SECURE

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

Analysis of Stress Drop Variations in the Strongest Earthquakes of the Amatrice-Visso-Norcia 2016-2017 Seismic Sequence

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WP2. Earthquake Source Characteristics and Seismic Wave Propagation in Central Appennines

MID-TERM MEETING SECURE (DYNAMIC PLANET PROJECT 2023–25)
JUNE 20, 2025 – MILAN- ITALY

Methods

SP: Spectral Fitting (Calderoni et al., 2019 and Calderoni & Abercrombie, 2023).
Applied to 97 events and 123 stations.

SR: Spectral Ratio of co-located events with different magnitudes (Calderoni et al., 2013 and Calderoni & Abercrombie, 2023).
Applied to 28 events and 123 stations.

GIT: Non-parametric inversion of source, attenuation, and site (Bindi et al., 2020; Morasca et al., 2022).
Model calibrated in Central Italy on a dataset of about 5000 events and 624 stations and applied to approximately 250 additional recordings in the same region (in Morasca et al., 2022).

CCT: Coda Calibration Technique (CCT, Mayeda et al., 2003; Morasca et al., 2022).
Calibrated on a dataset of 39 events ($3.5 < M_w < 6.33$) recorded by 14 stations and applied to approximately 250 additional recordings in the same region (Morasca et al., 2022).

CERT: Coda Envelope Spectral Ratios (this study).
Method applied to 27 target events (common with Calderoni & Abercrombie, 2023) using 14 stations (the same as for CCT).

Methodological Overview

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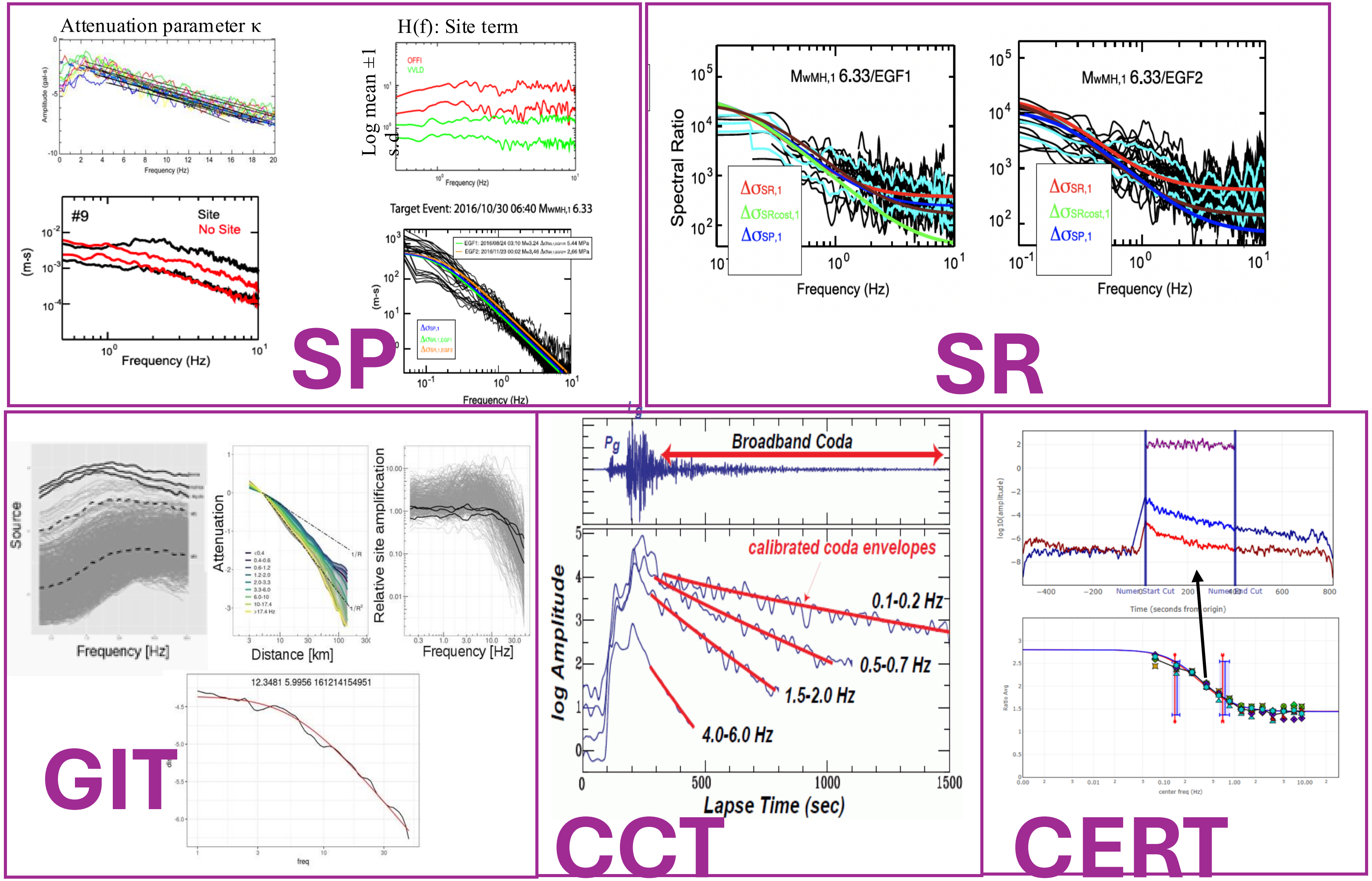


Window Length:

SP: 10-30” after T_S (95%)

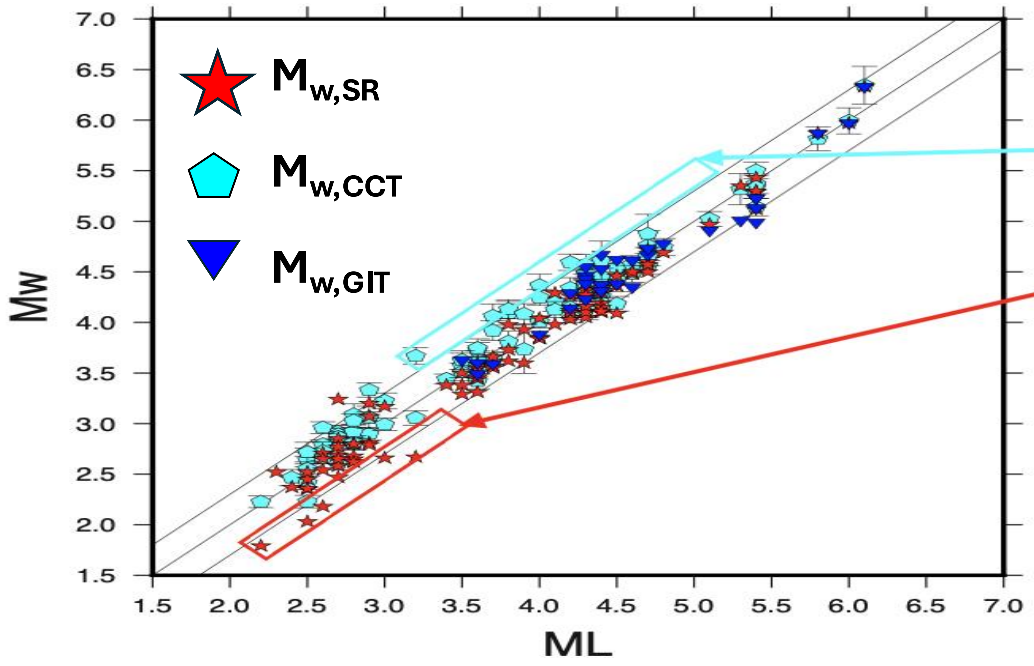
SR: 10” after T_S (95%)

GIT: distance-dependent accordingly to the fraction of cumulated energy.

CCT: frequency and magnitude dependent

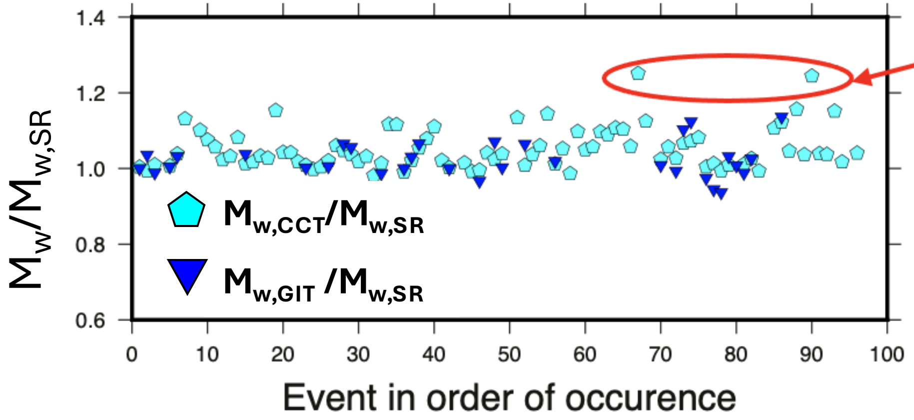
CERT: frequency and magnitude dependent

Comparison of Magnitude from CCT and GIT Using 96 SP-Based Reference Events



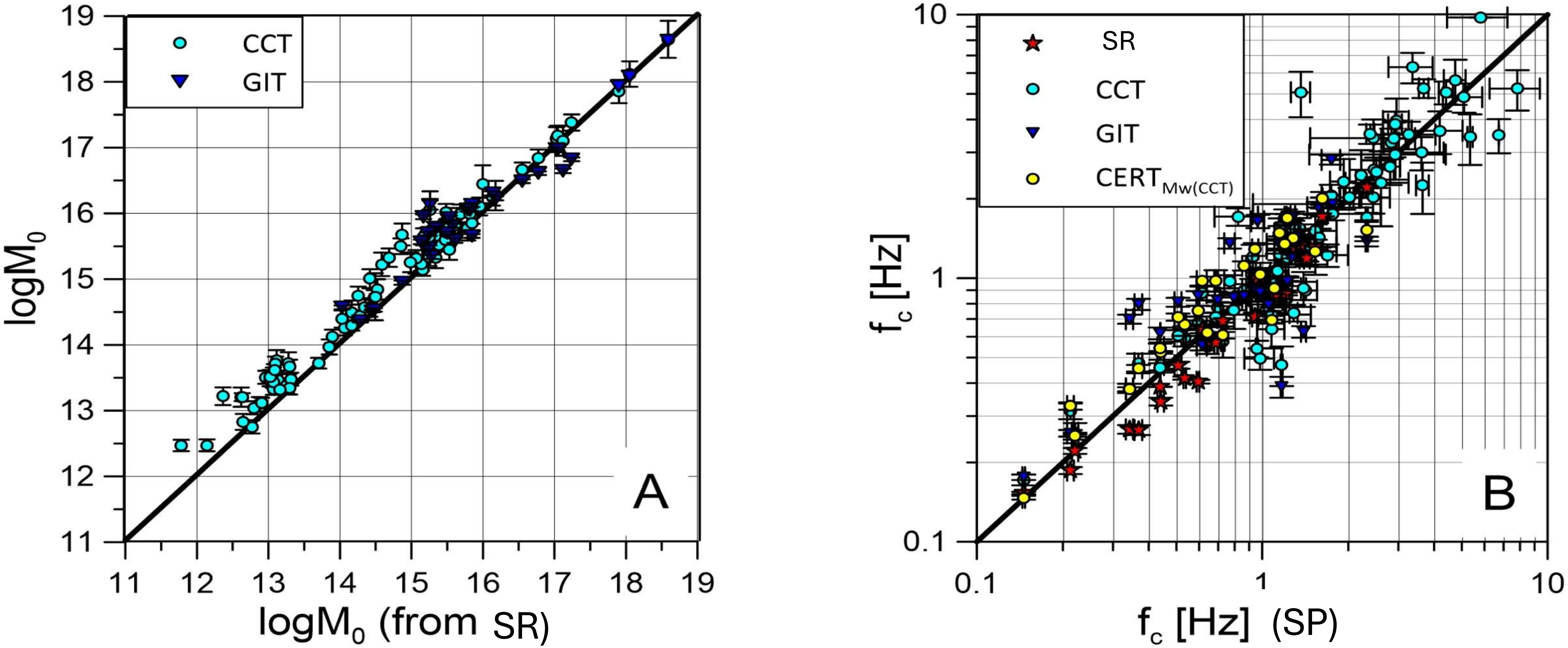
Compared to M_L:

- ✓ CCT overestimates M_L for $M_L > 3.0$
- ✓ SR underestimates M_L for $M_L < 3.0$



- ✓ **CCT overestimates $M_{w,SR}$ only for a few events (factor > 1.2).**
- ✓ Good agreement among $M_{w,SP}$, M_{wCCT}, and M_{wGIT}.

Comparison of Source Parameters from CCT, GIT, and CERT Using 96 SP-Based Reference Events



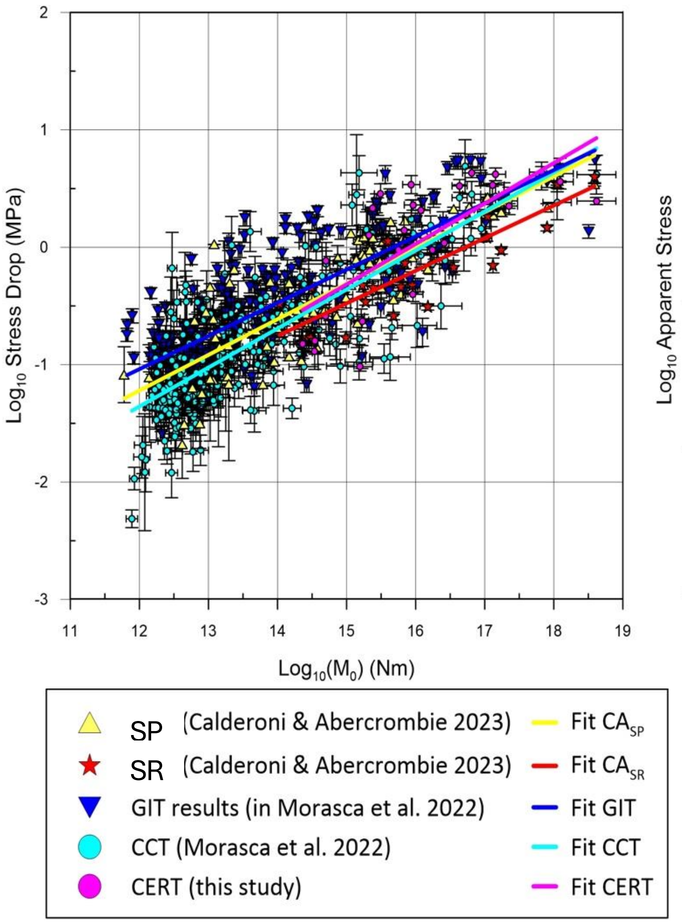
- ✓ There is excellent agreement among M_0 estimates and good consistency in f_c estimates.

$\Delta\sigma$ versus M_0: Scaling Laws for GIT, CCT, CERT, SR, and SP

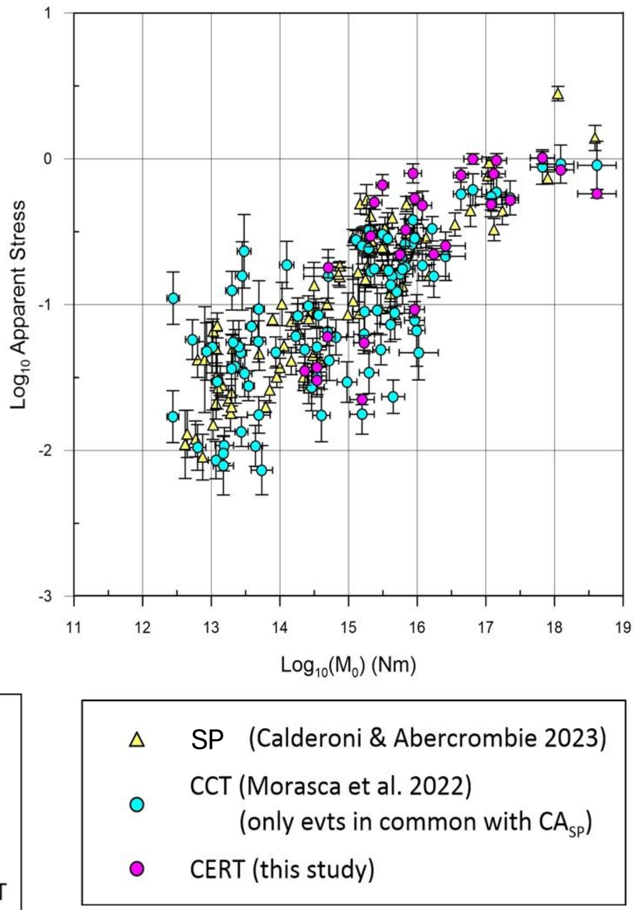
AVN 2016-2017			
Method	Slope	CC	Num. events
SR	0.28	85%	28
SP	0.30	84%	97
CCT	0.33	82%	286
GIT	0.28	78%	284
CERT	0.34	74%	27

CC= Correlation Coefficient

Stress Drop

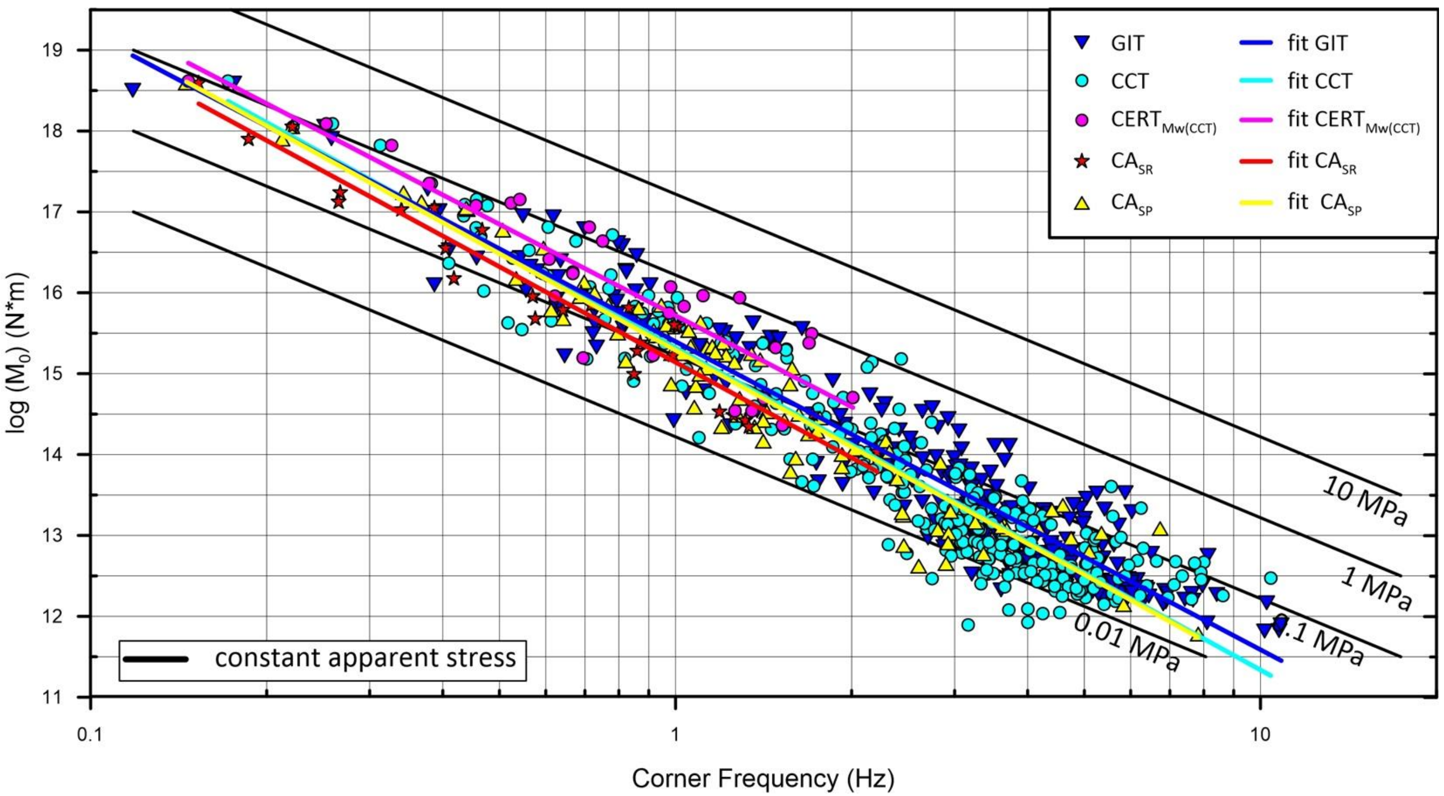


τ_a~100 common evts



✓ Good agreement is observed among the scaling laws across different methods, as well as among the estimates of stress drop ($\Delta\sigma$) and apparent stress (τ_a).

M_0 vesus f_c: Scaling Laws for GIT, CCT, CERT, SR, and SP



SP	$\log M_0 = -3.97 \pm 0.12 \log(f_c) + 15.29 \pm 0.04$
SR	$\log M_0 = -3.92 \pm 0.19 \log(f_c) + 15.14 \pm 0.07$
GIT*	$\log M_0 = -3.81 \pm 0.07 \log(f_c) + 15.40 \pm 0.04$
CCT*	$\log M_0 = -3.98 \pm 0.08 \log(f_c) + 15.32 \pm 0.04$
CERT	$\log M_0 = -3.75 \pm 0.35 \log(f_c) + 15.72 \pm 0.10$

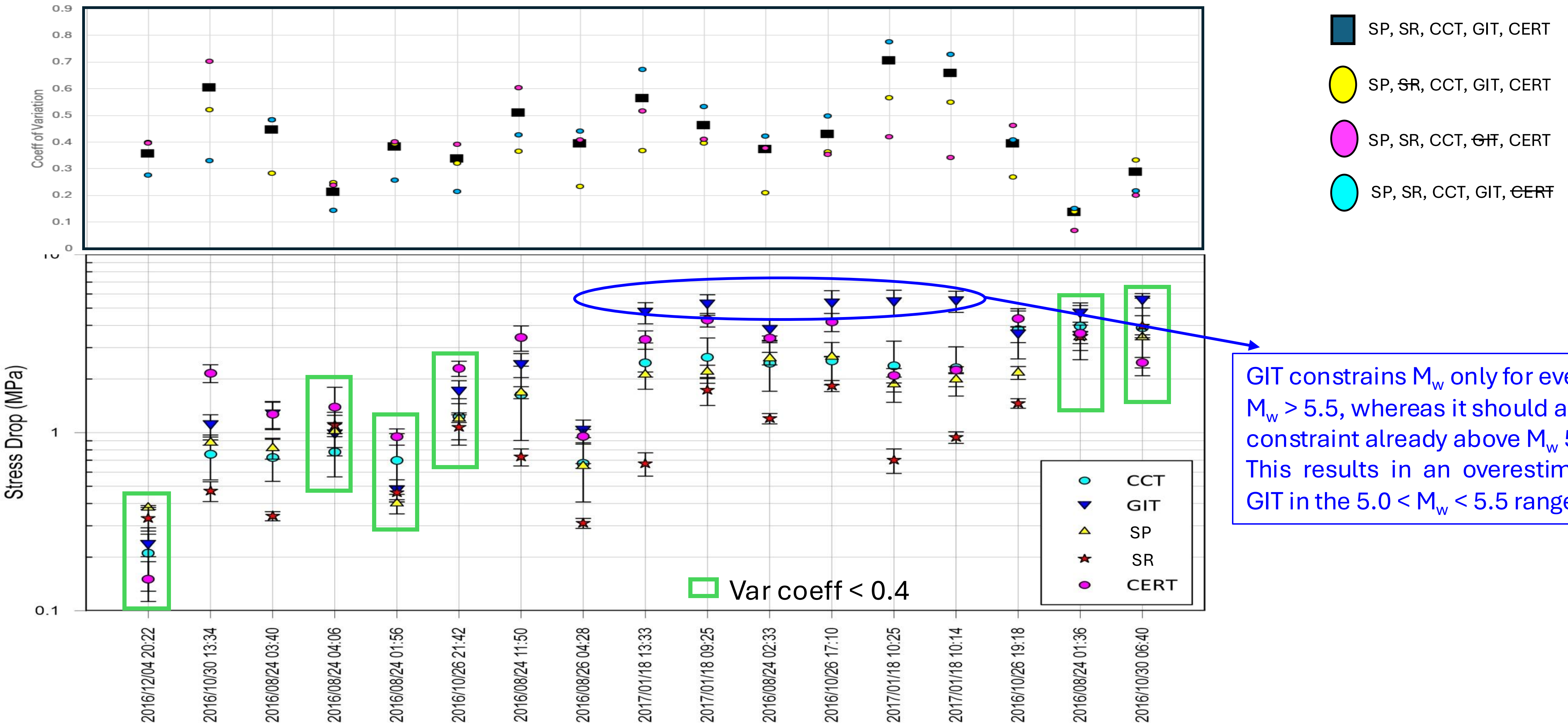
* Regression on published Datasets (Morasca et al., 2022)

✓ Scaling laws based on $\log(M_0)$ vs f_c show good agreement across the different methods.

Analysis on 17 Common Events: SP, SR, CCT, GIT, CERT

➢ Coefficient of Variation < 0.4

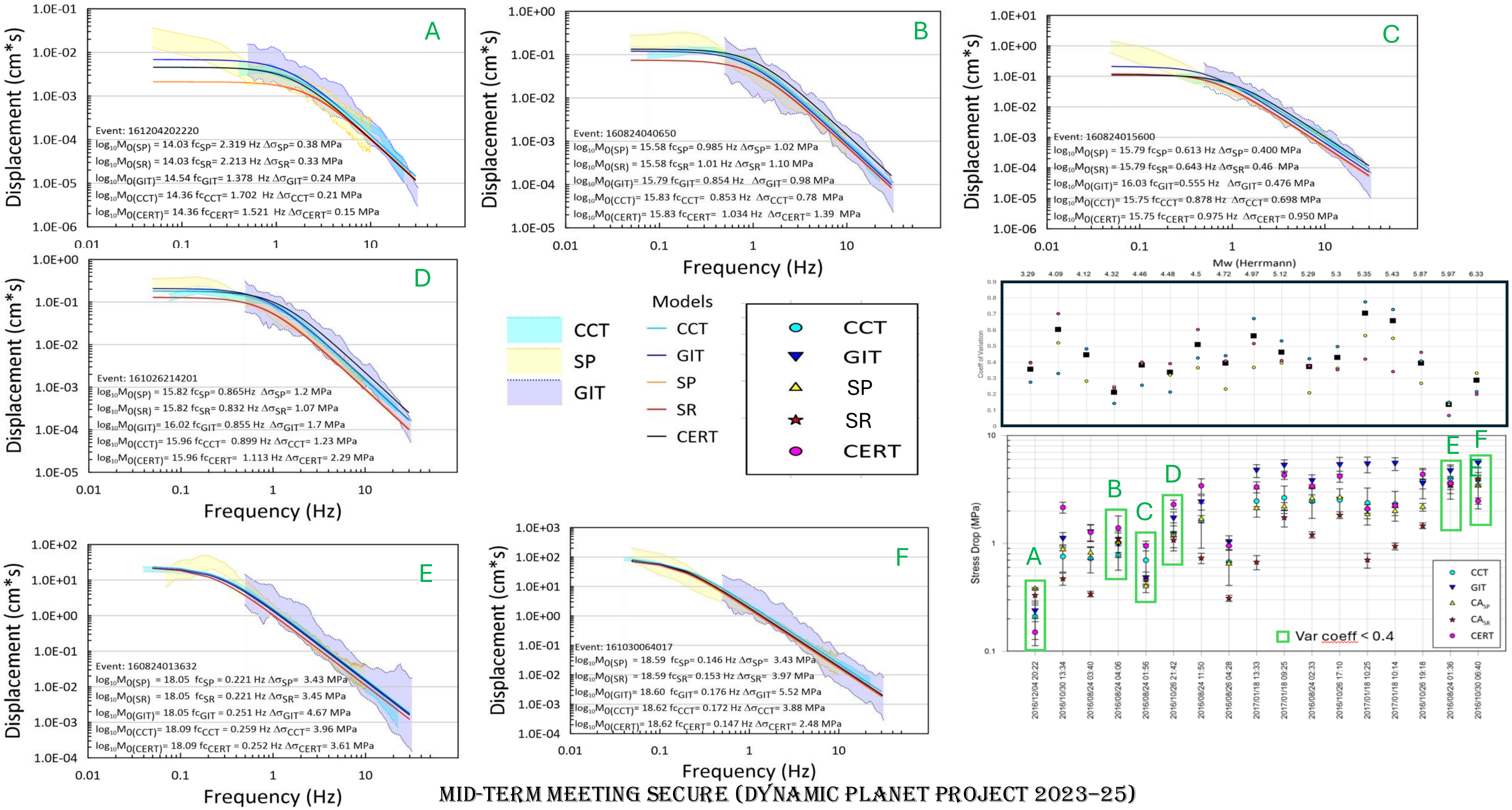
$M_{W,\,HM}$: 3.29 4.09 4.12 4.32 4.46 4.48 4.50 4.72 4.97 5.12 5.29 5.30 5.35 5.43 5.87 5.97 6.33



GIT constrains M_w only for events with $M_w > 5.5$, whereas it should apply the constraint already above M_w 5.0. This results in an overestimation by GIT in the $5.0 < M_w < 5.5$ range.

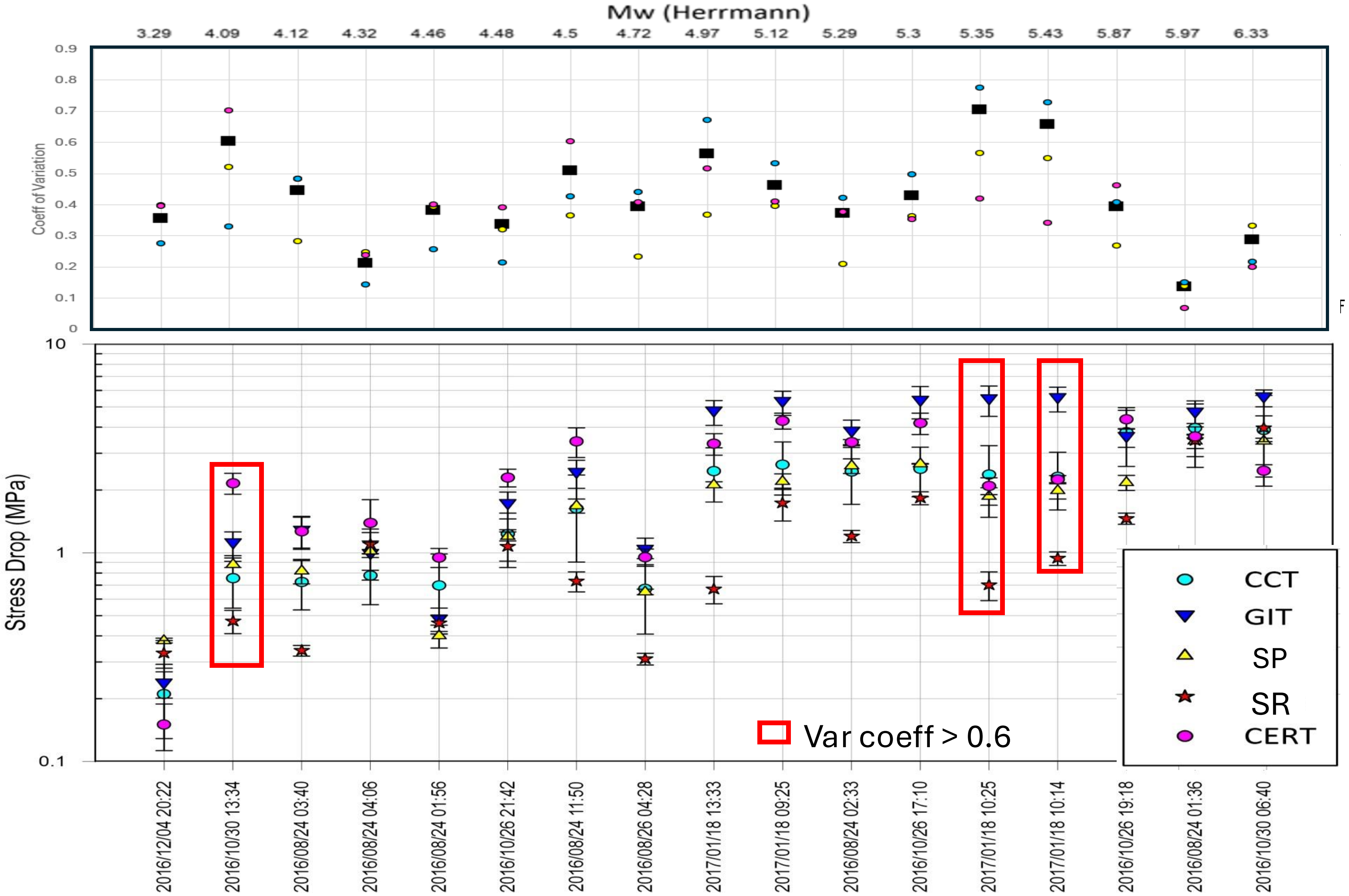
Analysis on 17 Common Events: SP, SR, CCT, GIT, CERT

➢ Coefficient of Variation < 0.4

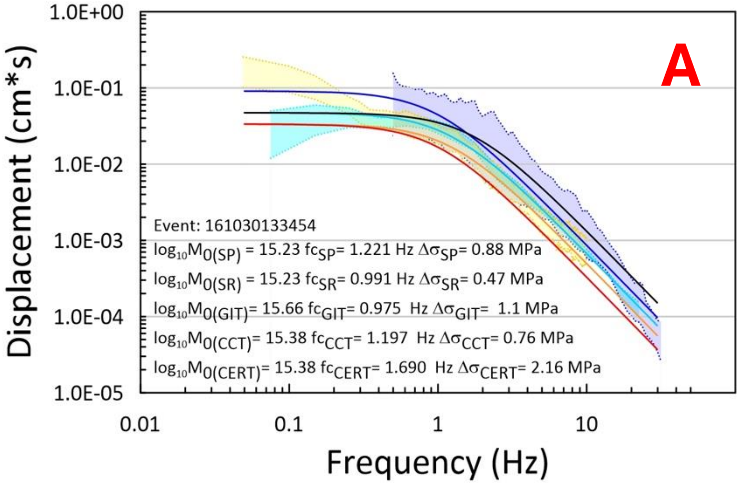


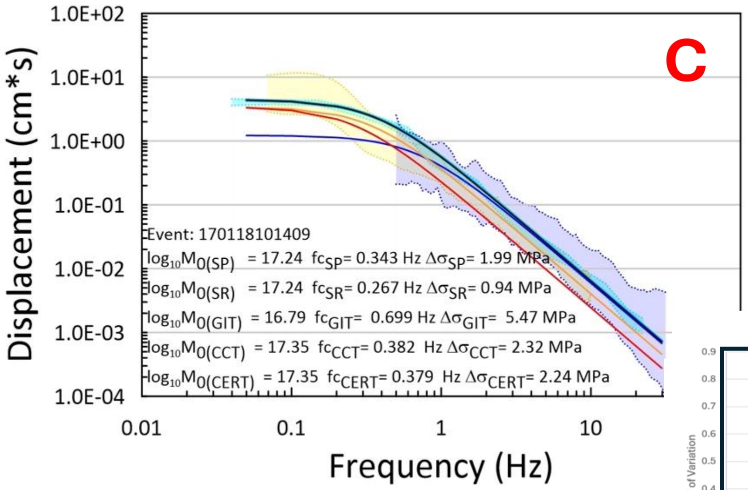
Analysis on 17 Common Events: SP, SR, CCT, GIT, CERT

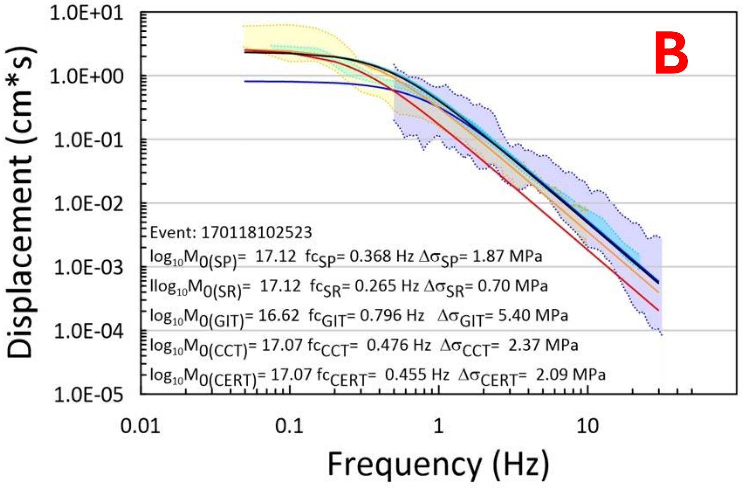
➢ cCefficient of Variation > 0.6

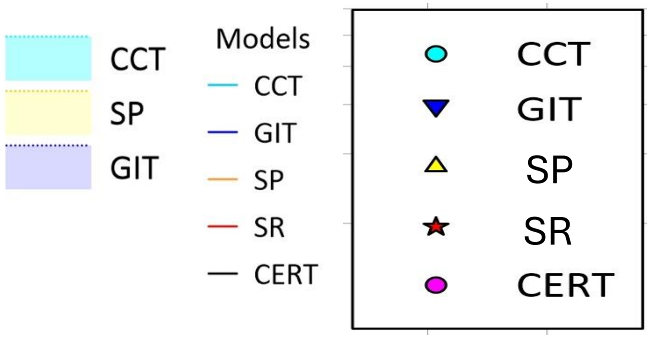


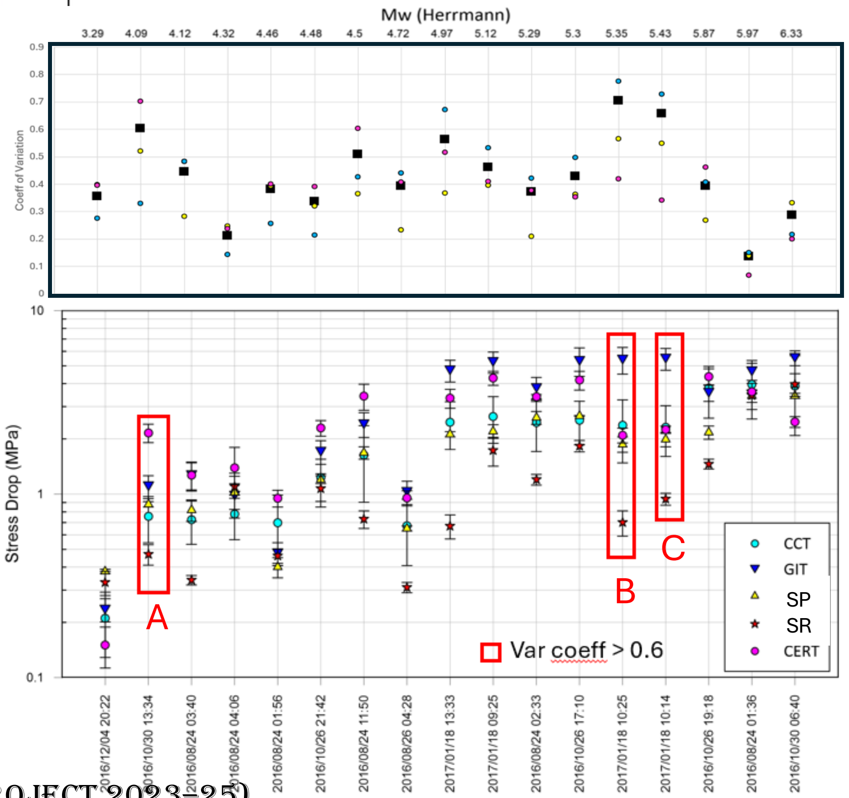
Analysis on 17 Common Events: SP, SR, CCT, GIT, CERT - coefficient of variation > 0.6





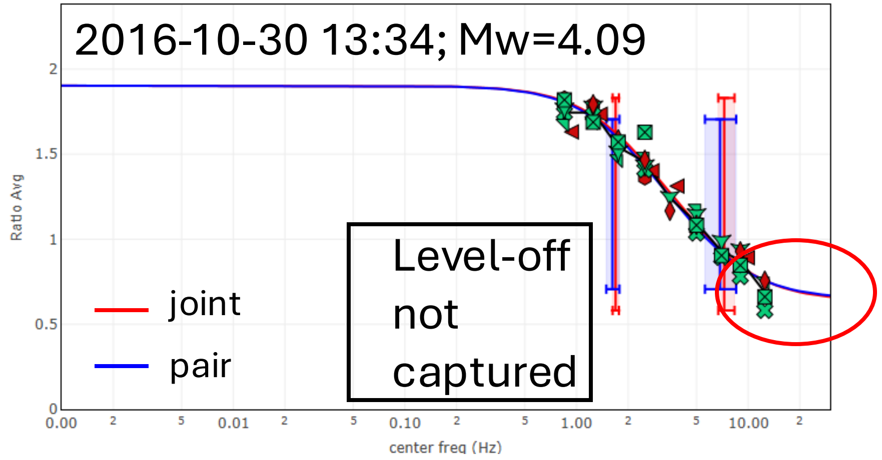


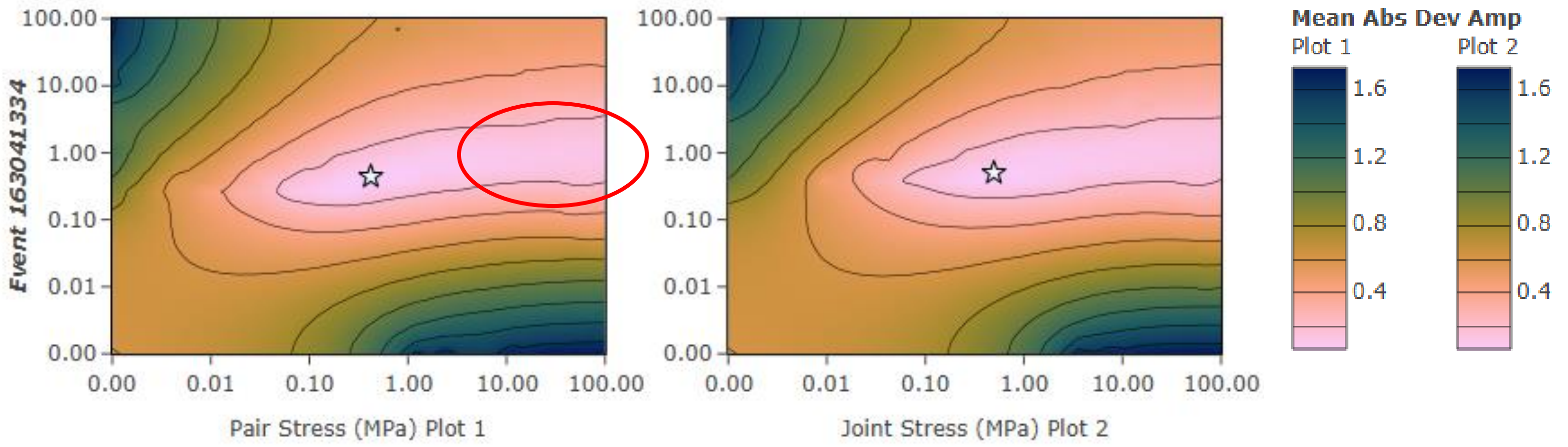




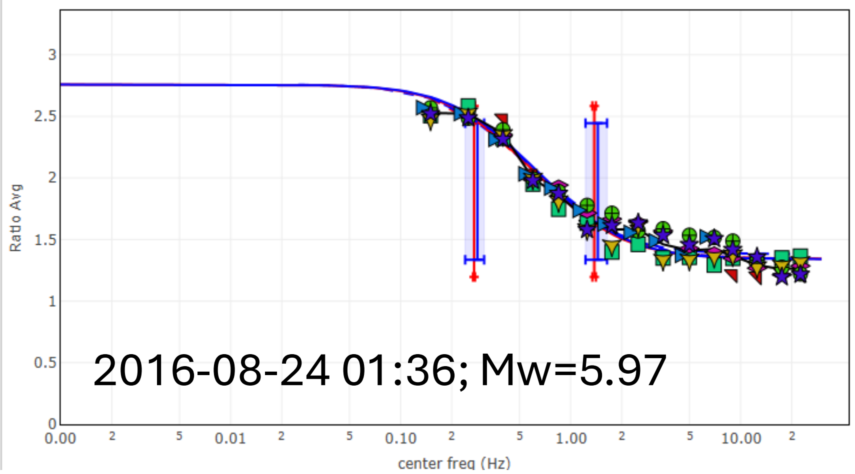
CASE A : $\Delta\sigma_{CERT} >> \Delta\sigma_{SP,CCT,SR}$

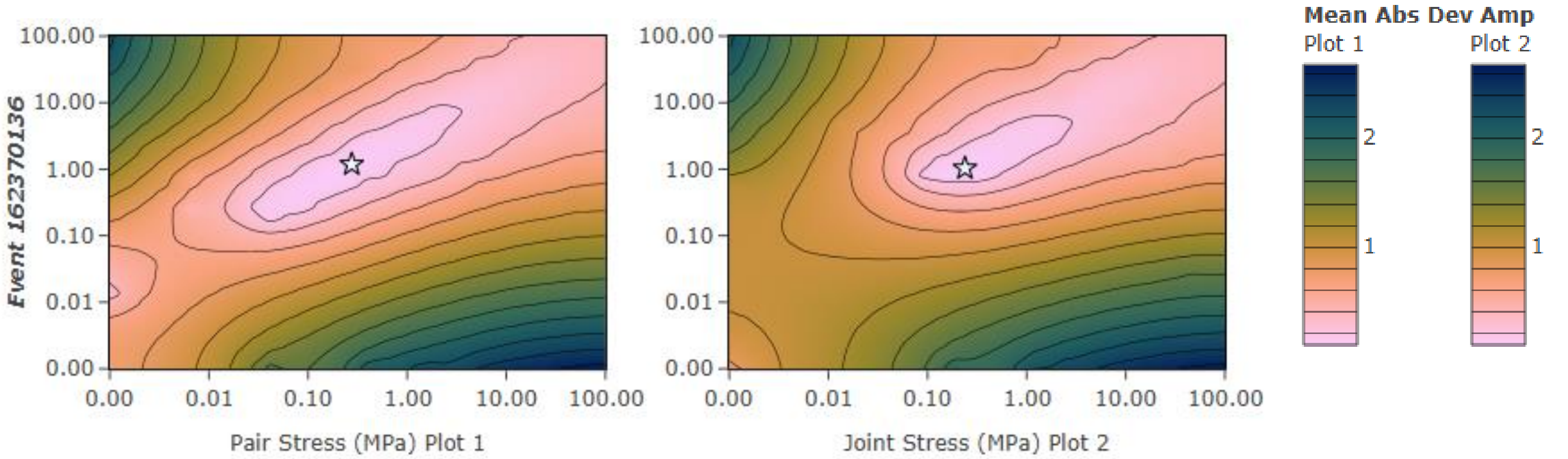
This happens probably because for one or both of the events we are not measuring high enough frequencies to catch the final level-off.





An example of better high frequency constraining: 2016-08-24 01:36; Mw=5.97

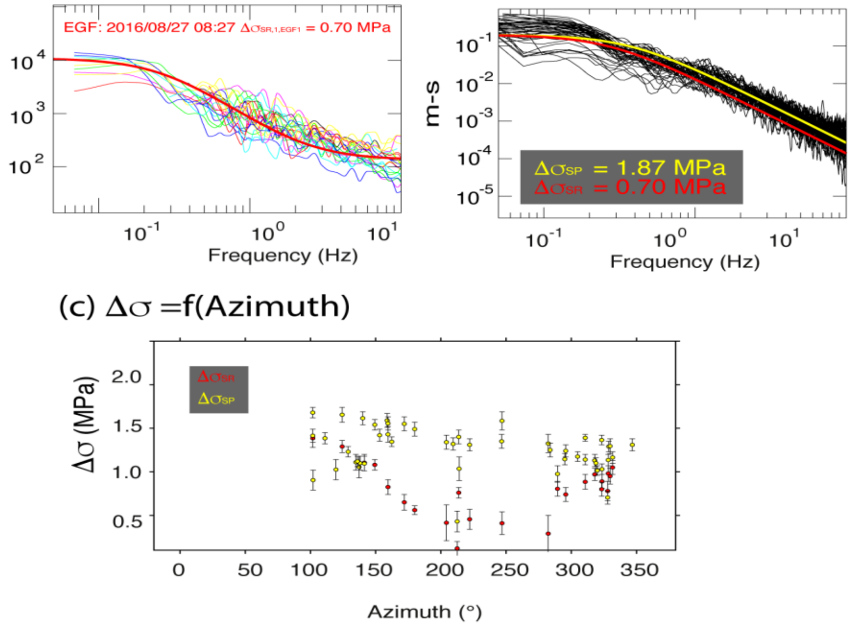




CASE B: $\Delta\sigma_{SR} << \Delta\sigma_{SP,CCT,CERT}$

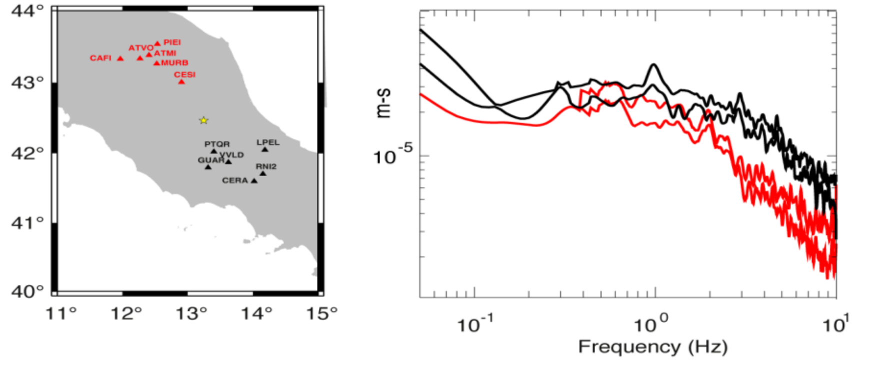
Target Event: 2016/01/18 10:25 $M_{WMH,1}$ 5.35

(a) Spectral Ratio (b) Displacement Spectra



EGF: 2016/08/27 08:27 $M_{w,2}$ 2.66

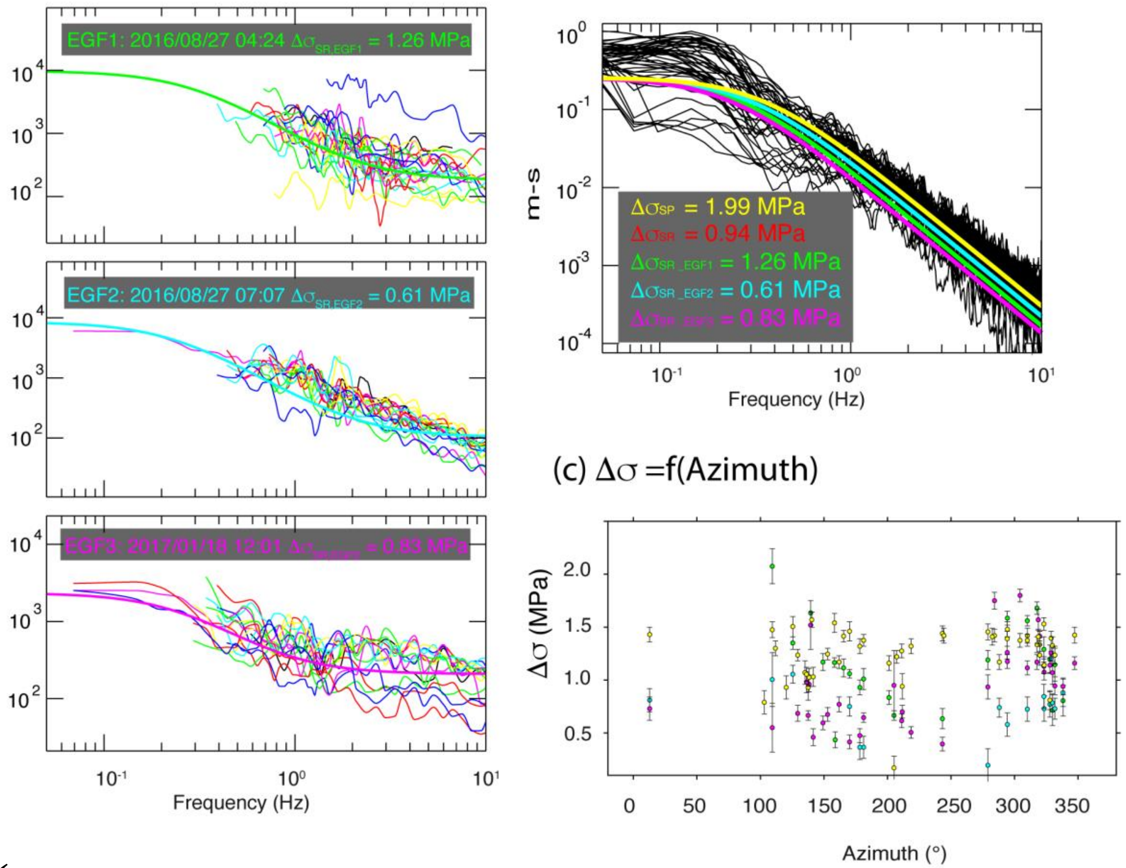
(a) Selected stations (b) Displacement Spectra



CASE C: $\Delta\sigma_{SR} << \Delta\sigma_{SP,\ CCT,\ CERT}$

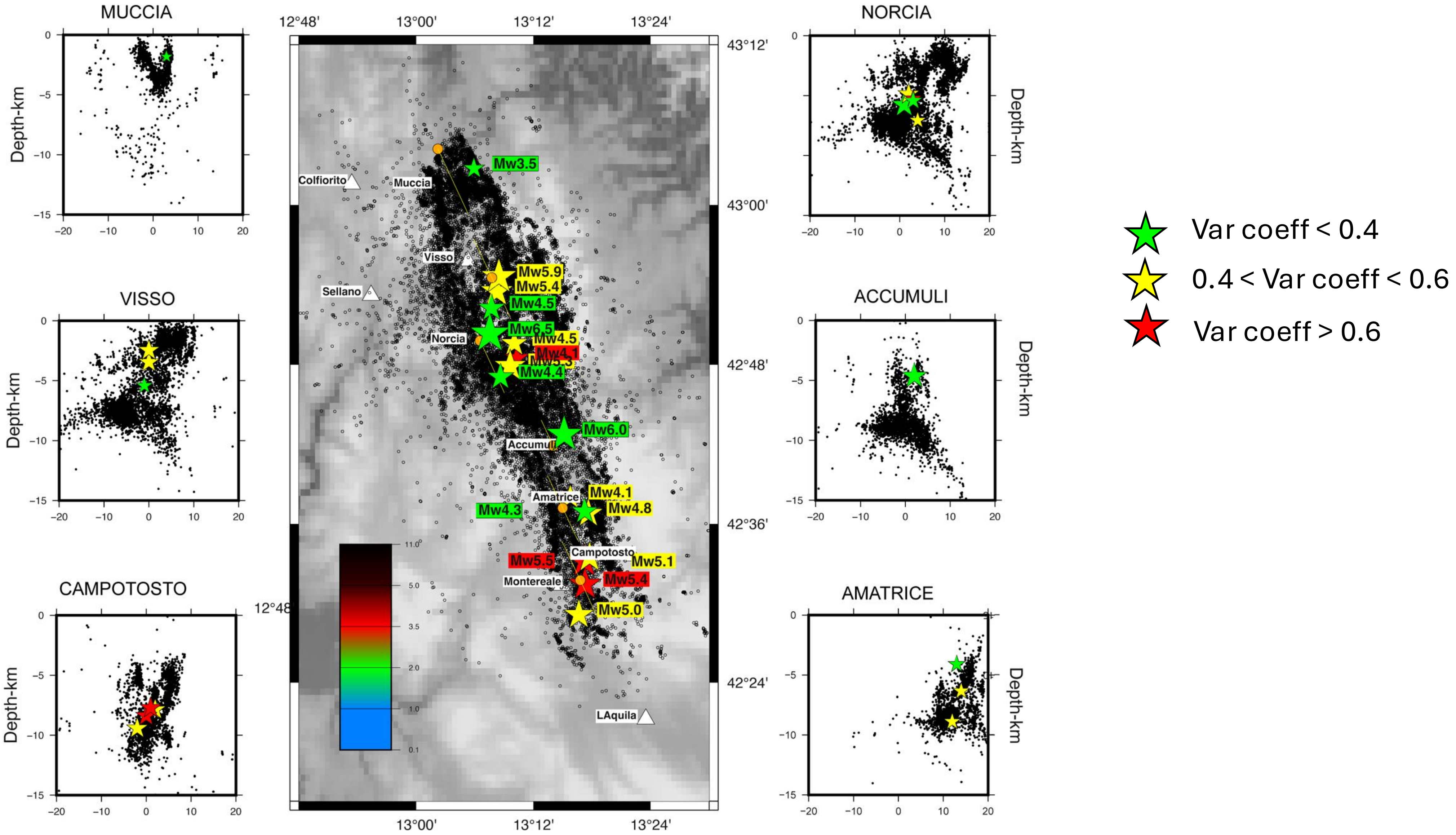
Target Event: 2017/01/18 10:14 Mw 5.43

(a) Spectral Ratio (b) Displacement Spectra

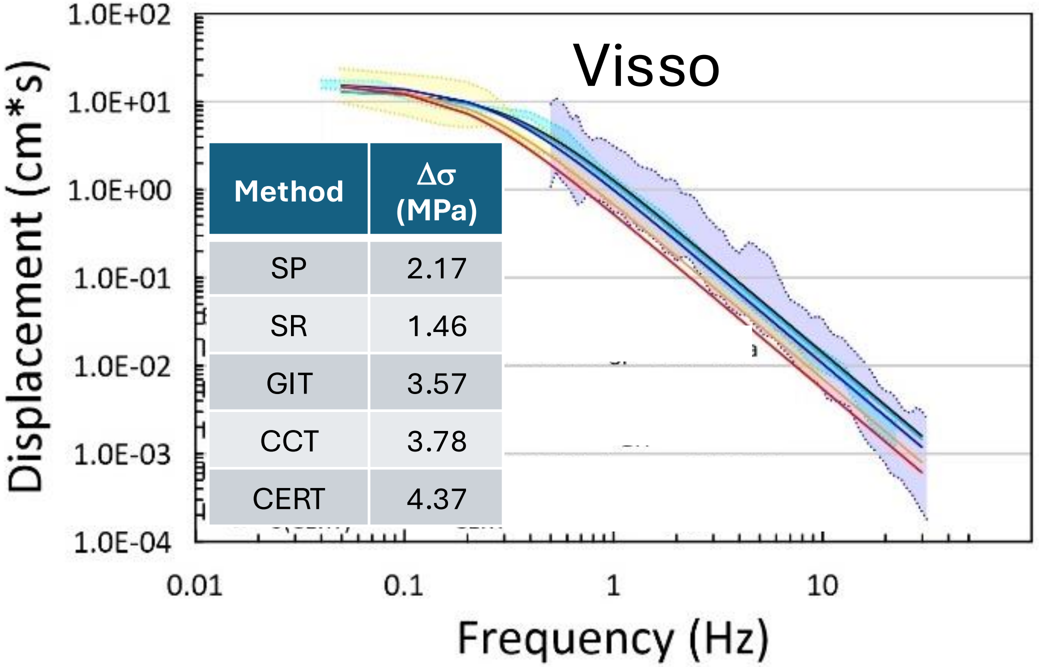


- ✓ EGF Directivity Effect: if the difference between the $\Delta\sigma_{SR}$ and $\Delta\sigma_{SP}$ is greater than a factor of 2 for a given EGF, it likely indicates significant source directivity in the EGF
- ✓ Another potential issue is the limited frequency band over which the analysis is performed.

Analysis on 17 Common Events: SP, SR, CCT, GIT, CERT

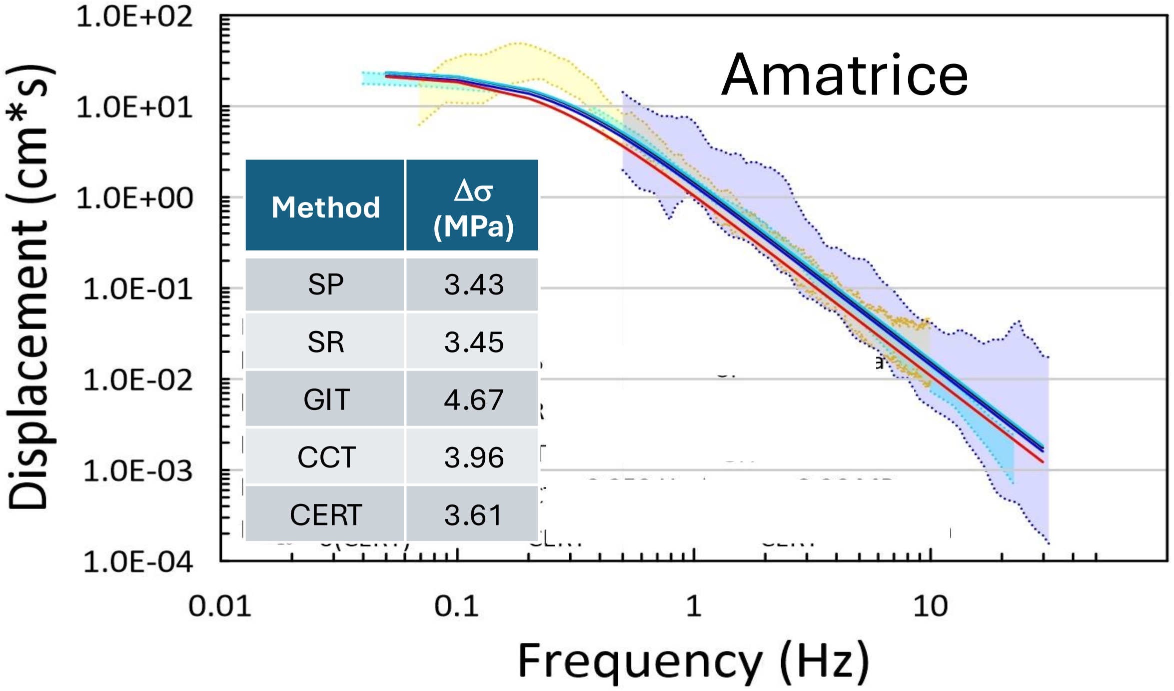


Amatrice-Visso-Norcia Mainshocks: Comparison of the Spectral Corrections for Propagation and Site Effects

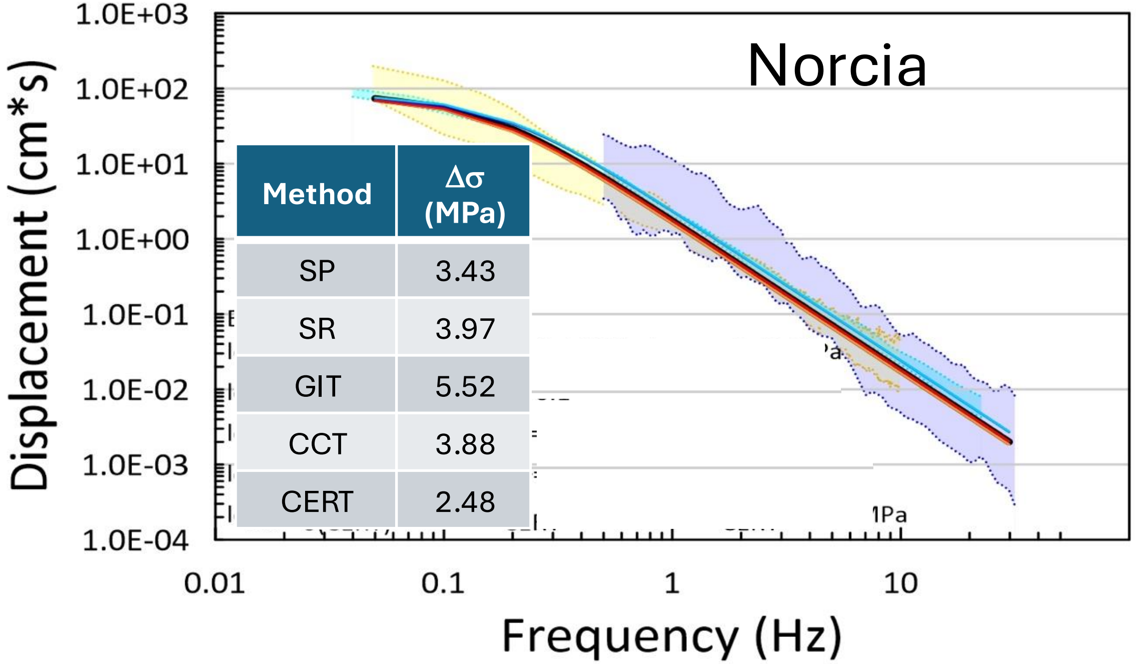


Method	Δσ (MPa)
SP	2.17
SR	1.46
GIT	3.57
CCT	3.78
CERT	4.37

✓ For the AVN mainshocks, stress drop estimates show excellent agreement across 5 different methods.



Method	Δσ (MPa)
SP	3.43
SR	3.45
GIT	4.67
CCT	3.96
CERT	3.61



Method	Δσ (MPa)
SP	3.43
SR	3.97
GIT	5.52
CCT	3.88
CERT	2.48

Conclusions

1. **Good agreement among methods** in the estimation of:
   - Moment magnitude (M_w) and seismic moment (M_0)
   - Stress drop ($\Delta\sigma$) and corner frequency (f_c)
   - Scaling laws: $\Delta\sigma = f(M_0)$, $\tau_a = f_c(M_0)$

2. **Analysis of 17 common events** using all 5 methods shows that:
   - Spectral corrections are generally consistent.
   - A few cases show a coefficient of variation > 0.6, likely due to strong medium heterogeneity, EGF directivity effects, or limited high-frequency resolution.

3. **AVN mainshocks:**
   - ➢ Stress drop estimates show excellent agreement across all methods.

Thank you for Attention!