



# OGS

Istituto Nazionale  
di Oceanografia  
e di Geofisica  
Sperimentale

Terremoti in Trentino, Studi e strumenti per la riduzione  
del rischio sismico, 14 Maggio 2024, Trento, Italia.

## Evoluzione, progressi recenti e prospettive del monitoraggio sismico in Italia

Relatore

Matteo Picozzi

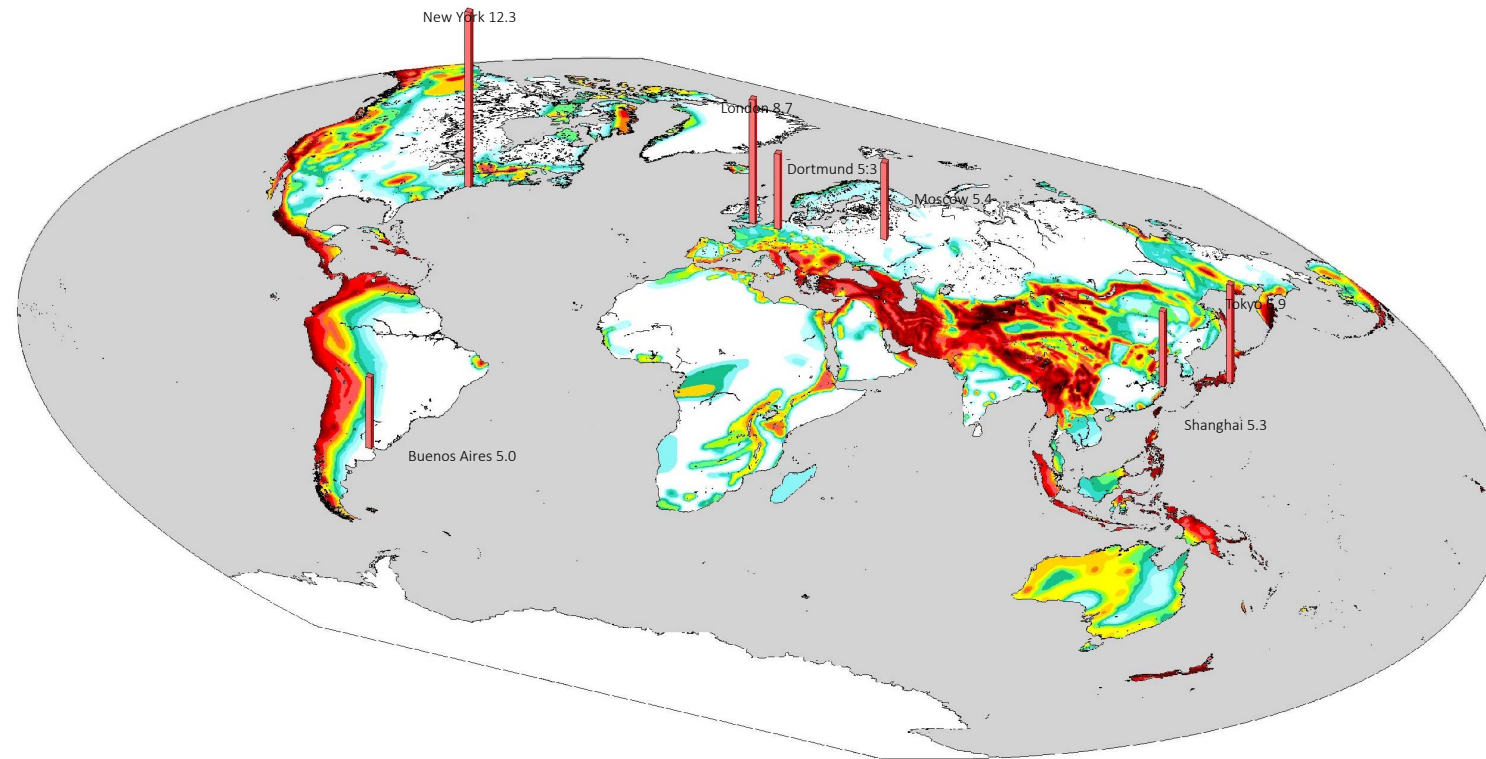
Direttore del Centro di Ricerche Sismologiche - CRS

in collaborazione con

D. Spallarossa, D. Bindi, D. Scafidi, A.G. Iaccarino, F. Cotton, V.  
Poggi, E. Rivalta, e molti altri



# Mappa GSHAP e città con +5 milioni di popolazione 7 nel 1950



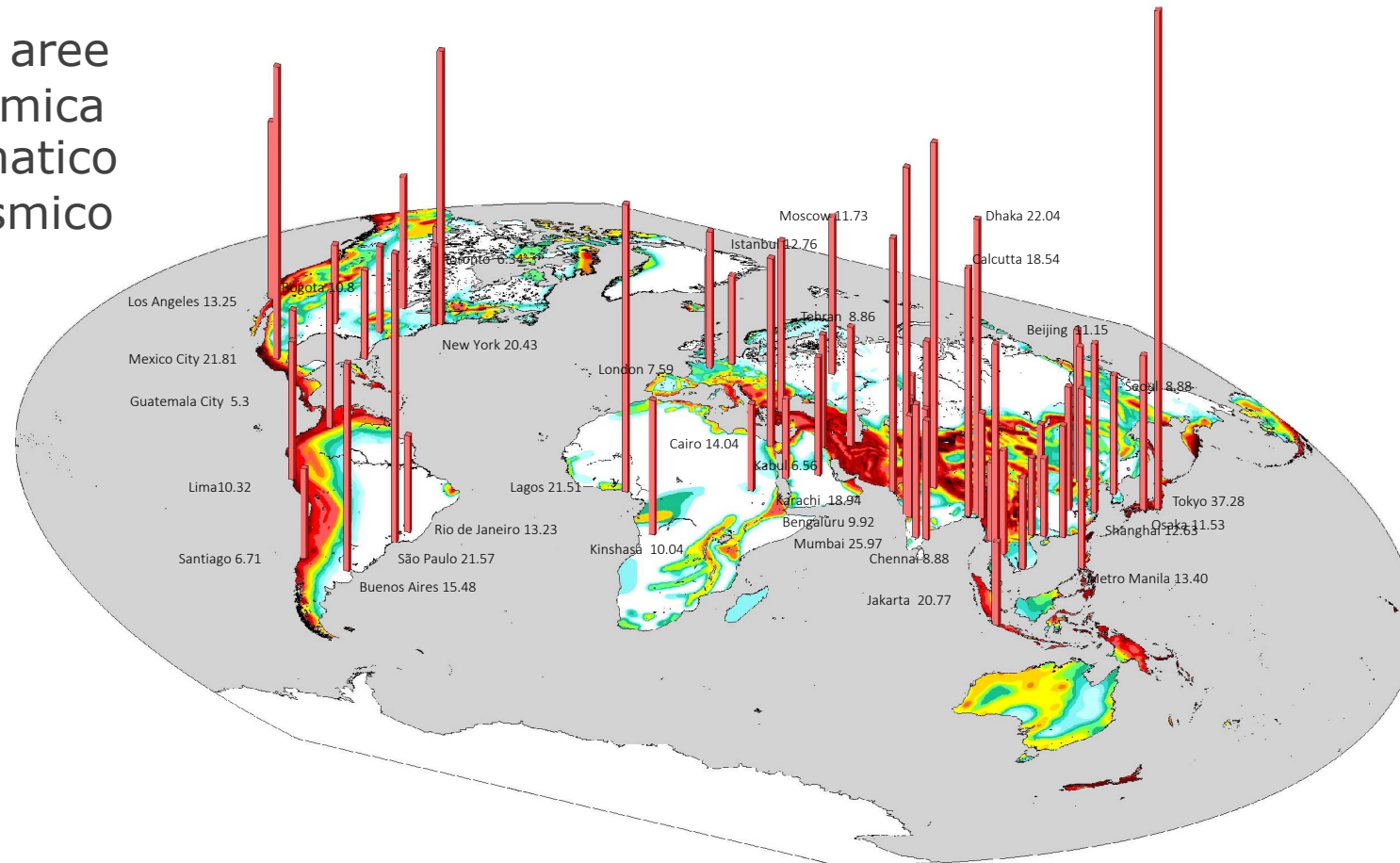


# Mappa GSHAP e città con +5 milioni di popolazione

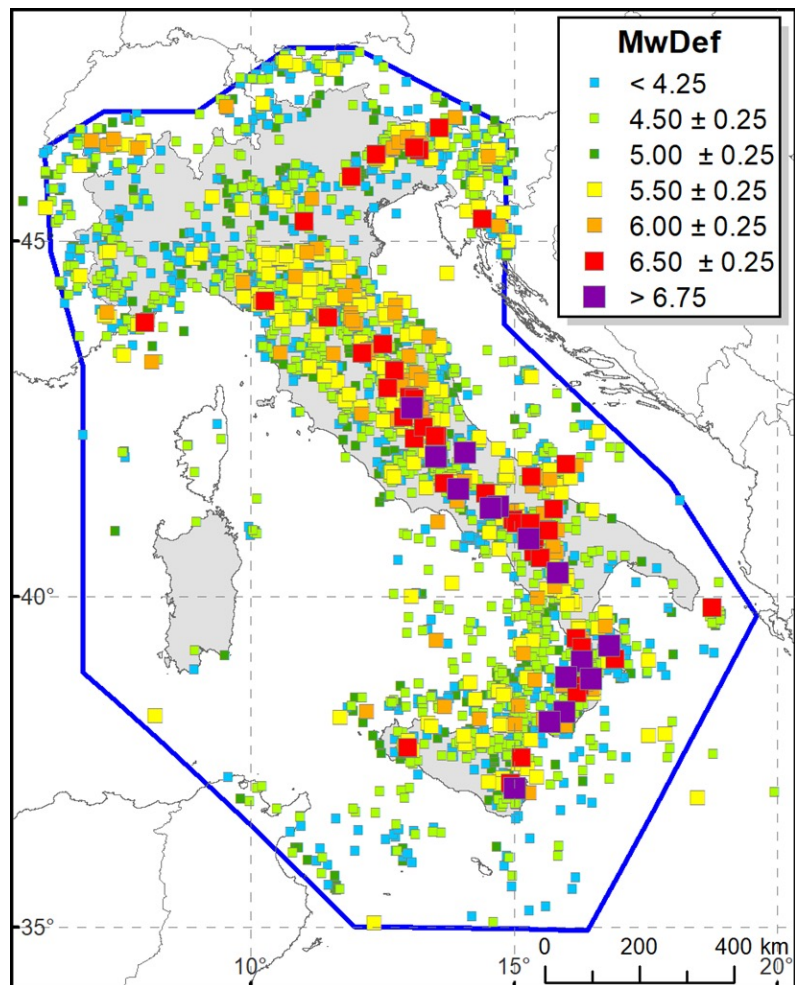
*7 nel 1950*

*2015, 60 città > 5 milion*

L'esplosione urbana in aree ad alta pericolosità sismica è seguita da un drammatico aumento del rischio sismico

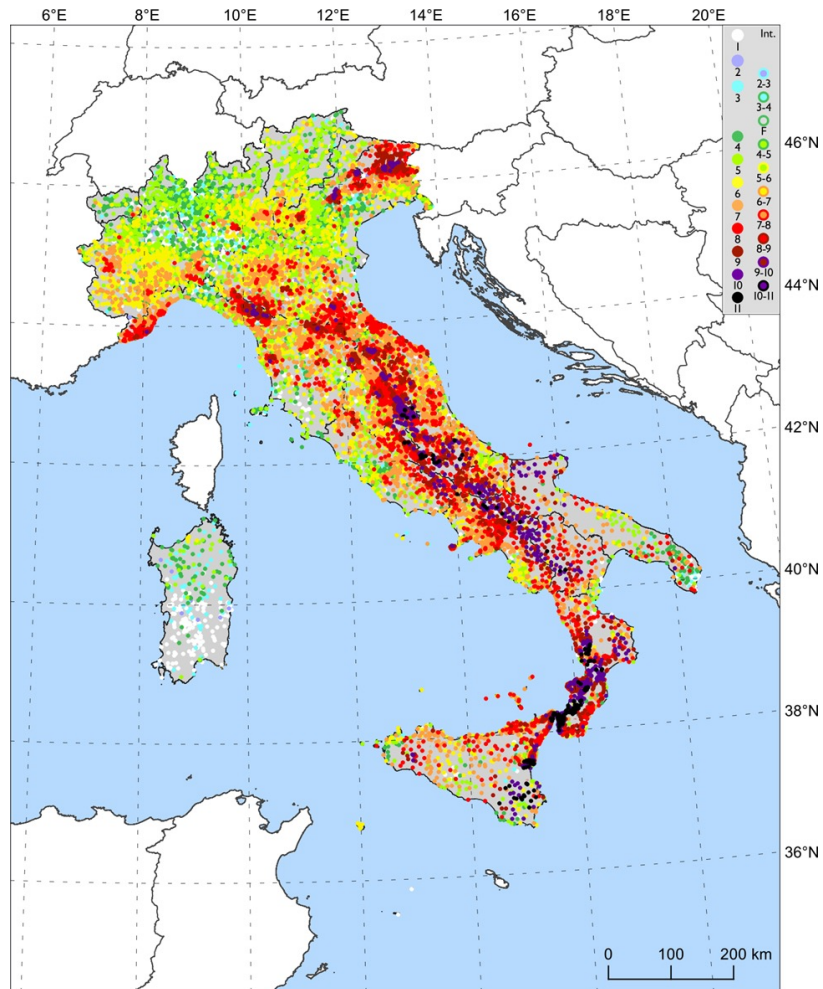


## Catalogo Parametrico dei Terremoti Italiani



<https://emidius.mi.ingv.it/CPTI/>

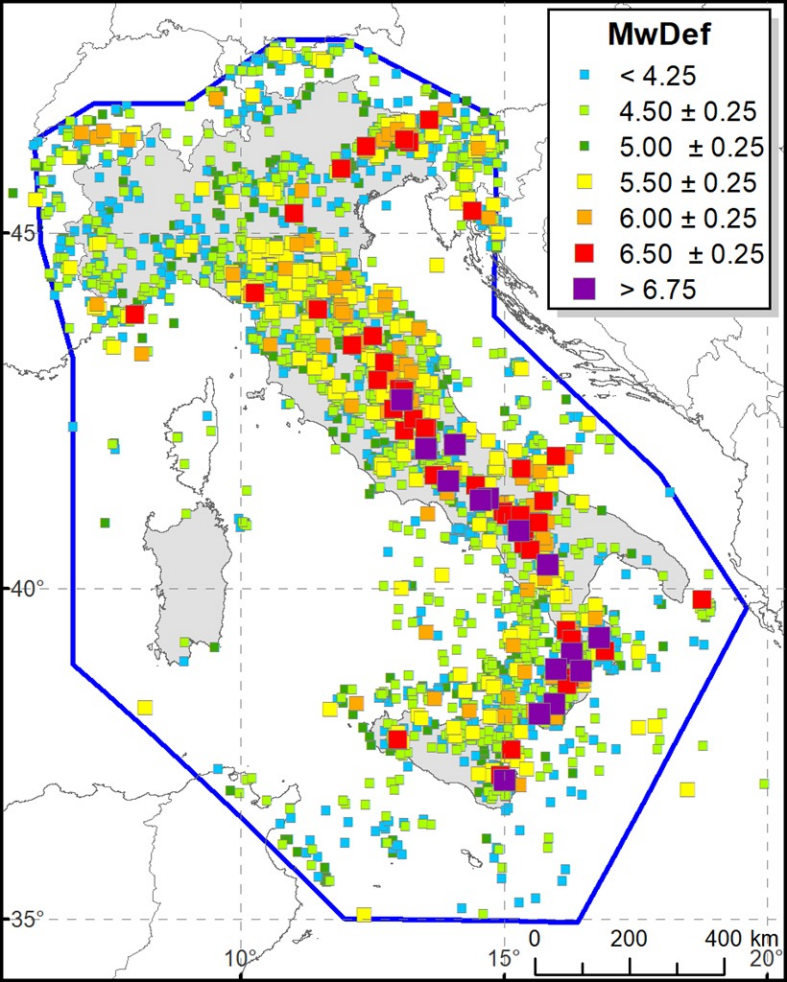
## Mappa delle massime intensità macrosismiche



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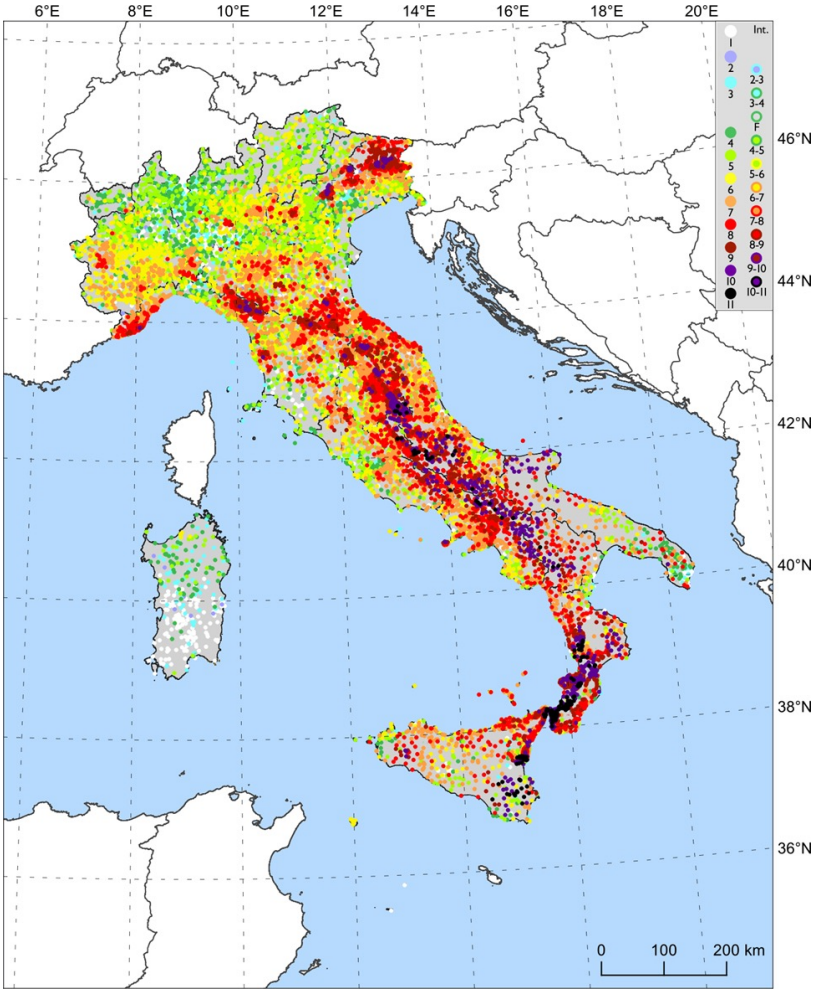


Catalogo Parametrico dei Terremoti Italiani

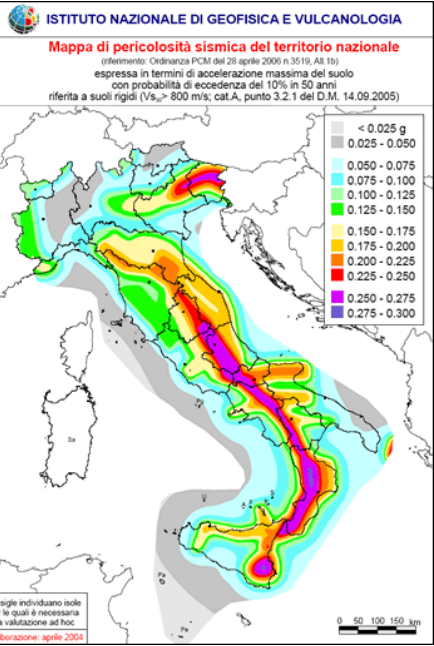


<https://emidius.mi.ingv.it/CPTI/>

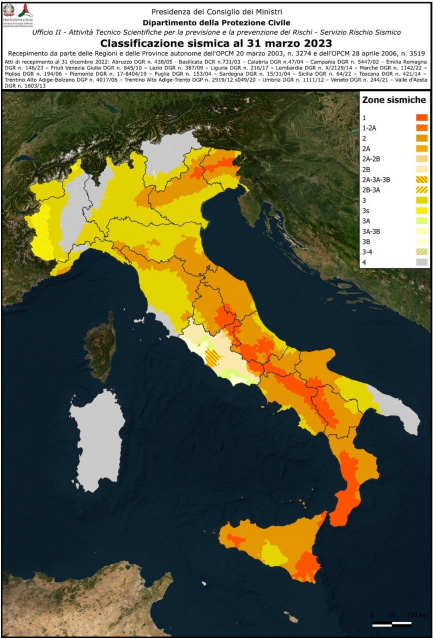
Mapa delle massime intensità macrosismiche



<https://emidius.mi.ingv.it/CPTI15-DBMI15/>



<http://zonesismiche.mi.ingv.it>  
<https://rischi.protezionecivile.gov.it>







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**open access to harmonized and interoperable scientific data and products applying FAIR principles**



## Servizio STATION

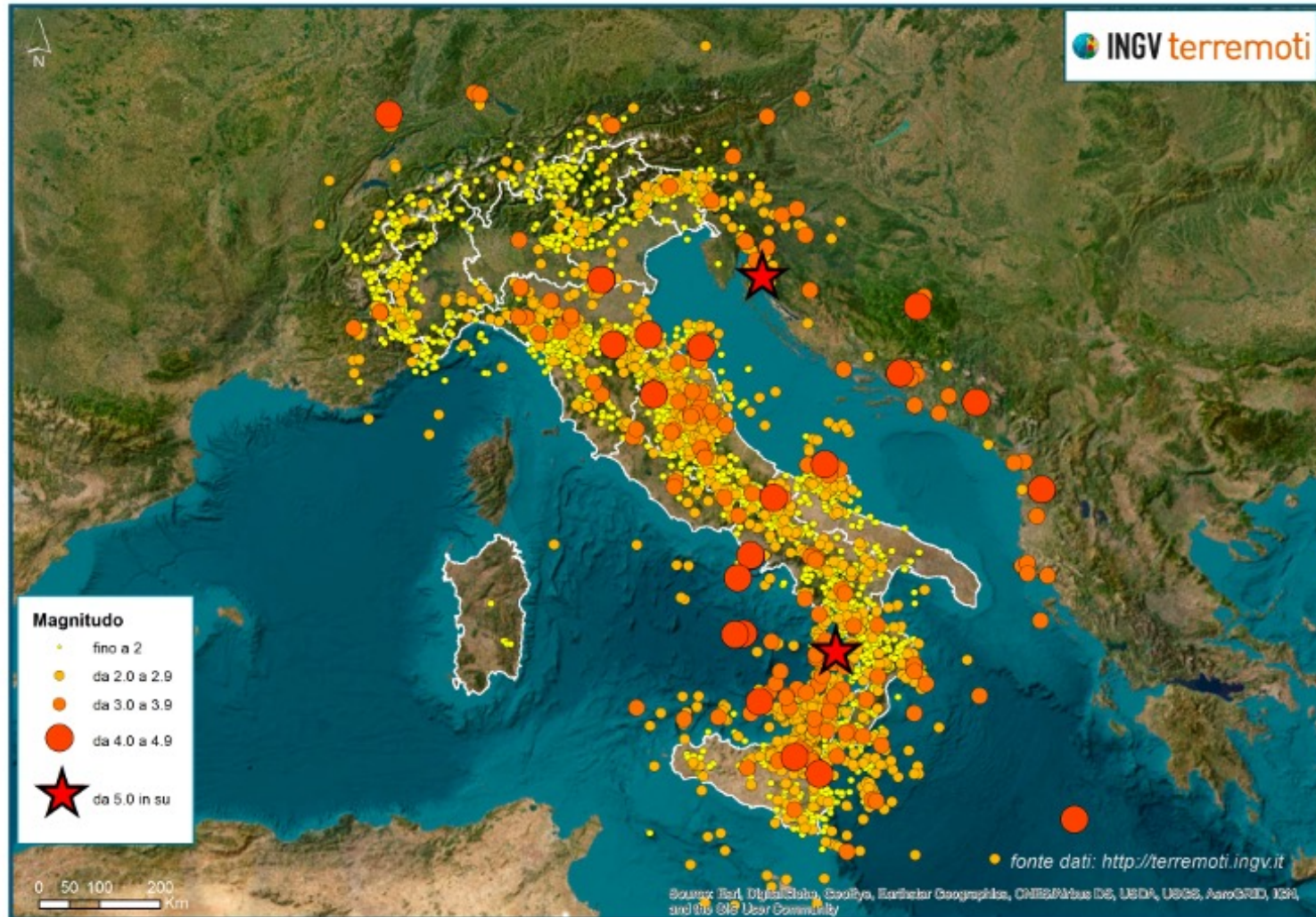
(Seismic sTATION and slte amplificatiON)



<https://distav.unige.it/rsni/station.php?lang=en>



# In Italia nel 2023 sono stati 16.307 i terremoti registrati



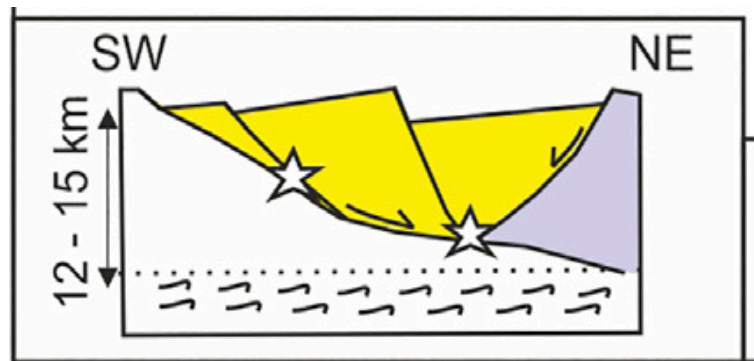
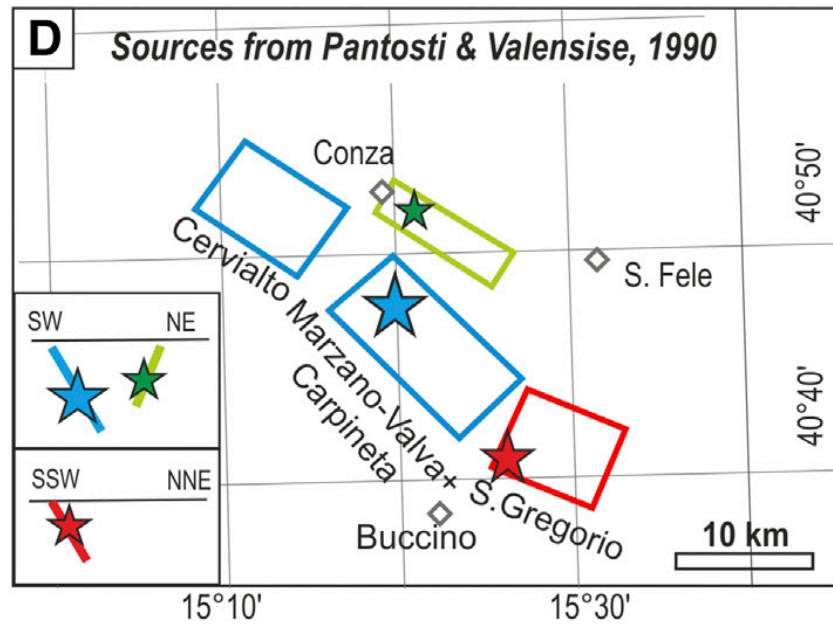
## I numeri del 2023

**16307** terremoti registrati e localizzati.

**2018** terremoti di magnitudo tra 2.0 e 2.9,  
**233** terremoti di magnitudo compresa tra 3.0 e 3.9,  
**26** terremoti di magnitudo compresa tra 4.0 e 4.9,  
**2** eventi di magnitudo superiore o uguale a 5.0

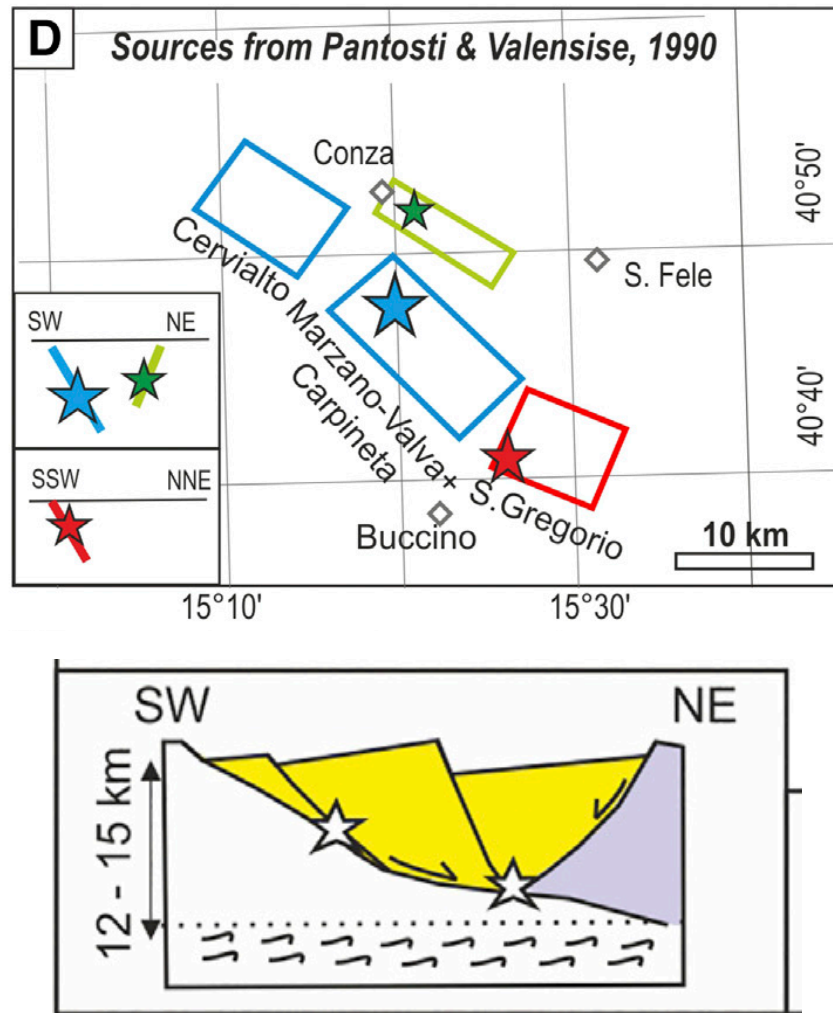
È lecito chiedersi,  
qual'è l'utilità nel  
registrare tutti  
questi terremoti?

## Ricostruzione schematica del terremoto Campano-Lucano del 1980



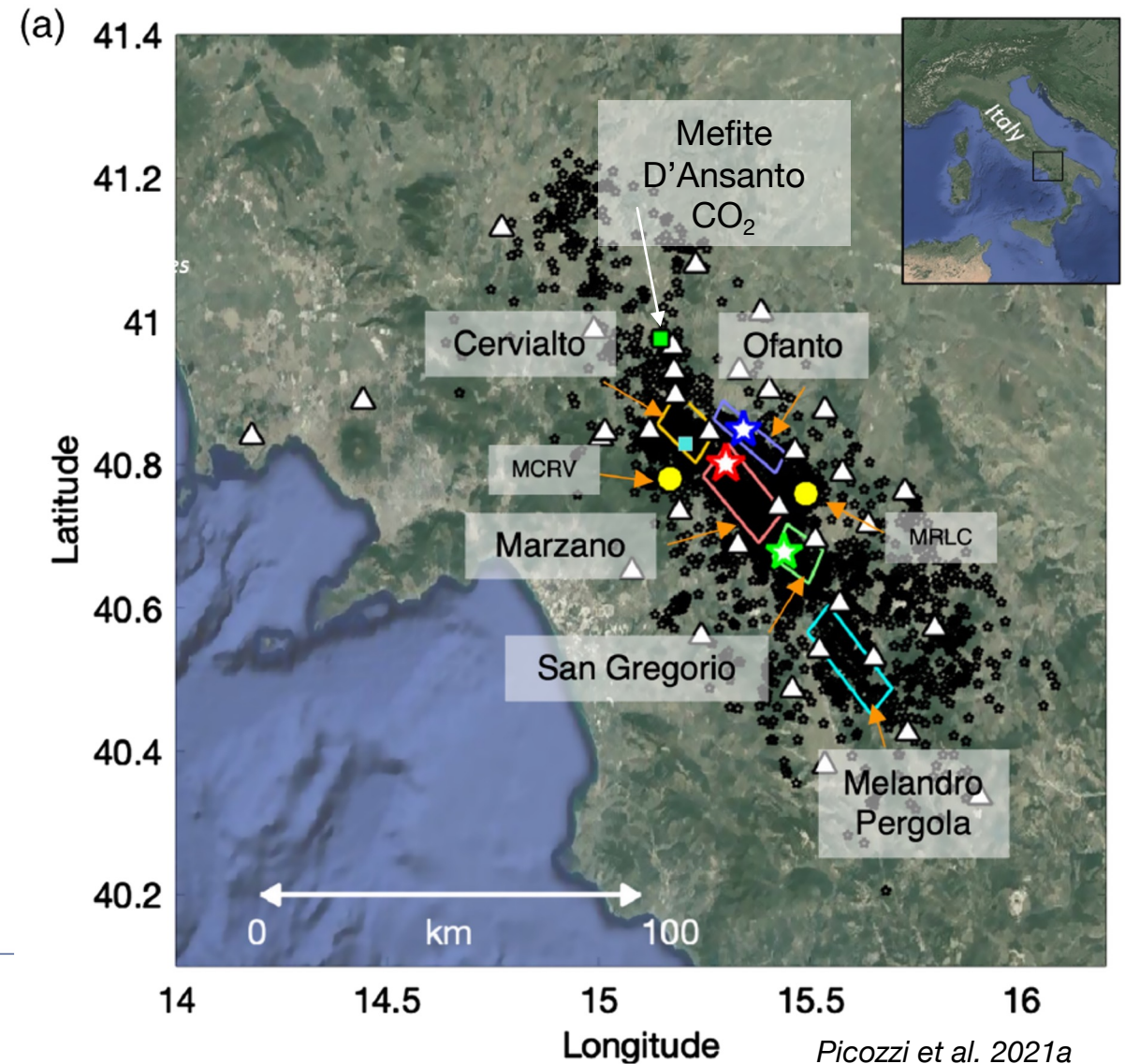


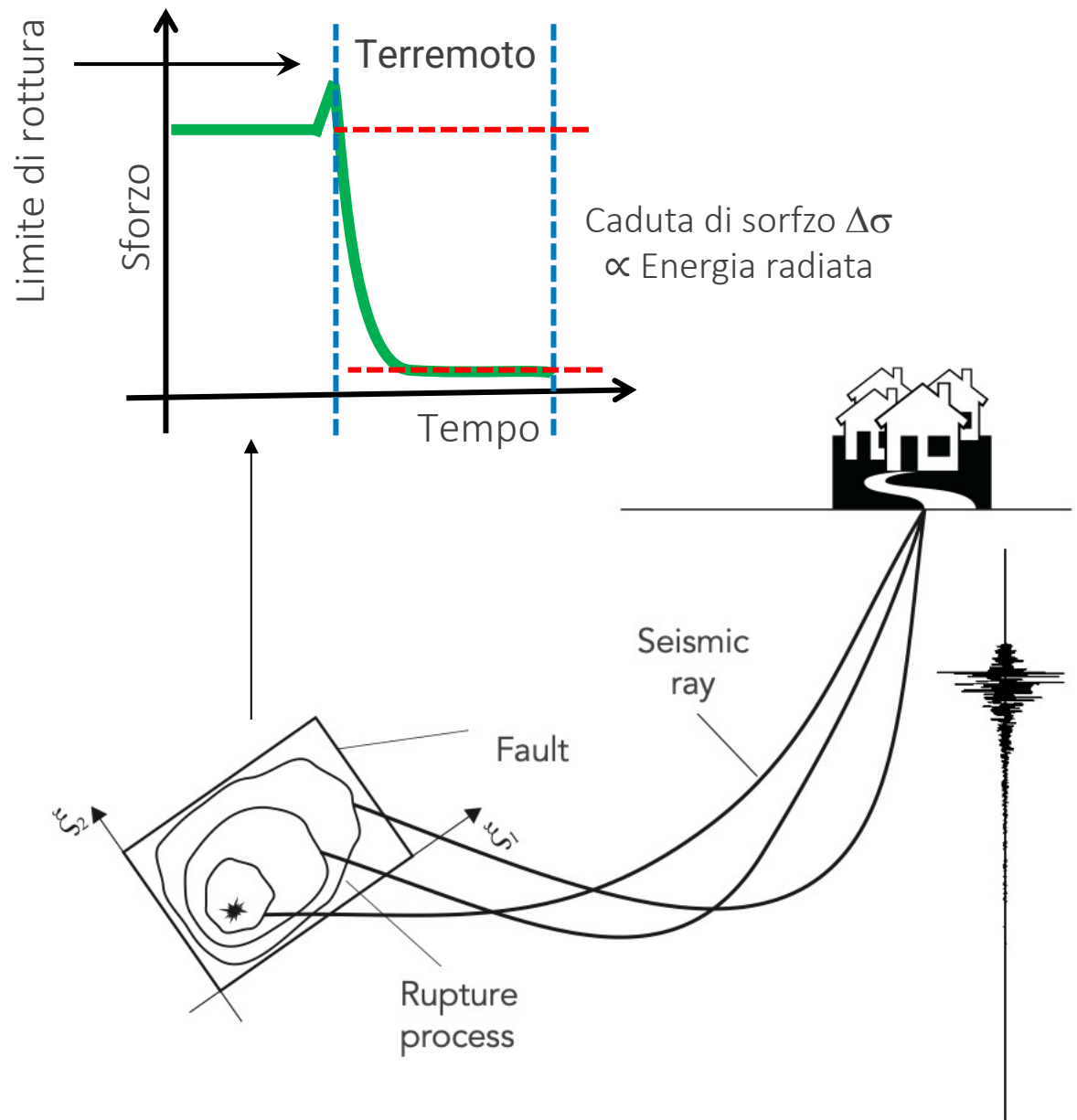
## Ricostruzione schematica del terremoto Campano-Lucano del 1980



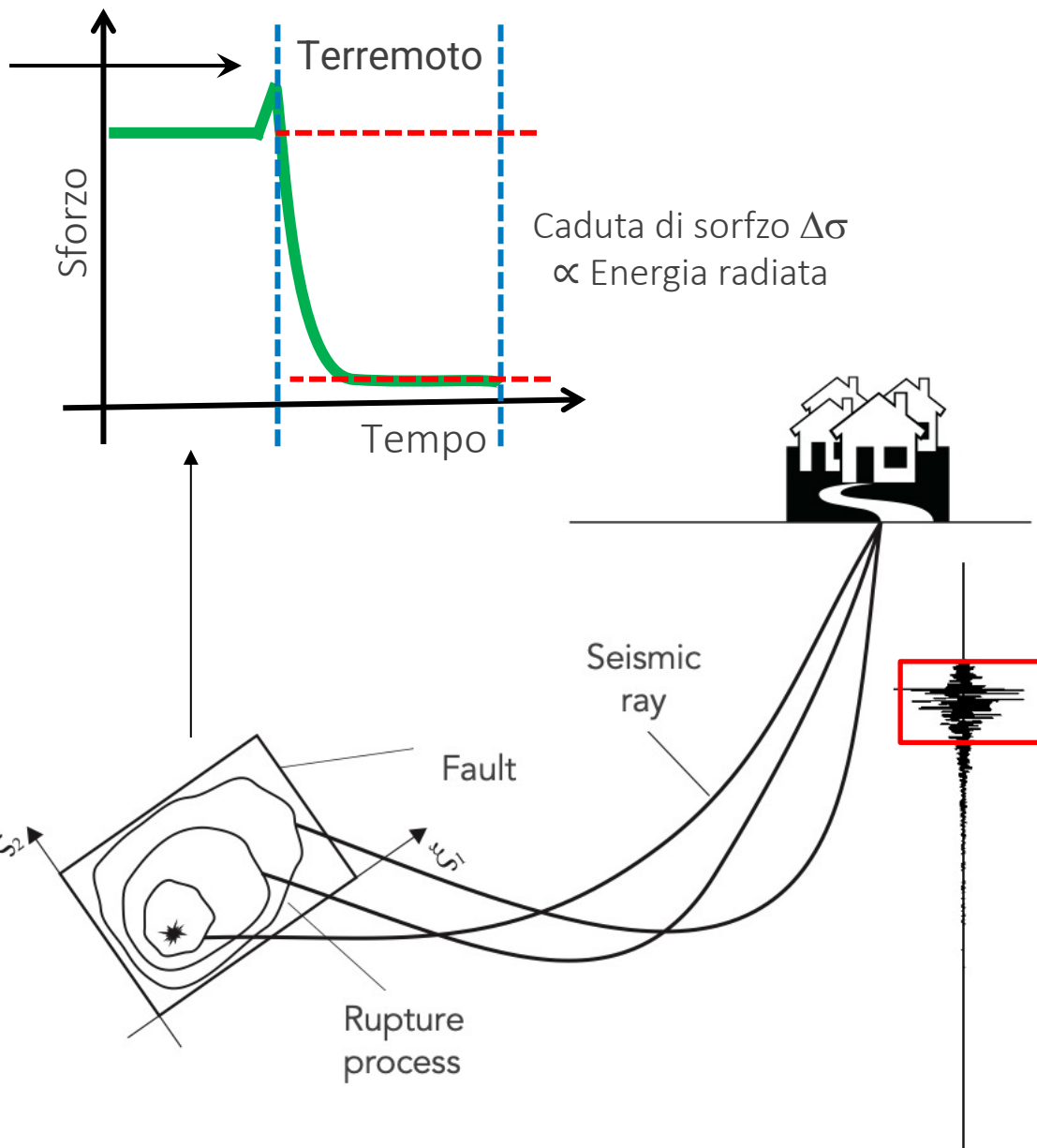
## DATASET

- 3016 earthquakes (2007-2020)
- 36200 acceleration and velocity waveforms

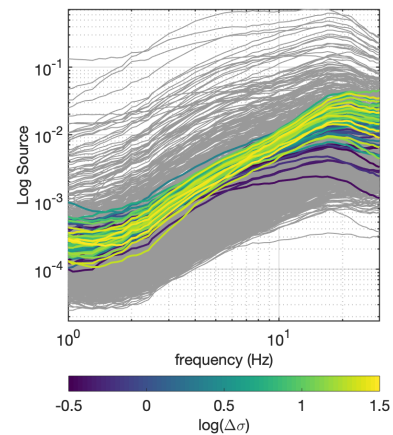




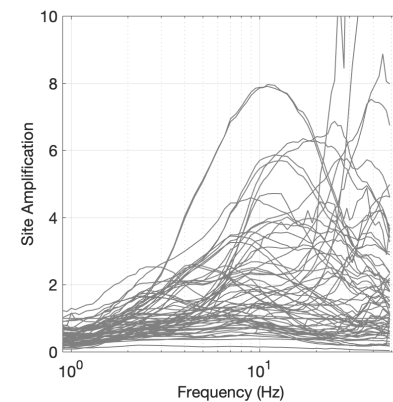
Limite di rottura



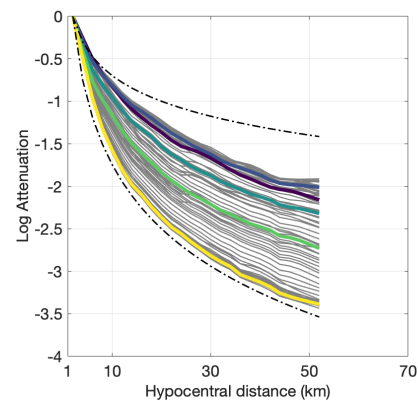
## Sorgente



## Risposta di sito

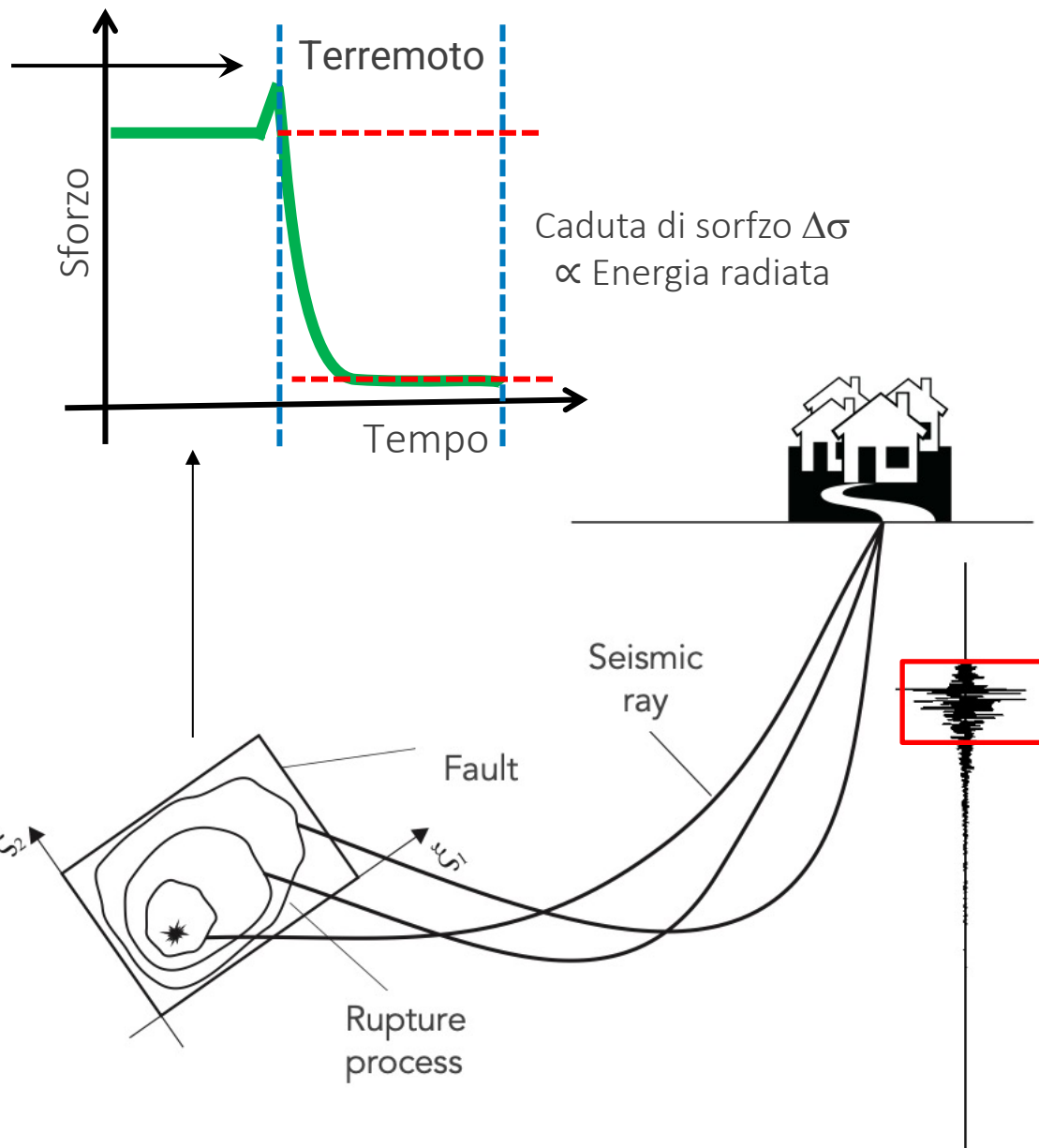


## Attenuazione

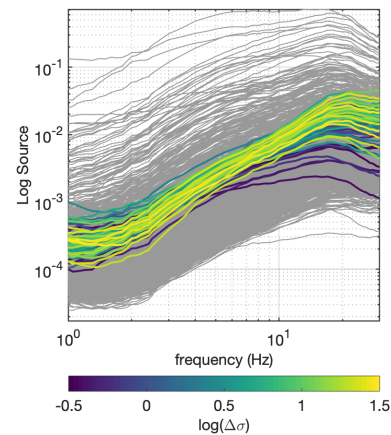




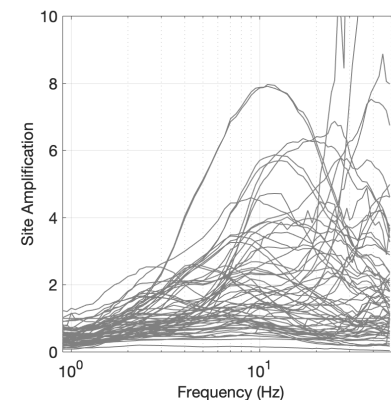
Limite di rottura



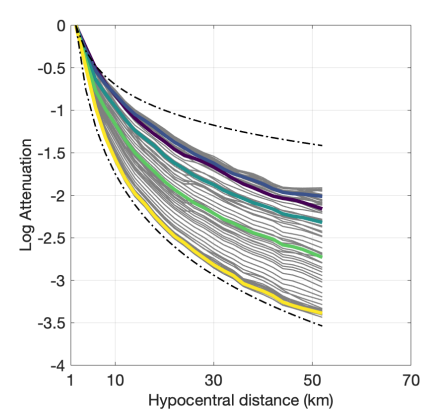
## Sorgente



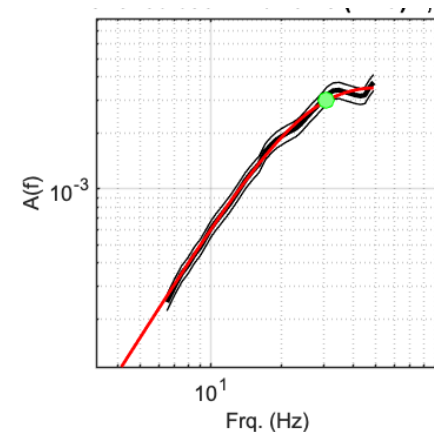
## Risposta di sito



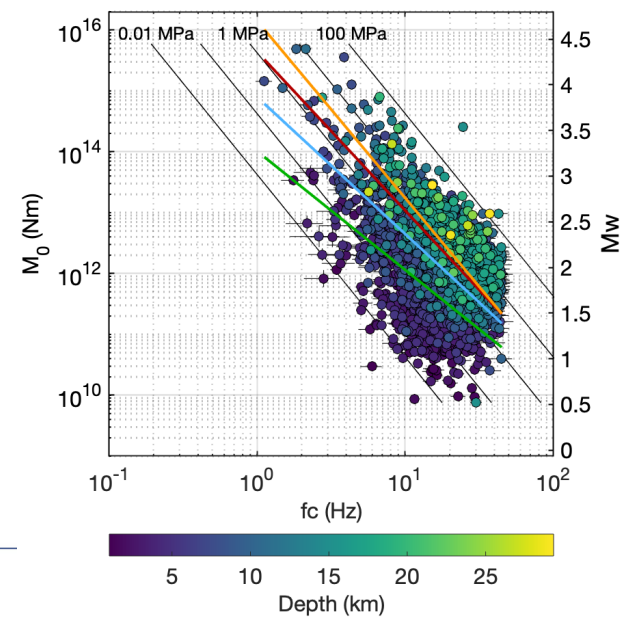
## Attenuazione



## Modellazione

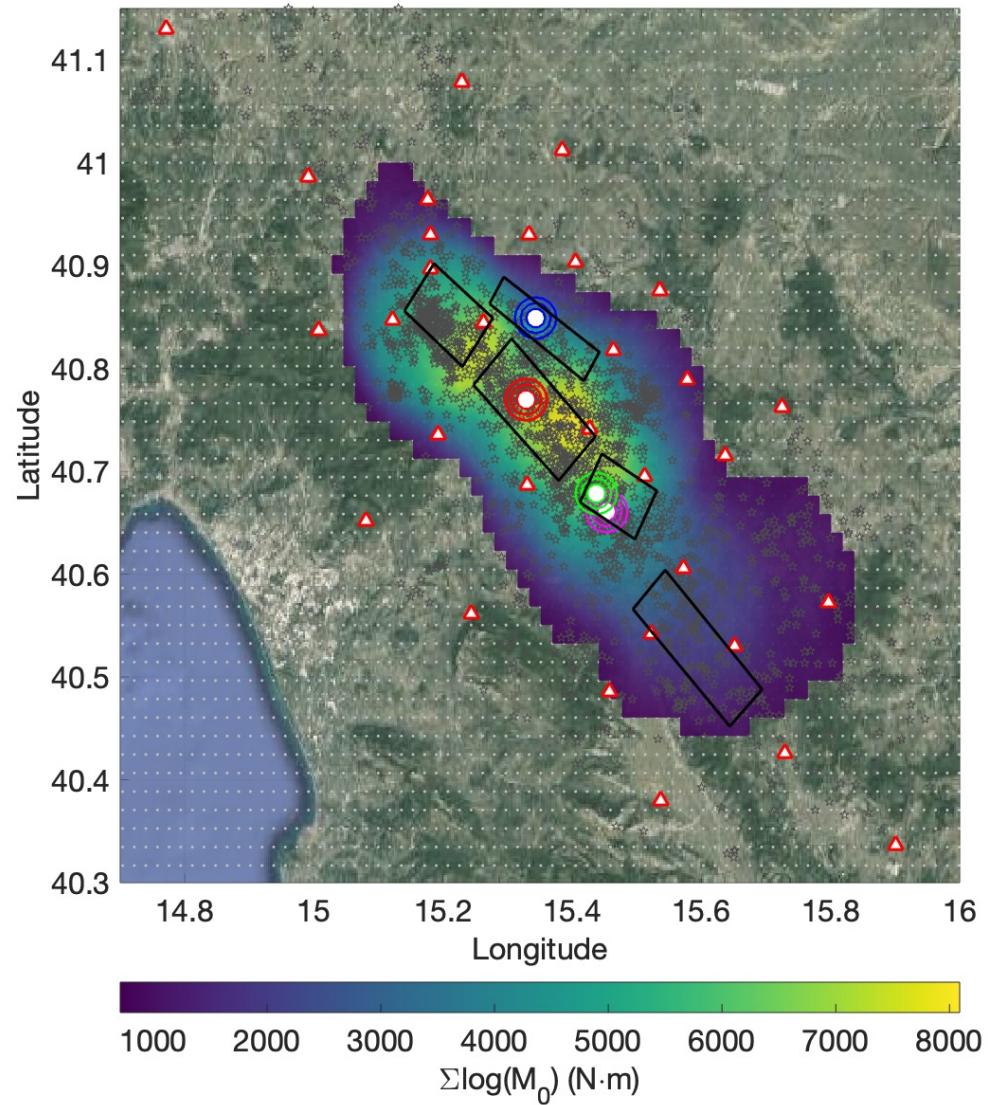


## Dimensione sorgenti e cadute di sforzo

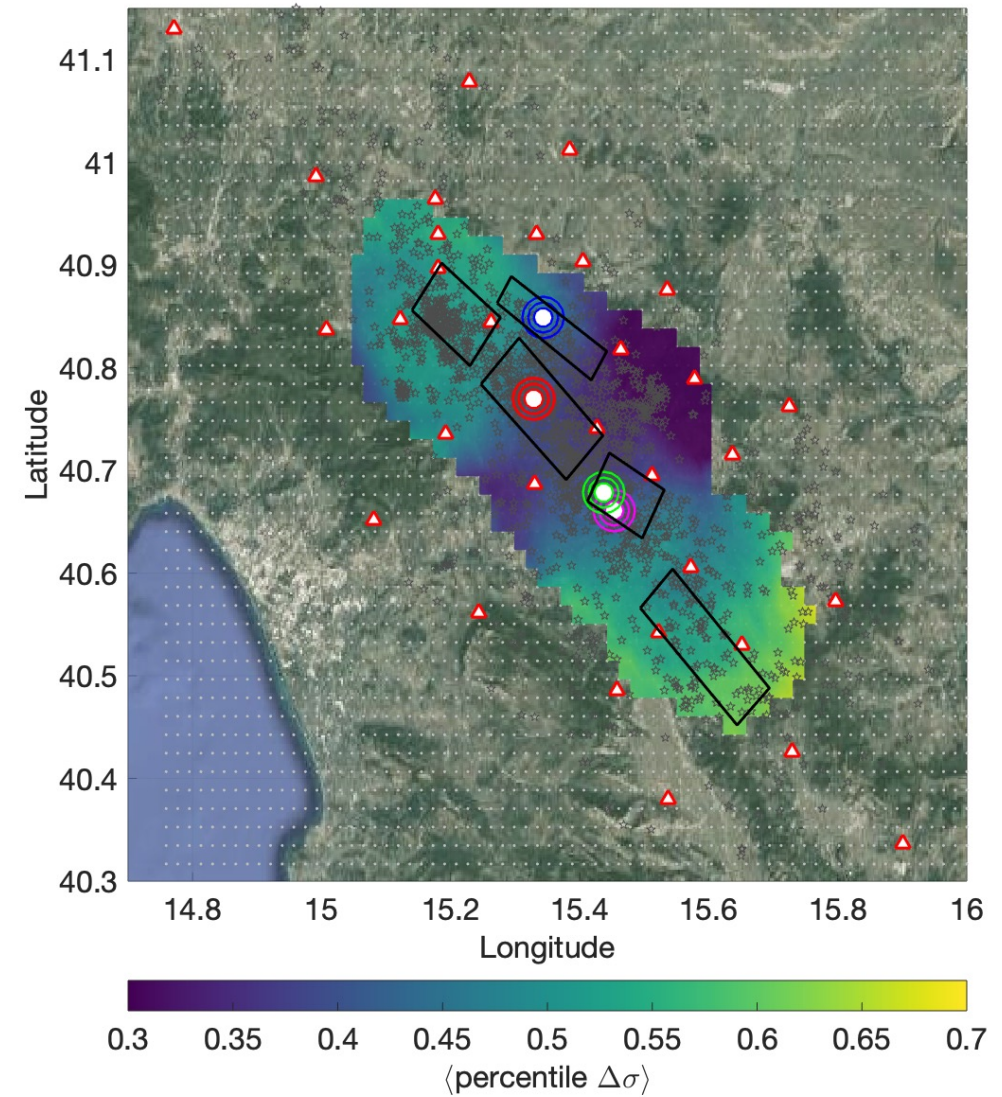


2007-2020

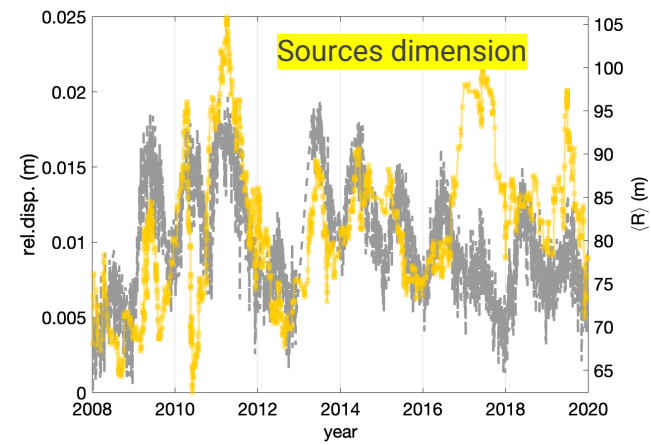
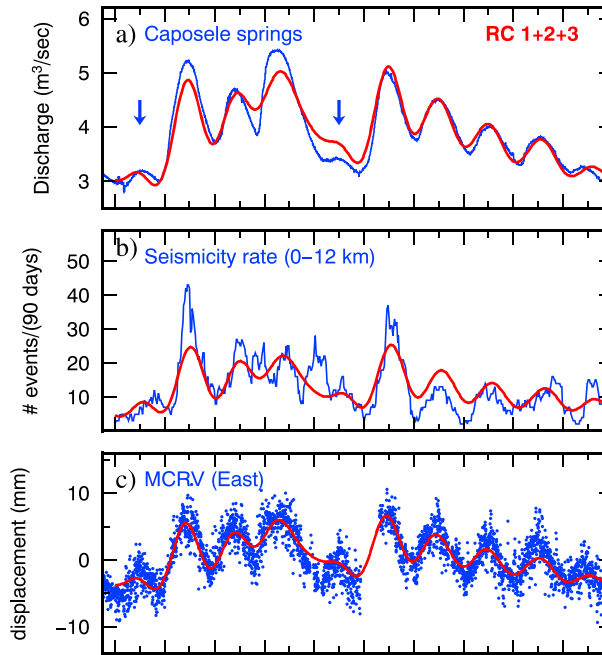
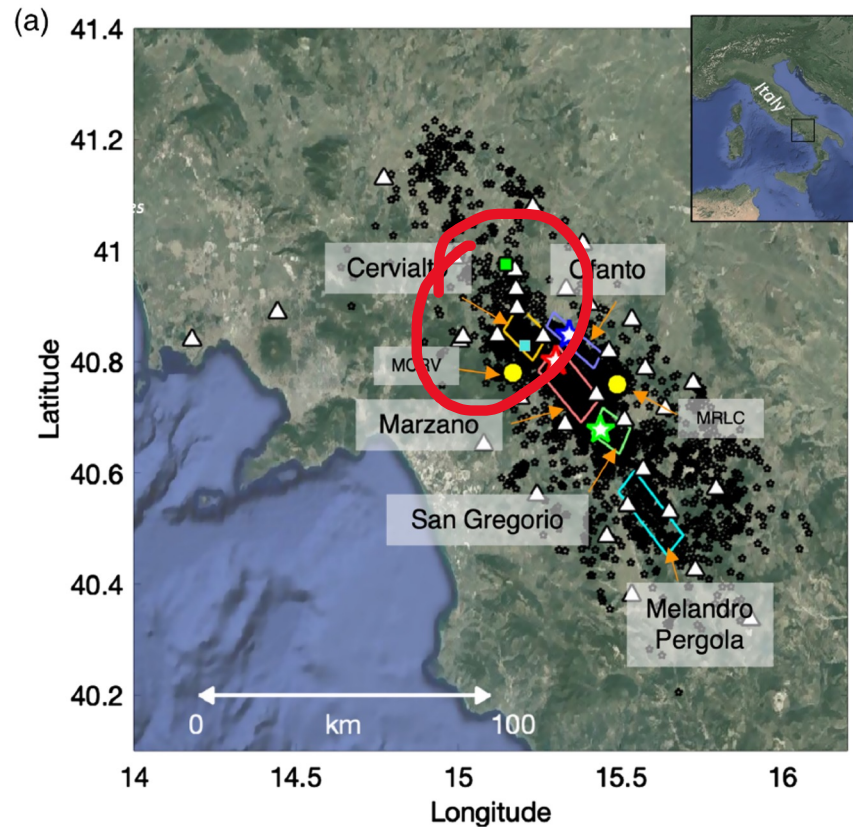
Accumulo della rottura



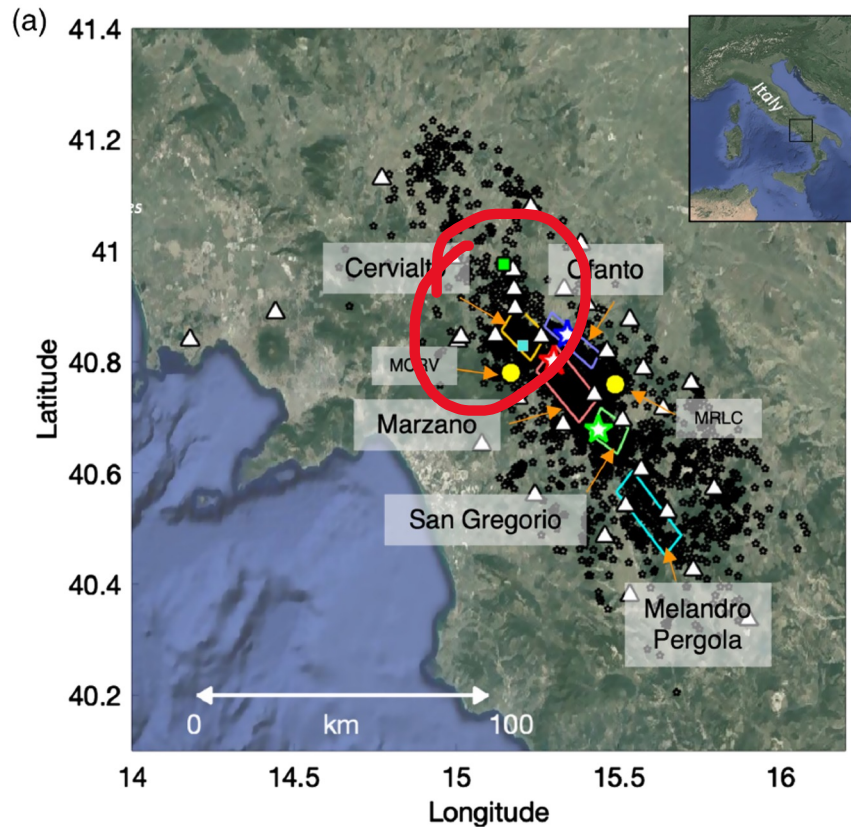
Anomalie nella Caduta di Sforzo



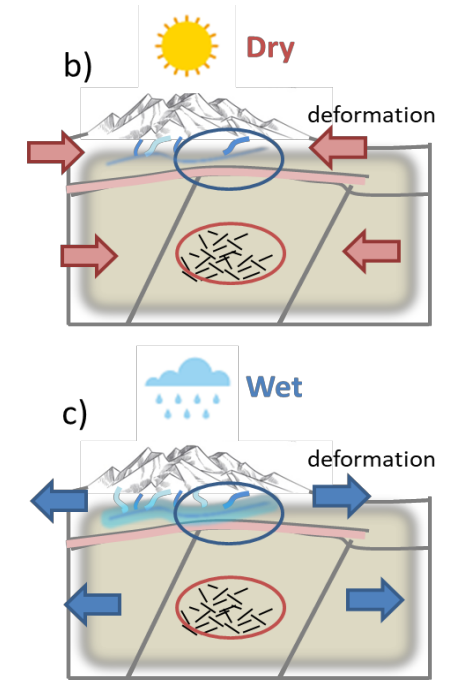
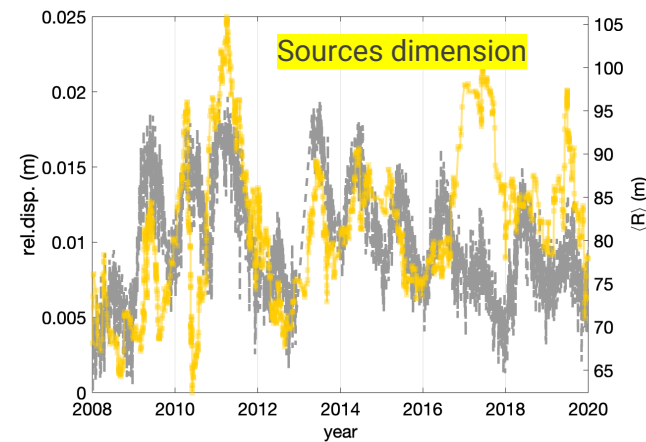
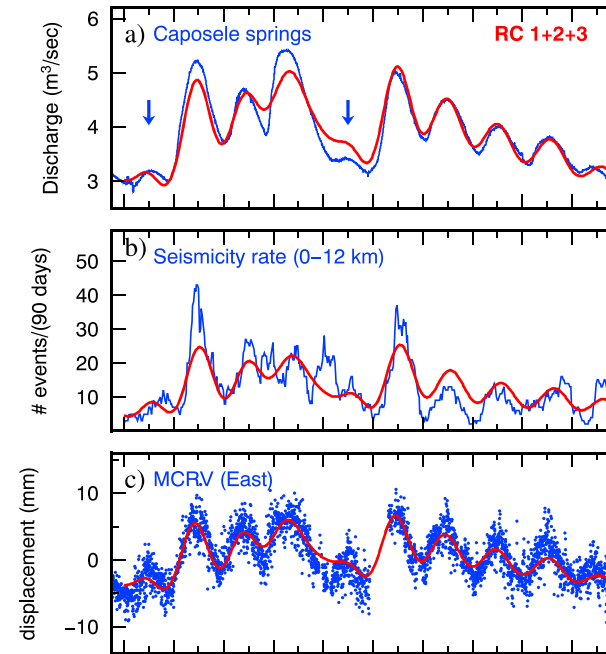






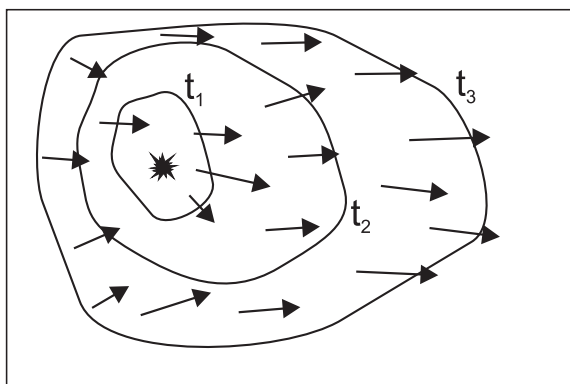


*D'Agostino et al. 2018*

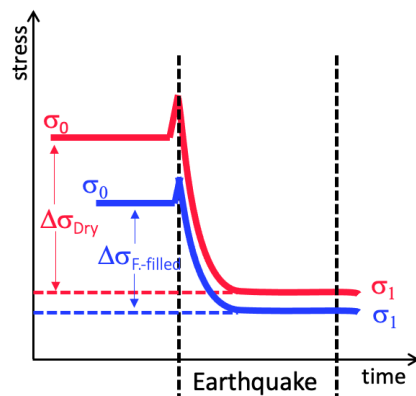
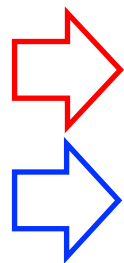


*De Landro et al. 2023*

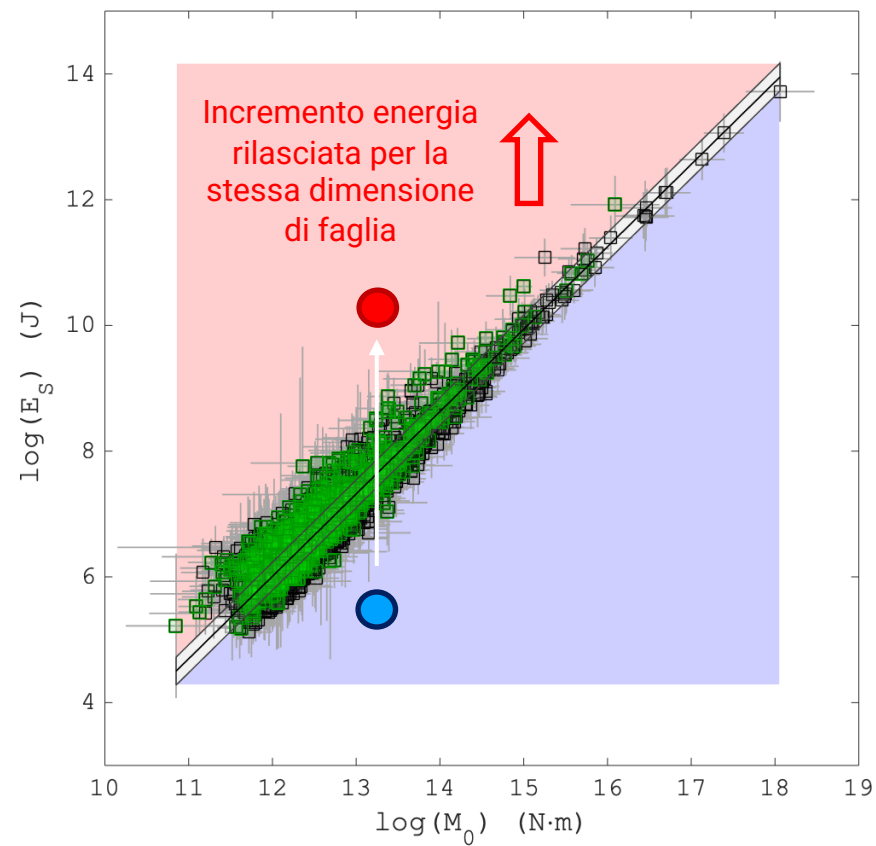
Le deformazioni  
poroelastiche generate  
dalla ricarica dell'acquifero  
carsico modulano il tasso  
di occorrenza della  
microsismicità e le sue  
caratteristiche



Momento sismico ( $M_0$ )  $\rightarrow$  Dimensione sorgente

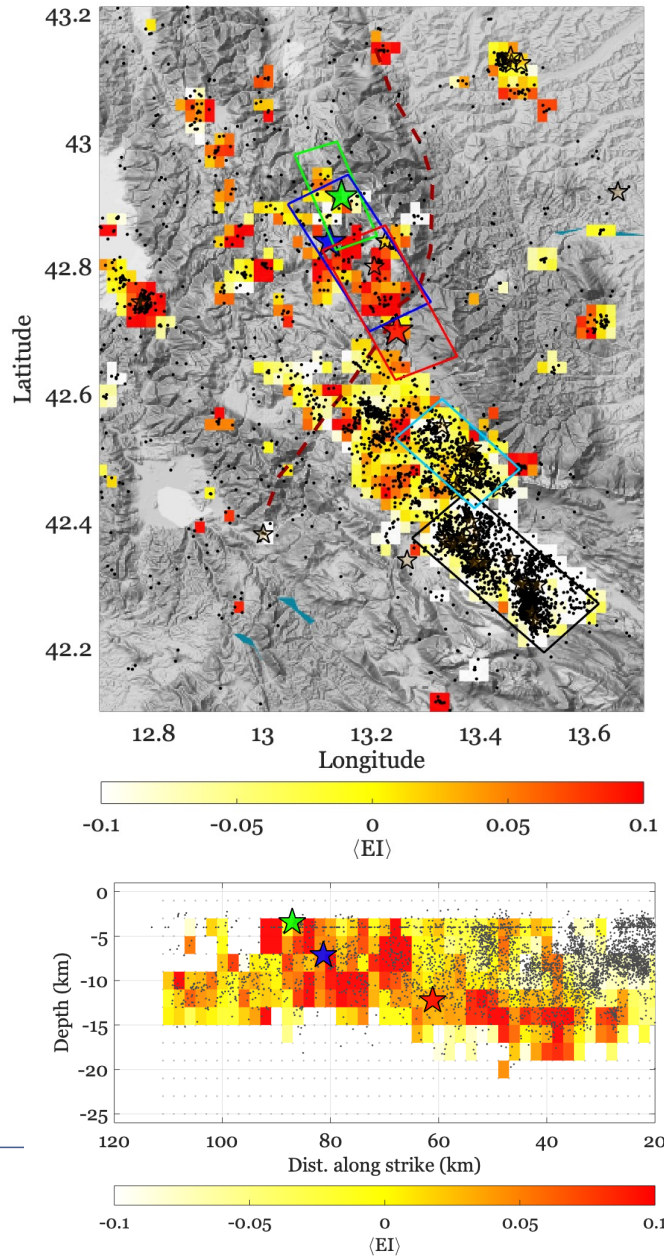
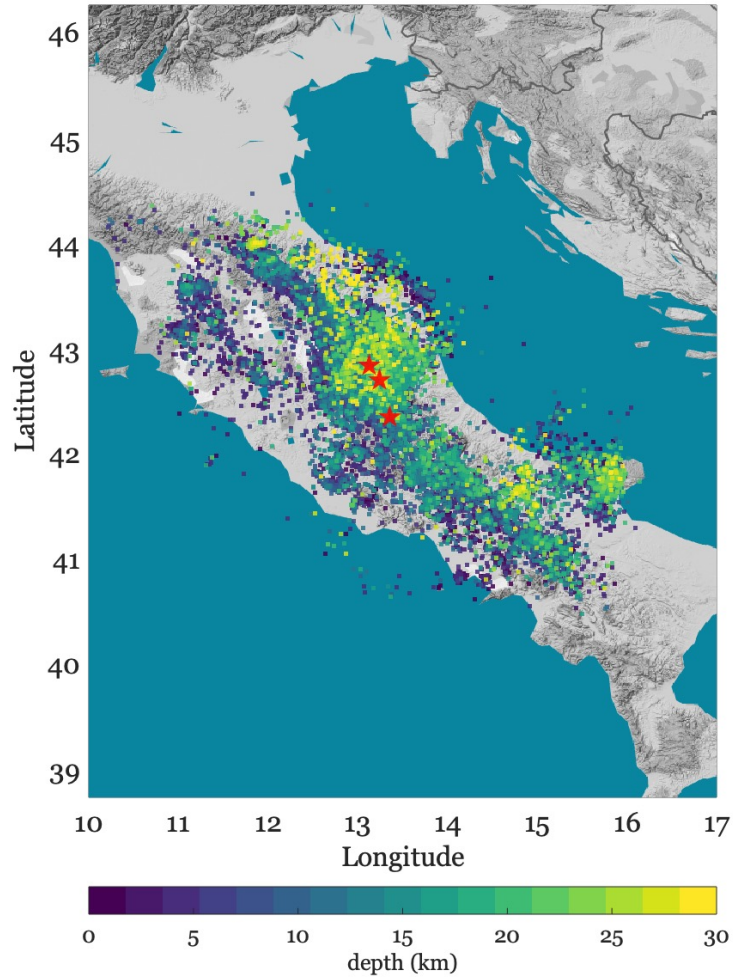


$\Delta\sigma \propto$  Energia radiata ( $E_s$ )



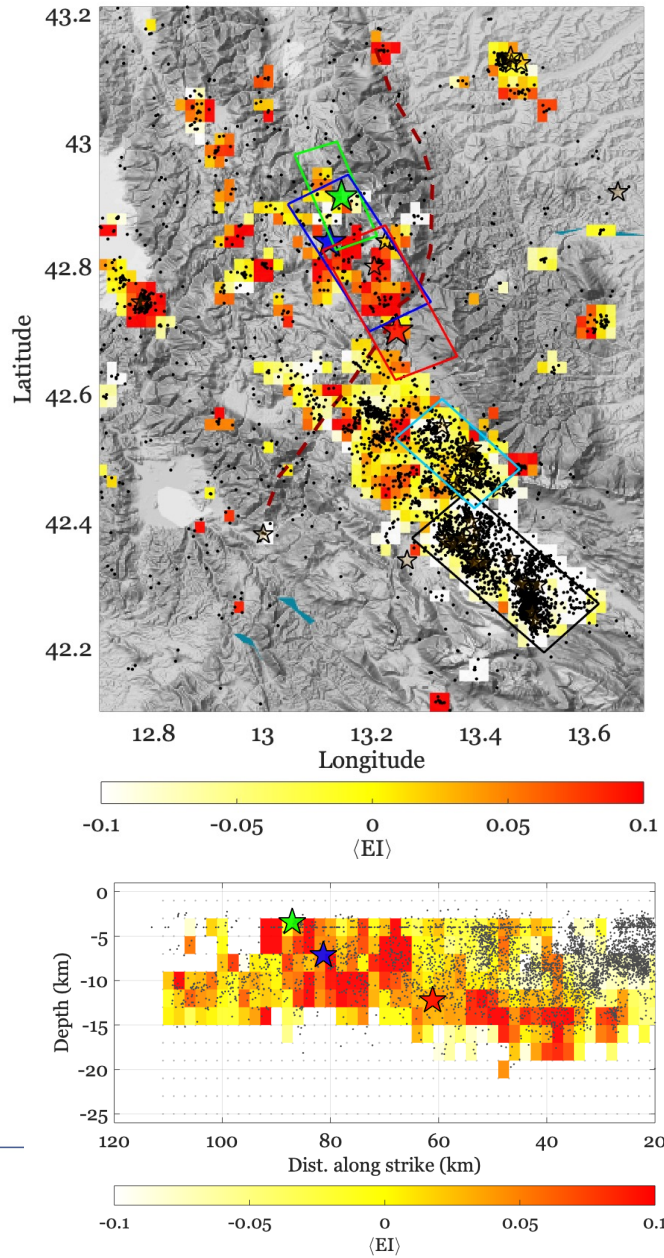
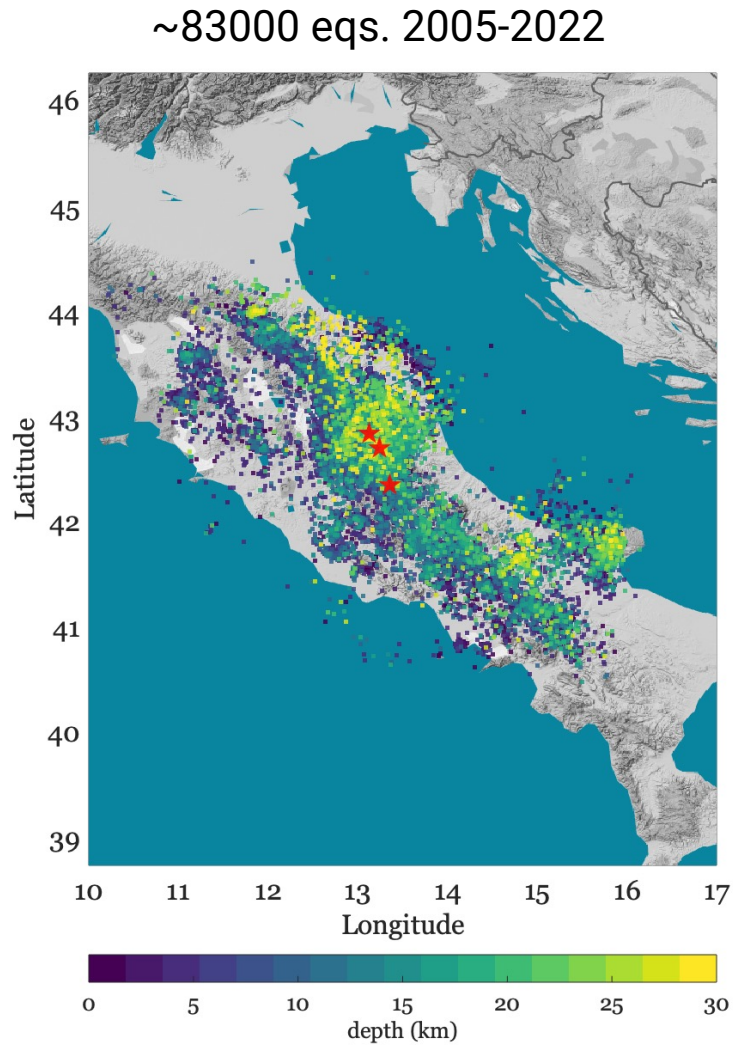
*Tra L'Aquila 2009 Mw 6.1 e  
Amatrice 2016 Mw 6.2*

~83000 eqs. 2005-2022

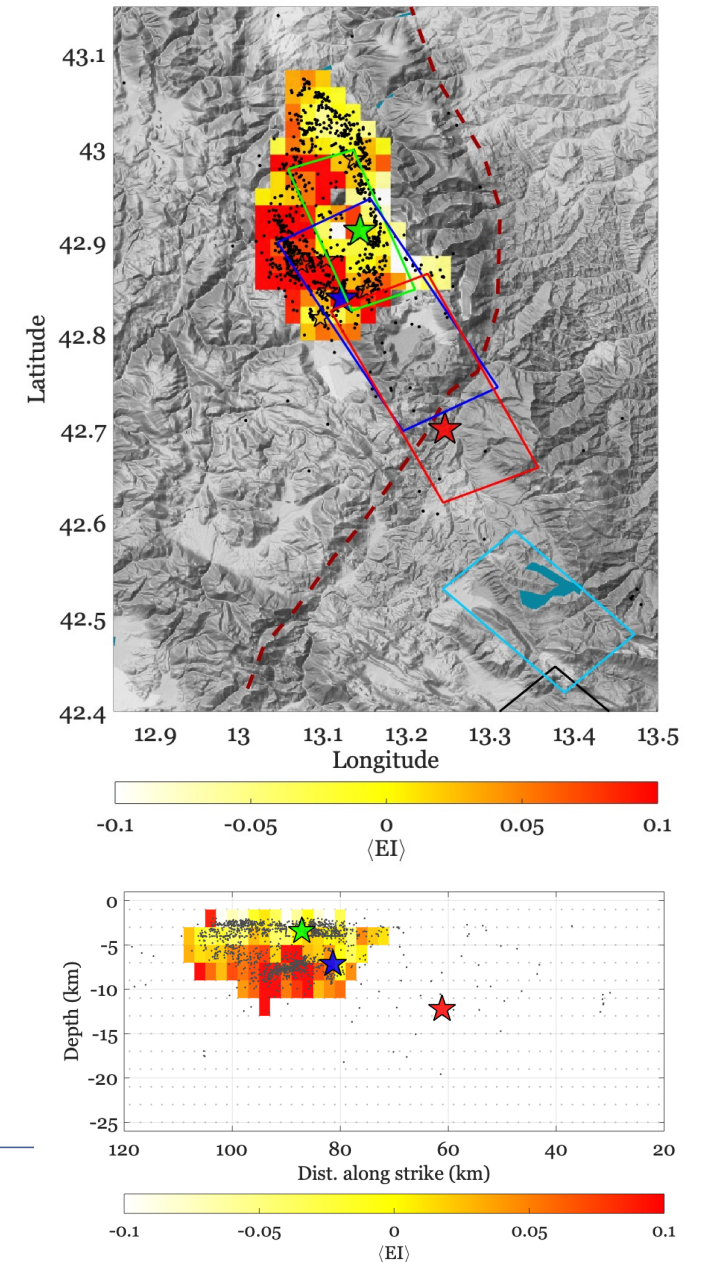


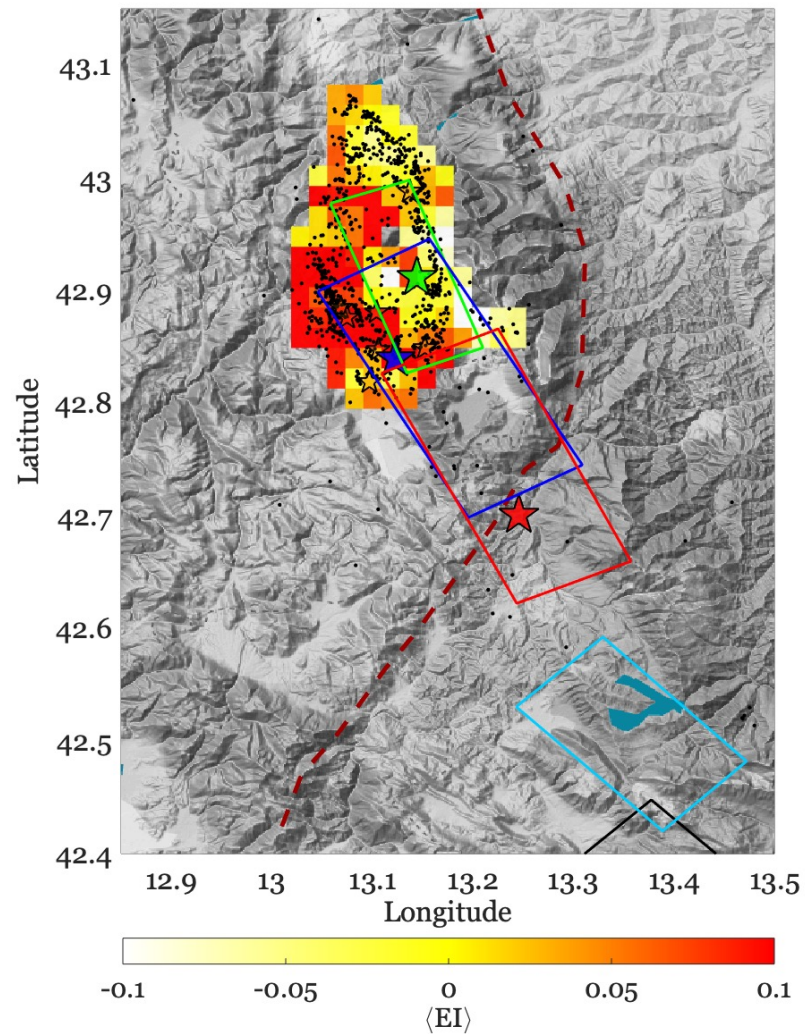


Tra L'Aquila 2009 Mw 6.1 e  
Amatrice 2016 Mw 6.2

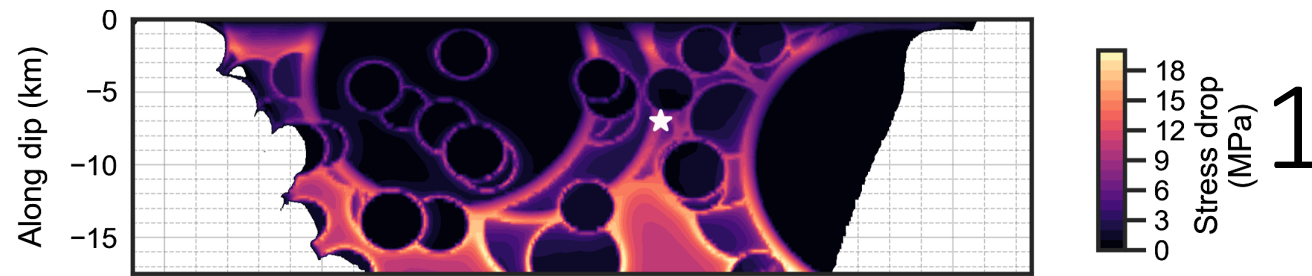


2016 - tra Visso Mw 6.1 e Norcia Mw 6.5

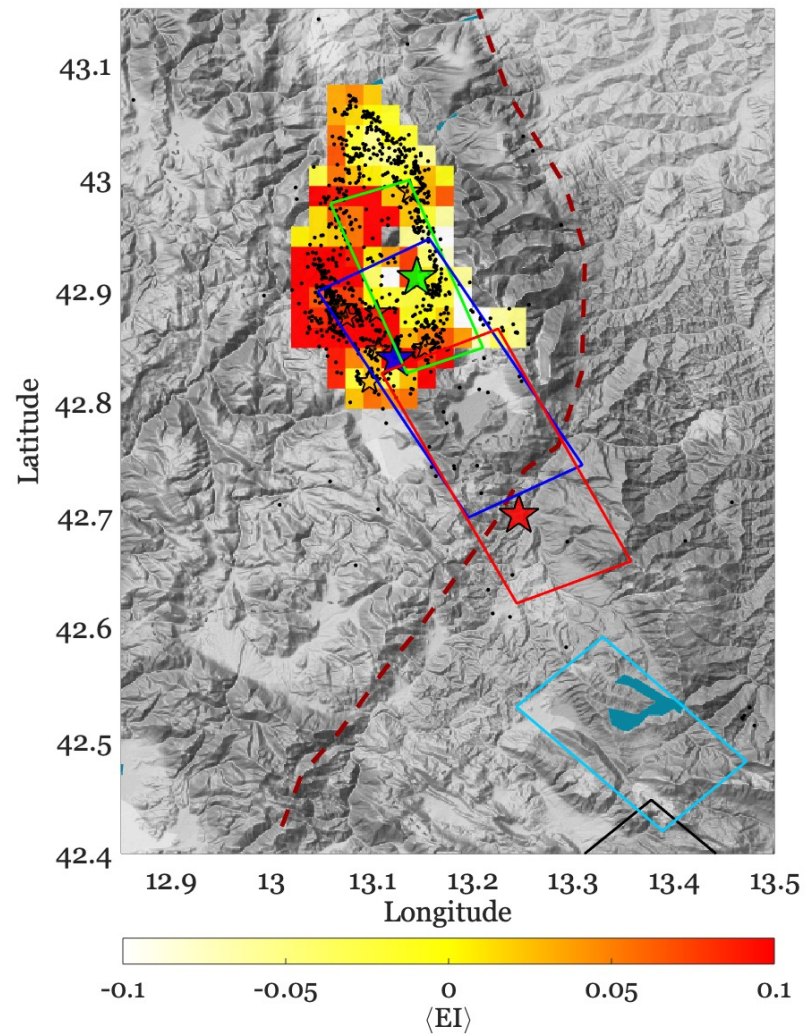




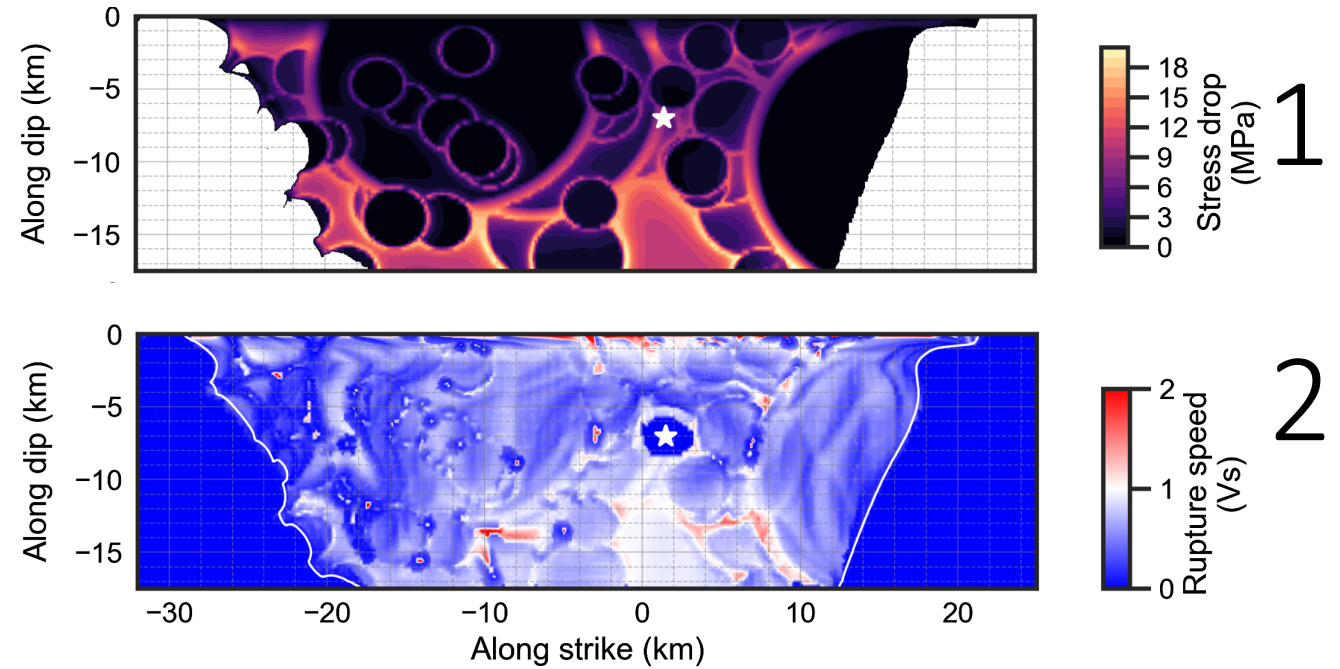
Generare un modello di faglia che tenga conto delle eterogeneità dello stress che permetta di simulare il moto del suolo in modo più realistico



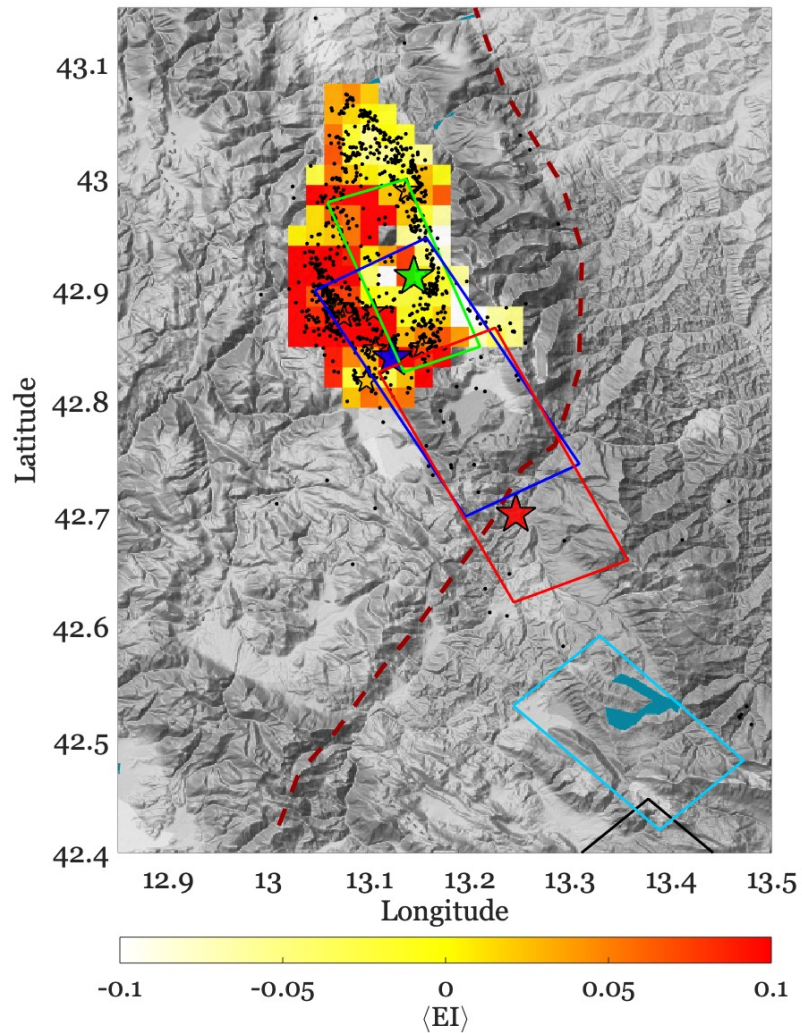




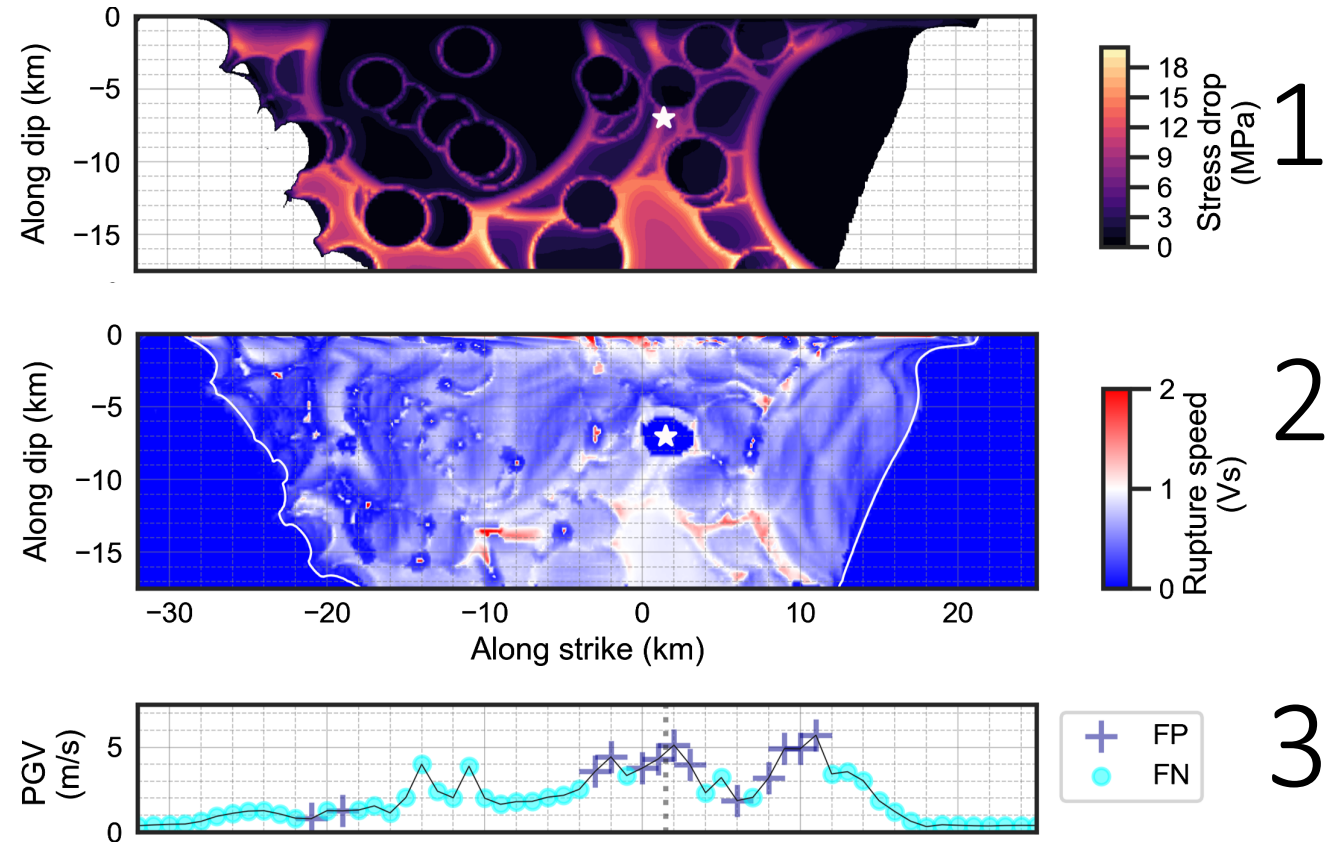
Generare un modello di faglia che tenga conto delle eterogeneità dello stress che permetta di simulare il moto del suolo in modo più realistico







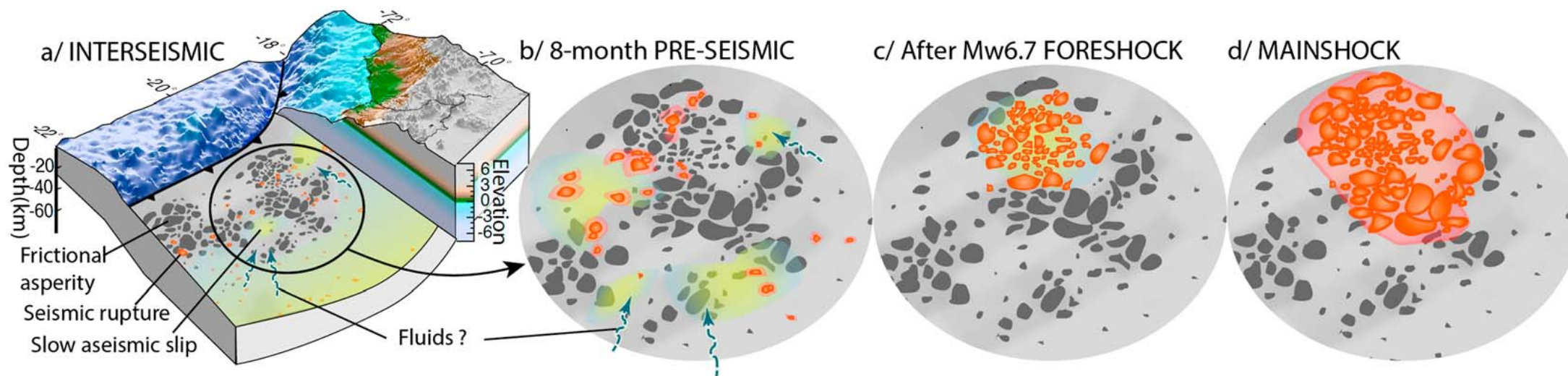
Generare un modello di faglia che tenga conto delle eterogeneità dello stress che permetta di simulare il moto del suolo in modo più realistico



Oral et al., 2022, doi: 10.1785/ 0120220064

# Cosa succede prima dei grandi terremoti?

2014 Chile megathrust (Mw8.1)

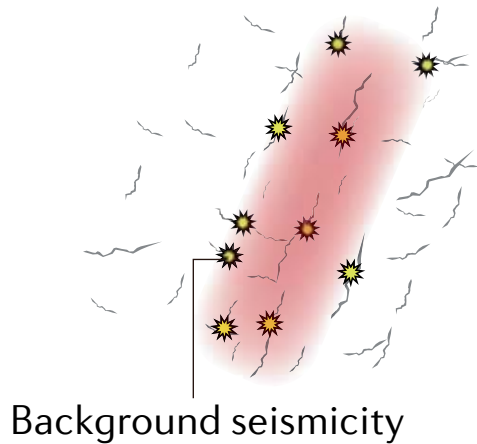


Socquet, A. et al. (2017) doi:10.1002/2017GL073023.

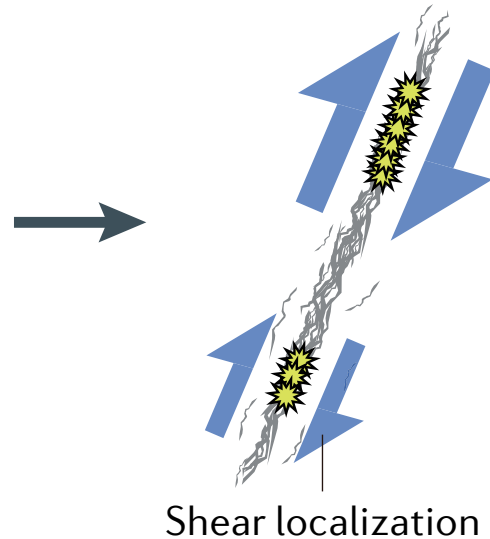
# Un possibile modello del processo di generazione dei grandi terremoti

Kato & Ben-Zion (2020)

**a Rock damage around an eventual rupture zone**

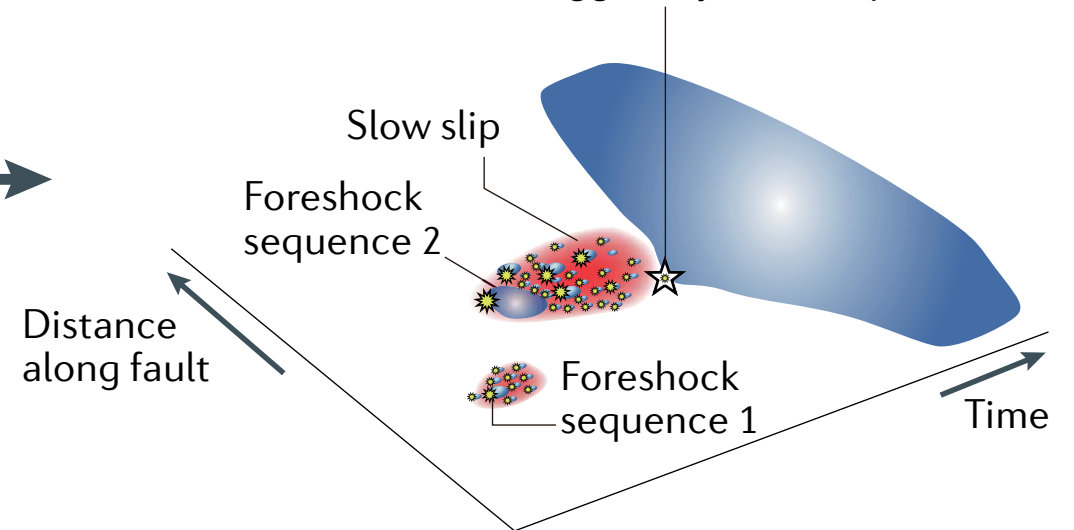


**b Localization of deformation**



**c Stress loading by a combination of slow slip and foreshocks**

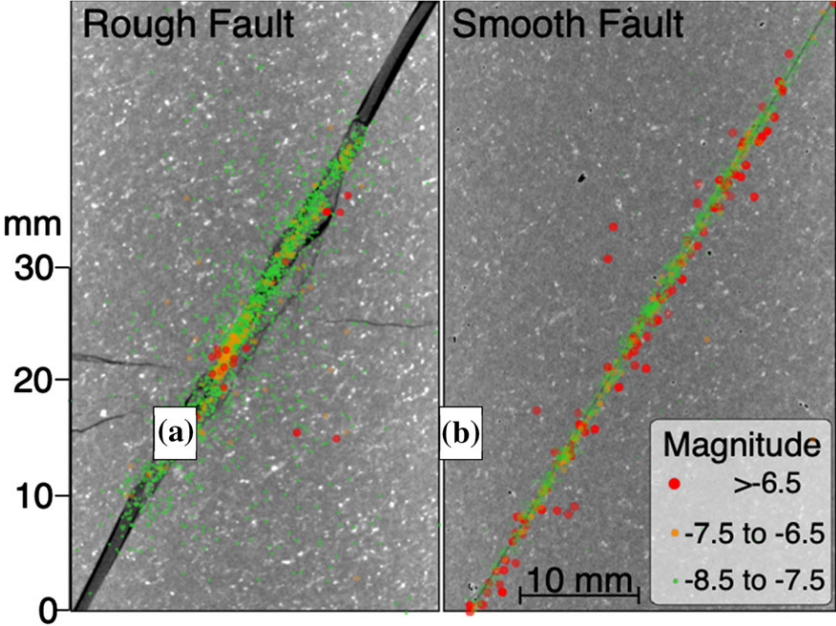
A small foreshock triggers dynamic rupture





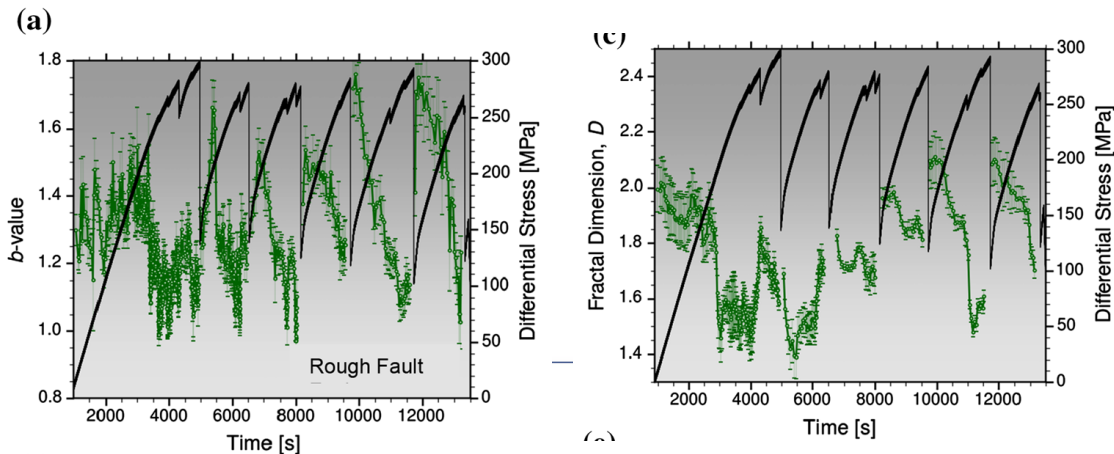
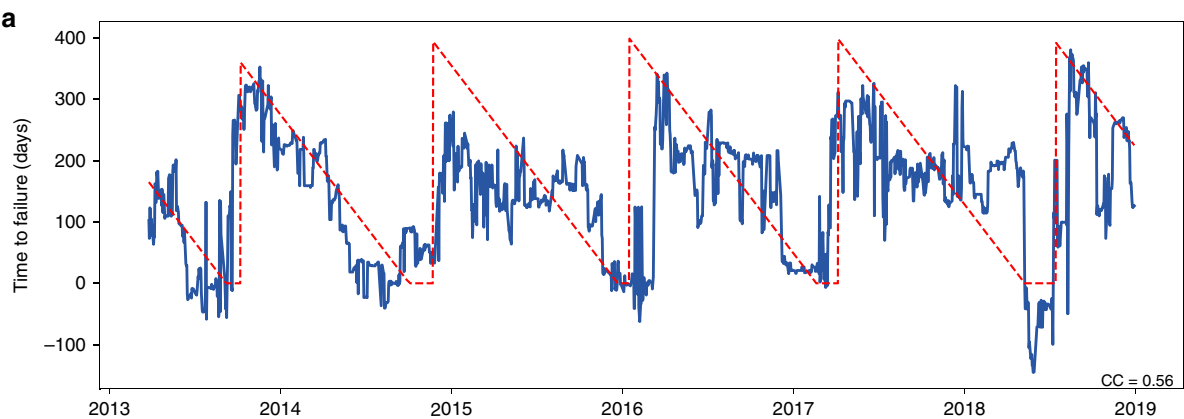
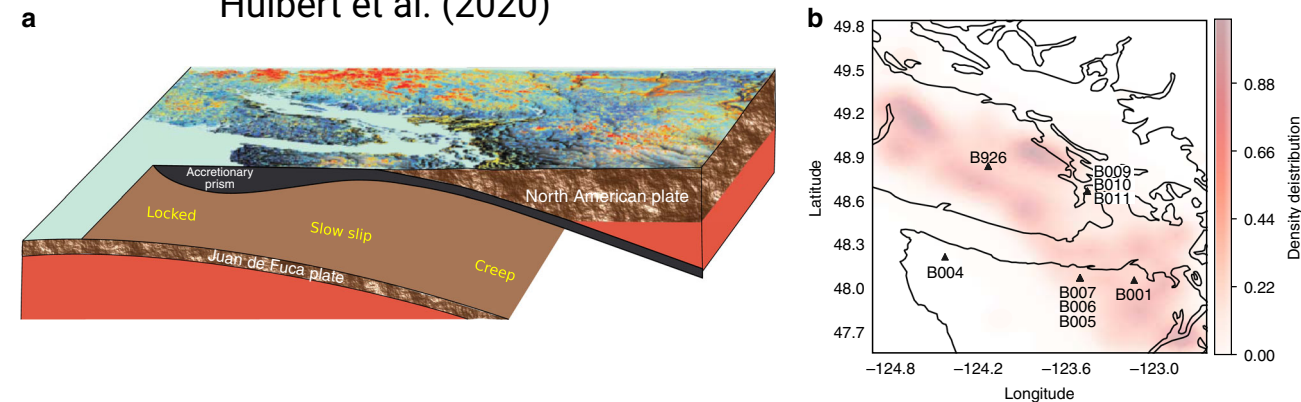
# Stick-Slip Failure

Dresen et al. (2020)



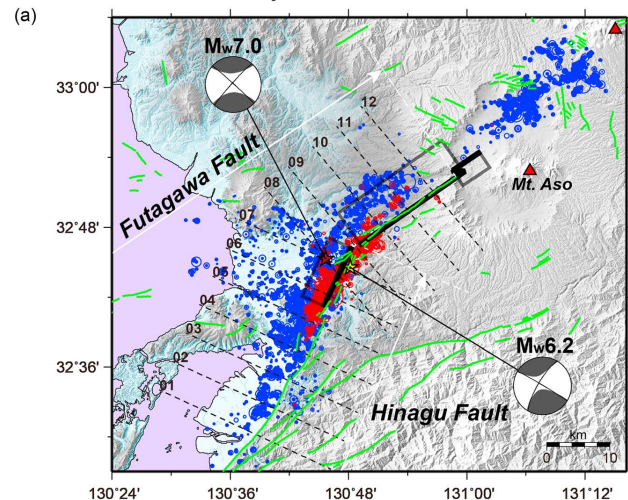
# Nucleation of slow slip in Cascadia

Hulbert et al. (2020)



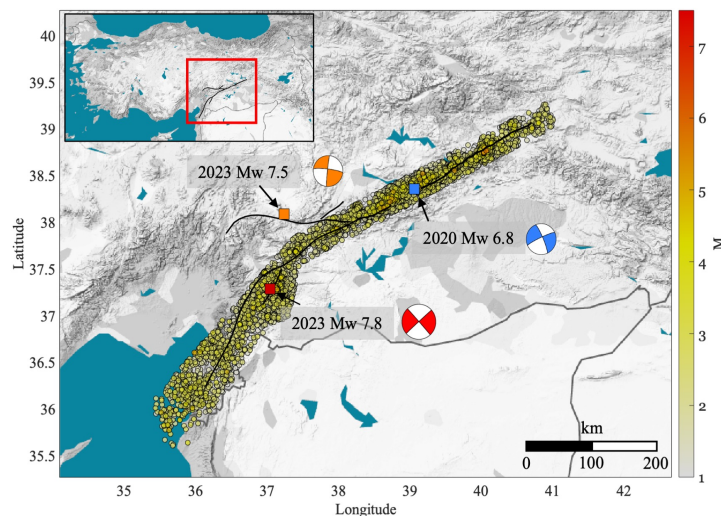
# Cominciamo ad osservare che molti grandi terremoti hanno una fase preparatoria (da analisi retrospettive)

## The 2016 Mw 7.0 Kumamoto earthquake, Japan



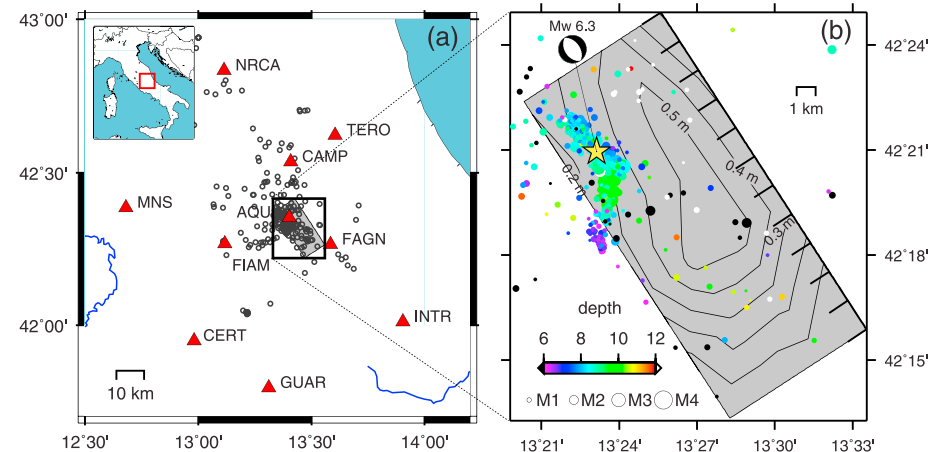
Kato, A., et al. (2016), doi:10.1002/2016GL070079.

## The 6 February 2023, Mw 7.8 Kahramanmaraş earthquake, southern Türkiye



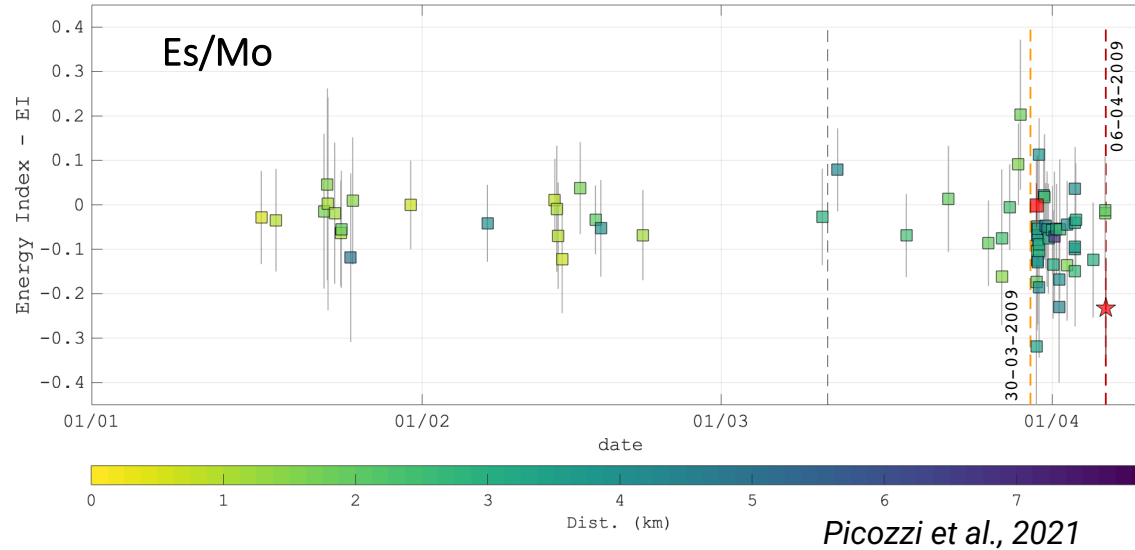
Picozzi et al., 2023, doi:10.1038/s41598-023-45073-8

## The 2009 Mw 6.3 L'Aquila earthquake, Italy

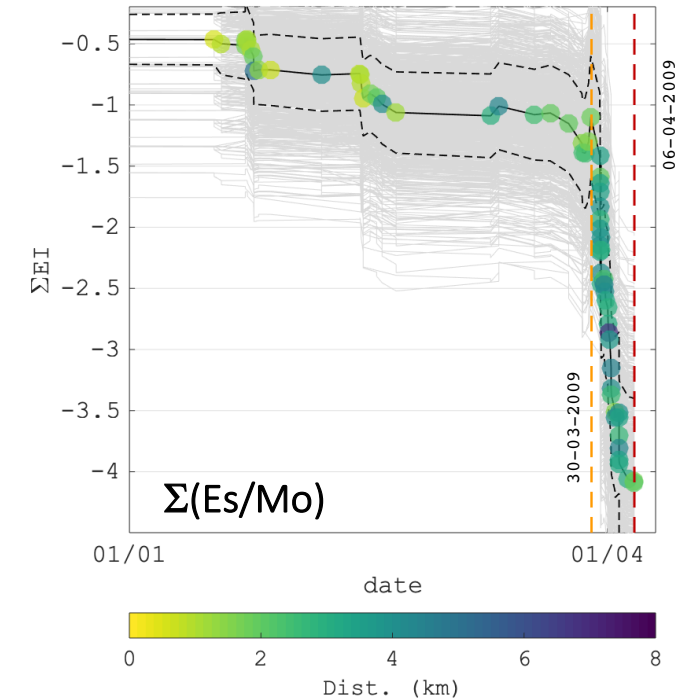


Sugan, M., et al. (2014), doi:10.1002/2014GL061199.

## The 2009 Mw 6.3 L'Aquila earthquake, Italy



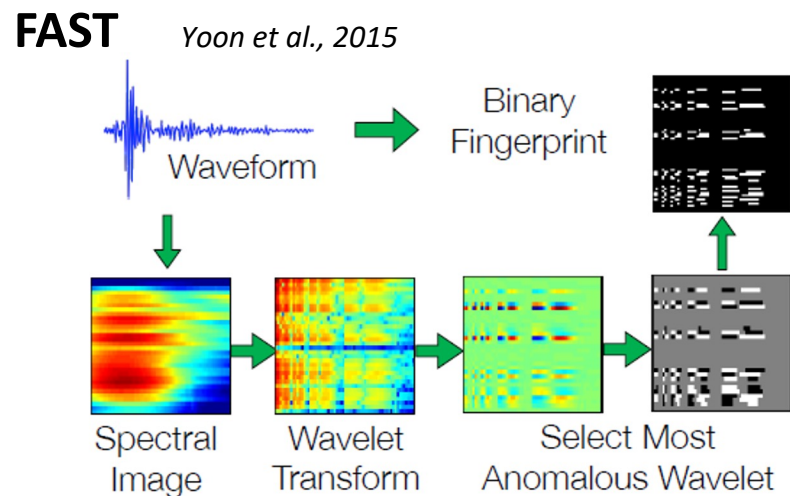
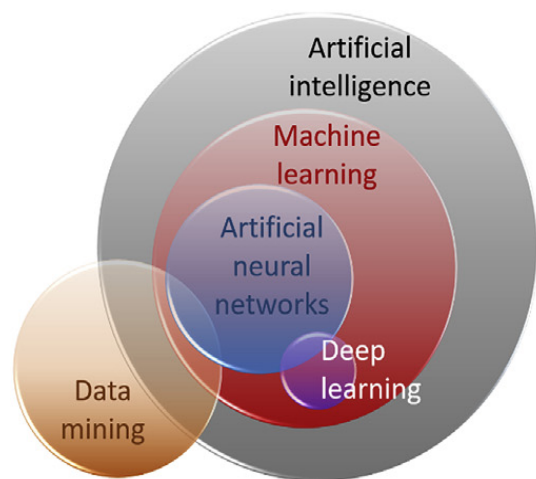
Picozzi et al., 2021



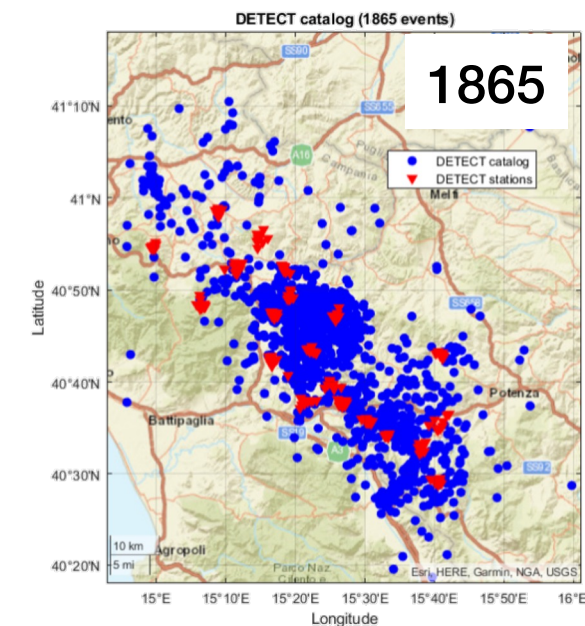
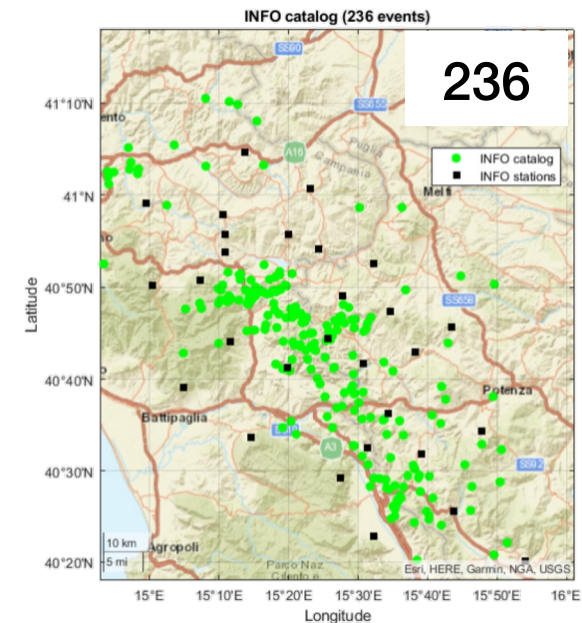
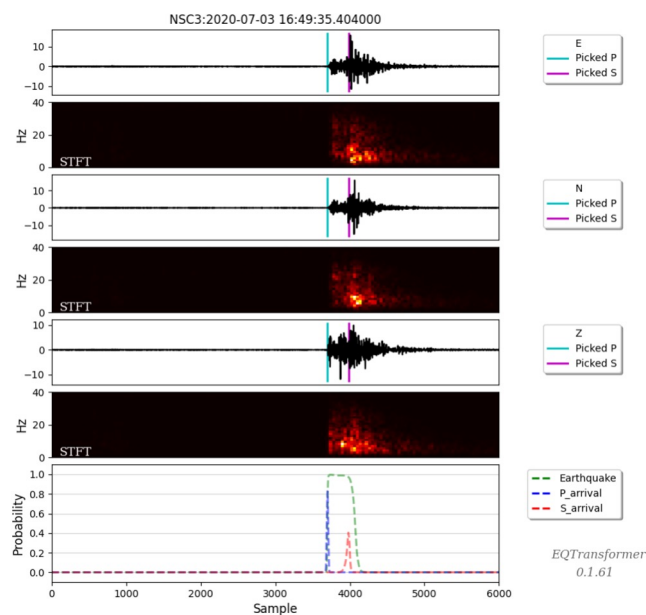
I foreshocks sembrano caratterizzati da caratteristiche dinamiche distinte da quelle degli eventi della sismicità di fondo  
(come suggerito anche da Chen & Shearer 2013, e Calderoni et al., 2019)



# AI and data science studies in seismology

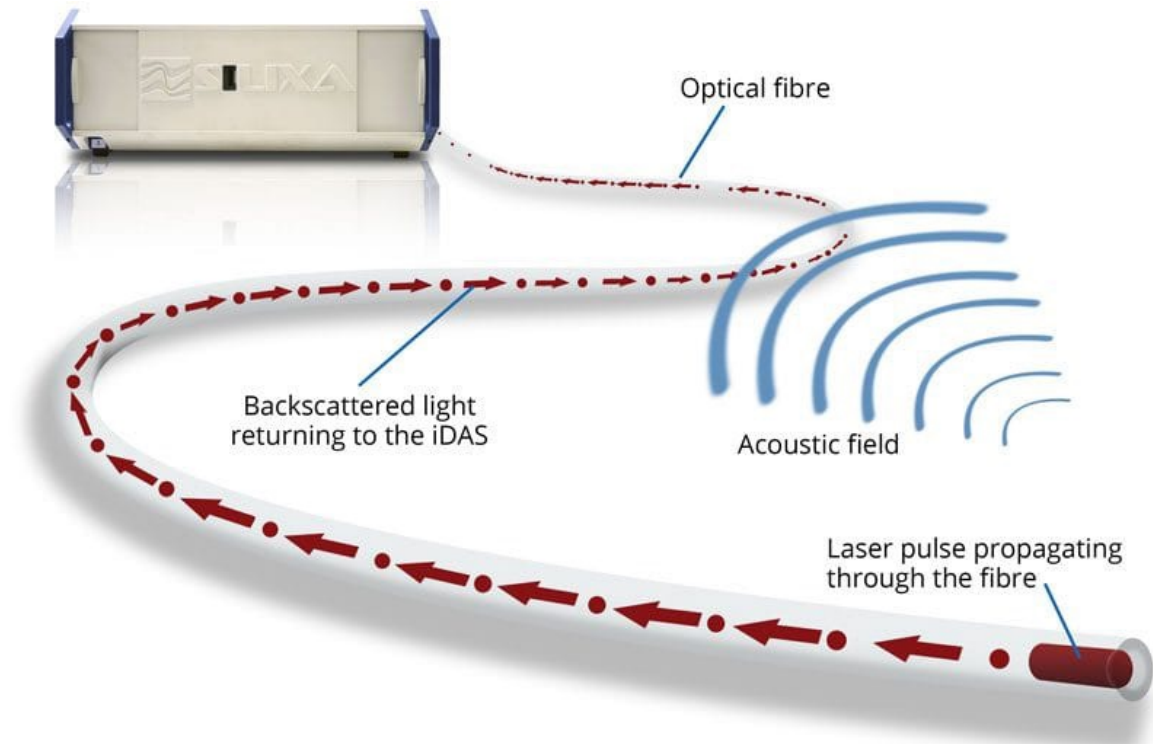
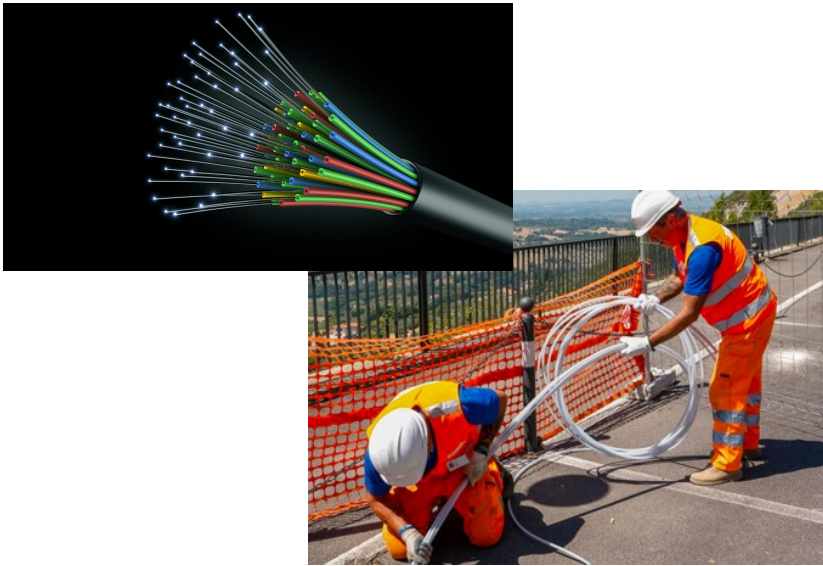


## EQTransformer (EQT) *Mousavi et al., 2020*



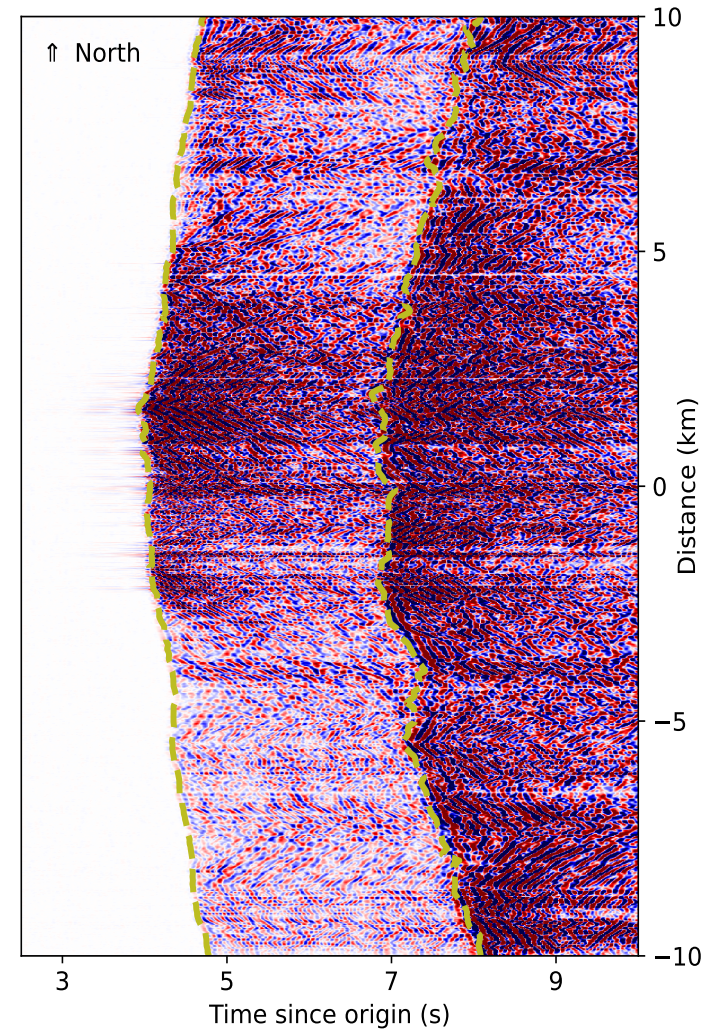
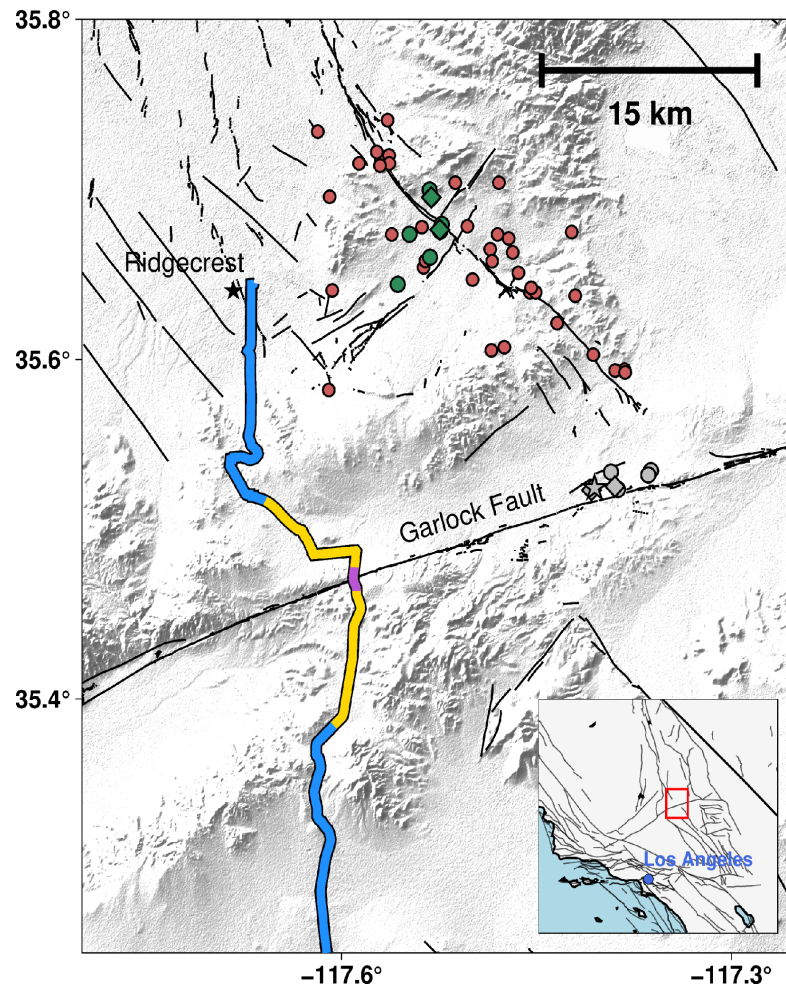
# Distributed Acoustic Sensing

La tecnologia **DAS (Distributed Acoustic Sensing)** permette di effettuare misure simultanee della deformazione dinamica (**strain**) del suolo su lunghi tratti di **fibra ottica** tramite appositi interrogatori laser.



L'elevata risoluzione spaziale ( $<4\text{m}$ ) e temporale ( $<1\text{ms}$ ) dei sistemi attuali, unitamente alla possibilità di campionare notevoli lunghezze di fibra ( $>20\text{km}$ ), rendono tale metodo particolarmente adatto al monitoraggio sismico regionale e della deformazione crostale.







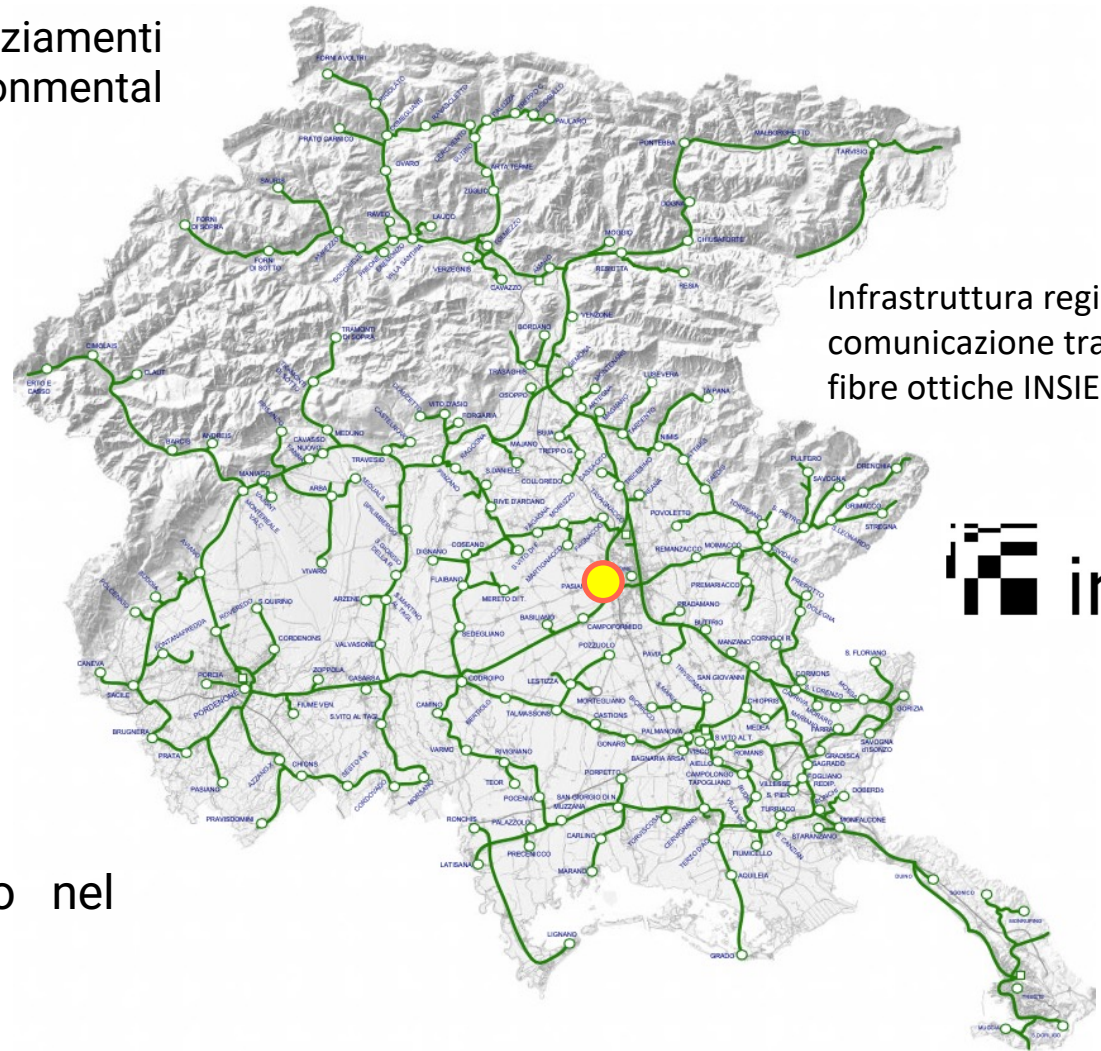
# DAS @OGS per il monitoraggio Regionale

Piano Nazionale di Ripresa e Resilienza (PNRR) → finanziamenti infrastrutturali del progetto ITINERIS (Italian Integrated Environmental Research Infrastructures System, WP7)

**5 interrogatori ottici iDAS** e relativa infrastruttura informatica.

l'utilizzo dell'esistente struttura regionale **INSIEL**, rappresenta il primo esperimento di applicazione di tale tecnologia per scopi scientifici su vasta scala sia in Italia che in Europa.

Per il futuro ci aspettiamo un importante impatto nel monitoraggio sismico per **Istituzioni e Protezione Civile**



Infrastruttura regionale di comunicazione tramite fibre ottiche INSIEL



Grazie per l'attenzione









Immaginiamo che la crosta sia un corpo fratturato con caratteristiche di autosimilarità ovvero che a qualunque ingrandimento lo si osservi appaia in forma simile



Scala decametrica

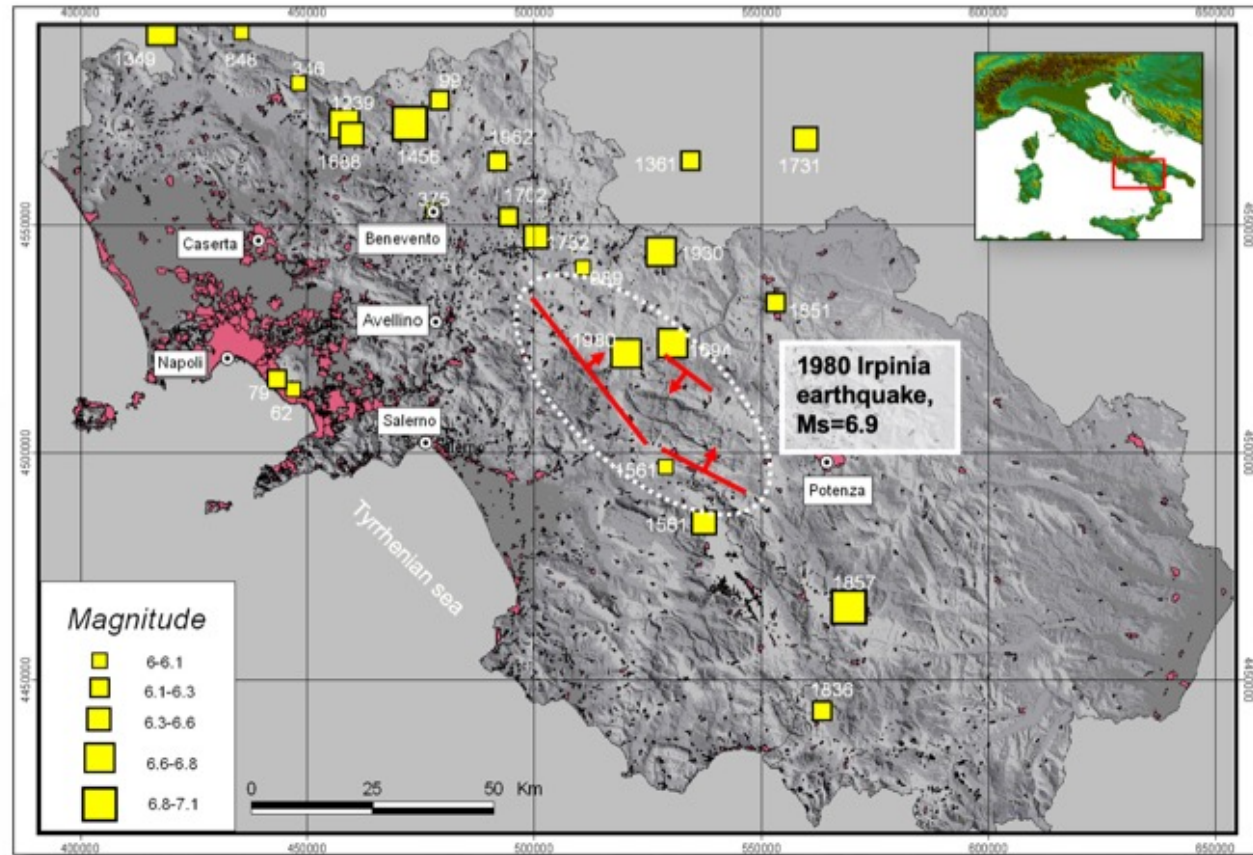


Scala decimetrica

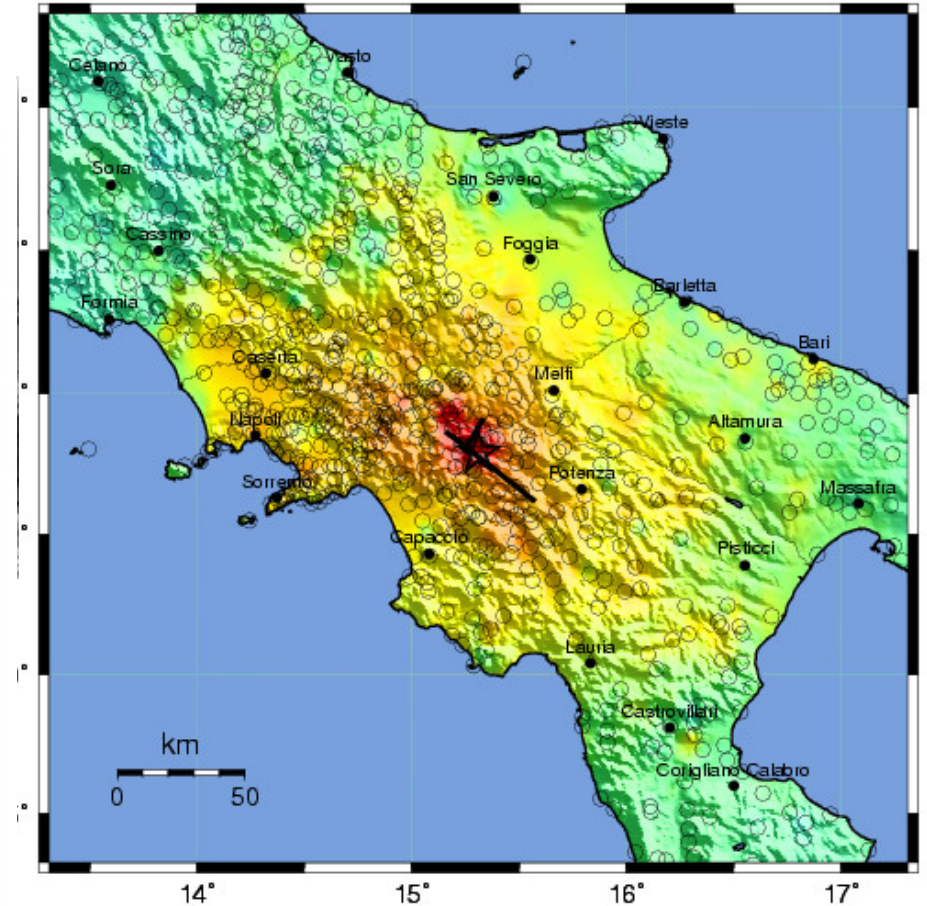
by D. Albarello

L'autosimilarità e' una caratteristica peculiare del processo di frattura

## Il terremoto del 1980



USGS ShakeMap : Irpinia, Italy  
Sun Nov 23, 1980 18:34:53 GMT M 6.9 N40.79 E15.31 Depth: 6.9km ID:198011231834

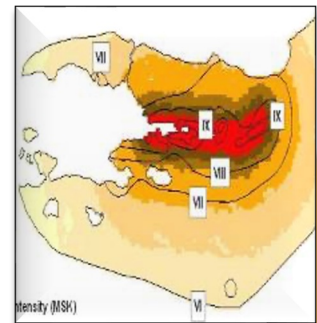


Map Version 1.1 Processed Sat Nov 8, 2008 09:13:19 AM MST

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC. (%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL. (cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

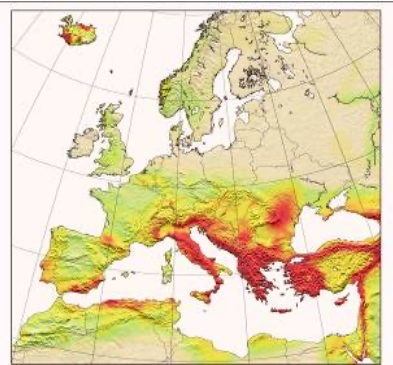


# Il ciclo dei terremoti

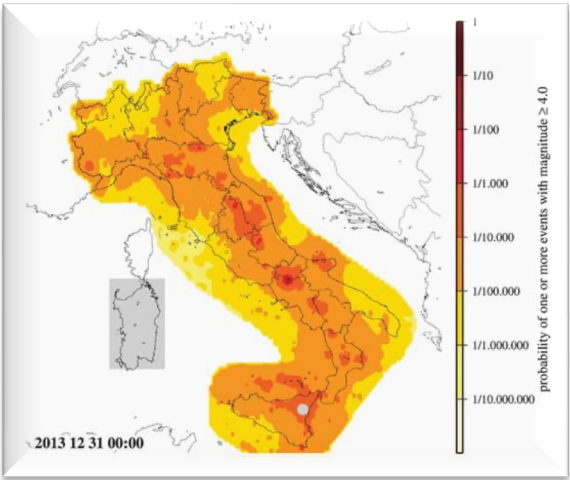


ShakeMaps  
& Rapid Loss  
Assessment

## Long-term Hazard

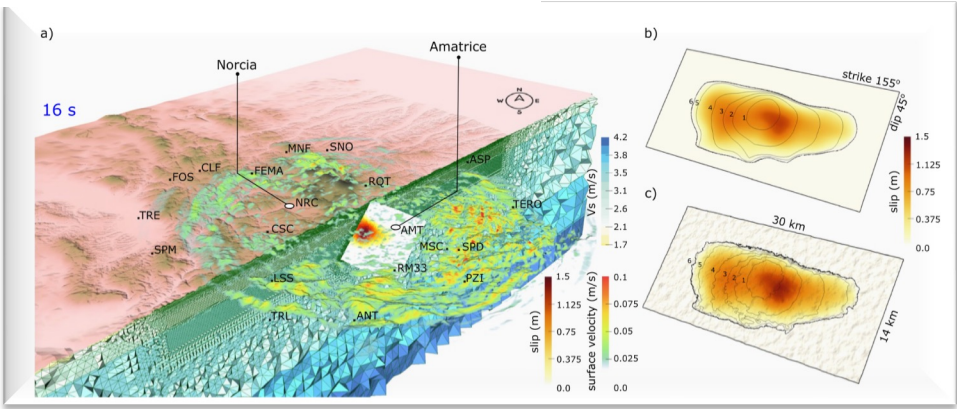


## Earthquake forecasting



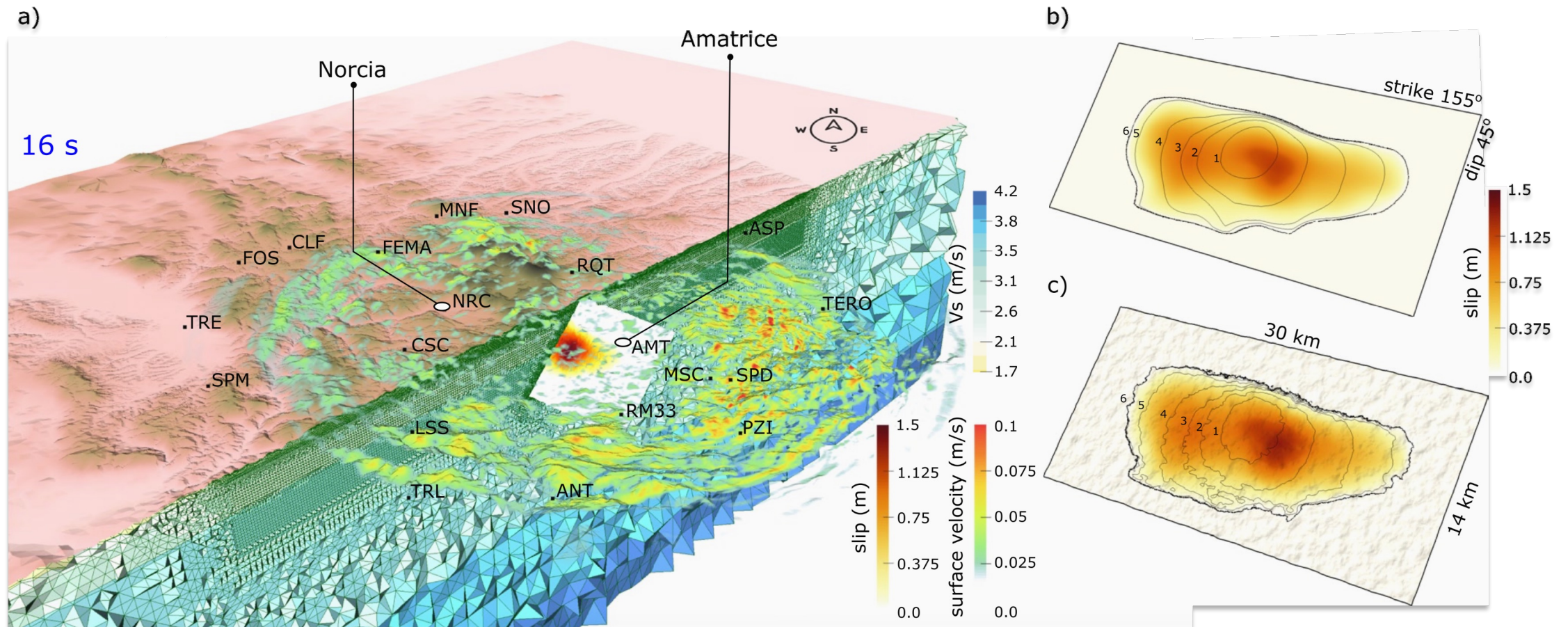
Marzocchi et al., 2014, doi: 10.1785/0220130219

## Earthquake scenario



Taufiqurrahman et al. (2022).  
<https://doi.org/10.1029/2022GL098872>

# Earthquake scenario



Taufiqurrahman et al. (2022). <https://doi.org/10.1029/2022GL098872>



# Maps of expected seismicity rates

M5.4 Visso - M6.5 Norcia

CRS-7

