



A probabilistic, multi-parametric real-time earthquake location method

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THE MAIN ISSUES

- Real-time applications for Early Warning Systems (EWS), which asks for very fast source parameter estimates (within a few seconds), the earthquake location procedure becomes a sensitive issue which requires the adoption of dedicated, non-trivial algorithmic solutions.
- The constraint of achieving a fast and robust solution even using a poor initial arrival-time data-set represents a hard complexity to be managed.
- The correct determination of hypocentral coordinates and origin time is essential to identify the source area and the causative fault of the ongoing event to assess the earthquake impact (together with the earthquake magnitude) and predict the expected ground shaking

THE MAIN GOALS OF THE PROPOSED METHODOLOGY

- Provide a reliable estimate of the location of an ongoing event, in the shortest possible time.
- Use a multi-parametric approach in order to increase the robustness of solution for a fixed number of available stations.
- Improve the reliability of location when more data is available in an evolutionary probabilistic framework.
- Provide a complete characterization of earthquake location, in terms of the spatial probability distribution of the solution.

WORK PRESENTATION TRAIL

1. Slide 6 show you a brief presentation of methodology main concepts.
2. Slides 7-10 show an example of platform run.
3. Slides 11-16 show the testing results on three different network geometry in term of :
 - The rapid convergence of solution [slide 13].
 - The performance increment using the multi-parametric approach [slides 14-15]
 - A comparative performance analysis with RTLOC software [slide 16] .



Strategy description

The presented location methodology is based on the jointly inversion of three independent observables:

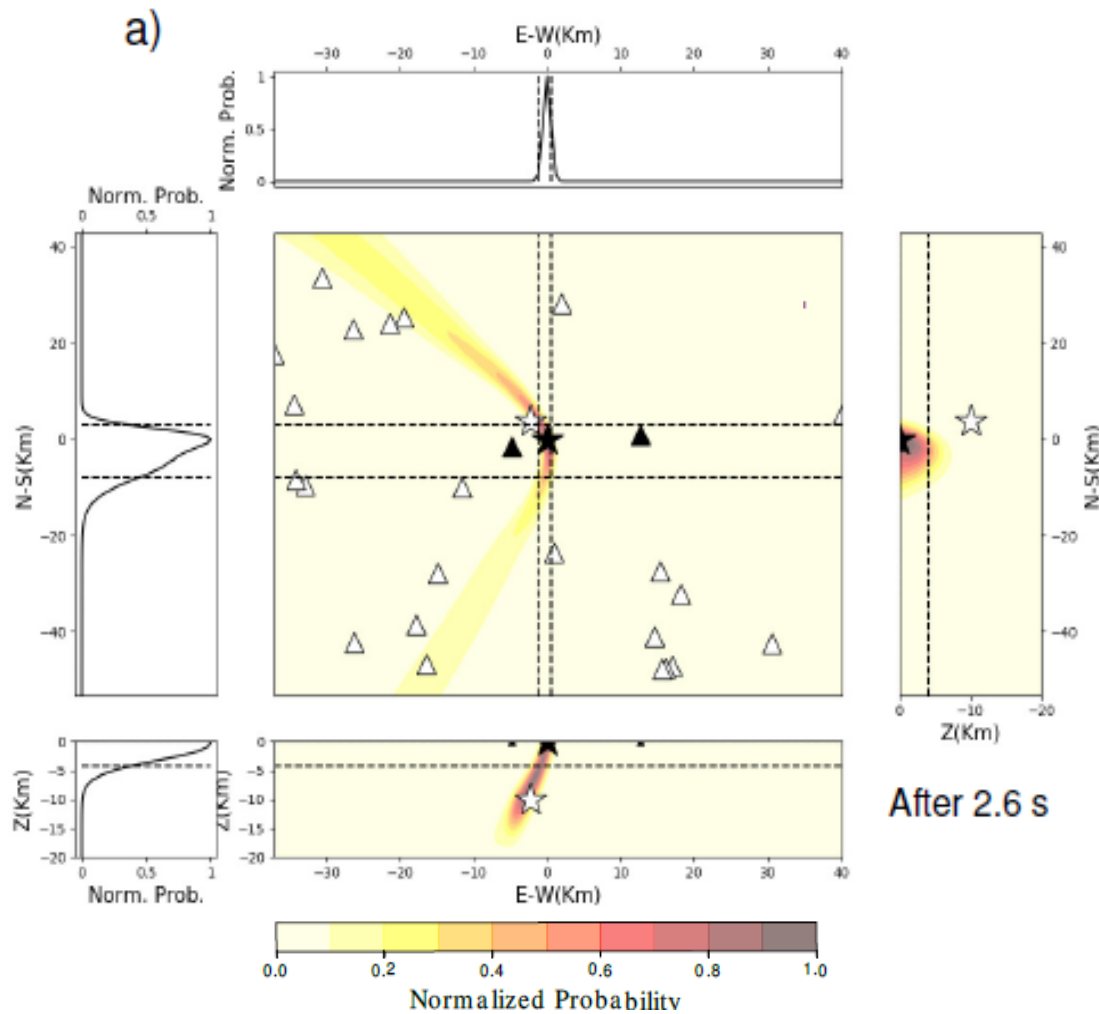
- **Differential arrival times Δt_{ij} .**
- **Differential amplitudes $\log \left(\frac{Amp_i}{Amp_j} \right)$.**
- **Real-time estimation of signal polarization direction (BAZ).**

Bayesian integration of three different observables, with their respective uncertainties, using a probabilistic framework.



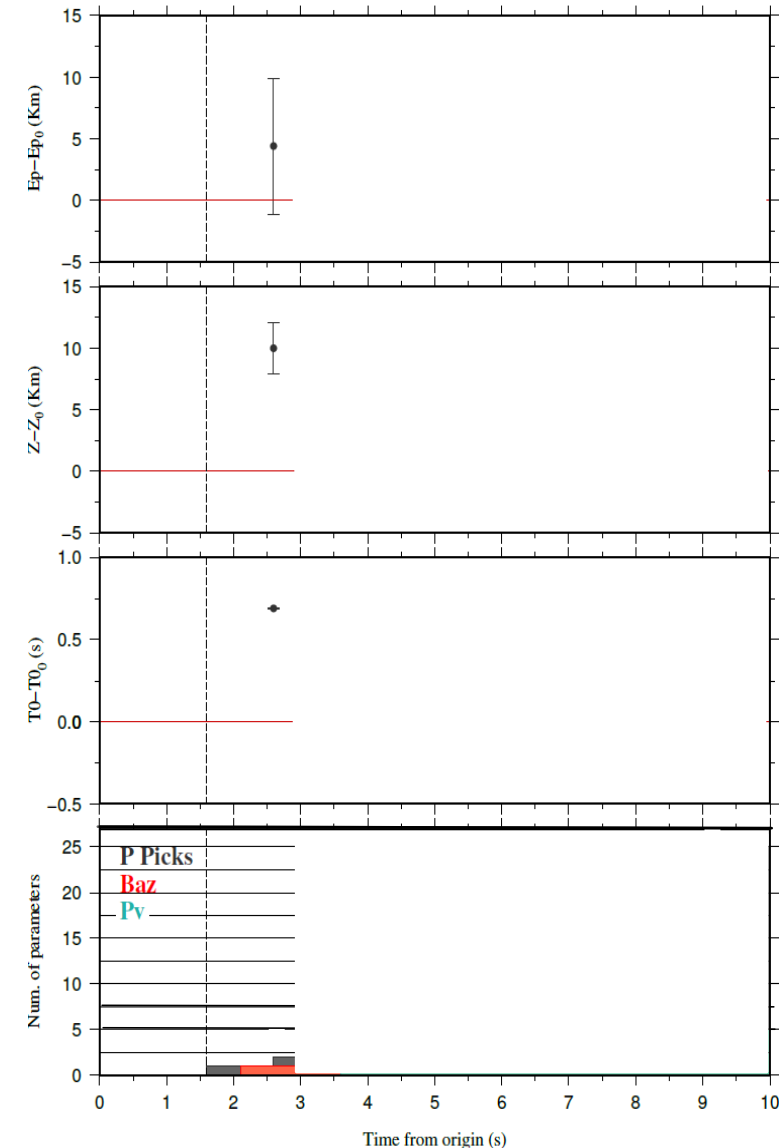
RUN EXAMPLE

Probability distribution map

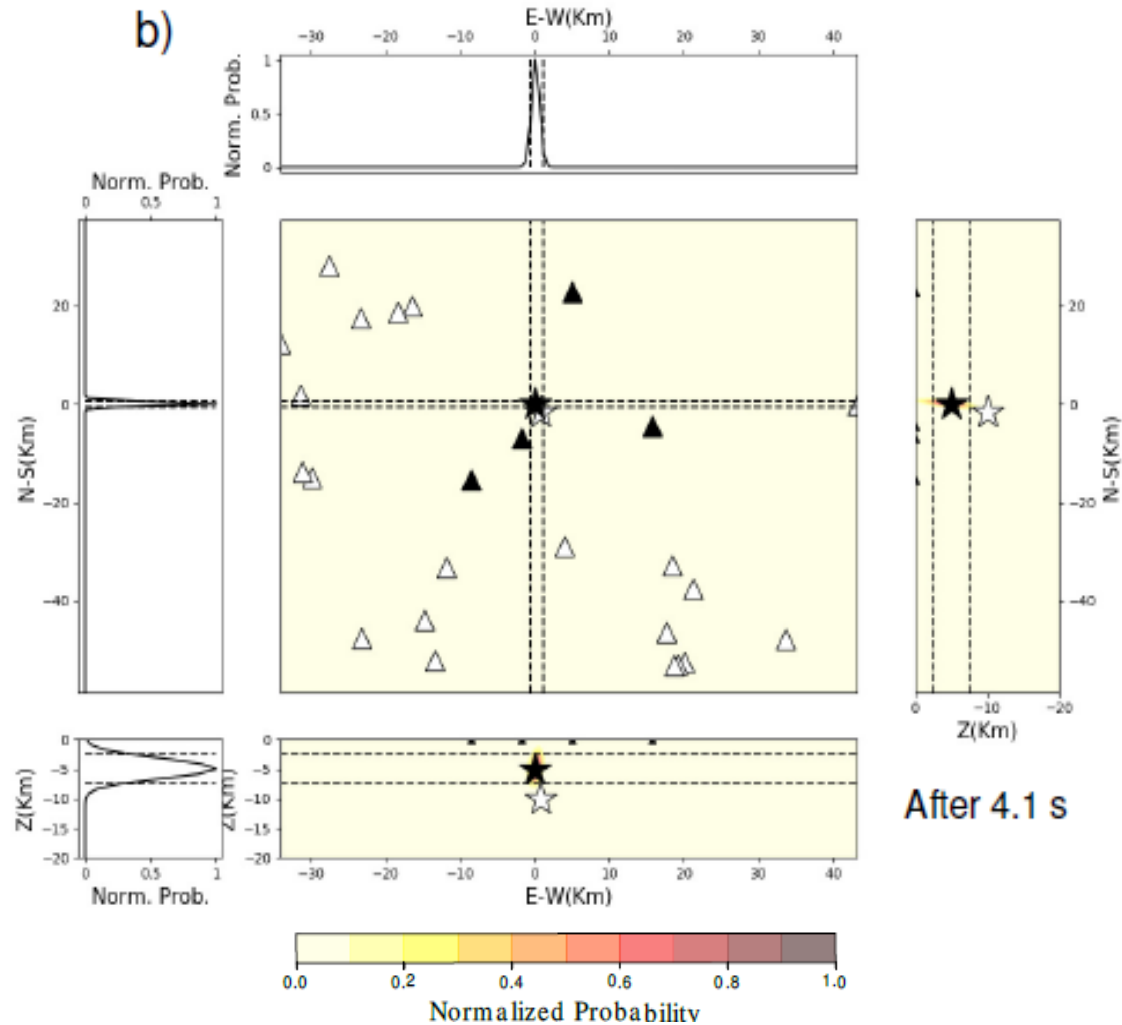


- ▲ Triggered stations
- △ No triggered stations
- ★ Procedure Location
- ☆ Bulletin Location

Time evolution plot

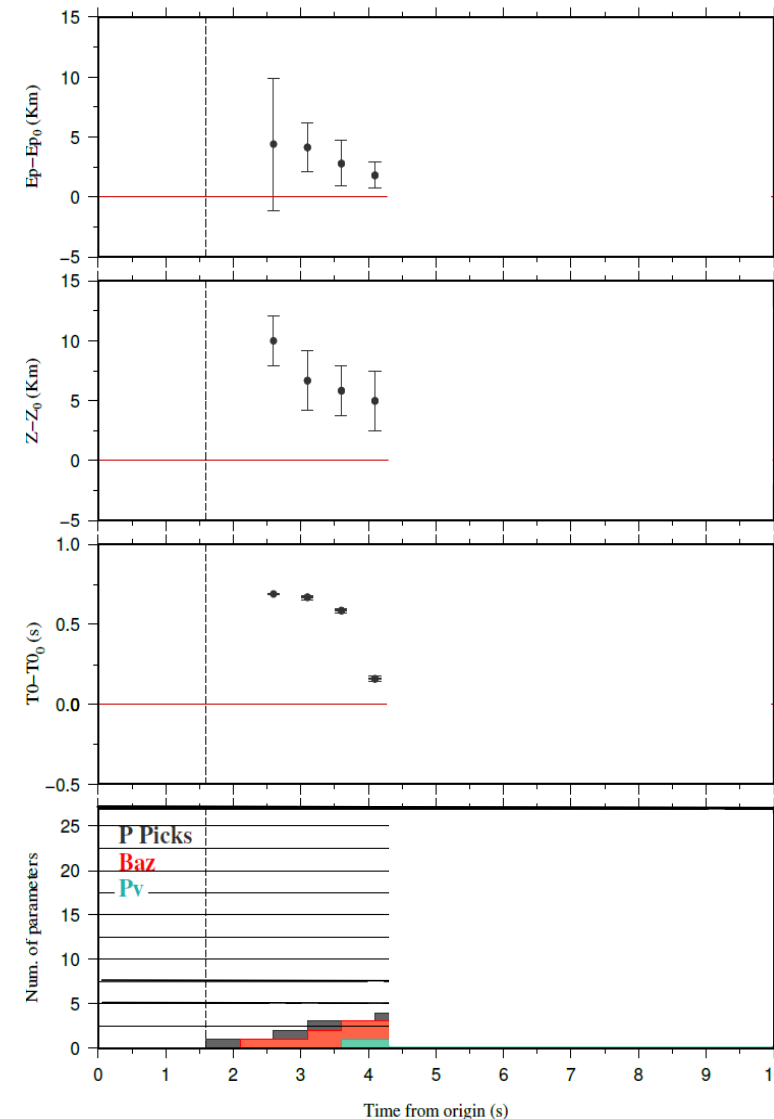


Probability distribution map

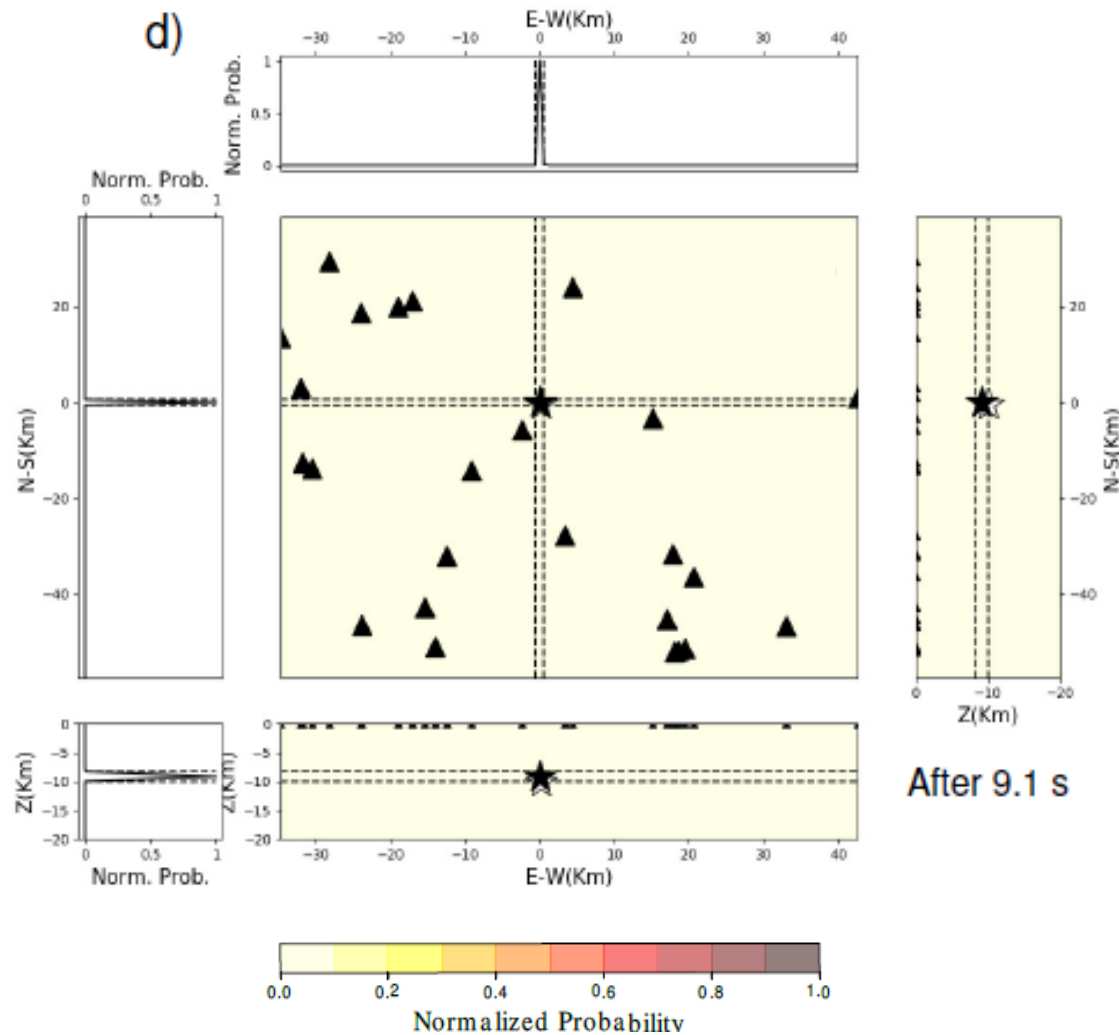


- ▲ Triggered stations
- △ No triggered stations
- ★ Procedure Location
- ☆ Bulletin Location

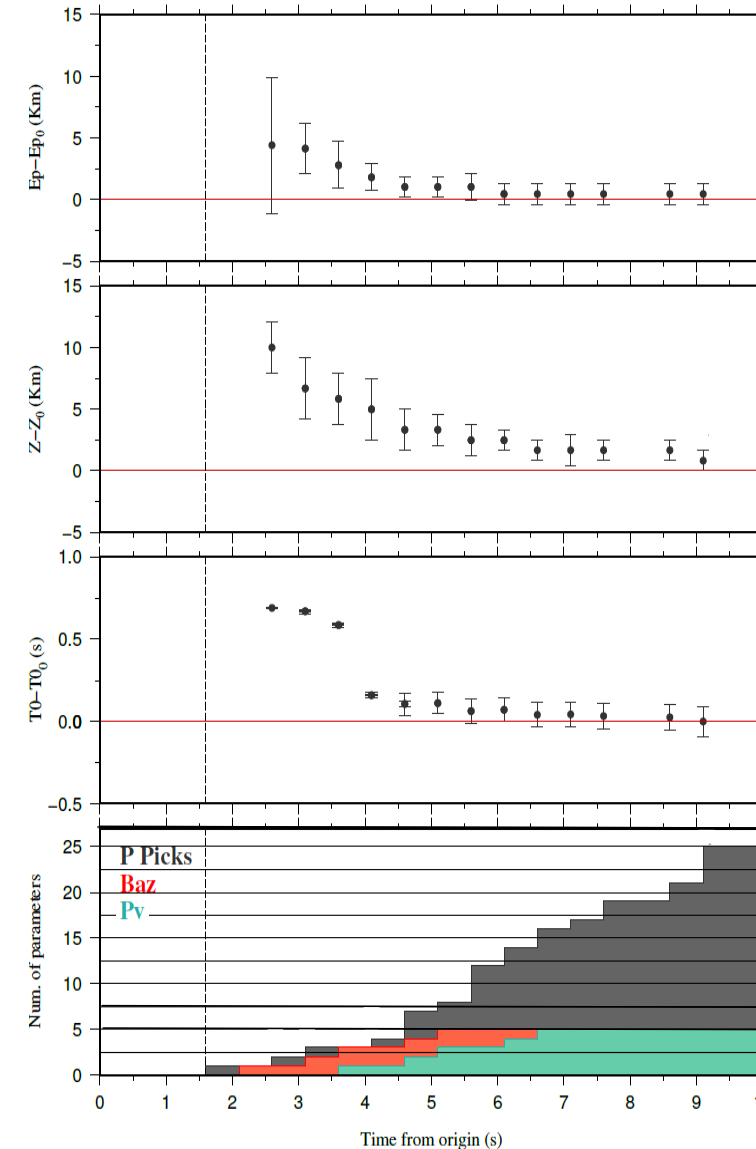
Time evolution plot



Probability distribution map



Time evolution plot

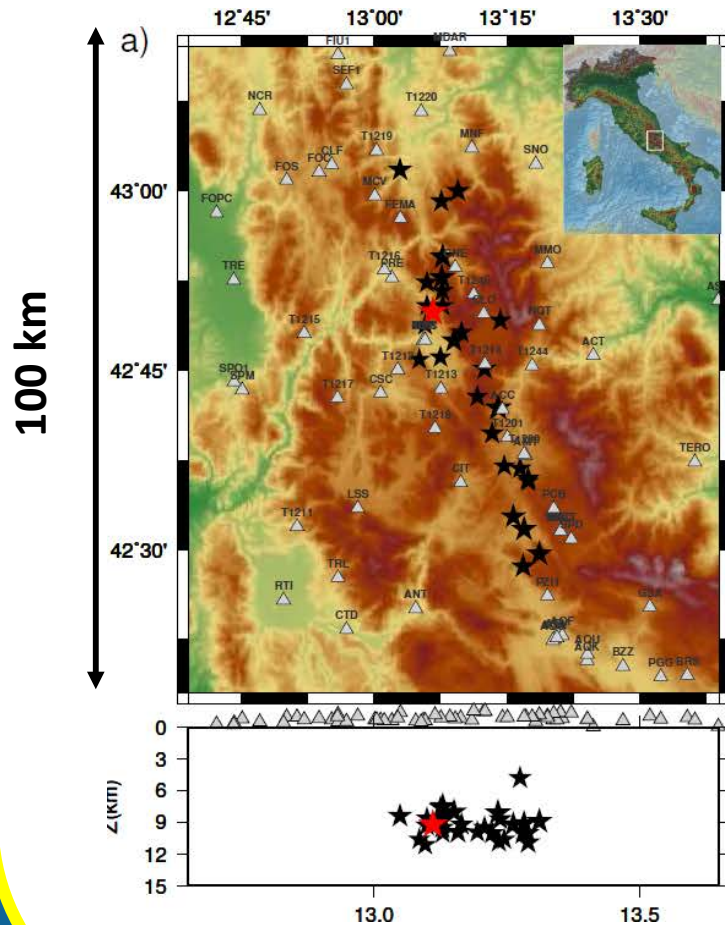




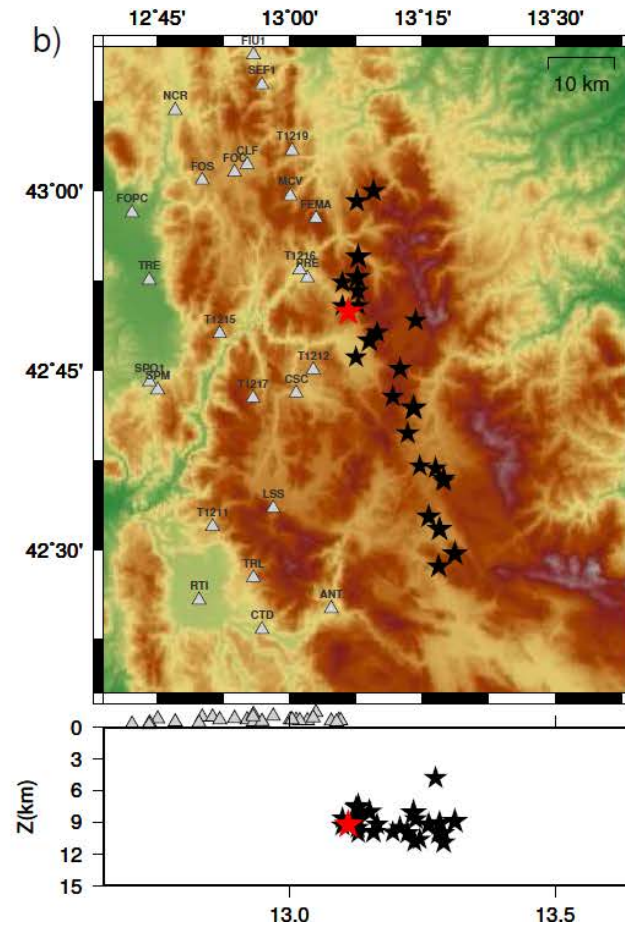
Performance testing

The data-set used for testing is composed by events of the Central Italy seismic sequence that occurred between August 2016 and January 2017 (about 135 earthquakes), 27 events with moment magnitude larger than 4.2. We have tested the methodology in three different network geometry.

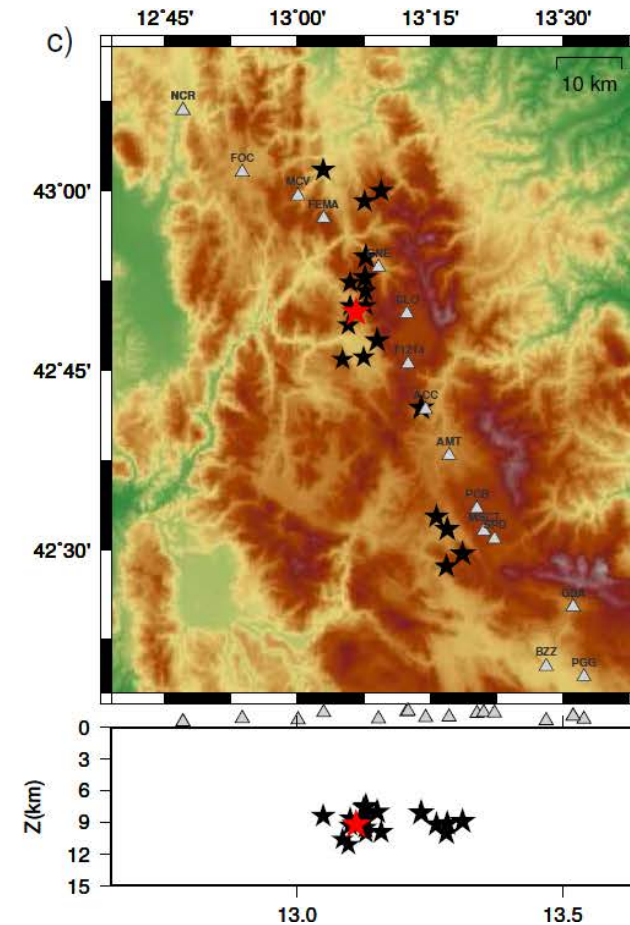
in-land network geometry



Off-shore network geometry



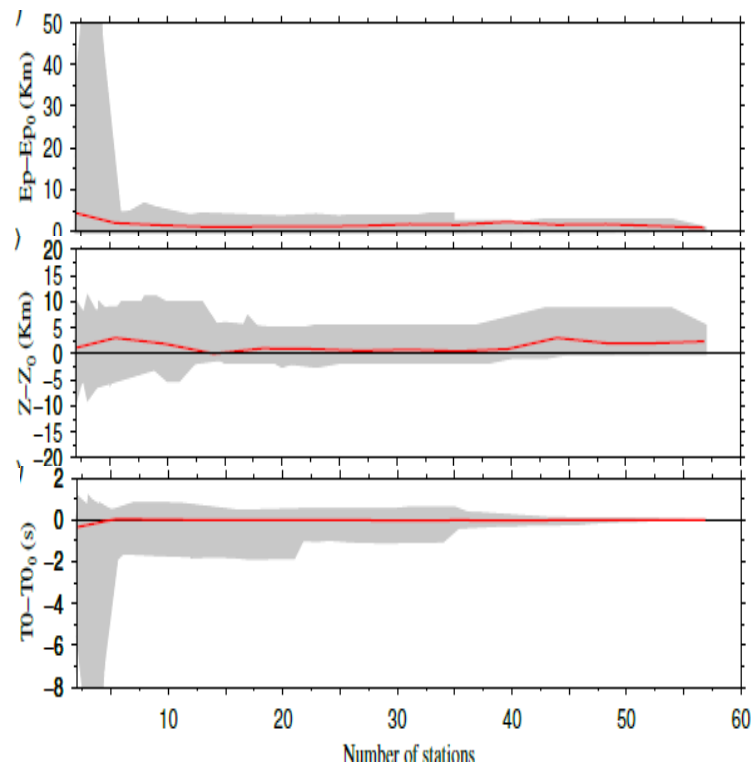
Linear network geometry



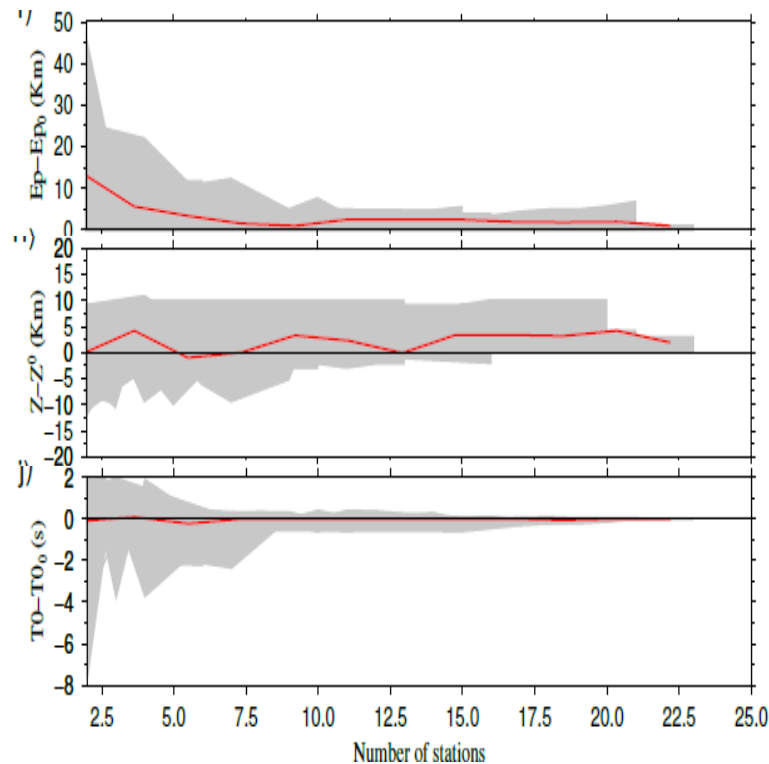
- RAN stations
- Bulletin Location
- Mainshock Location

Aggregate location evolutions in function of the number of stations for events of the three configurations.

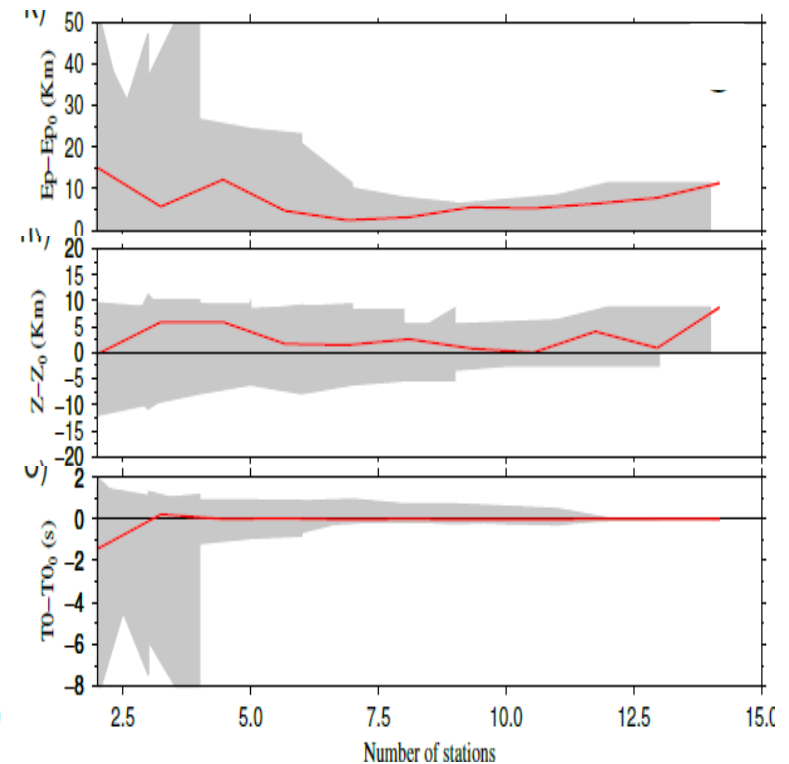
Dense network geometry



Off-shore network geometry



Linear network geometry

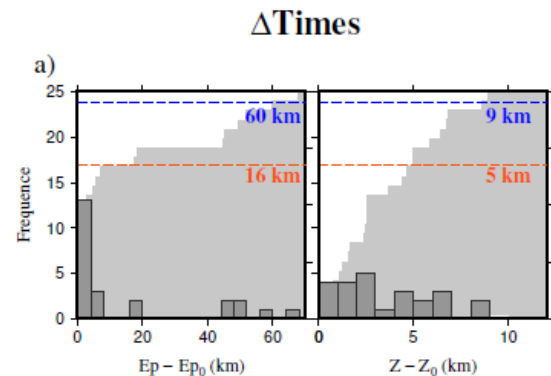


The grey area represents the curve dispersion and the solid red curves are the median values.

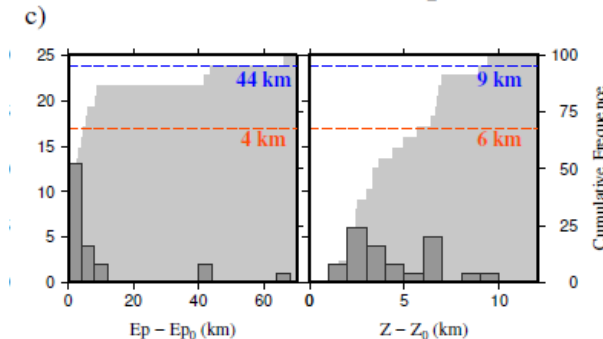
PERFORMANCE ANALYSIS (AFTER 2 SEC)

Comparison between the algorithm performance at 2 second after the first P pick by using only times [right side] and all parameters [left side]:

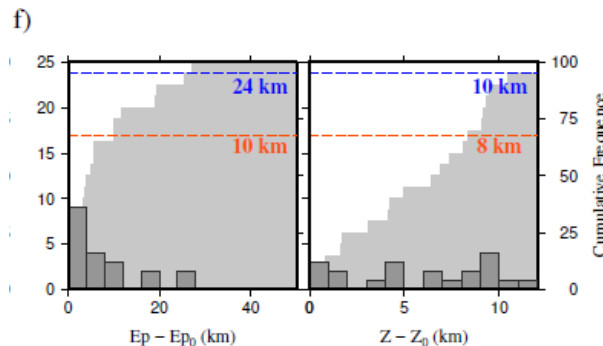
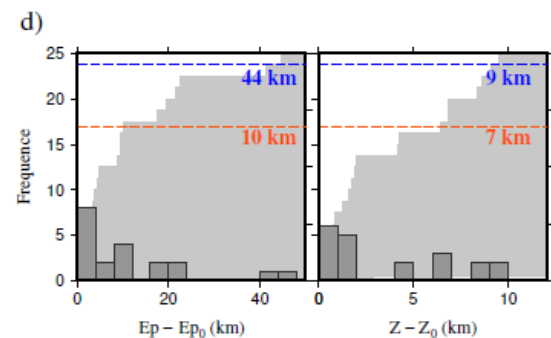
Dense network geometry



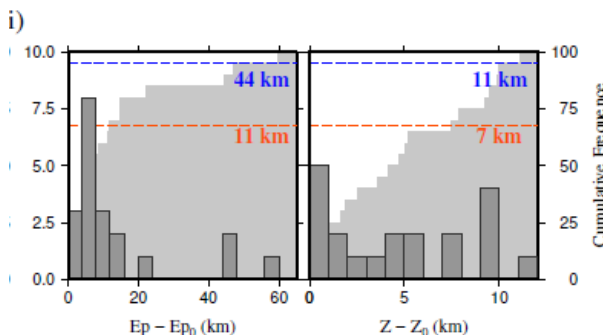
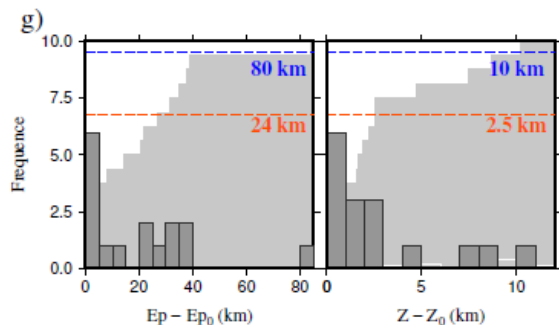
$\Delta\text{Times} + \text{Baz} + \Delta\text{Amp}$



Off-shore network geometry



Linear network geometry



Errors with respect to the reference localization of bulletin.

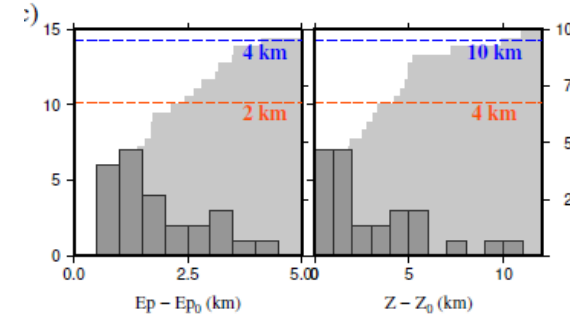
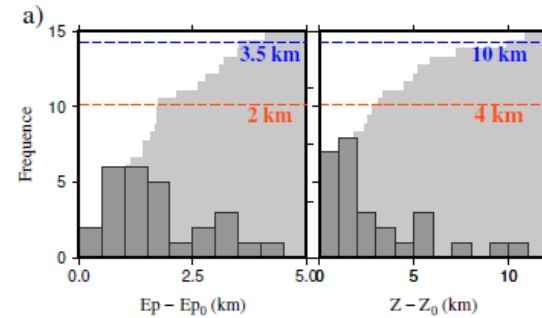
The light grey curve is the cumulative histogram of the distribution, and the dashed horizontal lines represent the limits of 68% (red) and 95% (blue) of the cumulative histogram.

Comparison between the algorithm performance at 4 second after the first P pick by using different data type combinations:

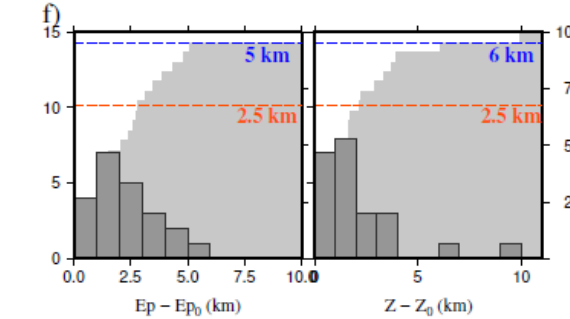
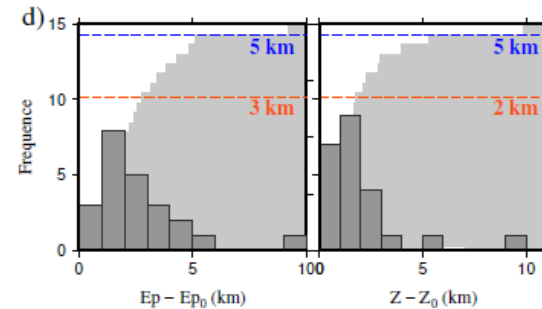
ΔTimes

$\Delta\text{Times} + \text{Baz} + \Delta\text{Amp}$

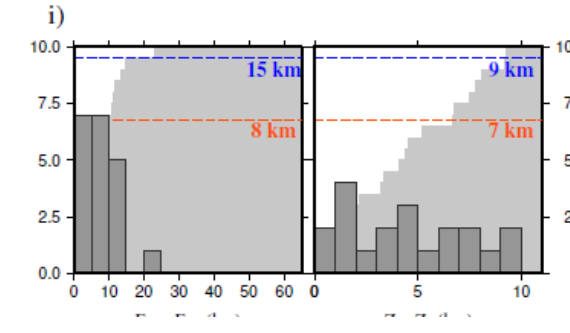
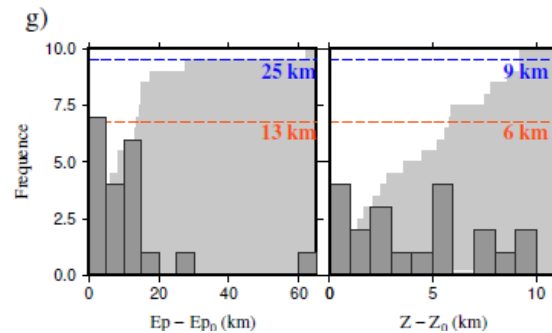
Dense network geometry



Off-shore network geometry



Linear network geometry

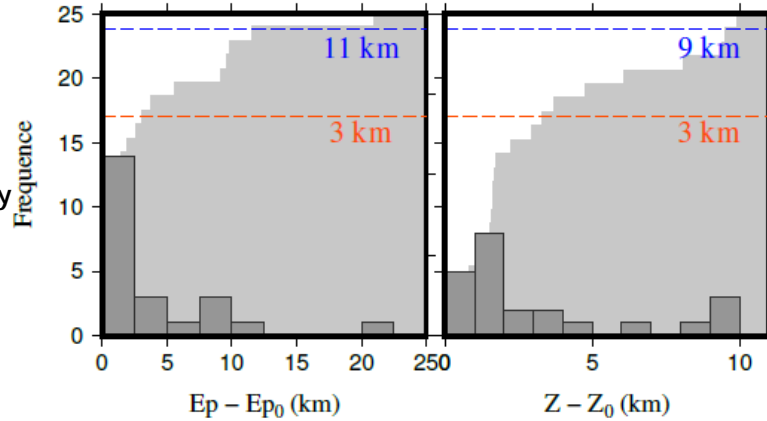


Errors with respect to the reference localization of bulletin.

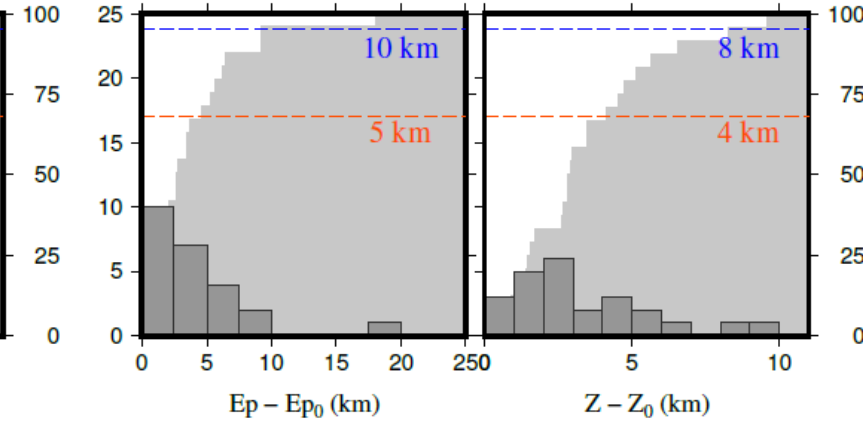
The light grey curve is the cumulative histogram of the distribution, and the dashed horizontal lines represent the limits of 68% (red) and 95% (blue) of the cumulative histogram.

Comparison between the performance at 3 second after the first P pick of the presented code and RTLOC Satriano et al., (2008).

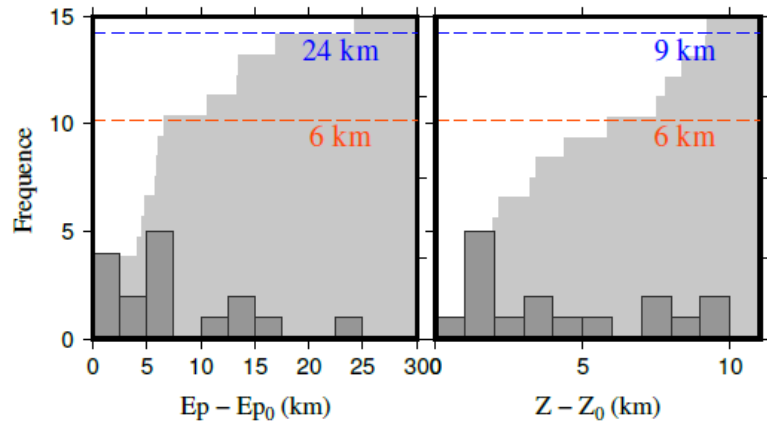
a) Proposed approach



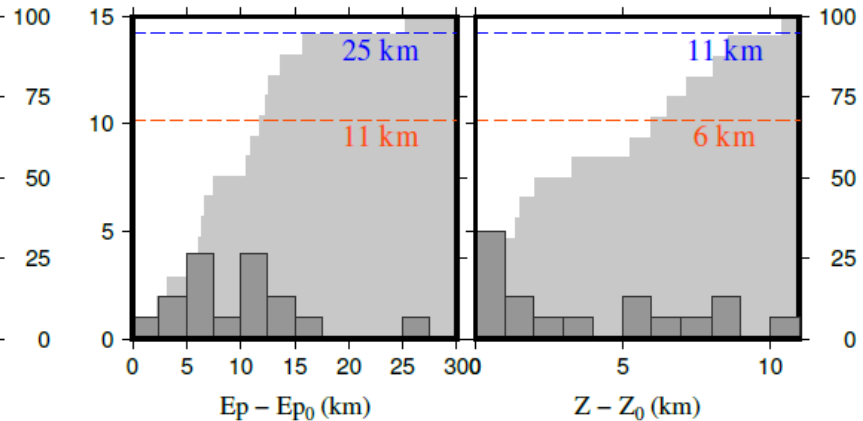
b) RTLOC



c)



d)



Errors with respect to the reference localization of bulletin.

The light grey curve is the cumulative histogram of the distribution, and the dashed horizontal lines represent the limits of 68% (red) and 95% (blue) of the cumulative histogram.

Off-shore network geometry

Linear network geometry



CONCLUSIONS

- The aggregate location evolution shows that, in median values, the location converge at the reference bulletin location with an error under 10 km after the trigger of a few number of stations. The final errors with respect to the reference localization in the linear and off-shore geometry is about 8-12 km due to a scarce azimuthal coverage of the network but in most part of cases the location is tolerable for Early Warning purposes.
- The testing analysis shows that the use of the differential amplitudes and of the BAZs increase the solution constraint especially in off-shore and linear geometry of network. In particular when a few number of stations is available using all parameters the error of locations is half of error obtained with the use of only differential time.
- Finally, after 3 sec from first pick the Comparison between the presented code and a consolidated software RTLOC, Satriano et al., (2008), shows (in the linear and off-shore network geometry) a sensitive increasing of performance in the earthquake hypocentral estimation with an error almost halved.