SECURE

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

Seismic Source Characteristics and Ground-Motion Variability in Central Italy: a bridge between WP2 and WP3

D. Bindi[1] **D. Spallarossa**[2] **M. Picozzi**[3,4]

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Contributions from D. Scafidi, G. Iaccarino, P. Morasca, F. Cotton, K. Mayeda .... et al

OGS Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Università di Genova DISTAV DIPARTIMENTO DI SCIENZE DELLA TERRA, DELL'AMBIENTE E DELLA VITA

GFZ Helmholtz Centre Potsdam

SECURE meeting@INGV Rome - January 30th, 2024

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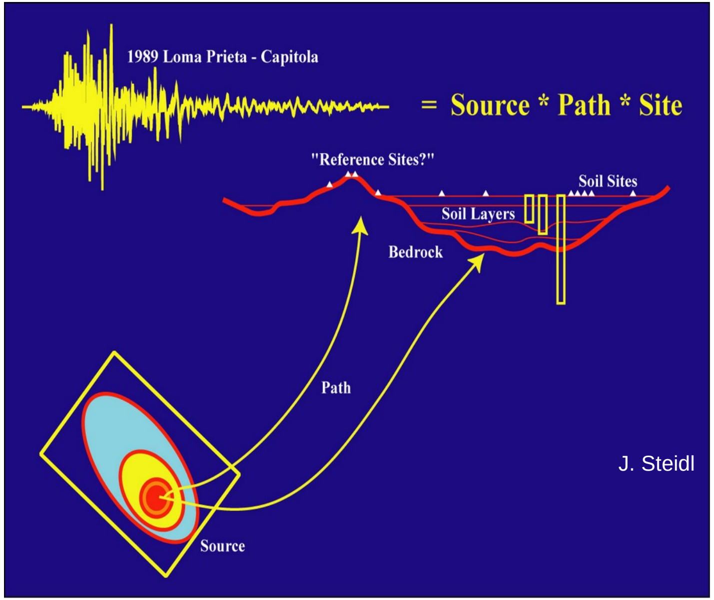
11:00 -12:00 **WP2 - Characterization of Earthquake Source and Seismic Wave Propagation in the Central Apennines**

Outline

- **Introduction to spectral decomposition**
- Reliability of source parameters
- Connection between source parameters and ground motion variability
- What's next

14:30 - 15:30 **WP3 - Ground Motion Predictions using Innovative Approaches**



Engineering-seismology: given a *{Magnitude, distance, vs30} scenario, compute the **distribution** of predicted GM intensities*

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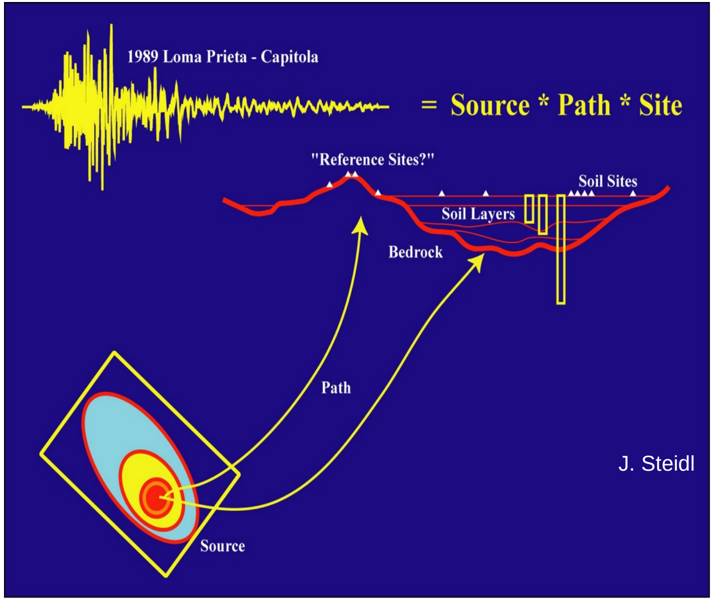
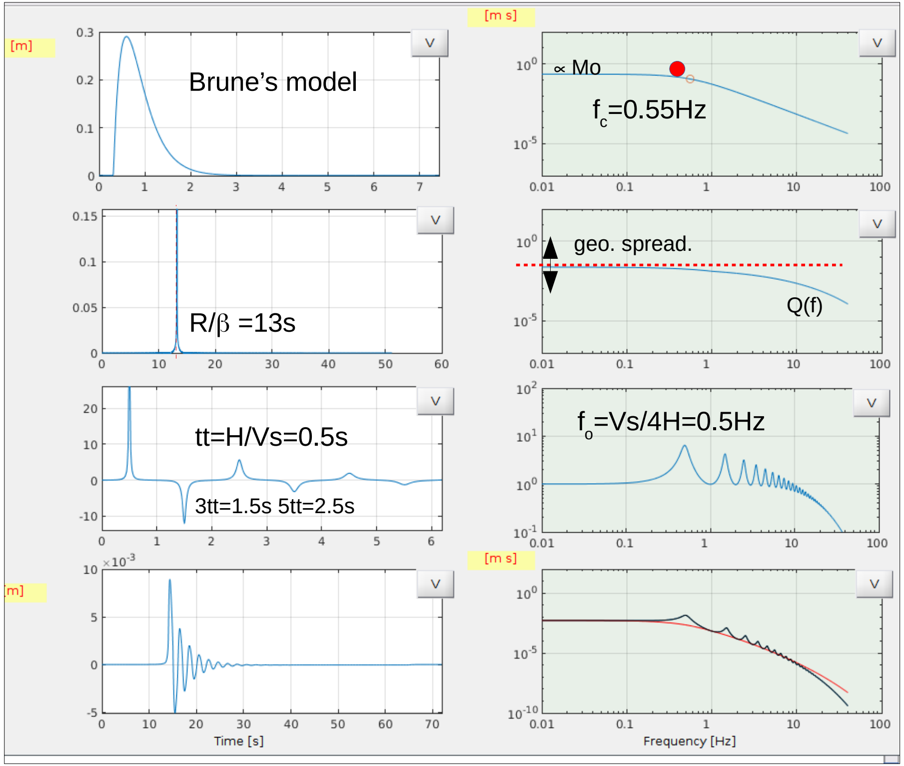
$$(S_j * G_{ij} * Z_i)(t) = u_i(R_{ij}, t) \qquad (\hat{S}_j \hat{G}_{ij} \hat{Z}_i)(\omega) = \hat{u}_i(R_{ij}, \omega)$$



Source S:
Mw 5.5
$\Delta\sigma$=10MPa]

Path G:
1/r,
Q=68f $^{0.4}$

Site Z:
H=100m, d=20,
Vs=200m/s



Engineering-seismology: given a *{Magnitude, distance, vs30} scenario, compute the distribution of predicted GM intensities*

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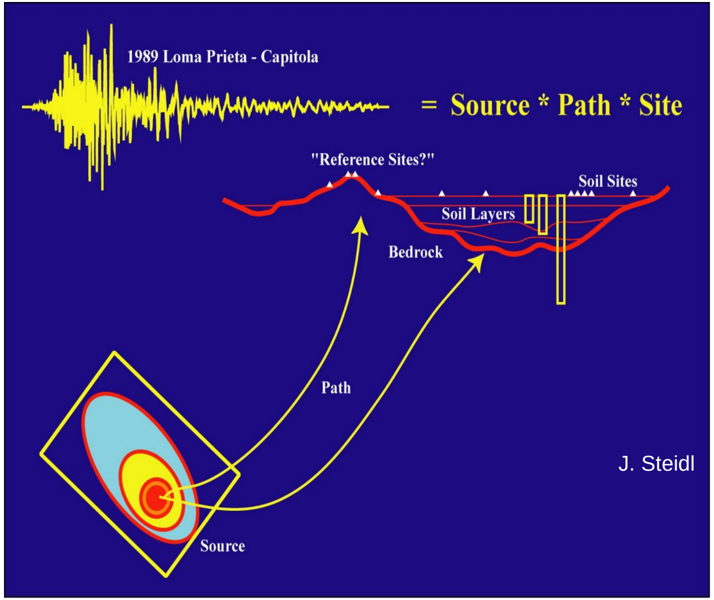
$$(S_j * G_{ij} * Z_i)(t) = u_i(R_{ij}, t) \qquad (\hat{S}_j \hat{G}_{ij} \hat{Z}_i)(\omega) = \hat{u}_i(R_{ij}, \omega)$$



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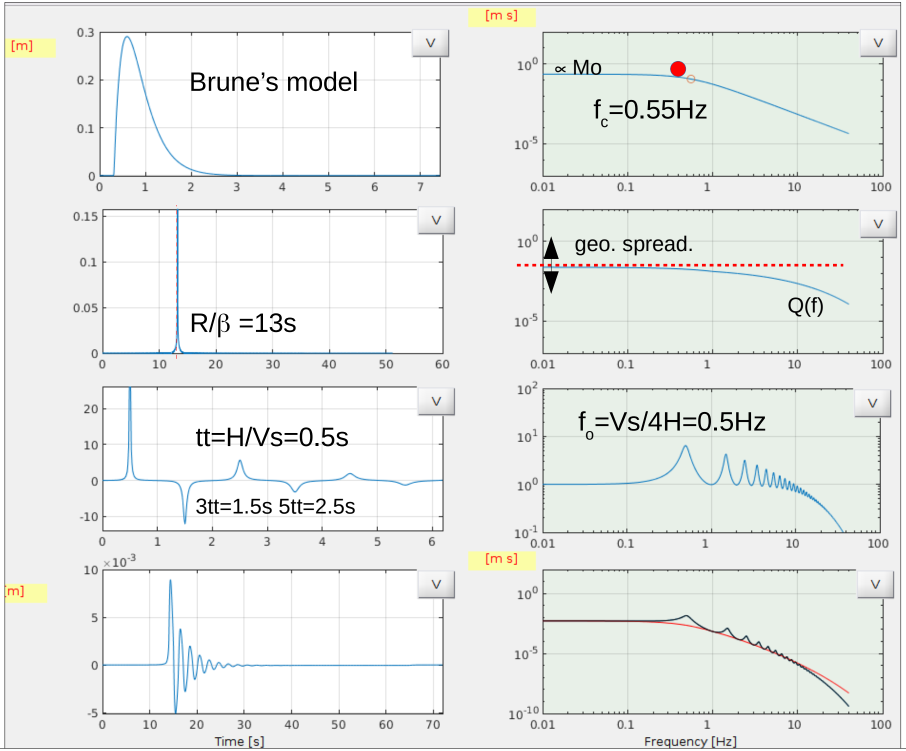
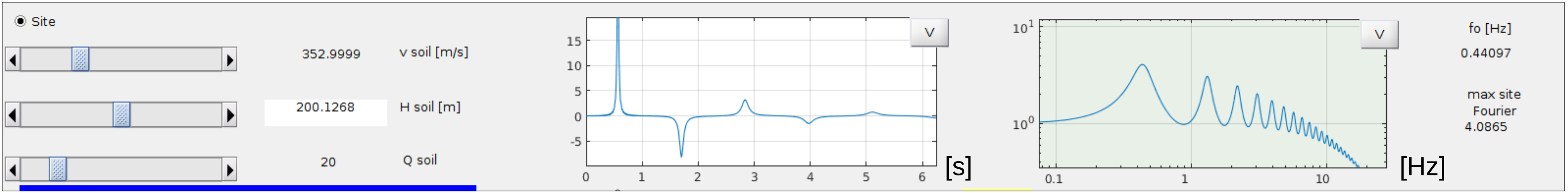
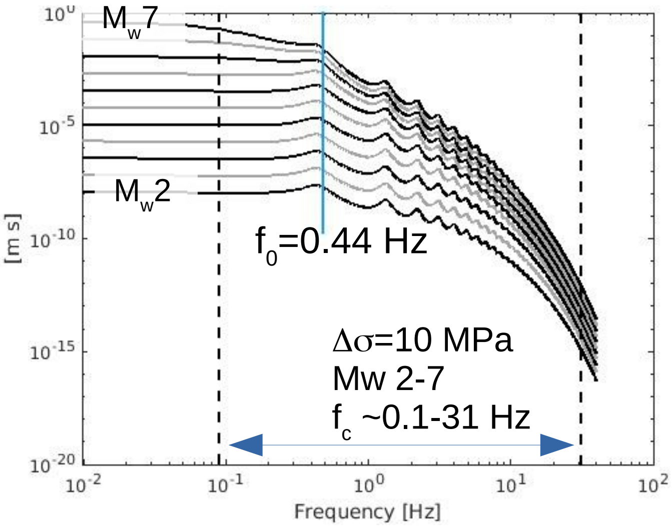


Engineering-seismology: given a *{Magnitude, distance, vs30} scenario, compute the distribution of predicted GM intensities*

Seismology: *From {seismogram and its FAS}, retrieve information about the single source, propagation and site components*



Same site different sources (different magnitudes, same stress drop) at the same distance



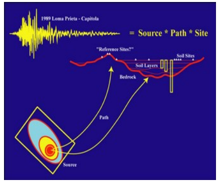
The site term Z leaves the “same” imprint on all recorded spectra

but ……

Spectral decomposition approach [GIT]

$$\boxed{\log_{10} U_{ij}(f, R_{ij}) = \log_{10} S_i(f) + \log_{10} G(f, R_{ij}) + \log_{10} Z_j(f)}$$

System of equation composed by iterating over all recordings ij (combination of earthquake i at station j)



Parametric:

Non-linear Least Squares

$$\log_{10} U_{ijk}(f_k, R_{ij}) = \overbrace{\log_{10}\left[M_{0_i} \frac{2R^{\theta\phi}}{4\pi\rho v_s^3}\right] - \log_{10}\left[1 + \left(\frac{f_k}{f_{c_i}}\right)^2\right]}^{\text{source}} \overbrace{- \gamma \log_{10} R_{ij} - \frac{\pi R_{ij} f_k}{\log_e(10) Q_0 f_k^{\alpha} v_s}}^{\text{propagation}} + \overbrace{\sum_{m=1}^{N_{stations}} \delta_{jm} \log_{10} Z_m(f_k)}^{\text{site}}$$

e.g. $$\frac{\partial \log_{10} U_{ijk}}{\partial f_{c_i}} = \frac{2 f_k^2}{\log_e(10) f_{c_i}(f_{c_i}^2 + f_k^2)}$$

Non-parametric:

Linear Least Squares

$$\log_{10} U_{ij}(f, R_{ij}) = \sum_{k=1}^{N_{event}} \delta_{ik} \log_{10} S_k(f) + a_n \log_{10} G_n(f) + a_{n+1} \log_{10} G_{n+1}(f) + \sum_{k=1}^{N_{stations}} \delta_{jk} \log_{10} Z_k(f)$$

where $a_n = (R_{n+1} - R_{ij}) / (R_{n+1} - R_n)$ $\quad a_{n+1} = 1 - a_n$ $\quad R_n \leqslant R_{ij} < R_{n+1}$

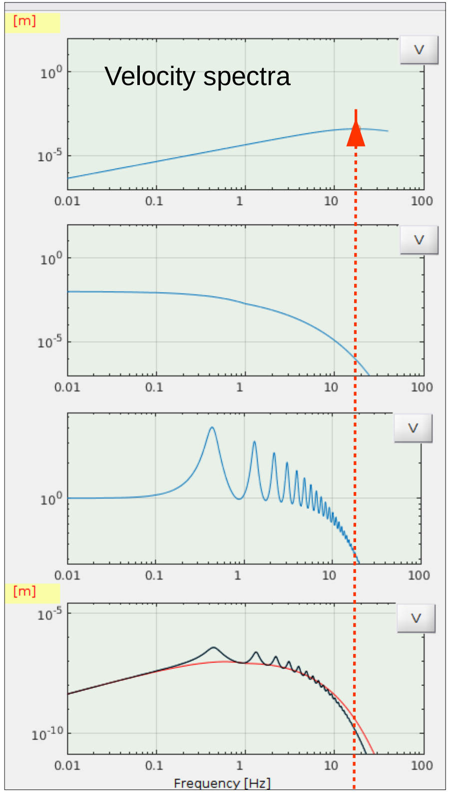
repeated for each frequency f

Attenuation filters high frequency source information

$\Delta\sigma$=10 MPa
Mw 2.5
f_c ~17.6 Hz

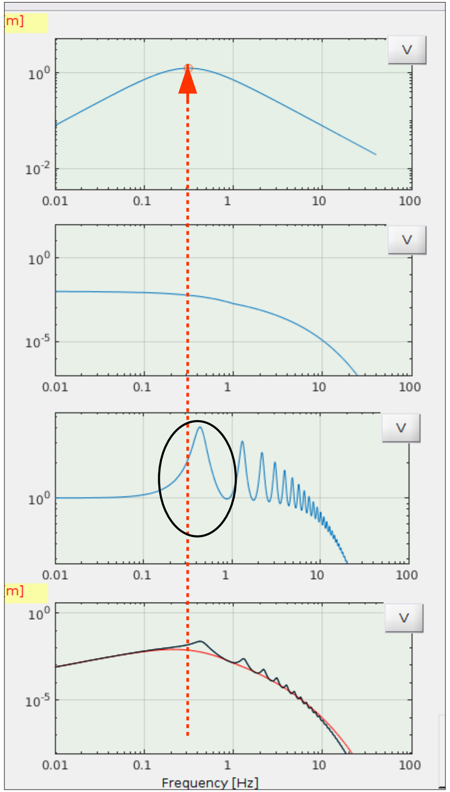
$Q = 68\ f^{0.4}$

k_o ~ 0.03 s



Different factors could be in competition

$\Delta\sigma$=10 MPa
Mw 6
f_c ~ 0.31 Hz



$$\log_{10} U_{ij}(f, R_{ij}) = \boxed{\sum_{k=1}^{N_{event}} \delta_{ik} \log_{10} S_k(f)} + \boxed{a_n \log_{10} G_n(f) + a_{n+1} \log_{10} G_{n+1}(f)} + \boxed{\sum_{k=1}^{N_{stations}} \delta_{jk} \log_{10} Z_k(f)}$$

The solution is the sum of three terms: there are **two unresolved degrees of freedom** require to add a-priori constraints (**the solution is not unique**)

Similarity with the local magnitude calibration:

$$\log_{10} A_{WA} = M_L + \log_{10} A_0 + Z$$

non-parametric

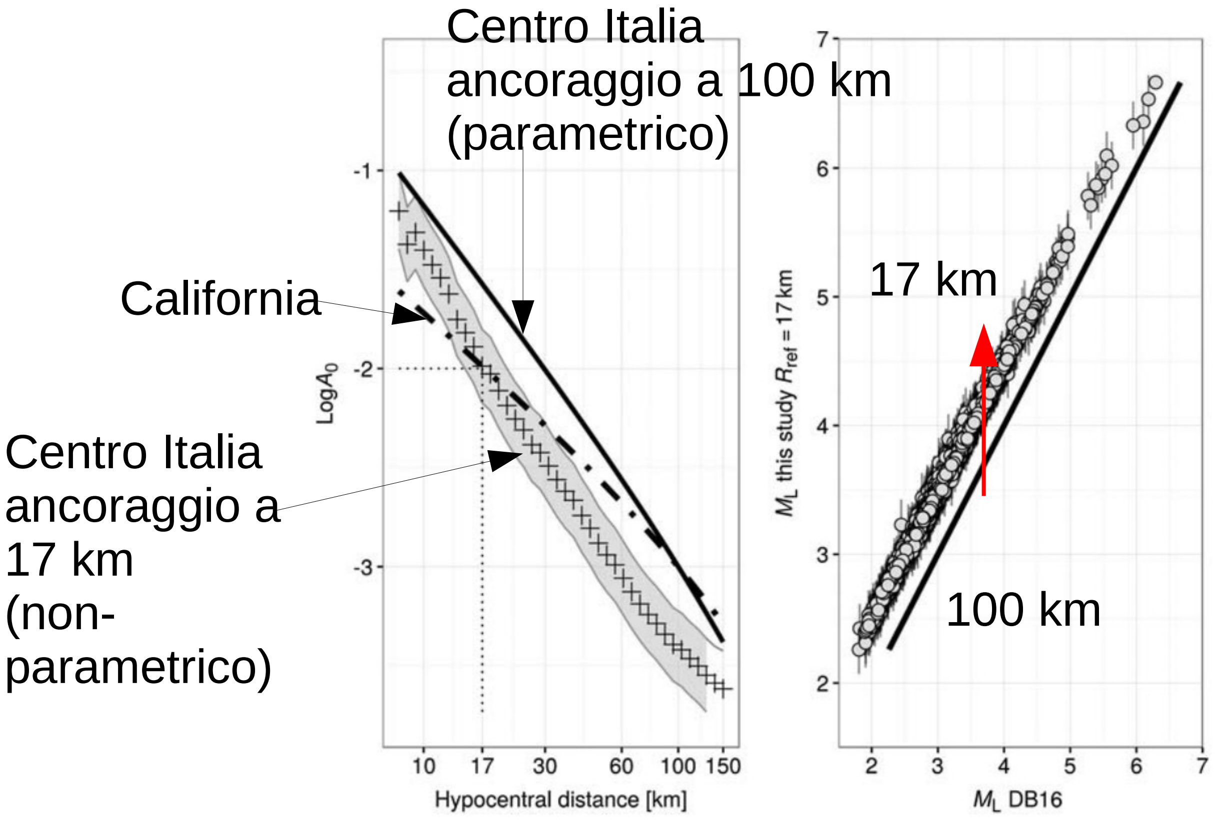
$$\log_{10} A_{kl}(R) = a_n \log_{10} A_0(R_n) + a_{n+1} \log_{10} A_0(R_{n+1}) + \sum_{i=1}^{N_{event}} M_i \delta_{ik} + \sum_{j=1}^{N_{stations}} Z_j \delta_{jl}$$

Z sums to 0

Parametric attenuation

$$\log_{10} A_0 = -n \log_{10}\left(\frac{R}{R_{ref}}\right) - k(R - R_{ref}) - V_{ref}$$

e.g. R_{ref}=100 km, V_{ref}=3
(a M_L3 produces 1 mm at 100 km)

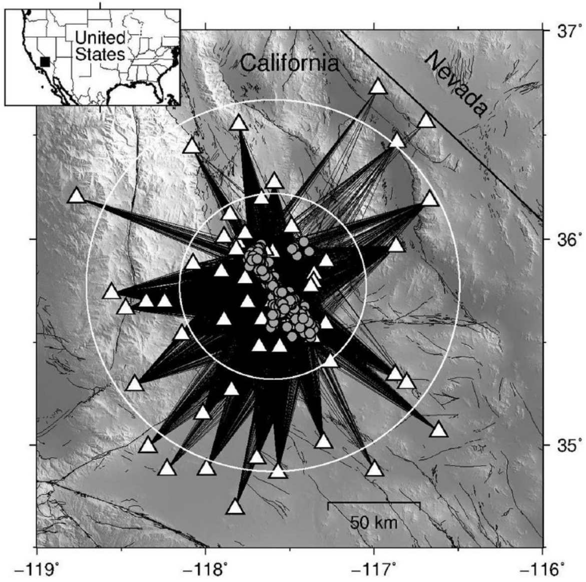


Centro Italia ancoraggio a 100 km (parametrico)
California
Centro Italia ancoraggio a 17 km (non-parametrico)
17 km
100 km
LogA0
Hypocentral distance [km]
ML this study Rref = 17 km
ML DB16
ML bulletin INGV

The Community Stress-Drop Validation Study—Part I: Source, Propagation, and Site Decomposition of Fourier Spectra

Dino Bindi[*1], Daniele Spallarossa[2], Matteo Picozzi[3], Adrien Oth[4], Paola Morasca[5], and Kevin Mayeda[6]

NON-UNIQUENESS → TRADE OFFS



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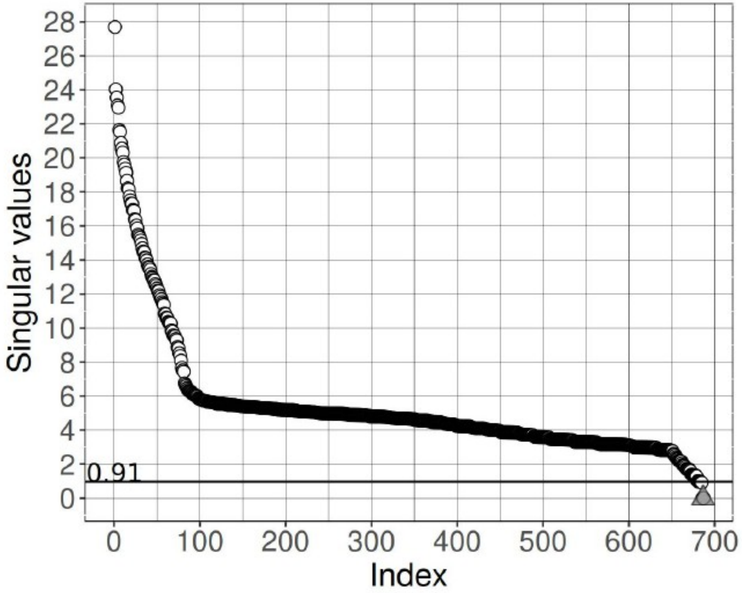
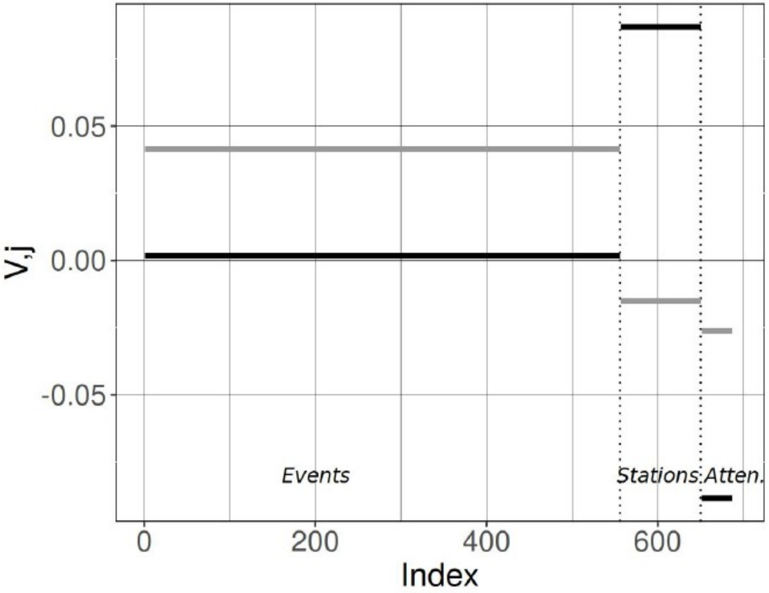
NON-UNIQUENESS→ TRADE OFFS

Base-vectors for the null space





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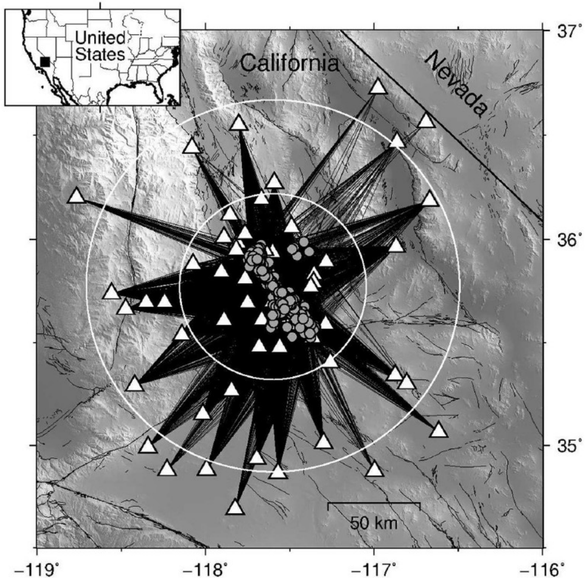
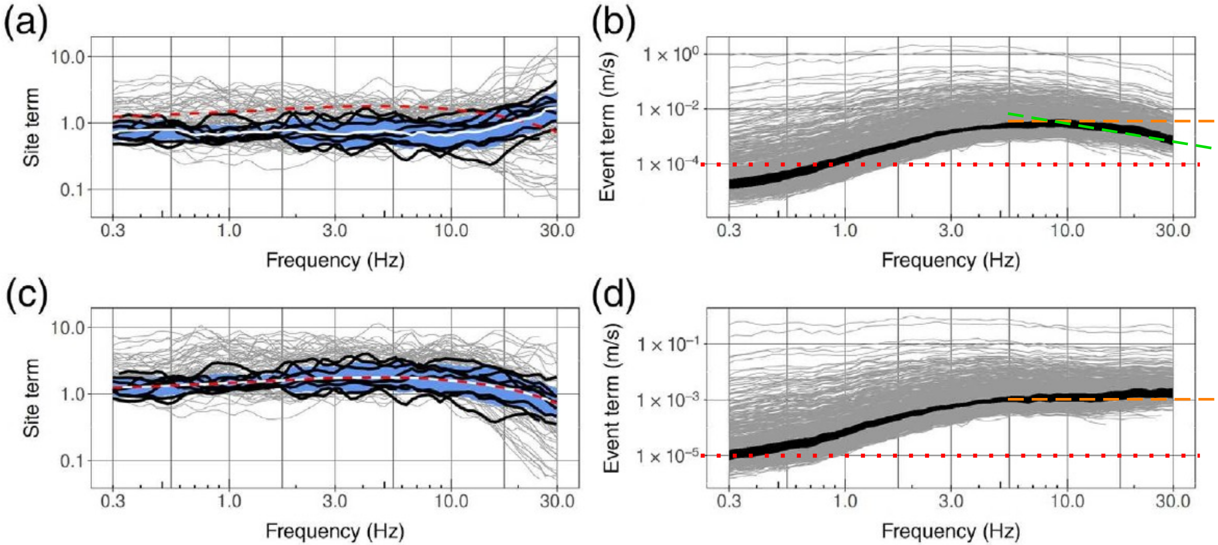


SITE AMPLIFICATIONS SOURCE SPECTRA

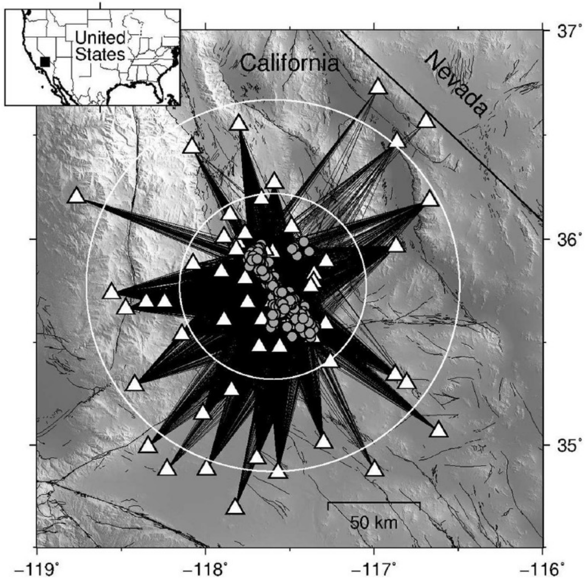


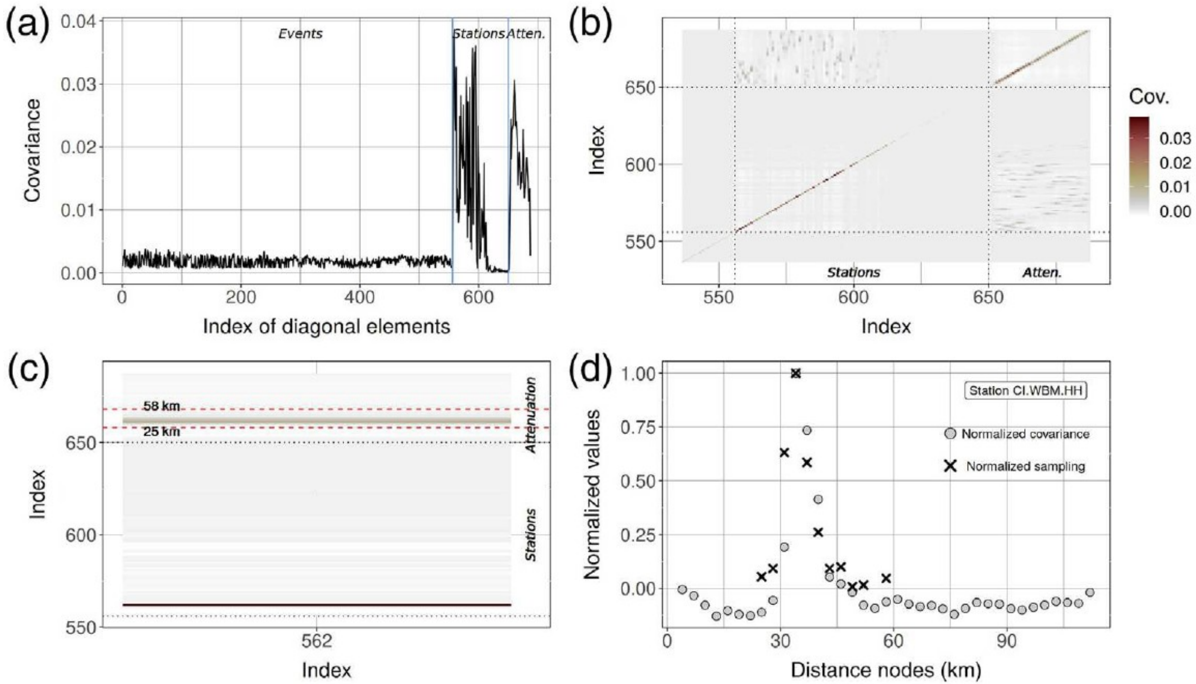
The Community Stress-Drop Validation Study—Part I: Source, Propagation, and Site Decomposition of Fourier Spectra

Dino Bindi[*1], Daniele Spallarossa[2], Matteo Picozzi[3], Adrien Oth[4], Paola Morasca[5], and Kevin Mayeda[6]

Correlations [geometry dependent]

COVARIANCE MATRIX





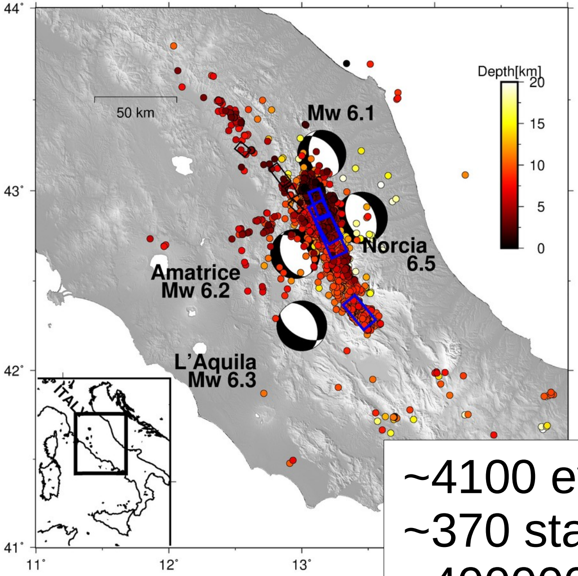
Outline

- Introduction to spectral decomposition
- **Reliability of source parameters**
- Connection between source parameters and ground motion variability
- What next

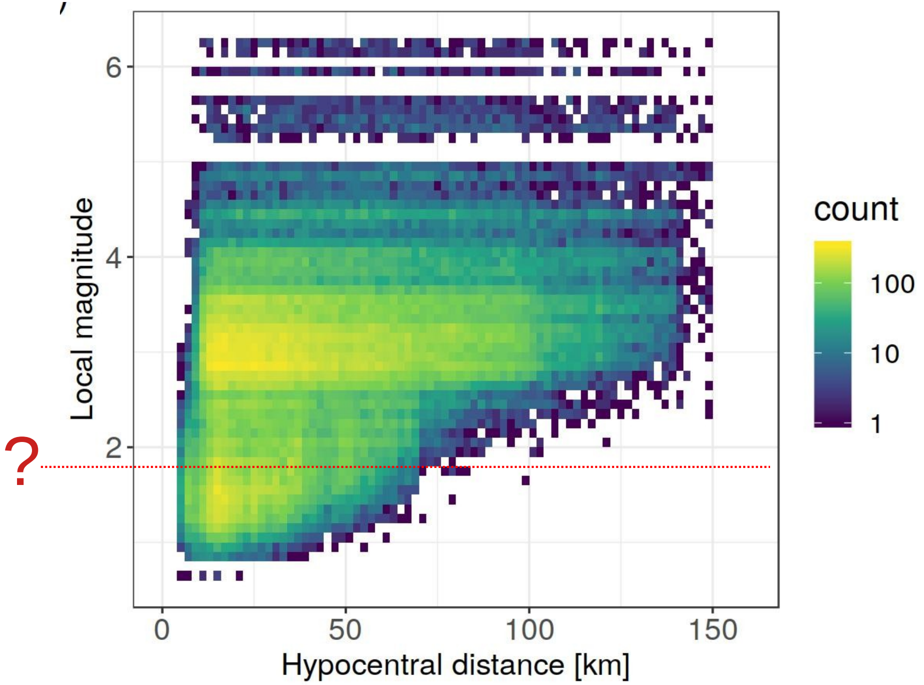
Questions:
→ **magnitude lower limit; limiting factors (attenuation)**
→ epistemic uncertainty: comparison of different methodologies

Reliability of Source Parameters for Small Events in Central Italy: Insights from Spectral Decomposition Analysis Applied to Both Synthetic and Real Data

Dino Bindi*[1], Daniele Spallarossa[2], Matteo Picozzi[3], and Paola Morasca[4]



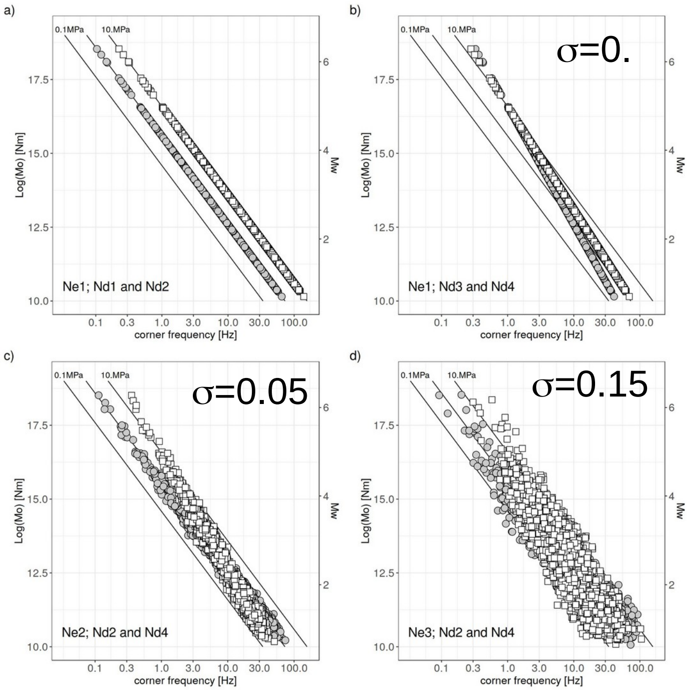
~4100 events
~370 stations
~400000 records



Cite this article as Bindi, D., D. Spallarossa, M. Picozzi, and P. Morasca (2020). Reliability of Source Parameters for Small Events in Central Italy: Insights from Spectral Decomposition Analysis Applied to Both Synthetic and Real Data, *Bull. Seismol. Soc. Am.* **XX**, 1–19, doi: 10.1785/0120200126

$$\text{FAS}(M_0, f_c, n_1, n_2, R_h, Q_0, \alpha, k_0; f, R) = S(M_0, f_c; f) G(n_1, n_2, R_h; R) A(Q_0, \alpha; R, f) Z(k_0; f).$$

Different source scaling



Source models

$$S(M_0, f_c; f) = \frac{F_V R^{\theta,\phi}}{4\pi\rho\beta^3} \frac{1}{R_{\text{ref}}} \frac{M_0 f^2}{1 + \left(\frac{f}{f_c}\right)^2},$$

$$\Delta\sigma = \frac{7}{16} \frac{M_o}{r^3}$$

$$M_o \propto f_C^{-(3+\epsilon)}$$

FAS $(M_0, f_c, n_1, n_2, R_h, Q_0, \alpha, k_0; f, R)$

$$= S(M_0, f_c; f)G(n_1, n_2, R_h; R)A(Q_0, \alpha; R, f)Z(k_0; f). \quad (1)$$

Attenuation model

$$G(n_1, n_2, R_h; R) = \begin{cases} \left(\frac{R_{\mathrm{ref}}}{R}\right)^{n_1} & \text{for } R \le R_h \\ \left(\frac{R_{\mathrm{ref}}}{R_h}\right)^{n_1}\left(\frac{R_h}{R}\right)^{n_2} & \text{for } R > R_h \end{cases},$$

in which the break-point distance is fixed to $R_h = 80$ km, and setting the slopes to $n_1 = 1$, $n_2 = 0.5$. The attenuation oper-

$$A(Q_0, \alpha; R, f) = e^{\frac{-\pi R f^{1-\alpha}}{Q_0 \beta}}.$$

: $Q = 250 f^{0.15}$,

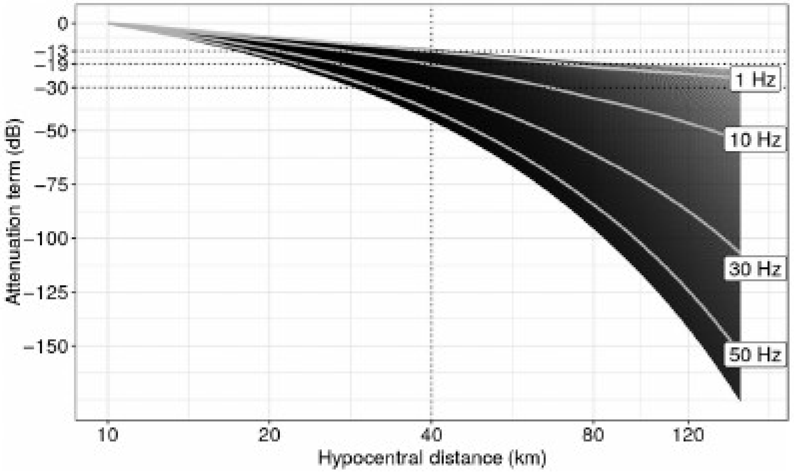
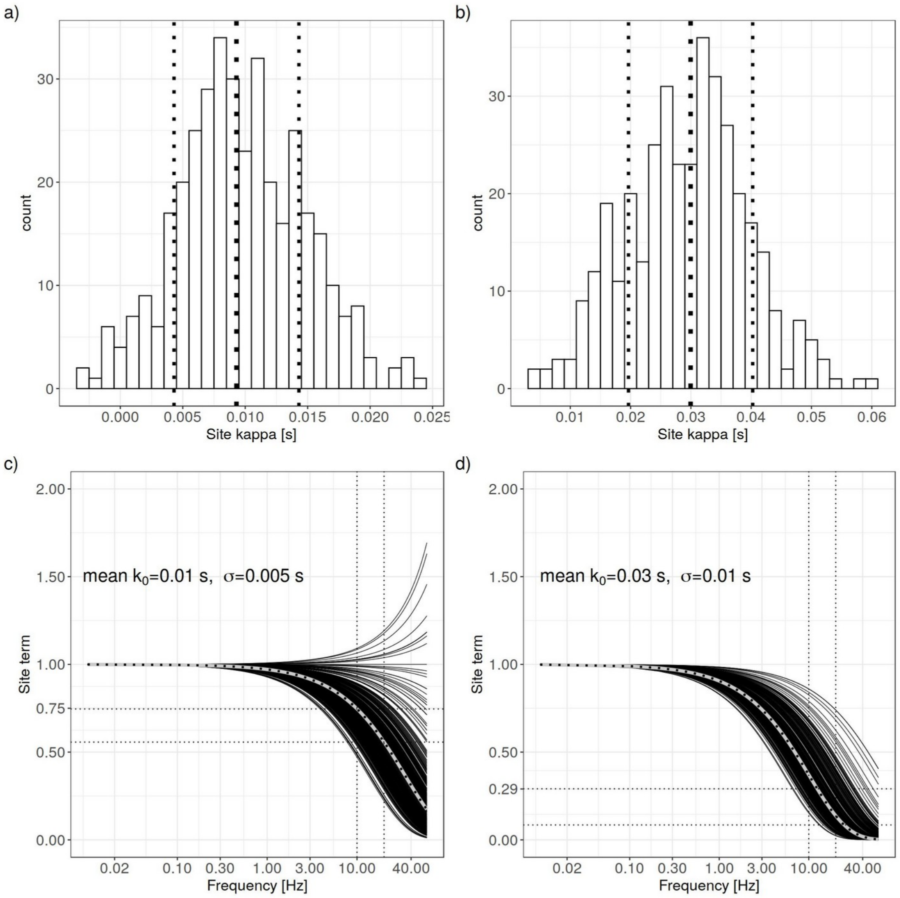
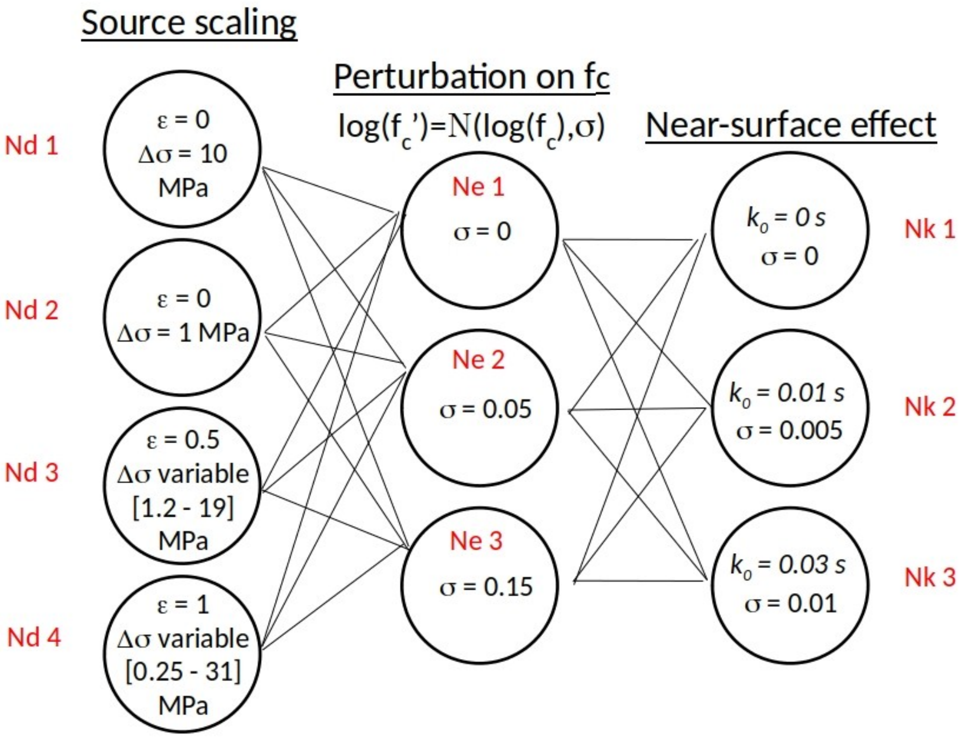


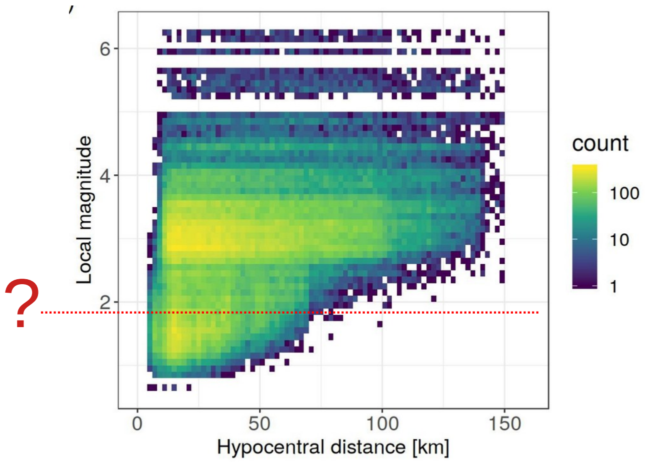
Figure 5. Spectral attenuation model used for generating the synthetics (see equations 6 and 7). The attenuation curves for selected frequencies are shown in gray.

Near-source effects

$$Z(k_o; f) = e^{-\pi k_0 f}$$





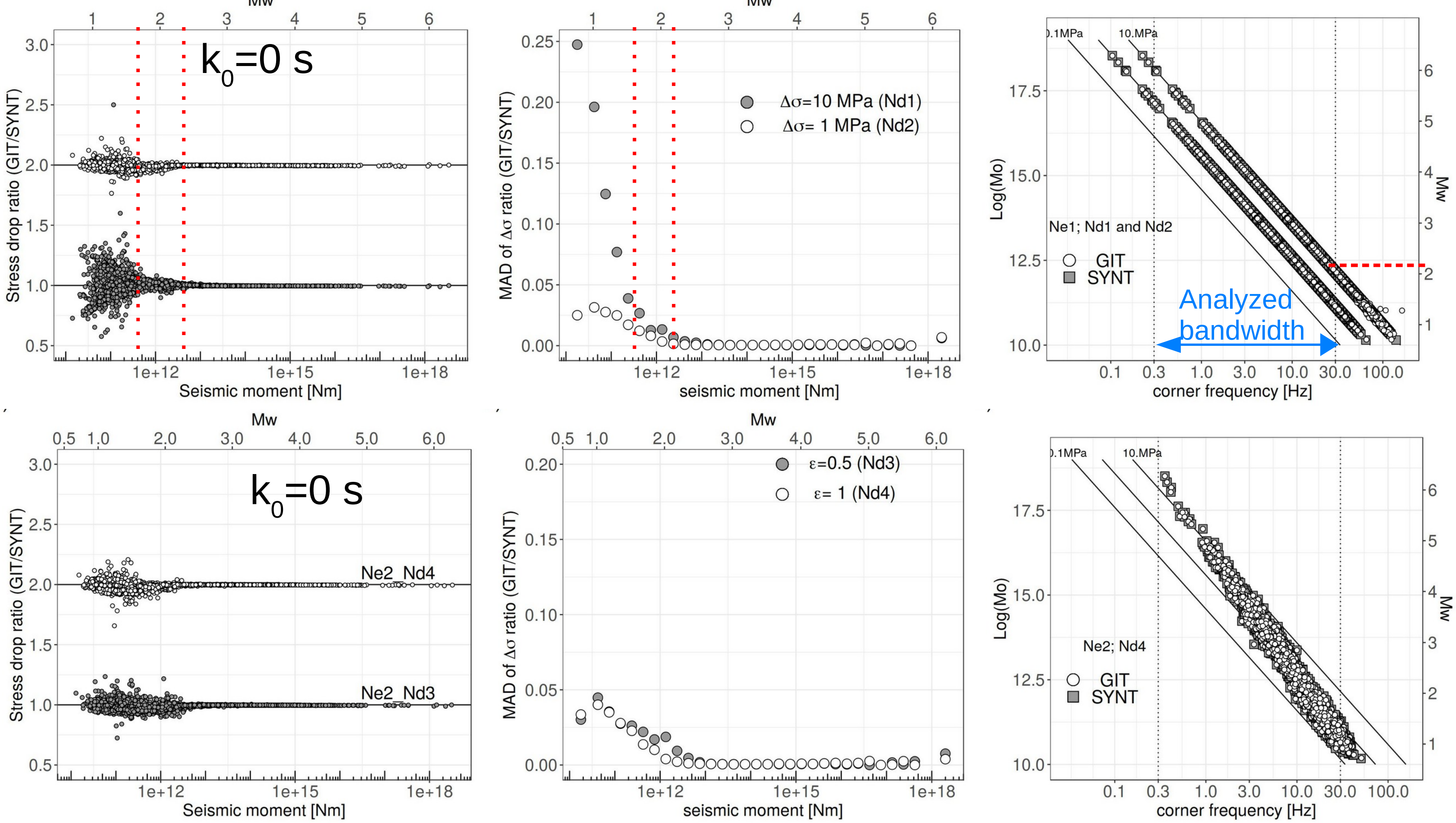


Checks:

1 simulated versus reconstructed spectra (e.g. RRMS, Correlation)

2 simulated versus retrieved(Mo,fc)

3 Δσ(retrieved)/Δσ(synthetic)



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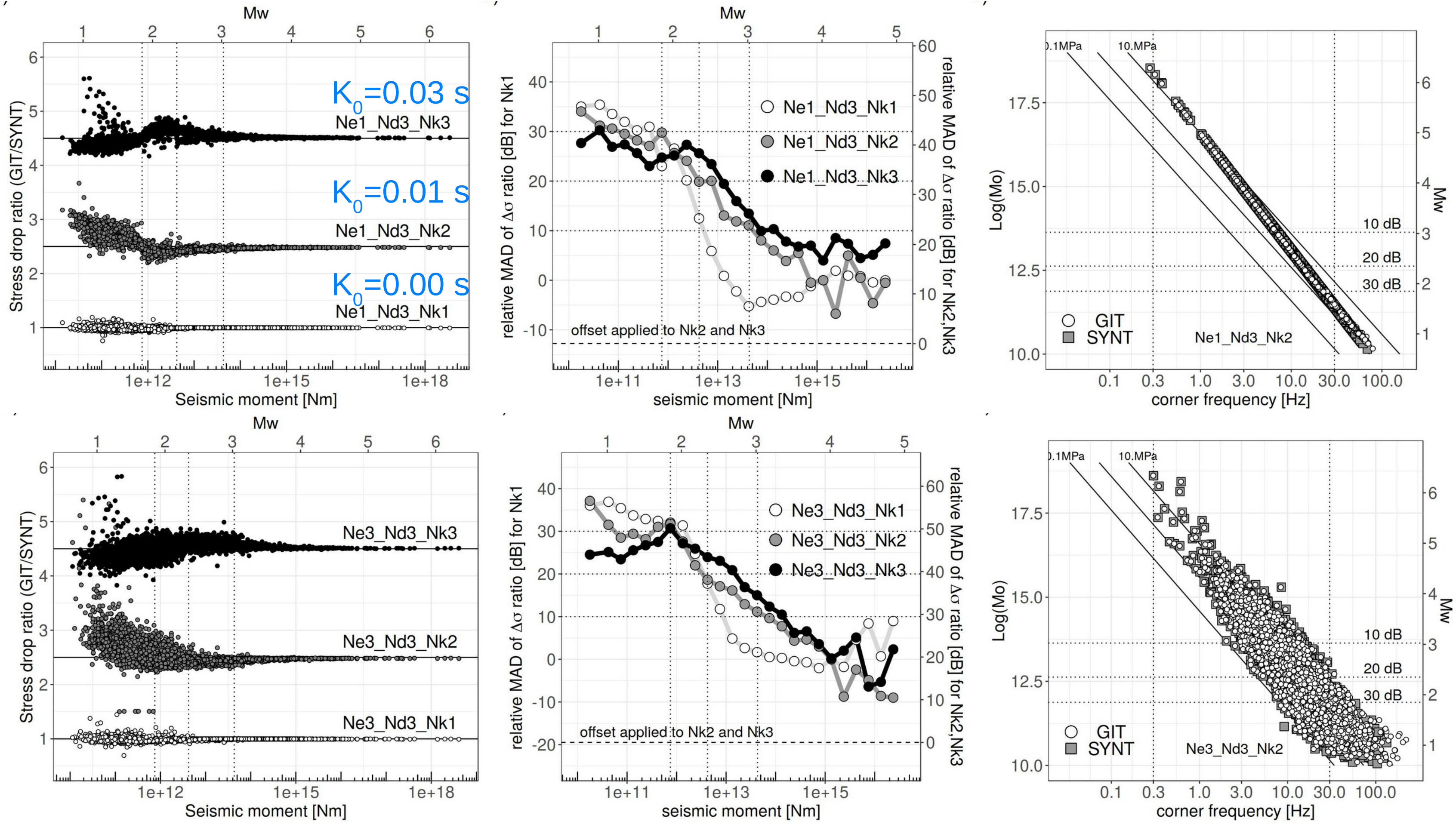
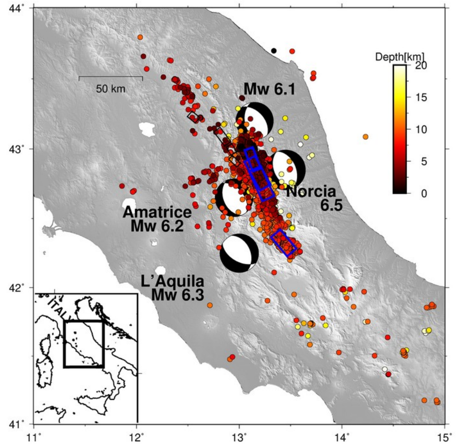
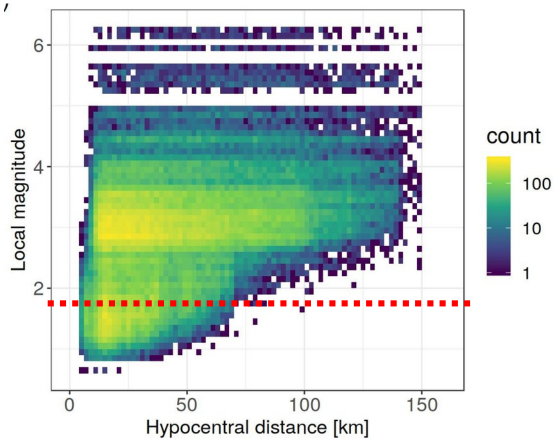
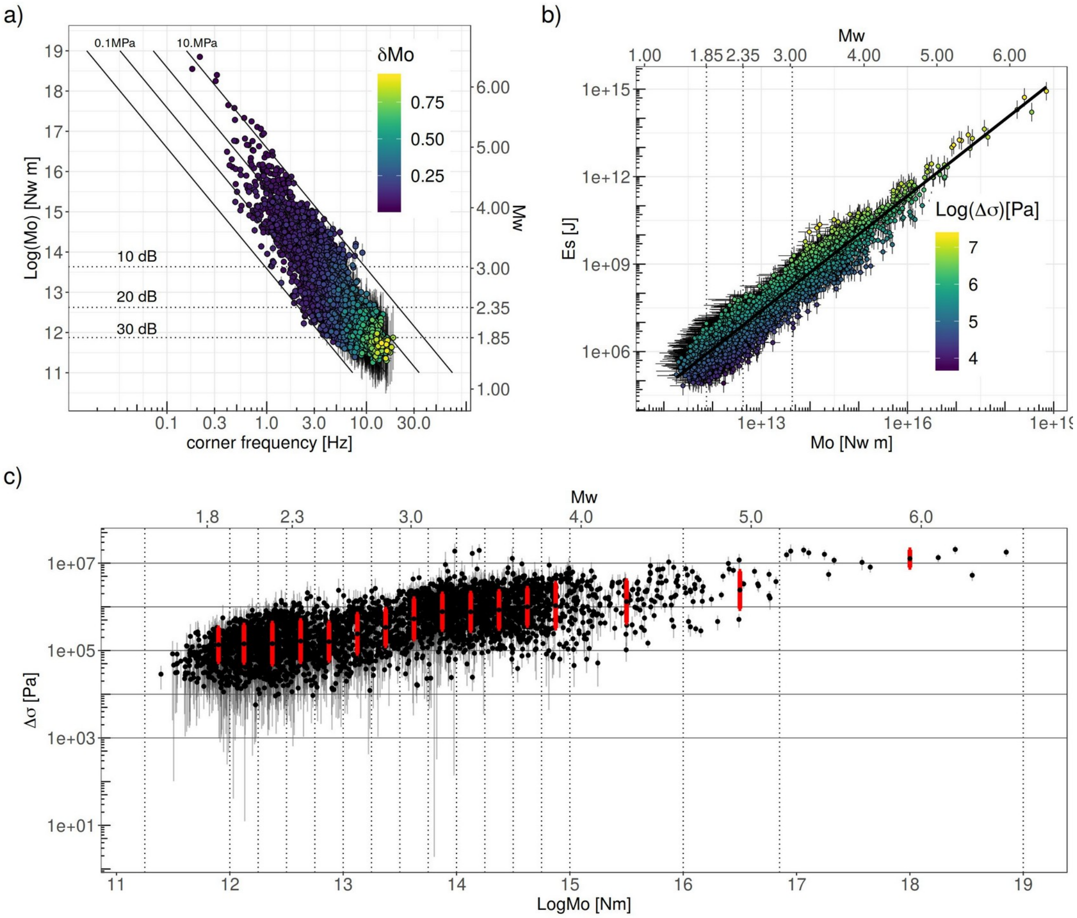


K_0=0.03 s
Ne1_Nd3_Nk3
K_0=0.01 s
Ne1_Nd3_Nk2
K_0=0.00 s
Ne1_Nd3_Nk1
Stress drop ratio (GIT/SYNT)
Seismic moment [Nm]
Mw
Ne1_Nd3_Nk1
Ne1_Nd3_Nk2
Ne1_Nd3_Nk3
relative MAD of Δσ ratio [dB] for Nk1
relative MAD of Δσ ratio [dB] for Nk2,Nk3
offset applied to Nk2 and Nk3
seismic moment [Nm]
0.1MPa
10.MPa
10 dB
20 dB
30 dB
GIT
SYNT
Ne1_Nd3_Nk2
Log(Mo)
corner frequency [Hz]
Ne3_Nd3_Nk3
Ne3_Nd3_Nk2
Ne3_Nd3_Nk1
Ne3_Nd3_Nk1
Ne3_Nd3_Nk2
Ne3_Nd3_Nk3
Ne3_Nd3_Nk2

nitude range 4–4.5. Figure 11b shows that, whereas the MAD for $\kappa_0 = 0$ increases below magnitude 3 as a consequence of the Q attenuation discussed for Figure 7, the relative MAD for the Nk2 and Nk3 models describe a continuously increasing variability of the $\Delta\sigma$ residuals for decreasing magnitude. With respect to the assumed reference value, the relative MAD increases of 10, 20, and 30 dB when the moment magnitude becomes smaller than about 3, 2.3, and 1.8, respectively. Similar observations are also drawn from Figure 11e for the Ne3 case. If we export these results to the analysis of the central Italy data set, we expect that the uncertainties on the source parameters increase for magnitudes in the range 2.3–3; for magnitudes in the range 1.8–2.3, the uncertainties further increase and biases likely start to affect the results; finally, below magnitude 1.8, the reliability of the results might be strongly reduced due to the attenuation effects related to Q and κ_0. Finally, Figure 11c,f shows that although $\Delta\sigma$ estimates for magnitudes below 2.3 are less reliable, the average scaling is well reconstructed over almost the entire magnitude range.


Depth[km]
50 km
Mw 6.1
Norcia
6.5
Amatrice
Mw 6.2
L'Aquila
Mw 6.3
ITALY


Local magnitude
Hypocentral distance [km]
count


a)
0.1MPa
10.MPa
δMo
10 dB
20 dB
30 dB
Log(Mo) [Nw m]
corner frequency [Hz]
Mw
b)
Mw
Es [J]
Log(Δσ)[Pa]
Mo [Nw m]
c)
Mw
Δσ [Pa]
LogMo [Nm]

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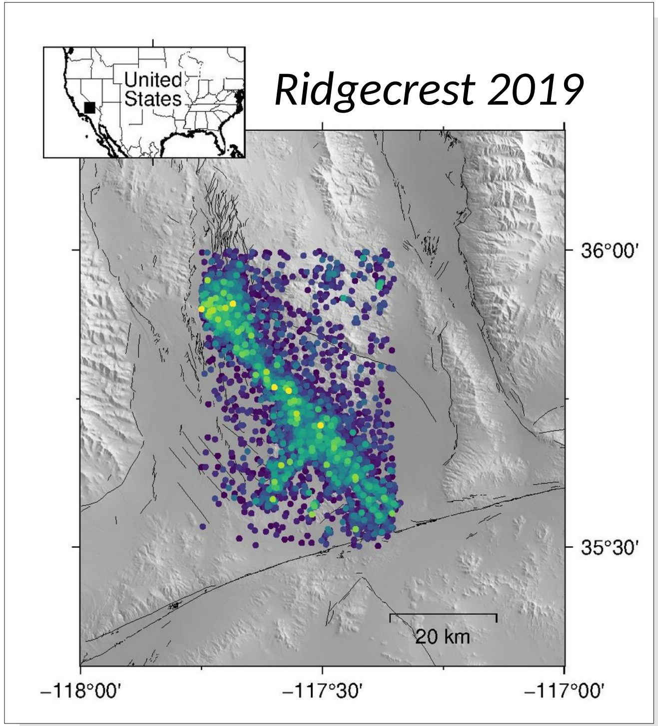
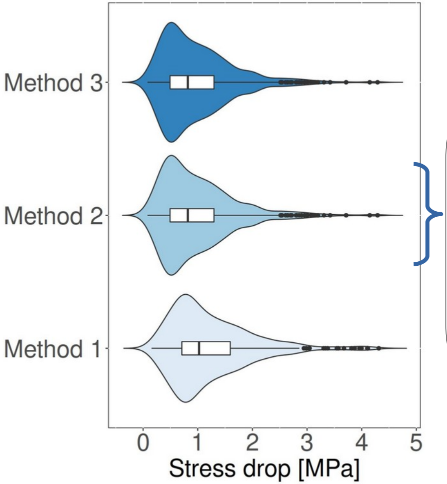
→ **epistemic uncertainty: comparison of different methodologies**



Benchmark data set
[from Trugman, 2020]

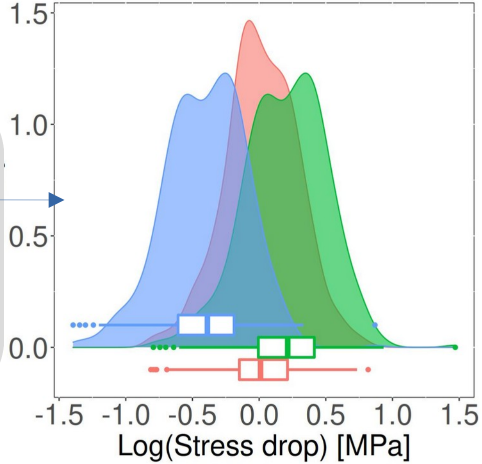
Different:
- **Methods (groups)**
- **Data selection & processing**



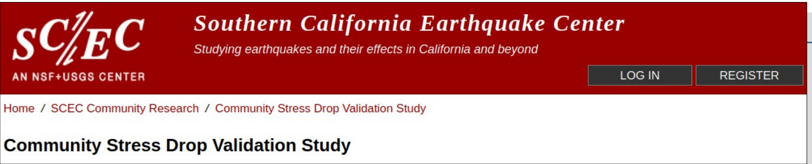
Between-Method

Approach1
Approach2
…
…
ApproachN

Method 2



Within-Method



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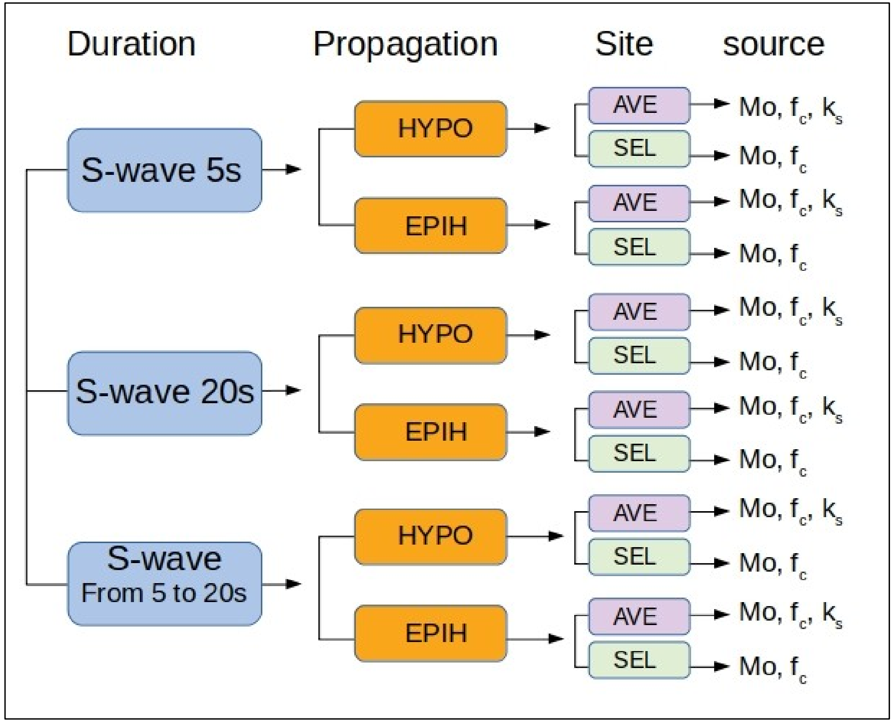
The Community Stress-Drop Validation Study—Part II: Uncertainties of the Source Parameters and Stress Drop Analysis

Dino Bindi[*1], Daniele Spallarossa[2], Matteo Picozzi[3], Adrien Oth[4], Paola Morasca[5], and Kevin Mayeda[6]

$$\log O_{ij}(f) = \log S_i(f) + \log P(R_{ij}, f) + \log Z_j(f)$$



Strategy for evaluating the epistemic uncertainties: logic-tree approach

HYPO: same spectral attenuation model for all earthquakes

EPIH: different attenuation models for different depth ranges

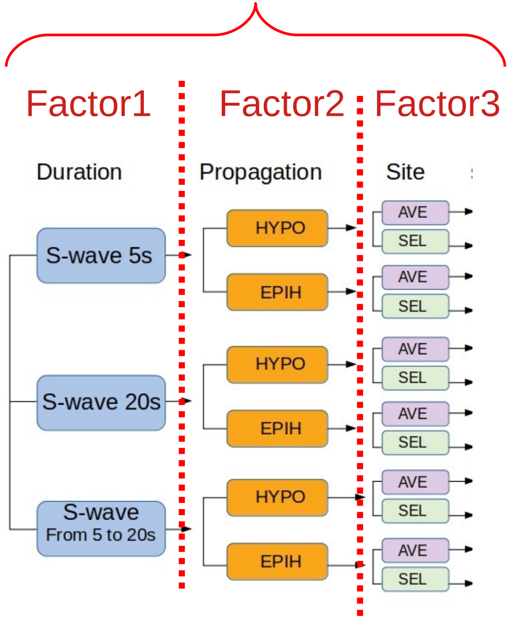
$$\log(f_c) = \boxed{e_1 + \eta_{\mathrm{event}}} + \overbrace{\eta_{\mathrm{duration}} + \eta_{\mathrm{propagation}} + \eta_{\mathrm{site}}} + \epsilon,$$

Event-specific intercept

$$\phi_{\mathrm{dps}} = \sqrt{\phi^2_{\mathrm{duration}} + \phi^2_{\mathrm{propagation}} + \phi^2_{\mathrm{site}}},$$

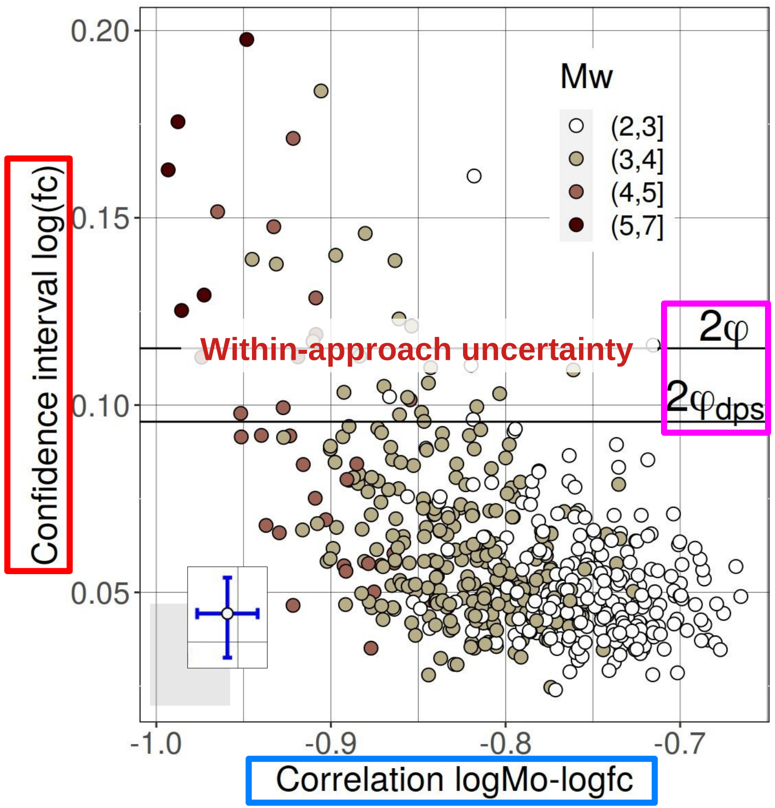
“within-method” standard deviation:

$$\phi = \sqrt{\phi^2_{\mathrm{dps}} + \phi^2_0},$$



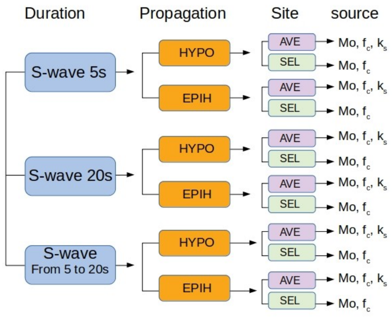
Mixed-effects regression analysis

SUMMARY OF THE RESULTS



$$\phi_{\mathrm{dps}} = \sqrt{\phi^2_{\mathrm{duration}} + \phi^2_{\mathrm{propagation}} + \phi^2_{\mathrm{site}}},$$

$$\phi = \sqrt{\phi^2_{\mathrm{dps}} + \phi^2_{0}},$$

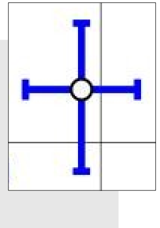


Within-method variability

Confidence intervals

```
> sigma(model)
[1] 0.04231737
> vcov(model)
              LMo            fc
LMo  0.0000486878 -0.0007384827
fc  -0.0007384827  0.0228986235
```

Covariance matrix



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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

Paola Morasca,[1] Dino Bindi,[2] Kevin Mayeda,[3] Jorge Roman-Nieves,[3] Justin Barno,[4] William R. Walter[4] and Daniele Spallarossa[5]

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[2] *Deutsches GeoForschungsZentrum GFZ, Potsdam, Germany*
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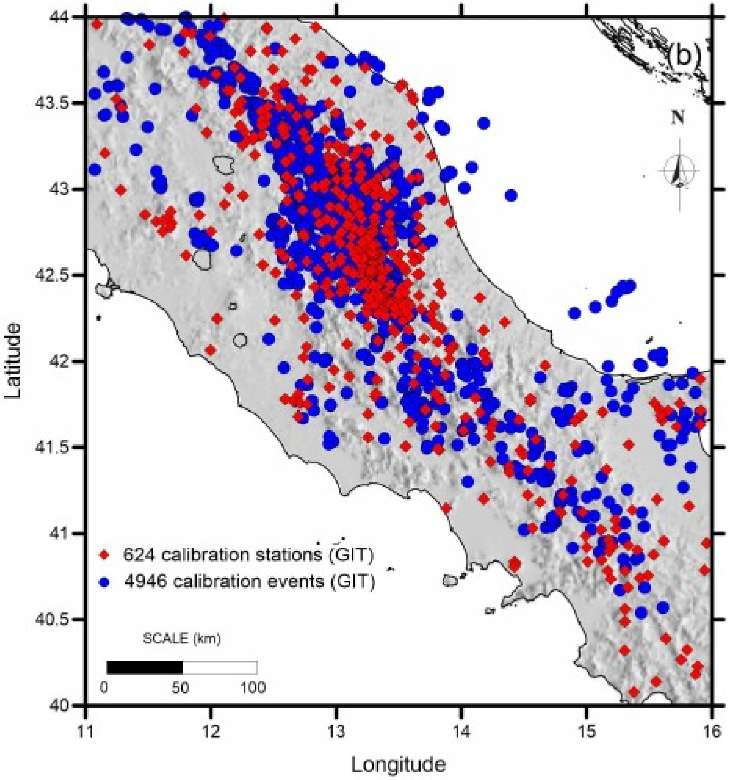
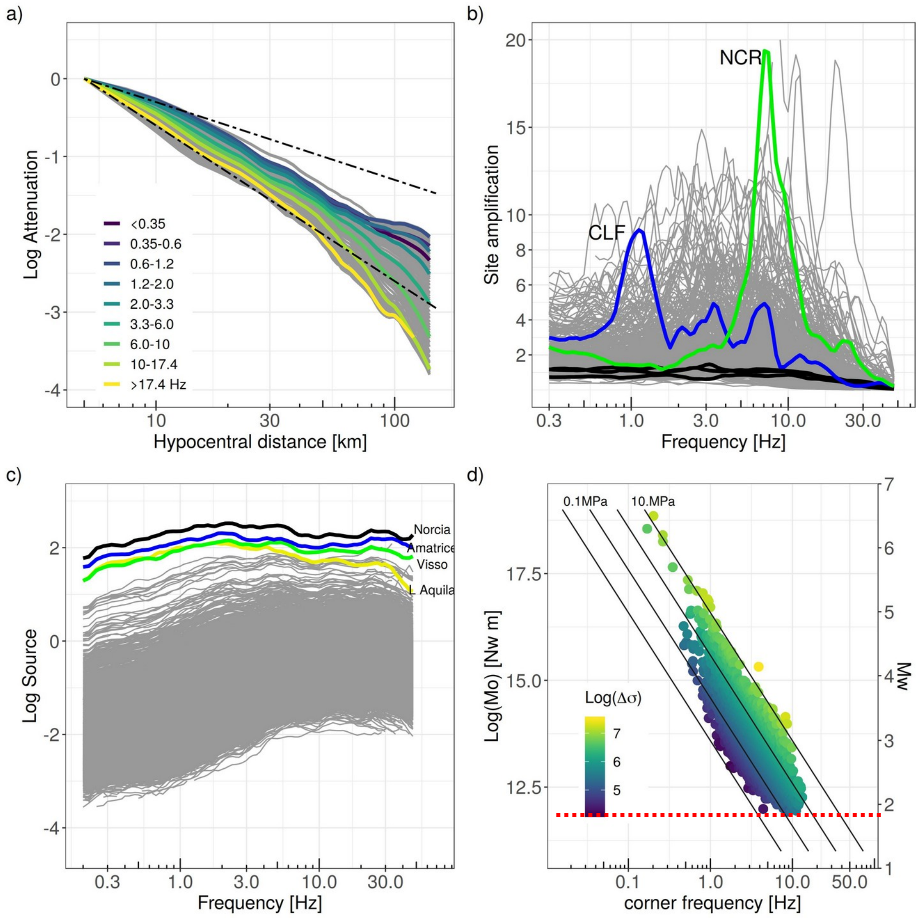
term Z. Following previous studies performed for the same area (Pacor *et al.* 2016a; Bindi *et al.* 2017), we impose that the average amplification of three selected stations (i.e. Leonessa, LSS; San Martino d'Ocre, RM03 and Spina Nuova, T1221) is equal to the amplification generated by a crustal velocity model with vs30 equal to 760 m s^{-1} multiplied by an exponential term $\exp(-\pi k_0 f)$ (Campbell & Boore 2016). Following Pacor *et al.* (2016a), we use $k_0 = 0.018$ s. We solve the linear system in a least-squares sense (Koenker & Ng 2017) and the results of the spectral amplitude decomposition are shown in Fig. S1. In particular, Fig. S1(a) shows the non-parametric and frequency-dependent attenuation values, whereas Figs S1(b) and (c) show the site amplification terms and the source spectra as isolated by the GIT decomposition, respectively.



PROPAGATION

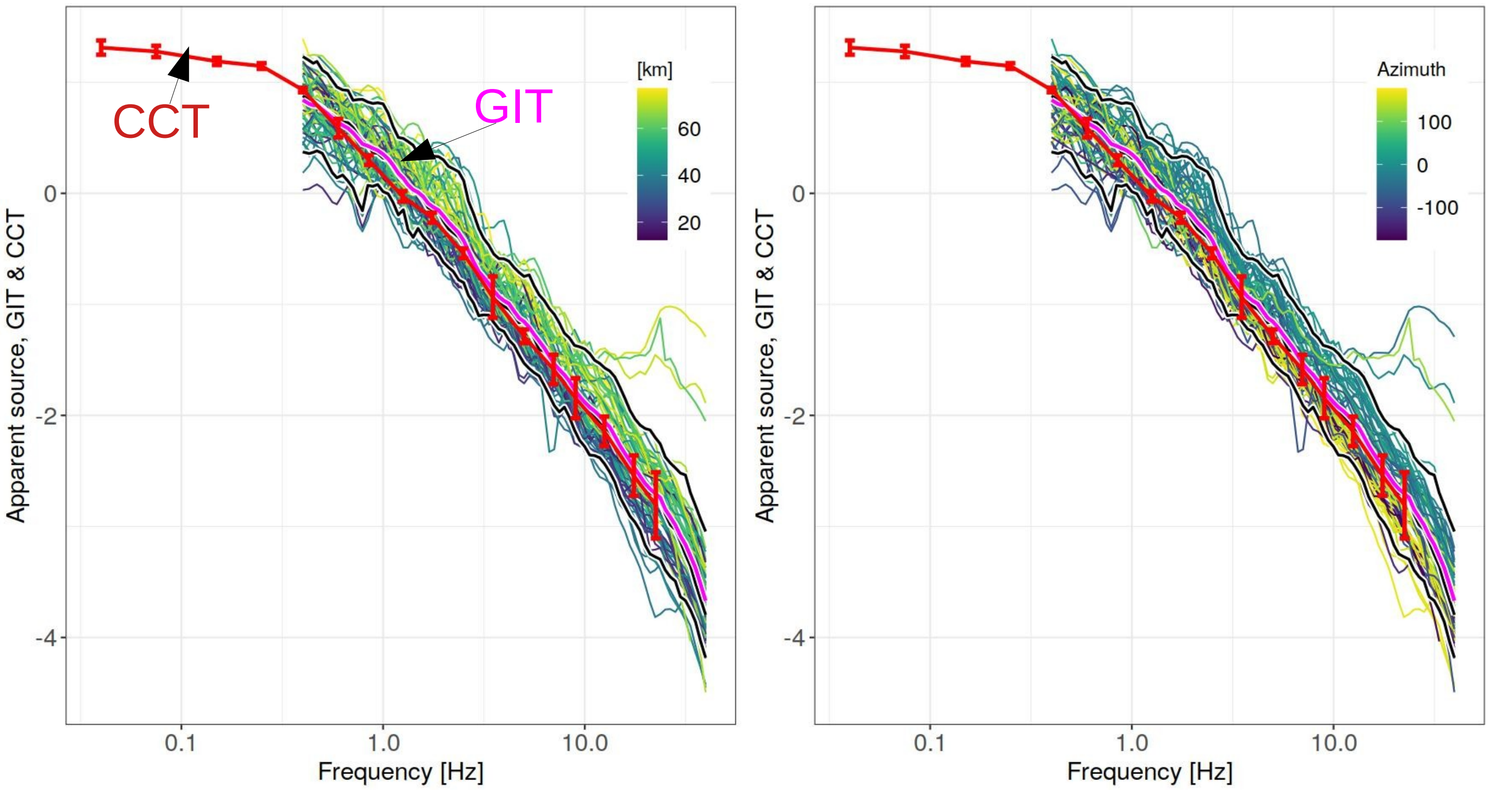
SITE AMPLIFICATIONS

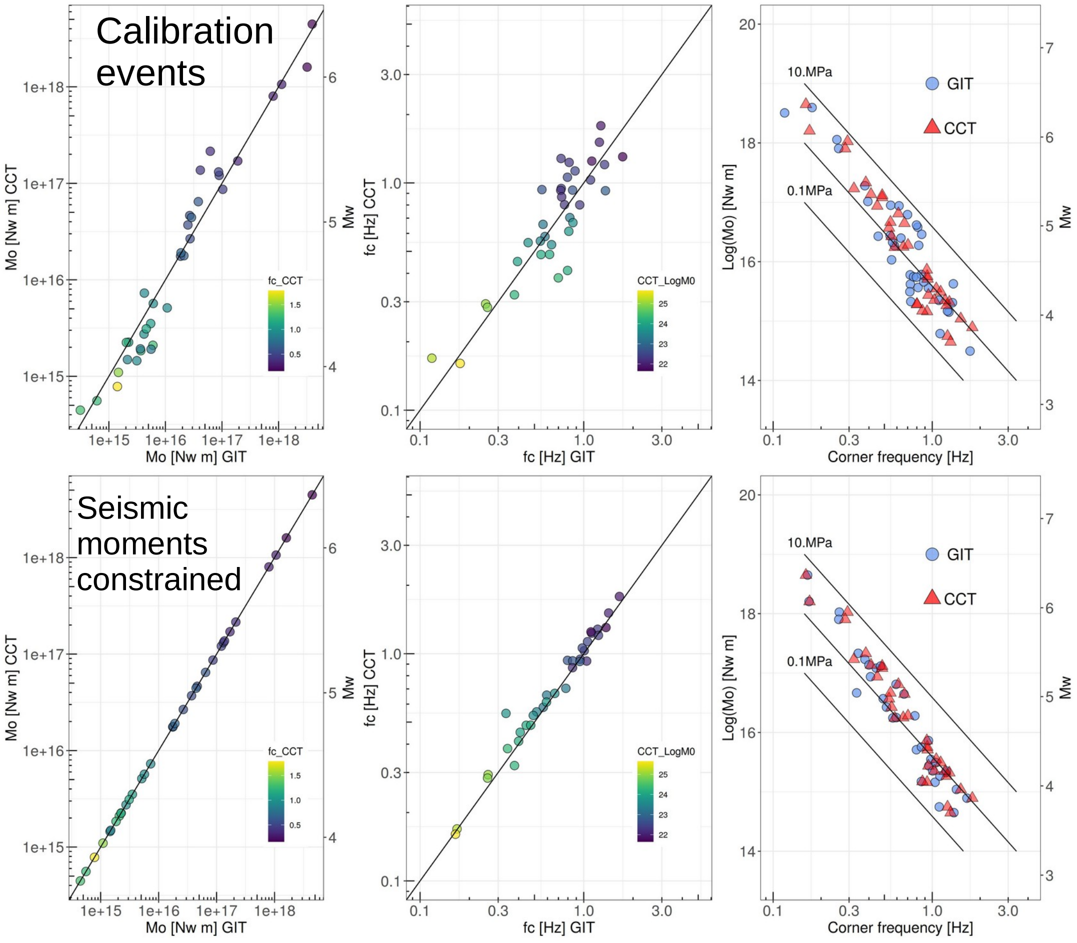
SOURCES

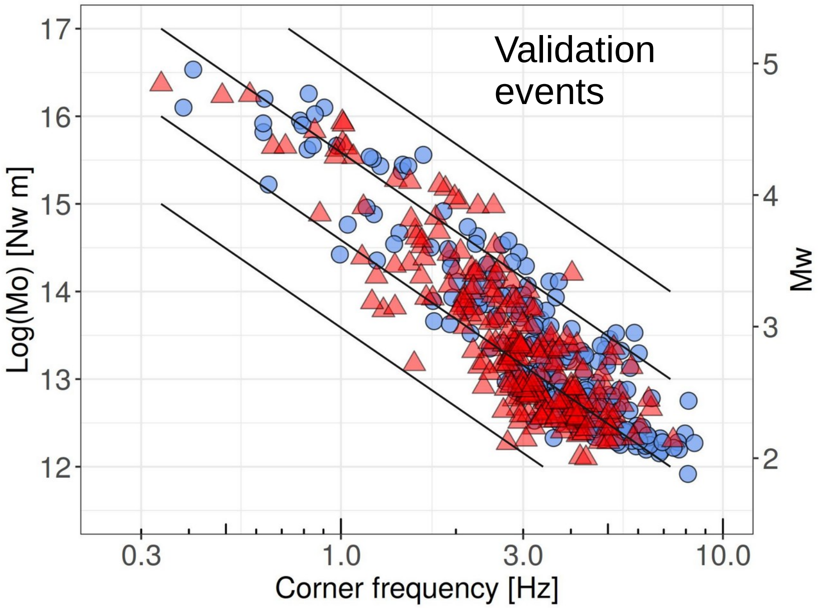


Post processing: Scaling

AMATRICE 2016




Calibration events
Seismic moments constrained
Mo [Nw m] CCT
Mo [Nw m] GIT
Mw
fc_CCT
fc [Hz] CCT
fc [Hz] GIT
CCT_LogM0
Log(Mo) [Nw m]
Corner frequency [Hz]
10.MPa
0.1MPa
GIT
CCT


Validation events
Log(Mo) [Nw m]
Corner frequency [Hz]
Mw

Outline

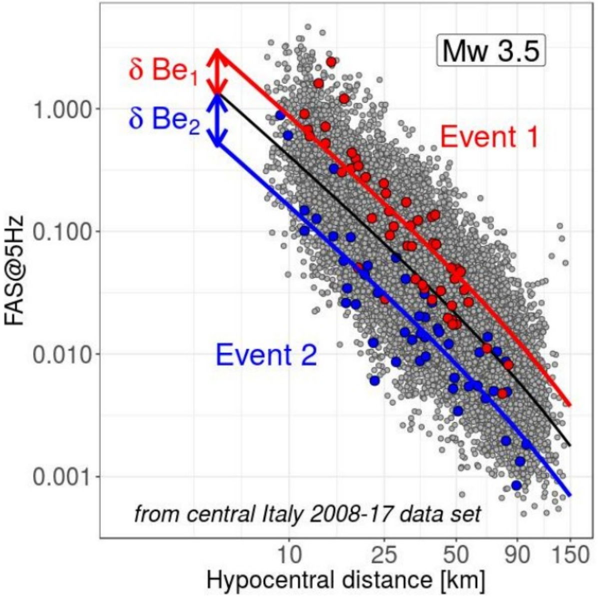
- Introduction to spectral decomposition
- Reliability of source parameters
- **Connection between source parameters and ground motion variability**
- What’s next

Questions:
Interpret the ground motion variability in terms of seismological models, e.g.:
→ **connection among between-events δB_e and stress drop $\Delta\sigma$**
→ **evaluate the role of the magnitude type**

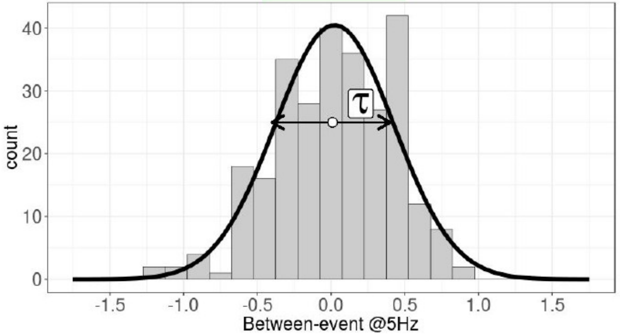
$$Log[FAS(f)] = \boxed{Scaling(R) + Scaling(M)} + \boxed{\delta S2S} + \boxed{\delta Be} + \epsilon$$

Station-term

Event-term



$$\sigma^2 = \boxed{\tau^2} + \boxed{\phi^2_{S2S}} + \phi^2_0$$



FAS in Far-field

$$\ln(FAS)(f) = \ln(source) + \ln(propagation) + \ln(site) + residuals$$

$$Source(f) = \frac{FR^{\theta\phi}}{4\pi\rho\beta^3}\frac{(2\pi f)^2 Mo}{1+\left(\frac{f}{f_c}\right)^2} = K_1 \frac{f^2 Mo}{1+\left(\frac{f}{f_c}\right)^2}$$

$f \gg f_c$ → $\sim Mo \ f_c^2$

$$\ln(source) = \ln(k_1) + \ln(Mo) + 2\ln(f_c)$$

$$\ln(source) = \ln(k_1) + 2\ln(k_2) + \frac{1}{3}\ln(Mo) + \boxed{\frac{2}{3}\ln(\Delta\sigma)}$$

(1)

$f \ll f_c$ → $\sim Mo \ f^2$

$$\ln(source) = \ln(k_1) + \ln(Mo) + 2\ln(f)$$

(2)

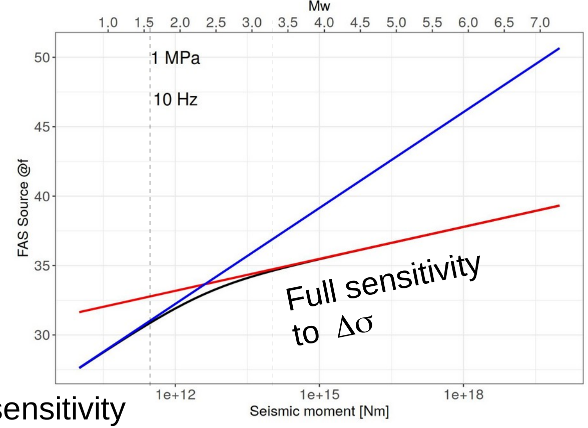
$$\Delta\sigma = \frac{7}{16}\frac{Mo}{r^3}$$ Eshelby 57

$$r = \frac{0.38\beta}{f_c}$$ Brune 70

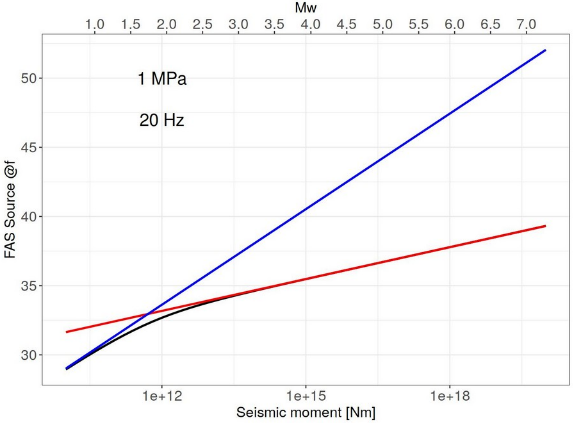
$$f_c = k_2\left(\frac{\Delta\sigma}{Mo}\right)^{1/3}$$

Case (1) ($f \gg f_c$) is typical of high frequencies of interest and **large events** with small f_c. In this case, if $\Delta\sigma$ is fixed, the source scales only with ln(Mo), and the stress drop determines the spectral amplitude, which is constant (not depending on frequency). Therefore, if an event has a stress drop deviating from $\Delta\sigma$, let's say $\Delta\sigma_i = \gamma_i \Delta\sigma$, where $\Delta\sigma$ is the average of the data set, then the term $\ln(\gamma_i)$ is going to affect the between-event residual of event *i*.

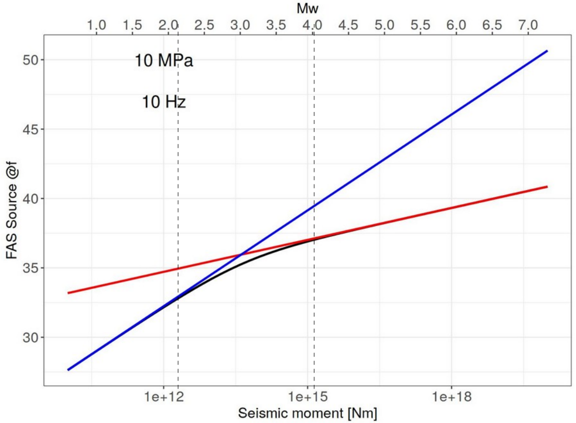
Case(2) ($f \ll f_c$) is typical of data sets with **small events** and usable bandwidth not extending towards high frequencies. In this case, the spectra are frequency dependent and depend only on ln(Mo), no role played by f_c (and therefore by $\Delta\sigma$). No relation between $\Delta\sigma$ and between-event.

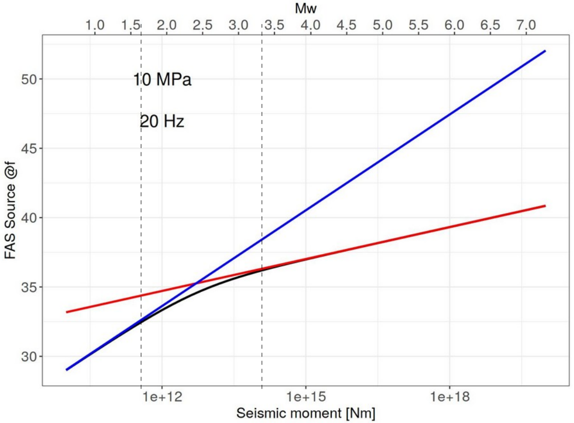


No sensitivity to $\Delta\sigma$



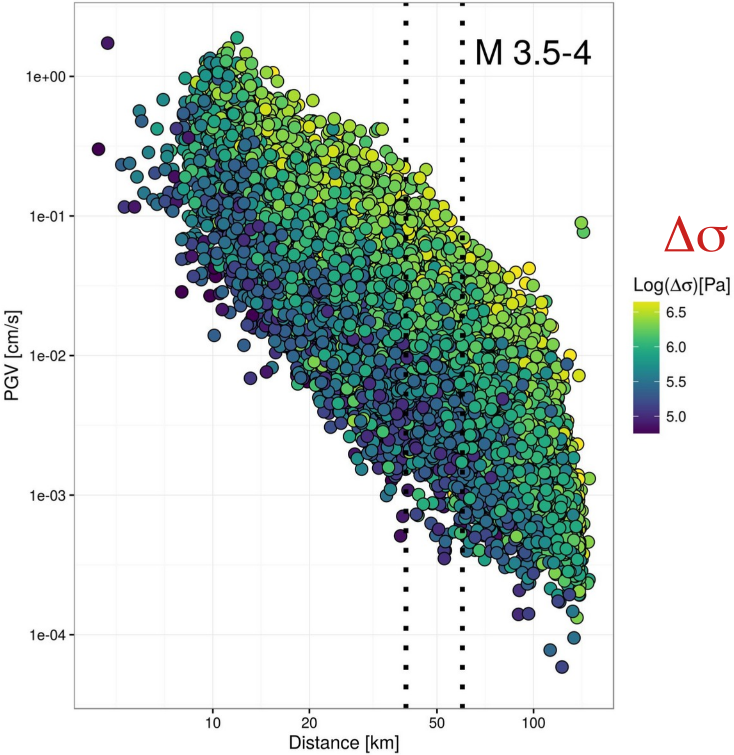
GMPE can include a single linear term M_w only if the magnitude range is such that either $f \ll f_c$ or $f \gg f_c$ is satisfied. When the magnitude range is wide and then the frequency range analyzed are both above and below fc, a quadratic term M_w^2 is needed.





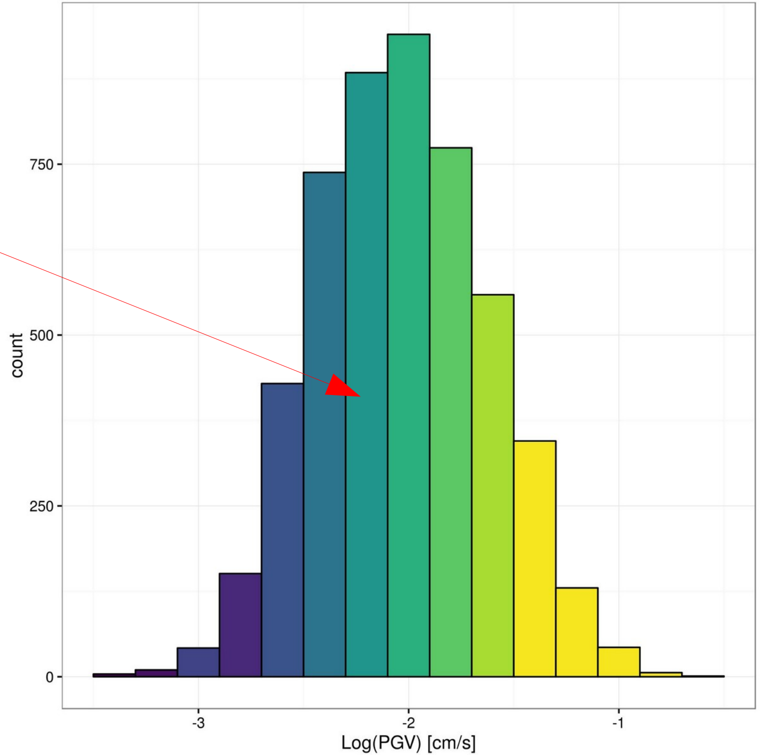
Since the slope of the asymptotic lines decreases when moving from low to high moment, **the black curve has to be concave down**, that is, the second derivative is negative. This requires a **negative coefficient** for the quadratic term.

PGV



Distance [km]

$\Delta\sigma$



Log(PGV)

Under the following scaling assumption

$M_0 f_c^{3+\epsilon} = costant$ with $\epsilon \leqslant 1$ where $\varepsilon = 0$ is the standard self-similar case

$$\ln(source) = \ln(k_1) + \ln(M_0) + 2\ln(f_c) = \ln(k_1) + \ln(Mo) + \frac{2}{\epsilon+3}\ln(k_k \Delta\sigma V_R^3 M_0^{-1}) = \ln(k_1) + \frac{2}{\epsilon+3}\ln(k_k) + \frac{\epsilon+1}{\epsilon+3}\ln(M_0) + \frac{2}{\epsilon+3}\ln(\Delta\sigma) + \frac{6}{\epsilon+3}\ln(V_R)$$

$\ln(source) = a(\epsilon) + b(\epsilon)\ln(M_0) + c(\epsilon)\ln(\Delta\sigma) + d(\epsilon)\ln(V_R)$ Where ε can be spatially variable

---

Source described by one parameter (magnitude)
I) self-similarity assumption
II) If we use Mw, the parameter used for both low and high frequencies is Mo

$$M_L = \frac{2}{3}\log M_0 + \frac{1}{3}\log(\Delta\sigma_s) + \log(v_a) + \log C_2 - \log A_0. \quad (14)$$

(Deichmann, BSSA, 2017)

Different GMPEs are calibrated for:
ML : local magnitude
Mw: moment magnitude
Me: energy magnitude

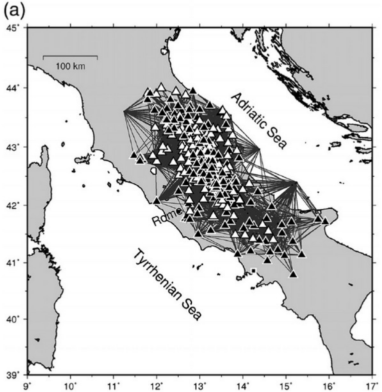
Bulletin of the Seismological Society of America, Vol. 109, No. 1, pp. 251–262, February 2019, doi: 10.1785/0120180239

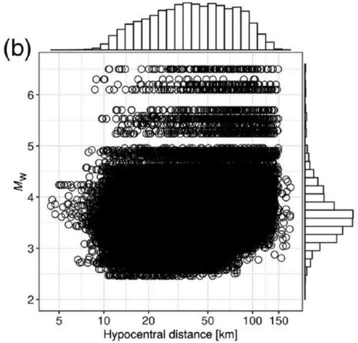
Impact of Magnitude Selection on Aleatory Variability Associated with Ground-Motion Prediction Equations: Part II—Analysis of the Between-Event Distribution in Central Italy

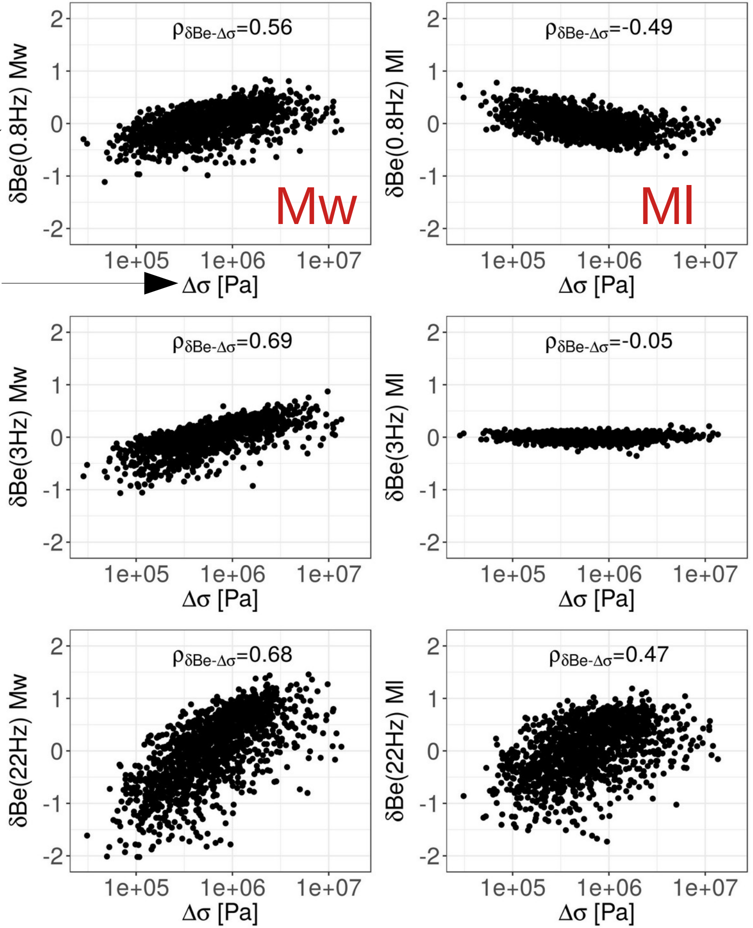
by Dino Bindi, Matteo Picozzi, Daniele Spallarossa, Fabrice Cotton,* and Sreeram Reddy Kotha*

GMM - WP3

GIT - WP2



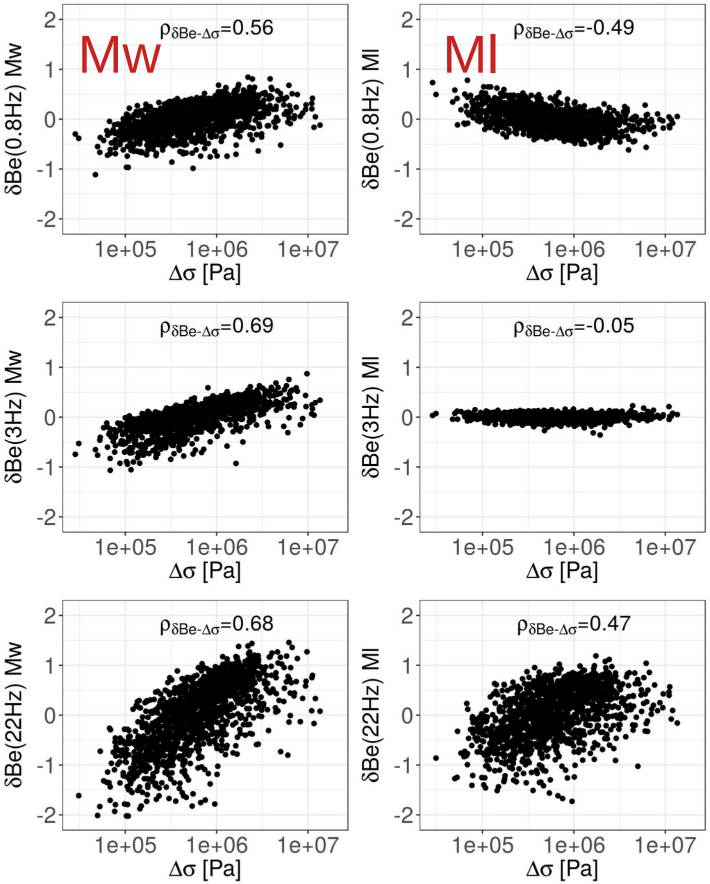




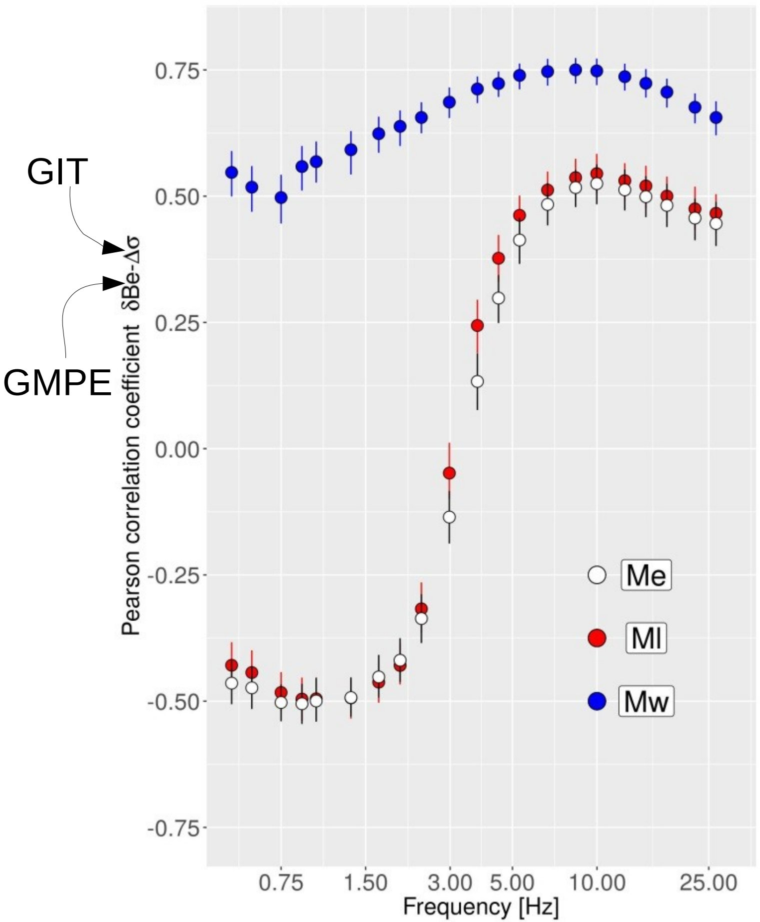
$$
\text{Source}(f) = \begin{cases} \frac{R^{\theta\phi}A}{4\pi\rho V_S^3 R_{\text{ref}}} M_0(2\pi f)^2 \frac{1}{1+\left(\frac{f}{f_c}\right)^2} \exp -[\pi k_{\text{source}}(f - f_k)] & \text{for } f > f_k \\ \frac{R^{\theta\phi}A}{4\pi\rho V_S^3 R_{\text{ref}}} M_0(2\pi f)^2 \frac{1}{1+\left(\frac{f}{f_c}\right)^2} & \text{otherwise} \end{cases} .
$$

GFZ Helmholtz Centre POTSDAM

HELMHOLTZ



Mw
ρδBe-Δσ=0.56
δBe(0.8Hz) Mw
Ml
ρδBe-Δσ=-0.49
δBe(0.8Hz) Ml
ρδBe-Δσ=0.69
δBe(3Hz) Mw
ρδBe-Δσ=-0.05
δBe(3Hz) Ml
ρδBe-Δσ=0.68
δBe(22Hz) Mw
ρδBe-Δσ=0.47
δBe(22Hz) Ml
2
1
0
-1
-2
1e+05
1e+06
1e+07
Δσ [Pa]

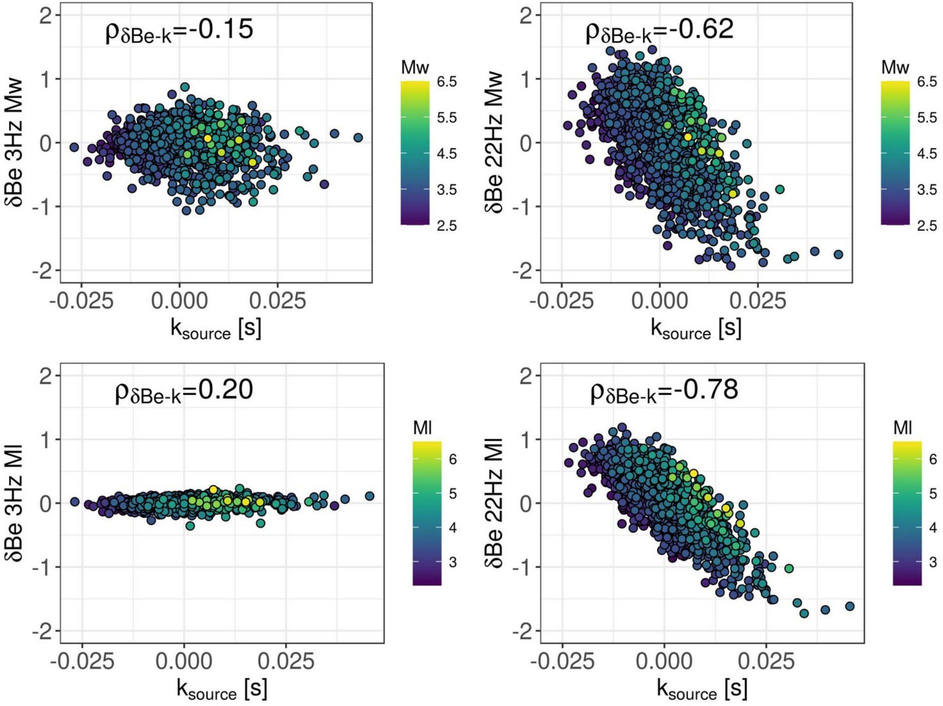


GIT
GMPE
Pearson correlation coefficient δBe-Δσ
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
0.75
1.50
3.00
5.00
10.00
25.00
Frequency [Hz]
Me
Ml
Mw

$$\mathrm{Source}(f) = \begin{cases} \frac{R^{\theta\phi}A}{4\pi\rho V_S^3 R_{\mathrm{ref}}} M_0 (2\pi f)^2 \frac{1}{1+\left(\frac{f}{f_c}\right)^2} \exp -[\pi k_{\mathrm{source}}(f - f_k)] & \text{for } f > f_k \\ \frac{R^{\theta\phi}A}{4\pi\rho V_S^3 R_{\mathrm{ref}}} M_0 (2\pi f)^2 \frac{1}{1+\left(\frac{f}{f_c}\right)^2} & \text{otherwise} \end{cases} .$$

Mw

Ml



Apparent source spectra

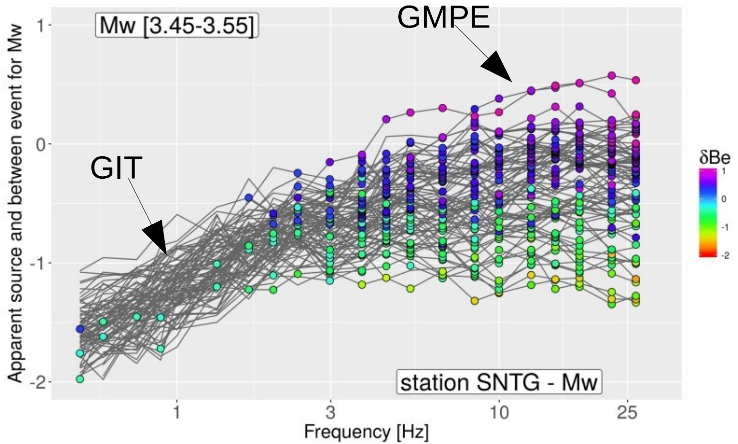
(i.e., recorded spectra corrected for attenuation and site effects)

Gray lines: spectra of events with Mw in the range [3.45-3.55] (recorded at station SNTG)

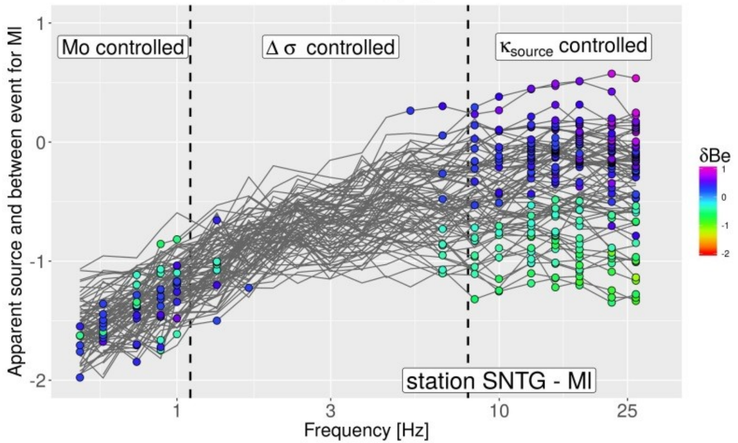
Circles correspond to $|\delta B_e|>0.2$

Gray lines and colored circles are coming from different analysis (GIT and GMPE, respectively)

Mw



ML



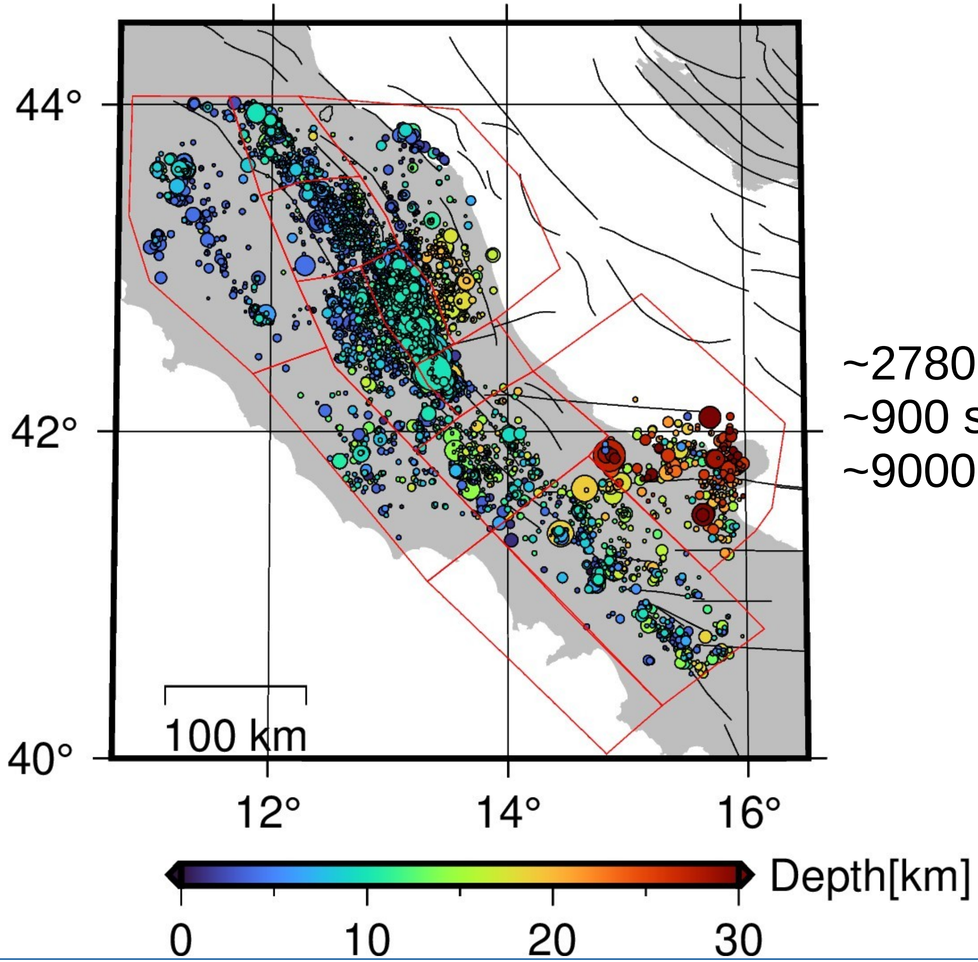
Outline

- Introduction to spectral decomposition
- Reliability of source parameters
- Example of results about source scaling
- Connection between source parameters and ground motion variability
- **What’s next**

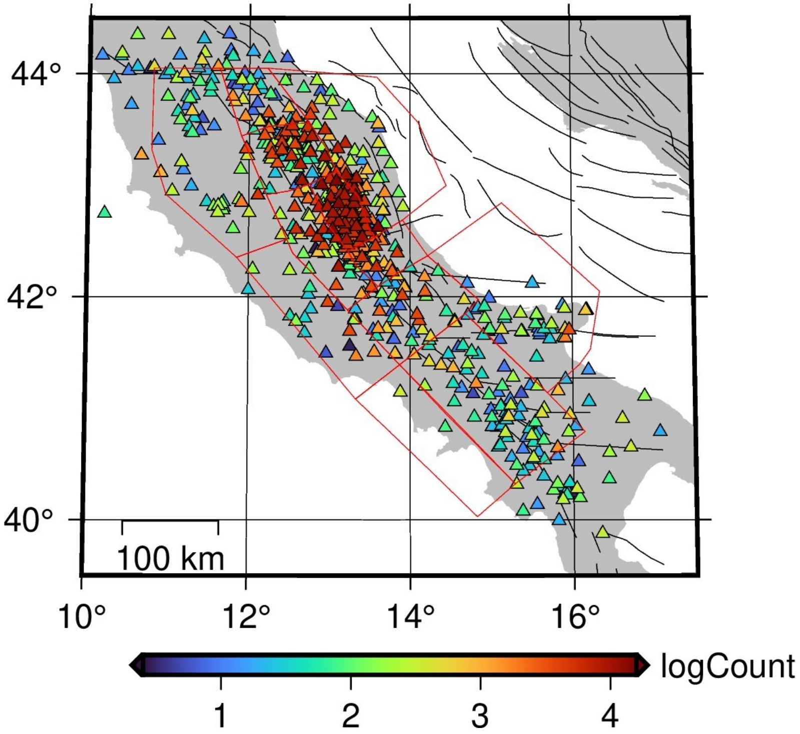
Questions:

→ **regional variability**

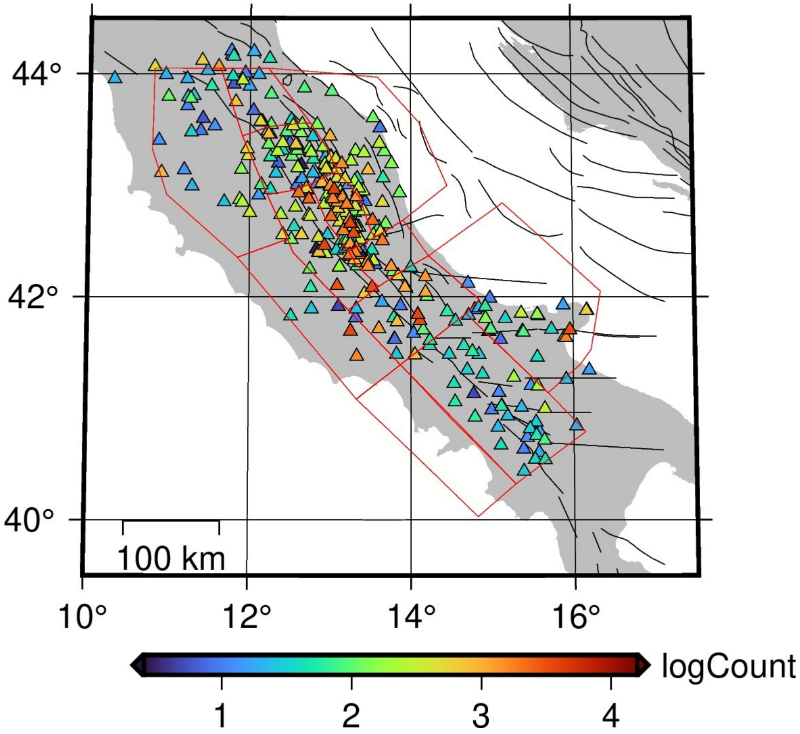
→ monitoring spatial-temporal variability



~27800 events Ml>1.5
~900 stations (counting HH and HG separately)
~900000 spectral amplitudes at 2.5Hz



nt	count
IV	609523
YR	150035
3A	48619
IT	28260
XJ	22028
XO	17342
3H	10326
MN	5436
TV	3521
OT	1429
7F	938
MZ	892
GU	813
IX	745
VD	194
ZH	157
GE	115
Y1	16
BA	15
IR	9
RR	4



Accelerometers

Next steps:

1 mixed-effects regression to investigate regional characteristics of Mo versus fc scaling, e.g.:

LogMo ~ Logfc + (1 + Logfc | Polygon)

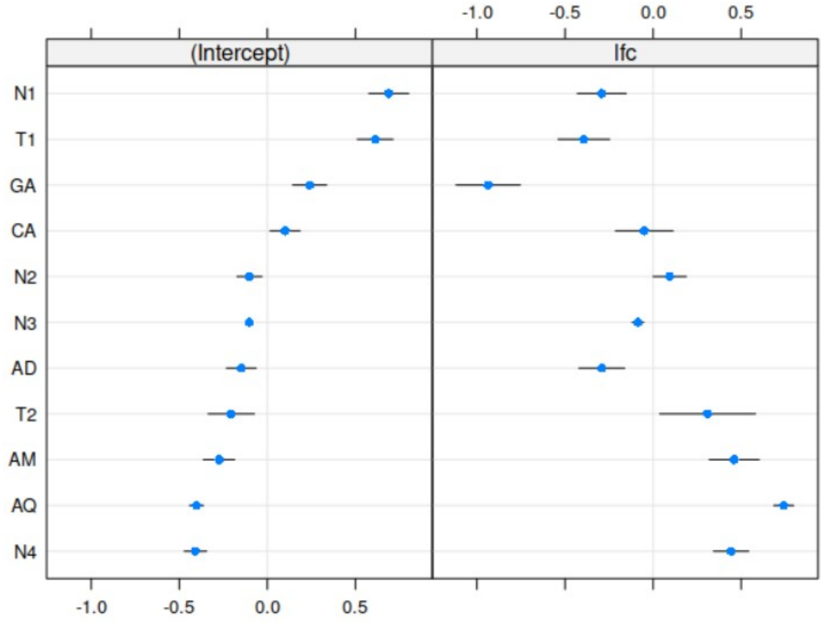
random intercepts and slopes

considering the Polygon grouping factors

Fixed effects: a= 14.0652+-0.1095

b=-2.4102 +- 0.1408

Random effects



Next steps:

1 mixed-effects regression to investigate regional characteristics of Mo versus fc scaling, e.g.:

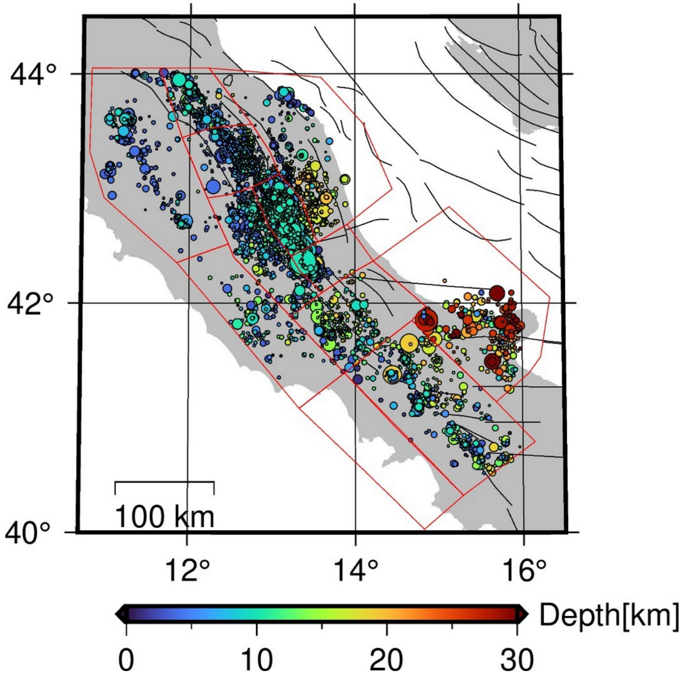
LogMo ~ Logfc + (1 + Logfc | Polygon)

random intercepts and slopes

considering the Polygon grouping factors

2 **regional velocity models to evaluate the spatial variability of $\Delta\sigma$**

SECURE-WP1



Next steps:

1 mixed-effects regression to investigate regional characteristics of Mo versus fc scaling, e.g.:

LogMo ~ Logfc + (1 + Logfc | Polygon)

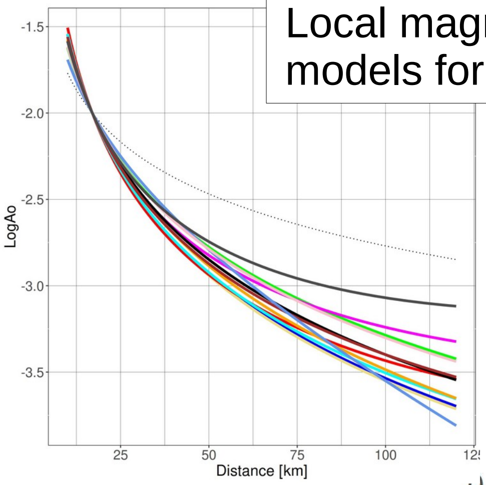
random intercepts and slopes

considering the Polygon grouping factors

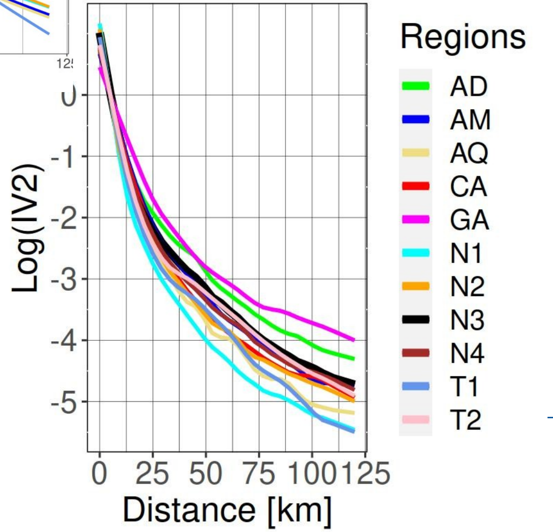
2 regional velocity models to evaluate the spatial variability of $\Delta\sigma$

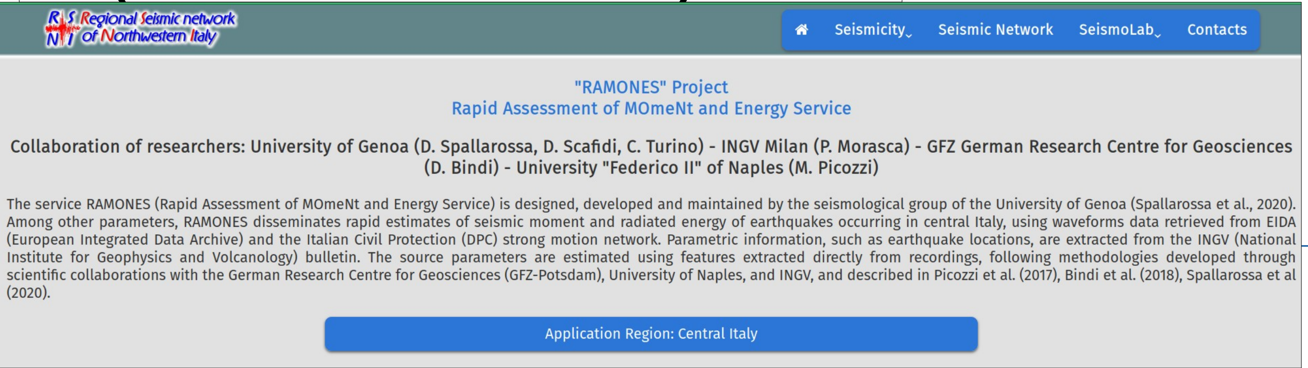
3 **regional local magnitude scales & regional models for Ramones (Mo and Er from features)**

Local magnitude attenuation models for different polygons



IV2 → Er





Regional Seismic network of Northwestern Italy

Seismicity Seismic Network SeismoLab Contacts

"RAMONES" Project
Rapid Assessment of MOmeNt and Energy Service

Collaboration of researchers: University of Genoa (D. Spallarossa, D. Scafidi, C. Turino) - INGV Milan (P. Morasca) - GFZ German Research Centre for Geosciences (D. Bindi) - University "Federico II" of Naples (M. Picozzi)

The service RAMONES (Rapid Assessment of MOmeNt and Energy Service) is designed, developed and maintained by the seismological group of the University of Genoa (Spallarossa et al., 2020). Among other parameters, RAMONES disseminates rapid estimates of seismic moment and radiated energy of earthquakes occurring in central Italy, using waveforms data retrieved from EIDA (European Integrated Data Archive) and the Italian Civil Protection (DPC) strong motion network. Parametric information, such as earthquake locations, are extracted from the INGV (National Institute for Geophysics and Volcanology) bulletin. The source parameters are estimated using features extracted directly from recordings, following methodologies developed through scientific collaborations with the German Research Centre for Geosciences (GFZ-Potsdam), University of Naples, and INGV, and described in Picozzi et al. (2017), Bindi et al. (2018), Spallarossa et al (2020).

Application Region: Central Italy

Next steps:

1 mixed-effects regression to investigate regional characteristics of Mo versus fc scaling, e.g.:

LogMo ~ Logfc + (1 + Logfc | Polygon)

random intercept and slopes

considering the Polygon grouping factors

2 regional velocity models to evaluate the spatial variability of $\Delta\sigma$

3 regional local magnitude scales & regional models for Ramones

4 **Monitoring the spatial and temporal variability of between-event to catch the emergency of a preparation phase (M. Picozzi)**

Spatiotemporal Evolution of Ground-Motion Intensity at the Irpinia Near-Fault Observatory, Southern Italy

Matteo Picozzi[*1], Fabrice Cotton[2,3], Dino Bindi[2], Antonio Emolo[1], Guido Maria Adinolfi[4], Daniele Spallarossa[5], and Aldo Zollo[1]

BSSA

Geophysical Research Letters

RESEARCH LETTER

10.1029/2021GL097382

Key Points:

- We observe foreshocks dynamic characteristics before the 2009, Mw 6.1 L'Aquila earthquake in central

Temporal Evolution of Radiated Energy to Seismic Moment Scaling During the Preparatory Phase of the Mw 6.1, 2009 L'Aquila Earthquake (Italy)

M. Picozzi[1], D. Spallarossa[2,3], A. G. Iaccarino[1], and D. Bindi[4]

JGR Solid Earth

RESEARCH ARTICLE

10.1029/2022JB025100

Key Points:

- ~23,000 microearthquakes of the 2016 central Italy seismic sequence are characterized in terms of their dynamic rupture properties

Detection of Spatial and Temporal Stress Changes During the 2016 Central Italy Seismic Sequence by Monitoring the Evolution of the Energy Index

Matteo Picozzi[1], Daniele Spallarossa[2,3], Dino Bindi[4], Antonio Giovanni Iaccarino[1], and Eleonora Rivalta[4,5]

scientific reports

OPEN

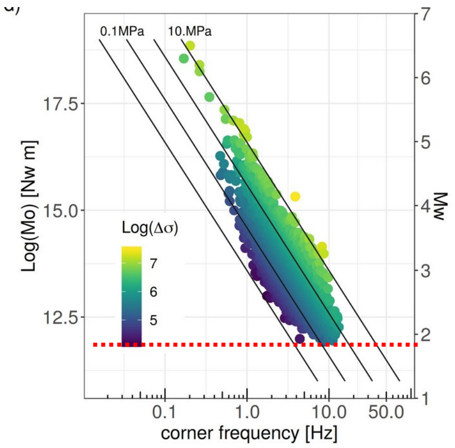
On catching the preparatory phase of damaging earthquakes: an example from central Italy

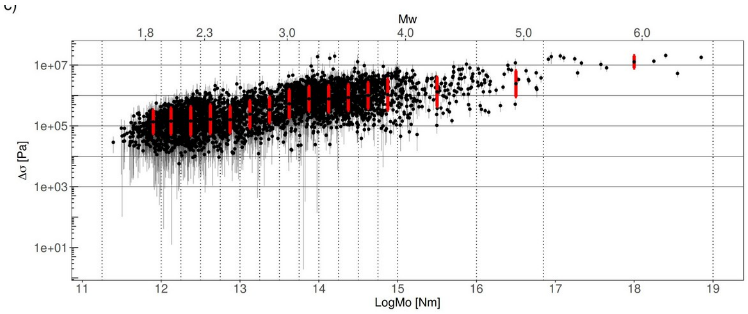
Matteo Picozzi[1], Antonio G. Iaccarino[1], Daniele Spallarossa[2] & Dino Bindi[3]

GFZ

Helmholtz Centre POTSDAM

Take home messages:

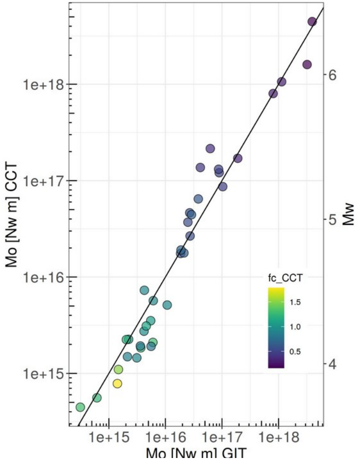


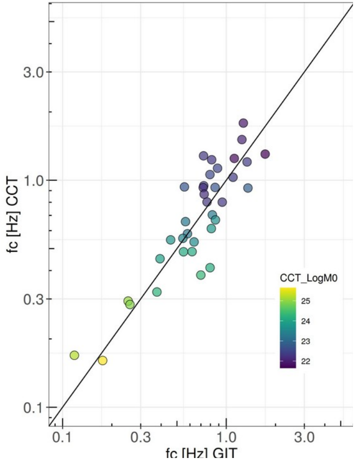


GIT

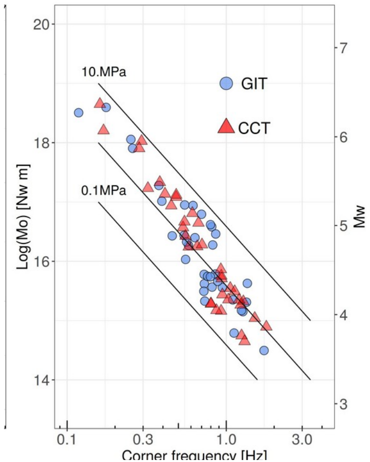
- M> ~1.8
- $\Delta\sigma=\Delta\sigma(M)$
- ~10MPa for M>5

Take home messages





Anchored to the same reference Mw catalog (average)

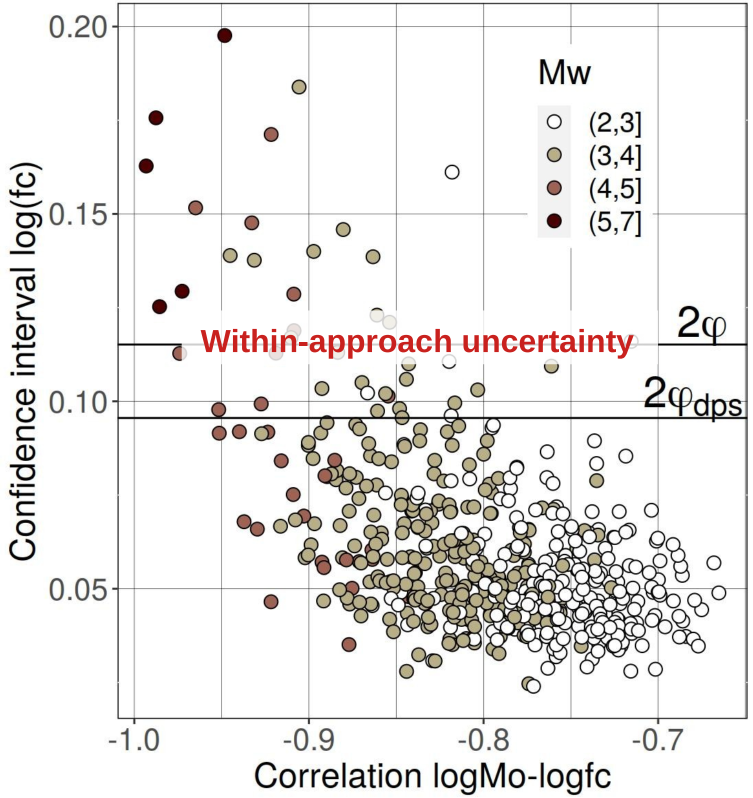


GIT

- M> ~1.8
- $\Delta\sigma=\Delta\sigma(M)$
- ~10MPa for M>5

Non-uniqueness → Constraints needed

Take home messages:

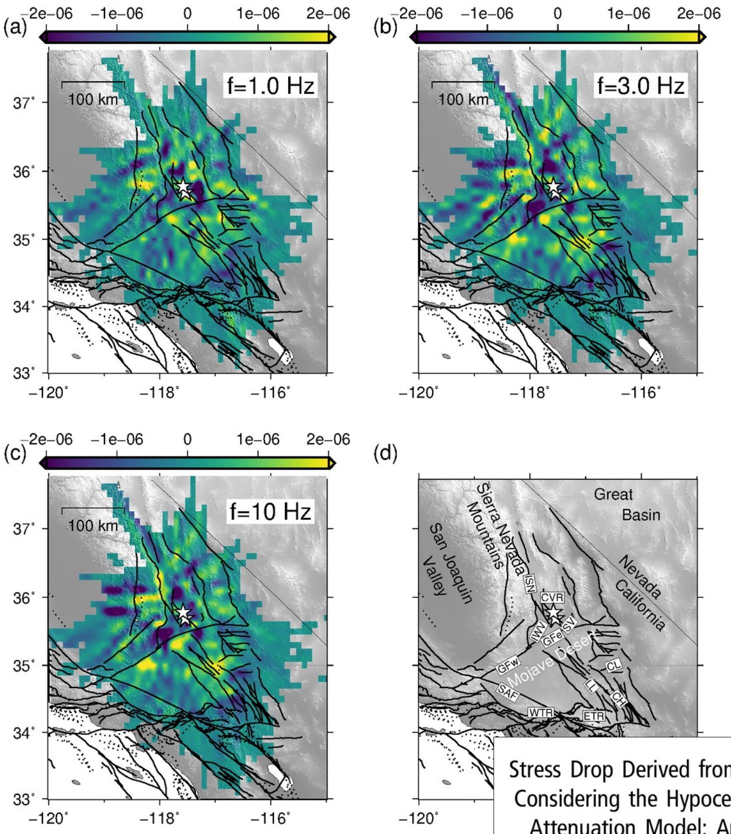


GIT

- M> ~1.8
- $\Delta\sigma=\Delta\sigma(M)$
- ~10MPa for M>5

Non-uniqueness → Constraints needed

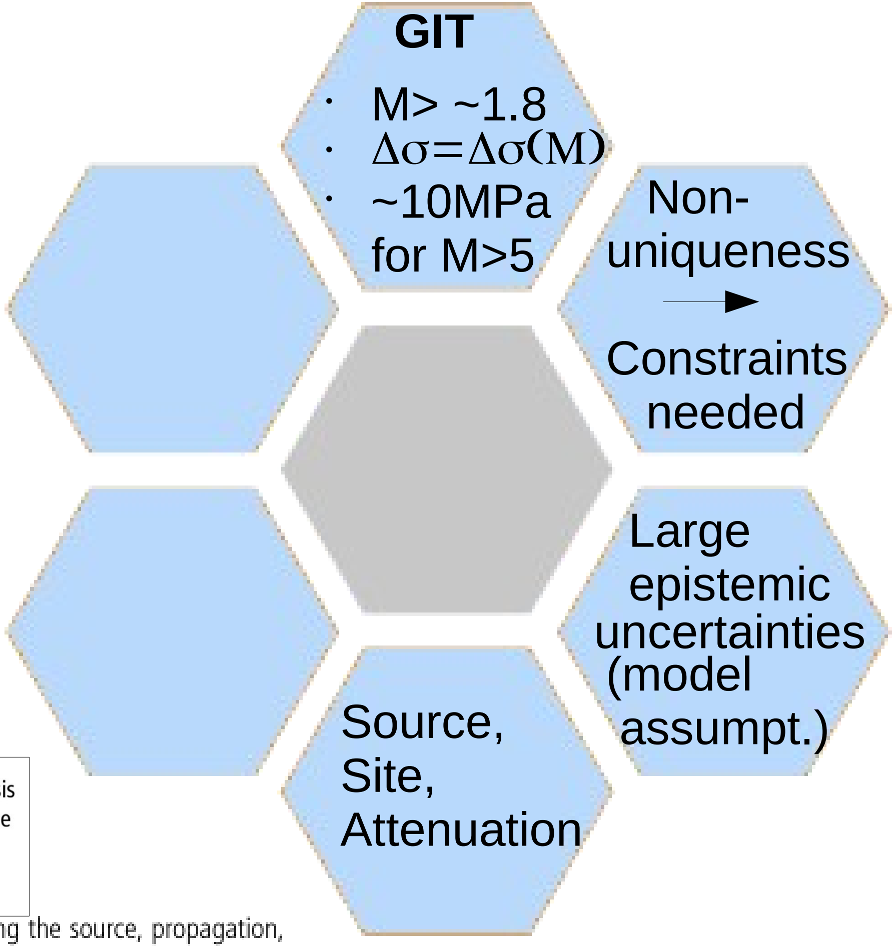
Large epistemic uncertainties (model assumpt.)



Stress Drop Derived from Spectral Analysis Considering the Hypocentral Depth in the Attenuation Model: Application to the Ridgecrest Region, California

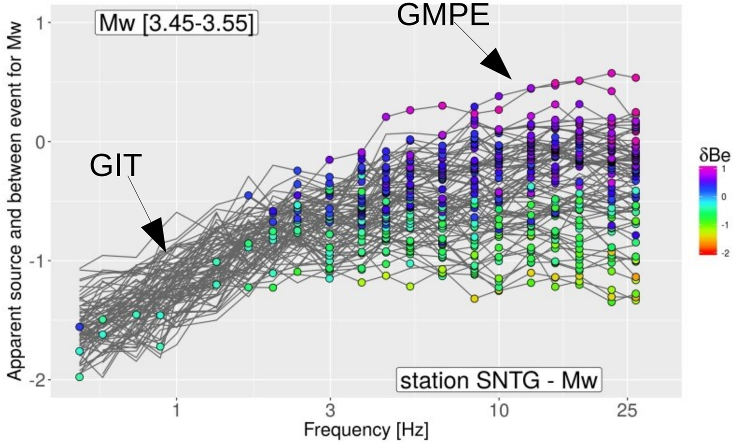
Dino Bindi[*1], Hoby N. T. Razafindrakoto[1], Matteo Picozzi[2], and Adrien Oth[3]

Figure 14. Residuals (observed spectral values minus prediction computed by combining the source, propagation, and site terms) imaged over a regular 8 × 8 km grid. Solutions for cells crossed by at least 10 rays are shown for three different frequencies: (a) 1.0 Hz, (b) 3.0 Hz, and (c) 10 Hz. (d) Fault traces are disseminated by Southern California Earthquake Center (see Data and Resources). CH, Calico–Hildalgo fault; CL, Coyote Lake fault; CVR,

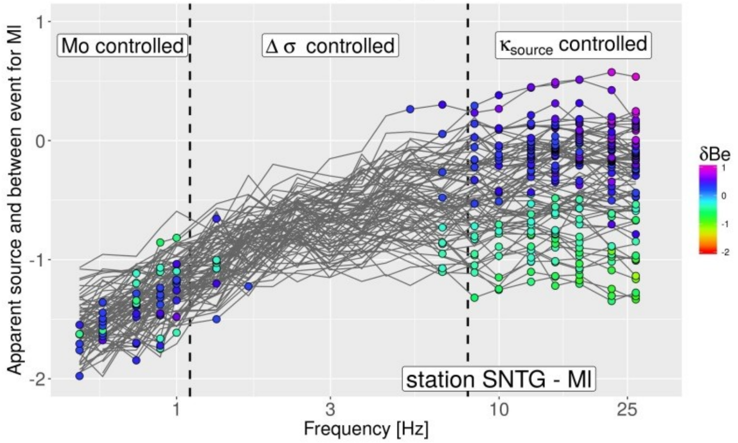


Take home messages

Mw



ML



GIT

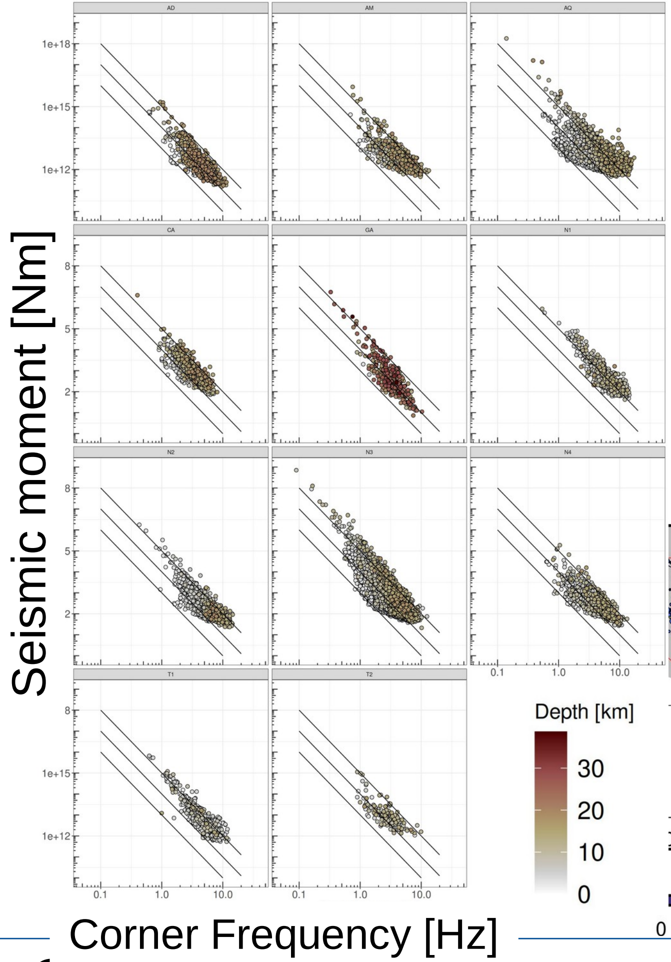
- M> ~1.8
- $\Delta\sigma=\Delta\sigma(M)$
- ~10MPa for M>5

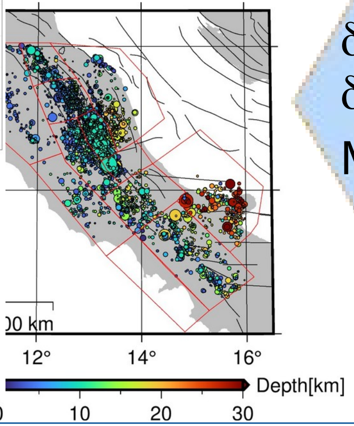
Non-uniqueness → Constraints needed

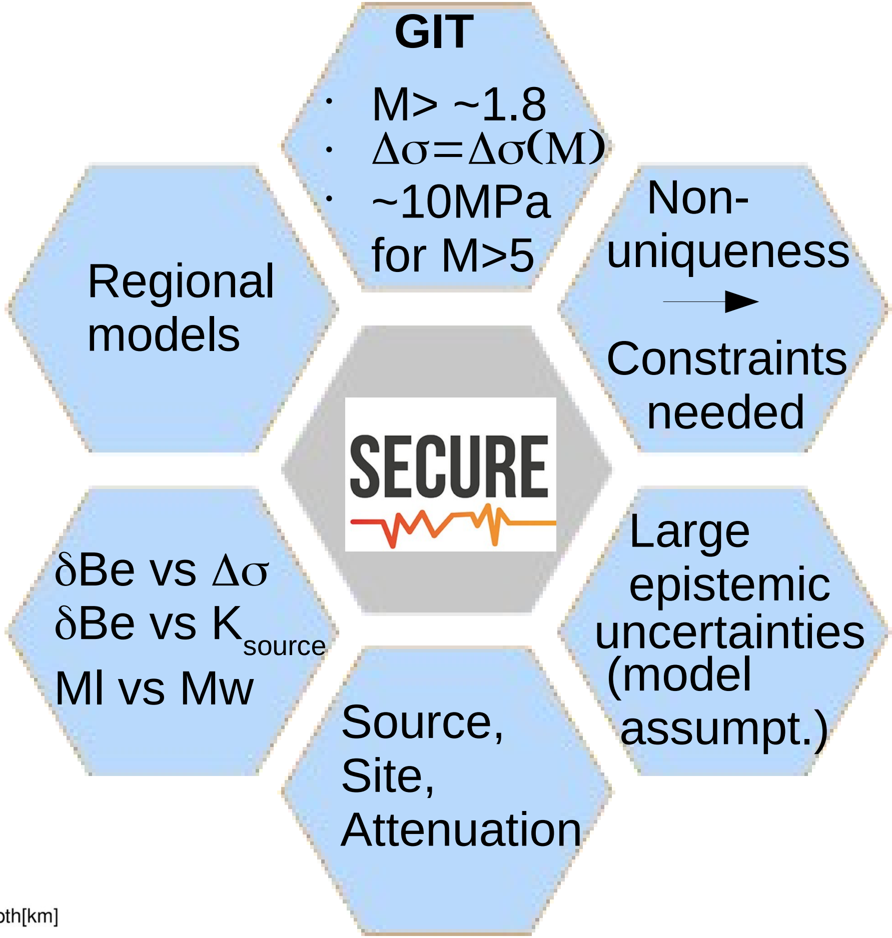
Large epistemic uncertainties (model assumpt.)

Source, Site, Attenuation

δBe vs Δσ
δBe vs K_{source}
Ml vs Mw







Take home messages

Seismic Source Characteristics and Ground-Motion Variability in Central Italy: a bridge between WP2 and WP3, D. Bindi, D. Spallarossa and M. Picozzi

Thank you !

References available at:

https://www.gfz-potsdam.de/en/staff/dino.bindi/sec26

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https://www.researchgate.net/profile/Dino_Bindi

Summary and take home messages

The Generalized Inversion Technique (GIT)

- allows to split the source, attenuation and site contributions to ground shaking providing non-parametric solutions that can be used for model selection

  but

- provides **relative solutions** to a-priori assumed reference conditions (e.g., reference site condition, reference Mw catalog, etc) [**non-uniqueness=trade-offs**]; large impact of **epistemic uncertainties** [even larger than statistical uncertainties]
- Attenuation and **near-surface attenuation** [low pass filters] limit the retrieval of small magnitude's source parameters [M**~1.8-2** for the analysed geometries] and limited bandwidth does not allow to resolve Mo and fc for large events [**Mo-fc correlation** ~-1]

The applications have shown

- What magnitude is used for developing GMM matters (Mw versus Ml)
- Correlation between stress-drop and inter-event residuals for GMM based on Mw
- GIT results can be used to study the scaling of source parameters (self-similarity), as input for attenuation tomographic studies [t*(f)], to investigate site effects