to Fucino Seismic Data for the Detection of Local Earthquakes

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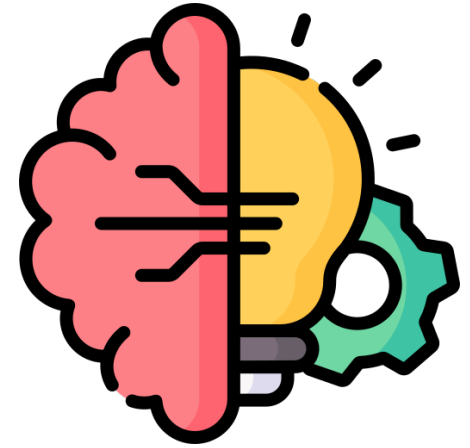


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Summary:

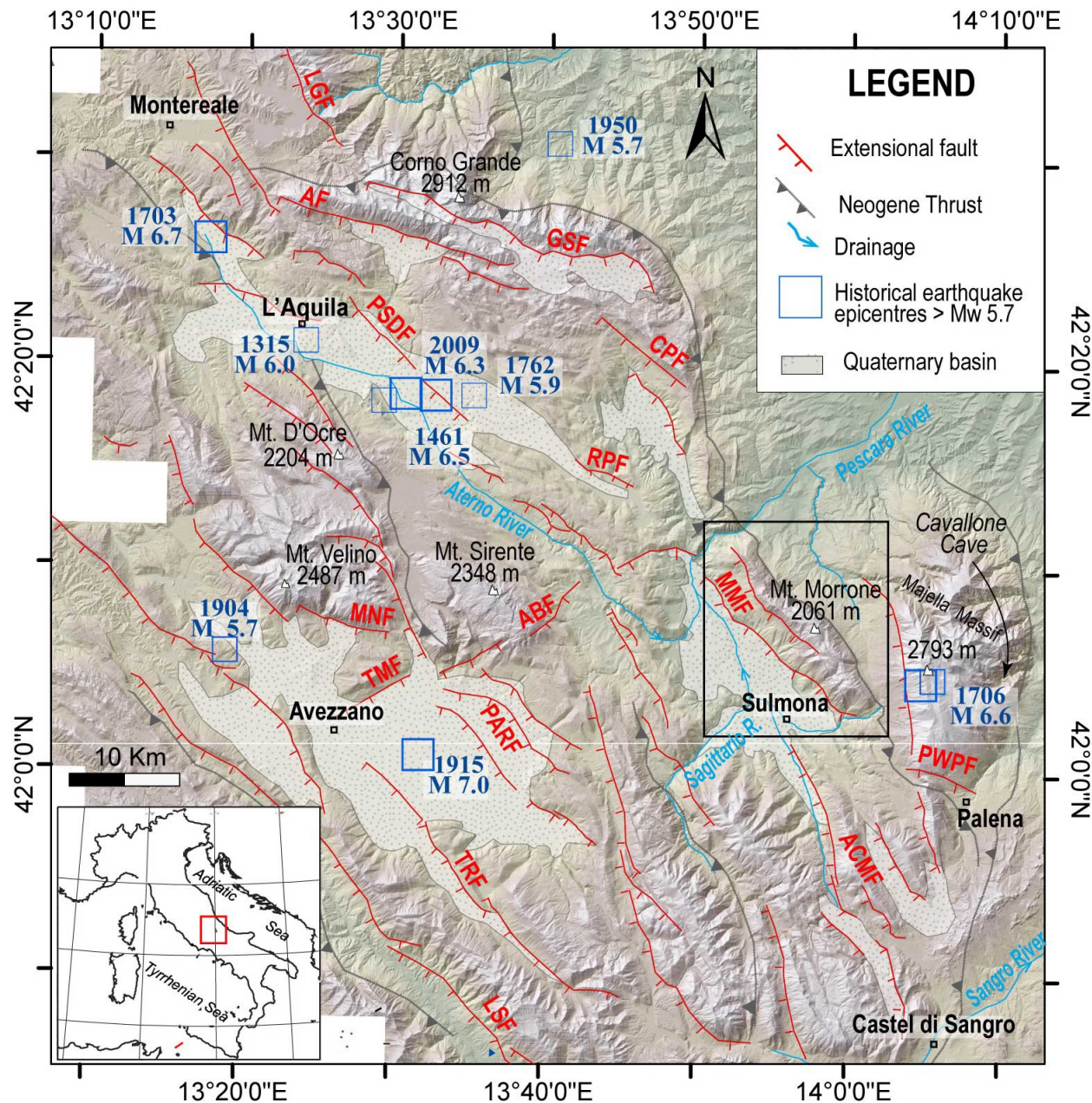


- Case Study and aim
- Method
- Results
- Conclusion and Future steps



Case Study and Aim:

- The largest **Plio-Quaternary tectonic depression** in the Apennines extensional belt (bounded by two main normal fault systems: WSW-ENE and NW-SE).
- NW-SE faults caused the 1915 Mw 7.0 earthquake and previous M6–7 events (paleoseismic evidence).
- WSW-ENE faults: **current activity and seismogenic potential remain uncertain.**
- Shallow fault architecture (<2 km) is well mapped; deep geometry and crustal structure (5–15 km) remain poorly constrained.
- Seismicity beneath the basin is low; more activity is seen to the north (2009 L'Aquila, Mw 6.3) and to the south (swarm-like events).



From Puliti et al., (2025).

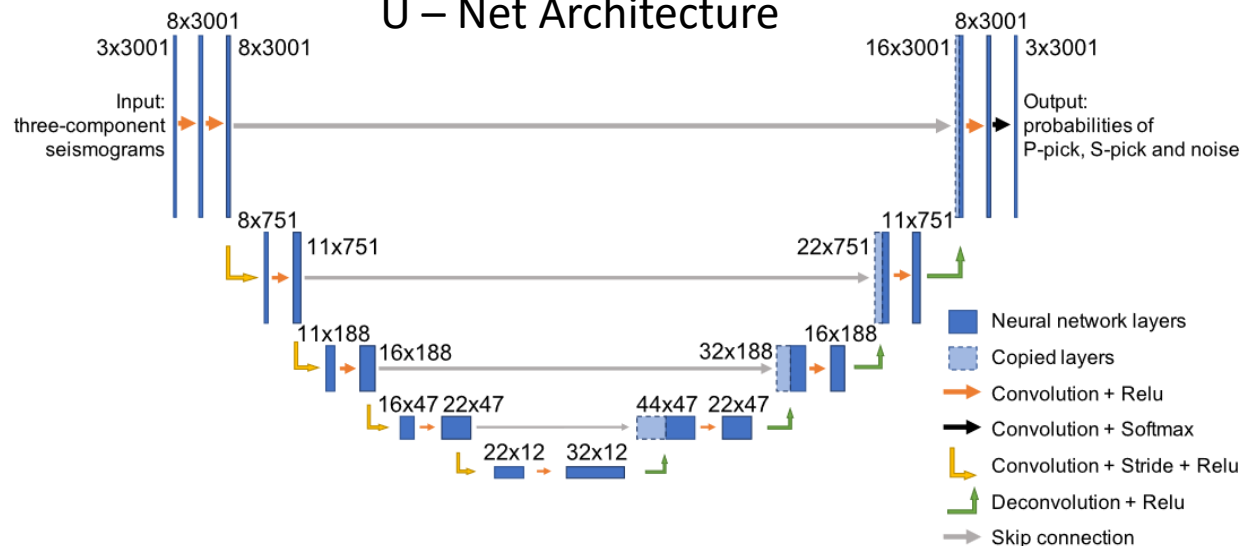
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Method:

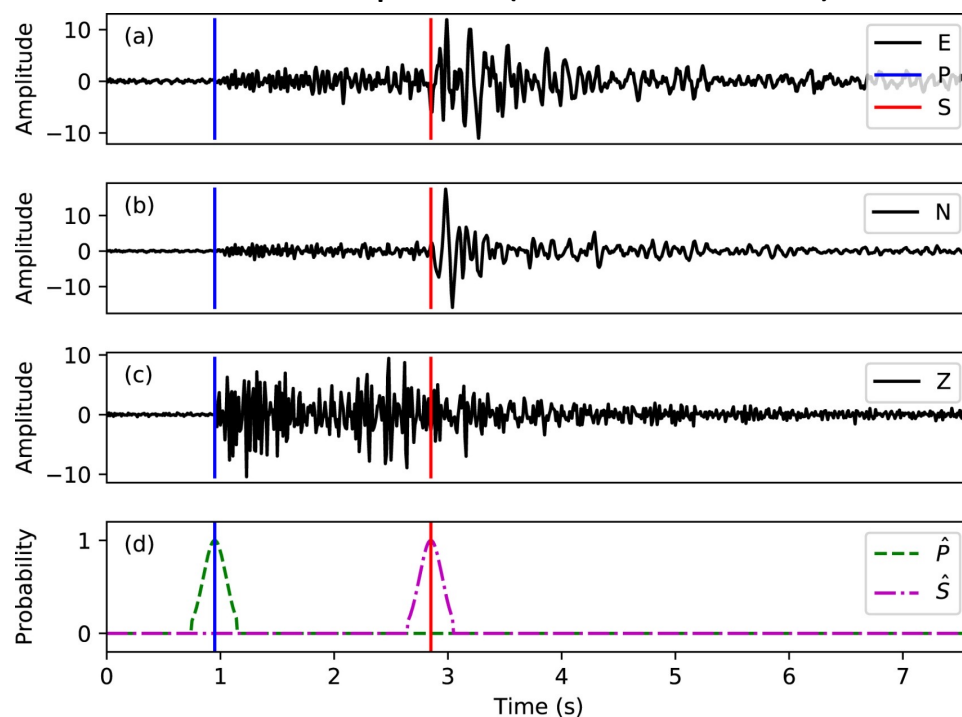
- **Seisbench** platform to provide P- and S- waves arrival times, association and initial earthquake absolute locations.



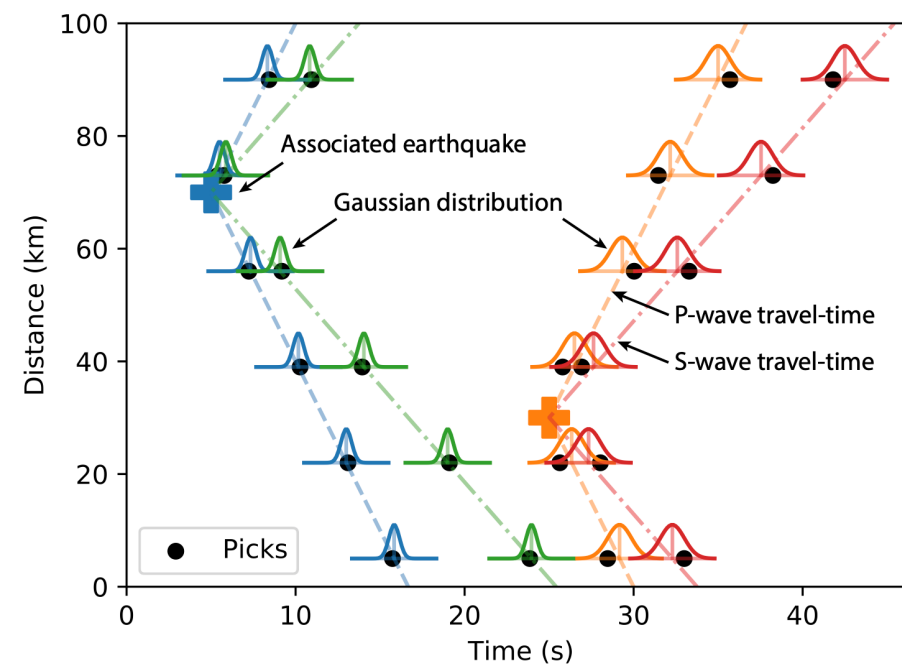
U – Net Architecture



PhaseNet picker (Zhu et al., 2019)



Gaussian Mixture Model Associator (GaMMA, from Zhu and Beroza, 2022)

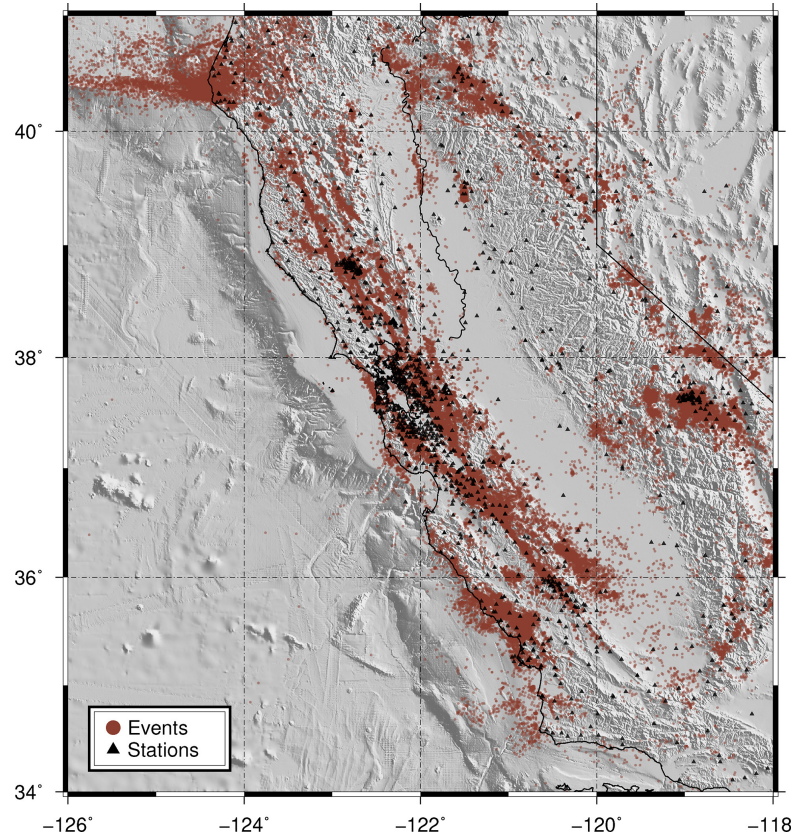


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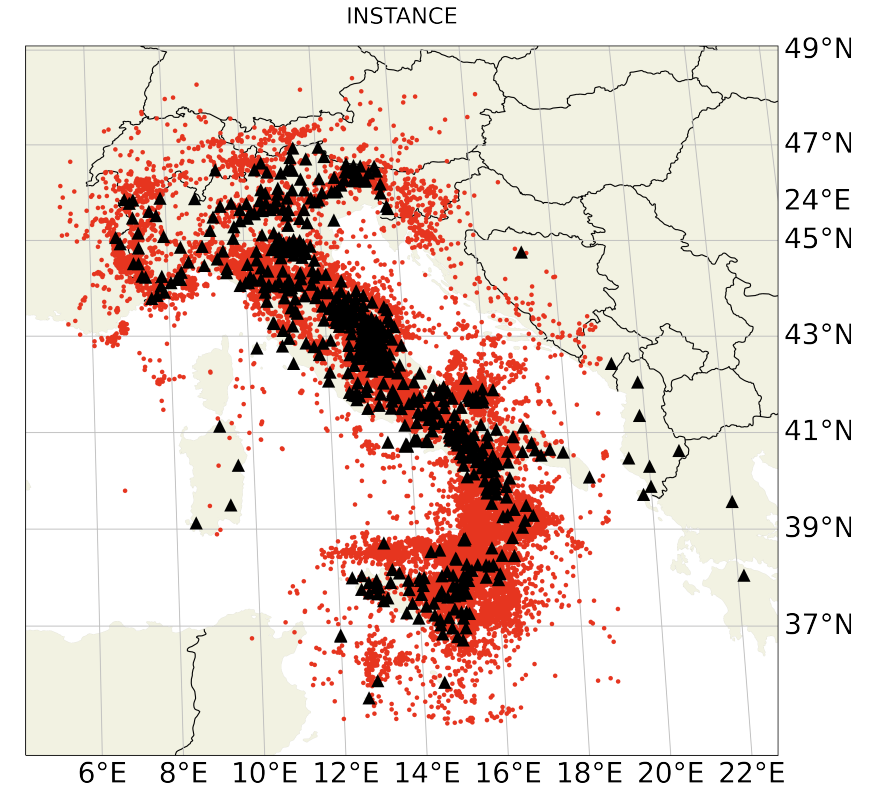
Method:

- Pretrained model using **INSTANCE dataset**.
- Comparison with the original version of PhaseNet picker.
- Comparison with manual picking.



Northern California Seismic Network **NCSN dataset** (2014).

234 117 earthquakes and 889 seismic stations

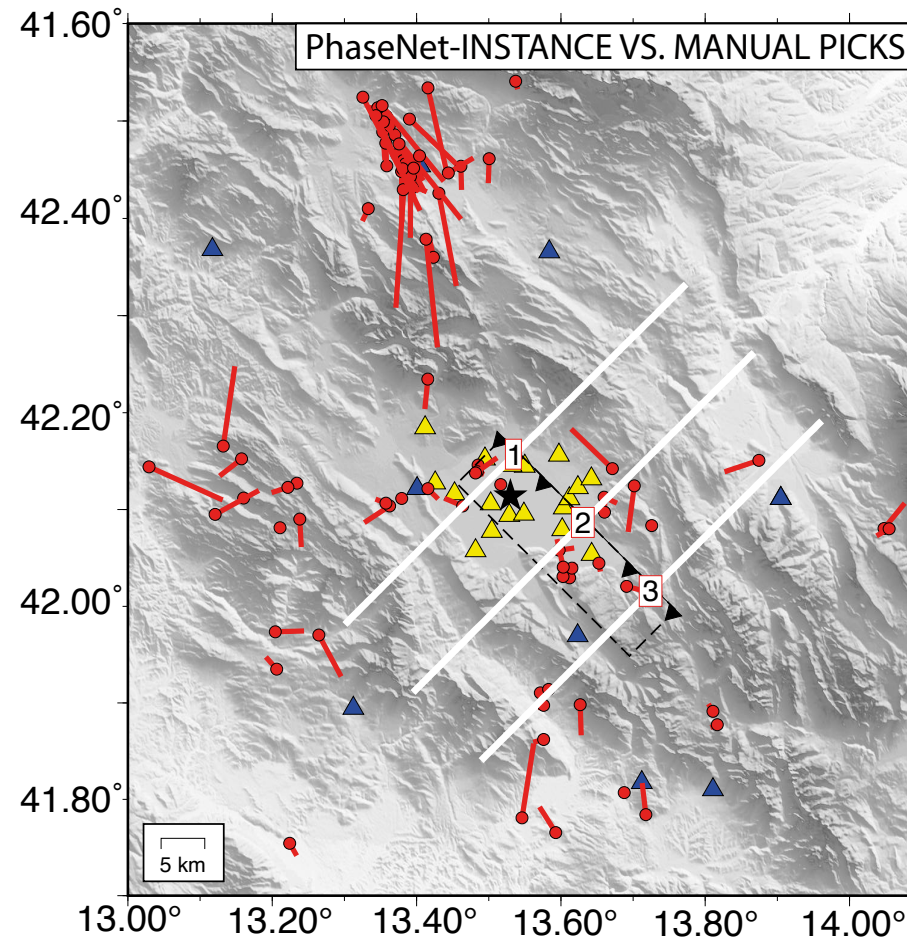
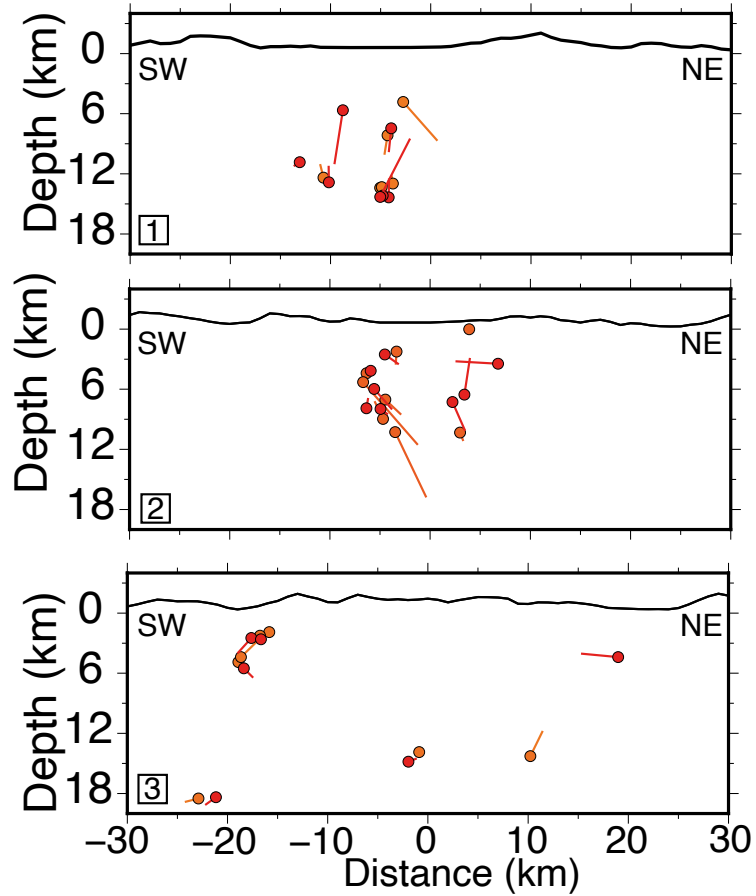


INSTANCE dataset (Michellini et al., 2021).

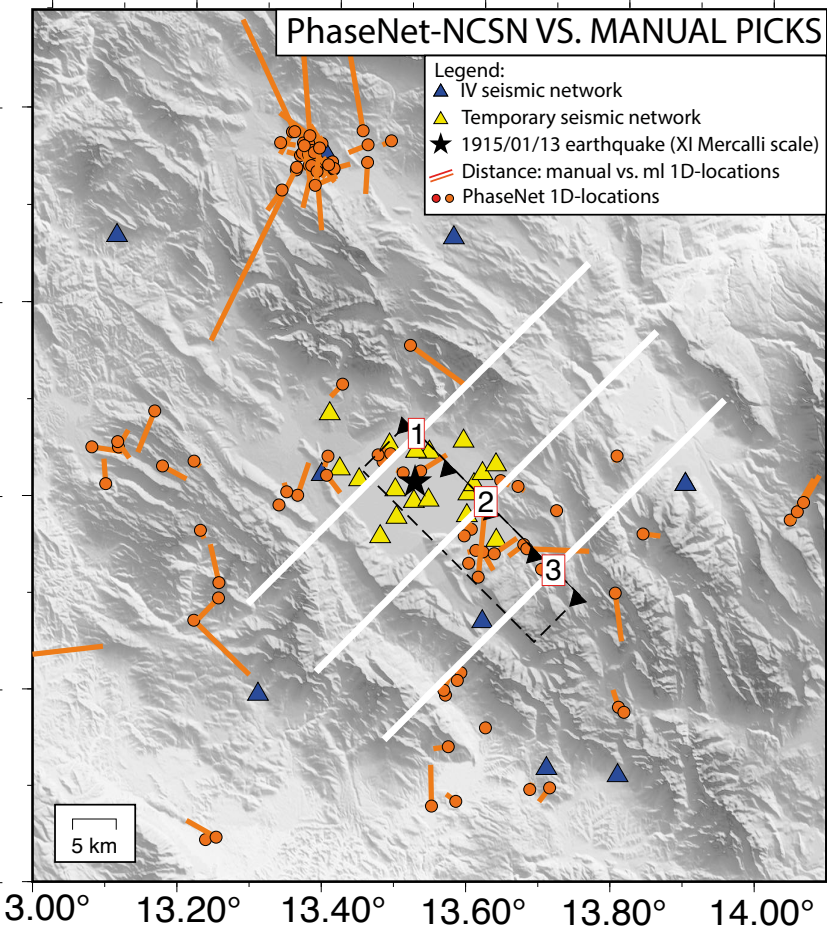
- ~1.2 million 3C waveform traces,
- ~50,000 earthquakes (time period: 2000-2021)
- ~130,000 noise traces. Magnitude scale of events ranges from 0 - 6.5.

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Results



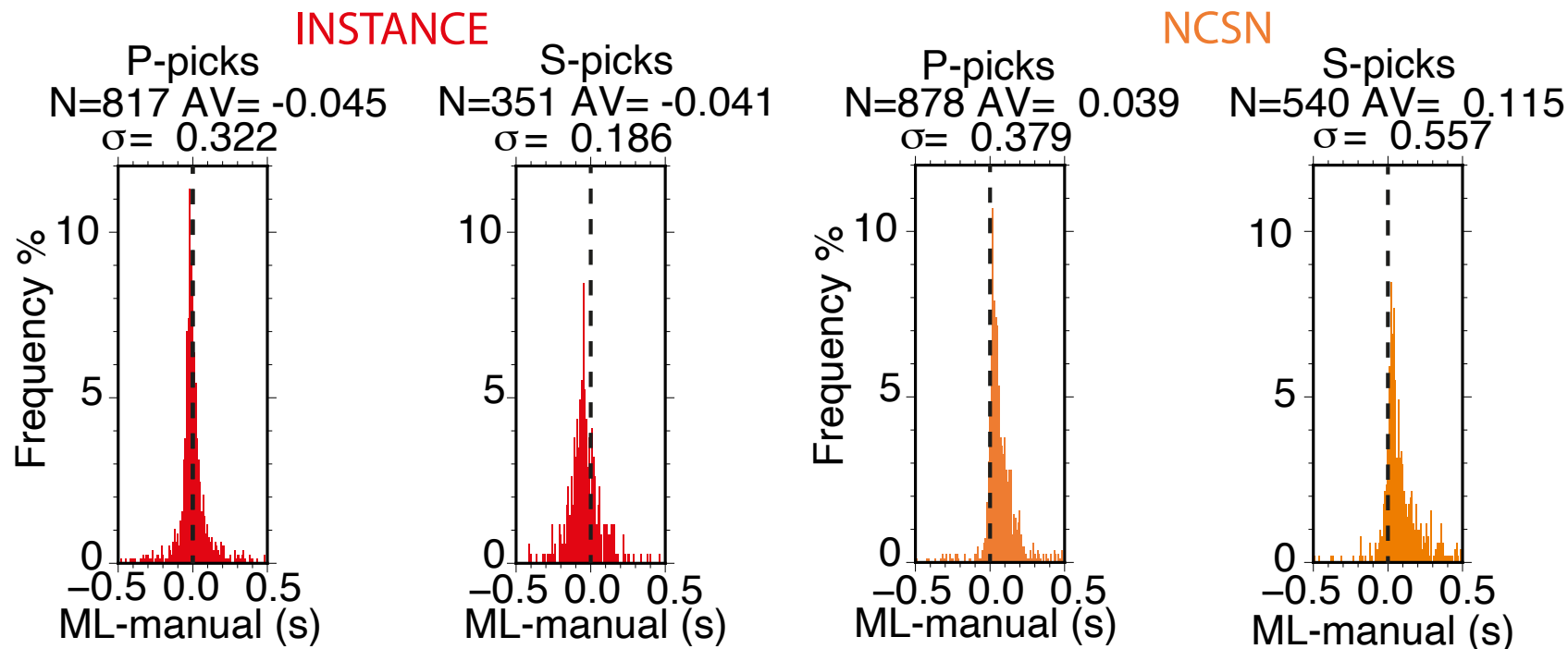
- October 2008-April 2009
- 18 seismic stations (stations, 2–3 km spacing, 125 Hz, 5s sensors)



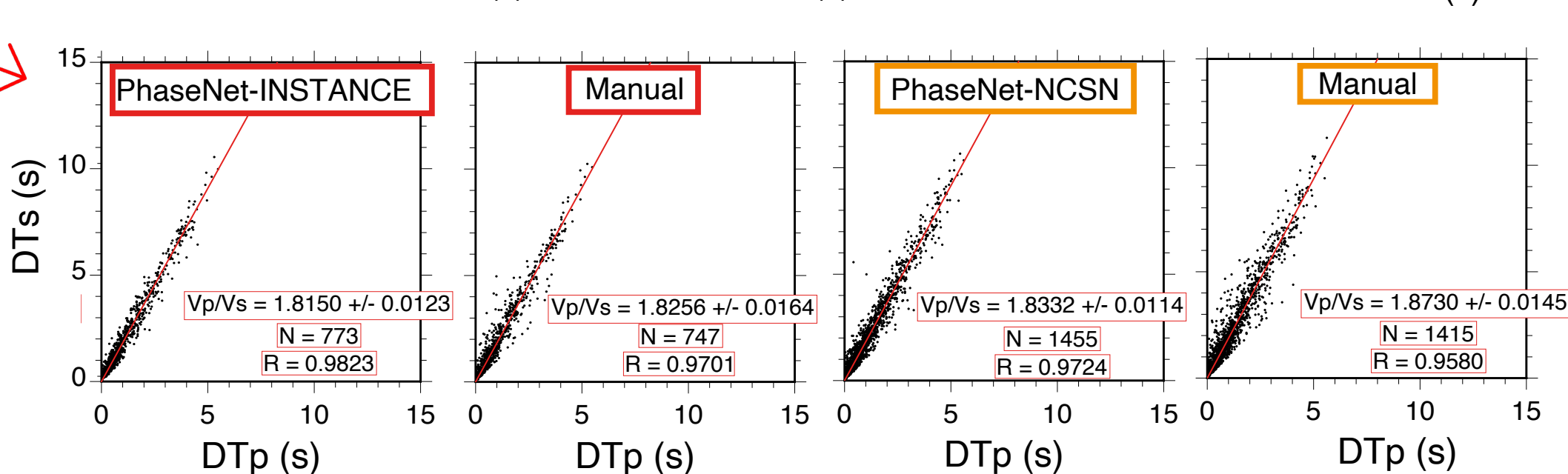
- Manual picking: 136 seismic events
- INSTANCE: 270 seismic events (**89/136**)
- NCSN: 628 seismic events (**96/136**)

Results

- Manual vs. PhaseNet picks

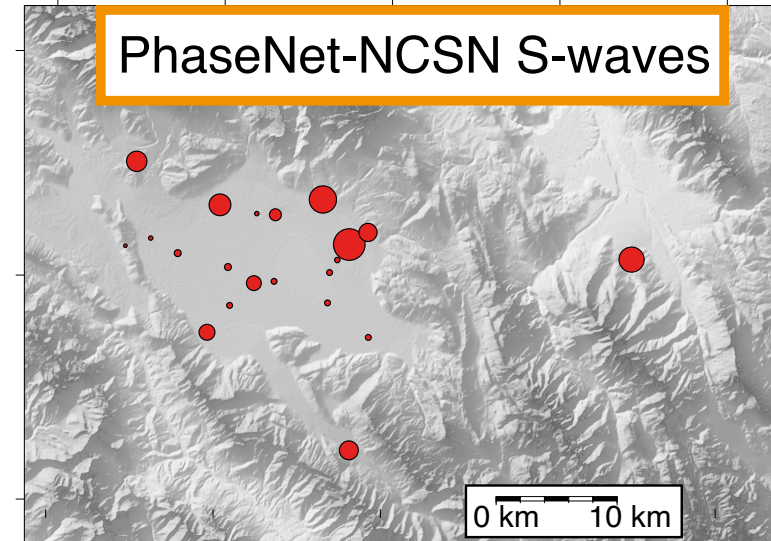
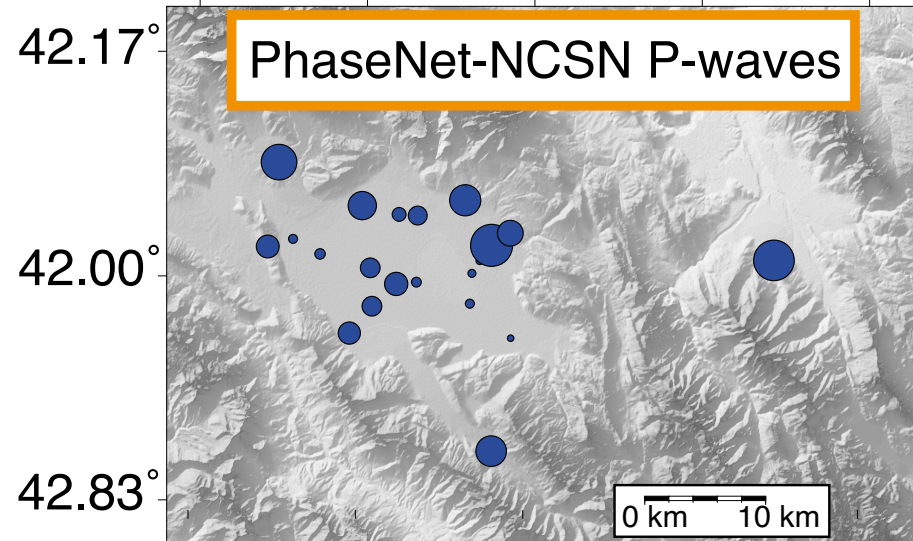
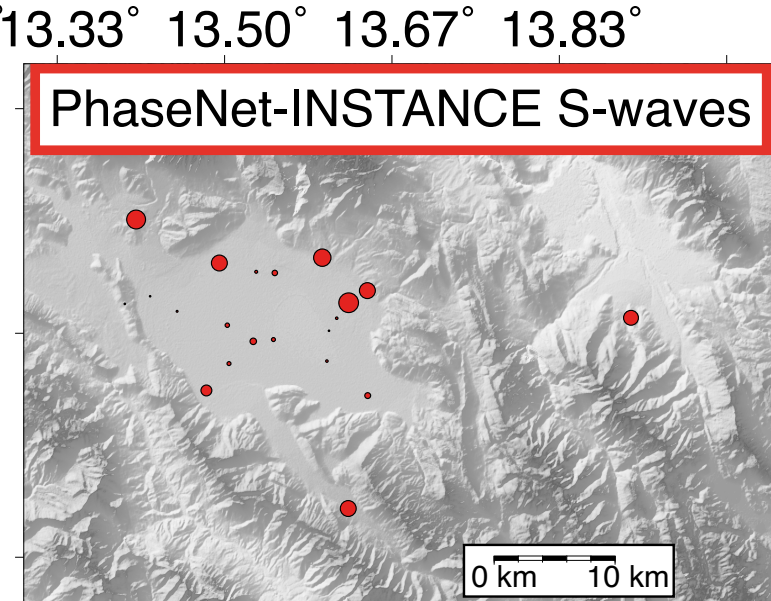
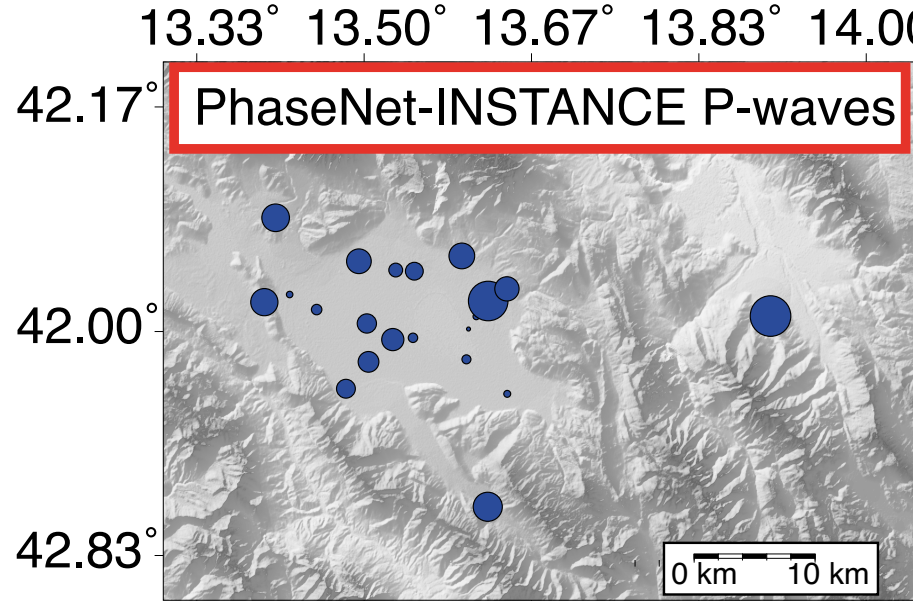


- Wadati diagram



Results

- NCSN vs. PhaseNet picks:
- Number of P- and S- waves for each stations



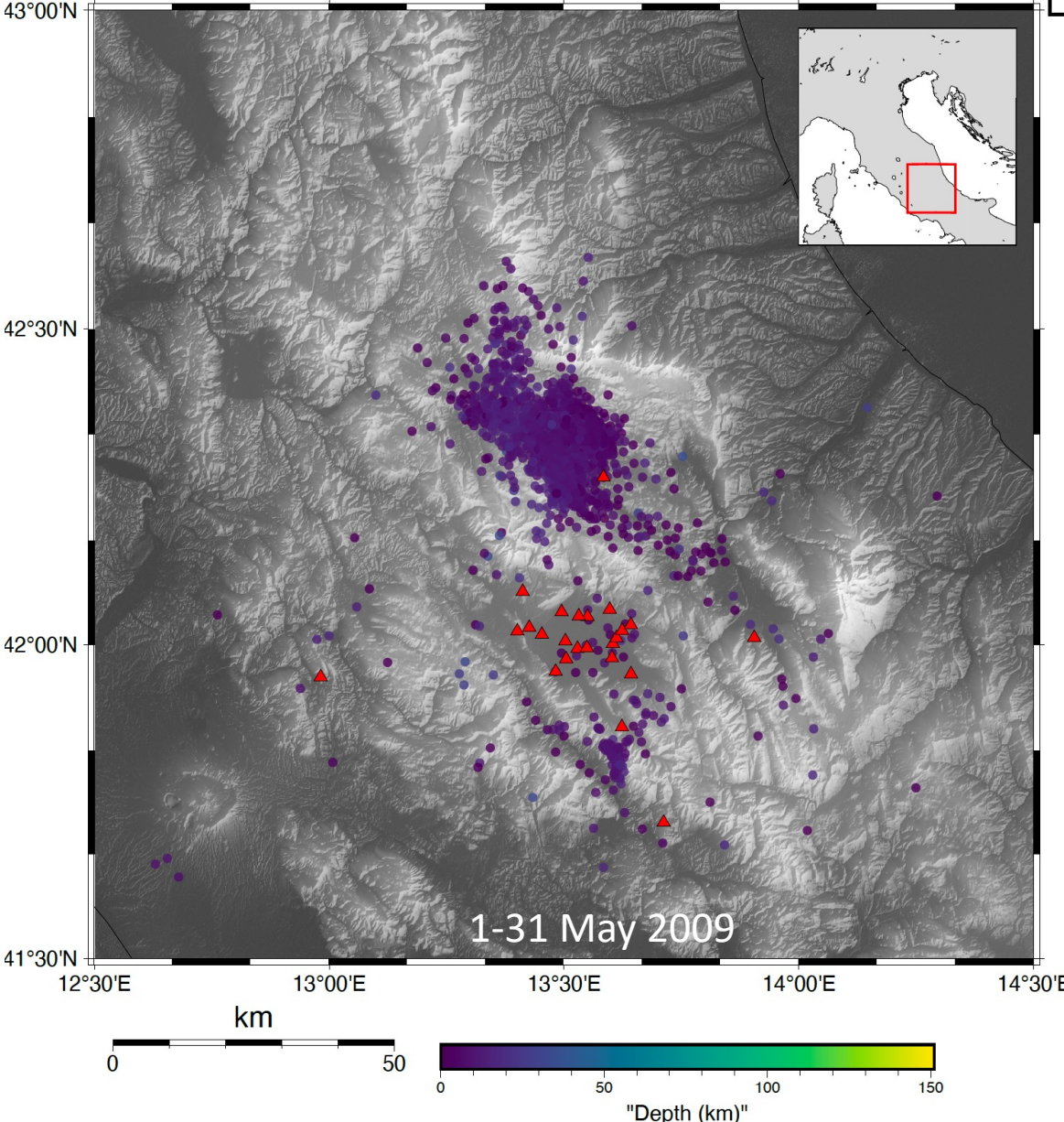
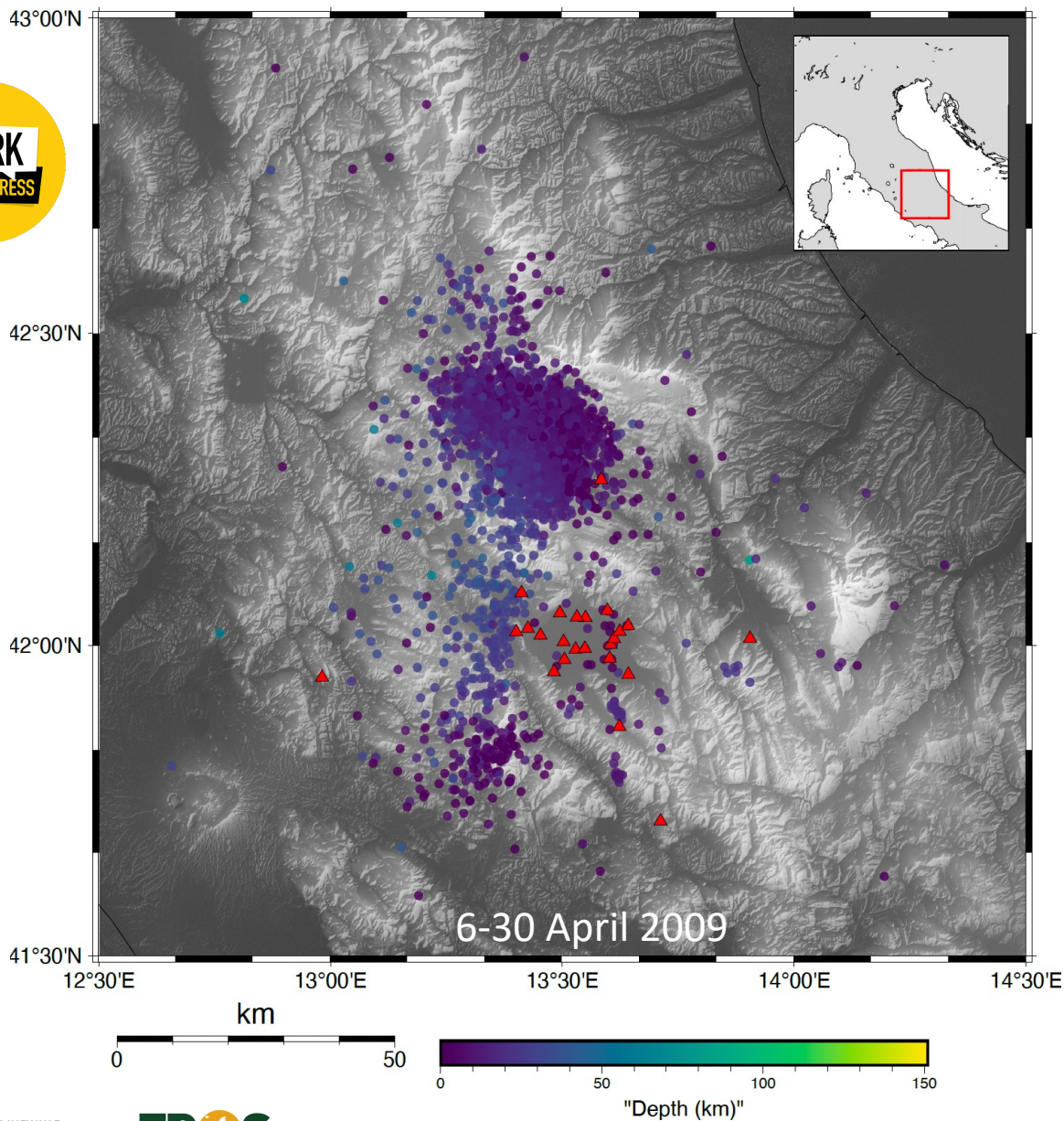


Conclusion and future steps

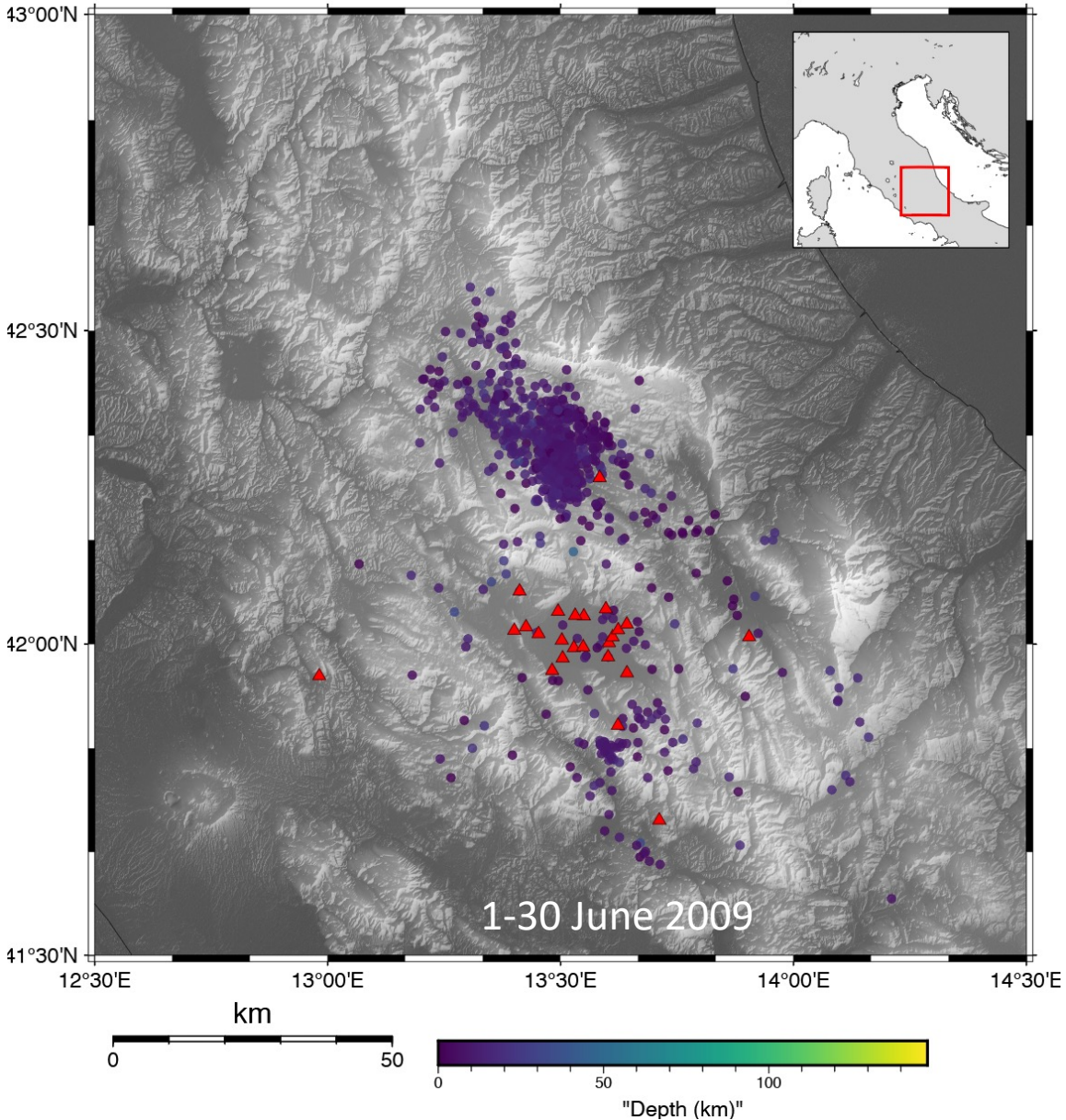
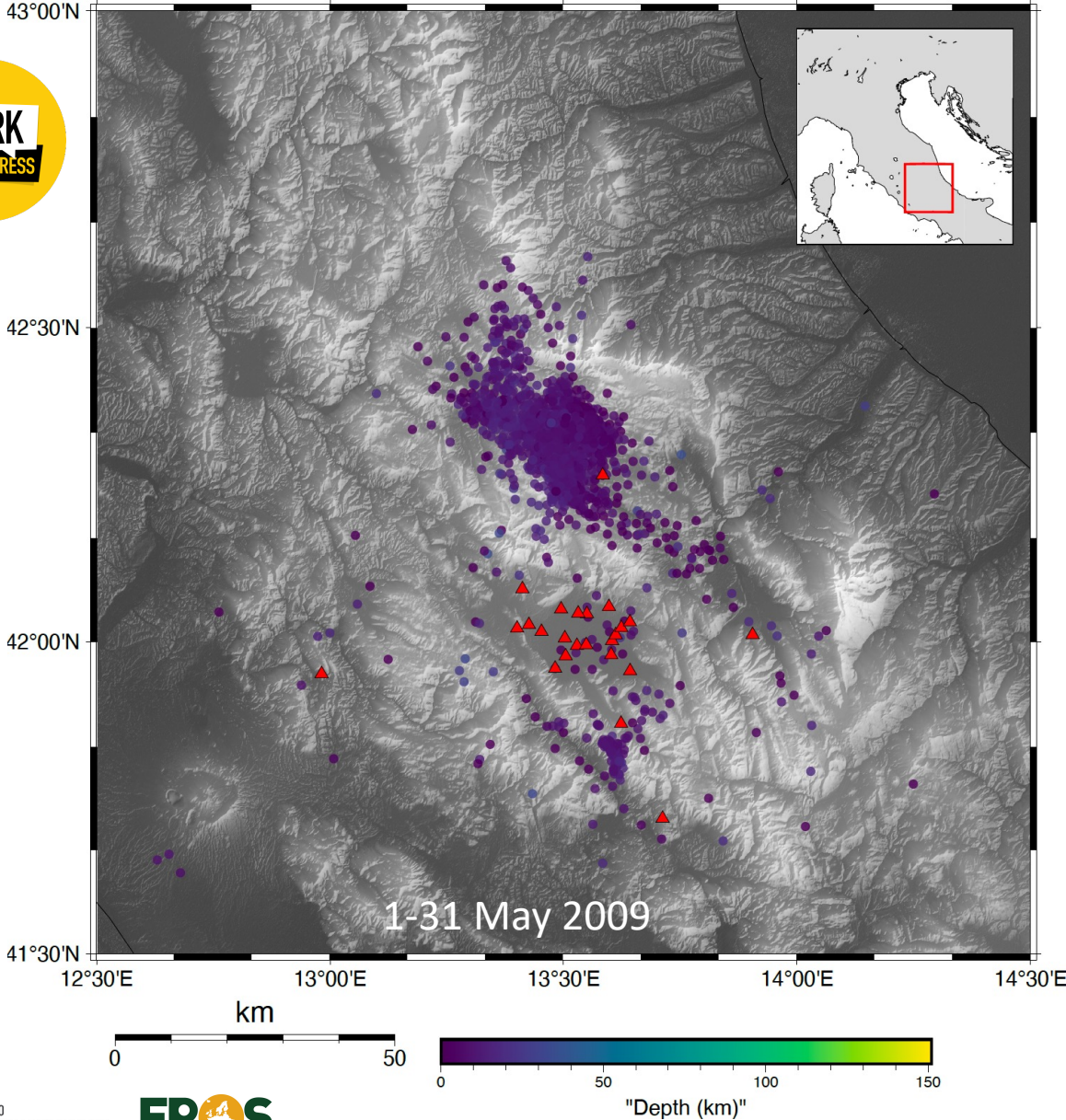
- Events from the **Italian-trained model are more clustered**, especially in the north, highlighting the importance of the training dataset.
 - With INSTANCE training, **P-picks align with manual picks**; S-picks are slightly early.
 - With NCSN training, **both P- and S-picks are delayed compared to manual picks**.
 - Fewer picks occur in areas with many stations due to noisy signals from temporary stations in the Fucino basin.
 - Wadati diagram shows **better pick alignment with PhaseNet-INSTANCE ($R \approx 98\%$)**, making it more suitable for Italy.
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- **Extending the picking period** to the entire 2009 year.
 - **Seismic tomography** using deep learning picking approach.



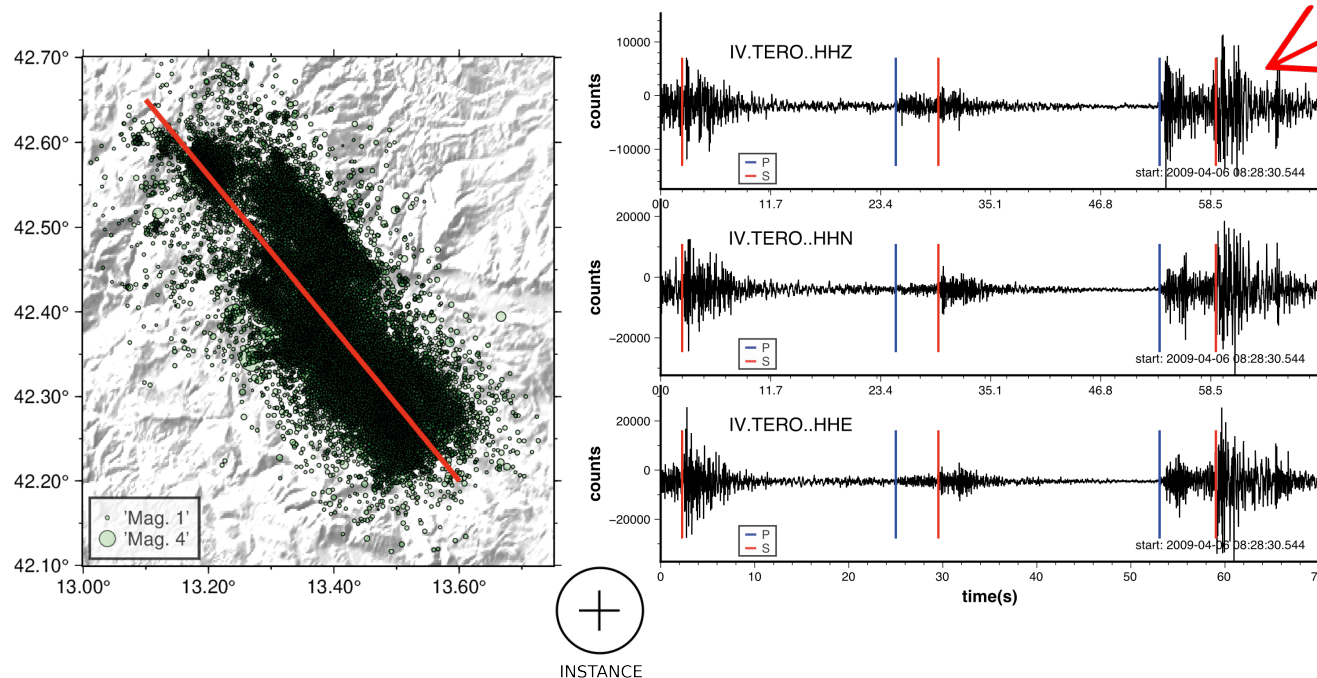
Conclusion and future steps



Conclusion and future steps

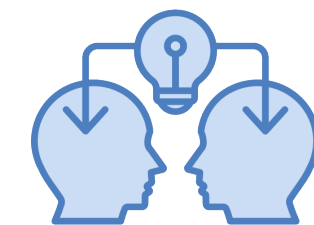
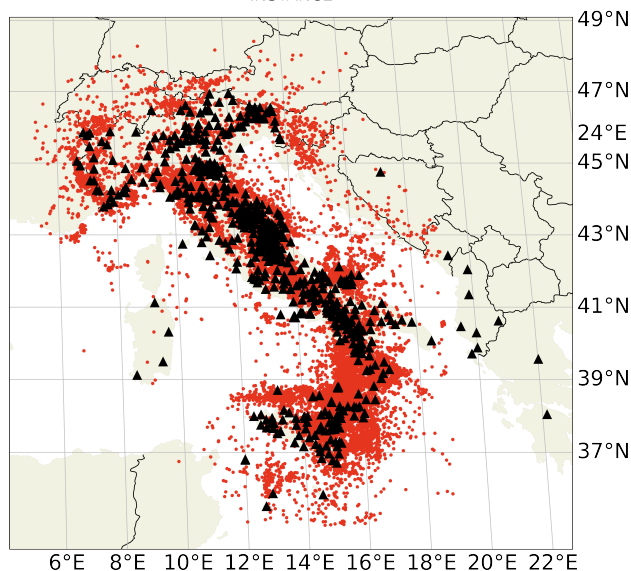


Conclusion and future steps



AQ2009 dataset (Bagagli et al., 2023)

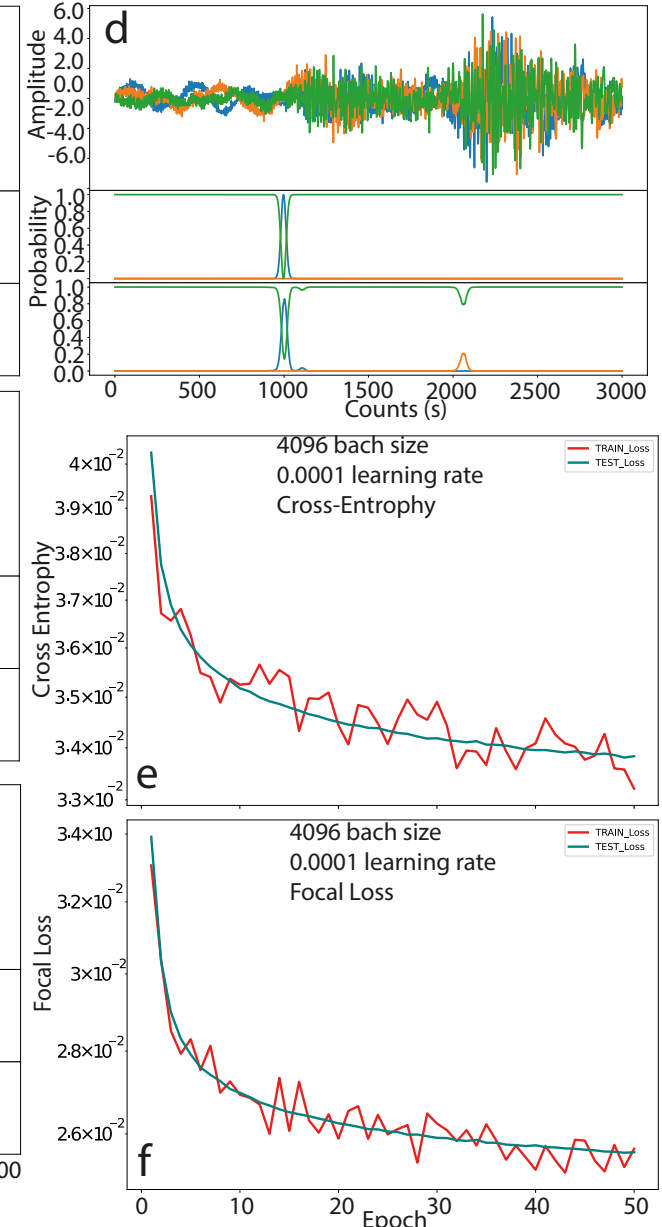
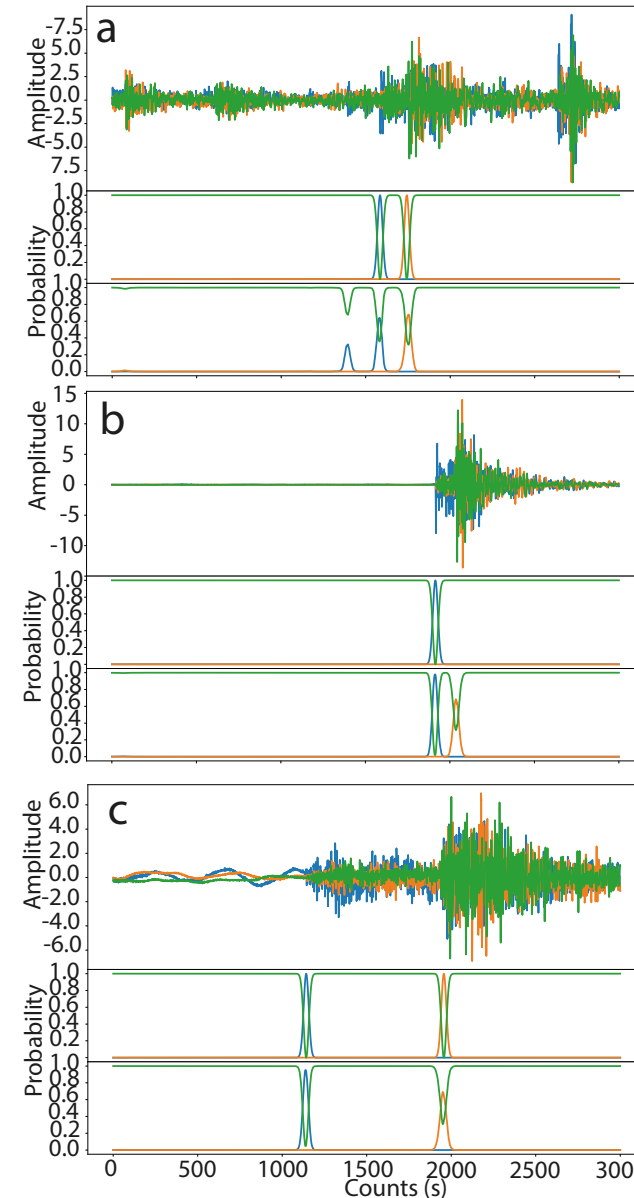
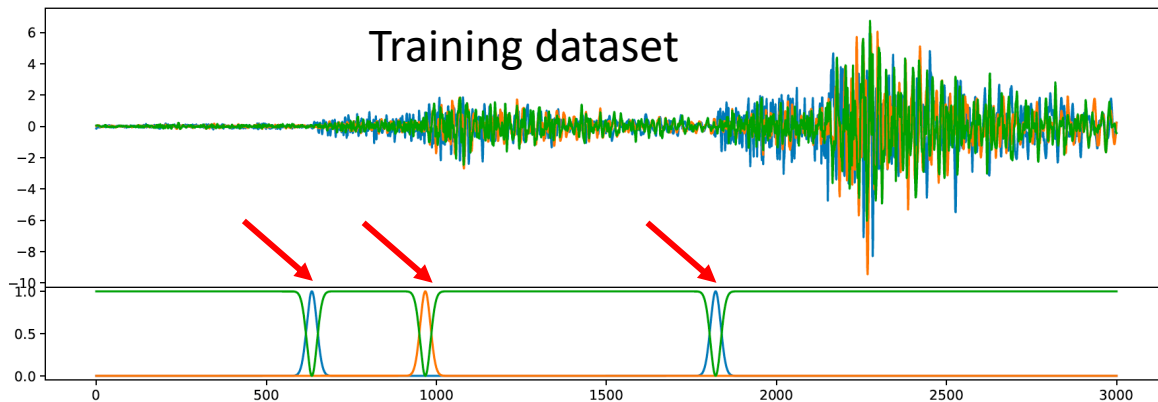
- 254 days of aftershocks (2009-04-06 up to 2009-12-20);
- 63,704 earthquakes;
- 1,258,006 3-component traces cut of 70 seconds;
- Absolute (HypoEllipse) and relative (HypoDD) locations;
- 3 seismic networks (MN, IV, XJ) for a total of 67 stations;
- Multiple P and S pick arrivals (up to 8 per cut) that allow improvements in current Machine Learning algorithms development and analysis.



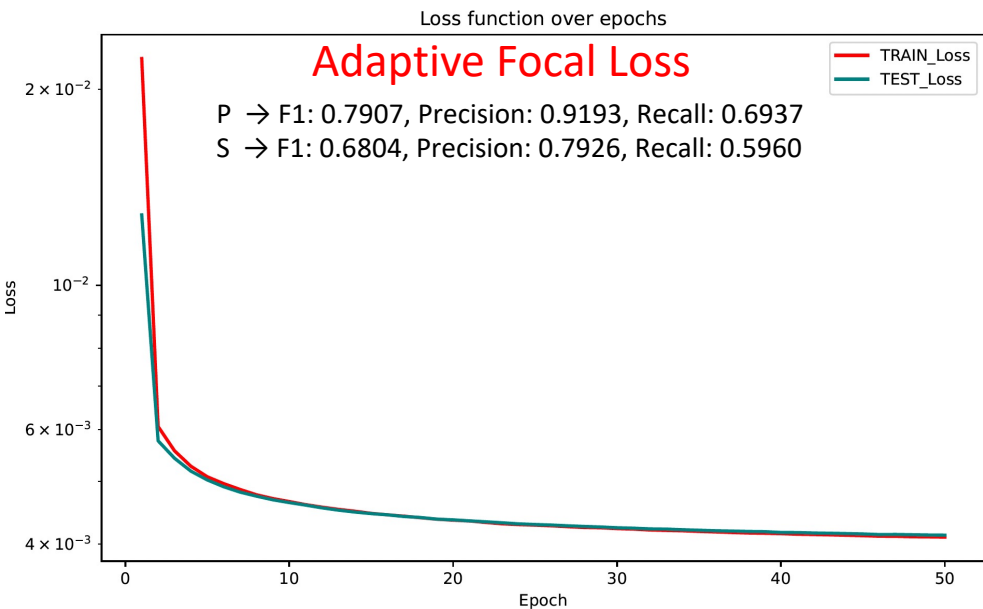
Transfer Learning
(INSTANCE + AQ2009)

Conclusion and future steps

- **Different amount of P- and S-waves**, with a ratio of ~ 4 (P: 1559462 vs. S: 388996).
- S- waves are recognized even if the label has not been defined (case b);
- more distant seismic events are well recognized (case c);
- PhaseNet manages to discern between the two phases even with a noisy signal (case d).
- The use of **the Focal Loss function** instead of Cross Entropy (default in PhaseNet) improved the S-Recall value (about 20%).



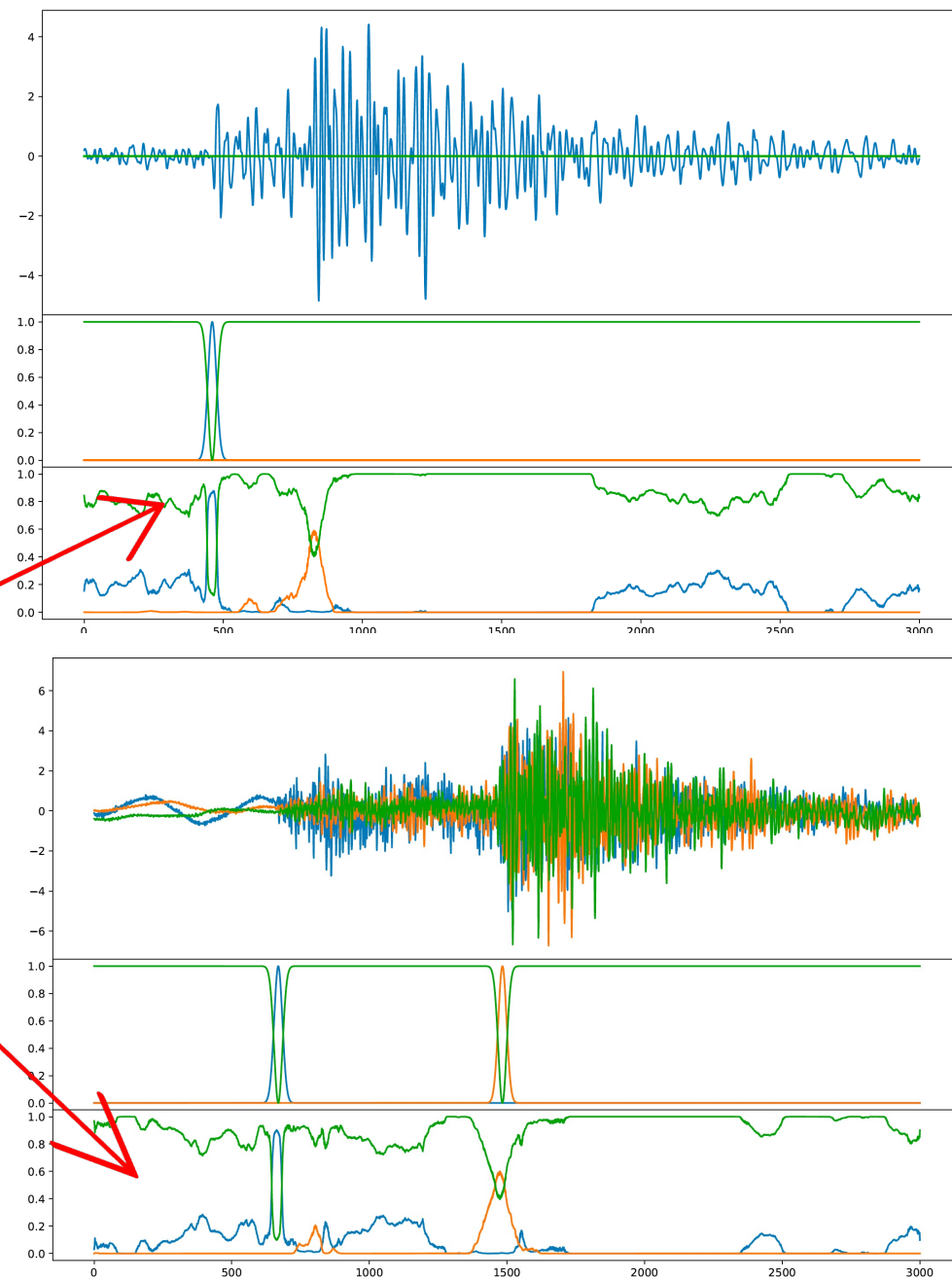
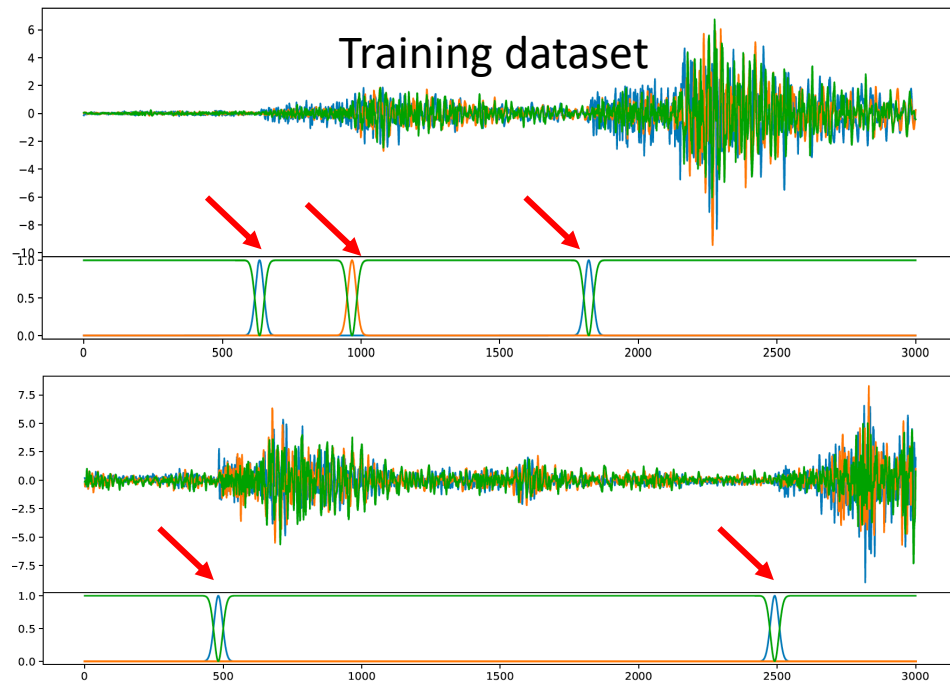
Conclusion and future steps



$$\alpha_{weights} = \frac{1}{\left(\frac{Precision + Recall}{2} + \varepsilon\right)}$$



Predictions

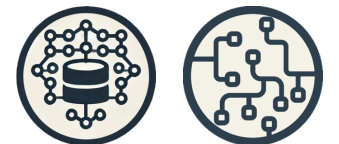


Thank you for your attention!!

Questions?

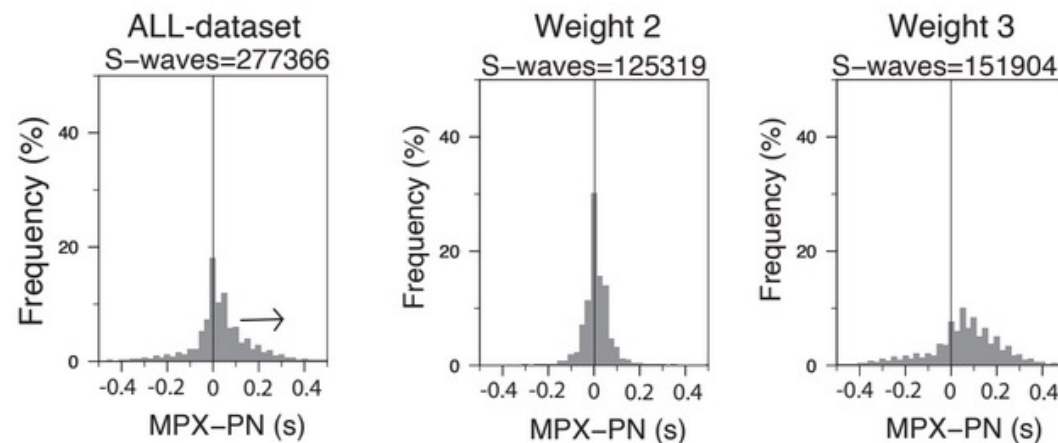
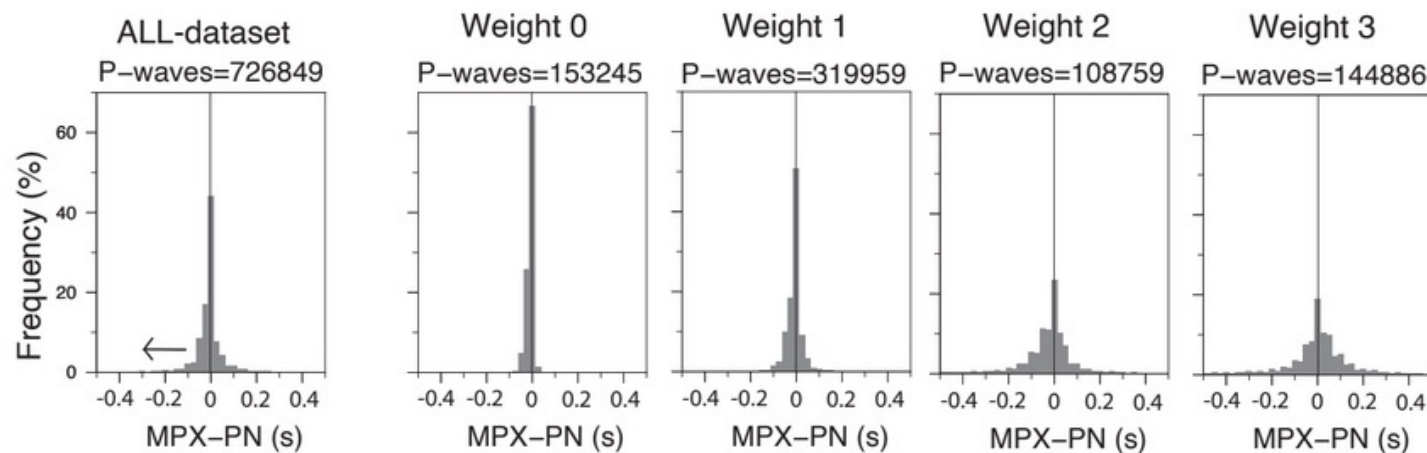
- References

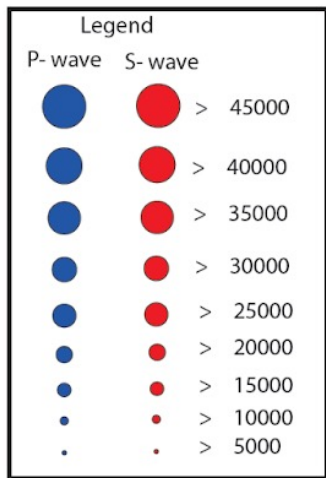
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Comparison with Aquila 2009 seismic catalog





0 km 10 km

