Diploma Programme
diploma.ictp.it

Computational Earthquake Hazard (ESP-EHZ)

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Introduction - Hazard, Vulnerability and Risk

- Hazard: the possibility that earthquakes will occur in a given region
- Vulnerability: the degree of loss resulting from the occurrence of the earthquakes, considering population and built environment
- Risk: the combination of hazard and vulnerability

Introduction - Hazard

- We shall concentrate on the seismic hazard, and we shall express it in terms of the ground shaking level expected in case an earthquake occur
- We shall use an approach based on the computation of synthetic seismograms, considering wave propagation from the earthquake source to the sites of interest
- We shall look at the phenomenon at different scales

Introduction - Regional Scale

- Seismic zonation based on the computation of synthetic seismograms on the nodes of a grid that covers the study area
- Average structural properties
- Simple source model (scaled point source)
- Cut-off frequency 1 Hz
- Maps of peak displacement, velocity and Design Ground Acceleration

Introduction - Local Scale

- Synthetic seismograms computed along selected profiles
- Laterally heterogeneous structural models
- Detailed source model
- Cut-off frequency up to 10 Hz
- Maps of ground motion amplification

Introduction - Methodology

- Regional scale: modal summation technique
- Local scale: hybrid technique
  (modal summation + finite difference)

Methodology - Modal Summation Technique

- Expression of the displacement generated by a double-couple point source in a flat layered halfspace

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

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

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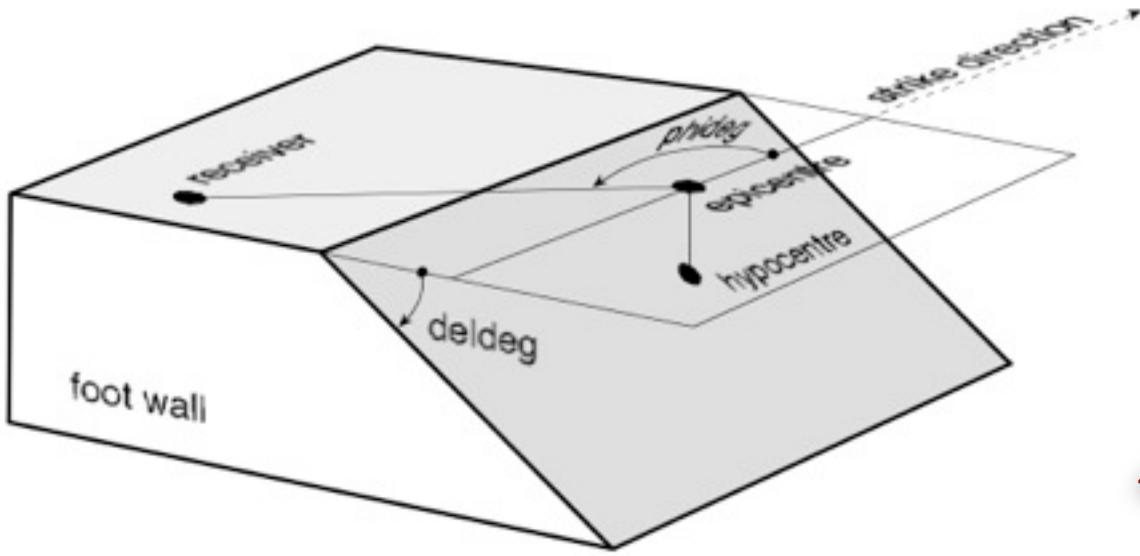
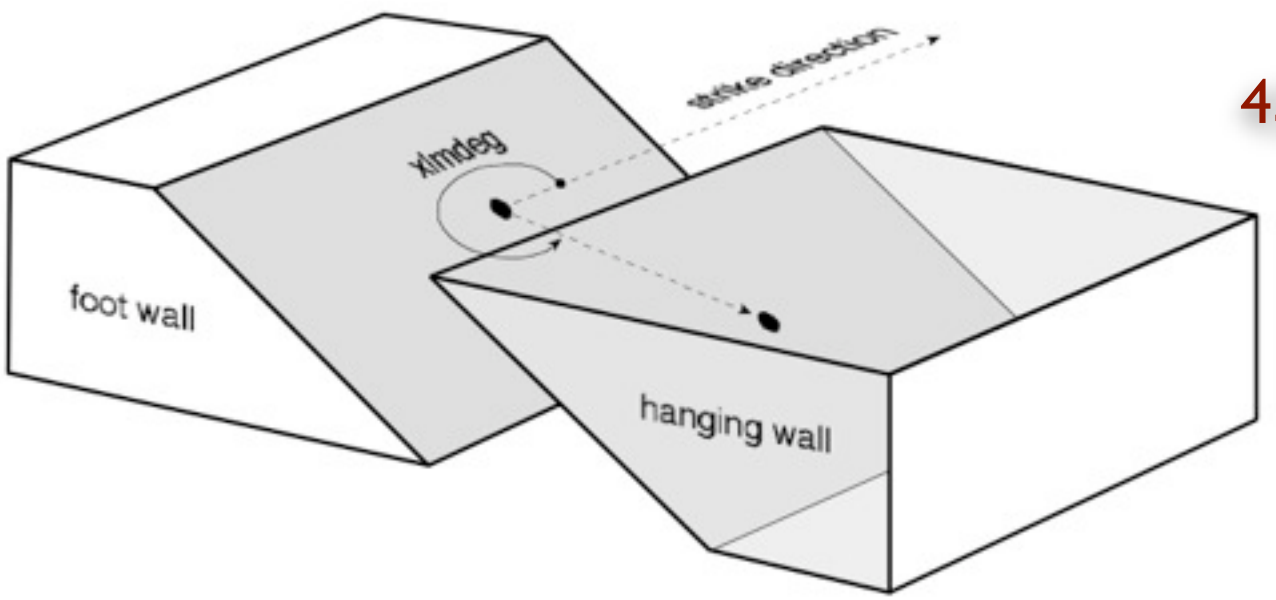
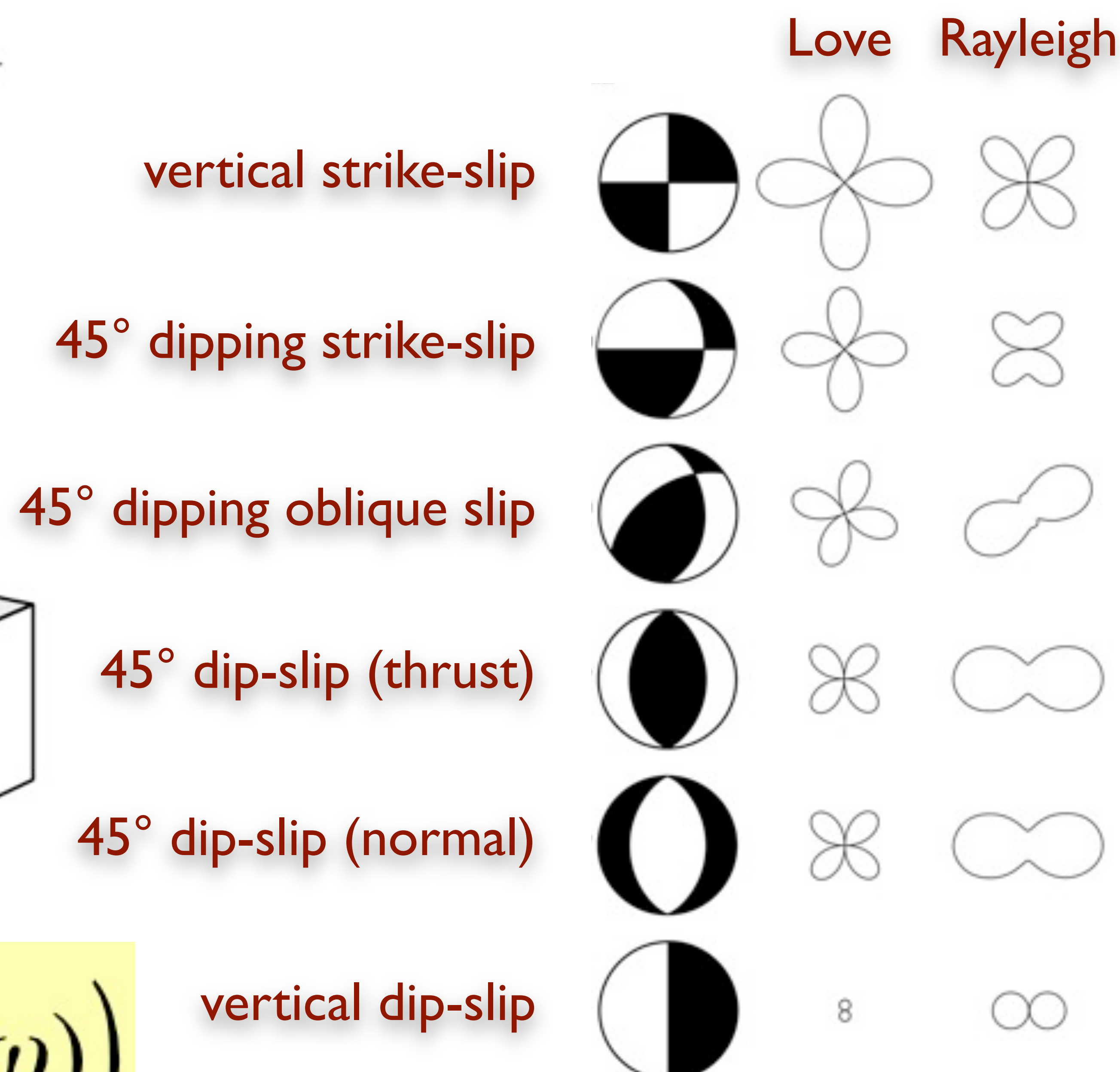
source | structure | receiver

Methodology - Modal Summation Technique

- Source definition and examples of radiation pattern







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

Methodology - Modal Summation Technique

- Expression of the source radiation pattern

$$\chi_L = i(d_{1L}\sin\varphi + d_{2L}\cos\varphi) + d_{3L}\sin 2\varphi + d_{4L}\cos 2\varphi$$

$$\chi_R = d_0 + i(d_{1R}\sin\varphi + d_{2R}\cos\varphi) + d_{3R}\sin 2\varphi + d_{4R}\cos 2\varphi$$

where

$$d_{1L} = G(h_s)\cos\lambda\sin\delta$$
$$d_{2L} = -G(h_s)\sin\lambda\cos 2\delta$$
$$d_{3L} = \frac{1}{2}V(h_s)\sin\lambda\sin 2\delta$$
$$d_{4L} = V(h_s)\cos\lambda\sin\delta$$

$$d_0 = \frac{1}{2}B(h_s)\sin\lambda\sin 2\delta$$
$$d_{1R} = -C(h_s)\sin\lambda\cos 2\delta$$
$$d_{2R} = -C(h_s)\cos\lambda\cos\delta$$
$$d_{3R} = A(h_s)\cos\lambda\sin\delta$$
$$d_{4R} = -\frac{1}{2}A(h_s)\sin\lambda\sin 2\delta$$

$$A(h_s) = -\frac{F_x^*(h_s)}{F_z(0)}$$
$$B(h_s) = -\left(3 - 4\frac{\beta^2(h_s)}{\alpha^2(h_s)}\right)\frac{F_x^*(h_s)}{F_z(0)} - \frac{2}{\rho(h_s)\,\alpha^2(h_s)}\frac{\sigma_{zz}^*(h_s)}{\dot{F}_z(0)/c}$$
$$C(h_s) = -\frac{1}{\mu(h_s)}\frac{\sigma_{zx}(h_s)}{\dot{F}_z(0)/c}$$
$$G(h_s) = -\frac{1}{\mu(h_s)}\frac{\sigma_{zy}^*(h_s)}{\dot{F}_y(0)/c}$$
$$V(h_s) = \frac{\dot{F}_y(h_s)}{\dot{F}_y(0)/c} = \frac{F_y(h_s)}{F_y(0)/c}$$

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

Methodology - Modal Summation Technique

- Example of quantities associated with a structure

$$\sqrt{c_m v_m I_m} \quad \sqrt{v_m I_m}$$

Methodology - Modal Summation Technique

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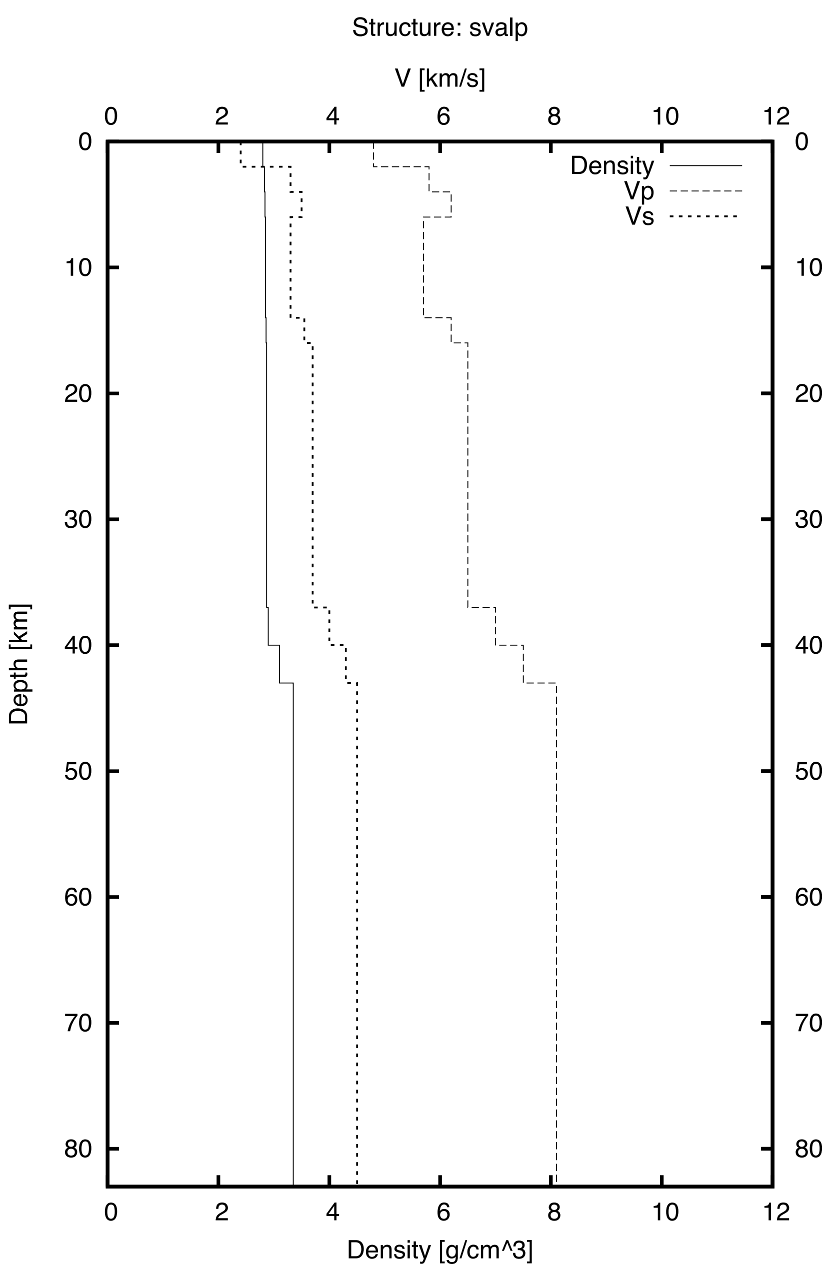
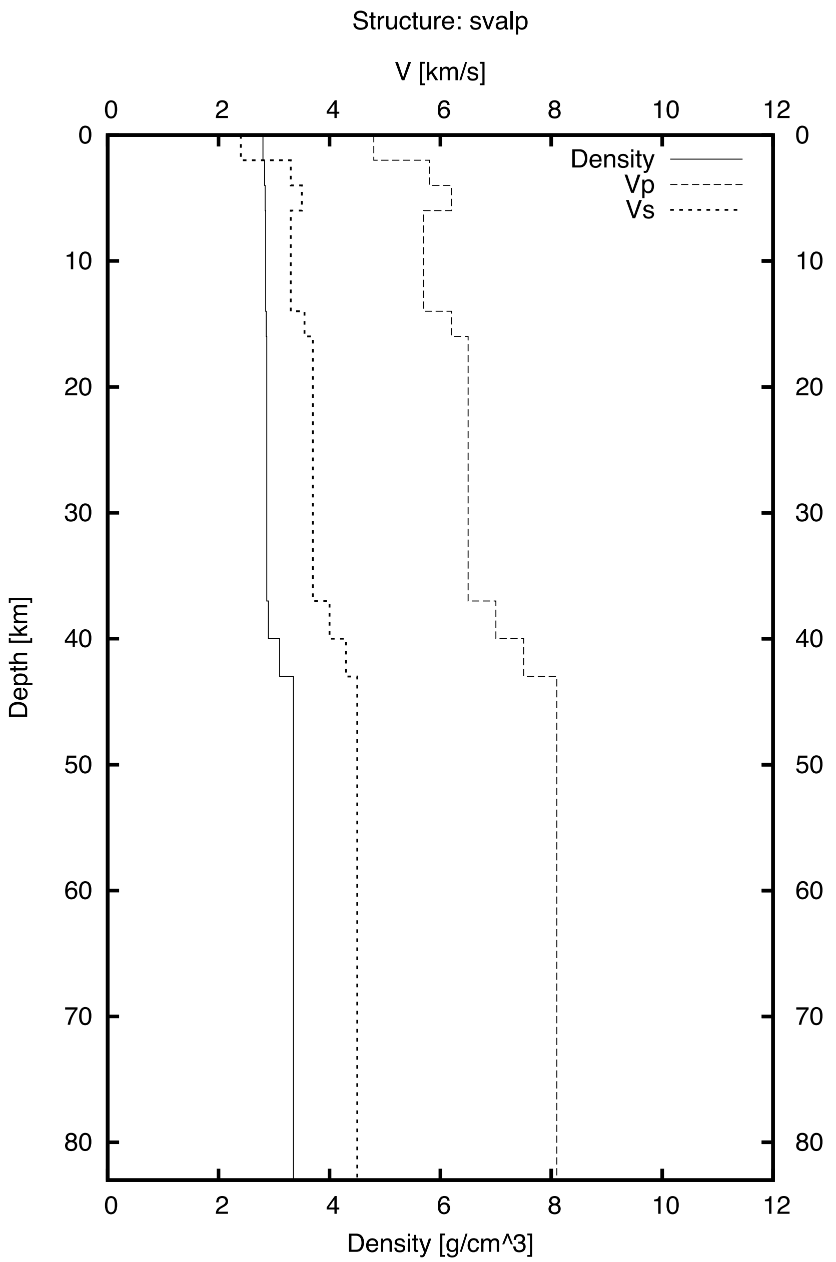
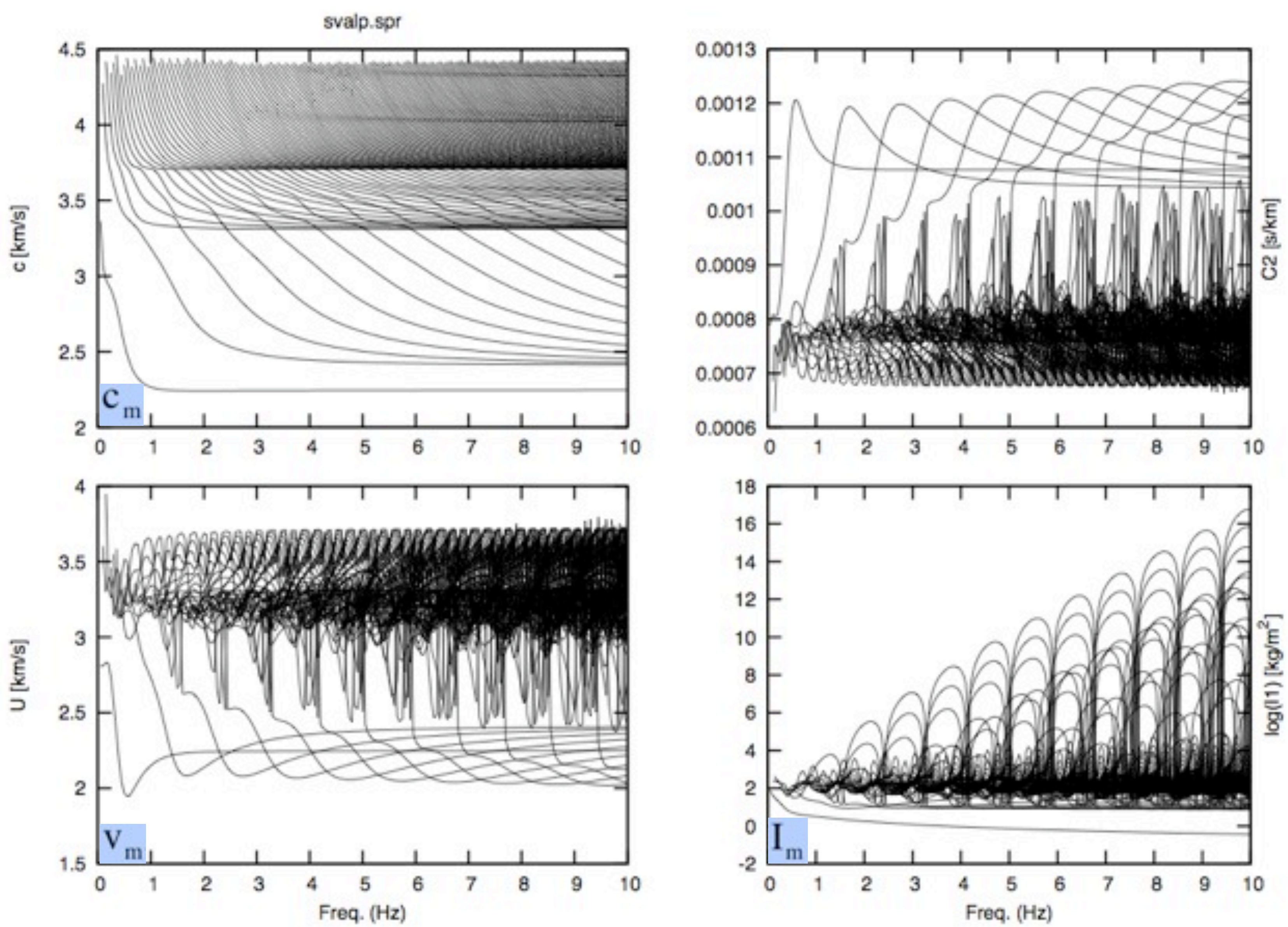


Methodology - Modal Summation Technique

- Example of quantities associated with a structure

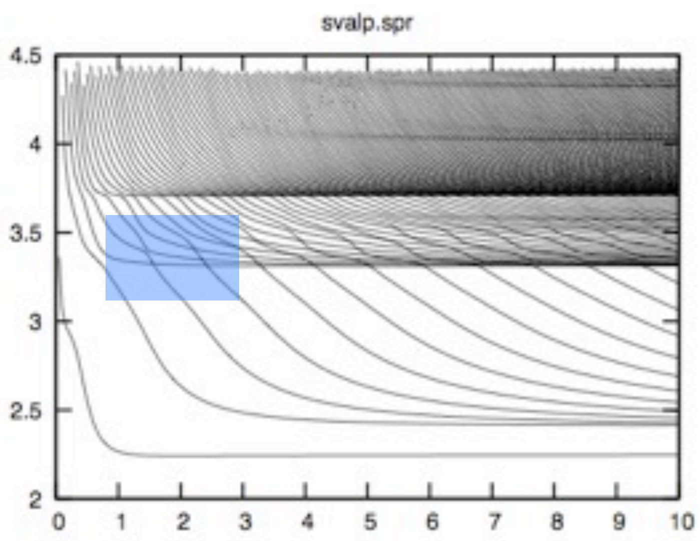
$$\sqrt{c_m v_m I_m} \qquad \sqrt{v_m I_m}$$





Methodology - Modal Summation Technique

- Phase velocity dispersion curve



Methodology - Modal Summation Technique

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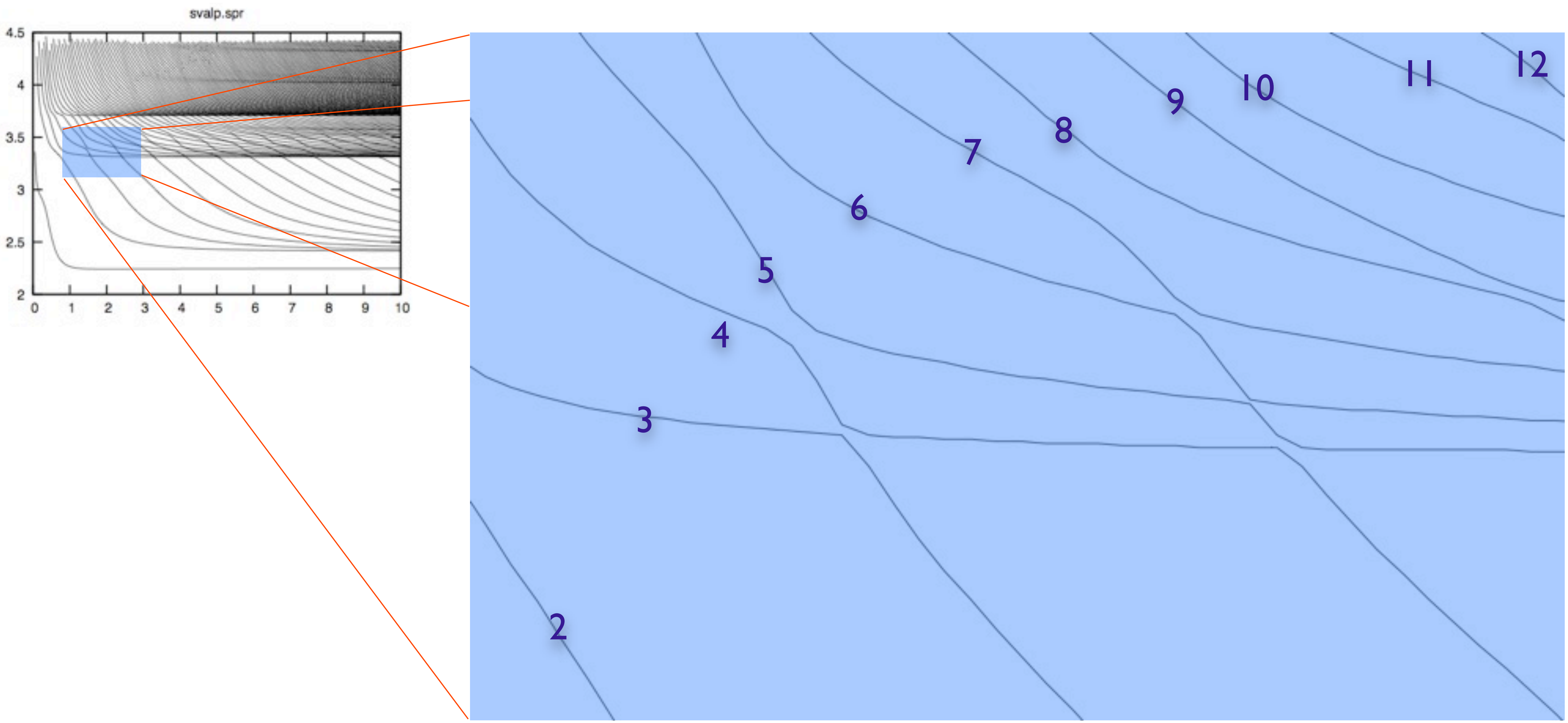

Methodology - Modal Summation Technique

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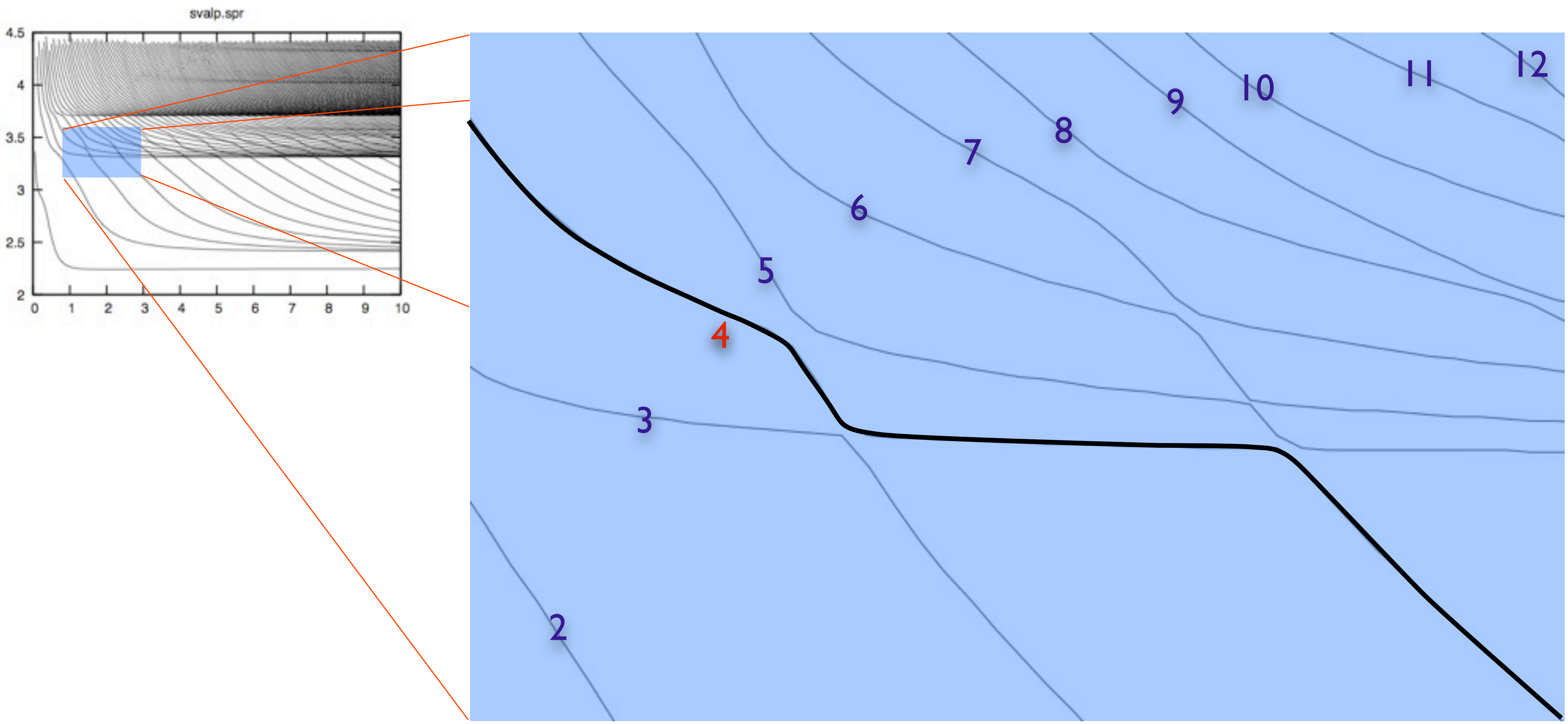

Methodology - Modal Summation Technique

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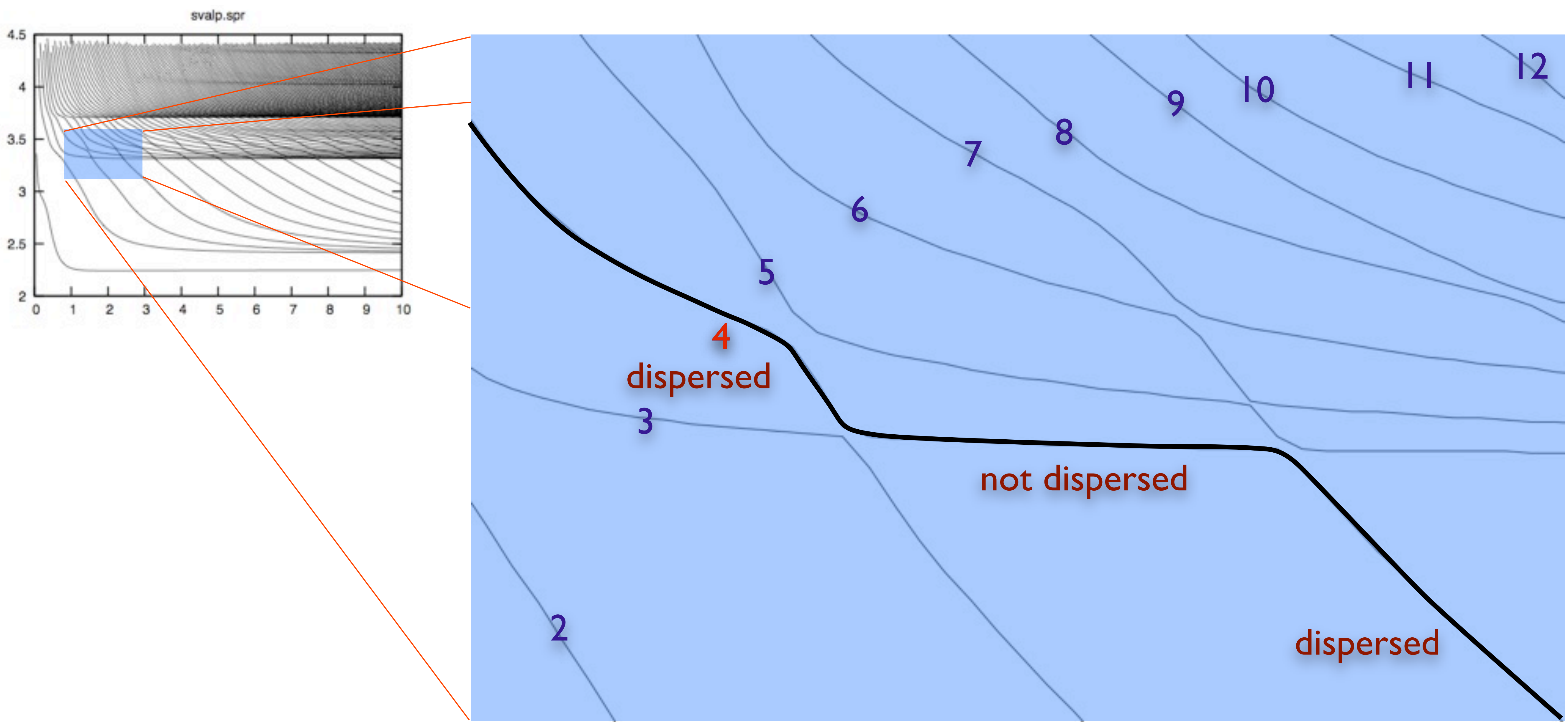
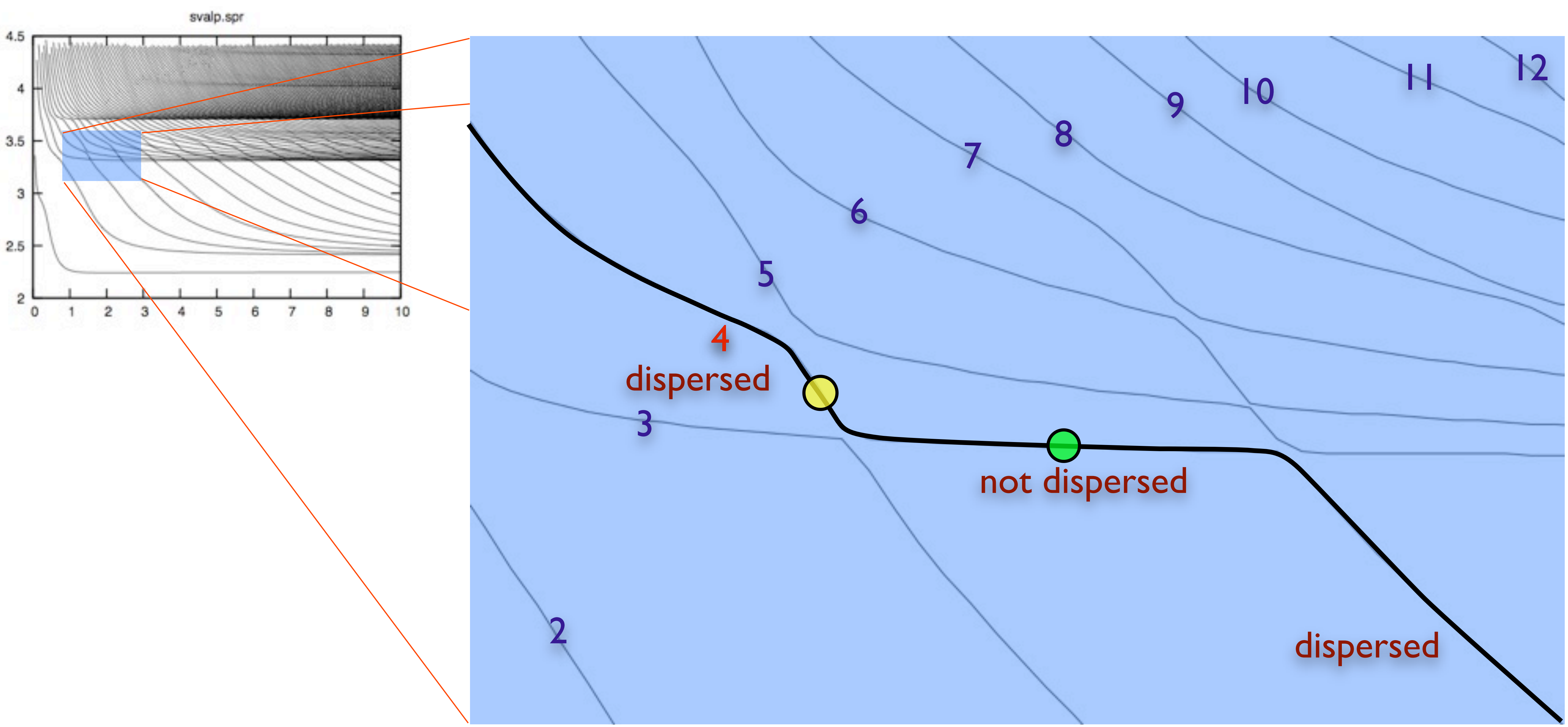


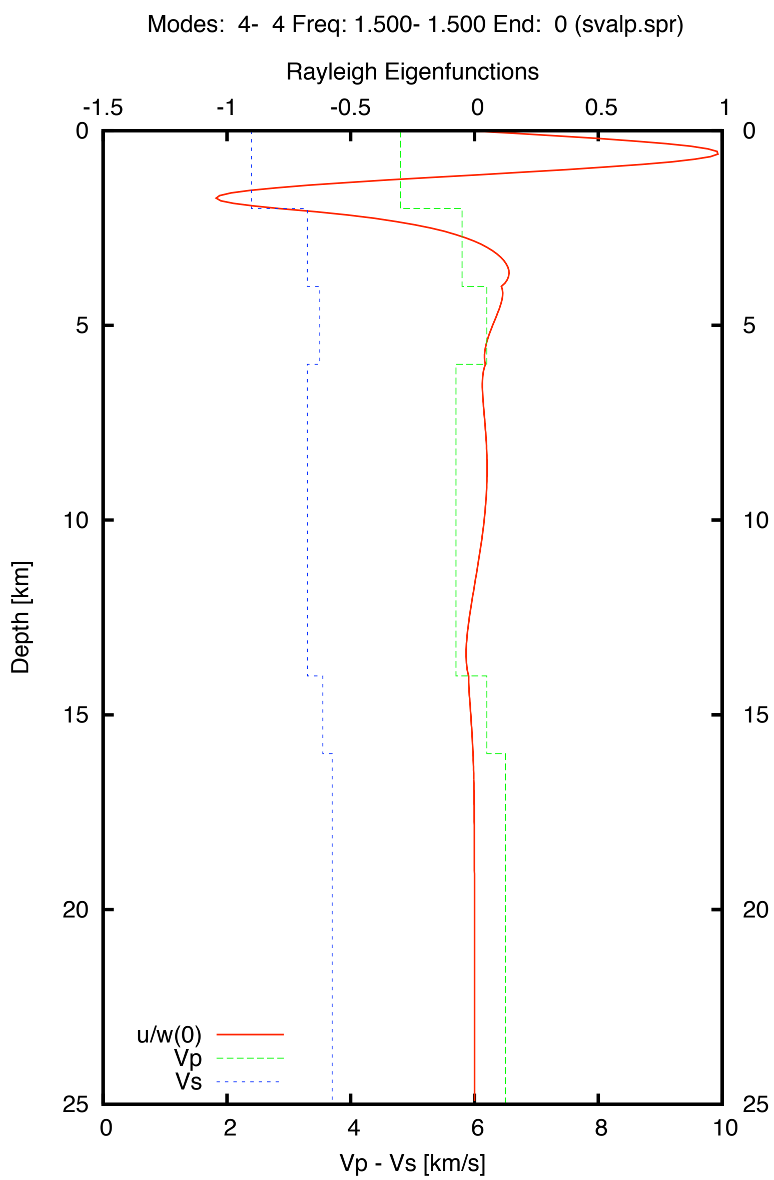
Methodology - Modal Summation Technique

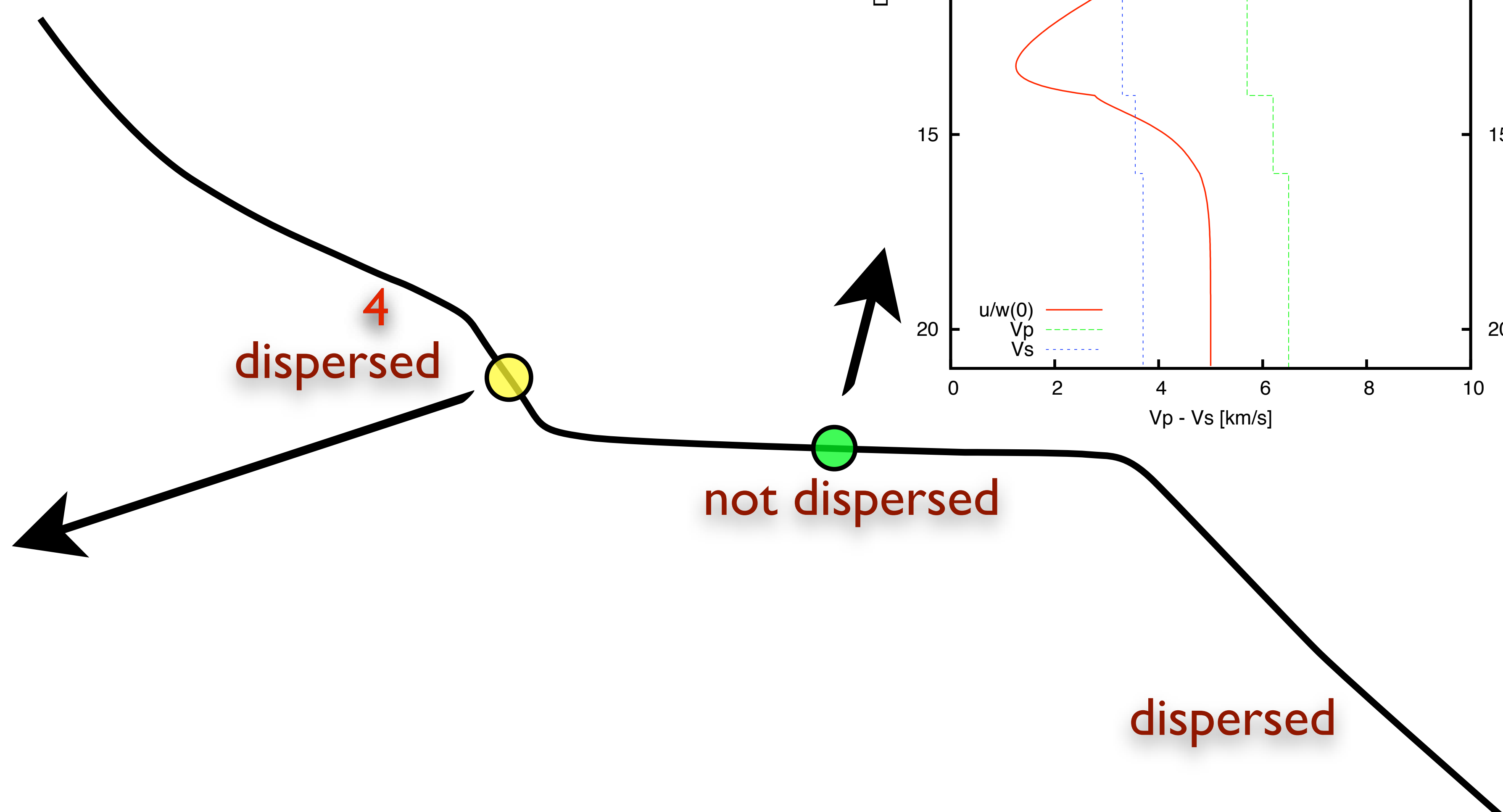
- Phase velocity dispersion curve

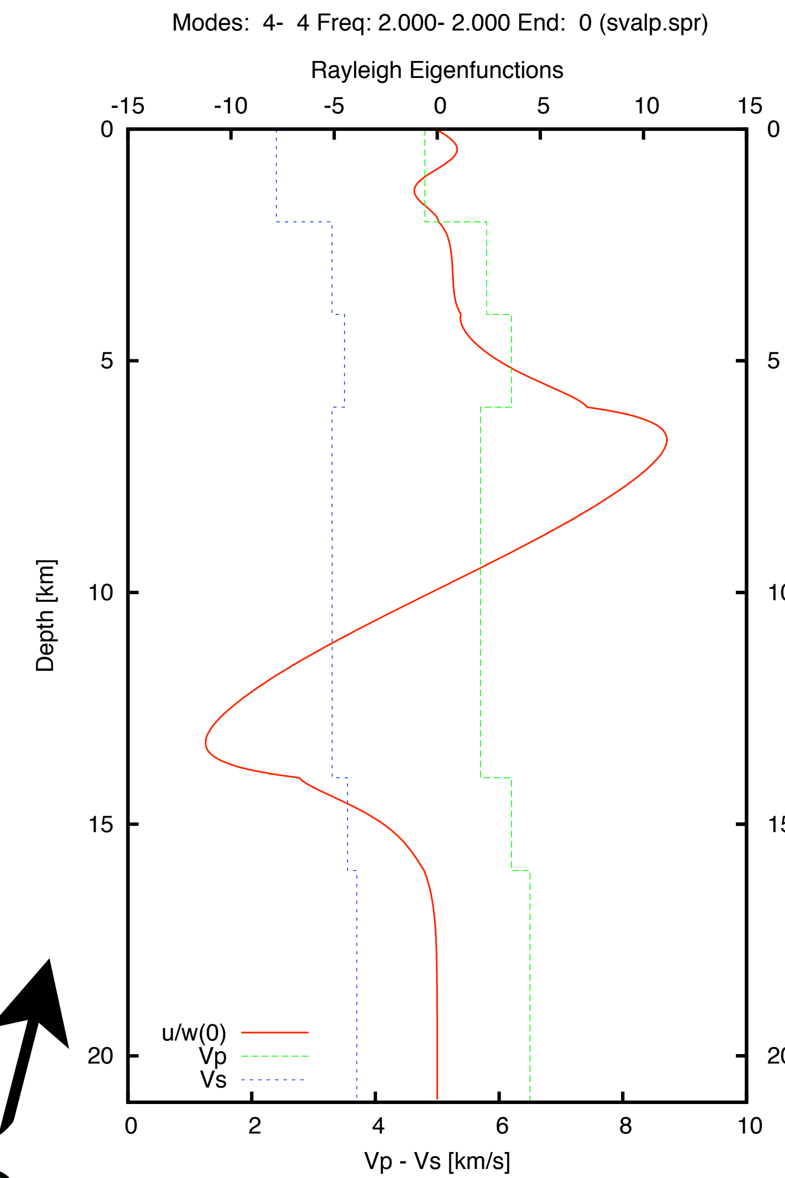


Methodology - Modal Summation Technique

- Eigenfunctions







Methodology - Modal Summation Technique

- Synthetic seismograms

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

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

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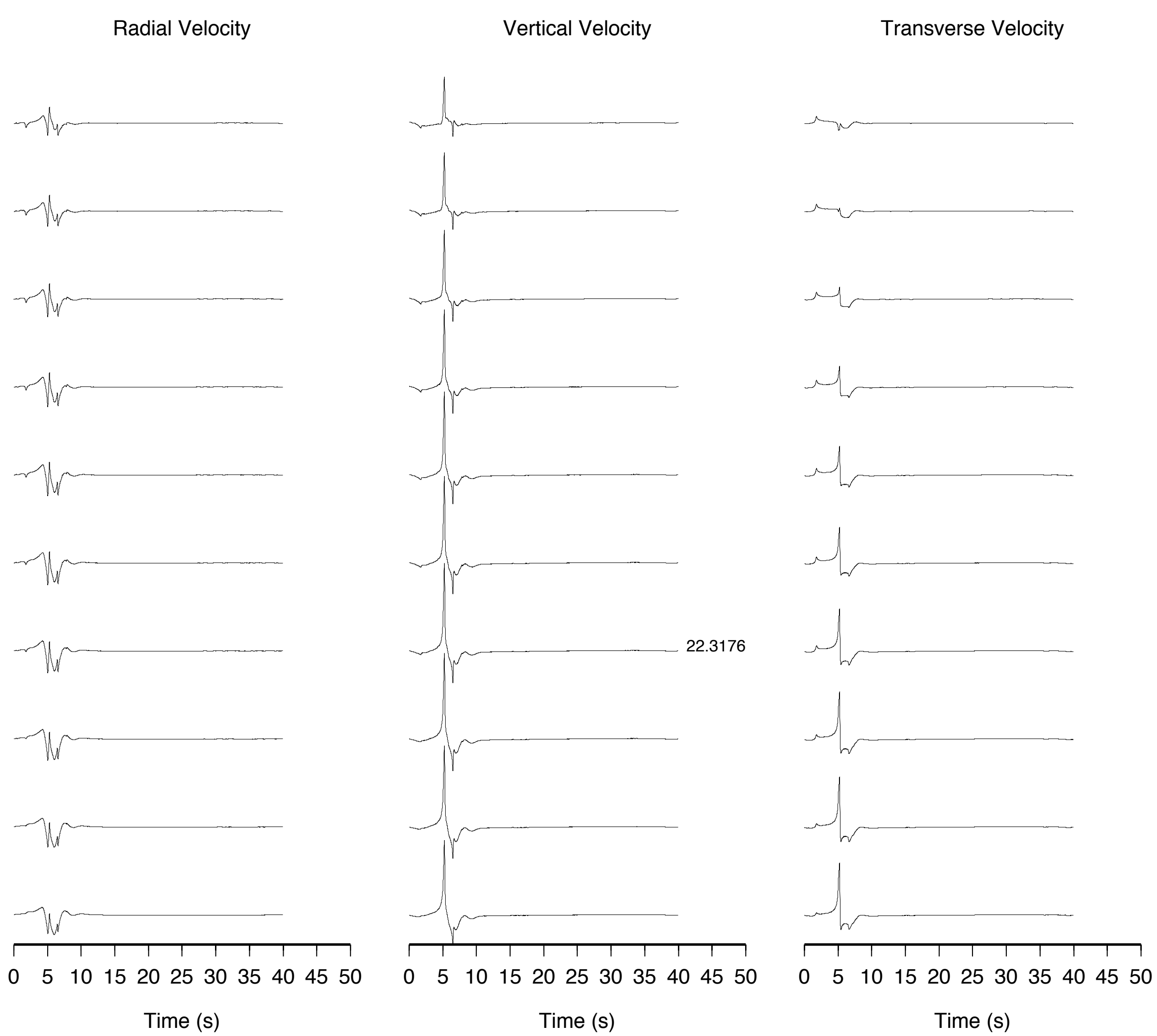

Methodology - Modal Summation Technique

- Synthetic seismograms
- Parametric tests

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

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

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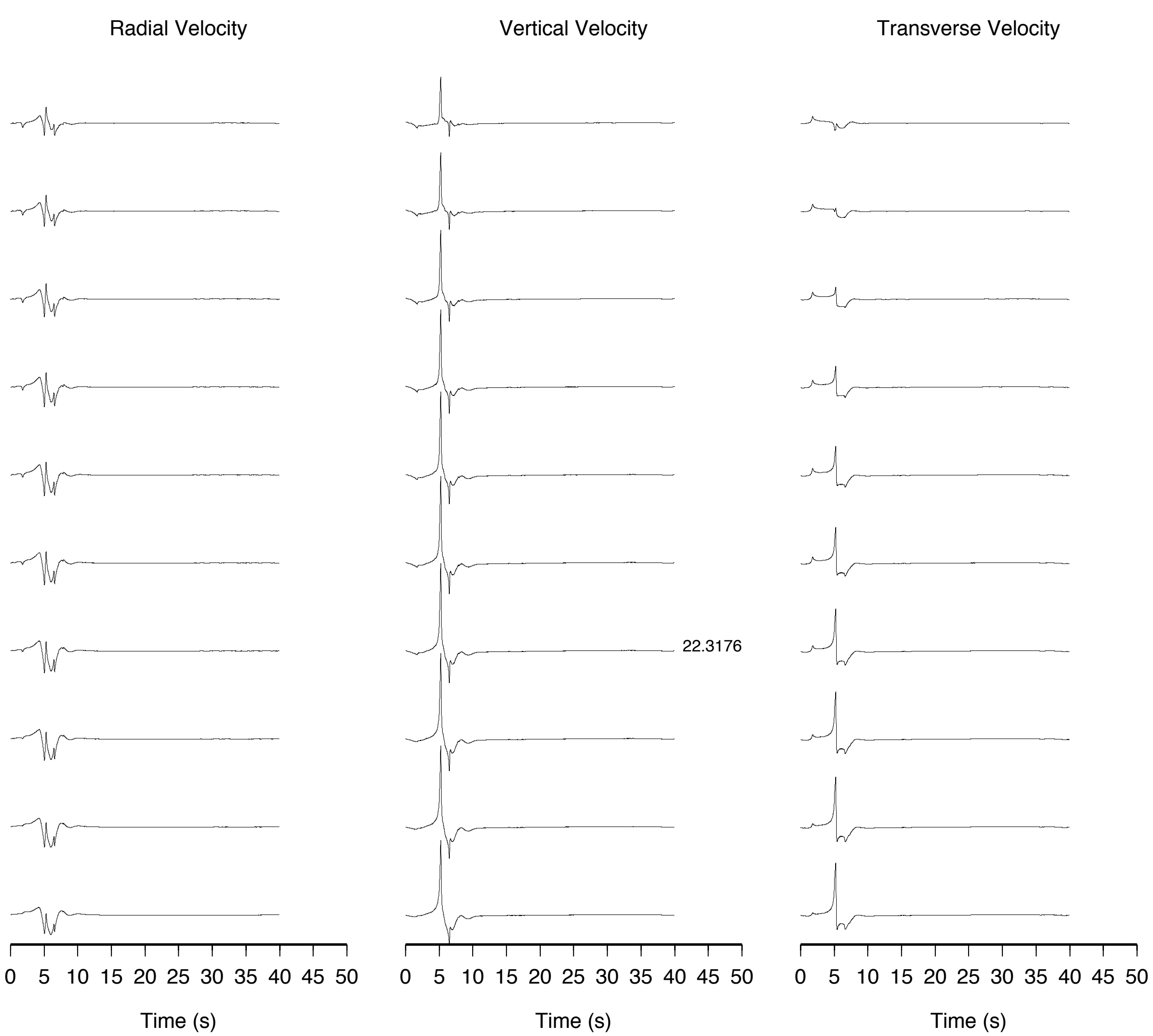

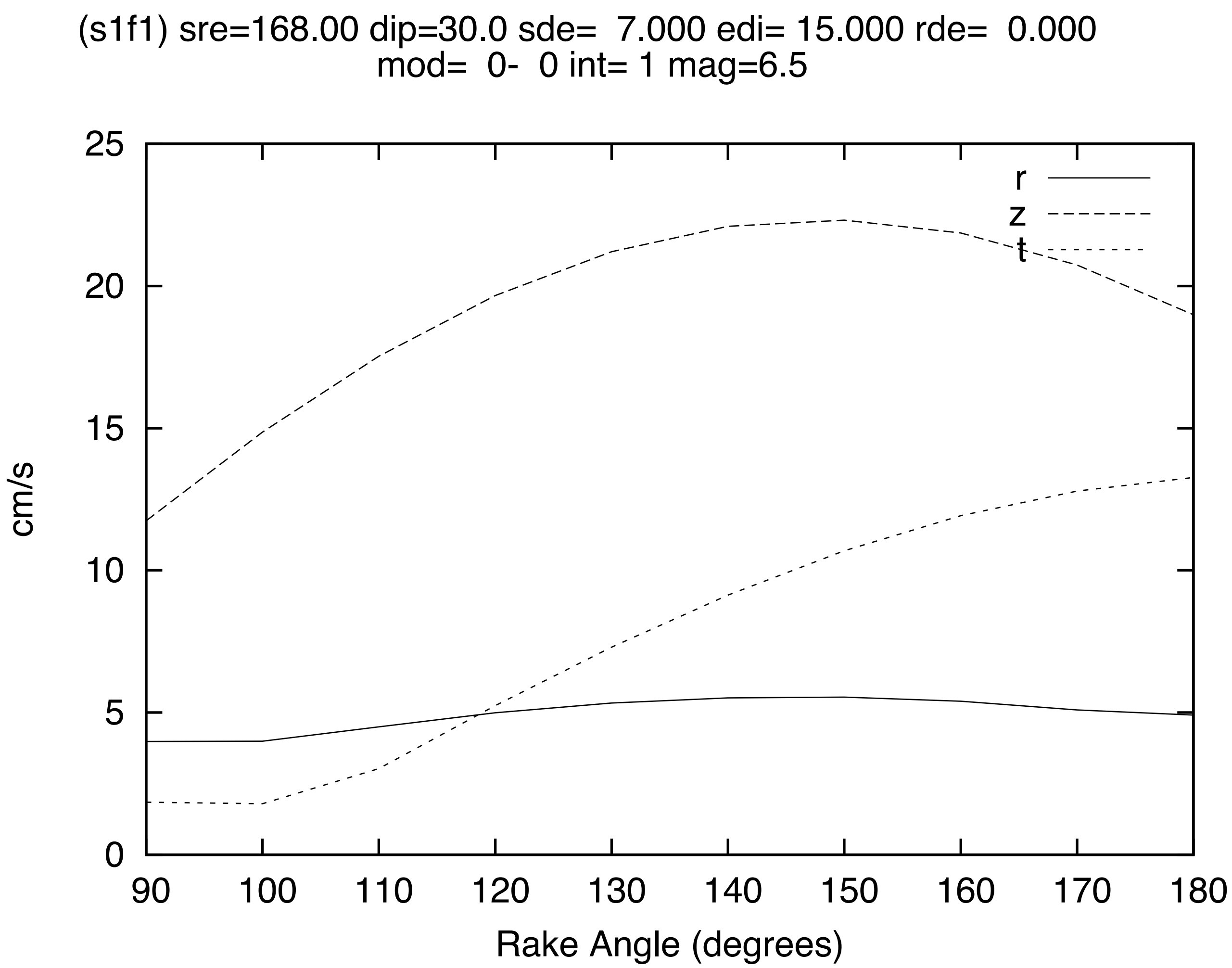

Regional Scale - Modal Summation Technique

- Earthquake scenarios for single events

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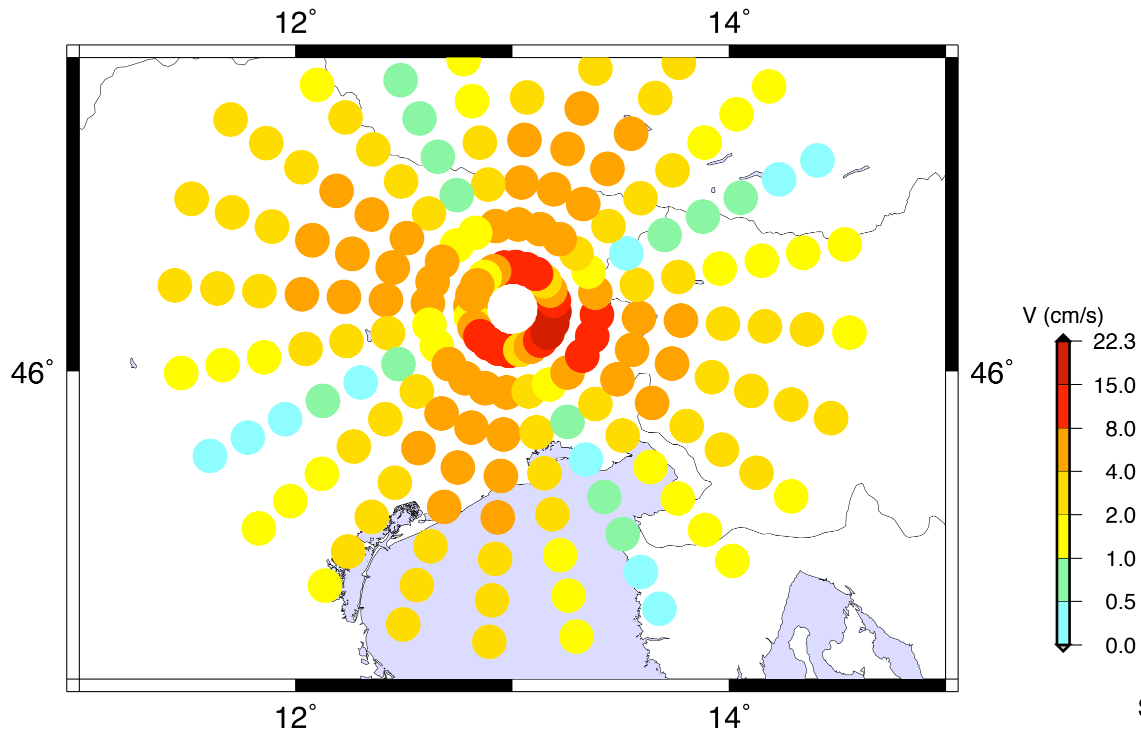

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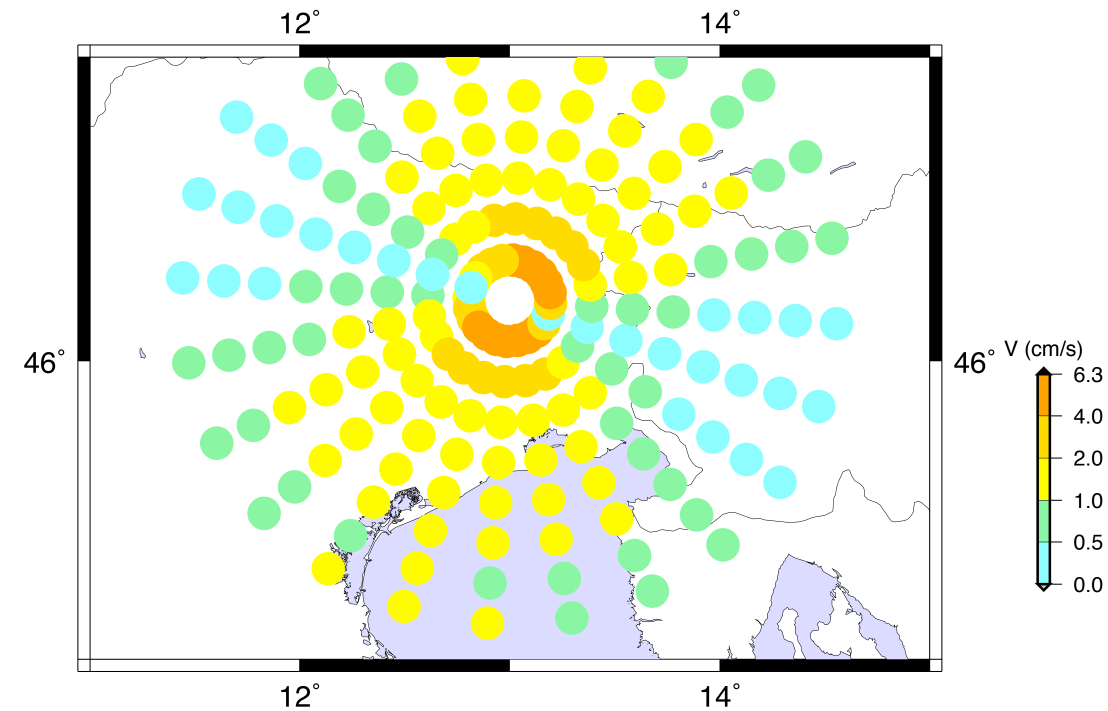

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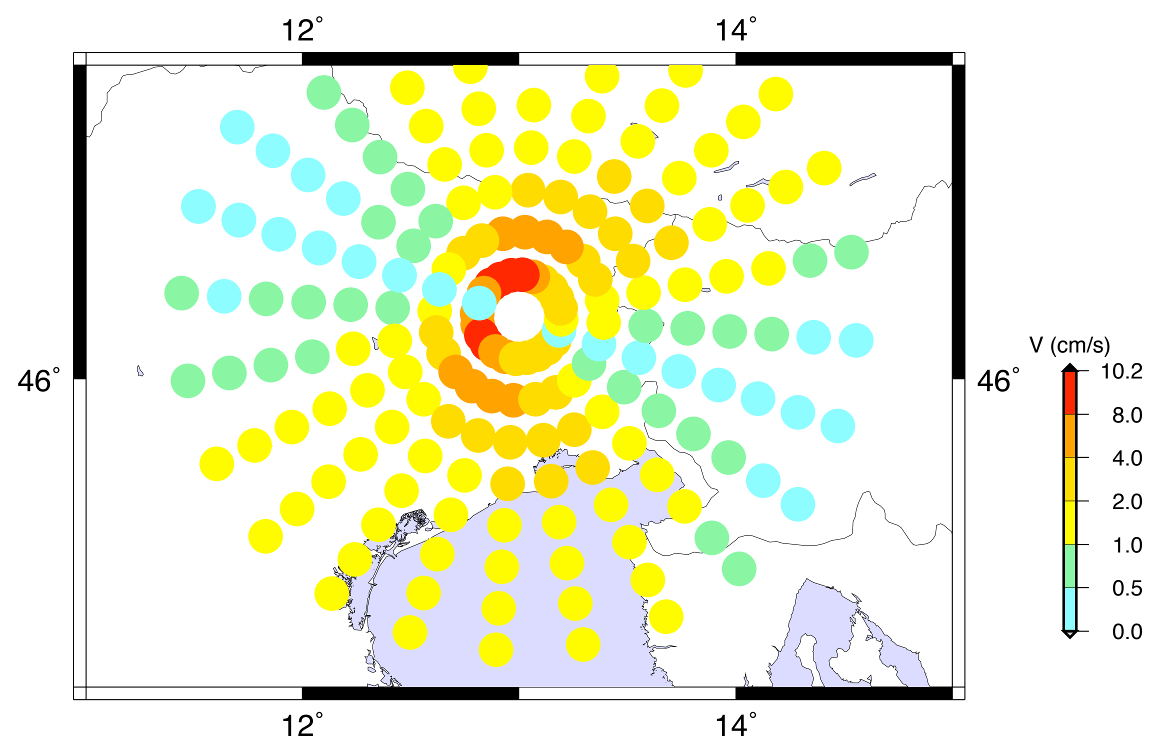
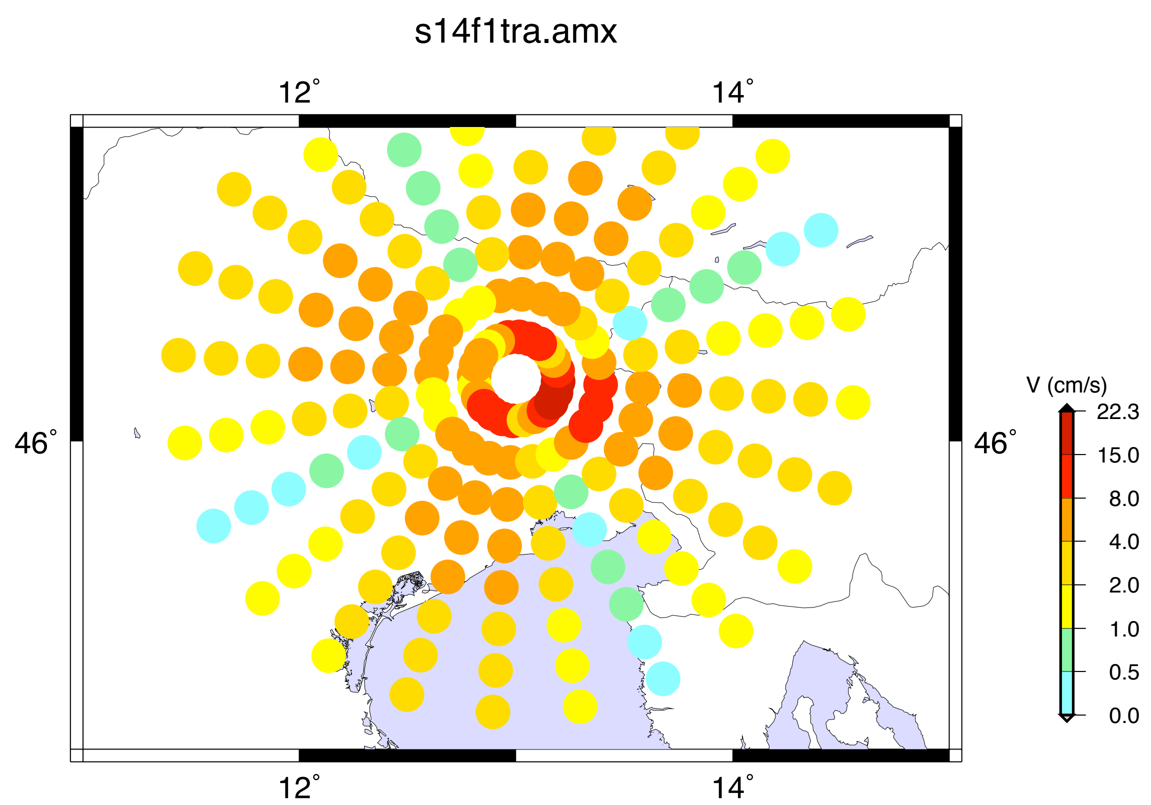
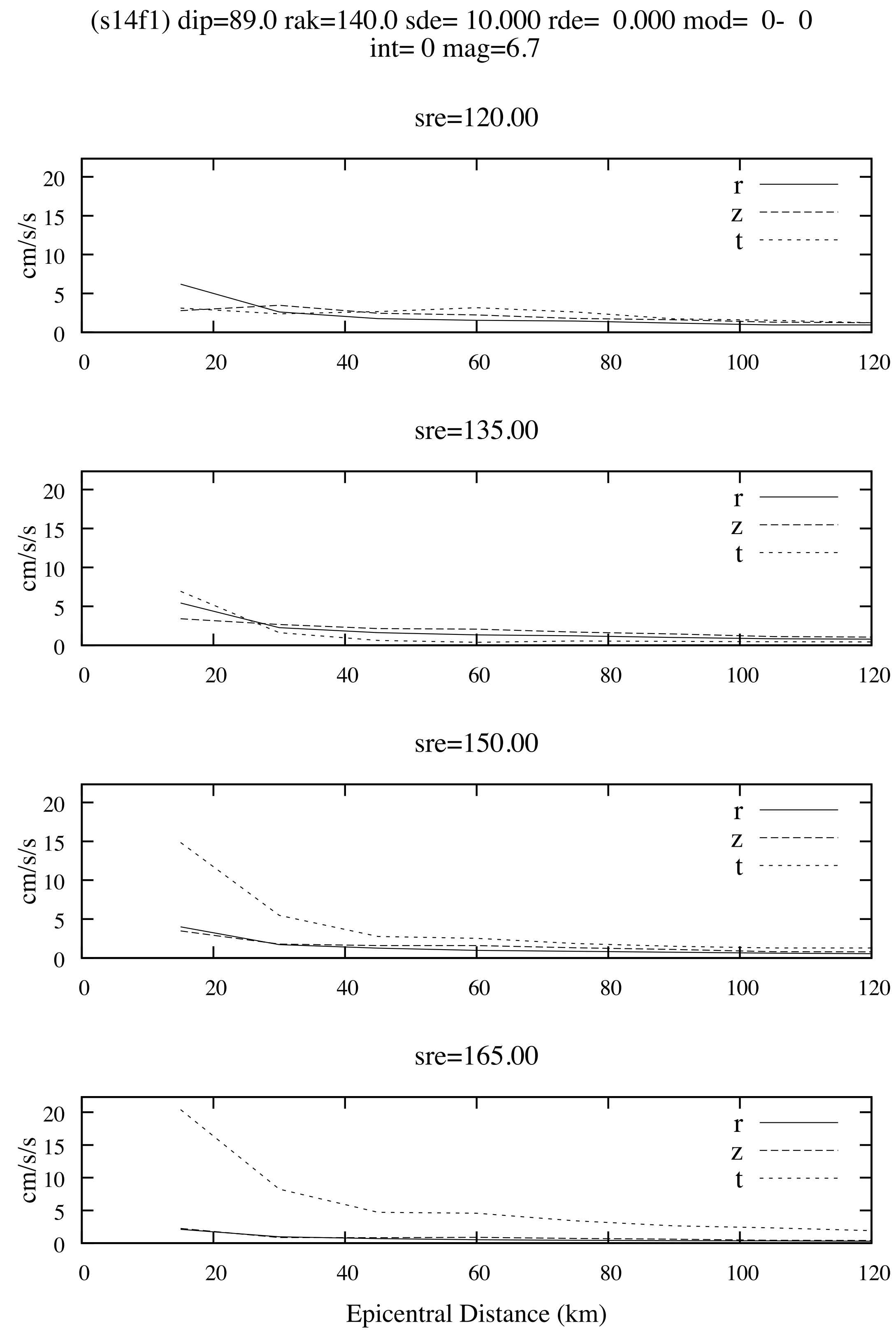


Regional Scale - Modal Summation Technique

- Earthquake scenarios

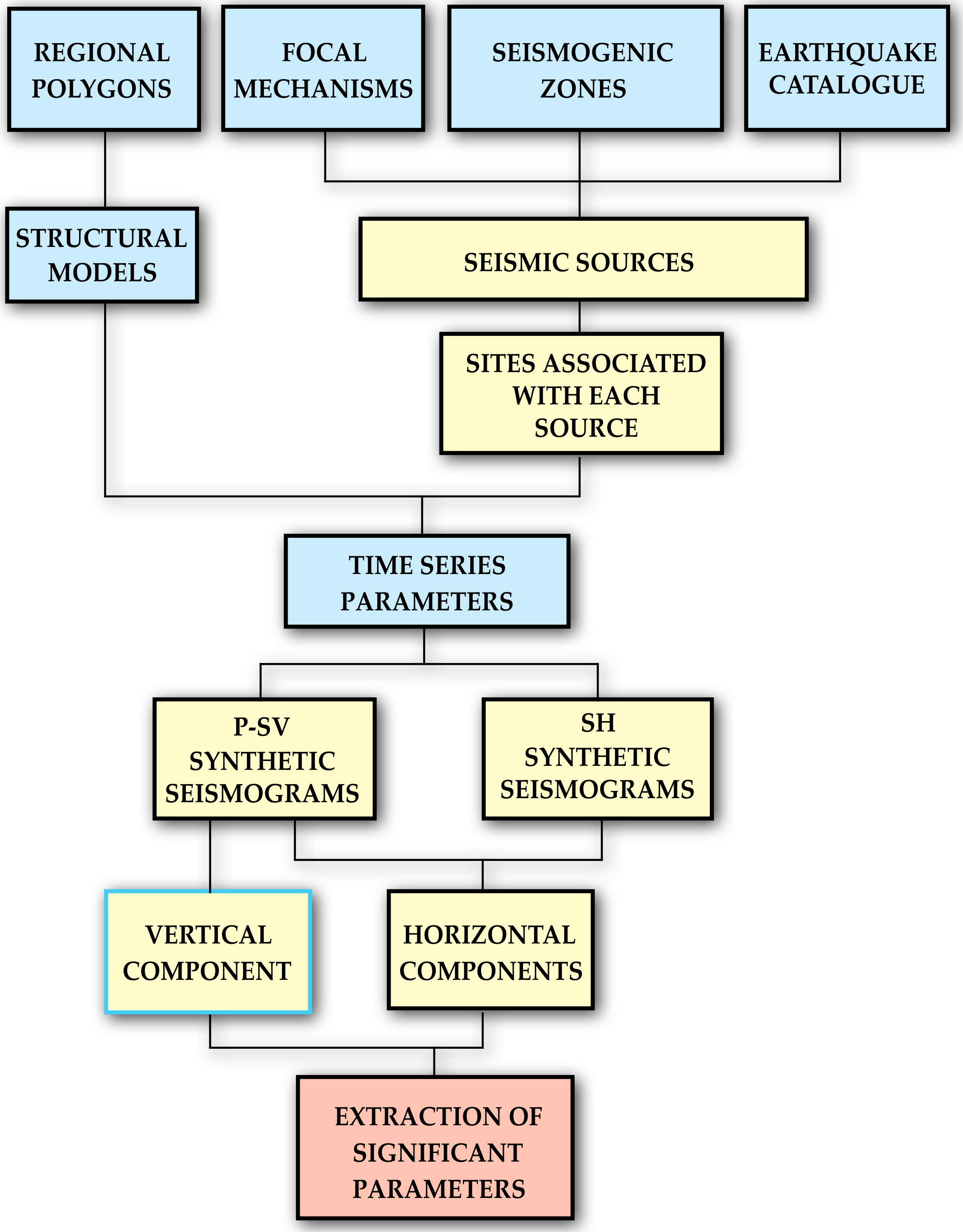




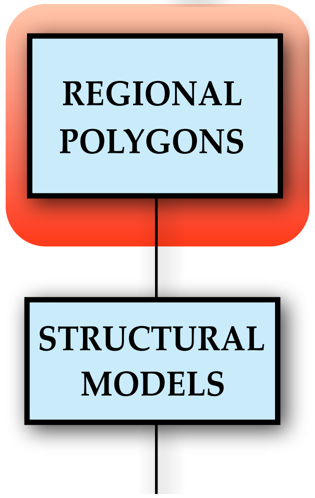
Regional Scale - Seismic zoning

- Neodeterministic seismic hazard assessment
- Collection of available data about:
  - Structural properties
  - Historical seismicity
  - Tectonic regime
  - Seismogenic zones
  - ...

Regional Scale - Flowchart



Regional Scale - Definition of Structures




```
Polygons◇that◇define◇different◇structural◇regions◇(lon,lat)¬
region0001¬
◇◇◇◇◇◇◇◇◇◇◇◇12.000◇◇38.250¬
◇◇◇◇◇◇◇◇◇◇◇◇12.000◇◇37.750¬
◇◇◇◇◇◇◇◇◇◇◇◇14.000◇◇37.000¬
◇◇◇◇◇◇◇◇◇◇◇◇15.500◇◇37.500¬
◇◇◇◇◇◇◇◇◇◇◇◇15.000◇◇38.250¬
region0002¬
◇◇◇◇◇◇◇◇◇◇◇◇15.000◇◇38.500¬
◇◇◇◇◇◇◇◇◇◇◇◇15.000◇◇38.250¬
◇◇◇◇◇◇◇◇◇◇◇◇15.500◇◇37.500¬
◇◇◇◇◇◇◇◇◇◇◇◇16.250◇◇37.750¬
◇◇◇◇◇◇◇◇◇◇◇◇17.250◇◇39.000¬
◇◇◇◇◇◇◇◇◇◇◇◇17.250◇◇39.500¬
◇◇◇◇◇◇◇◇◇◇◇◇15.750◇◇39.500¬
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region0003¬
◇◇◇◇◇◇◇◇◇◇◇◇16.250◇◇40.750¬
◇◇◇◇◇◇◇◇◇◇◇◇16.000◇◇40.000¬
◇◇◇◇◇◇◇◇◇◇◇◇15.750◇◇39.500¬
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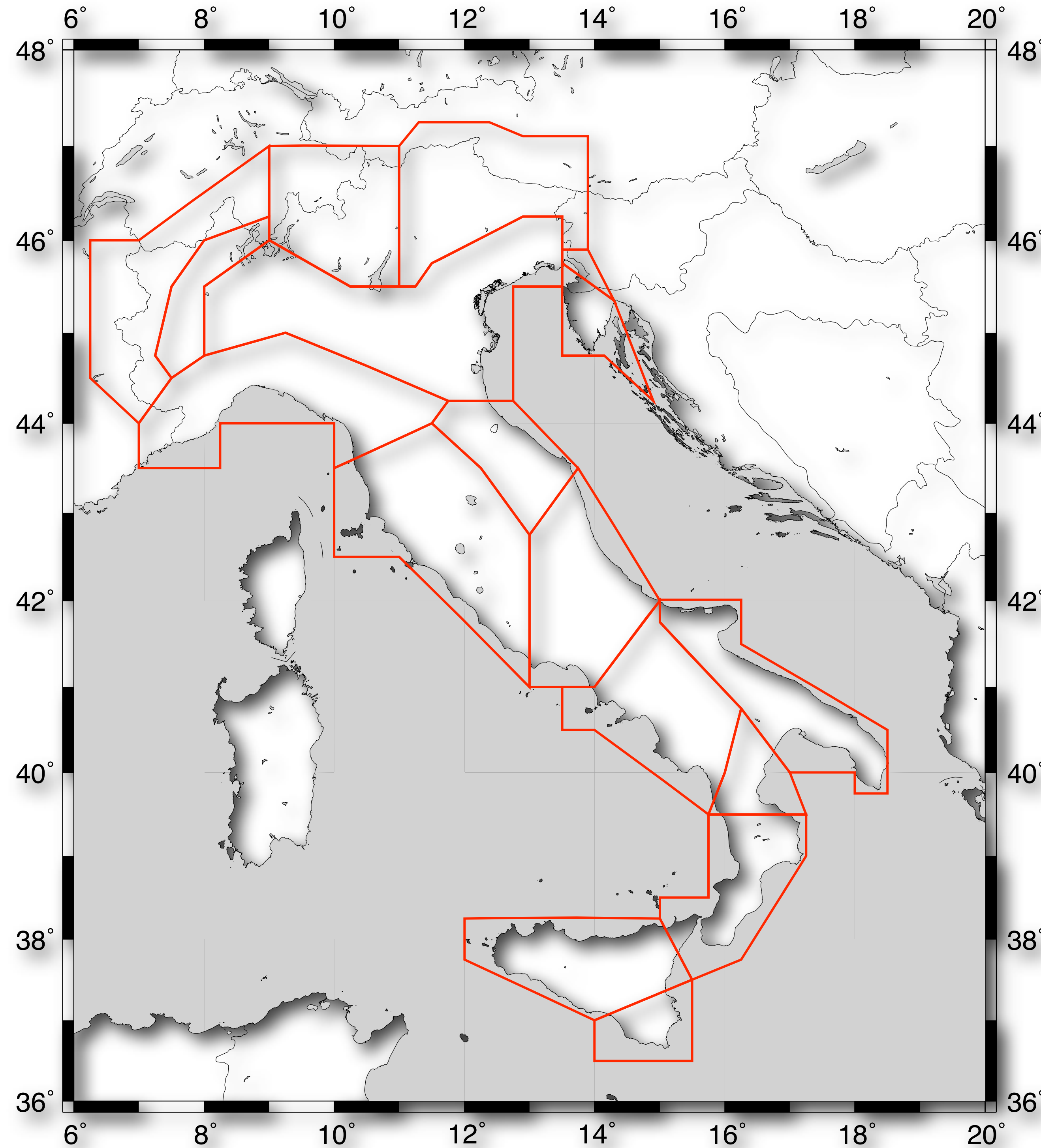
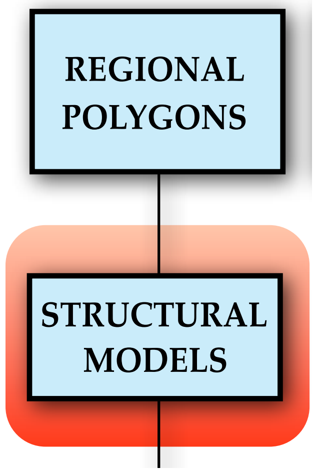
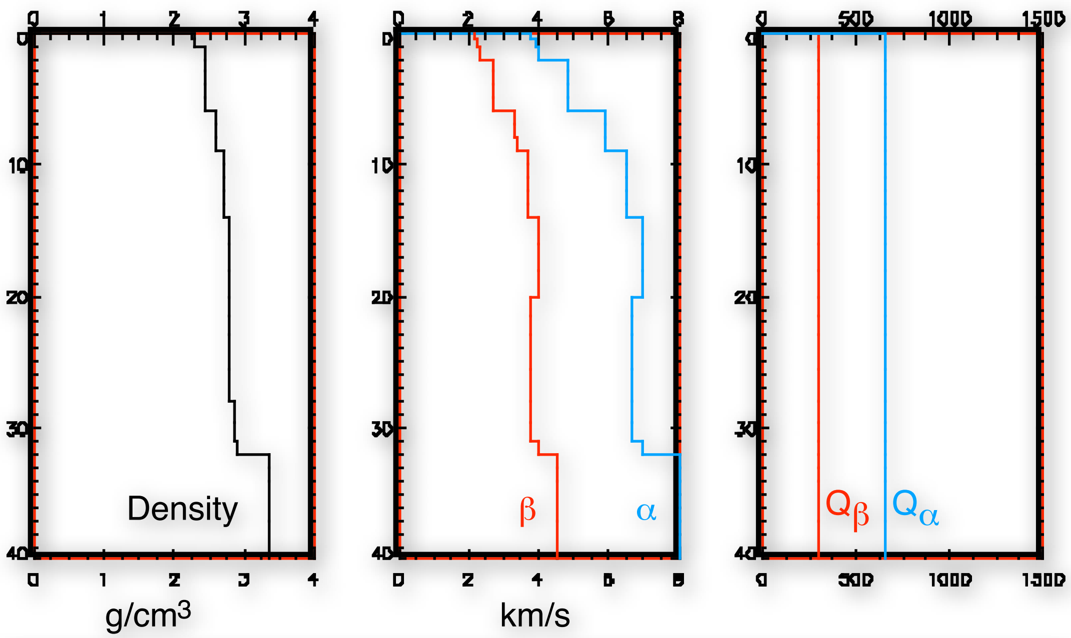
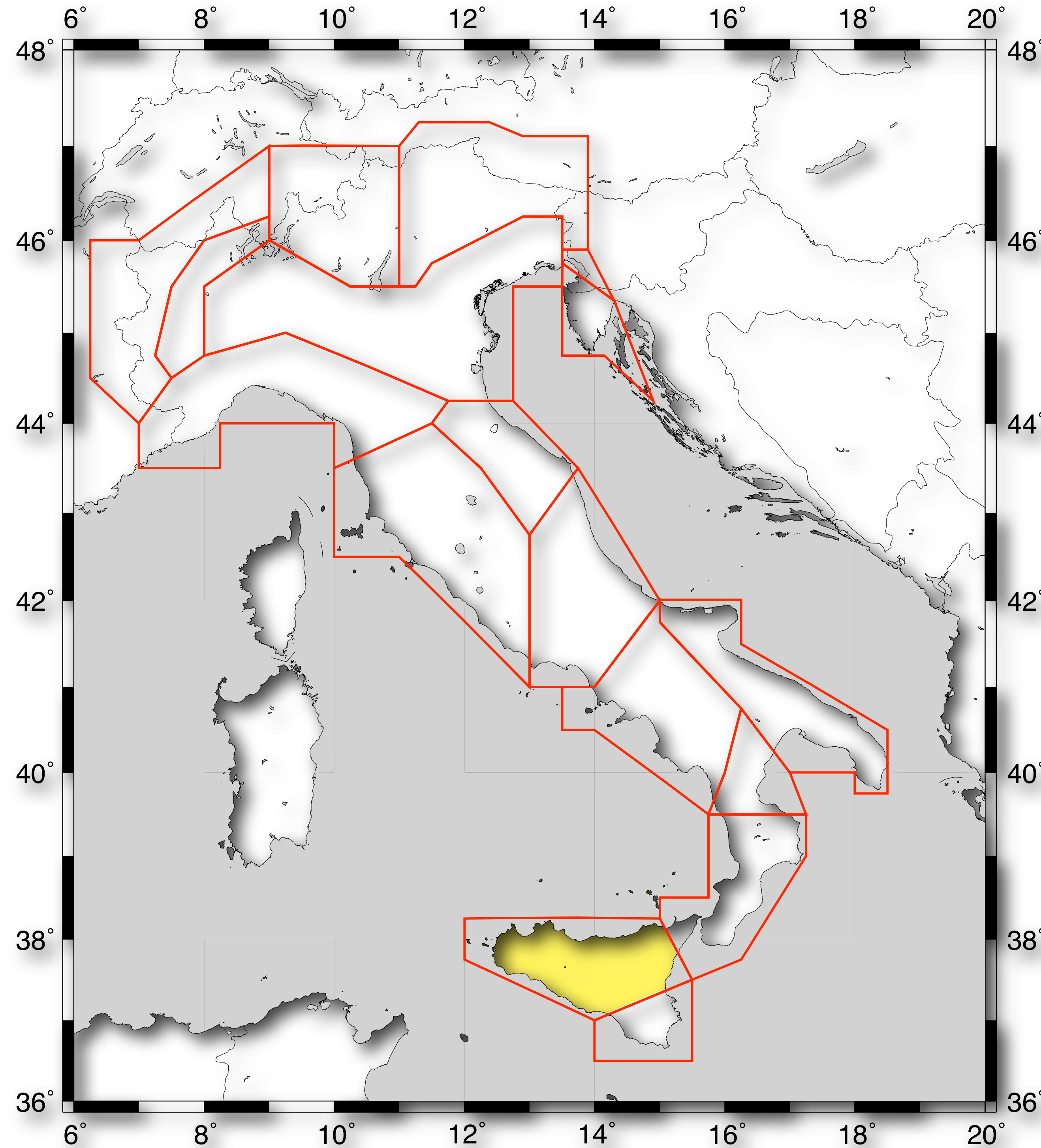


Regional Scale - Definition of Structures

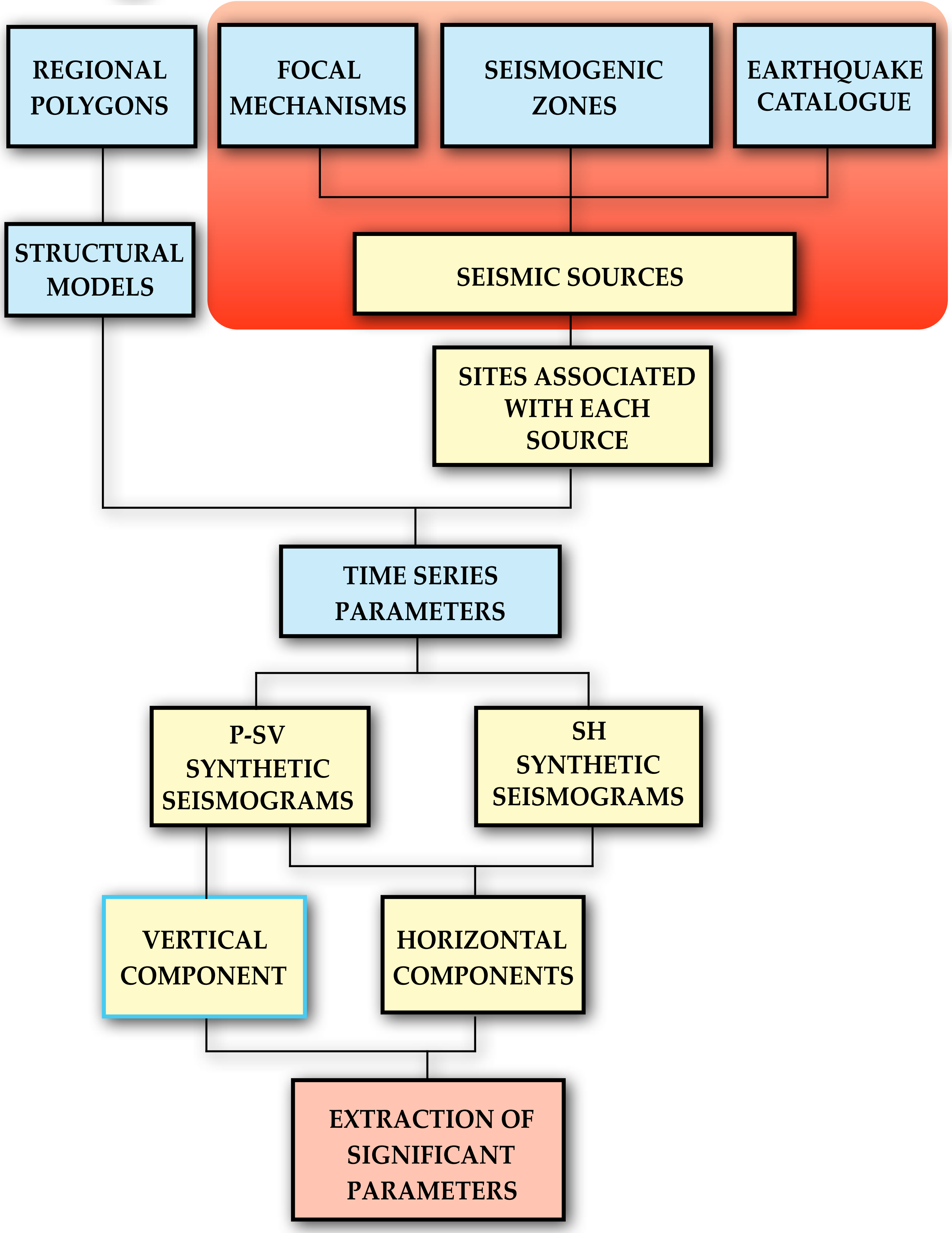




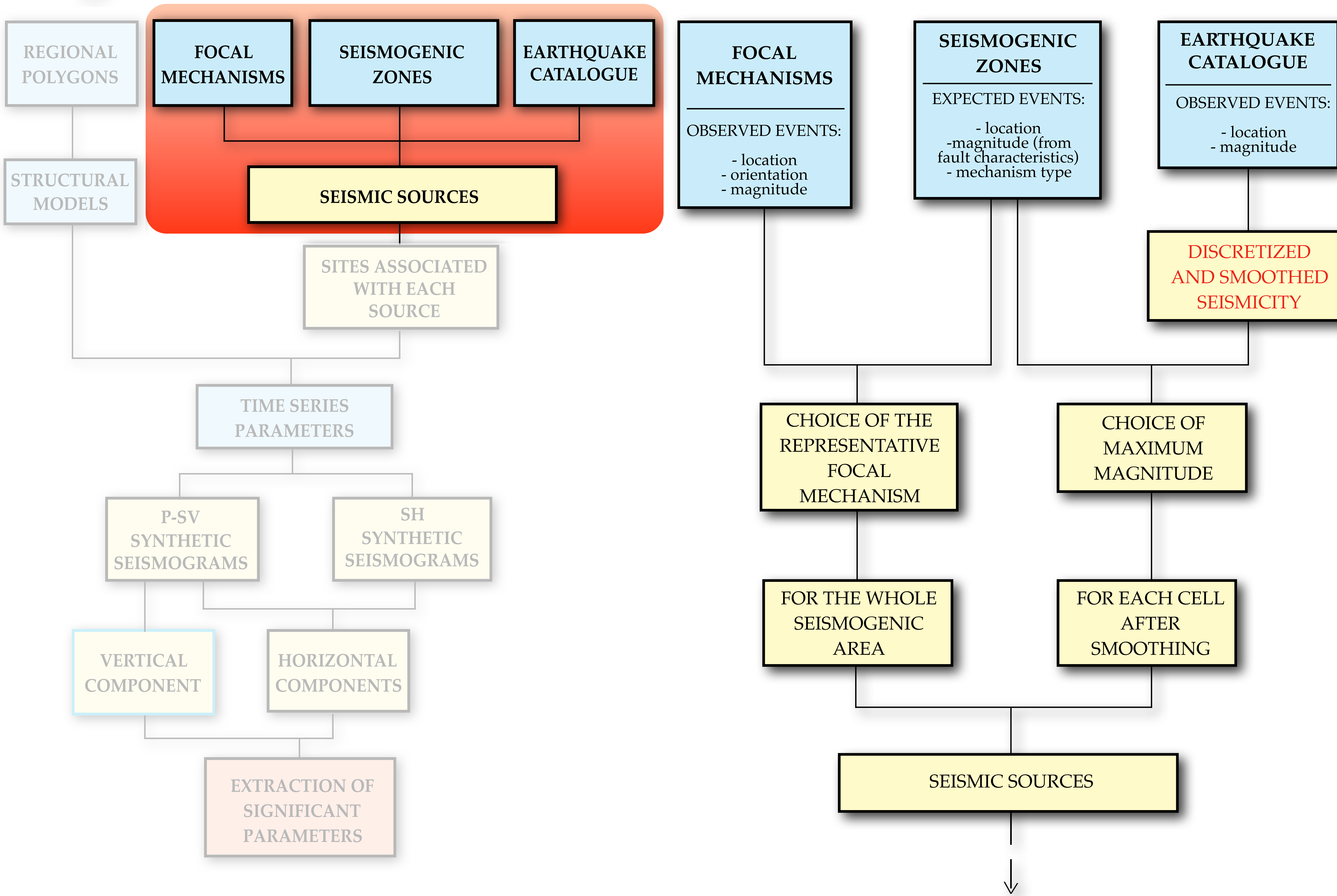
thk(km)	rho	Vp(km/s)	Vs(km/s)	Qp	Qs	depth(km)
0.5000	2.30	3.800000	2.200000	660.00	300.00	0.50000
0.5000	2.30	3.900000	2.250000	660.00	300.00	1.00000
1.0000	2.45	4.000000	2.300000	660.00	300.00	2.00000
4.0000	2.45	4.800000	2.700000	660.00	300.00	6.00000
3.0000	2.60	5.900000	3.350000	660.00	300.00	9.00000
5.0000	2.70	6.500000	3.700000	660.00	300.00	14.00000
6.0000	2.80	7.000000	4.000000	660.00	300.00	20.00000
8.0000	2.80	6.700000	3.750000	660.00	300.00	28.00000
...						
...						
25.0000	4.55	11.392000	6.340000	1320.00	600.00	990.00000
25.0000	4.58	11.434000	6.360000	1375.00	625.00	1015.00000
25.0000	4.60	11.476000	6.375000	1450.00	660.00	1040.00000
25.0000	4.63	11.518000	6.390000	1500.00	685.00	1065.00000
25.0000	4.66	11.560000	6.405000	1580.00	720.00	1090.00000
25.0000	4.68	11.600000	6.420000	1650.00	750.00	1115.00000



Regional Scale - Definition of Sources



Regional Scale - Definition of Sources



Regional Scale - Definition of Sources

FOCAL MECHANISMS

OBSERVED EVENTS:

- location
- orientation
- magnitude

SEISMOGENIC ZONES

EXPECTED EVENTS:

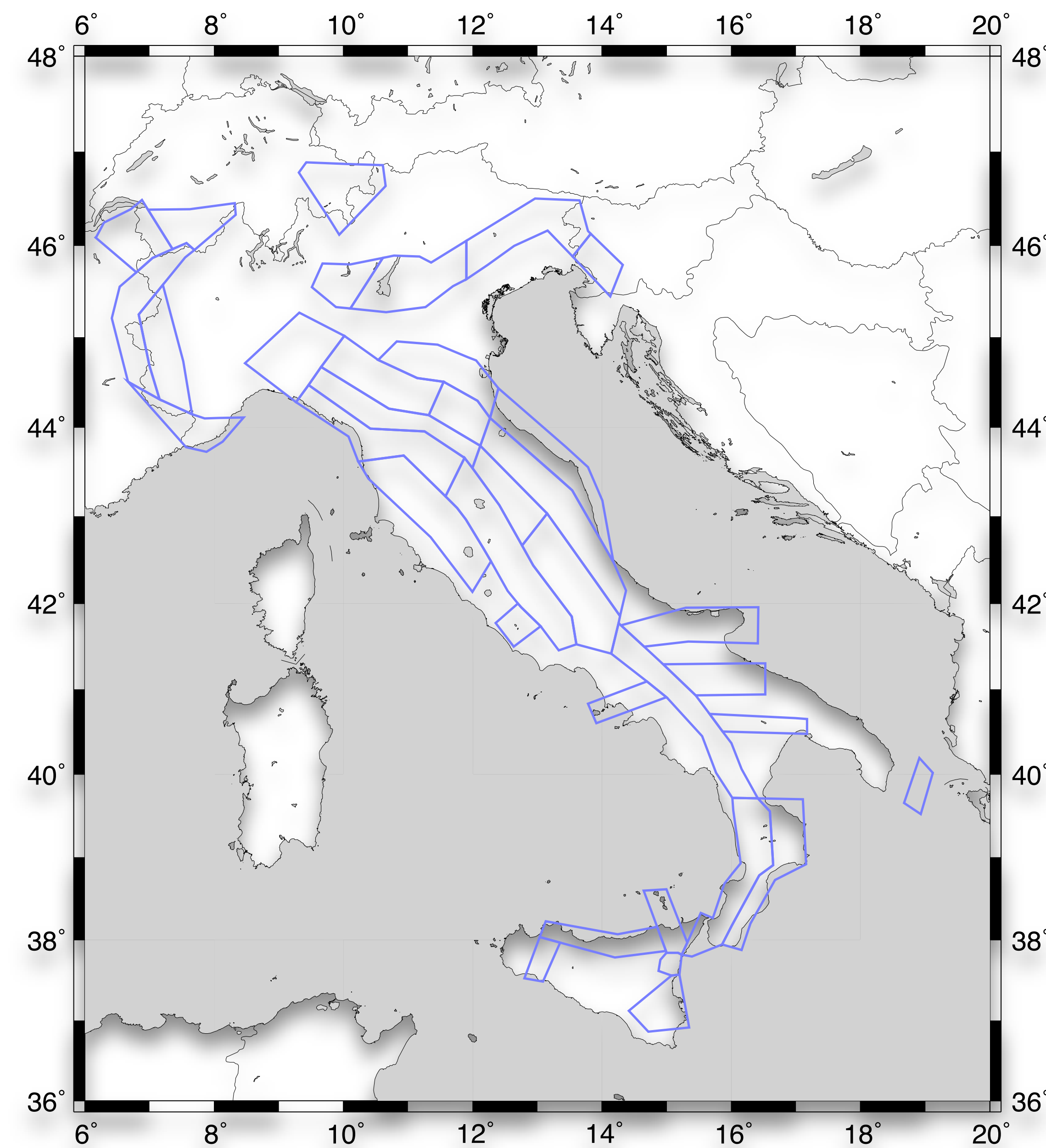
- location
- magnitude (from fault characteristics)
- mechanism type

EARTHQUAKE CATALOGUE

OBSERVED EVENTS:

- location
- magnitude

```
ZS9 Seismogenic Zones
newzon0901
                 6.977  46.381
                 7.358  45.958
                 7.356  45.957
                 7.049  45.861
                 6.794  45.707
                 6.165  46.083
                 6.178  46.094
                 6.280  46.225
                 6.296  46.244
                 6.708  46.386
                 6.709  46.386
                 6.881  46.485
                 6.977  46.381
newzon0902
                 7.626  46.388
                 8.321  46.449
                 8.335  46.327
                 7.693  45.949
                 7.572  46.024
                 7.358  45.958
                 6.977  46.381
                 7.626  46.388
...
...
```



Regional Scale - Definition of Sources

FOCAL MECHANISMS

OBSERVED EVENTS:

- location
- orientation
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SEISMOGENIC ZONES

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- location
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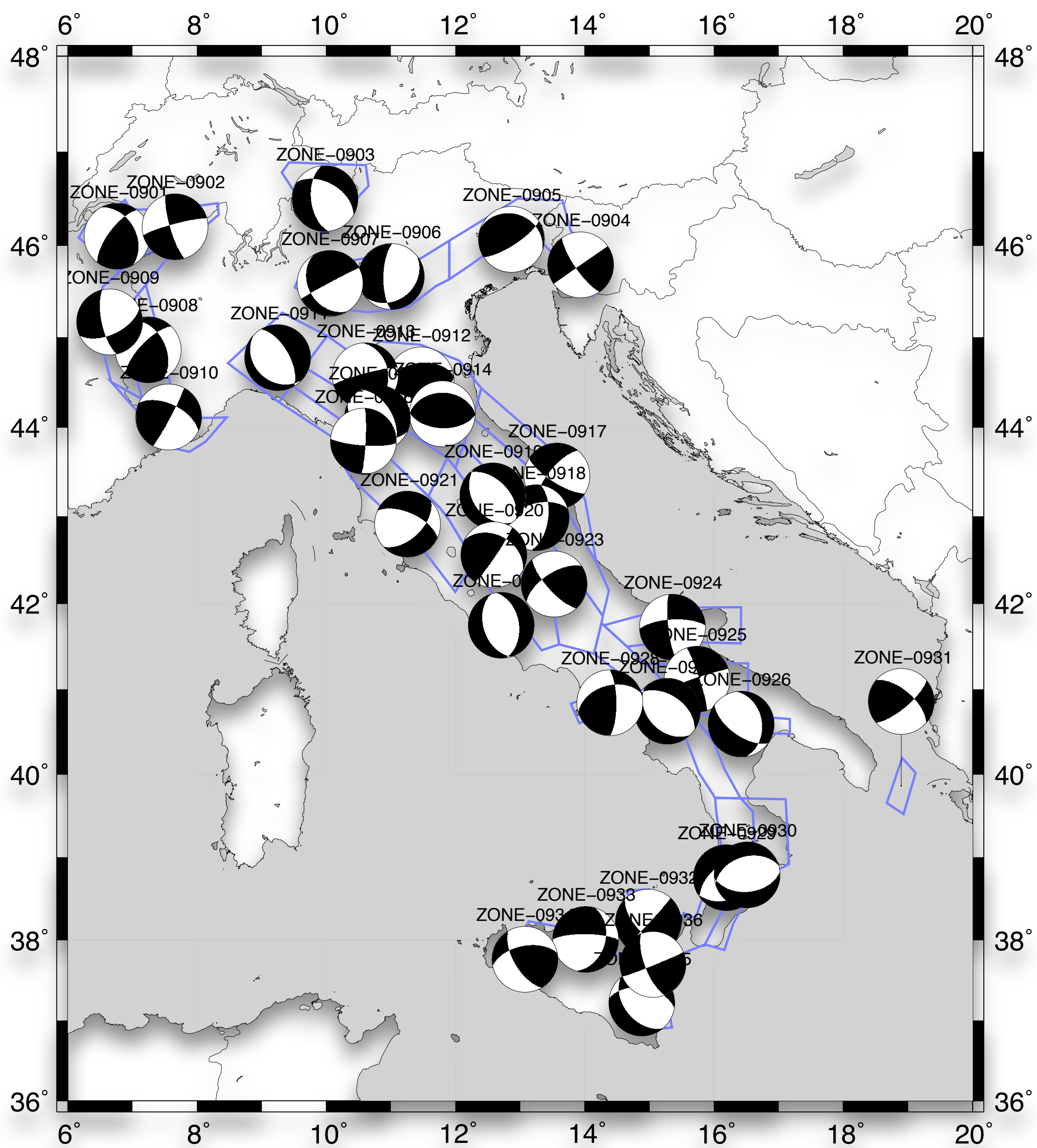
EARTHQUAKE CATALOGUE

OBSERVED EVENTS:

- location
- magnitude

```
------------------------------ ZS9.fps---------------------------
NUMBEA YEARMODY HRMISEC LA.TITN LON.GITE DEPT MLMDMSMBMA AGEN Area
NUMBEF ST1 D1 RA1   ST2 D2 RA2   PDI PI   TDI TI   BDI BI Q REFE Area
-----------------------------------------------------------------
   01A 00000000 0000000 47.362N  11.327E  000  0 0 0 043       ZONA1
00001F 322 72 192
   02A 00000000 0000000 47.047N   9.018E  000  0 0 0 045       ZONA2
00002F 093 42 184
   03A 00000000 0000000 46.499N   9.980E  000  0 0 0 050       ZONA3
00003F 300 50 229
   04A 00000000 0000000 45.853N  15.086E  000  0 0 0 053       ZONA4
00004F 078 44 056
   05A 00000000 0000000 46.064N  12.861E  000  0 0 0 066       ZONA5
00005F 289 23 140
   06A 00000000 0000000 46.096N   6.761E  000  0 0 0 053       ZONA6
00006F 332 43 032
   07A 00000000 0000000 46.199N   7.656E  000  0 0 0 048       ZONA7
00007F 164 78 353
...
...
```



Regional Scale - Definition of Sources

FOCAL MECHANISMS

OBSERVED EVENTS:

- location
- orientation
- magnitude

SEISMOGENIC ZONES

EXPECTED EVENTS:

- location
-magnitude (from fault characteristics)
- mechanism type

EARTHQUAKE CATALOGUE

OBSERVED EVENTS:

- location
- magnitude

```
-217 6 0 0 0 0 4325  1125  0656656656  00
-174 0 0 0 0 0 4225  1267  0660660660  00
-100 0 0 0 0 0 4317  1350  0584580580  00
 -99 0 0 0 0 0 4280  1310  0557540555  00
 -91 0 0 0 0 0 4465  1078  0566553553  00
 -91 0 0 0 0 0 3810  1565  0630630630  00
 -76 0 0 0 0 0 4240  1287  0660660660  00
 -56 4 0 0 0 0 4343  1367  0584580580  00
  17 0 0 0 0 0 3780  1520  0514476495  00
  62 2 5 0 0 0 4078  1442  0587584584  00
  79 825 7 0 0 4080  1438  0577569569  00
  99 0 0 0 0 0 4135  1480  0630630630  00
 101 0 0 0 0 0 4223  1398  0630630630  00
 346 0 0 0 0 0 4138  1443  0600600600  00
 361 0 0 0 0 0 3750  1400  0660660660  00
 374 0 0 0 0 0 3810  1565  0630630630  00
 375 0 0 0 0 0 4113  1478  0600600600  00
 725 0 0 0 0 0 4440  1222  0557540555  00
 778 0 0 0 0 0 4567  1225  0584580580  00
 801 42920 0 0 4190  1248  0537510527  00
...
...
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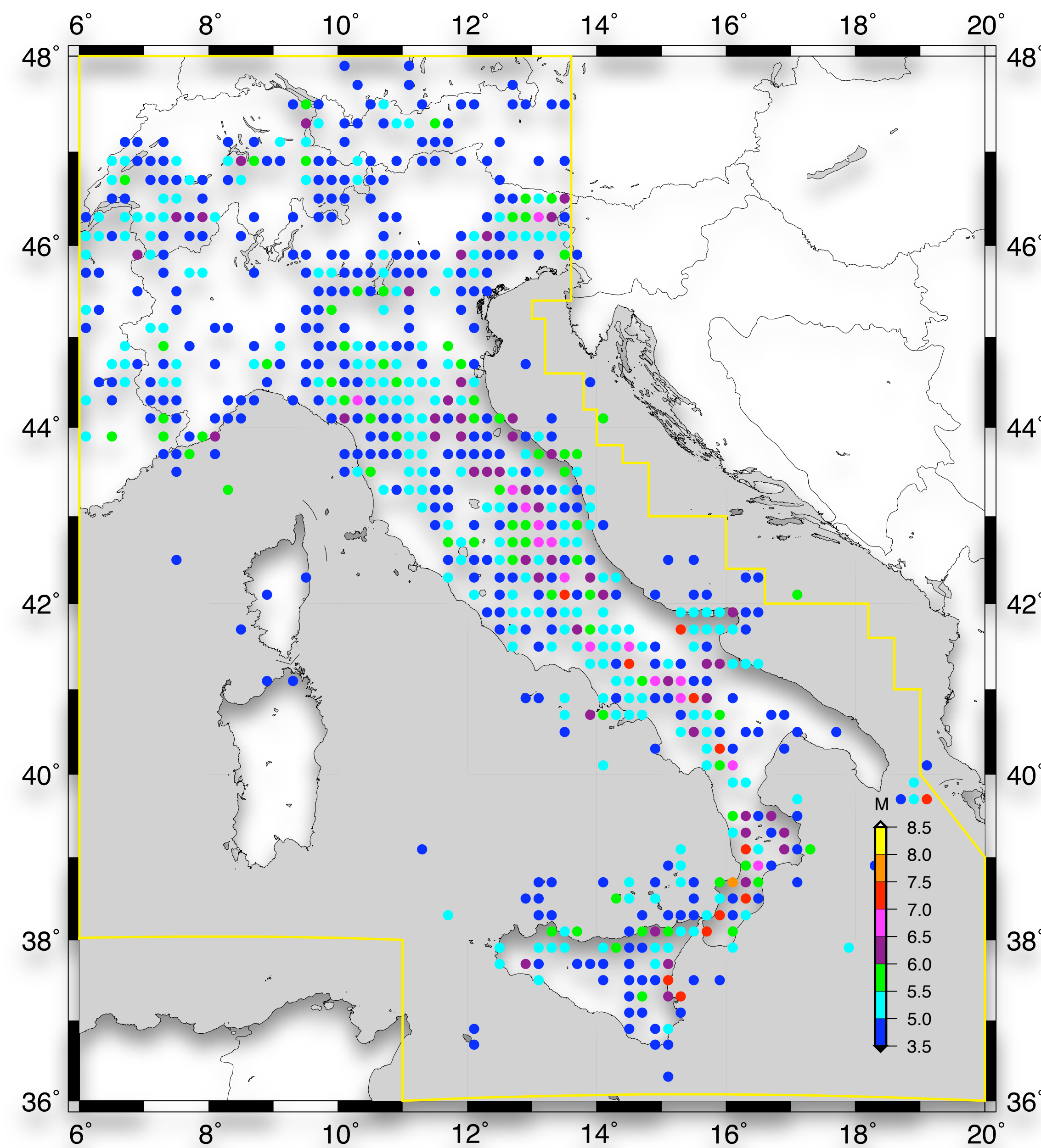


Regional Scale - Definition of Sources

FOCAL MECHANISMS

OBSERVED EVENTS:

- location
- orientation
- magnitude

SEISMOGENIC ZONES

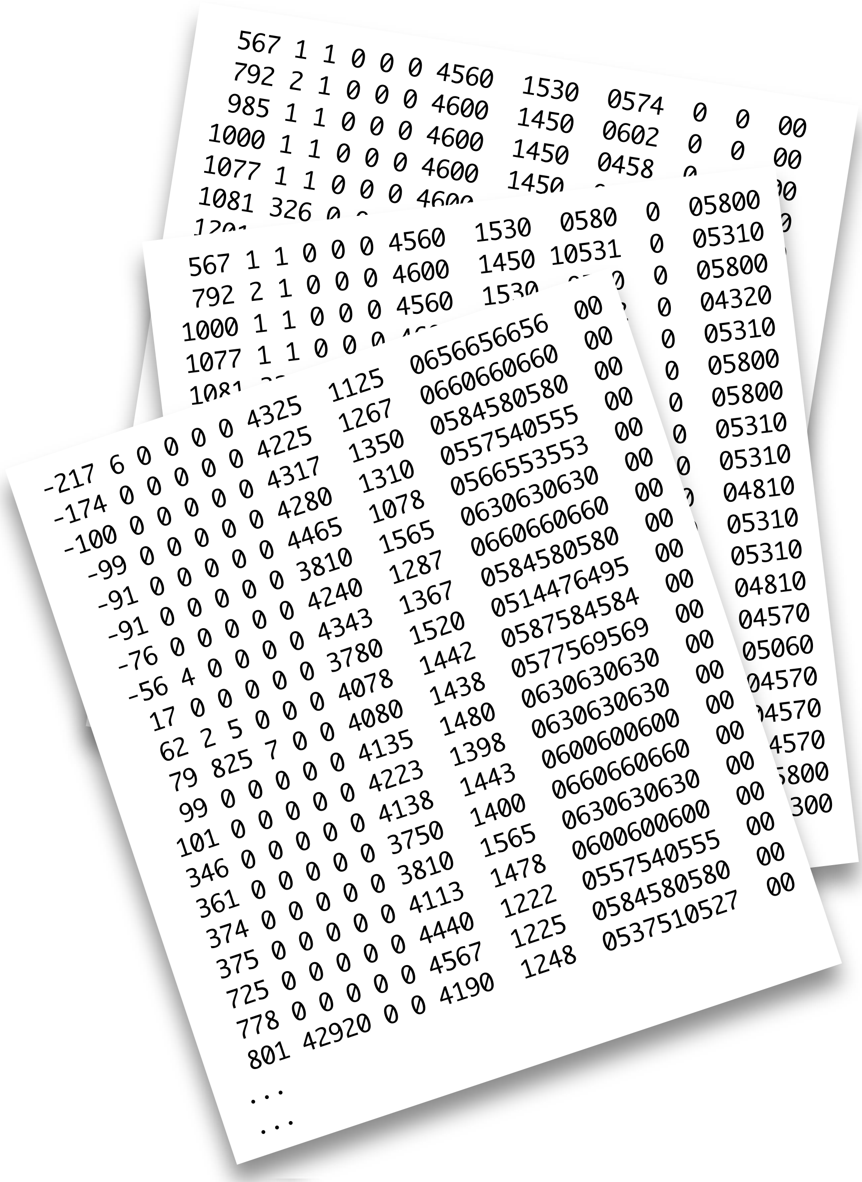
EXPECTED EVENTS:

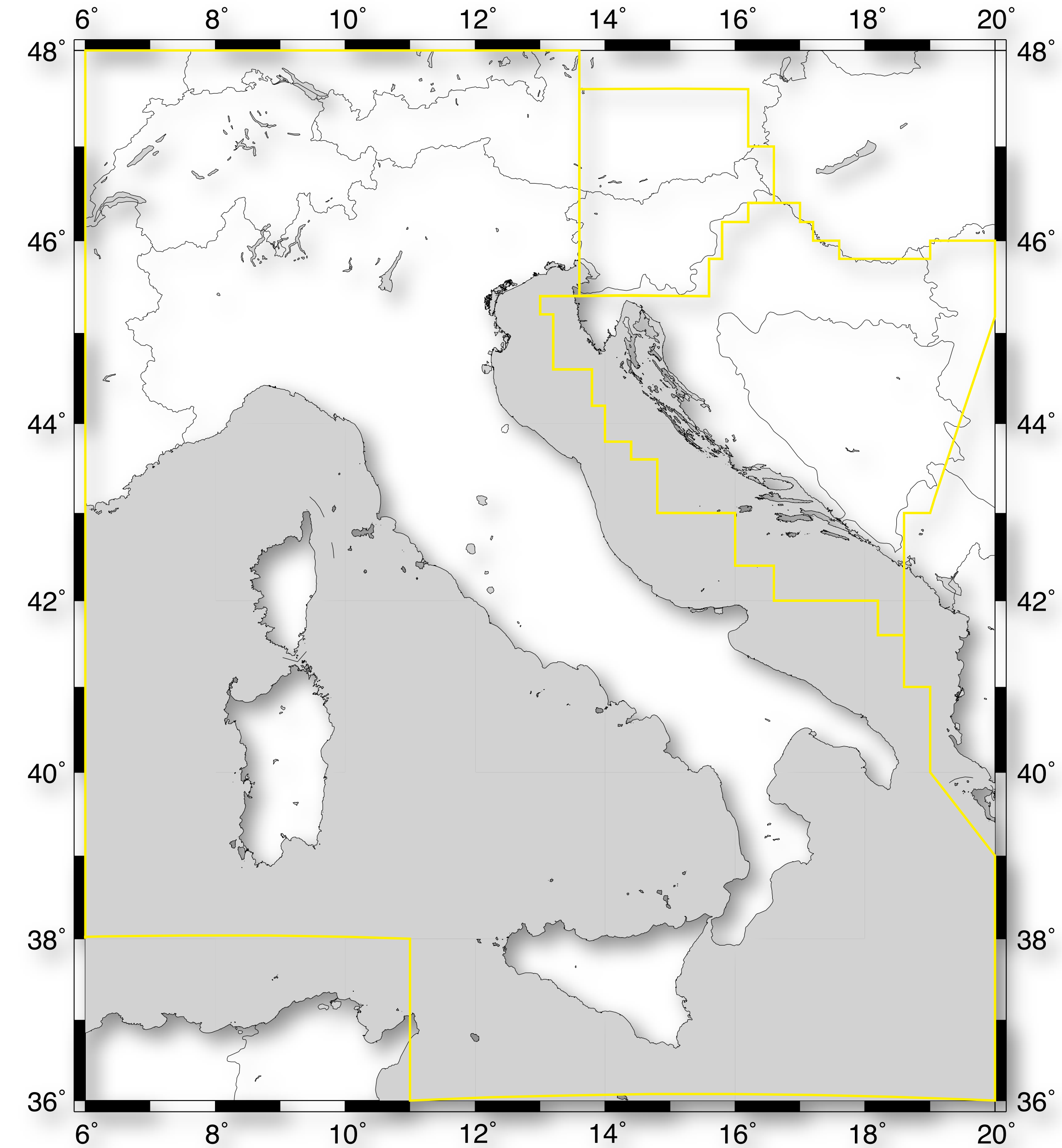
- location
- magnitude (from fault characteristics)
- mechanism type

EARTHQUAKE CATALOGUE

OBSERVED EVENTS:

- location
- magnitude





Regional Scale - Definition of Sources

FOCAL MECHANISMS

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- location
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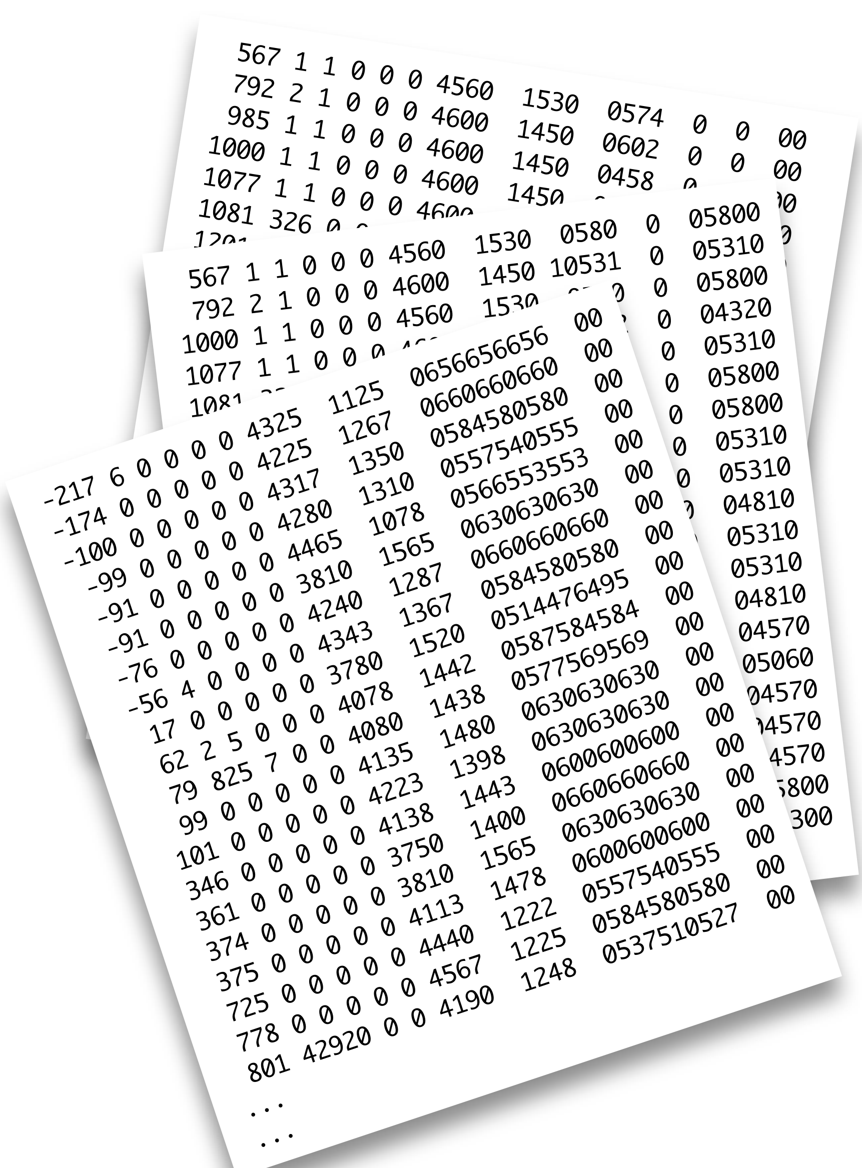
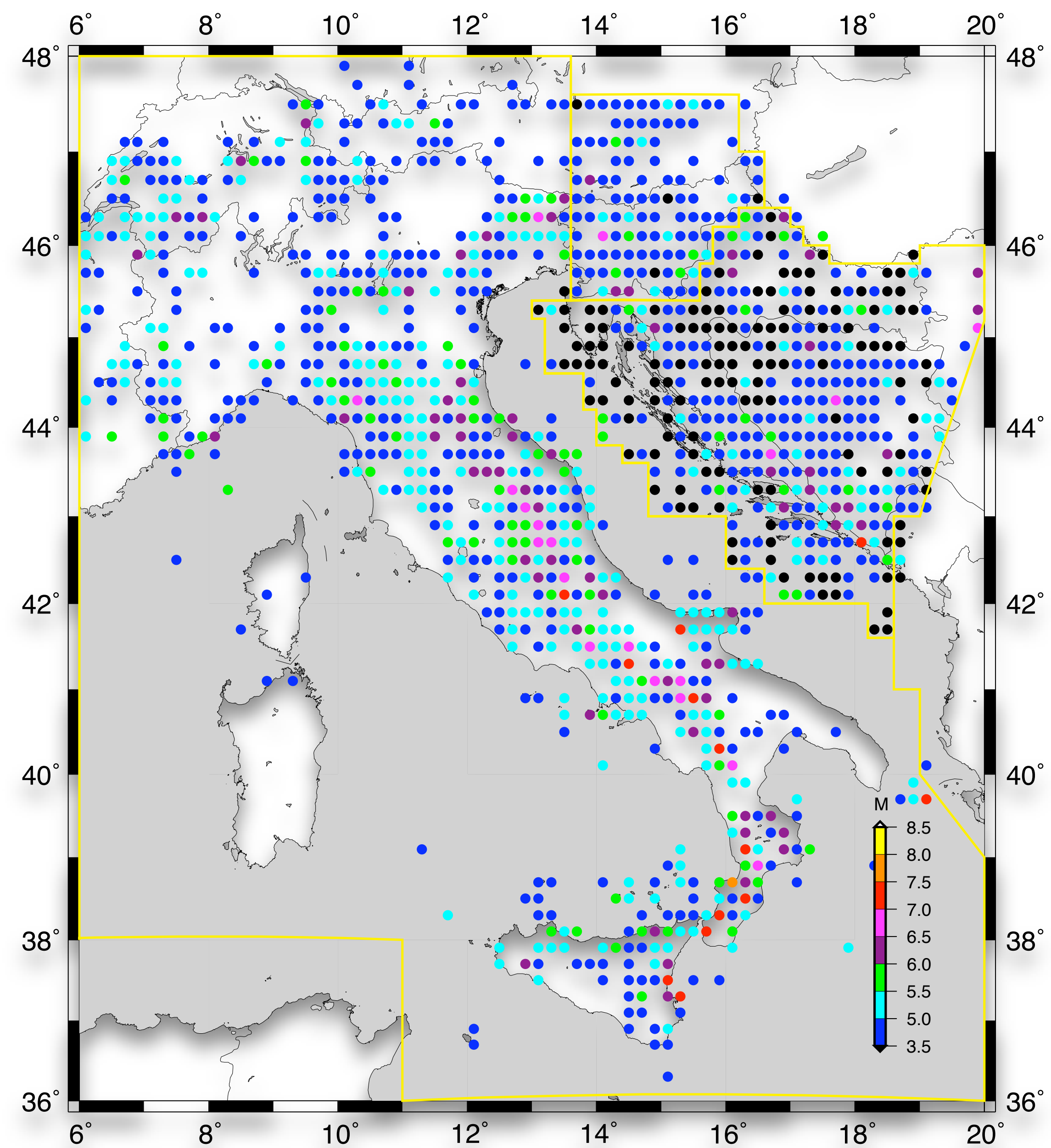
EARTHQUAKE CATALOGUE

OBSERVED EVENTS:

- location
- magnitude





Regional Scale - Definition of Sources

FOCAL MECHANISMS

OBSERVED EVENTS:
- location
- orientation
- magnitude

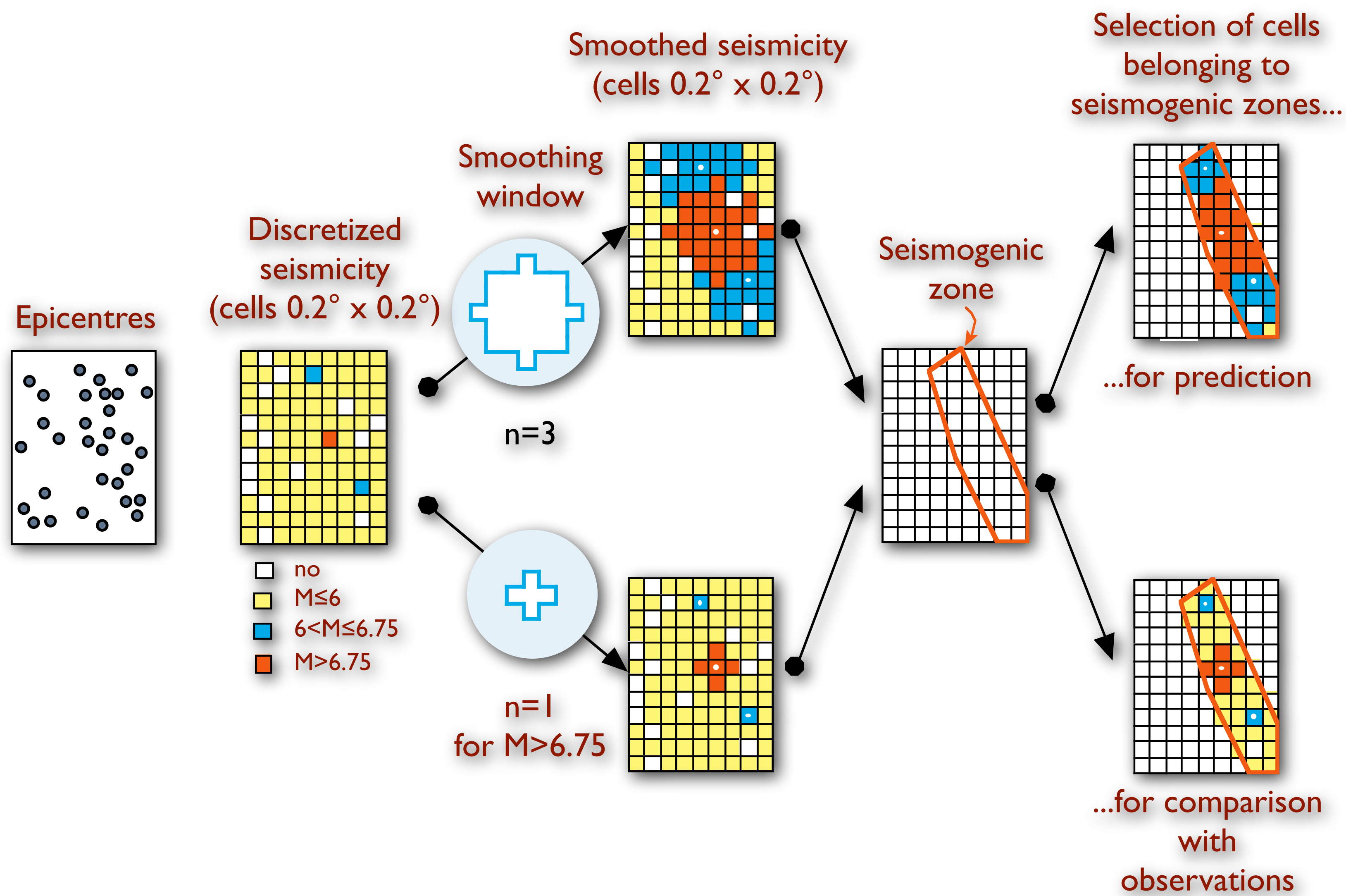
SEISMOGENIC ZONES

EXPECTED EVENTS:
- location
- magnitude (from fault characteristics)
- mechanism type

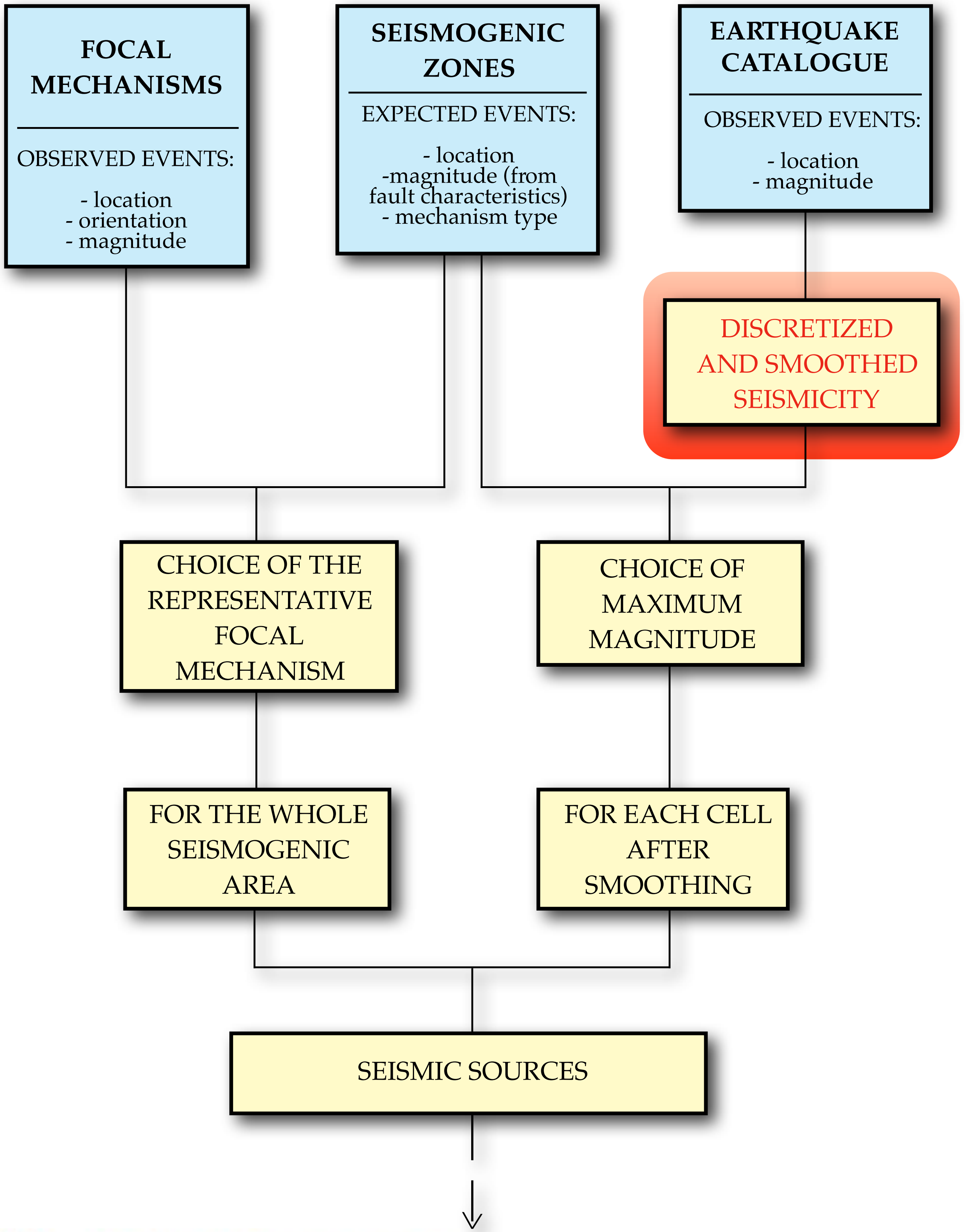
EARTHQUAKE CATALOGUE

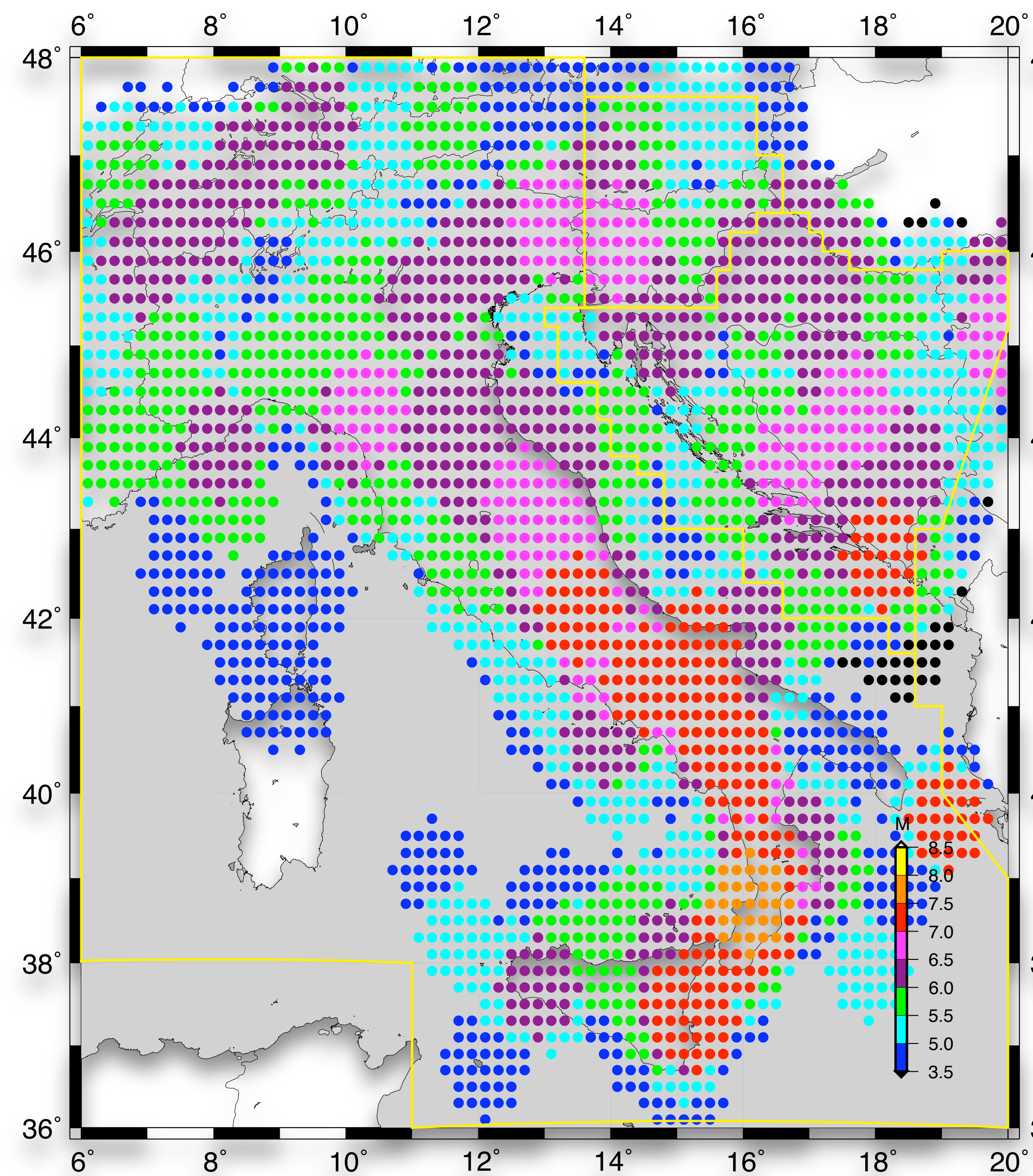
OBSERVED EVENTS:
- location
- magnitude

Discretization and smoothing of seismicity

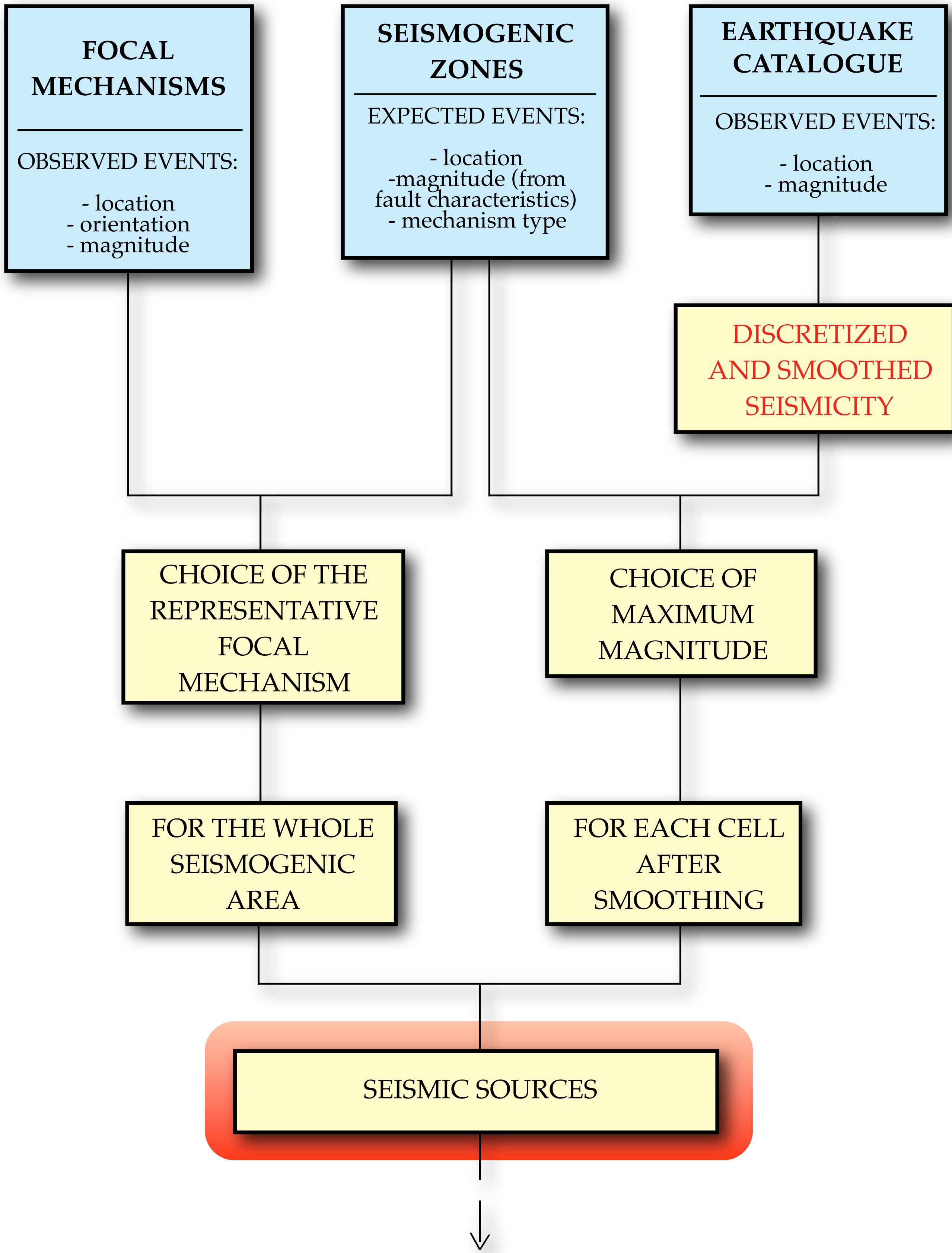


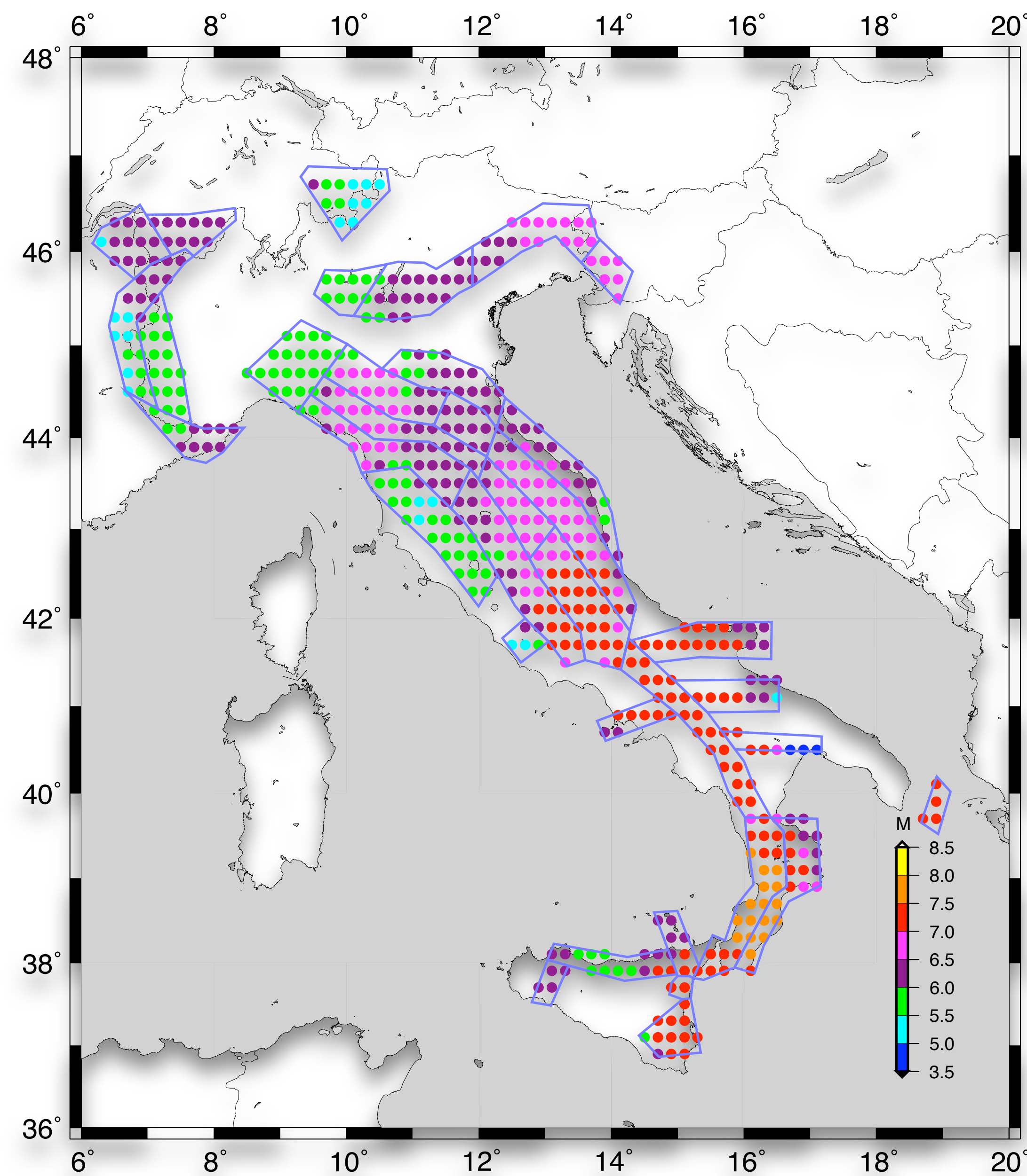
Regional Scale - Definition of Sources





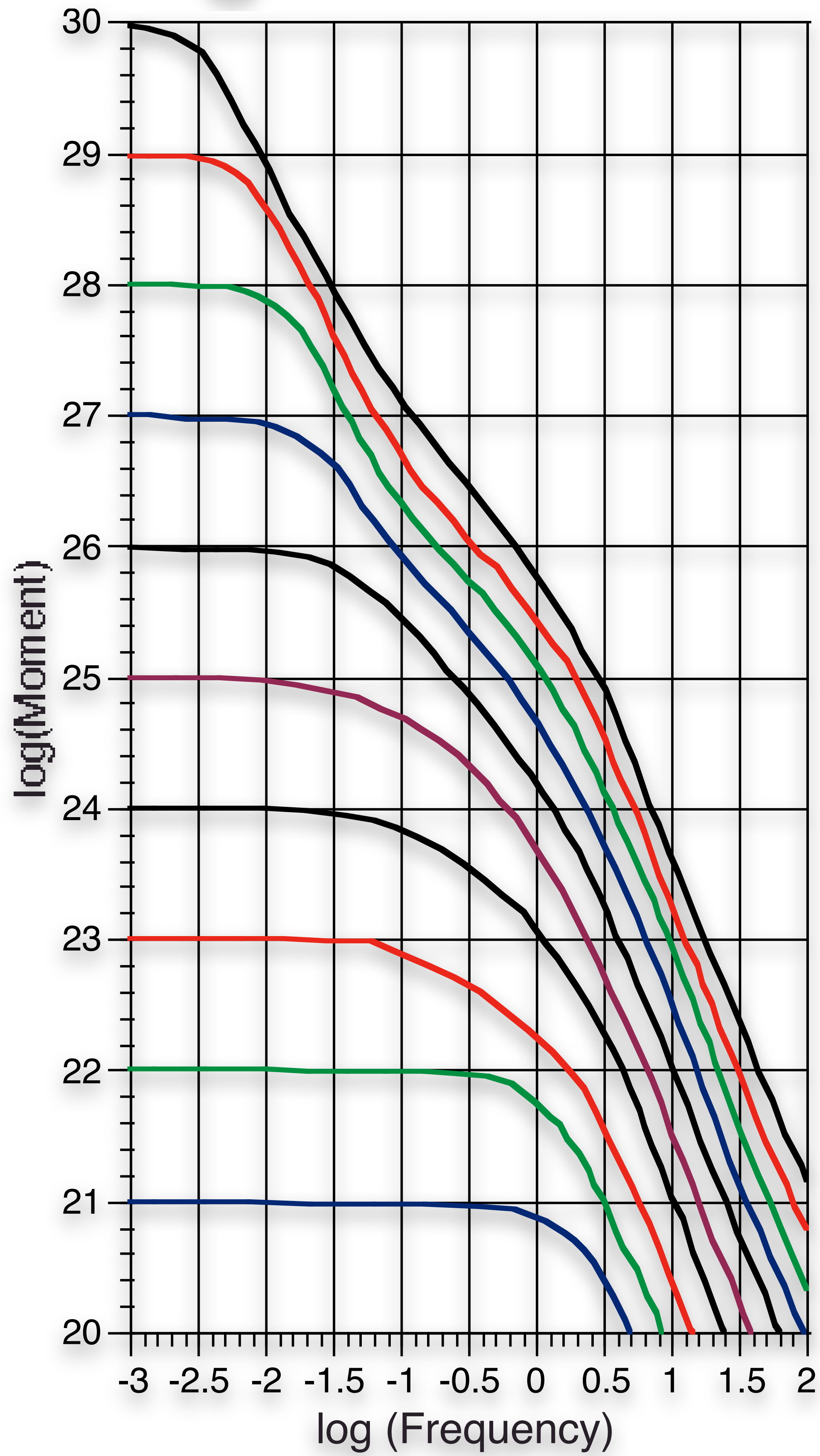
Regional Scale - Definition of Sources



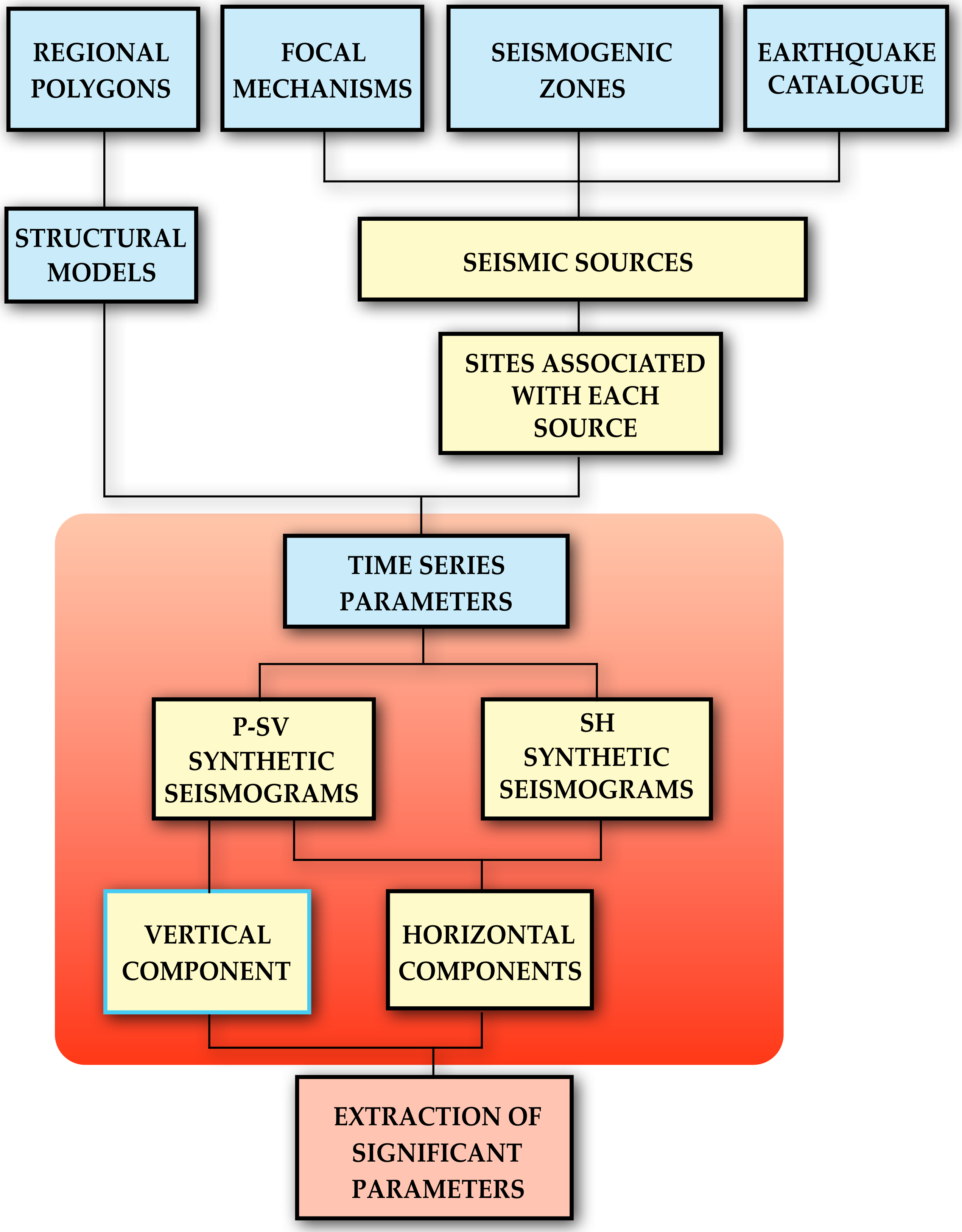


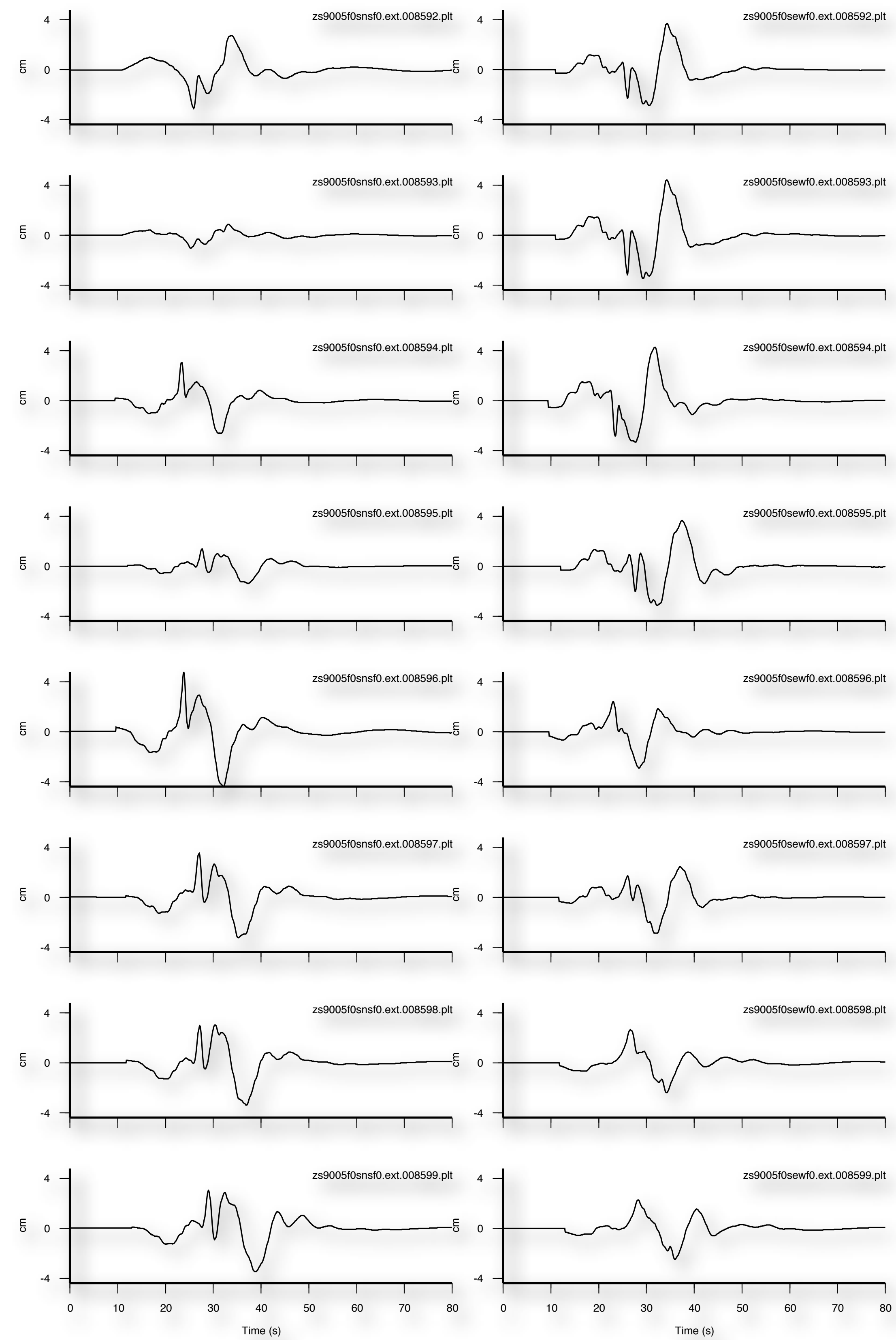
Regional Scale - Spectral scaling law

- The moment-magnitude relation by Kanamori (1977) is used
- At first synthetic seismograms are computed for a unitary scalar seismic moment
- Then they are scaled for magnitude in the frequency domain according to the spectral law by Gusev (1983) as reported in Aki (1987)

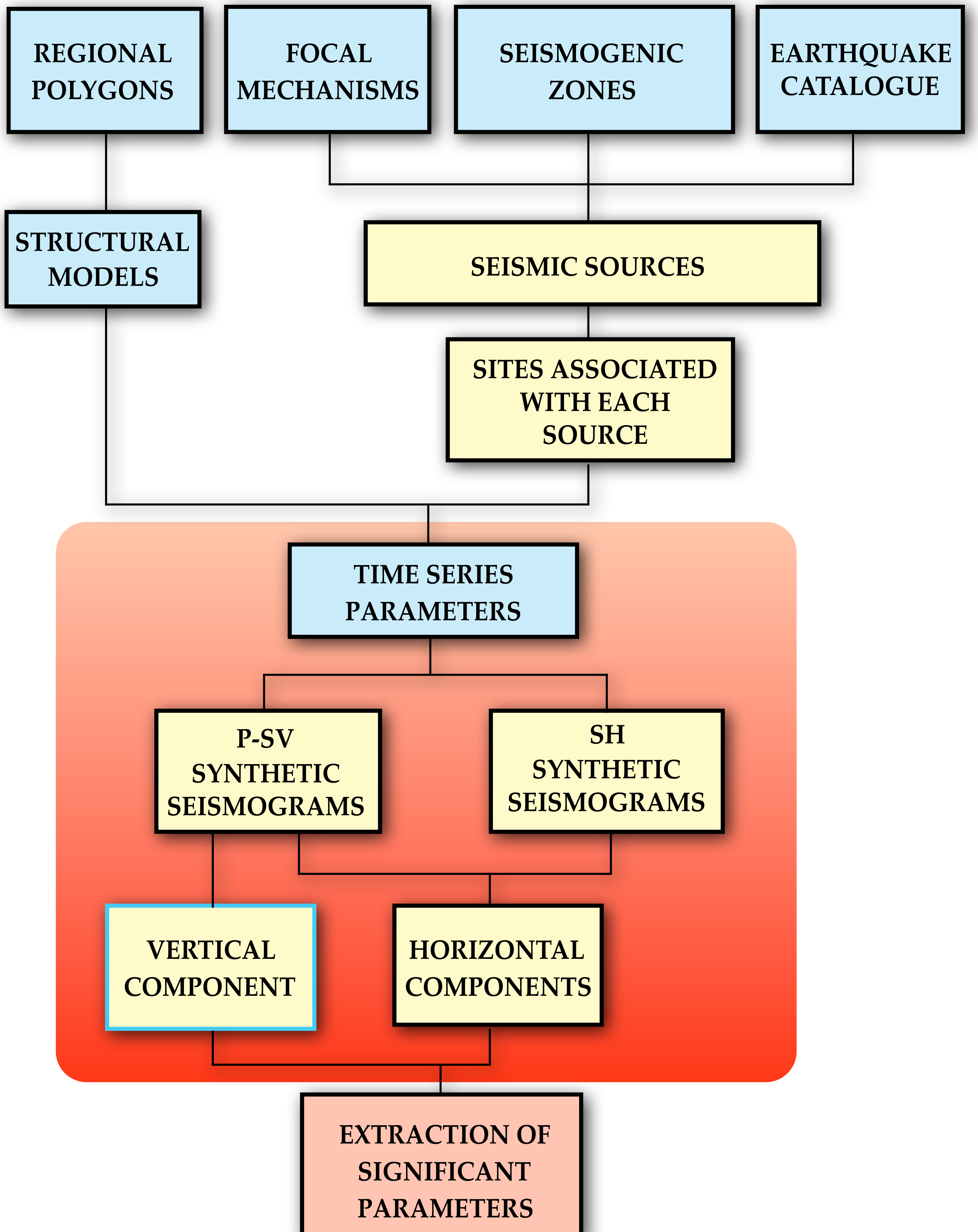


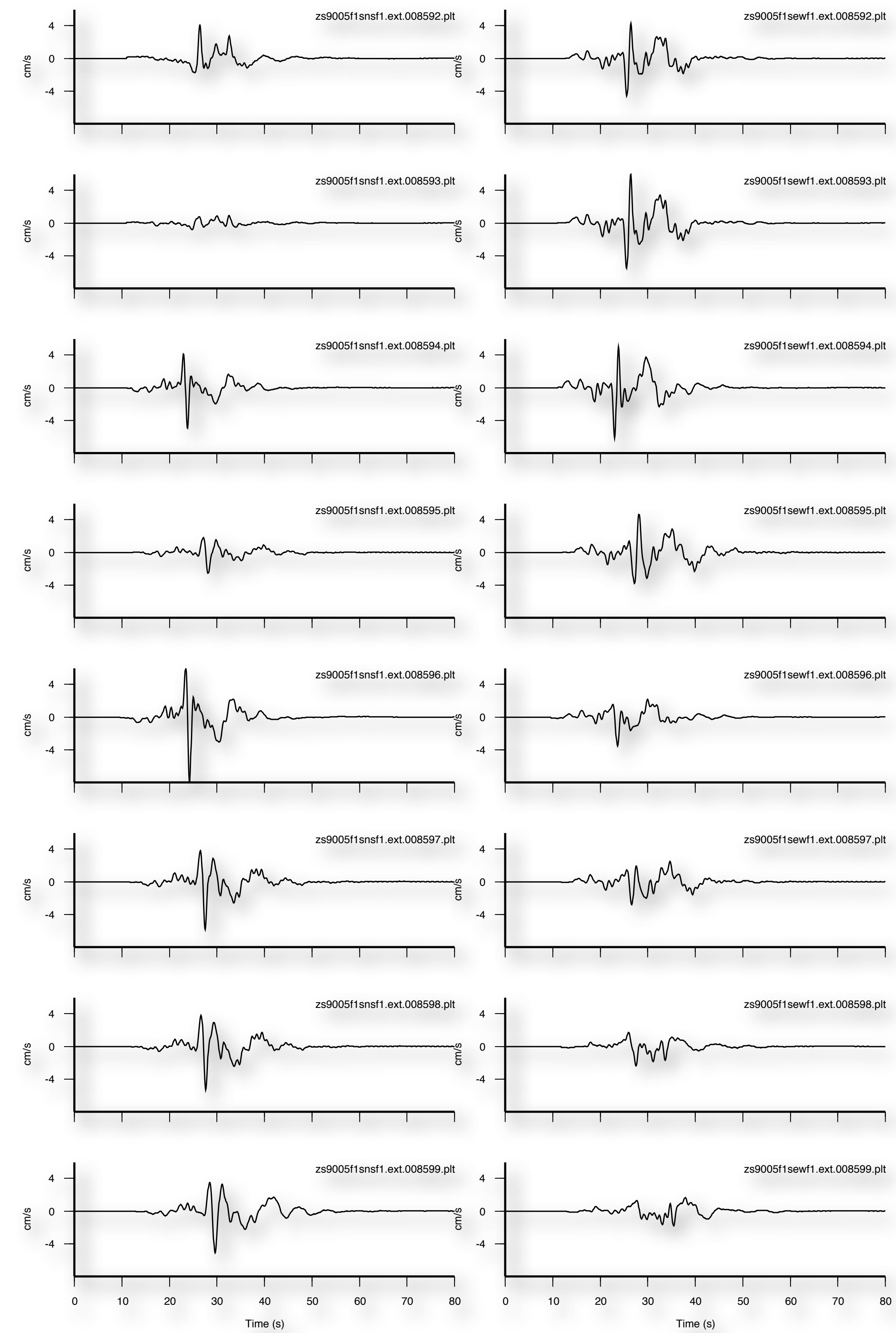
Regional Scale - Seismograms



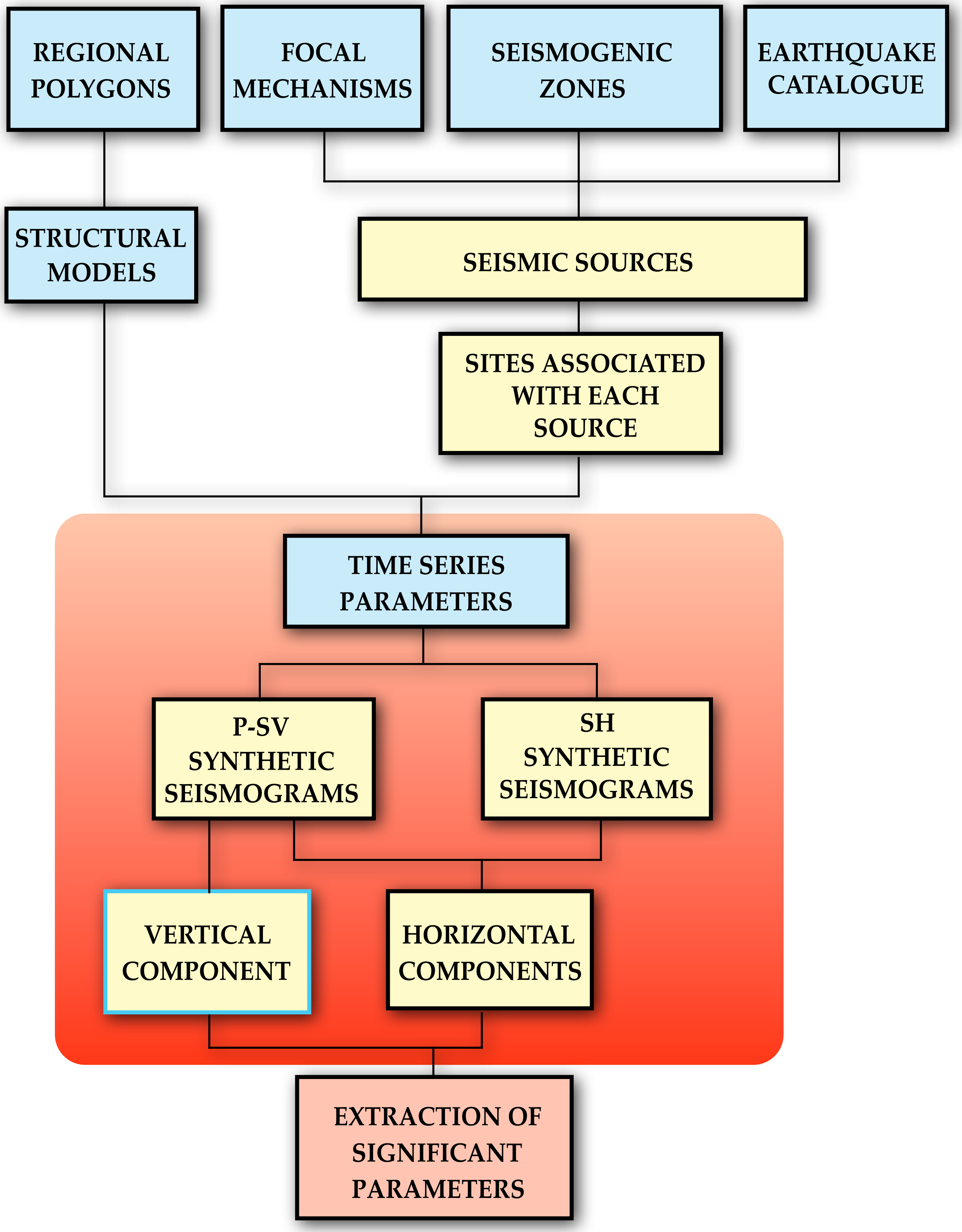


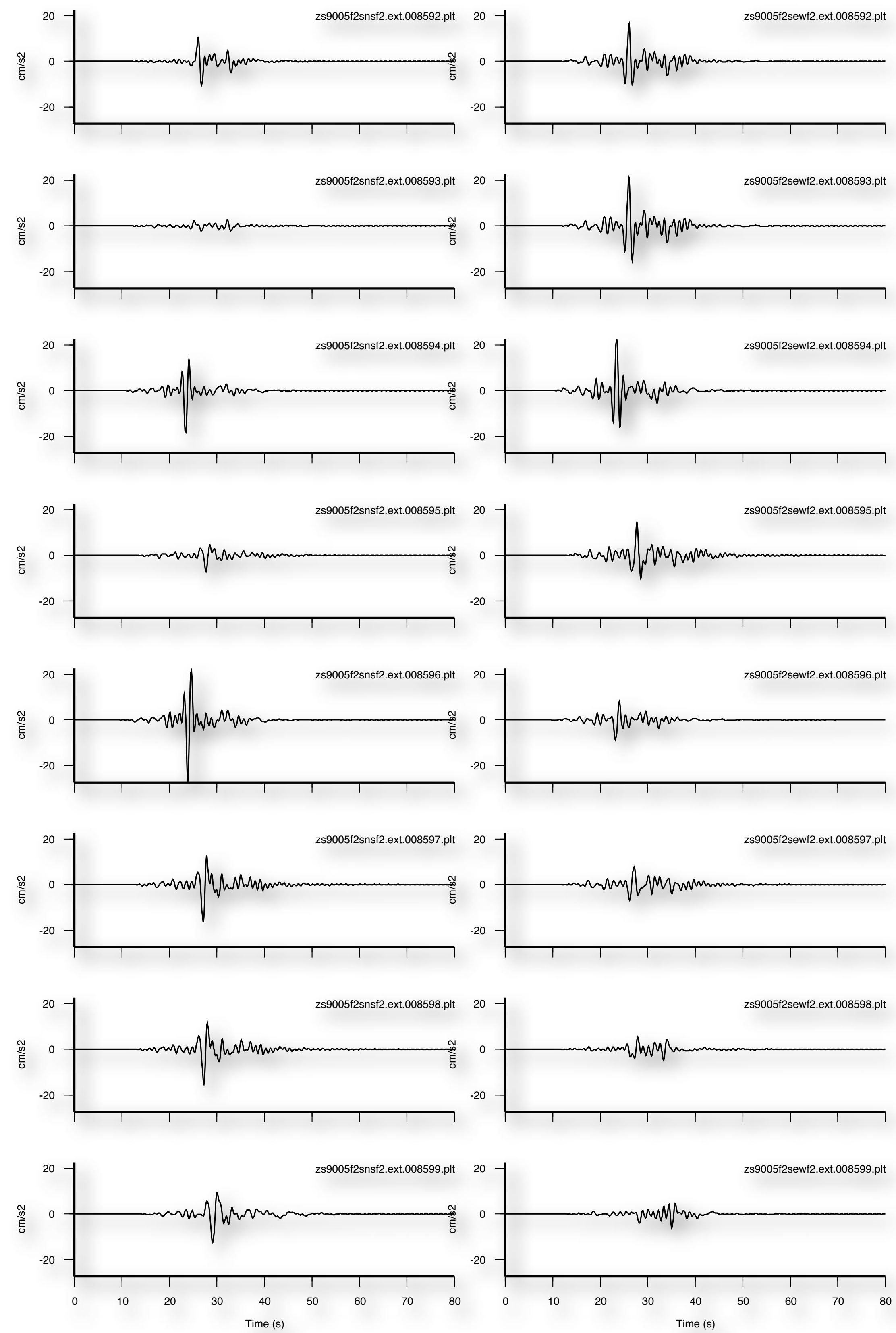
Regional Scale - Seismograms





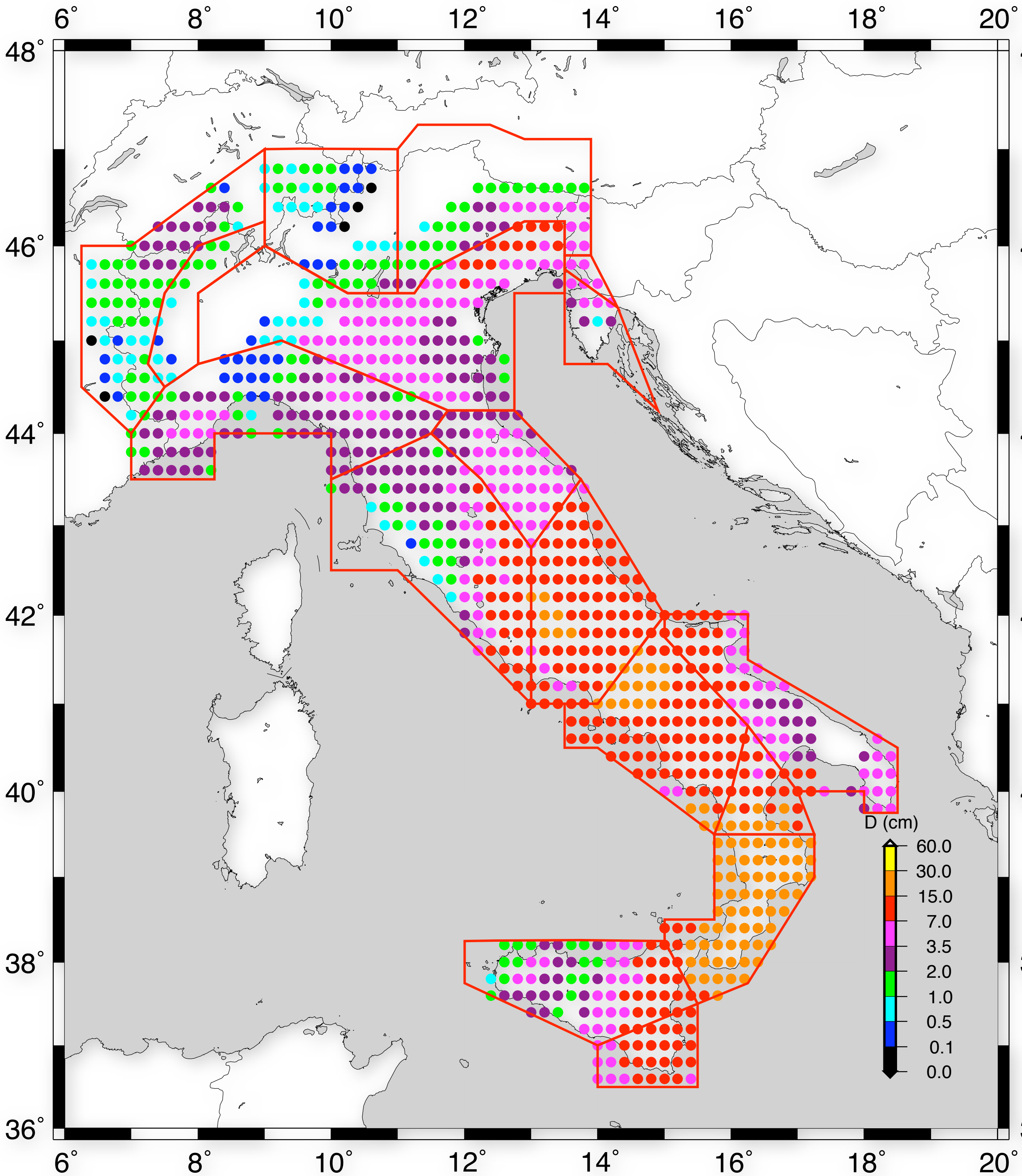
Regional Scale - Seismograms



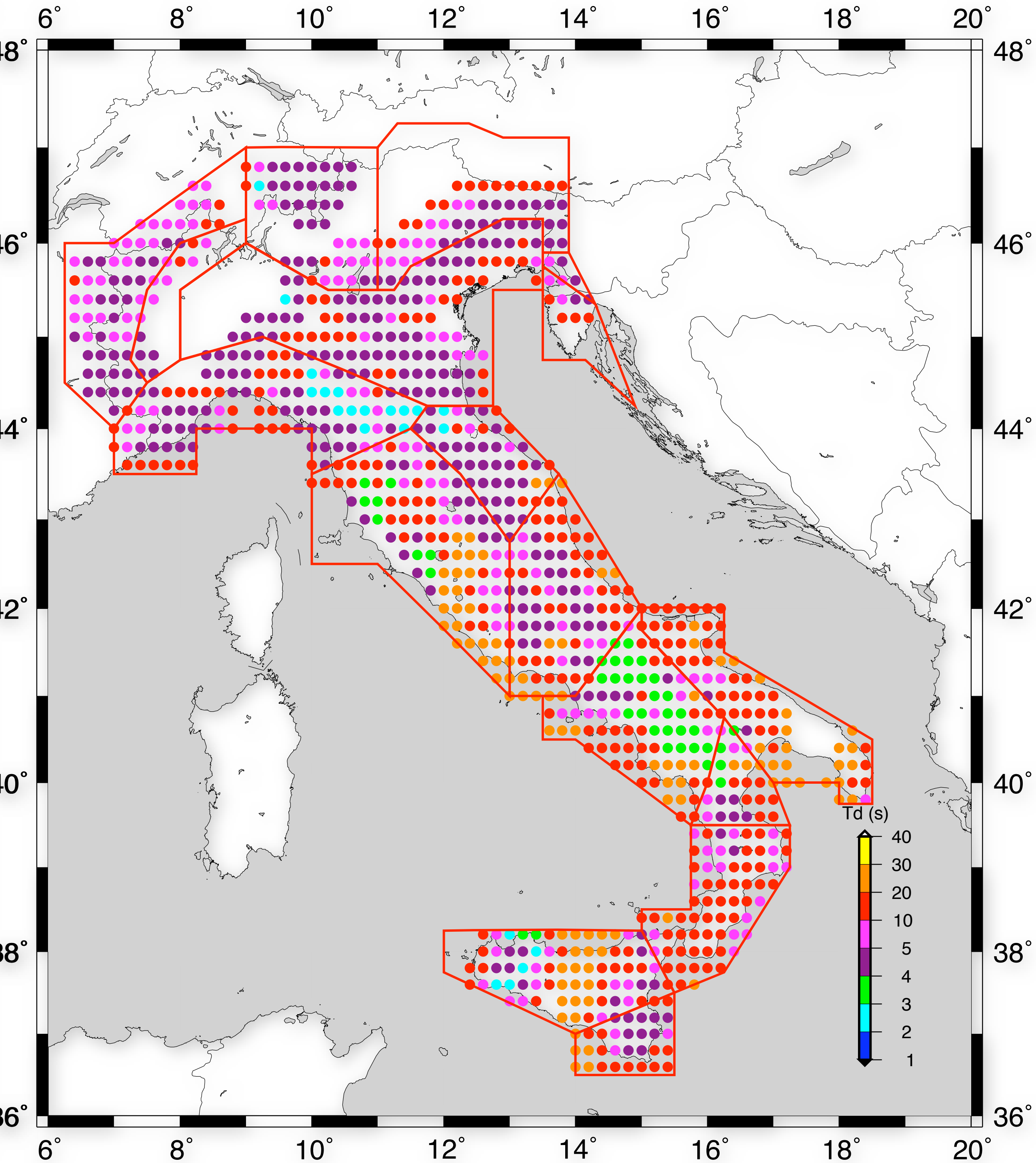


Displacement

Amplitude of Peaks from Time Series (1Hz)

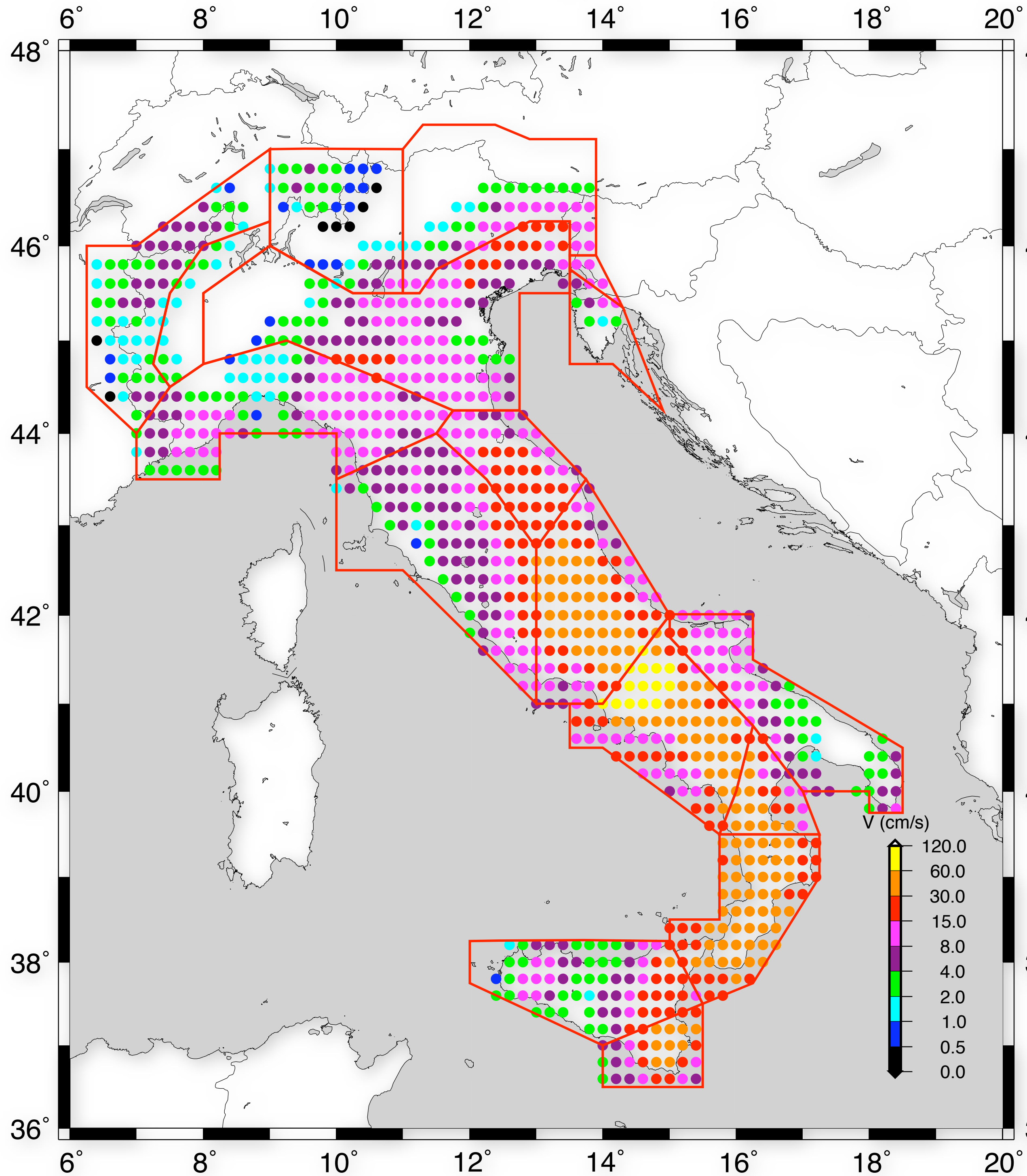


T of Peaks from Fourier Spectra

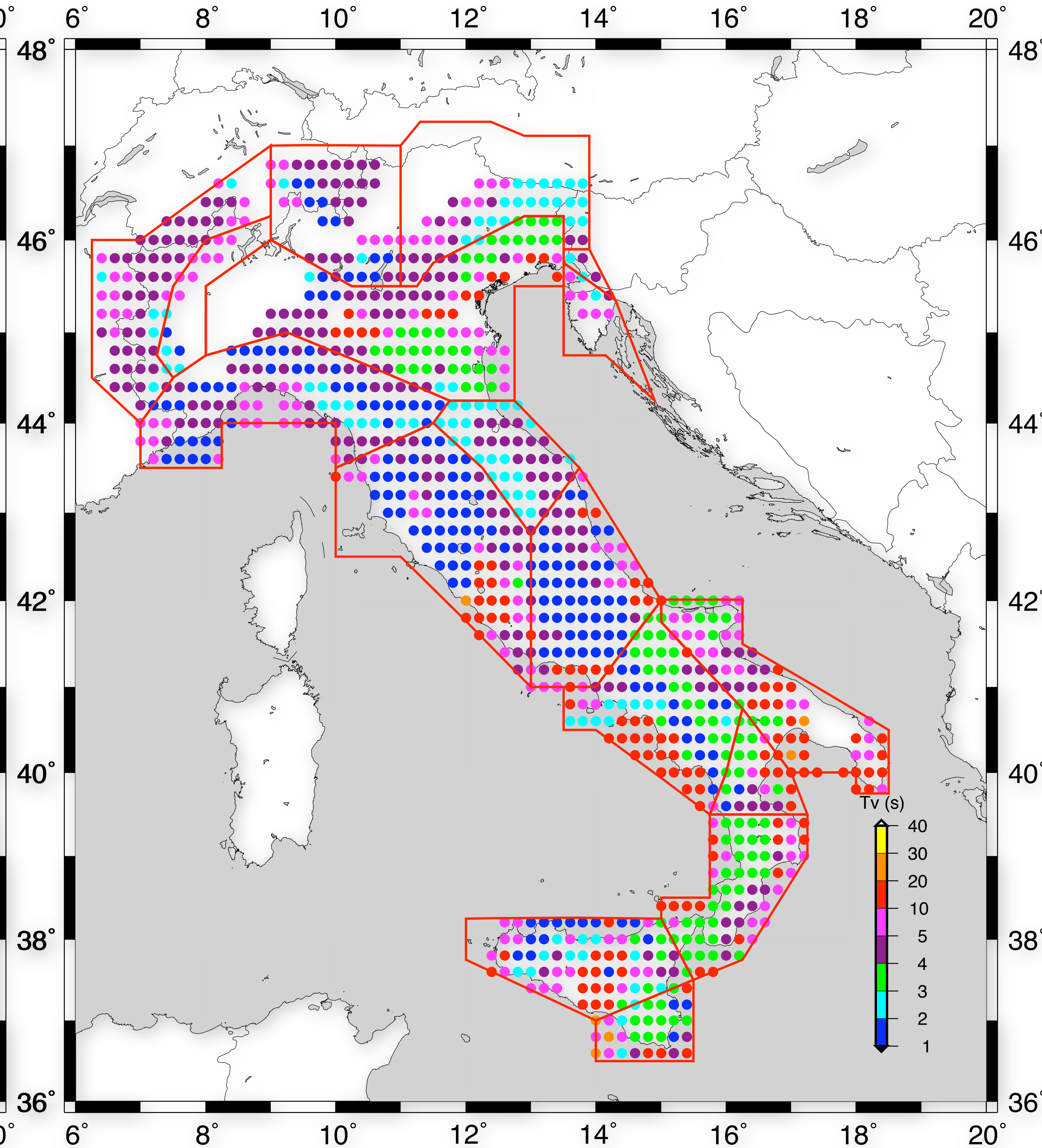


Velocity

Amplitude of Peaks from Time Series (1Hz)

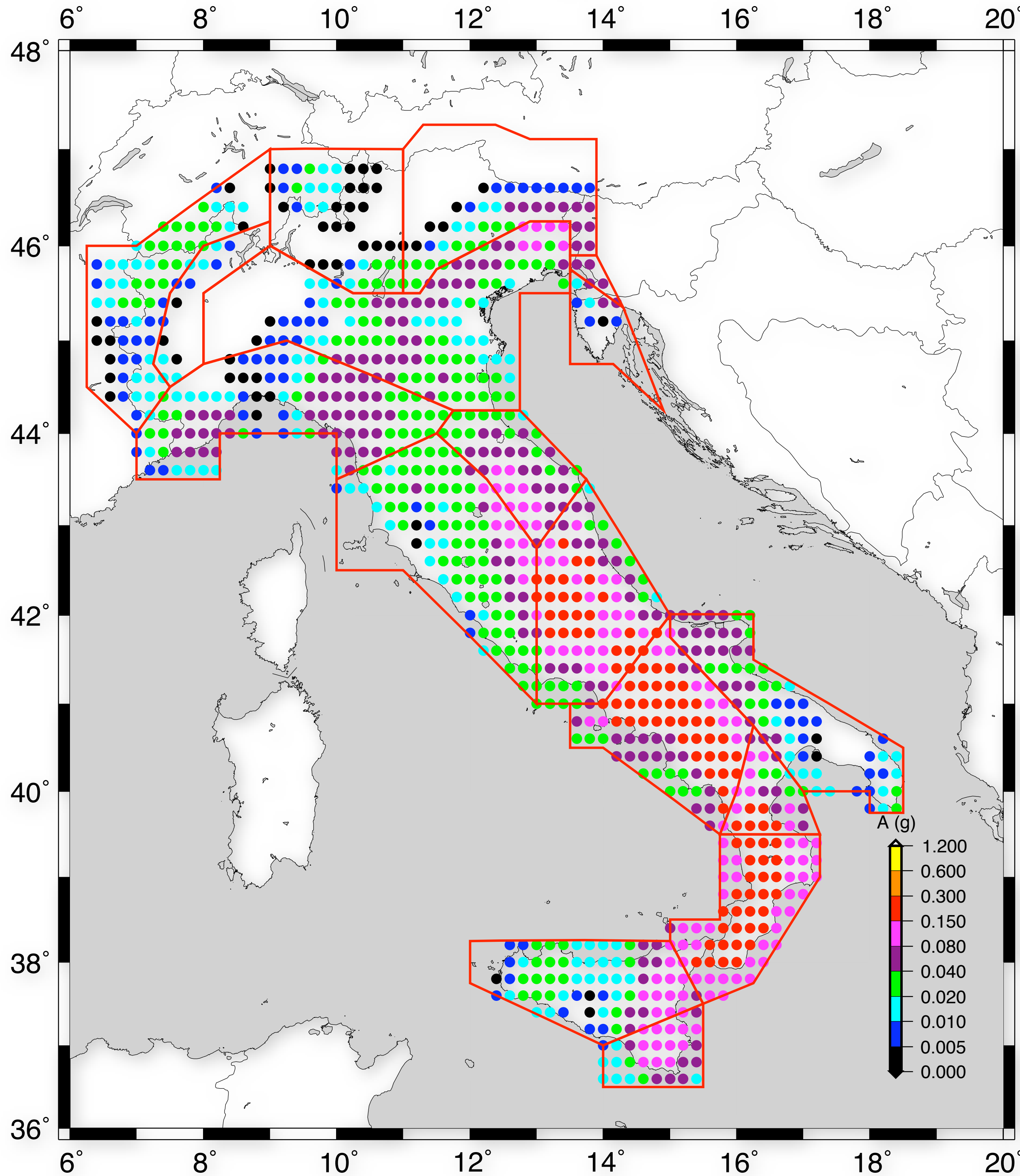


T of Peaks from Fourier Spectra

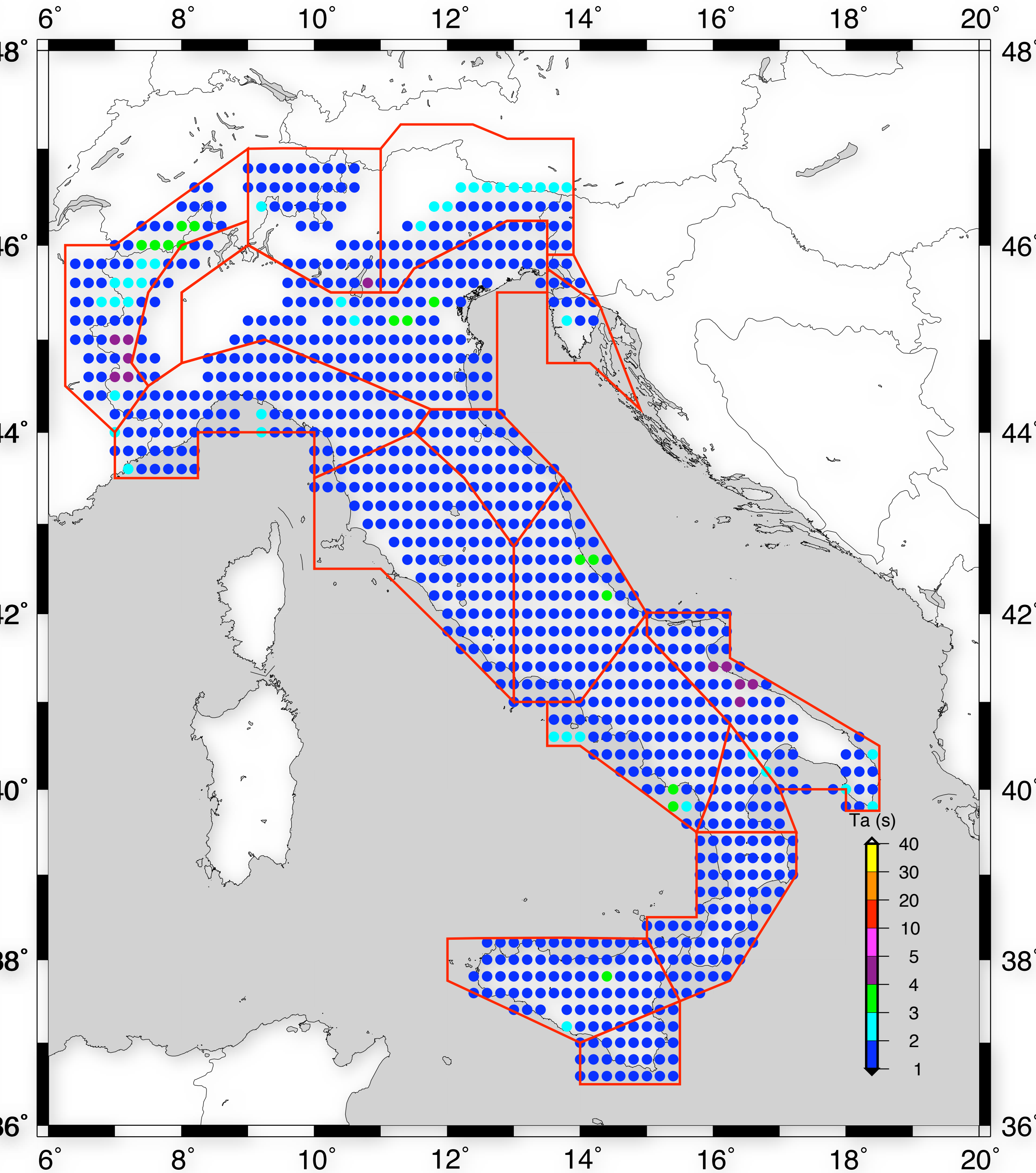


Acceleration

Amplitude of Peaks from Time Series (1Hz)

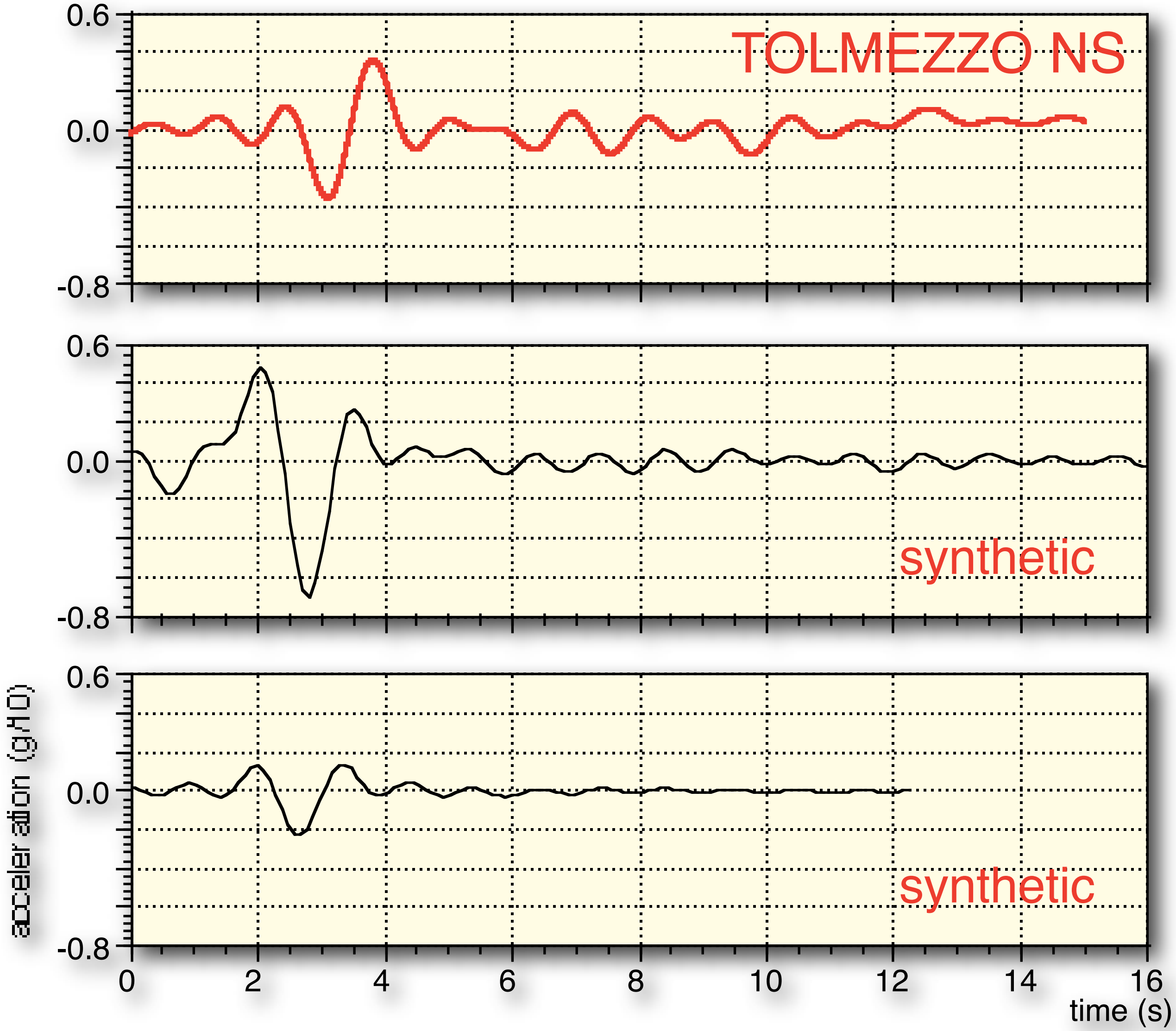


T of Peaks from Fourier Spectra



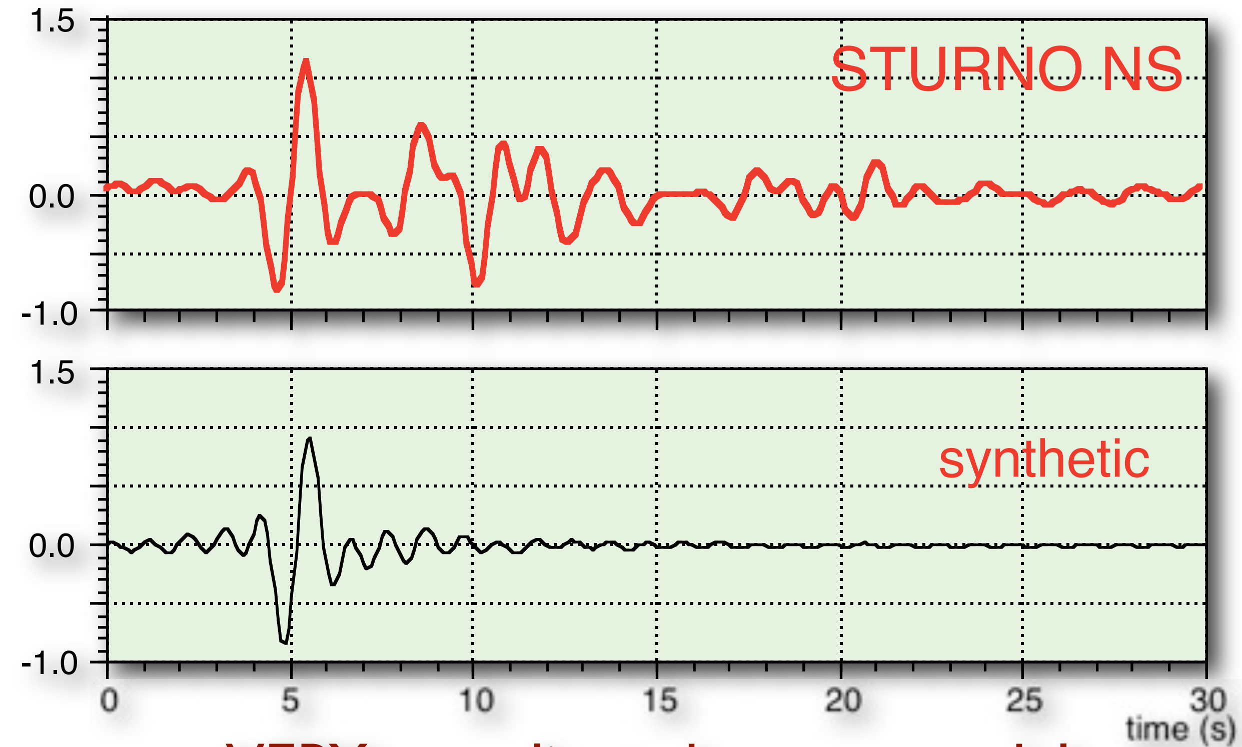
Regional Scale - Check (1 Hz cutoff)

Friuli, 6 May 1976 (North-Eastern Italy)



Comparison with two grid nodes close to the Tolmezzo station

Irpinia, 23 October 1980 (Southern Italy)

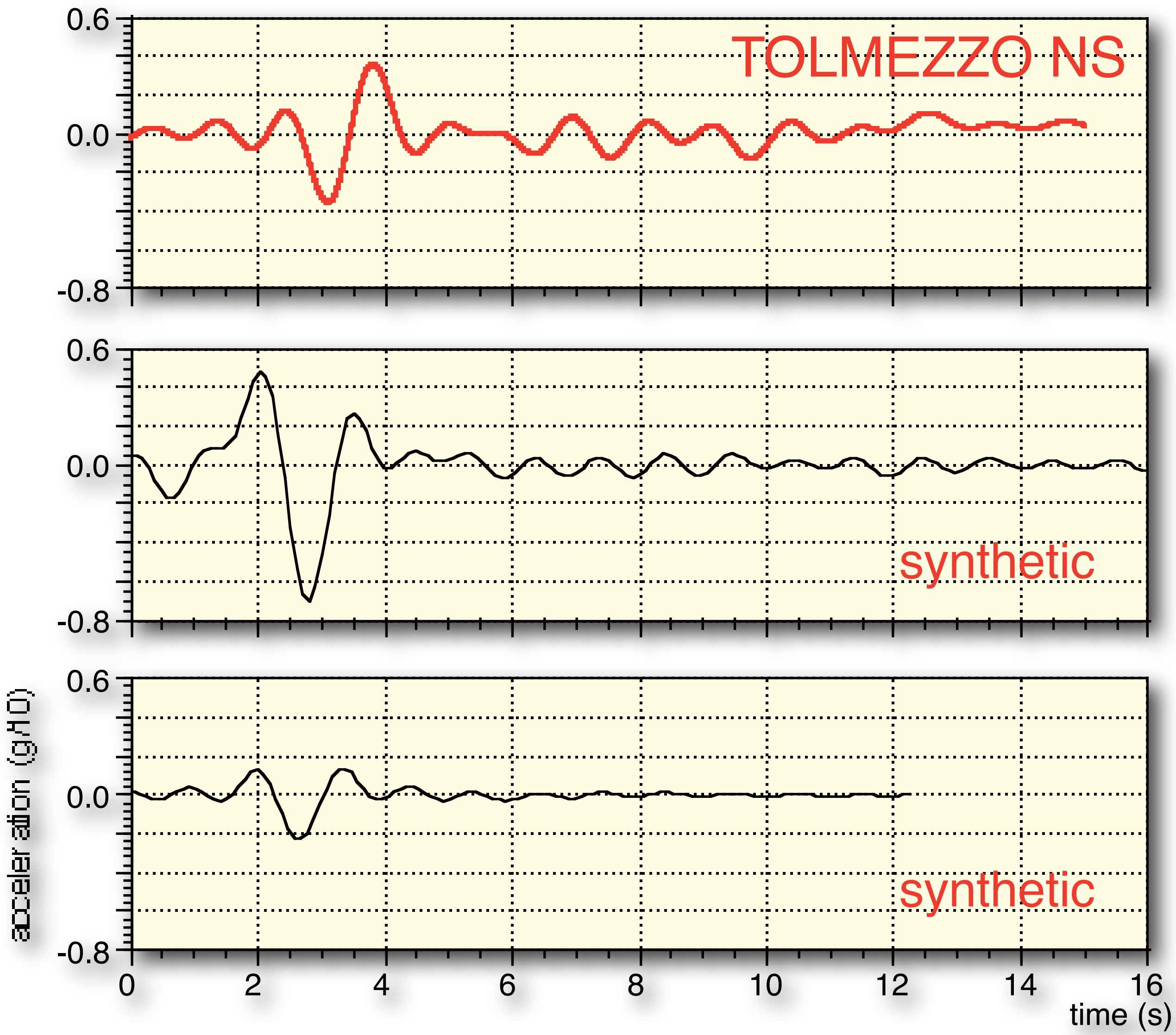


VERY complicated source model

Point-source inadequate to reproduce duration, but peak value is OK

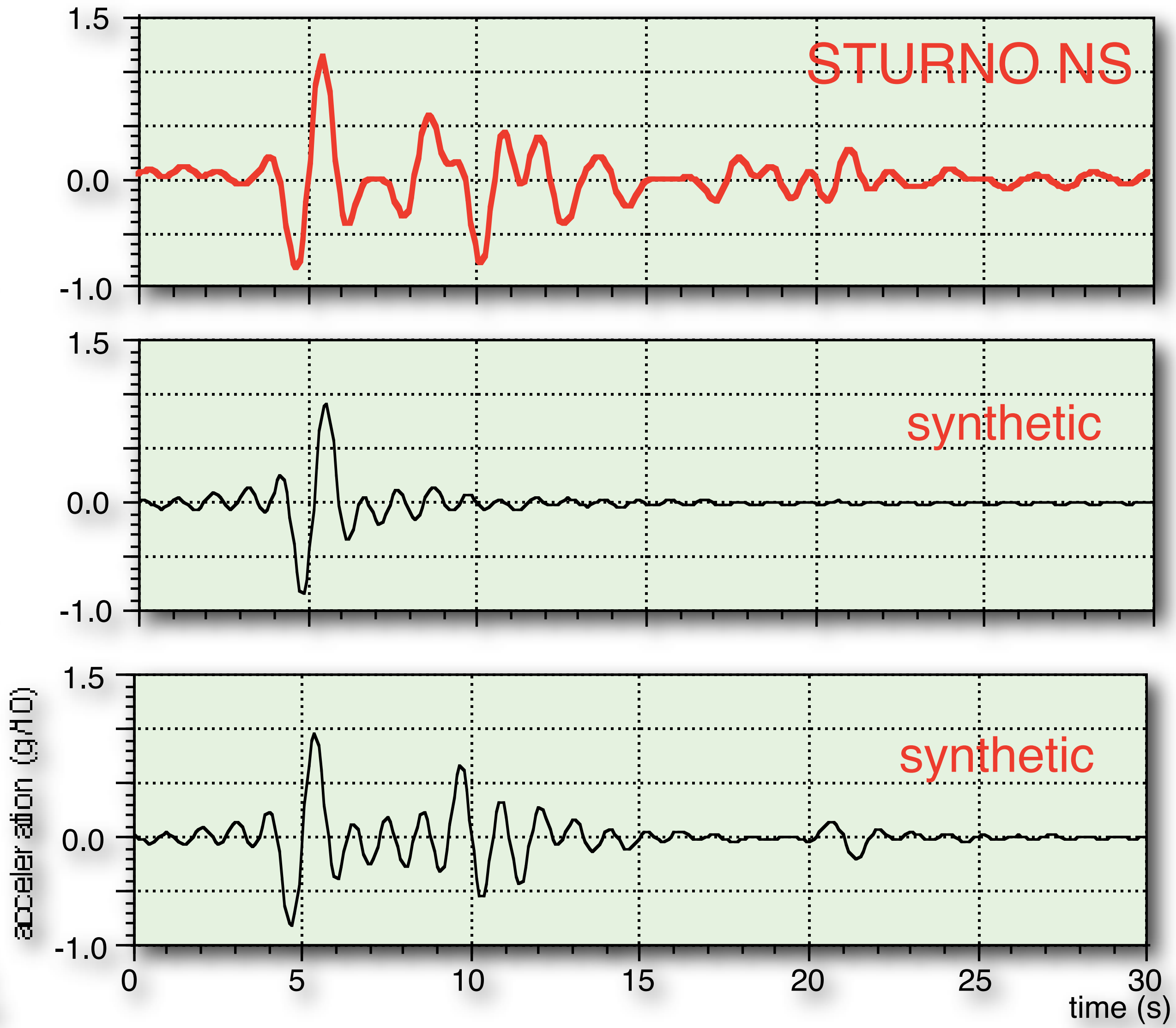
Regional Scale - Check (1 Hz cutoff)

Friuli, 6 May 1976 (North-Eastern Italy)



Comparison with two grid nodes close to the Tolmezzo station

Irpinia, 23 October 1980 (Southern Italy)

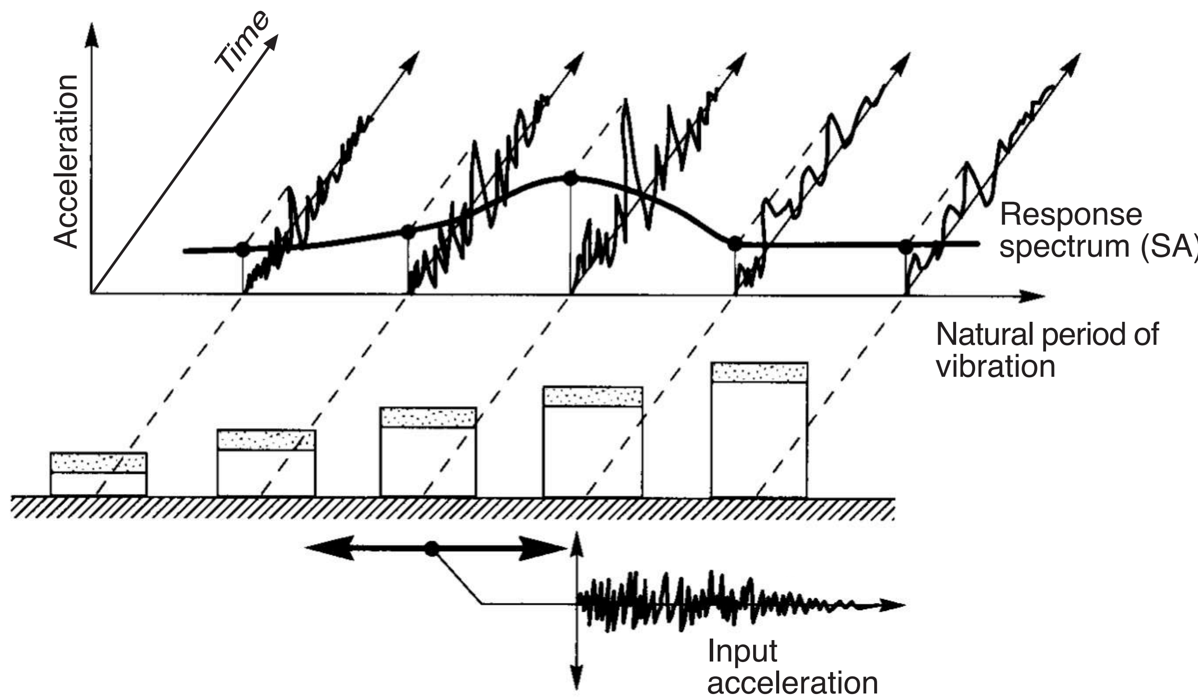


With a sequence of point sources the duration can be reproduced but this is deliberately neglected since rupturing process is not known a priori

Design Ground Acceleration (DGA)

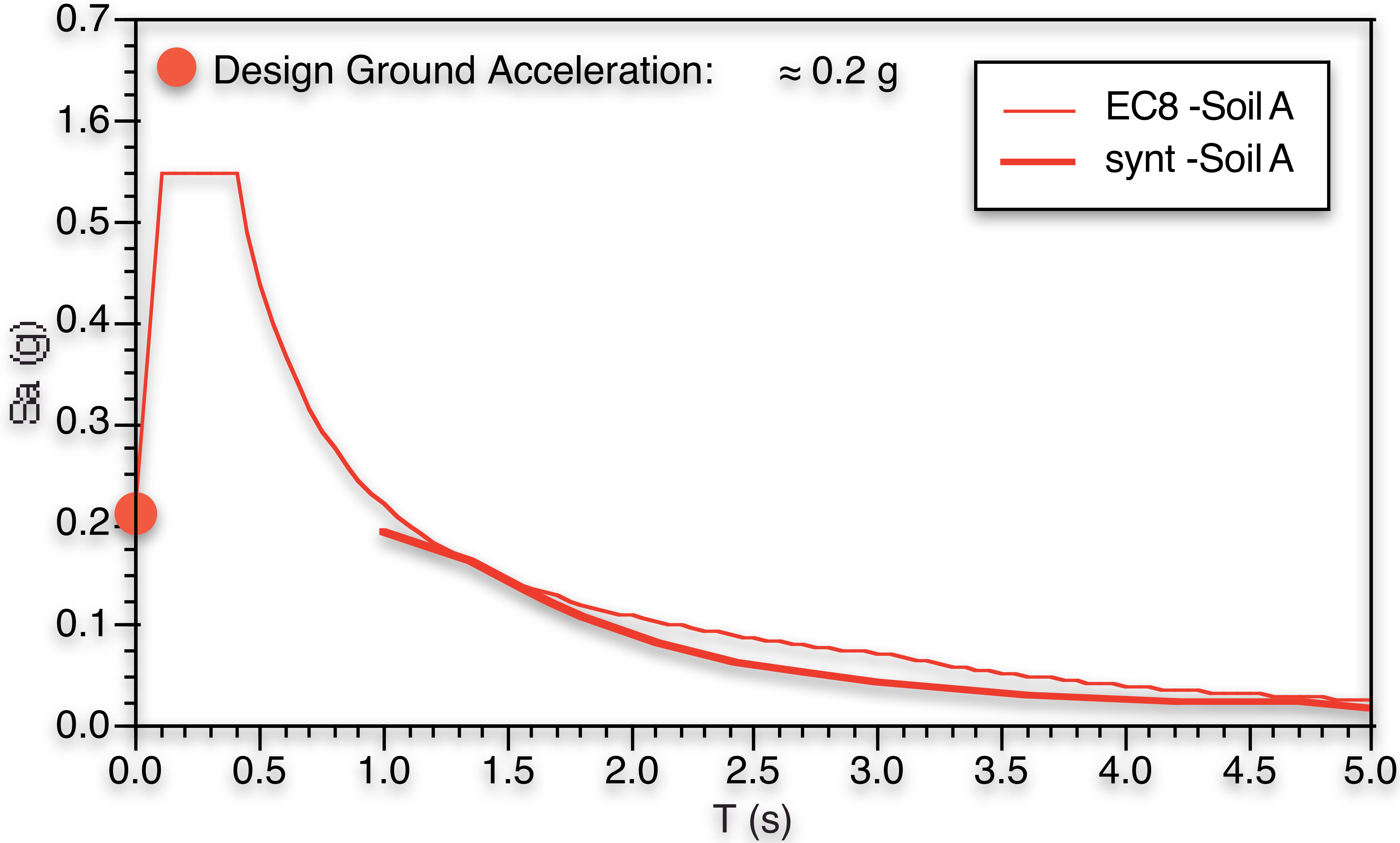
- To obtain an estimate of PGA, overcoming the 1 Hz limitation chosen in the modelling, the shape of Design Spectra can be used

Response Spectrum



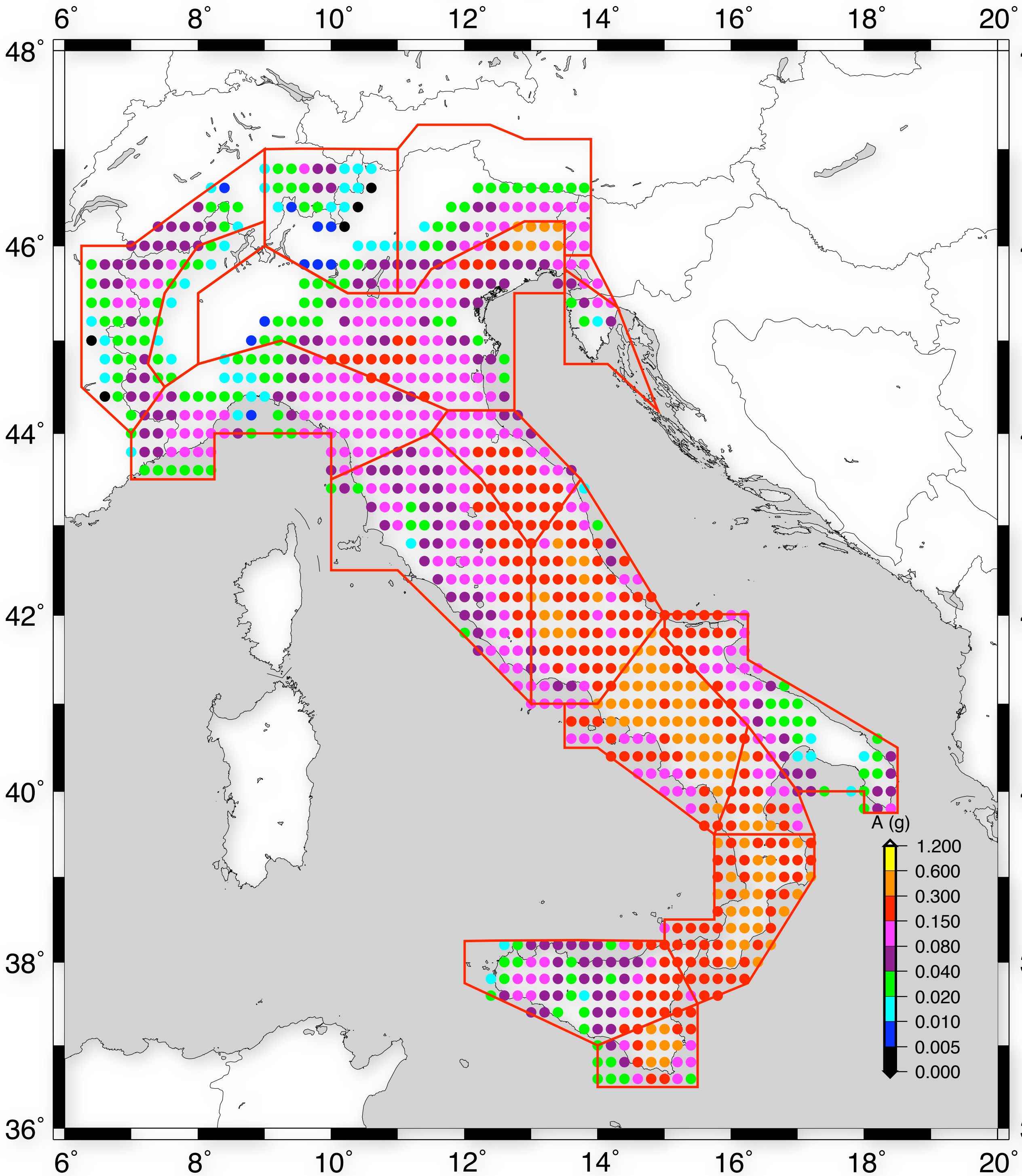
Design Ground Acceleration (DGA)

- To obtain an estimate of PGA, overcoming the 1 Hz limitation chosen in the modelling, the shape of Design Spectra can be used

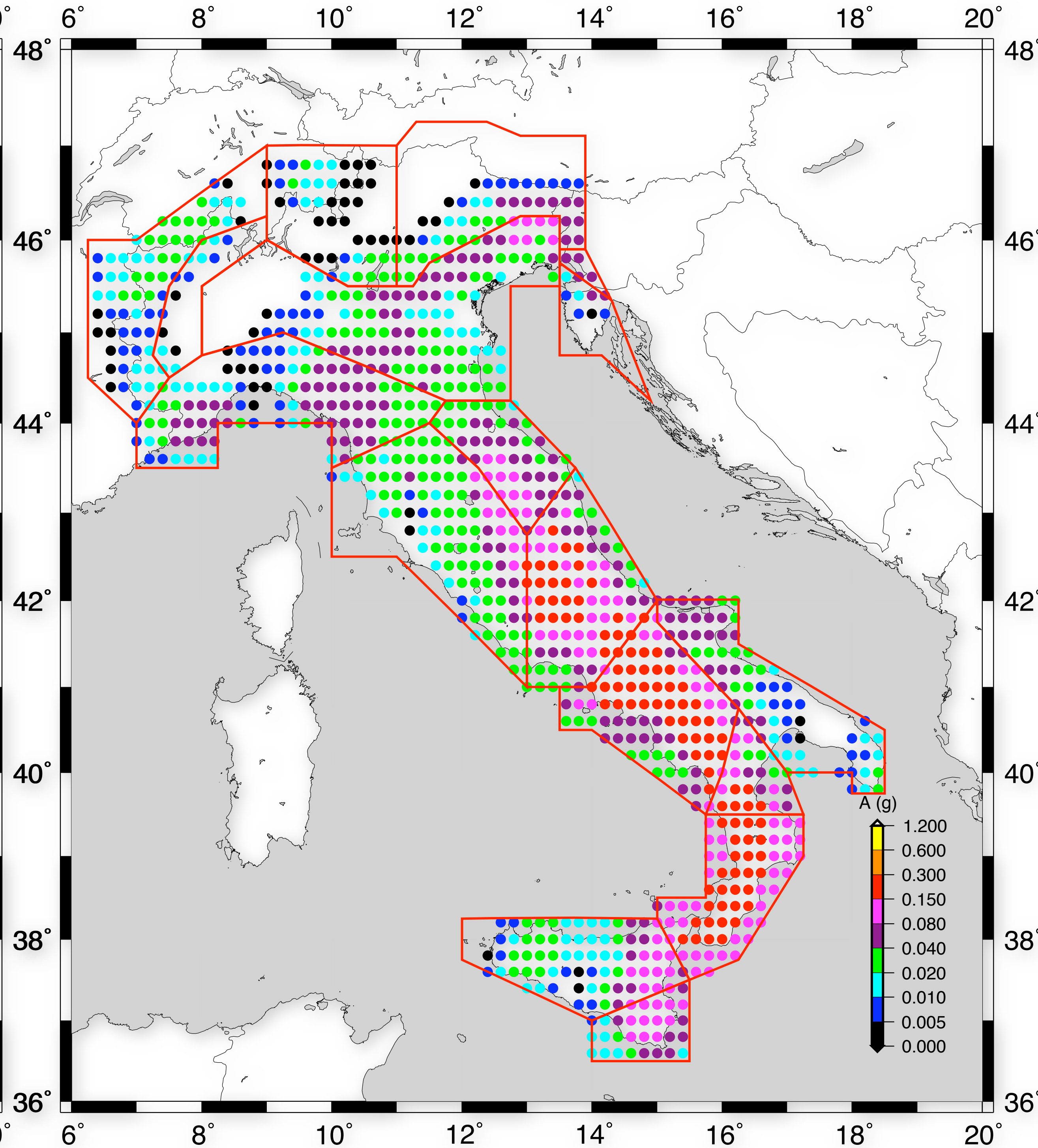


Acceleration

DGA Extrapolated by Means of Design Spectrum

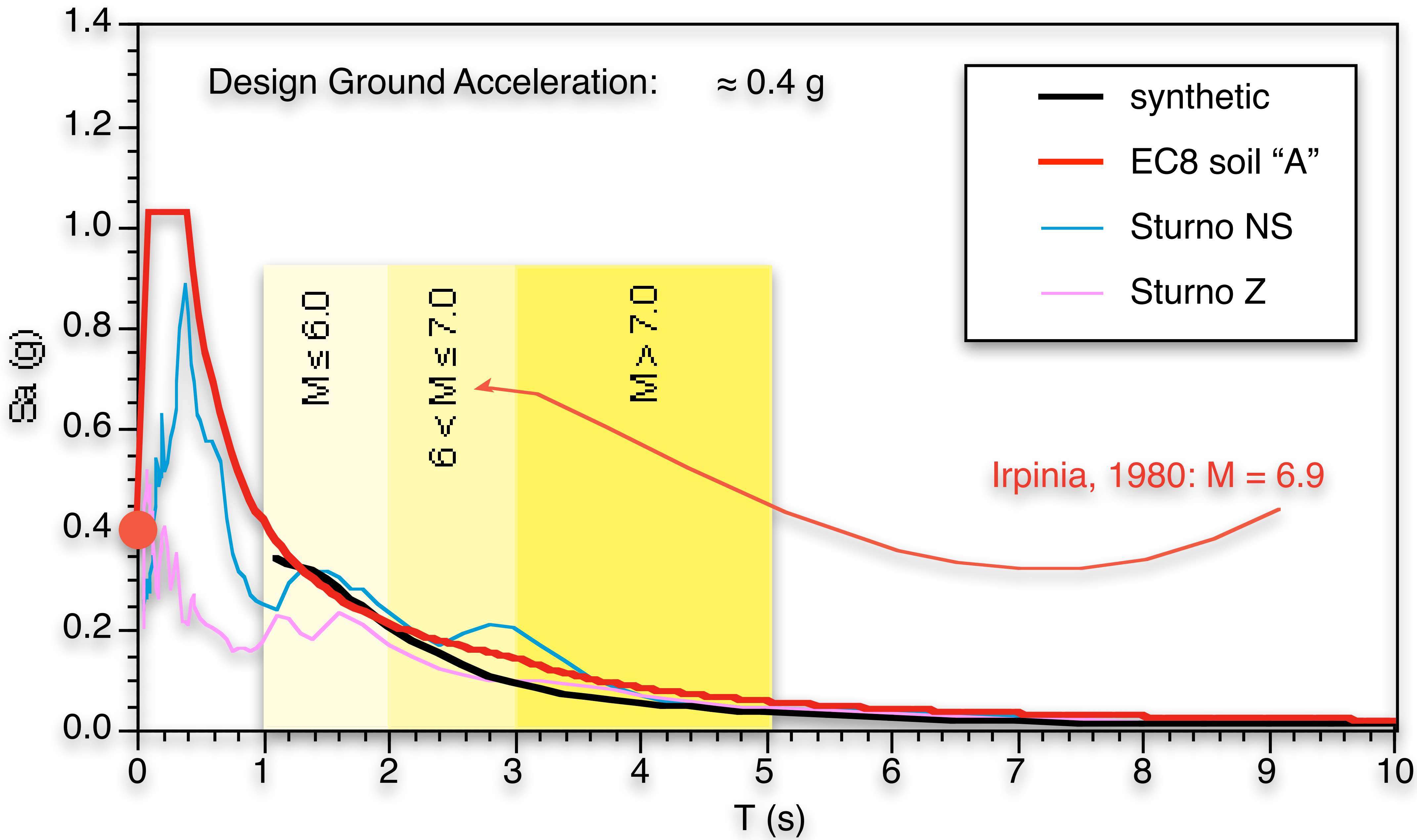


Amplitude of Peaks from Time Series (1Hz)



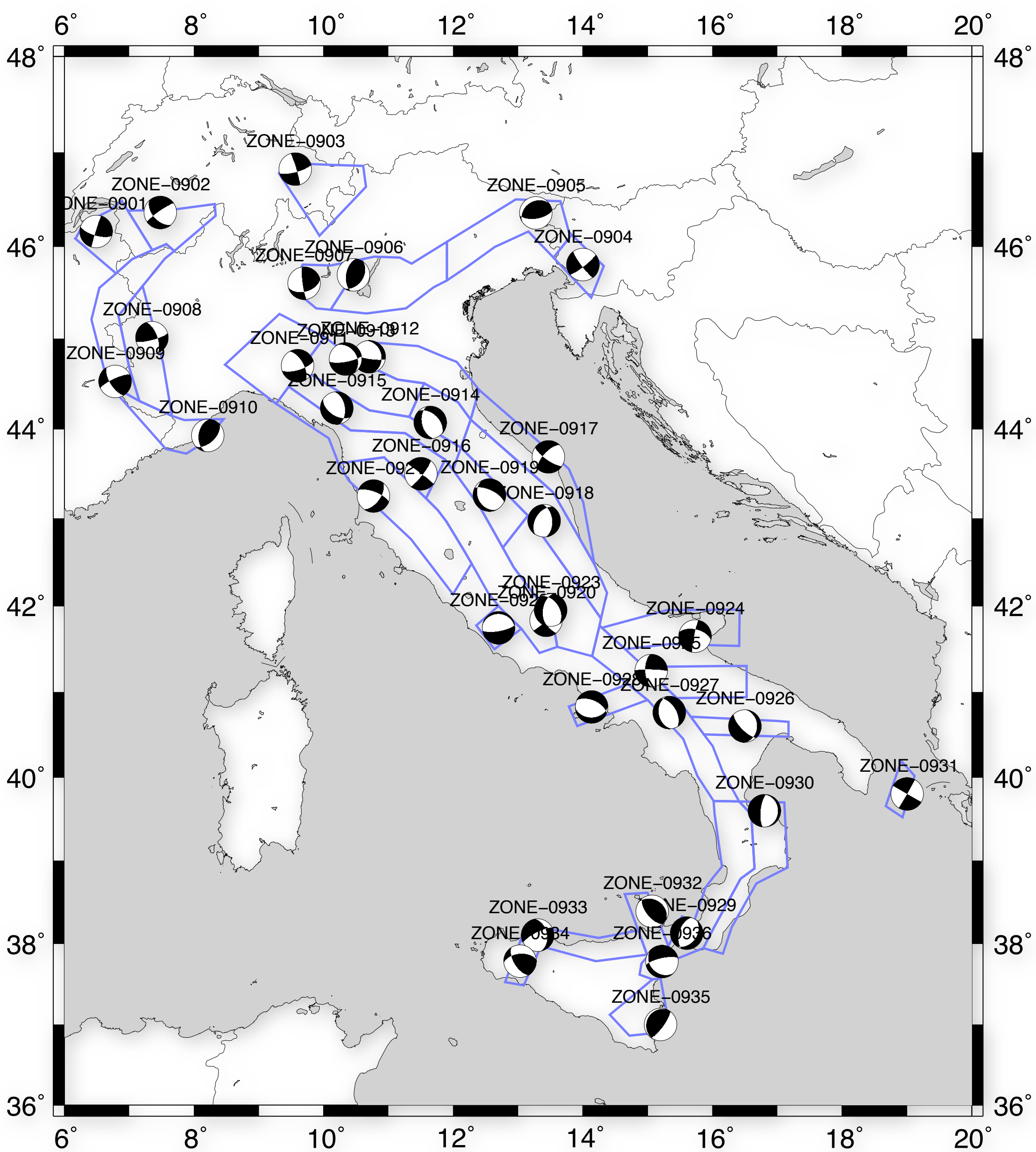
Design Ground Acceleration (DGA)

- The procedure gives good results when applied to the case of the Irpinia 1980 earthquake. The DGA predicted by the modelling is similar the actual DGA obtained from recordings

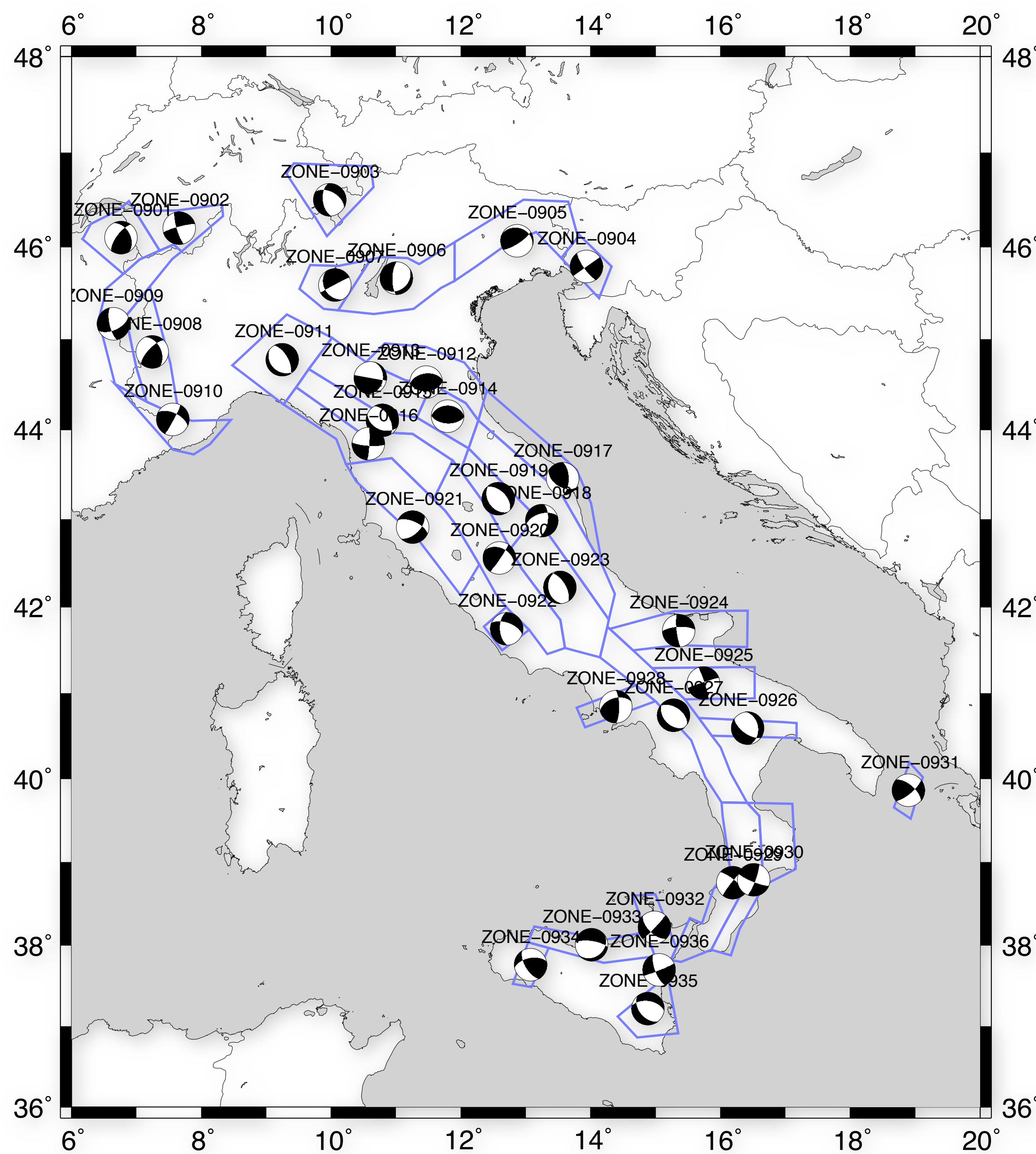


Parametric Test on Source Mechanism

Automatic Average

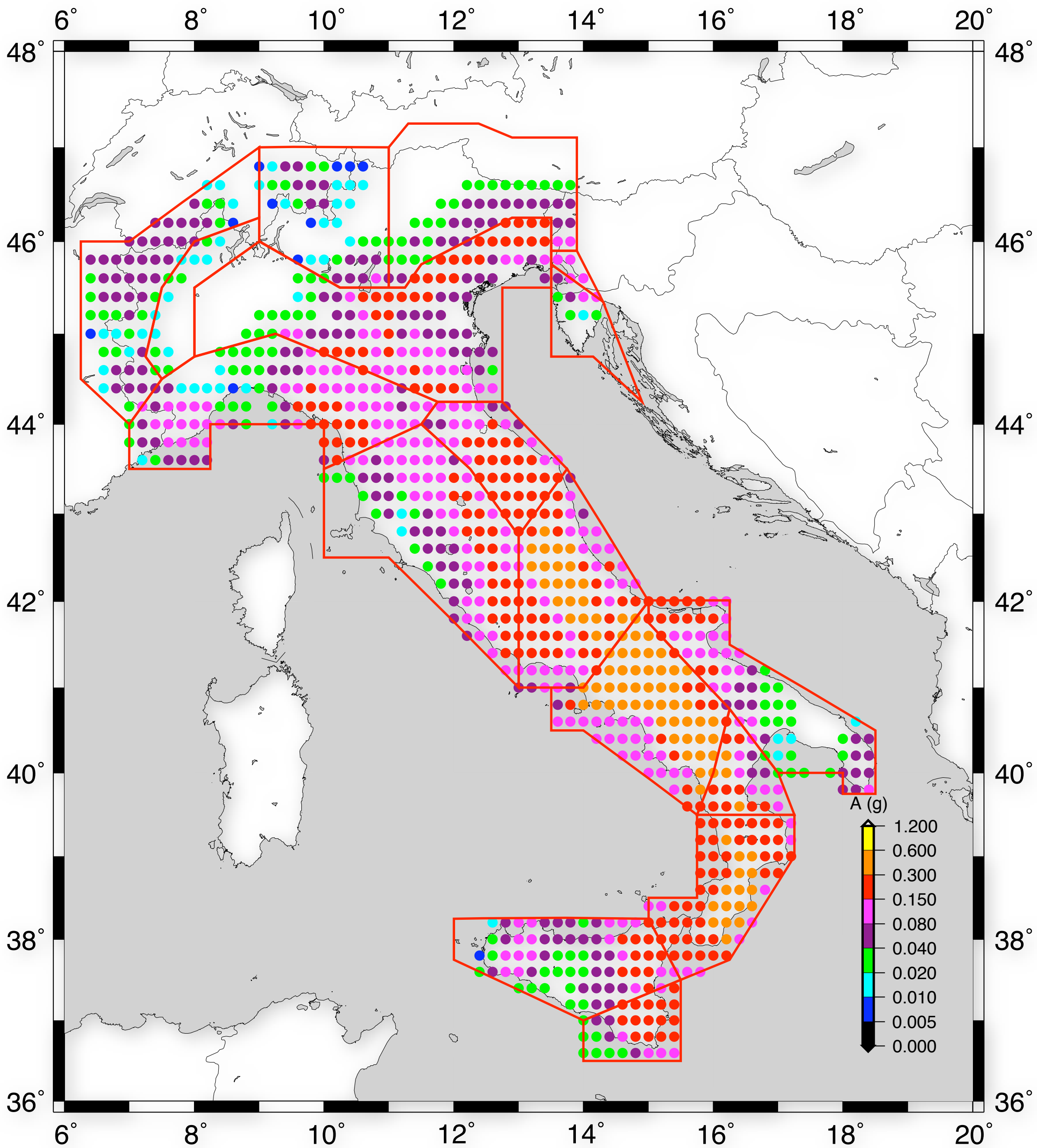


Expert's Choice

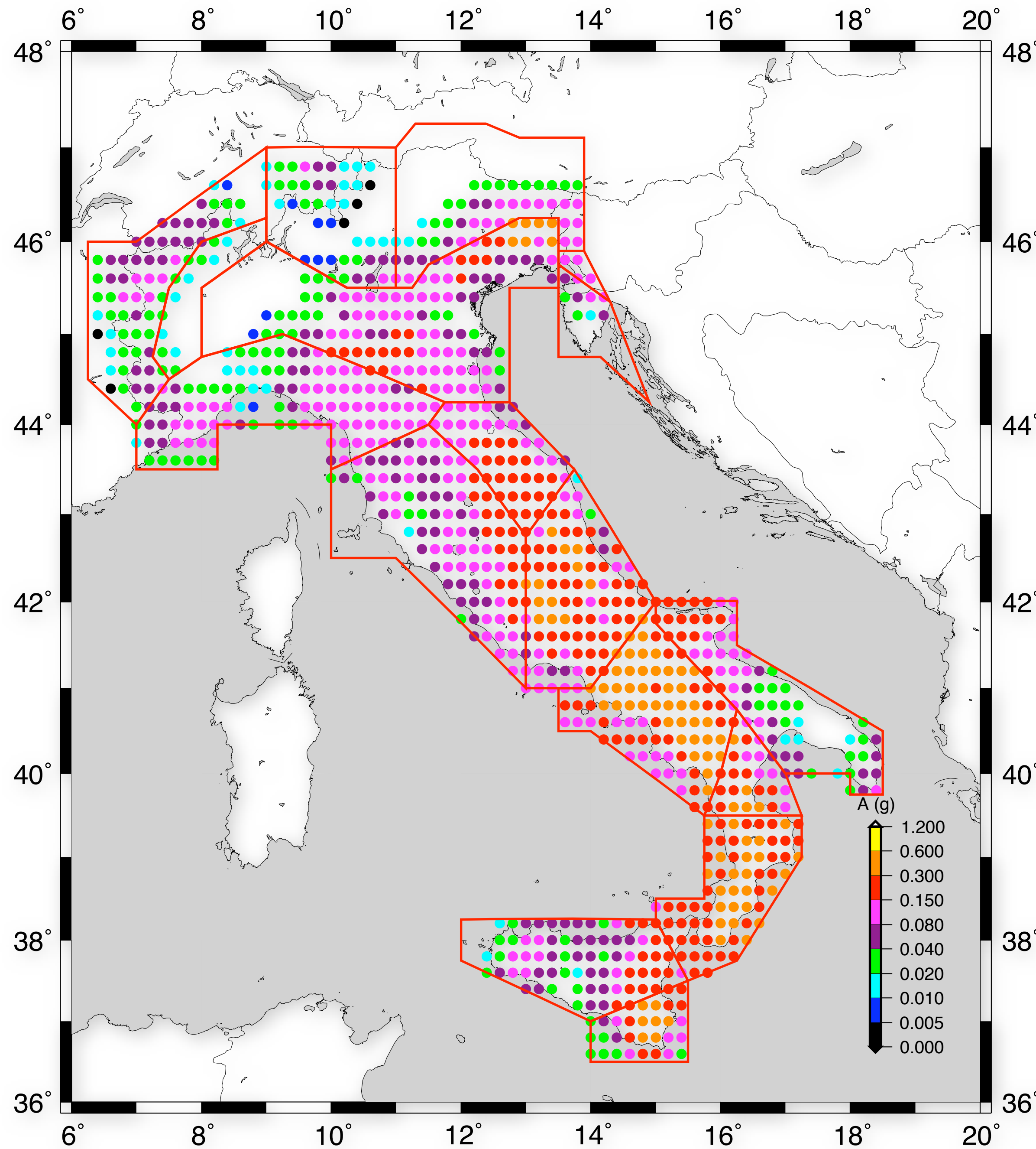


Parametric Test on Source Mechanism

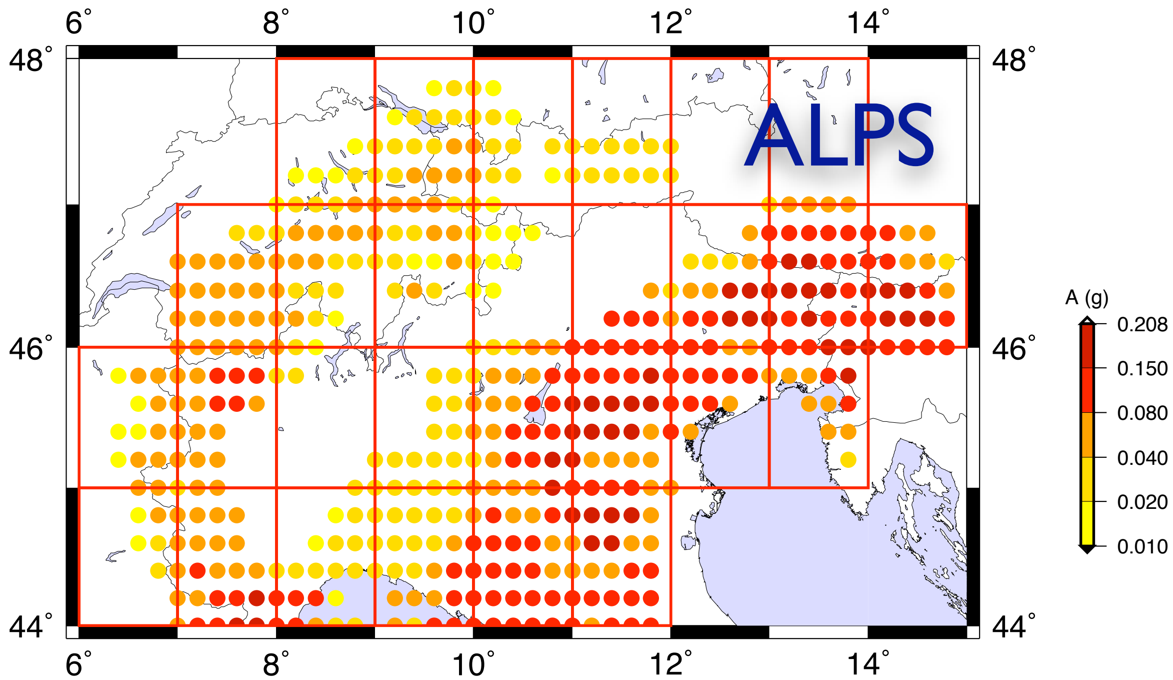
Automatic Average

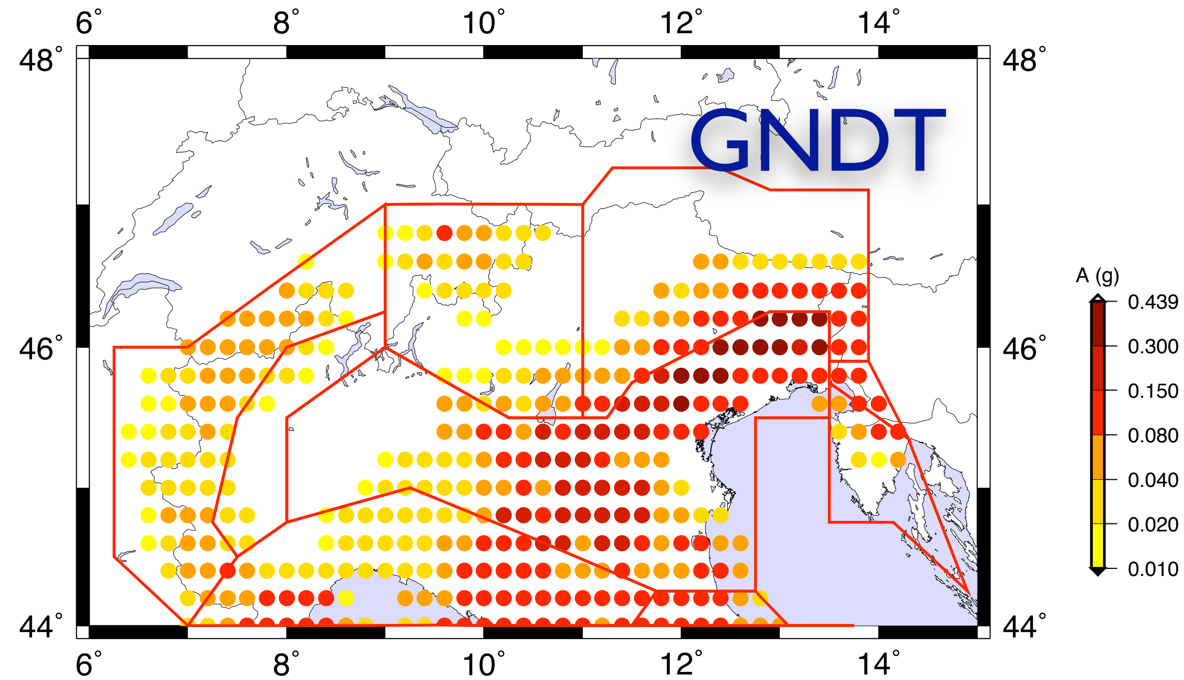


Expert's Choice

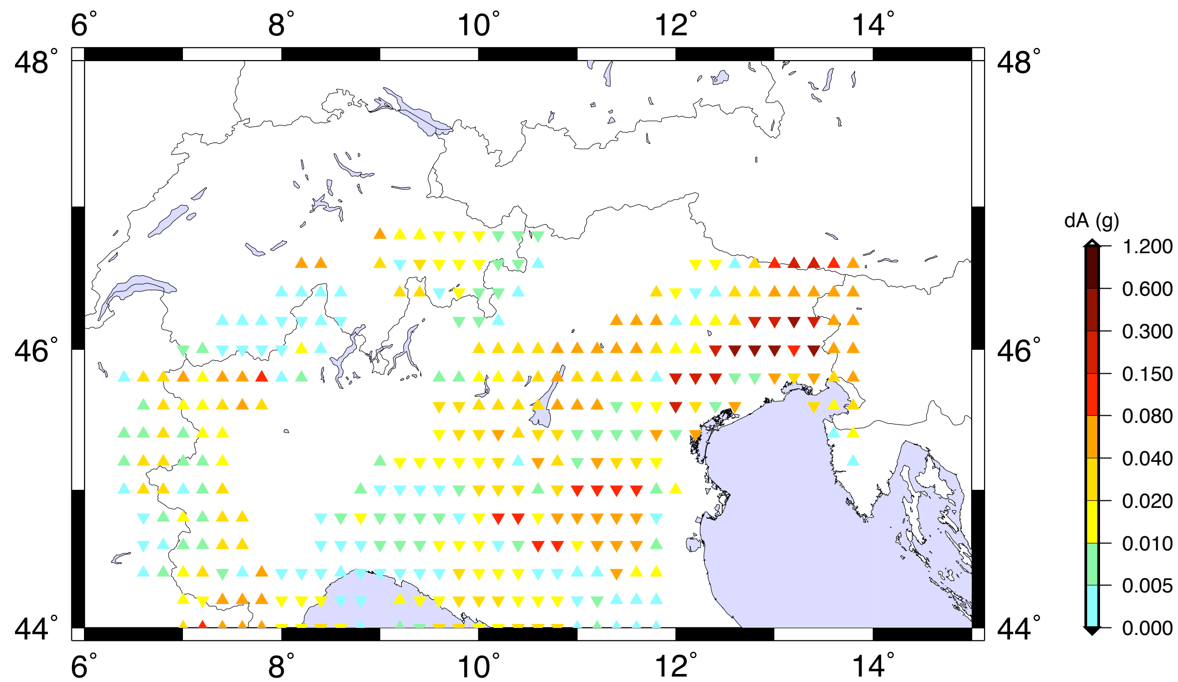


Parametric Test on Structural Properties

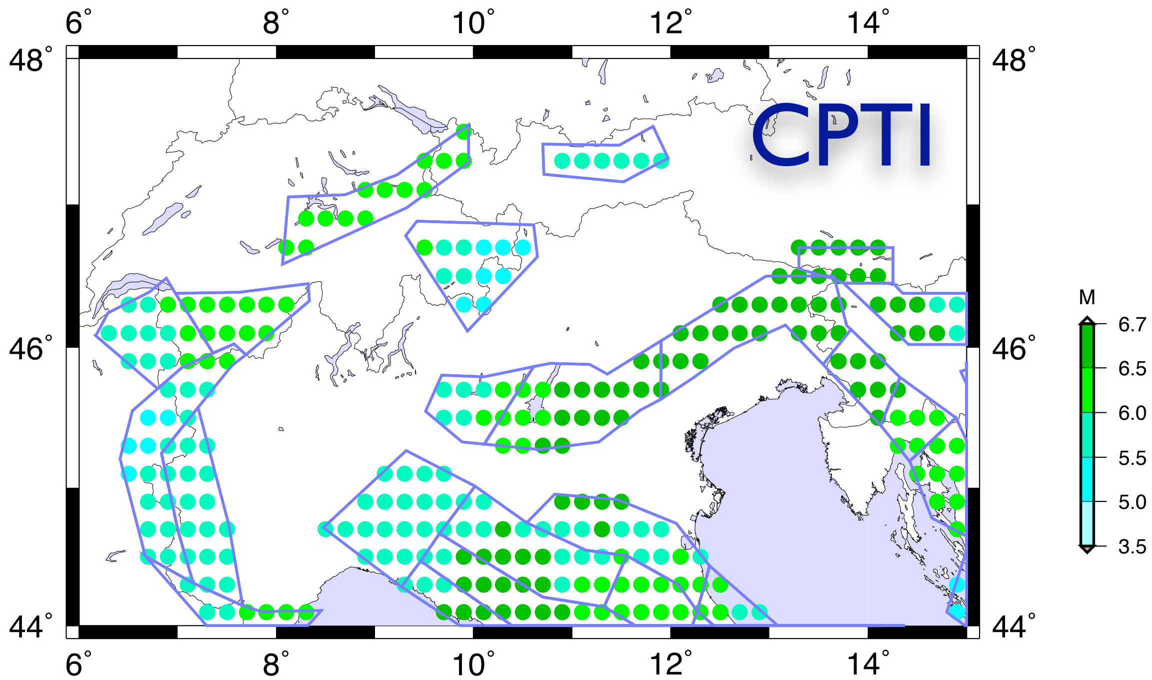


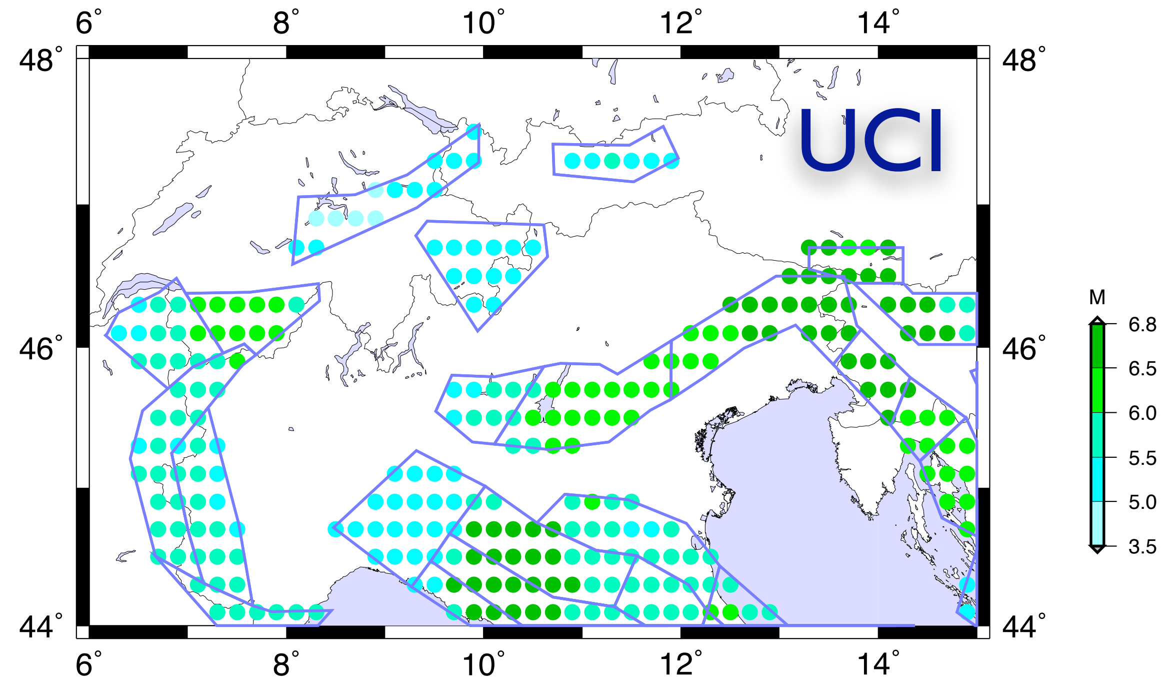


ALPS - GNDT

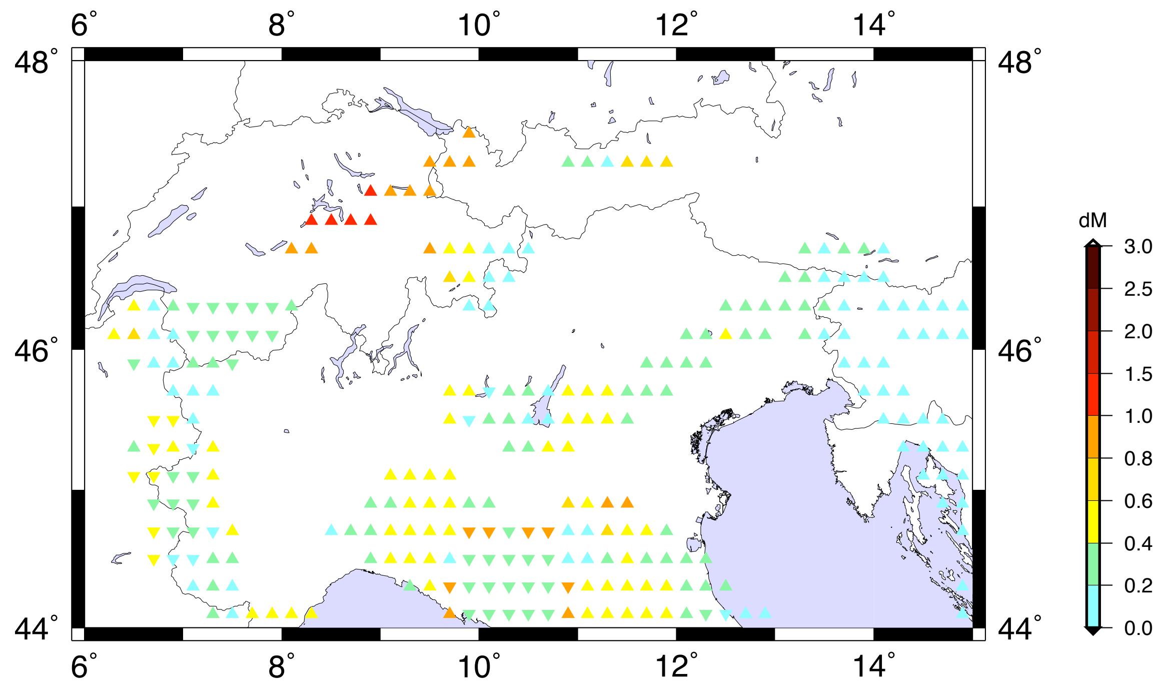


Parametric Test on Earthquake Catalogue

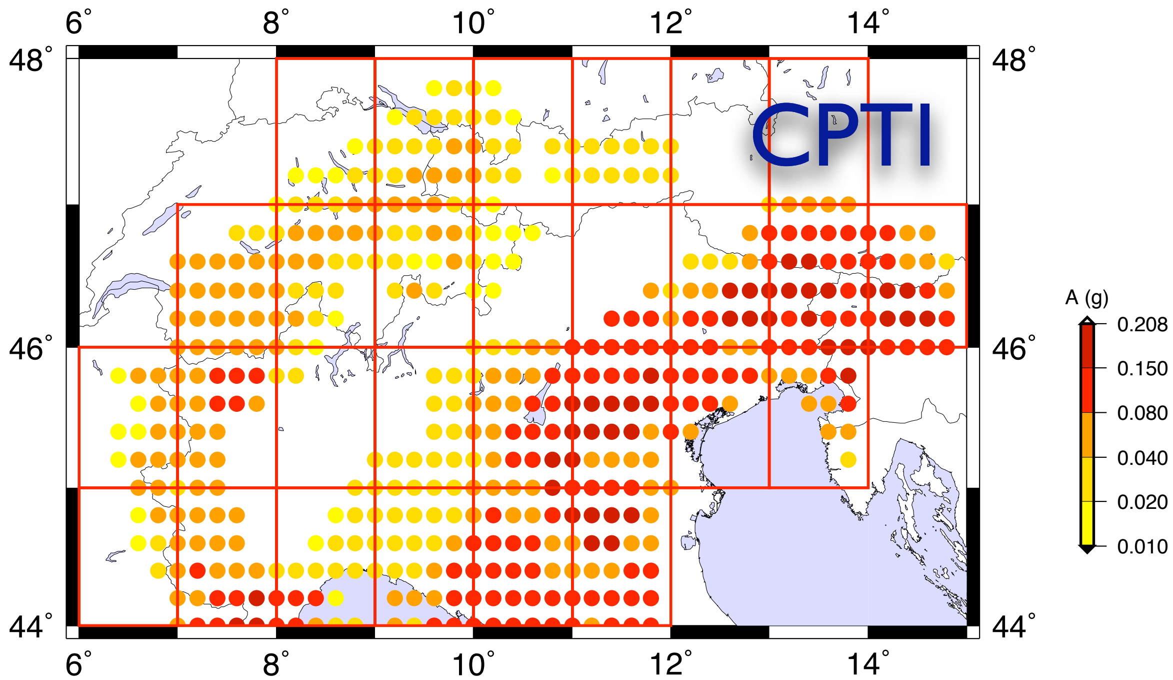


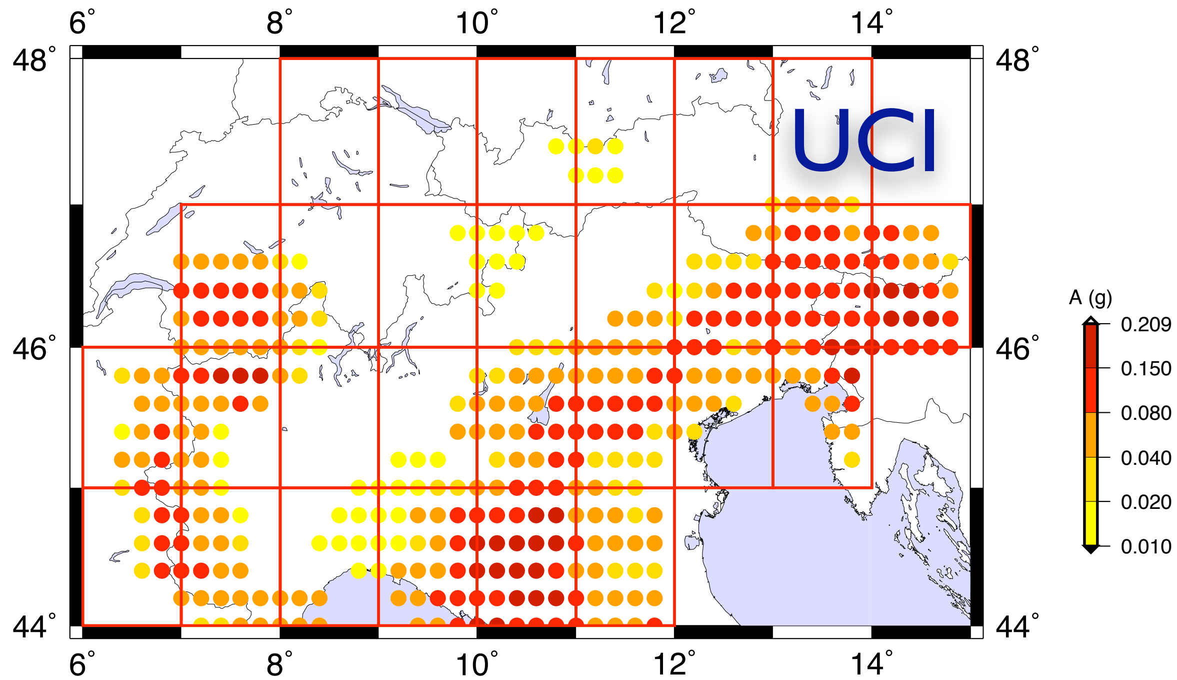


CPTI - UCI

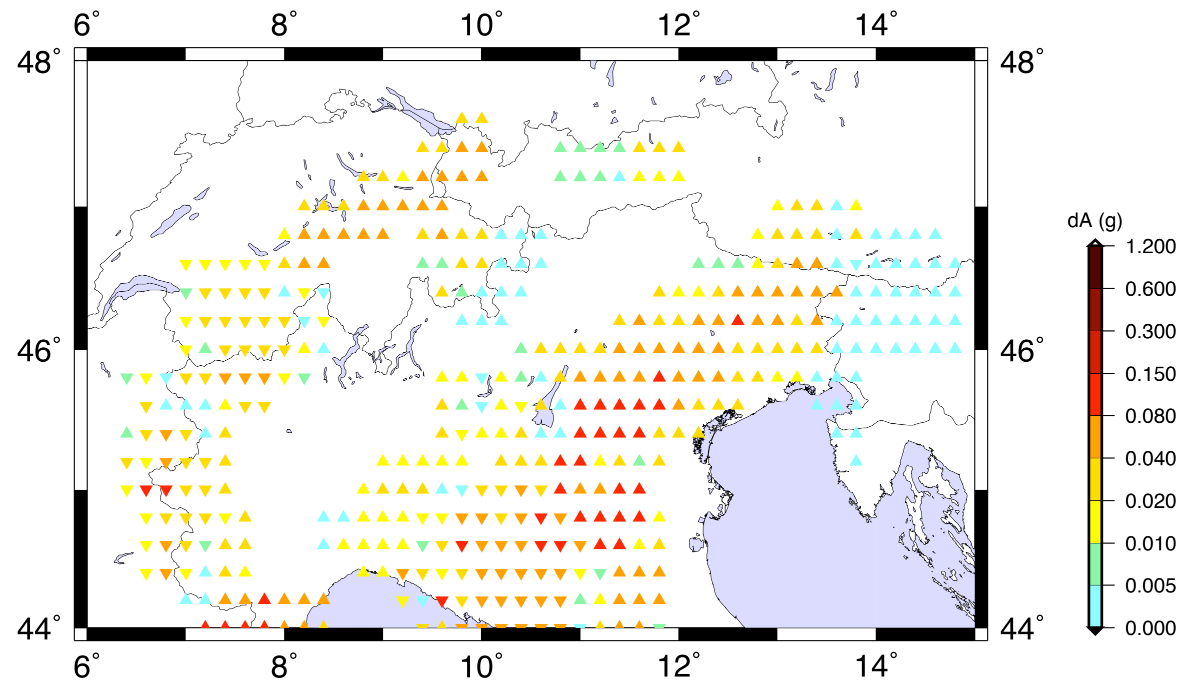


Parametric Test on Earthquake Catalogue

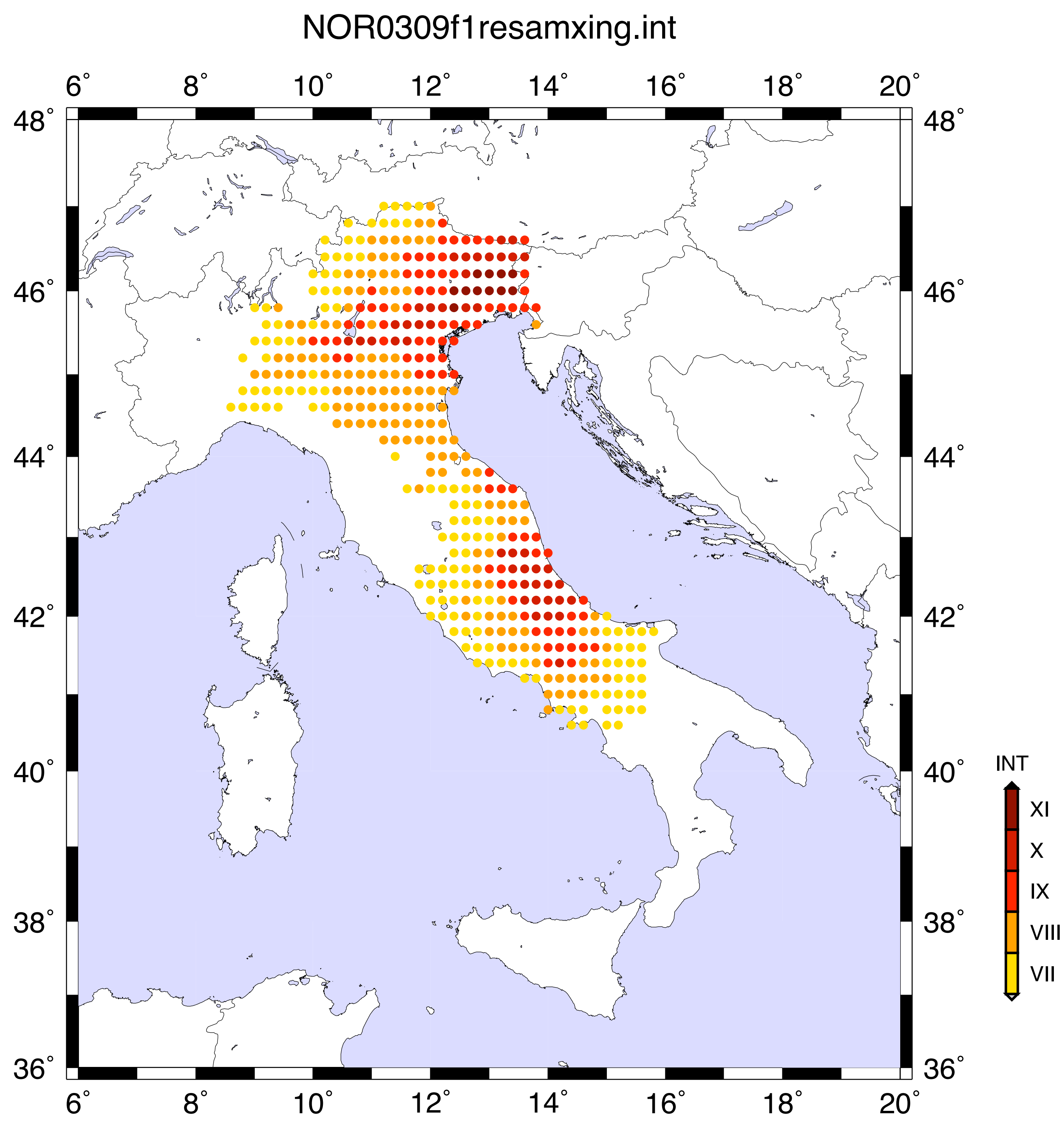


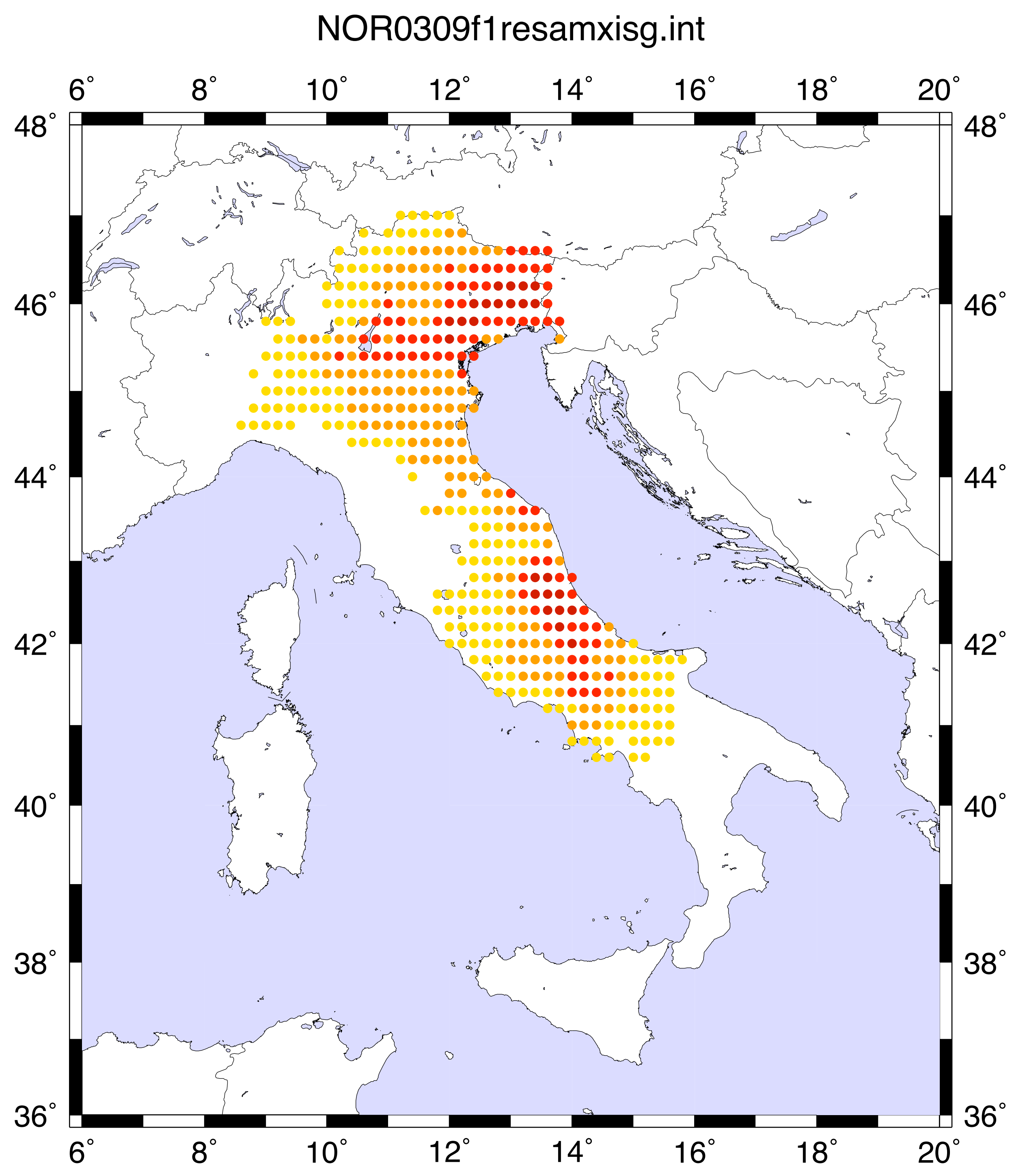


CPTI - UCI

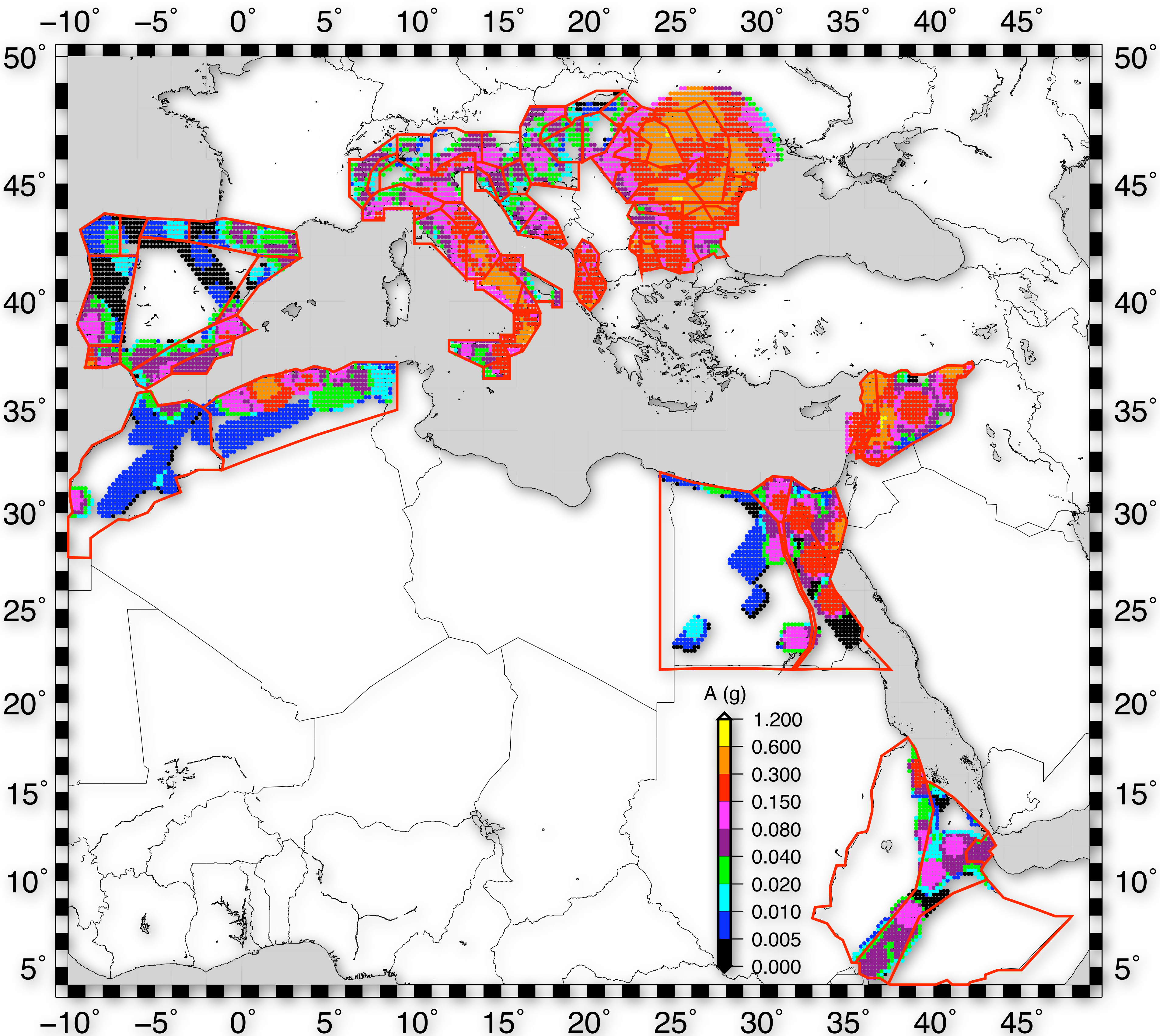


Intensity Scenarios





- The deterministic procedure has been applied to several countries in the world. Here the map of DGA is shown



Regional Scale - Homogeneity!

- If seismogenic zones are not defined according to homogeneous criteria, hazard results will be hardly comparable (source: GSHAP)

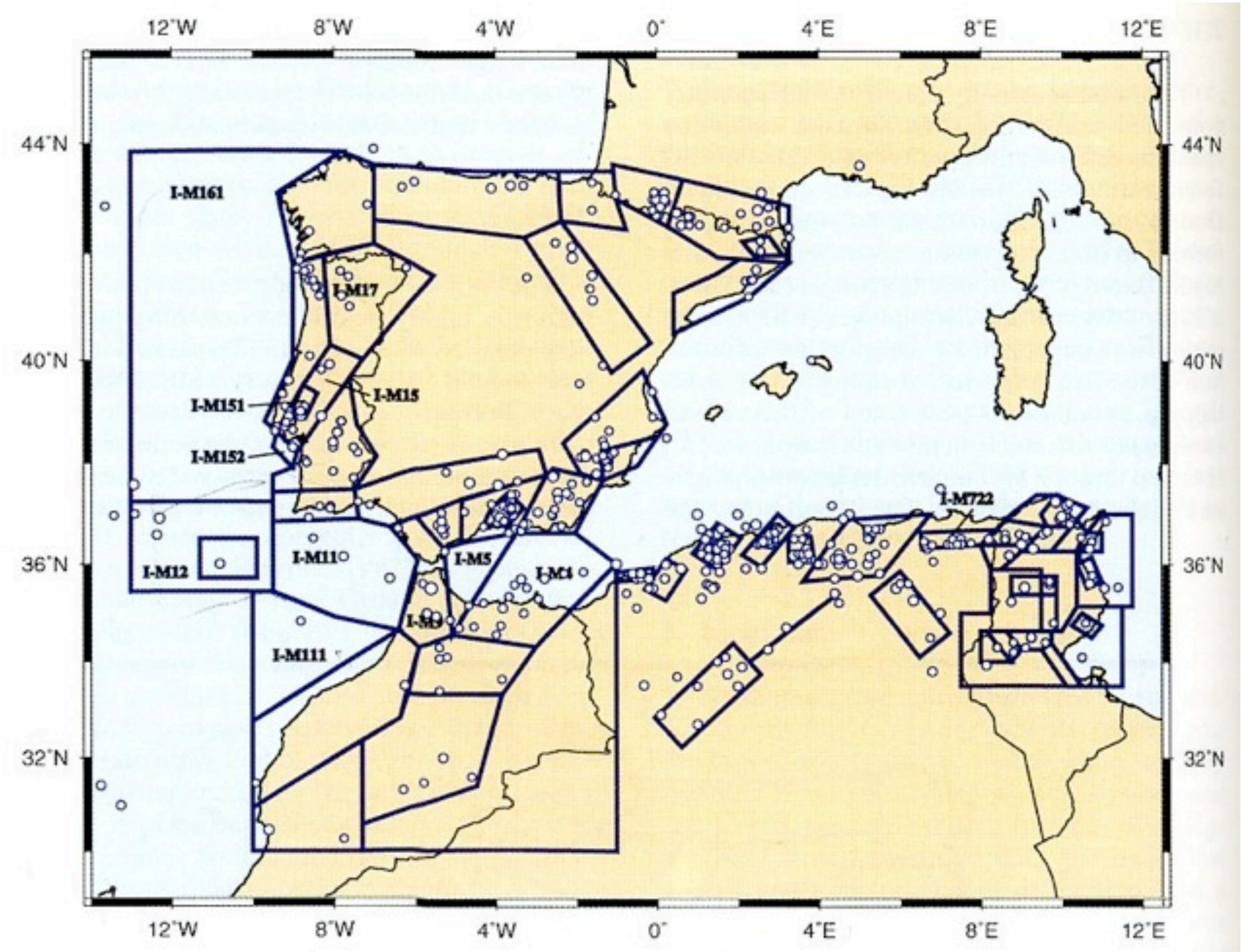
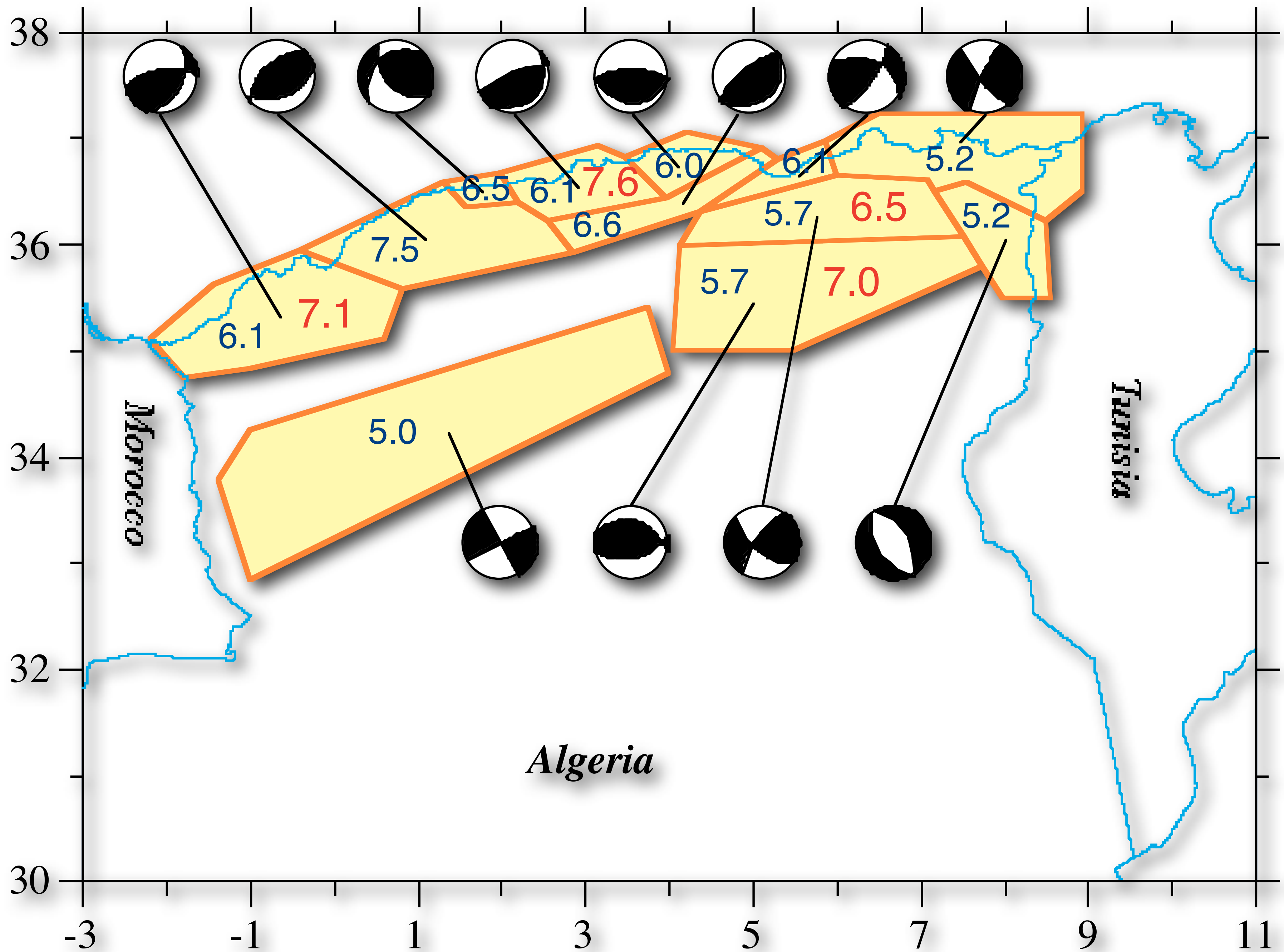


Fig. 2. Final distribution of earthquake source zones for the Ibero-Maghreb region, and epicenters of the generated List of Significant Earthquakes with $M \geq 4.5$ from 1900 to 1989.

Regional Scale - Seismogenic Potential

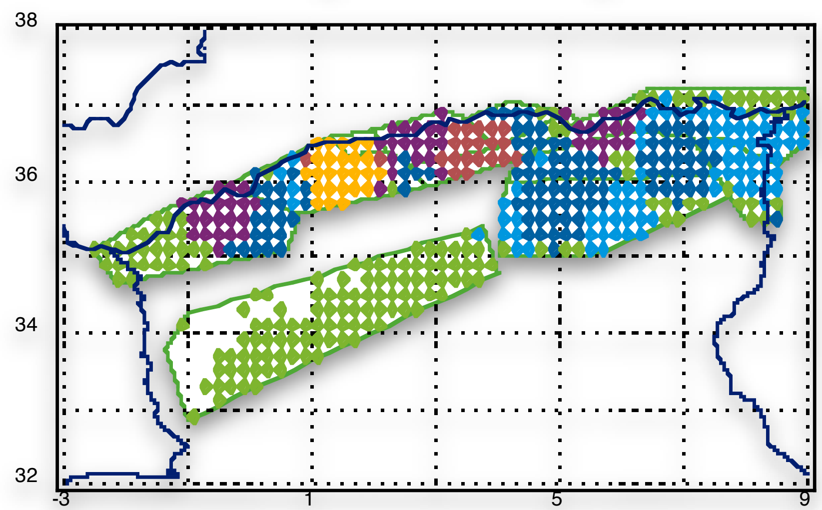
- If the earthquake catalogue is not complete even in the high magnitude range, computations can be eventually performed analysing the seismogenic potential of the active faults

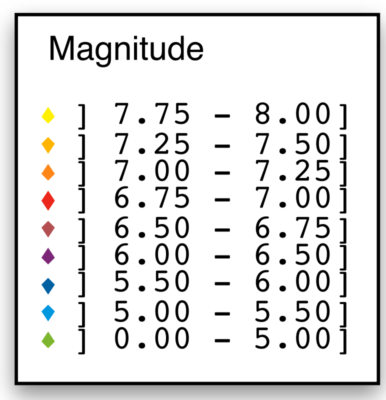


Regional Scale - Seismogenic Potential

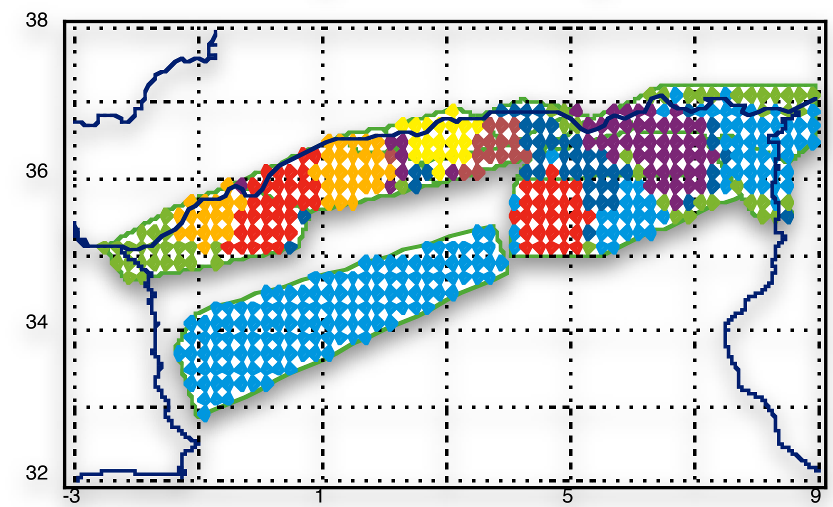
- If the earthquake catalogue is not complete even in the high magnitude range, computations can be eventually performed analysing the seismogenic potential of the active faults

Max OBSERVED magnitude (smoothed)





Max EXPECTED magnitude (smoothed)

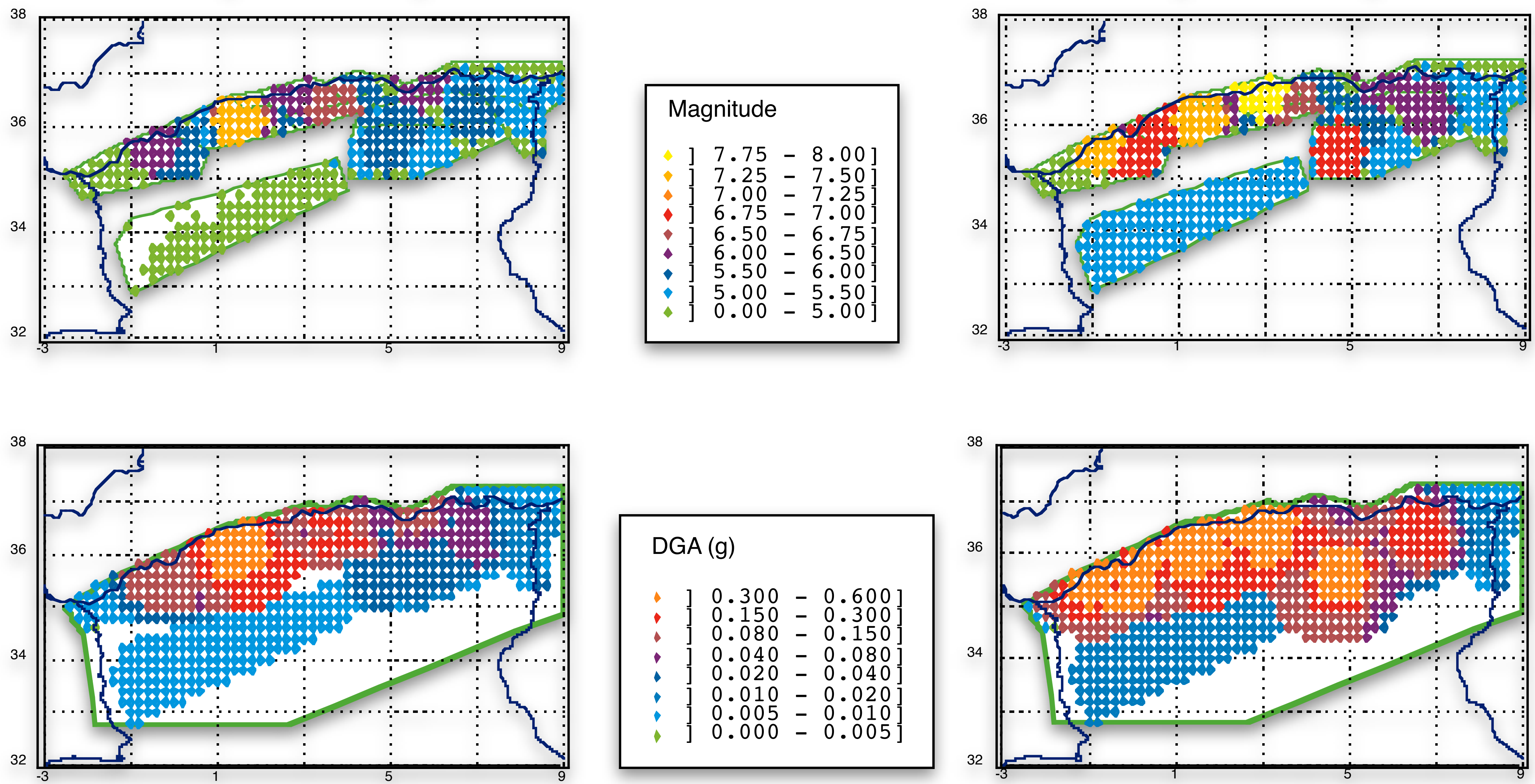


Regional Scale - Seismogenic Potential

- If the earthquake catalogue is not complete even in the high magnitude range, computations can be eventually performed analysing the seismogenic potential of the active faults

Max OBSERVED magnitude (smoothed)

Max EXPECTED magnitude (smoothed)

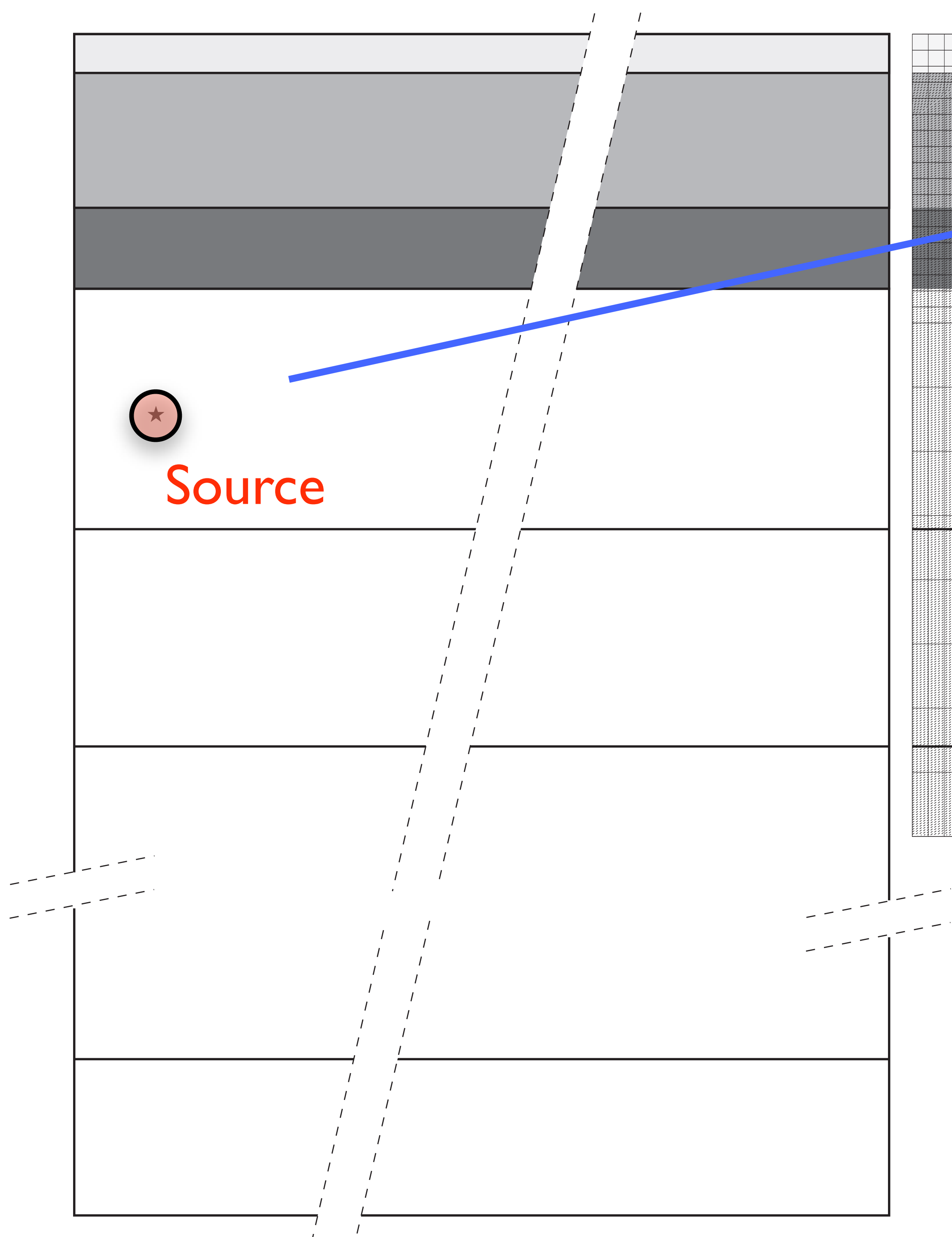


Local Scale - Introduction

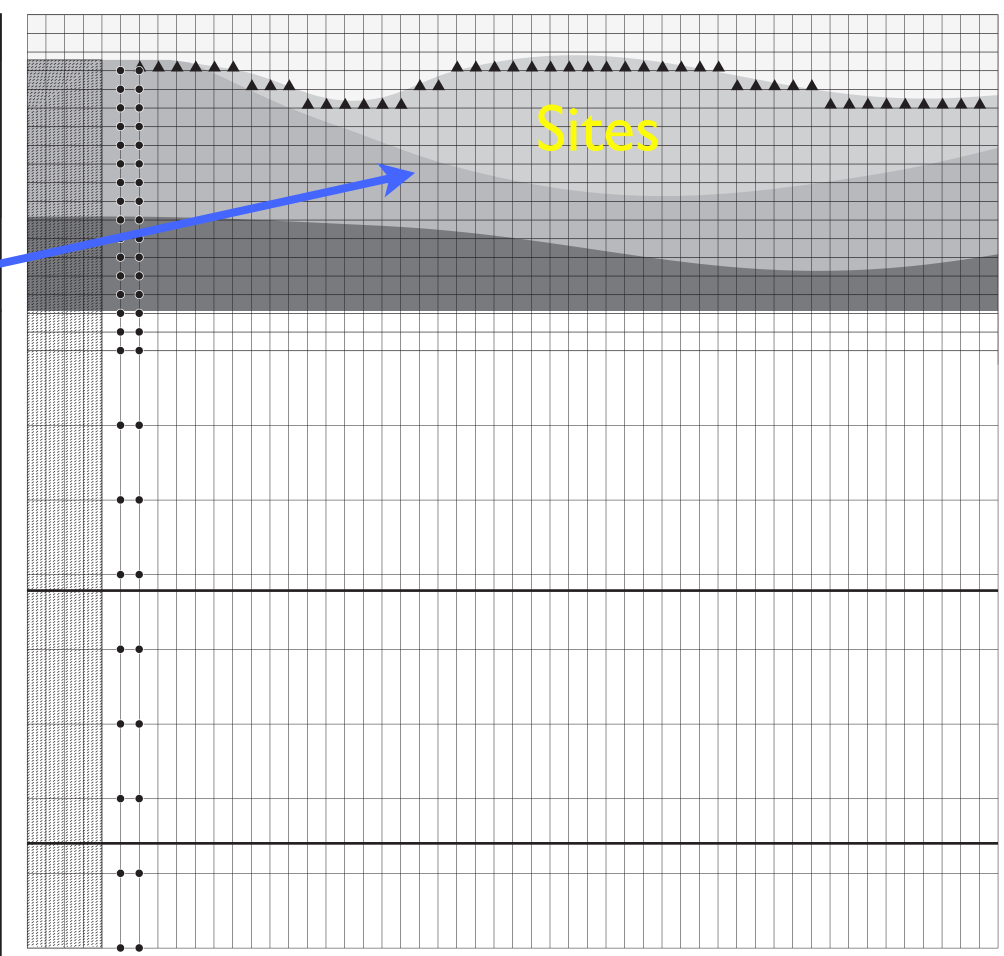
- Synthetic seismograms computed along selected profiles
- Laterally heterogeneous structural models
- Detailed source model
- Cut-off frequency up to 10 Hz
- Maps of ground motion amplification

Local Scale - Definition of Model

Modal Summation



Finite Difference



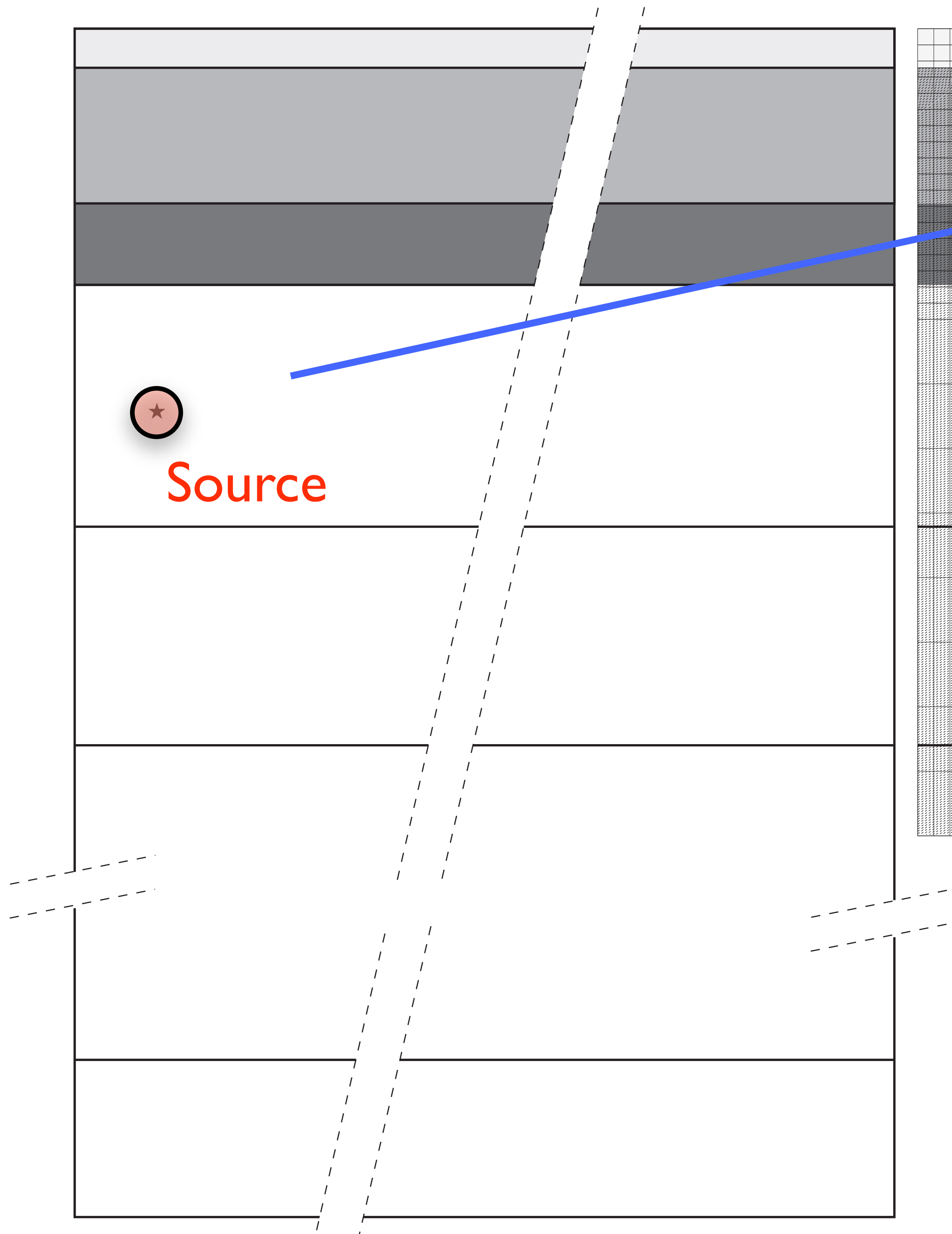
★ Source
• Input for FD computations
▲ Sites
Absorbing boundary

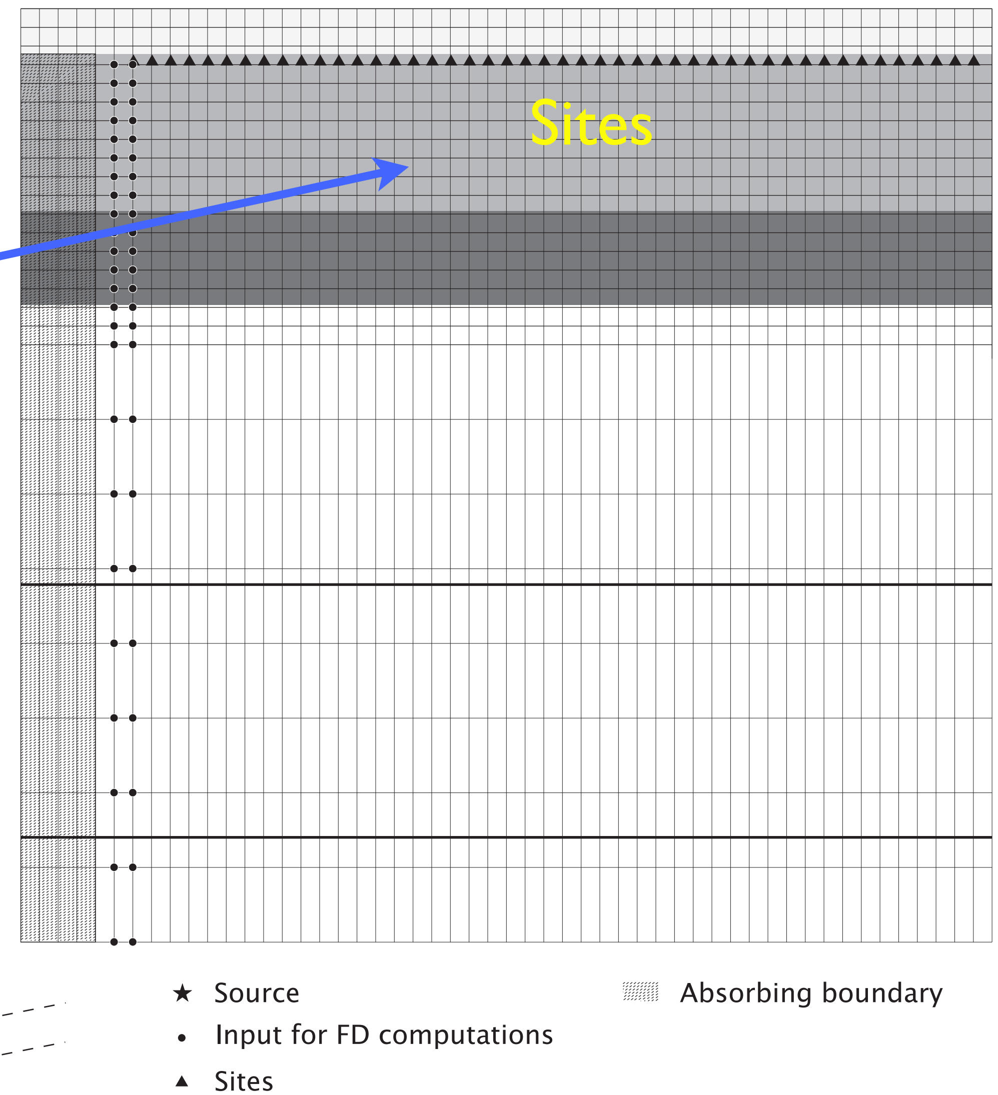
Material	Density (g/cm3)	Vp (km/s)	Qp	Vs (km/s)	Qs
Air	0	0	0	0	0
Sed1	1.8	0.8	100	0.4	50
Sed2	1.9	0.9	100	0.5	50
Sed3	2.0	1.0	100	0.6	50

Local Scale - Definition of Model

Modal Summation

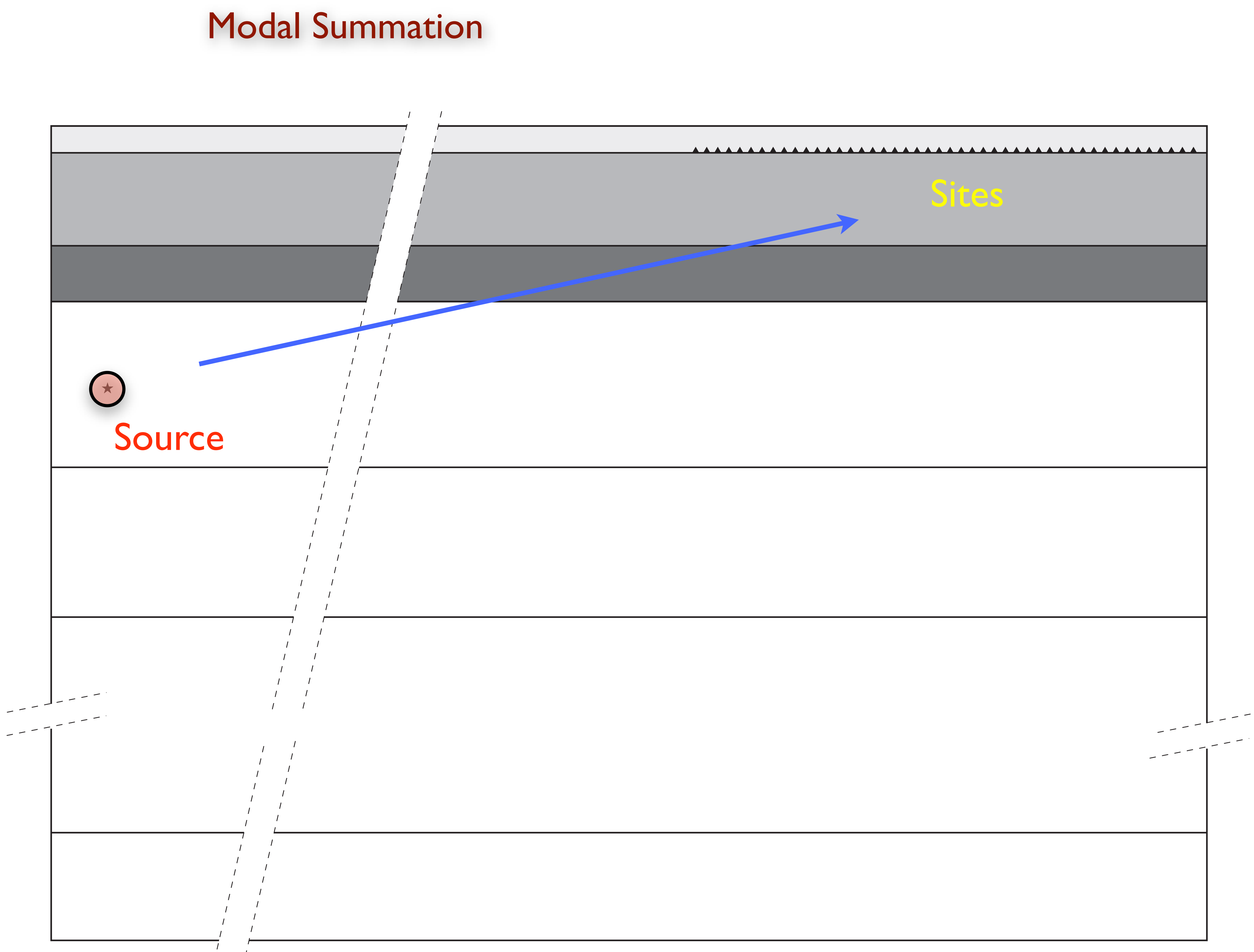
Finite Difference





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

Local Scale - Definition of Model



Local Scale - Input Definition

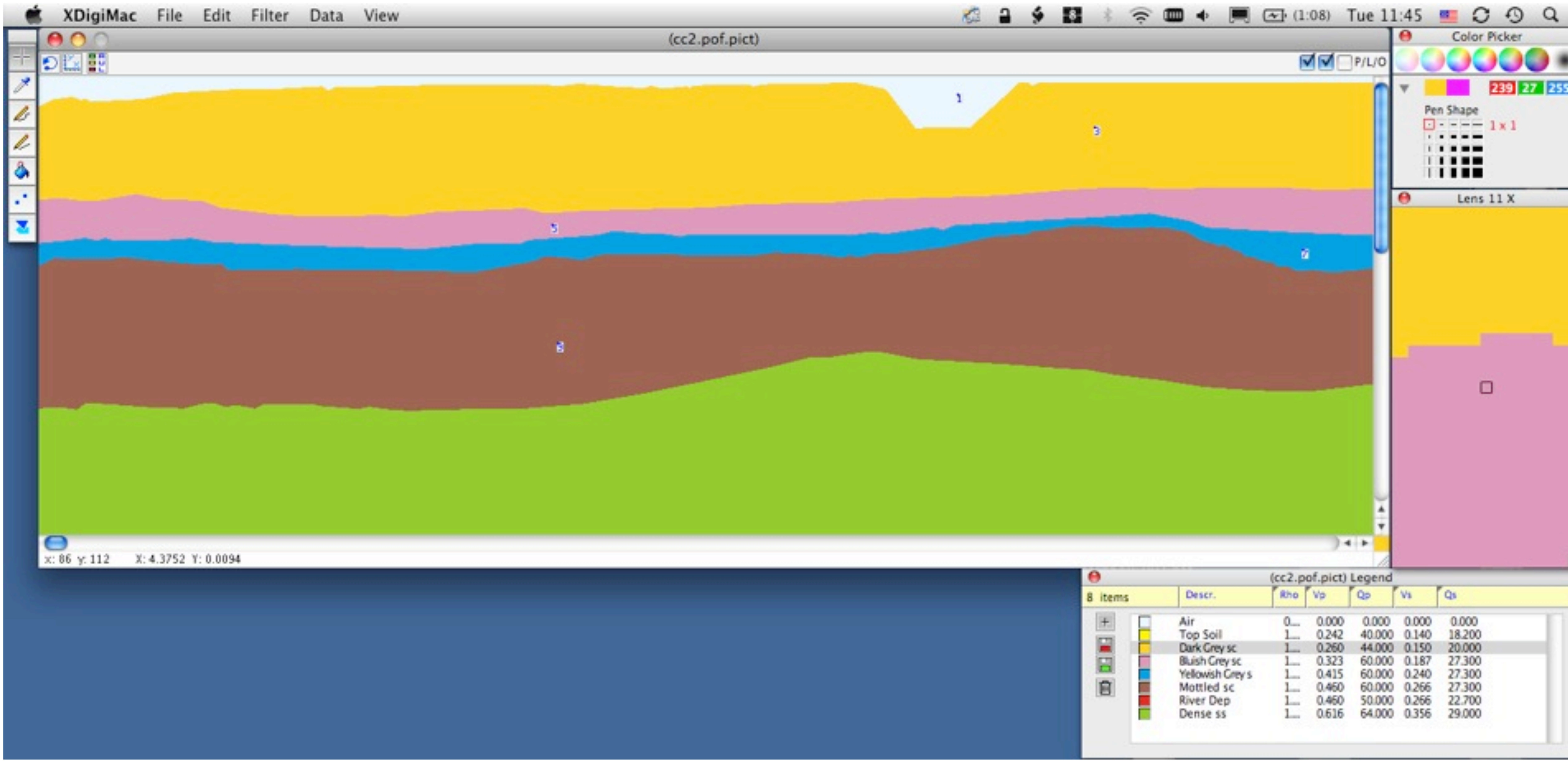
```
Parameters file for program pfdg9
---------------------------------------------------------------------------
Modal summation model
---------------------------------------------------------------------------
test.spr                         Modes for 1D structure
0         First mode to use (1=fundamental, 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

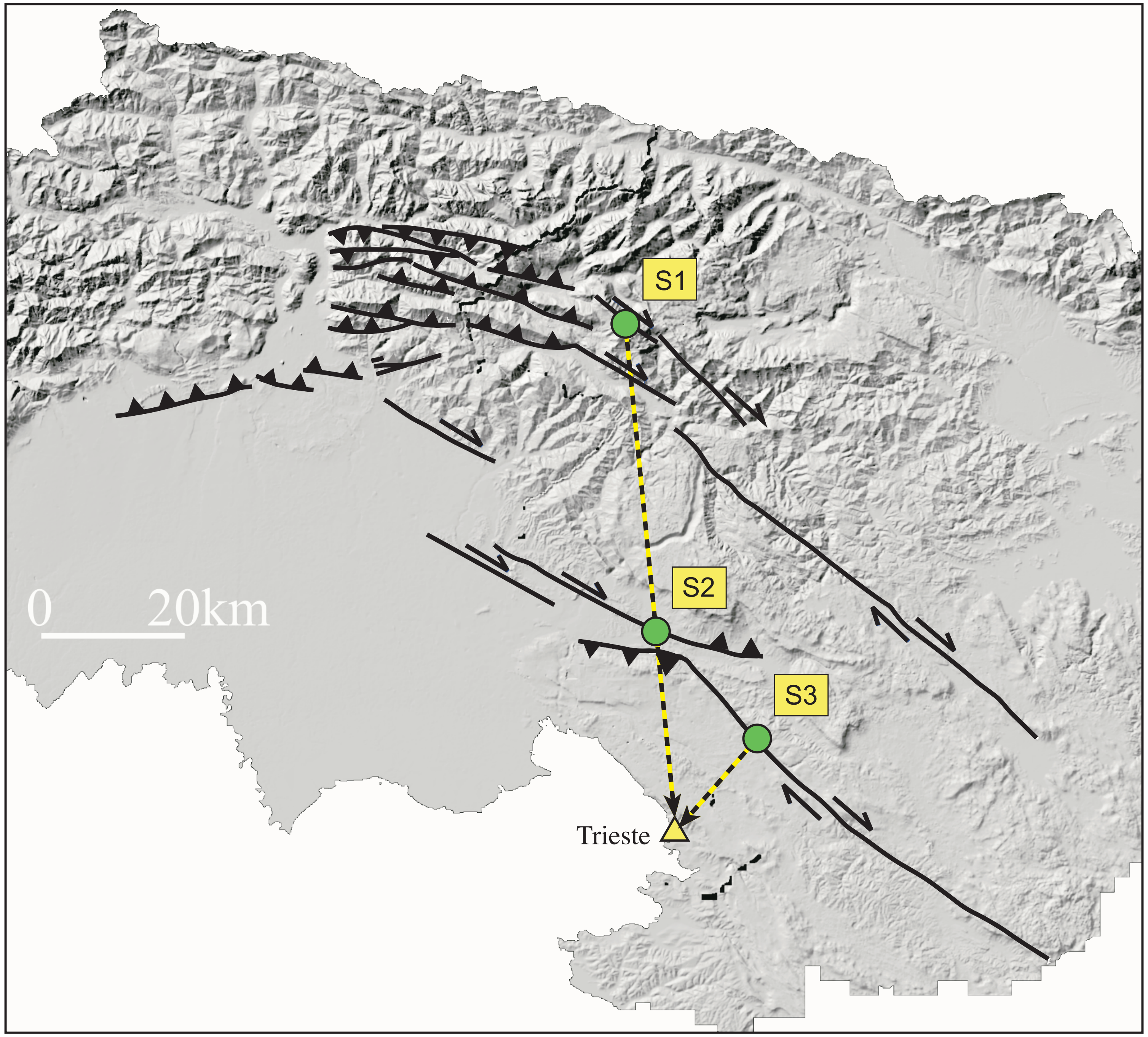
Local Scale - Input Definition

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

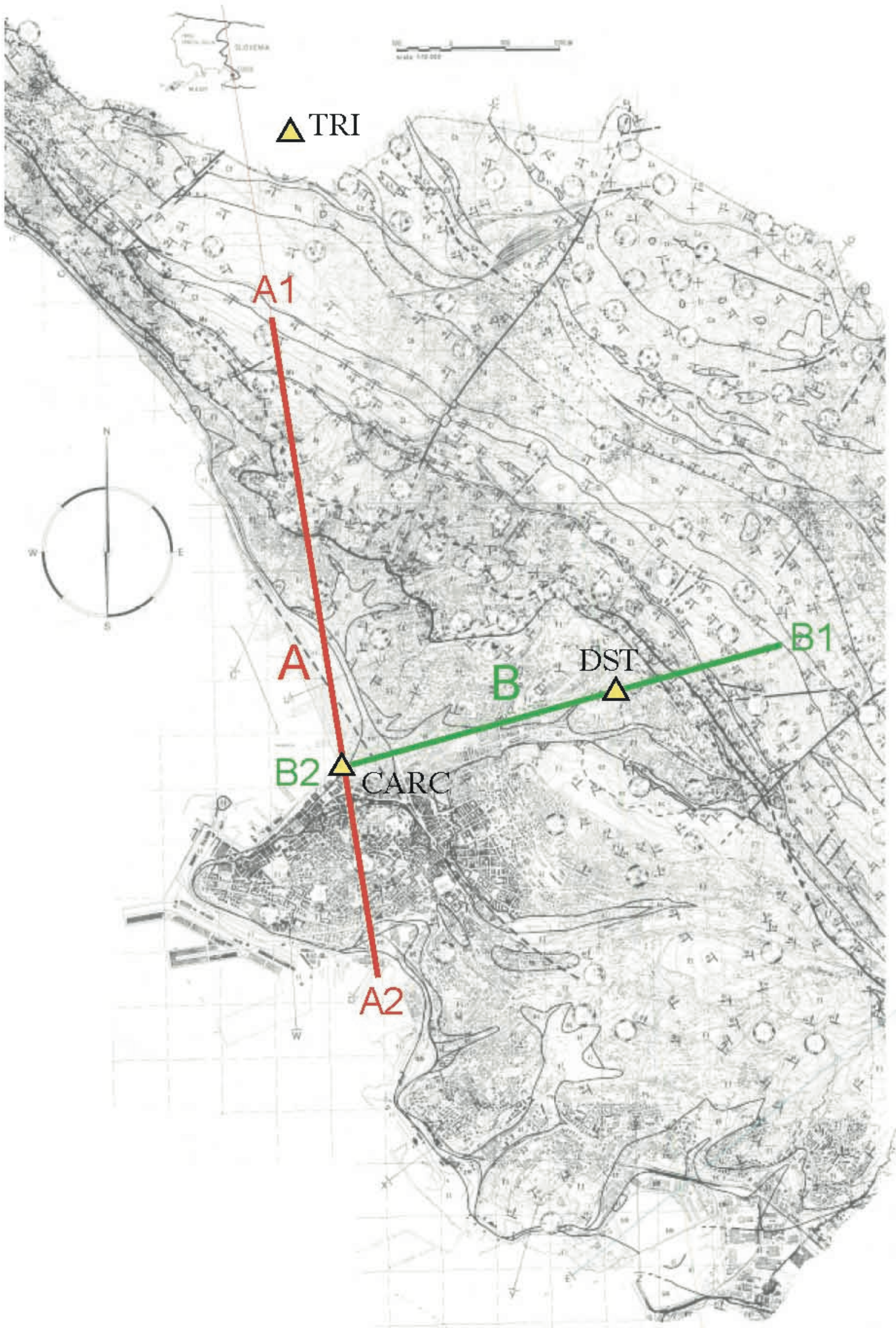


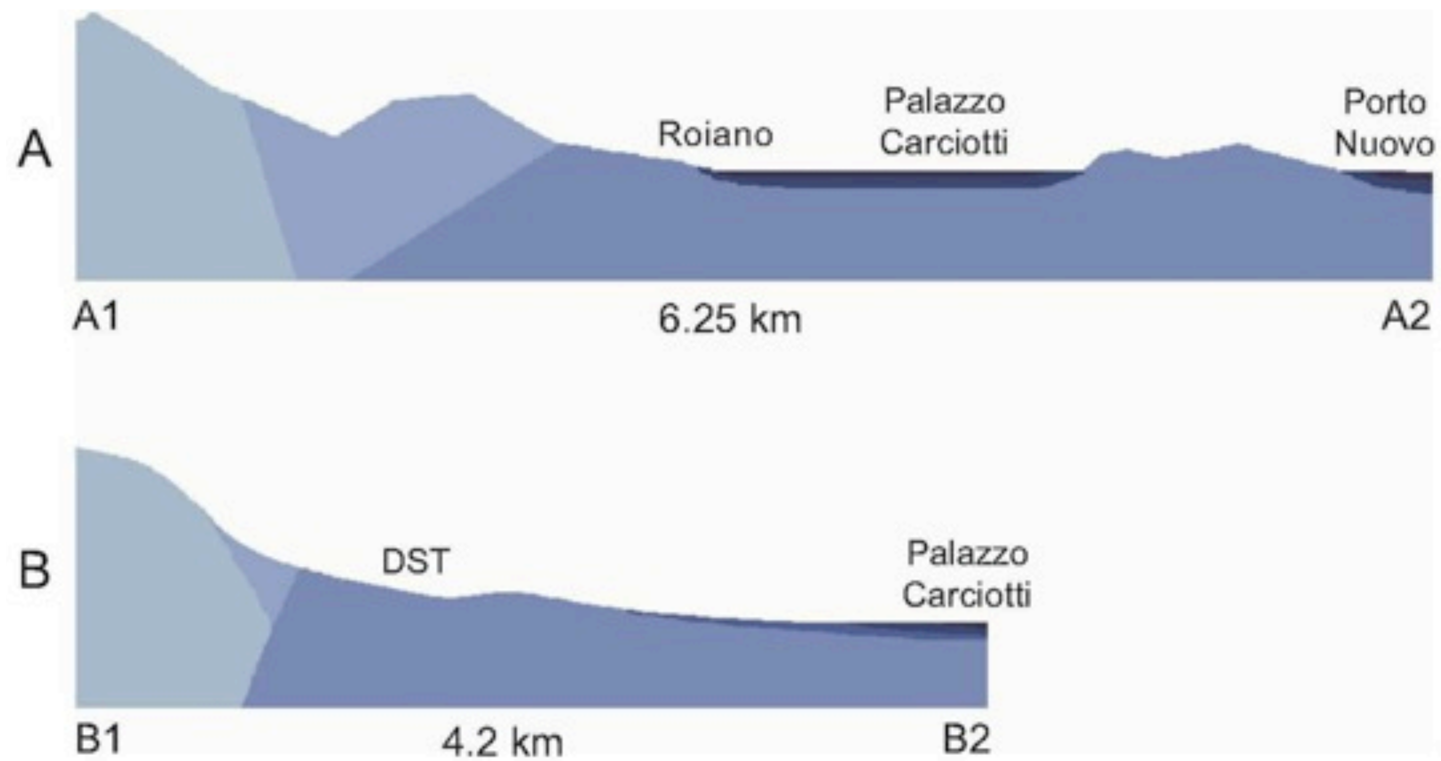
Local Scale - Choice of Scenario Earthquakes

- Regional zonation
- Morphostructural analysis
- Active faults
- Earthquake prone areas



Local Scale - Choice of Profiles

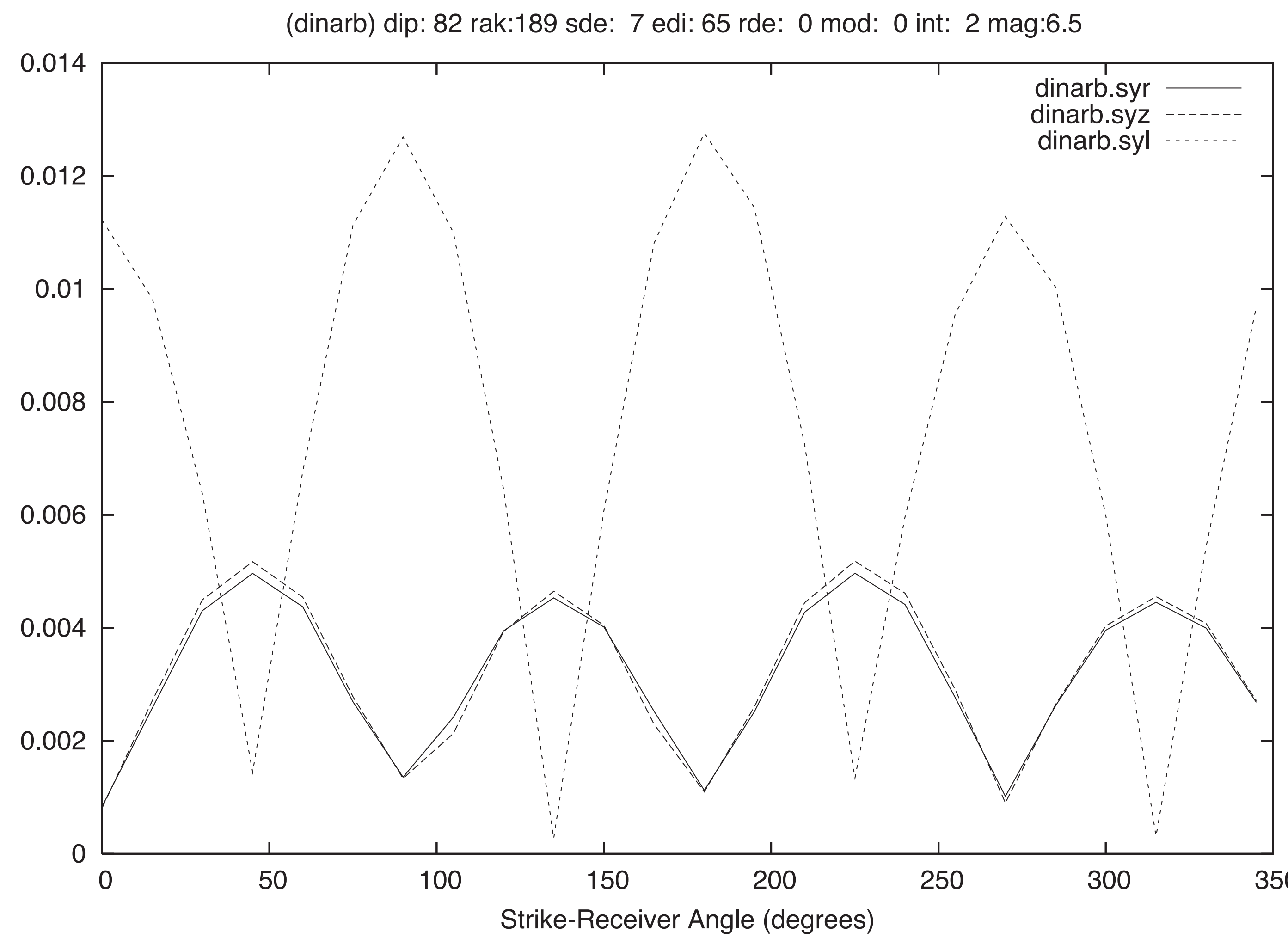




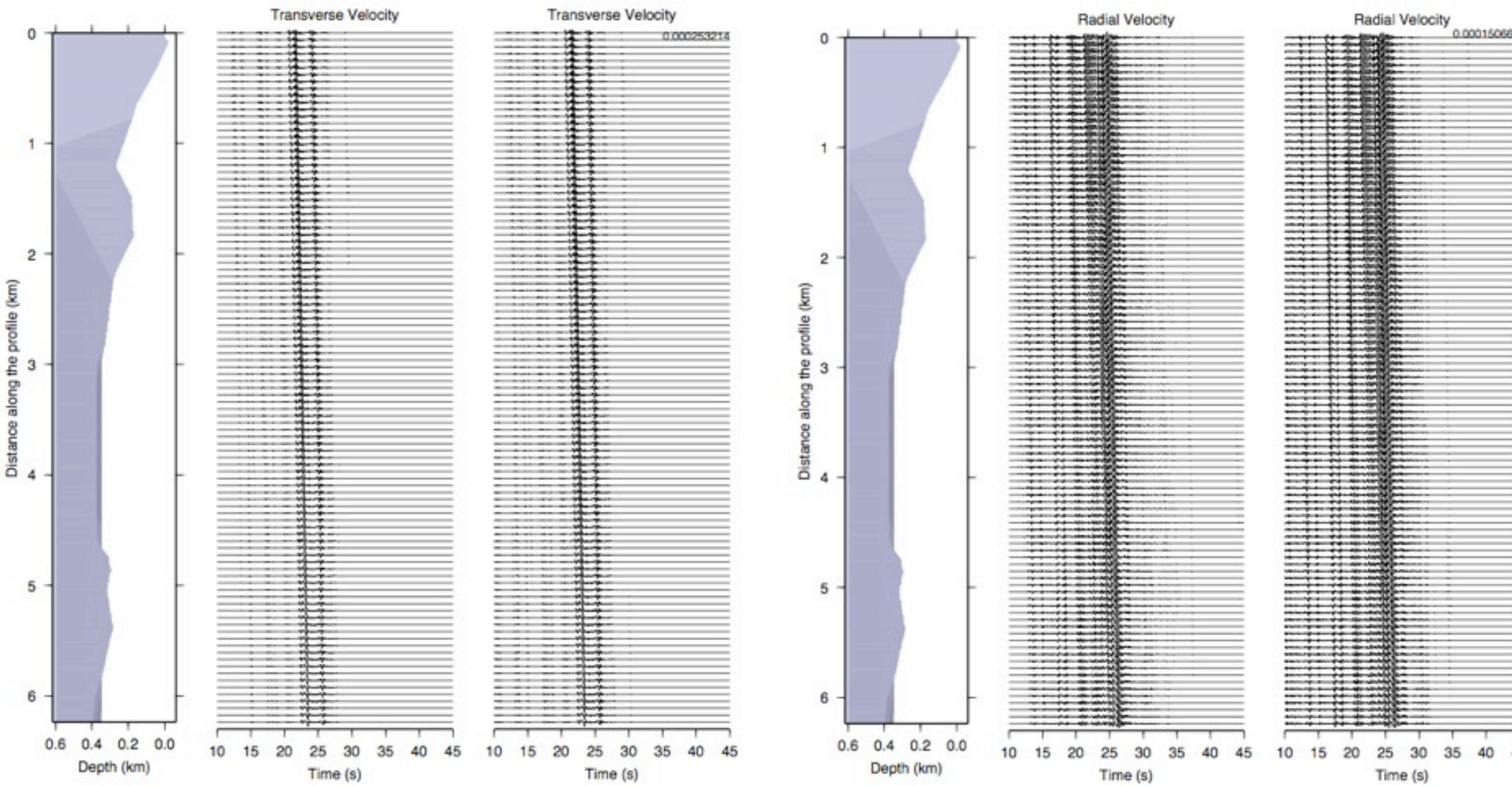
Litotipo	Densità (g/cm^3)	Vp (km/s)	Vs (km/s)	Qp	Qs
Riporti	1.8	0.4	0.2	30	15
Sed. Marini	1.9	0.8	0.4	40	20
Alluvioni	1.95	1.0	0.5	40	20
Flysch	2.0	1.8	1.0	100	50
Marne	2.0	1.9	1.1	200	100
Arenarie	2.1	2.0	1.2	200	100
Calcari	2.3	2.5	1.4	200	100

Local Scale - Preliminary Parametric Test

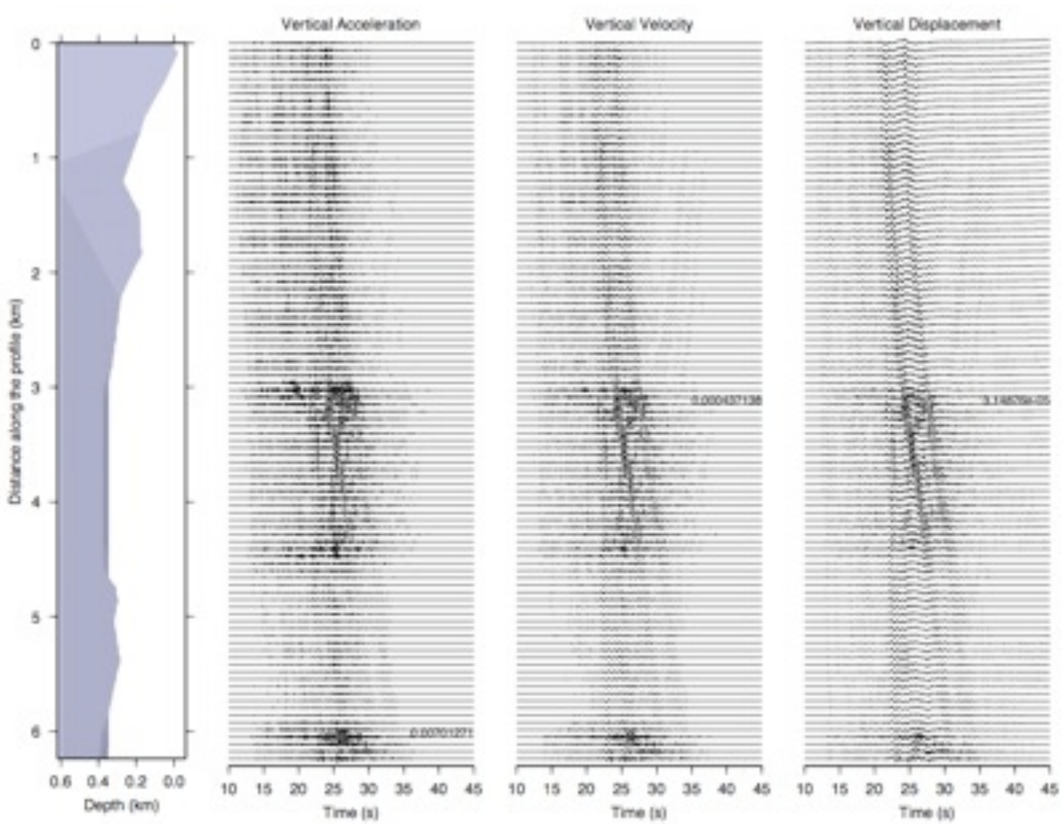
- Radiation Pattern
  - Source Depth
  - Epicentral Distance
  - ......

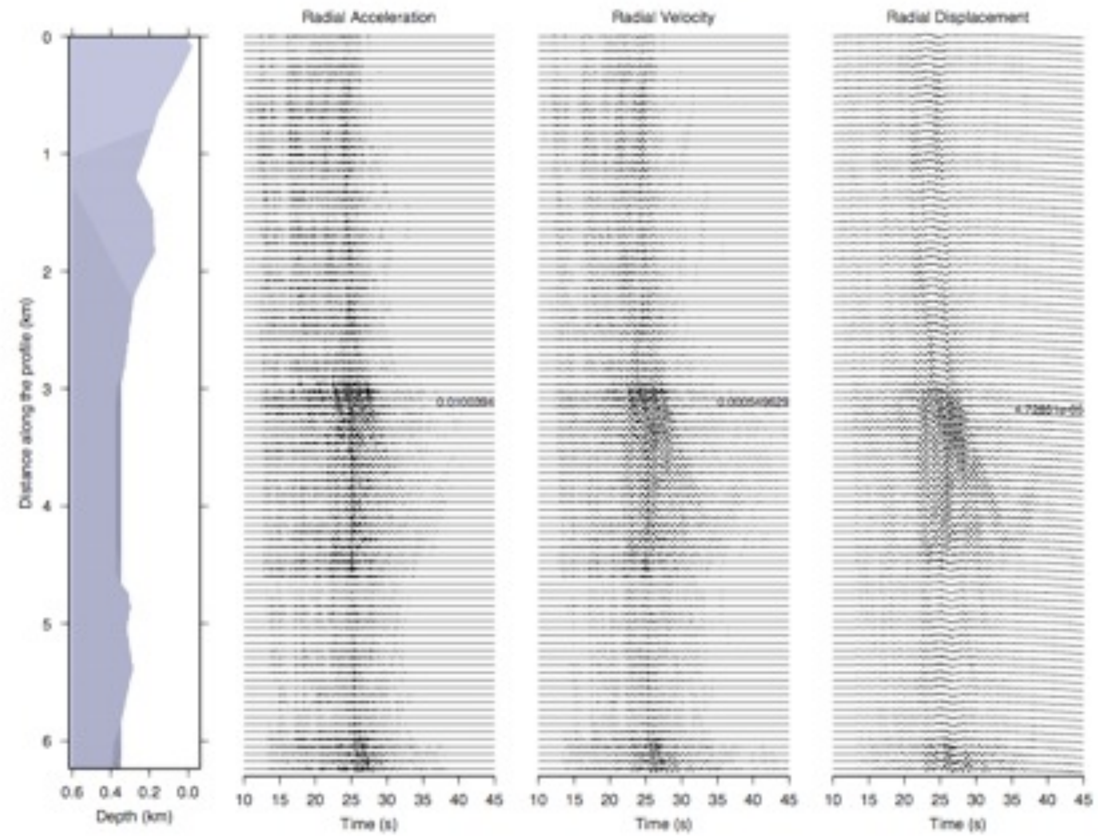


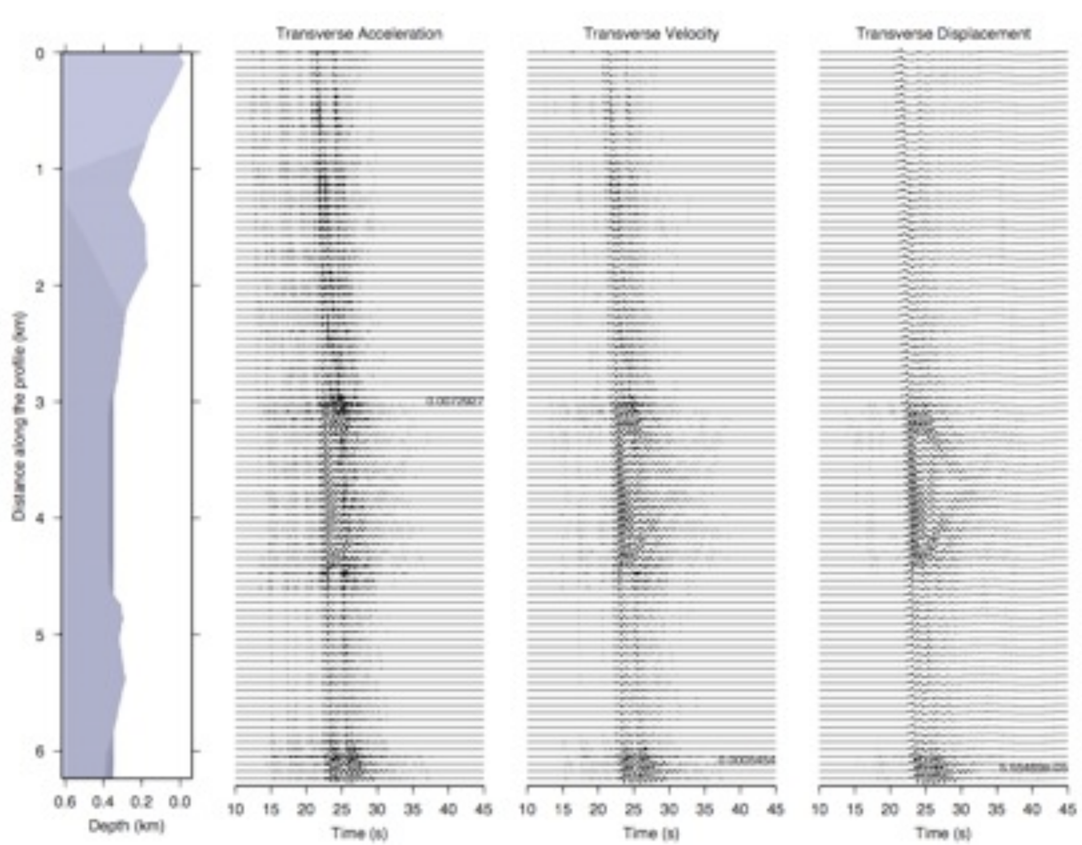
Local Scale - Synthetic Seismograms 1D Test



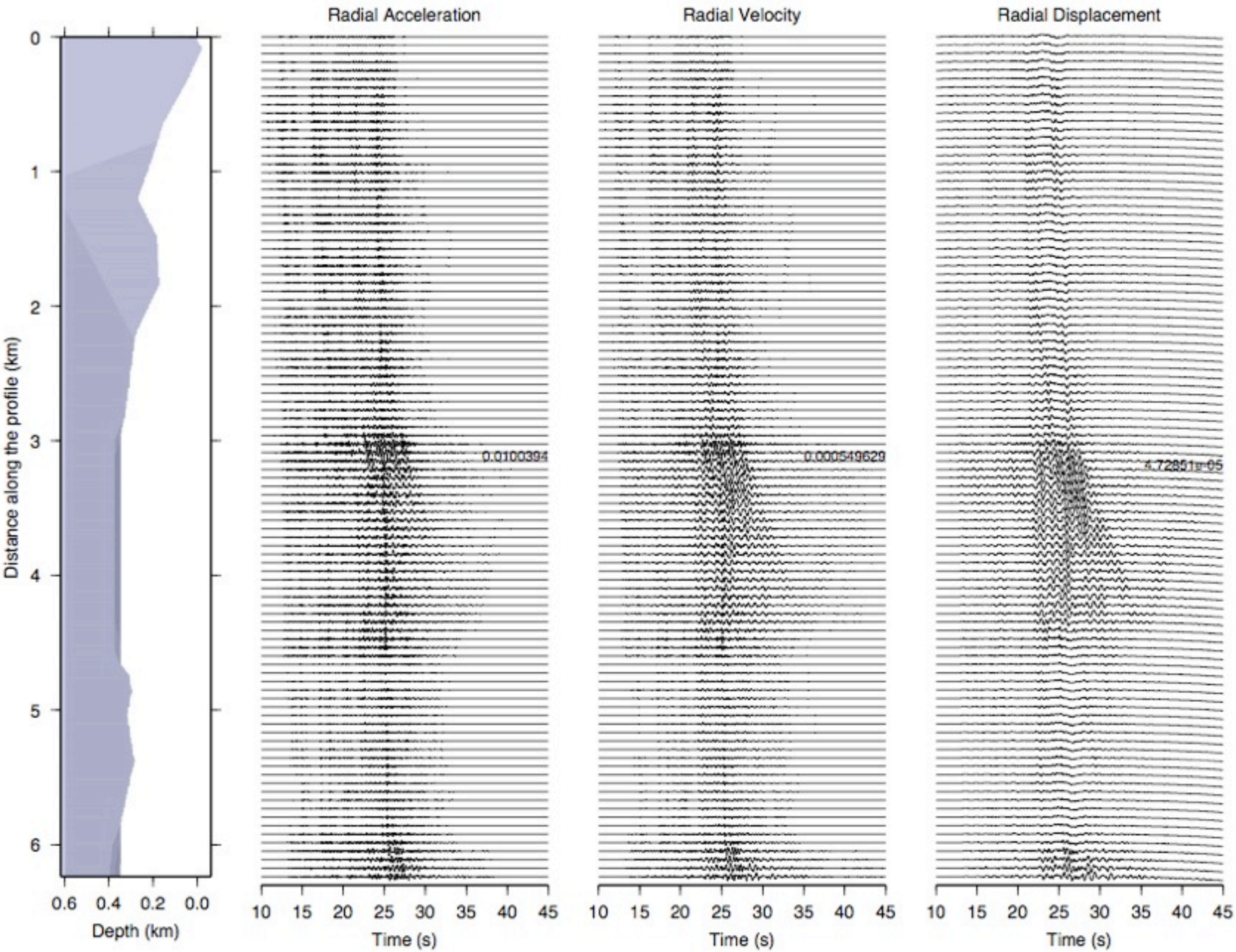
Local Scale - Synthetic Seismograms 2D





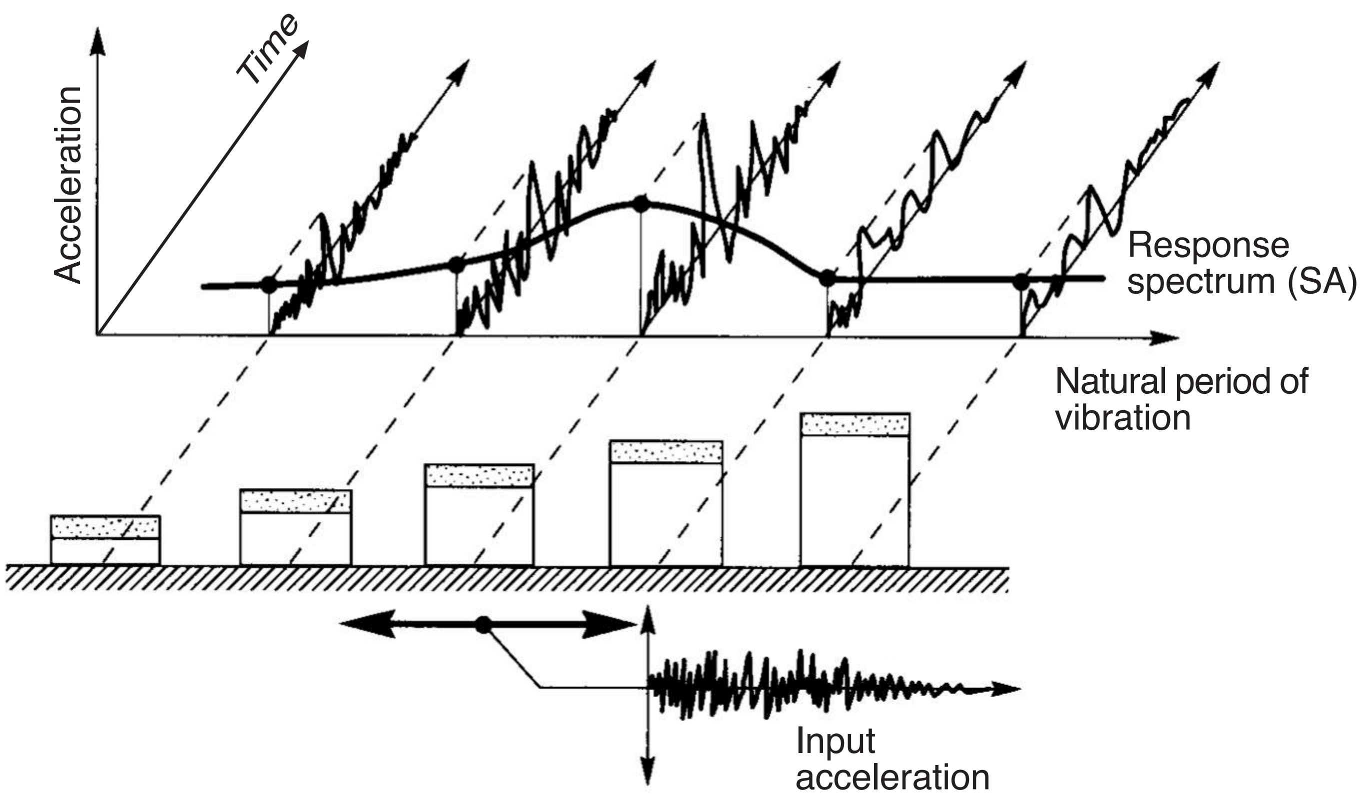


Local Scale - Synthetic Seismograms 2D



Local Scale - Response Spectra

Response Spectrum



Modelling of spectral amplification

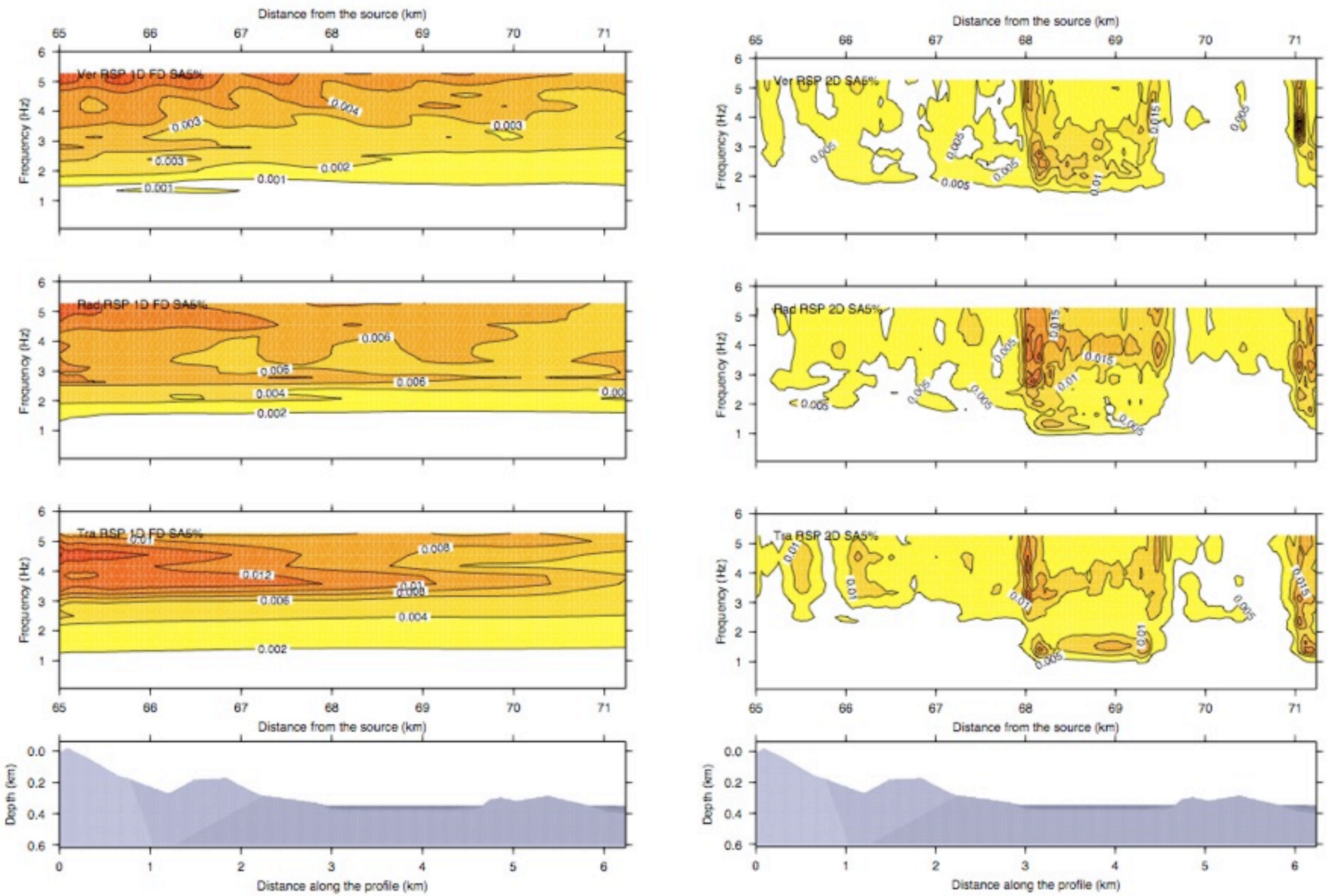
Response spectra can be computed using synthetic seismograms as input motion.

To estimate the spectral amplification due to a change in the model, computations of the synthetic seismogram can be repeated changing any parameter of the model.

Example: two synthetic seismograms are generated modifying the properties of the structural model. The ratio between their response spectra will show the relative amplifications due to the change of the structure.

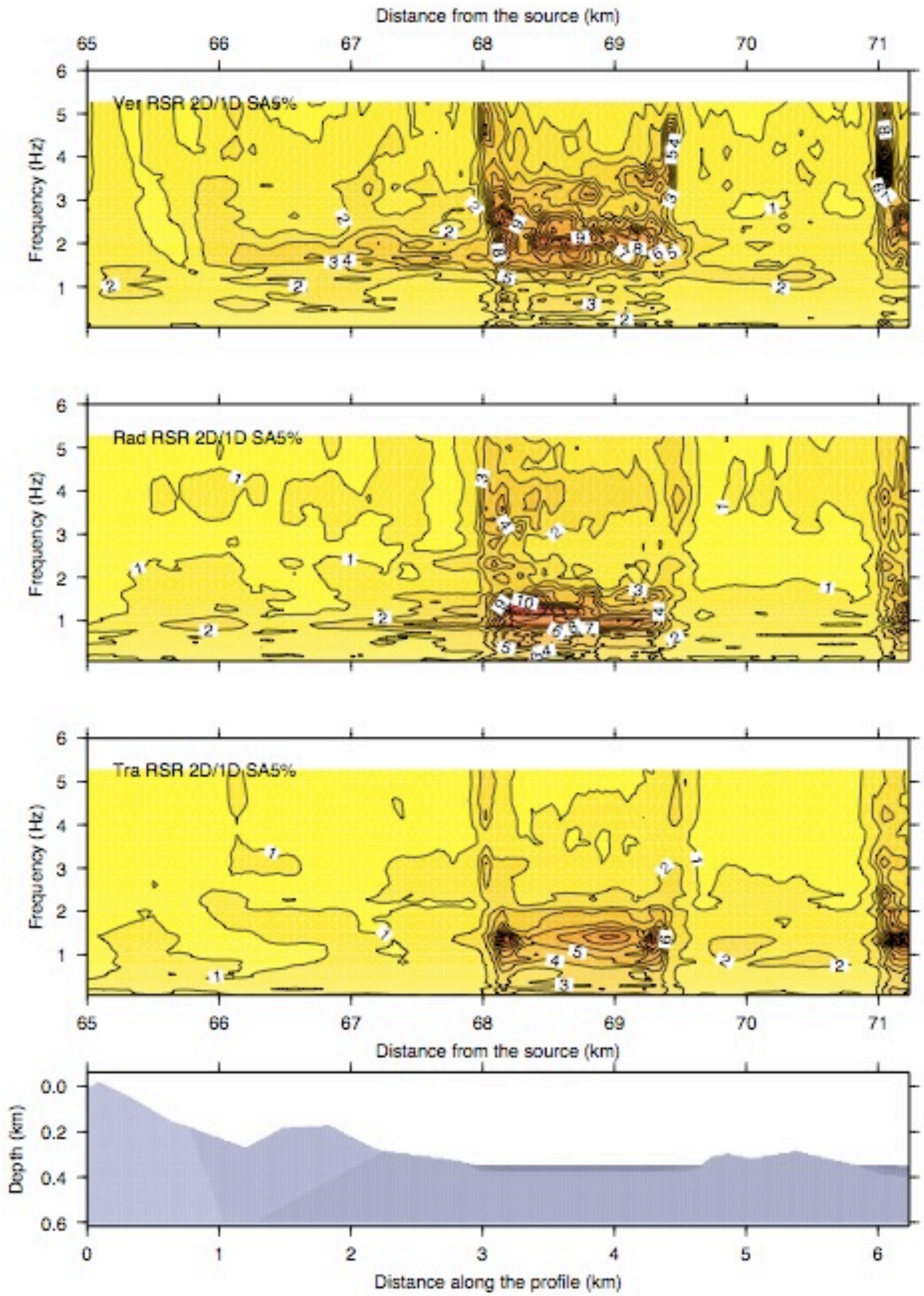
Usually, one synthetic seismogram is generated for a bedrock model, and kept as a reference. The second synthetic seismogram is computed considering a structural model representative of the site conditions, possibly taking into account lateral heterogeneities.

Local Scale - Response Spectra



Local Scale - Response Spectra

- 2D/1D RSR



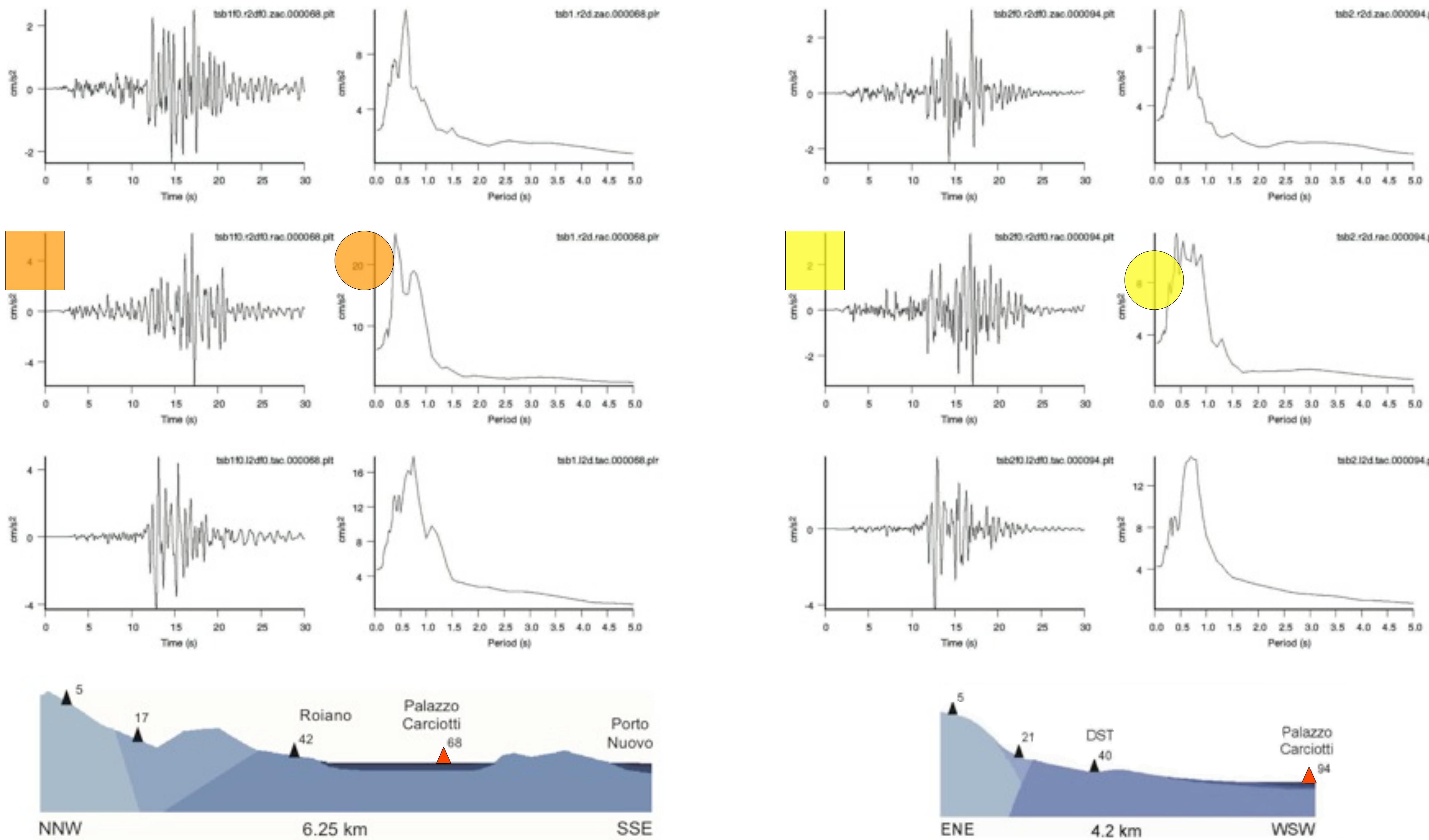
Local Scale - Seismograms and Response Spectra

- Same site at the intersection of two profiles

Z

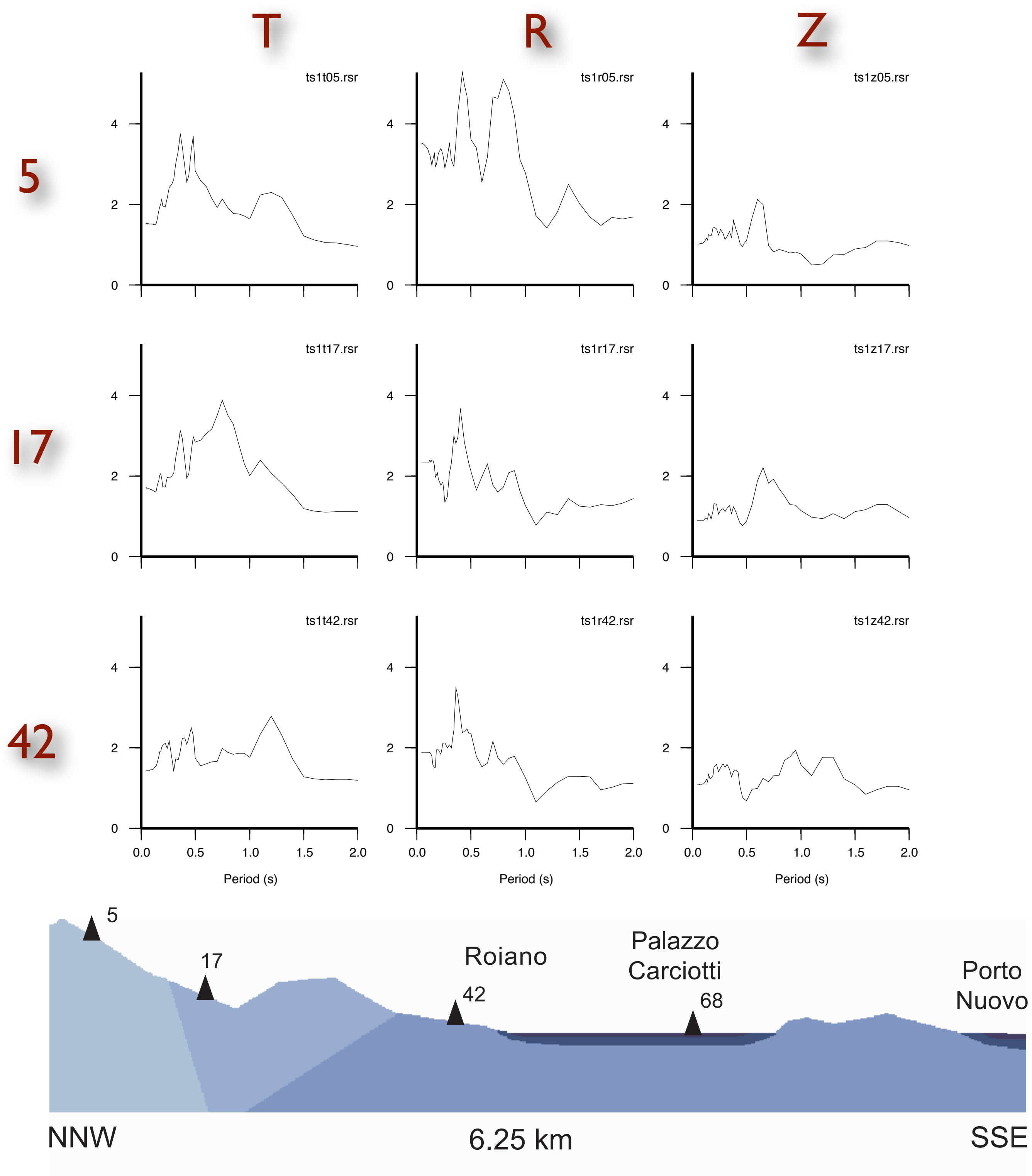
R

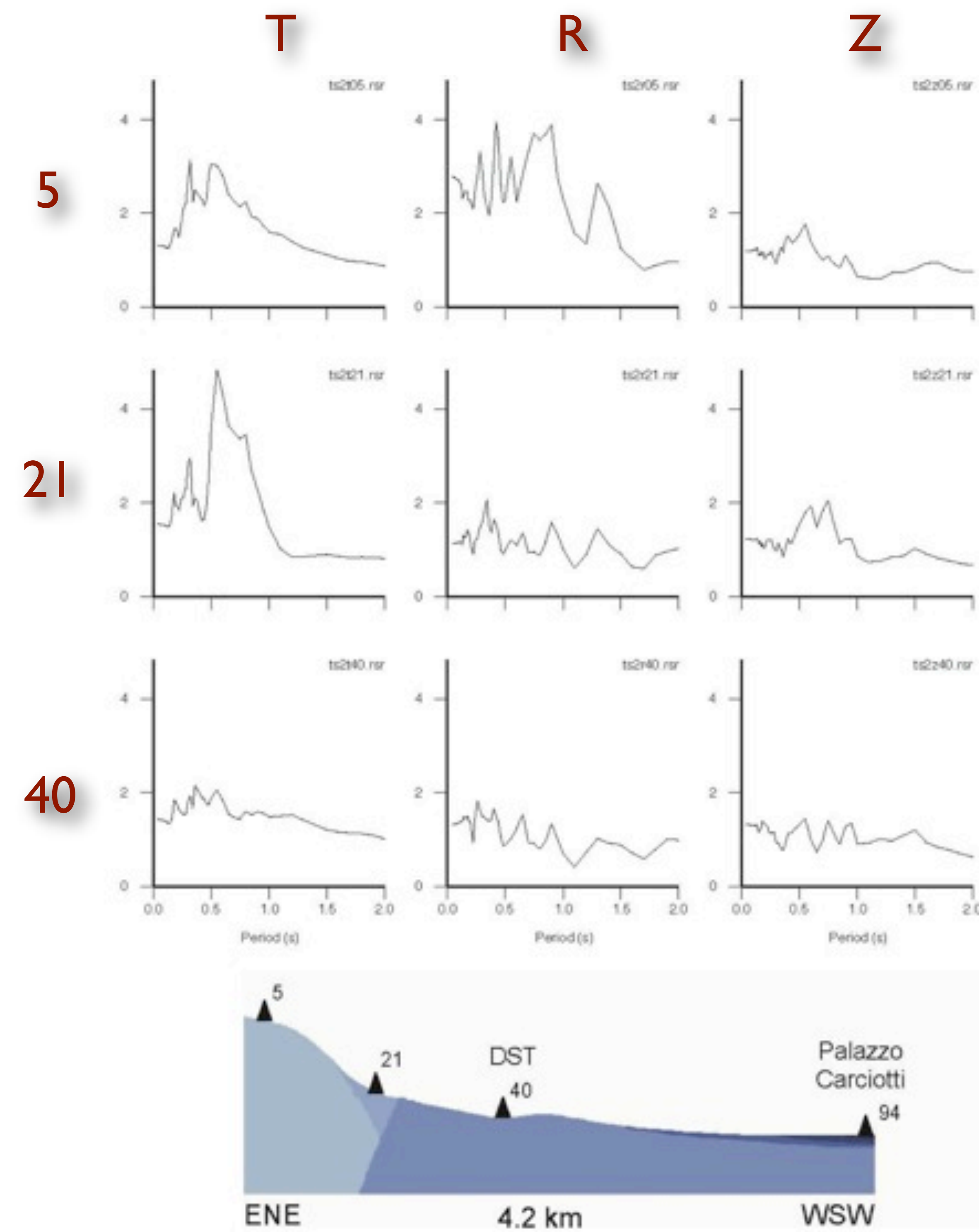
T



Local Scale - Response Spectra Ratio

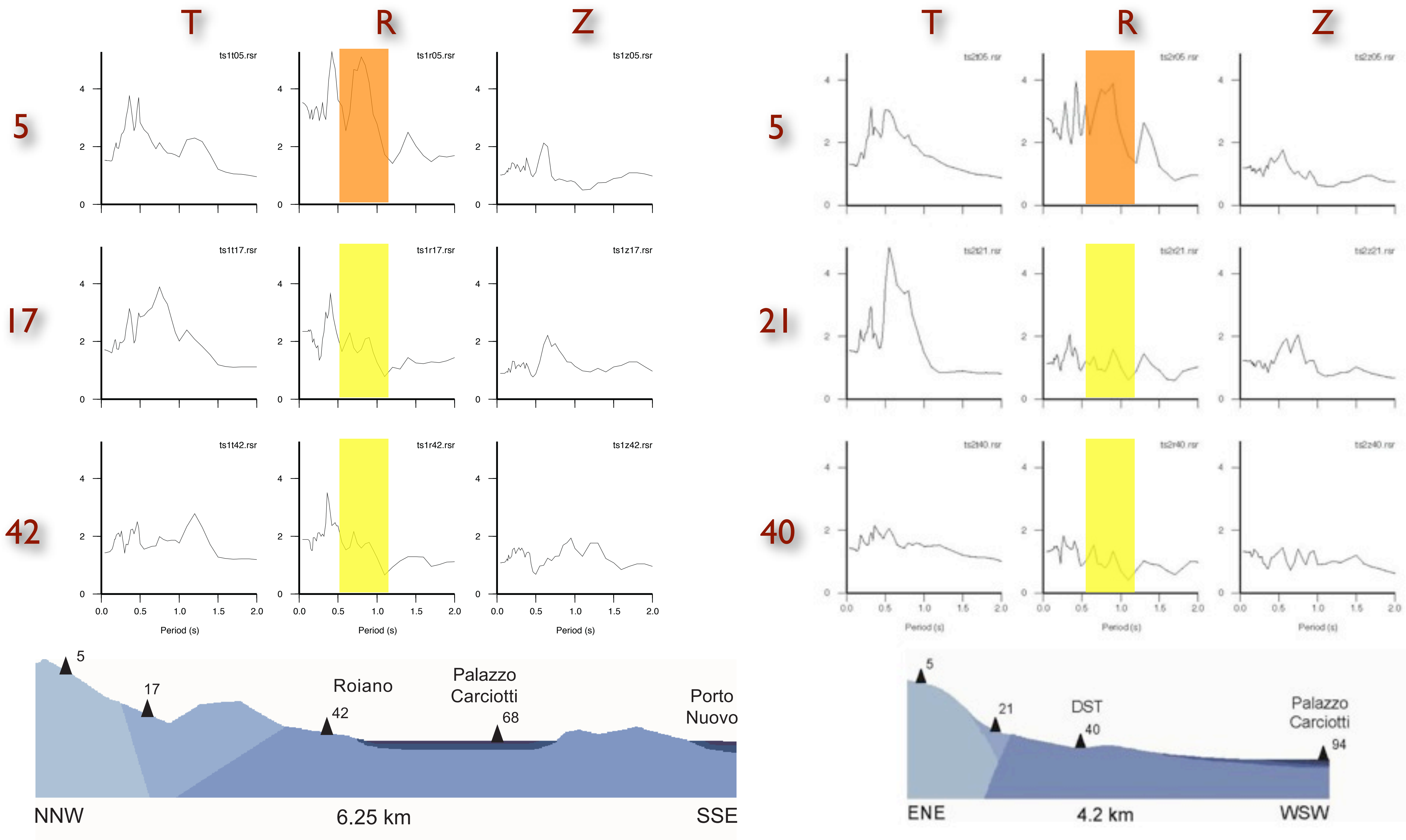
- Choice of reference site





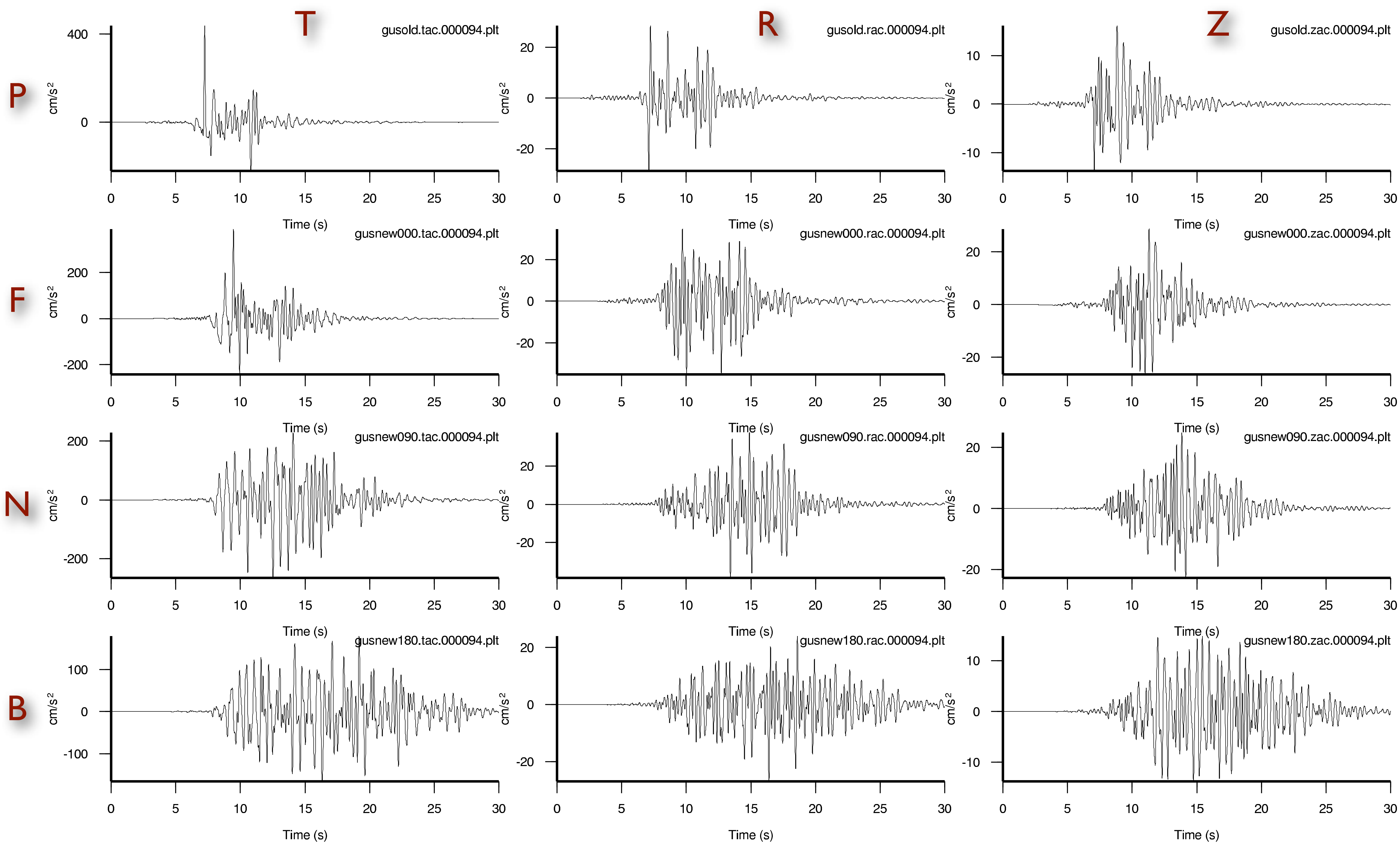
Local Scale - Response Spectra Ratio

- Choice of reference site



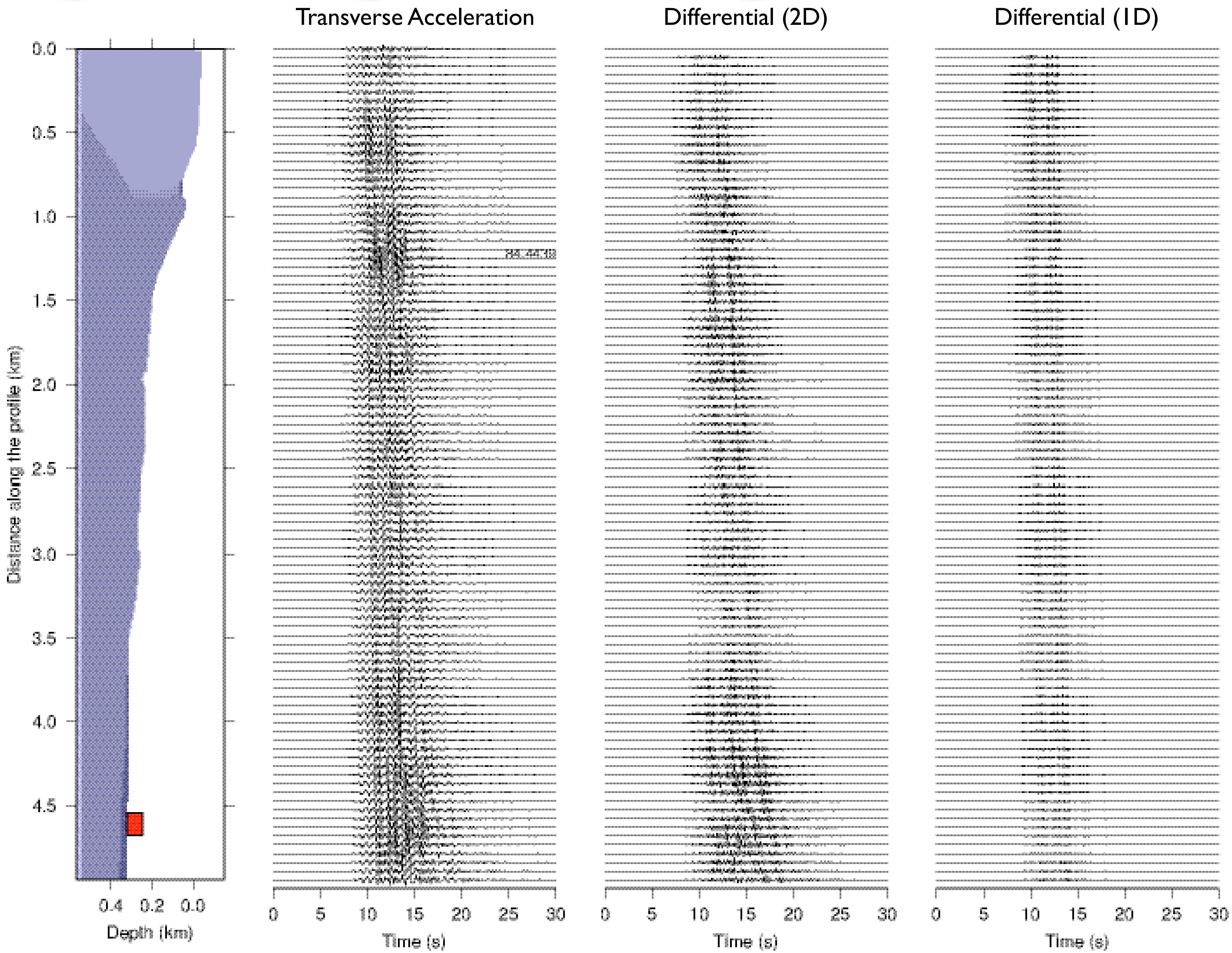
Local Scale - Source Model

- Seismic Source of finite dimension and complicated rupturing process



Local Scale - Differential Motion

- Significant for elongated structures (bridges, lifelines etc)



Local Scale - Engineering Analysis

- The data set of synthetic seismograms can be 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.
- Evaluate the response of relevant man-made structures, in terms of displacements and stresses, with respect to a set of possible scenario earthquakes