The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

SMR/1882-5

Seismic Hazard in Asia

4 - 8 December 2006

Synthetic Seismograms for Deterministic Seismic Zoning and Microzoning

Input Data Preparation and Modelling

F. Vaccari[1, 2]

[1] Department of Earth Sciences
University of Trieste

[2] ICTP SAND Group, Trieste

Synthetic Seismograms for Deterministic Seismic Zoning and Microzoning

Input Data Preparation and Modelling

Franco Vaccari

Dipartimento di Scienze della Terra, Università di Trieste
ICTP - The Abdus Salam International Centre for Theoretical Physics

Trieste, Italy

e-mail contact: vaccari@dst.units.it

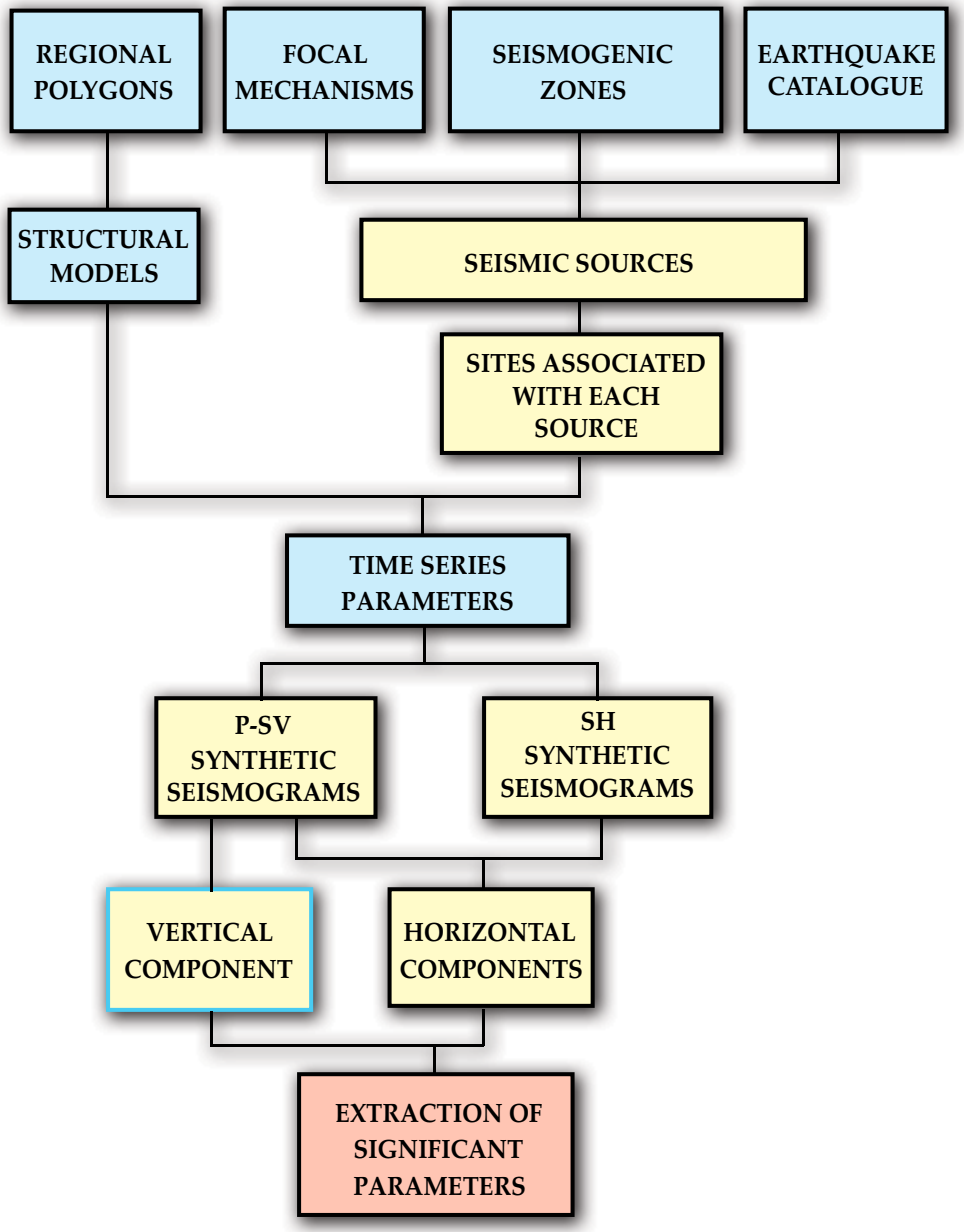
Introduction - Regional Scale

- 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

Regional Scale - Flowchart

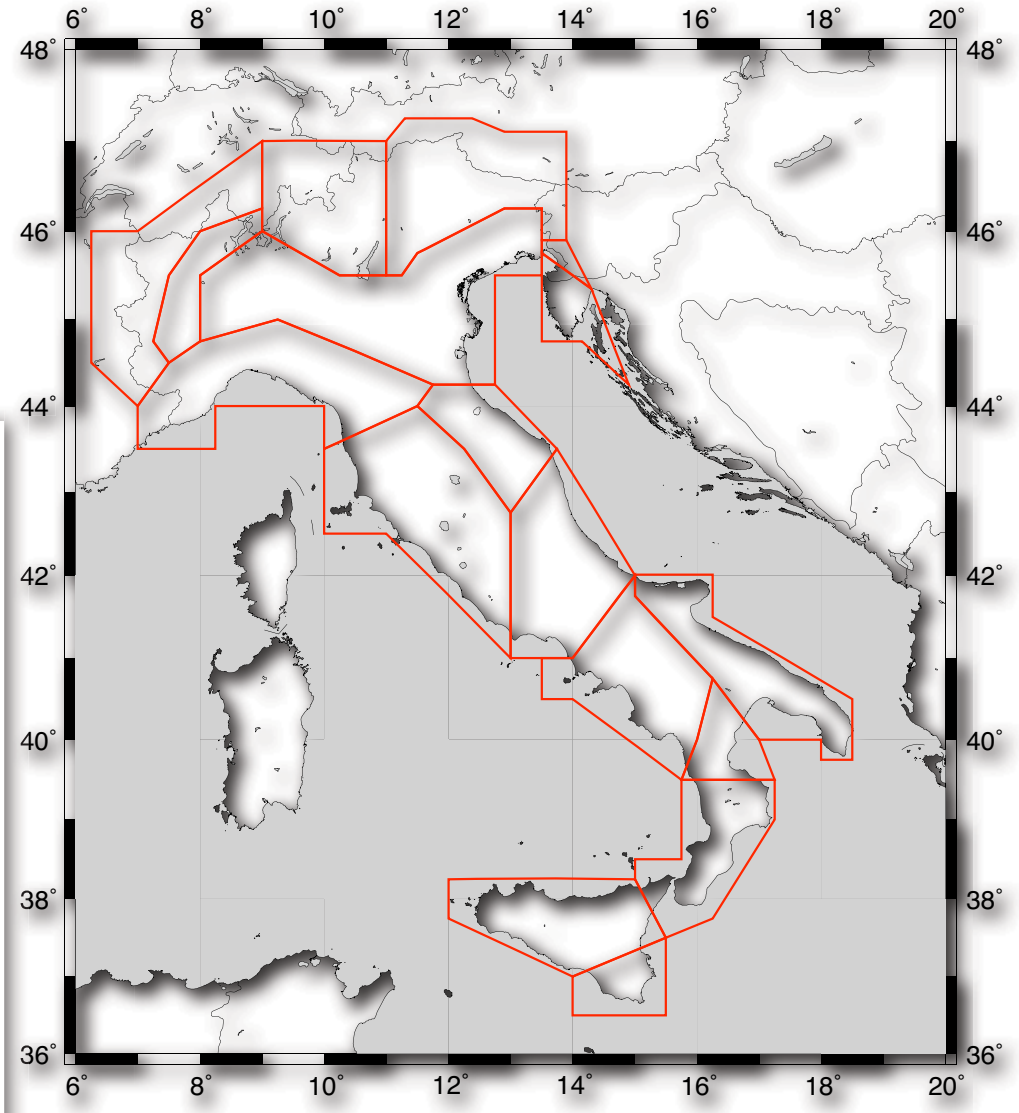


Regional Scale - Definition of Structures

REGIONAL POLYGONS

STRUCTURAL MODELS

```
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
             15.750  38.500
region0003
             16.250  40.750
             16.000  40.000
             15.750  39.500
             17.250  39.500
             17.000  40.000
...
...
```

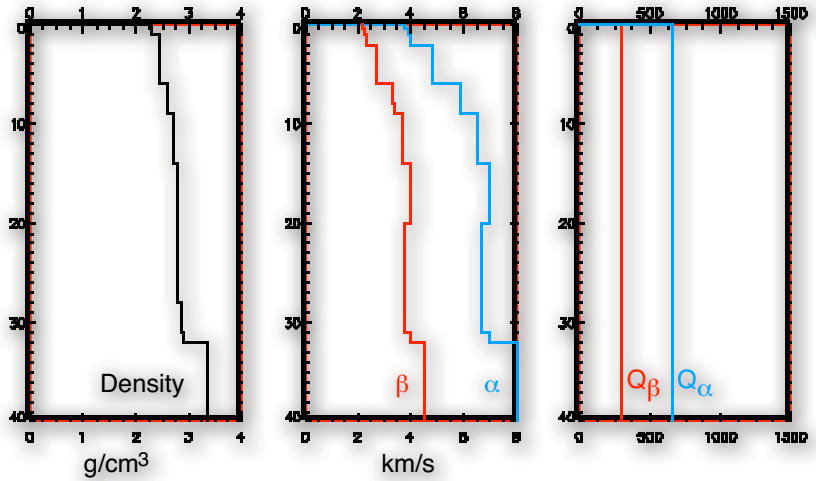


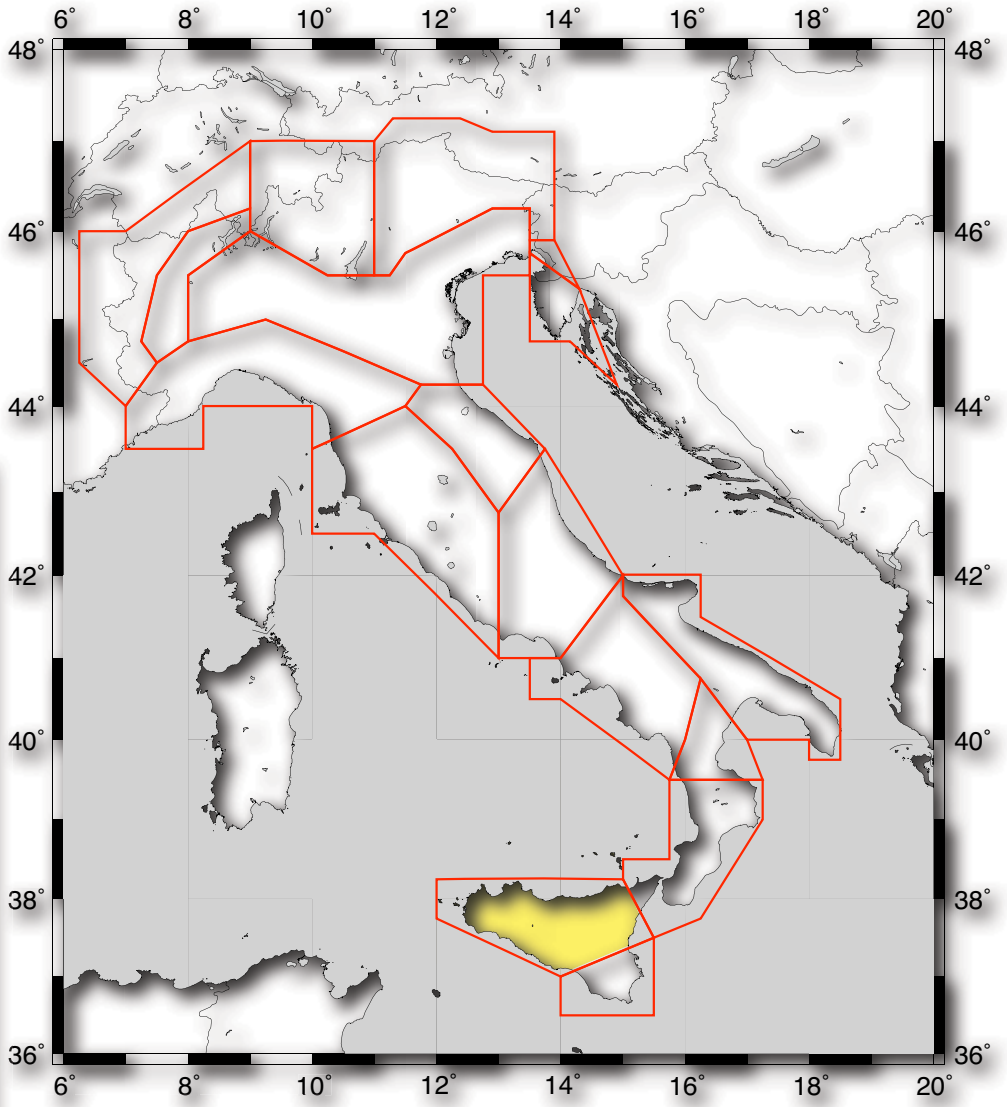
Regional Scale - Definition of Structures

REGIONAL POLYGONS

STRUCTURAL MODELS

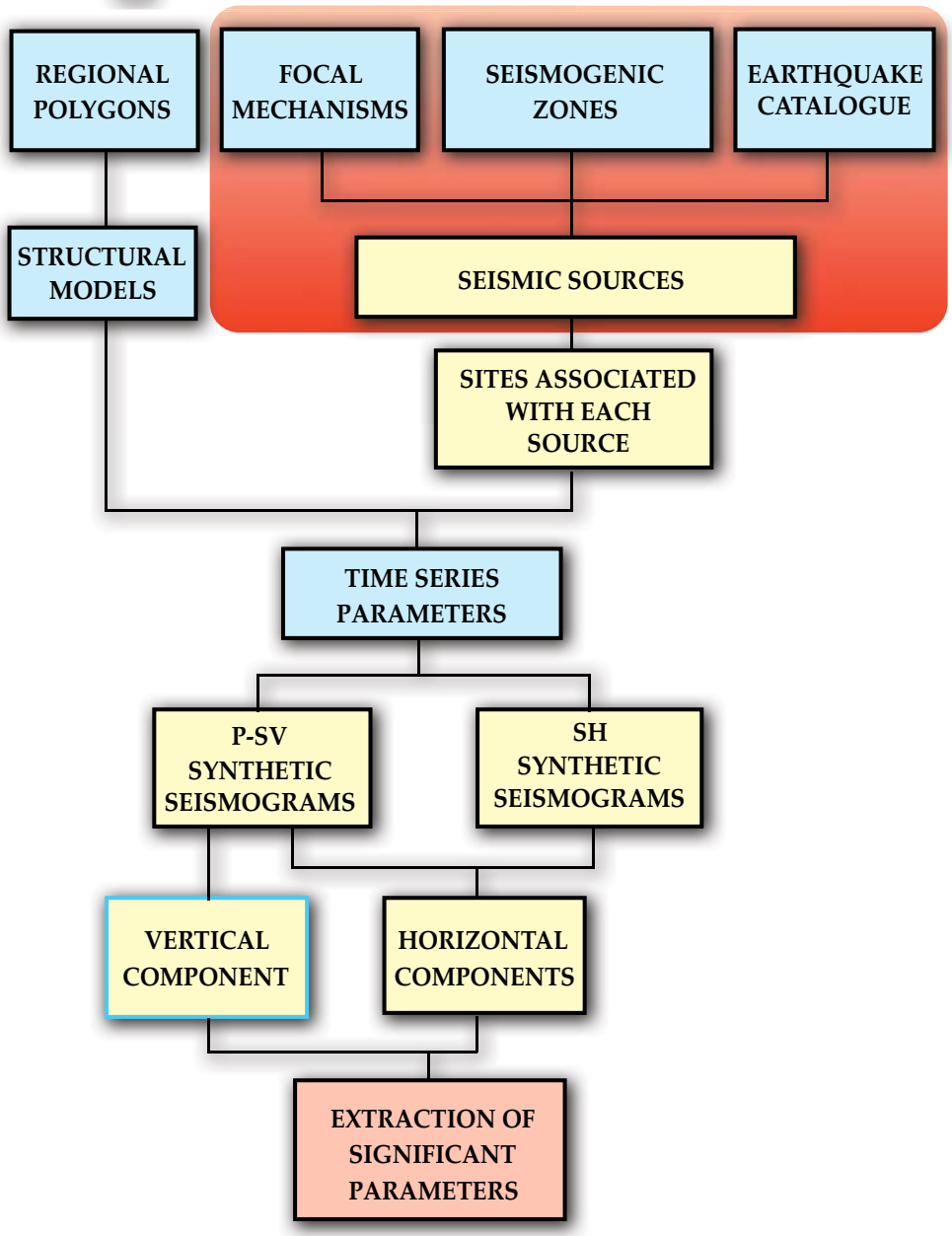
thk(km)	rho	Vp(km/s)	Vs(km/s)	Qp	Qs	depth(km)	layer
0.5000	2.30	3.800000	2.200000	660.01	300.00	0.50000	1
0.5000	2.30	3.900000	2.250000	660.00	300.00	1.00000	2
1.0000	2.45	4.000000	2.300000	660.01	300.00	2.00000	3
4.0000	2.45	4.800000	2.700000	659.99	300.00	6.00000	4
3.0000	2.60	5.900000	3.350000	660.01	300.00	9.00000	5
5.0000	2.70	6.500000	3.700000	660.00	300.00	14.00000	6
6.0000	2.80	7.000000	4.000000	659.97	300.00	20.00000	7
8.0000	2.80	6.700000	3.750200	660.01	299.99	28.00000	8
3.0000	2.85	6.700000	3.750200	660.01	299.99	31.00000	9
1.0000	2.90	7.000000	4.000000	659.97	300.00	32.00000	10
68.0000	3.35	8.000000	4.500000	660.00	300.00	100.00000	11



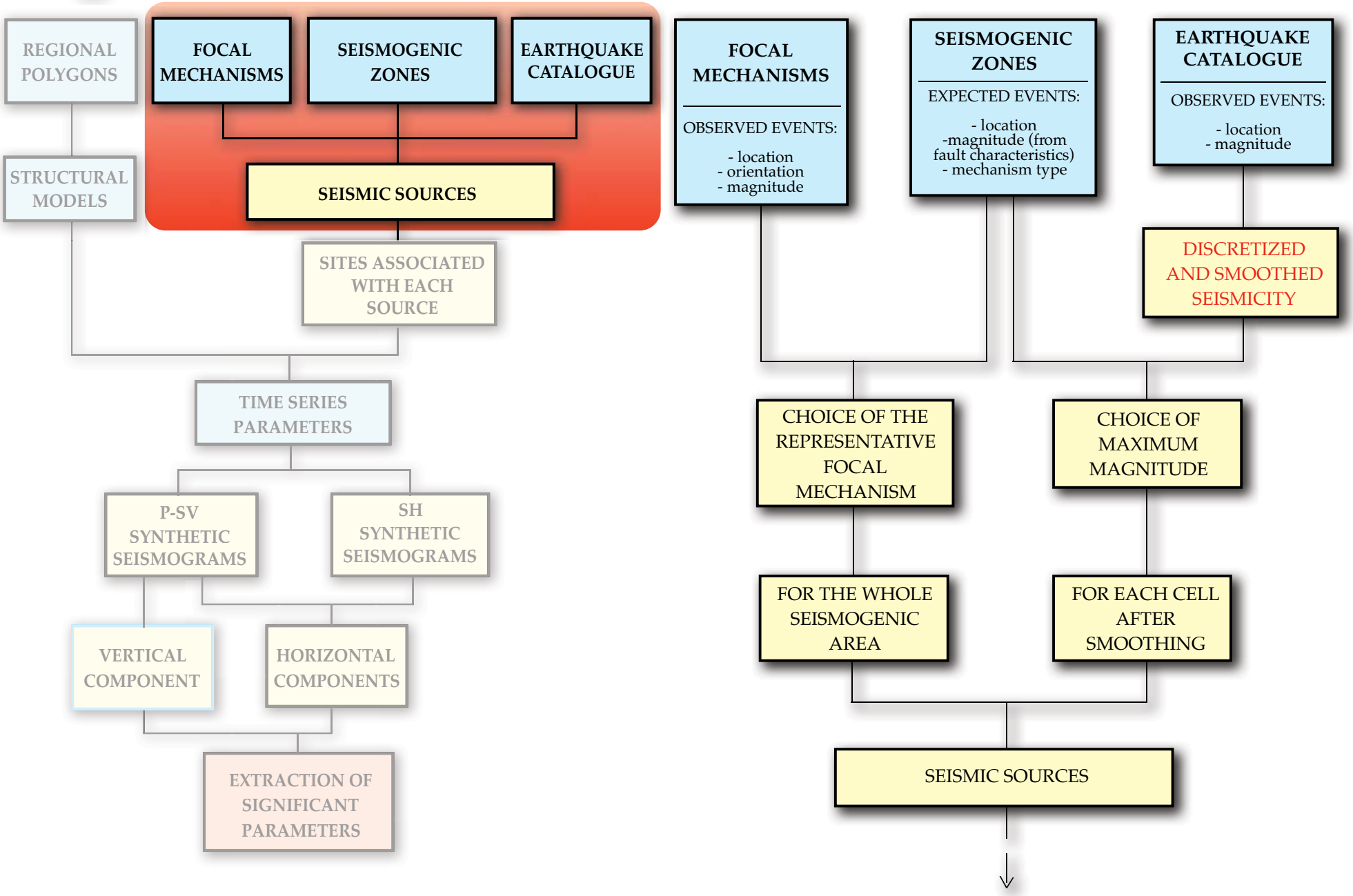


Down to ~1000 km

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:

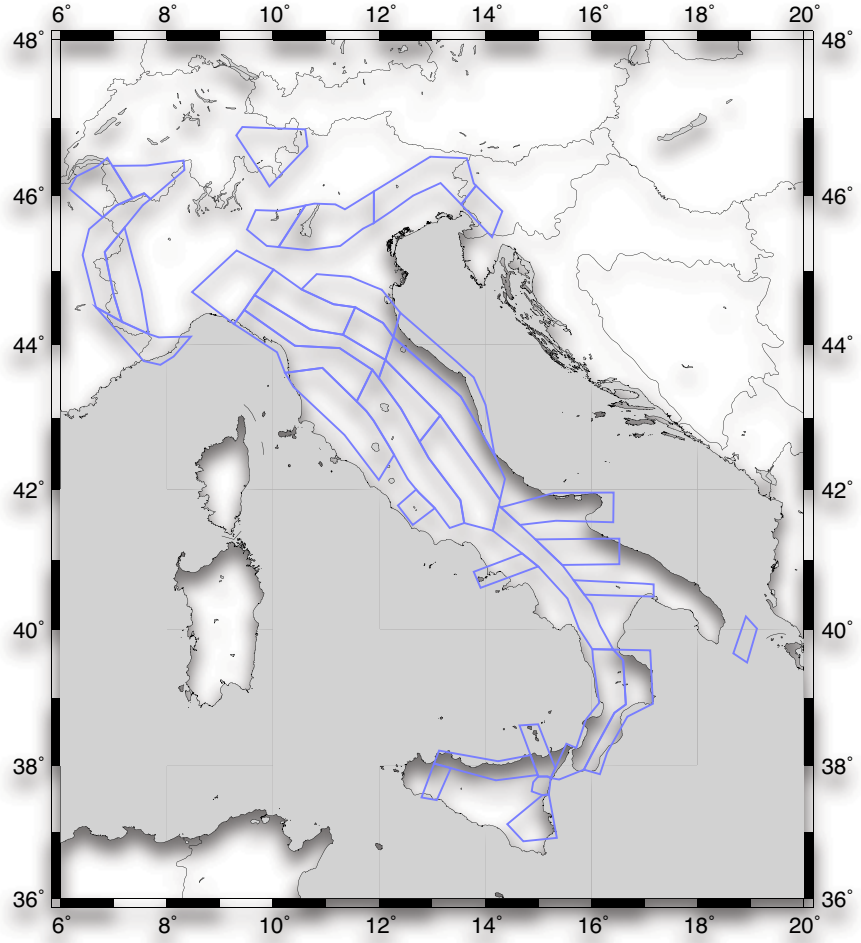
- location
- magnitude (from fault characteristics)
- mechanism type

EARTHQUAKE CATALOGUE

OBSERVED EVENTS:

- location
- magnitude

```
seismogenic zones (lon, lat)
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
...
...
```



Regional Scale - Definition of Sources

FOCAL MECHANISMS

OBSERVED EVENTS:

- location
- orientation
- magnitude

SEISMOGENIC ZONES

EXPECTED EVENTS:

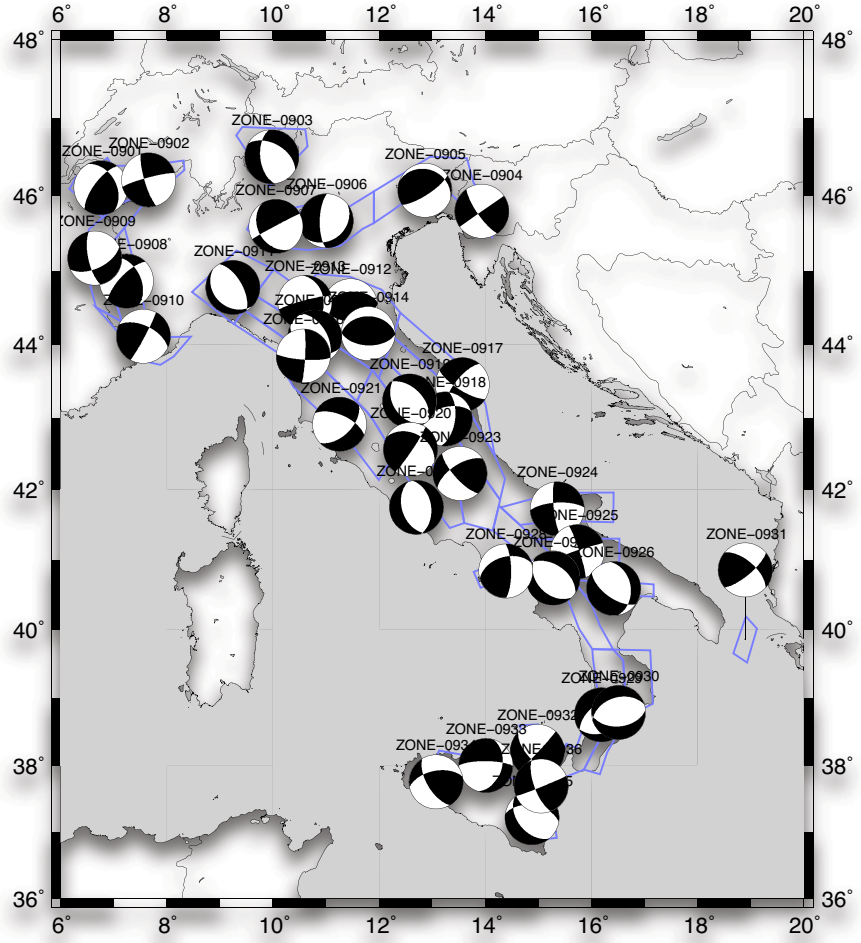
- location
- magnitude (from fault characteristics)
- mechanism type

EARTHQUAKE CATALOGUE

OBSERVED EVENTS:

- location
- magnitude

```
-------------------- fault plane solutions ----------------------------------
numbea yearmody hrmisec la.titn lon.gite dept mlmdmsmbma agen areadescri
numbef st1 d1 ra1  st2 d2 ra2   pdi pi  tdi ti  bdi bi q refe areadescri
numbem m00 sf refe dura f2 m0xx er1 m0yy er2 m0zz er3 m0xy er4 m0xz er5 m0yz er6
numbet hdr sf m0 tval td taz nval nd naz pval pd paz ast ad ara bst bd bra refer
numbeu sf smrr er1 smtt er2 smff er3 smrt er4 smrf er5 smtf er6
--------------------------------------------------------------------------------
00044A 19591223  929000 37.720n  14.610e  770  0 0 0 053      sicily
00044F 077 43 004  344 87 132   041 29  289 34  161 43   0001 sicily
00054A 19671031 2108000 37.840n  14.600e  380  0 0 0 050      sicily
00054F 009 61 189  274 80 333   228 27  324 13  077 60   0001 sicily
00057A 19680115  133000 37.890n  13.080e  200  0 0 0 051      sicily
00057F 040 82 046  302 46 168   163 23  272 37  049 45   0001 sicily
00058A 19680115  201000 37.780n  13.030e   30  0 0 0 054      sicily
00058F 204 70 015  108 75 159   157 04  065 25  255 65   0001 sicily
00058B 19680115  201085 37.750n  12.983e  100  0 0 054 0      sicily
00058G 270 50 035  156 64 134   216 08  116 50  313 39   0002 sicily
00059A 19680116 1642000 37.860n  12.990e  140  0 0 0 051      sicily
00059F 327 59 030  220 64 145   274 03  181 42  008 48   0001 sicily
00059B 19680116 1642443 37.857n  12.976e  360  0 0 051 0      sicily
00059G 250 58 018  150 75 147   203 11  106 34  309 54   0002 sicily
00060A 19680125  956000 37.710n  13.060e   40  0 0 0 050      sicily
00060F 004 90 195  274 79 358   230 08  138 09  002 79   0001 sicily
...
...
```



Regional Scale - Definition of Sources

FOCAL MECHANISMS

OBSERVED EVENTS:

- location
- orientation
- magnitude

SEISMOGENIC ZONES

EXPECTED EVENTS:

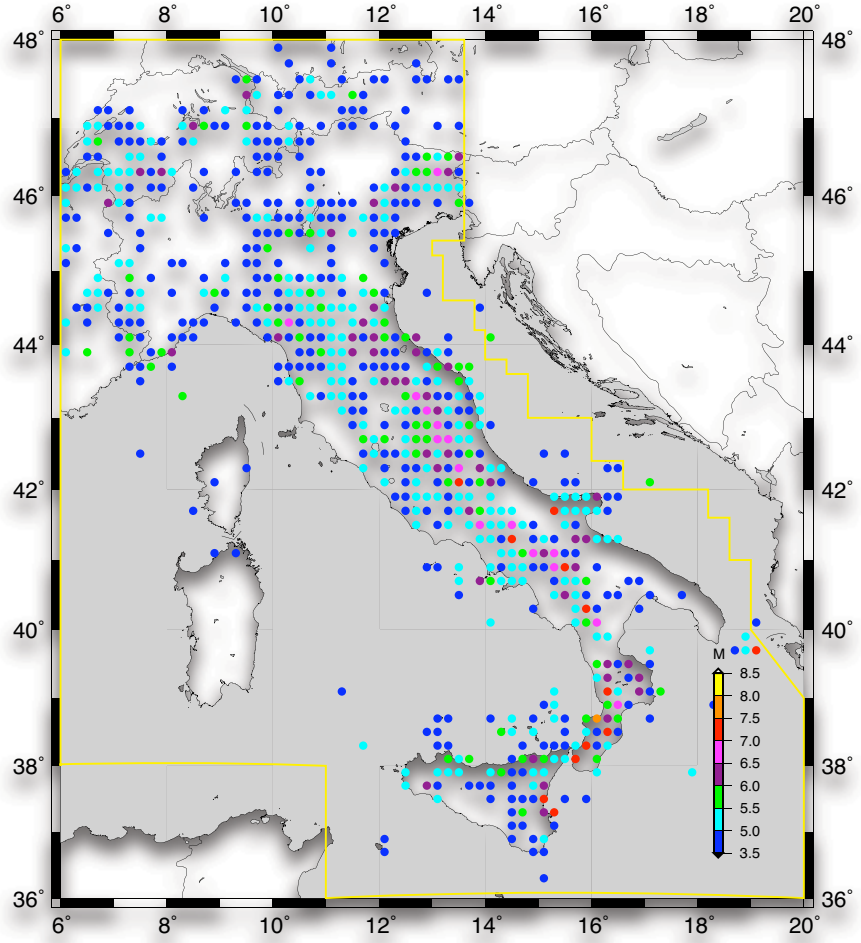
- location
- magnitude (from fault characteristics)
- mechanism type

EARTHQUAKE CATALOGUE

OBSERVED EVENTS:

- location
- magnitude

```
1005 0 0 0 0 0 4347  1188  0520520  05200
1005 0 0 0 0 0 4150  1375  0520520  05200
1065 32711 0 0 4553  1022  0520520  05200
1087 9 0 0 0 0 4125  1560  0500500  05000
1097 0 0 0 0 0 4560  1530  0620620  06200
1117 1 313 0 0 4545  1104  0640640  06400
1120 0 0 0 0 0 4142  1387  0550550  05500
11251011 0 0 0 4113  1478  0550550  05500
1139 122 0 0 0 4110  1483  0420420  04200
1148 0 0 0 0 0 4377  1123  0500500  05000
1168 110 0 0 0 4372  1040  0420420  04200
1169 2 4 0 0 0 3733  1520  0730730  07300
1170 3 9 0 0 0 4157  1333  0520520  05200
1182 815 0 0 0 4442   890  0440440  04400
1184 0 0 0 0 0 3942  1620  0640640  06400
1194 0 0 0 0 0 4400  1192  0500500  05000
1196 0 0 0 0 0 4393  1092  0440440  04400
1198 0 0 0 0 0 4082  1417  0500500  05000
1200 0 0 0 0 0 4000  1608  0660660  0  00
1201 5 415 0 0 4710  1420  0620620  06200
1217 1 8 0 0 0 4442   890  0420420  04200
1222122511 0 0 4553  1062  0590590  05900
1223 0 0 0 0 0 4184  1604  0620620  06200
...
...
```



Regional Scale - Definition of Sources

FOCAL MECHANISMS

OBSERVED EVENTS:

- location
- orientation
- magnitude

SEISMOGENIC ZONES

EXPECTED EVENTS:

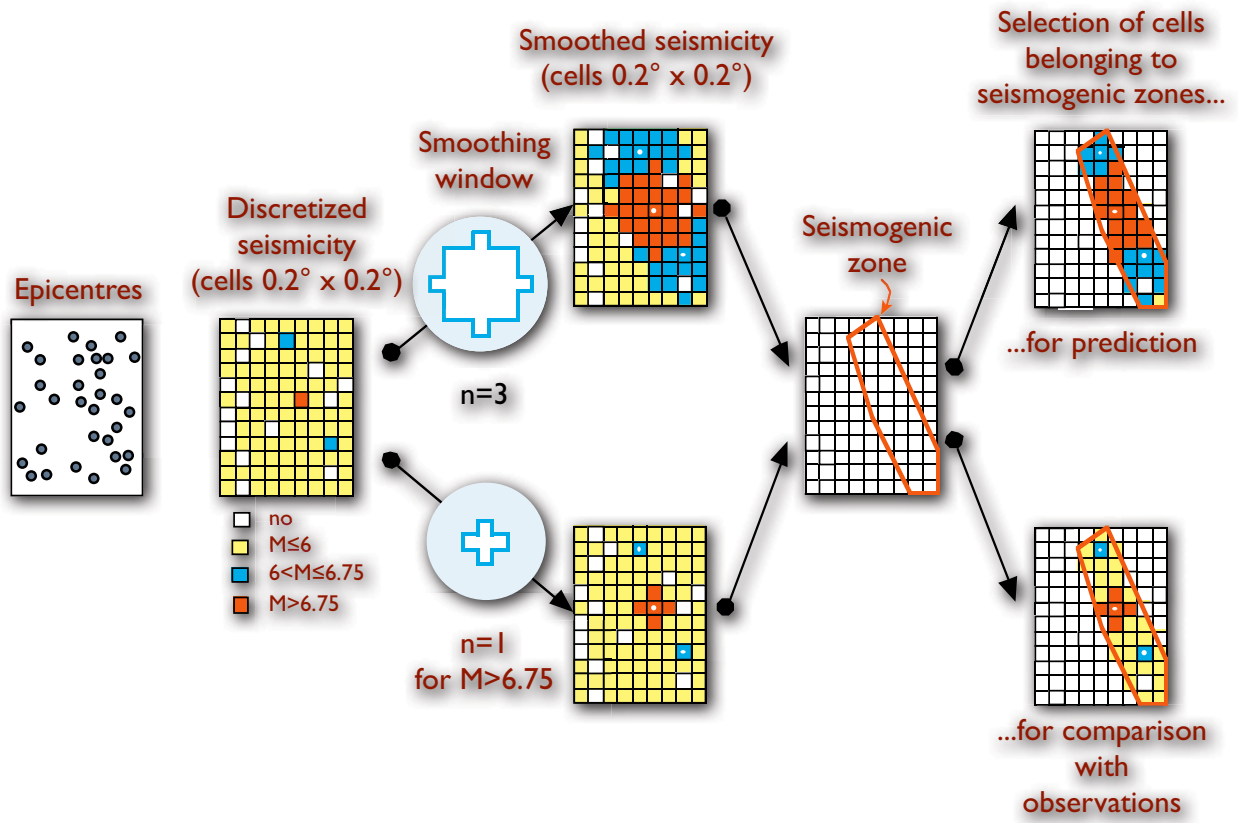
- location
- magnitude (from fault characteristics)
- mechanism type

EARTHQUAKE CATALOGUE

OBSERVED EVENTS:

- location
- magnitude

Discretization and smoothing of seismicity



Regional Scale - Definition of Sources

FOCAL MECHANISMS

OBSERVED EVENTS:

- location
- orientation
- magnitude

SEISMOGENIC ZONES

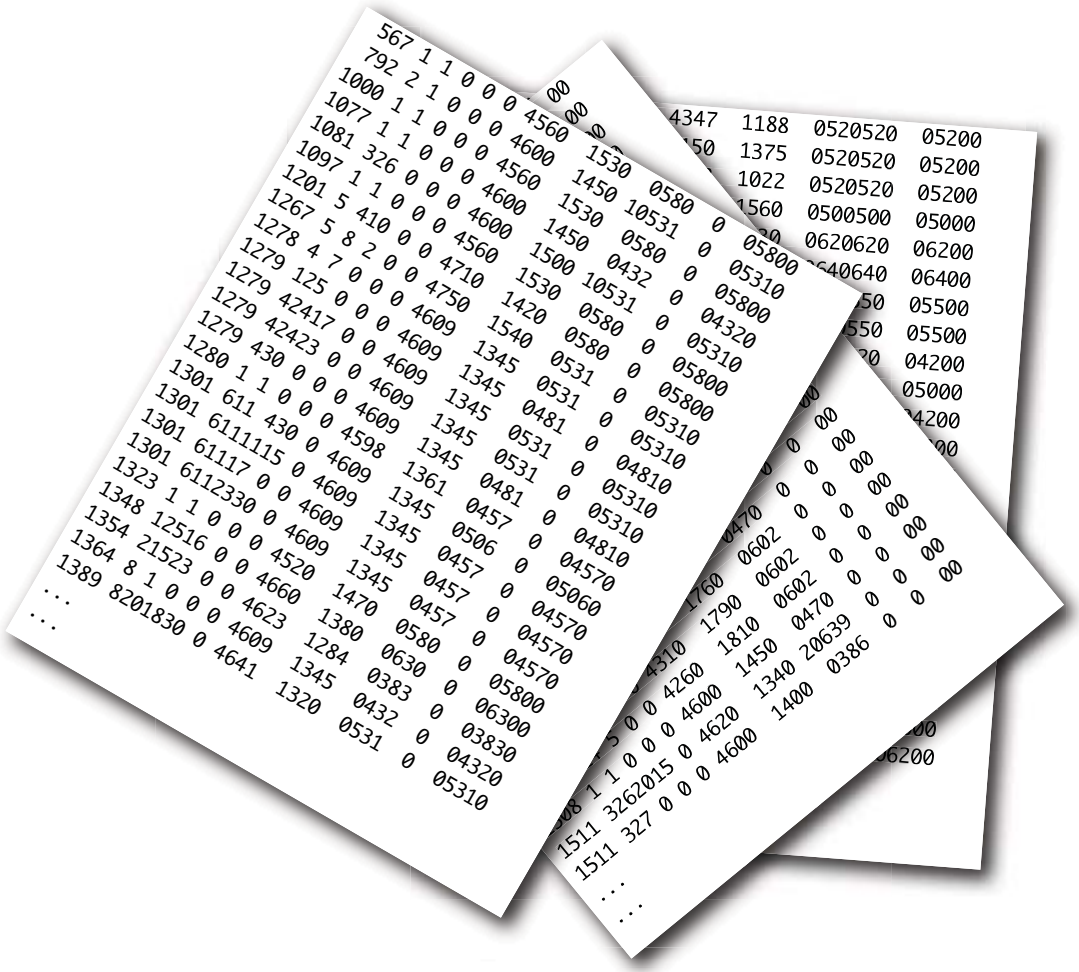
EXPECTED EVENTS:

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

EARTHQUAKE CATALOGUE

OBSERVED EVENTS:

- location
- magnitude



Regional Scale - Definition of Sources

FOCAL MECHANISMS

OBSERVED EVENTS:

- location
- orientation
- magnitude

SEISMOGENIC ZONES

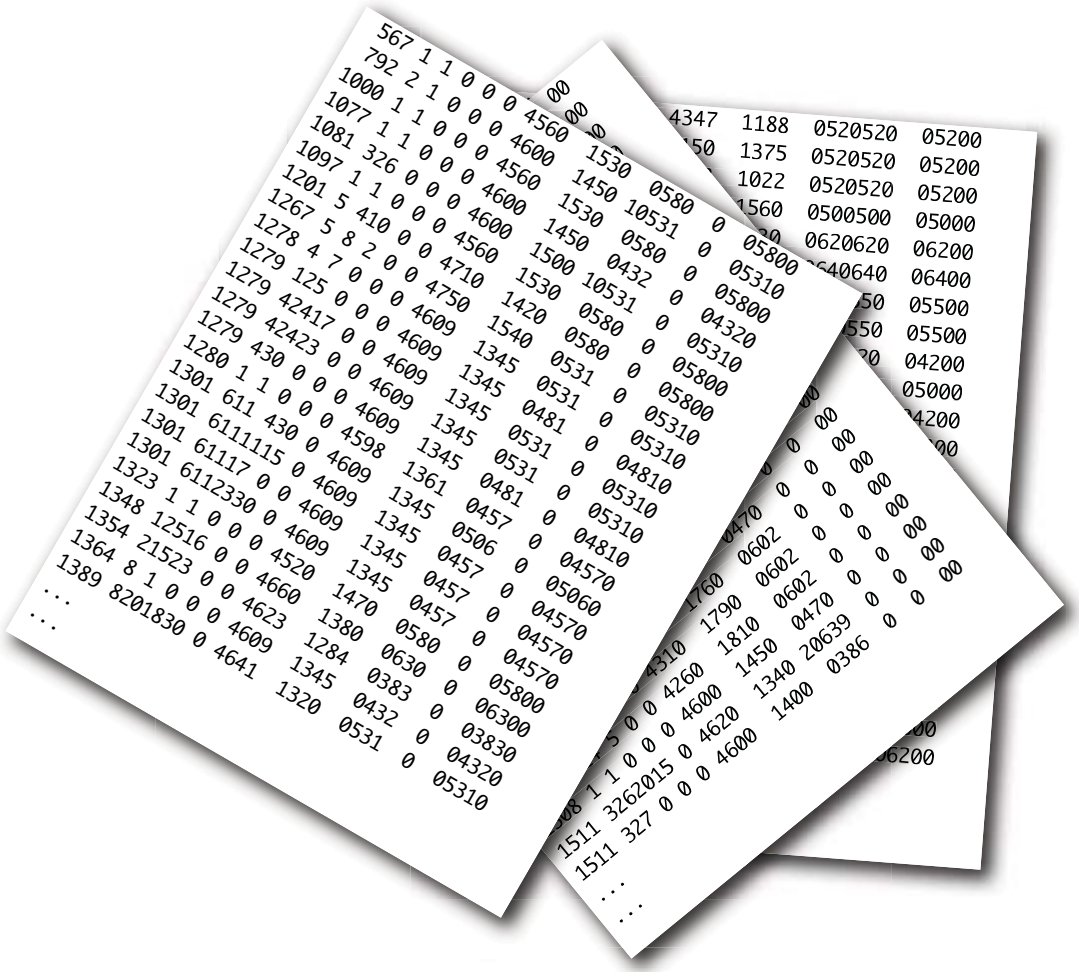
EXPECTED EVENTS:

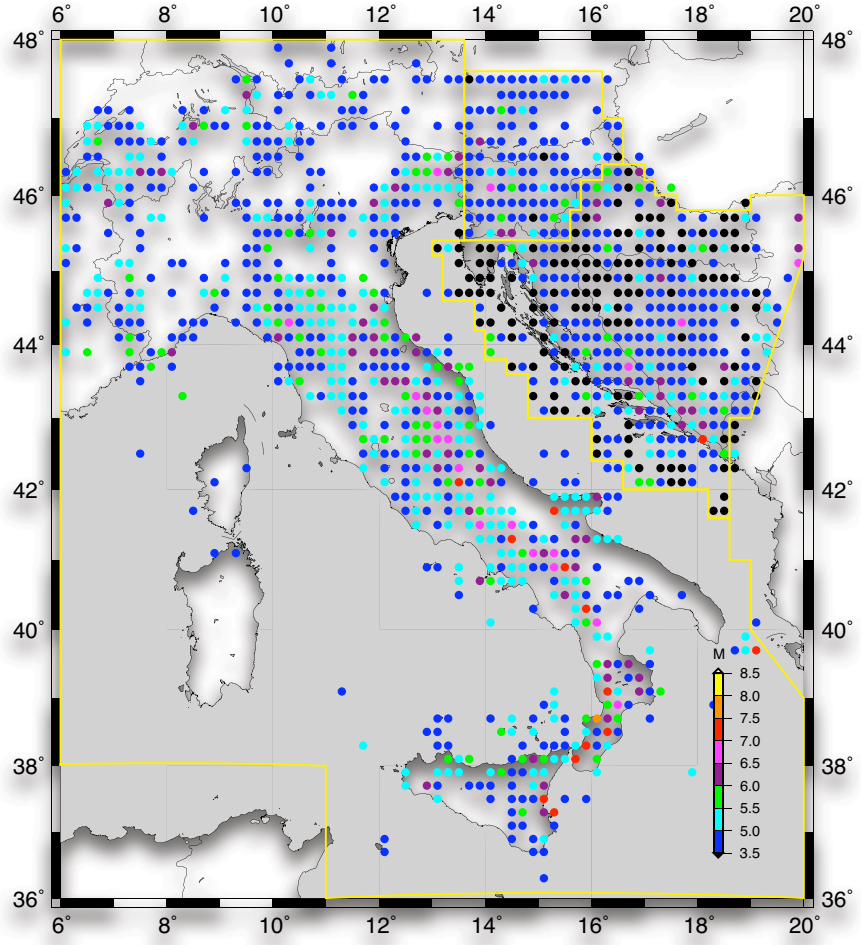
- location
- magnitude (from fault characteristics)
- mechanism type

EARTHQUAKE CATALOGUE

OBSERVED EVENTS:

- location
- magnitude





Regional Scale - Definition of Sources

FOCAL MECHANISMS

OBSERVED EVENTS:

- location
- orientation
- magnitude

SEISMOGENIC ZONES

EXPECTED EVENTS:

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

EARTHQUAKE CATALOGUE

OBSERVED EVENTS:

- location
- magnitude

DISCRETIZED AND SMOOTHED SEISMICITY

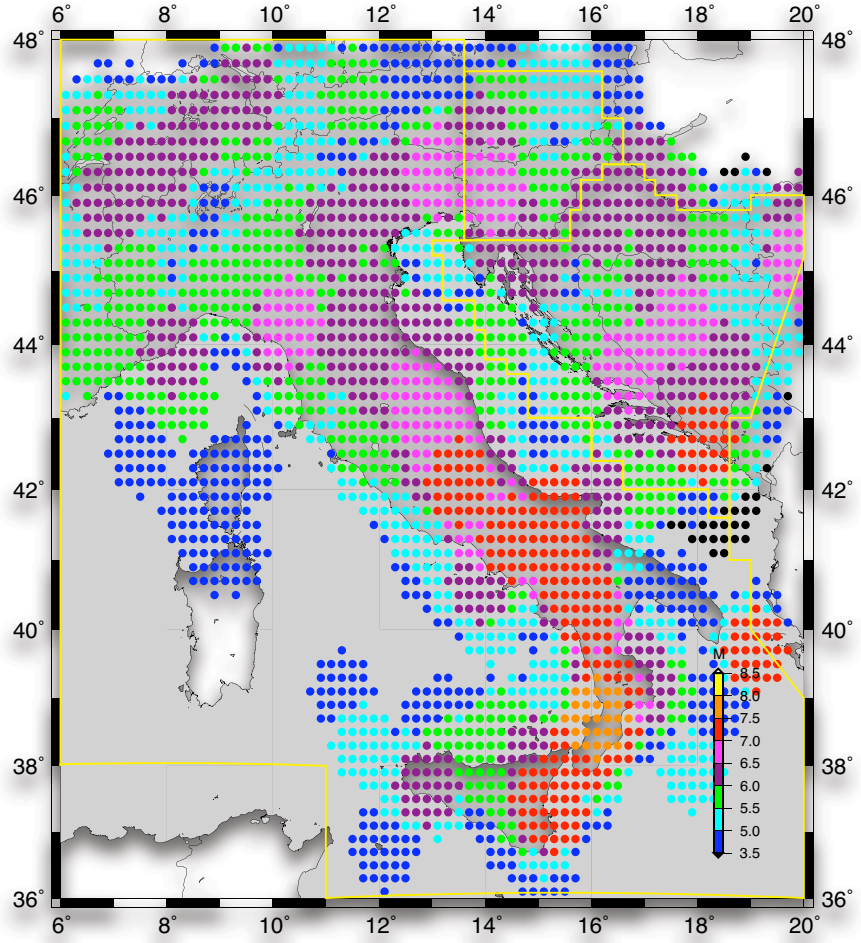
CHOICE OF THE REPRESENTATIVE FOCAL MECHANISM

CHOICE OF MAXIMUM MAGNITUDE

FOR THE WHOLE SEISMOGENIC AREA

FOR EACH CELL AFTER SMOOTHING

SEISMIC 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

DISCRETIZED AND SMOOTHED SEISMICITY

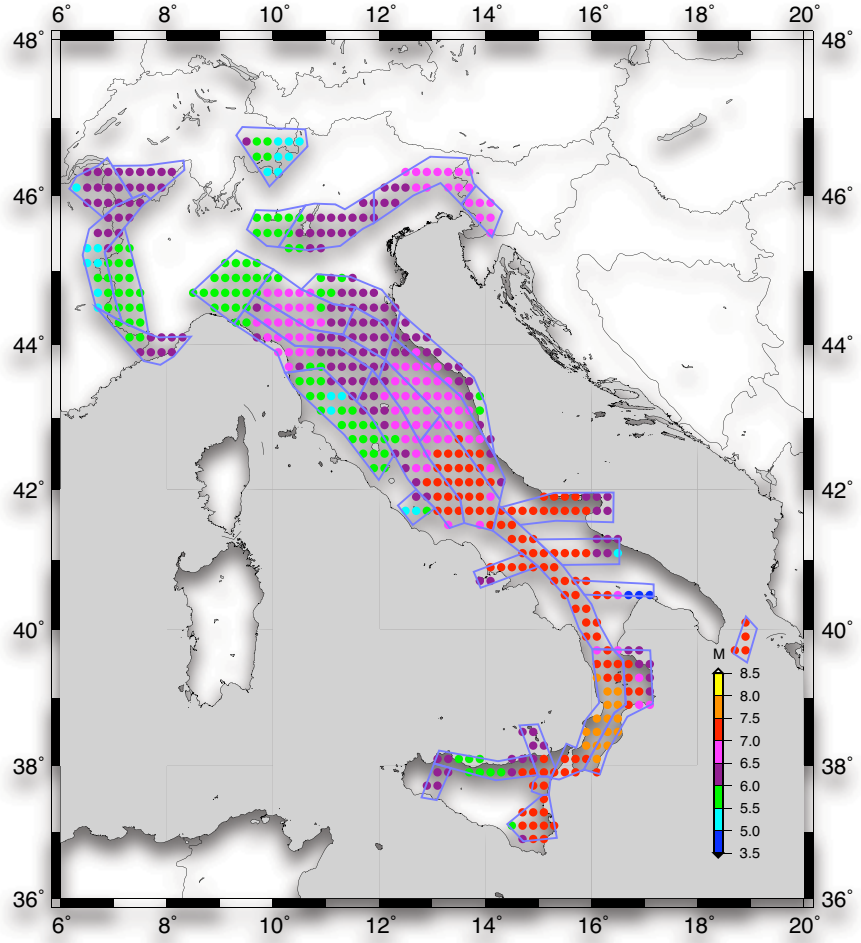
CHOICE OF THE REPRESENTATIVE FOCAL MECHANISM

CHOICE OF MAXIMUM MAGNITUDE

FOR THE WHOLE SEISMOGENIC AREA

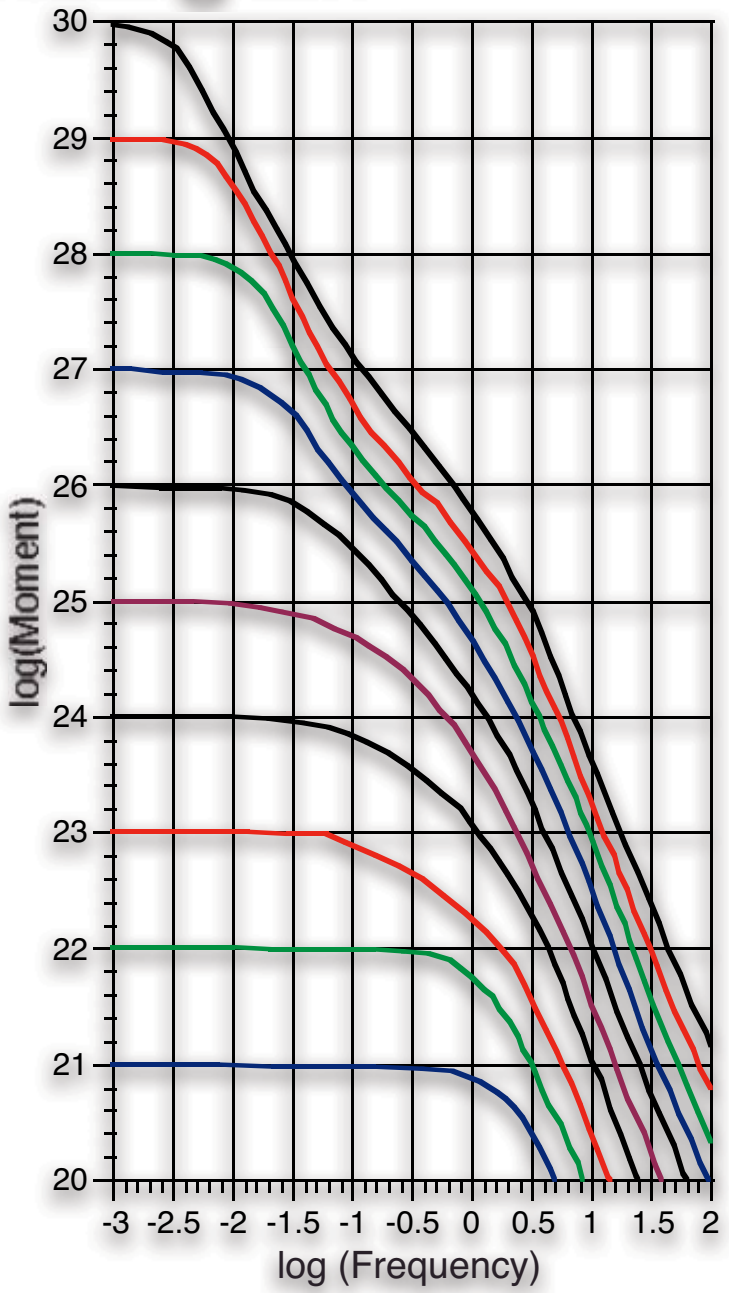
FOR EACH CELL AFTER SMOOTHING

SEISMIC SOURCES

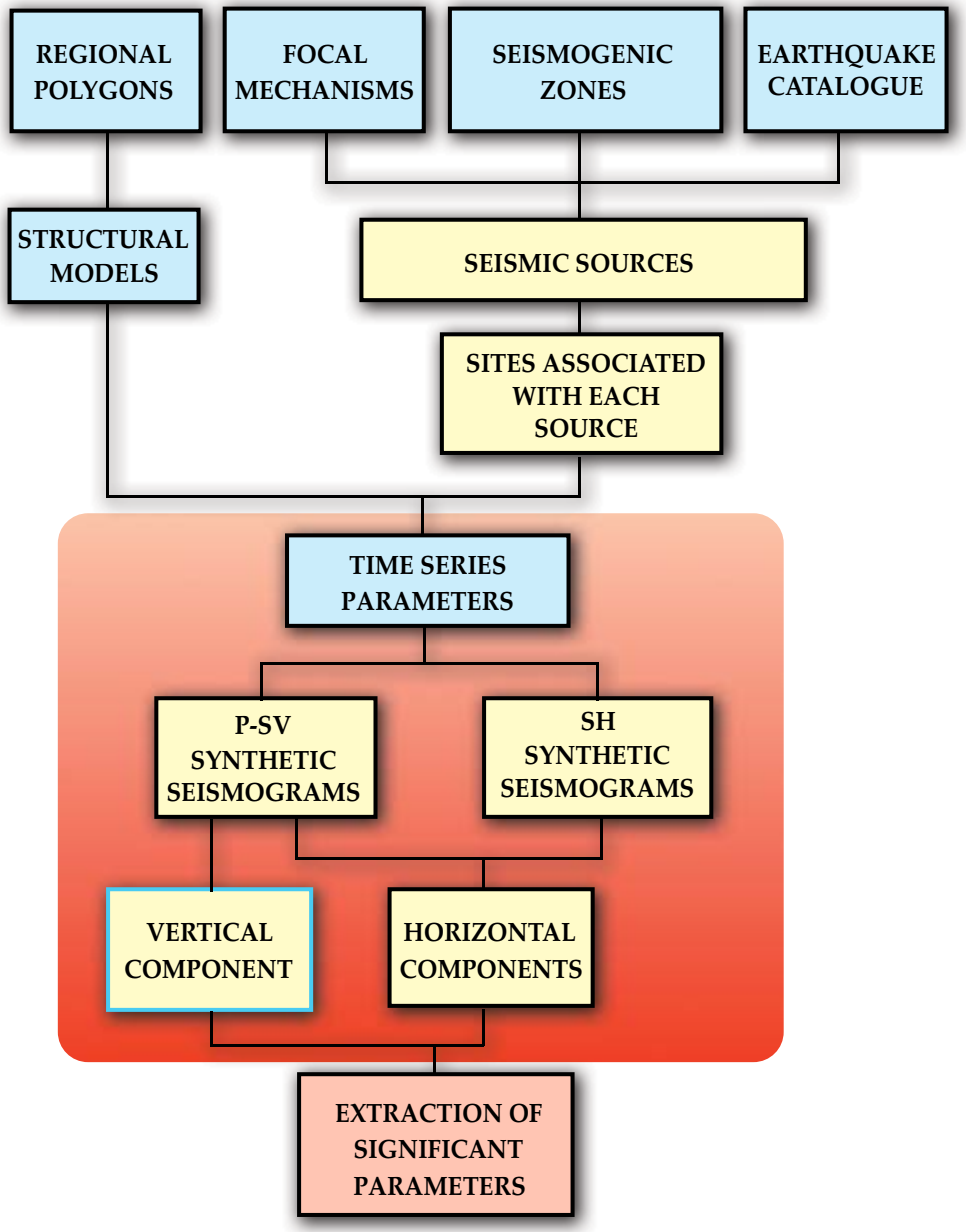


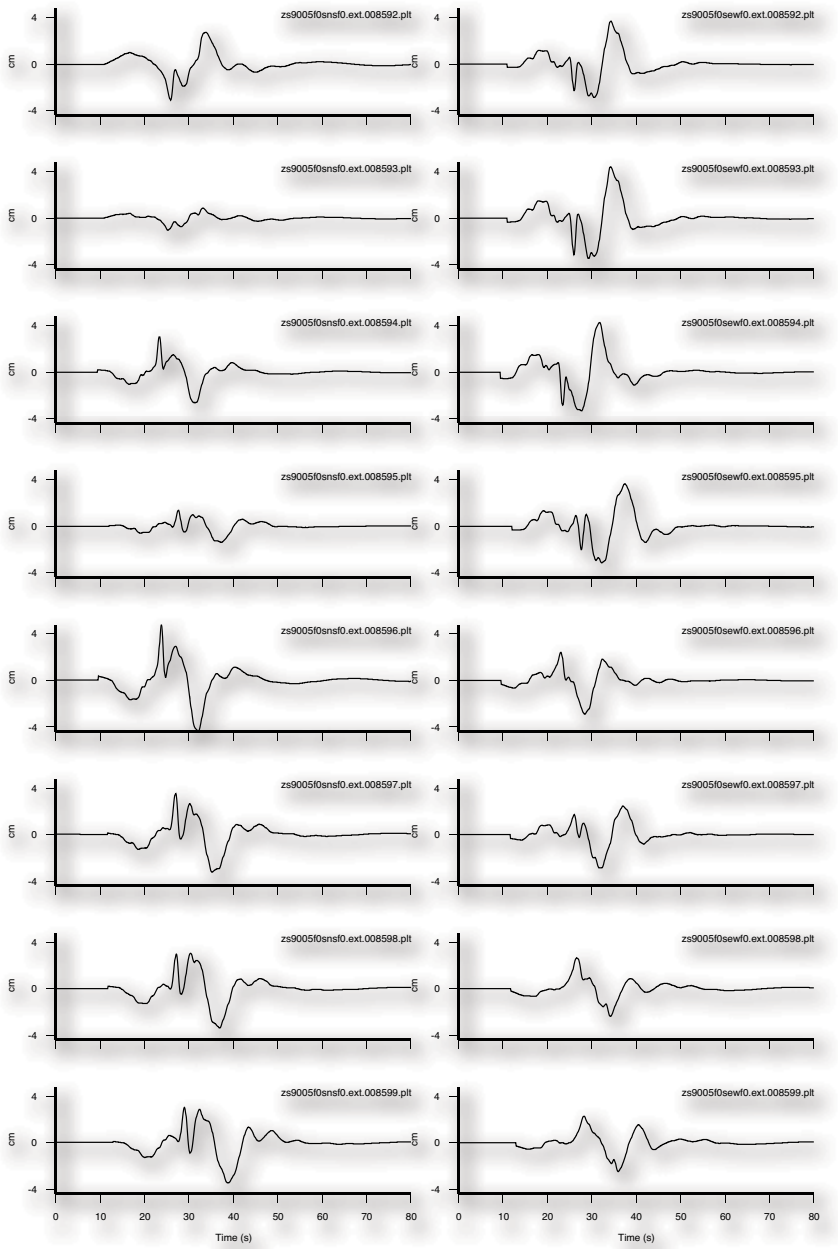
Regional Scale - Spectral scaling law

- 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)

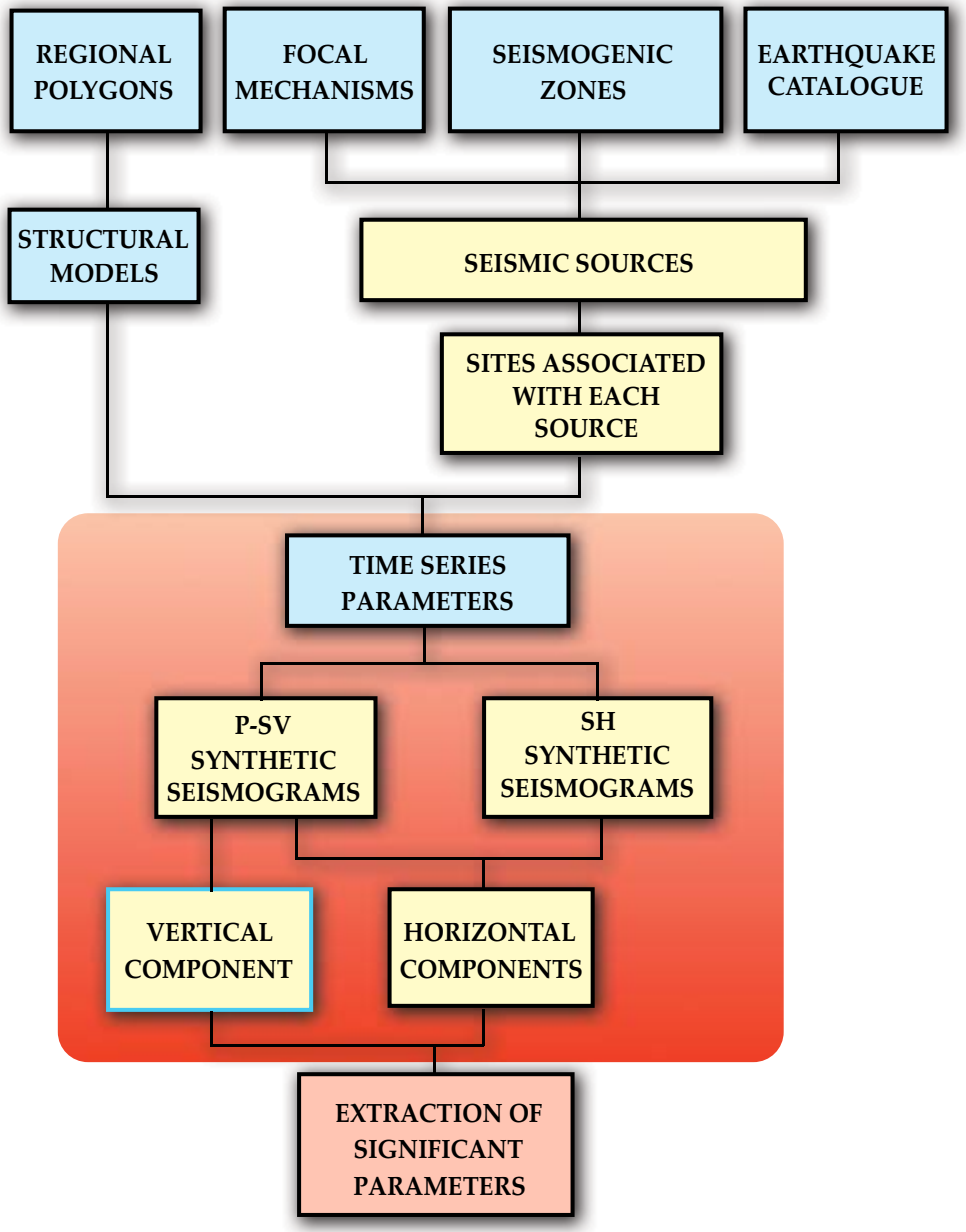


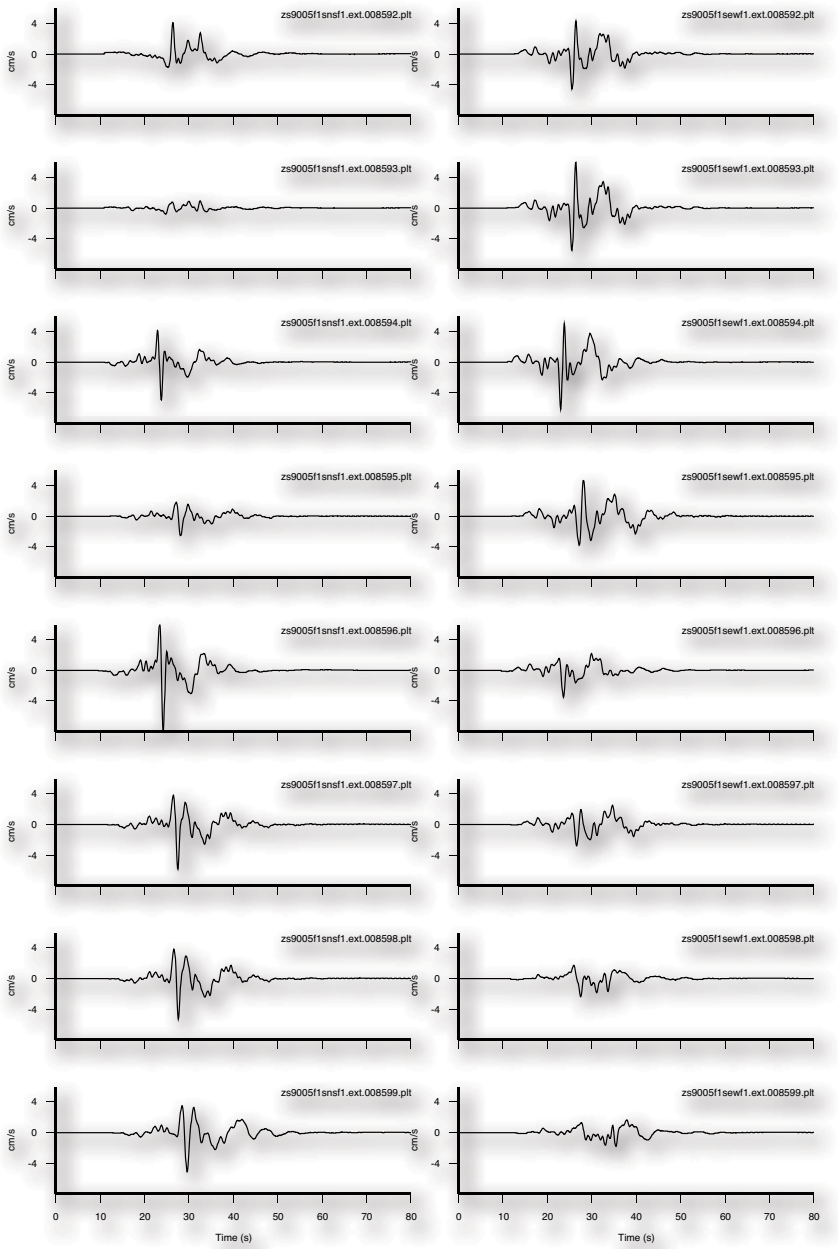
Regional Scale - Seismograms



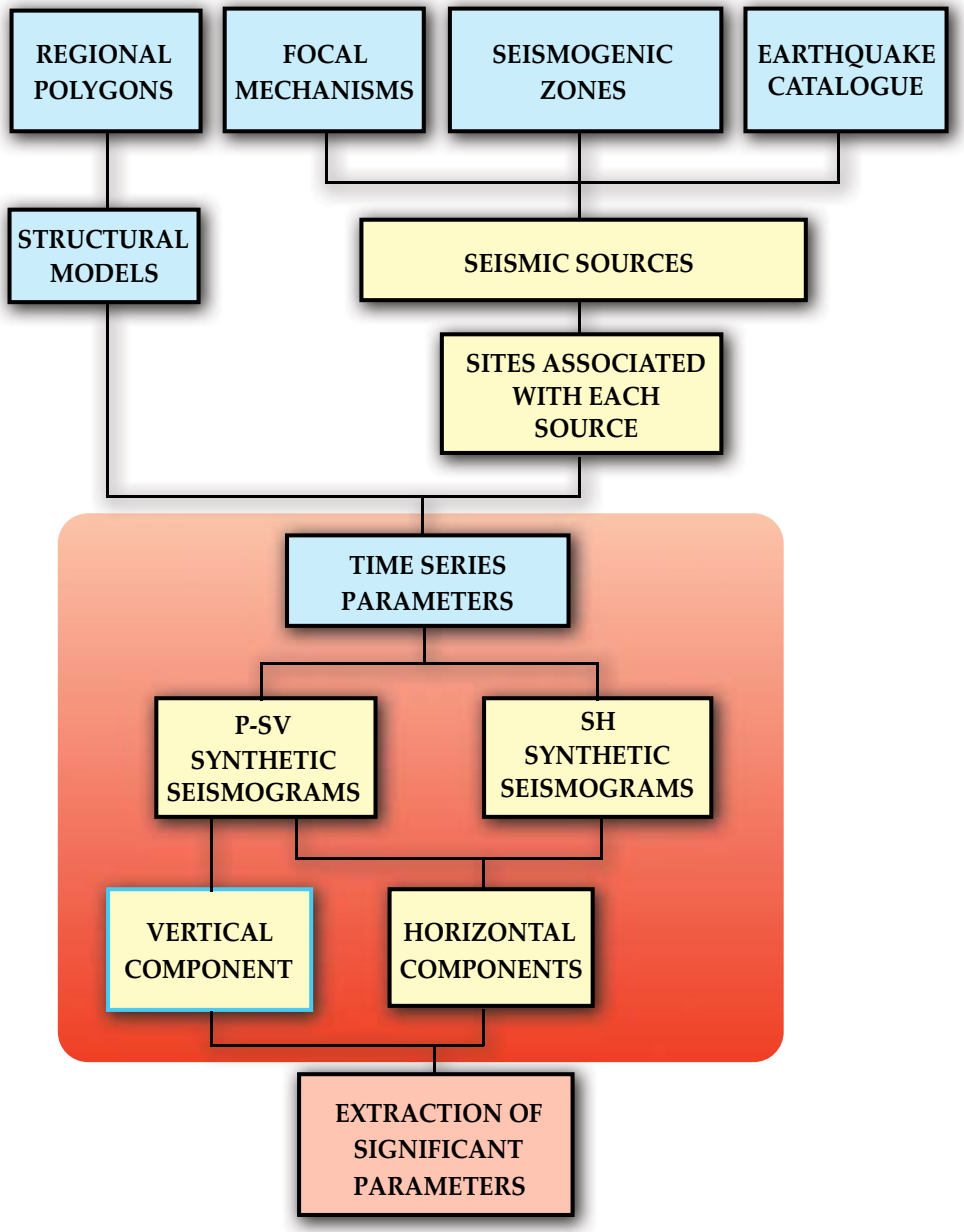


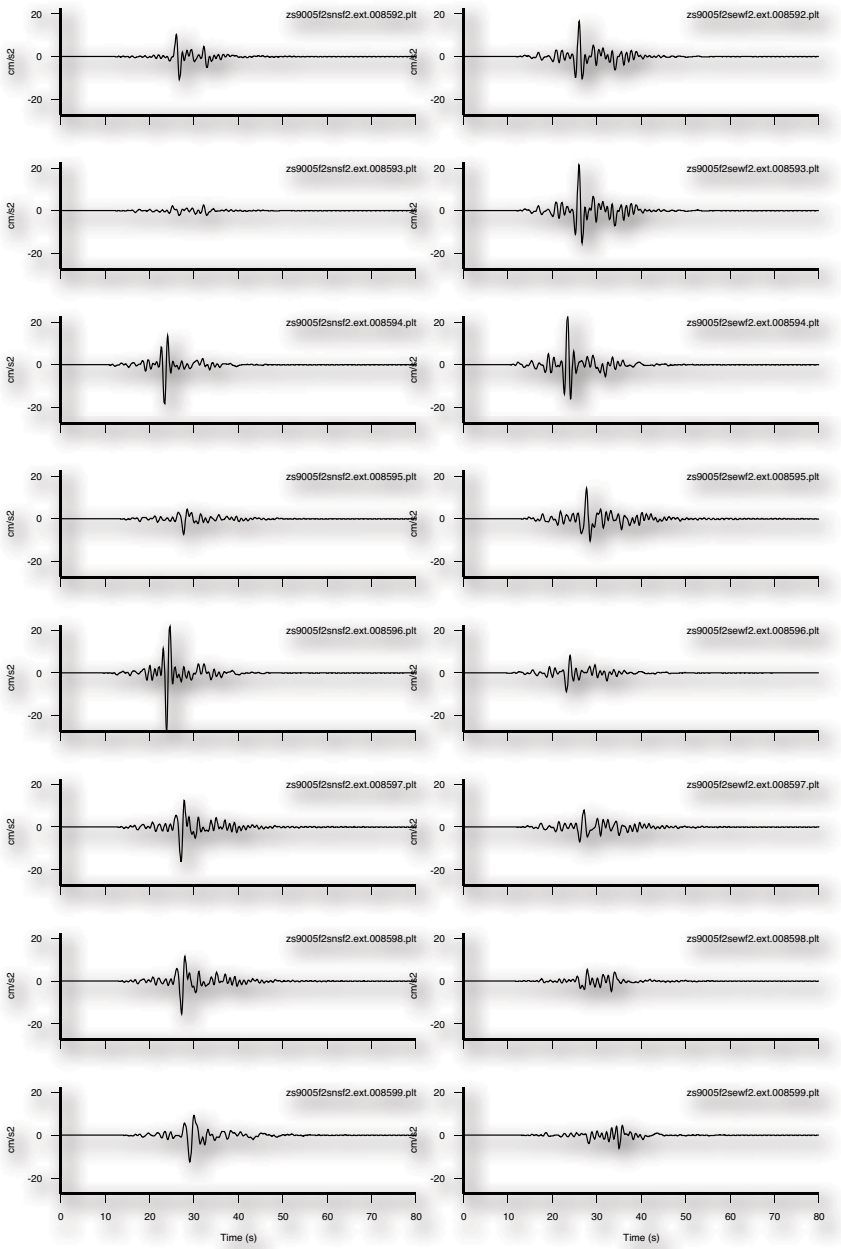
Regional Scale - Seismograms





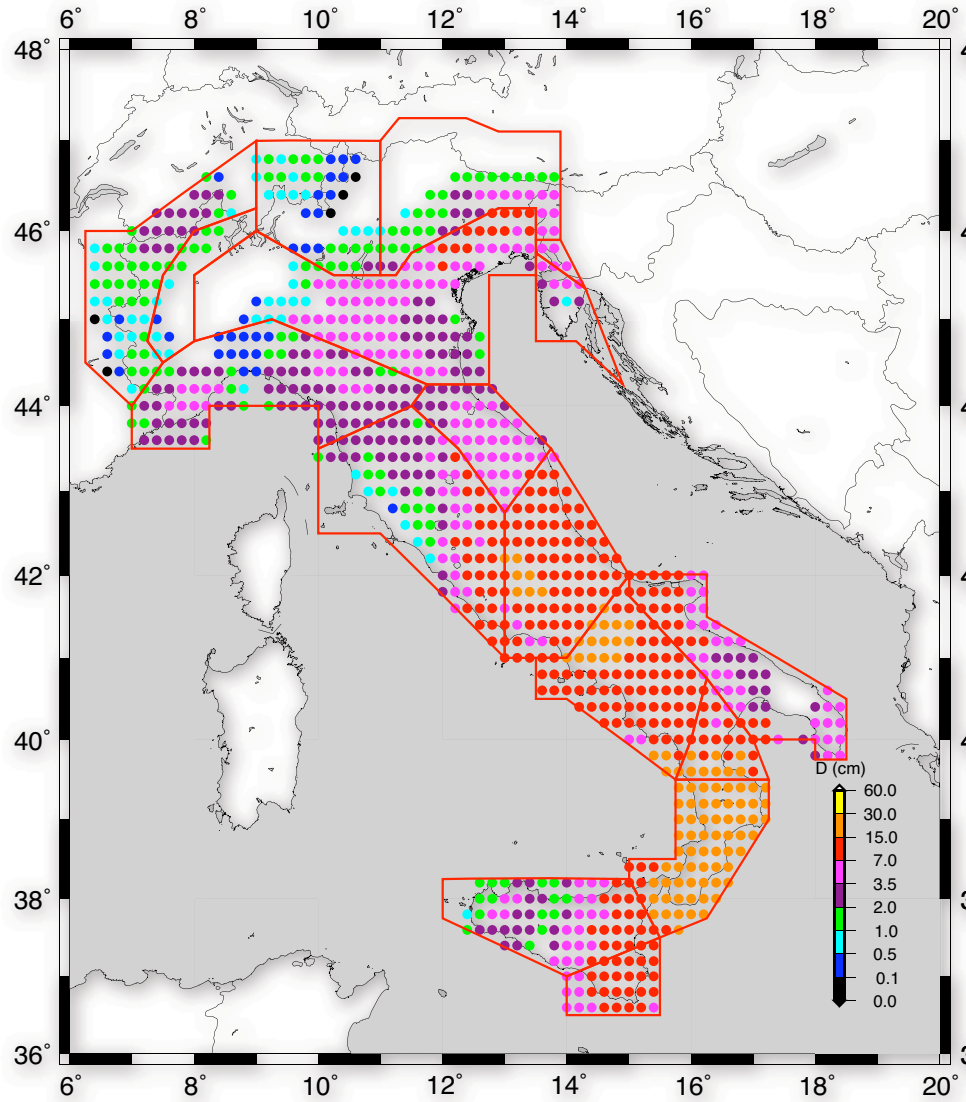
Regional Scale - Seismograms



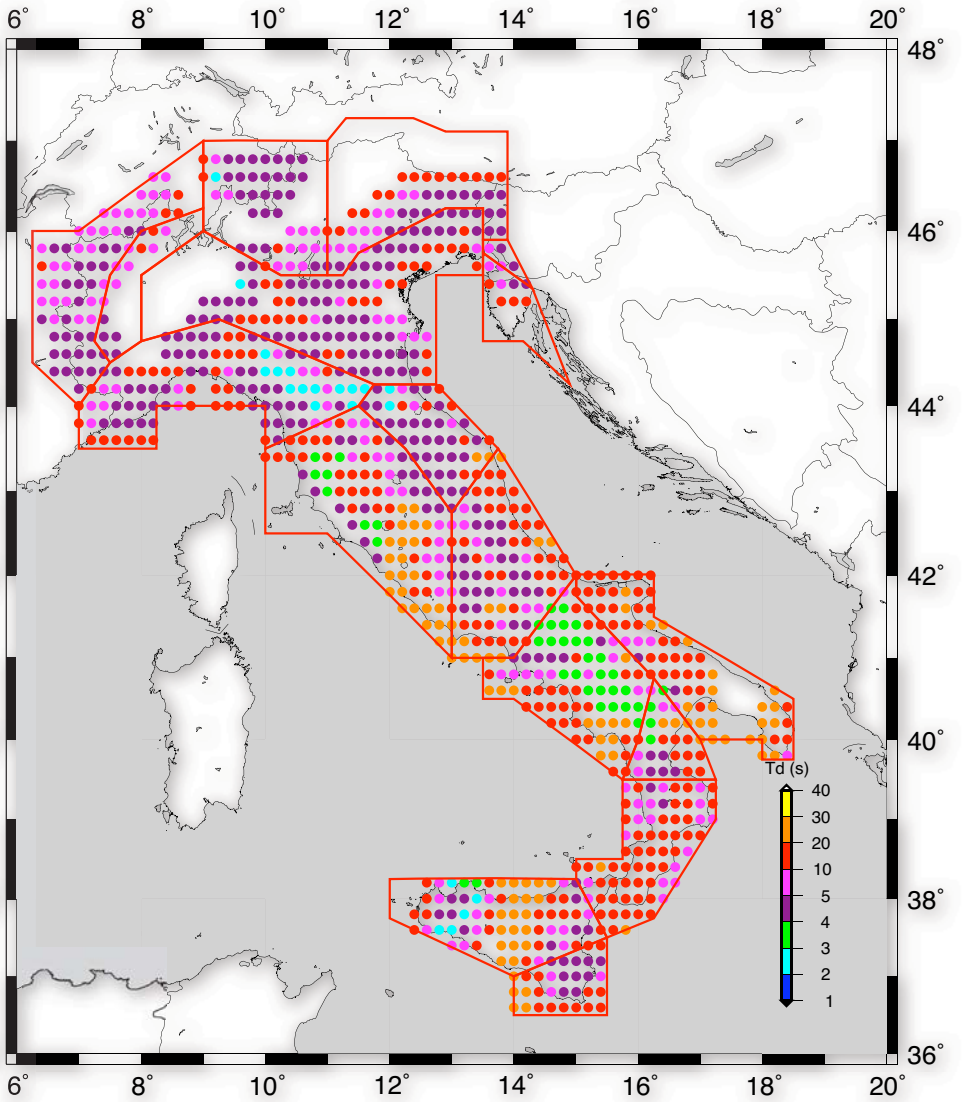


Displacement

Amplitude of Peaks from Time Series (1Hz)

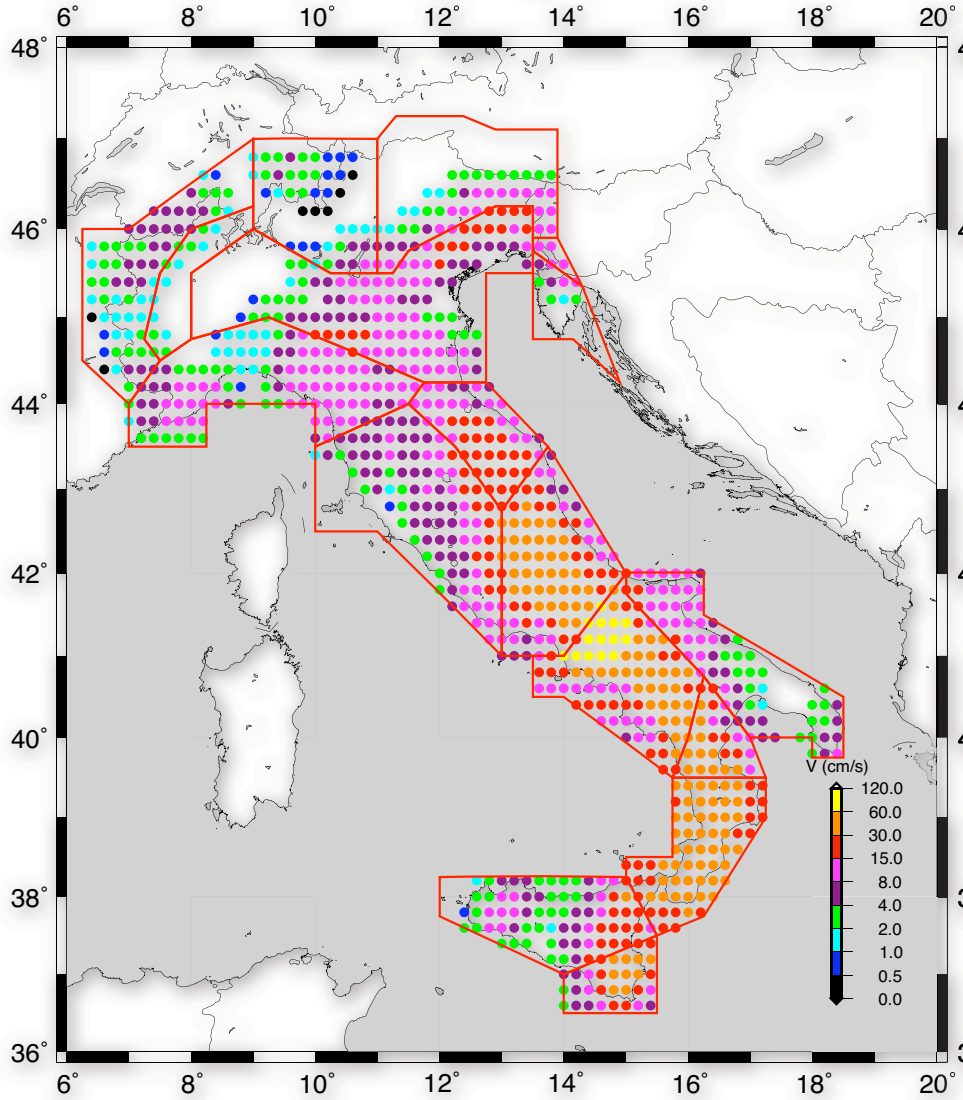


T of Peaks from Fourier Spectra

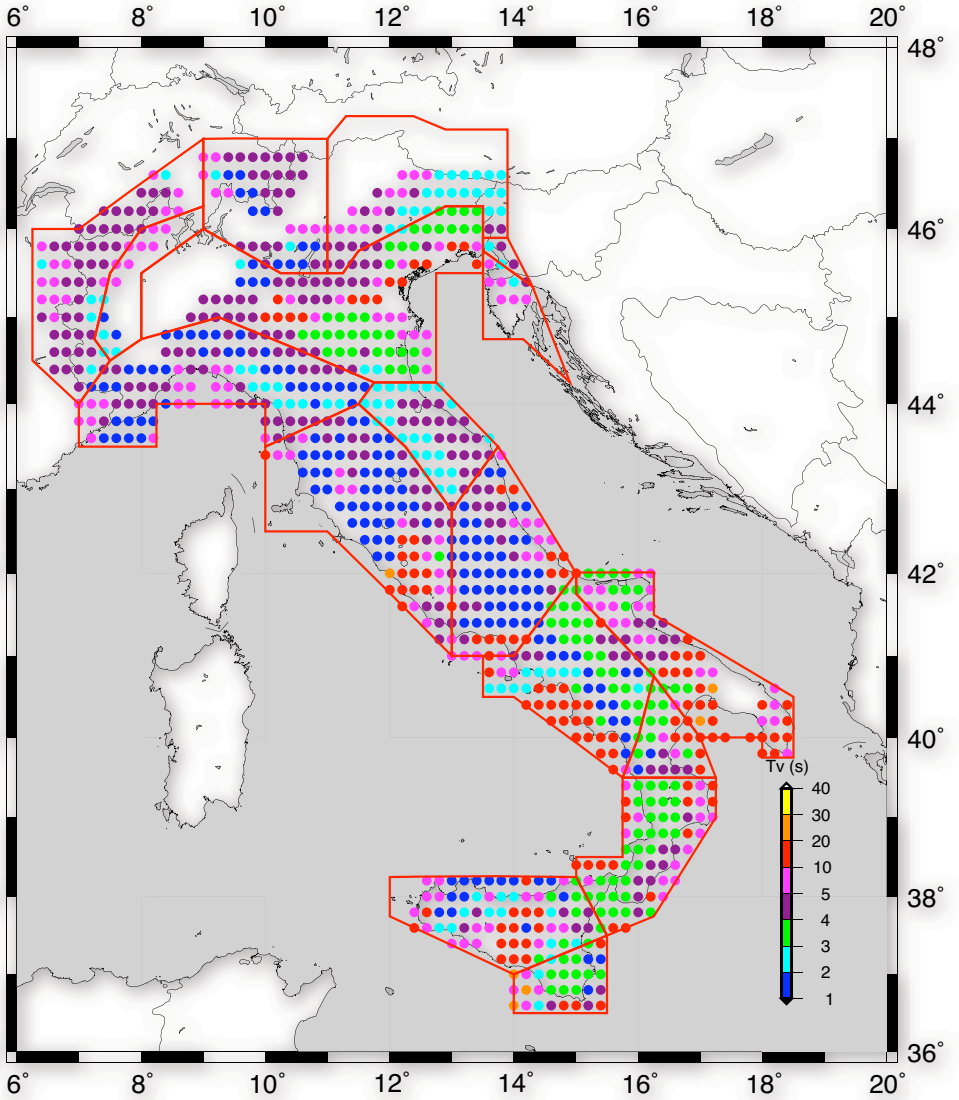


Velocity

Amplitude of Peaks from Time Series (1Hz)

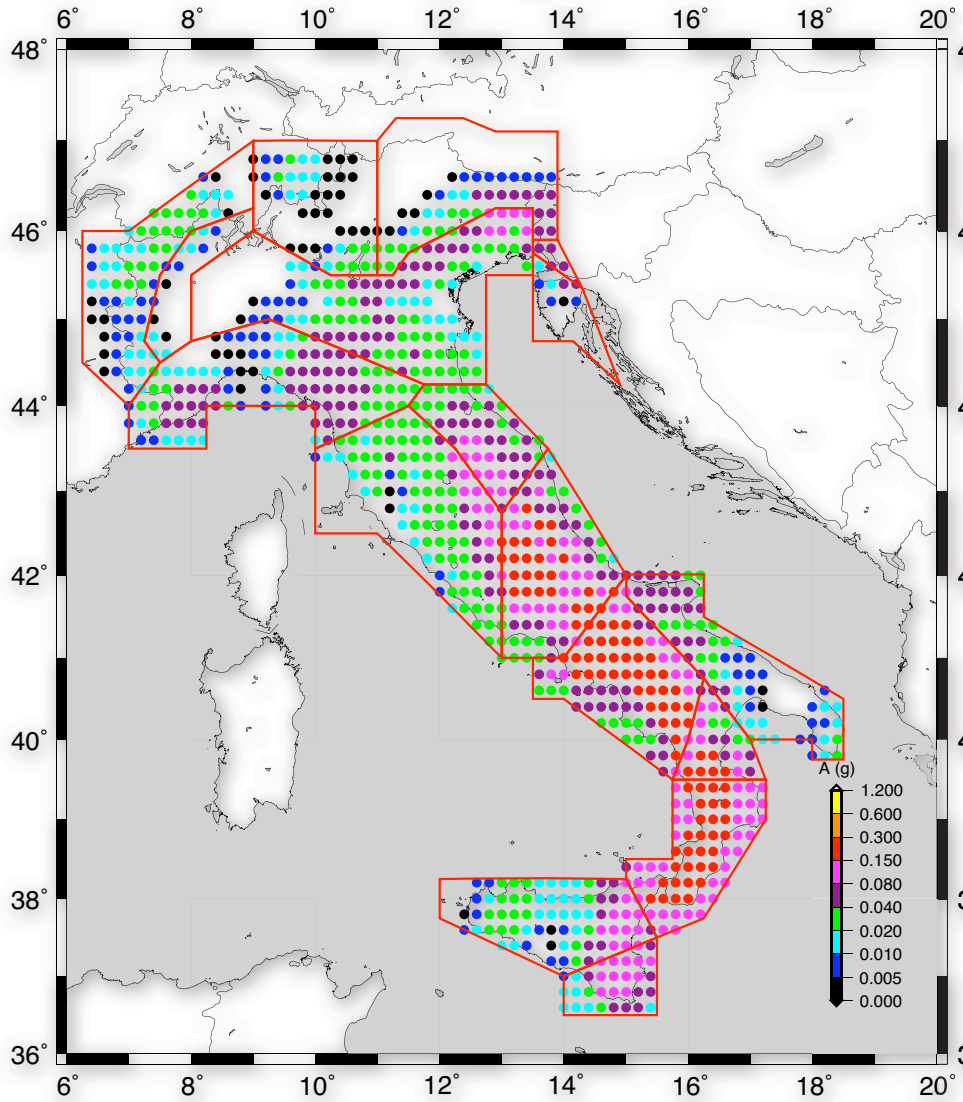


T of Peaks from Fourier Spectra

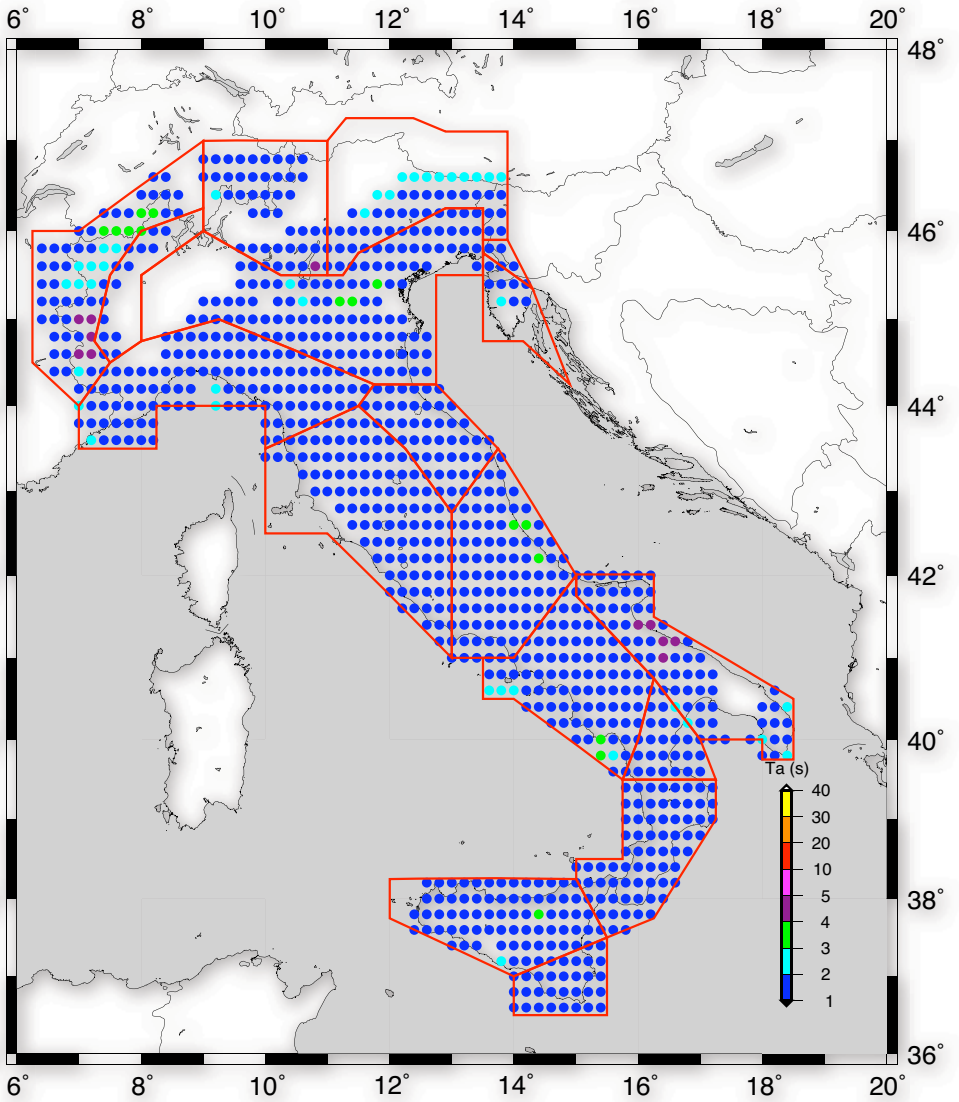


Acceleration

Amplitude of Peaks from Time Series (1Hz)

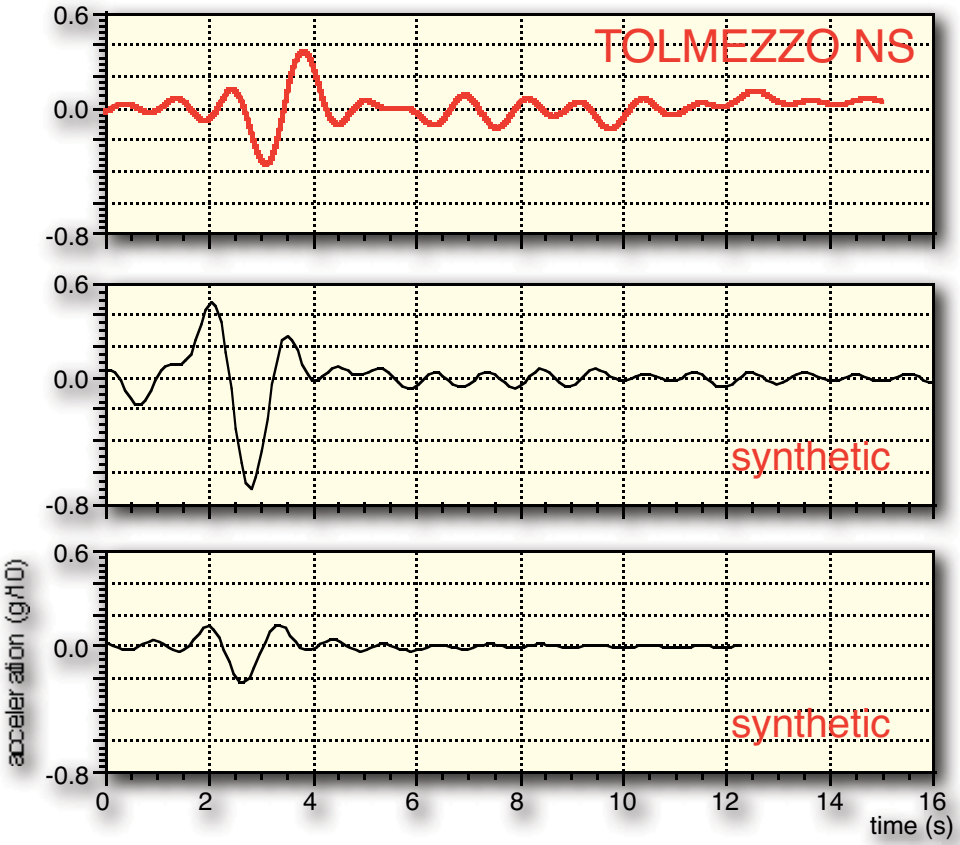


T of Peaks from Fourier Spectra



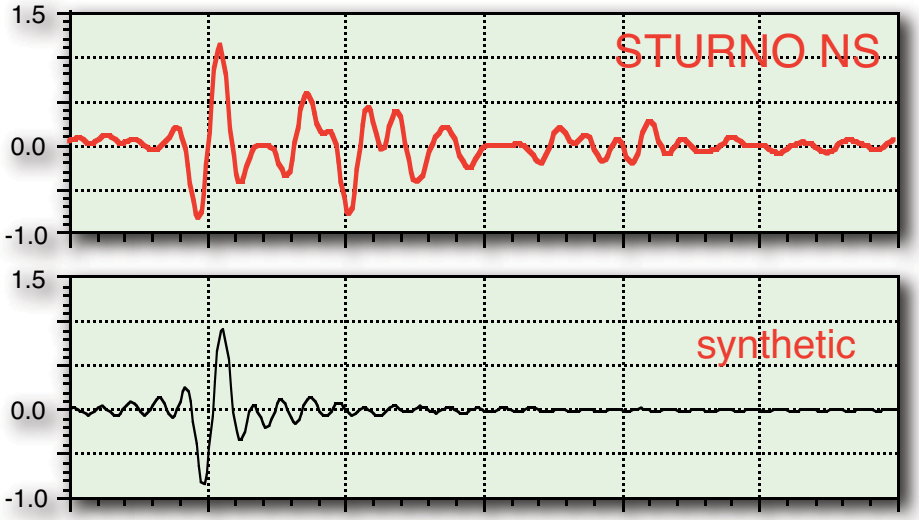
Regional Scale - Check (1 Hz cutoff)

Friuli, 6 May 1976 (North-Eastern Italy)



Comparison with two grid nodes close to the Tolmezzo station

Irpinia, 23 October 1980 (Southern Italy)

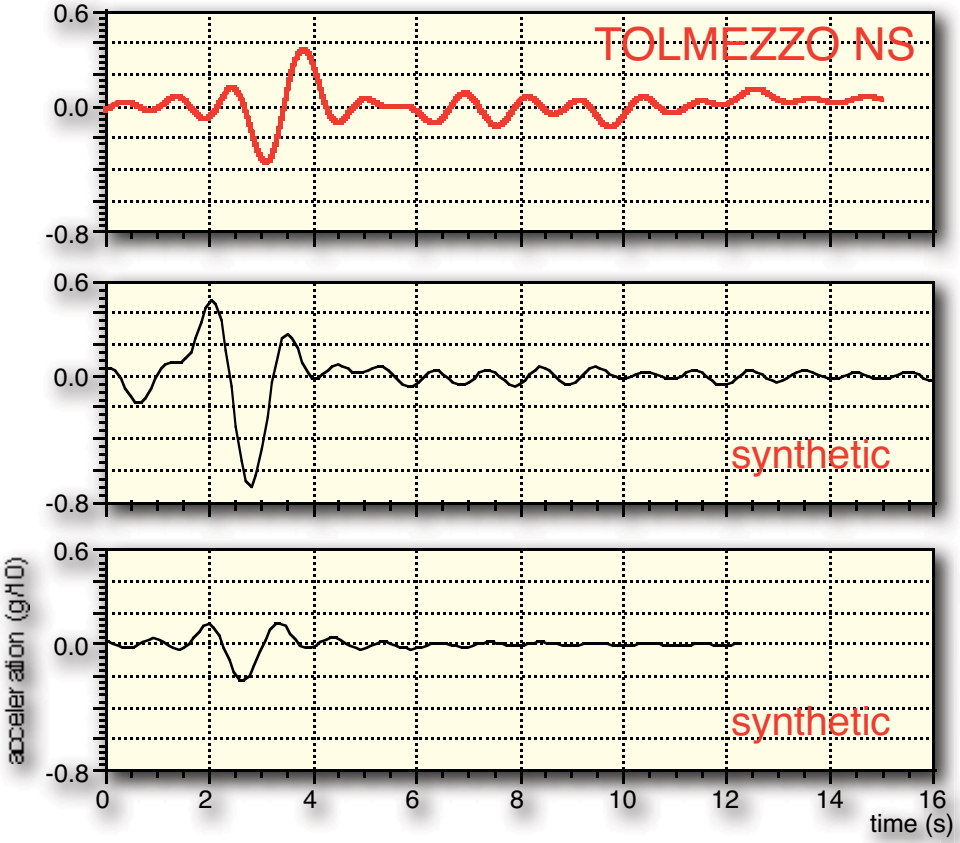


VERY complicated source model

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

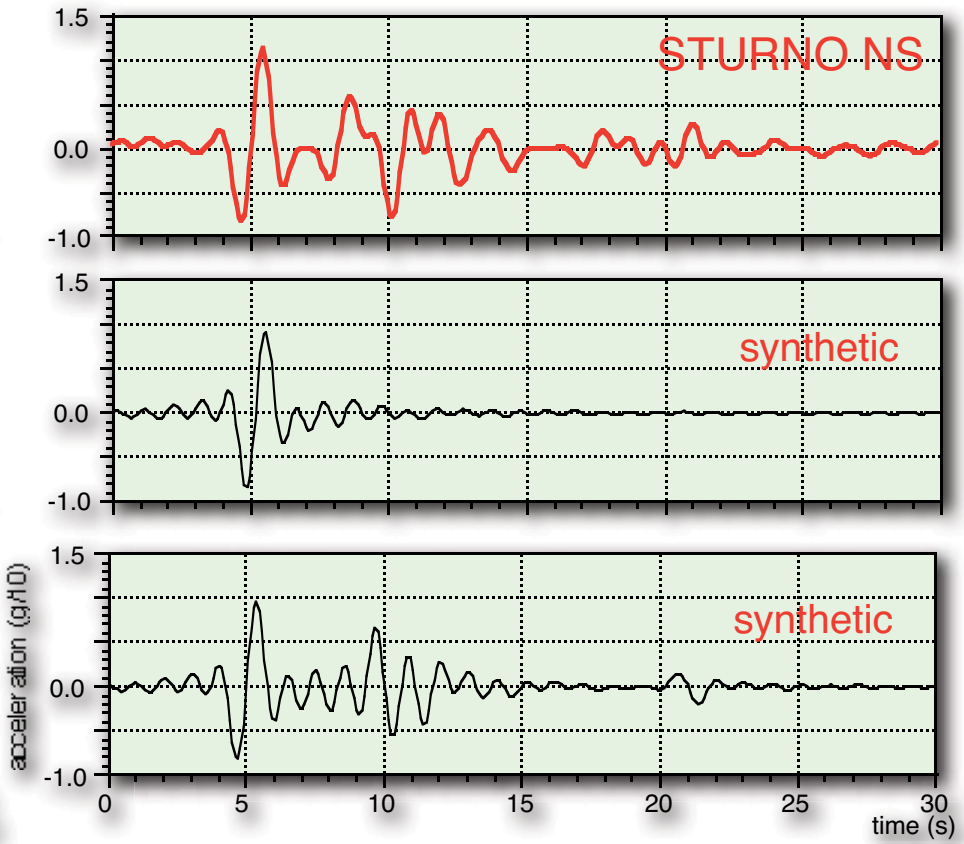
Regional Scale - Check (1 Hz cutoff)

Friuli, 6 May 1976 (North-Eastern Italy)



Comparison with two grid nodes close to the Tolmezzo station

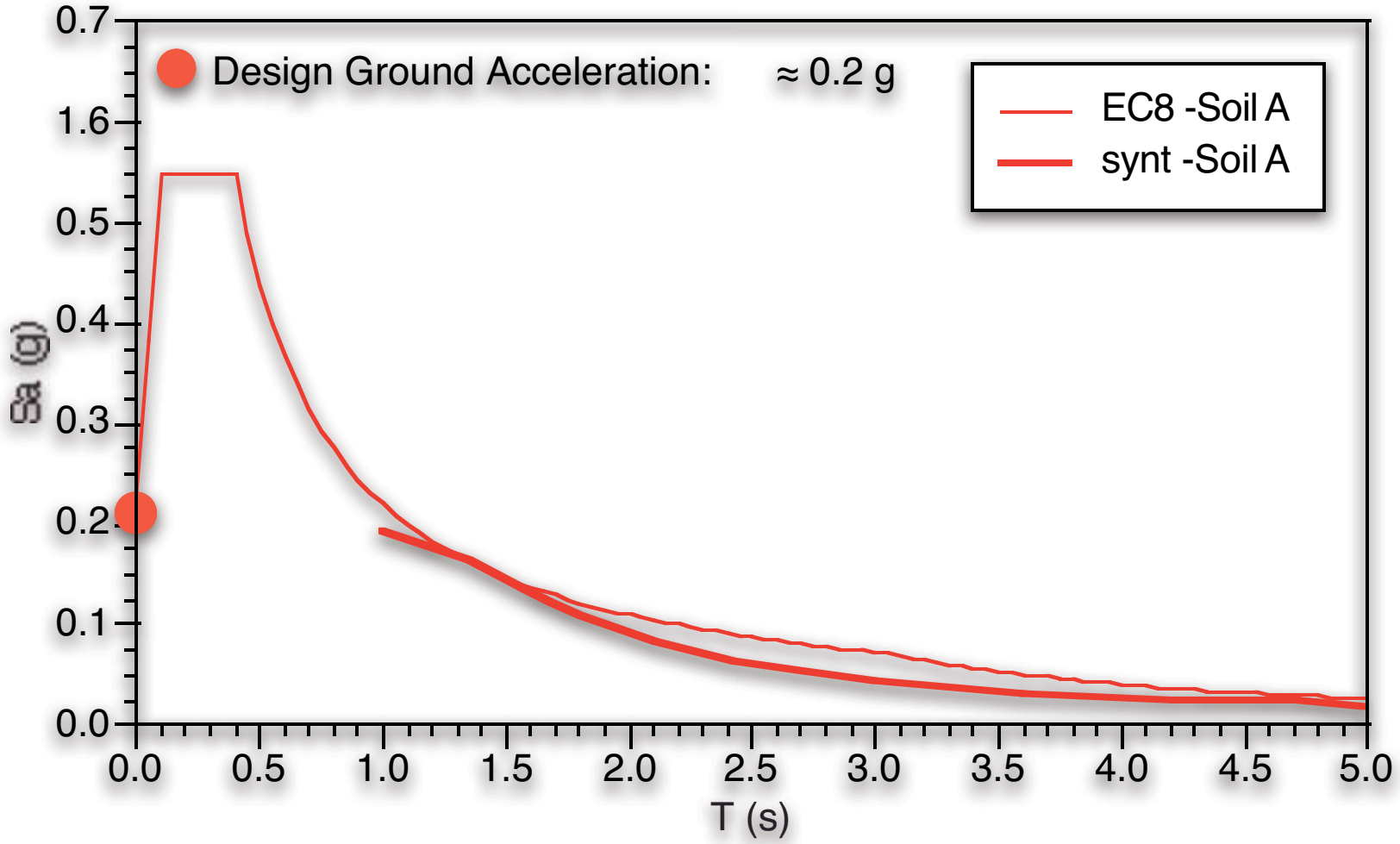
Irpinia, 23 October 1980 (Southern Italy)



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

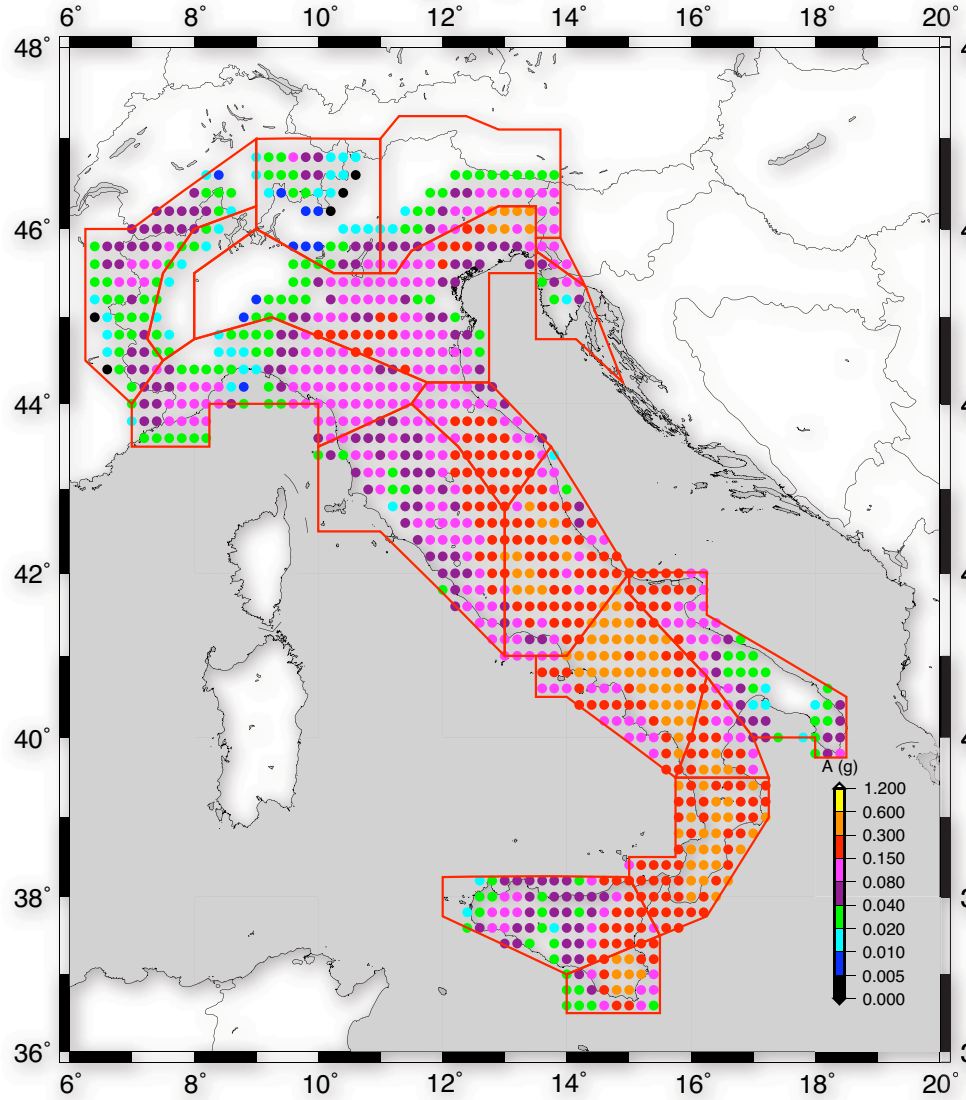
Design Ground Acceleration (DGA)

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

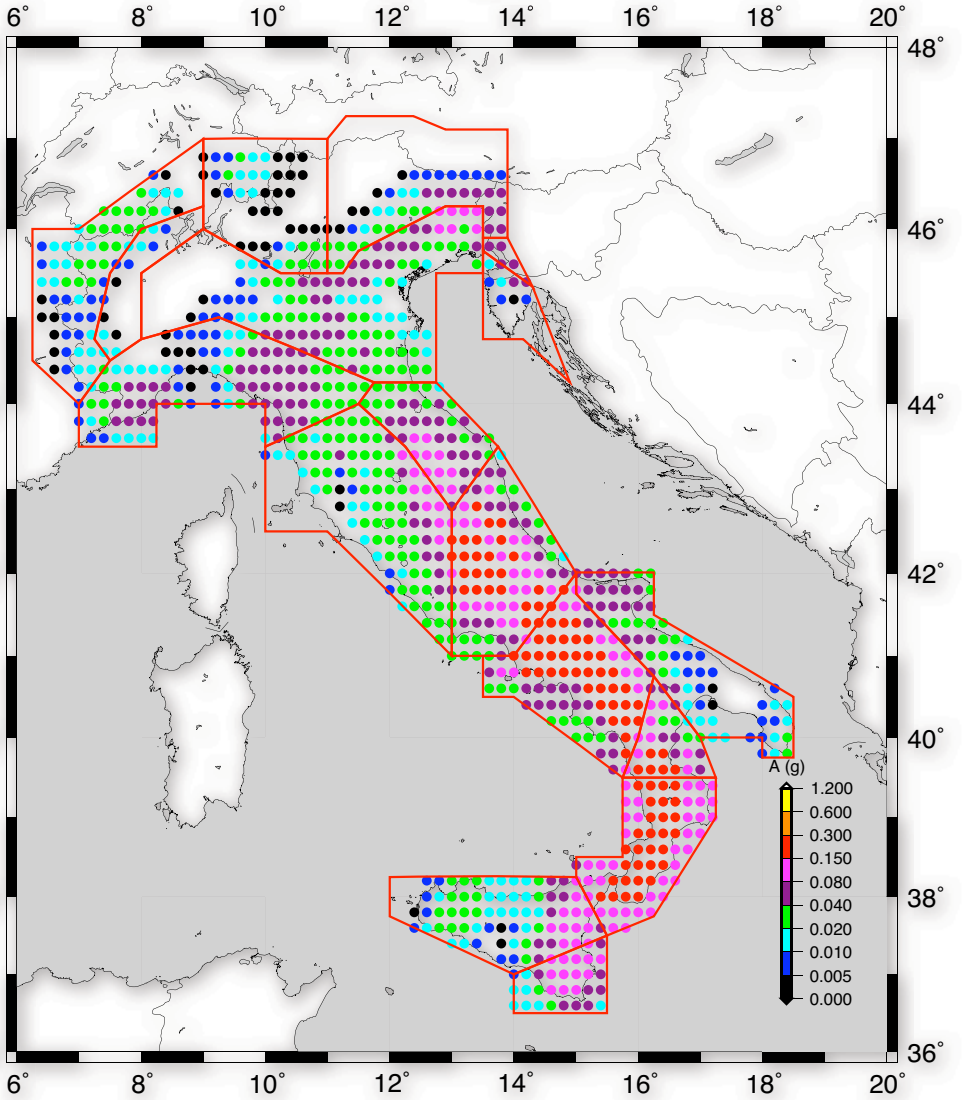


Acceleration

DGA Extrapolated by Means of Design Spectrum

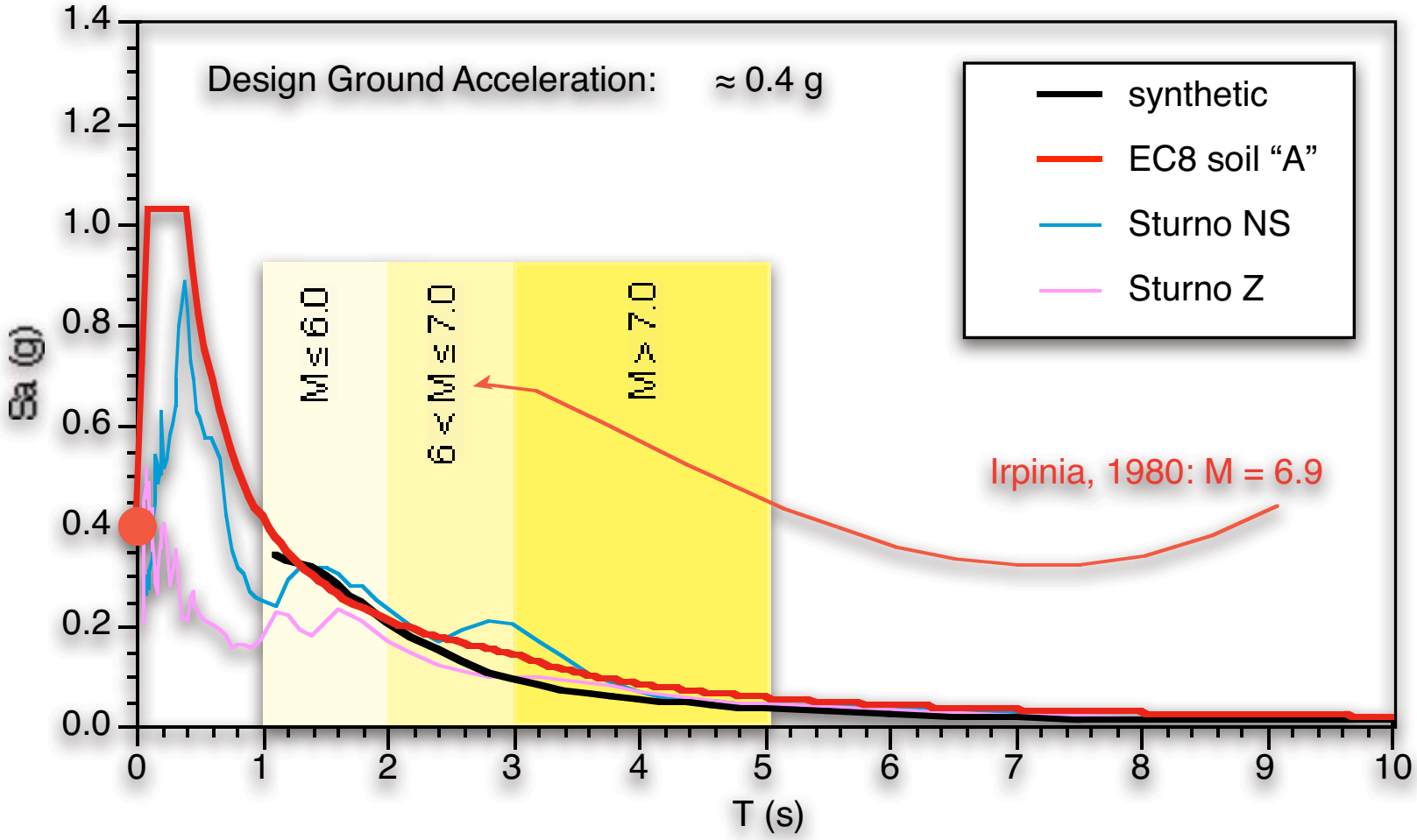


Amplitude of Peaks from Time Series (1Hz)



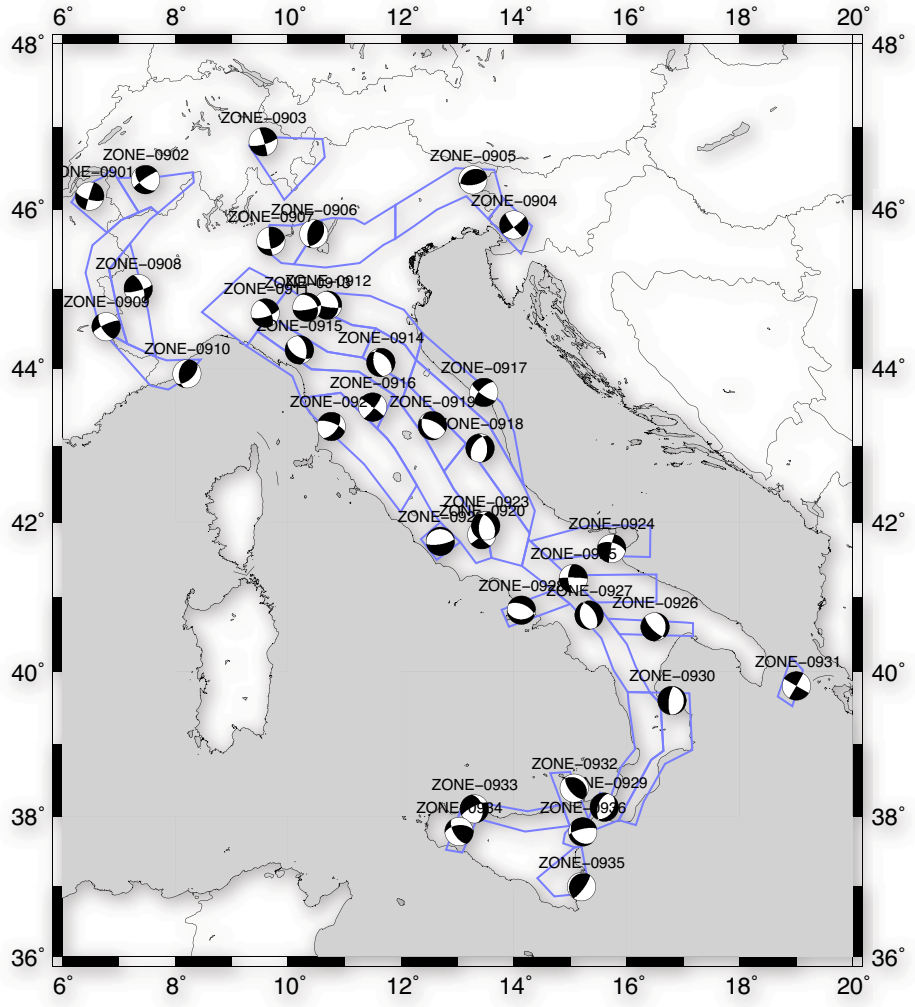
Design Ground Acceleration (DGA)

- 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

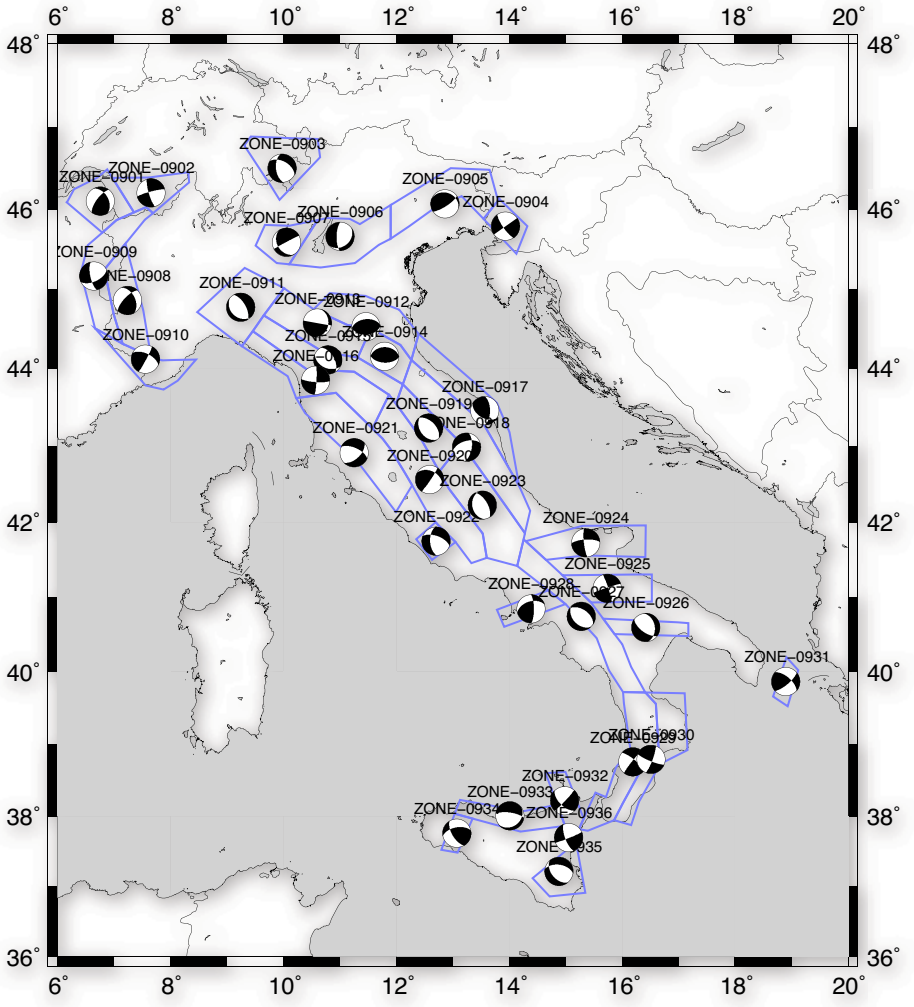


Parametric Test on Source Mechanism

Automatic Average

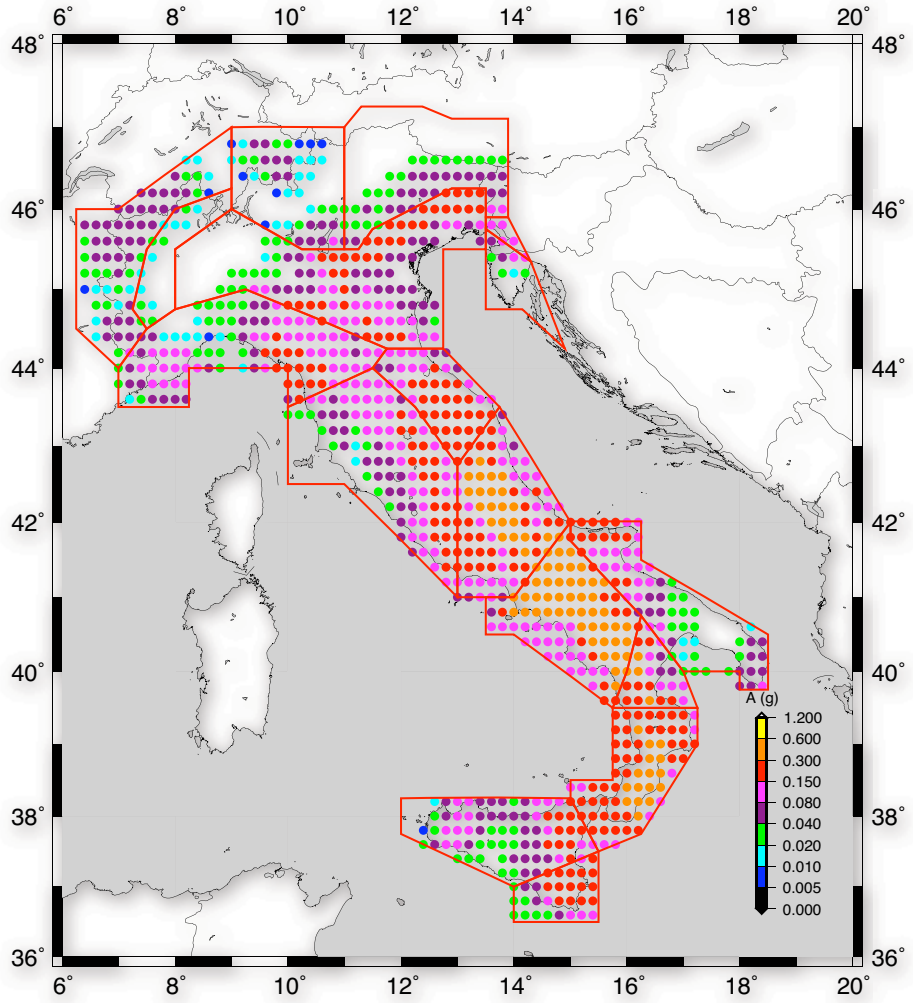


Expert's Choice

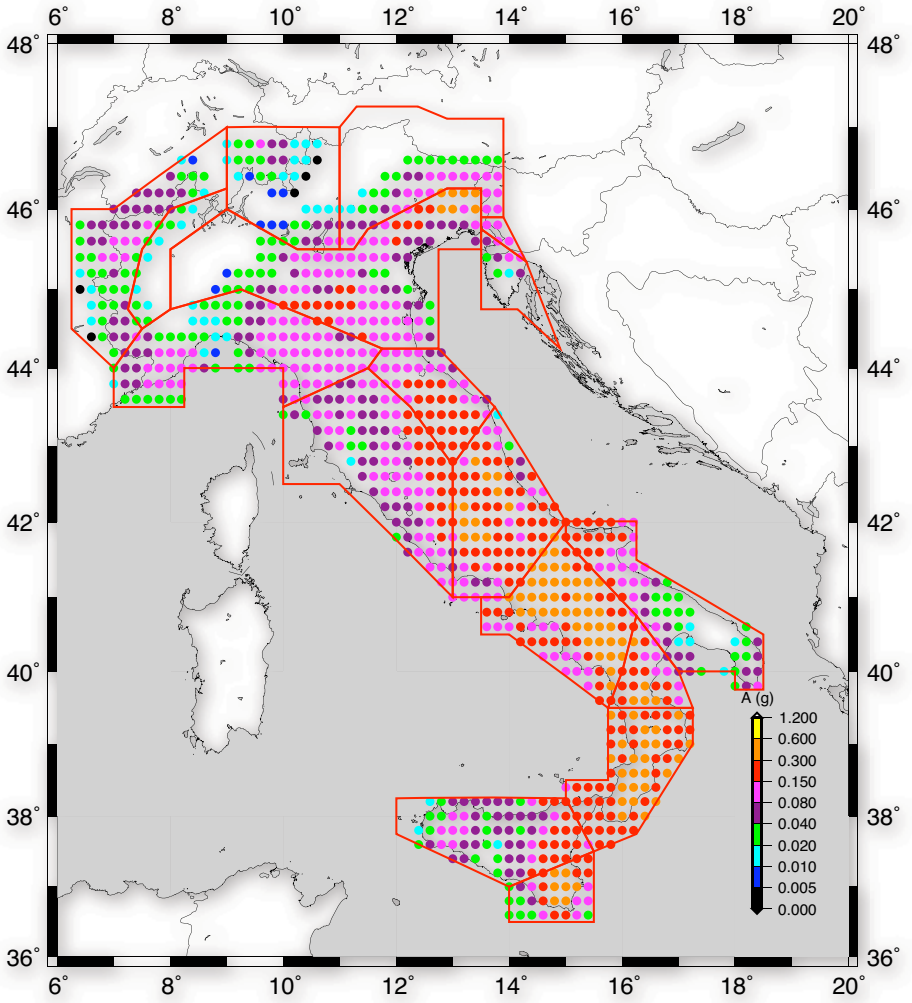


Parametric Test on Source Mechanism

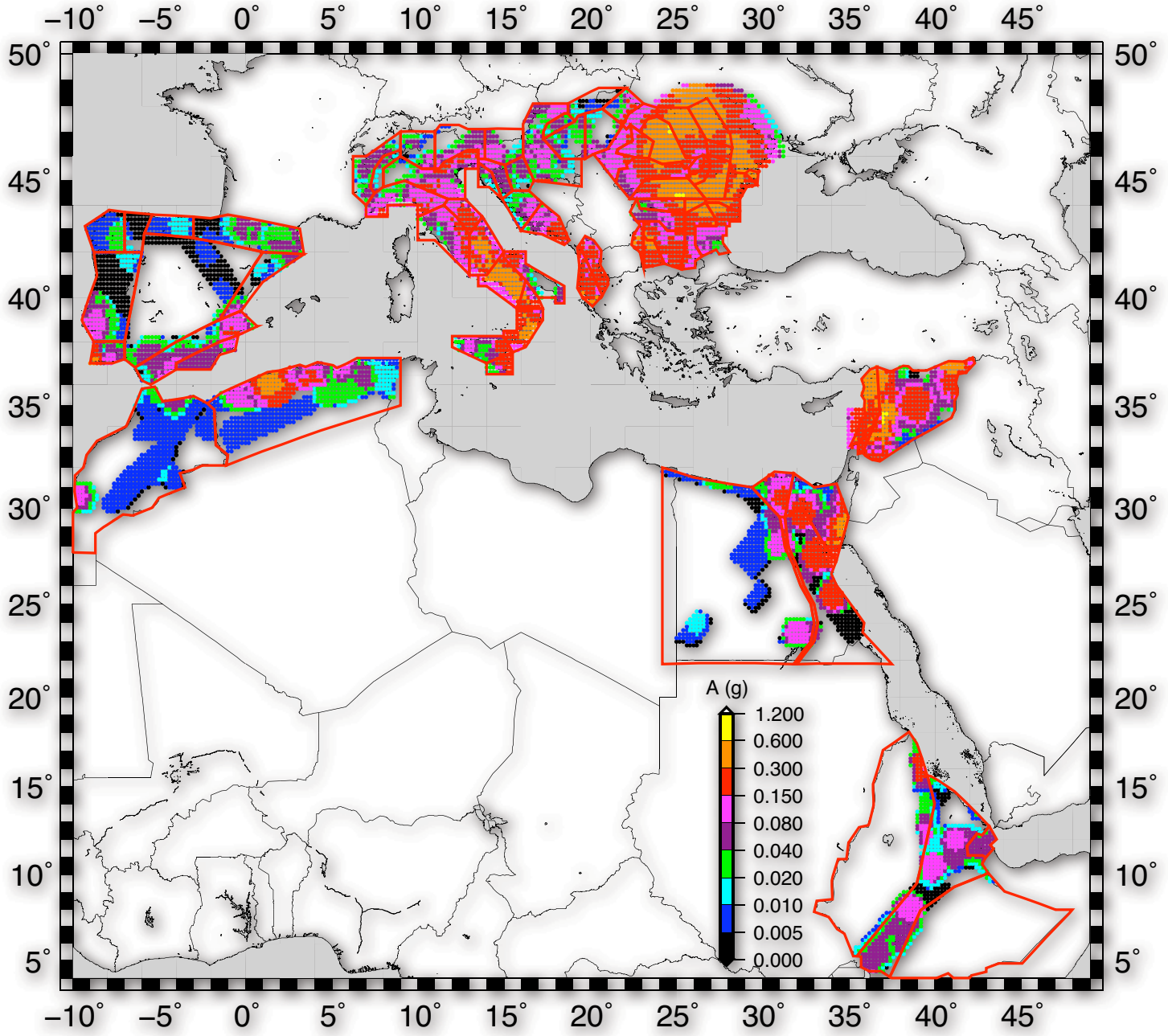
Automatic Average



Expert's Choice



- 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)

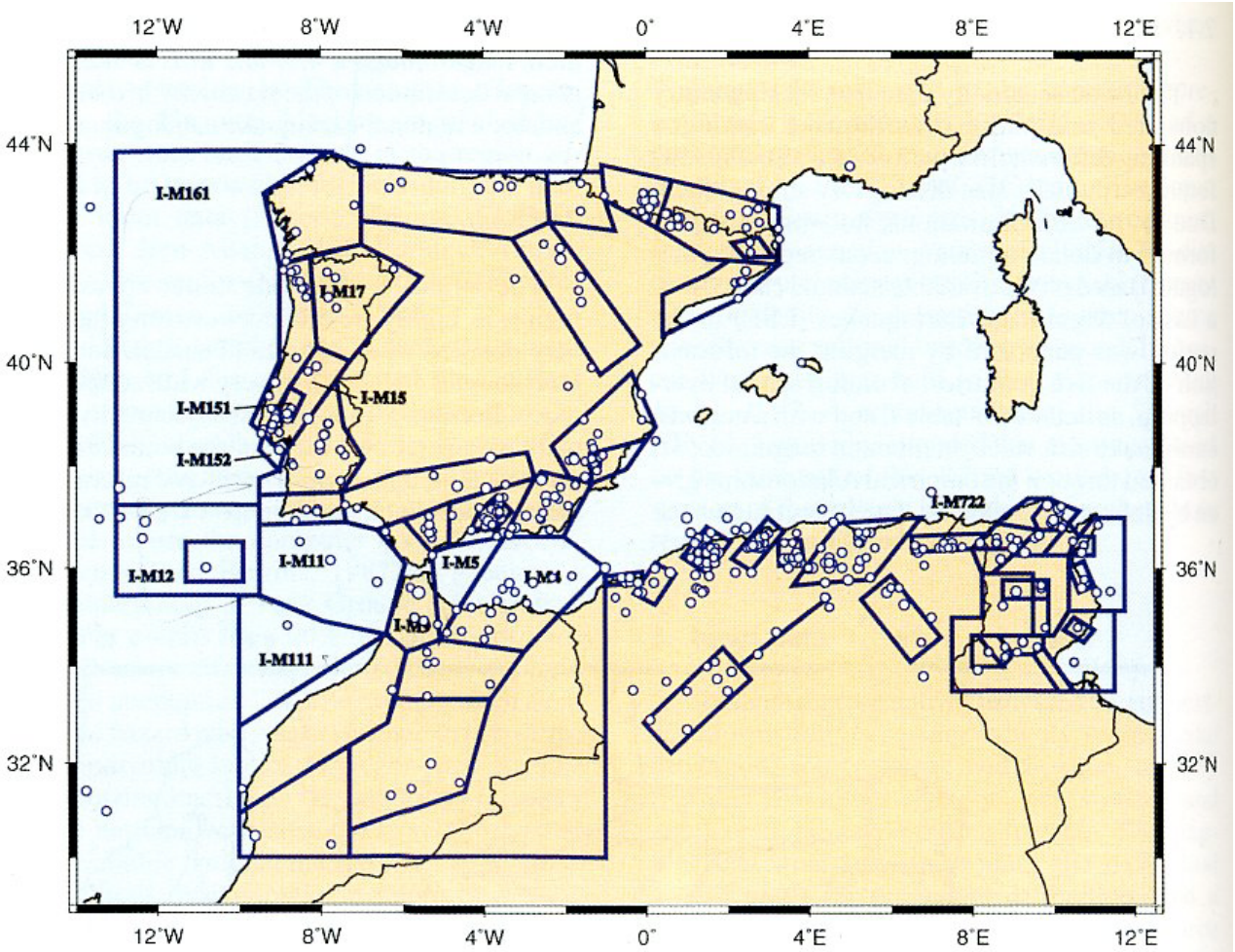
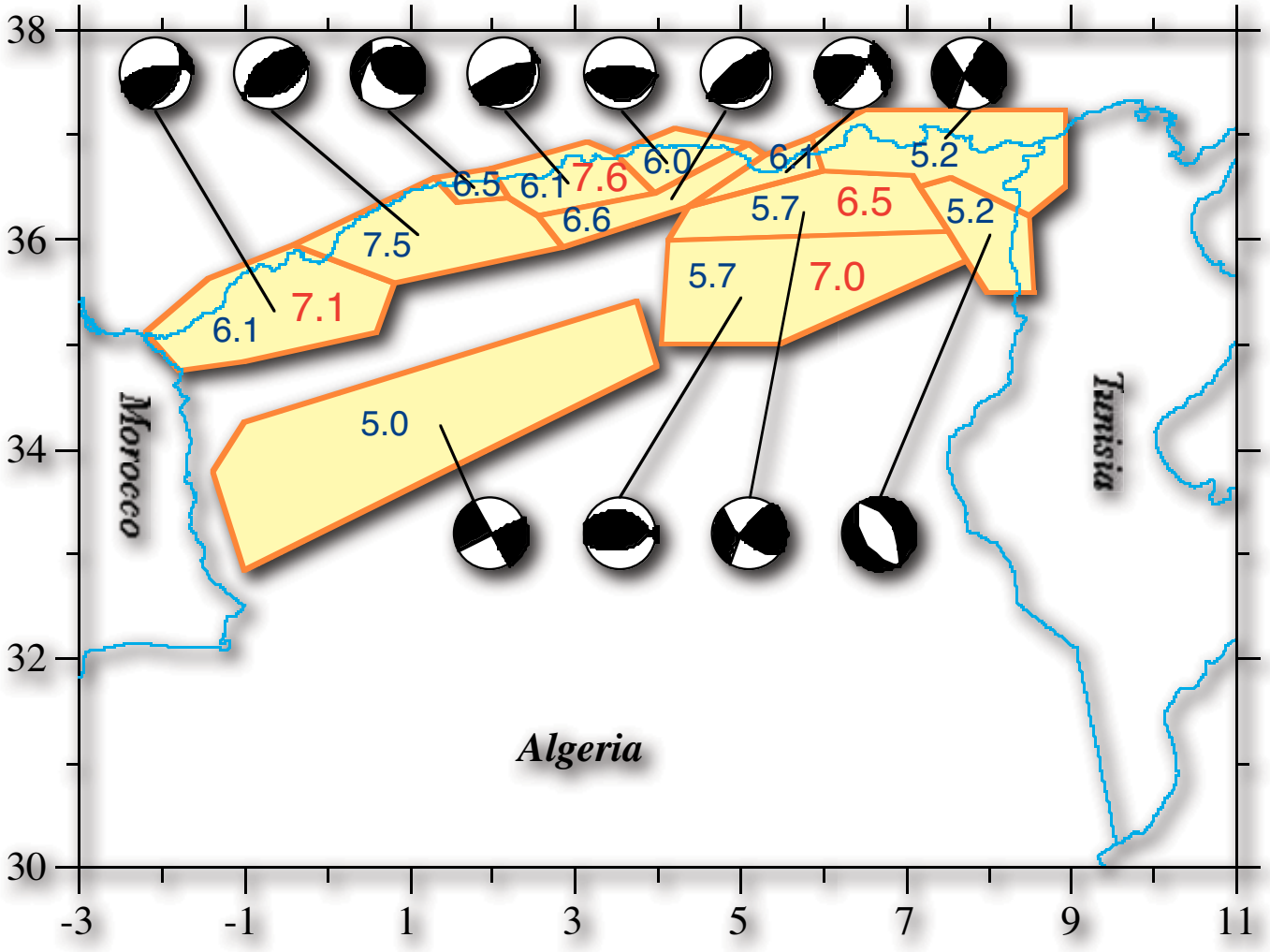


Fig. 2. Final distribution of earthquake source zones for the Ibero-Maghreb region, and epicenters of the generated List of Significant Earthquakes with $M \geq 4.5$ from 1900 to 1989.

Regional Scale - Seismogenic Potential

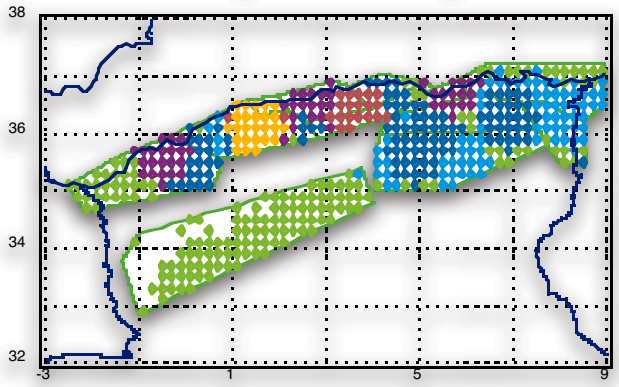
- If the earthquake catalogue is not complete even in the high magnitude range, computations can be eventually performed analysing the seismogenic potential of the active faults

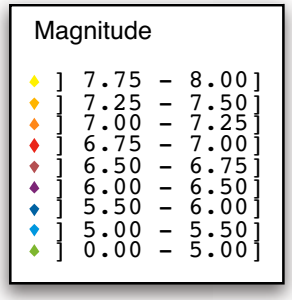


Regional Scale - Seismogenic Potential

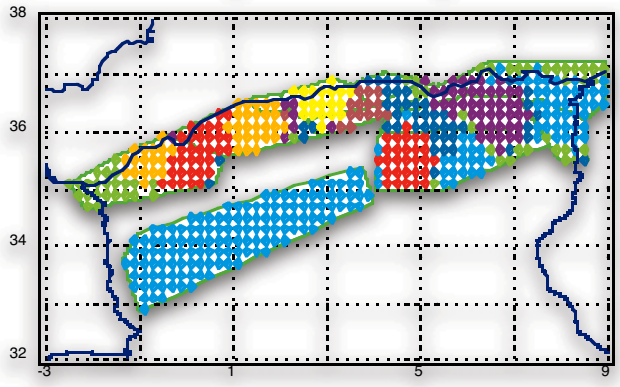
- If the earthquake catalogue is not complete even in the high magnitude range, computations can be eventually performed analysing the seismogenic potential of the active faults

Max OBSERVED magnitude (smoothed)





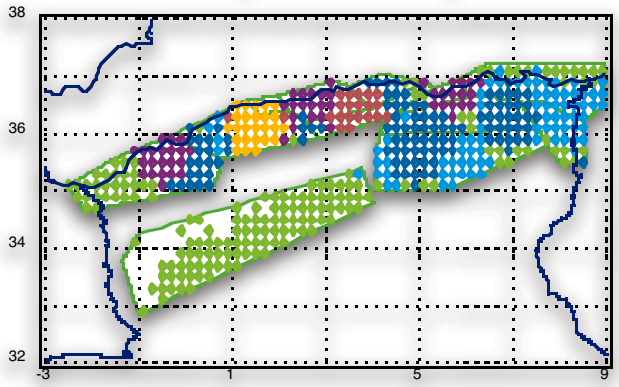
Max EXPECTED magnitude (smoothed)



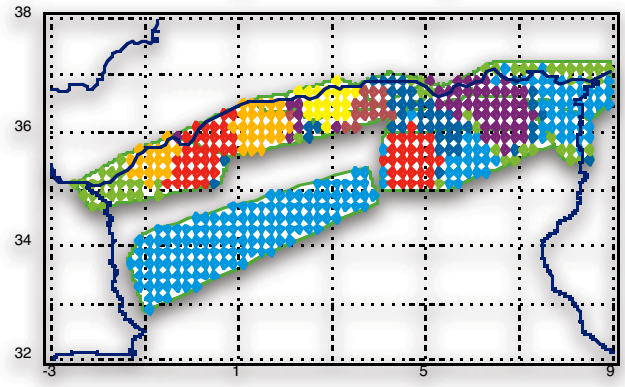
Regional Scale - Seismogenic Potential

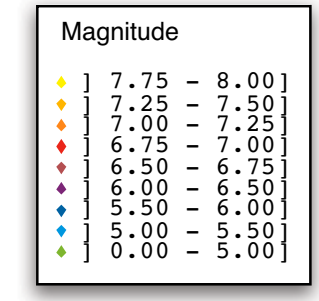
- If the earthquake catalogue is not complete even in the high magnitude range, computations can be eventually performed analysing the seismogenic potential of the active faults

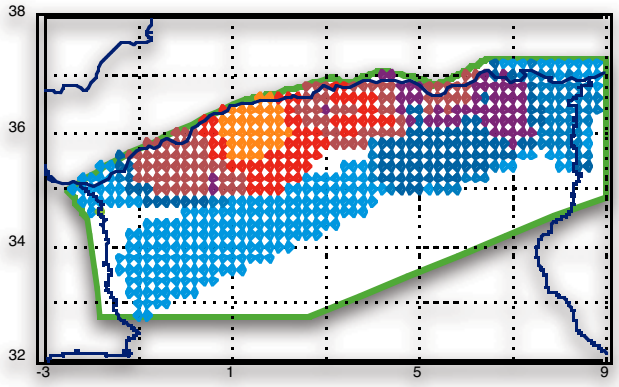
Max OBSERVED magnitude (smoothed)

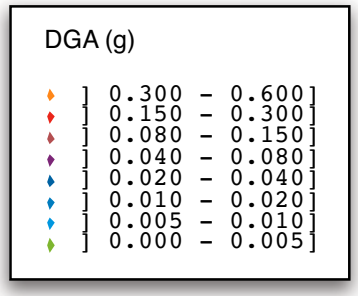


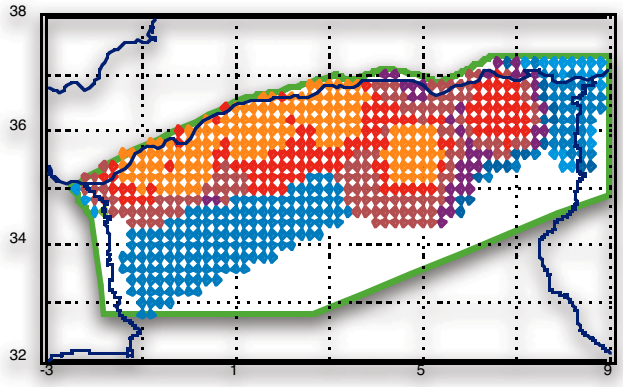
Max EXPECTED magnitude (smoothed)











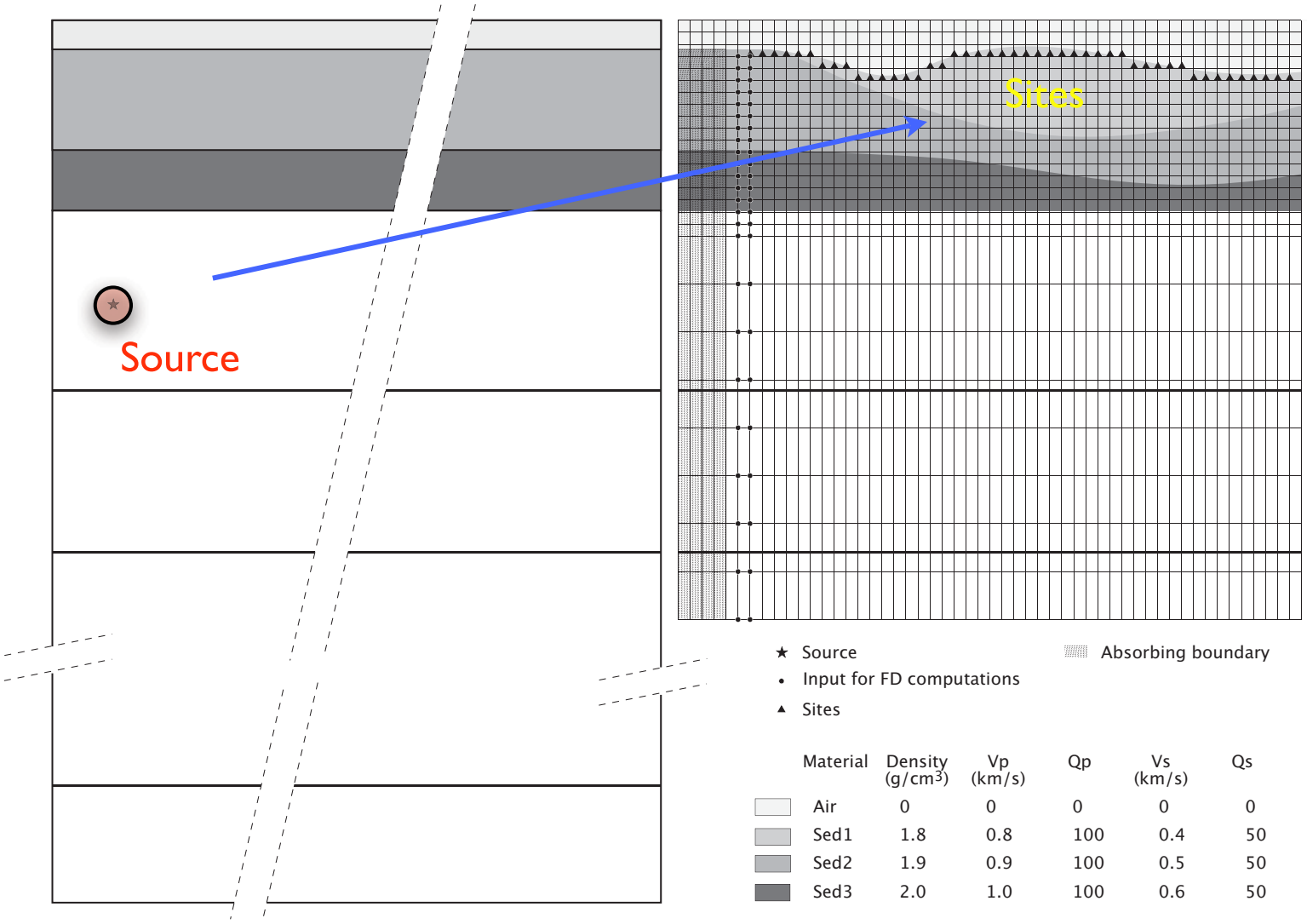
Local Scale - Introduction

- 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



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

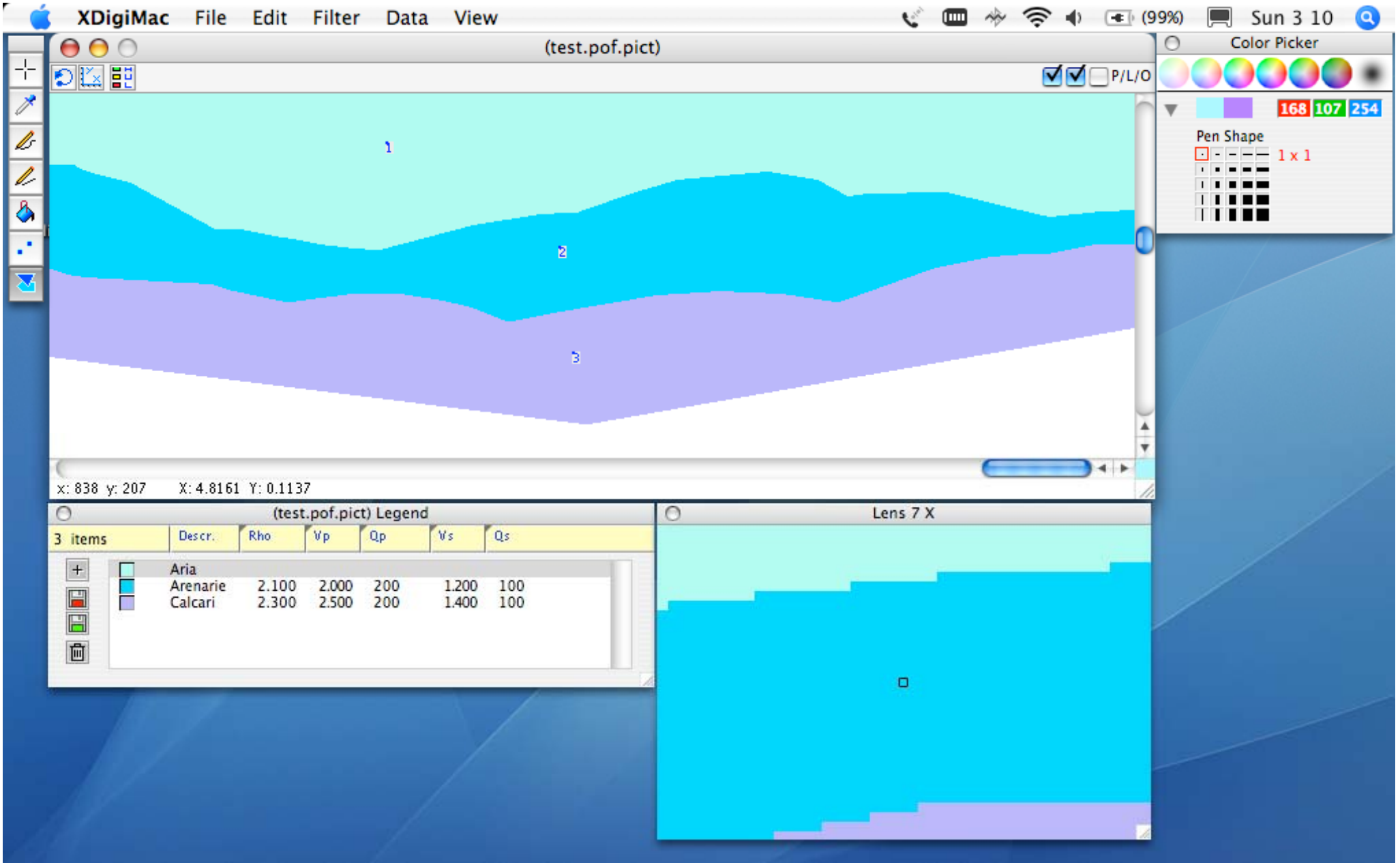
Local Scale - Input Definition

```
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

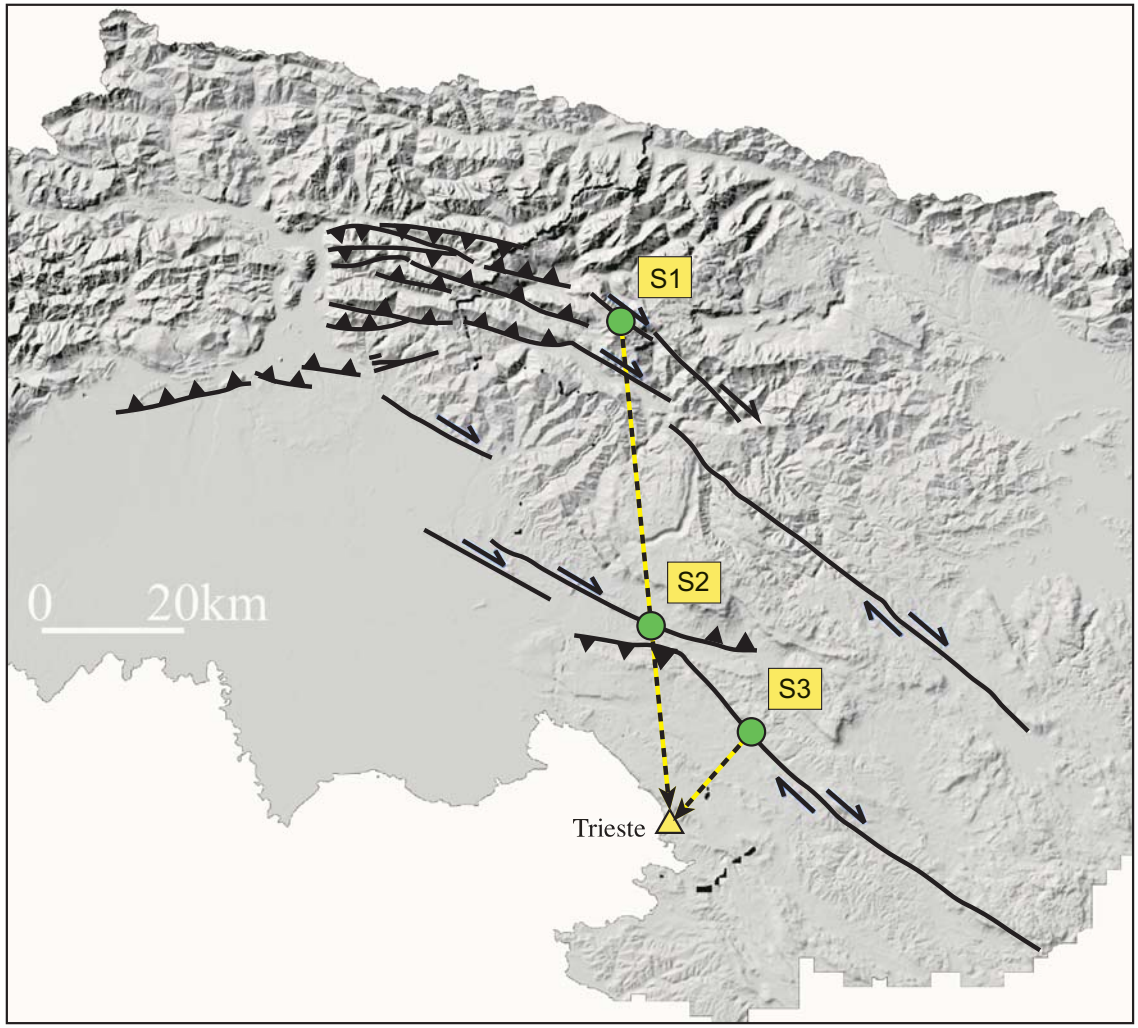
Finite Difference

Local Scale - Input Definition

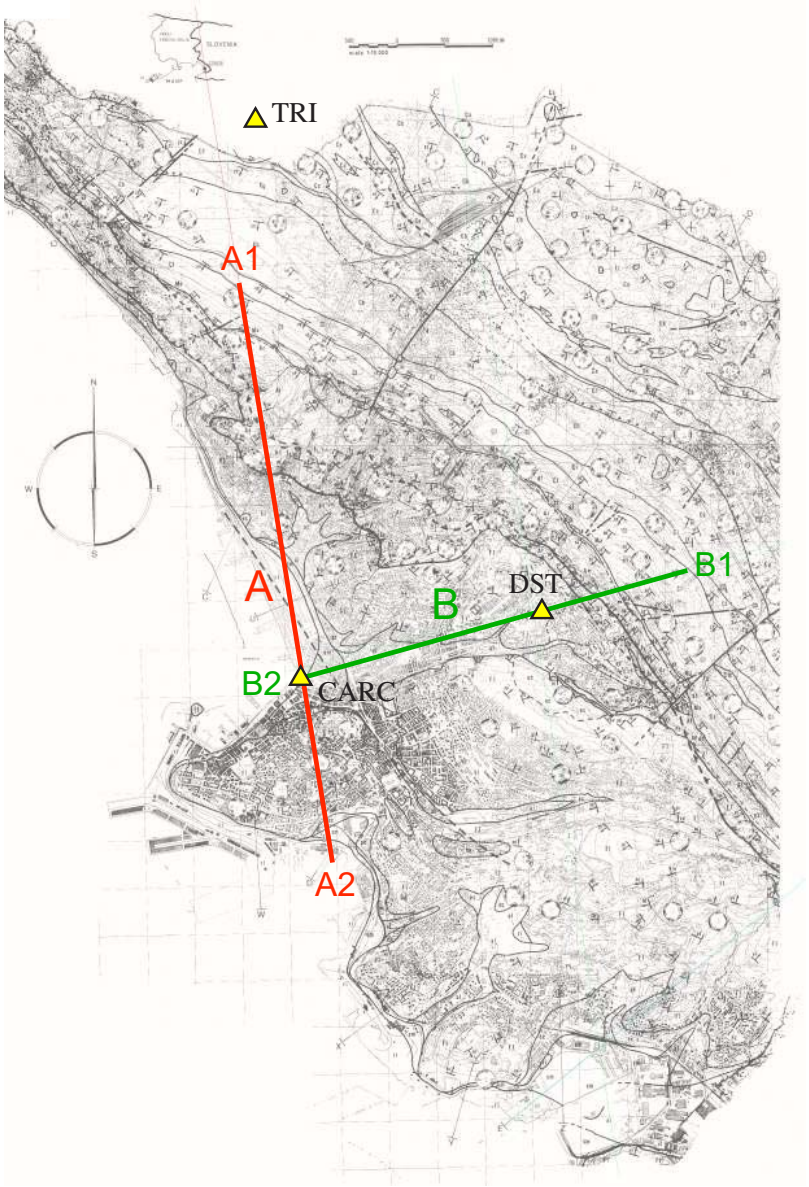


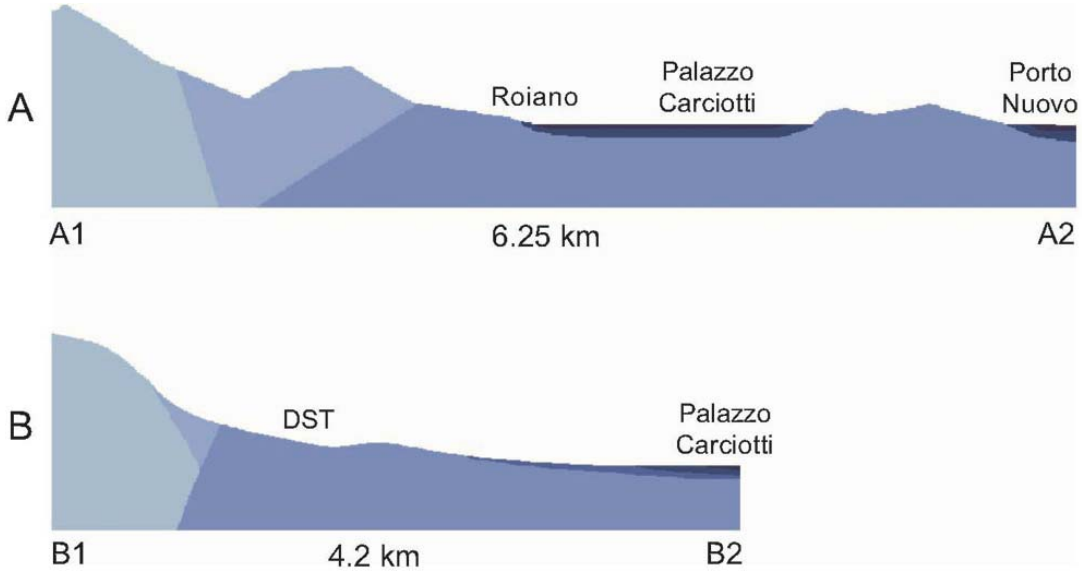
Local Scale - Choice of Scenario Earthquakes

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



Local Scale - Choice of Profiles

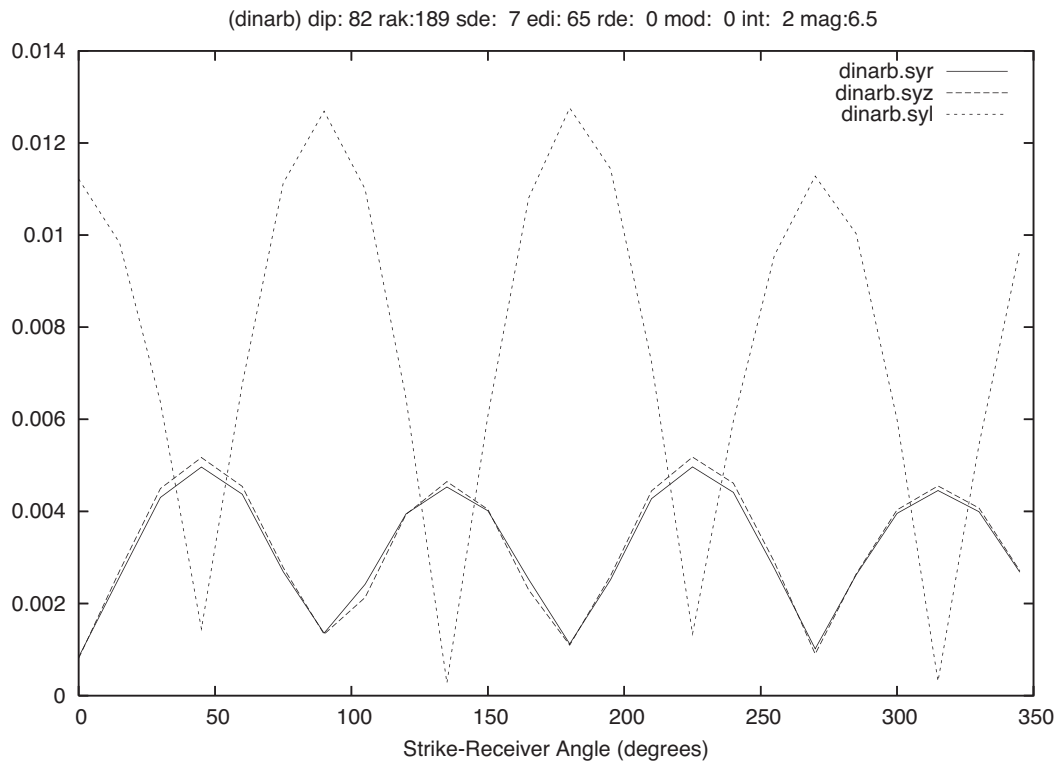




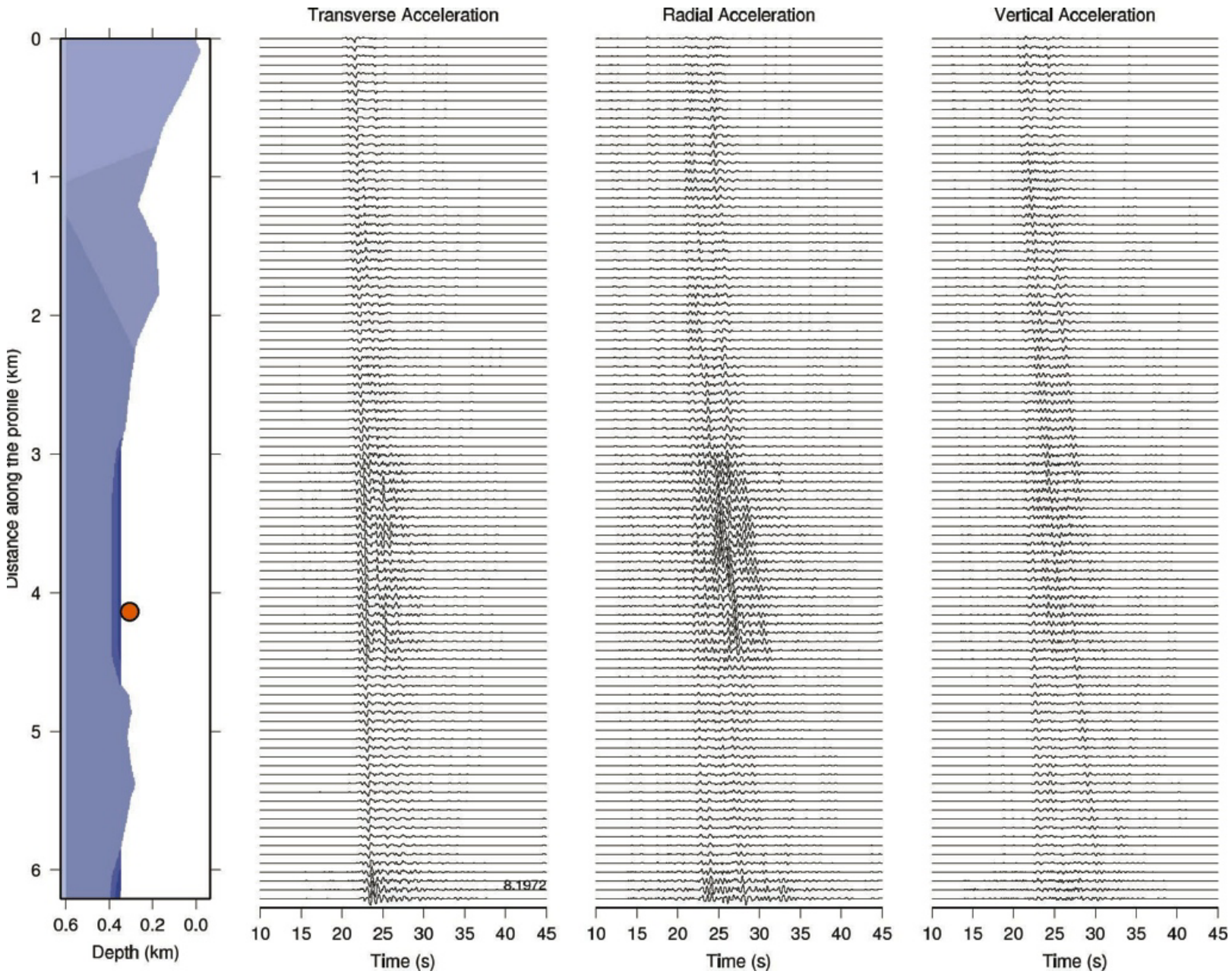
Litotipo	Densità (g/cm^3)	Vp (km/s)	Vs (km/s)	Qp	Qs
Riporti	1.8	0.4	0.2	30	15
Sed. Marini	1.9	0.8	0.4	40	20
Alluvioni	1.95	1.0	0.5	40	20
Flysch	2.0	1.8	1.0	100	50
Marne	2.0	1.9	1.1	200	100
Arenarie	2.1	2.0	1.2	200	100
Calcari	2.3	2.5	1.4	200	100

Local Scale - Preliminary Parametric Test

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



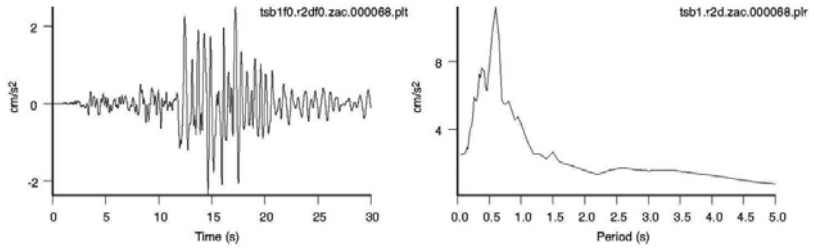
Local Scale - Synthetic Seismograms

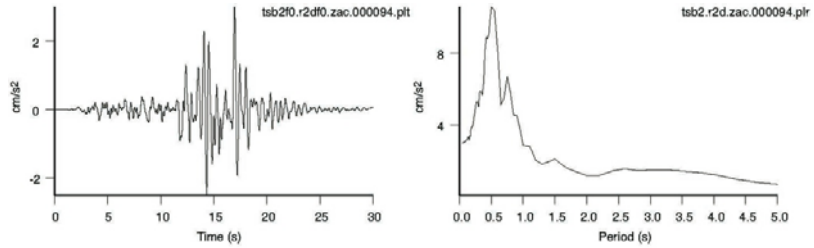


Local Scale - Response Spectra

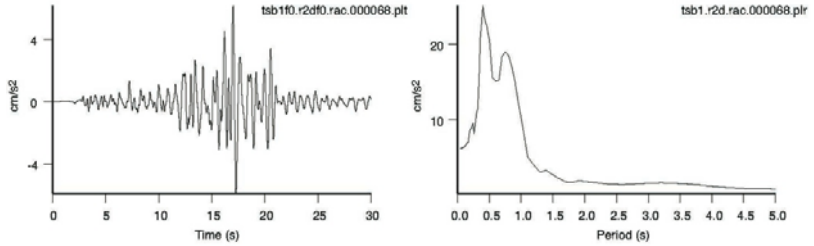
- Same site at the intersection of two profiles

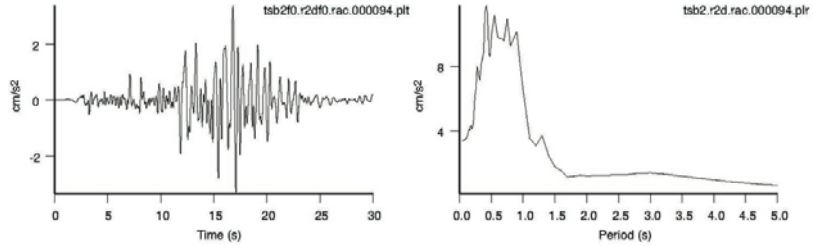
Z



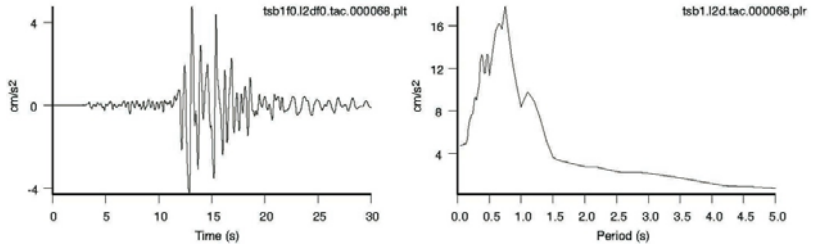


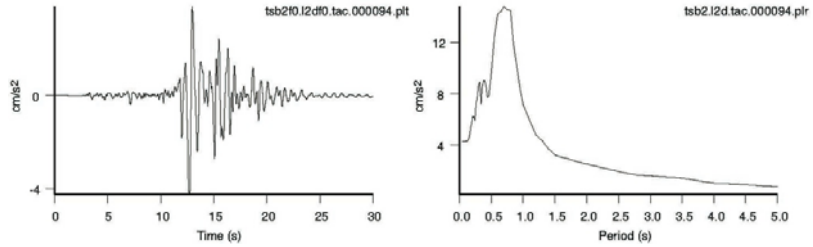
R





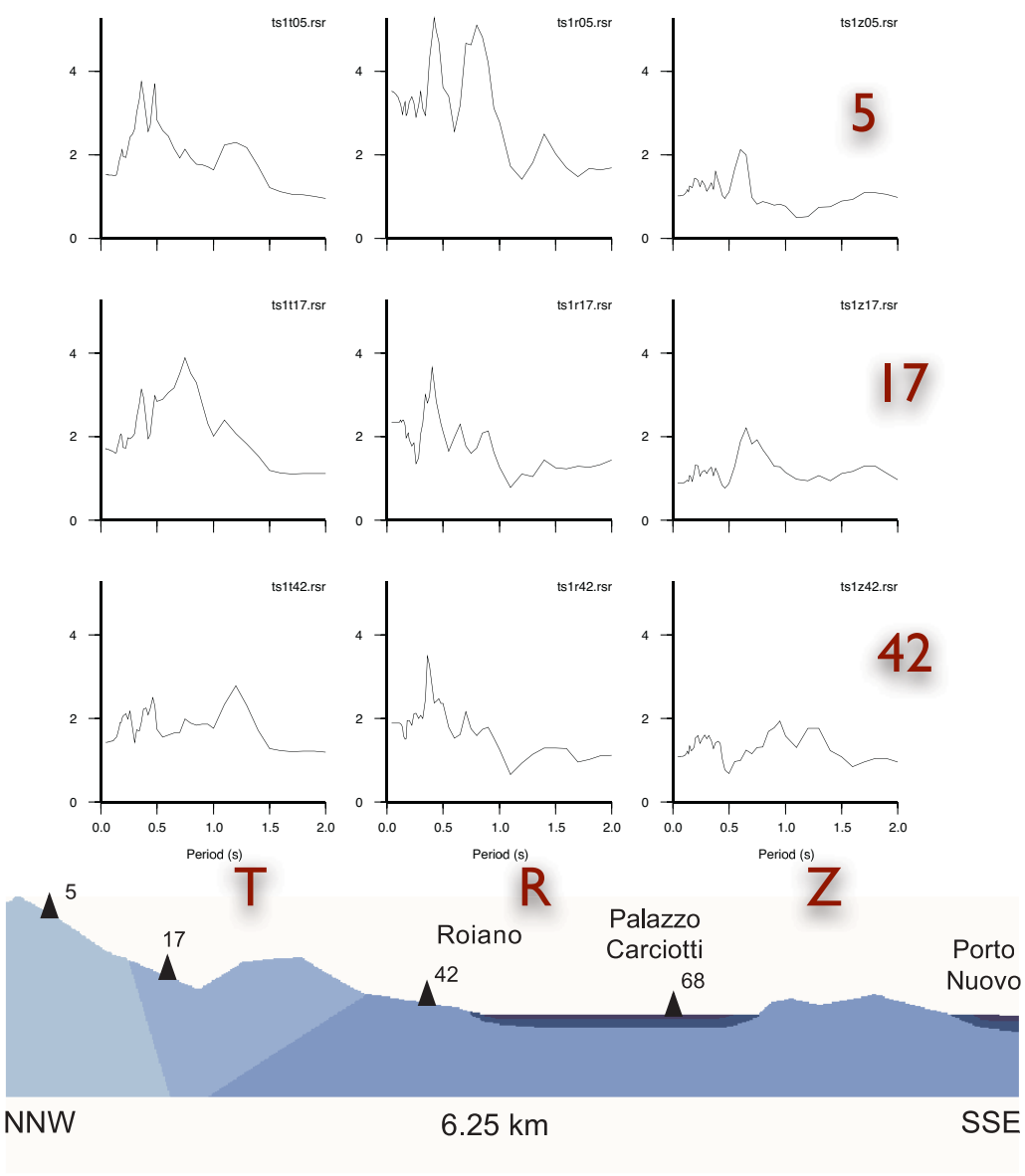
T

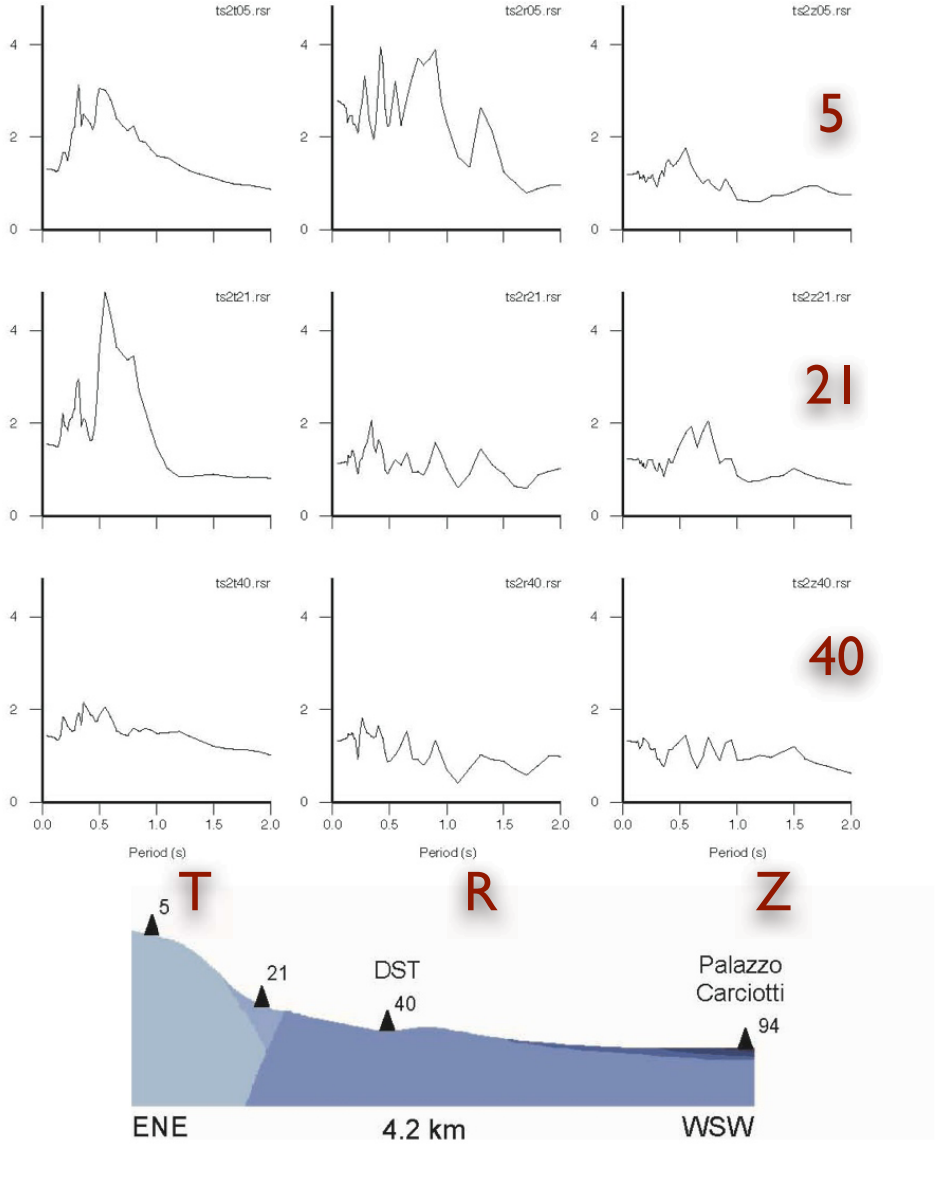




Local Scale - Response Spectra Ratio

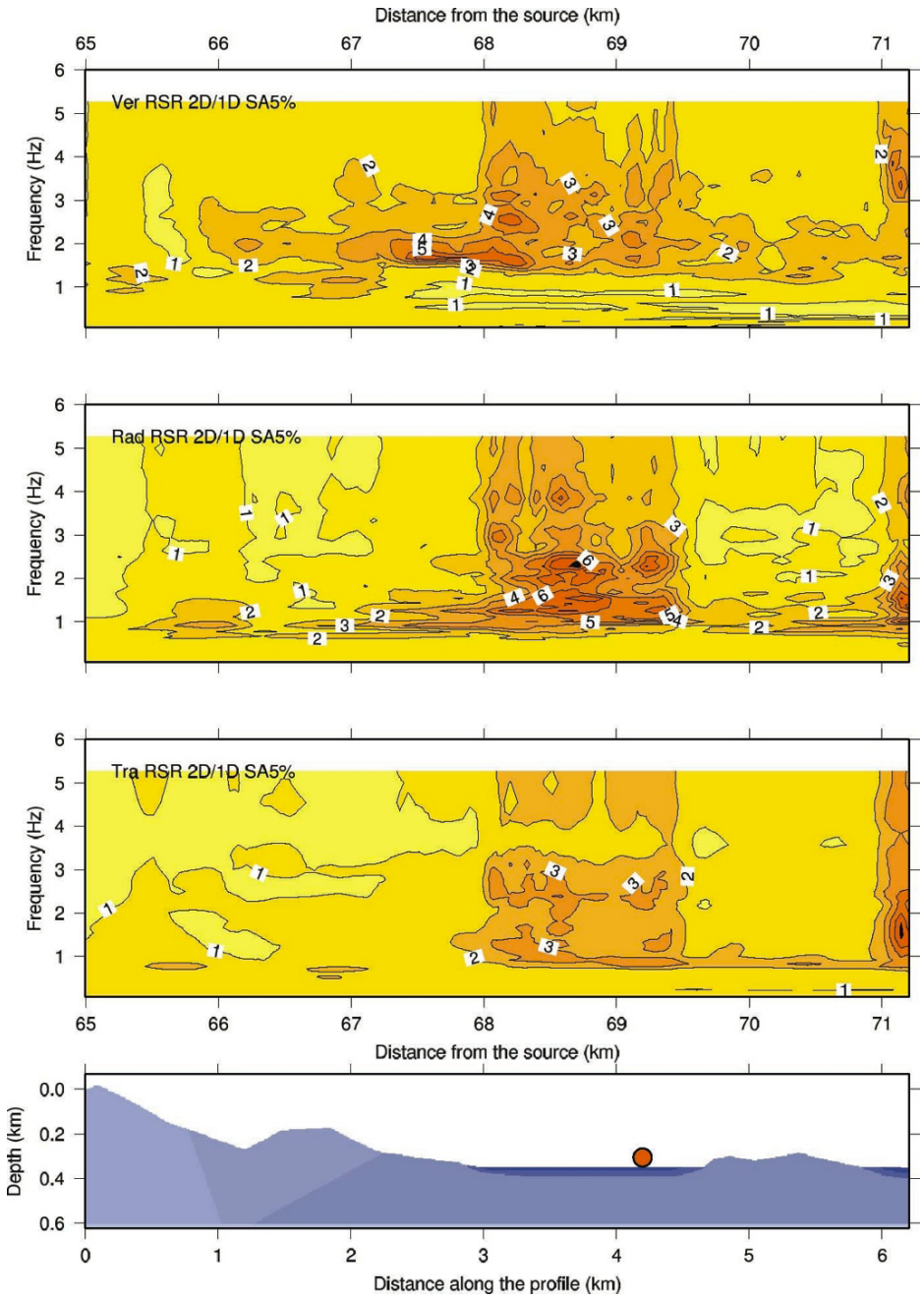
- Choice of reference site





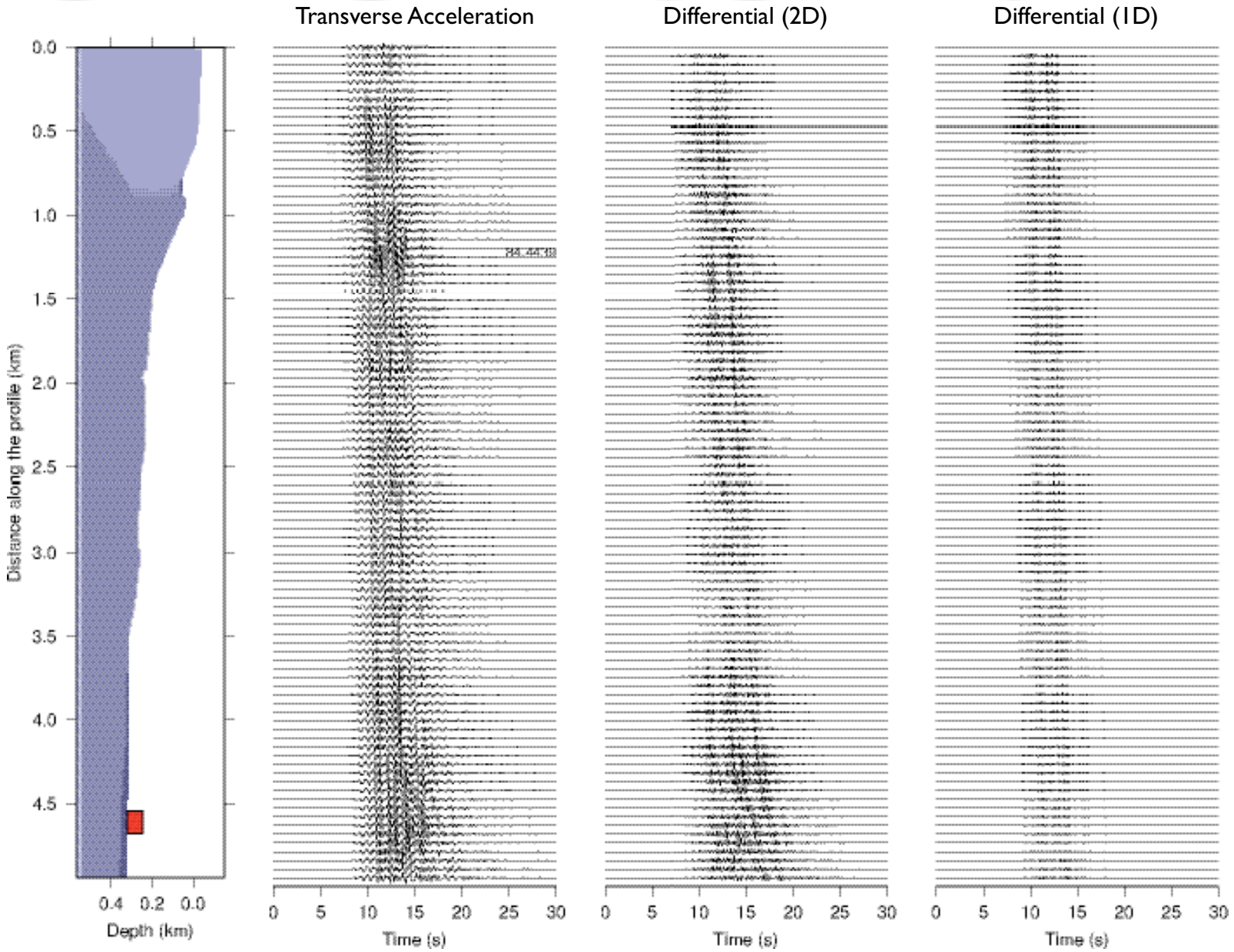
Local Scale - Response Spectra Ratio

- 2D/1D RSR



Local Scale - Differential Motion

- Significant for elongated structures (bridges, lifelines etc)



Conclusions

- Parametric analyses can help understanding the influence of each input data set on the deterministic results, but degrees of freedom must be reduced as much as possible
- Calibration of synthetic results can be made using single observations and/or global data sets
- Lateral heterogeneity can produce strong spatial variations in the ground motion even at small incremental distances, that can hardly be reproduced by the stochastic models commonly used in engineering practice
- In absolute terms, the differential motion amplitude is comparable with the input motion amplitude when displacement, velocity and acceleration domains are considered
- Differential motion can cause an increment greater than one unit in the seismic intensity experienced by bridges, with respect to the average intensity affecting the area where the bridge is built