Università degli Studi di Messina

EGU General Assembly 2025 | ESSI2.10 – Monday 28 April 2025

MIFT

Ministero dell'Università e della Ricerca | PRIN

CUP J53C24002960006

Comparison of moment tensor inversion methods in a Bayesian framework

Thomas Mancuso[1], Cristina Totaro[1], and Barbara Orecchio[1]

[1]*University of Messina, Department of Mathematical and Computer Sciences, Physical Sciences and Earth Sciences, Messina, Italy*

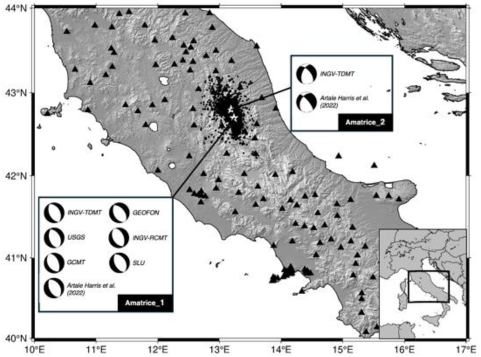
Go to 2-minute presentation

In recent decades, significant progress has been made in estimating moment tensors and their uncertainties using **Bayesian inference**.

BEAT
BAYESIAN EARTHQUAKE ANALYSIS TOOL

MCMTpy

We applied the **BEAT** (Vasyura-Bathke et al., SRL 2020) and **MCMTpy** (Yin and Wang, SRL 2022) software to the 2016 M_w 6.0 Amatrice mainshock and a M_w 3.2 event from the same Central Italy sequence to evaluate their performance across different magnitude ranges.



Go to main slides

Overview

Methodological Tests

Results

Conclusions

Sharing is encouraged

This presentation participates in OSPP

EGU

Outstanding Student & PhD candidate Presentation contest

Abstract

Contacts

PICO Navigation

The 'Home' button take you to the section menu

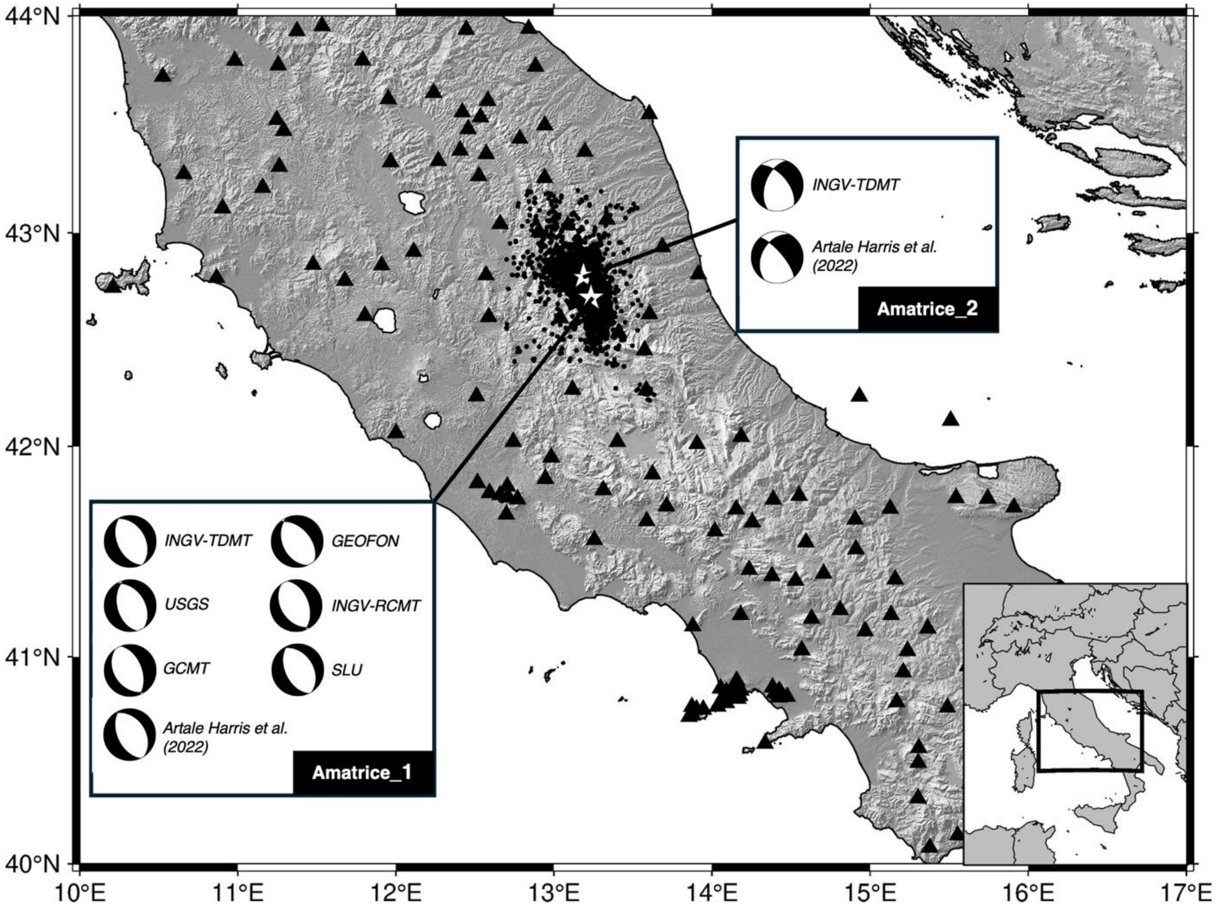
The left/right arrows take you to the previous/next page

2-minute presentation

In recent decades, significant progress has been made in estimating moment tensors and their uncertainties using **Bayesian inference**.

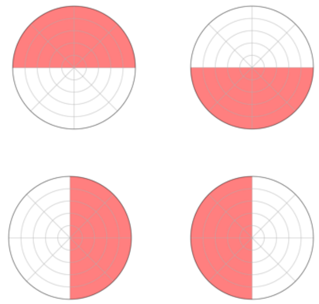
BAYESIAN EARTHQUAKE ANALYSIS TOOL

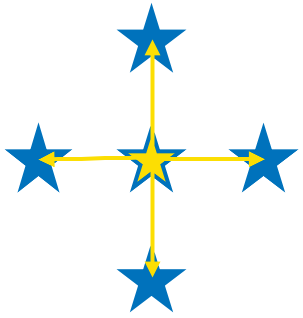
We applied the **BEAT** (Vasyura-Bathke et al., SRL 2020) and **MCMTpy** (Yin and Wang, SRL 2022) software to the 2016 M_w 6.0 Amatrice mainshock and a M_w 3.2 event from the same Central Italy sequence to evaluate their performance across different magnitude ranges.

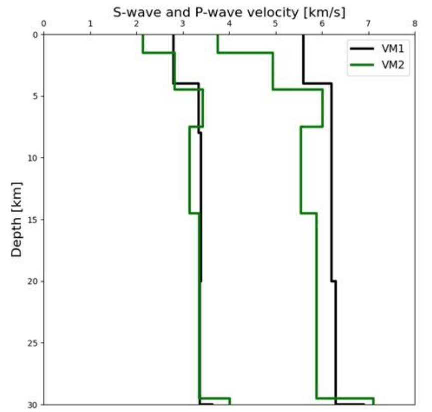


2-minute presentation

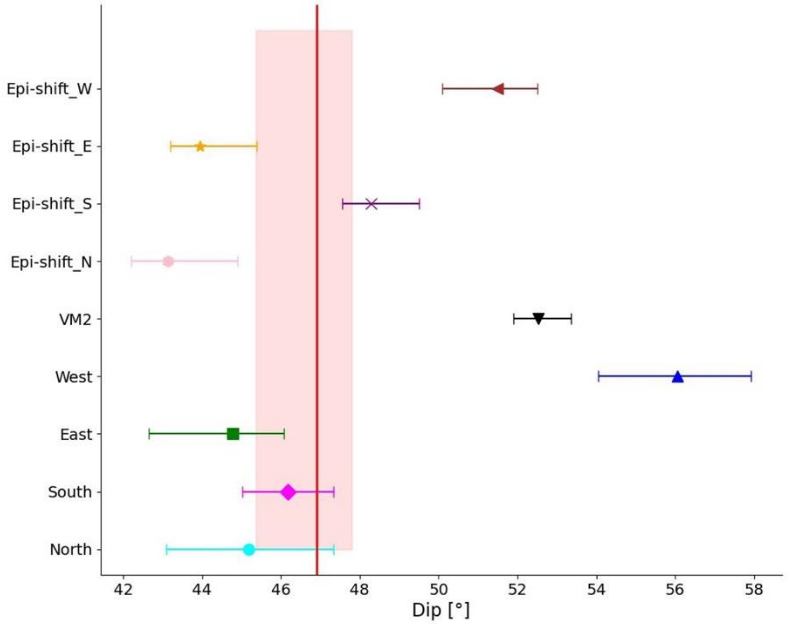
We focused on the performance evaluations by proposing a series of **methodological tests** which simulate different data setup as **not-optimal network geometry**, **epicentral location errors**, biases in the **velocity model**.

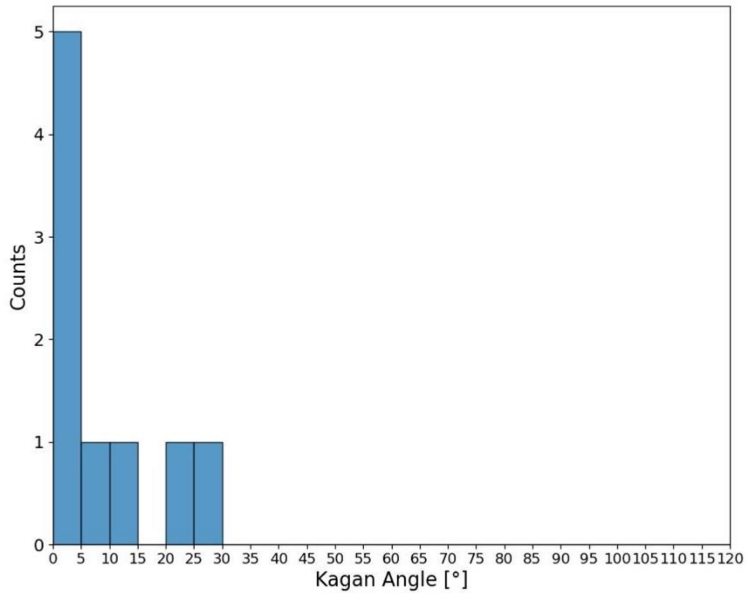




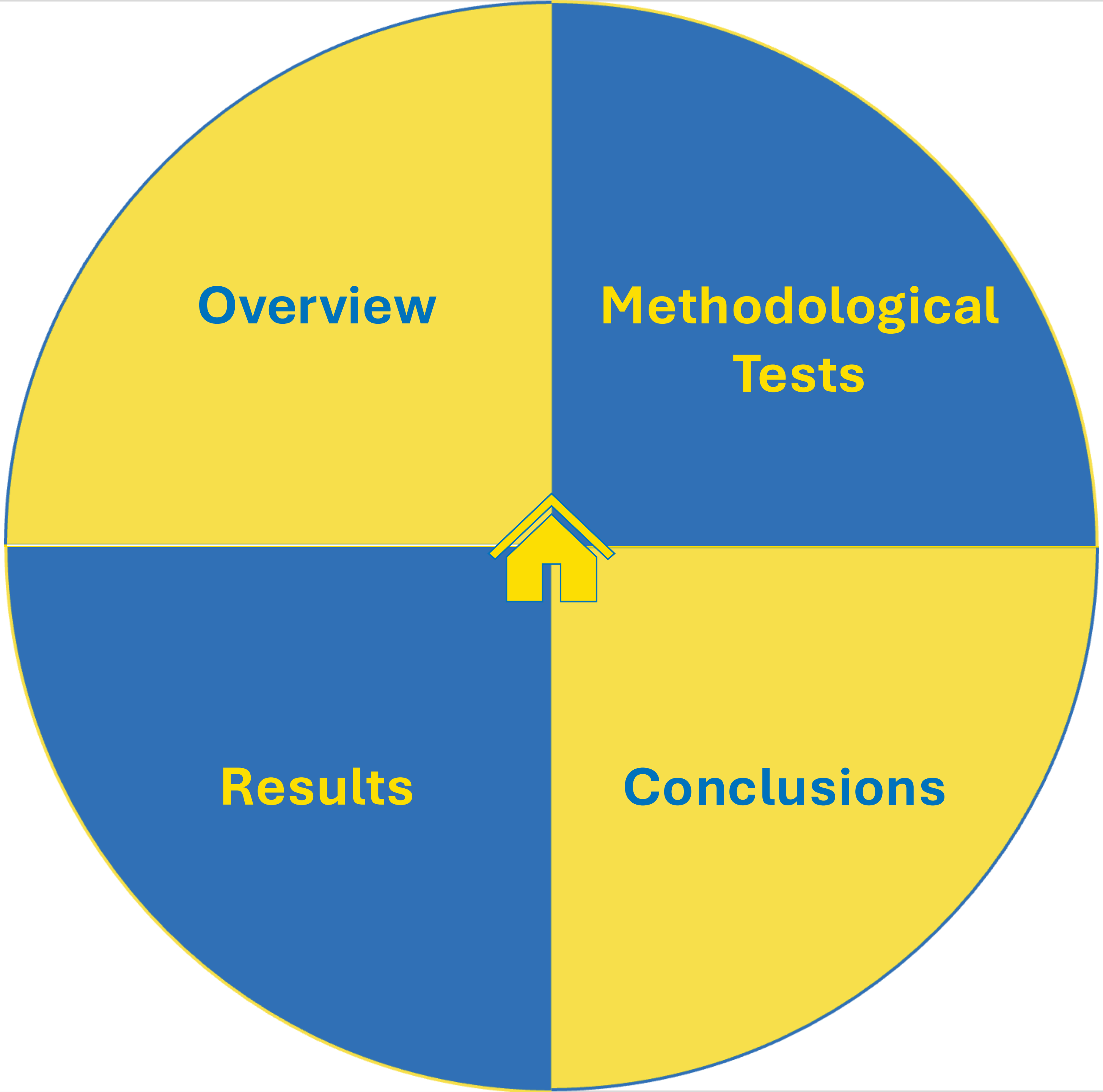


We **(i)** explored the software stability, **(ii)** identified their limitations in resolving DC moment tensors and **(iii)** evaluated the related uncertainty estimates.





Section menu



PICO Navigation

Click on a section of the 'beachball' to navigate to the corresponding slide

Overview

Seismic moment tensors are fundamental tools in seismological studies helping to clarify the relationships between earthquakes, seismic faults, and active tectonics and to estimate seismogenic stress fields. In addition to the widely known standard techniques, in the last decades several inversion approaches have been developed aimed at improving moment tensor solutions and related uncertainty estimates. In this framework **we explored two recently developed software working in a Bayesian framework** (**MCMTpy** and **BEAT**) by using real data and by proposing several inversion tests. We selected as test-cases two earthquakes belonging to the 2016-2017 Central Italy seismic sequence (i.e., the M_w 6.0 Amatrice mainshock and a M_w 3.2 aftershock) representative of two different magnitude levels.

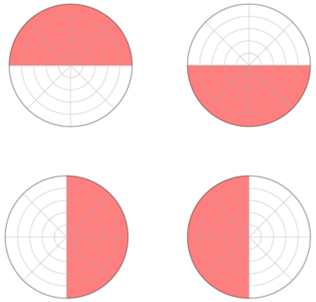
Test-Cases

Info Software

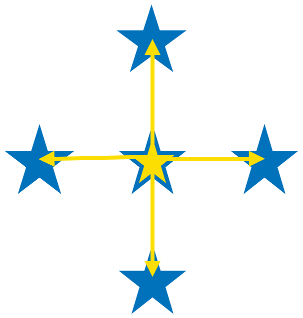
Abstract

Methodological Tests

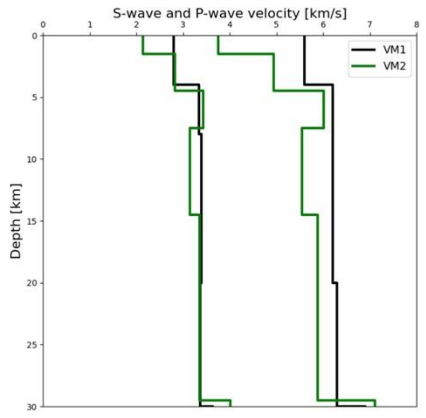
STATION COVERAGE



SOURCE LOCATION



VELOCITY MODEL



Reference Studies

D'Amico et al., BGTA 2011: ***Testing the stability of moment tensor solutions for small earthquakes in the Calabro-Peloritan Arc region (southern Italy);***

Scognamiglio et al., GJI 2016: ***Uncertainty estimations for moment tensor inversions: the issue of the 2012 May 20 Emilia earthquake***;

Scolaro et al., SPRINGERNAT 2018: ***Estimating stability and resolution of waveform inversion focal mechanisms;***

Petersen et al., SE 2021: ***Regional centroid MT inversion of small to moderate earthquakes in the Alps using the dense AlpArray seismic network: challenges and seismotectonic insights***.

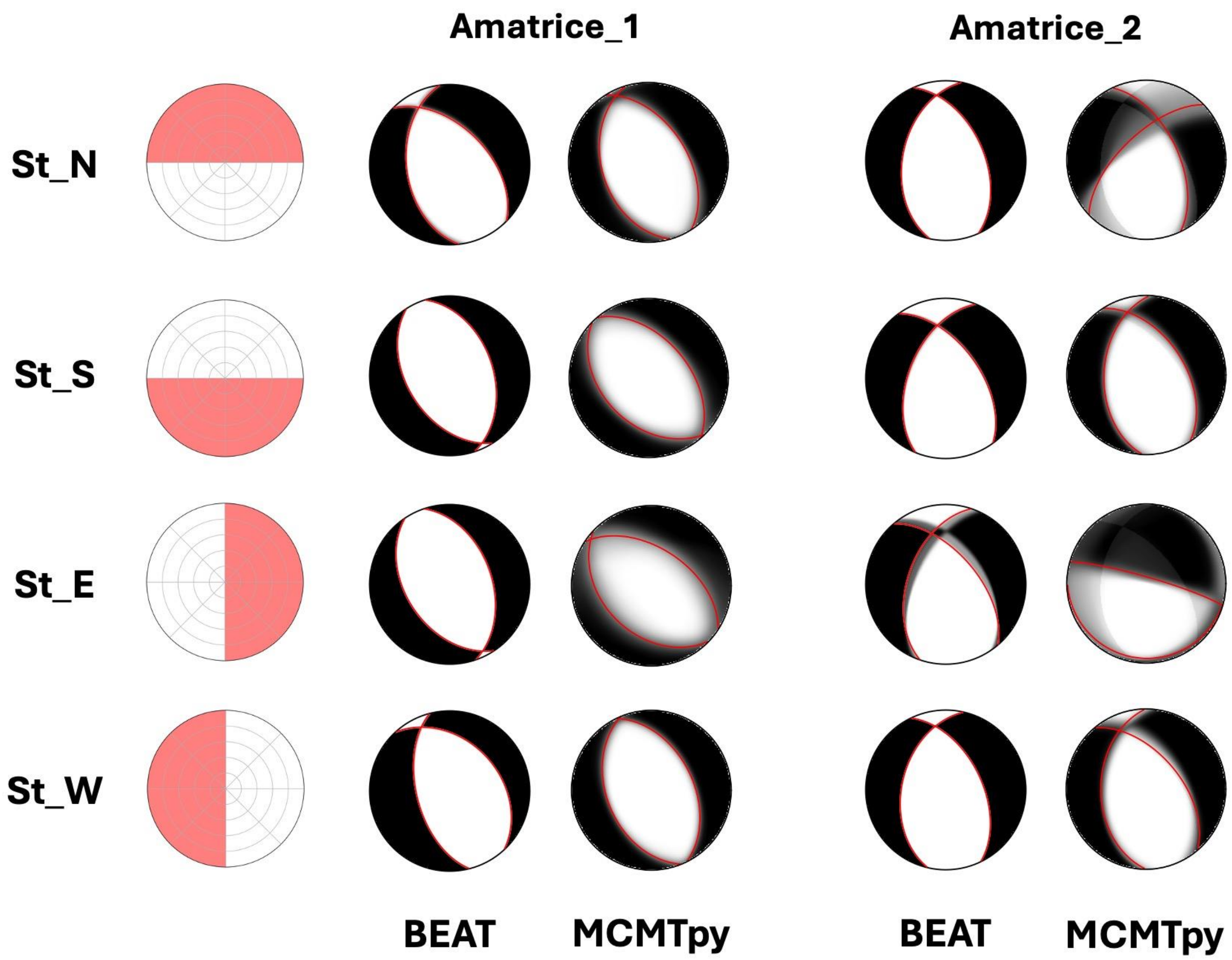
PICO Navigation

Click the yellow button to go to the corresponding slide

Results – Station Coverage

We tested four different configurations and performed the inversion considering only the stations located to the North, South, East, and West of the epicenter (St_N/S/E/W in Figure), respectively.

The **BEAT** focal mechanisms are very similar when compared to the optimal ones, with Kagan angles (KAs) lower than 30°. Instead, the **MCMTpy** mechanisms show significant differences (e.g., 45° < KA < 60°) for the *Amatrice_2* earthquake, being affected by large azimuthal gaps (>180°) and few number of recording stations (e.g., only four stations covering the East quadrant).

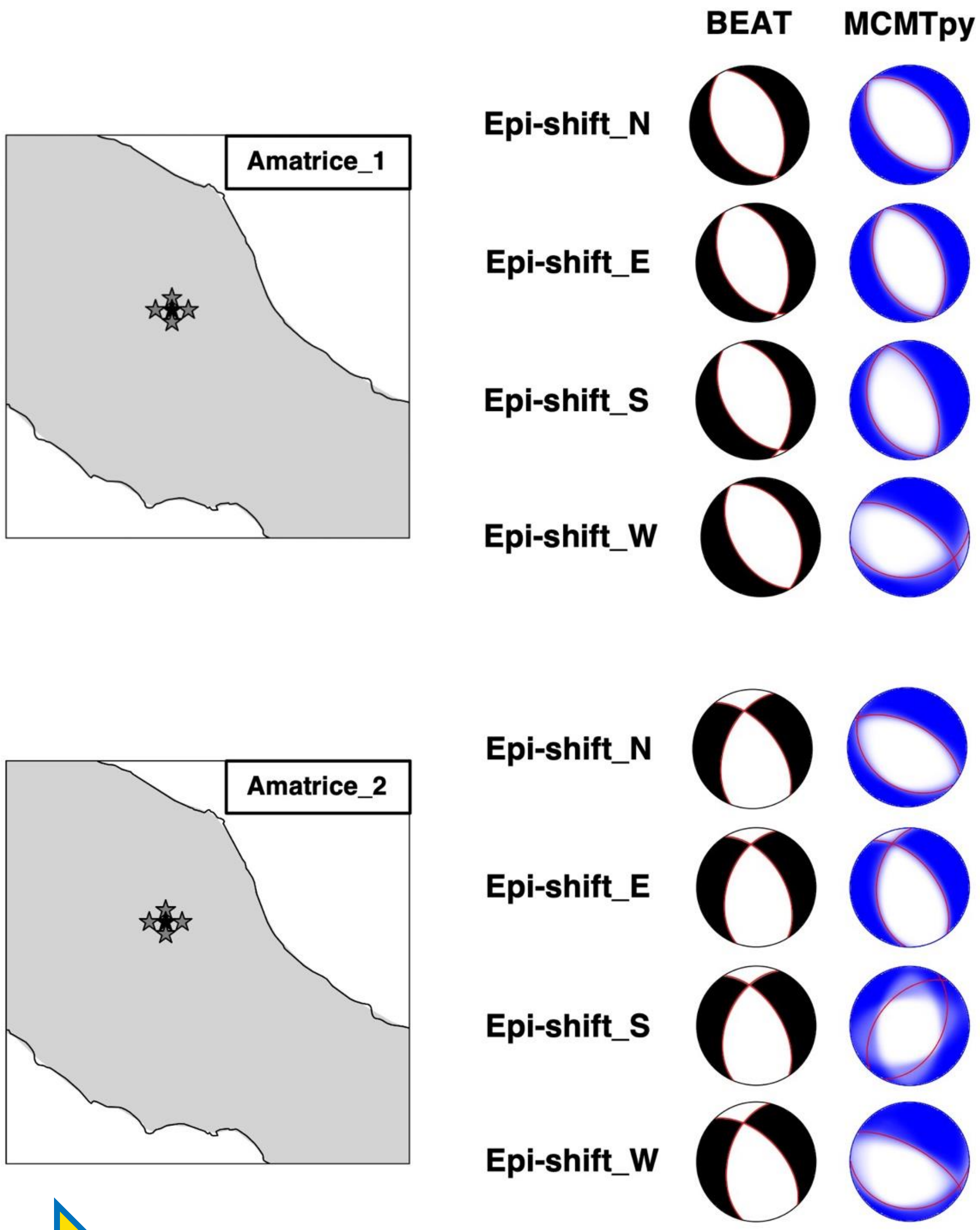


PICO Navigation
Click on the image to display its corresponding caption

Results – Source Location

We tested four scenarios by shifting epicentral location 10km towards North, South, East and West for each event (Epi-shift N/S/E/W in Figure).

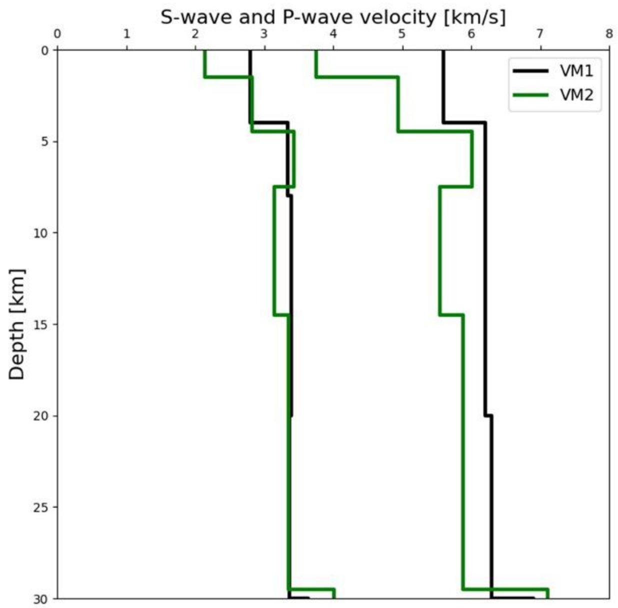
The results show that the mislocation does not produce significant differences by using the **BEAT** algorithm, thus supporting the stability of the related results. A quite different behavior is observed for **MCMTpy** showing in some cases marked differences witnessed by KAs significantly greater than 30° (up to ~65°).

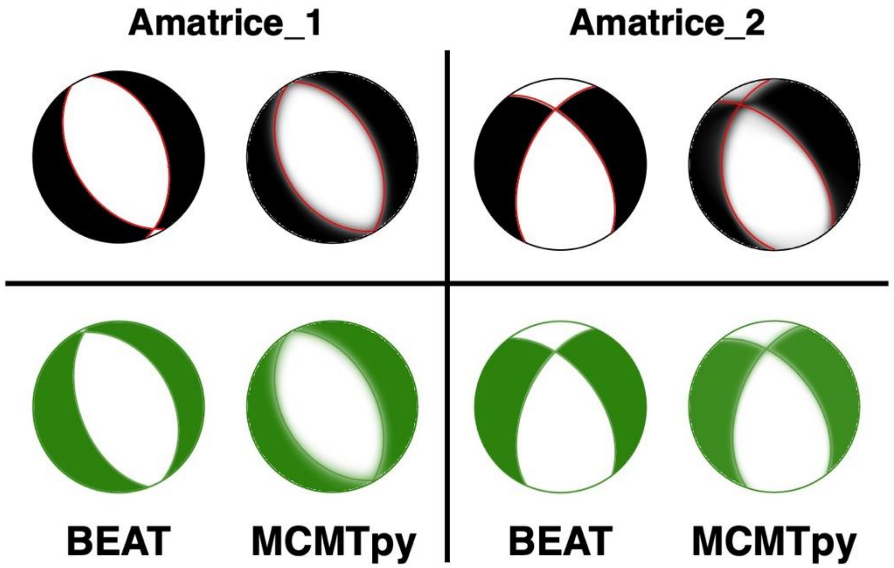


PICO Navigation

Click on the image to display its corresponding caption

Results – Velocity Model



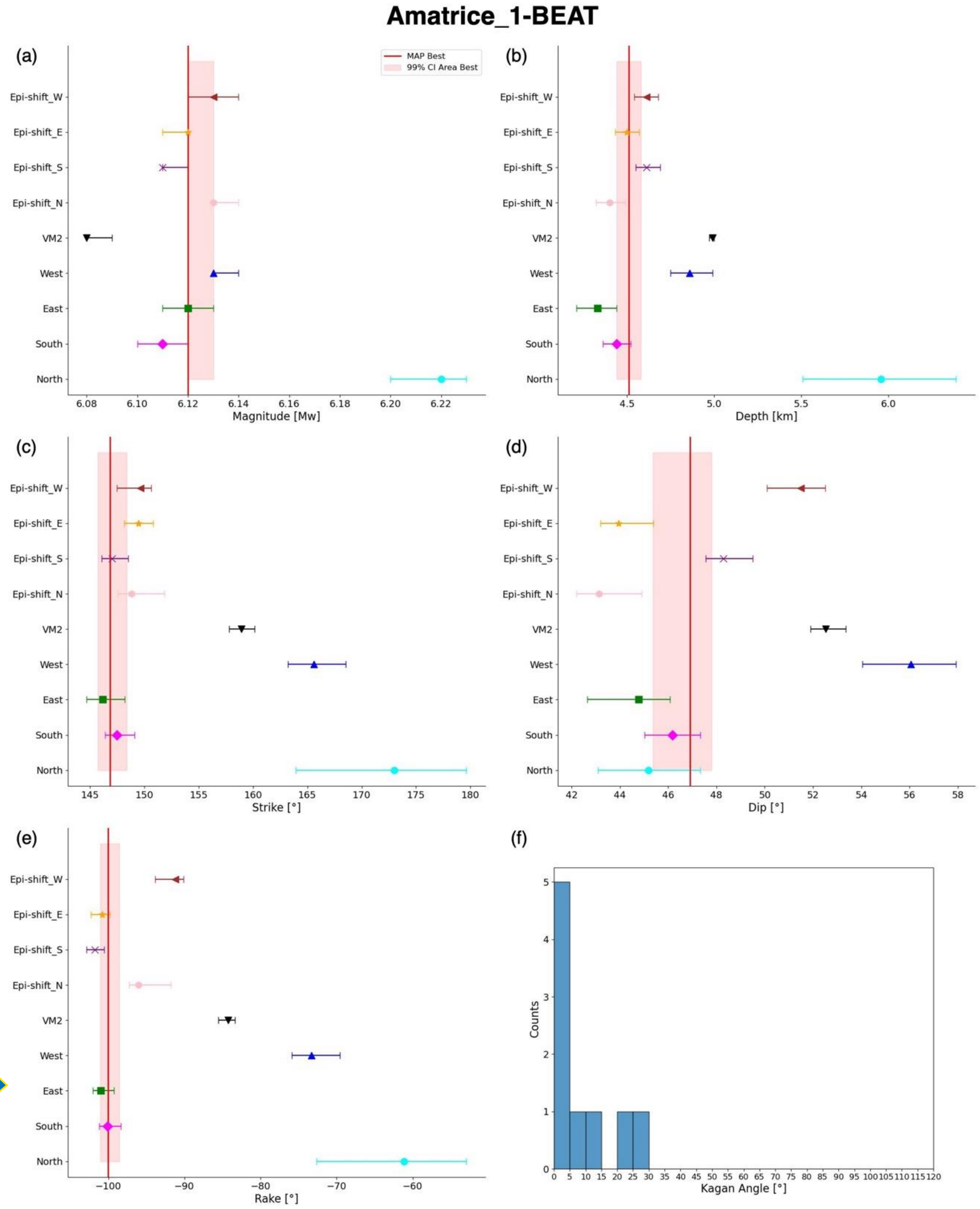


In order to evaluate the influence of velocity models on moment tensor inversion, **we computed DC solutions by using two 1D velocity models** regionally calibrated for the tested area: **VM1** (Carannante et al., JGR SE 2013) and **VM2** (CIA model; Hermann et al., BSSA 2011). In these cases**, the good stability of the obtained mechanisms is evident for both events and algorithms**.

Conclusions

The overall evaluation of test results indicates that both algorithms furnish quite reliable solutions also in not-optimal conditions; in particular, it is noticeable **the very high stability of BEAT results in all tested configurations**.

A visual inspection of the uncertainties range for the investigated parameters indicates that they are quite small with respect to the differences observed in the performed tests. We observe **a quite good performance of the two algorithms**, probably slightly better for MCMTpy with respect to BEAT, even if **a true full comparison is not possible also because of the different approaches and uncertainty definitions**.



PICO Navigation

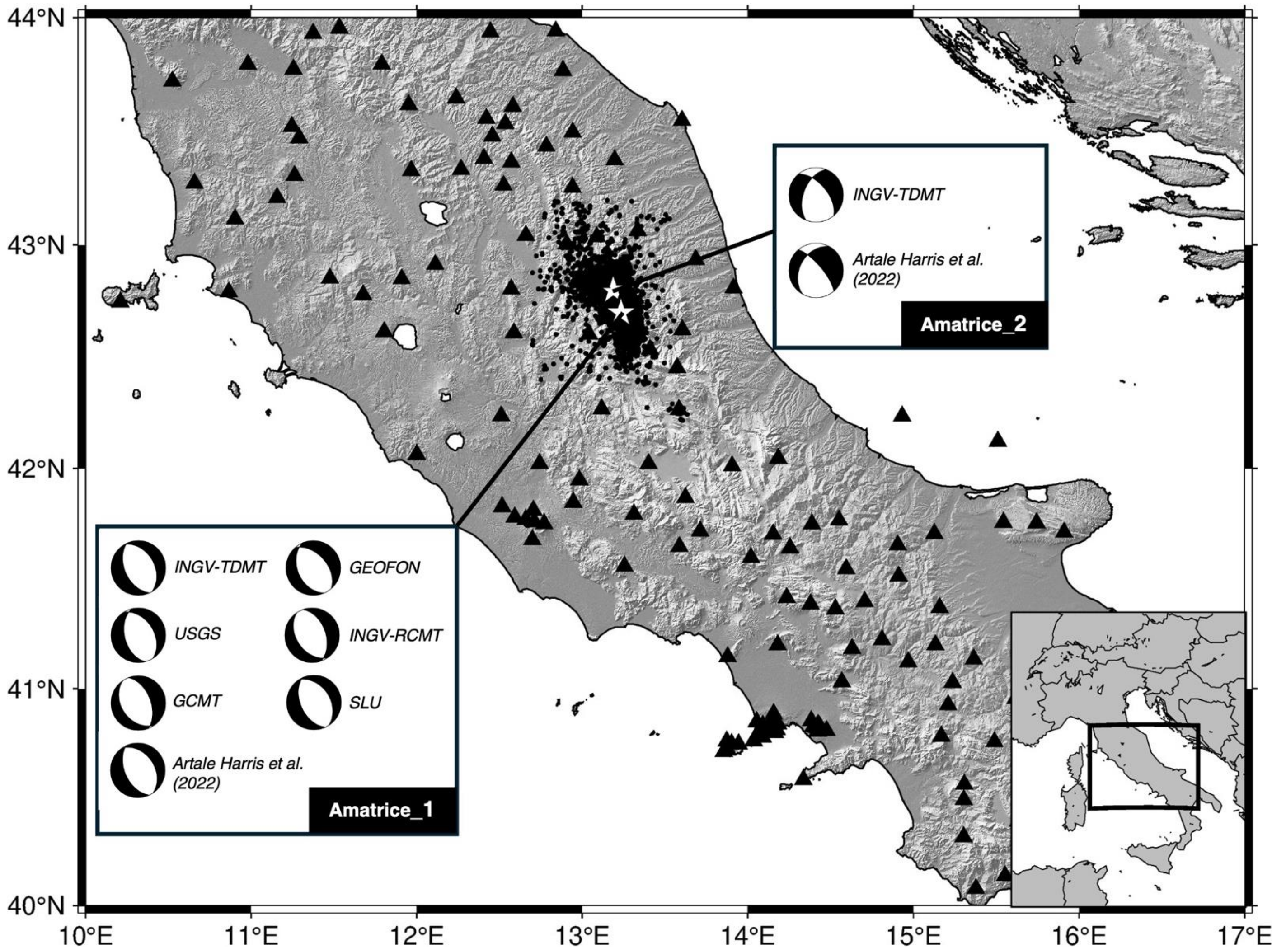
Click on the image to display its corresponding caption

Test-Cases

The Central Italy region is well known for its high seismicity and complex tectonics deriving from the interaction between preexisting contractional structures and Quaternary extensional faults (Pizzi et al., *Tectonics* 2017).

In this area the main structural and geological features were widely investigated, as testified by the huge scientific literature. In addition, the seismic network shows high density and optimal azimuthal coverage, leading to furnish a wealth of new high-quality seismological data in the last decades. For these reasons, the Amatrice-Visso-Norcia seismic activity offers an optimal background for the purpose of our study.

We **selected two earthquakes** (white stars in Figure) **occurred on 24 August 2016 at 01:36 UTC (*Amatrice_1*, M_w 6.0) and at 06:54 UTC (*Amatrice_2*, M_w 3.2)**, as representative of different magnitude levels.



close

PICO Navigation
Click on the image to display its corresponding caption

Info Software

BEAT (Bayesian Earthquake Analysis Tool)

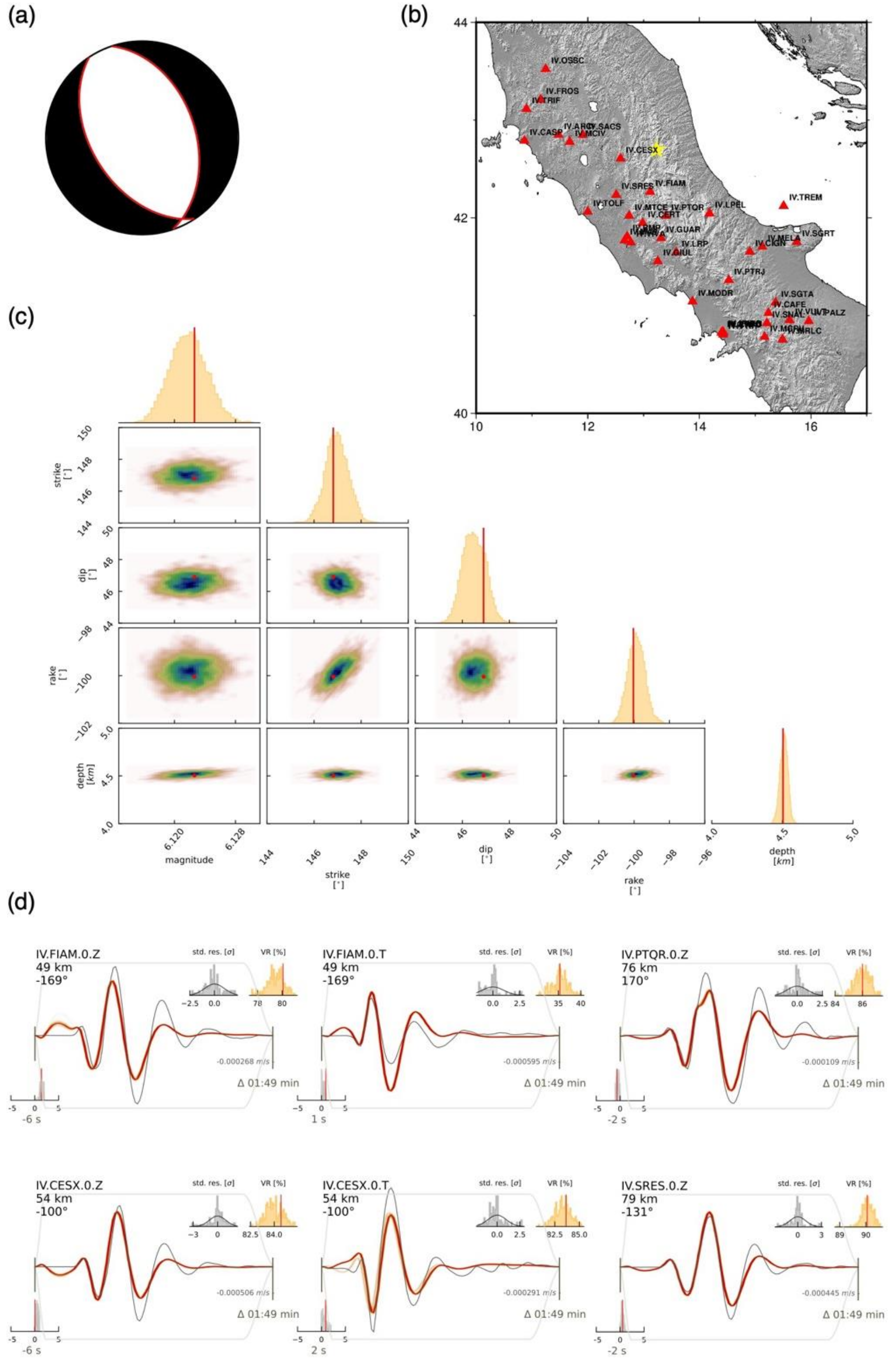
The **Bayesian Earthquake Analysis Tool (BEAT)** is an open-source Python software to conduct source-parameter estimation studies by employing a Bayesian framework with a flexible problem definition **(Vasyura-Bathke et al., SRL 2020)**.

To efficiently explore the model parameter space, BEAT first optimizes the noise scaling (or hyperparameters) of each individual trace using a Metropolis algorithm. Subsequently, it samples the full problem using as default algorithm, a **sequential Monte Carlo (SMC) sampler** (Del Moral et al., RSSS B SM 2006, Minson et al., GJI 2013; Vasyura-Bathke et al., GJI 2021).

BEAT
BAYESIAN EARTHQUAKE ANALYSIS TOOL

https://github.com/hvasbath/beat

close

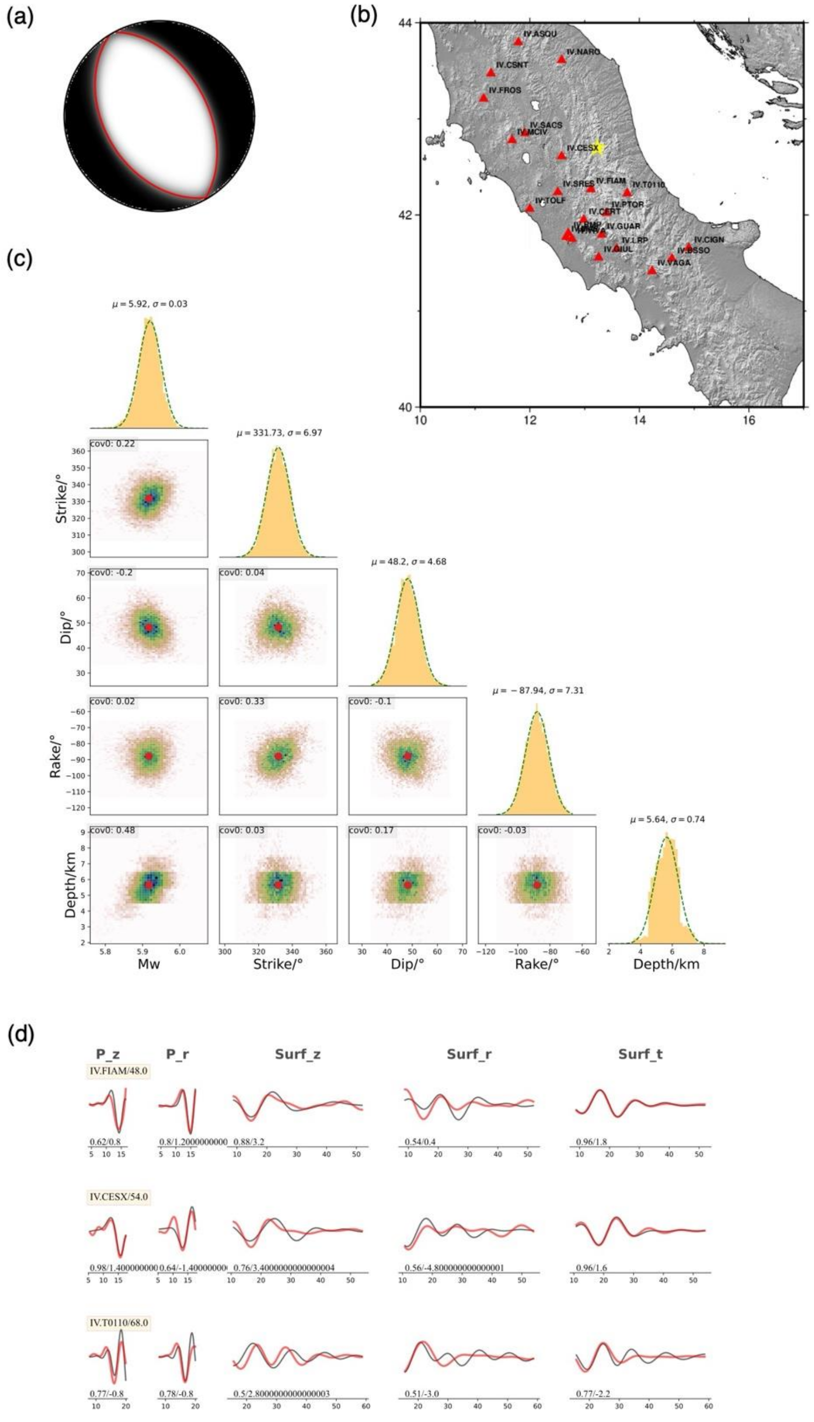


Info Software

MCMTpy

The **MCMTpy (Yin and Wang, SRL 2022)** software is based on the **Cut-And-Paste (CAP) waveform inversion algorithm** (Zhao and Helmberger, BSSA 1994; Zhu and Helmberger, BSSA 1996) and **Bayesian inference**. Like the CAP methodology, MCMTpy breaks each waveform into **Pnl** and **surface wave segments** which are weighted differently during the inversion process.

MCMTpy uses both phase arrival time and waveform data to sample the PPD of source parameters through the **Metropolis-Hastings (M-H) algorithm** (Metropolis et al., 1953; Hastings, *Biometrika* 1970).



https://github.com/OUCyf/MCMTpy

close

Info

DC solutions of the **Amatrice_1** and **Amatrice_2** earthquakes for different azimuthal station distributions. Each row reports the fuzzy beachballs obtained by using only the stations located in the North, South, East and West quadrants, as indicated in the polar plots.

close

Info

Results of the source location tests for the **Amatrice_1** (top) and **Amatrice_2** (bottom) earthquakes. On the left: map displaying epicentral locations shifted 10 km towards the North (**Epi-shift**_N), South (**Epi-shift_S**), East (**Epi-shift_E**), and West (**Epi-shift_W**) with respect to the INGV reference location. Right: black and blue fuzzy beachballs indicating **BEAT** and **MCMTpy** solutions obtained for each test.

close

Info

DC solutions estimated for **Amatrice_1** and **Amatrice_2** by using different velocity models for GFs computation. The plot on the left shows the velocity models considered for the test: **VM1** (Carannante et al., JGR SE 2013) and **VM2** (Herrmann et al., BSSA 2011). On the right, for the two selected earthquakes are reported as **black beachballs** the solutions associated to the model **VM1**, and as **green beachballs** those associated to model **VM2**.

close

Info

Comparisons between the best solution and the results obtained from all the tests performed for the **Amatrice_1** event by using the **BEAT** algorithm. (a-e) For each estimated parameter the test results (MAP and uncertainty range) are reported with a colored symbol and the related error bar. The best solution and its uncertainty range are also displayed with a red line and pink area, respectively. (f) Histogram of the Kagan angles between the test results and the best solution.

close

Info

Map of the study region (see inset for location) showing the recording stations managed by the INGV (black triangles) and the epicenters of the events (black circles) occurred between August 24 and October 25, 2016, in the framework of the 2016-2017 sequence of Central Italy. The white stars indicate the location of the earthquakes investigated in the present study (i.e., **Amatrice_1** and **Amatrice_2**). For both the selected events moment tensor solutions available from literature and catalogues are also reported.

close

Info

Results obtained by using the **BEAT** algorithm for the Amatrice_1 earthquake. (a) Fuzzy beachball illustrating the MT solution uncertainty. (b) Distribution of seismic stations (red triangles) used for the computation. The yellow star shows the event epicenter location. (c) 1D and 2D marginal posterior distributions of the source parameters. Red vertical lines in the histograms and red dots in the 2D correlation maps mark the maximum a posteriori (MAP) solution; in the correlation plots, blue colors are regions of high probability. (d) Waveform fits between observed (black curves) and synthetic (red curves) velocity waveforms. For each trace: text in the upper left corner indicates network code, station name and component, epicentral distance and azimuth; grey and orange histograms in the upper right corner display the standardized residuals and weighted variance reduction (VR), with red lines marking the MAP solution; the bottom left gray histogram represents station-specific time shifts.

close

Info

Results obtained by using the **MCMTpy** algorithm for the Amatrice_1 earthquake. (a) Fuzzy beachball illustrating the MT solution uncertainty. (b) Distribution of seismic stations (red triangles) used for the computation. The yellow star shows the event epicenter location. (c) 1D and 2D marginal posterior distributions of the source parameters. μ and σ are the mean and standard deviation values of the samples in the 1D histograms, respectively. The green dotted lines are the corresponding Gaussian functions fitting posterior distributions. (d) Waveform fits between observed (black curves) and synthetic (red curves) velocity waveforms. Correlation coefficient and time shift of each waveform phase are shown. P_z and P_r represent the Z and R components of the P-wave inverted segment, respectively. Surf_z, Surf_r, and Surf_t represent the Z, R, and T components of the surface-wave.

close

Contacts

Thomas Mancuso

thomas.mancuso@studenti.unime.it

Dr. Cristina Totaro

cristina.totaro@unime.it

Prof. Barbara Orecchio

barbara.orecchio@unime.it

close