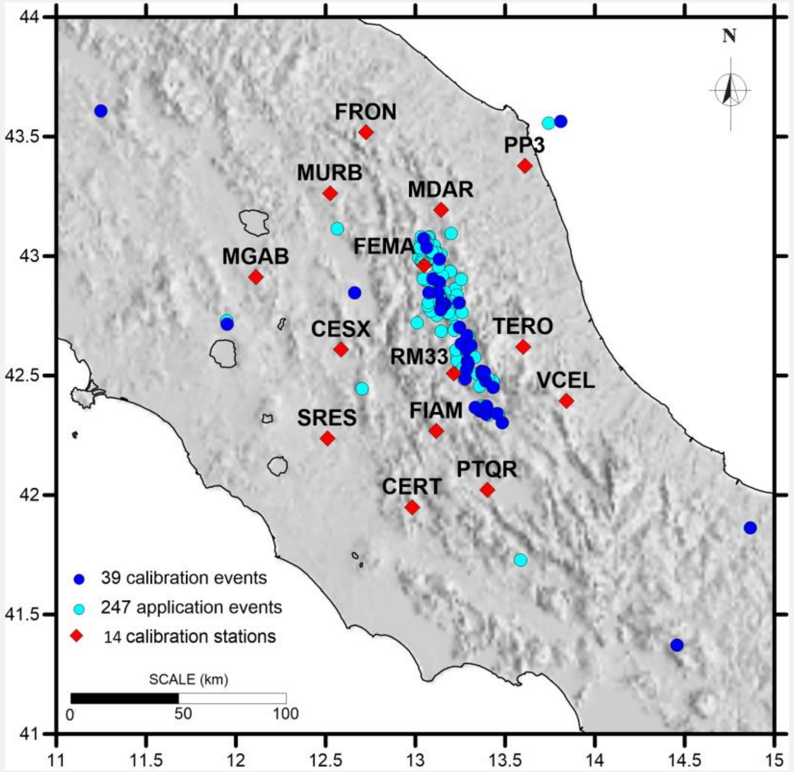
# Alcune tecniche per la stima dei parametri di sorgente in Centro Italia

**Morasca P., Mayeda K, Bindi D., D’Amico M., Spallarossa, D., Picozzi, M., Pacor, F.**

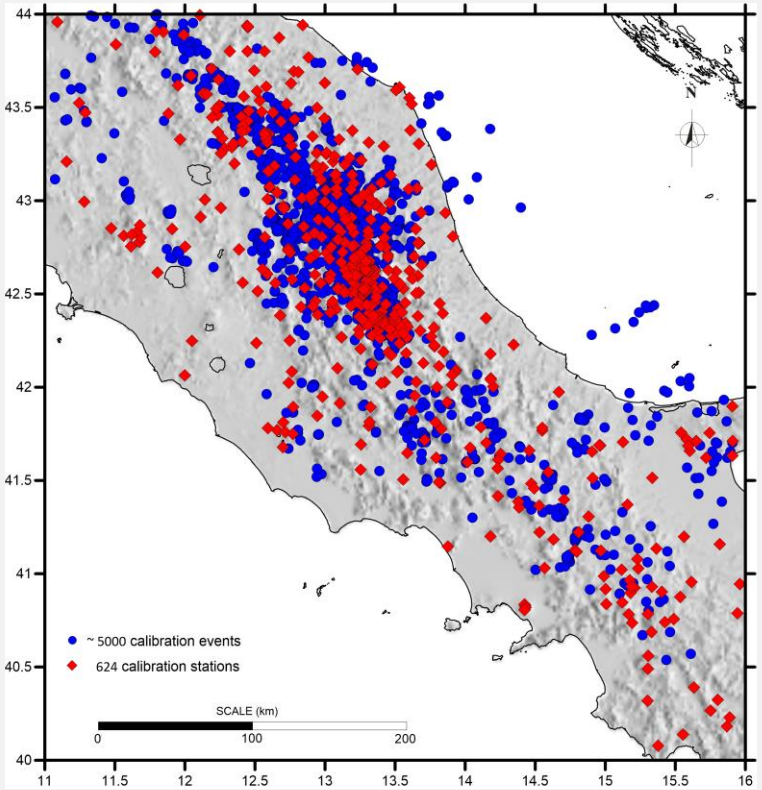
# Coda Calibration and GIT calibration

## CCT calibration Dataset



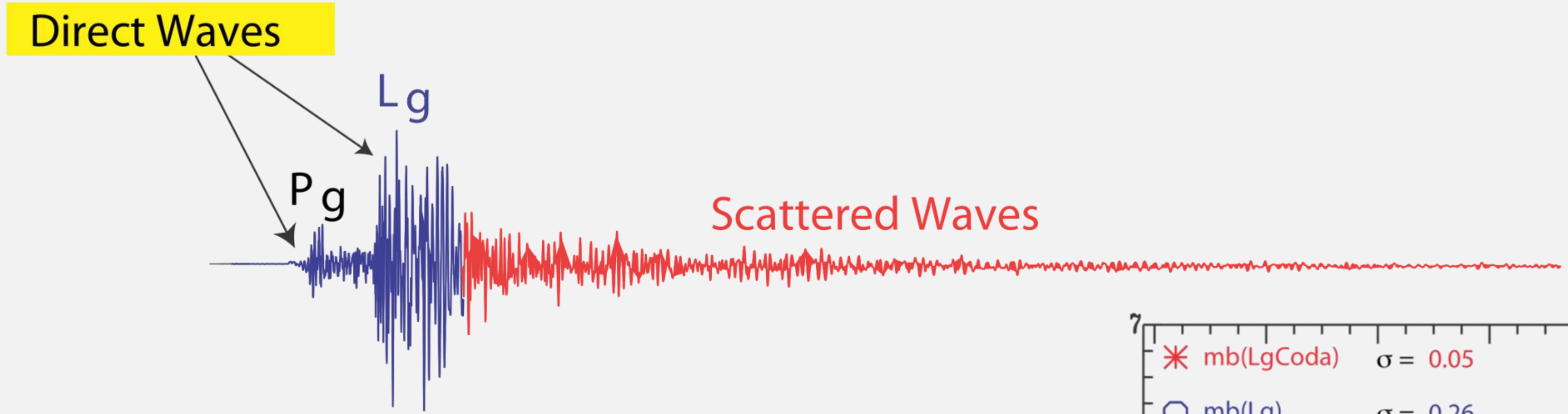

39 events
14 stations

## GIT calibration Dataset




~ 5000 events
+ 600 stations

# What is *coda* and what are its advantages?

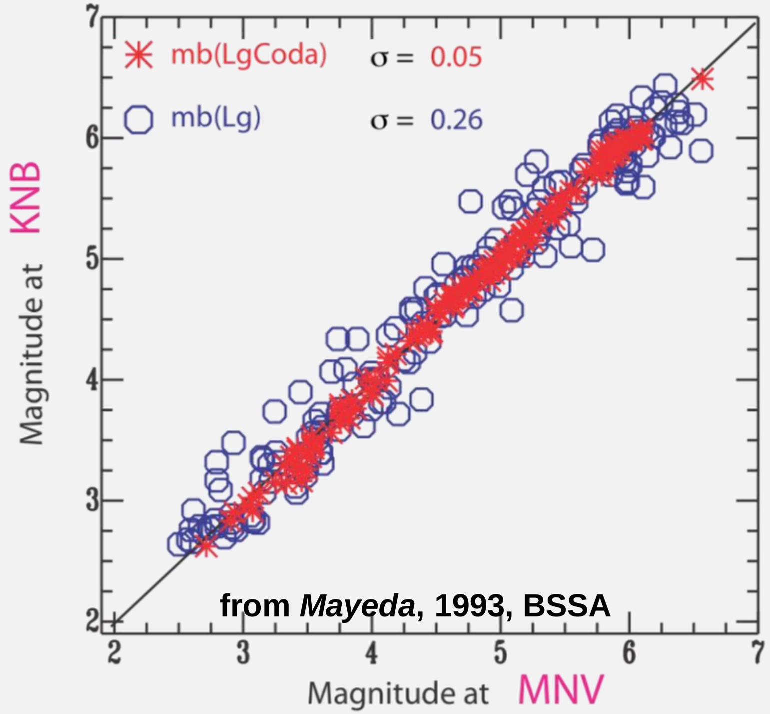



**Problem**:

Direct waves are sensitive to geologic structure between source and receiver as well as source radiation pattern. These issues require multiple station averaging.

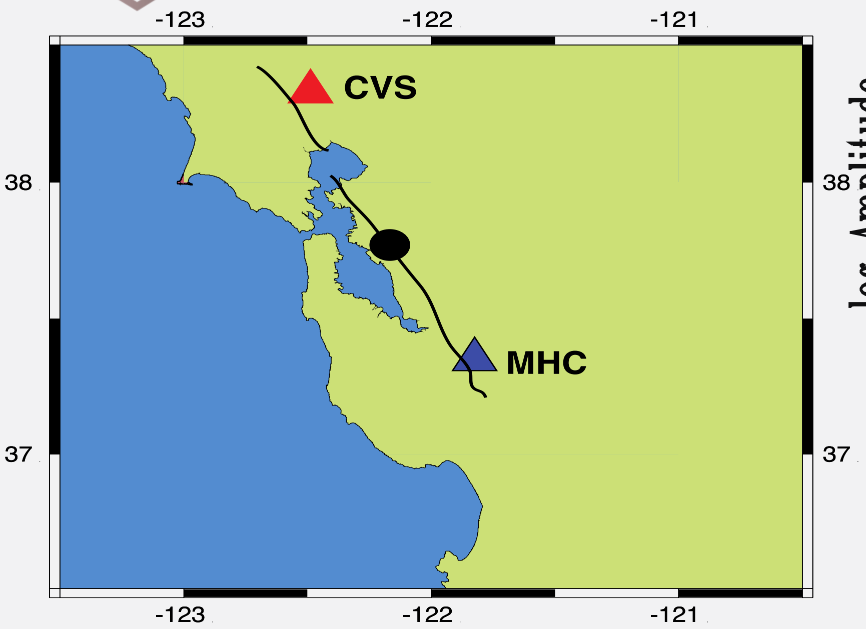
**Solution**:

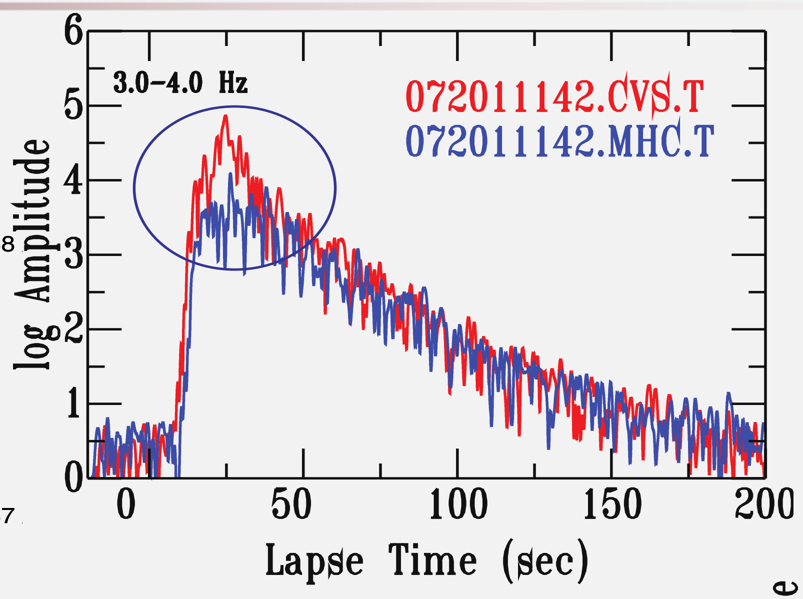
Scattered waves average over both path and source heterogeneity.  We will likely never know small length-scale features well enough for 3-D modeling, but a stochastic empirical approach has been shown to work.

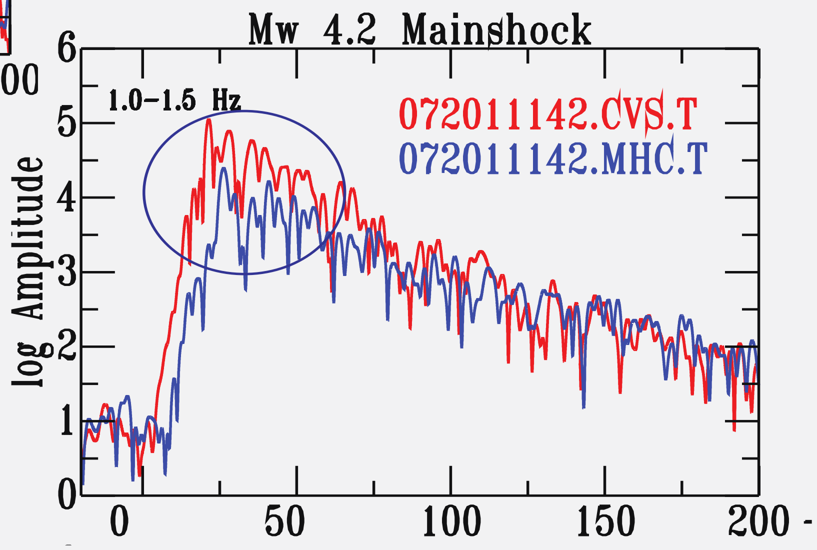



from *Mayeda*, 1993, BSSA

# Radiation pattern and directivity




We point to an example of the $M_w$ 4.2 July 20, 2007 event in Oakland, CA that exhibited strong *S*-wave directivity to the north-west toward station CVS. In contrast, the coda after a few 10s of seconds homogenized.

Low sensitivity to the source heterogeneity

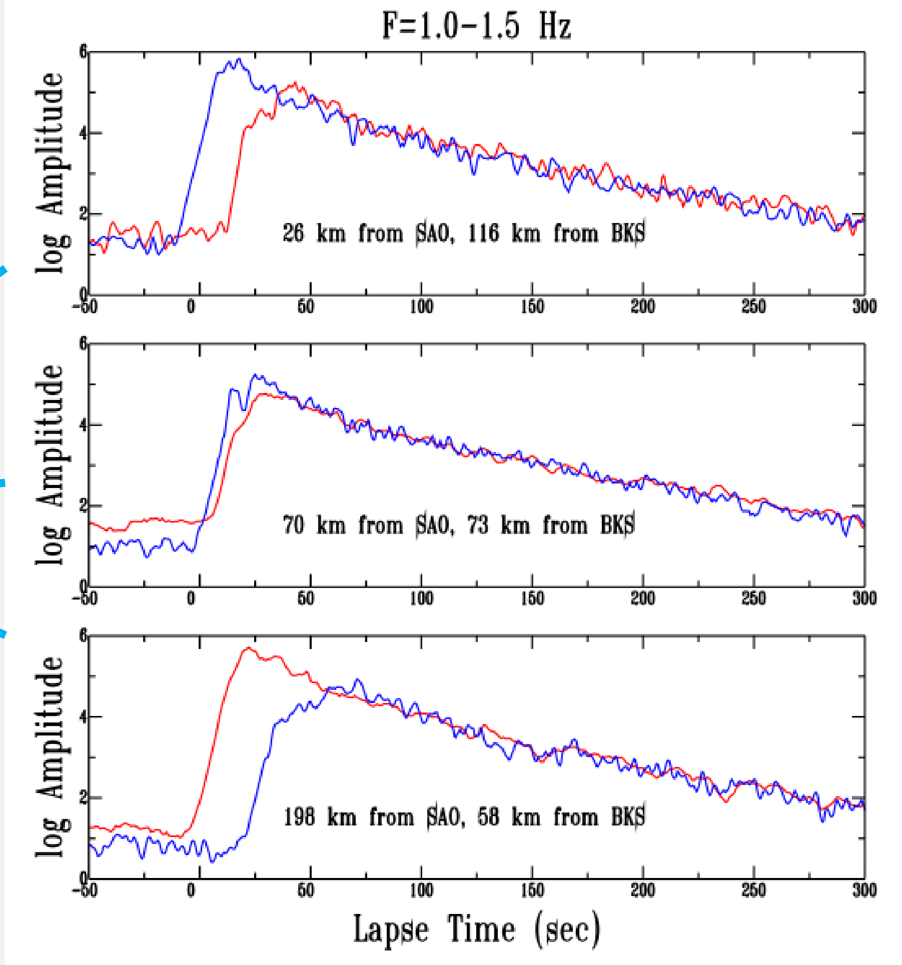
Example in Northern California from *Mayeda & Malagnini* (GRL 2010)

# Coda energy becomes homogenously distributed in space and time

3 events at 3 different distances from two stations, BKS & SAO

Low sensitivity to the path heterogeneity


simple, empirical path corrections are required

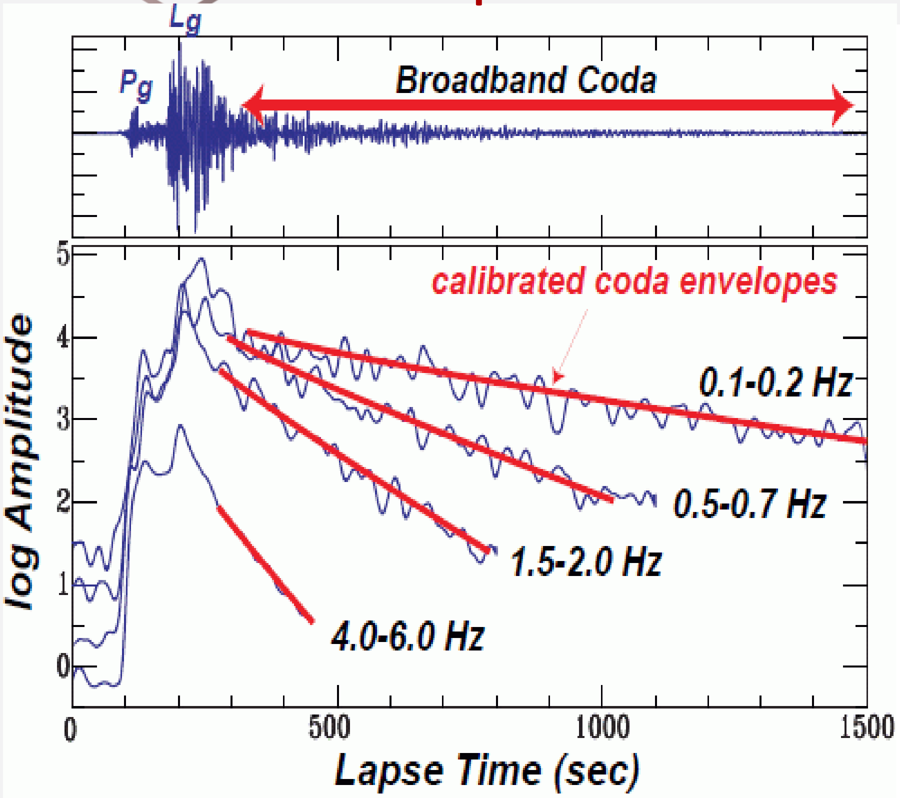




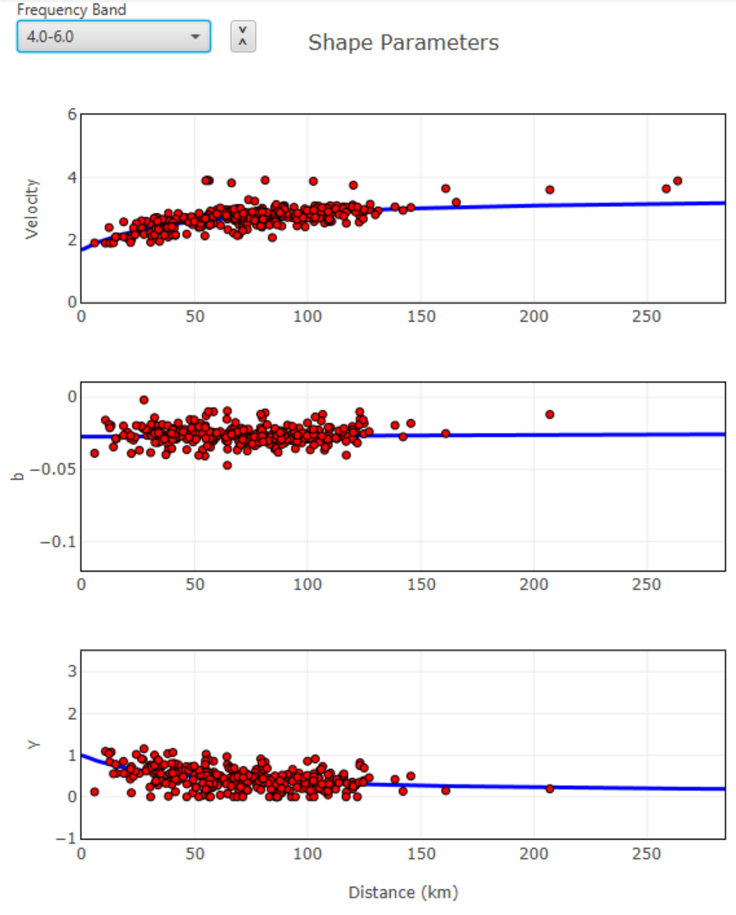

Example in Northern California from *Mayeda et al*. (GRL 2005)

# Coda Calibration Technique

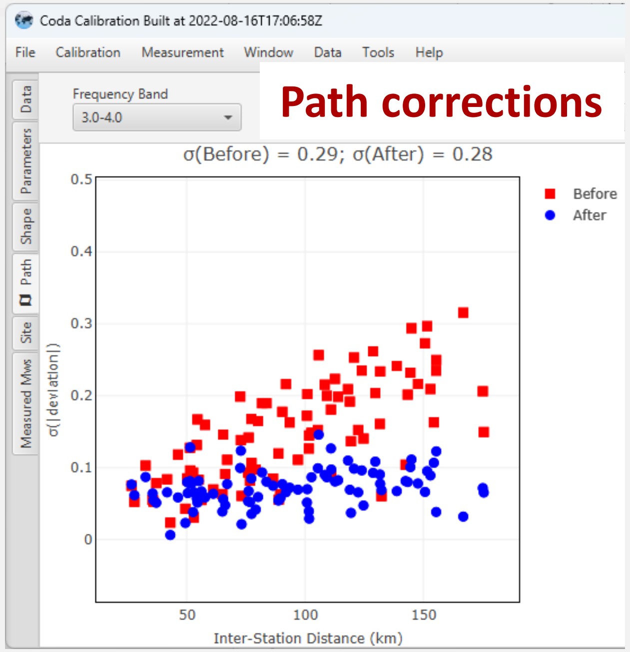
## Envelopes

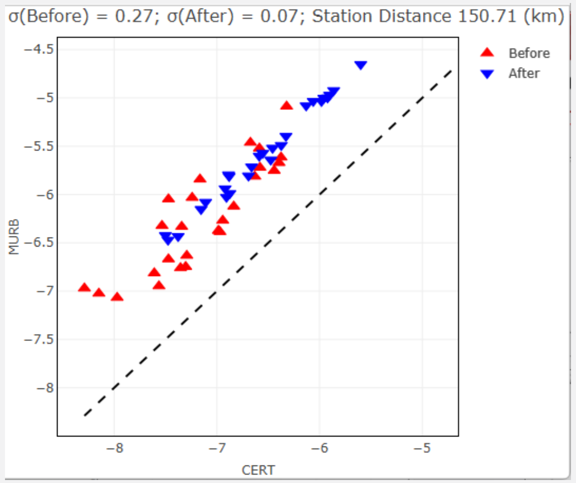



## Shape parameters




## Path corrections



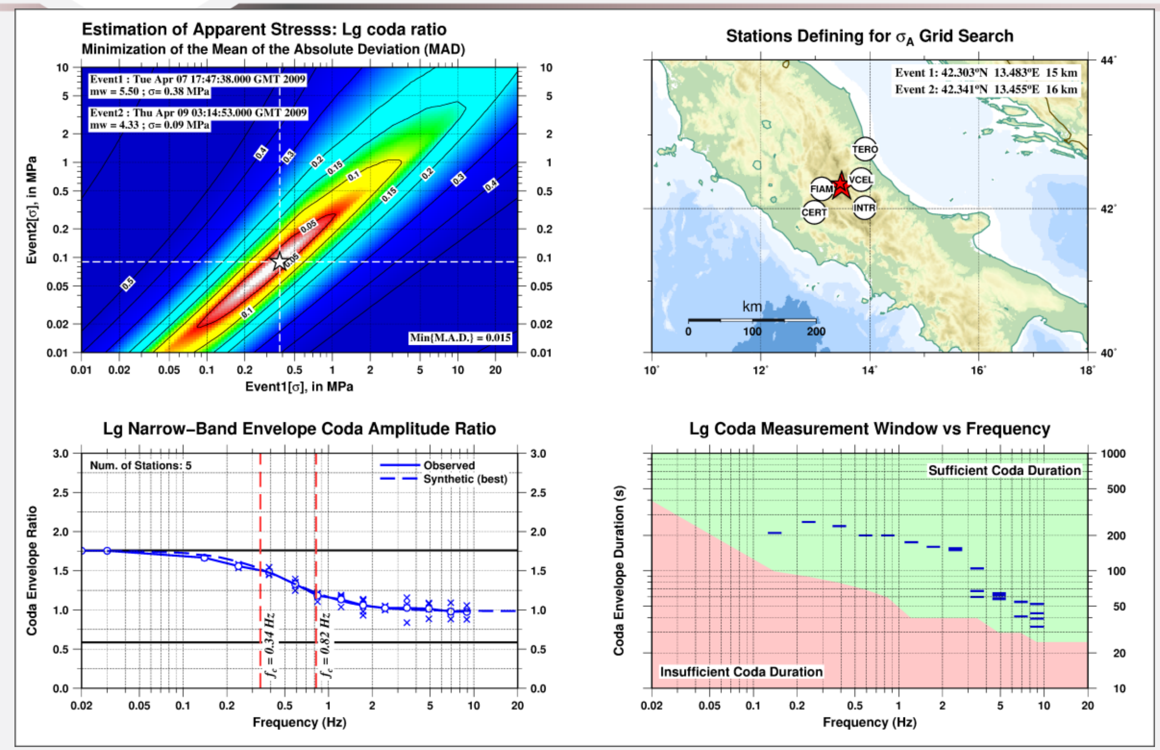



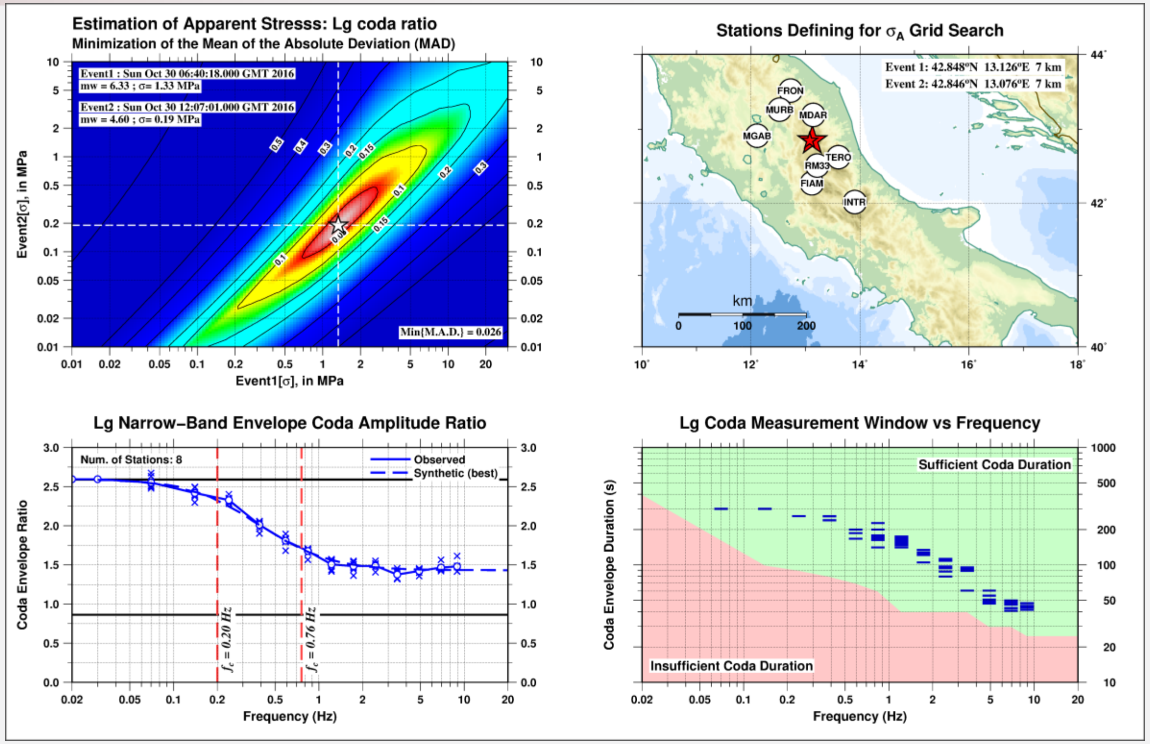

S-wave source amplitude | Site term | S-to-coda transfer function | Path term

$$A_c(f,t,r) = W_0(f) \times S(f) \times T(f) \times P(r,f) \times H(t-(r/v(r)) \times (t-r/v(r))-\gamma(r) \times \exp[b(r) \times (t-r/v(r))]$$

# Coda Calibration Technique

## Site corrections




Independent source constraints are used to constrain the frequency-dependent site terms, thereby **eliminating the need to assume a source scaling** for the entire region **or assuming a stress drop for selected empirical Green's function events**.

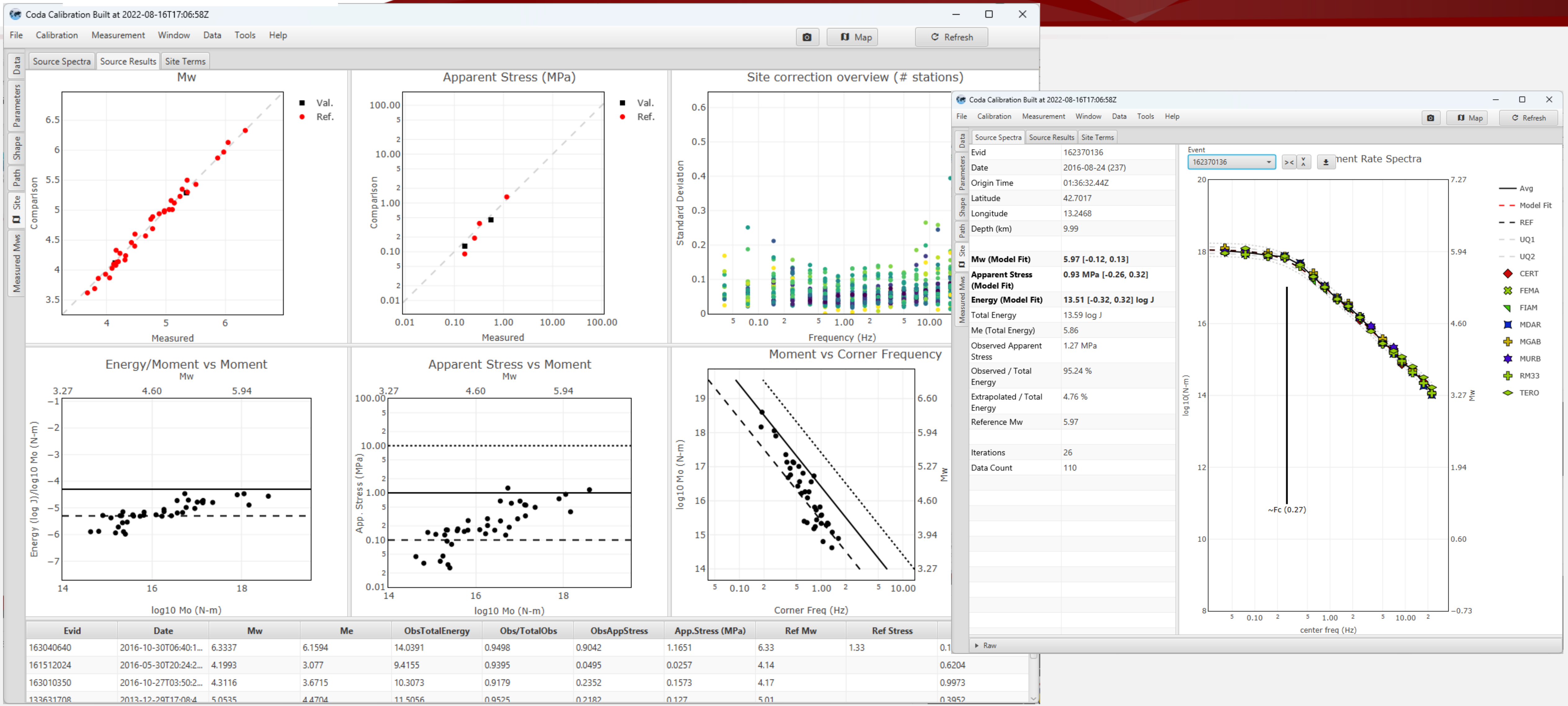
Coda spectral ratios outlined in *Mayeda et al.,* (2007) provide very stable, averaged apparent stress estimates that are free of path and site effects.

We then invert for the best fitting *Brune* source spectra to find the best fit. We use the resulting ground-truth (GT) source spectra along with independent moment magnitudes as source constraints to determine all site correction terms in CCT.

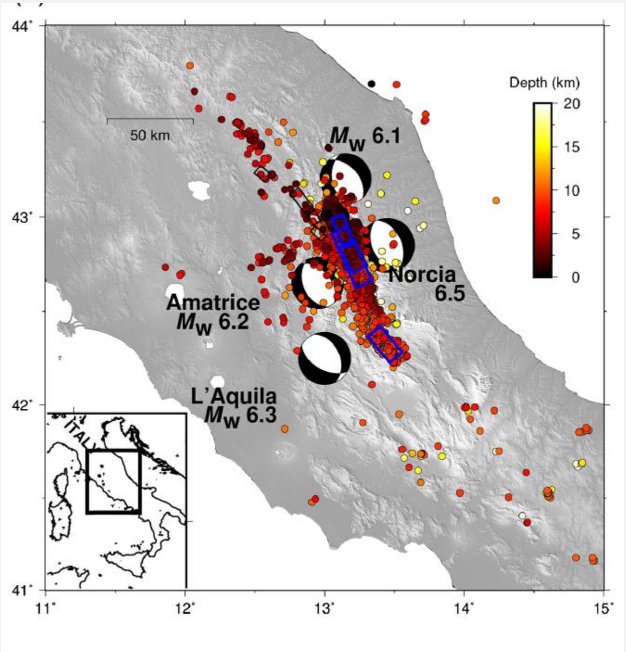
| eventId | refMw | datetime | Ref AppStr(Mpa) |
|---|---|---|---|
| 163040640 | 6.33 | 2016-10-30 06:40:18.010 | 1.33 |
| 90971747 | 5.5 | 2009-04-07 17:47:37.710 | 0.38 |
| 163041207 | 4.6 | 2016-10-30 12:07:00.870 | 0.19 |
| 90990314 | 4.33 | 2009-04-09 03:14:52.600 | 0.09 |

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

# Coda Calibration Technique



# GIT Calibration (non-parametric)



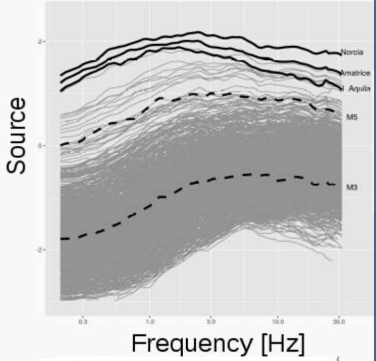

$$\log_{10}\mathrm{FAS}_{ij}\left(f, R_{ij}, M_i\right) = \log_{10}\mathrm{Source}_i\left(f, M_i\right) + \log_{10}\mathrm{Path}\left(f, R_{ij}\right) + \log_{10}\mathrm{Site}_j\left(f\right)$$

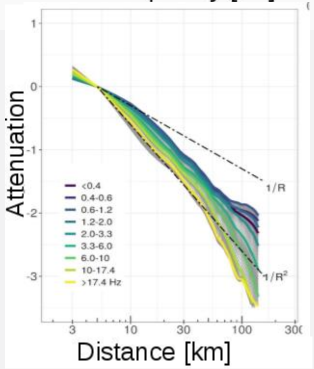
Linear system
Two unresolved degrees of freedom

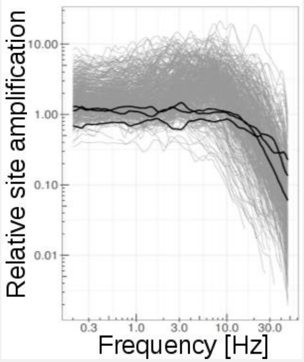
GIT

Constraints:

- LogA(5km,f)=0
- 3 reference stations (LSS,RM03; T1221) on rock and with an average $k_o$ = 0.018 s

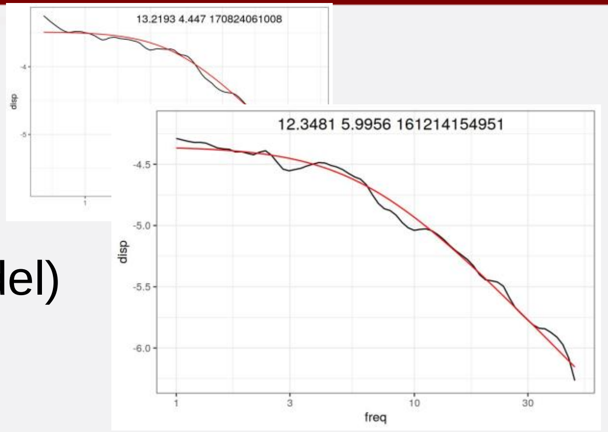


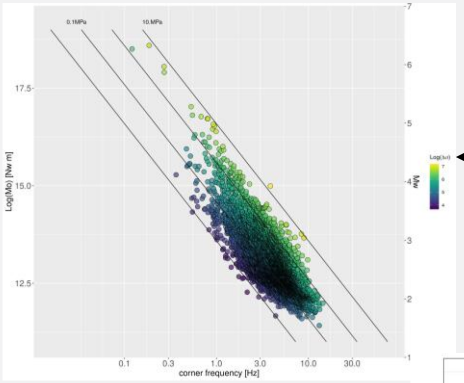




Fit an $\omega^2$ model

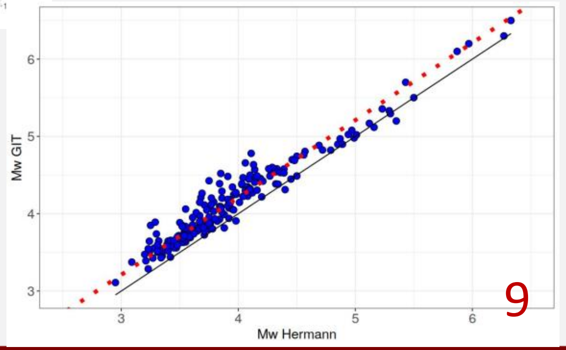
(or any other model)



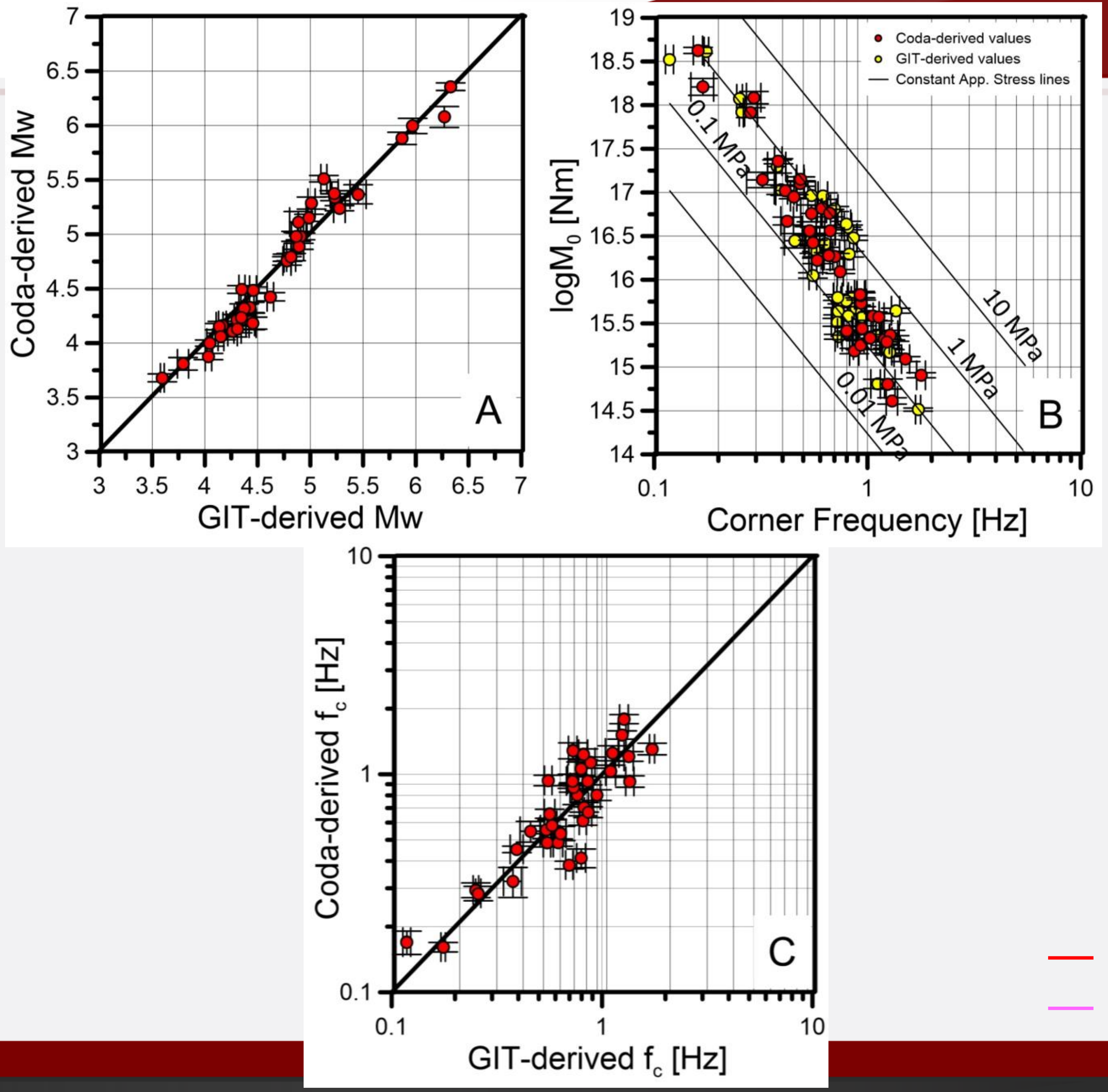

Determine source parameters Mo, $f_c$

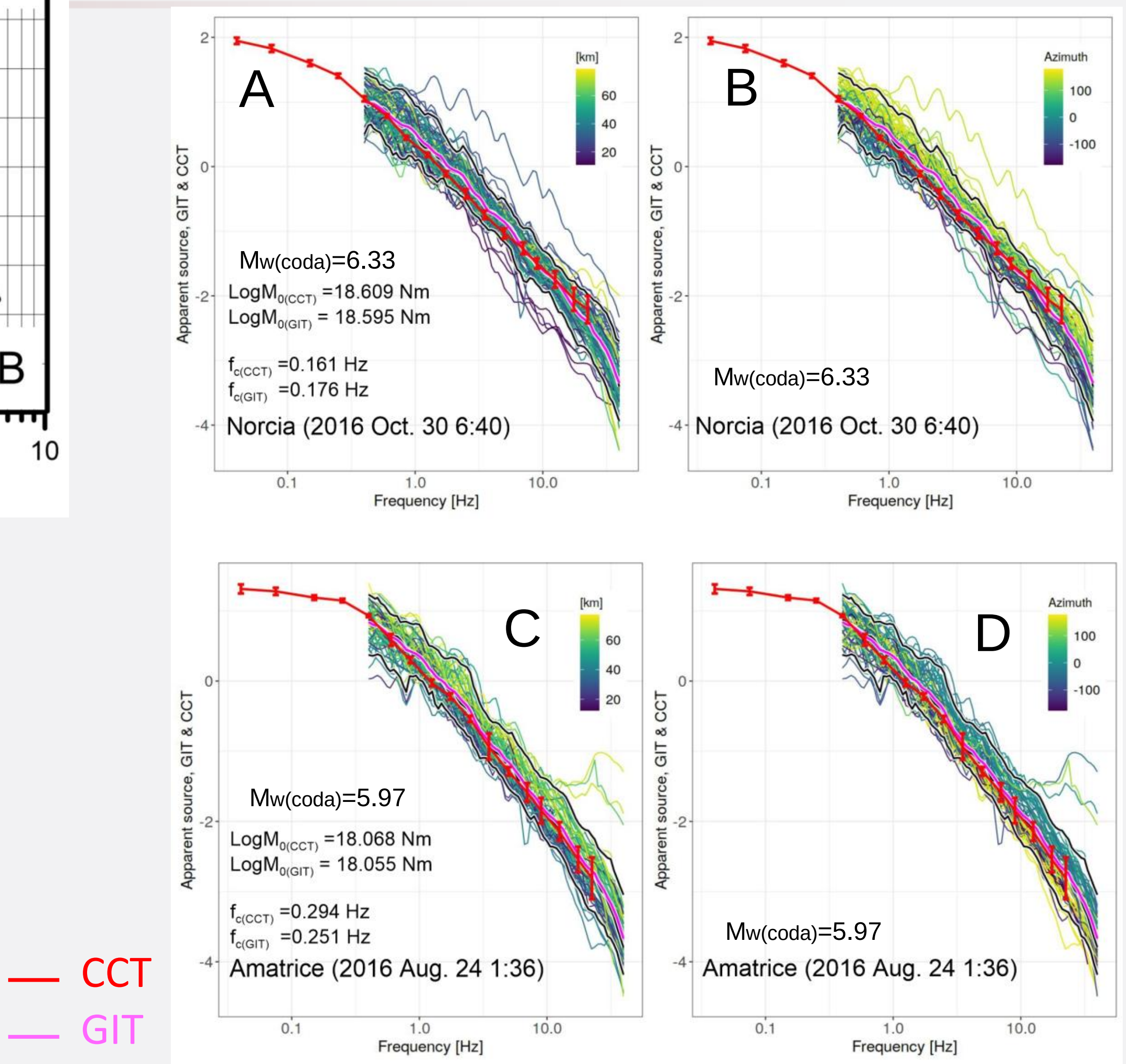



Anchor average Mo to a reference scale (here Hermann's values)

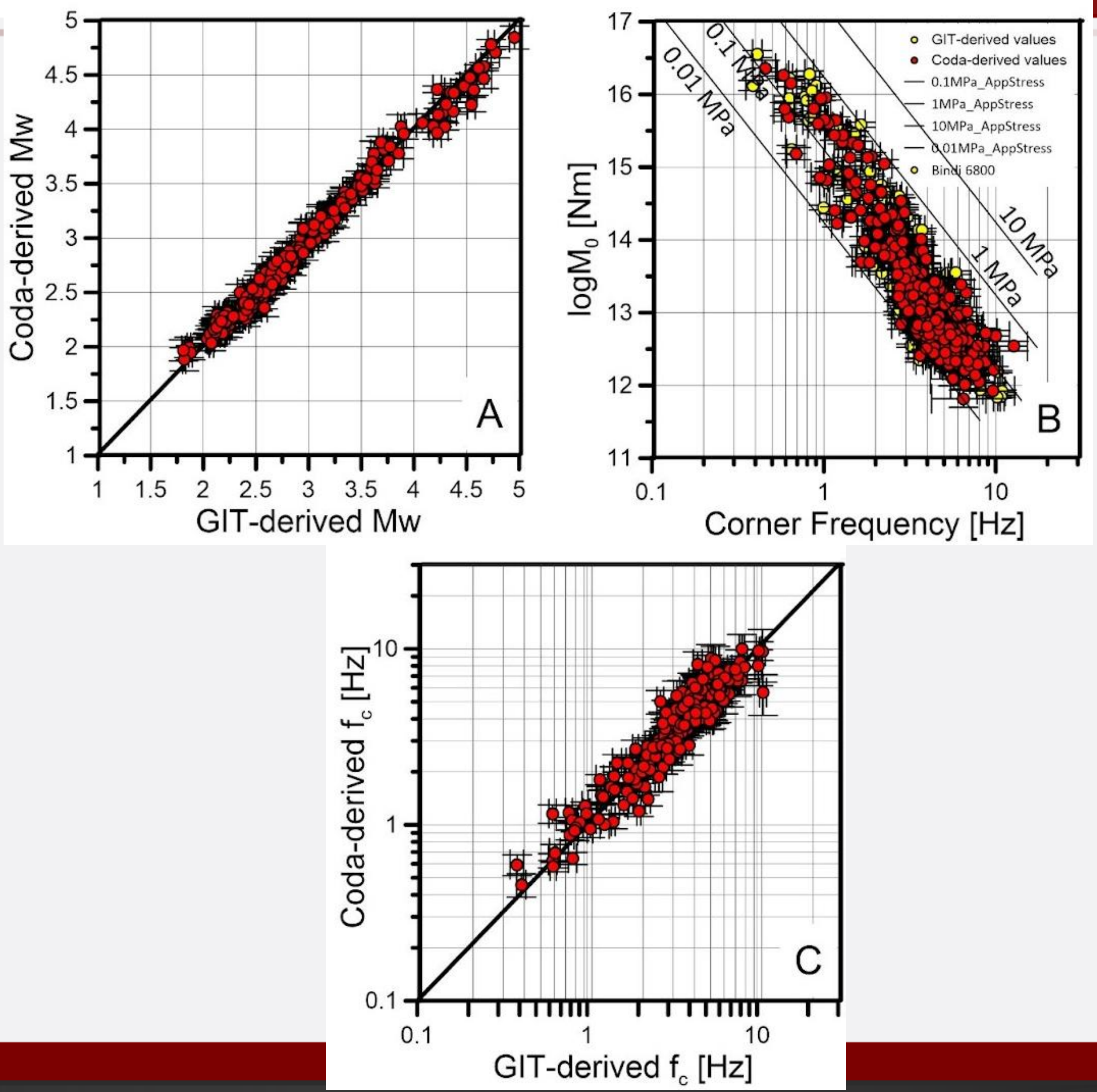


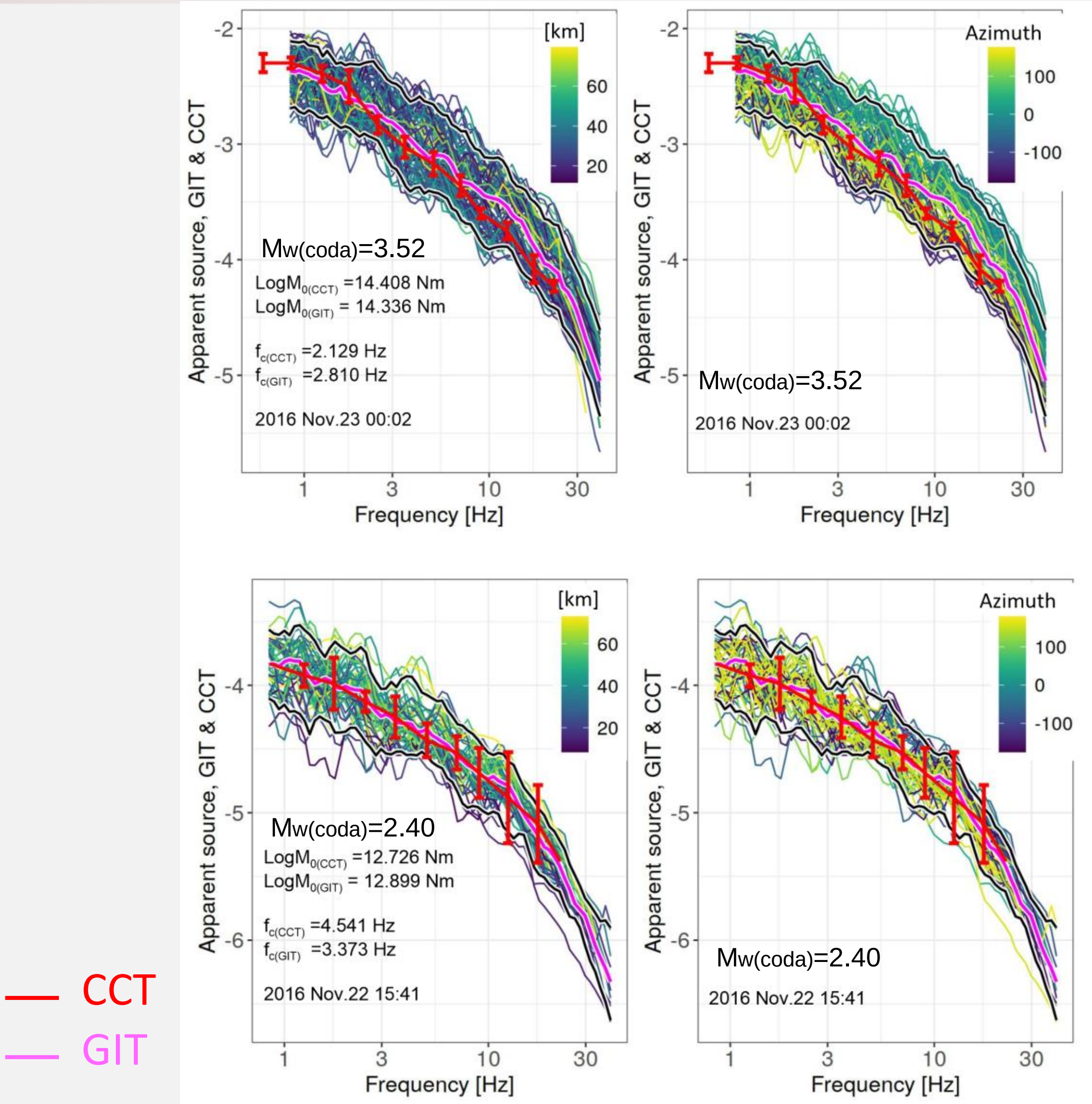
# $M_w$ and Corner Frequencies Agree Between GIT and CCT methods



# $M_w$ and Corner Frequencies Agree Between GIT and CCT methods



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**Data:**
https://shake.mi.ingv.it/source-parameters/

# References for Calibrations in CI

## Coda Derived Source Parameters

DESCRIPTION

This page collects consistent estimations of source parameters and source spectra for earthquakes recorded in different regions and ranging over a wide magnitude range. The consistency is due to the application of the same methodology, the coda calibration technique, developed by Mayeda et al. (2003) and recently implemented in a java-based code, the coda calibration tool (CCT, https://github.com/LLNL/coda-calibration-tool).
The main strength of the method is the use of narrowband coda waves measurements, which show low sensitivity to source and path heterogeneity. Additionally, we use independent ground-truth (GT) reference spectra for which apparent stresses are independently calculated through the coda spectral ratio (Mayeda et al., 2007), to break the path and site trade-off. The use of GT spectra eliminates the need to assume source scaling for the region, reducing the impact of a-priori model assumptions on the interpretation of scaling laws of source parameters and their variability.

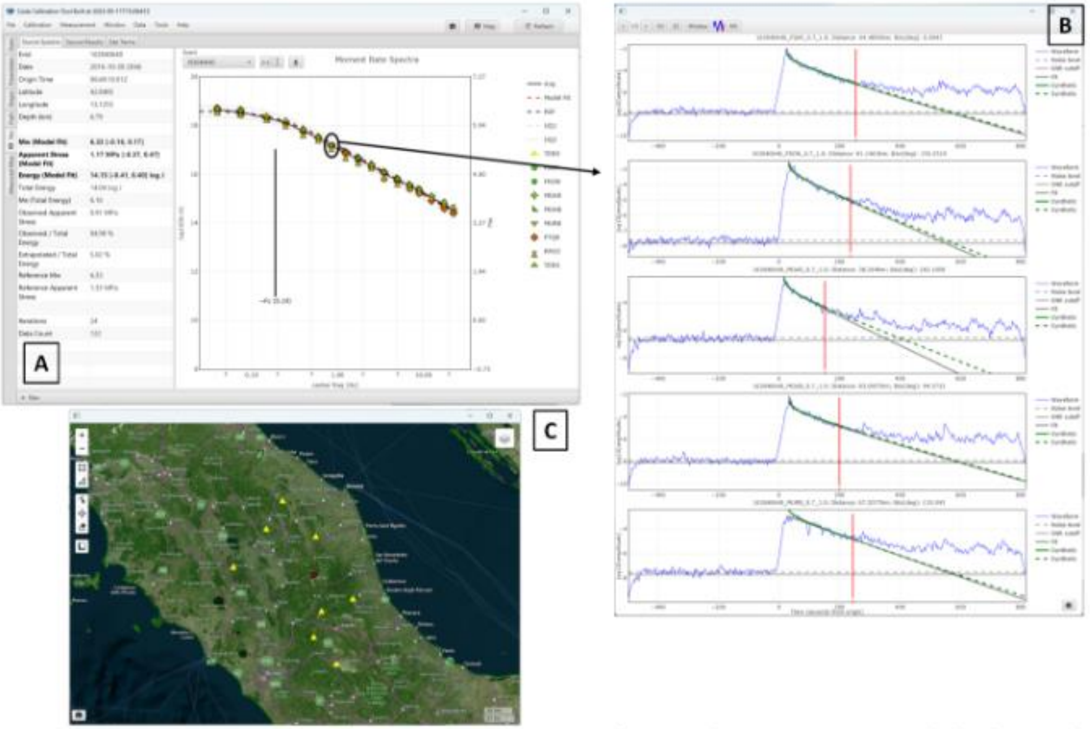


Figure: A) Example source spectra summary page from CCT providing source parameter information such as seismic moment, Mw, total radiated energy and apparent stress. B) The corresponding interactive map showing the event and stations used. C) Example of coda envelopes for different stations at the frequency band 0.7-1 Hz for the considered event.

Geophysical Journal International

*Geophys. J. Int.* (2022) **231**, 1573–1590
https://doi.org/10.1093/gji/ggac268
Advance Access publication 2022 July 23
GJI Seismology

### Source scaling comparison and validation in Central Italy: data intensive direct *S* waves versus the sparse data coda envelope methodology

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Accepted 2022 July 20. Received 2022 May 23; in original form 2021 November 26

https://doi.org/10.1093/gji/ggac268

# Tools

Coda Calibration Tool Documentation

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## Coda Calibration Tool (CCT) 1.0.20 documentation

2022-07-31; Version 1.0; Authors Barno, Justin | Mayeda, Kevin

### About CCT

The Coda Calibration Tool (CCT) is a Java-based application that stems from a collaborative project by scientists from the USNDC (AFTAC/SDS) and DOE (LLNL) as well as significant input from seismologists from the University of Utah, INGV (Milan) and USGS (Golden, CO), Natural Resources Canada. This tool consolidates research-mode scripts circa 1995 (SAC, C-shell, Fortran) into a robust platform-independent tool using the empirical 1-D method outlined by Mayeda and Walter (1996) and Mayeda et al. (2003).

CCT provides a fast and efficient means of calibrating and processing local and regional coda envelopes to estimate stable source spectra, moment magnitude, and apparent stress, that are roughly 3-to-4 times less variable than estimates derived from traditional direct wave estimates. The source parameters represent averaged values and are virtually free of lateral path heterogeneity and source radiation anisotropy.

The methodology has two options for dealing with potential regional source scaling. In the first (and preferred) case, independent, ground-truth reference source spectra are used in the calibration process to constrain the frequency-dependent site terms. In the second case, reference events with independent $M_w$ estimates are used to constrain the long-period site terms, but for the higher frequencies we impose a Brune (1970) source spectrum with an a priori source scaling, currently set so that the apparent stress increases as ~$M_o$ 0.25.

### Tutorial Guide for New Users

The following is a step-by-step guide for a specific example taken from the San Francisco Bay Area region using broadband waveform data from the UC Berkeley Seismological Laboratory.

**Note**

For a new dataset and region, you should expect to run CCT multiple times before settling on a final coda calibration.

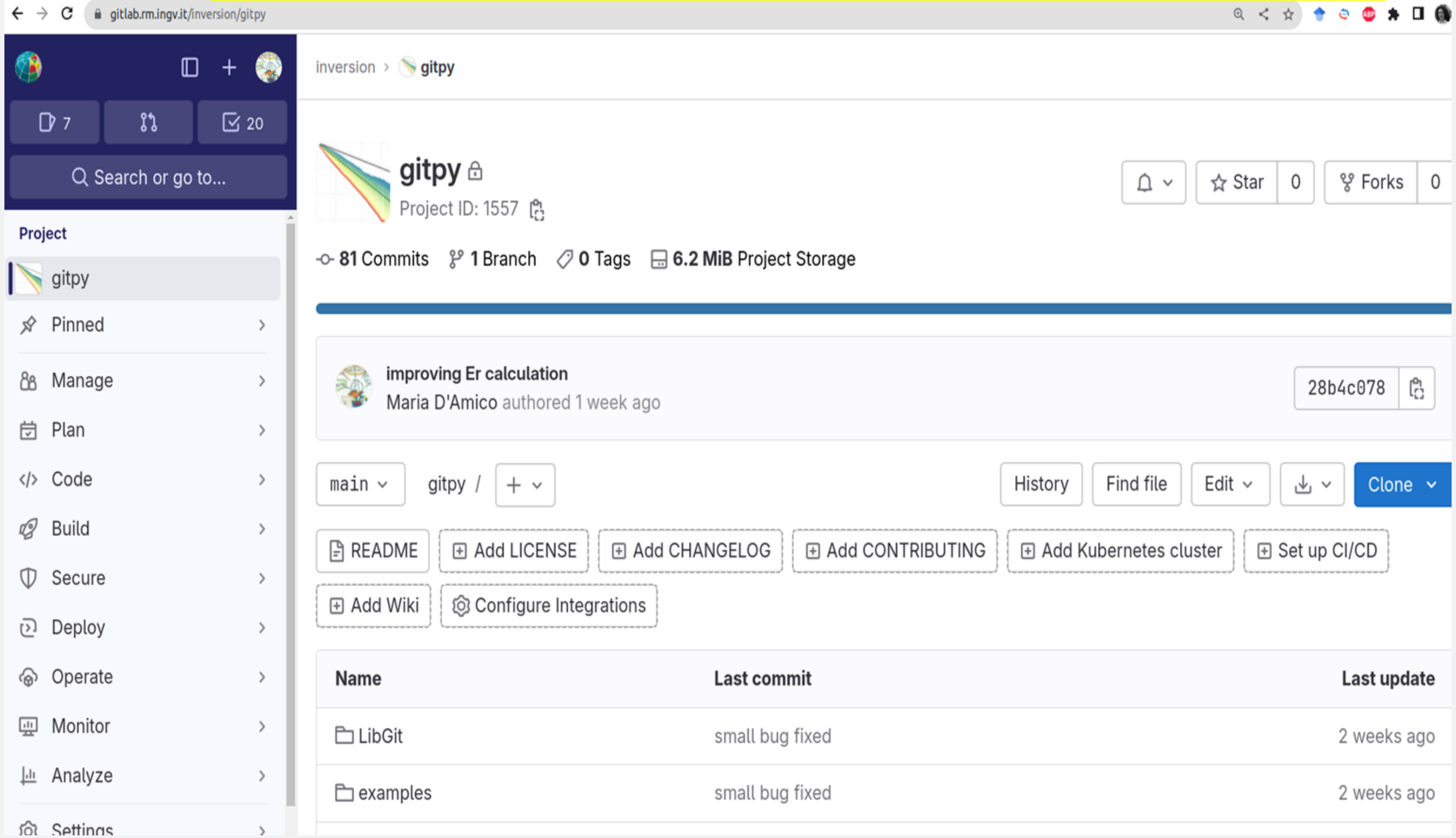
on GitHub

Coda Calibration Tool (CCT)
Coda Envelope Ratio Tool (CERT)

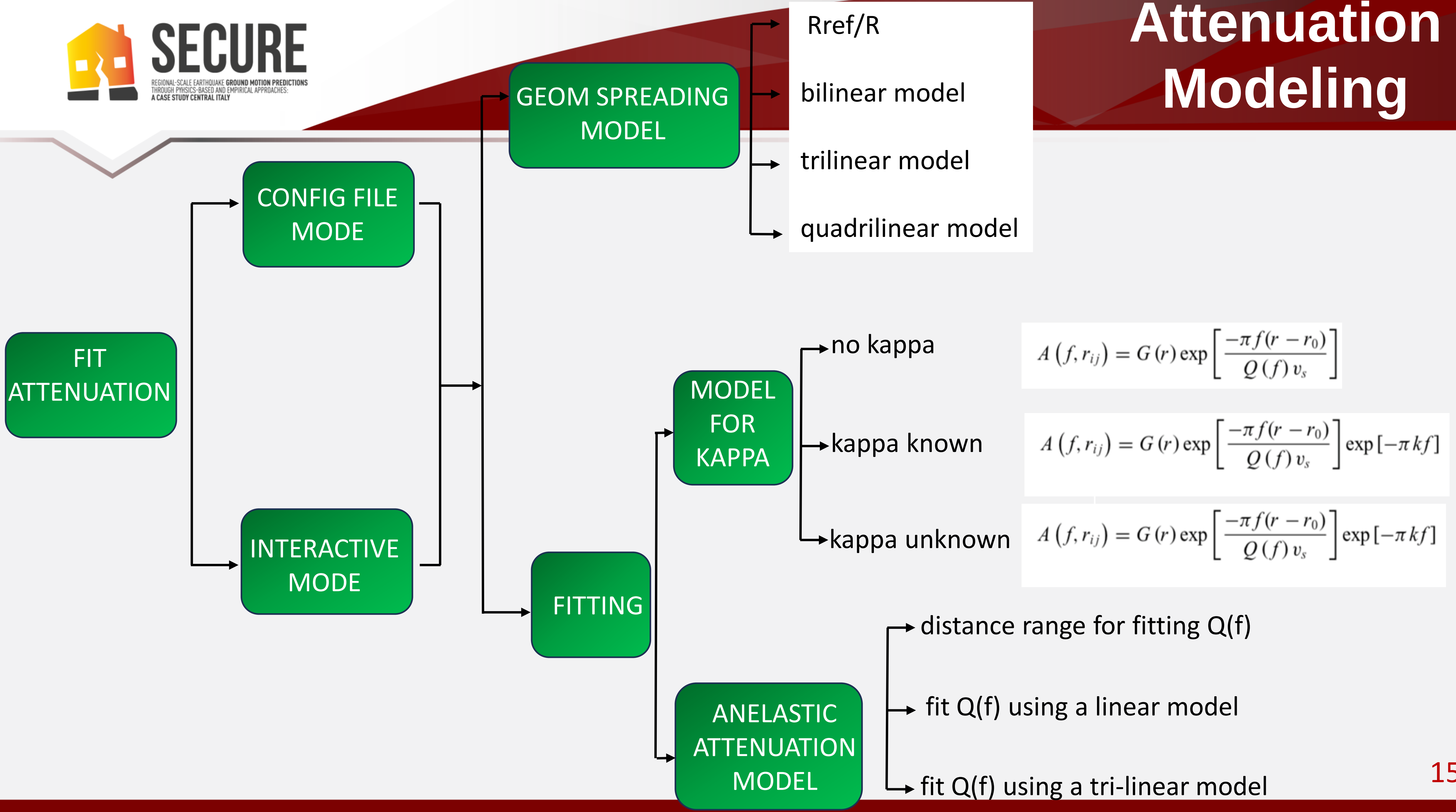
# GitPy

## Generalized Inversion Technique code in Python

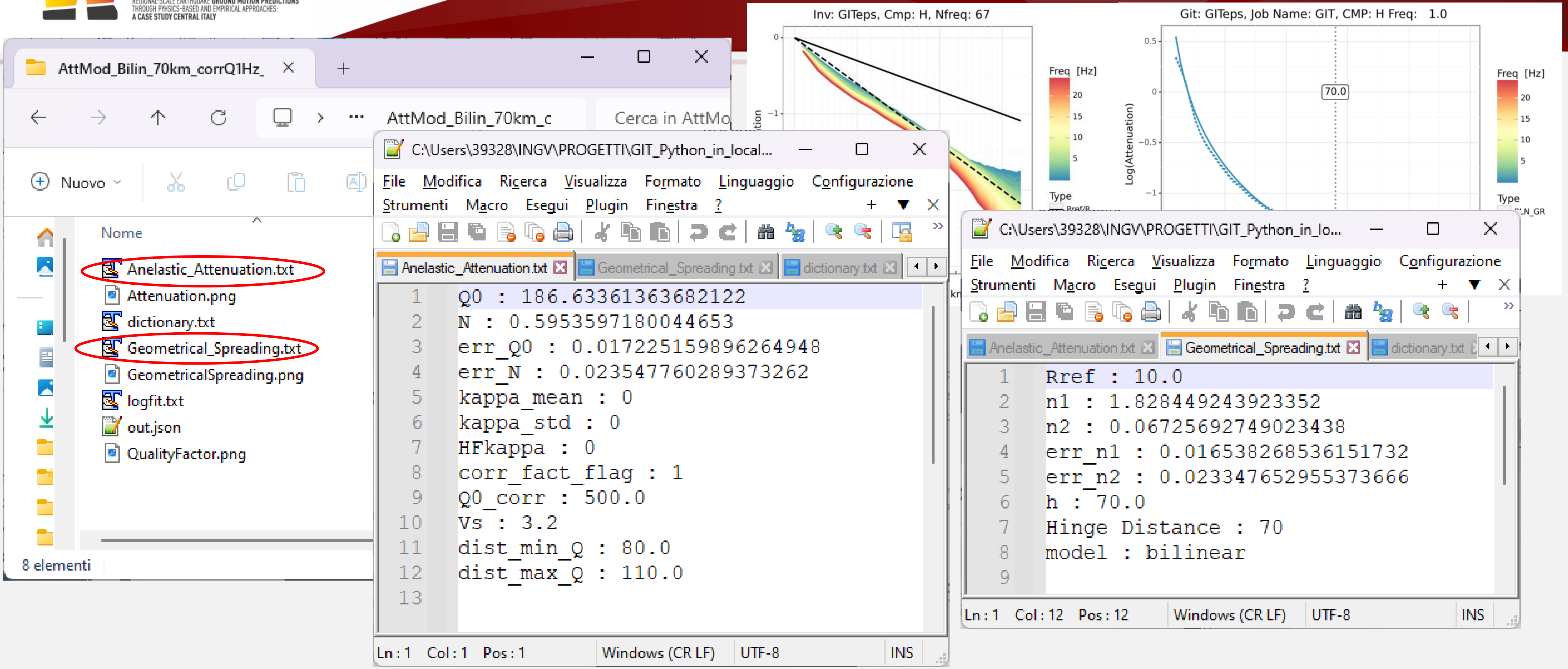
https://gitlab.rm.ingv.it/inversion/gitpy



# Attenuation Modeling



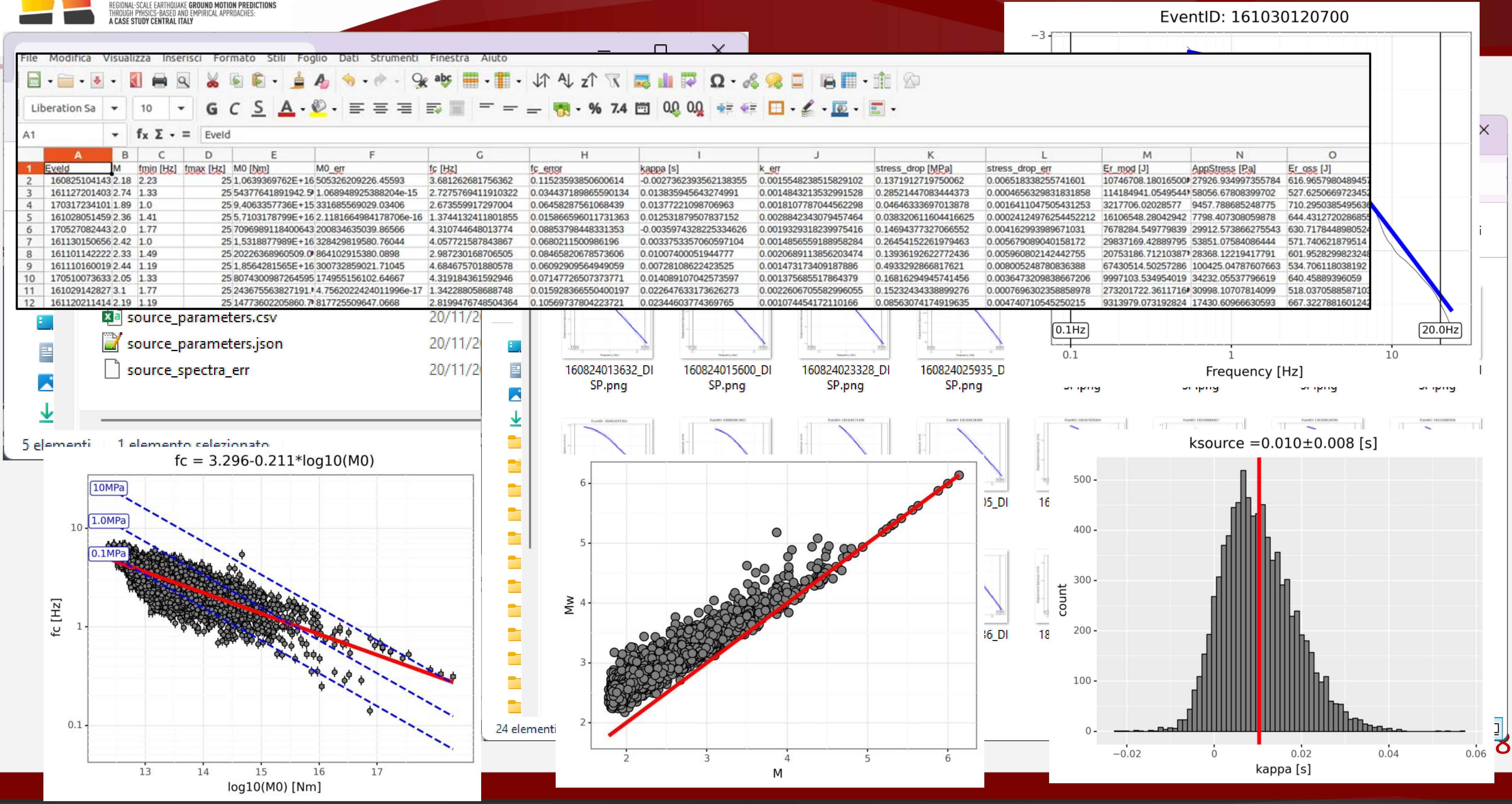
# Output Attenuation



# Source Modeling

- FIT SOURCE
  - CRUSTAL MODEL
    - Homogeneous (constant vs and rho)
    - Heterogeneous (variable vs and rho)
  - FITTING
    - simultaneous fit for M0 and fc
    - three steps from Bindi and Kota 2020
    - F-range: fmin and fmax from table
    - F-range: fmin is automatically calculated and fmax=30 Hz
  - KAPPA

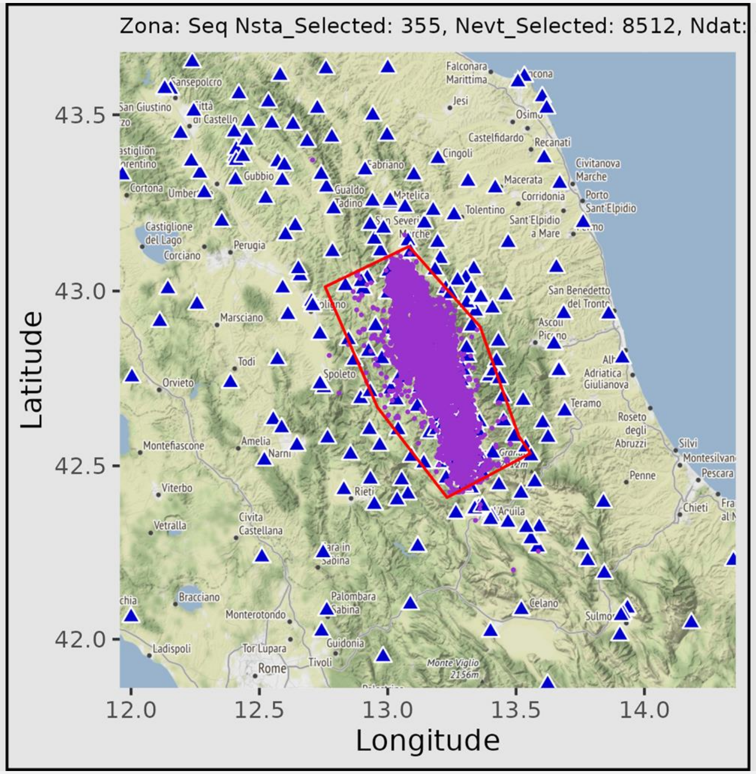
# Output Source Modeling

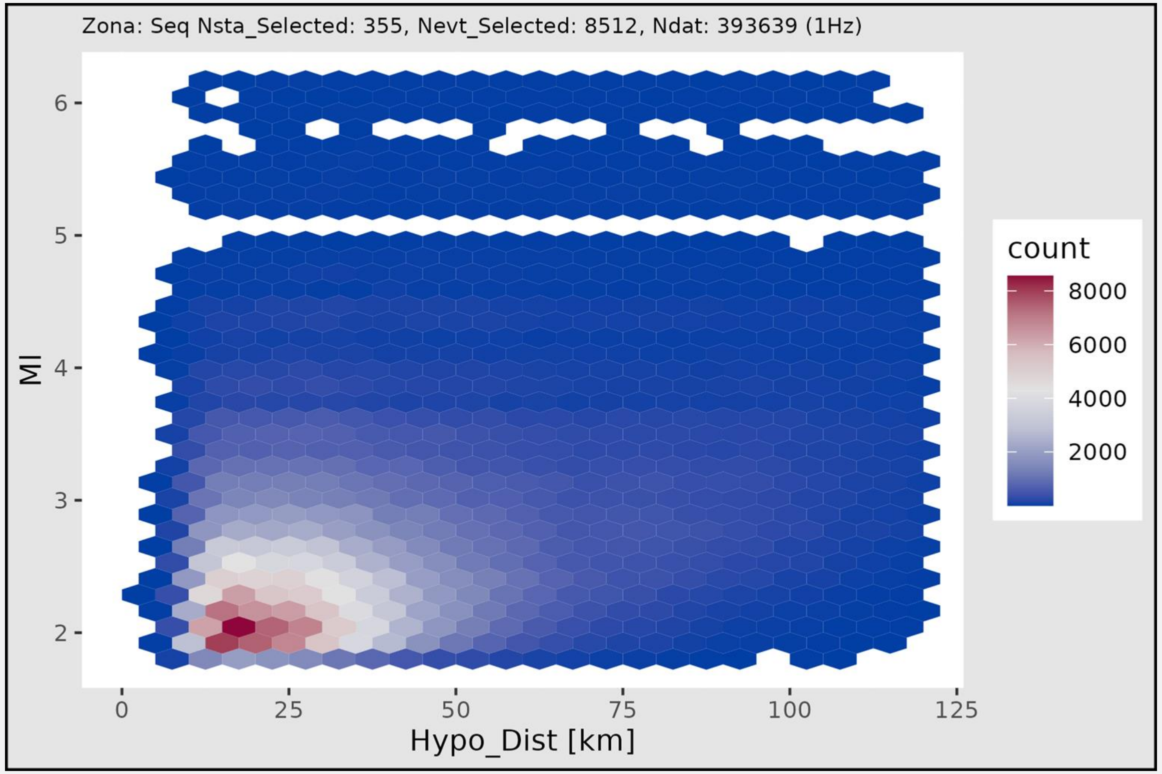



| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | EveId | M | fmin [Hz] | fmax [Hz] | M0 [Nm] | M0_err | fc [Hz] | fc_error |
| 2 | 160825104143 | 2.18 | 2.23 | 25 | 1,0639369762E+16 | 505326209226.45593 | 3.681262681756362 | 0.11523593850600614 |
| 3 | 161127201403 | 2.74 | 1.33 | 25 | 54377641891942.5 | 1.068948925388204e-15 | 2.7275769411910322 | 0.034437189865590134 |
| 4 | 170317234101 | 1.89 | 1.0 | 25 | 9,4063357736E+15 | 331685569029.03406 | 2.673559917297004 | 0.06458287561068439 |
| 5 | 161028051459 | 2.36 | 1.41 | 25 | 5,7103178799E+16 | 2.1181664984178706e-16 | 1.3744132411801855 | 0.015866596011731363 |
| 6 | 170527082443 | 2.0 | 1.77 | 25 | 7096989118400643 | 200834635039.86566 | 4.310744648013774 | 0.08853798448331353 |
| 7 | 161130150656 | 2.42 | 1.0 | 25 | 1,5318877989E+16 | 328429819580.76044 | 4.057721587843867 | 0.0680211500986196 |
| 8 | 161101142222 | 2.33 | 1.49 | 25 | 20226368960509.0 | 864102915380.0898 | 2.987230168706505 | 0.08465820678573606 |
| 9 | 161110160019 | 2.44 | 1.19 | 25 | 1,8564281565E+16 | 300732859021.71045 | 4.684675701880578 | 0.06092909564949059 |
| 10 | 170510073633 | 2.05 | 1.33 | 25 | 8074300987264595 | 174955156102.64667 | 4.319184361592946 | 0.07147726507373771 |
| 11 | 161029142827 | 3.1 | 1.77 | 25 | 243675563827191. | 4.7562022424011996e-17 | 1.342288058688748 | 0.015928366550400197 |
| 12 | 161120211414 | 2.19 | 1.19 | 25 | 14773602205860.7 | 817725509647.0668 | 2.8199476748504364 | 0.10569737804223721 |

| | I | J | K | L | M | N | O |
|---|---|---|---|---|---|---|---|
| 1 | kappa [s] | k_err | stress_drop [MPa] | stress_drop_err | Er_mod [J] | AppStress [Pa] | Er_oss [J] |
| 2 | -0.0027362393562138355 | 0.0015548238515829102 | 0.1371912719750062 | 0.006518338255741601 | 10746708.18016500 | 27926.934997355784 | 616.9657980489457 |
| 3 | 0.013835945643274991 | 0.0014843213532991528 | 0.28521447083444373 | 0.0004656329831831858 | 114184941.0549544 | 58056.67808399702 | 527.6250669723452 |
| 4 | 0.01377221098706963 | 0.0018107787044562298 | 0.04646333697013878 | 0.0016411047505431253 | 3217706.02028577 | 9457.788685248775 | 710.2950385495636 |
| 5 | 0.012531879507837152 | 0.0028842343079457464 | 0.038320611604416625 | 0.00024124976254452212 | 16106548.28042942 | 7798.407308059878 | 644.4312720286855 |
| 6 | -0.0035974328225334626 | 0.0019329318239975416 | 0.14694377327066552 | 0.004162993989671031 | 7678284.549779839 | 29912.573866275543 | 630.7178448980524 |
| 7 | 0.0033753357060597104 | 0.0014856559188958284 | 0.26454152261979463 | 0.005679089040158172 | 29837169.42889795 | 53851.07584086444 | 571.740621879514 |
| 8 | 0.01007400051944777 | 0.0020689113856203474 | 0.13936192622772436 | 0.005960802142442755 | 20753186.71210387 | 28368.12219417791 | 601.9528299823248 |
| 9 | 0.00728108622423525 | 0.001473173409187886 | 0.4933292866817621 | 0.008005248780836388 | 67430514.50257286 | 100425.04787607663 | 534.706118038192 |
| 10 | 0.014089107042573597 | 0.001375685517864379 | 0.16816294945741456 | 0.0036473209838667206 | 9997103.534954019 | 34232.05537796619 | 640.45889396059 |
| 11 | 0.022647633173626273 | 0.0022606705582996055 | 0.15232434338899276 | 0.0007696302358858978 | 273201722.3611716 | 30998.10707814099 | 518.0370588587103 |
| 12 | 0.02344603774369765 | 0.001074454172110166 | 0.08563074174919635 | 0.004740710545250215 | 9313979.073192824 | 17430.60966630593 | 667.3227881601242 |

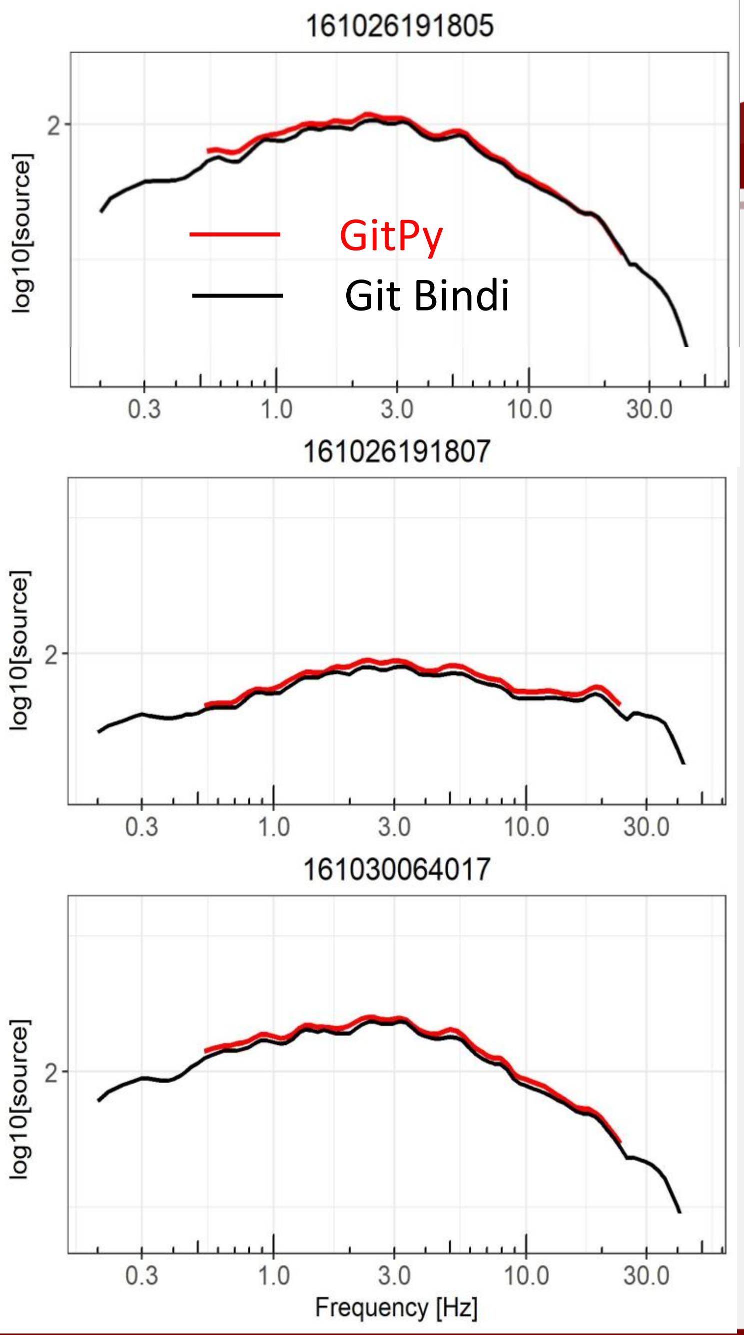
# Tests

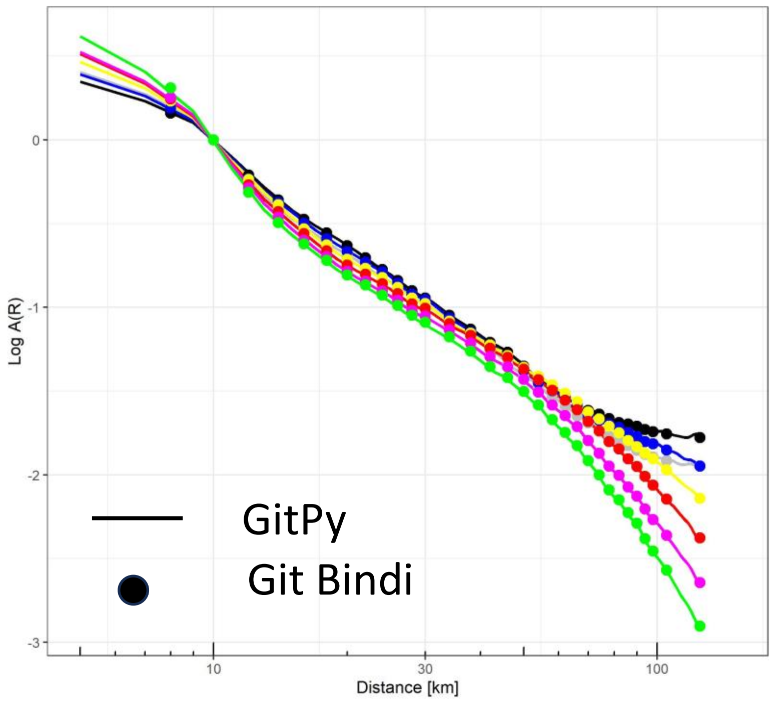


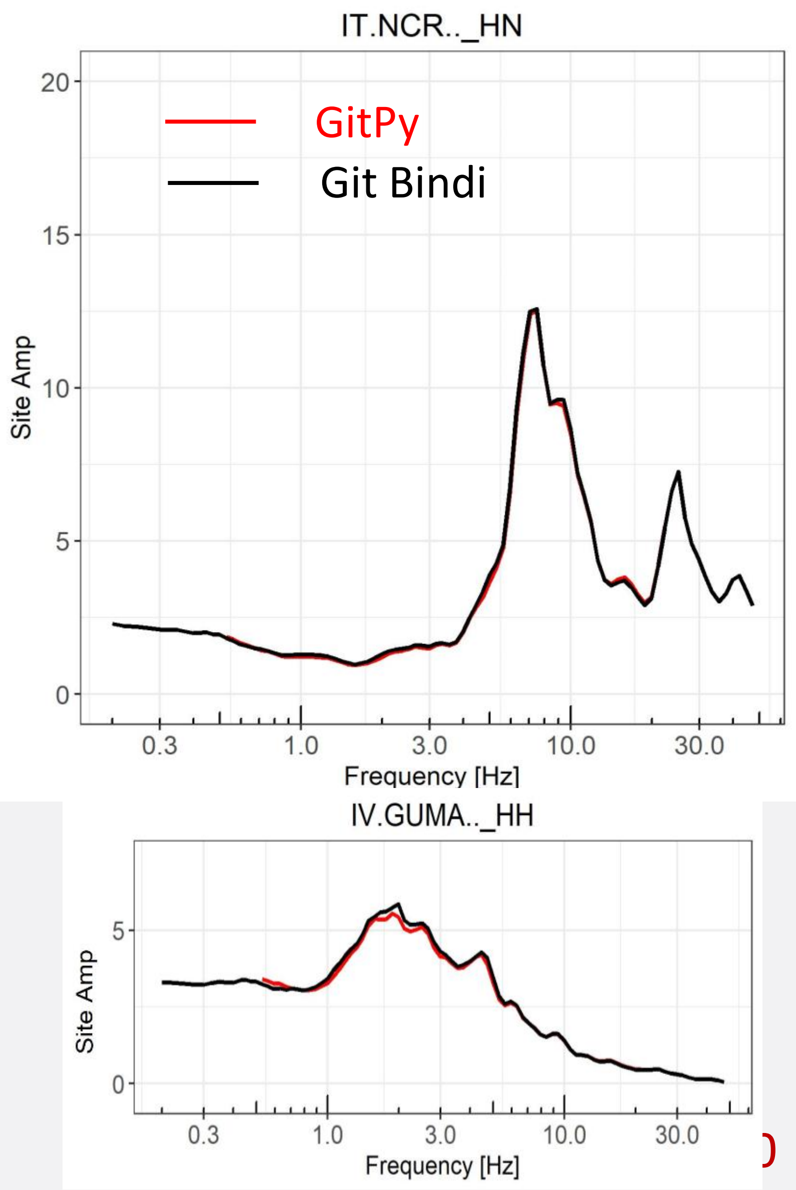




Total events: 8534
Total stations: 355
Max dist: 120 km
Ml range: 1.78 – 6.14

# Tests : curve non .parametriche



# Grazie per l’attenzione!