POLITECNICO DI MILANO

INGV – DPC Agreement 2007-2009

Final meeting of the seismological *S* projects

Rome, ISPRA Conference Room, June 30 – July 2 2010

Project S4: "Italian strong motion database" - Task 4

Responsibles: F. Pacor (INGV) and R. Paolucci (PoliMI)

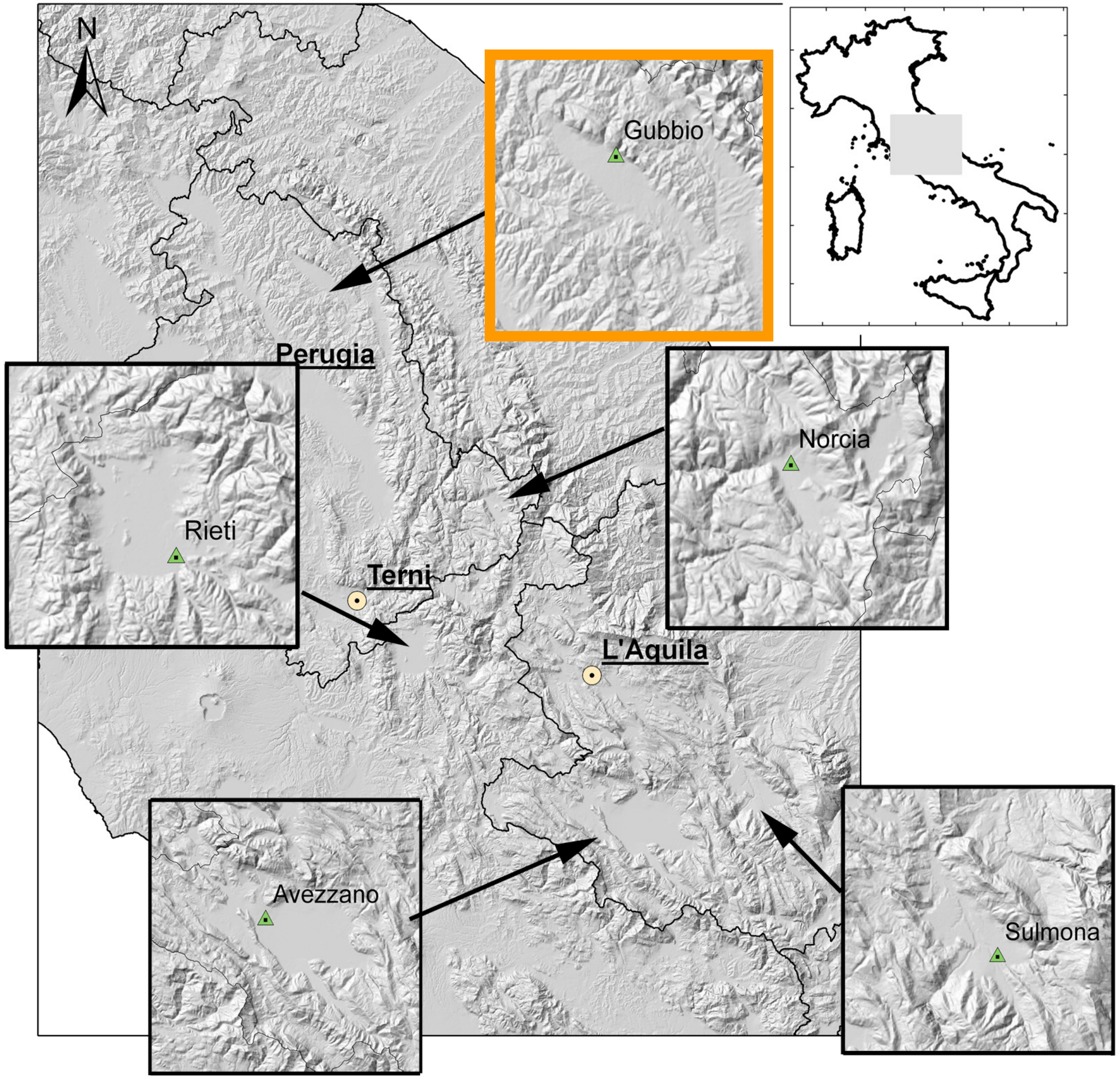
1D,2D and 3D numerical modeling of seismic site response: the case of Gubbio basin

C. Smerzini[1], R. Paolucci[2] and M. Stupazzini[2]

[1]PhD student, ROSE School, IUSS Pavia

[2]Department of Struct. Eng., Politecnico di Milano

Introduction



Intra-mountain alluvial basins are a typical surface expression of the extensional tectonic regime that dominates the seismic activity (M ≤ 6.5-7) in Central/Southern Italy along the Apennines chain.

The strong ground motion records obtained at GBP (Gubbio Piana) during the 1997 Umbria-Marche seismic sequence provide one of the clearest examples of earthquake ground motion with prominent long period contributions of surface waves.

Objectives of the work

The main objective of this work is to study and compare results of different numerical simulations of long period earthquake ground motion in the Gubbio basin, during the M_W6 Sept 26 1997 Umbria-Marche mainshock, based on the following assumptions:

a) **3D** model of the basin with 3D kinematic characterization of the seismic source;

b) **2D** models of longitudinal and transverse cross-sections of the basin subject to both vertical and oblique plane wave incidence with time dependence at outcropping bedrock obtained by the 3D simulations;

c) **1D** simplified model under vertical plane wave propagation using, as input, the same reference ground motion as in the 2D case.

3D and 2D numerical simulations were performed using the spectral element code ***GeoELSE***, exploiting in 3D its implementation on parallel computer architectures.

Previous studies:

- Project S3 (Task 6) DPC-INGV Agreement 2004-2006
- Pacor et al. (2007), Bull Earth. Eng, 5.
- Bindi et al. (2009), Bull. Seism. Soc. Am., 99 (2A)

} ***seismic site characterization***

- Project S5 DPC-INGV Agreement 2004-2006
- Stupazzini et al. (2007), EGU, Vienna.

} ***preliminary numerical modeling***

GeoELSE (Geo ELasticity by Spectral Elements)

Developers

• Politecnico di Milano, DIS (Department of Structural Engineering)

E. Faccioli, R. Paolucci, L. Scandella, C. Smerzini, M. Stupazzini, M. Vanini, C. Zambelli

• Politecnico di Milano, MOX (Modeling and Scientific Computing)

P. Antonietti, I. Mazzieri, A. Quarteroni, F. Rapetti

• CRS4 (Center for Advanced Research, Studies and Development in Sardinia)

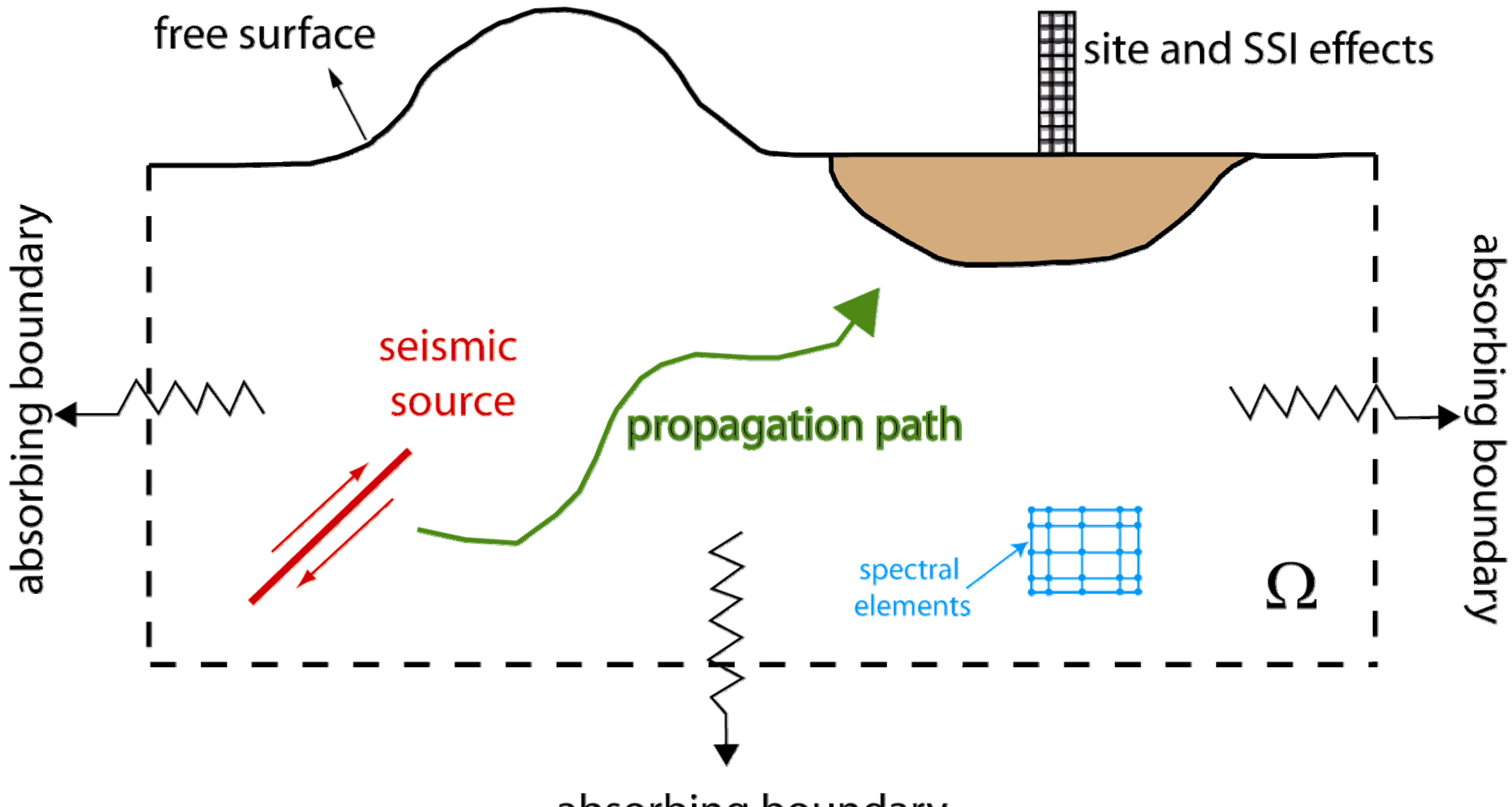
F. Maggio, L. Massidda, A. Quarteroni

Web site: http://geoelse.stru.polimi.it

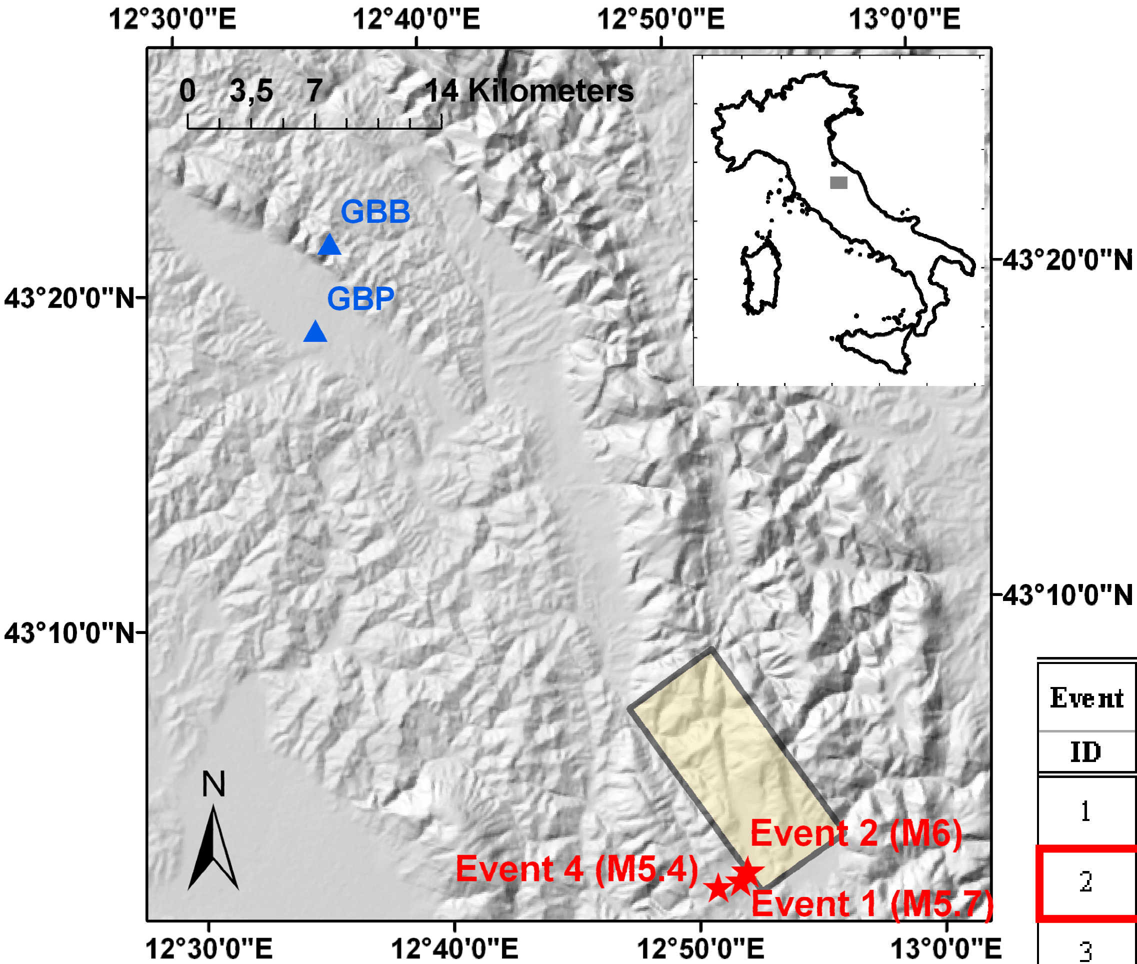
GeoELSE (Geo ELasticity by Spectral Elements)

Aim of GeoELSE: perform linear and non linear seismic wave propagation analyses in heterogeneous media, including within the same numerical model:

- **seismic fault rupture**
- **propagation path**
- **complex site response and dynamic SSI effects**

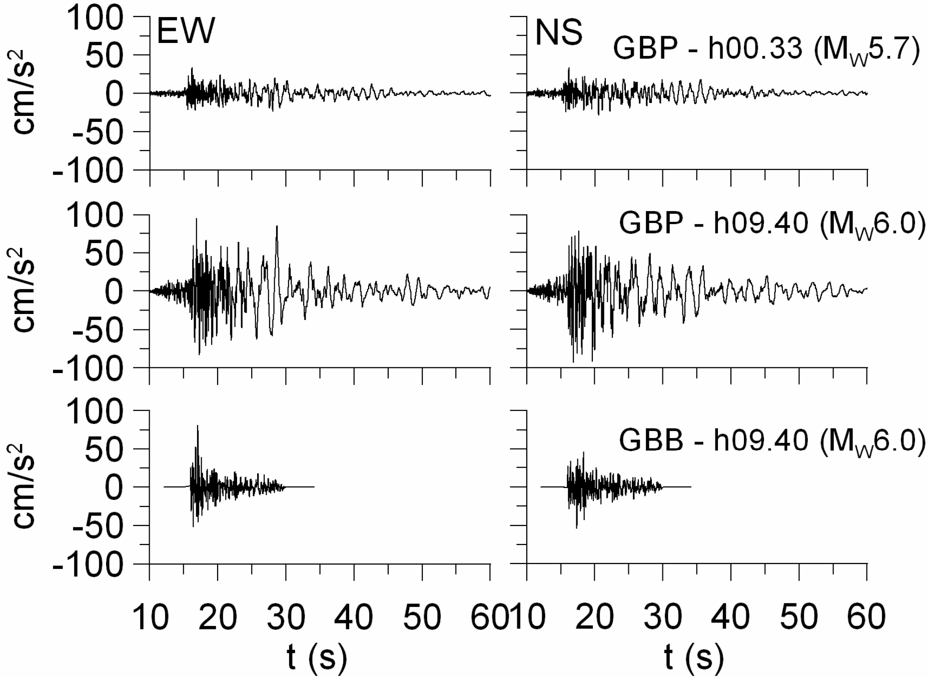


The Umbria-Marche seismic sequence



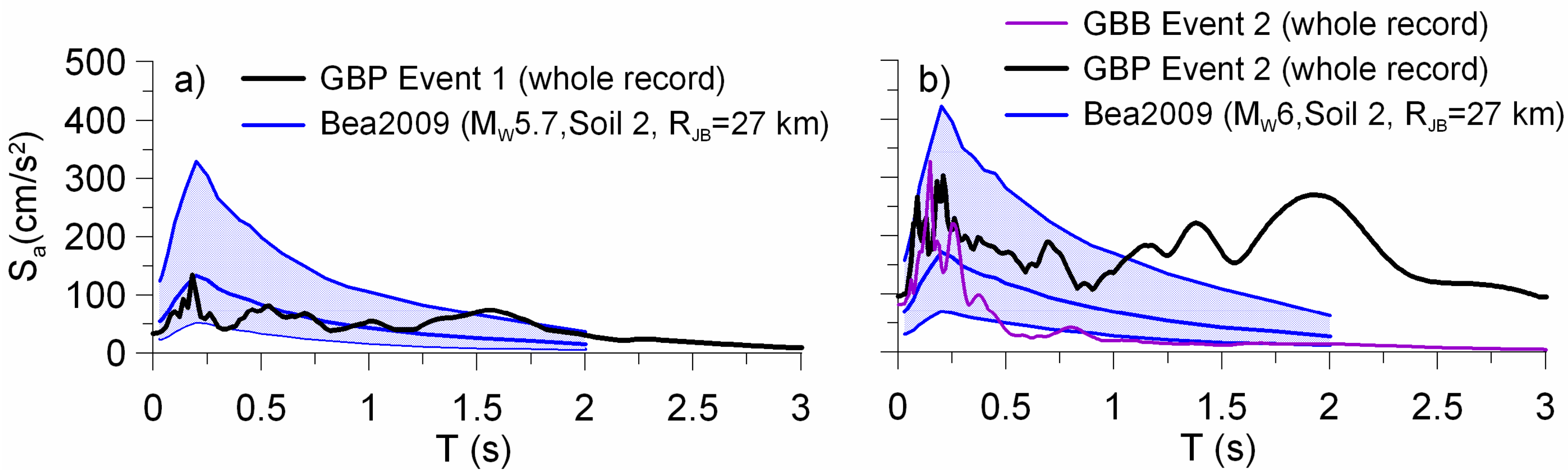
Event ID	Event Date (time)	Mw	R_e (km) GBP	R_e (km) GBB	PGV_h (cm/s) GBP	PGV_h (cm/s) GBB
1	26/09/1997 (00:33:12)	5.7	40.57		3.74	
2	26/09/1997 (09:40:25)	6.0	39.57	43.19	18.06	2.88
3	03/10/1997 (08:55:22)	5.2	35.67	39.32	2.26	0.76
4	06/10/1997 (23:24:53)	5.4	38.07	41.66	5.17	1.41
5	14/10/1997 (15:23:09)	5.6	52.59		2.15	
6	03/04/1998 (07:26:36)	5.1	19.71	22.84	3.96	1.49

Observational evidences of long period ground motions



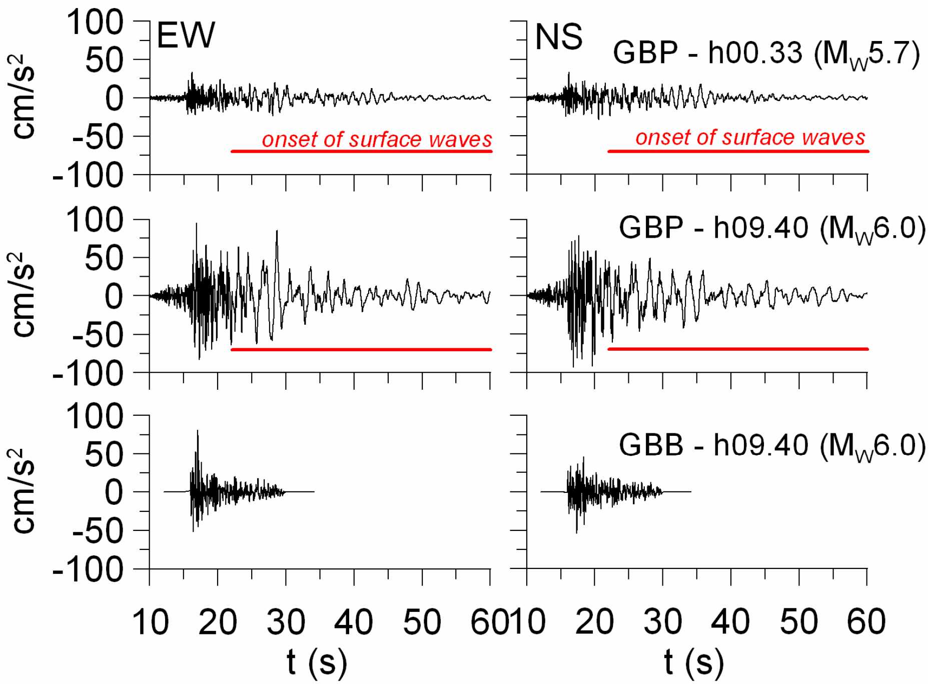
M_W 5.7 26.09.1997 (Event 1)

M_W 6.0 26.09.1997 (Event 2)



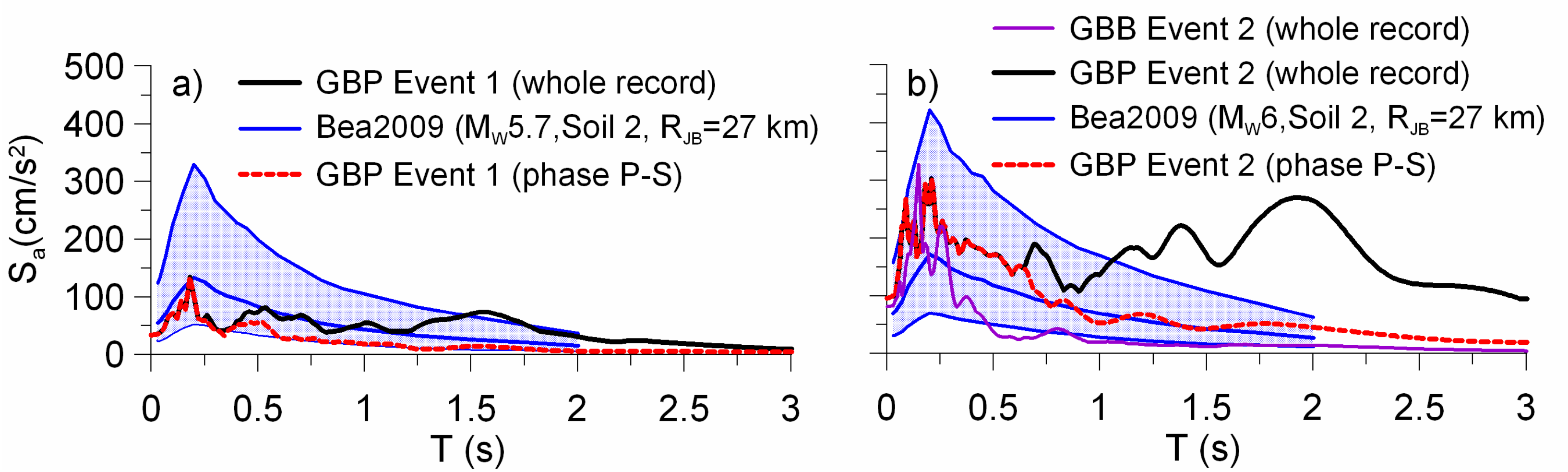
Bea2009: Bindi et al. (2009)

Observational evidences of long period ground motions



M_W 5.7 26.09.1997 (Event 1)

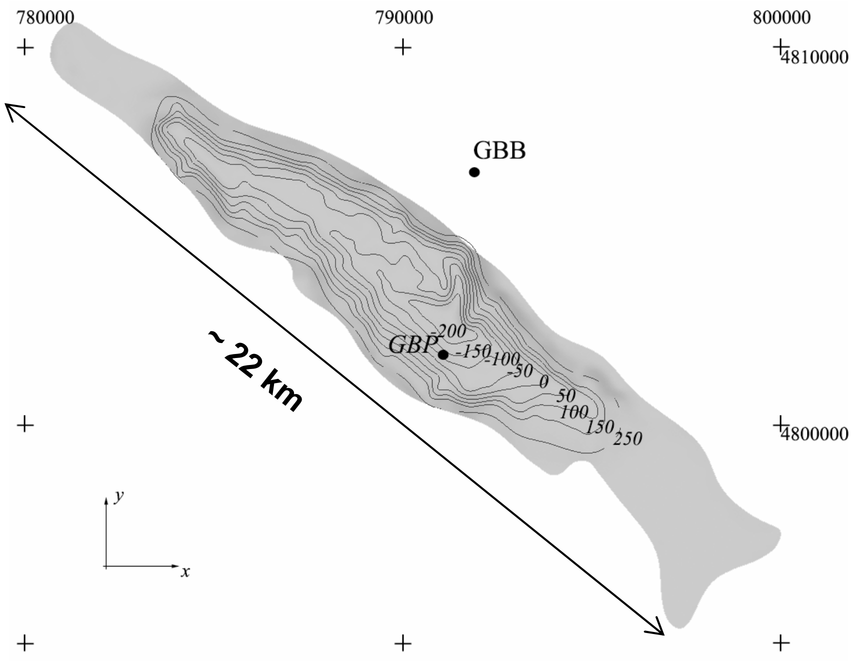
M_W 6.0 26.09.1997 (Event 2)

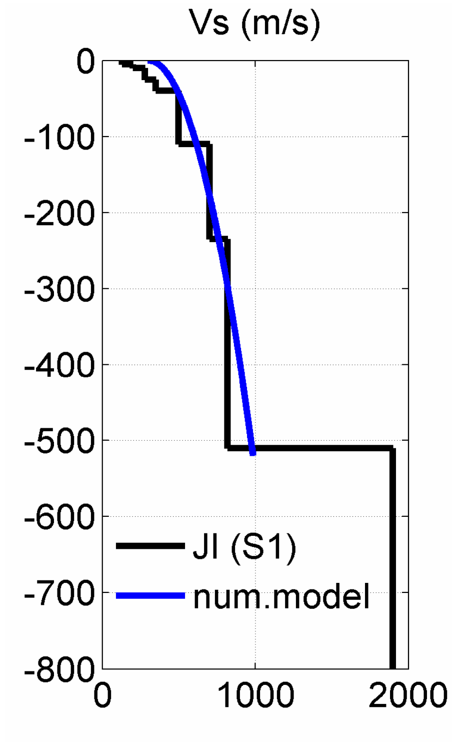


Bea2009: Bindi et al. (2009)

3D numerical model of the Gubbio basin

Bedrock topography contour lines (in m a.s.l.)





Comparison between the V_S profile at GBP obtained from a Joint Inversion technique (H/V + 2D array surveys) and that adopted in the numerical model

Simplified homogeneous description of the alluvial soft sediments, expressed in terms of a polynomial variation of V_S and V_P with depth (z):

$$V_P = 1000+30z^{1/2} \text{ (m/s)} \qquad \rho = 1900 \text{ (kg/m}^3\text{)}$$

$$V_S = 250+30z^{1/2} \text{ (m/s)} \qquad Q_S = 50$$

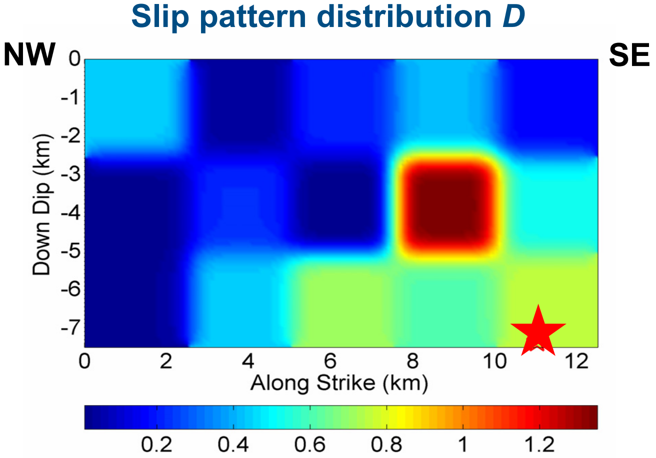
3D kinematic finite source model

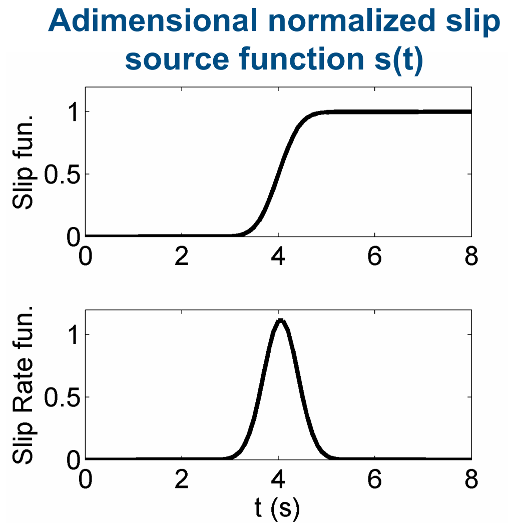
An extended fault is simulated as a distribution of double couple point sources $\{\underline{x}_{DC}^{n}\}$, whose mathematical representation is given by the seismic moment tensor density:

$$m_{ij}^{n}(\underline{x}_{DC}^{n},t)=\frac{M_{0}^{n}(\underline{x}_{DC}^{n},t-\tau^{n})}{V^{n}}\left[s_{i}n_{j}+s_{j}n_{i}\right] \quad \text{with} \quad M_{0}^{\ n}=\mu^{n}A^{n}D^{n}s(t-\tau^{n})\delta(\underline{x}-\underline{x}_{DC}^{n})$$

so that: $\sum_{n} M_{0}^{n}=M_{0}^{EQ}$

Each point source is shifted in time according to τ_k depending on the distance from the hypocenter.





Hypocenter (°N,°E,Z)	M_0 (N m)	L x W (km)	Strike (°)]	Dip (°)	Rake (°)	Depth of upper points (km)	V_R (km/s)	rise time τ (s)
43.03°N 12.87°E 5700 m	1.0 10^{18}	12.5 x 7 5	144	42	270	0 7	2.6	1.0

Hernandez et al. (2004)

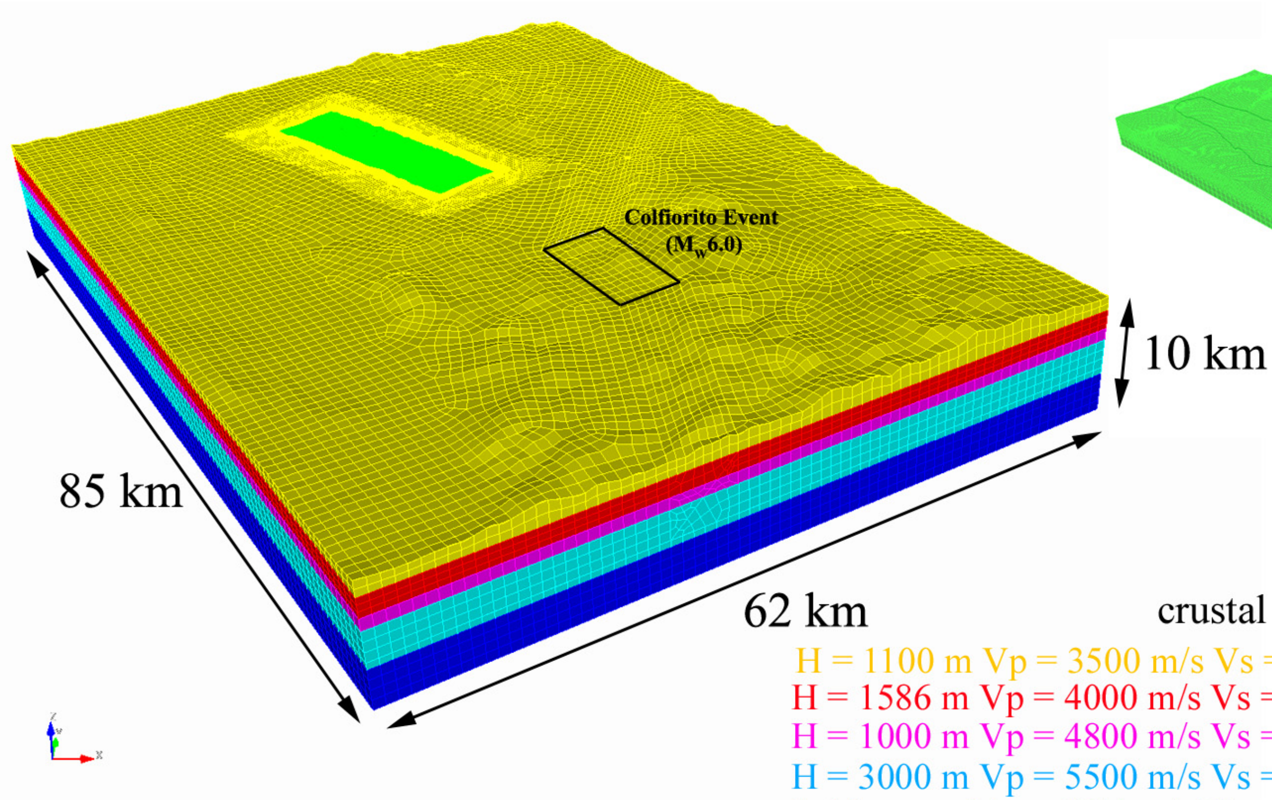
3D numerical model by spectral elements

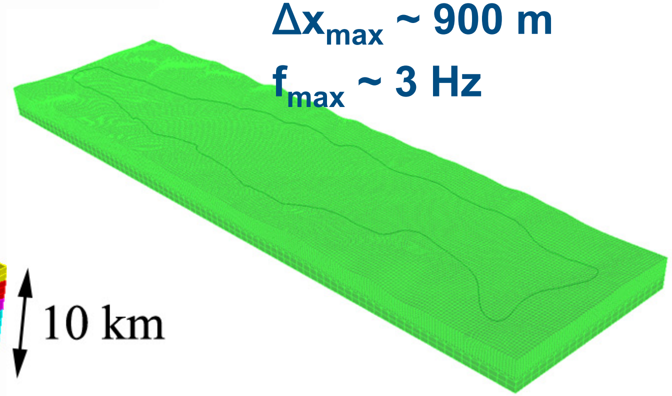
 # SEs = 361'752

Δx_{min} ~ 100 m (basin)

Δx_{max} ~ 900 m

f_{max} ~ 3 Hz





crustal model

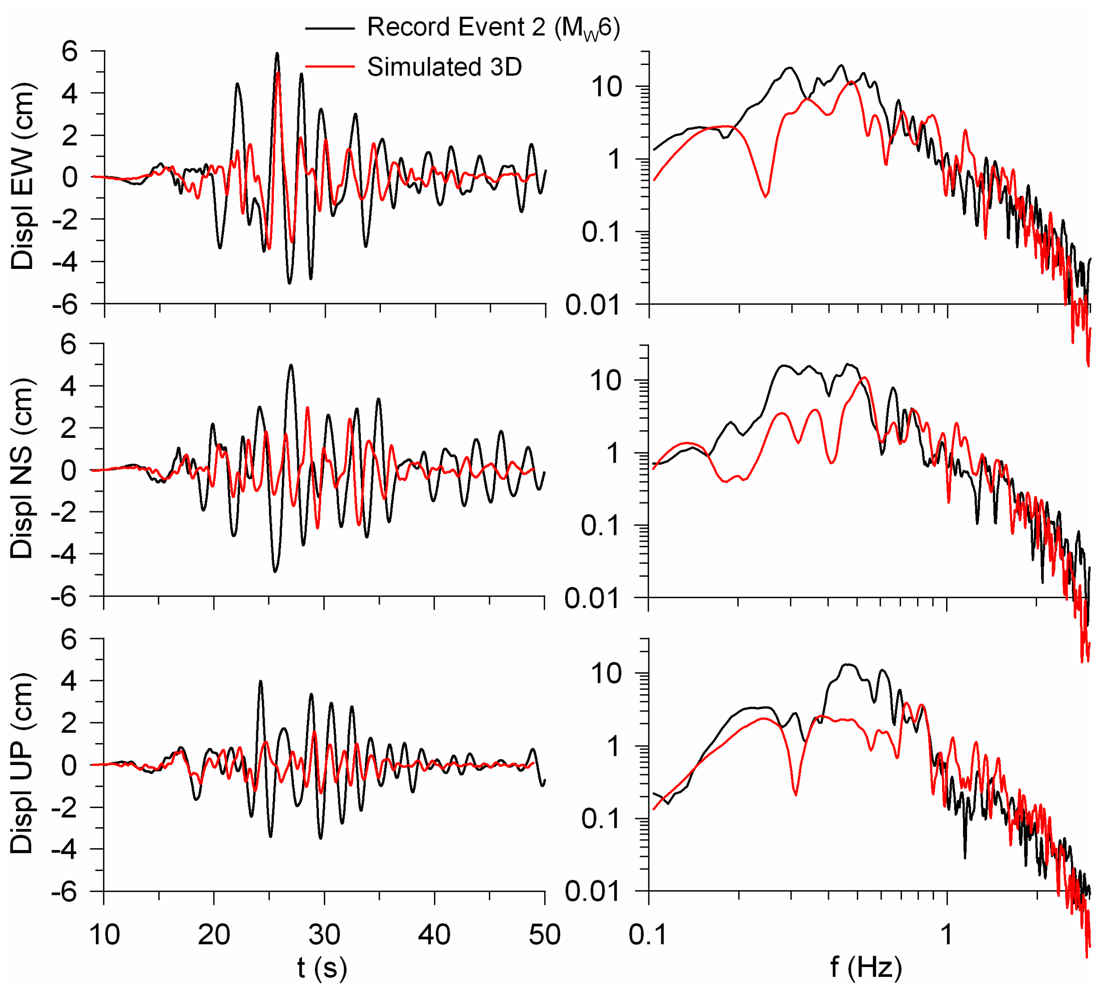
H = 1100 m Vp = 3500 m/s Vs = 1800 m/s ρ = 2.2 t/m³ Q = 80
H = 1586 m Vp = 4000 m/s Vs = 2200 m/s ρ = 2.4 t/m³ Q = 100
H = 1000 m Vp = 4800 m/s Vs = 2666 m/s ρ = 2.6 t/m³ Q = 150
H = 3000 m Vp = 5500 m/s Vs = 3055 m/s ρ = 2.8 t/m³ Q = 250
halfspace Vp = 6300 m/s Vs = 3500 m/s ρ = 2.9 t/m³ Q = 300

SD	Elements #	Nodes #	$\Delta t_{simulation}$ (s)	Total simulated time (s)	Total CPU time (64 CPUs) (min)	Set-up time (s)
3	361'752	9'962'500	$3.4483 \cdot 10^{-4}$	80	1'921 (~ 32 hours)	1'121 (~18.7 min)
4	361'752	23'498'665	$3.4483 \cdot 10^{-4}$	100	8'962 (~149.4 hours)	6'103 (~102 min)

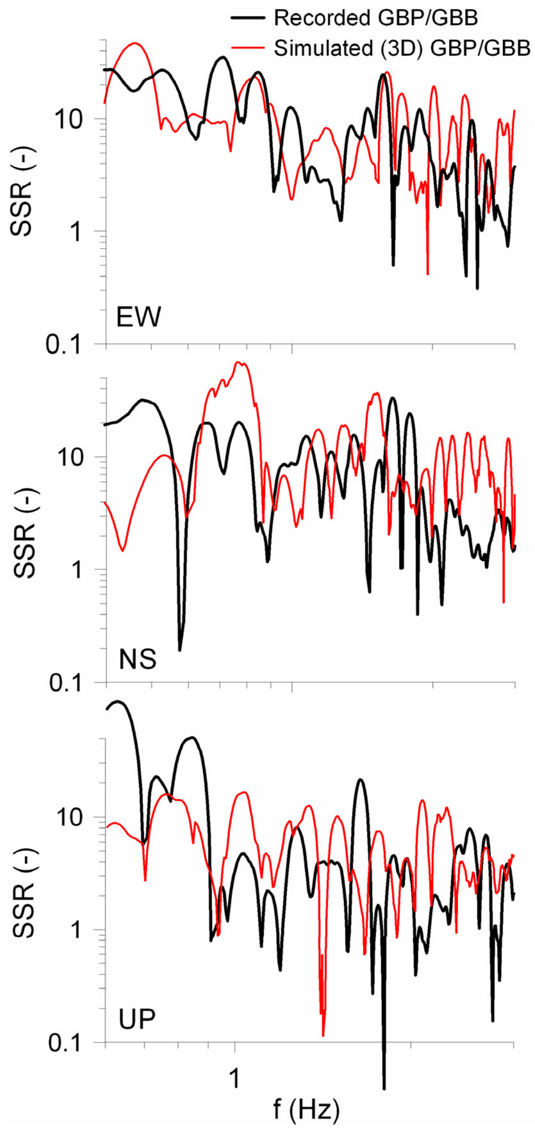
Comparison with strong motion recordings

GBP (0.1-3 Hz)

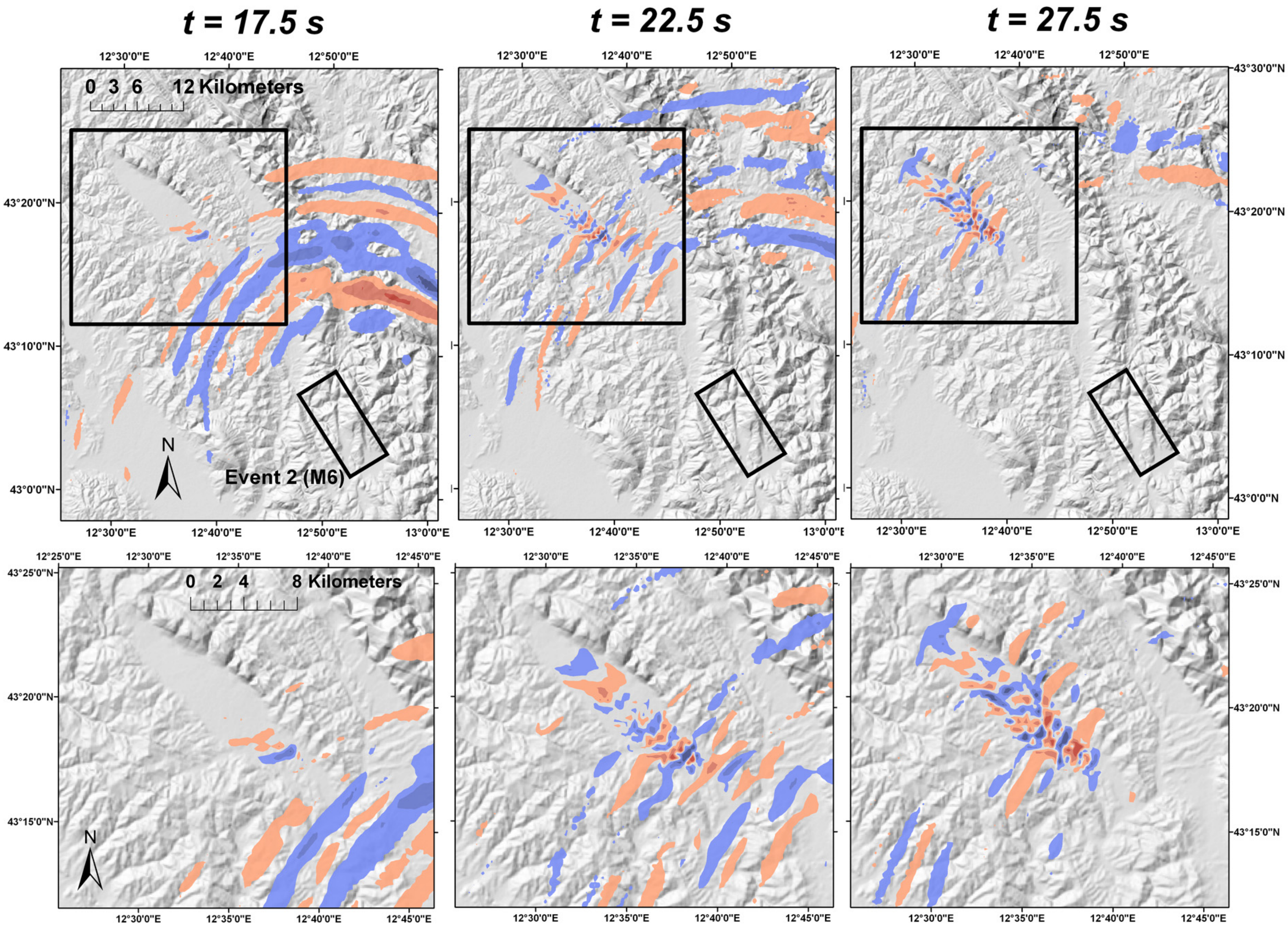
Displacement time histories and Fourier amplitude spectra



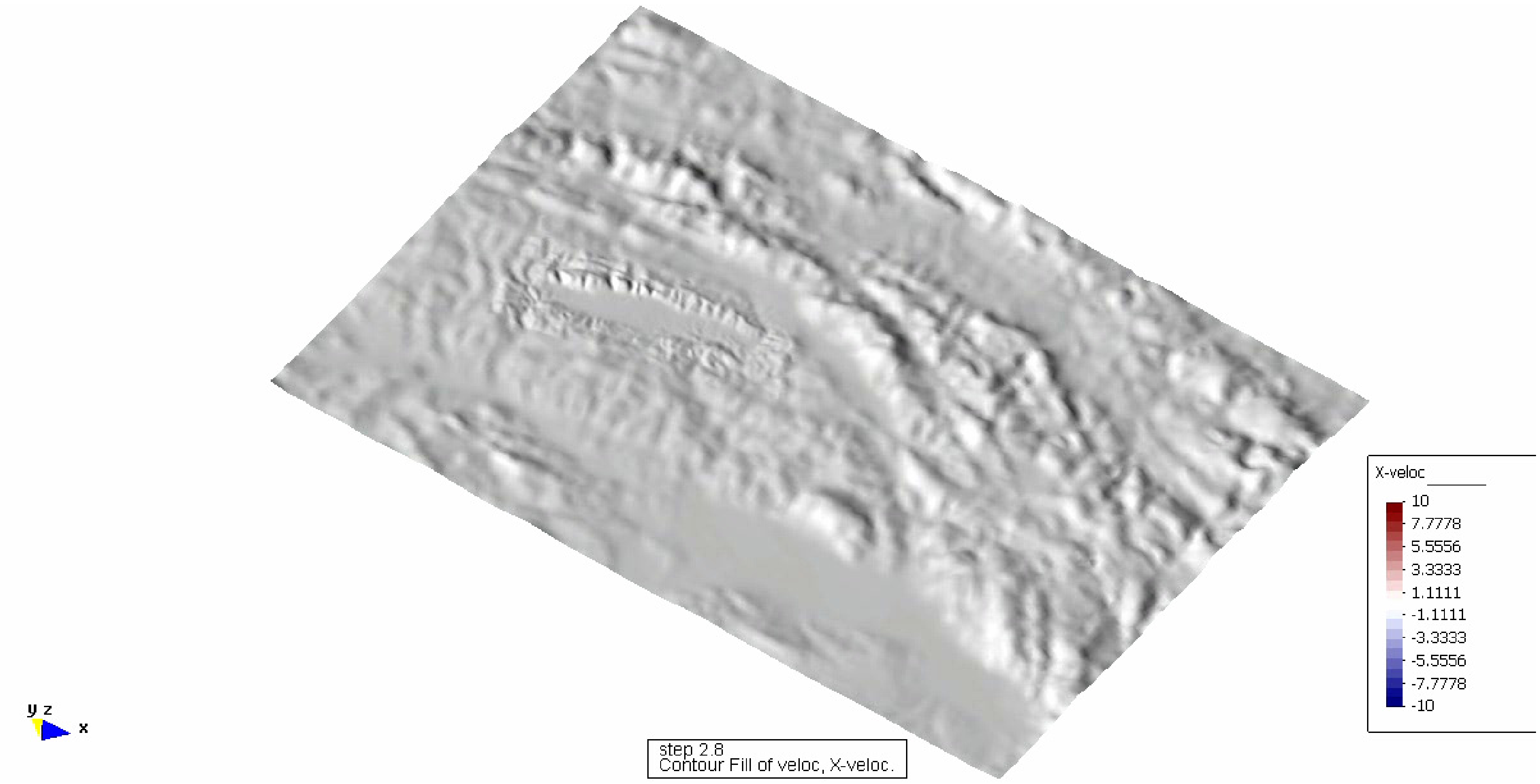
Standard Spectral Ratios (SSR) GBP/GBB



Snapshots of fault parallel velocity component



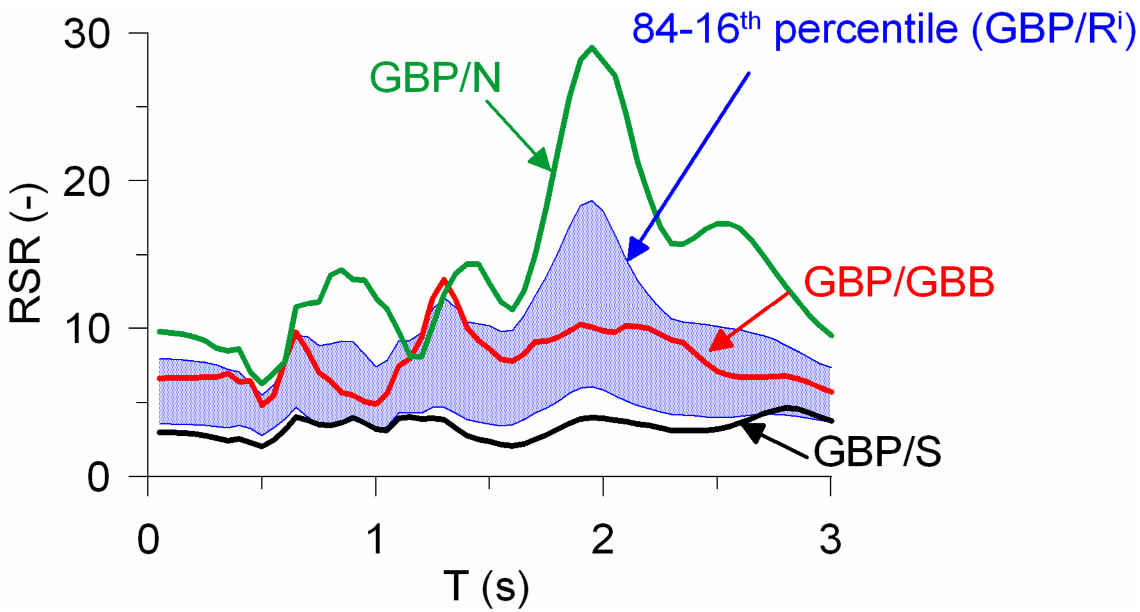
Fault Parallel velocity (m/s)

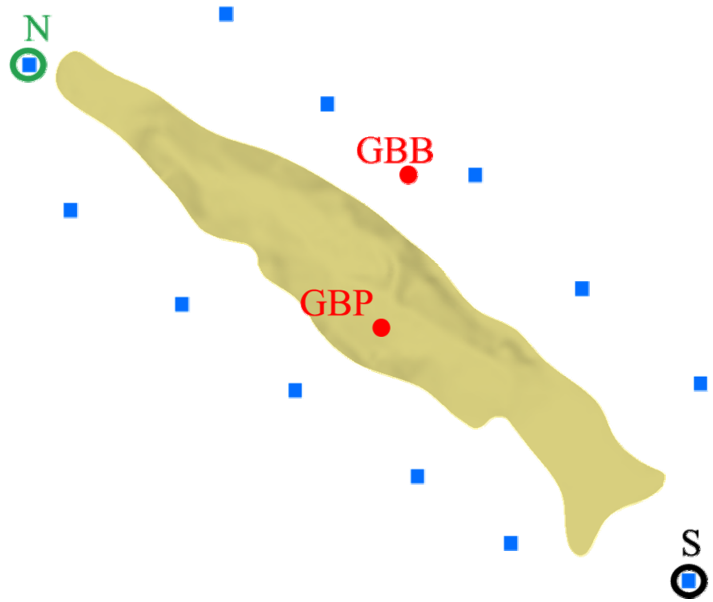


Dependence of *RSR* on reference rock site

To provide a quantitative measure of seismic site effects in the Gubbio plain, the Response Spectral Ratios (*RSR*) are computed as the ratio of the response spectrum (GM = horizontal geometric mean) at GBP over that obtained for a nearby reference rock station.

The variability of *RSR*s is evaluated by considering a set of reference ground motions $\{R_i\}$.





*RSR*s show a considerable variability depending on the reference rock ground motion and on its relative location with respect to the seismic source and the basin (note GBP/N vs. GBP/S). In general, it is found that *RSR*s with respect to the sites on the southern edge are in the low dispersion band.

2D and 1D numerical simulations

Starting from the same numerical model used in the 3D analyses, simpler 1D and 2D numerical approaches have been adopted to compare results with the ones obtained by 3D simulations.

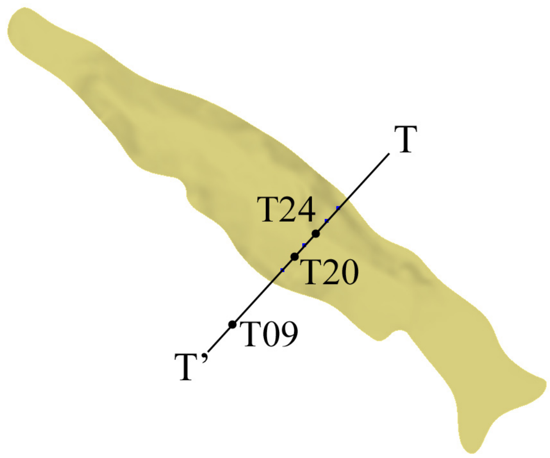
- **2D:** seismic response of longitudinal (LL’) and transverse (TT’) cross-section of the Gubbio basin subject to vertical and oblique plane wave propagation, exploiting the implementation in GeoELSE of the *Domain Reduction Method* (DRM)

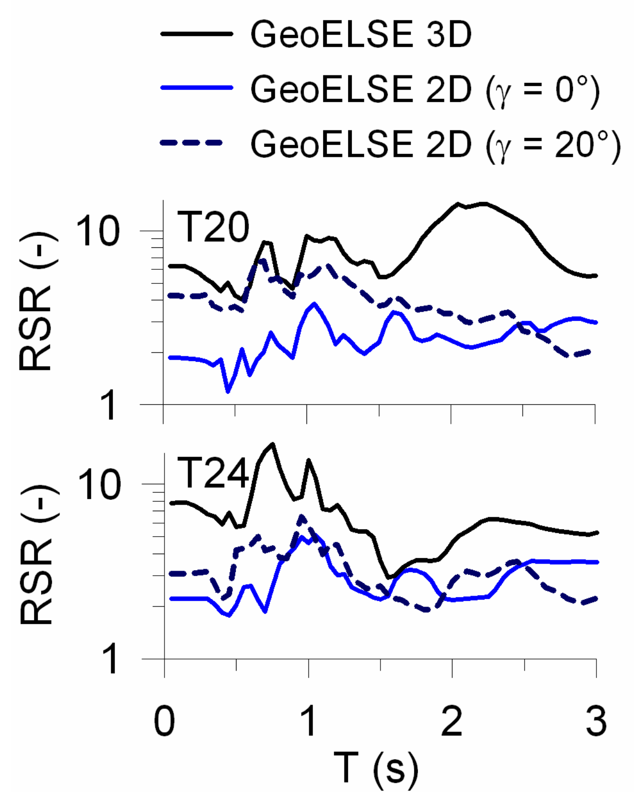
- **1D:** seismic response of a representative soil column below GBP under vertical plane propagation.

As input for 1D and 2D simulations, the output at outcropping bedrock from the 3D model has been used.

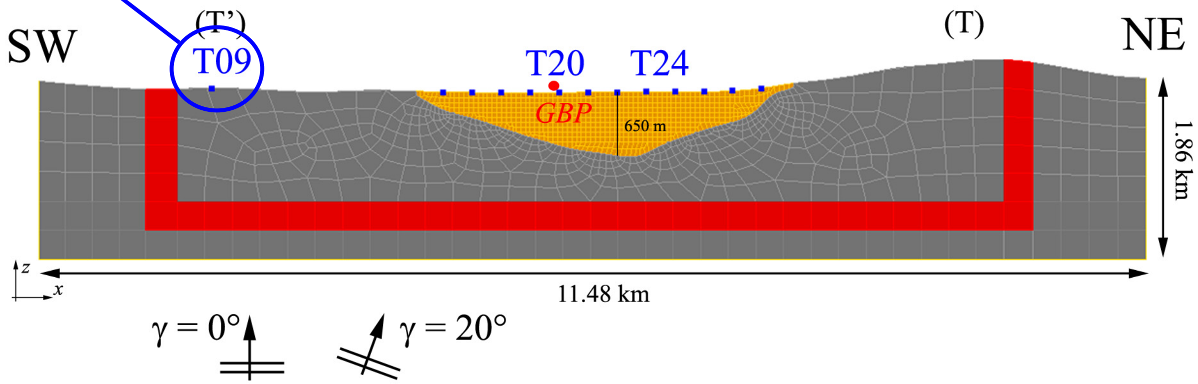
To provide a consistent comparison the same stratigraphic profile was considered for 1D, 2D and 3D models.

Comparison with 2D solutions (transverse)

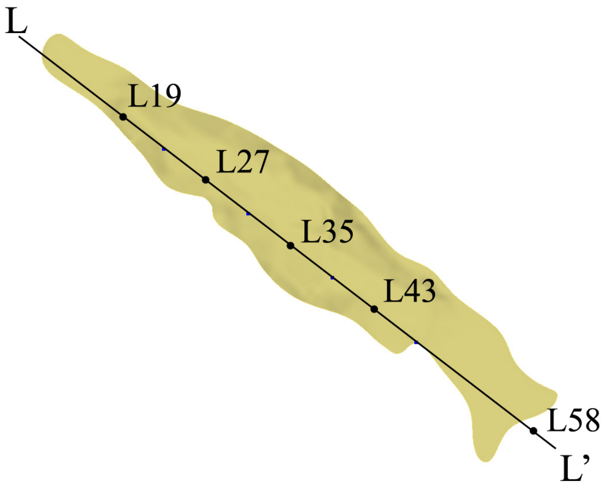


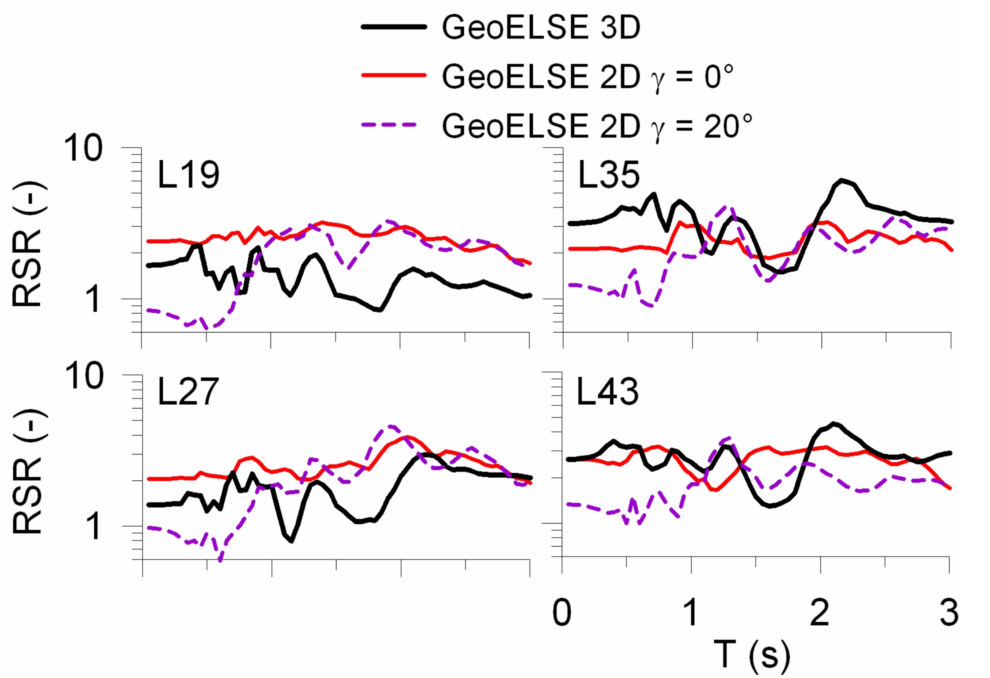


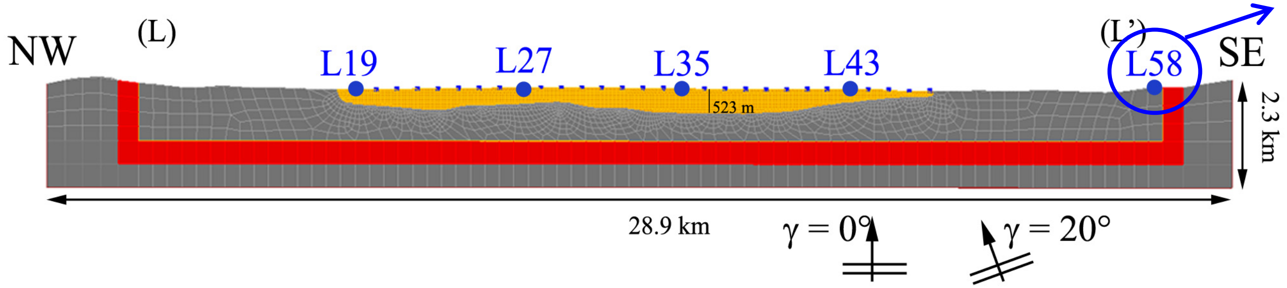
reference rock site (from 3D)



Comparison with 2D solutions (longitudinal)



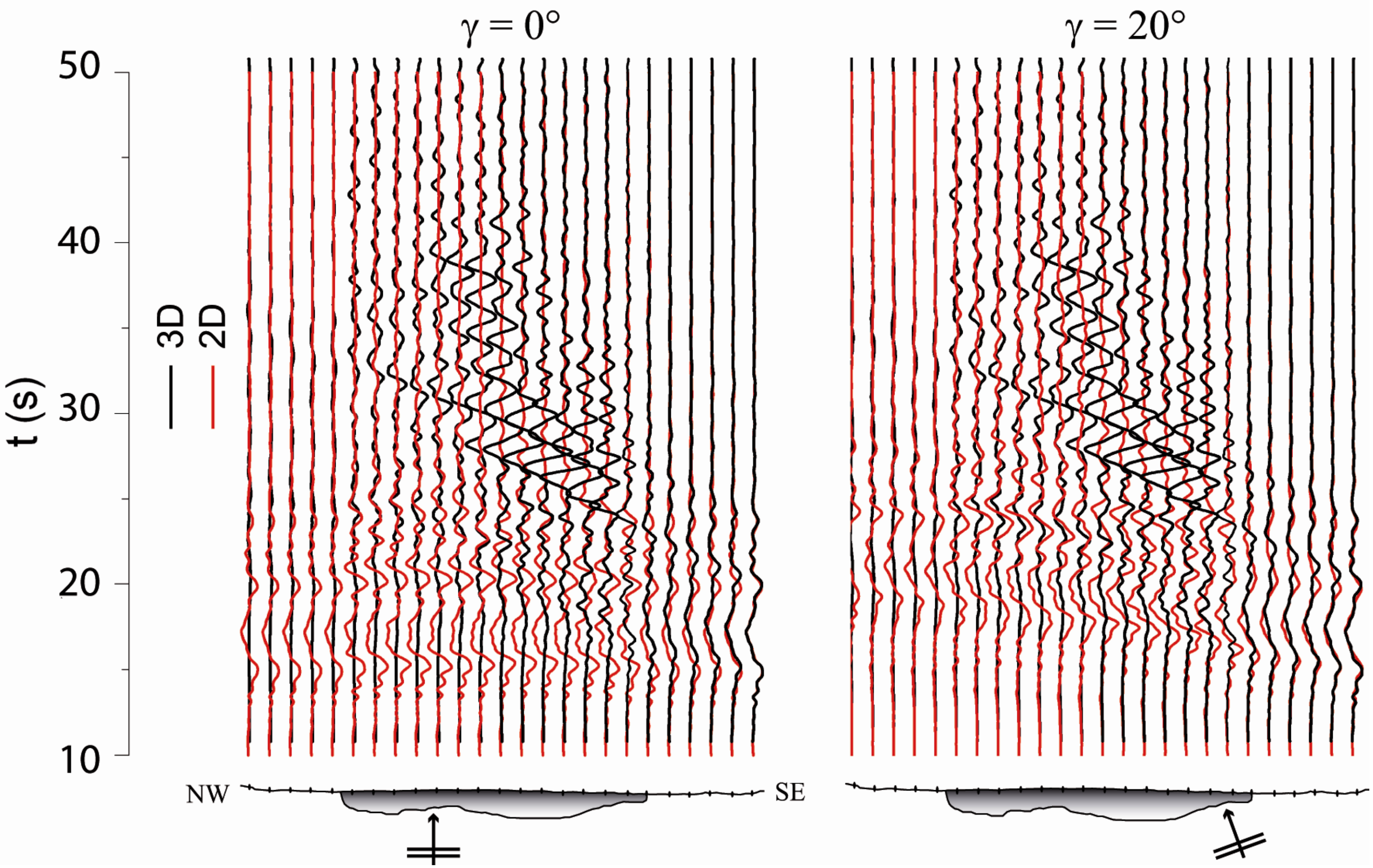




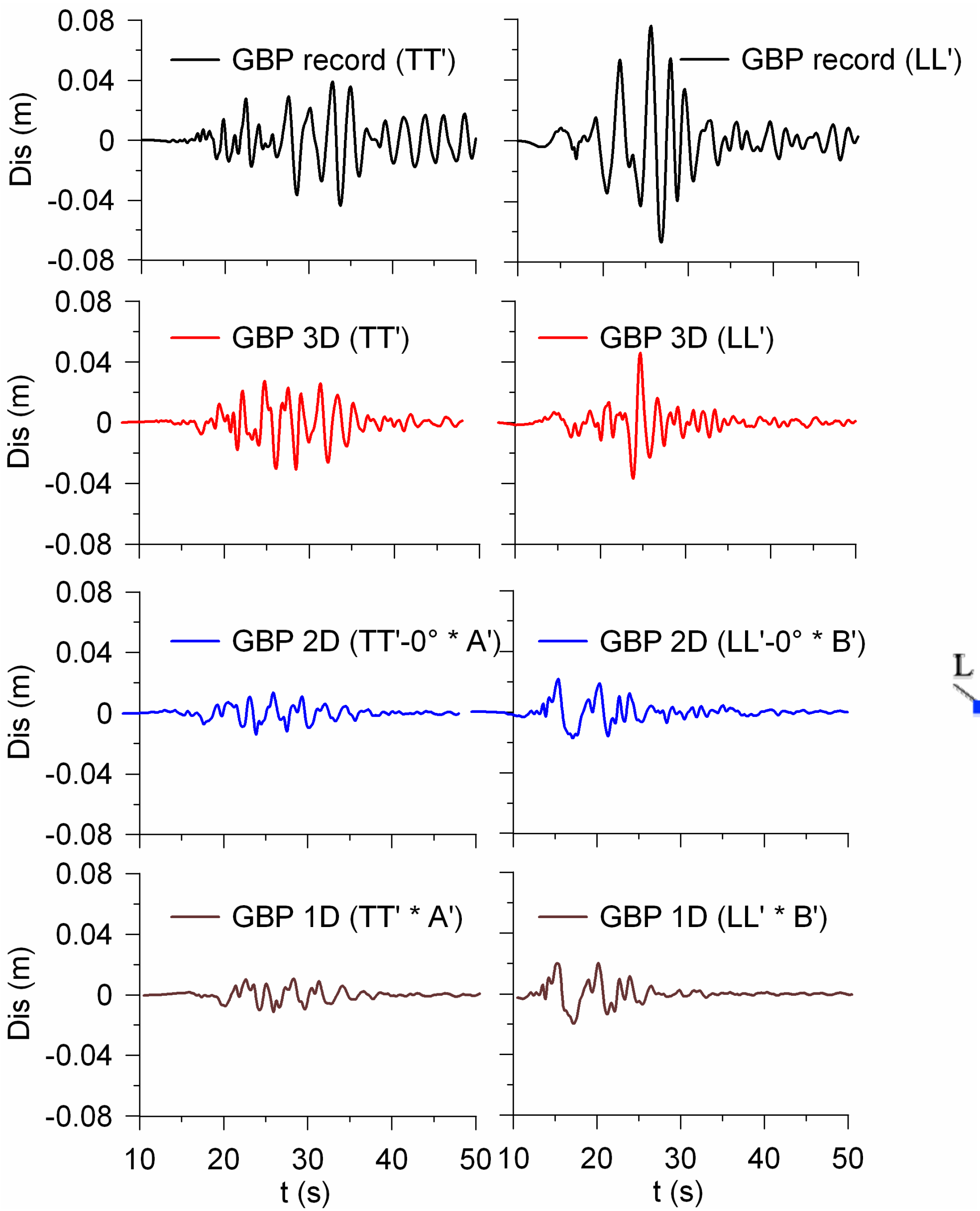
reference rock site (from 3D)

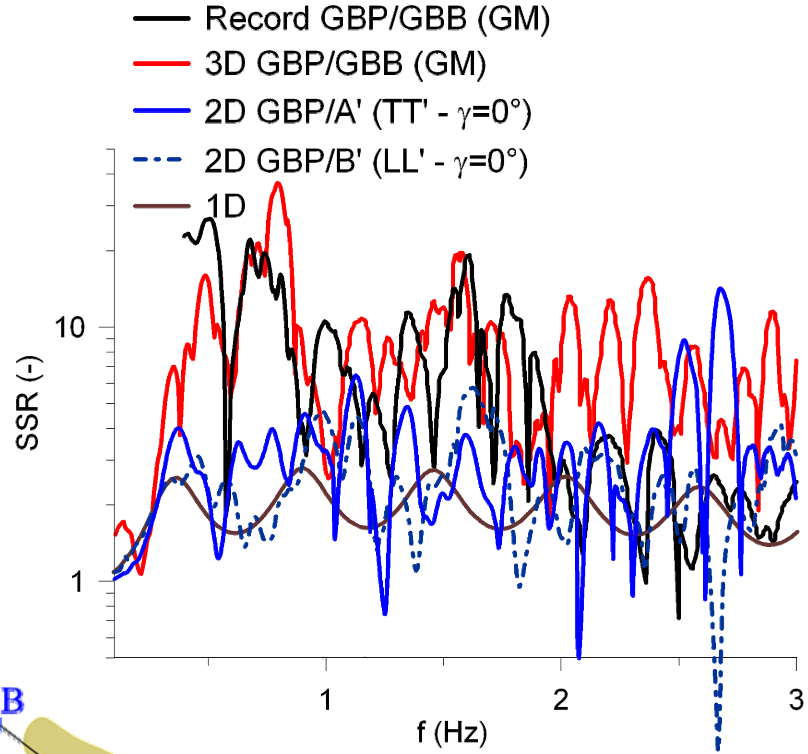
3D vs. 2D synthetics

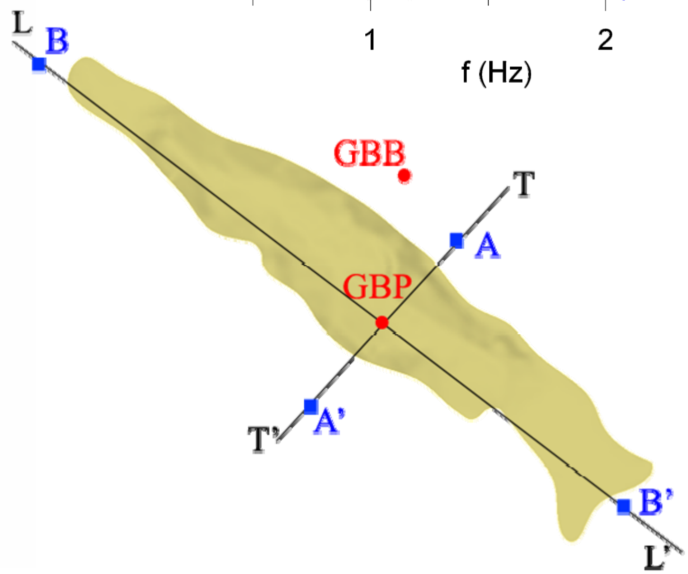
Displacement time histories along the longitudinal cross-section



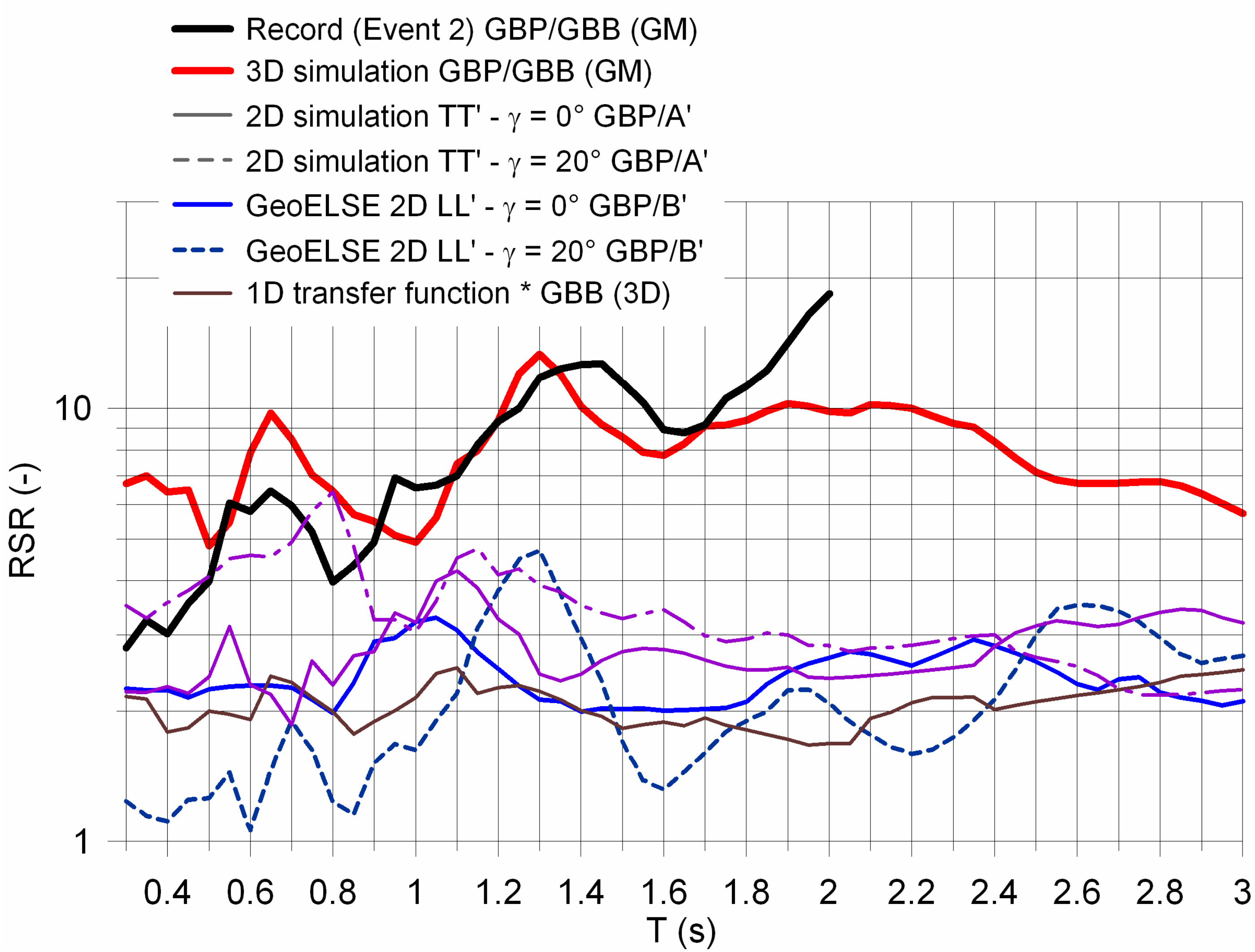
Comparison of 1D vs. 2D vs. 3D numerical results







Comparison of 1D vs. 2D vs. 3D numerical results



Concluding remarks

- 3D results were successful to predict the observed large amplification of ground motion at periods beyond about 1 s, due to the prominent onset of surface waves originated at the southern edge of the basin and propagating northwards.

- 1D and 2D numerical approaches fail to reproduce such large amplification levels, even when an oblique incidence of plane waves is considered. The proper modeling of the 3D concavity of the southern edge of the basin turns out to play a major role to reproduce the complexity of ground motion inside the Gubbio plain.

- 3D results are less accurate than 1D/2D approaches in the high frequency range, $f > 2$ Hz, due to the computational limitations at high frequency and the scarcity of detailed soil profiles.

- In spite of these limitations, 3D numerical modeling has a dramatic importance to assess earthquake ground motions, when either seismic source and/or complex site effects have a predominant role.

Concluding remarks

- Standard Spectral Ratio techniques, commonly used for the evaluation of seismic site effects, show a strong variability with respect to the reference rock site and to its relative position with respect to the seismic source and the basin.

- A preliminary parametric study on the response of Gubbio basin as a function of earthquake magnitude suggests that *SSR*s are period-dependent, even for linear soil behavior.

- Non linear site effects were neglected as a first order approximation, since ground strains at large epicentral distances are expected to be relatively small.

Thank you!