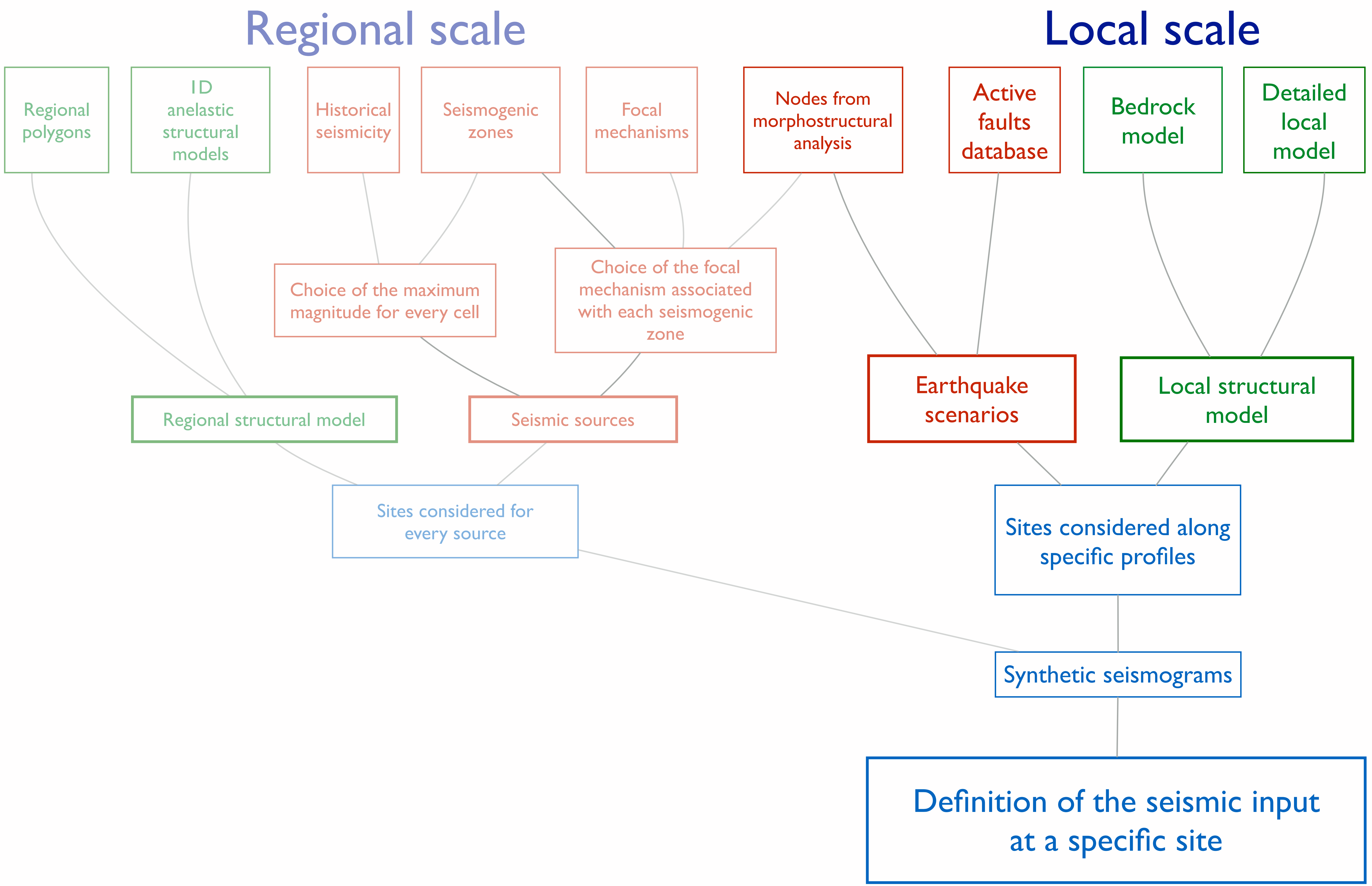
Local Scale - Towards SI



Introduction - Local scale

- Synthetic seismograms along selected profiles
- Laterally heterogeneous structural models
- Detailed source models
- Cutoff frequency up to 10 Hz
- Time series, amplification maps

Introduction - Methodology

- Regional scale: modal summation
- Local scale: hybrid methodology (modal summation + finite differences)

Methodology - Modal summation

- Displacement generated by a double-couple in layered half-space (Panza, 1985, Florsch et al 1991)

$$u_y^L(x,z,\omega) = \sum_{m=1}^{\infty} \frac{e^{-i3\pi/4}}{\sqrt{8\pi\omega}} \frac{e^{-ik_m x - \omega x C_{2m}}}{\sqrt{x}} \frac{\left(\chi_m^L(h_s,\omega)\right)}{\sqrt{c_m v_m I_m}} \frac{\left(F_y(z,\omega)\right)}{\sqrt{v_m I_m}}$$

$$u_x^R(x,z,\omega) = \sum_{m=1}^{\infty} \frac{e^{-i3\pi/4}}{\sqrt{8\pi\omega}} \frac{e^{-ik_m x - \omega x C_{2m}}}{\sqrt{x}} \frac{\left(\chi_m^R(h_s,\omega)\right)}{\sqrt{c_m v_m I_m}} \frac{\left(F_x(z,\omega)\right)}{\sqrt{v_m I_m}}$$

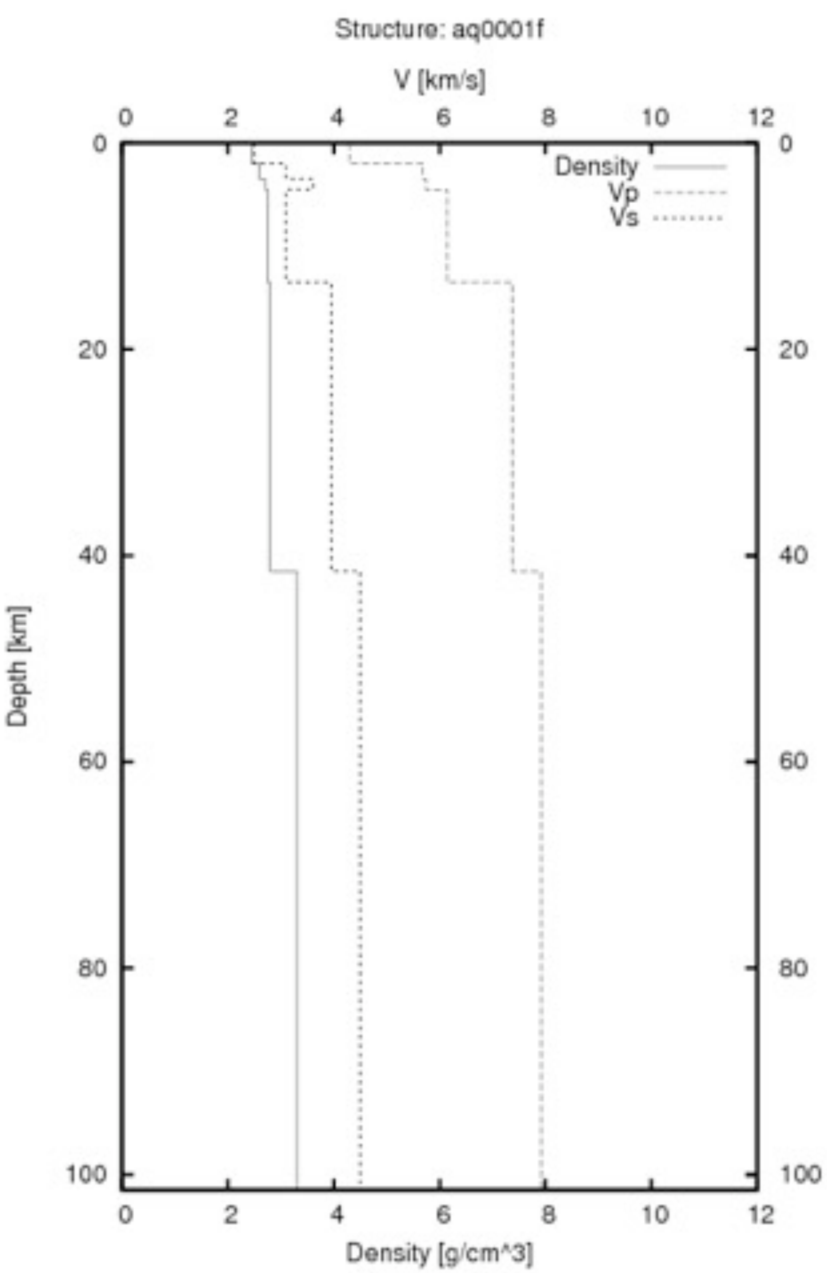
$$u_z^R(x,z,\omega) = \sum_{m=1}^{\infty} \frac{e^{-i\pi/4}}{\sqrt{8\pi\omega}} \frac{e^{-ik_m x - \omega x C_{2m}}}{\sqrt{x}} \frac{\left(\chi_m^R(h_s,\omega)\right)}{\sqrt{c_m v_m I_m}} \frac{\left(F_z(z,\omega)\right)}{\sqrt{v_m I_m}}$$

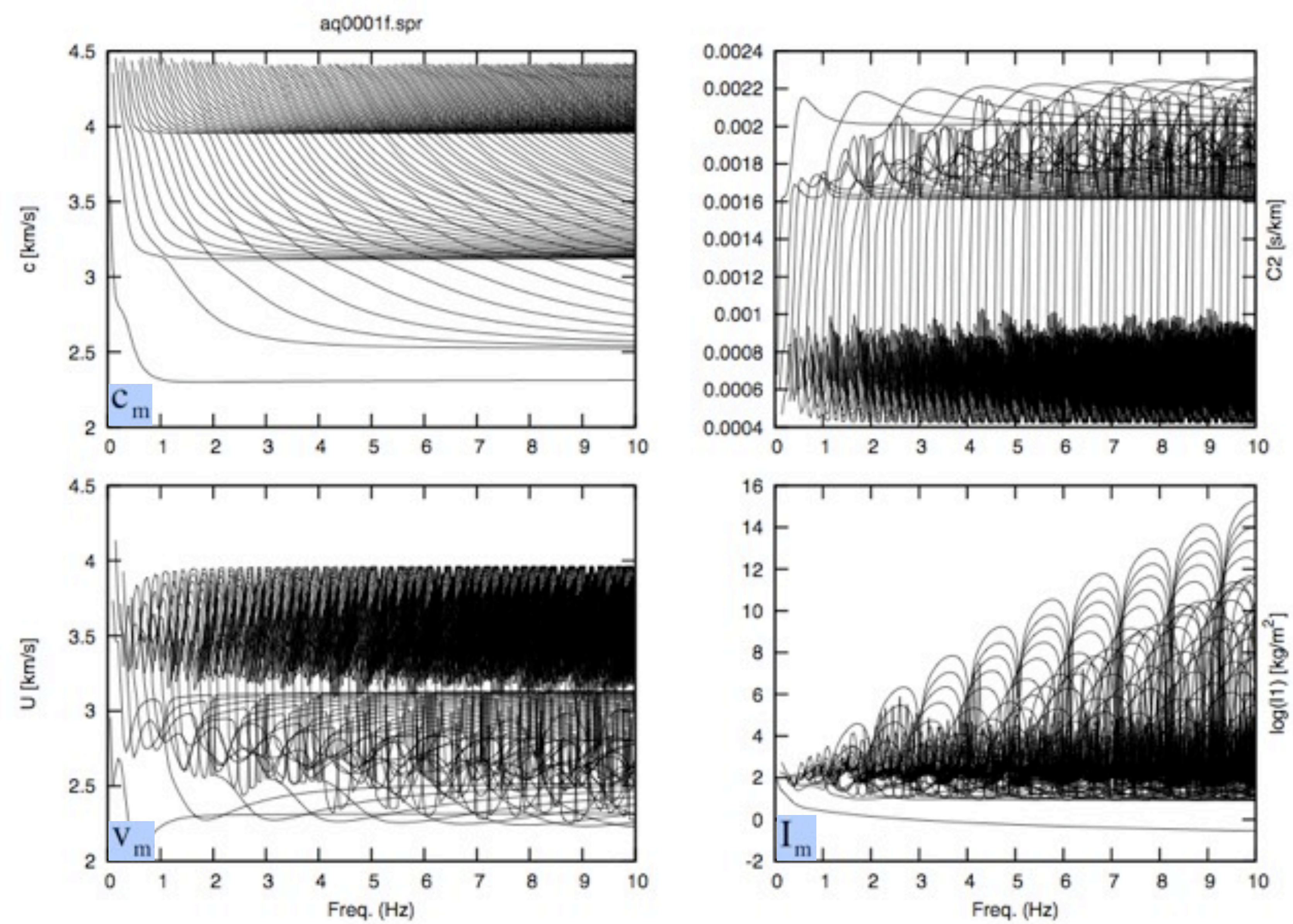
source propagation site

Methodology - Modal summation

- Examples of structural quantities

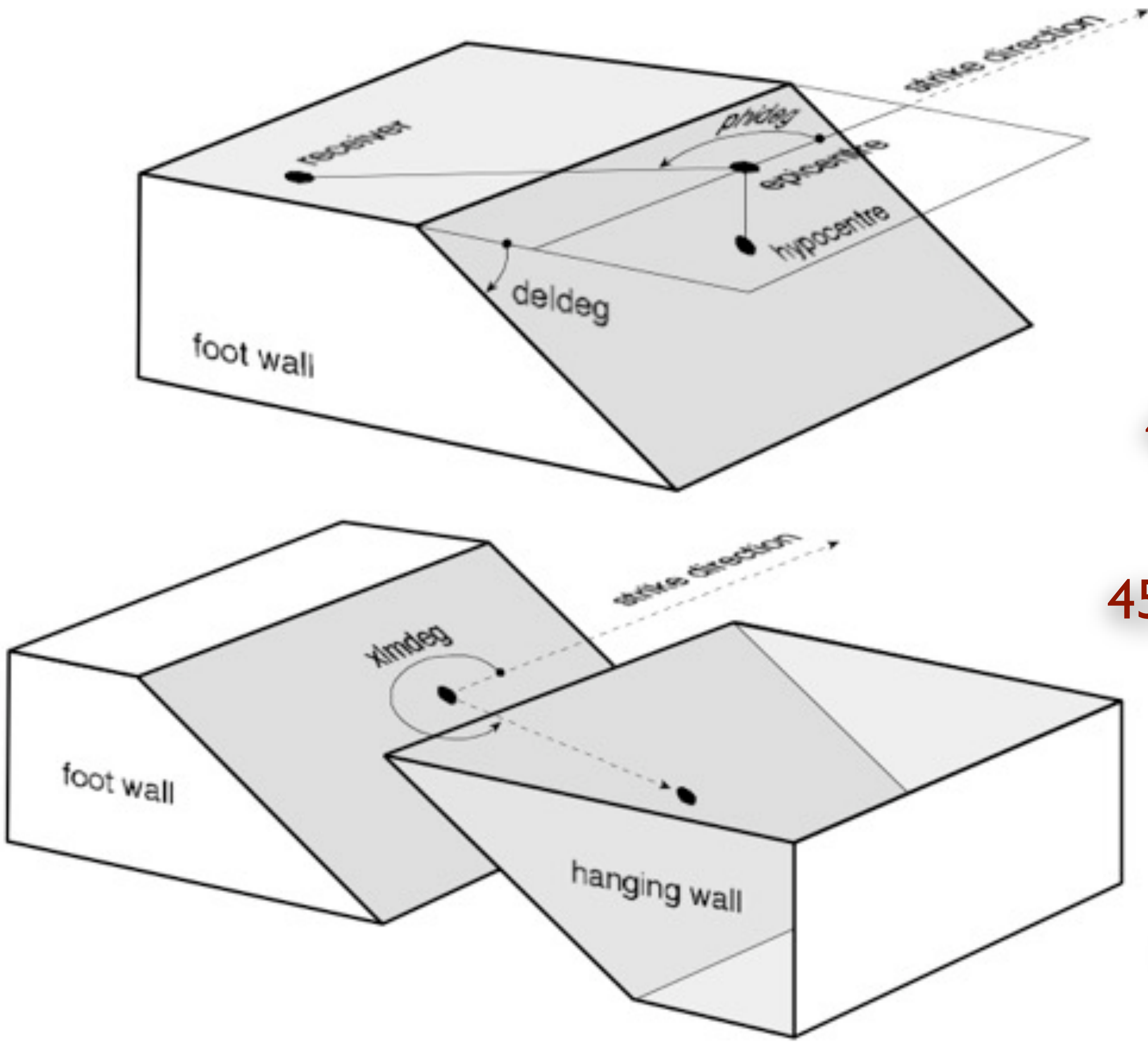
$$\sqrt{c_m V_m I_m} \qquad \sqrt{V_m I_m}$$

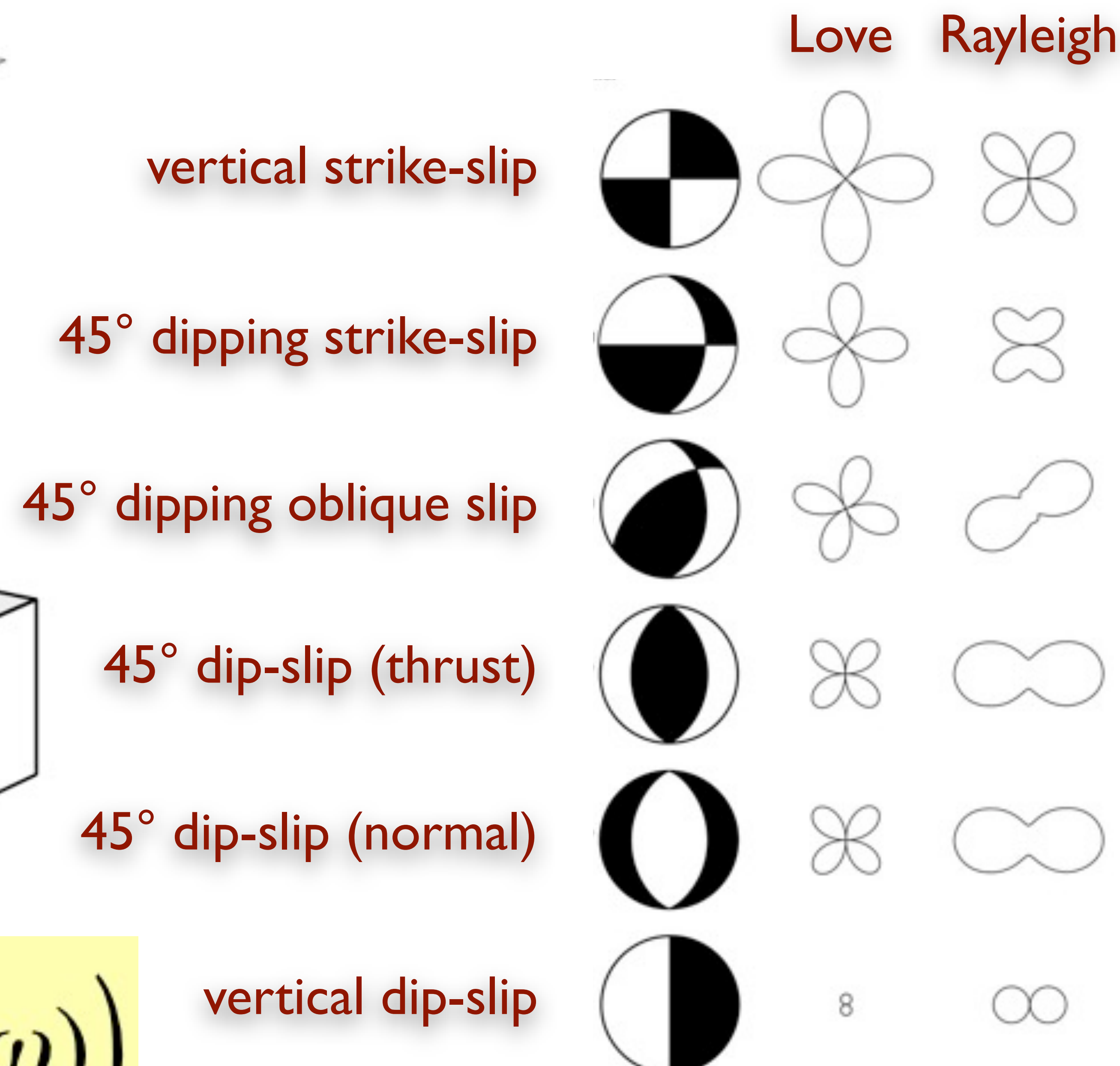




Methodology - Modal summation

- Source definition and radiation pattern

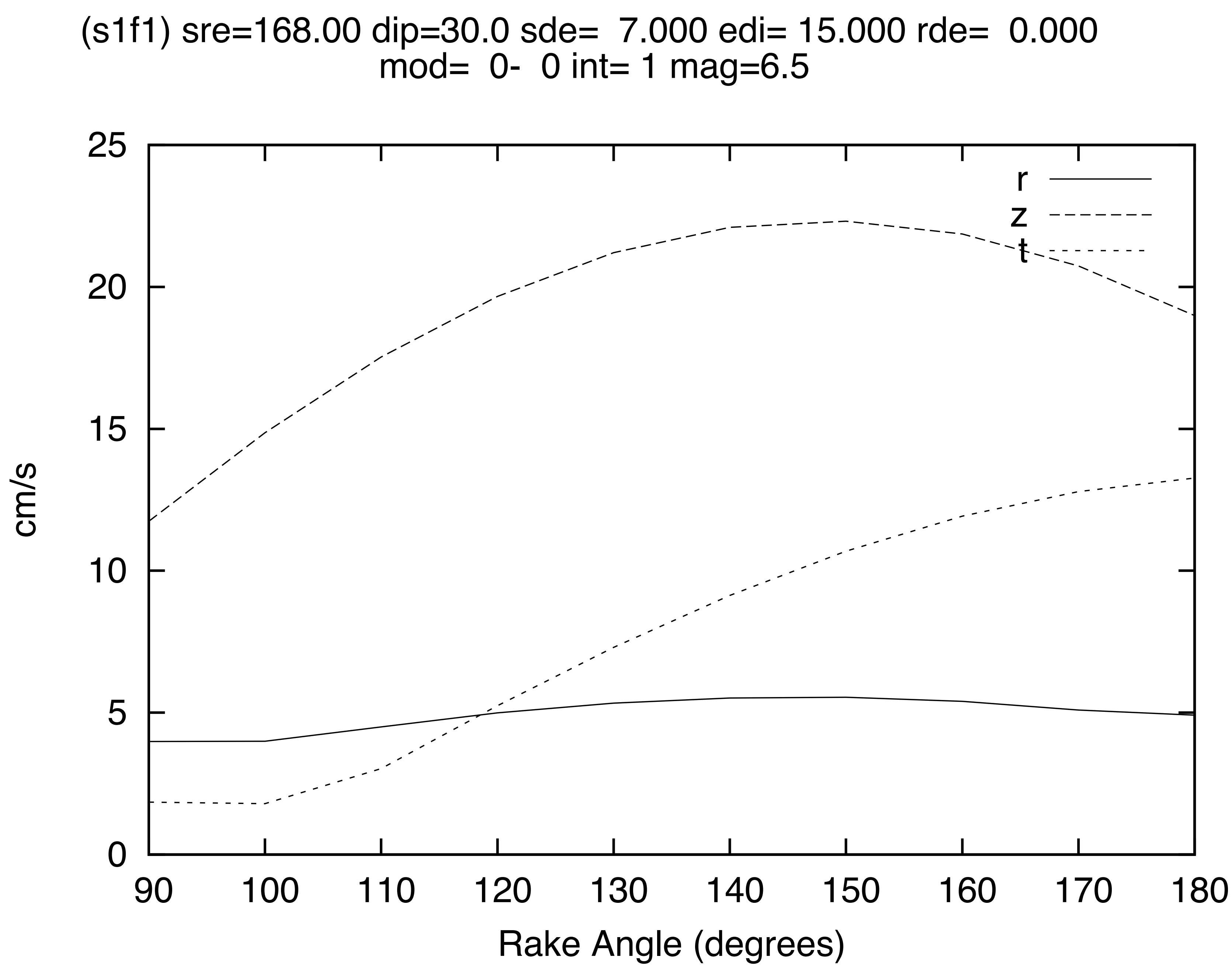




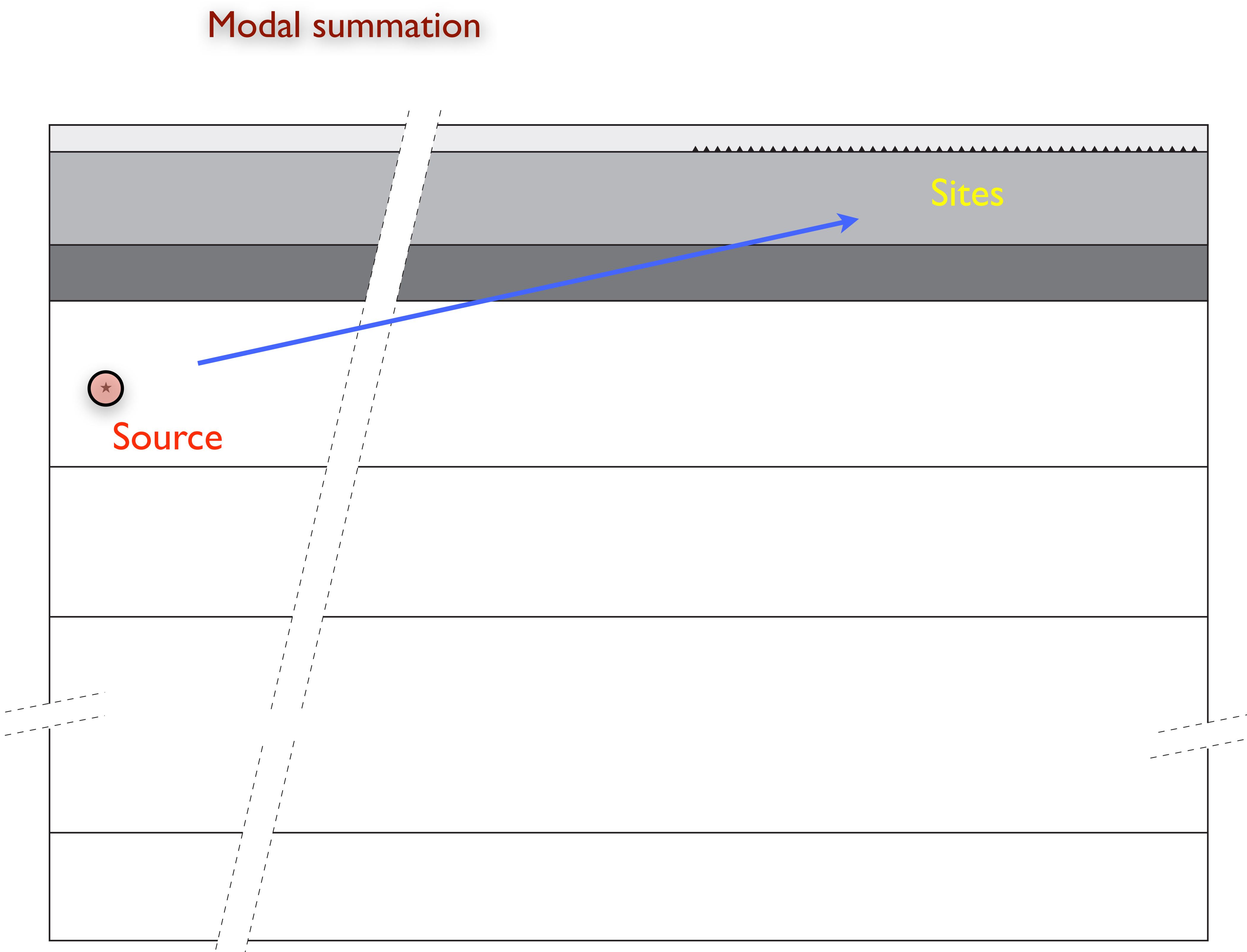
$$\left(\chi_m^L(h_s,\omega)\right) \qquad \left(\chi_m^R(h_s,\omega)\right)$$

Methodology - Modal summation

- 1D parametric tests: rake variation



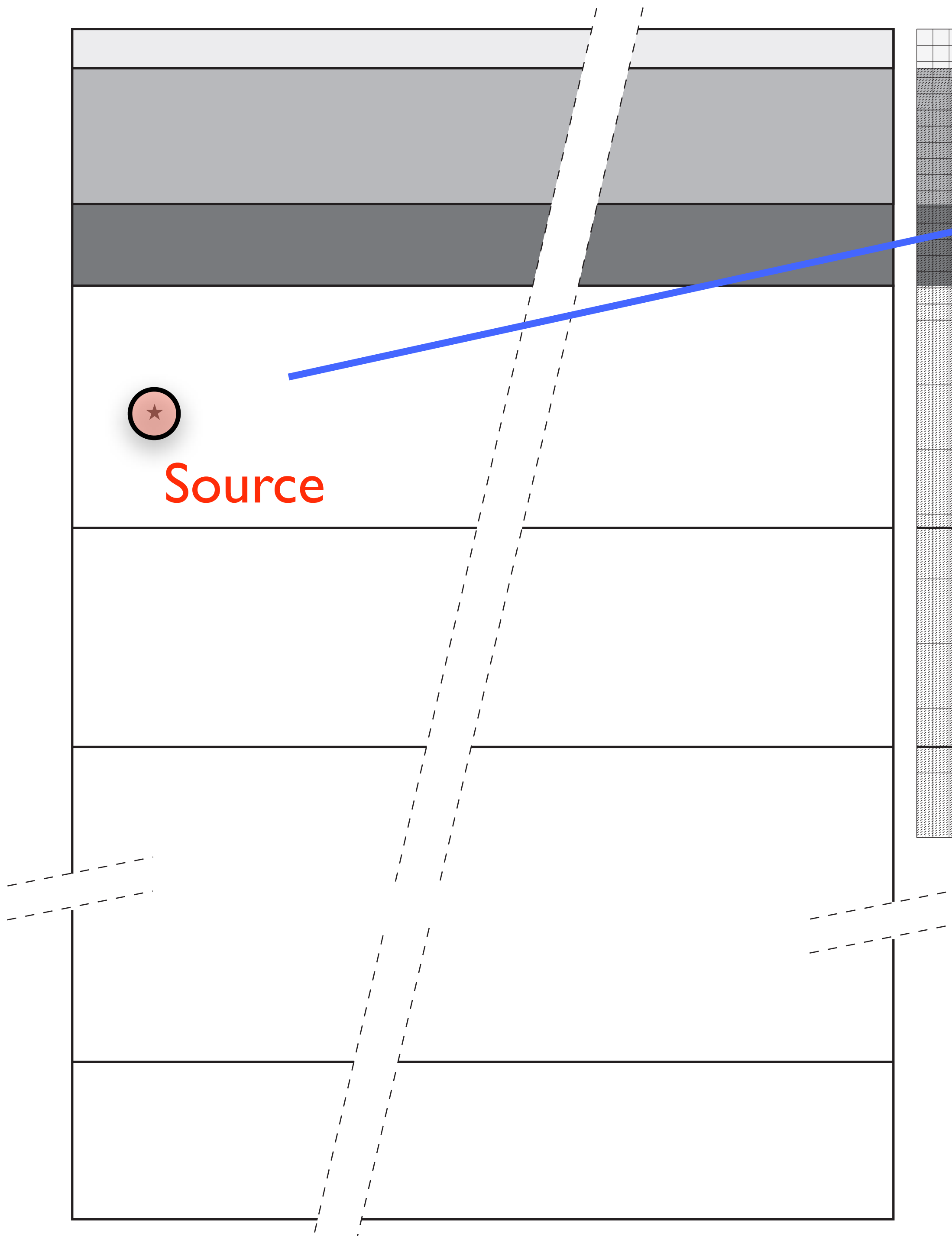
Methodology - Modal summation (regional scale)

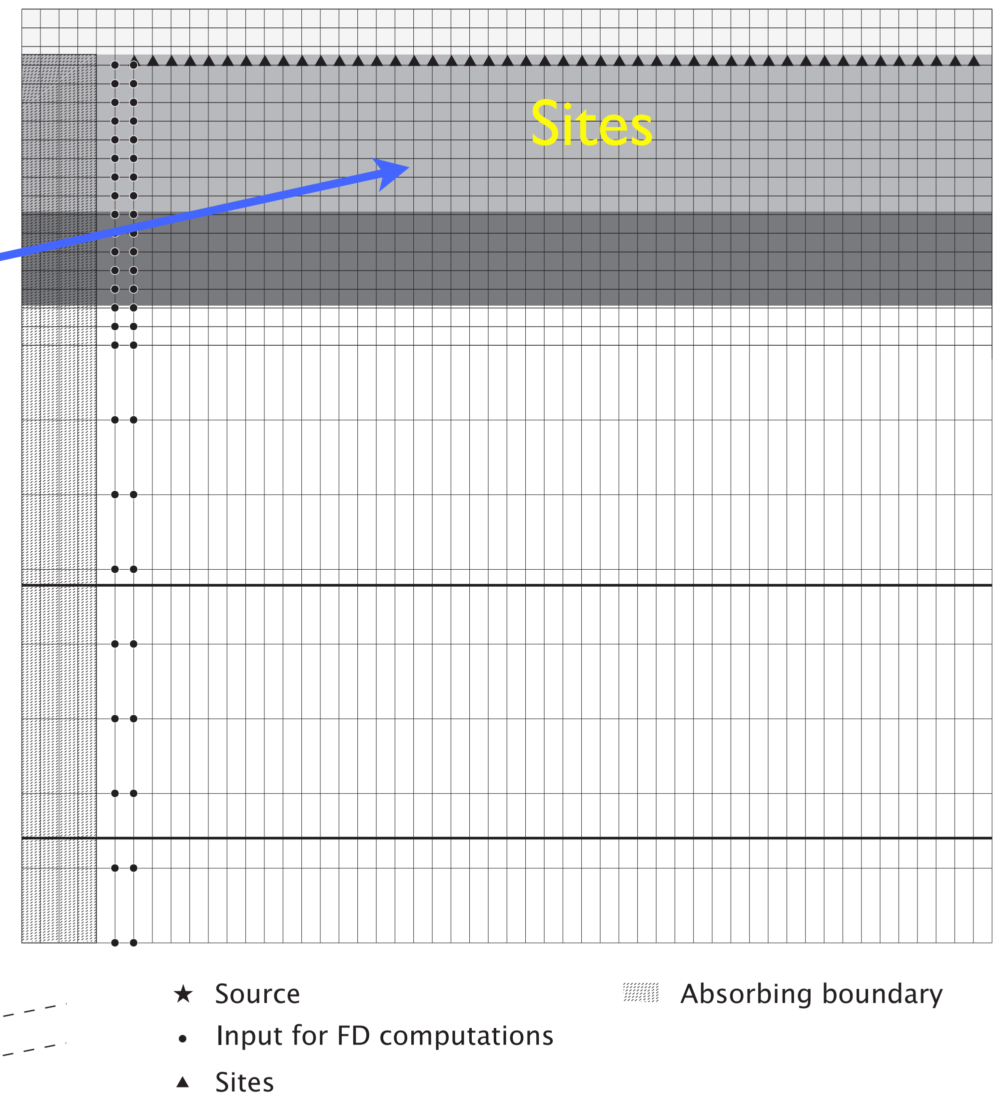


Methodology - Hybrid technique

Modal summation

Finite Differences

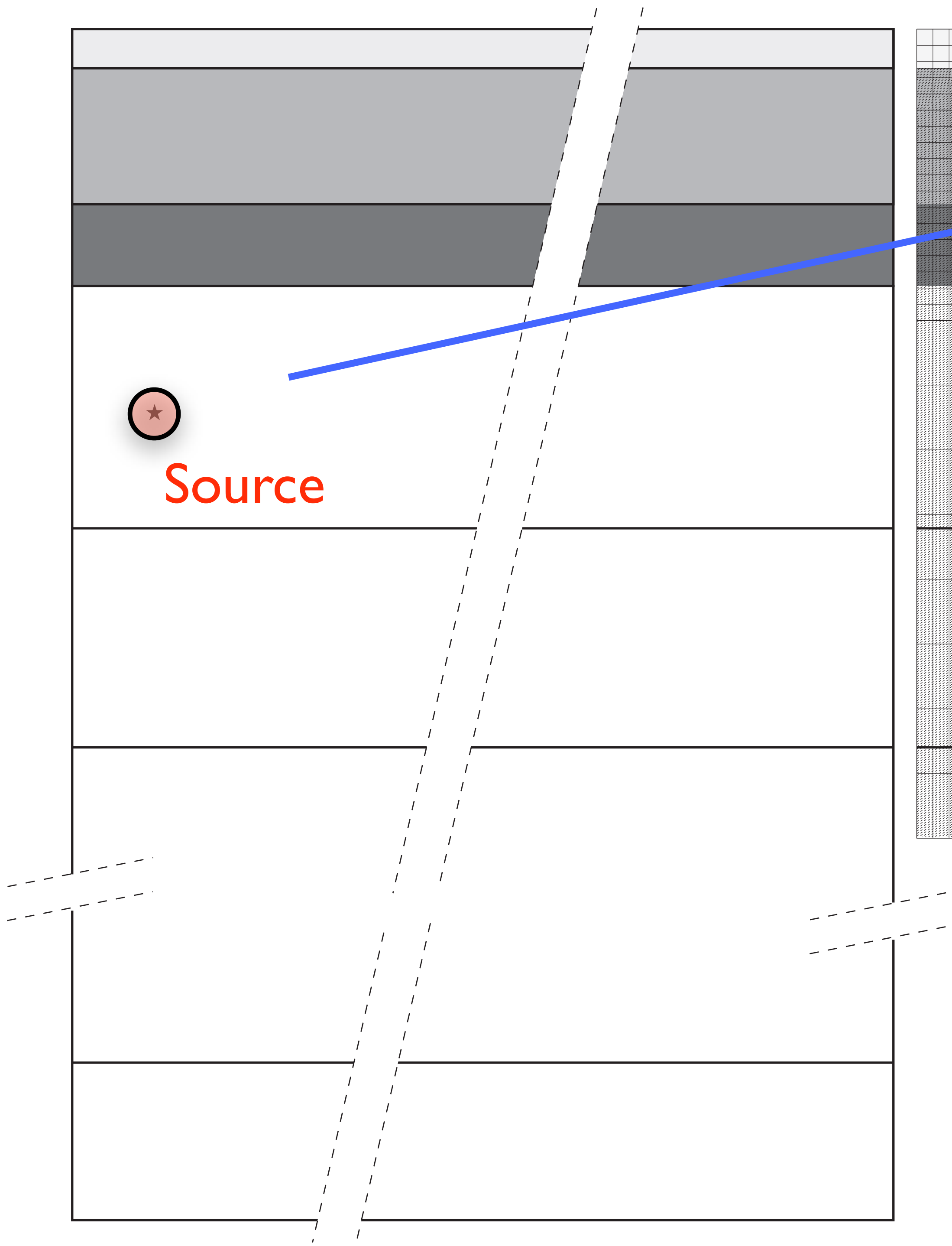




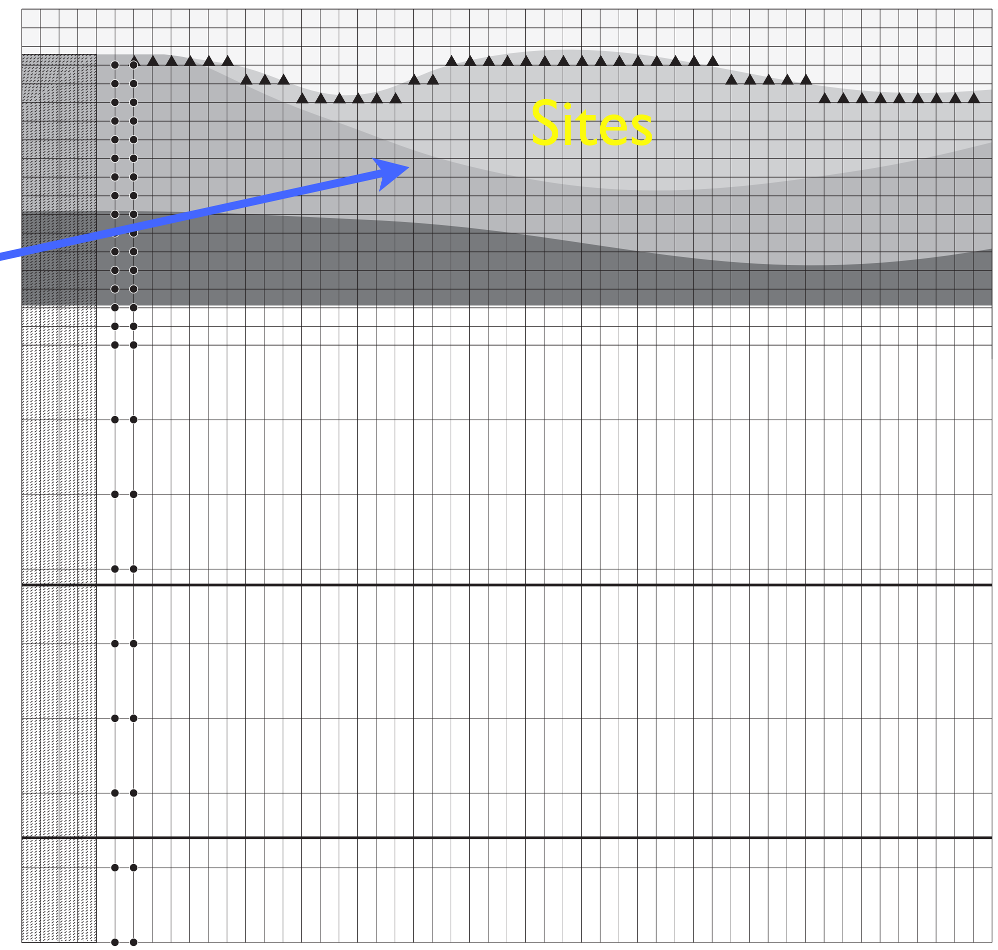
	Material	Density (g/cm3)	Vp (km/s)	Qp	Vs (km/s)	Qs
	Air	0	0	0	0	0
	Sed1	1.8	0.8	100	0.4	50
	Sed2	1.9	0.9	100	0.5	50
	Sed3	2.0	1.0	100	0.6	50

Methodology - Hybrid technique (local scale)

Modal summation



Finite Differences

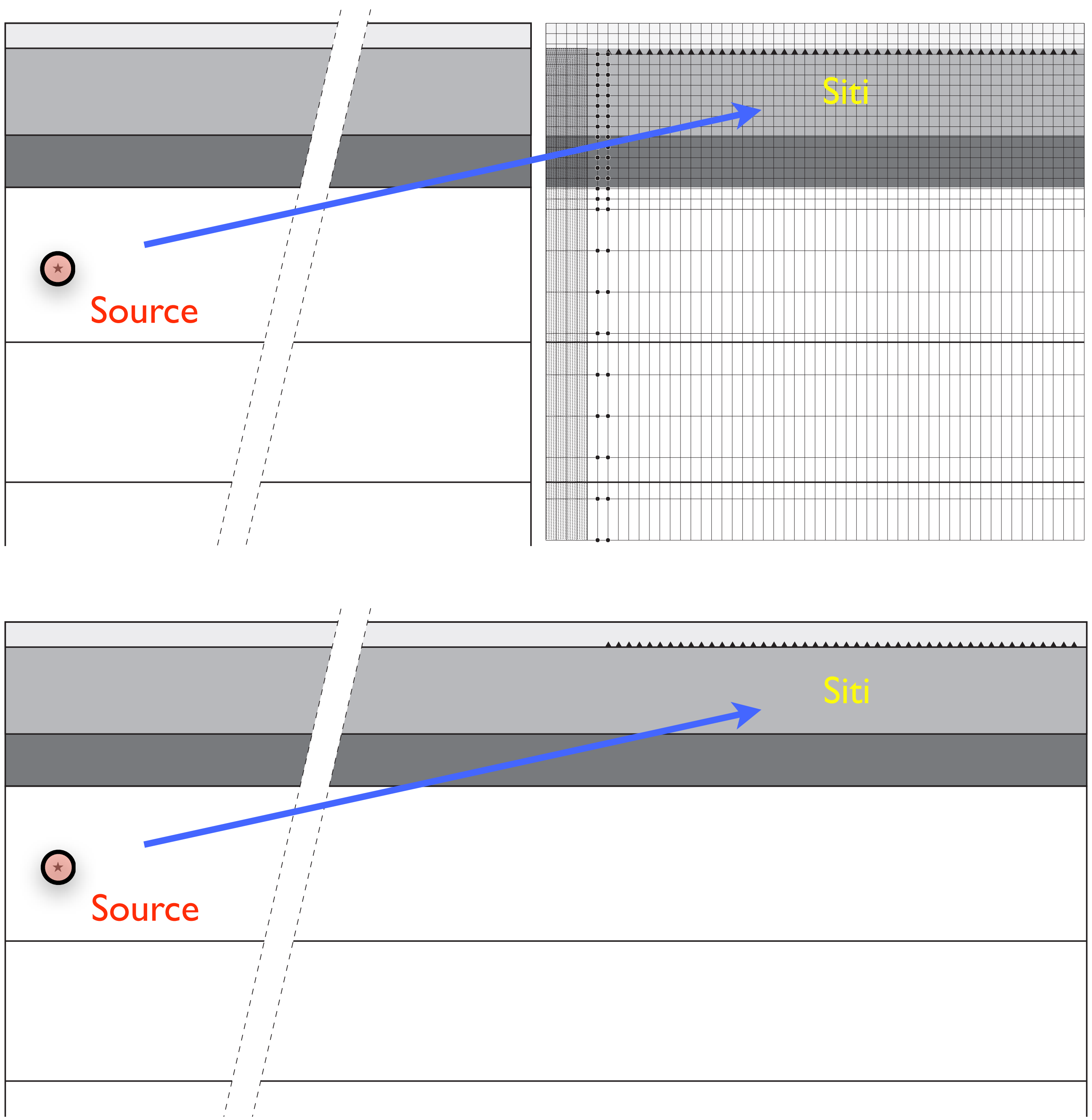


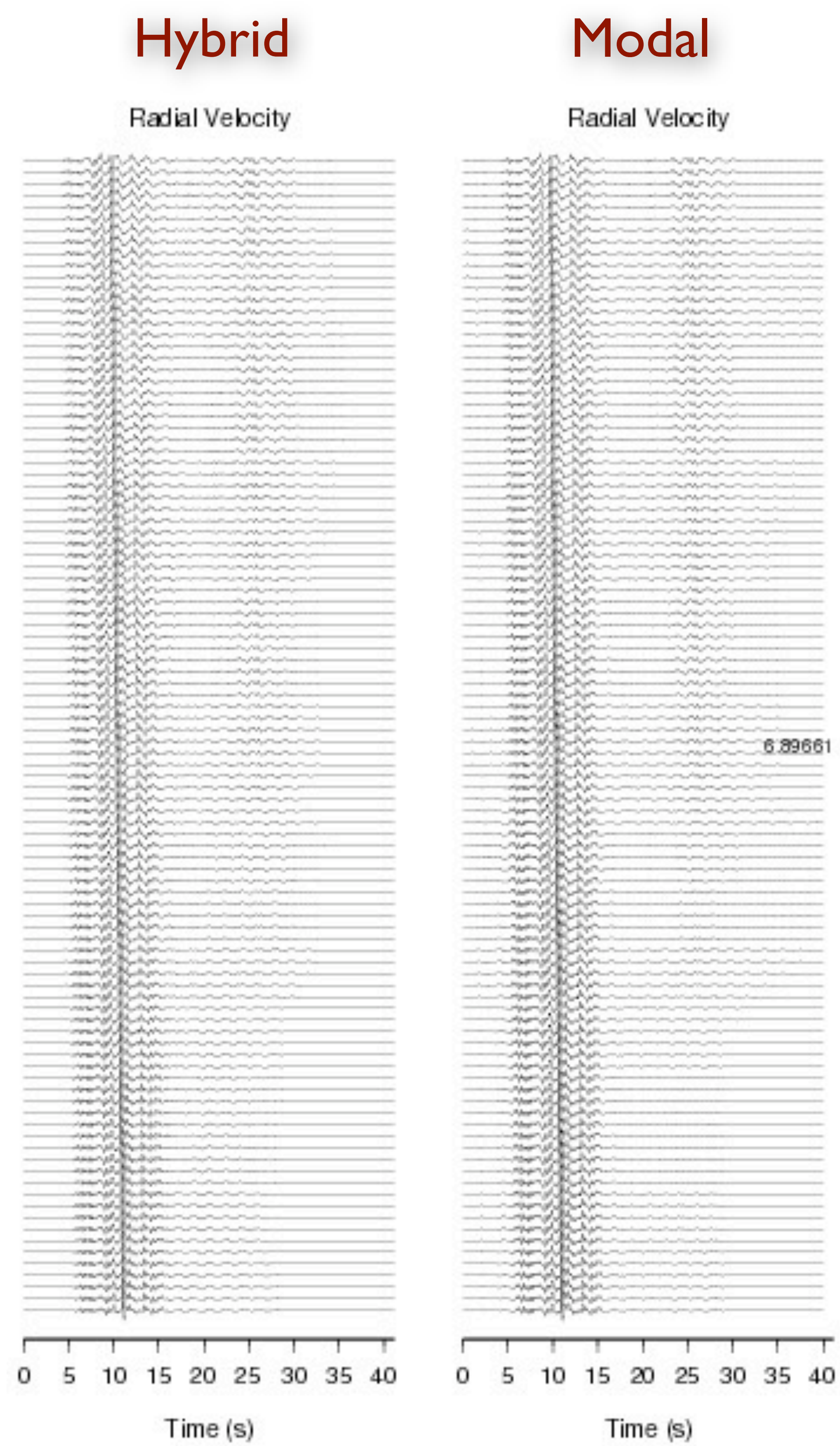
★ Source
• Input for FD computations
▲ Sites
Absorbing boundary

	Material	Density (g/cm^3)	Vp (km/s)	Qp	Vs (km/s)	Qs
	Air	0	0	0	0	0
	Sed1	1.8	0.8	100	0.4	50
	Sed2	1.9	0.9	100	0.5	50
	Sed3	2.0	1.0	100	0.6	50

Methodology - Hybrid method

Quality test





Local Scale - Input Definition

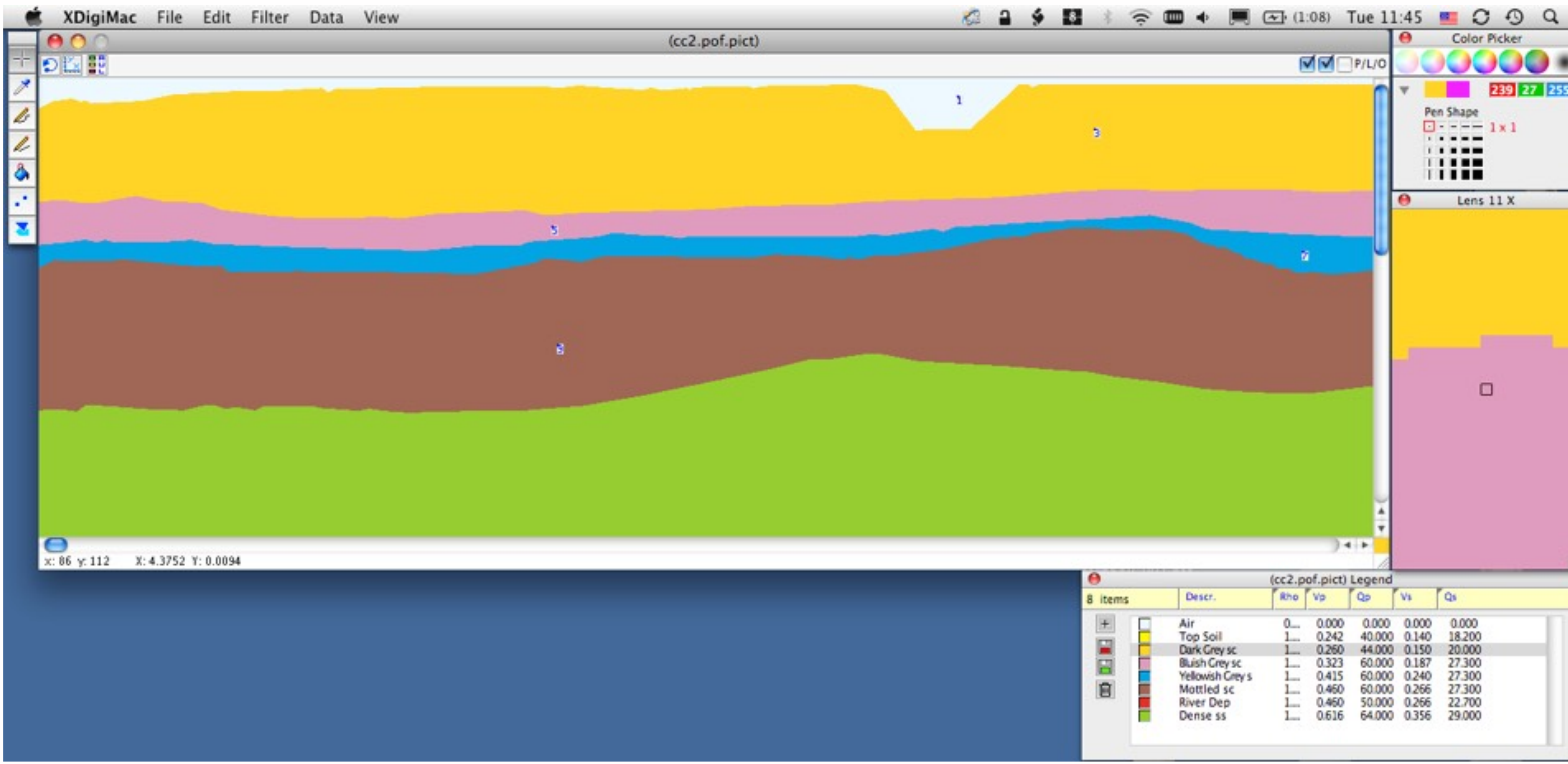
```
Parameters file for program pfdg10
--------------------------------------------------------------------------
Modal summation model
--------------------------------------------------------------------------
test.spr                          Modes for 1D structure
0         First mode to use (1=fundamental, 0=all)
0         Last mode to use (0=all)
10.0      Low pass filter cutoff frequency (xcutof)
.50       Ratio between filter's max freq with unit response and xcutof
.02       Low pass filter amplitude at cutoff
0         Interpolation for modal summation part
5.000     Source depth (km)
125.0     strike-receiver angle (SH modelling)
45.0      fault dip            (SH modelling)
90.0      fault rake           (SH modelling)
125.0     strike-receiver angle (P-SV modelling)
45.0      fault dip            (P-SV modelling)
90.0      fault rake           (P-SV modelling)
7.5       Source-2D model origin distance (km)
--------------------------------------------------------------------------
Finite differences model
--------------------------------------------------------------------------
test                           Generated FD model
test.pof                      Polygons with 2D part definition
2800      Max number of grid points along x
600       Max number of grind points along z
0         Force an air layer of 5 grid points without topography (0=no, 1=yes)
0.0       Min velocity (km/s) for grid definition (0=auto -> look for min Vs)
0         FD model length from 1st column of seismograms (km) (0=auto)
0.00      FD model depth (km) (0=auto)
0.000     Grid spacing (km) (0=auto)
0         dz multiplier (0=auto)
0.000     Depth where step along z changes (0=auto)
0         Number of absorbing points along x (0=auto)
0         Number of absorbing zones (0=auto)
0         Lowest Q for absorbing zones (0=auto)
0         Highest Q for absorbing zones (0=auto)
1         Geom. spreading (0=no, 1=yes) for SH (suggested: 0 far/short,1 near/long)
1         Geom. spreading (0=no, 1=yes) for P-SV (suggested: 1)
10        Time window length (s) for 1D SH (0=auto)
10        Time window length (s) for 1D P-SV (0=auto)
10        Time window length (s) for 2D SH (0=auto)
10        Time window length (s) for 2D P-SV (0=auto)
00        Shift in origin time (SH)
00        Shift in origin time (P-SV)
------------------------------------------------------------------
```

Modal Summation

Finite Difference

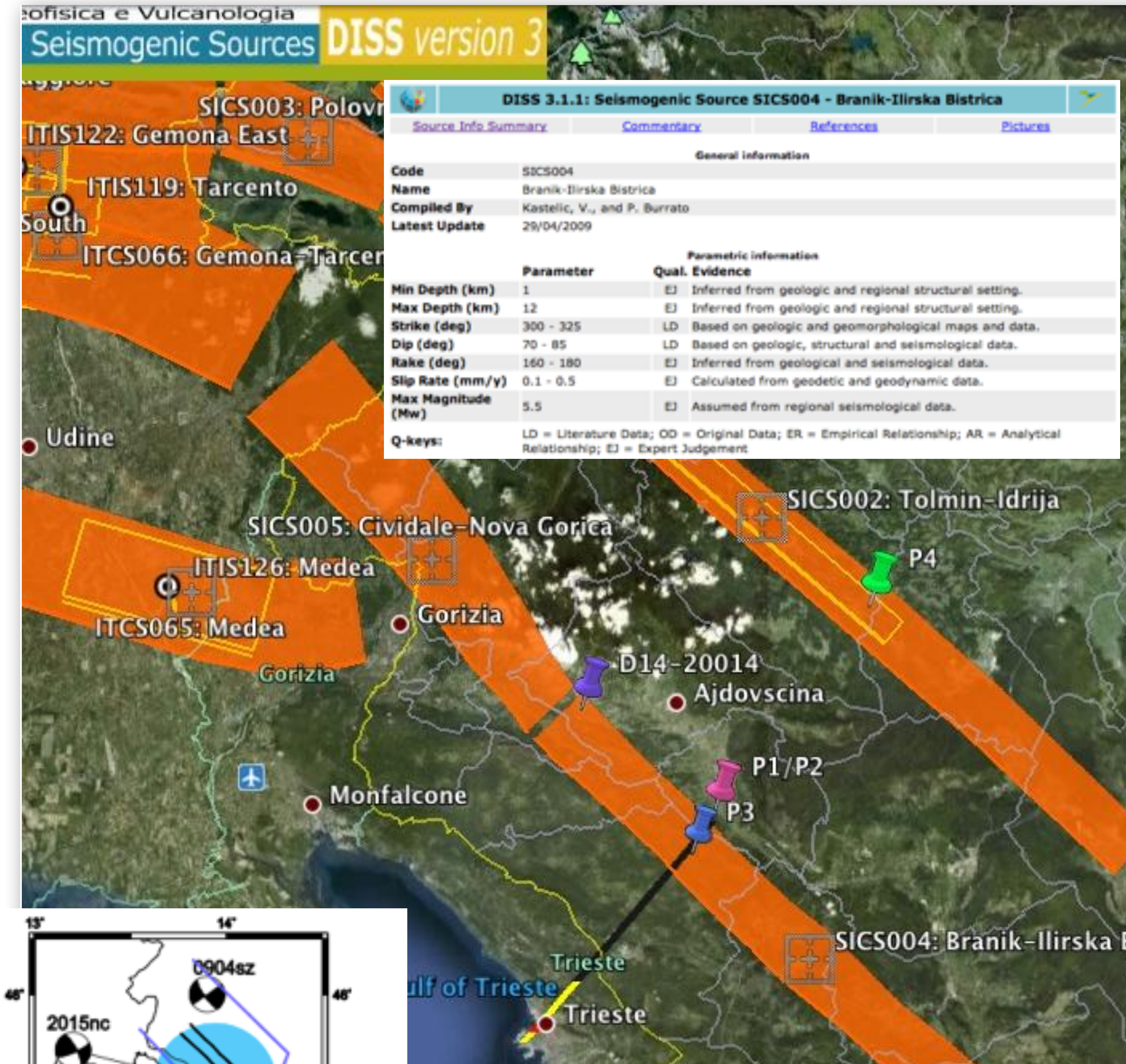
Local Scale - Input Definition

Ad-hoc software dedicated to the digitization of the layer geometry and the definition of the layer properties



Local Scale - Scenario Earthquakes (Trieste)

- P1. Source P1/P2, bedrock structure dinarb, Bovec mechamism with strike=315°, dip=82°, rake=189°, hypocentral depth=7.6 km, epicentral distance=18 km, magnitude 6
- P2. Same scenario of P1, but using as bedrock structure the Italian cellular model (Project S1 INGV-DPC)
- P3. Source P3, cell structure, Idrija mechanism with strike=310°, dip=80°, rake=176°, hypocentral depth=10 km, epicentral distance=13.5 km, magnitude 6
- P4. Source P4, cell structure, Idrija mechanism with strike=310°, dip=80°, rake=176°, hypocentral depth=10 km, epicentral distance=37 km, magnitude 6.8



DISS 3.1.1: Seismogenic Source SICS004 - Branik-Ilirska Bistrica

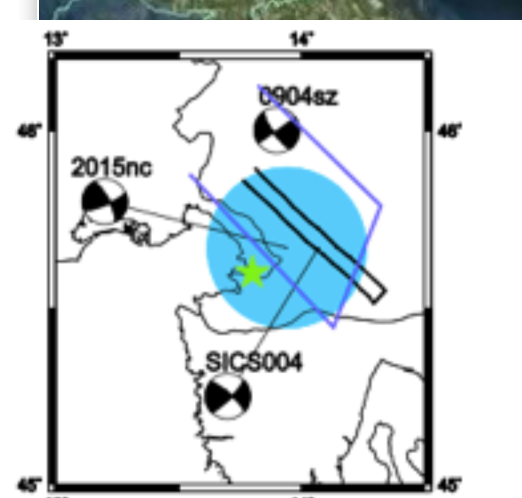
Source Info Summary | Commentary | References | Pictures

General information

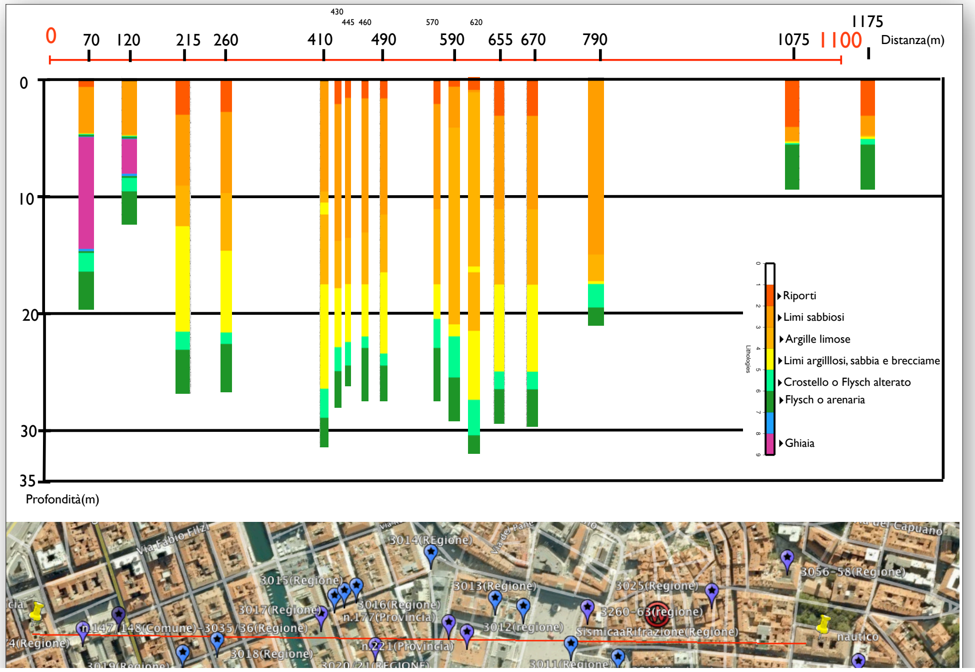
Code	SICS004
Name	Branik-Ilirska Bistrica
Compiled By	Kastelic, V., and P. Burrato
Latest Update	29/04/2009

Parametric information

	Parameter	Qual.	Evidence
Min Depth (km)	1	EJ	Inferred from geologic and regional structural setting.
Max Depth (km)	12	EJ	Inferred from geologic and regional structural setting.
Strike (deg)	300 - 325	LD	Based on geologic and geomorphological maps and data.
Dip (deg)	70 - 85	LD	Based on geologic, structural and seismological data.
Rake (deg)	160 - 180	EJ	Inferred from geological and seismological data.
Slip Rate (mm/y)	0.1 - 0.5	EJ	Calculated from geodetic and geodynamic data.
Max Magnitude (Mw)	5.5	EJ	Assumed from regional seismological data.
Q-keys:	LD = Literature Data; OD = Original Data; ER = Empirical Relationship; AR = Analytical Relationship; EJ = Expert Judgement		

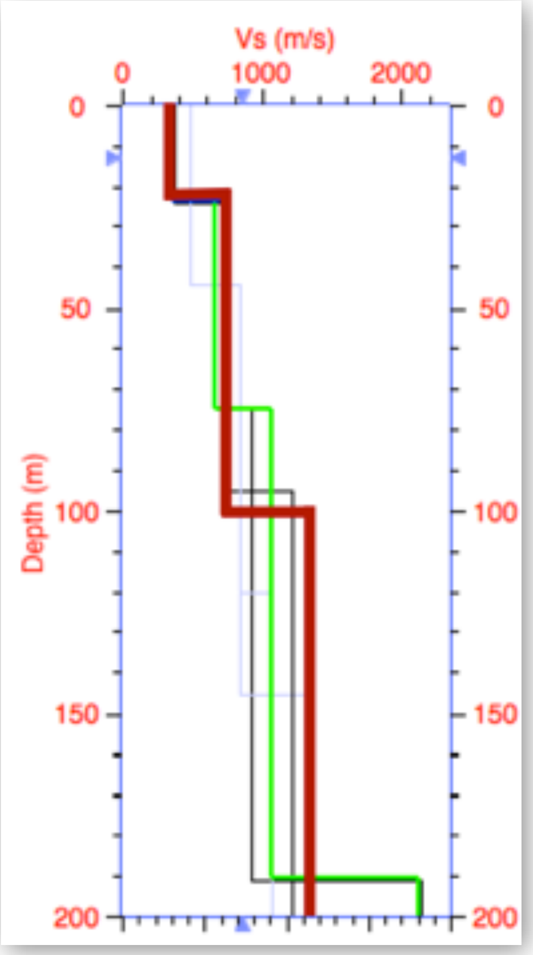


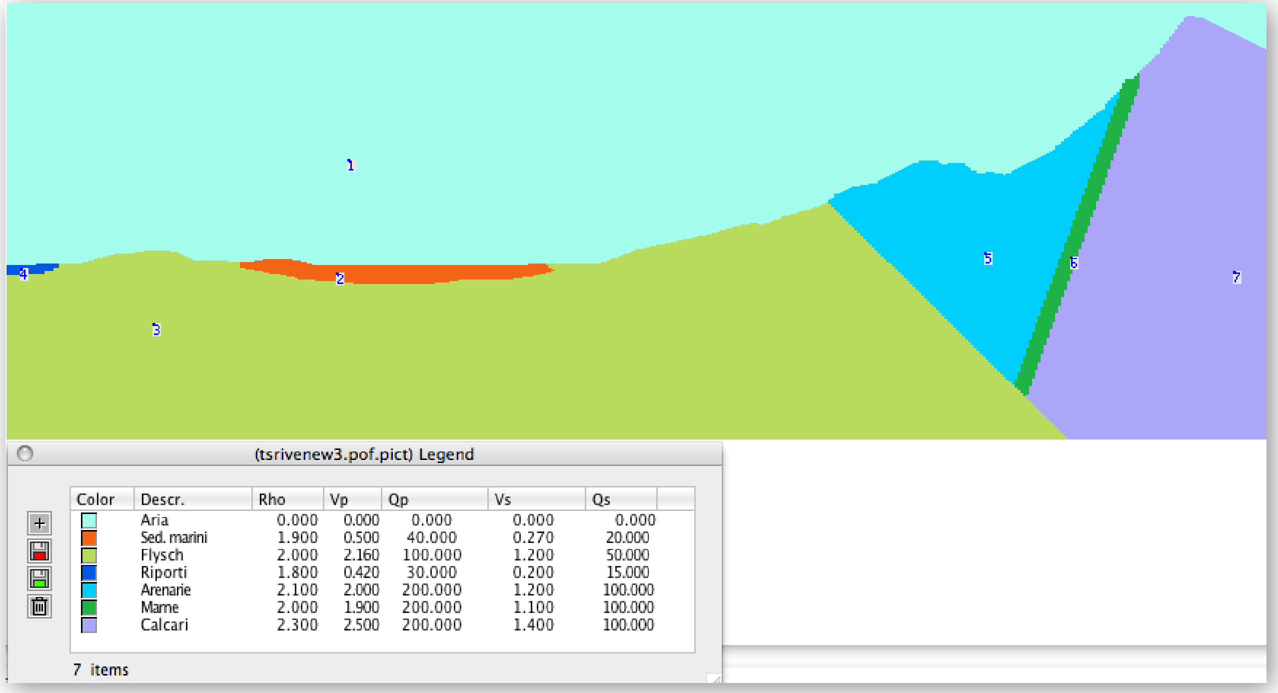
Local scale - Selected profile in Trieste



Geological section from boreholes for the profile Provincia- Nautico

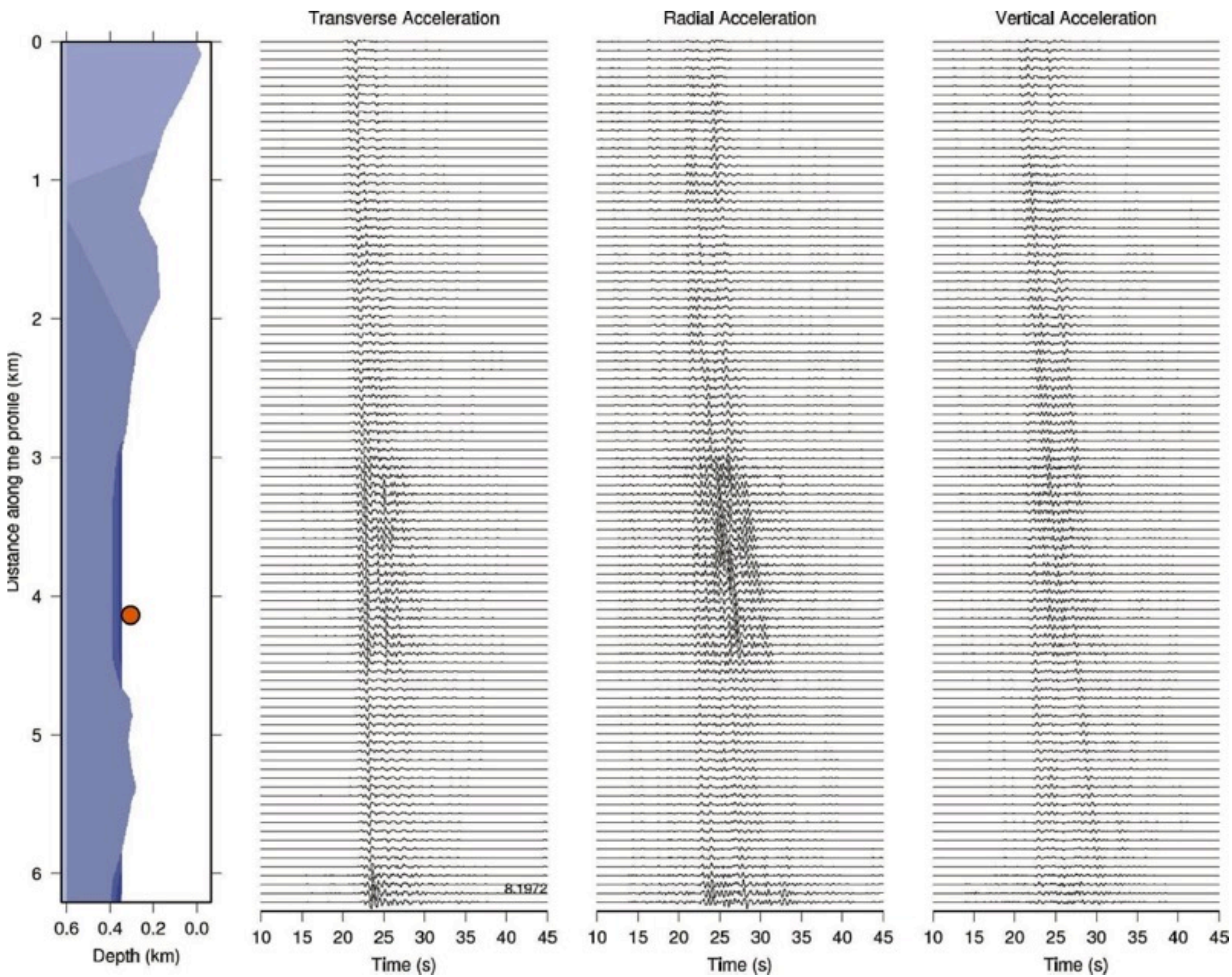
Inversion of dispersion curves obtained from cross-correlation of seismic ambient noise measures





Color	Descr.	Rho	Vp	Qp	Vs	Qs
	Aria	0.000	0.000	0.000	0.000	0.000
	Sed. marini	1.900	0.500	40.000	0.270	20.000
	Flysch	2.000	2.160	100.000	1.200	50.000
	Riporti	1.800	0.420	30.000	0.200	15.000
	Arenarie	2.100	2.000	200.000	1.200	100.000
	Marne	2.000	1.900	200.000	1.100	100.000
	Calcari	2.300	2.500	200.000	1.400	100.000

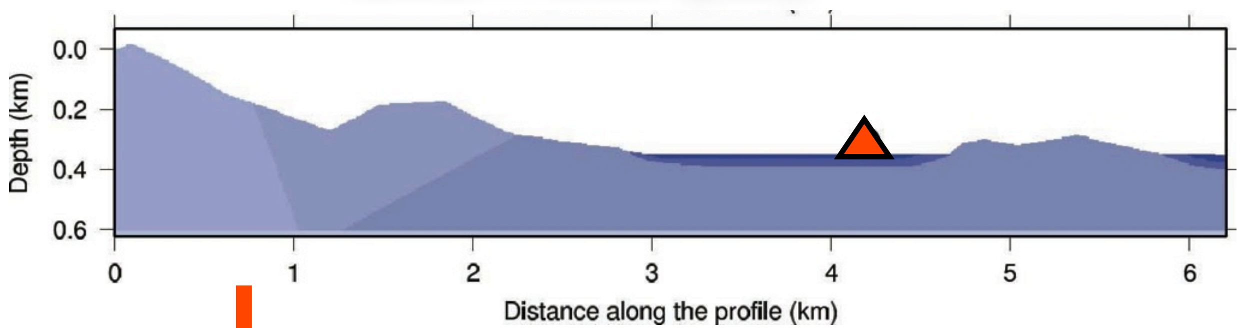
Local Scale - Synthetic Seismograms



Profile 1 - Bedrock "B" - Dist. 17 km - M=6.0

Local Scale - Response Spectra Ratio

Local Model (2D)

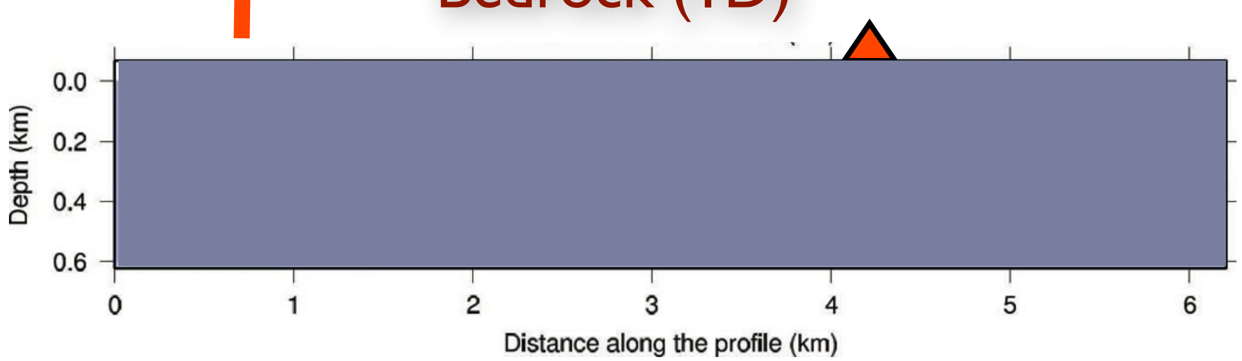


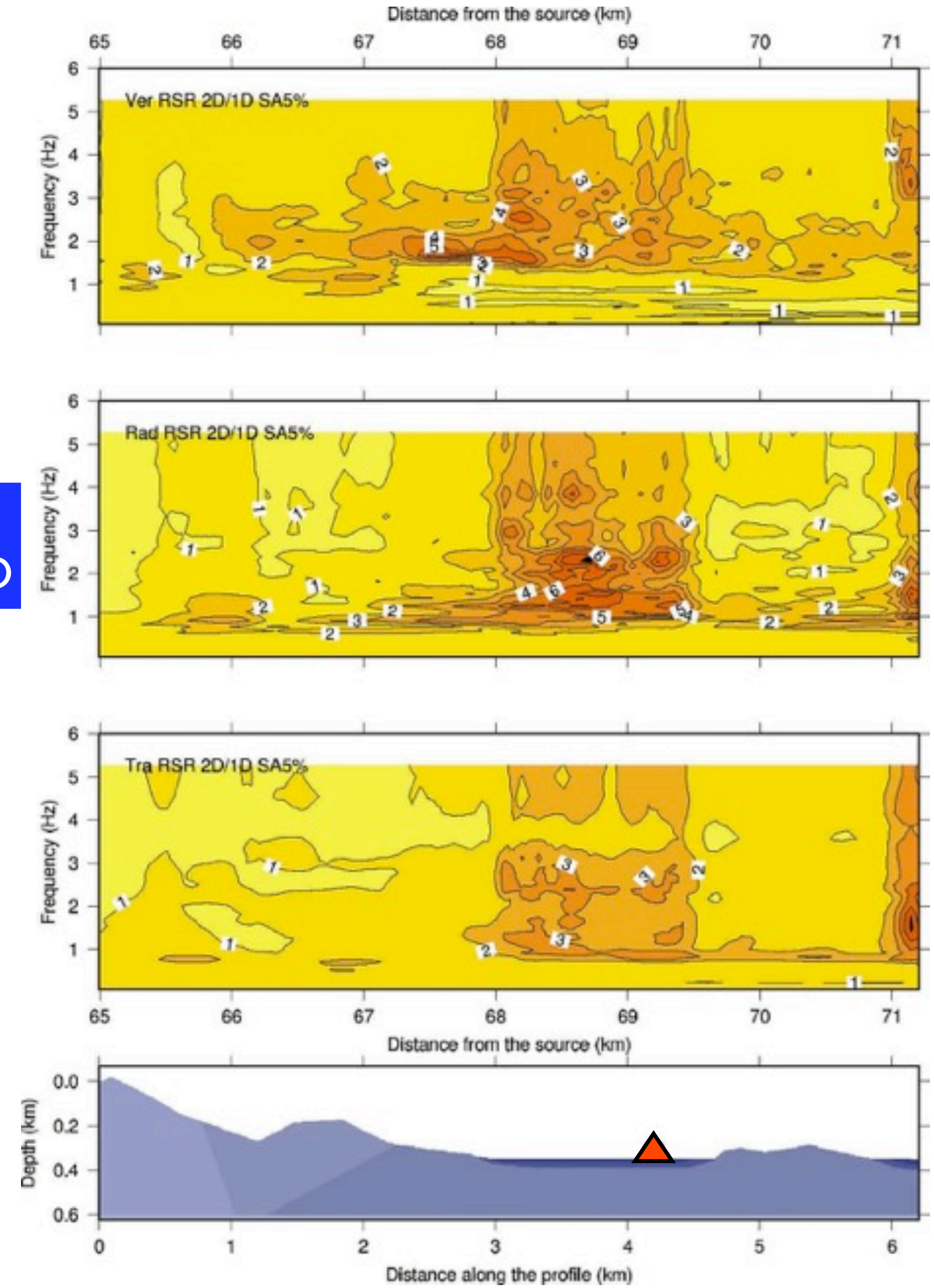
2D seismogram → 2D response spectra

1D seismogram → 1D response spectra

→ RSR 2D/1D

Bedrock (1D)

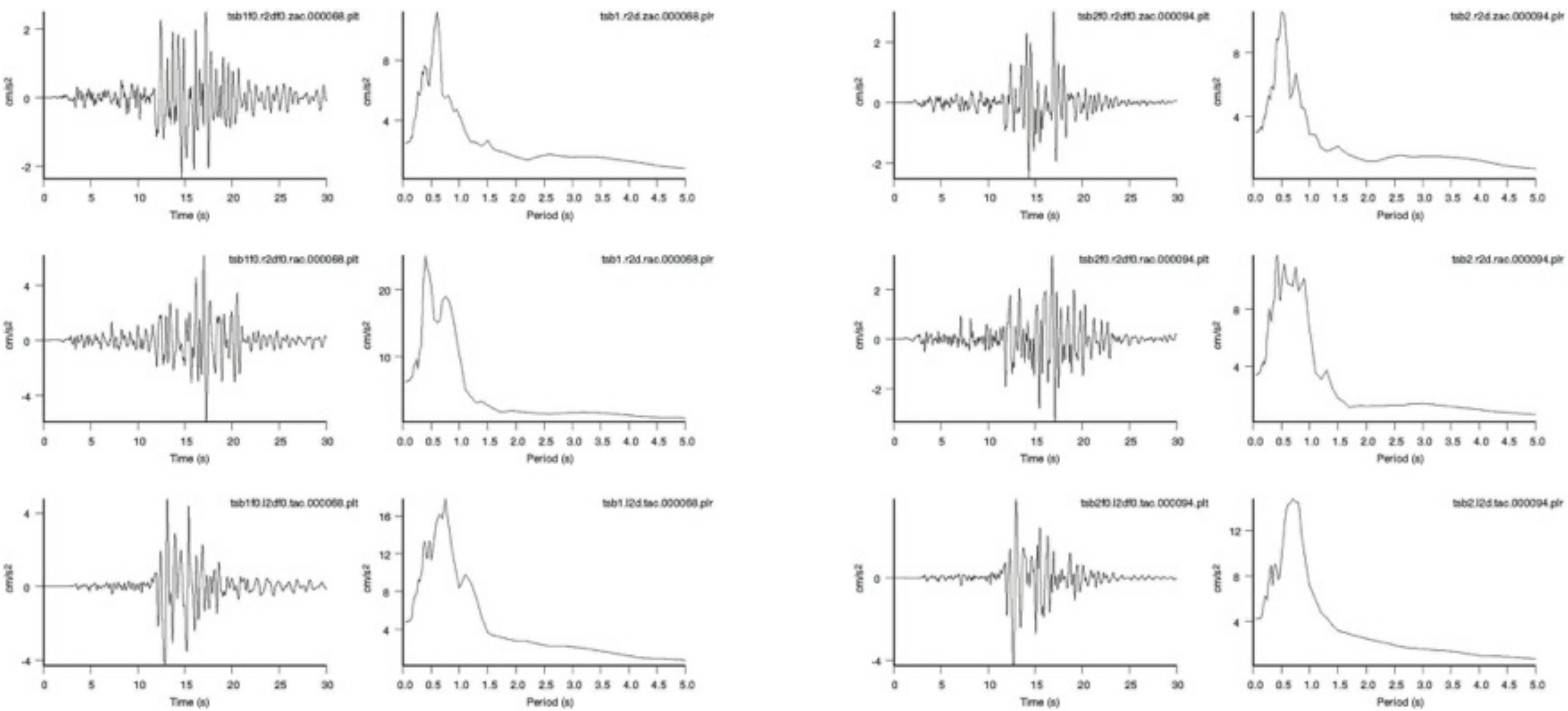




Site effects in Trieste city centre may cause a significant amplification (up to 5 times at engineering relevant frequencies) of the seismic signal at bedrock, hence intensity may reach IX (MCS) or VIII (MSK).

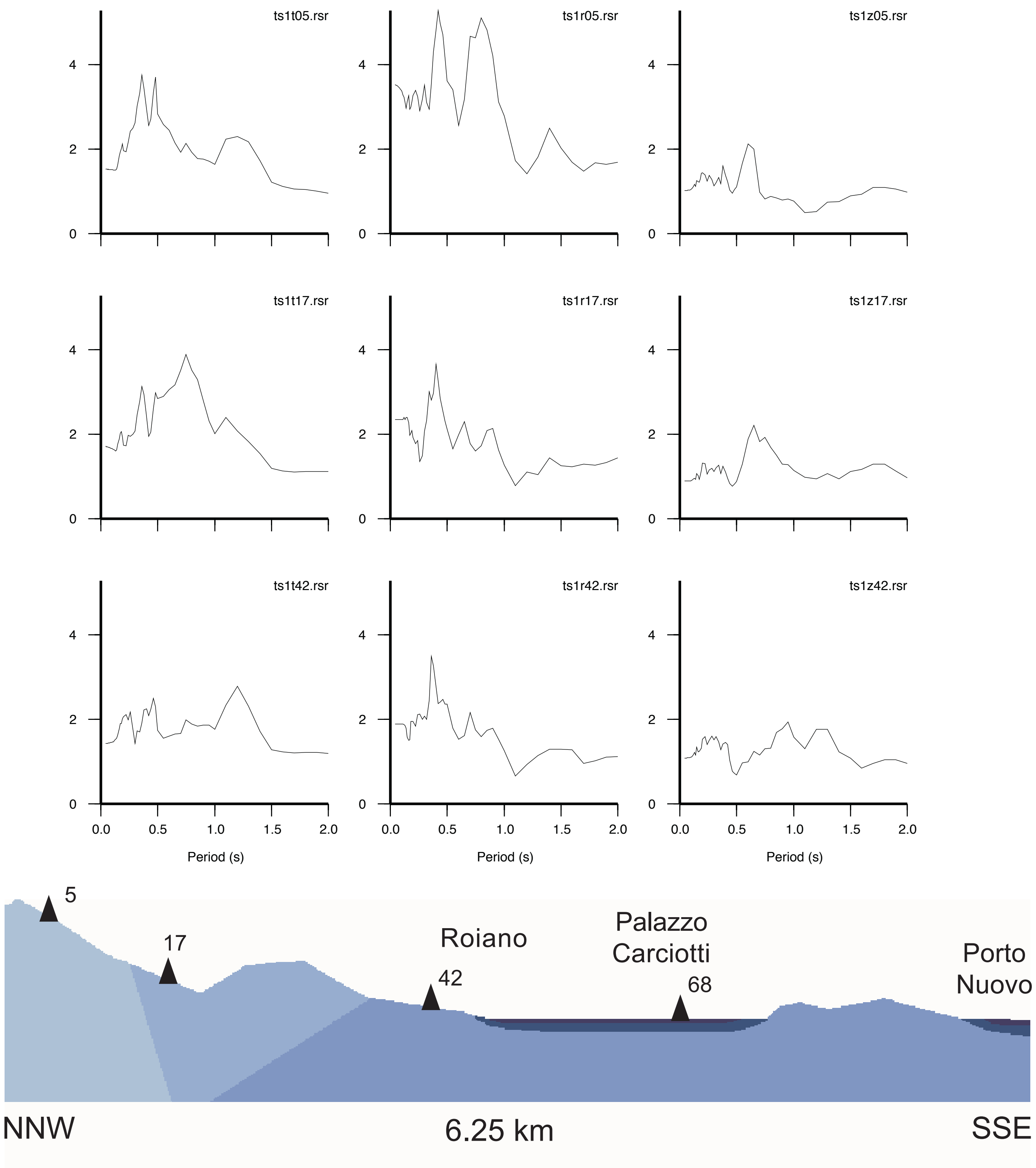
Local Scale - Response Spectra

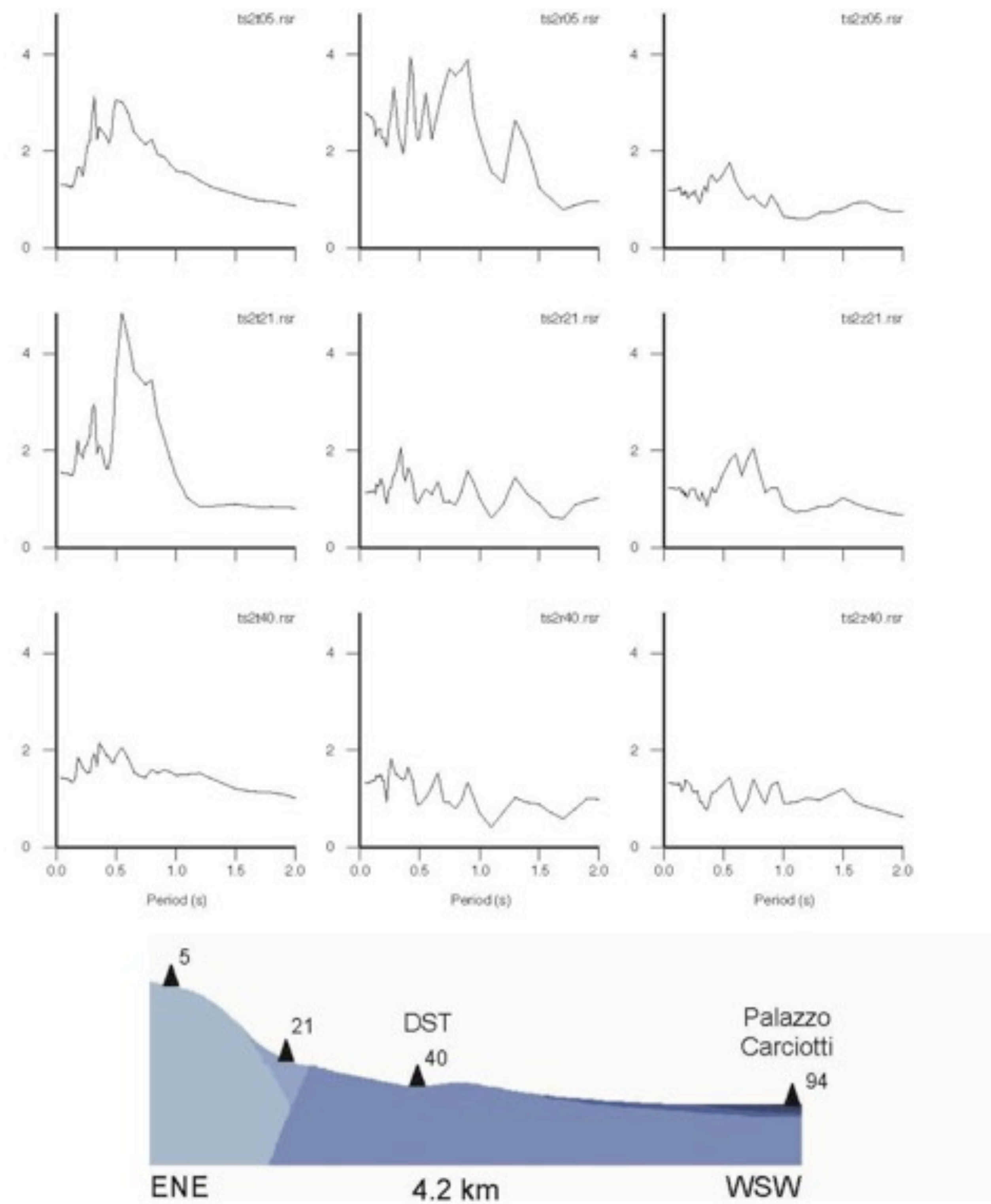
- Same site at the intersection of two profiles



Local Scale - Response Spectra Ratio

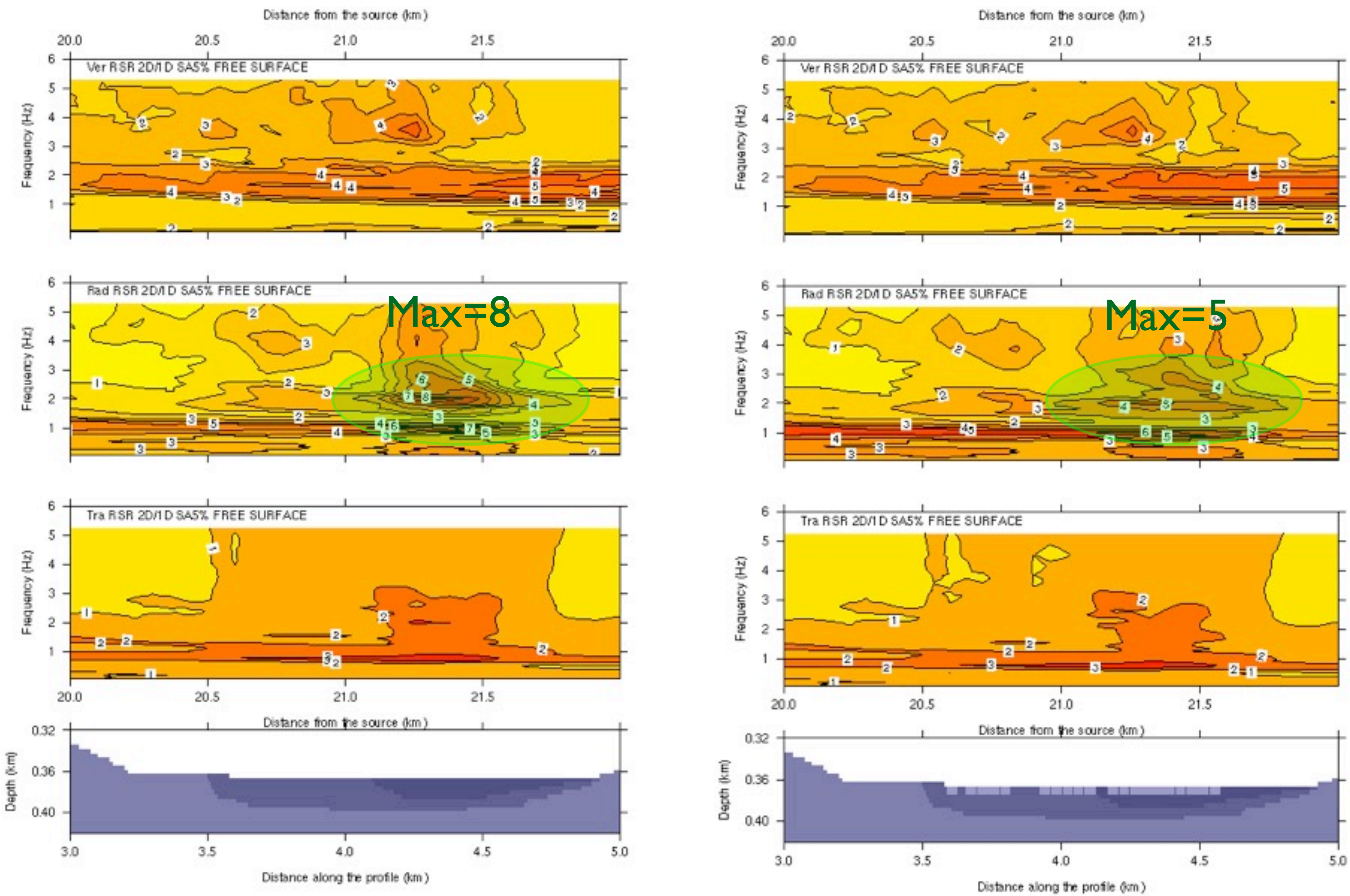
Choice of reference site





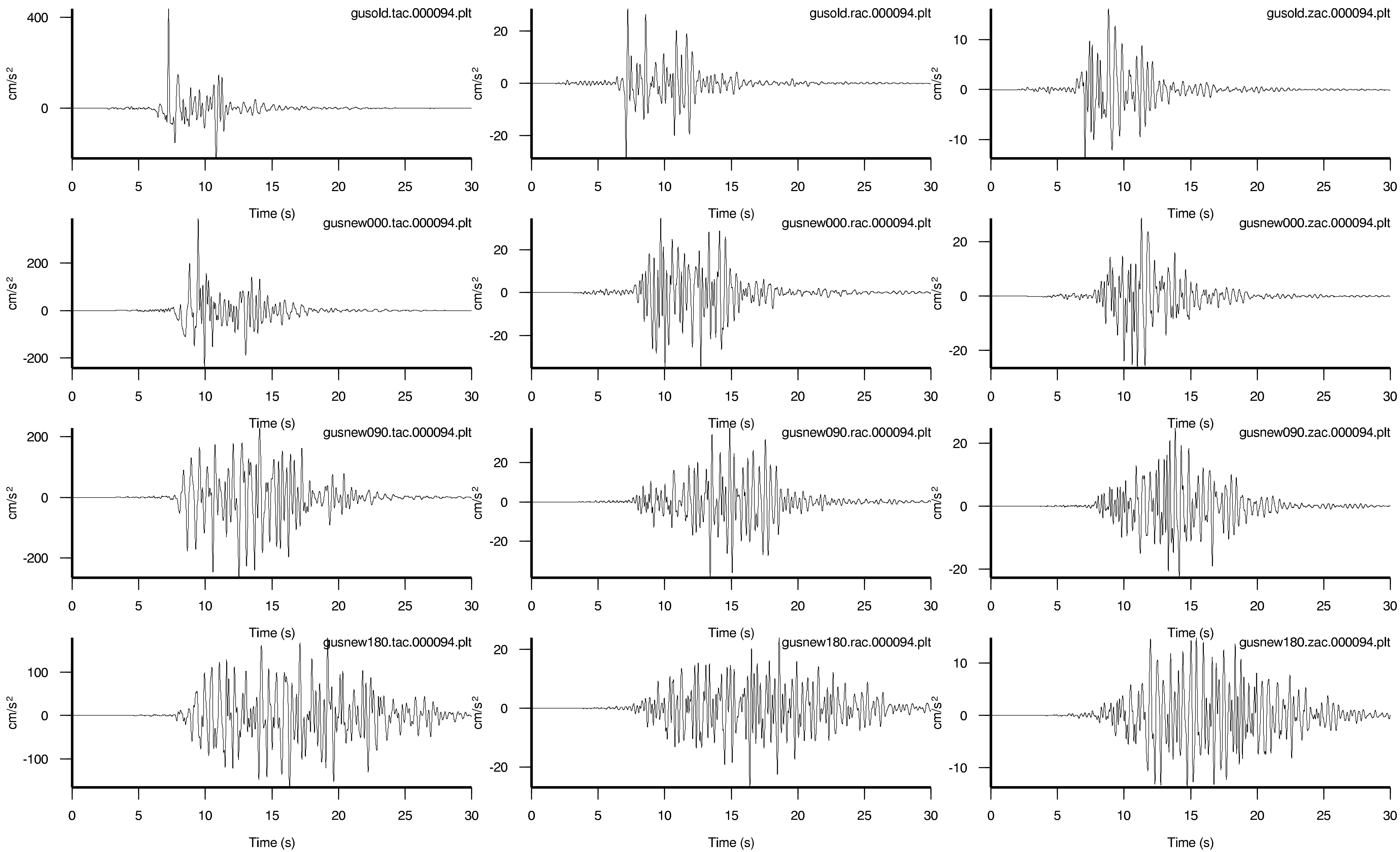
Local Scale - RSR with soil structure interaction

Rive - Dist. 17 km - M=6.0
Foundations and Amplifications (RSR 2D/1D)



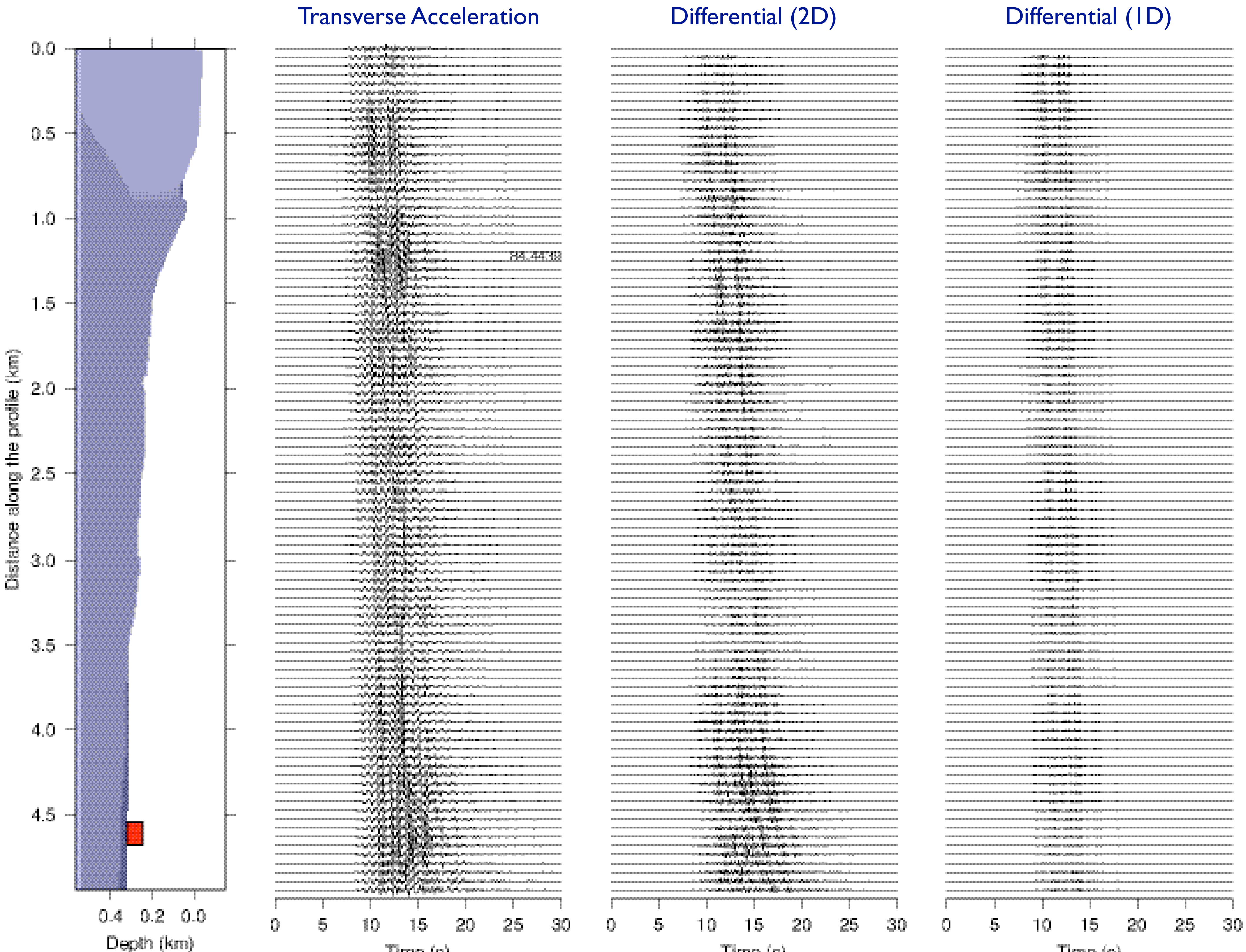
Local Scale - Source Model

- Seismic Source of finite dimension and complicated rupturing process



Local Scale - Differential Motion

- Significant for elongated structures (bridges, lifelines etc)

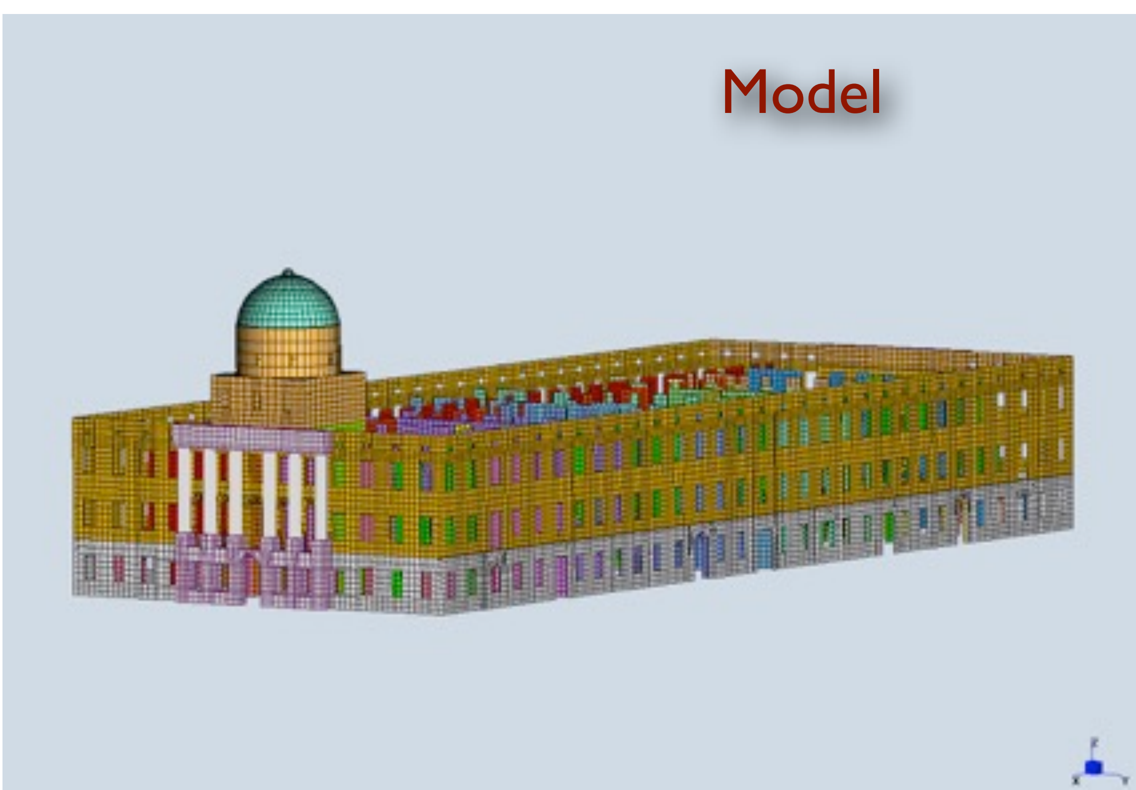


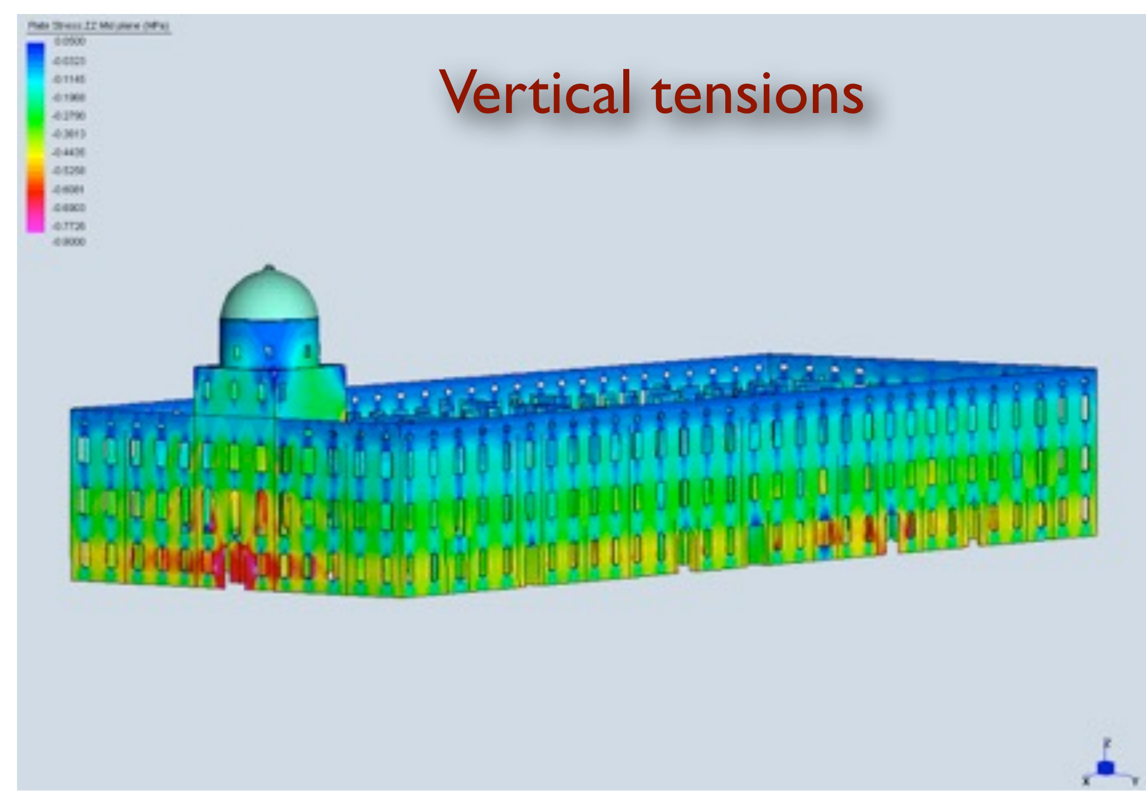
Engineering analysis - Triest case

- The data set of synthetic seismograms can be fruitfully used and analysed by civil engineers for design and reinforcement actions, and therefore supply a particularly powerful and economical tool for the prevention aspects of Civil Defence.

- Non-linear dynamic analysis considering the seismic input provided by the complete synthetic accelerograms as obtained from microzoning ⇒

  Evaluate the response of relevant man-made structures, in terms of displacements and stresses, with respect to a set of possible scenario earthquakes





MCSI approach

Earthquake scenarios for target site(s)

↓

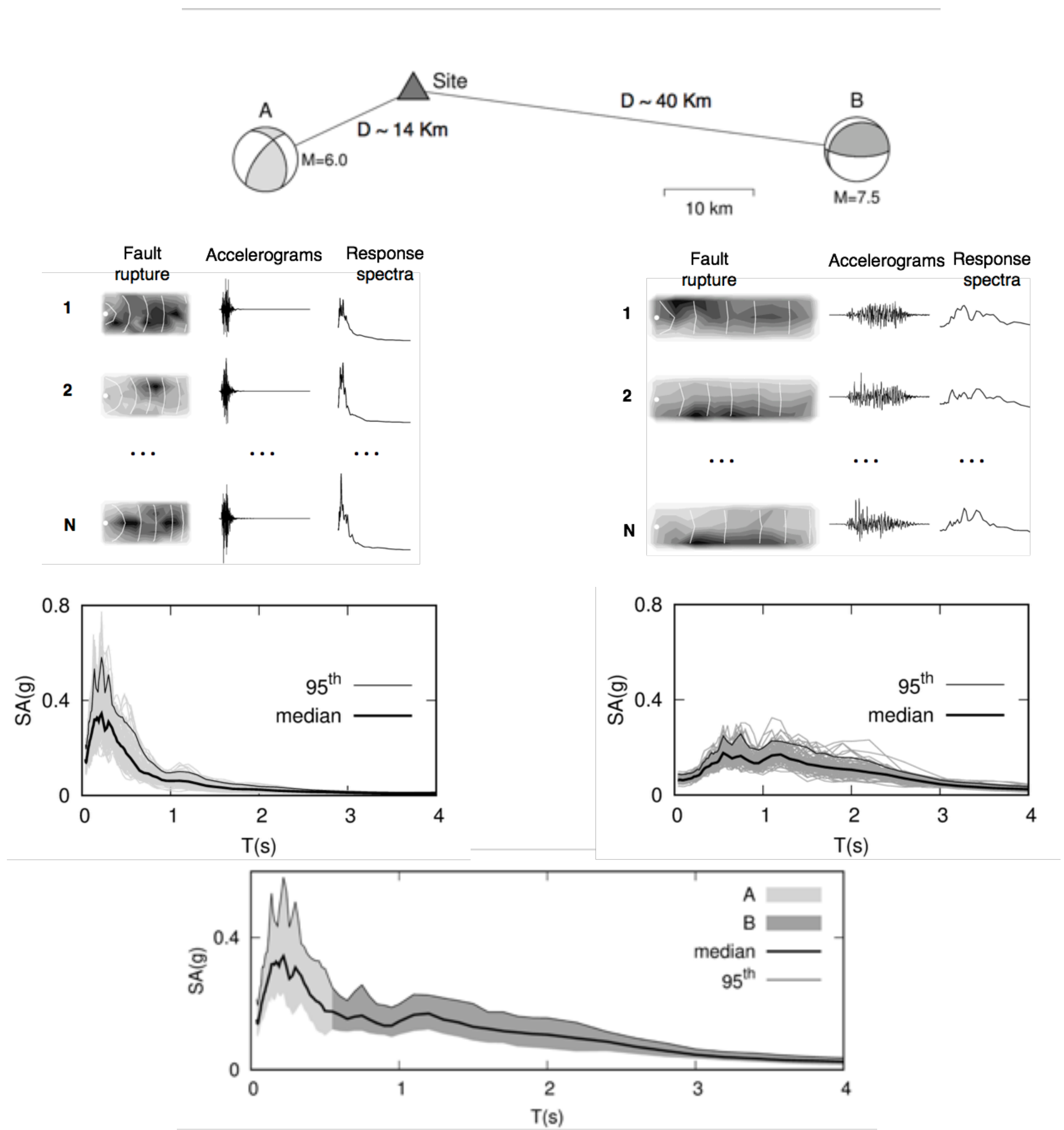
Accelerations for every scenario and multiple realizations of rupture processes

↓

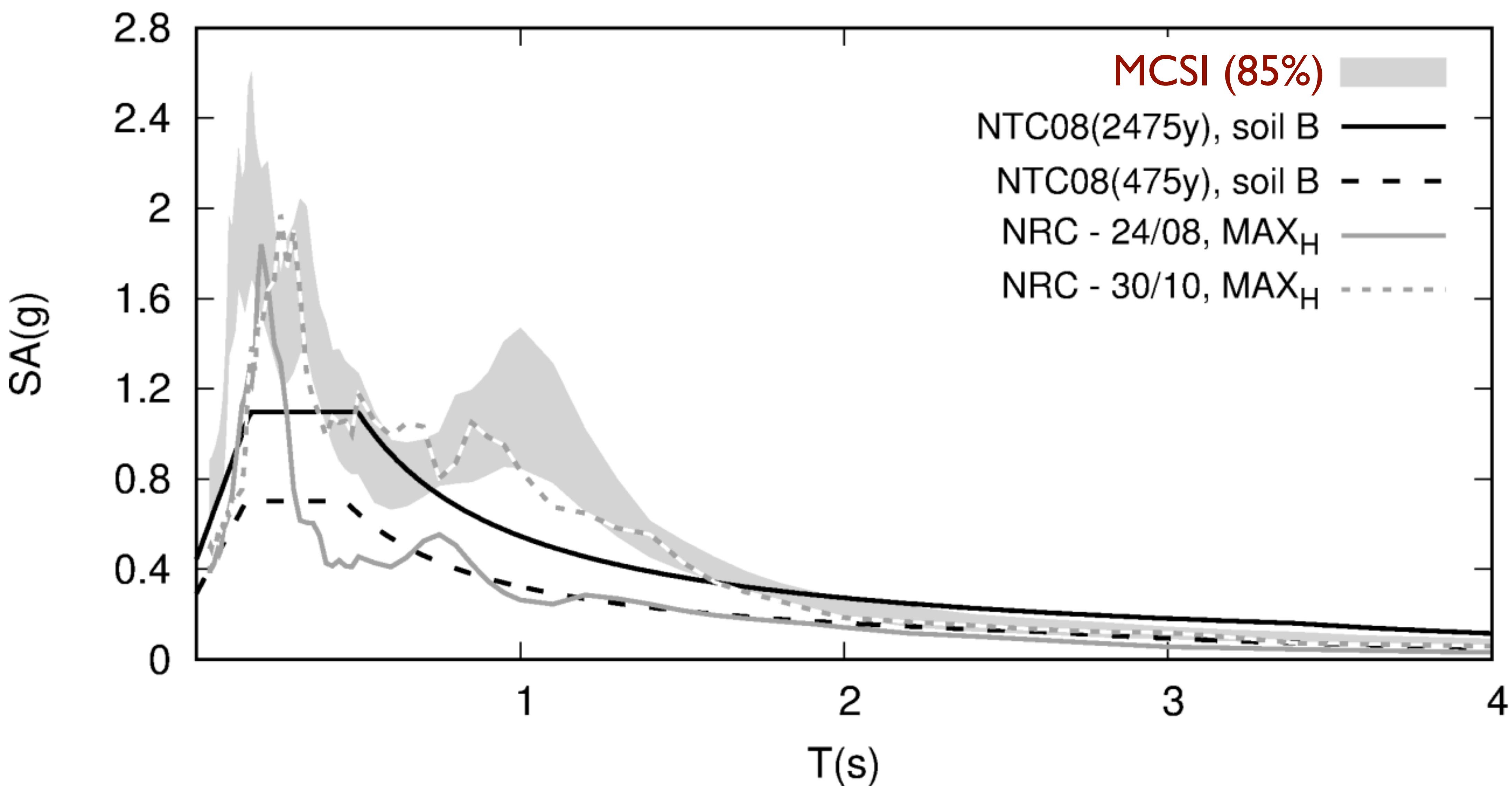
Response spectra statistical analysis

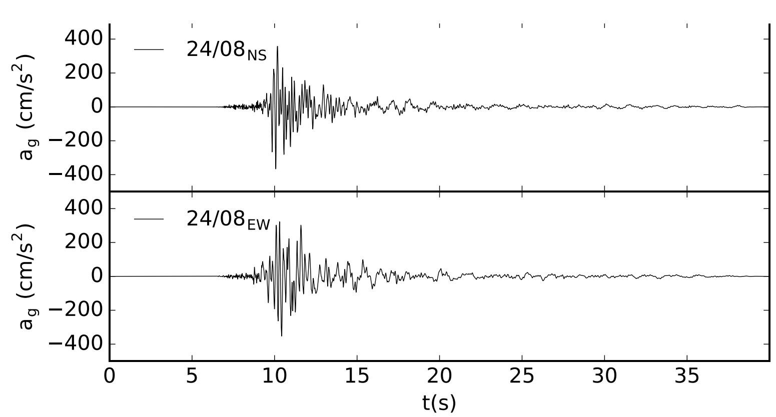
↓

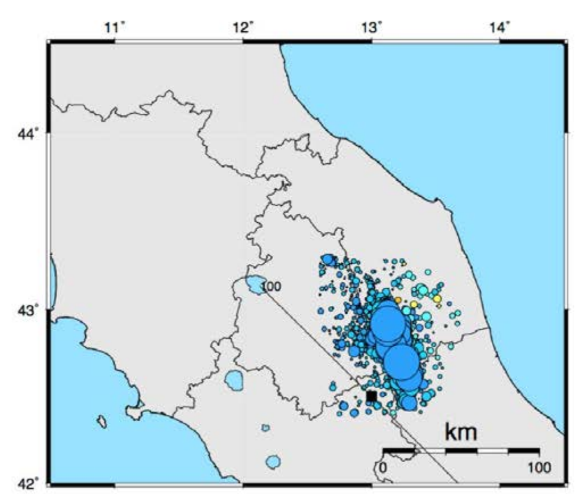
MCSI spectra

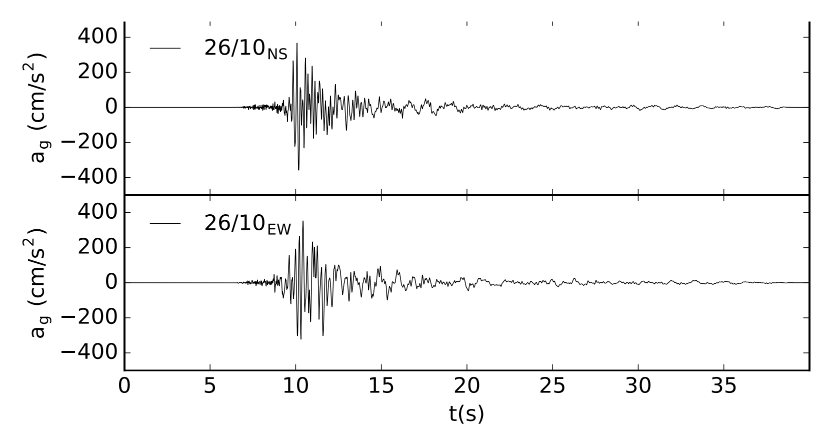


Response spectra - Central Italy









Fasan et al., 2017. A seismological and engineering perspective on the 2016 Central Italy earthquakes. IJEIE