VARIABILITA' DELLO SCUOTIMENTO SISMICO: ANALISI EMPIRICHE E MODELLI

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INGV

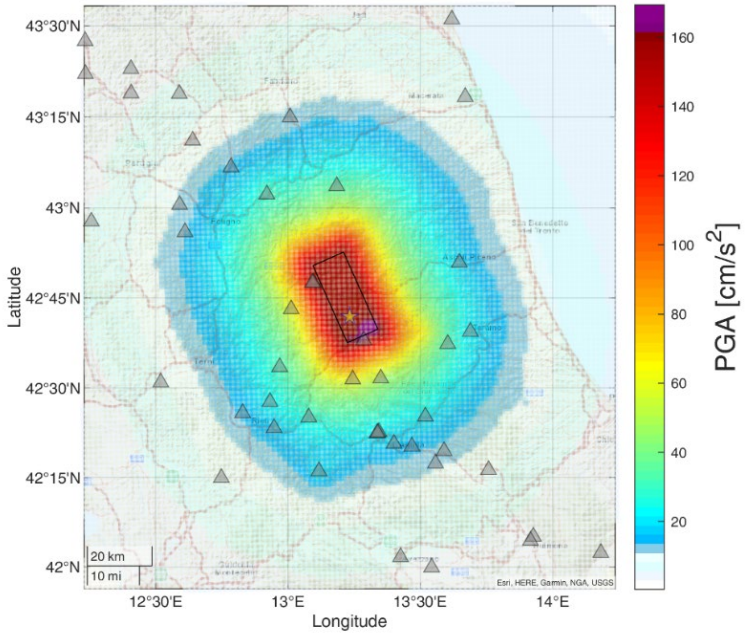
SECURE REGIONAL-SCALE EARTHQUAKE **GROUND MOTION PREDICTIONS** THROUGH PYHSICS-BASED AND EMPIRICAL APPROACHES: **A CASE STUDY CENTRAL ITALY**

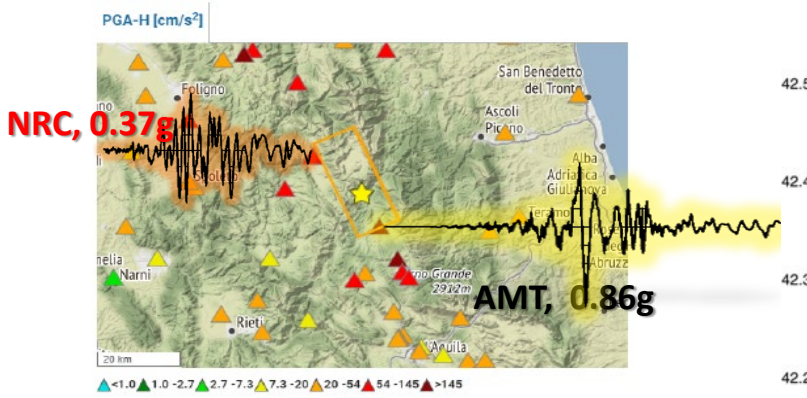
Roma, 30 gennaio 2024

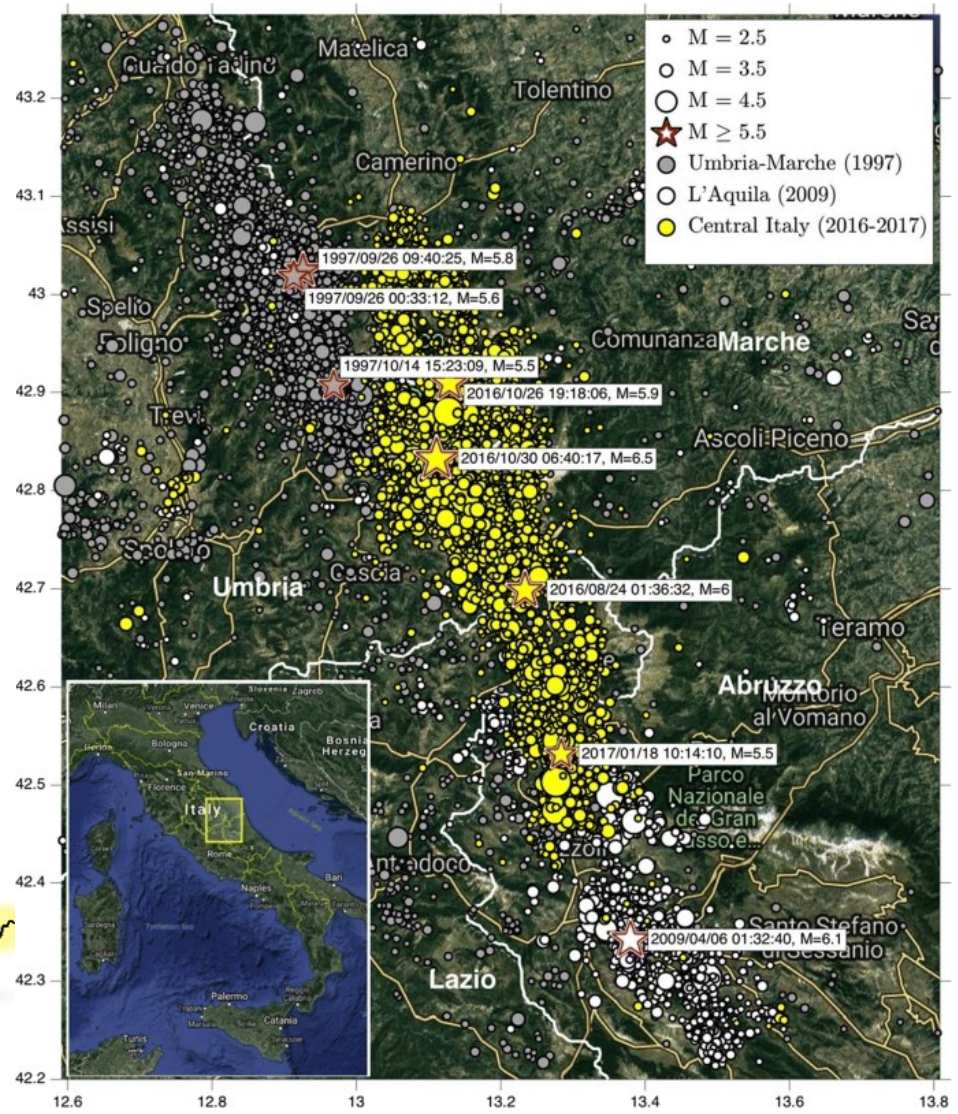
SECURE PROJECT - TASK3: STRATEGIE PER MIGLIORARE LA MODELLAZIONE DELLO SCUOTIMENTO SISMICO

Studio delle sorgenti di variabilità del moto sismico attraverso modelli non ergodici

- Correlazioni tra termini ripetibili e i parametri sismologici
- Valutazione della variabilità sintetica
- Variabilità spaziale: anisitropia di sorgente e propagazione
- Modellazione parametrica della direttività







MODELLI NON ERGODICI IN CENTRO ITALIA

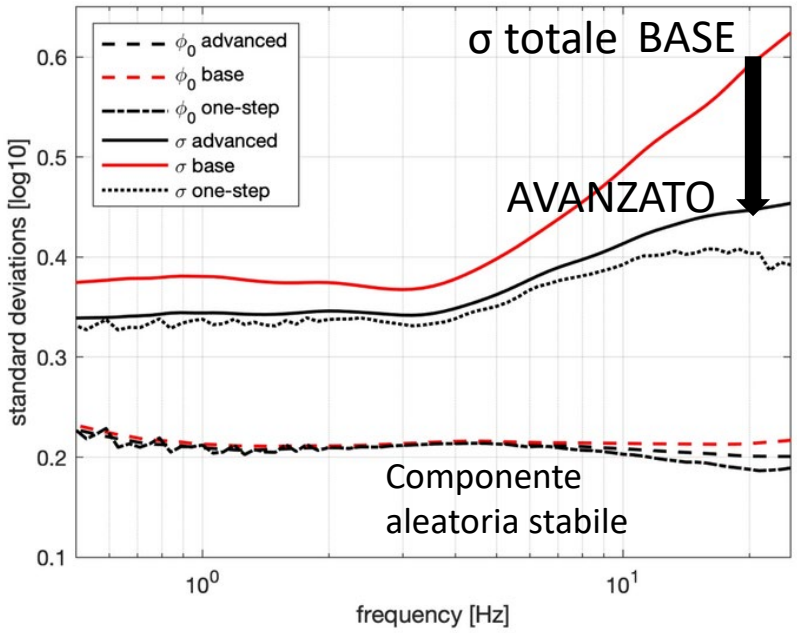
Modello BASE NE integrato con parametri aggiuntivi sismologici e geofisici

$$\log_{10} Y = a + F_M(M, \Delta\sigma, k_s) + F_R(M,R) + F_S(V_{s,30}, k_o) + \delta B_e + \delta S2S_s + \delta L2L_e + \delta P2P_{es} + \varepsilon_{es}$$

Termini modello AVANZATO:

- ……..
- b'_3 stress-drop scaling
- b'_4 kappa source scaling
- ……
- d'_1 site scaling
- d'_2 high-frequency attenuation

- $\delta B'_e$, $\delta S2S'_s$, $\delta L2L'_r$, $\delta P2P'_p$, $\delta W'_0$



- Stress-drop **Δσ**
- Kappa source $\mathbf{k_s}$

- **Vs30**
- Kappa site $\mathbf{k_0}$

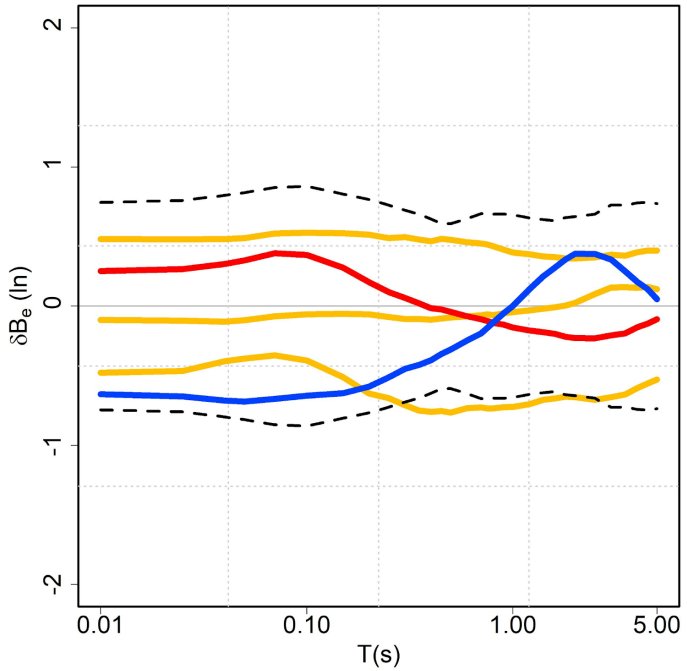
- **Altri parametri?**

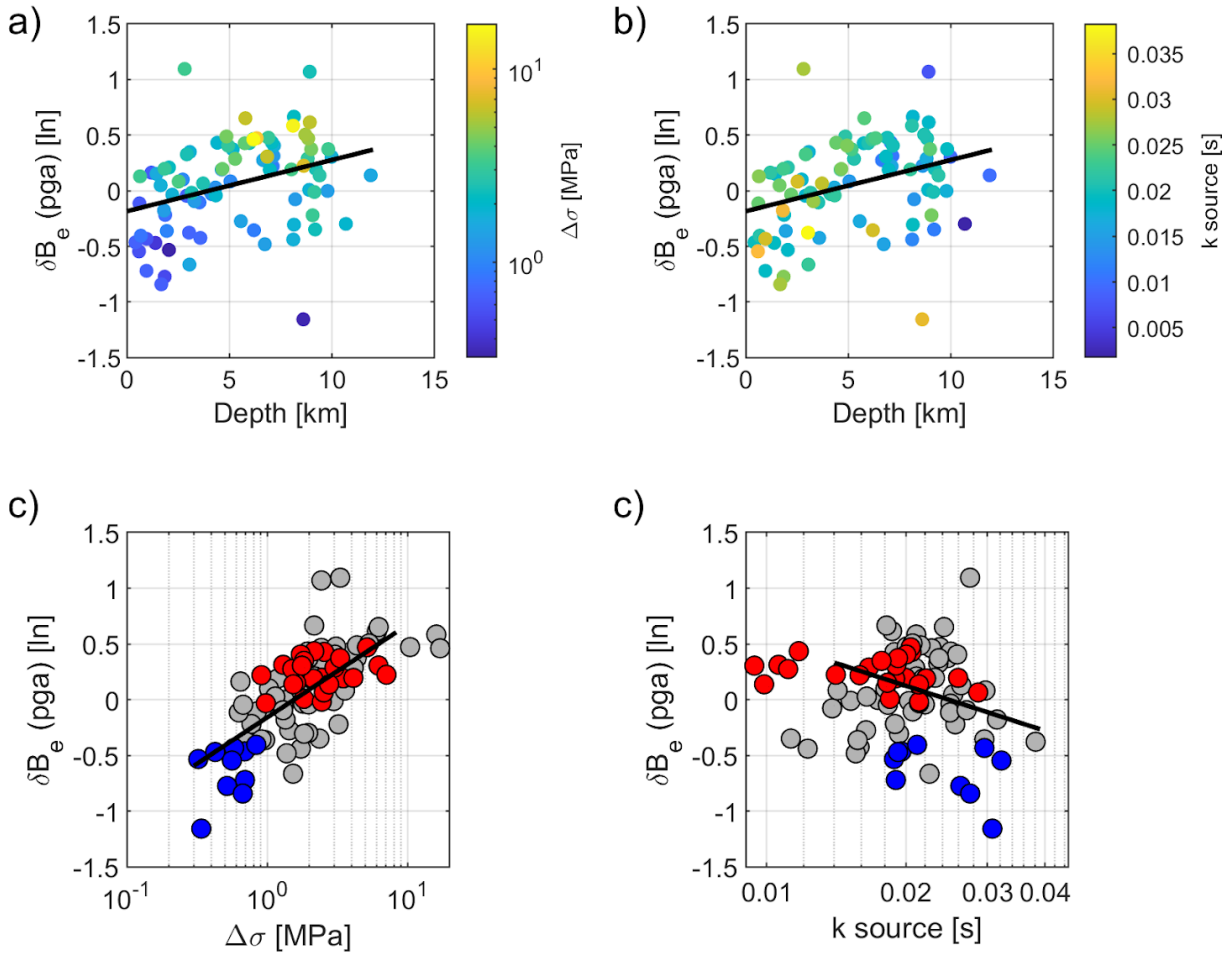
- **68**% della variabilità inter-evento in alta frequenza
- **35**% della variabilità site-to-site in alta frequenza

Sgobba et al., 2023 *Bull Earthquake Eng*

VARIABILITA' INTER - EVENTO: LA PROFONDITA'

$$R_{es} = \delta B_e + \delta S2S_s + \delta L2L_e + \delta P2P_{es} + \varepsilon_{es}$$



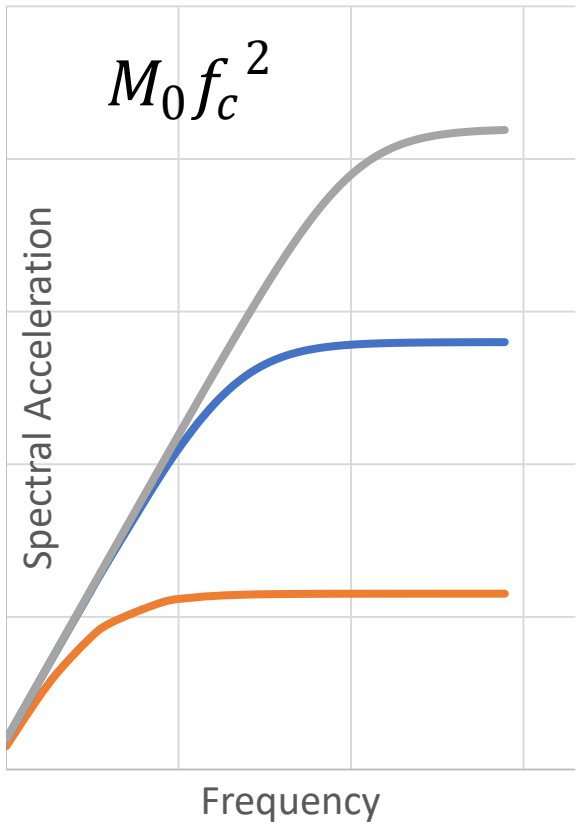


VSE: H < 3 km; $\Delta\sigma$ < 1MPa, k_s >0.02s

Mascandola et al., *submitted to GJI*

Aggiornamento: Introdurre la dipendenza dalla profondità ipocentrale

VARIABILITA' INTER-EVENTO E INTER-SCENARIO



HIC model

$$f_c = \frac{a v_r}{L}$$

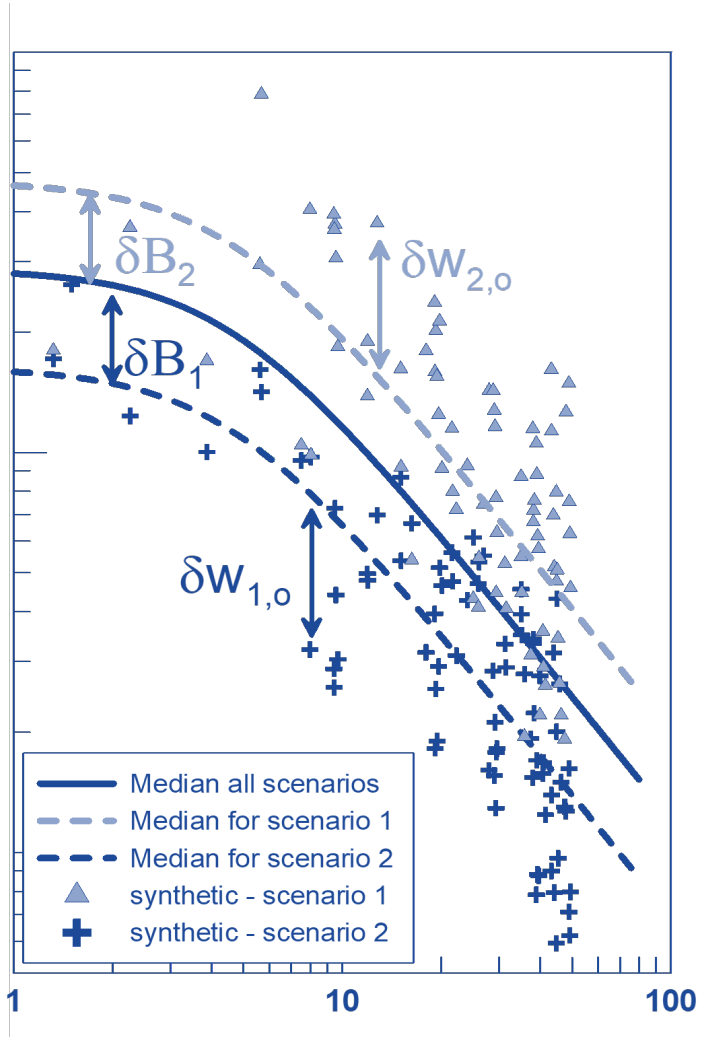
-**a** *tuning parameter controlling the strength of high-frequency radiation*

$S = L^2$ *fault lenght*

v_r = *Rupture velocity*

$$\Delta\sigma = \frac{7}{16}\left(\frac{f_c}{k\beta}\right)^3 M_0$$

$$\Delta\sigma = \frac{7}{16}\left(\frac{a v_r}{k\beta}\right)^3 \frac{M_0}{S^{3/2}}$$



Nelle simulazioni cinematiche il parametro di stress è una combinazione di parametri di sorgente (rupture velocity **vr,** rupture size **L**, and proportionality constant **a**).

Cejka et al., 2024 *submitted BSSA*

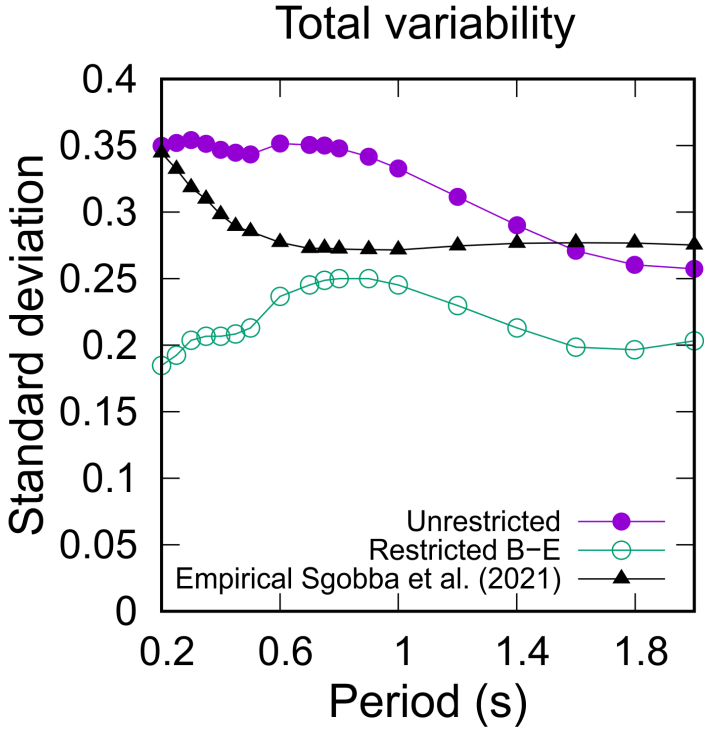
VARIABILITA' INTER-SCENARIO E PARAMETRO DI STRESS

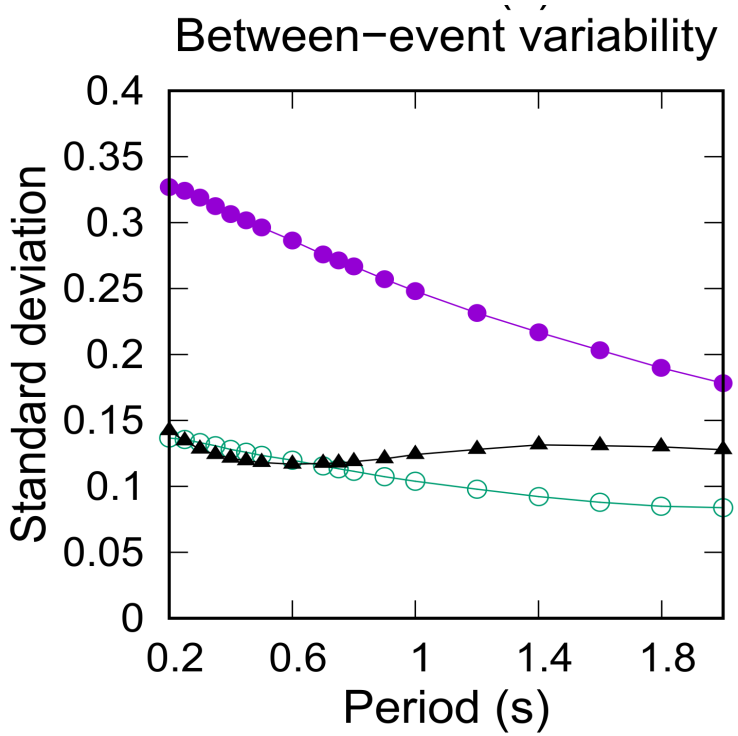
$$R_{ij} = C' + C_S \log S + C_a \log a + C_{vr} \log v_r + \varepsilon_k + \eta_{ok}$$

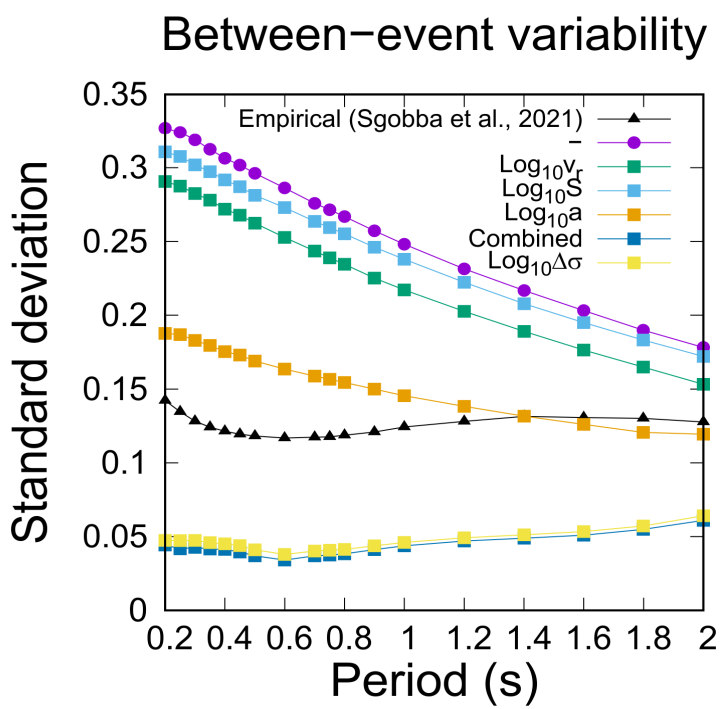
$$R_{ij} = C'' + C_{\Delta\sigma} \log \Delta\sigma + \varepsilon'_k + \eta'_{ok}$$

Stress parameter [0.2 – 10] MPa

std(log Δσ) = 0.48 to std(log $\Delta\sigma_{restricted}$) = 0.20





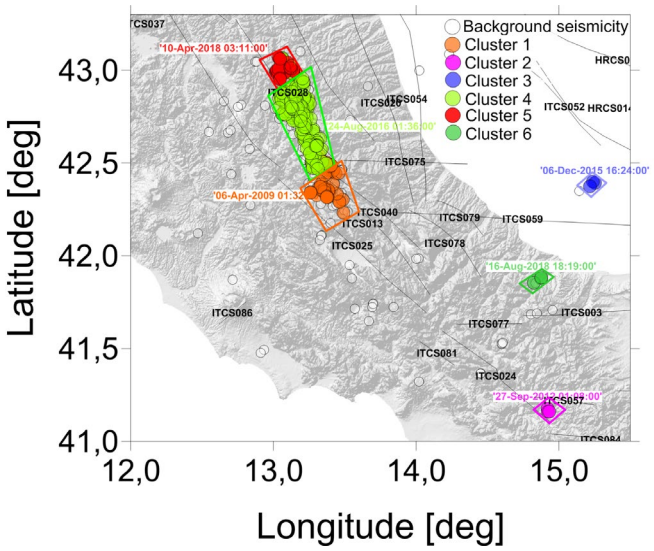


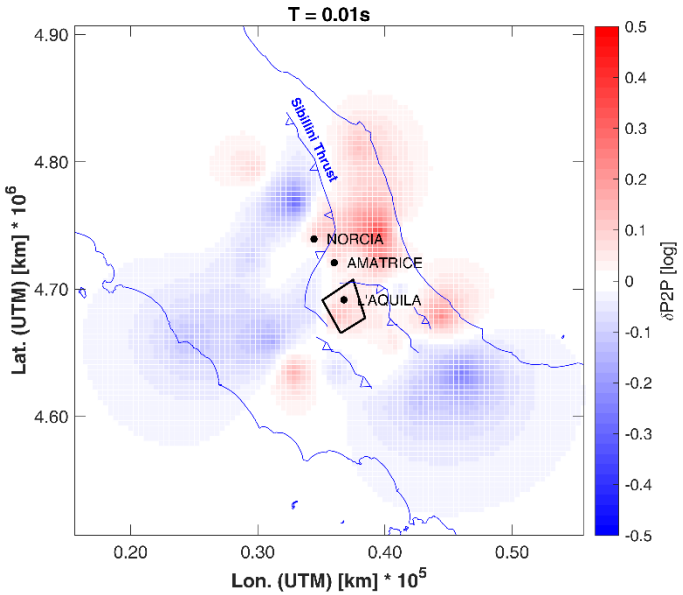
$$\tau \sim C_{\Delta\sigma}\, \mathrm{std}(\log \Delta\sigma) = 0.63\, \mathrm{std}(\log \Delta\sigma) \approx 2/3\, \mathrm{std}(\log \Delta\sigma)$$

Cejka et al., 2024 *submitted BSSA*

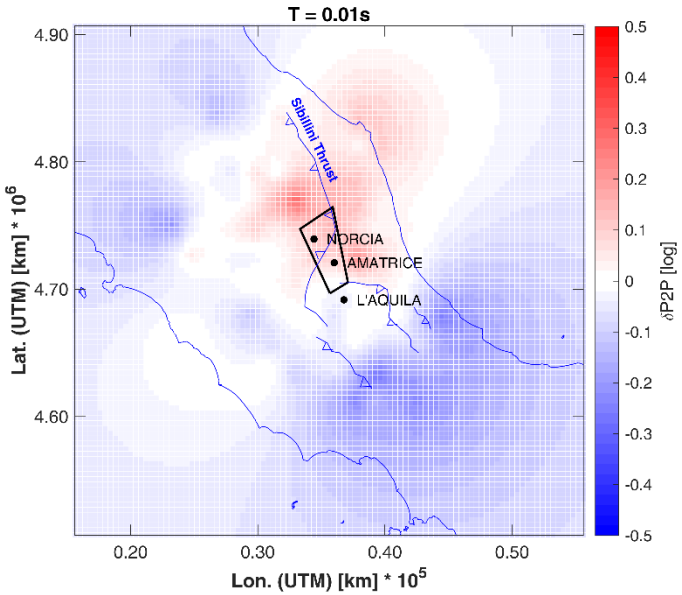
Aggiornamento: vincolare la variabilità dello stress drop in centro Italia

VARIABILITA’ INTRA - EVENTO - PERCORSO

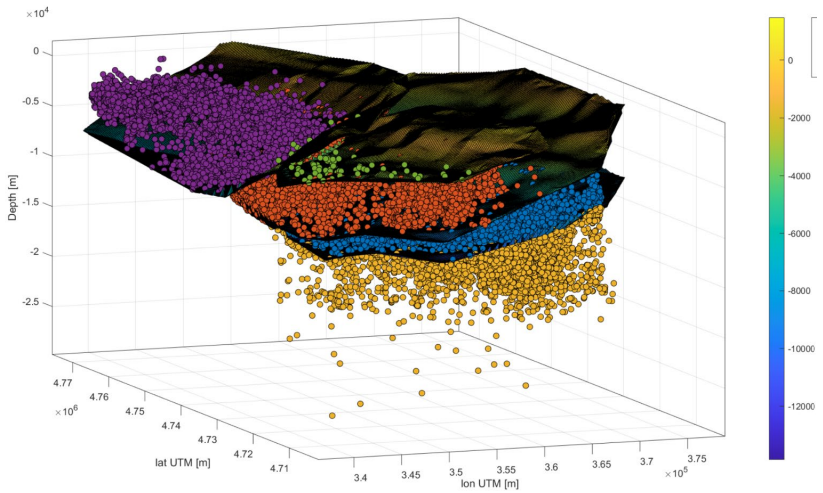




Cluster#1



Cluster#4



$$R_{es} = \delta B_e + \delta S2S_s + \delta L2L_e + \delta P2P_{es} + \varepsilon_{es}$$

Aggiornamento: Introdurre la nuova zonazione nel modello NE del centro Italia

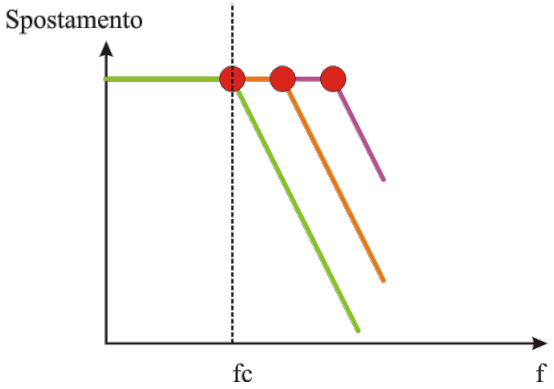
VARIABILITA' INTRA - EVENTO - DIRETTIVITA'

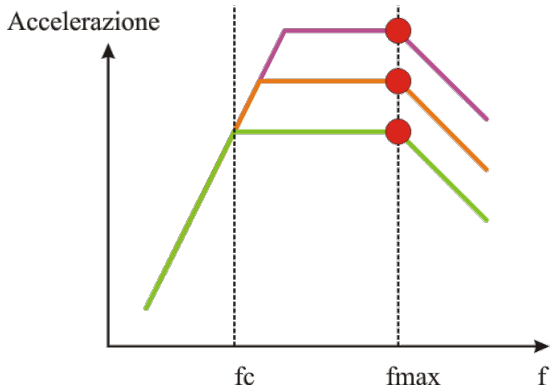
$$R_{es} = \delta B_e + \delta S2S_s + \delta L2L_e + \delta P2P_{es} + \varepsilon_{es}$$

$$\varepsilon_{es} = \delta D2D_{es} + \varepsilon'_{es}$$

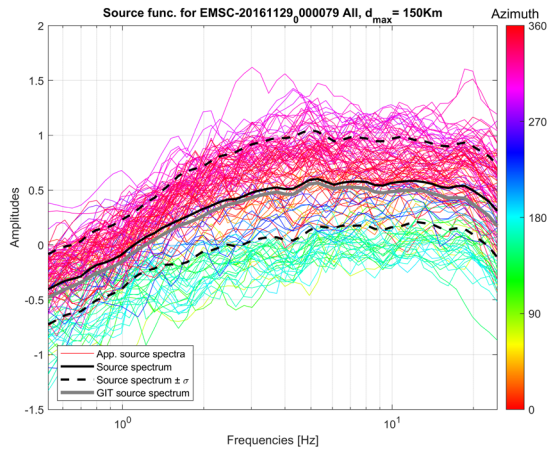
$$C_d = \sqrt{\frac{k^2}{\left[1 - \left(\frac{v_r}{c}\right)\cos(\theta - \theta_0)\right]^2} + \frac{(1-k)^2}{\left[1 + \left(\frac{v_r}{c}\right)\cos(\theta - \theta_0)\right]^2}}$$

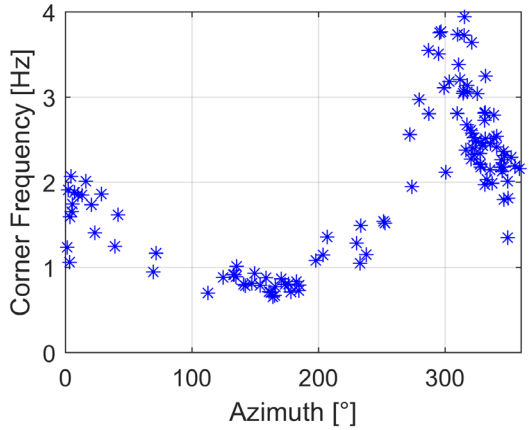
Boatwright, 2007

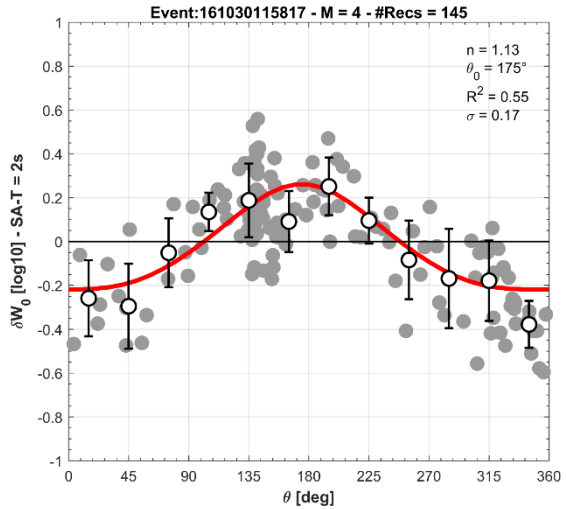


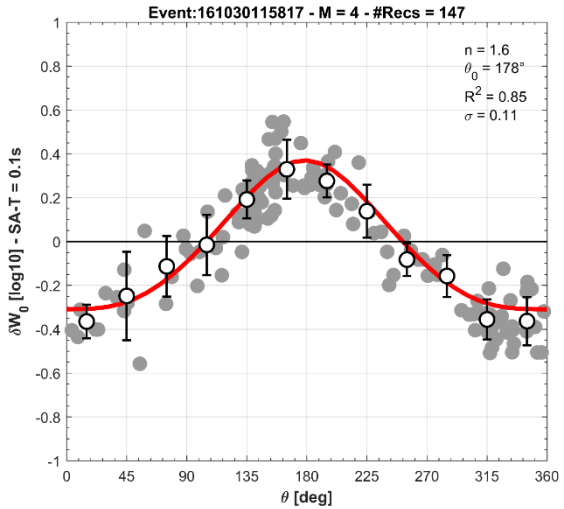


$$f_a = f_c C_d^n$$

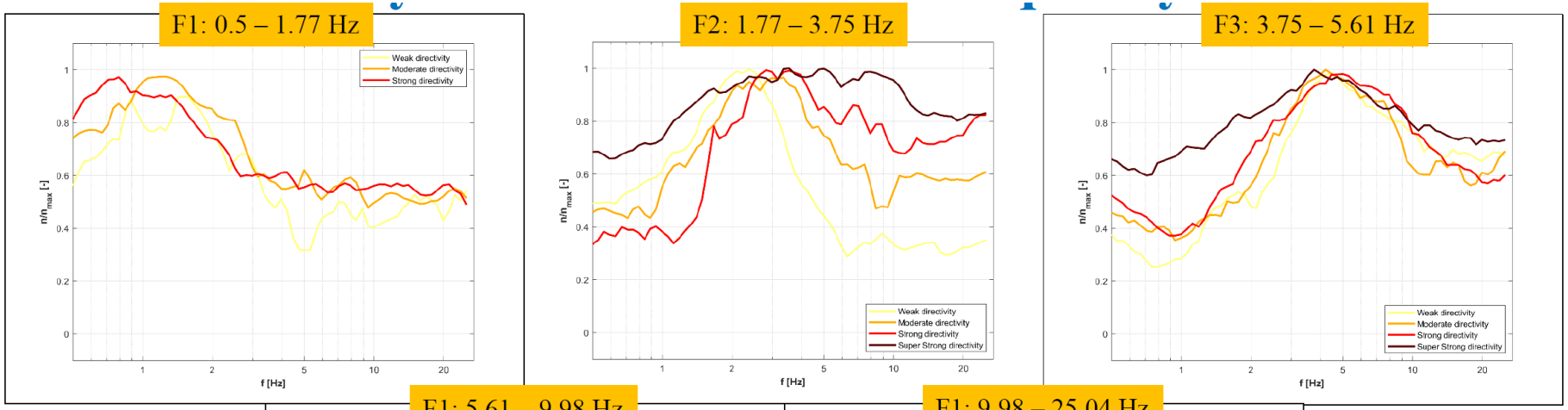








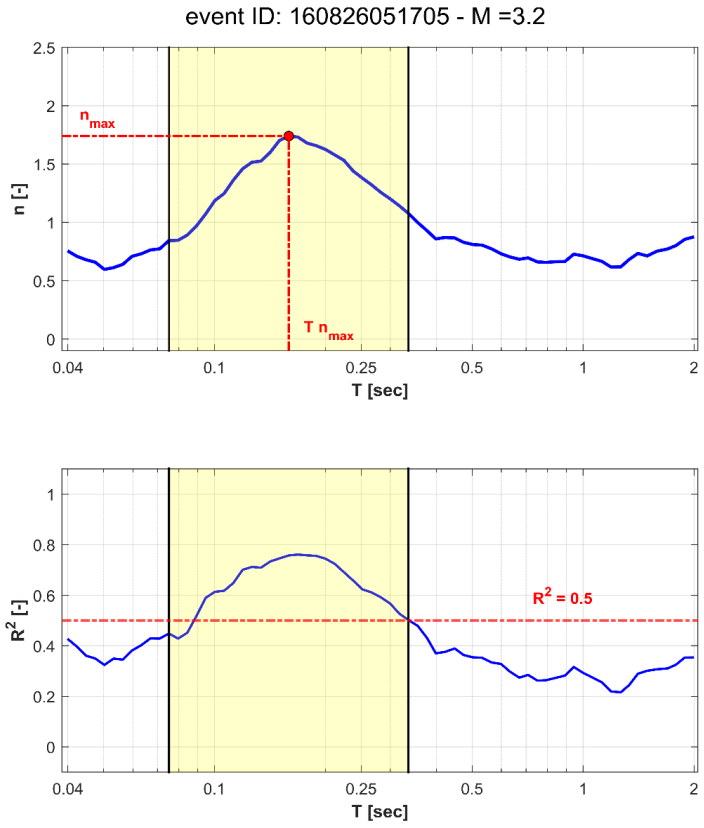
VARIABILITA' INTRA - EVENTO - DIRETTIVITA'

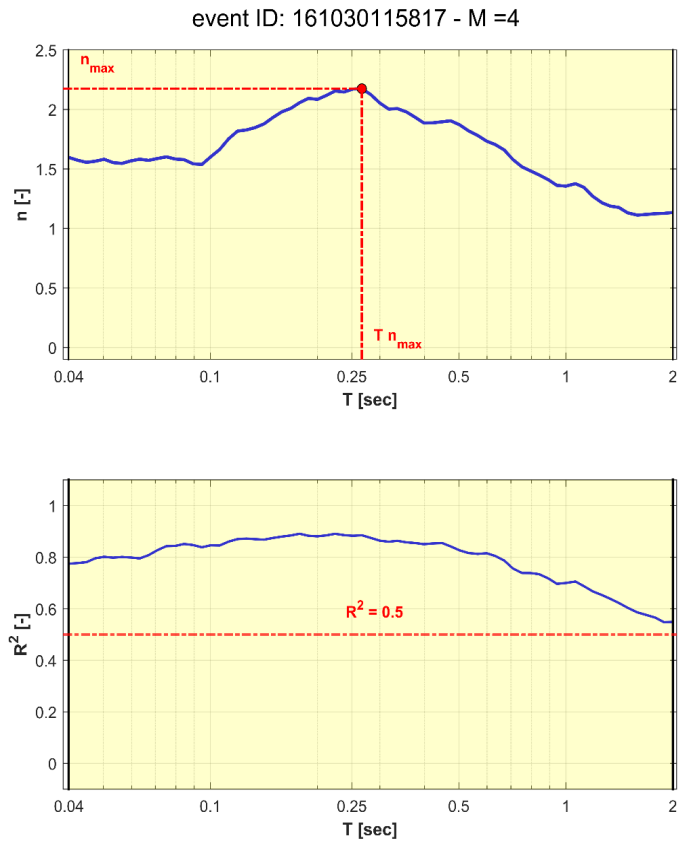


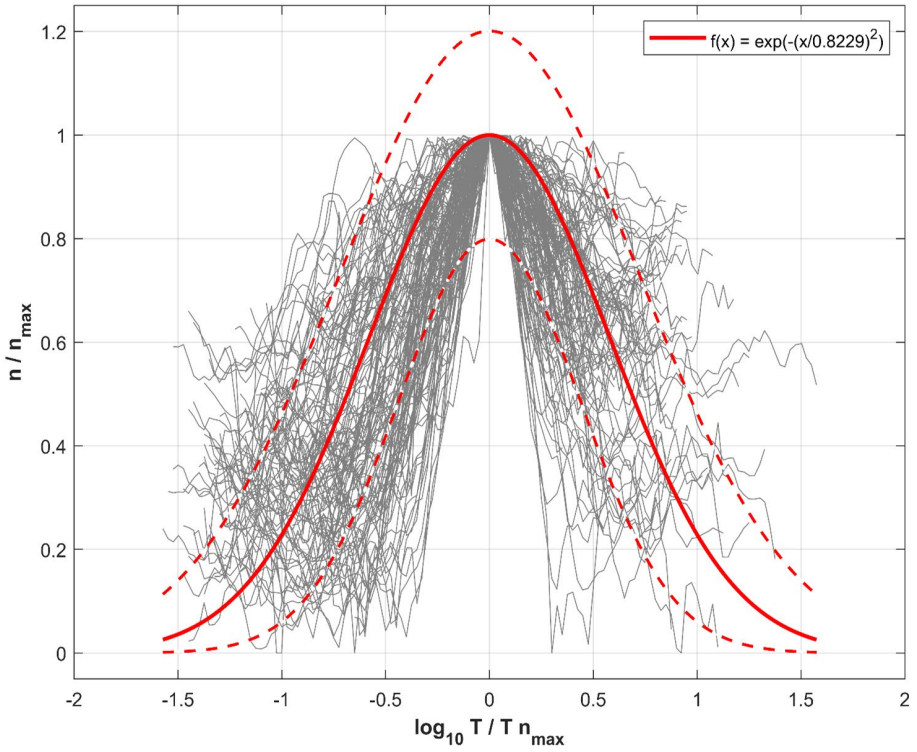
Proprietà C_d^n

- La funzione è piccata in bande di frequenze diverse, ma sempre oltre la fc
- L'ampiezza e la larghezze di banda è variabile
- La direzione di propagazione non cambia con la frequenza
- La direttività caratterizza circa 1/3 degli eventi

MODELLO DIRETTIVITA' PER CENTRO ITALIA

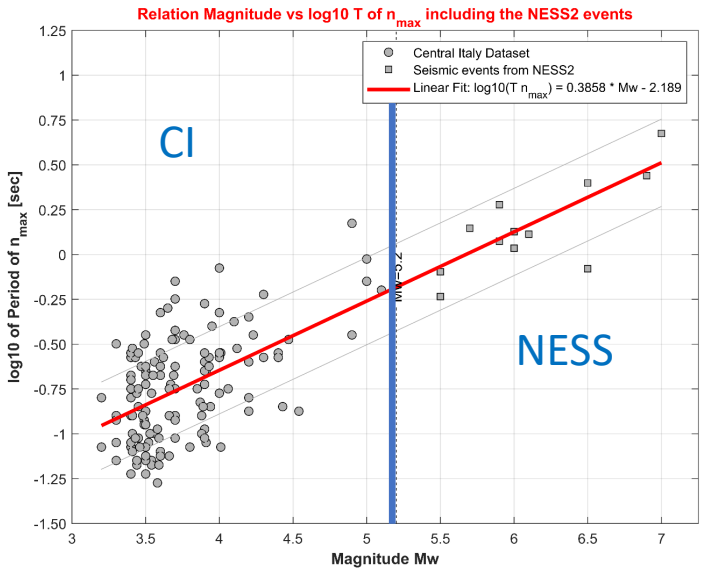




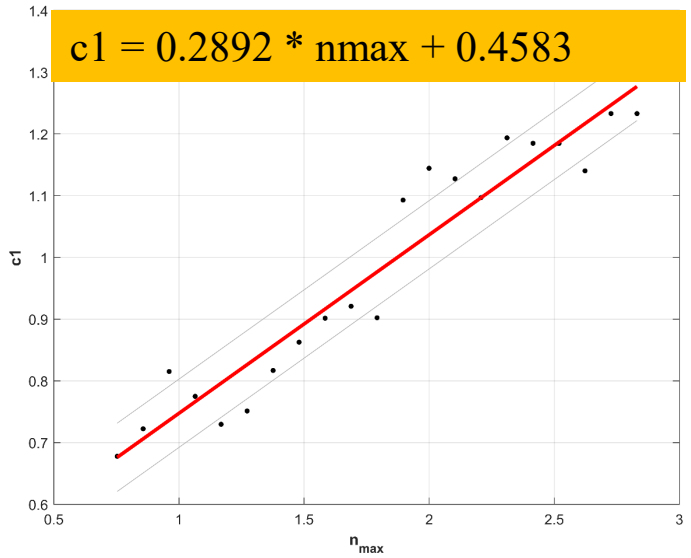


$$\frac{n}{n_{max}} = a_1 * \exp\left(- \left(\left(\log 10 \frac{T}{T_{n_{max}}} - b_1\right) / c_1\right) \wedge 2\right.$$

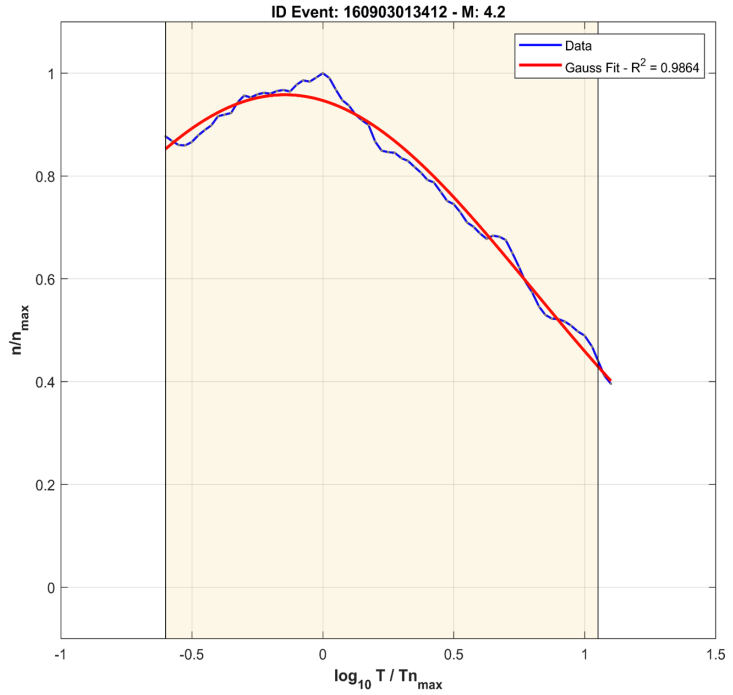
MODELLO DIRETTIVITA' PER CENTRO ITALIA

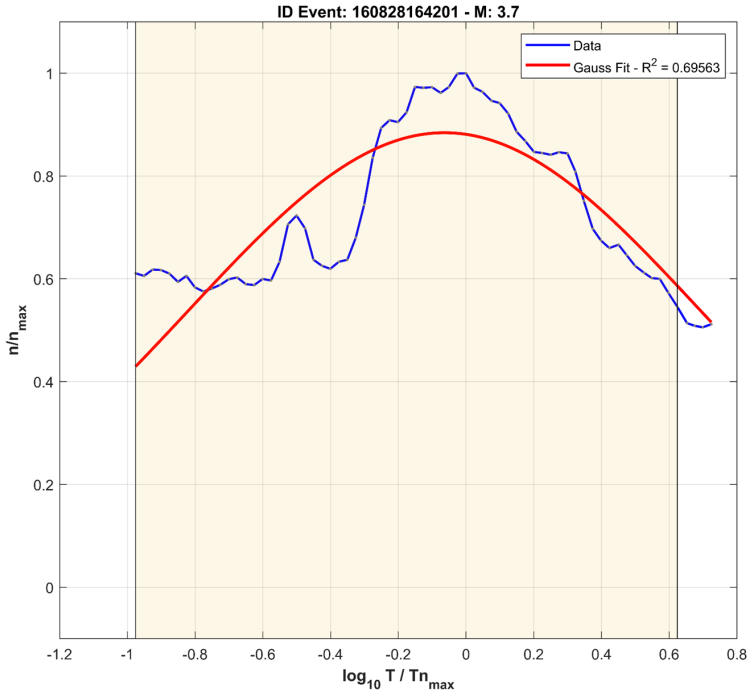


log10(T nmax) = 0.3858 * Mw - 2.189



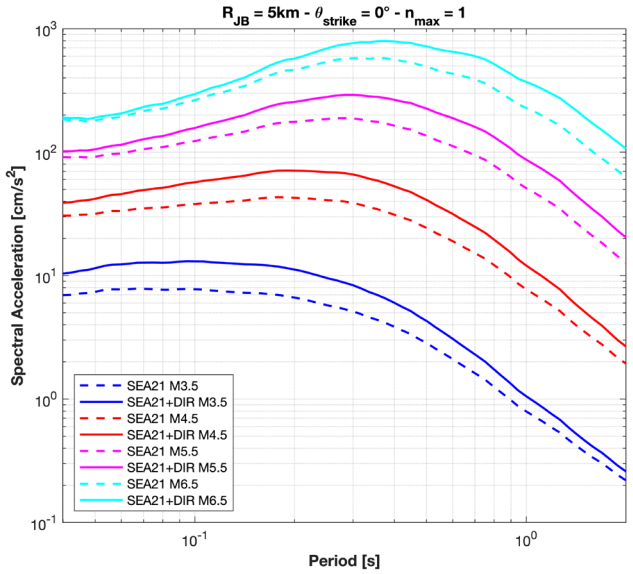
c1 = 0.2892 * nmax + 0.4583



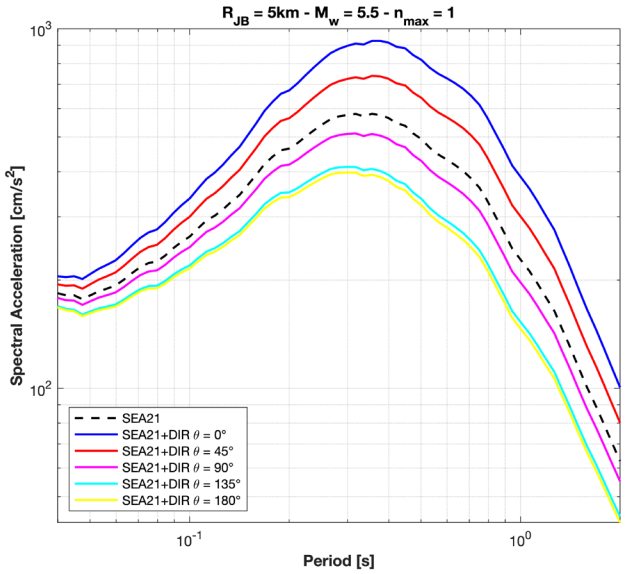


Colavitti et al., 2024 *in preparation*

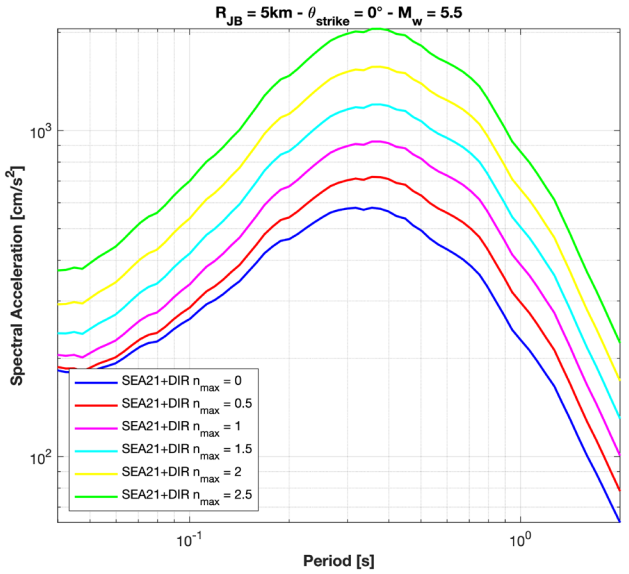
SCENARI DIRETTIVI



Effetto della Magnitudo



Effetto della posizione

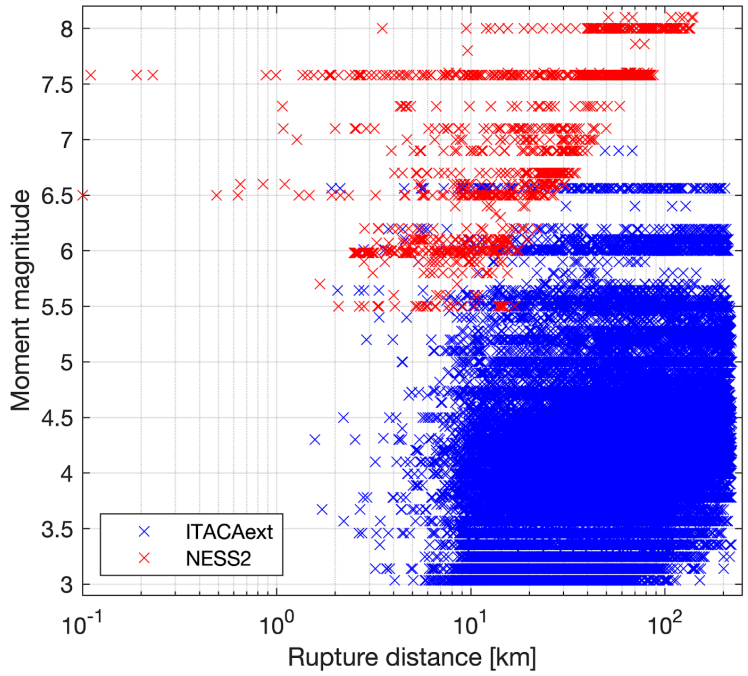


Effetto di n

REGIONALIZZAZIONE MODELLO ITALIANO

In corso lo sviluppo di un modello non-ergodico a scala nazionale

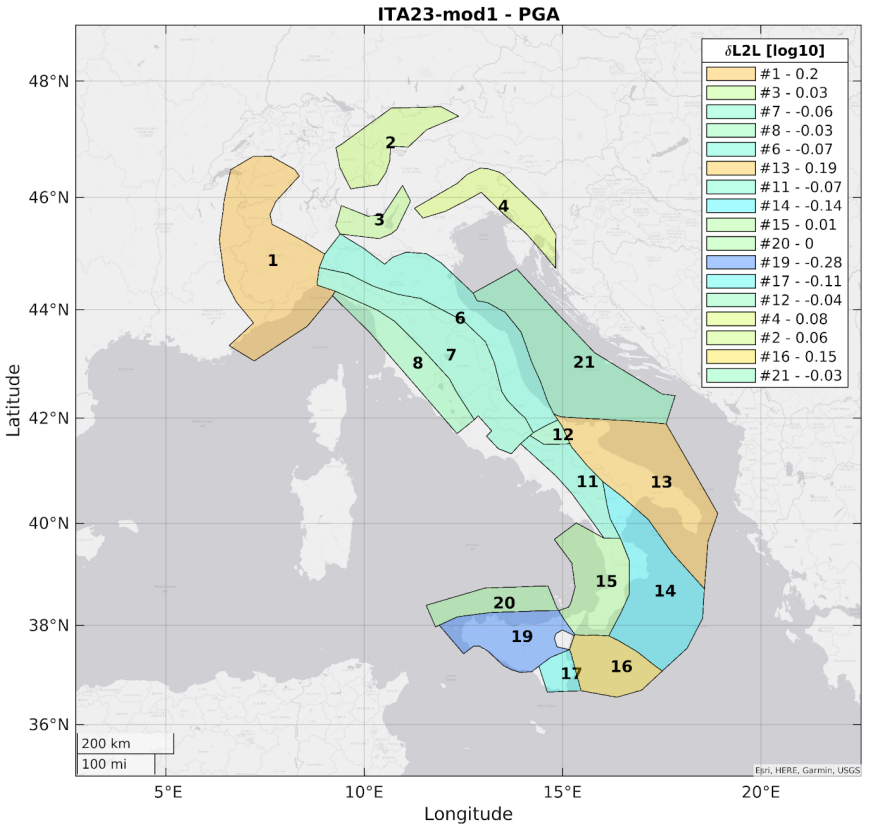
<u>Dataset ITACAext e NESS</u> per catturare sia gli effetti di campo vicino che le differenze regionali nella propagazione



Recordings: **42.887**

Events: **2.052**

Stations: **2.072**

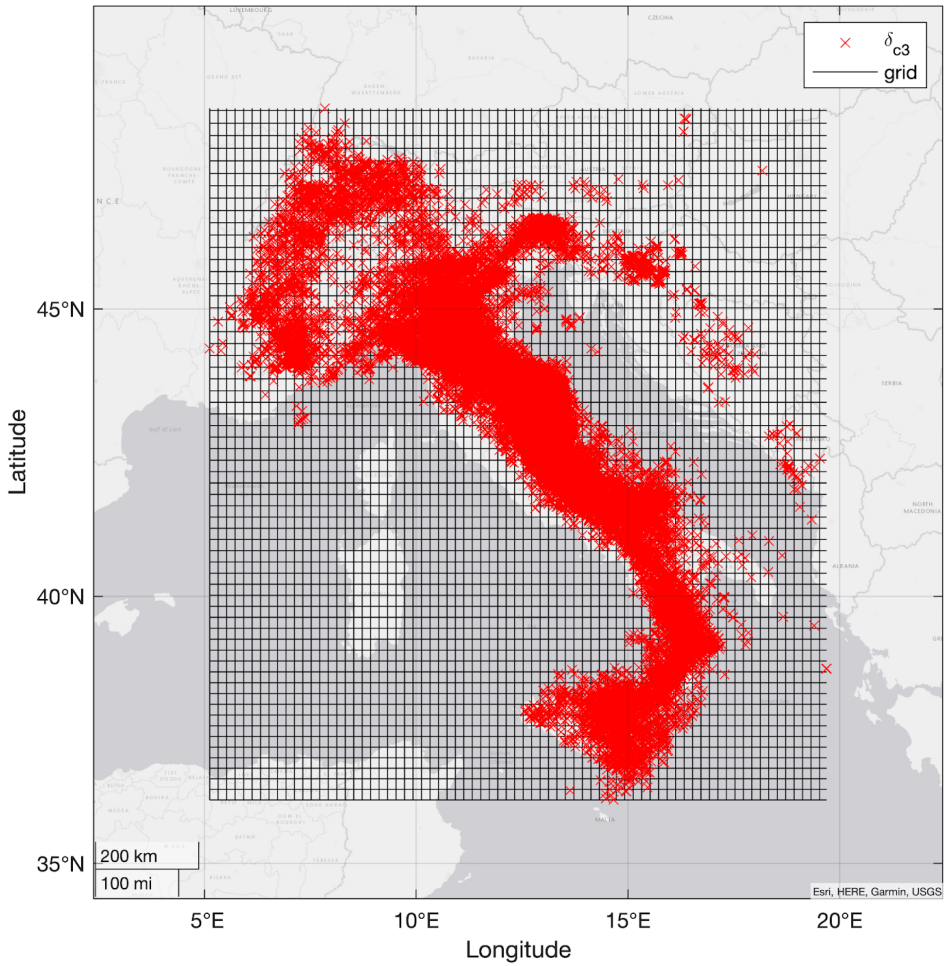


$$\log_{10}Y = a + F_M(M, SOF) + F_D(M, R) + F_S(V_{S,30}) + \delta B_e|\text{eventi} + \delta S2S_s|\text{stazioni} +$$

$$+ \delta L2L_z|\text{source\_zones} + \delta c_3(\text{radq}(R^2 + h^2)\text{-}R_r)|\text{path\_grid} + \delta W_{0,es}$$

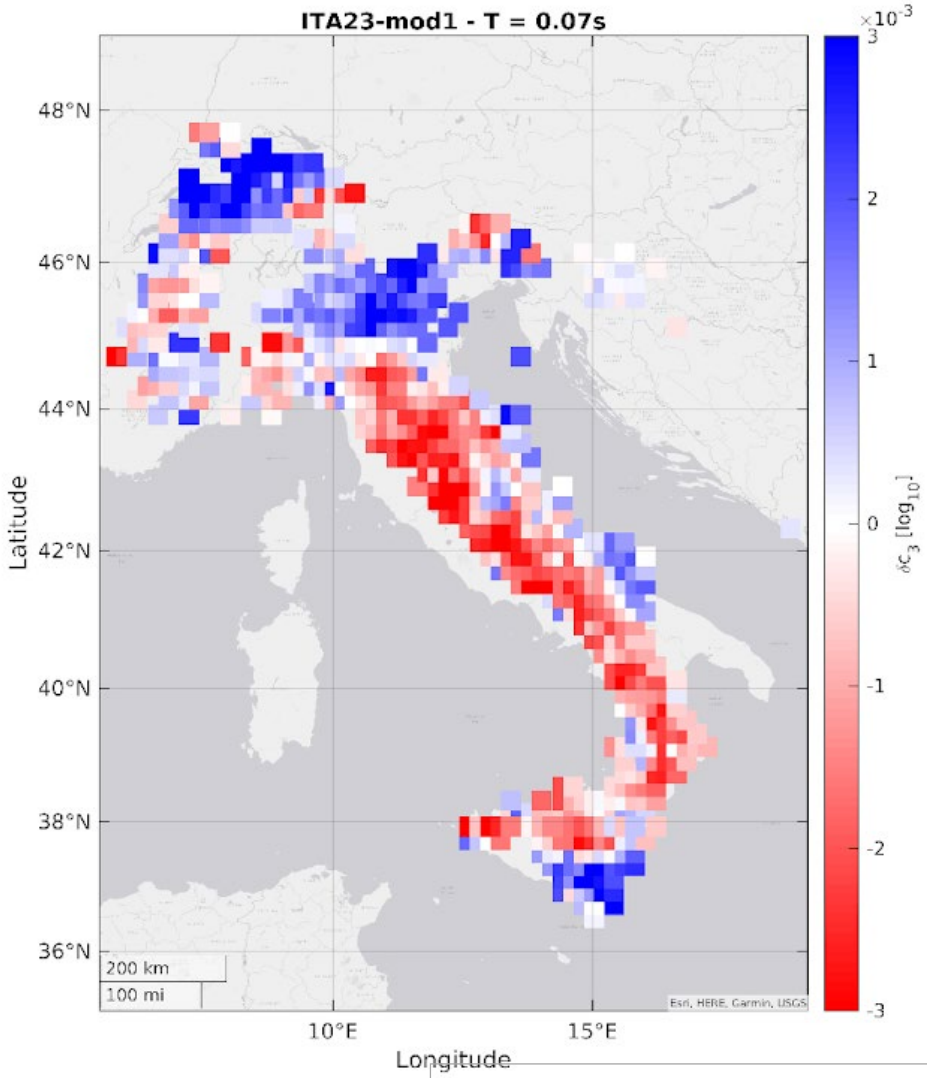
PROPAGAZIONE

path_grid: 0.2°x0.2°
Punto mediano del percorso sorgente - sito



Brunelli et al., 2023 *BGTA*

$\delta c_3(\mathrm{radq}(R^2 + h^2)\text{-}R_r)|\mathrm{path\_grid}$



Rosso:
l'attenuazione è più rapida del modello mediano

Blu:
L'attenuazione è più lenta del modello mediano

Lanzano et al., 2024 *in preparation*

SVILUPPI 2024

- ✓Stimare la variabilità epistemica del modello Italiano
- ✓Calibrare il modello NE centro Italia, con nuove stime dei parametri dei parametri sismologi
- ✓Introdurre la variabile temporale nei modelli GMM
- ✓Valutare i modelli GMM durante le sequenze sismiche
- ✓Introdurre la direttività in Fourier
- ✓Inversione degli spettri apparenti per stimare i modelli di sorgente