Computational Aspects
of the
Neodeterministic Seismic Hazard Assessment

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Cairo, 25-29 October 2014

Neo-deterministic approach

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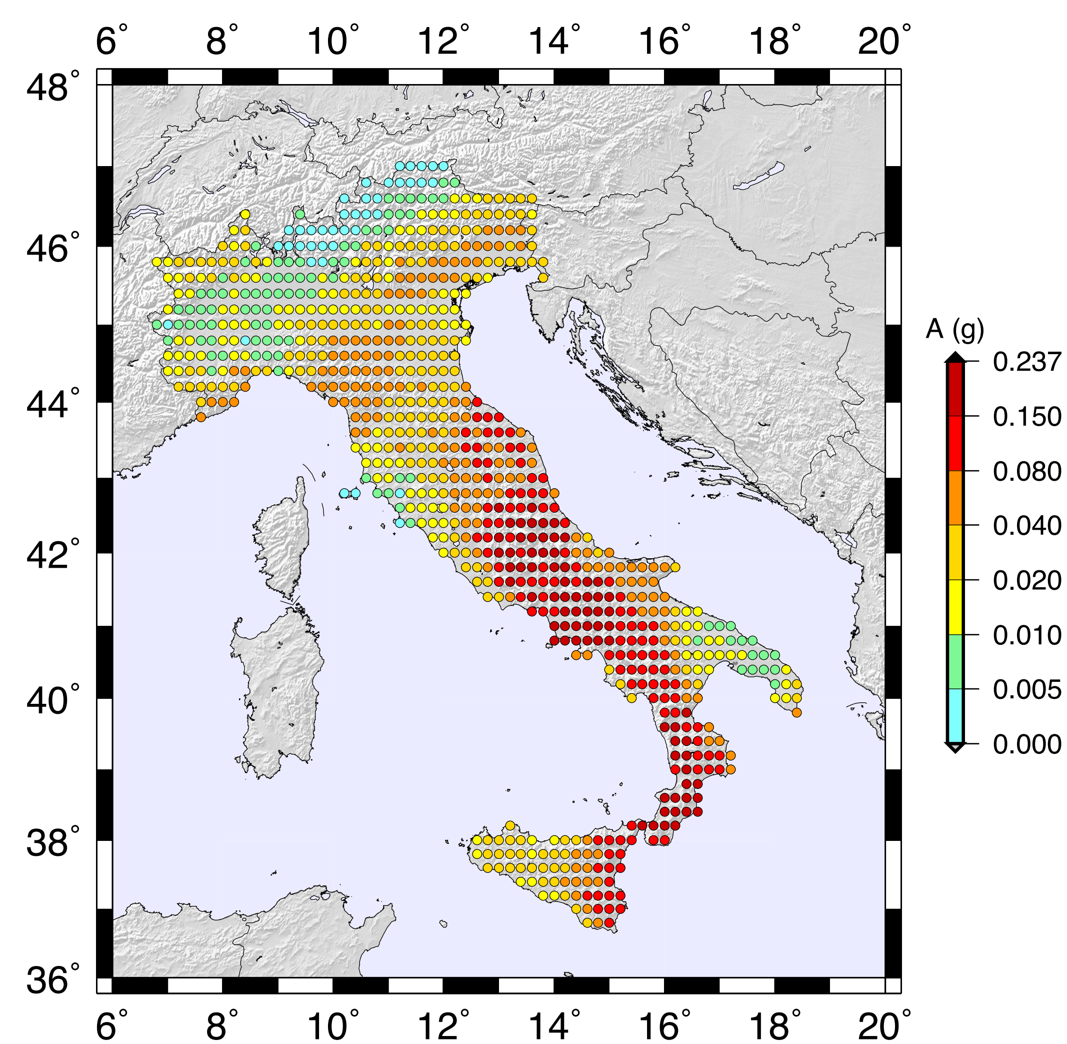
- Modelling of ground shaking scenarios
  - Regional scale: on a grid of sites covering the studied area
  - Local scale: along laterally heterogeneous profiles

Neo-deterministic approach

- Modelling of ground shaking scenarios
  - Regional scale: on a grid of sites covering the studied area
  - Local scale: along laterally heterogeneous profiles
- Collection of available data
  - Structural properties
  - Historical seismicity
  - Tectonic regime
  - Active seismogenic zones
  - ...
  -

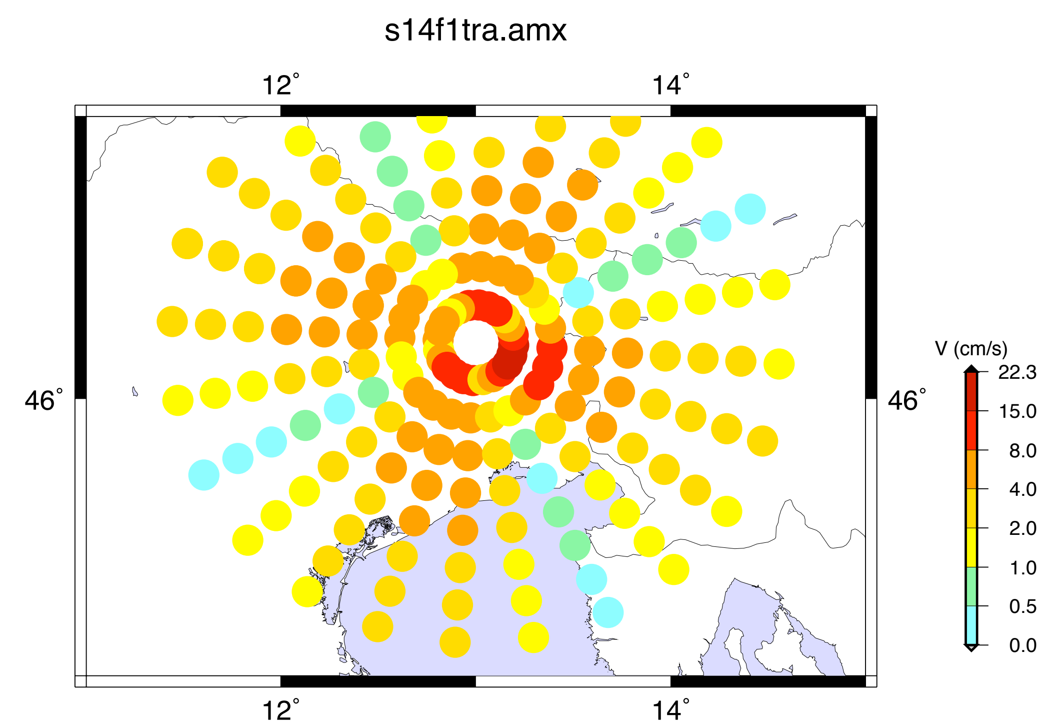
Scenarios - Regional Scale

- 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
- Easy parametric tests
- Modal summation technique



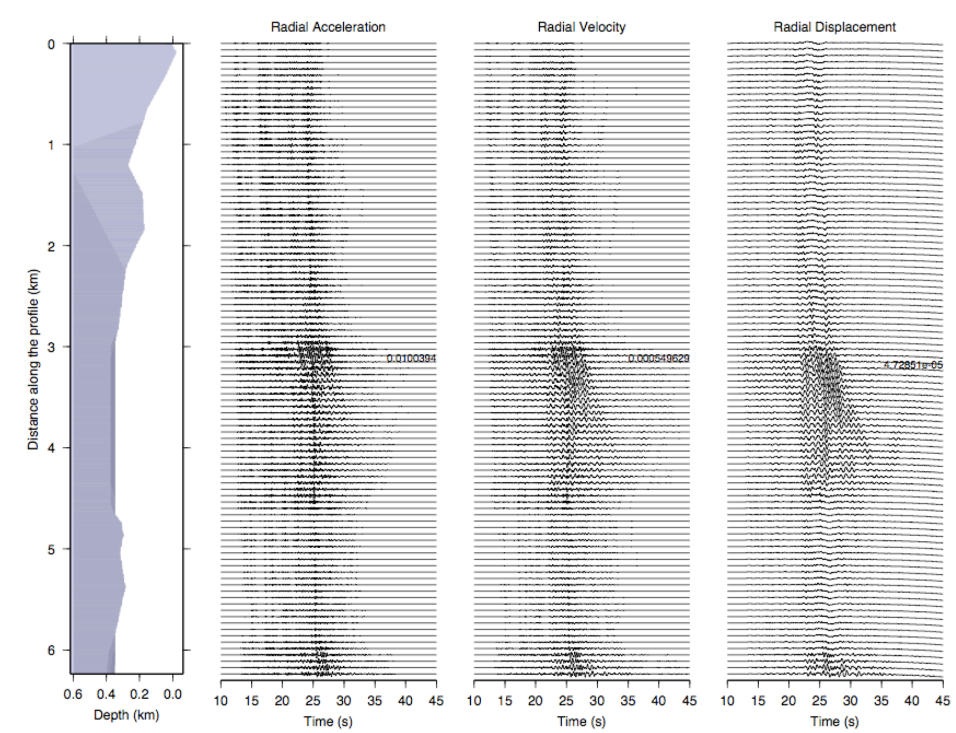
Scenarios - Event Scale

- Ground-shaking scenario for a single, specific event
- Average structural properties
- Simple or detailed source model
- Cut-off frequency 1 or 10 Hz
- Maps of peak displacement, velocity and acceleration
- Modal summation technique



Scenarios - 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
- Hybrid technique (modal summation + finite difference)



Once upon a time...

- 1985: it all started...

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  - Synthetic seismograms: the Rayleigh waves modal summation (Panza, 1985)

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

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source | structure | receiver

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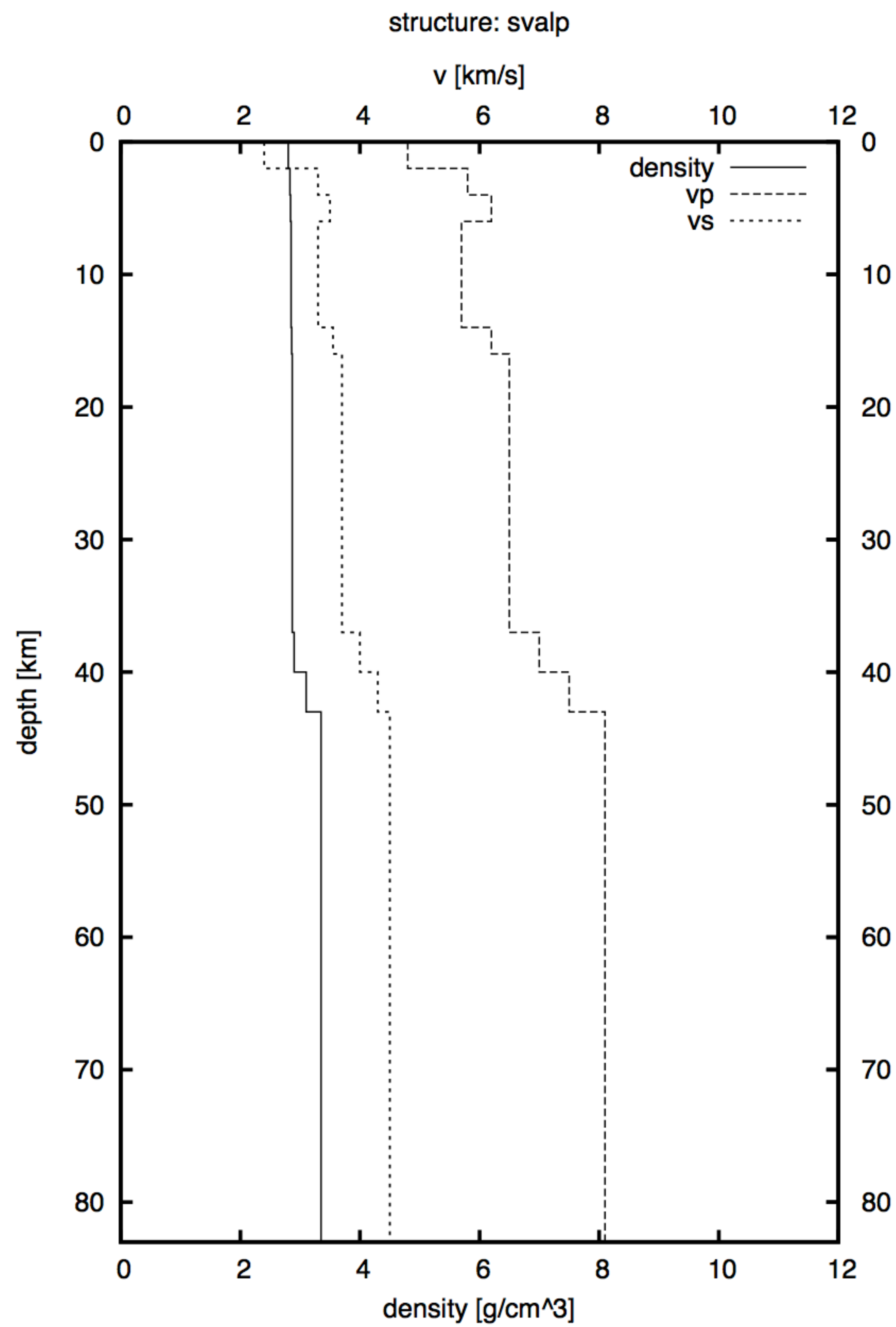

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```
INPUT FOR RAYLEIGH WAVES MODES - PART1
**********************************************************************
NAME OF STRUCTURE                            :     SVALP.S          NAMESTR
MAXIMUM FREQUENCY                            :  0.10000E+02         XMAXFR
TOTAL NUMBER OF SOLID LAYERS                 :        89            N
NUMBER OF OCEANIC LAYERS                     :         0            MSMAX
MAX. NUMBER OF MODES TO BE COMPUTED          :         0            MODETR
M A N T L E   C H A N N E L   (XMAXFR=10===>LITHOSPHERIC) PARAMETERS
----------------------------------------------------------------------
PRESENCE OF TYPE 2 CHANNEL IN LID            :         0            ICHLID
S-WAVE VELOCITY OF TYPE2 CHANNEL ( - 12% ) :  0.00000E+00           UMIN
CORRESPONDING S-WAVE PHASE ATTENUATION       :  0.00000E+00         UMINAT
S-WAVE VELOCITY AT BOTTOM OF TYPE2 CHANNEL :  0.00000E+00           UMAX
CORRESPONDING S-WAVE PHASE ATTENUATION       :  0.00000E+00         UMAXAT
HIGHEST INTERFACE OF TYPE 1 CHANNEL          :        27            ITOPMC
LOWEST INTERFACE OF TYPE 1 CHANNEL           :        44            ICH1
MIN. S-WAVE VELOCITY IN TYPE 1 CHANNEL       :  0.33001E+01         BCH
CORRESPONDING S-WAVE PHASE ATTENUATION       :  0.75755E-03         BC99AT
MAX.S-WAVE VELOC.(AVER.ABOV.TYPE1 CHANNEL) :  0.28501E+01           BLCRST
MAX.S-WAVE PHASE ATT.(ABOVE TYPE1 CHANNEL) :  0.10417E-02           BCCRAT
C R U S T A L   C H A N N E L  (XMAXFR=10==>UPPERCRUSTAL) PARAMETERS
----------------------------------------------------------------------
PRESENCE OF TYPE 2 CHANNEL IN THE CRUST      :         0            ICHCRS
S-WAVE VELOCITY OF TYPE2 CHANNEL ( - 12% ) :  0.00000E+00           UCMIN
CORRESPONDING S-WAVE PHASE ATTENUATION       :  0.00000E+00         UMINA2
S-WAVE VELOCITY AT BOTTOM OF TYPE2 CHANNEL :  0.00000E+00           UCMAX
CORRESPONDING S-WAVE PHASE ATTENUATION       :  0.00000E+00         UMAXA2
HIGHEST INTERFACE OF TYPE 1 CHANNEL          :         0            ITOPCC
LOWEST INTERFACE OF TYPE 1 CHANNEL           :         0            ICH2
MIN. S-WAVE VELOCITY IN TYPE 1 CHANNEL       :  0.00000E+00         BCHCR
CORRESPONDING S-WAVE PHASE ATTENUATION       :  0.00000E+00         BC99A2
PROP.AV.CRUST.S-WAVE VEL.ABOV.TYPE1 CHANNEL:  0.00000E+00           BUCRST
MAXIMUM CRUST.S-WAVE PH.ATTENUATION          :  0.00000E+00         BUCATT
S T R U C T U R E   P A R A M E T E R S
--------------------------------------------------------------------------
LIQUID PART
--------------------------------------------------------------------------
   THICKNESS     DENSITY       P-WAVE
                              VELOCITY
    THKSEA(I)   RHOSEA(I)    ALPSEA(I)
 0.00000E+00 0.00000E+00 0.00000E+00
--------------------------------------------------------------------------
SOLID PART
--------------------------------------------------------------------------
   THICKNESS     DENSITY       P-WAVE      P-WAVE       S-WAVE      S-WAVE
                              VELOCITY  ATTENUATION   VELOCITY  ATTENUATION
   THKNES(I)      RHO(I)       A1(I)       A2(I)        B1(I)       B2(I)
 0.20000E+00 0.28000E+01 0.48000E+01 0.26042E-03 0.24000E+01 0.10417E-02
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 0.20000E-01 0.28000E+01 0.48000E+01 0.26042E-03 0.24002E+01 0.10417E-02
 0.25000E-01 0.28300E+01 0.58000E+01 0.21552E-03 0.33000E+01 0.75758E-03
 0.22500E+00 0.28300E+01 0.58000E+01 0.21552E-03 0.33000E+01 0.75758E-03
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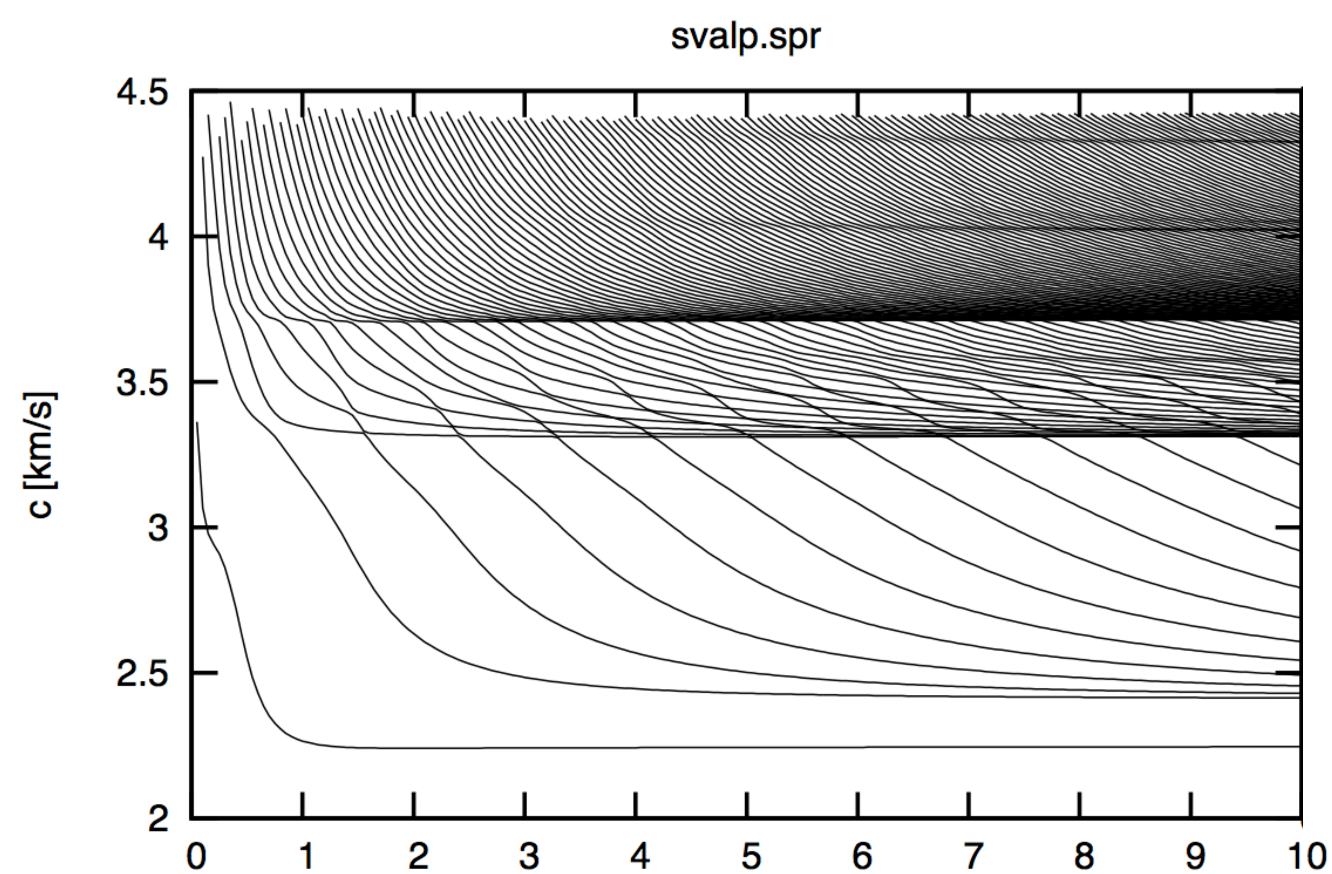

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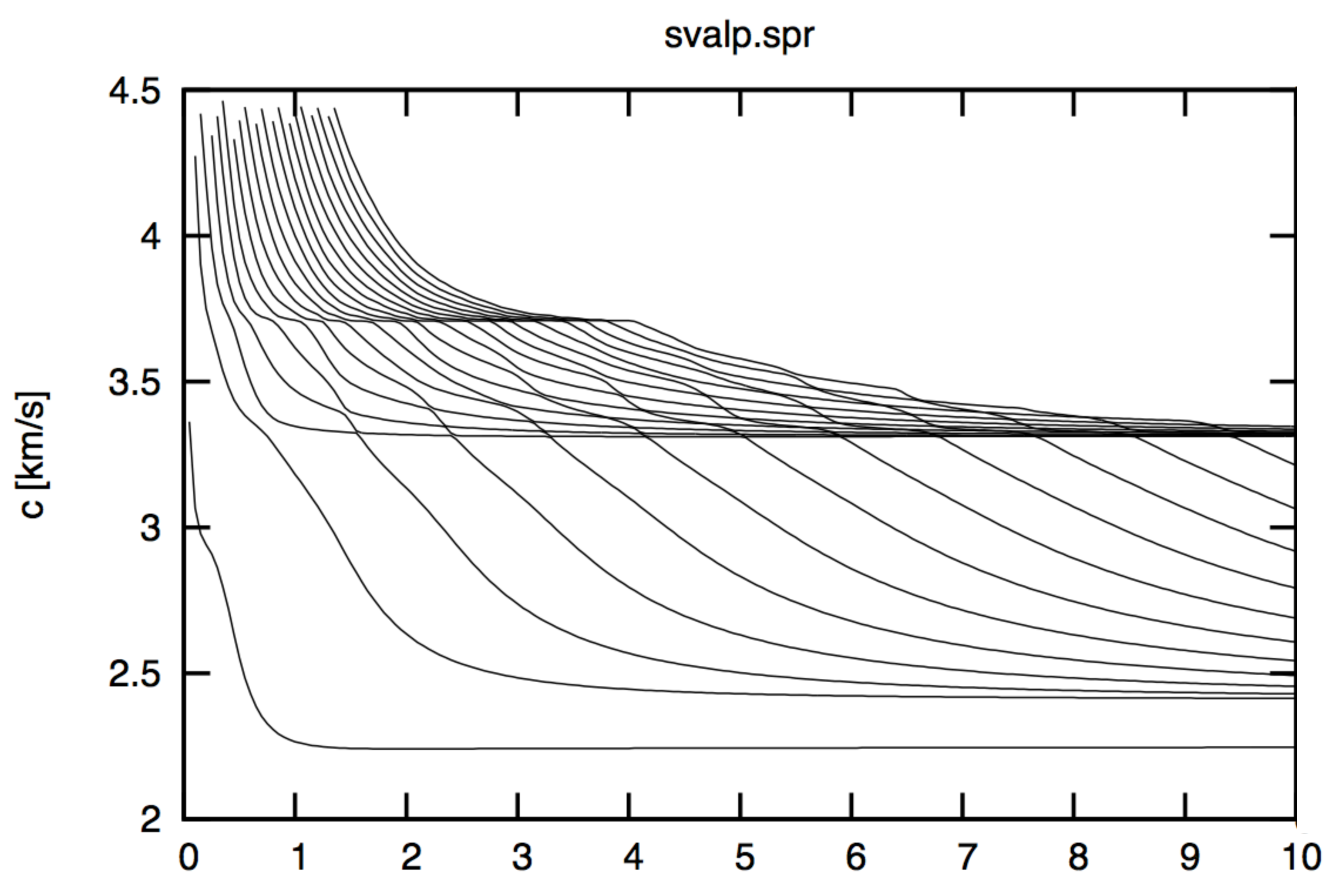

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    - Do it again...

```
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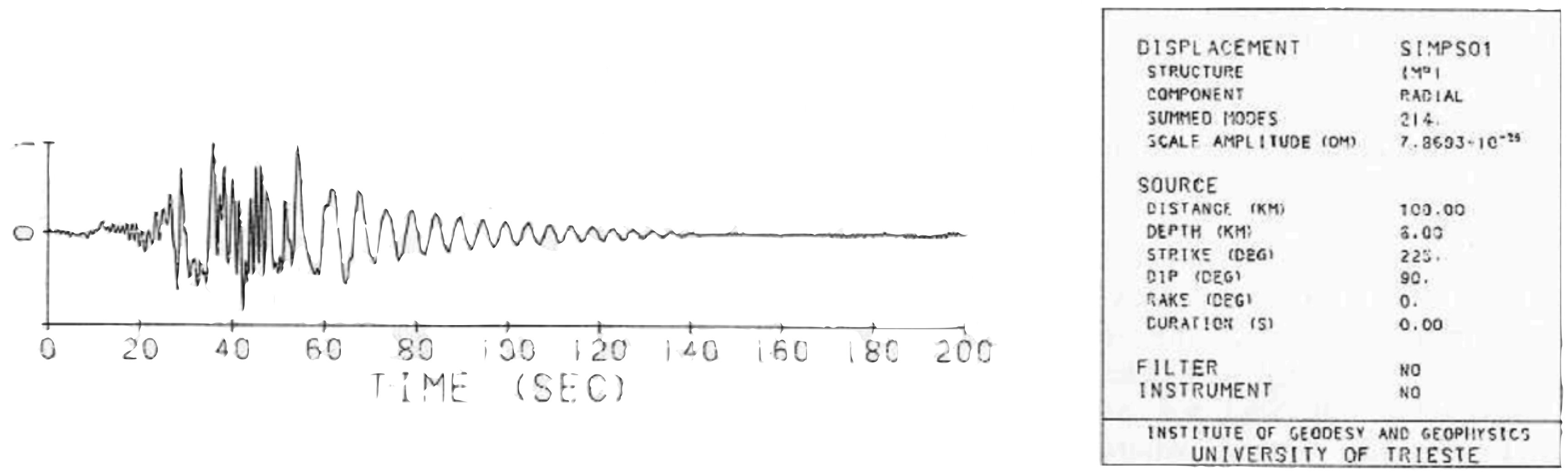

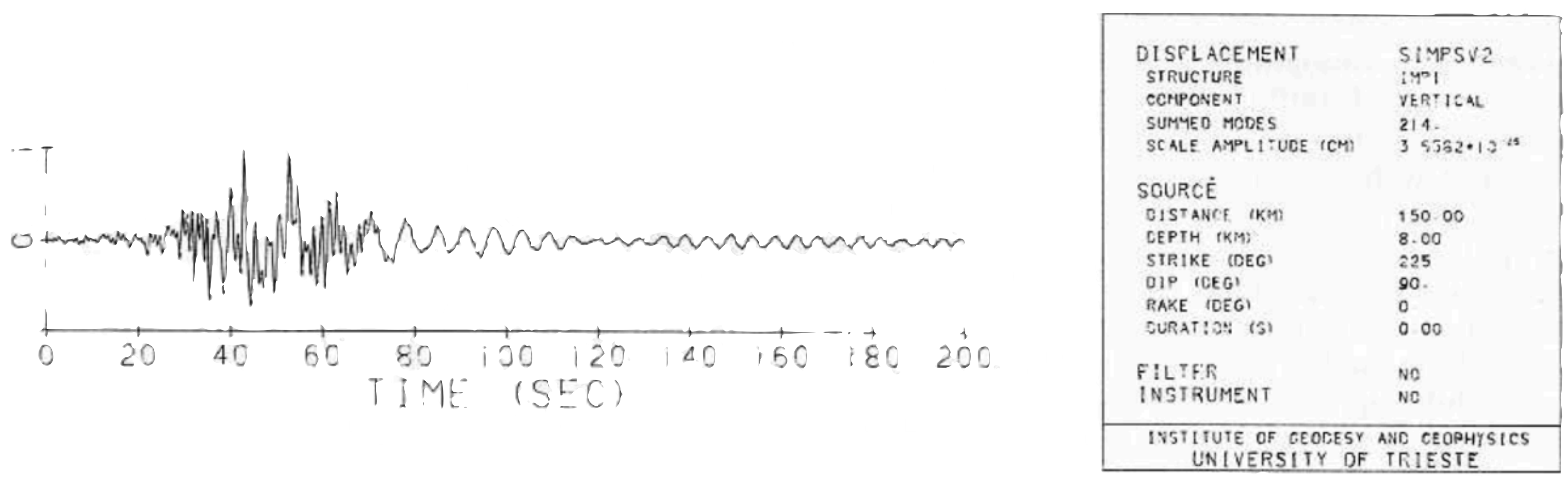

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source   structure   receiver

Once upon a time...

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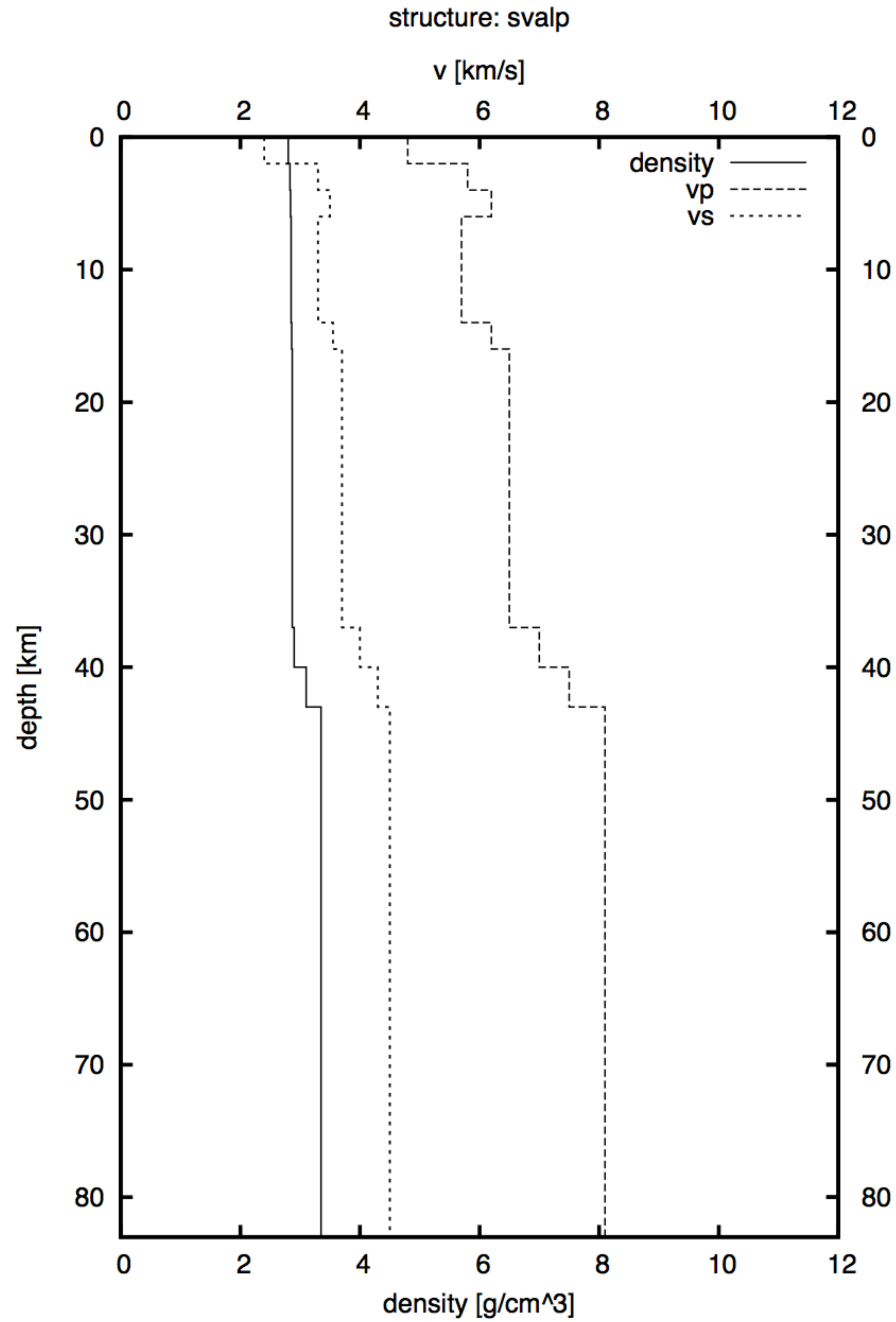
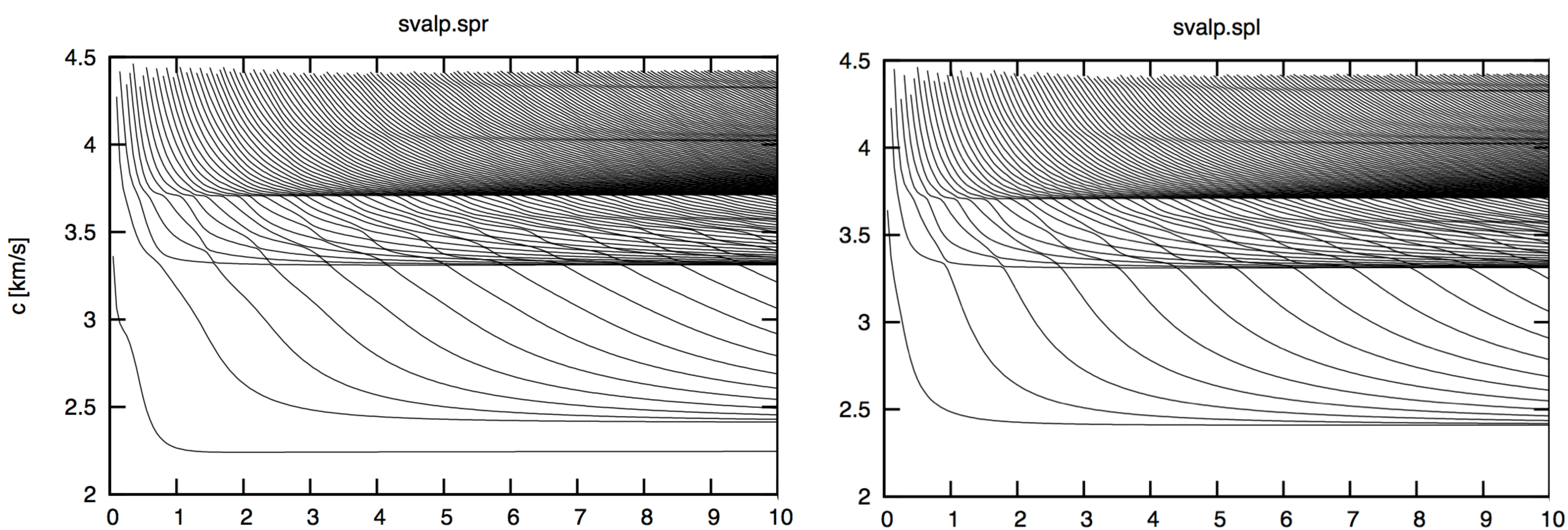
  - Structure definition



Once upon a time...

- 1991: SH waves as well...
  - Job submission on the IBM 3090 Mainframe Computer in Bologna (ENEA):
    - Submit at any time...
    - Cross fingers...
    - Get the results in a couple of hours...



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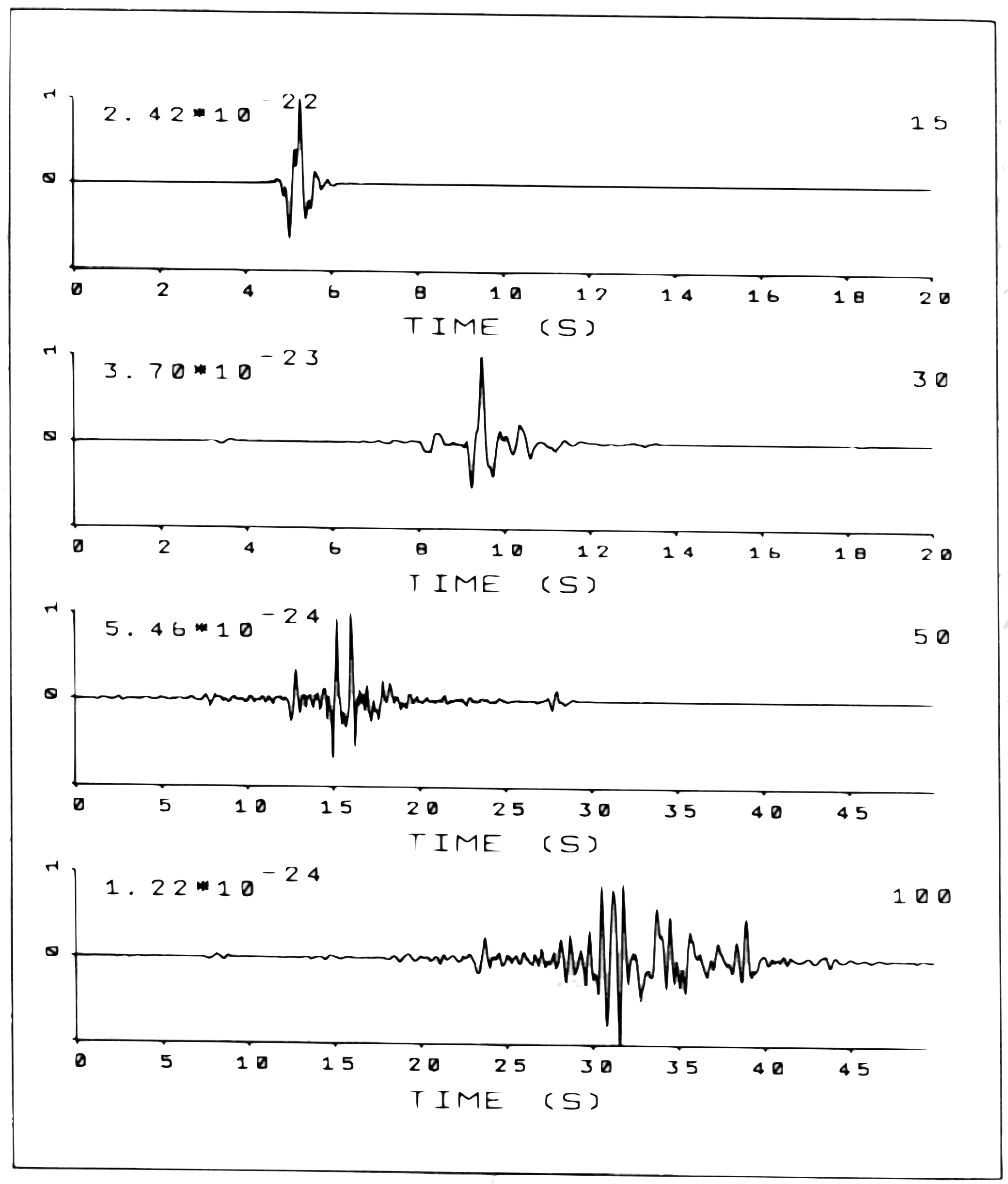

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- 1993: Seismic zonation at national scale!
  - Zoning of the Italian territory in terms of expected peak ground acceleration derived from complete synthetic seismograms (Costa et al., 1993)

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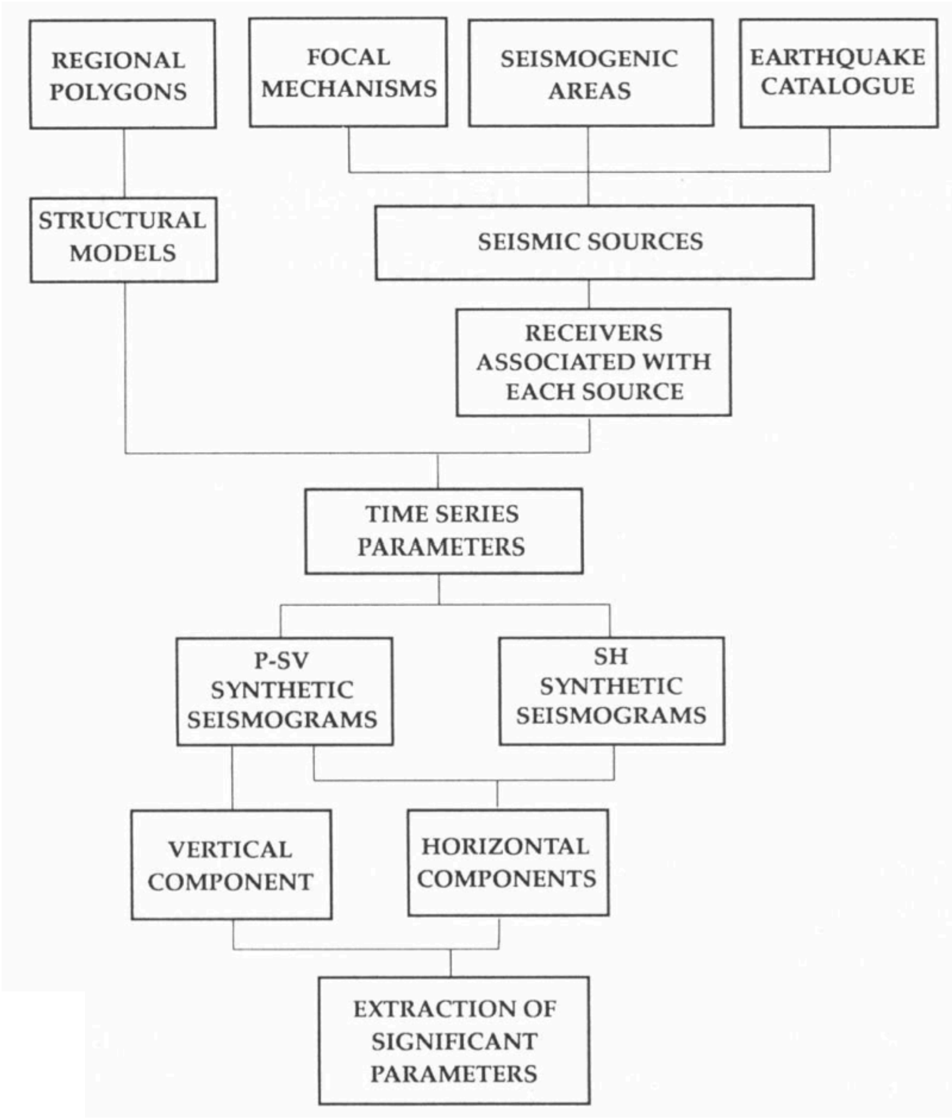
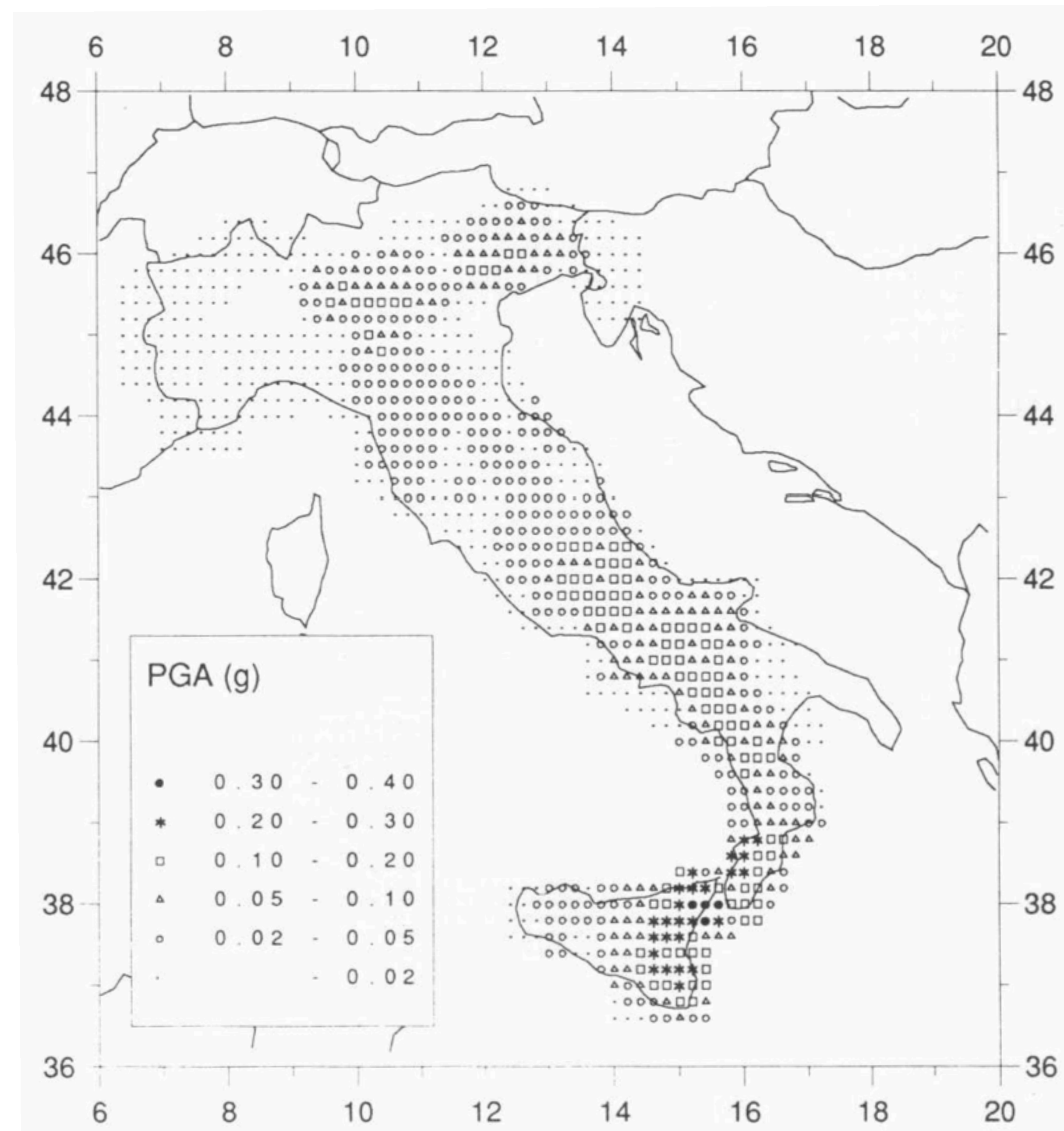


Once upon a time...

- 1993: Seismic zonation at national scale!
  - Job submission on local Unix workstation:
    - 😉 Submit at any time...
    - 😃 Get the results in a day...



Once upon a time...

- 1993: Seismic zonation at local scale!

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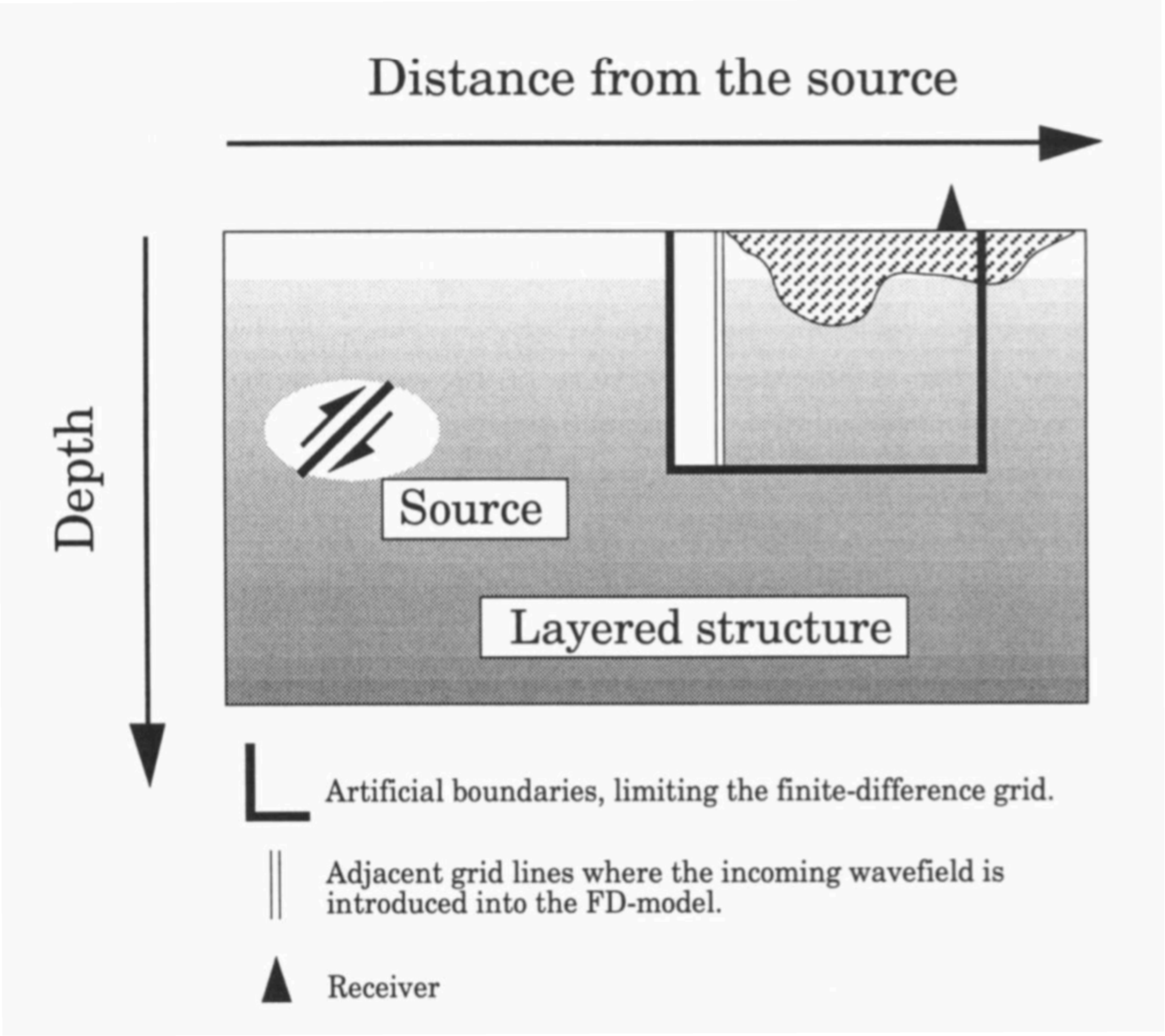
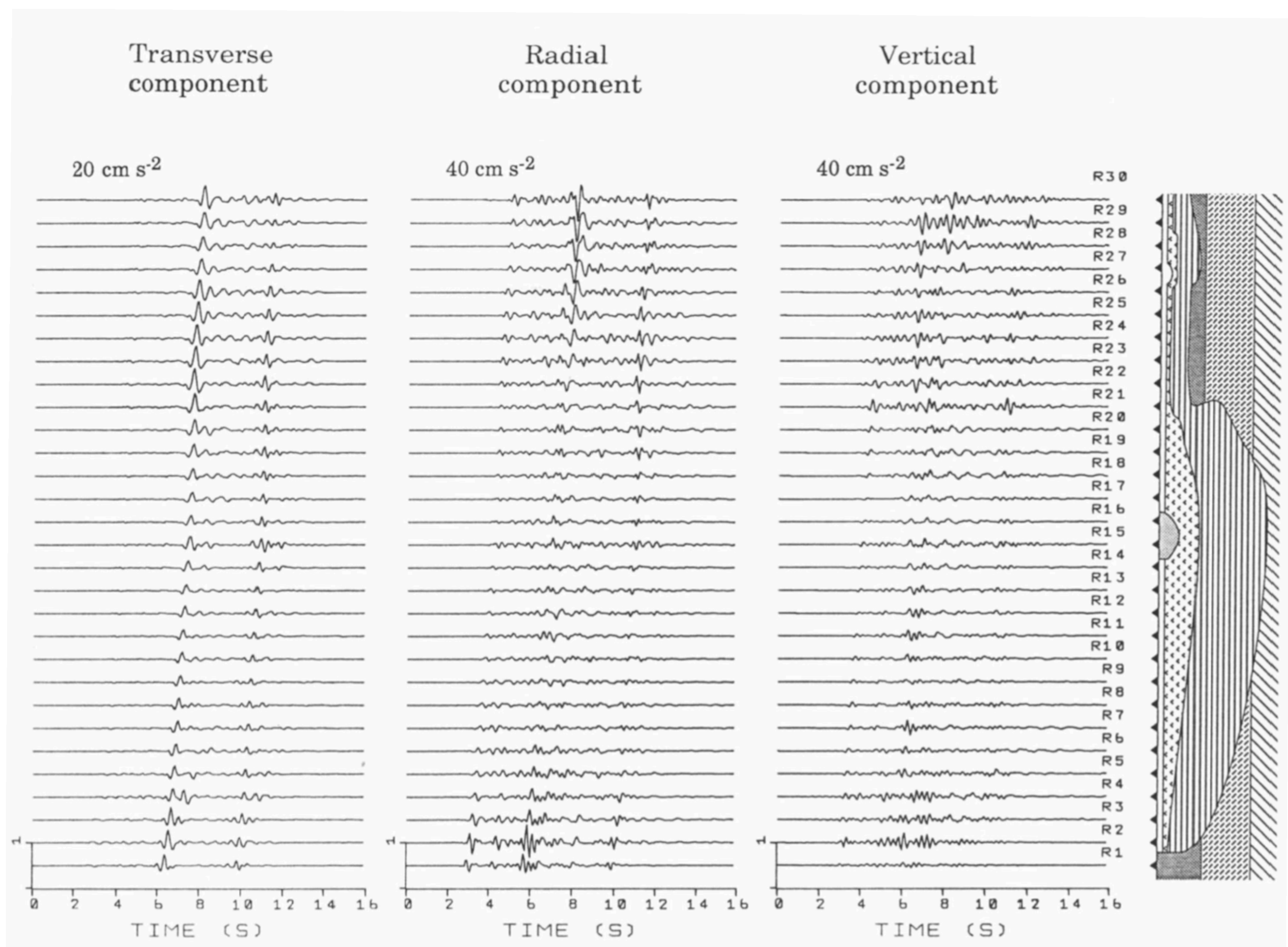
  - A new method for the realistic estimation of seismic ground motion in megacities: the case of Rome (Fäh et al, 1993)



Once upon a time...

- 1993: Seismic zonation at local scale!
  - Job submission on local Unix workstation:
    - Submit any time...
    - Get the results in a week...



Once upon a time...

- 1993: Seismic zonation at local scale!
  - A week, that is, about the same time that it took to prepare a model...

```
model t1.                  dx=dz=0.005 km  depth= 24.025km
     ibstart ibstop iclay iclayl iclayr   nout ndis nvel nacc ngsp nbwd
           1      2     2      1      0      4    1    1    1    1    1
          t0        tstep          s0        sstep       time0
     3.00000      2.00000     0.51000      0.02000     3.00000
        freq           dx           dz mdim ndim nlmax  ms   ns  nfb nf
    10.00000      0.00500     0.00500  504  522    6  102    0   46 10
      thknes           rh           a1          dqa          b1          dqb
     2.00000      2.80000     4.80000    400.00000     2.40000    200.00000
     2.00000      2.83000     5.80000    400.00000     3.30000    200.00000
     2.00000      2.84000     6.20000    400.00000     3.50000    200.00000
     8.00000      2.85000     5.70000    400.00000     3.30010    200.00000
     2.00000      2.86000     6.20000    400.00000     3.55000    200.00000
    21.05000      2.87000     6.50000    400.00000     3.70000    200.00000
    dma      dmx     dna     dnz      drho       da1      dqa      db1      dqb
 0.0000  0.4975  0.0000  2.0000     2.800     4.800   397.100    2.400   180.500 1
 0.0000  0.4975  2.0000  4.0000     2.830     5.800   397.100    3.300   180.500 1
 0.0000  0.4975  4.0000  6.0000     2.840     6.200   397.100    3.500   180.500 1
 0.0000  0.4975  6.0000 14.0000     2.850     5.700   397.100    3.300   180.500 1
 0.0000  0.4975 14.0000 16.0000     2.860     6.200   397.100    3.550   180.500 1
 0.0000  0.4975 16.0000 37.0500     2.870     6.500   397.100    3.700   180.500 1
 0.0000  0.4475  0.0000  2.0000     2.800     4.800   354.200    2.400   161.000 1
 0.0000  0.4475  2.0000  4.0000     2.830     5.800   354.200    3.300   161.000 1
 0.0000  0.4475  4.0000  6.0000     2.840     6.200   354.200    3.500   161.000 1
 0.0000  0.4475  6.0000 14.0000     2.850     5.700   354.200    3.300   161.000 1
 0.0000  0.4475 14.0000 16.0000     2.860     6.200   354.200    3.550   161.000 1
 0.0000  0.4475 16.0000 37.0500     2.870     6.500   354.200    3.700   161.000 1
 0.0000  0.3975  0.0000  2.0000     2.800     4.800   311.300    2.400   141.500 1
 0.0000  0.3975  2.0000  4.0000     2.830     5.800   311.300    3.300   141.500 1
 0.0000  0.3975  4.0000  6.0000     2.840     6.200   311.300    3.500   141.500 1
 0.0000  0.3975  6.0000 14.0000     2.850     5.700   311.300    3.300   141.500 1
 0.0000  0.3975 14.0000 16.0000     2.860     6.200   311.300    3.550   141.500 1
 0.0000  0.3975 16.0000 37.0500     2.870     6.500   311.300    3.700   141.500 1
 0.0000  0.3475  0.0000  2.0000     2.800     4.800   268.400    2.400   122.000 1
 0.0000  0.3475  2.0000  4.0000     2.830     5.800   268.400    3.300   122.000 1
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 0.0000  0.2975  0.0000  2.0000     2.800     4.800   225.500    2.400   102.500 1
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```

Nowadays...

- Seismic zonation at national scale
  - Executing the same computation on modern desktop or laptop computers is a matter of hours...

Nowadays...

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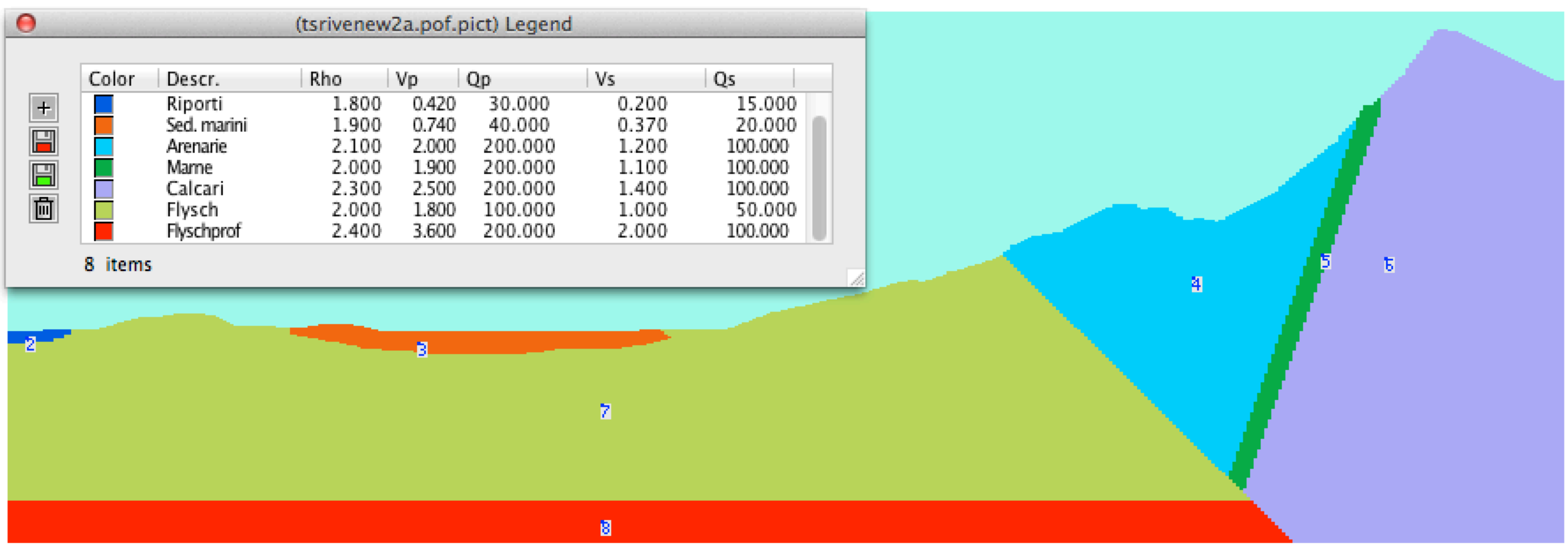
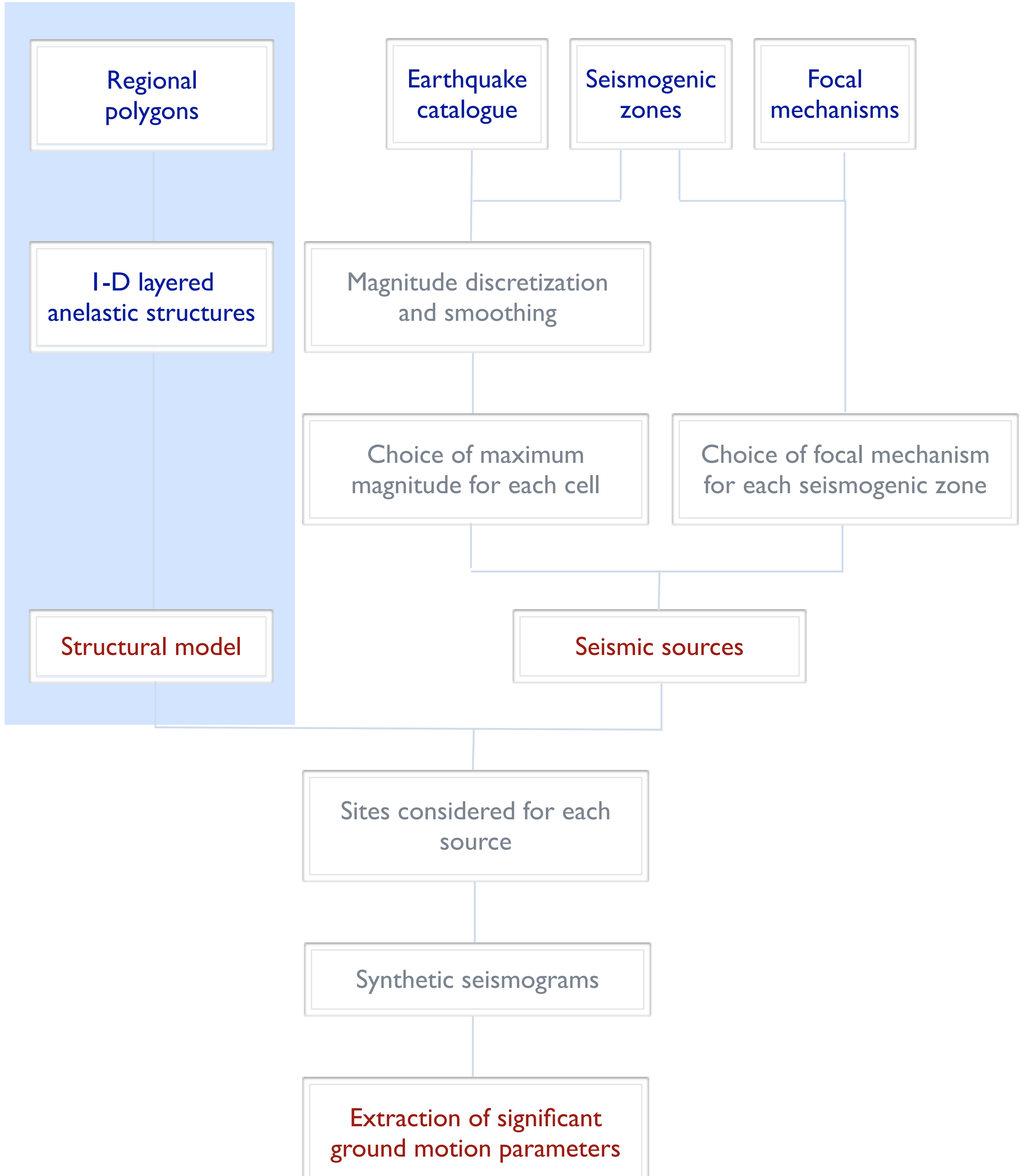
  - Executing the same computation on modern desktop or laptop computers is a matter of hours...
  - ... and preparing the model is even faster than that



Nowadays - Regional scale



Regional scale - Structural model

Regional polygons

1-D layered anelastic structures

Structural model

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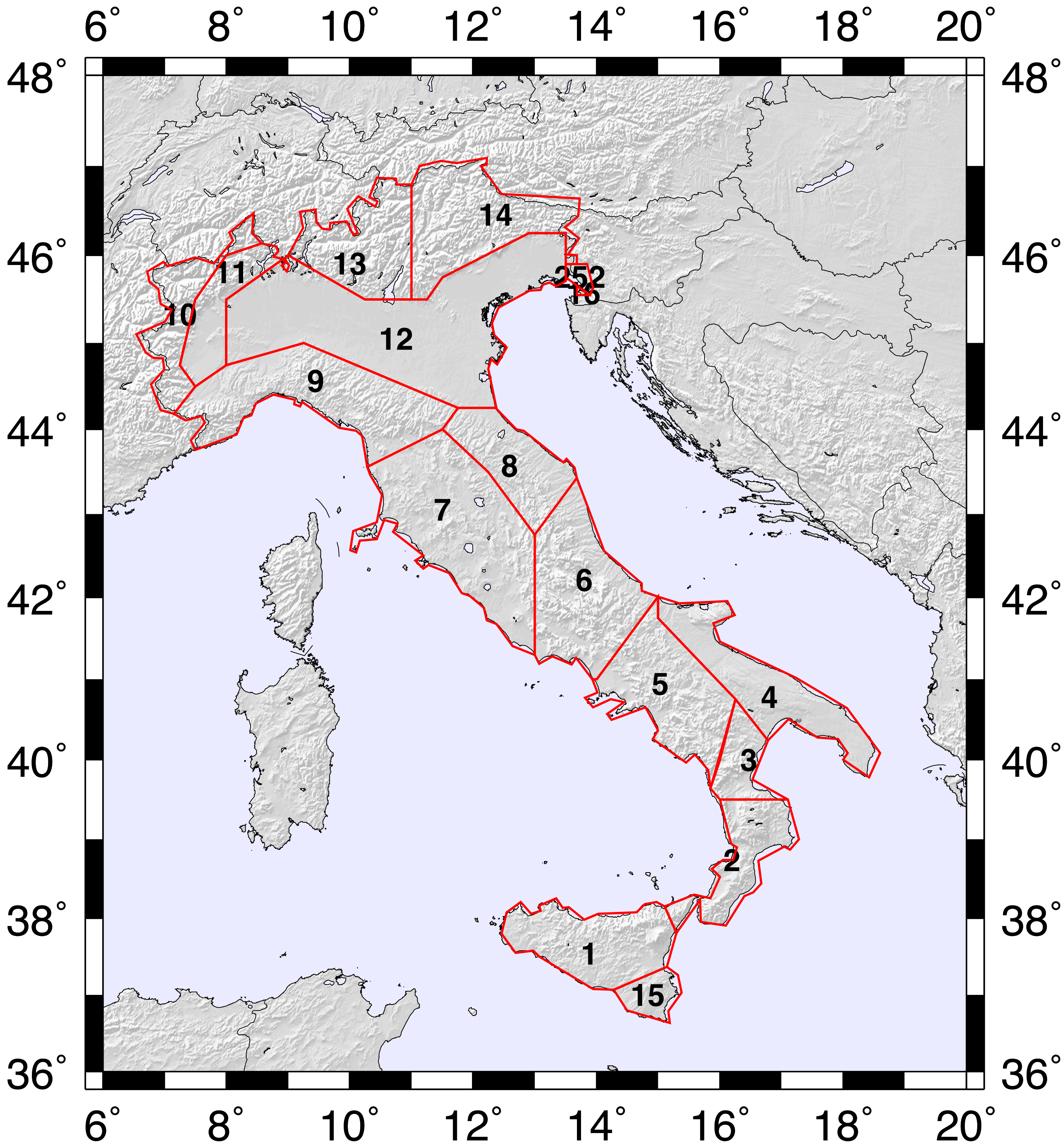
1-D layered anelastic structures

Structural model



Regional scale - Structural model

Regional polygons

1-D layered anelastic structures

Structural model

```
Polygons that define different structural regions (lon,lat)
region0001
            12.550  38.070
            12.770  38.200
            12.940  38.050
            13.090  38.090
            13.070  38.160
            13.350  38.250
            13.450  38.125
            13.550  38.135
            13.800  37.980
            14.025  38.050
            14.650  38.070
            14.780  38.180
            14.980  38.200
            15.110  38.150
            15.300  37.810
            15.140  37.370
            14.280  37.070
            13.940  37.080
            12.980  37.580
            12.690  37.549
            12.460  37.800
region0002
            15.110  38.150
            15.300  37.810
            15.680  38.235
            15.690  37.950
            16.100  37.900
...
...
...
            15.140  37.370
            15.323  37.264
            15.381  37.030
            15.160  36.795
            15.190  36.641
            14.501  36.801
            14.280  37.070
region0016
            13.900  45.550
            13.680  45.550
            13.680  45.650
region0252
            13.850  45.900
            13.950  45.638
            13.900  45.550
            13.500  45.750
            13.500  45.900
```

Regional scale - Structural model

Regional polygons

1-D layered anelastic structures

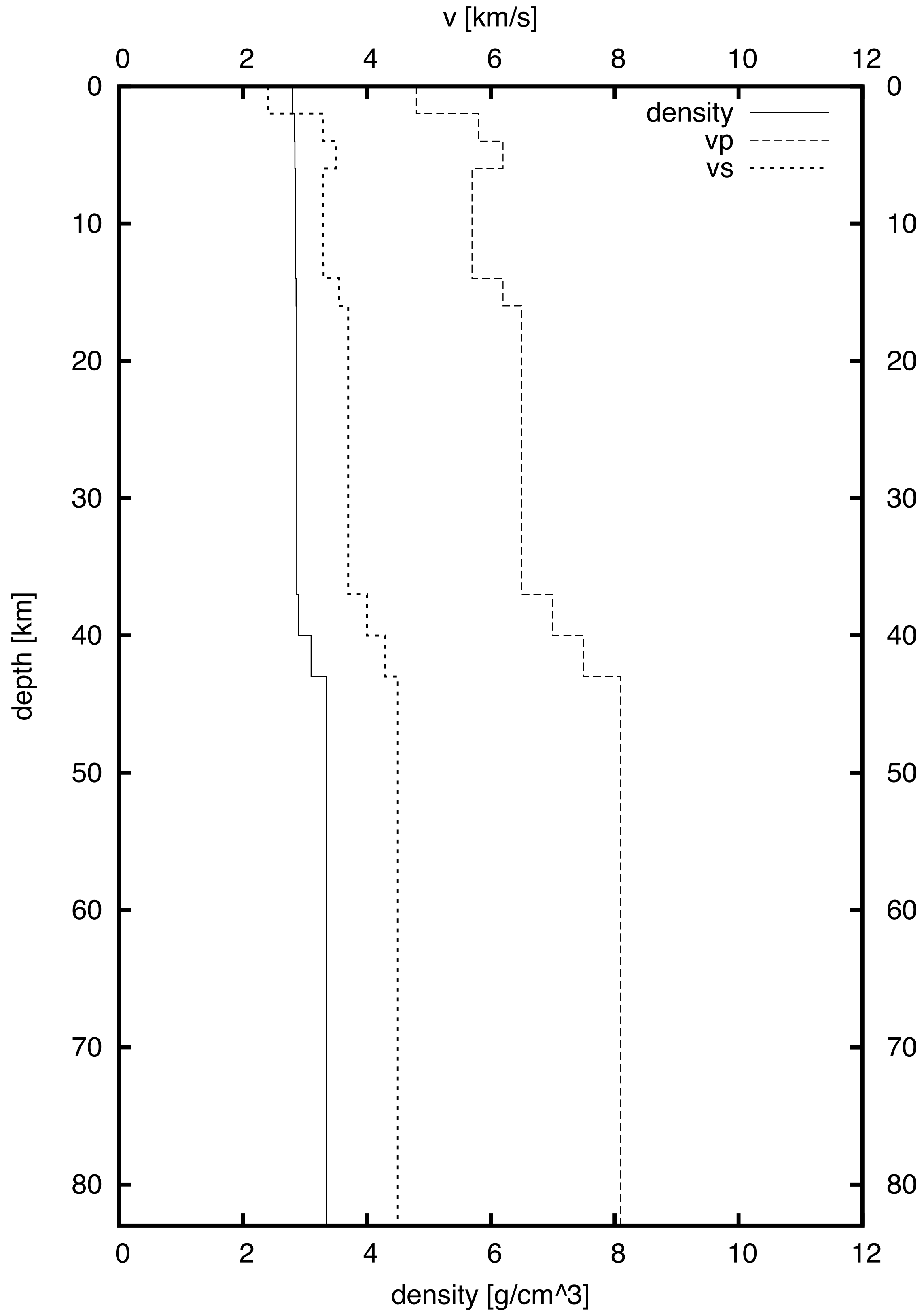
Structural model

Regional scale - Structural model

Regional polygons

1-D layered anelastic structures

Structural model



Regional scale - Structural model

Regional polygons

1-D layered anelastic structures

Structural model

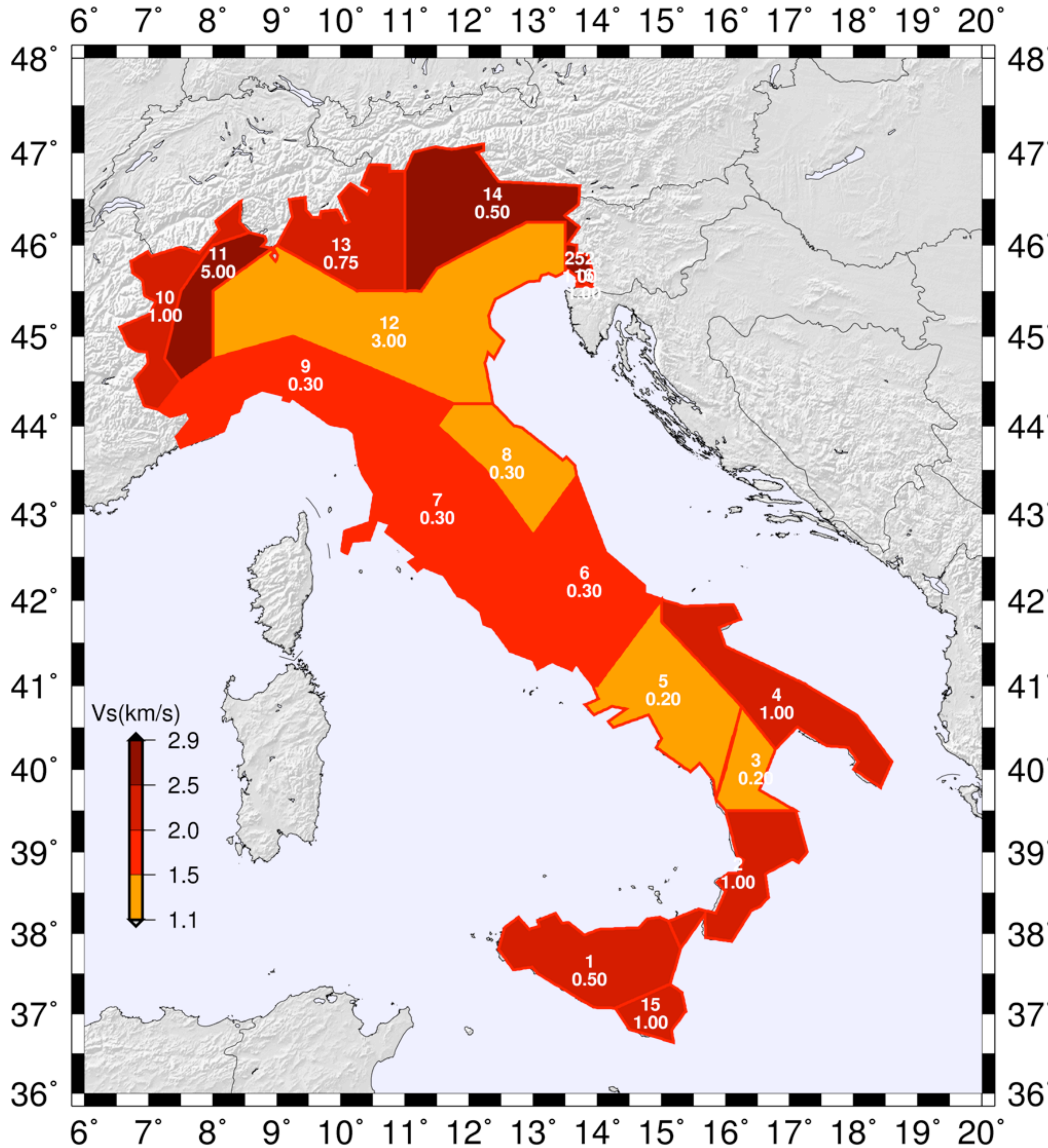
thk(km)	rho	Vp(km/s)	Vs(km/s)	Qp	Qs	depth(km)	layer
0.5000	2.300	3.800000	2.200000	660.00	300.00	0.50000	1
0.5000	2.300	3.900000	2.250000	660.00	300.00	1.00000	2
1.0000	2.450	4.000000	2.300000	660.00	300.00	2.00000	3
4.0000	2.450	4.800000	2.700000	660.00	300.00	6.00000	4
3.0000	2.600	5.900000	3.350000	660.00	300.00	9.00000	5
5.0000	2.700	6.500000	3.700000	660.00	300.00	14.00000	6
6.0000	2.800	7.000000	4.000000	660.00	300.00	20.00000	7
8.0000	2.800	6.700000	3.750200	660.00	300.00	28.00000	8
3.0000	2.850	6.700000	3.750300	660.00	300.00	31.00000	9
1.0000	2.900	7.000000	4.000000	660.00	300.00	32.00000	10
68.0000	3.350	8.000000	4.500000	660.00	300.00	100.00000	11
100.0000	3.400	8.000000	4.150600	220.00	100.00	200.00000	12
10.0000	3.450	8.200000	4.400000	220.00	100.00	210.00000	13
10.0000	3.450	8.250000	4.450000	220.00	100.00	220.00000	14
10.0000	3.450	8.300000	4.500000	220.00	100.00	230.00000	15
10.0000	3.450	8.350000	4.550000	220.00	100.00	240.00000	16
10.0000	3.450	8.400000	4.600000	220.00	100.00	250.00000	17
60.0000	3.500	8.400000	4.600100	220.00	100.00	310.00000	18
9.0000	3.500	8.700000	4.750000	330.00	150.00	319.00000	19
10.0000	3.520	8.740000	4.750100	330.00	150.00	329.00000	20
...							
...							
...							
25.0000	3.950	9.576000	5.285000	330.00	150.00	565.00000	30
25.0000	4.000	9.630000	5.313000	330.00	150.00	590.00000	31
25.0000	4.050	9.683000	5.340000	330.00	150.00	615.00000	32
25.0000	4.100	9.736000	5.367000	374.00	170.00	640.00000	33
25.0000	4.200	9.782000	5.390000	440.00	200.00	665.00000	34
25.0000	4.250	10.014000	5.518000	506.00	230.00	690.00000	35
25.0000	4.300	10.180000	5.630000	572.00	260.00	715.00000	36
25.0000	4.350	10.190000	5.746000	638.00	290.00	740.00000	37
25.0000	4.400	10.492000	5.850000	704.00	320.00	765.00000	38
25.0000	4.410	10.677000	5.950000	770.00	350.00	790.00000	39
25.0000	4.420	10.852000	6.044000	836.00	380.00	815.00000	40
25.0000	4.425	11.025000	6.140000	902.00	410.00	840.00000	41
25.0000	4.435	11.180000	6.230000	968.00	440.00	865.00000	42
25.0000	4.450	11.224000	6.250000	1045.00	475.00	890.00000	43
25.0000	4.475	11.267000	6.275000	1100.00	500.00	915.00000	44
25.0000	4.500	11.310000	6.297000	1166.00	530.00	940.00000	45
25.0000	4.525	11.350000	6.322000	1232.00	560.00	965.00000	46
25.0000	4.550	11.392000	6.340000	1320.00	600.00	990.00000	47
25.0000	4.575	11.434000	6.360000	1375.00	625.00	1015.00000	48
25.0000	4.600	11.476000	6.375000	1452.00	660.00	1040.00000	49
25.0000	4.630	11.518000	6.390000	1507.00	685.00	1065.00000	50
25.0000	4.660	11.560000	6.405000	1584.00	720.00	1090.00000	51
25.0000	4.680	11.600000	6.421000	1650.00	750.00	1115.00000	52

Regional scale - Structural model

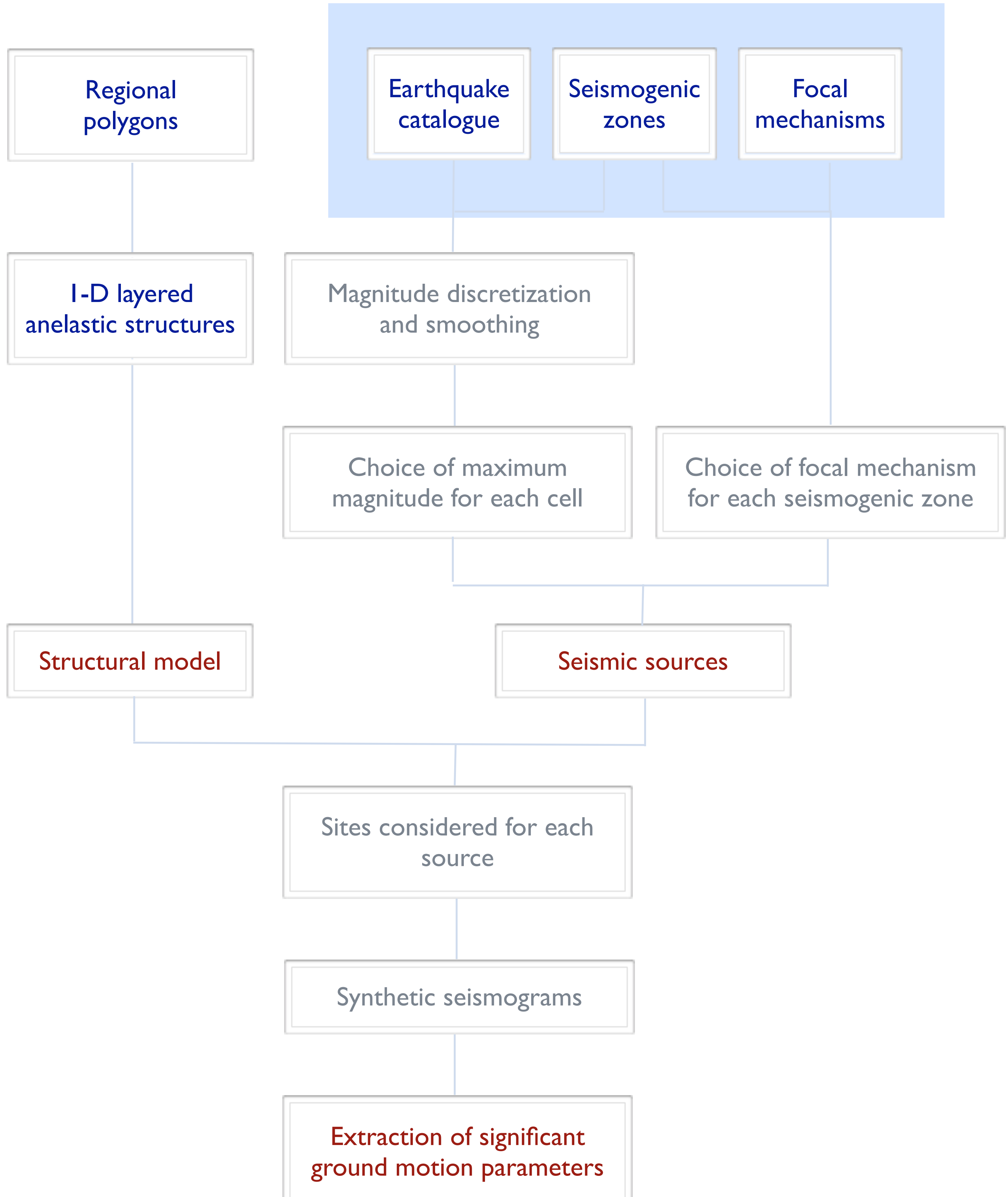
Regional polygons

1-D layered anelastic structures

Structural model



Regional scale - Sources



Regional scale - Sources

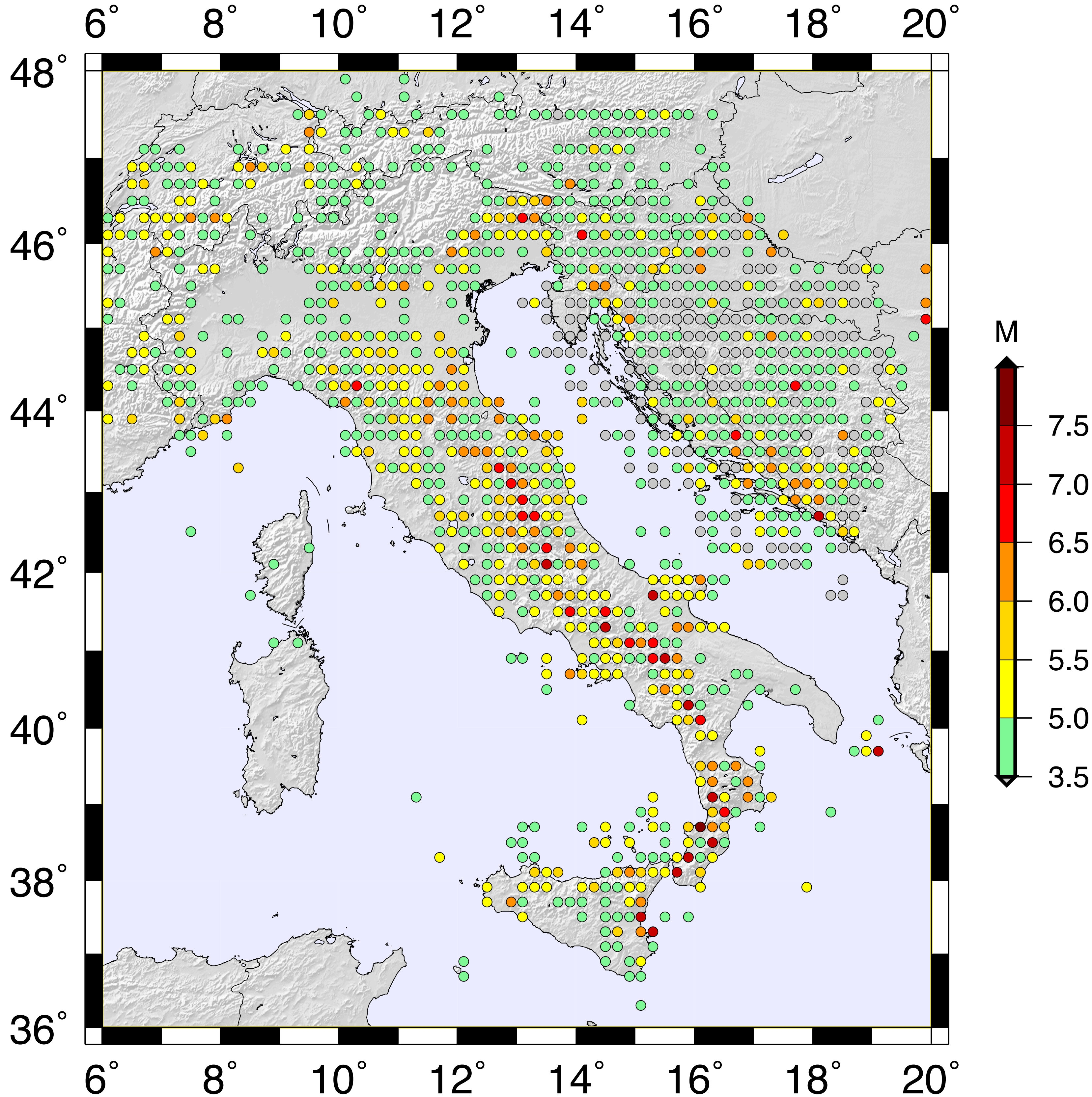
Earthquake catalogue	Seismogenic zones	Focal mechanisms

Regional scale - Sources

Earthquake catalogue

Seismogenic zones

Focal mechanisms



Regional scale - Sources

Earthquake catalogue | Seismogenic zones | Focal mechanisms

```
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
...
...
...
1988 31512 3 0 4483  1073  5440360  04400
1988 426 053 0 4228  1658  5450450  0   00
198810281848 0 3780  1509  5350320  03500
1989 9132154 0 4587  1118 10470400  04700
198910232119 0 4175  1273  5440350  04400
198912261959 0 4352   755  5440440  0   00
1990 5 5 721 0 4073  1563 10500390  05000
19901213 024 0 3727  1507  5530530  05200
1991 5261226 0 4069  1574  5470390  04700
19911120 154 0 4674   946  5520520  0   00
1992 218 330 0 4226  1418  5420360  04200
```

Regional scale - Sources

Earthquake catalogue

Seismogenic zones

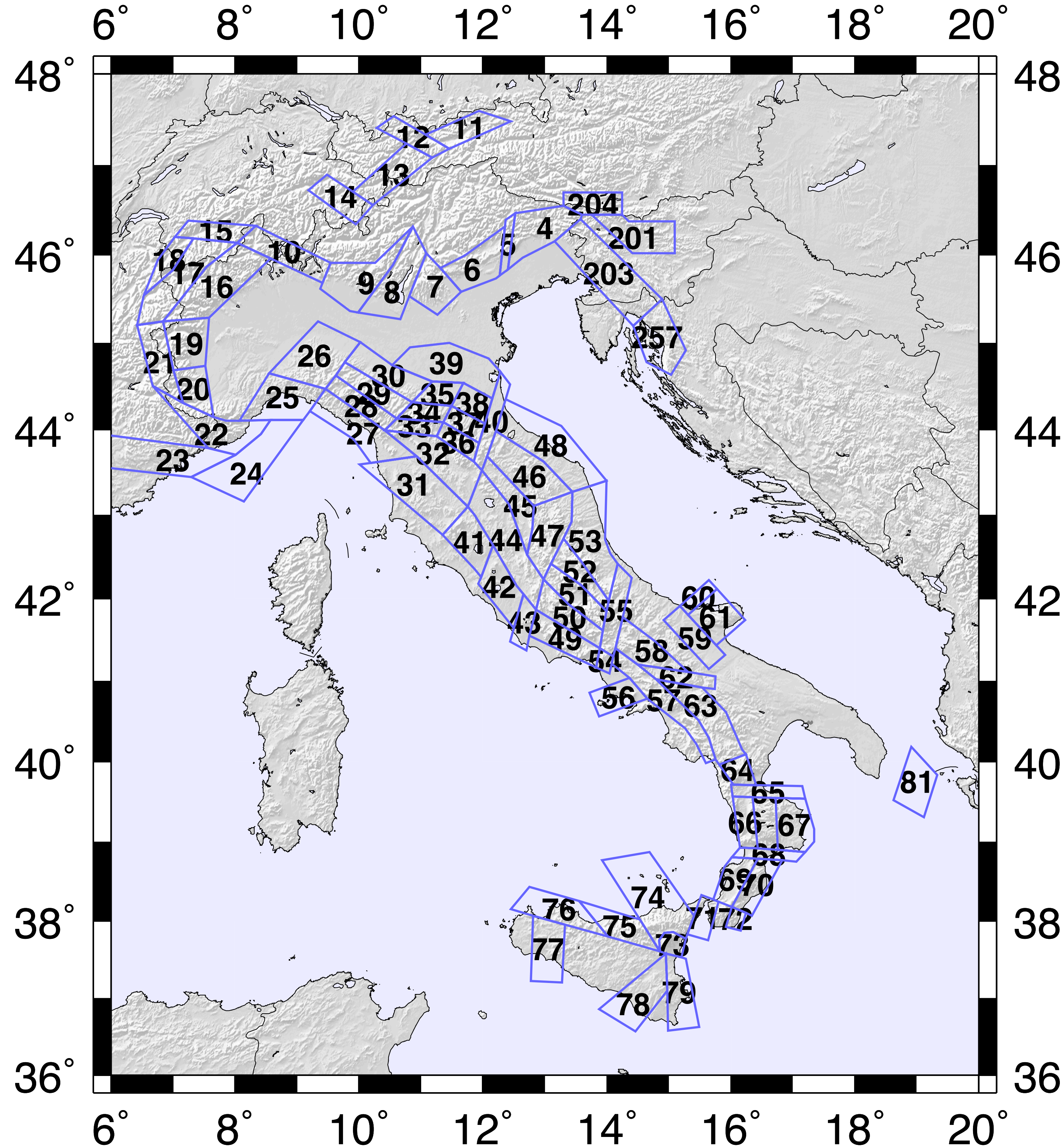
Focal mechanisms

Regional scale - Sources

Earthquake catalogue

Seismogenic zones

Focal mechanisms



International School on "Advanced Modeling of Seismic Hazard in Africa", Cairo, 25-29 October 2014

Regional scale - Sources

Earthquake catalogue | Seismogenic zones | Focal mechanisms

```
Polygons that define seismogenic zones (lon,lat)
seismo0257
            15.278  44.918
            15.036  44.635
            14.644  44.783
            14.422  45.193
            14.890  45.500
seismo0004
            12.520  46.468
            13.300  46.550
            13.600  46.450
            13.580  46.400
            13.160  46.156
            12.636  45.972
            12.403  45.840
...
...
...
seismo0079
            14.955  37.582
            15.196  37.529
            15.273  37.511
            15.486  36.630
            14.984  36.582
            14.969  37.098
seismo0081
            19.334  39.834
            19.110  39.310
            18.618  39.527
            18.911  40.190
```

Regional scale - Sources

Earthquake catalogue

Seismogenic zones

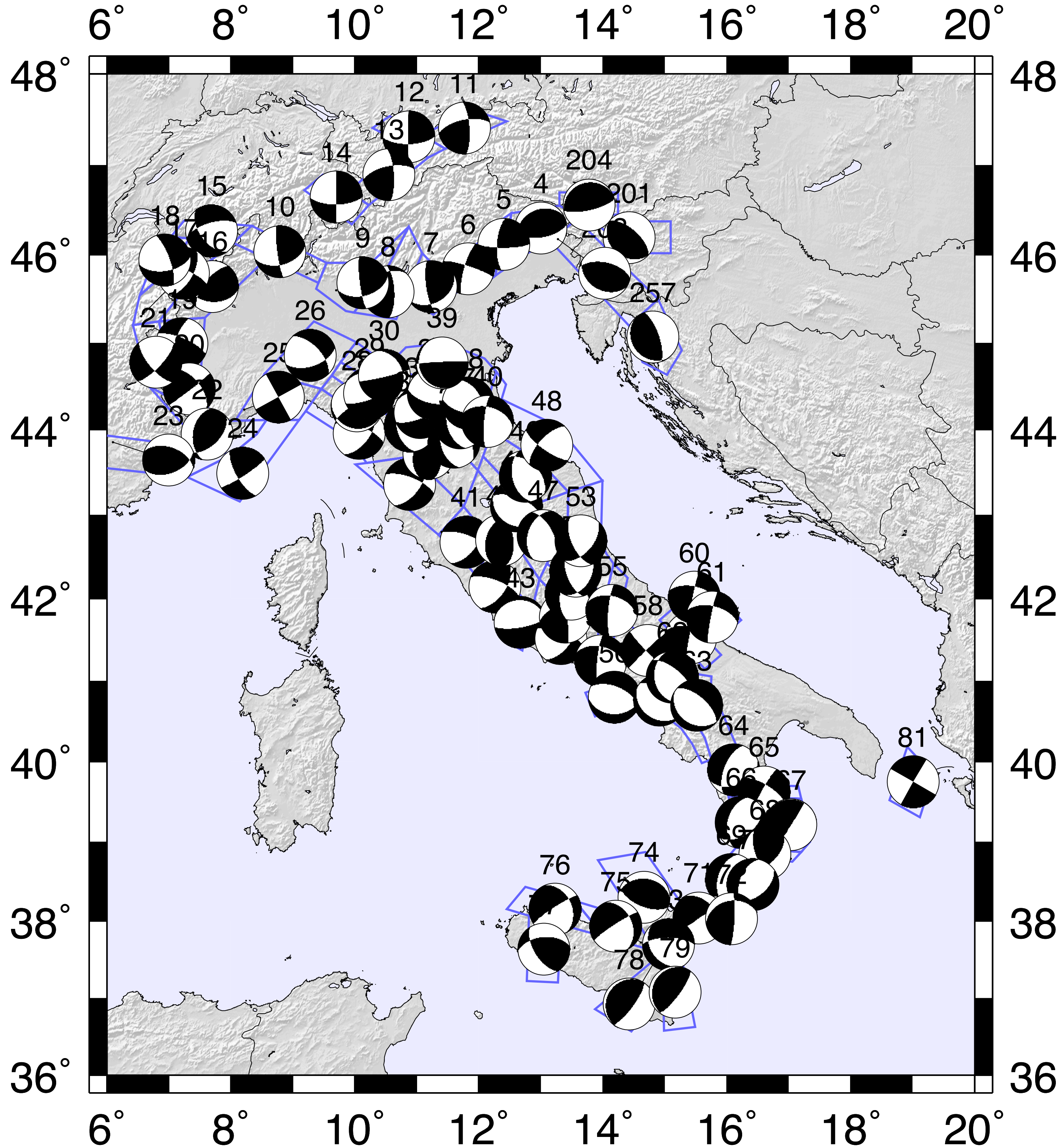
Focal mechanisms

Regional scale - Sources

Earthquake catalogue

Seismogenic zones

Focal mechanisms



Regional scale - Sources

Earthquake catalogue | Seismogenic zones | Focal mechanisms

```
-------------------- FPGNDT.DAT --Revised- July 1, 1977 ------------------------
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
--------------------------------------------------------------------------------
   44A 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
   54A 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
   57A 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
   58A 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
...
...
...
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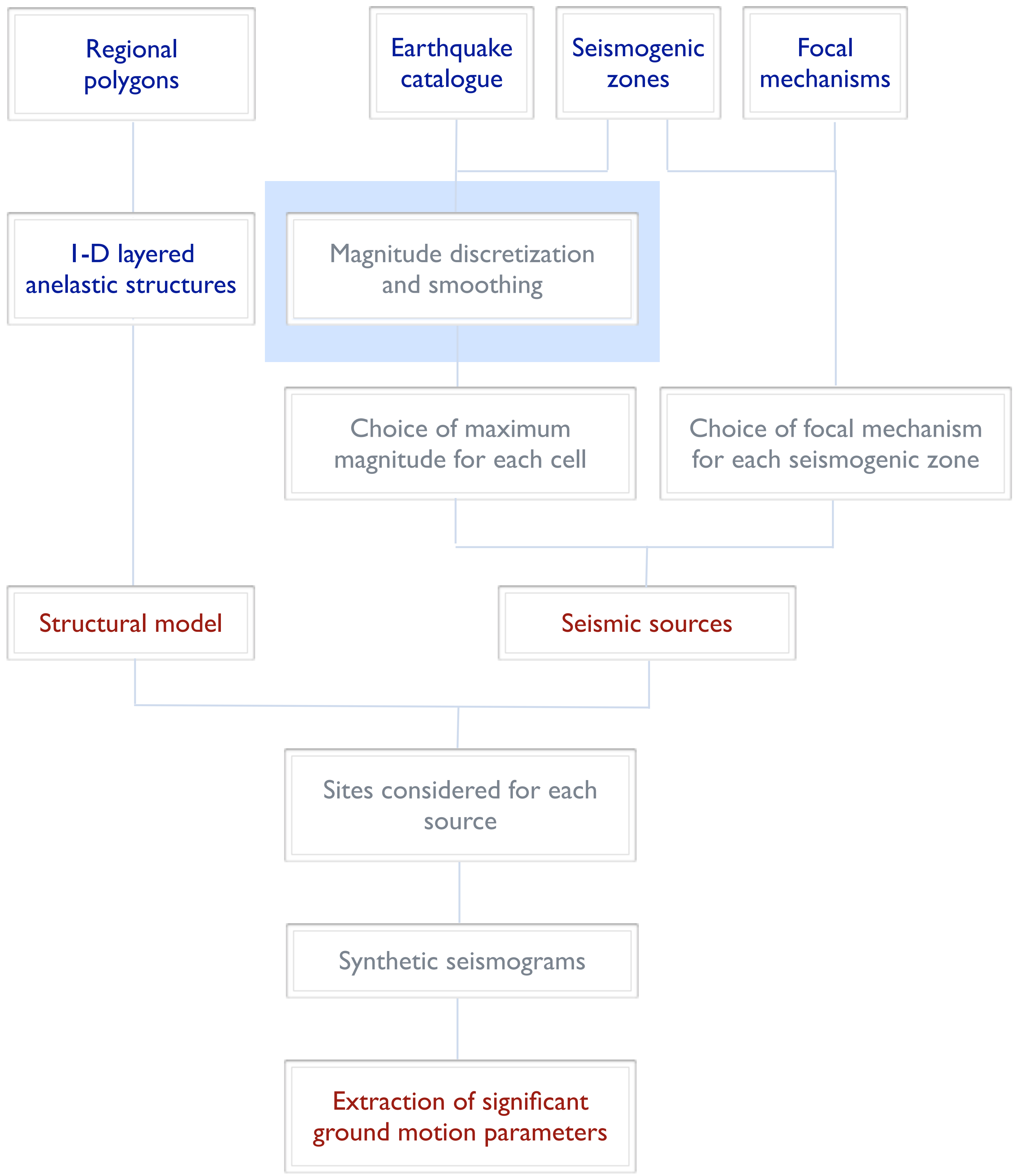
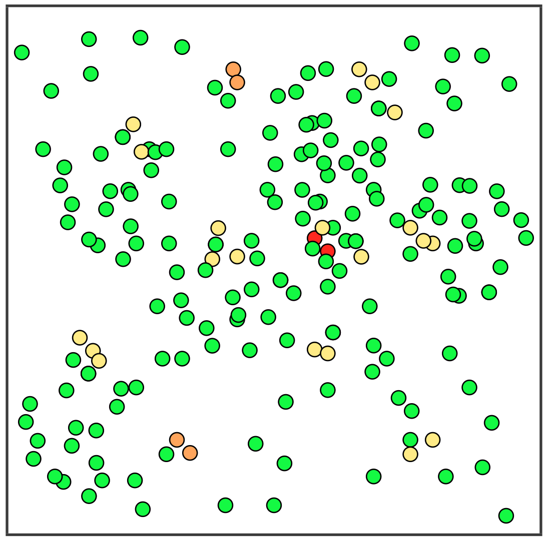
Regional scale - Sources



Regional scale - Sources

Seismicity

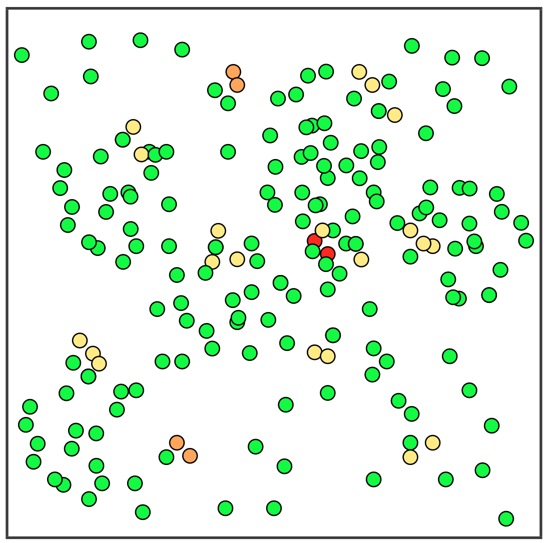


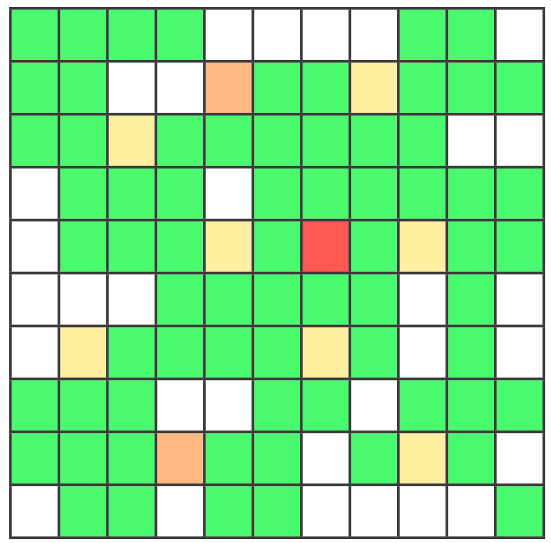
Magnitude discretization
and smoothing

Regional scale - Sources

Magnitude discretization
and smoothing

Seismicity → I - Discretization

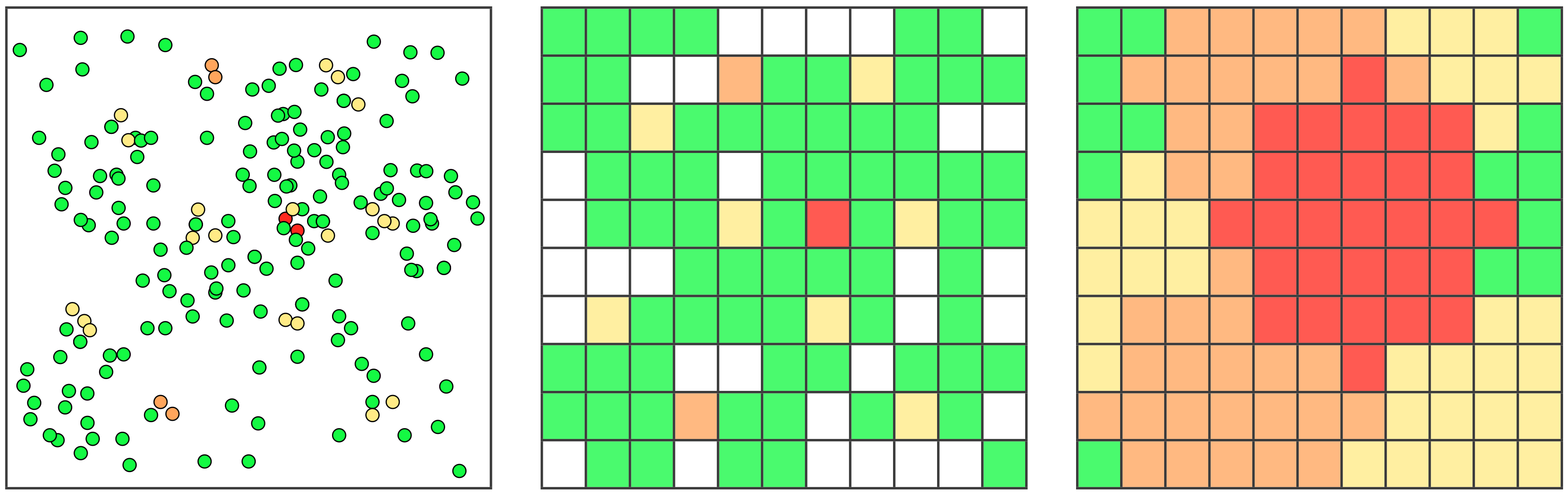




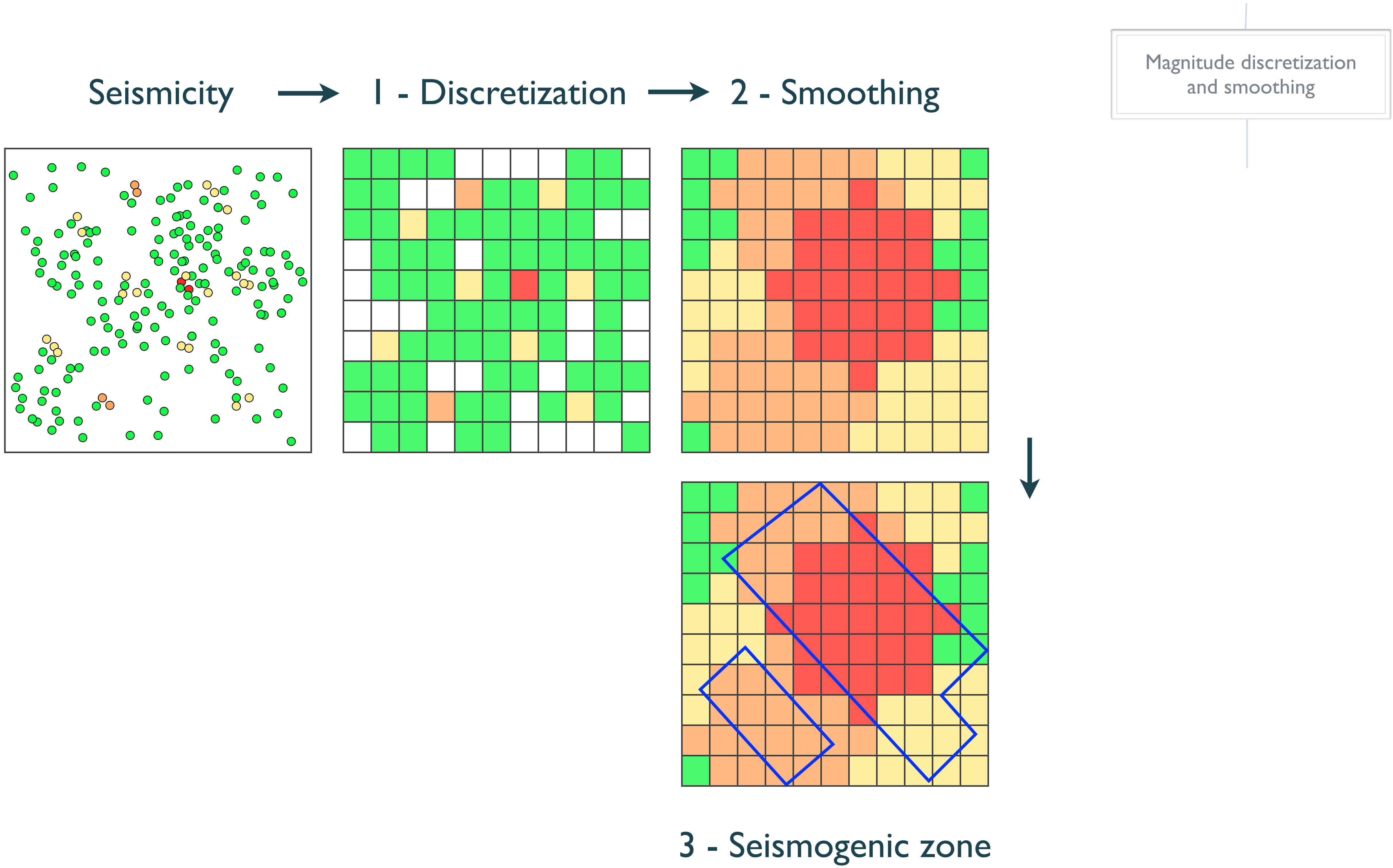
Regional scale - Sources

Magnitude discretization
and smoothing

Seismicity ⟶ 1 - Discretization ⟶ 2 - Smoothing

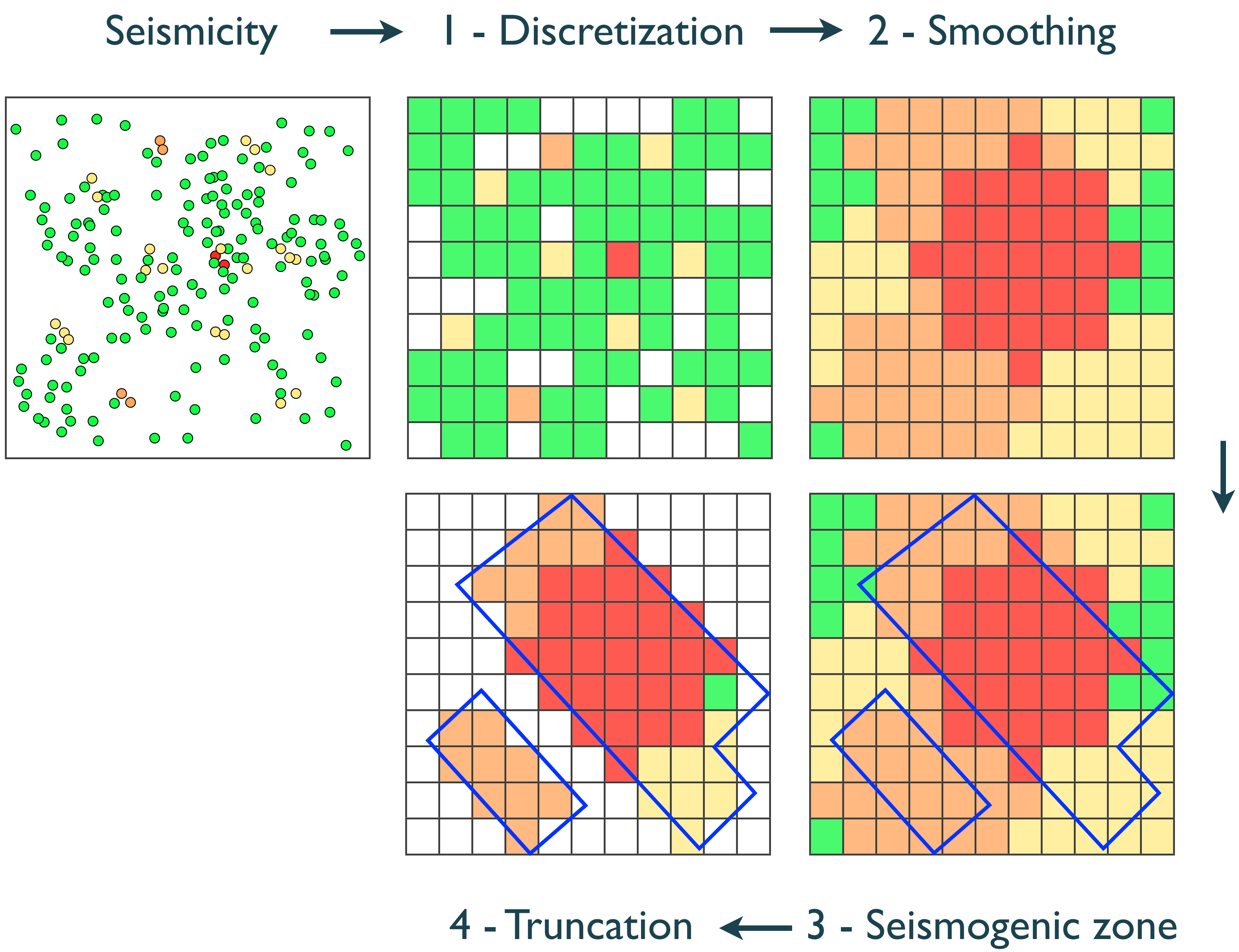


Regional scale - Sources



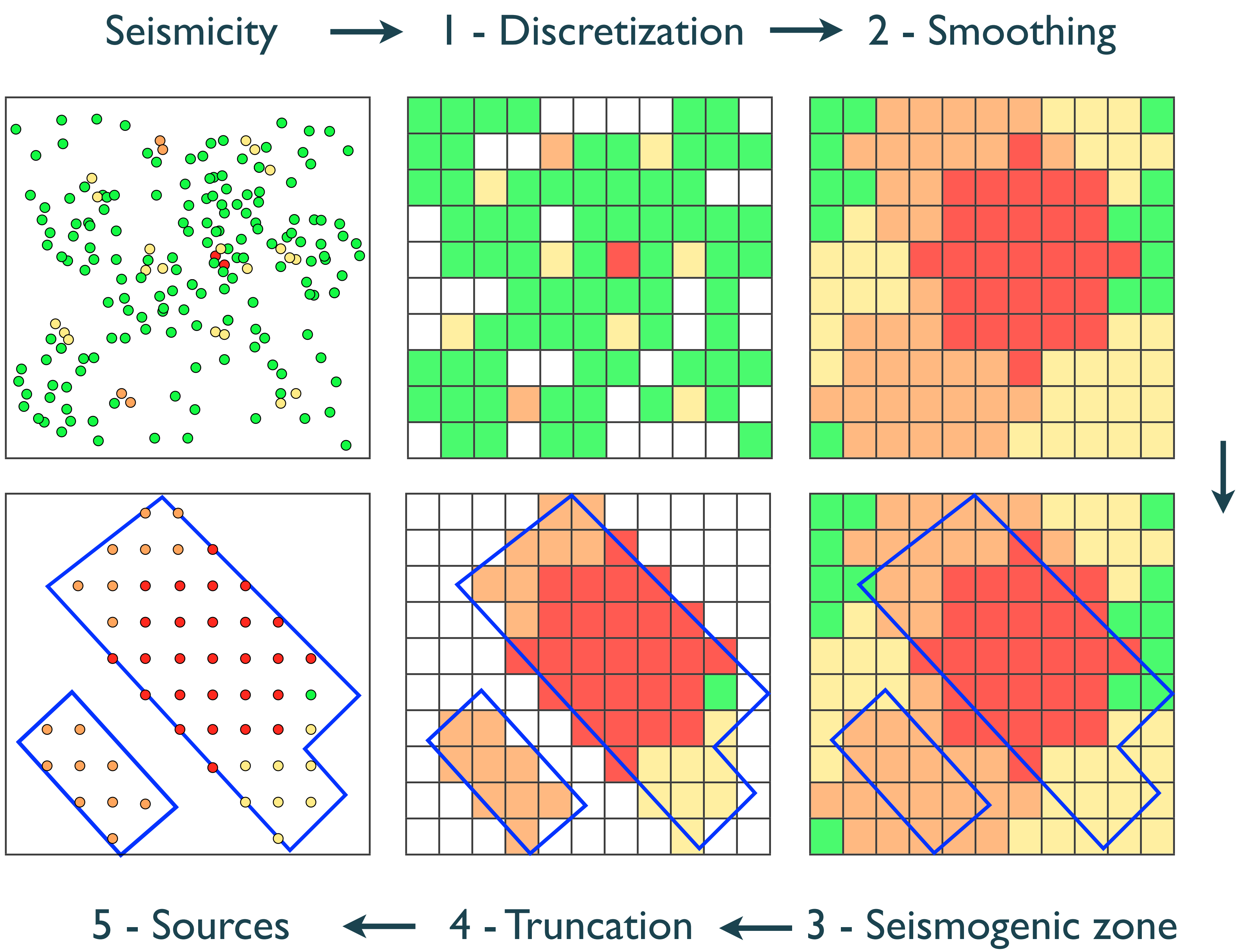
Regional scale - Sources

Magnitude discretization
and smoothing



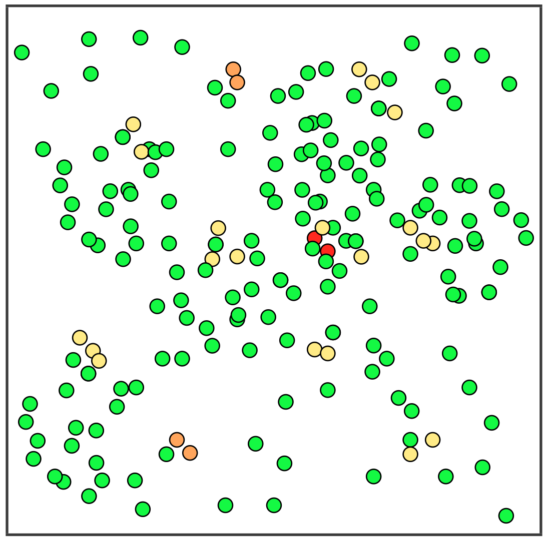
Regional scale - Sources

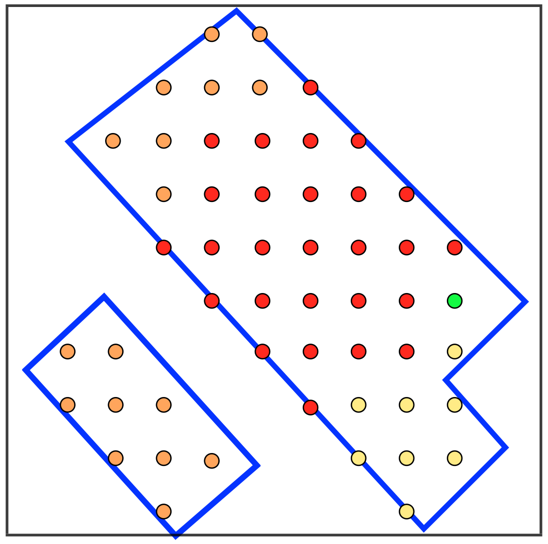
Magnitude discretization and smoothing



Regional scale - Sources

Seismicity





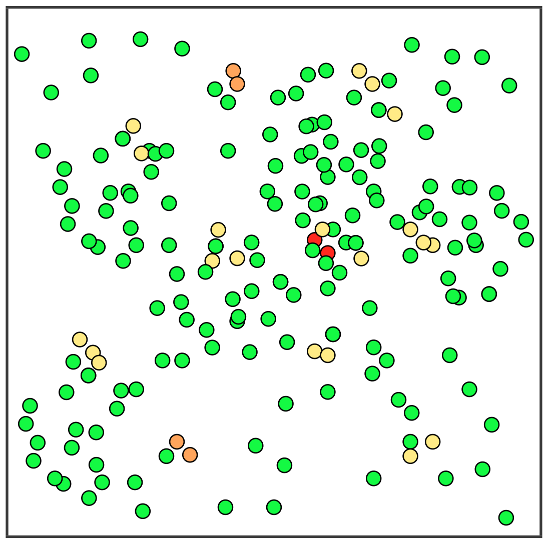
Sources

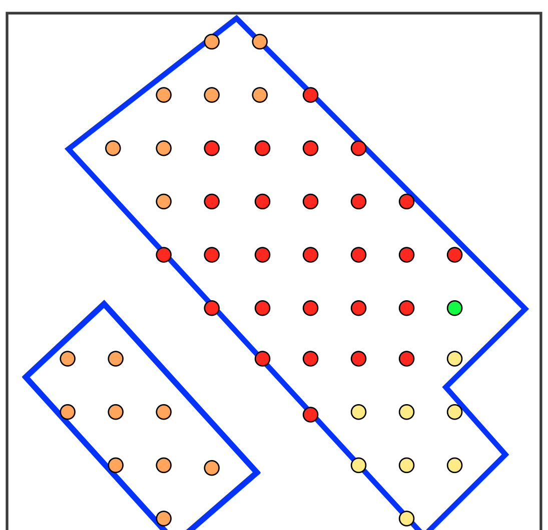
Magnitude discretization and smoothing

Regional scale - Sources

Magnitude discretization
and smoothing

Seismicity



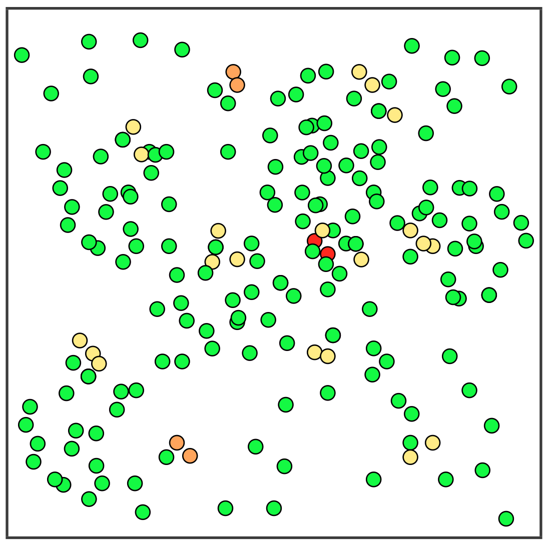


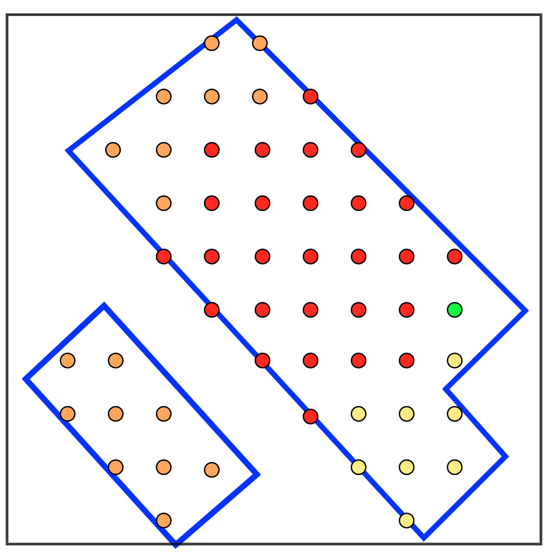
Sources

- Why do we do this?

Regional scale - Sources

Seismicity





Sources

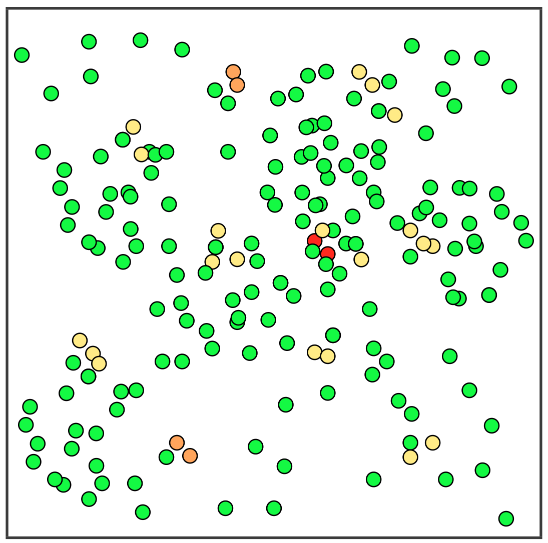
Magnitude discretization and smoothing

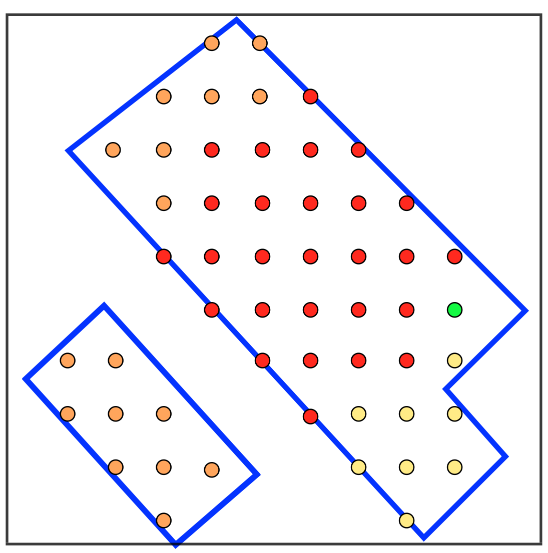
- Why do we do this?
  - To account for mislocations of events in the catalogue

Regional scale - Sources

Magnitude discretization
and smoothing

Seismicity





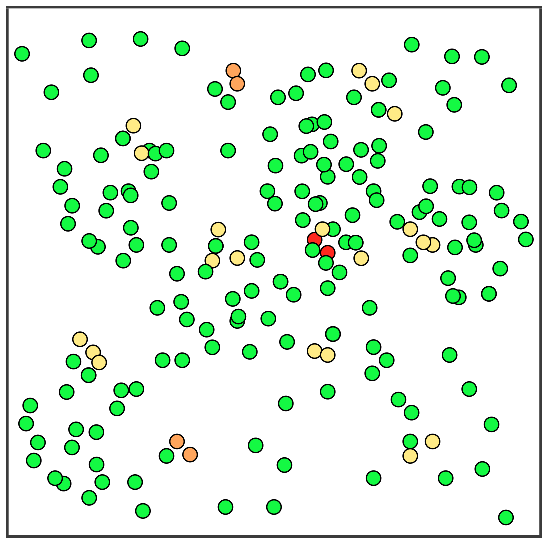
Sources

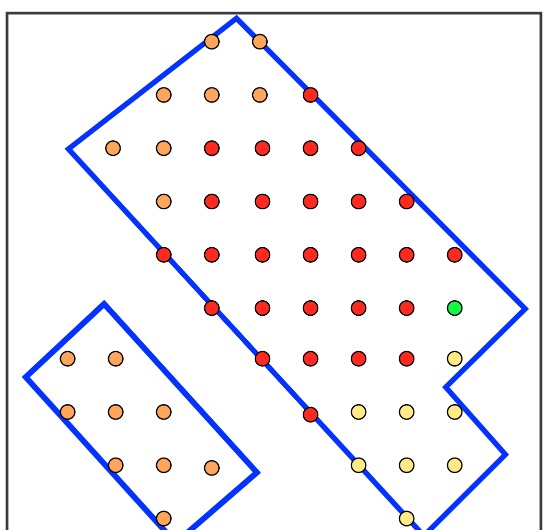
- Why do we do this?
  - To account for mislocations of events in the catalogue
  - To account (roughly) for fault dimensions

Regional scale - Sources

Magnitude discretization and smoothing

Seismicity





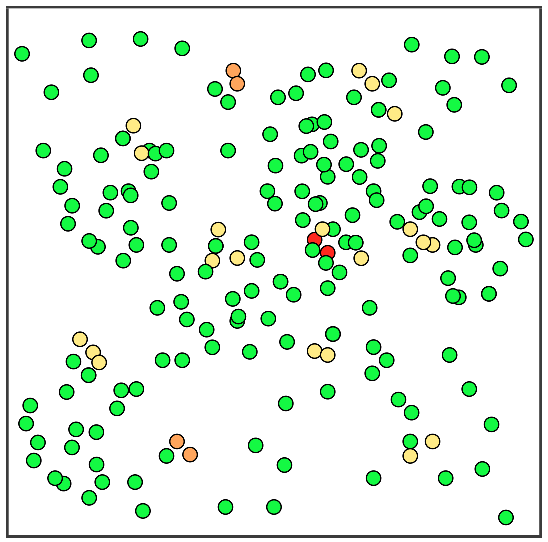
Sources

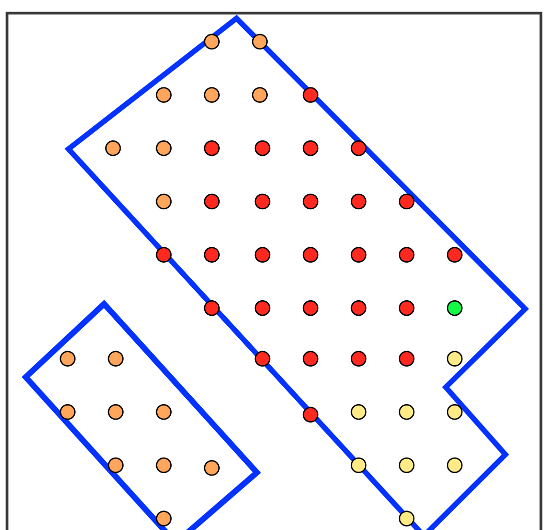
- Why do we do this?
  - To account for mislocations of events in the catalogue
  - To account (roughly) for fault dimensions
  - To account for the location of future events

Regional scale - Sources

Magnitude discretization and smoothing

Seismicity

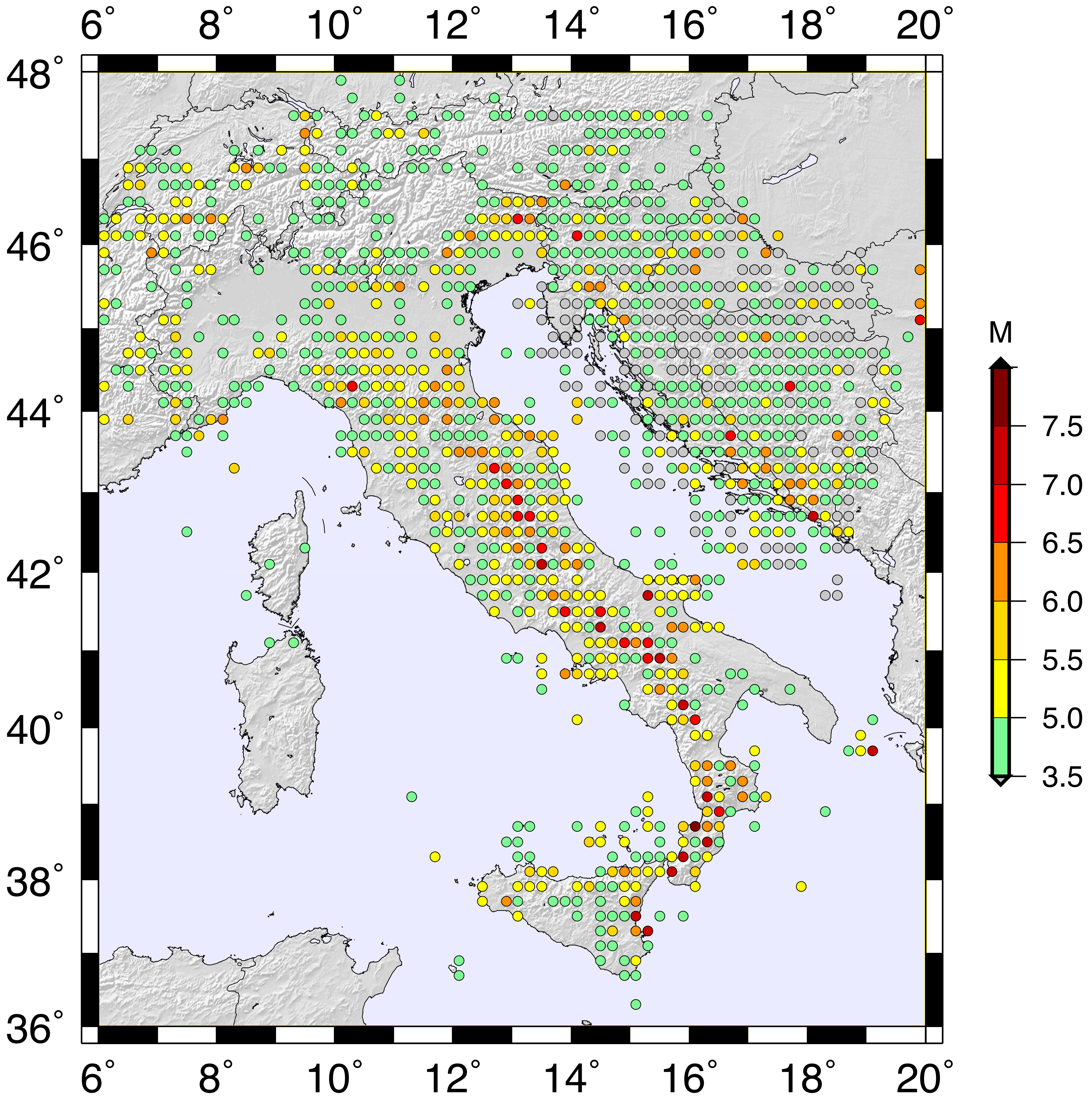




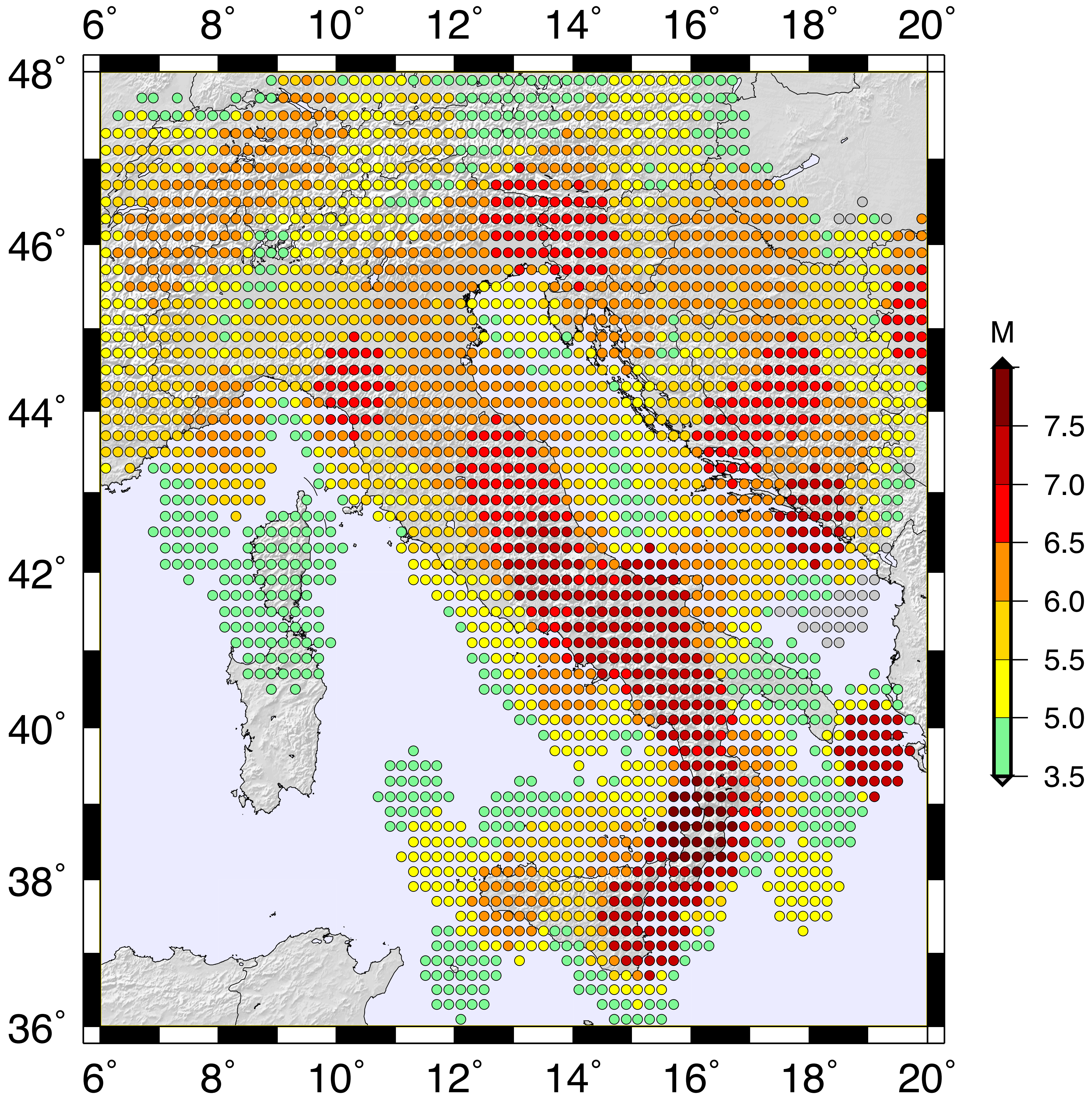
Sources

- Why do we do this?
  - To account for mislocations of events in the catalogue
  - To account (roughly) for fault dimensions
  - To account for the location of future events
  - In essence: to be conservative...

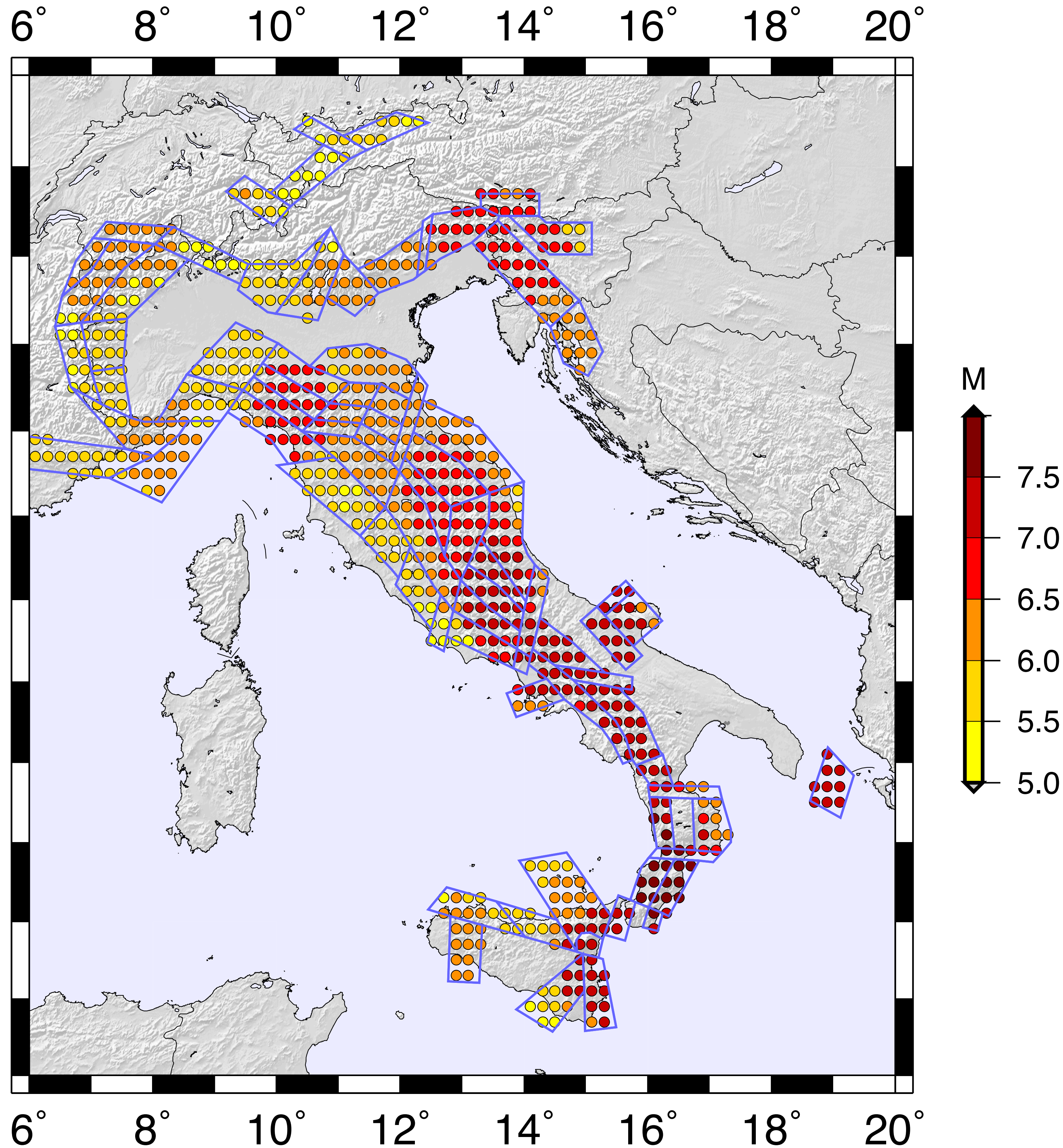
Regional scale - Discretized Magnitude



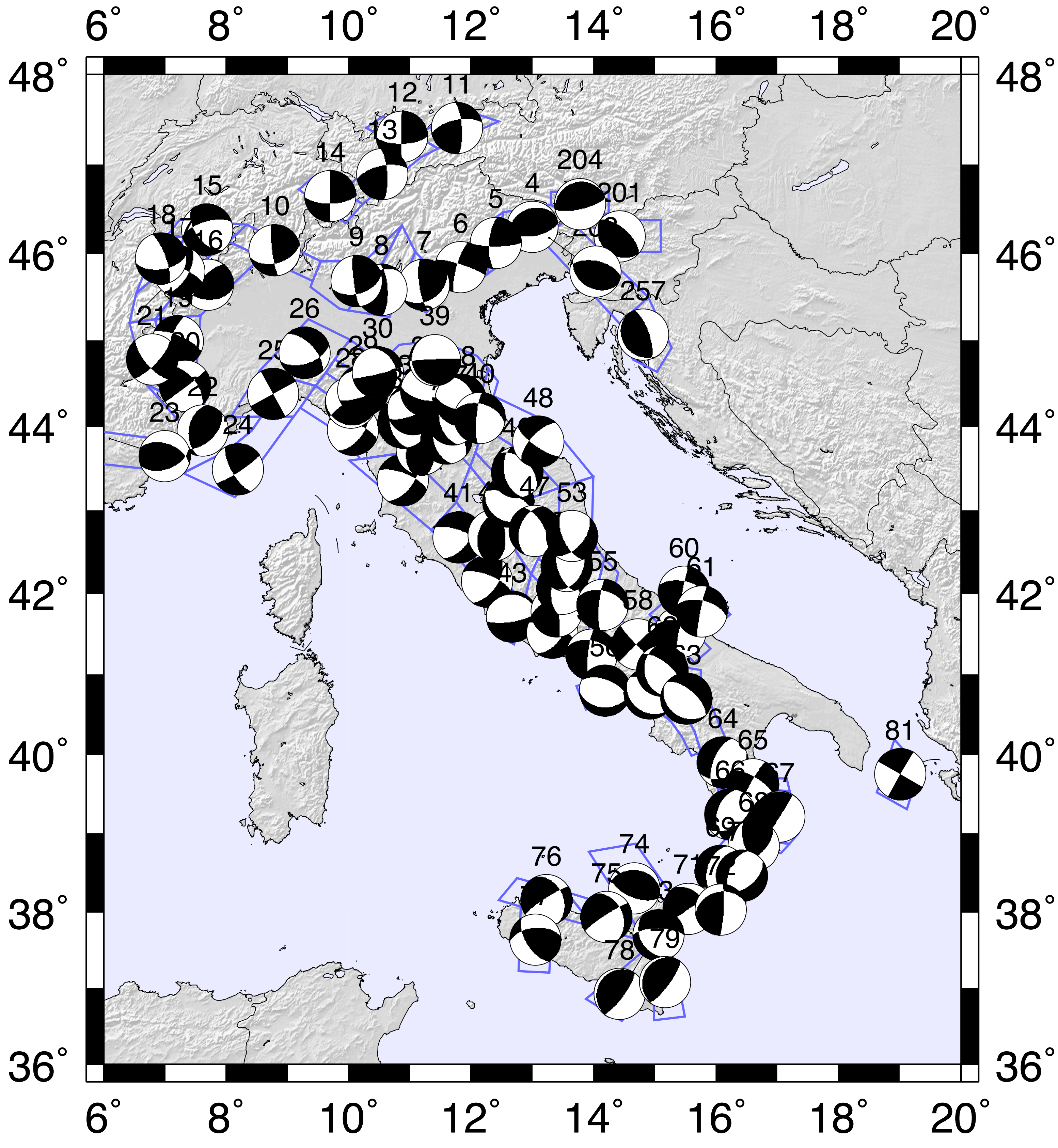
Regional scale - Smoothed magnitude



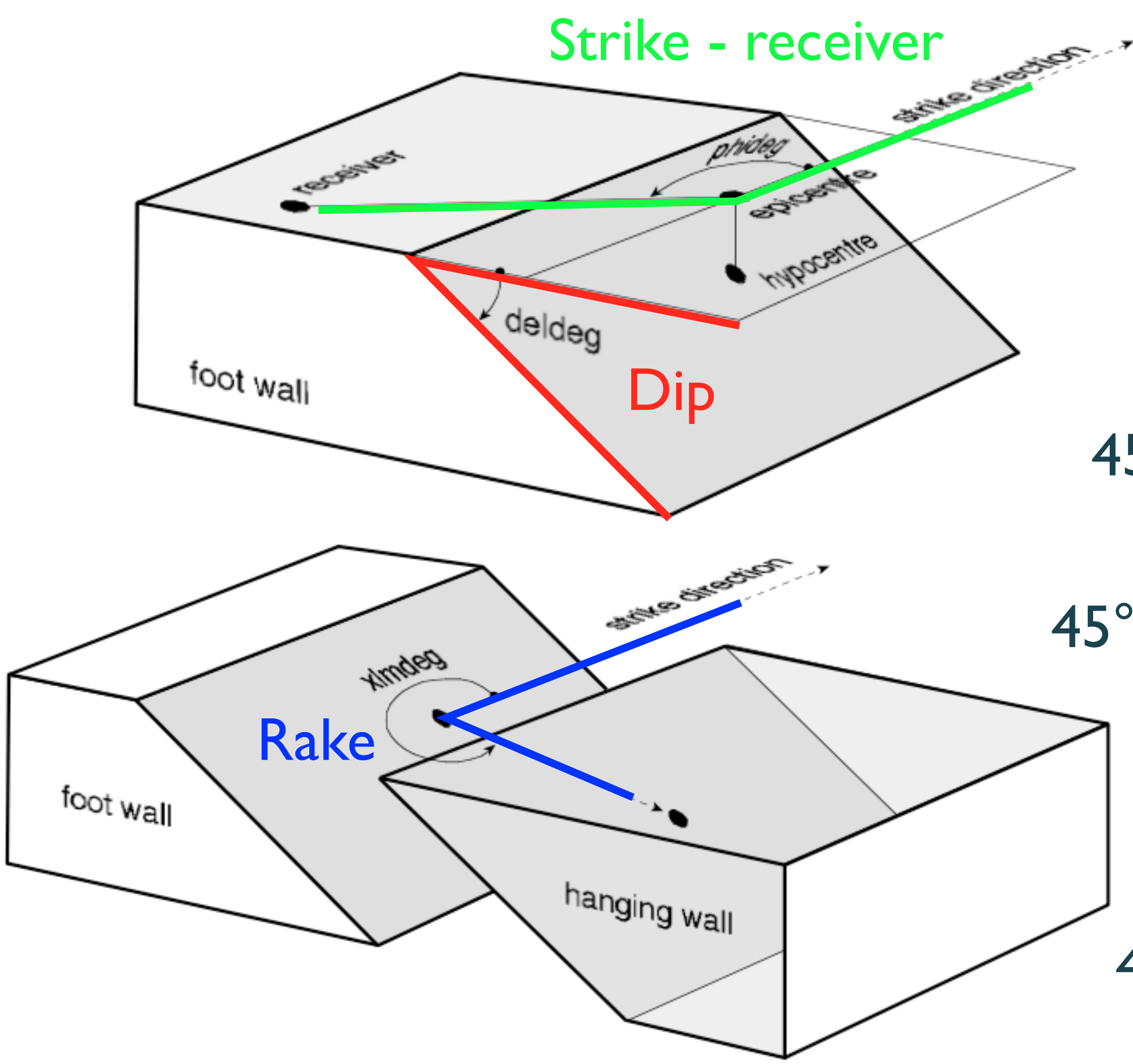
Regional scale - Sources inside SZ



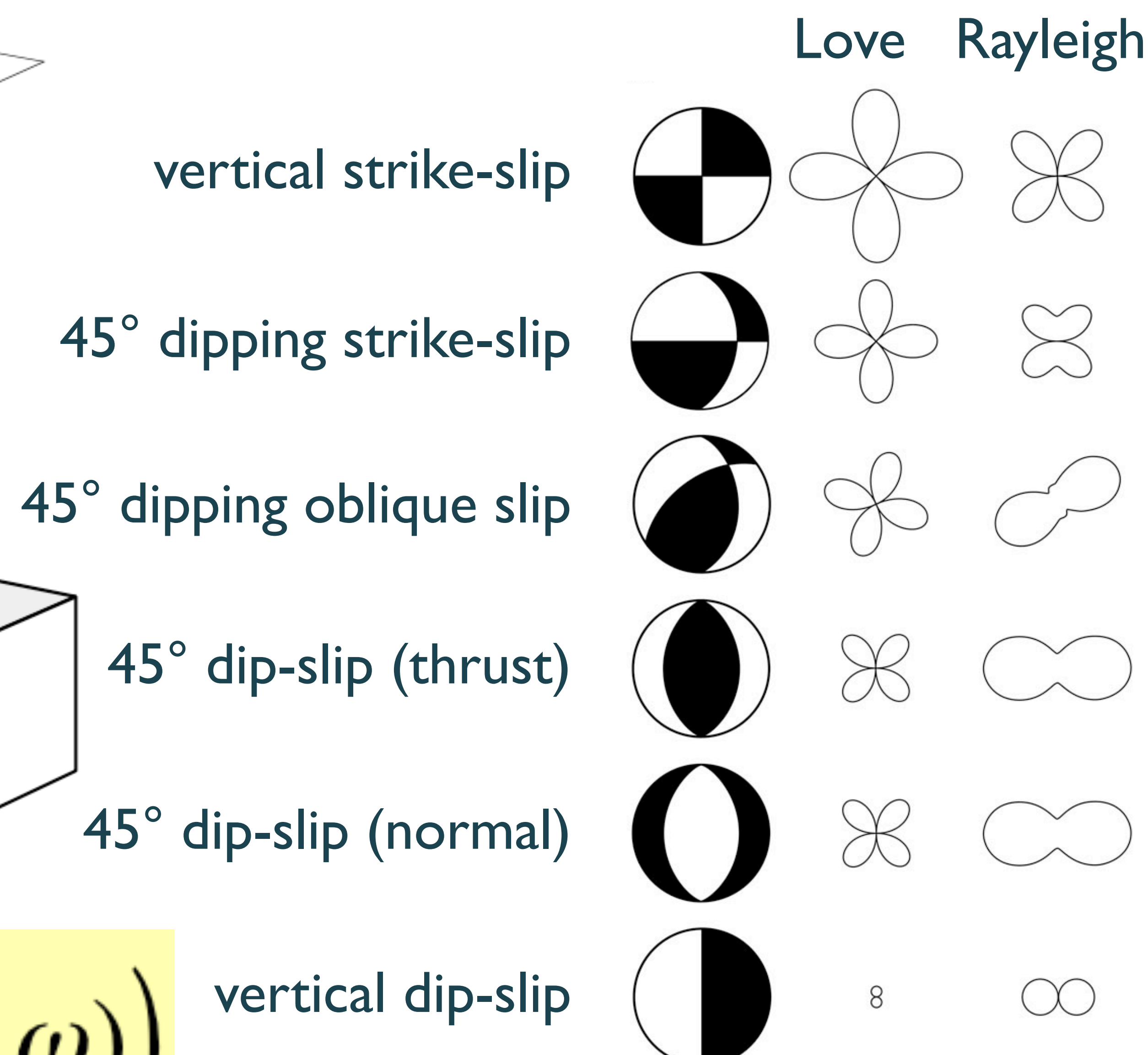
Regional scale - Sources inside SZ



Source definition - Radiation pattern

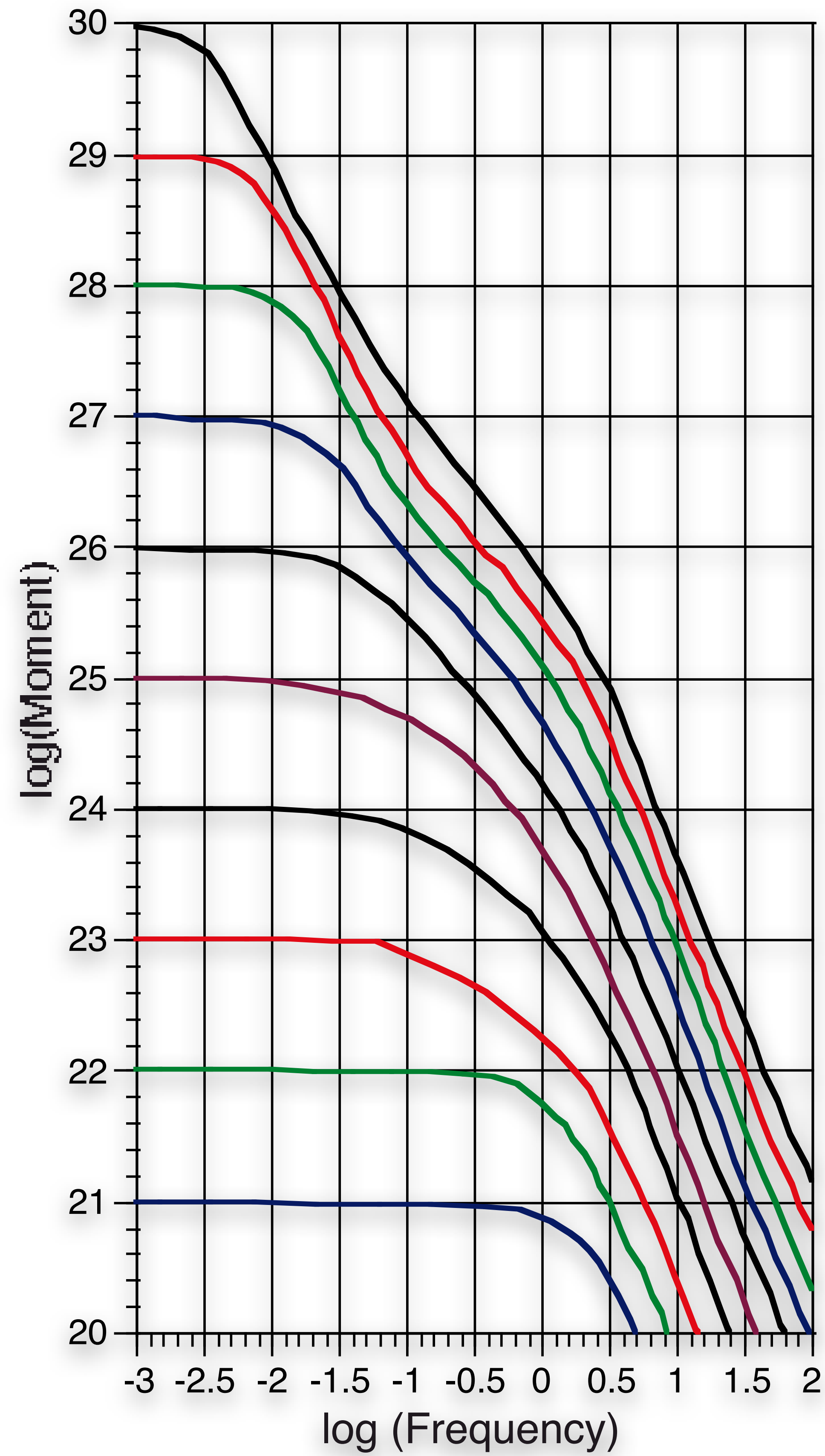


$$\left(\chi_m^L(h_s,\omega)\right) \qquad \left(\chi_m^R(h_s,\omega)\right)$$



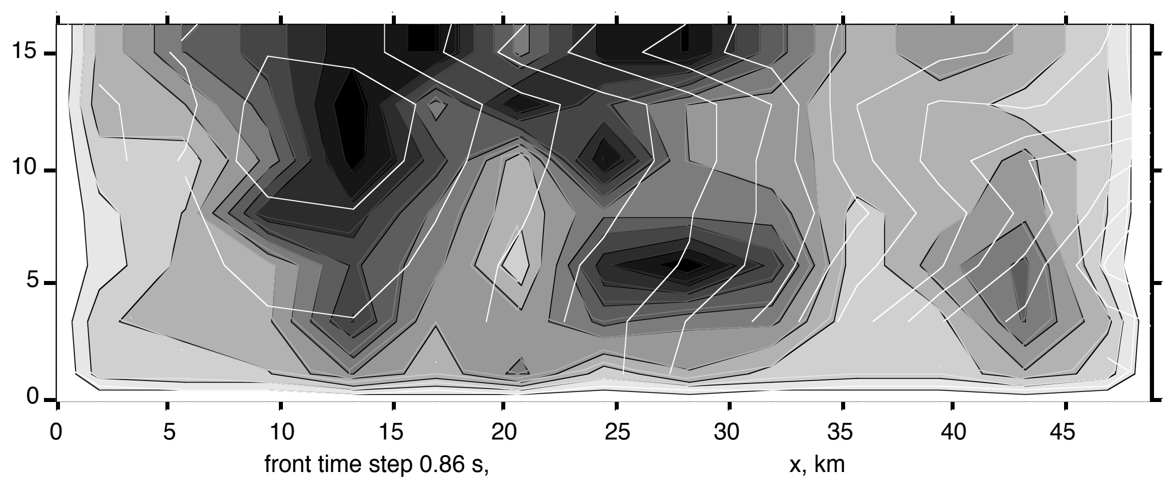
Source definition - Scaled point source

- The moment-magnitude relation by Kanamori (1977) is used
- At first synthetic seismograms are computed for a unitary scalar seismic moment (1 dyn cm)
- Then they are scaled for magnitude in the frequency domain according to the spectral law by Gusev (1983) as reported in Aki (1987)



Source definition - Scaled point source

Source kinematic model



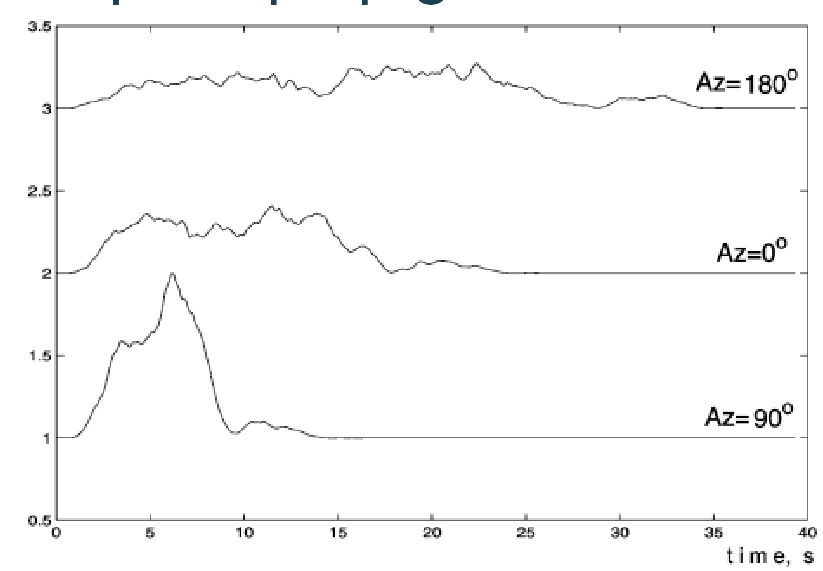
2-dimensional final slip distribution over a source rectangle, shown as a density plot (Mw=7.0).

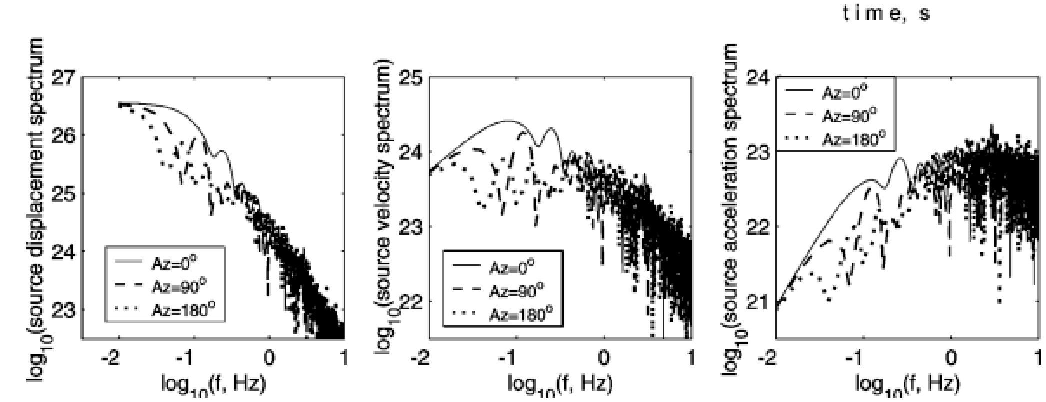
Rupture front evolution was simulated kinematically from random rupture velocity field.

(Gusev, 2011)

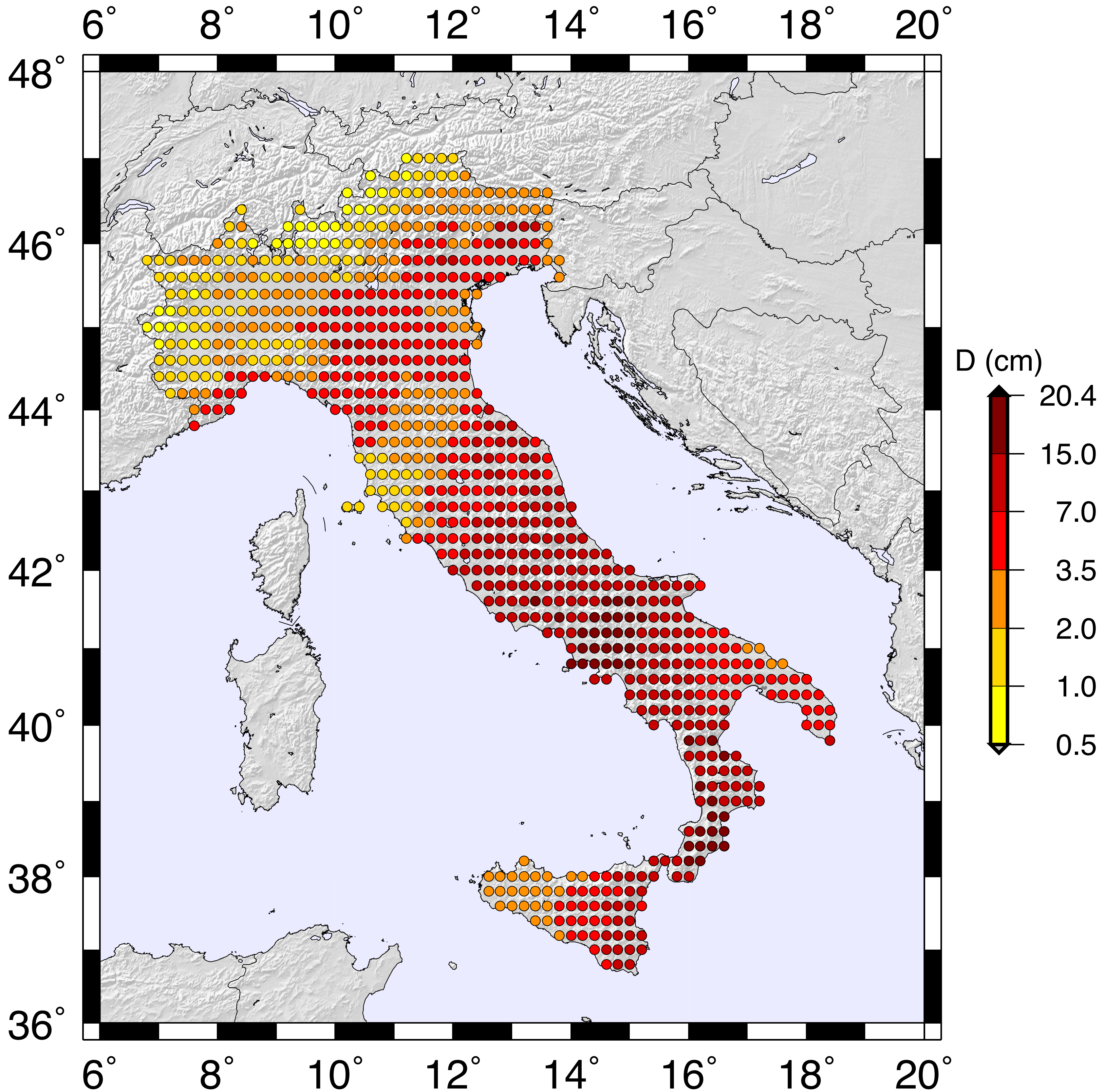
Far-field source time histories and their spectra.

"Displacement" far-field functions (arbitrary scale) for the simulated case of mostly unilateral rupture propagation

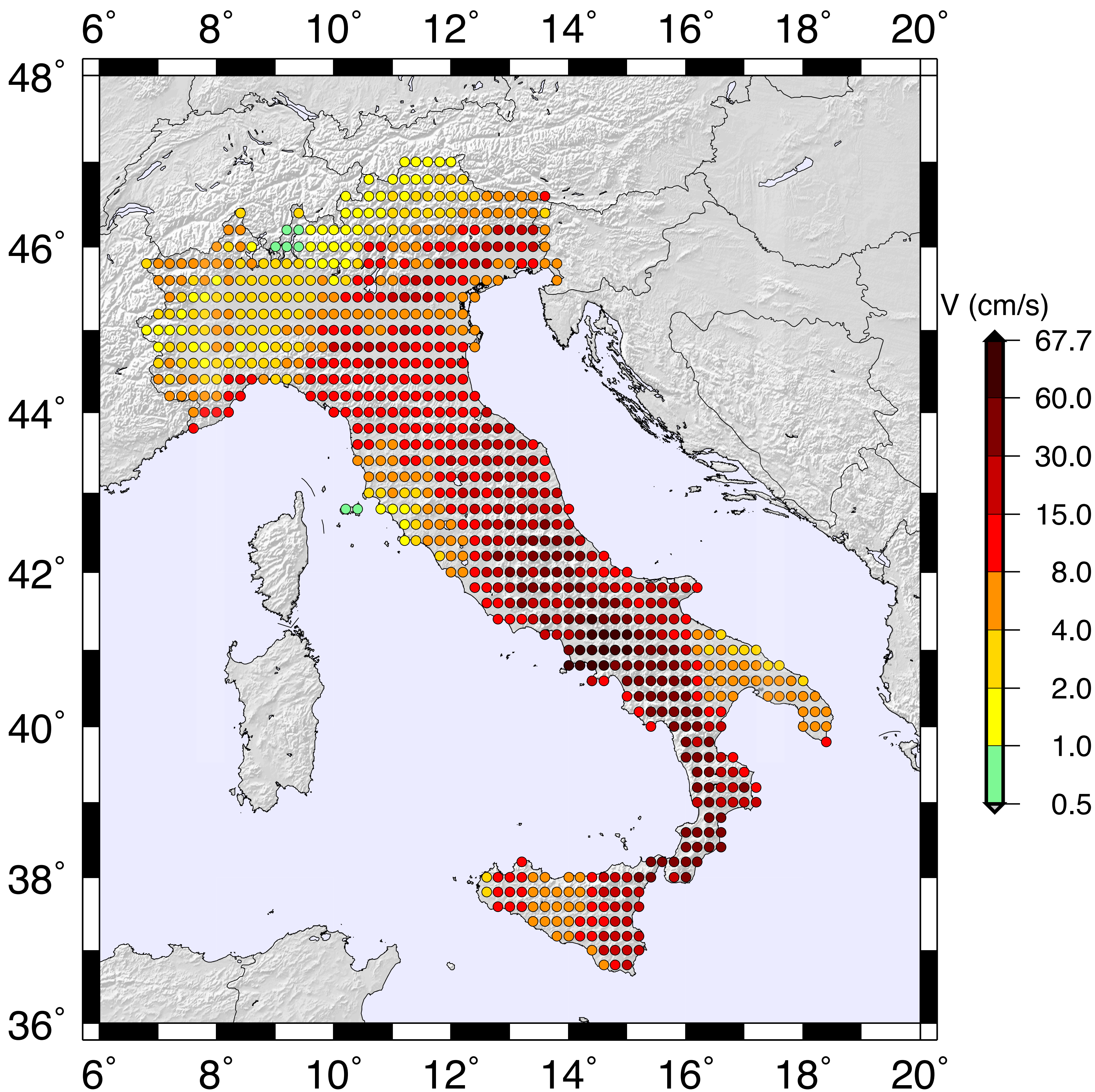




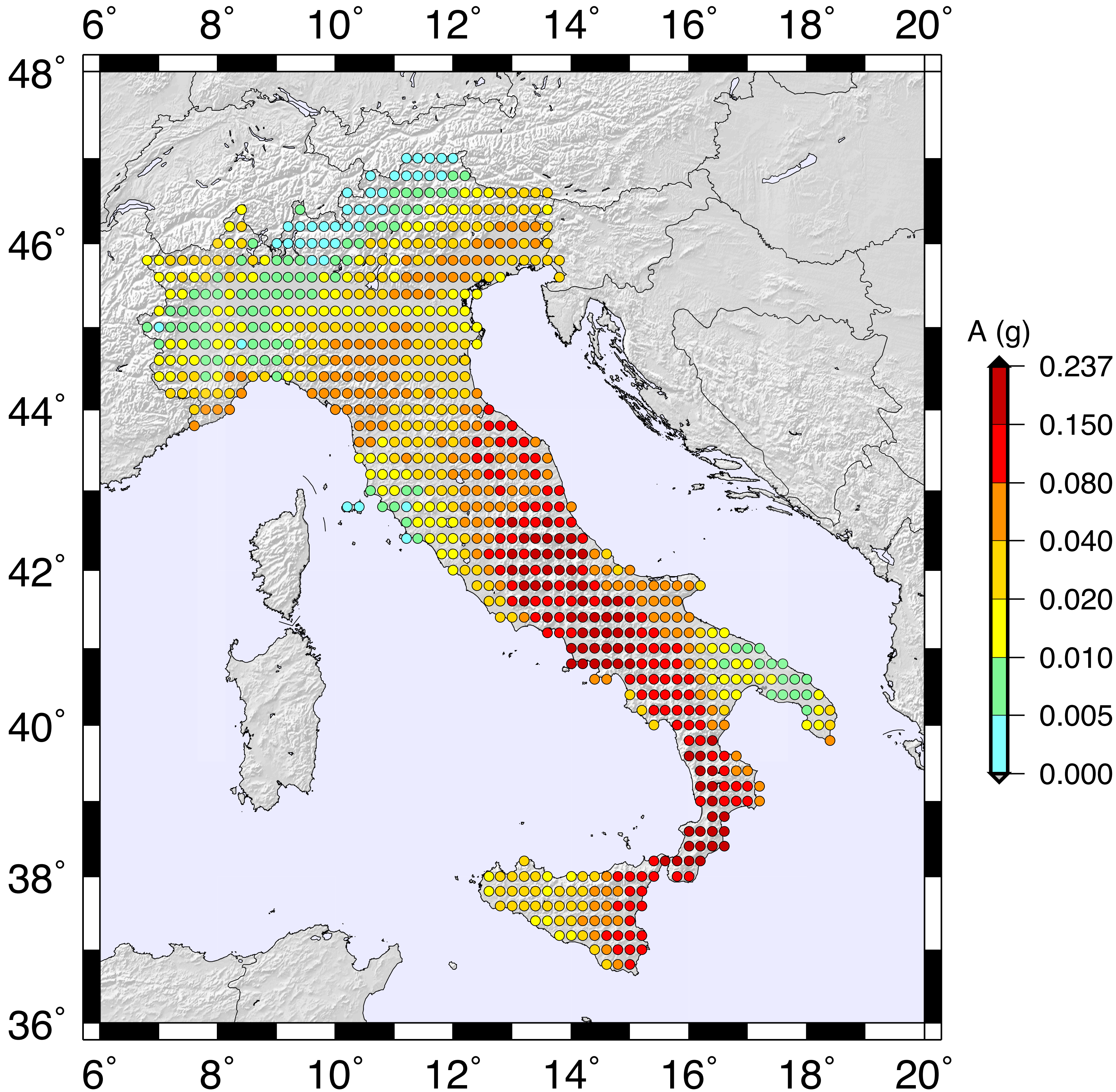
Example computation - Ground shaking



Example computation - Ground shaking

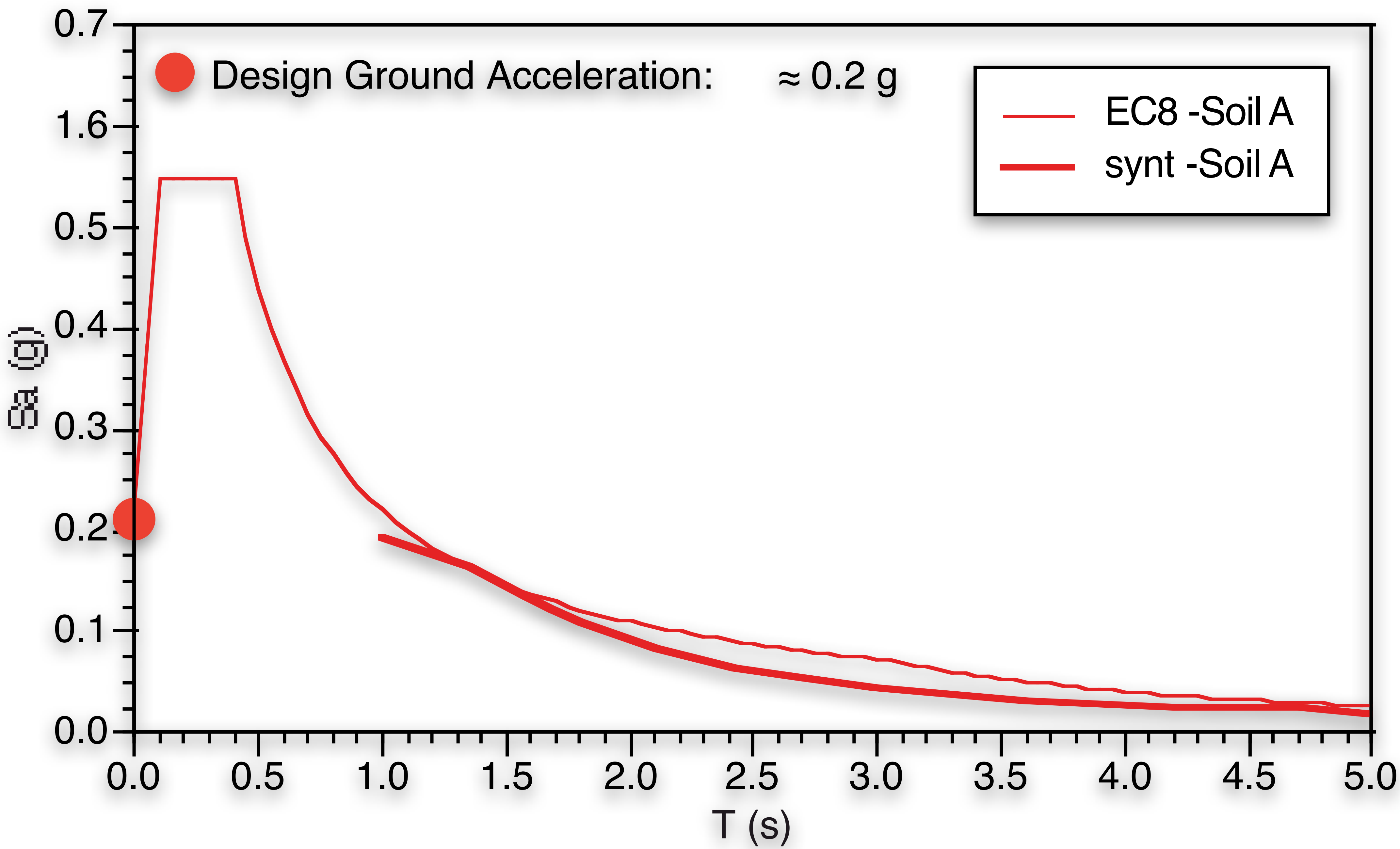


Example computation - Ground shaking

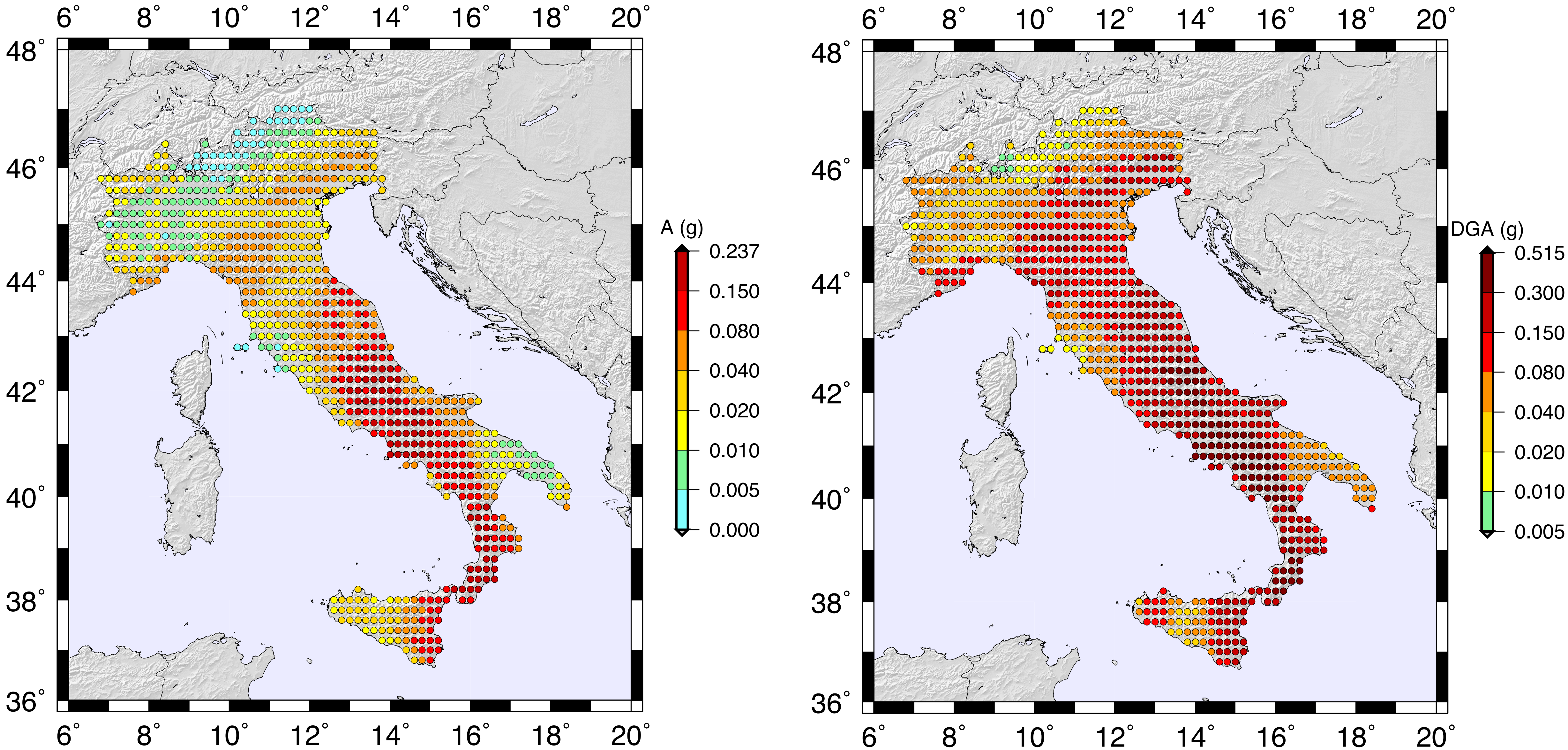


From 1Hz acceleration to DGA

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

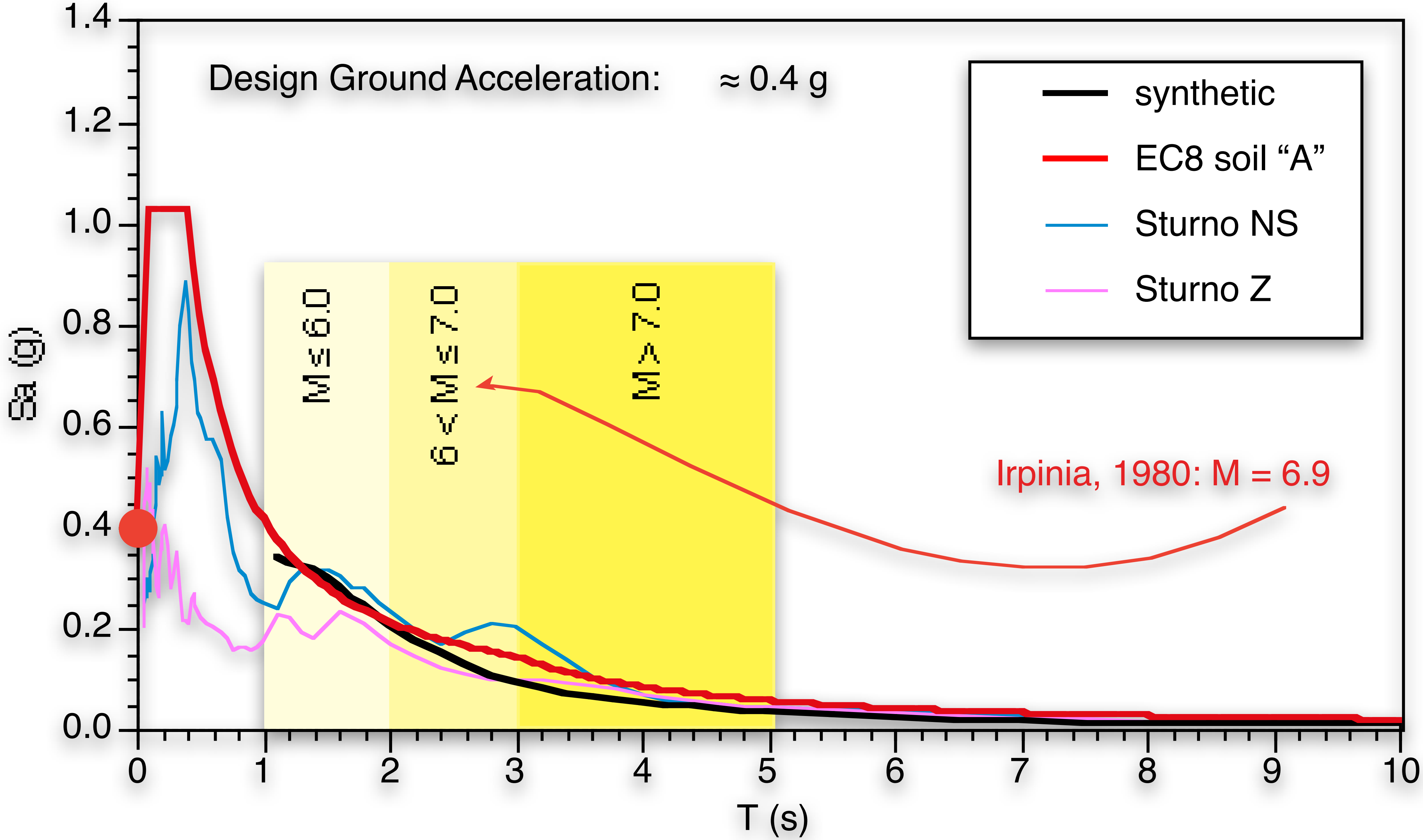


From 1Hz acceleration to DGA



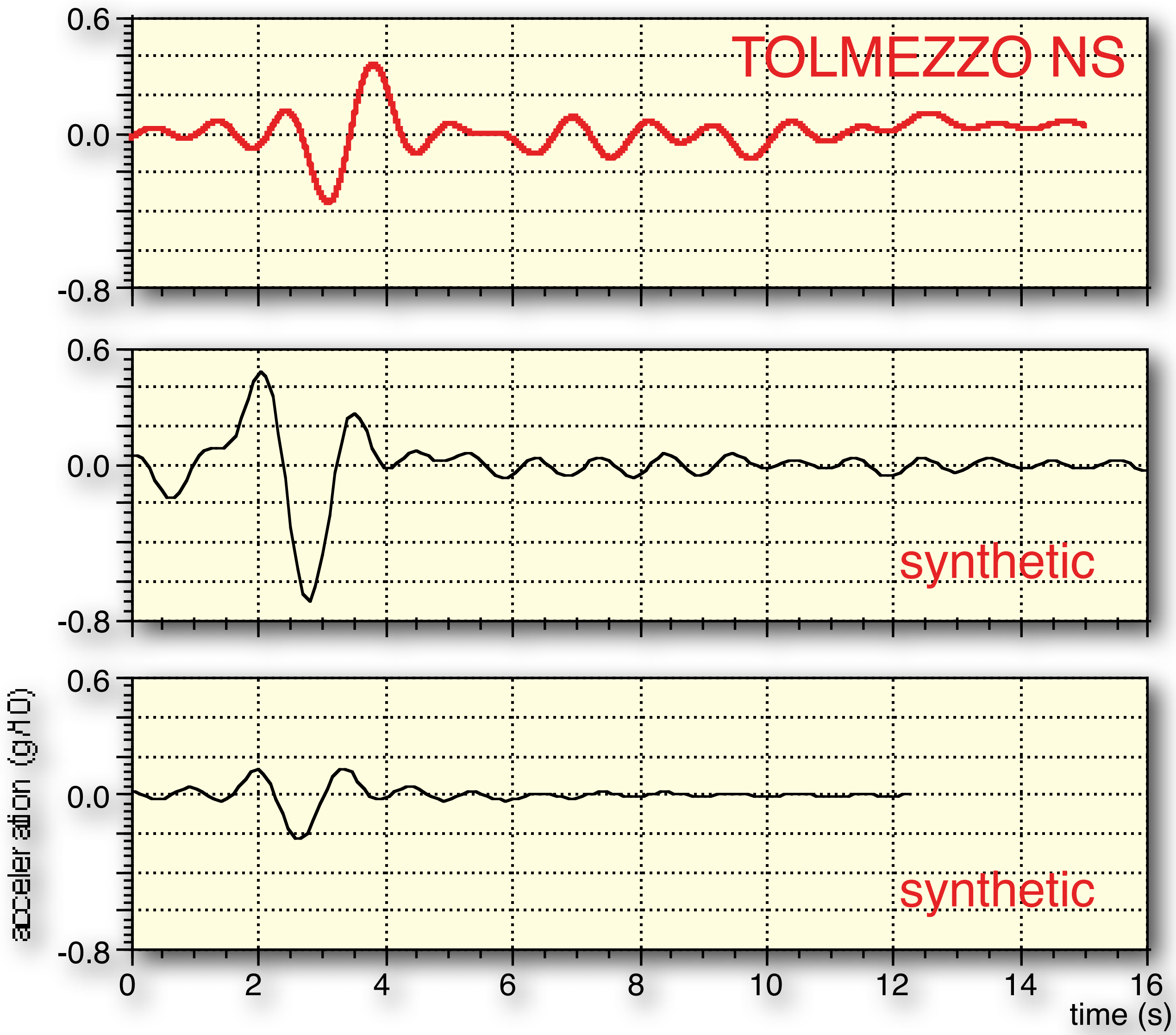
From 1Hz acceleration to DGA

- 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



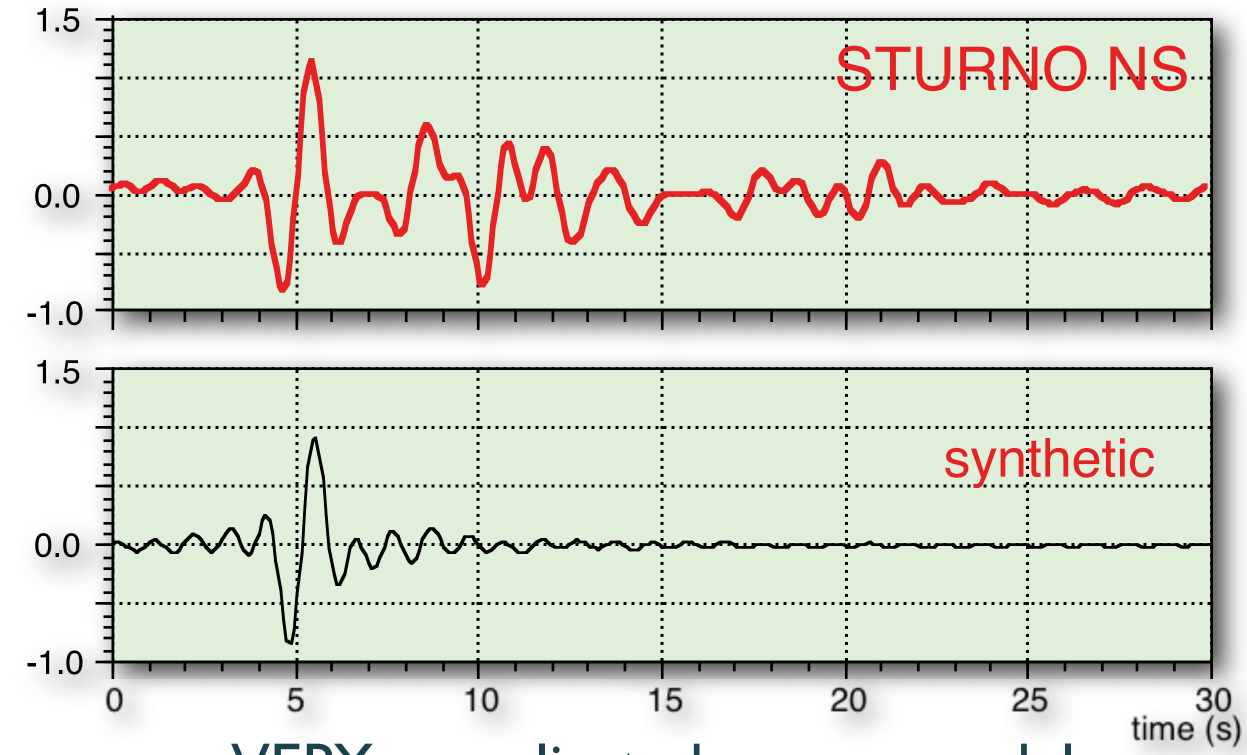
Regional Scale - Check (1 Hz cutoff)

Friuli, 6 May 1976 (North-Eastern Italy)



Comparison with two grid nodes close to the Tolmezzo station

Irpinia, 23 October 1980 (Southern Italy)

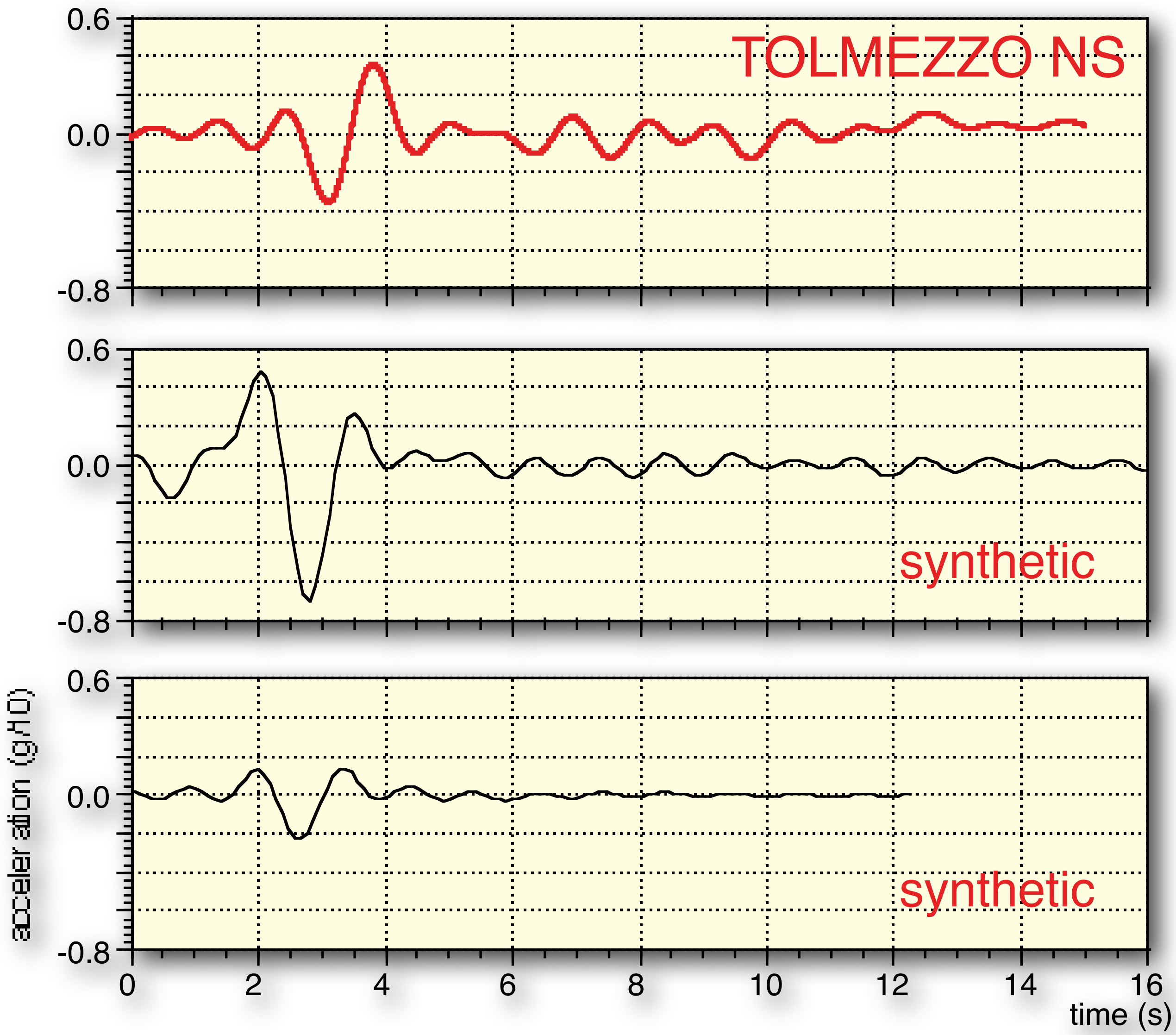


VERY complicated source model

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

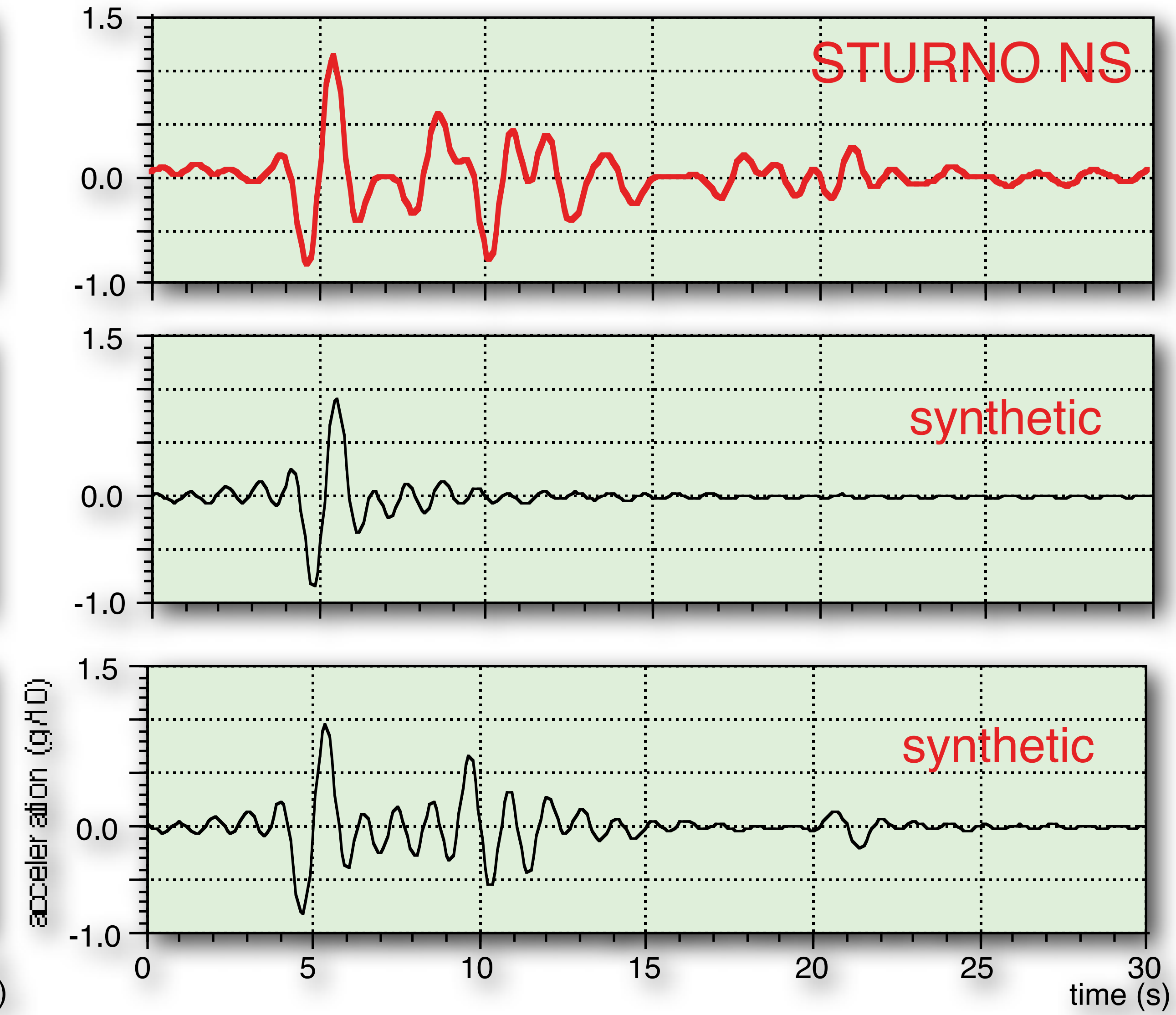
Regional Scale - Check (1 Hz cutoff)

Friuli, 6 May 1976 (North-Eastern Italy)



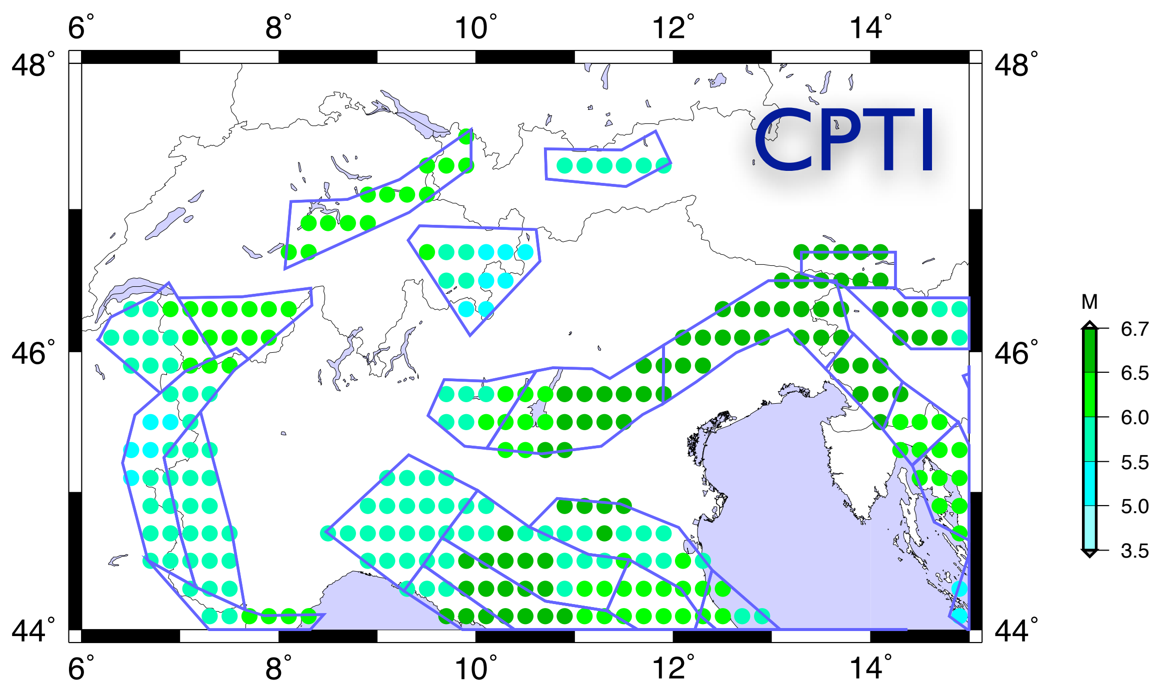
Comparison with two grid nodes close to the Tolmezzo station

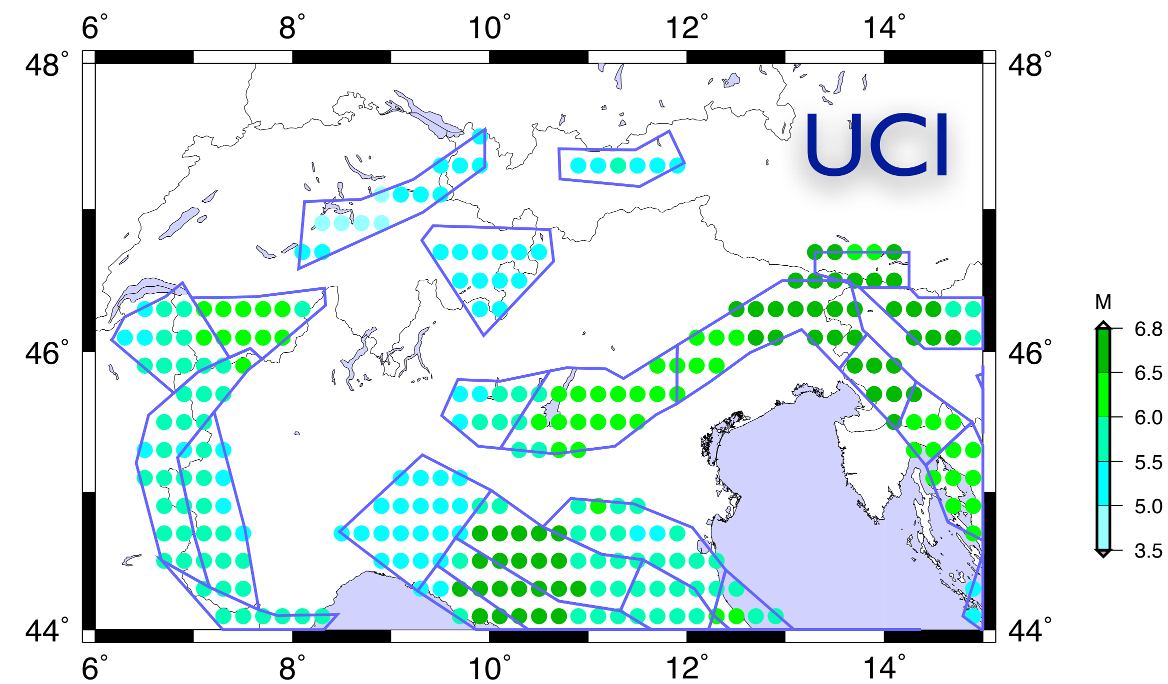
Irpinia, 23 October 1980 (Southern Italy)



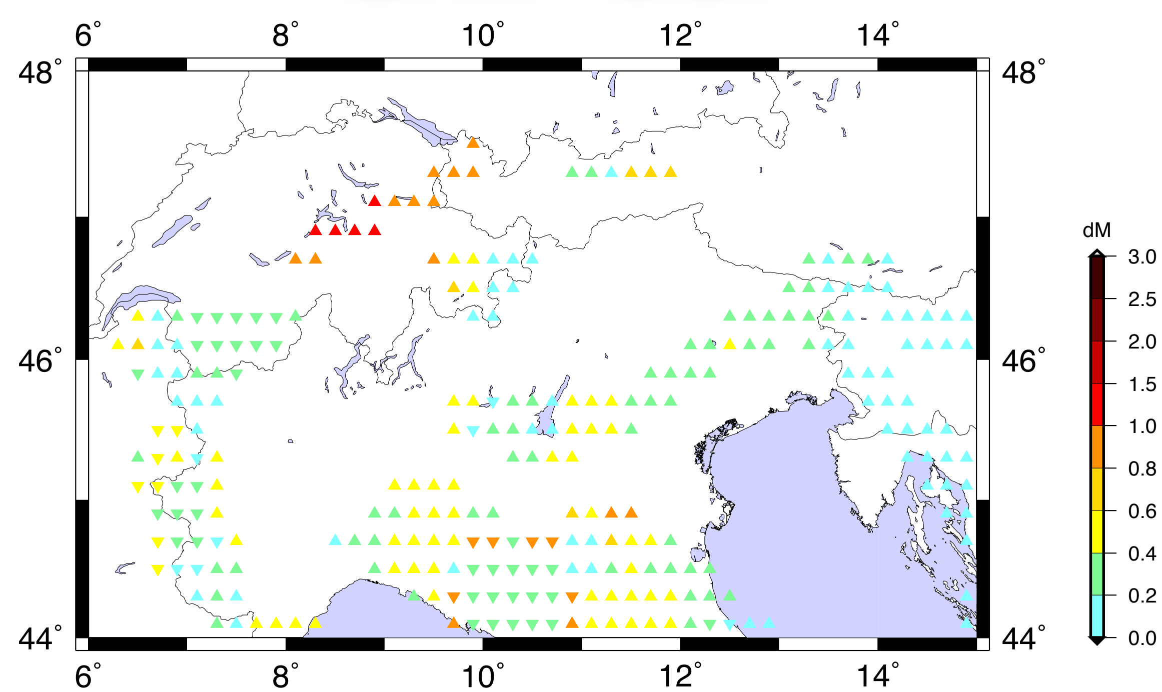
With a sequence of point sources the duration can be reproduced but this is deliberately neglected since rupturing process is not known a priori

Parametric Test on Earthquake Catalogue

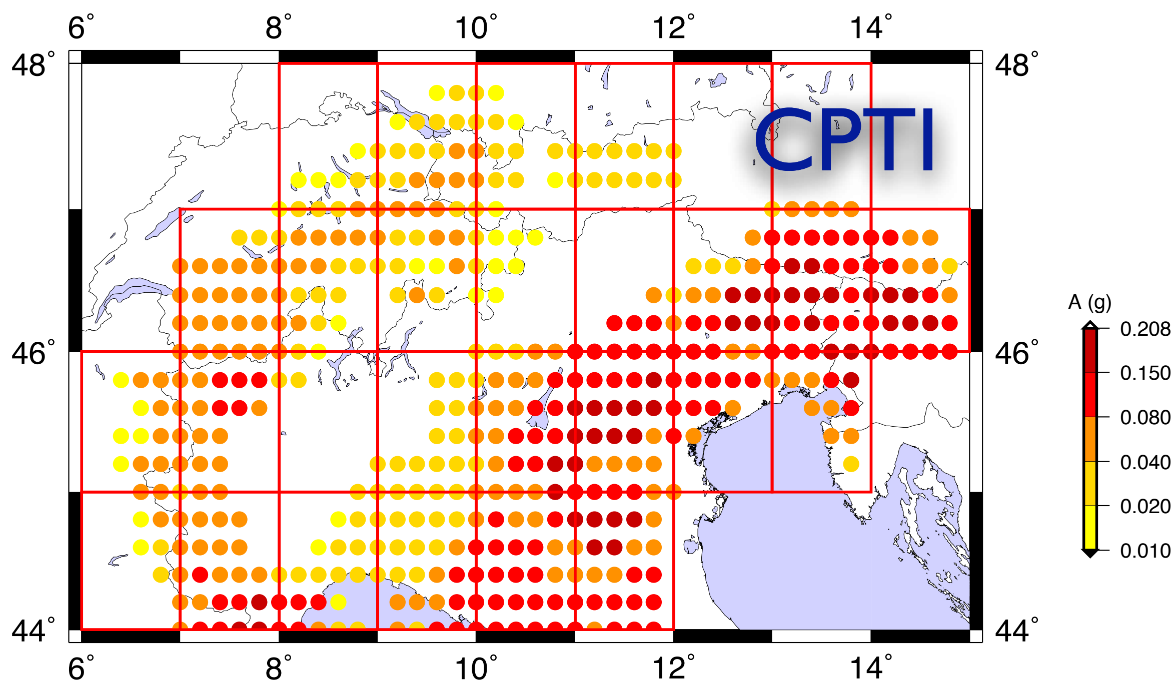


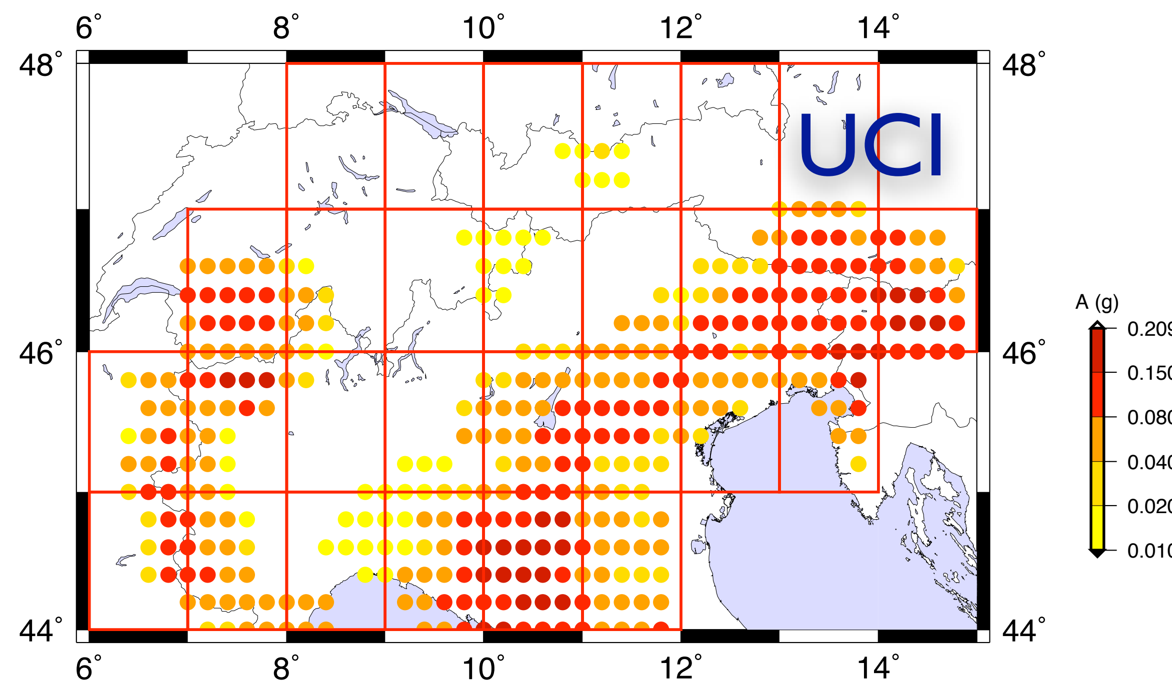


CPTI - UCI

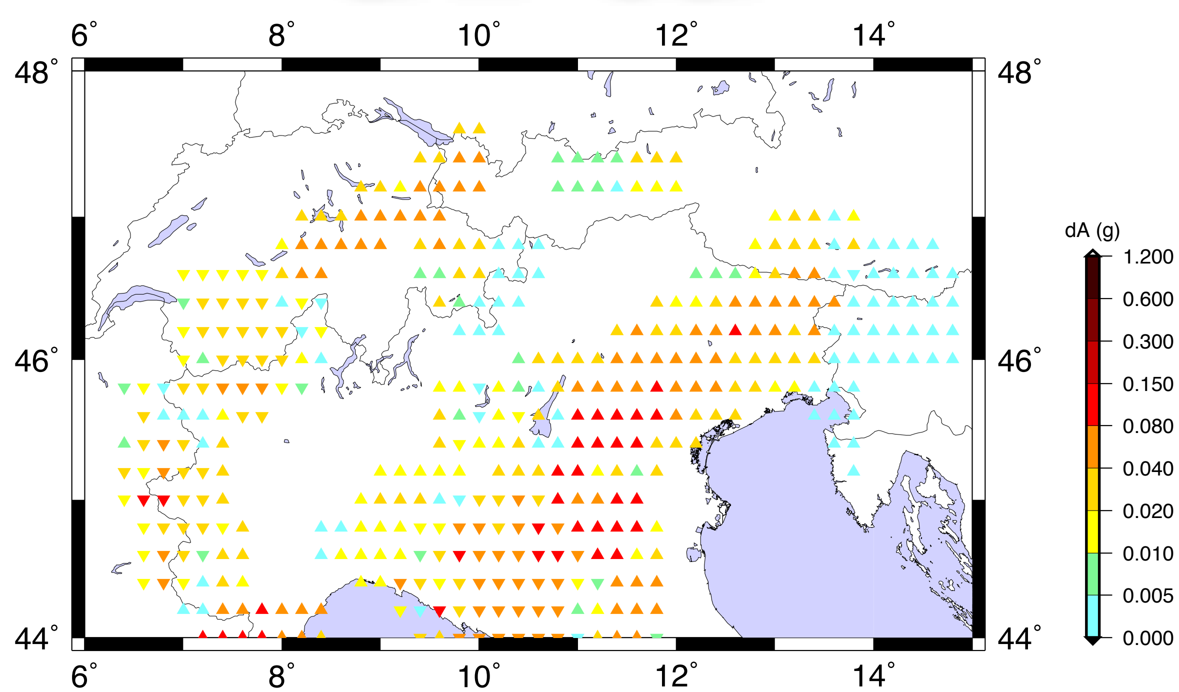


Parametric Test on Earthquake Catalogue





CPTI - UCI



Regional Scale - Homogeneity!

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

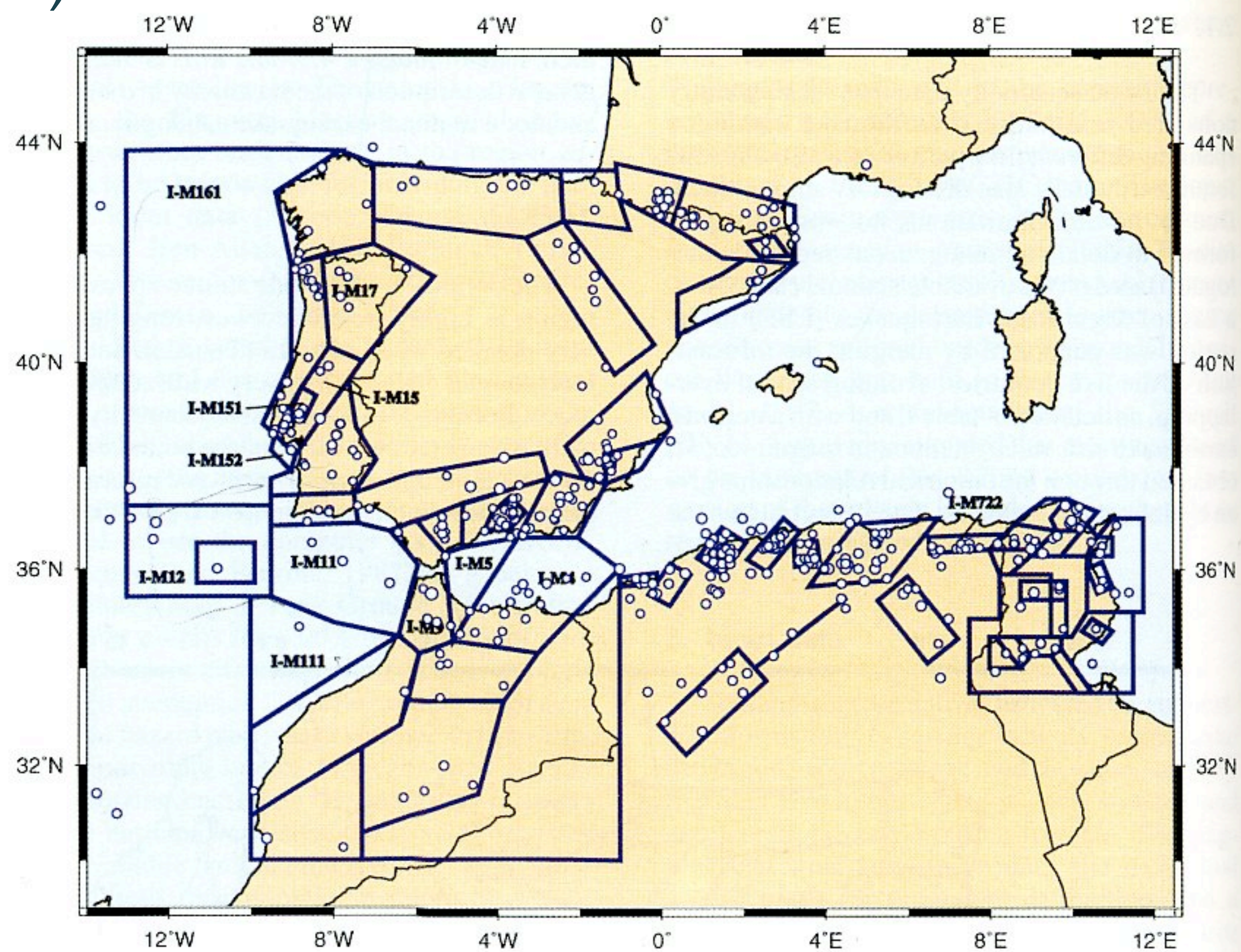
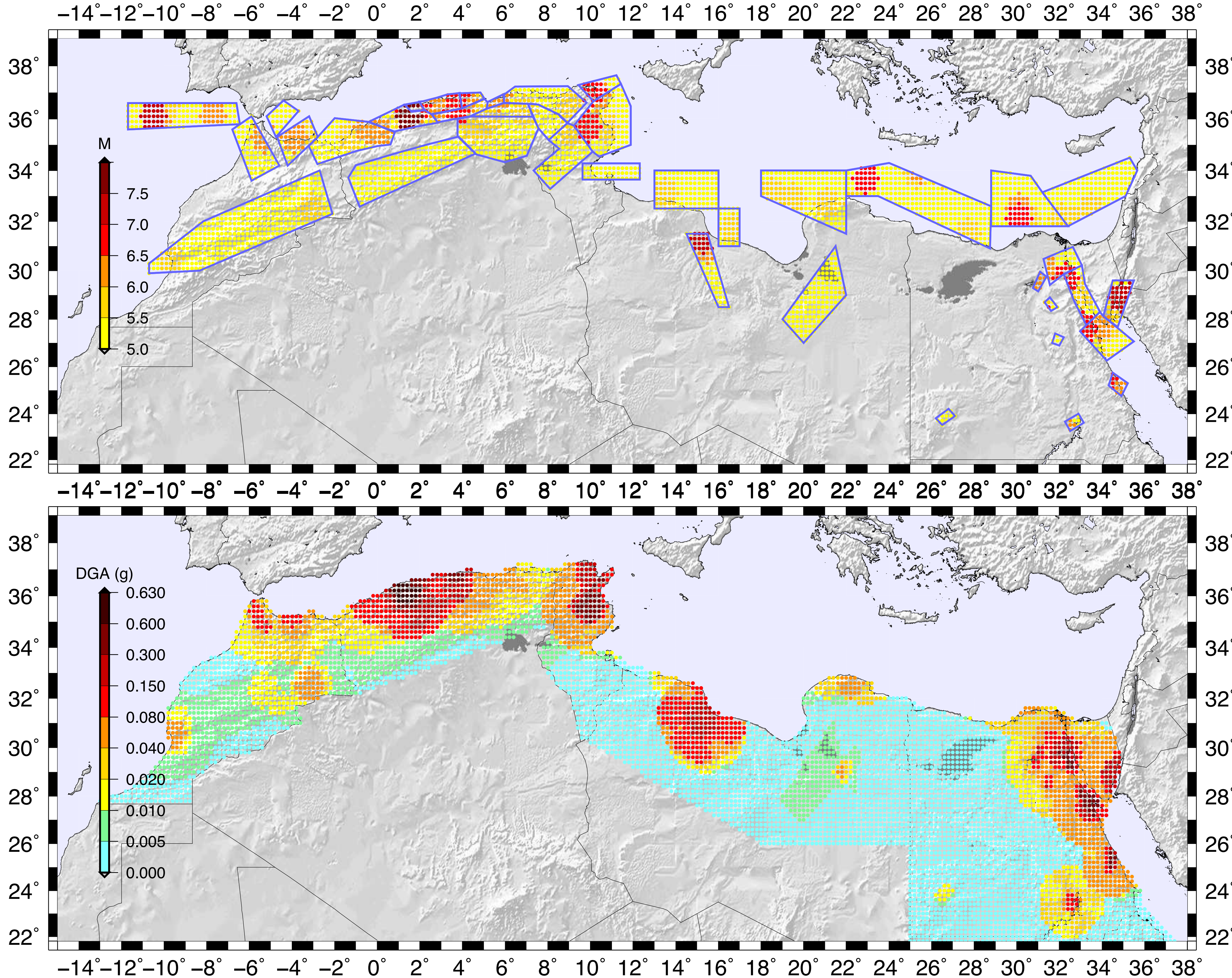
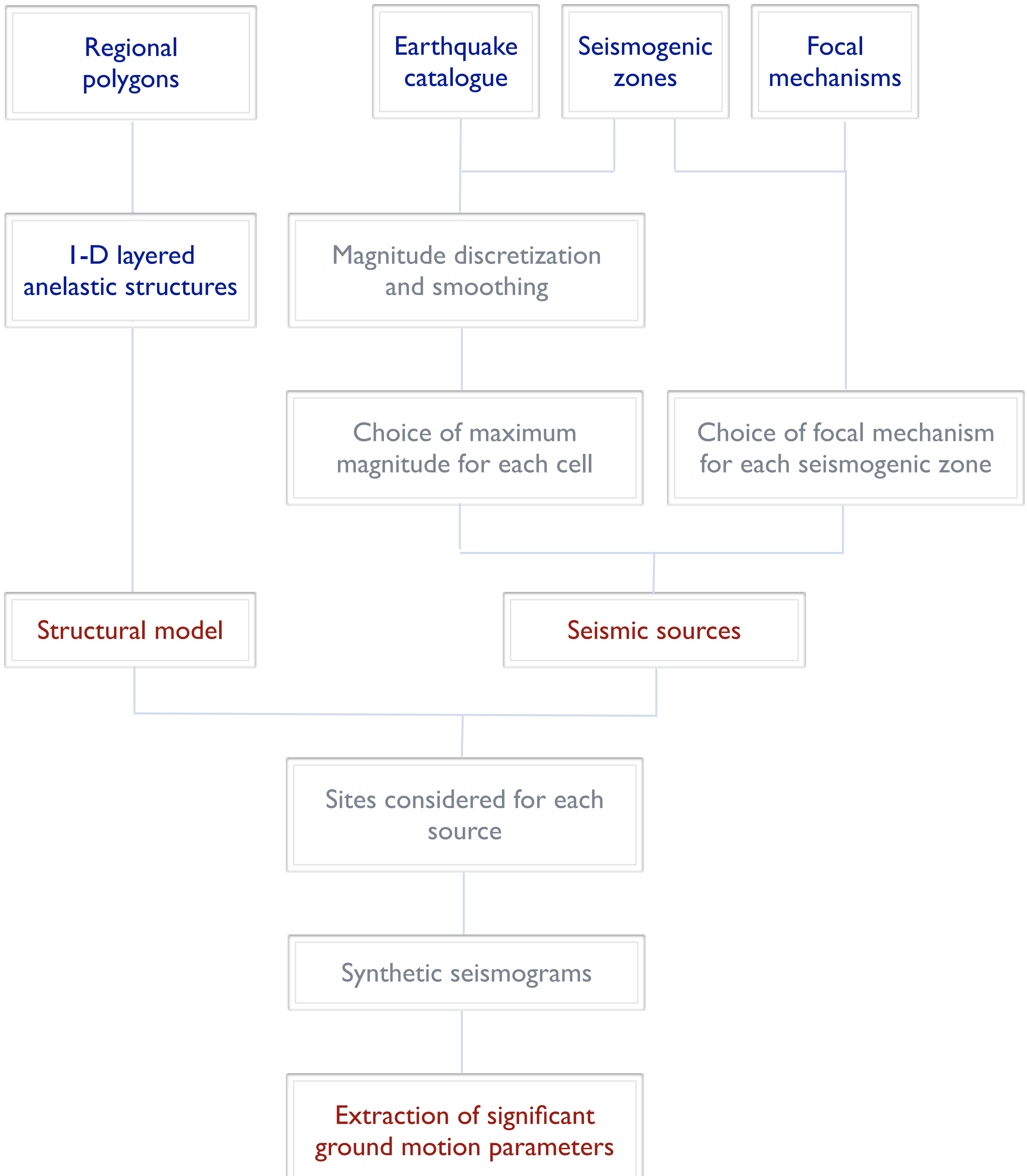


Fig. 2. Final distribution of earthquake source zones for the Ibero-Maghreb region, and epicenters of the generated List of Significant Earthquakes with $M \geq 4.5$ from 1900 to 1989.

Regional Scale - Homogeneity!



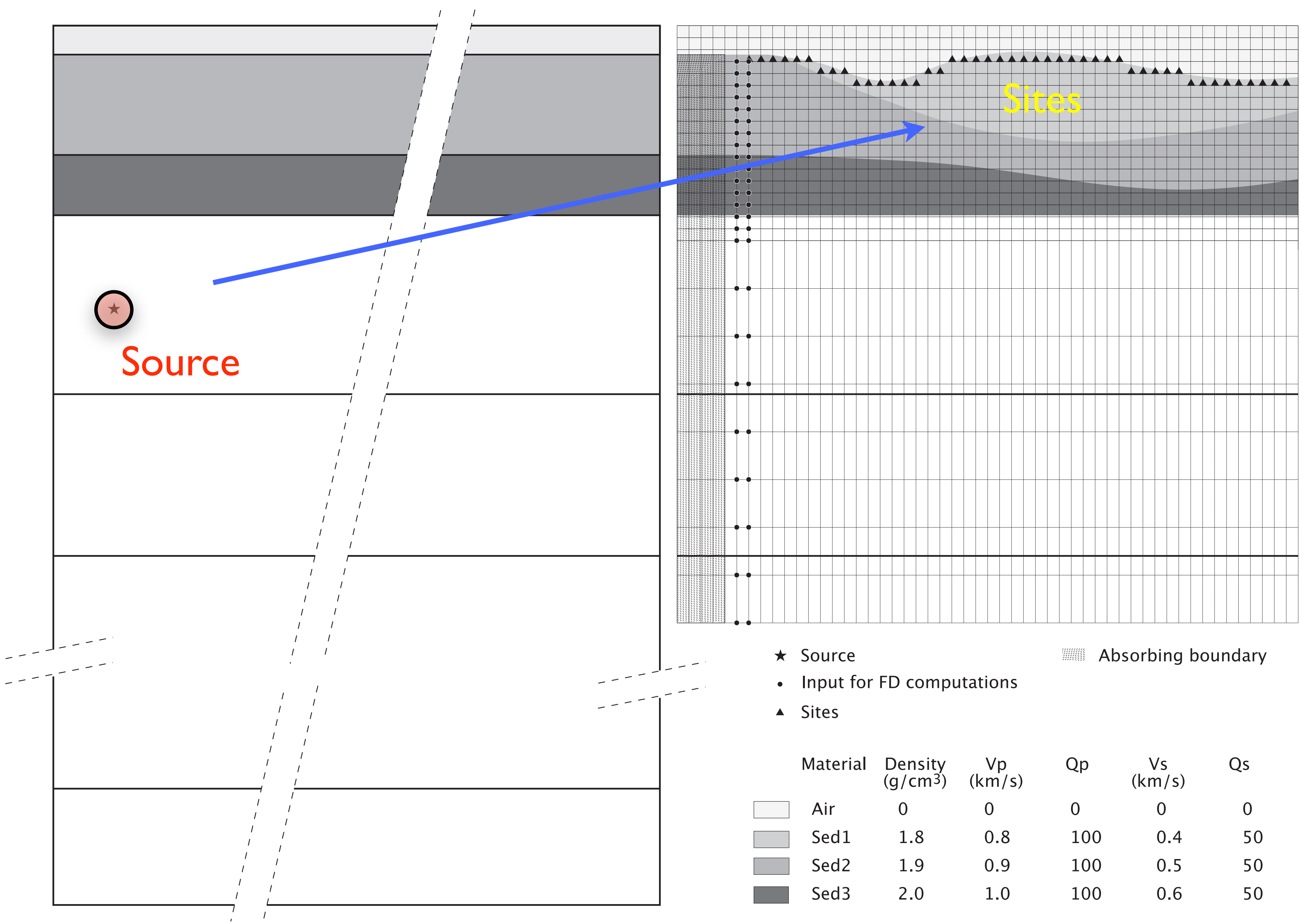
Regional Scale - Implementation



- FORTRAN codes
  - gfortran compiler (any should work)
- Plotting tools
  - GMT
  - gnuplot
- Shell scripts

Local Scale - Definition of Model

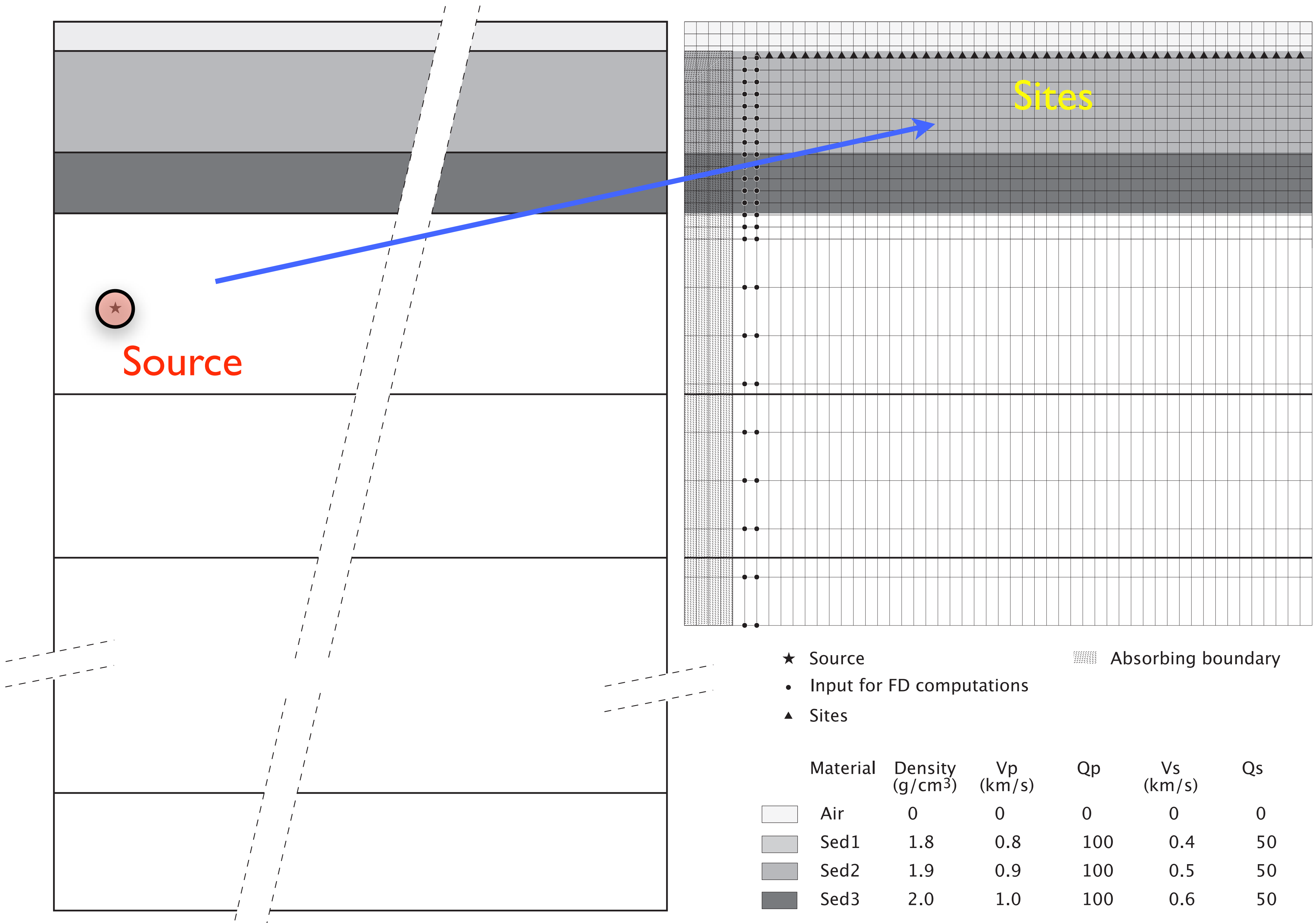
Modal Summation | Finite Difference



	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

Local Scale - Definition of Model

Modal Summation | Finite Difference



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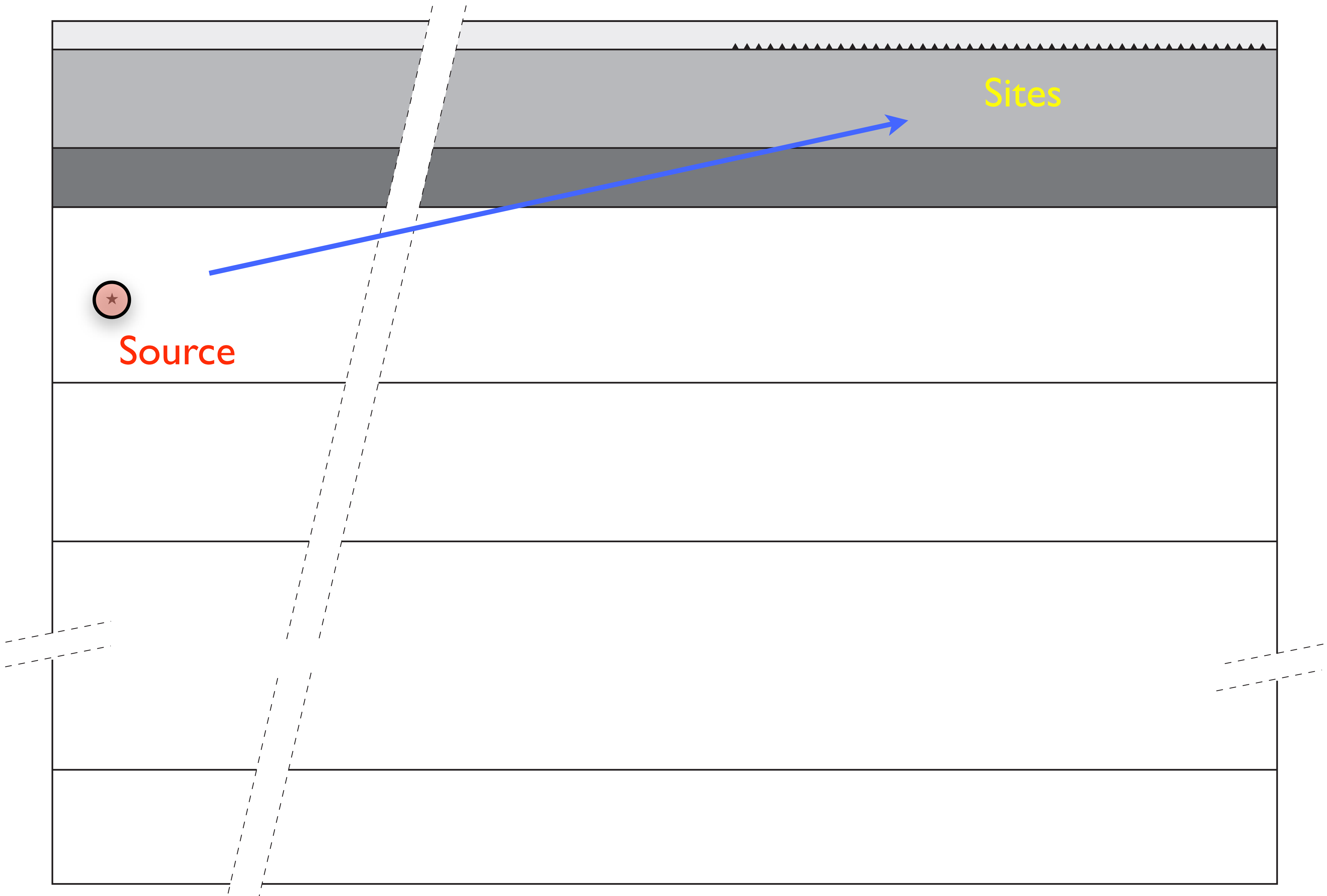
	Sed3	2.0	1.0	100	0.6	50

Local Scale - Definition of Model

Modal Summation



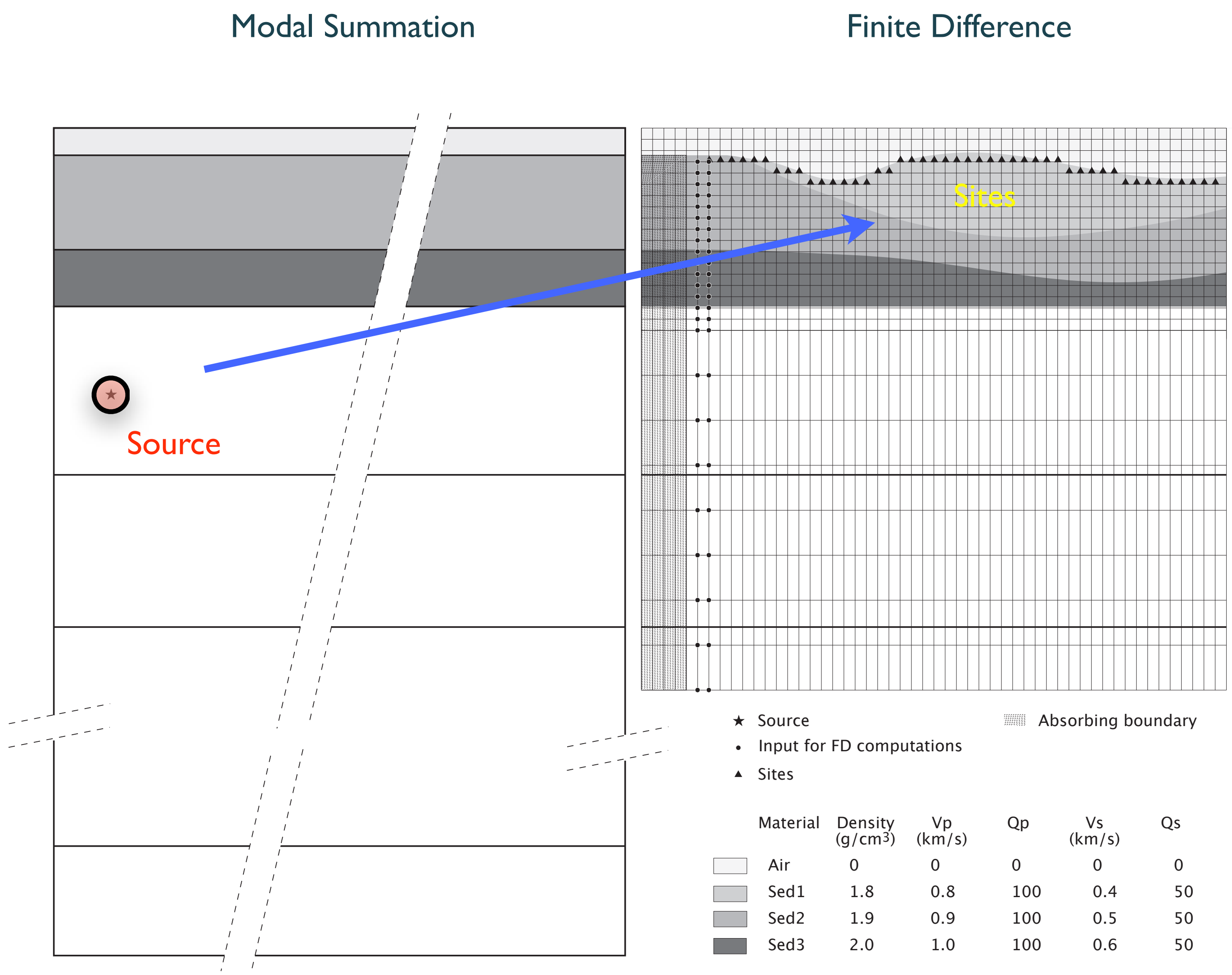
Local Scale - Input Definition

```
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

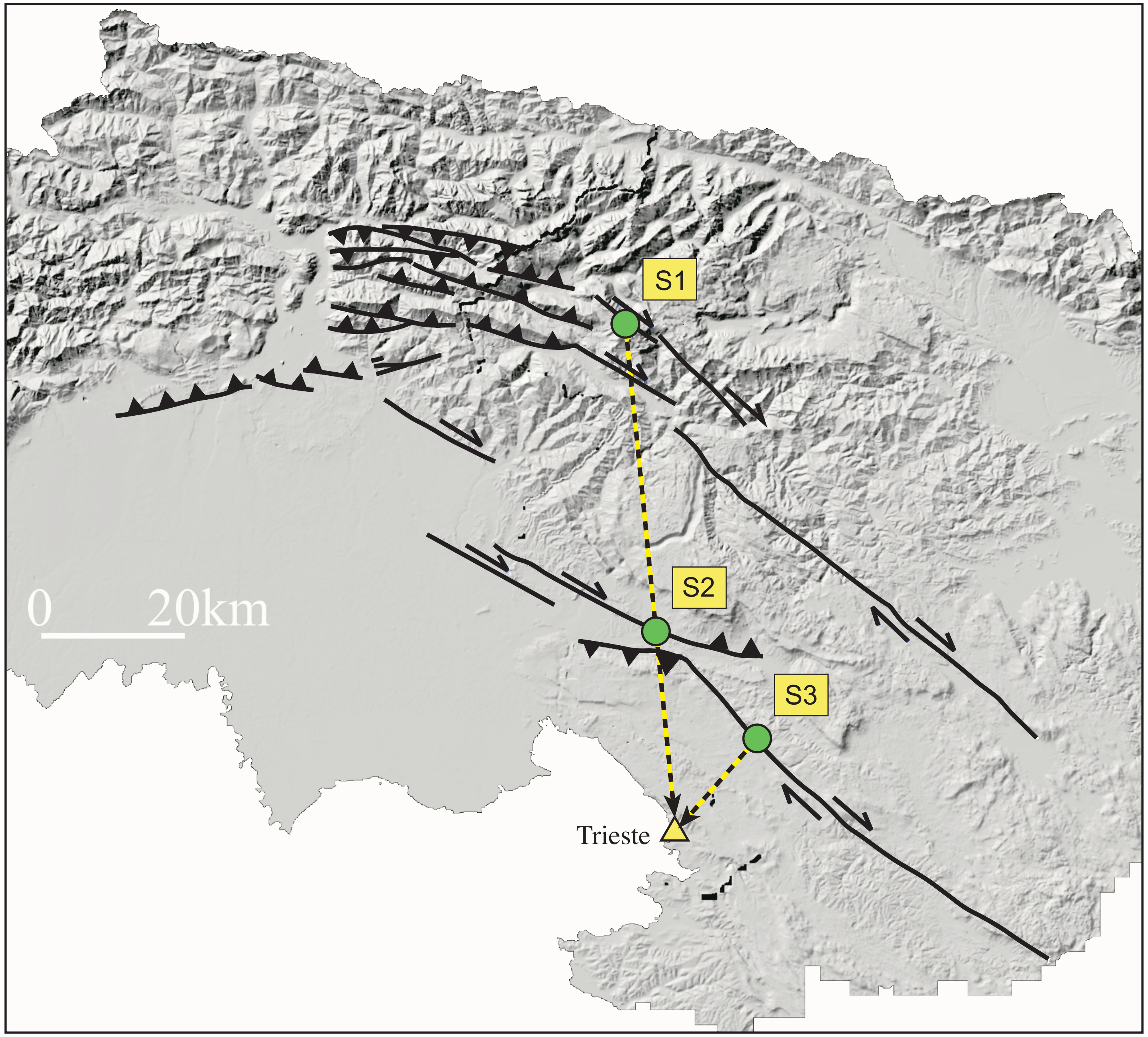
Local Scale - Implementation



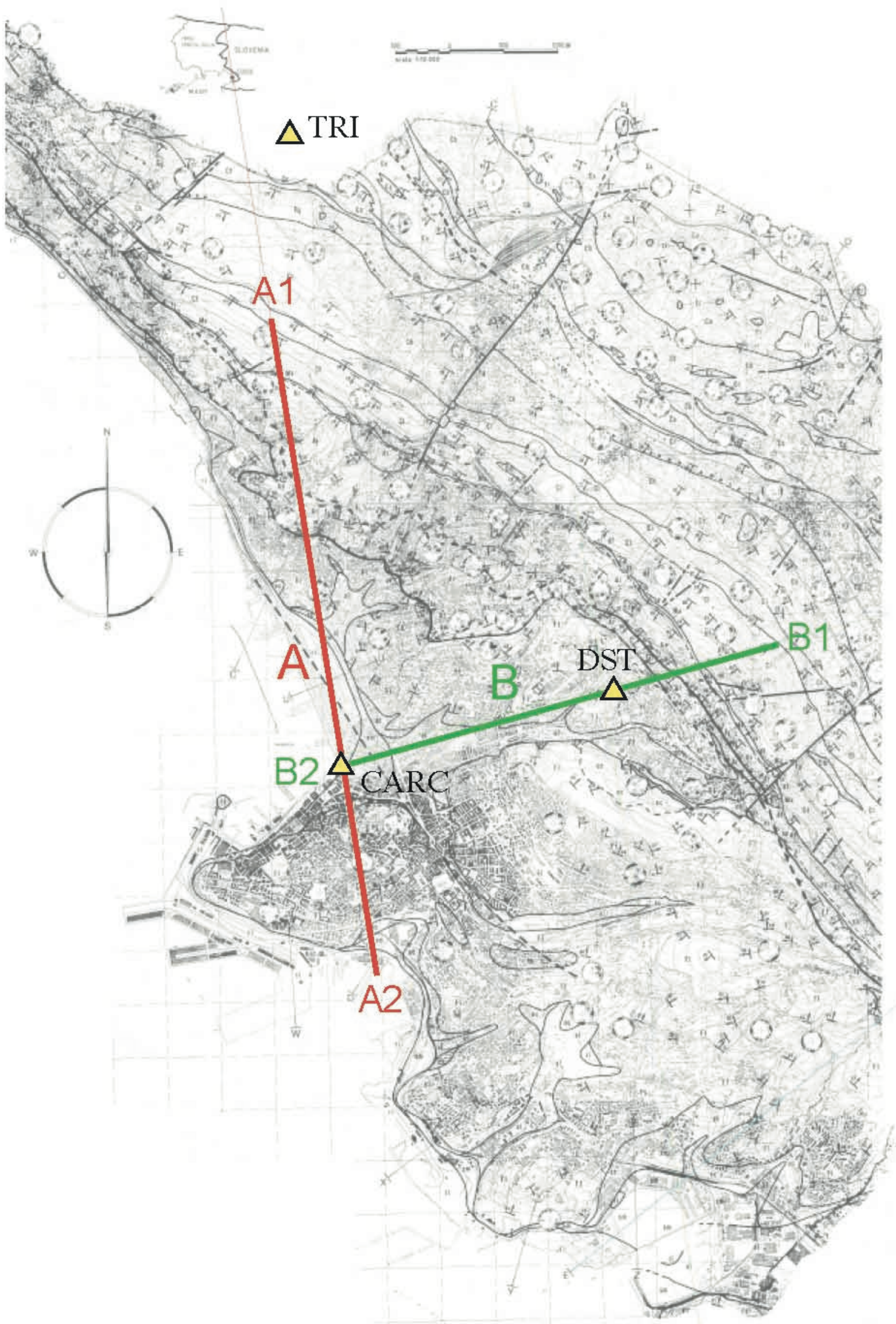
- FORTRAN codes
  - gfortran compiler (any should work)
- Plotting tools
  - GMT
  - gnuplot
- Shell scripts
- Perl scripts

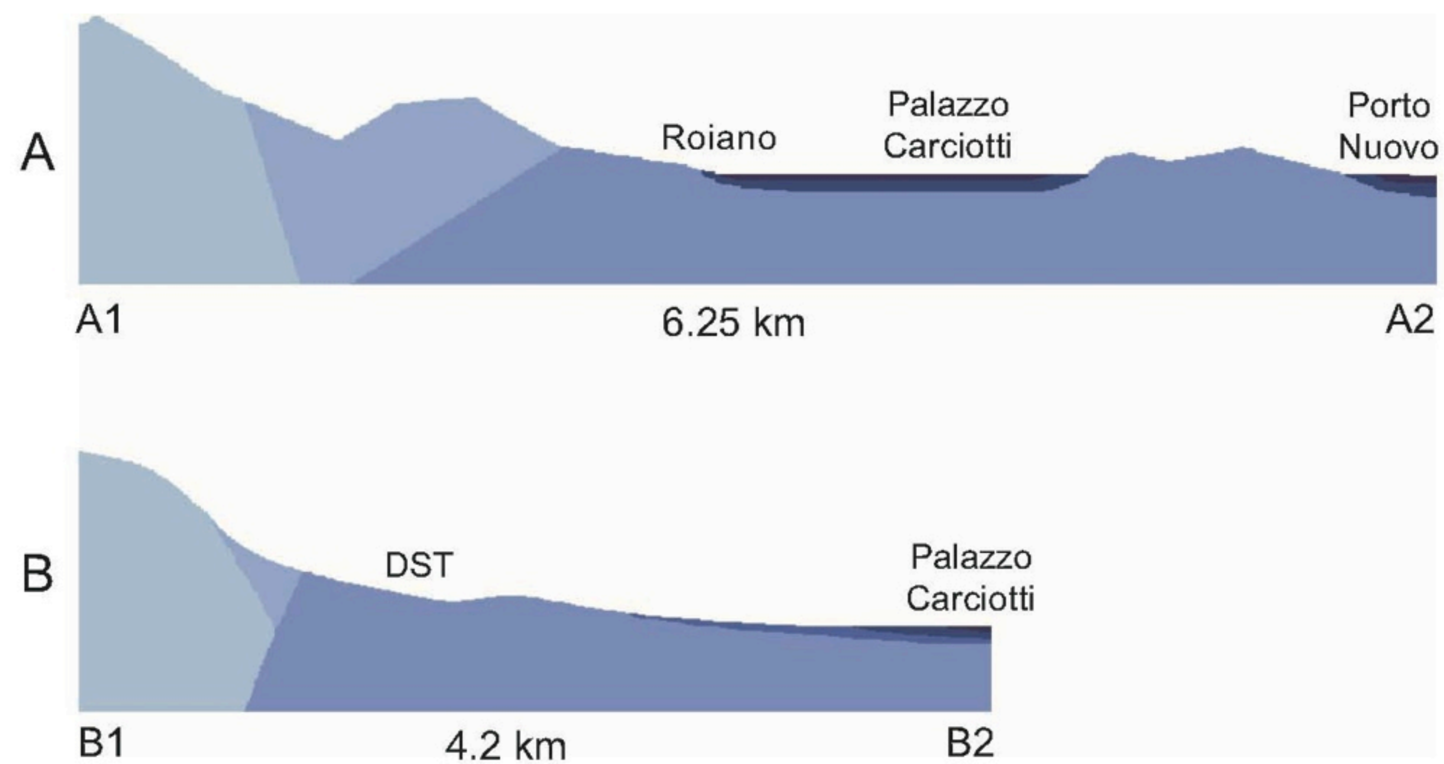
Local Scale - Choice of Scenario Earthquakes

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



Local Scale - Choice of Profiles

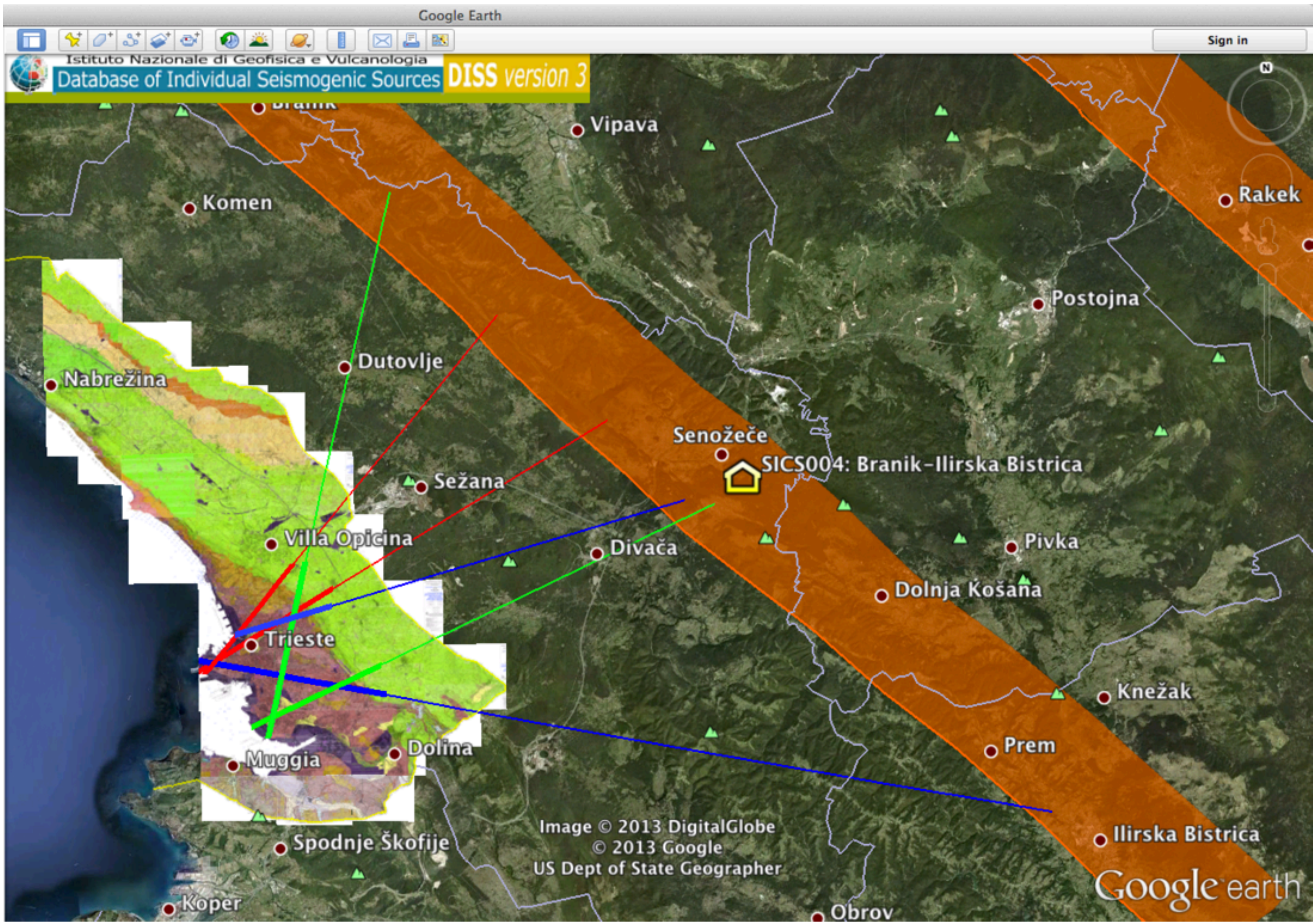




	Litotipo	Densità (g/cm^3)	Vp (km/s)	Vs (km/s)	Qp	Qs
	Riporti	1.8	0.4	0.2	30	15
	Sed. Marini	1.9	0.8	0.4	40	20
	Alluvioni	1.95	1.0	0.5	40	20
	Flysch	2.0	1.8	1.0	100	50
	Marne	2.0	1.9	1.1	200	100
	Arenarie	2.1	2.0	1.2	200	100
	Calcari	2.3	2.5	1.4	200	100

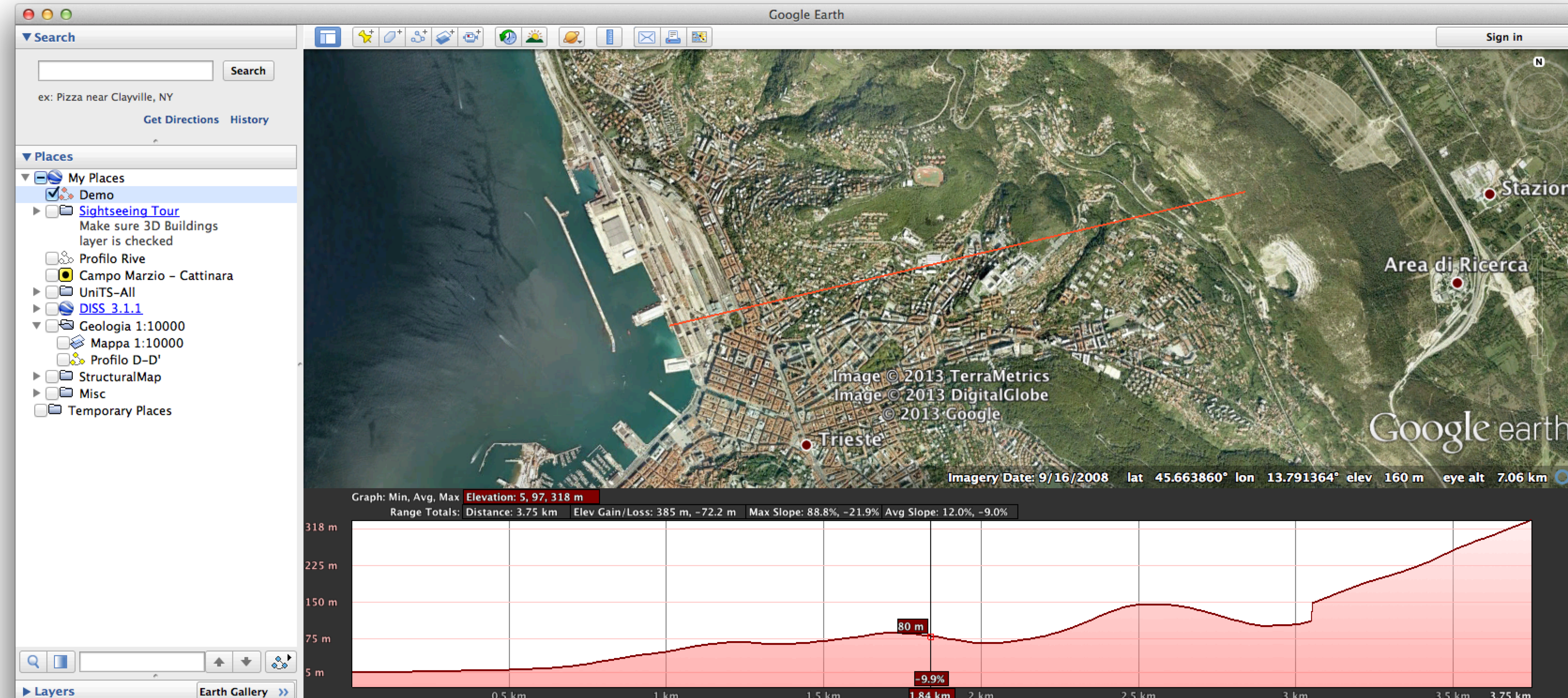
Local Scale - Choice of Profiles

- Profiles definition in Google Earth



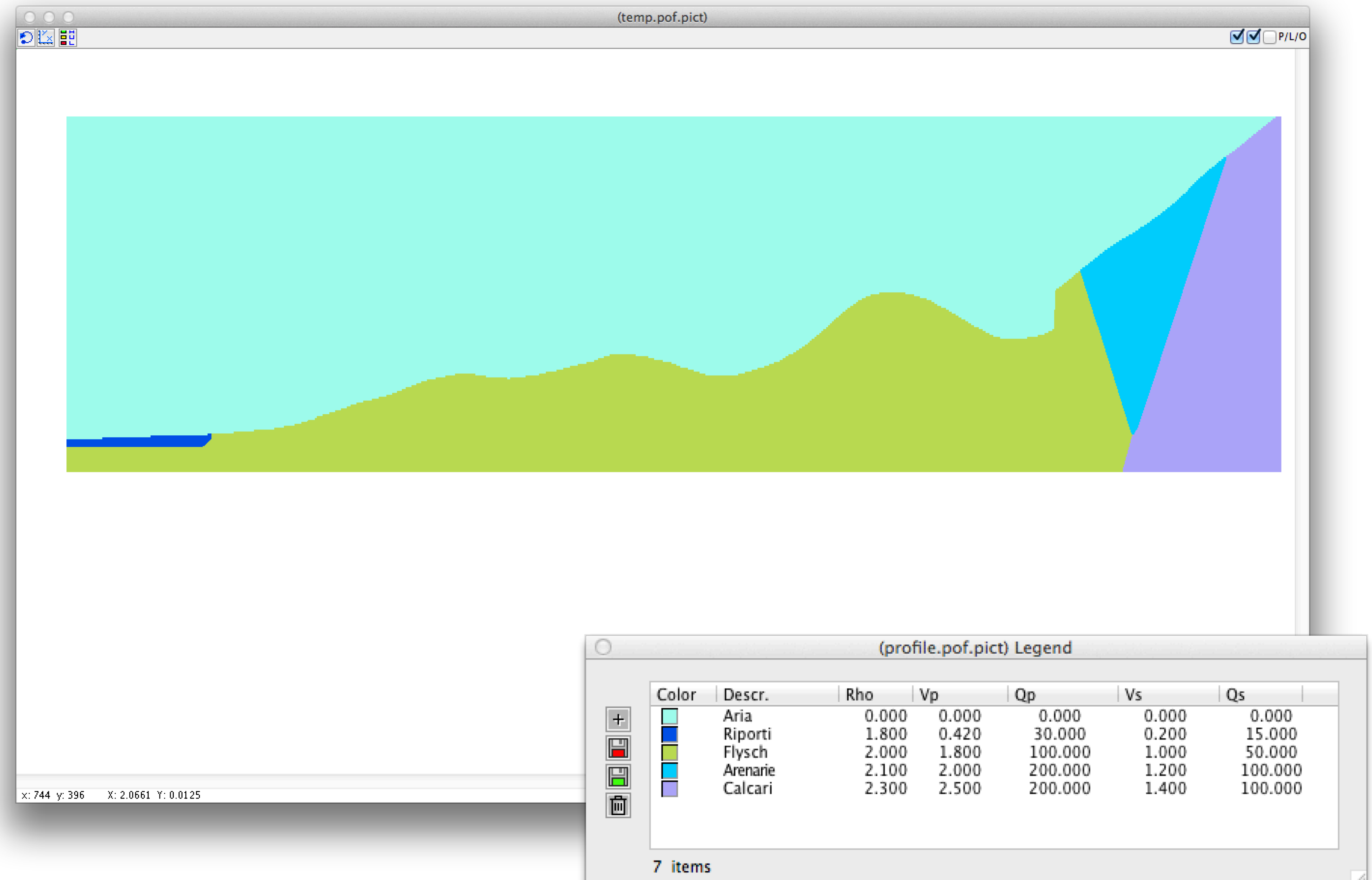
Local Scale - Choice of Profiles

- Definition of the profile topography



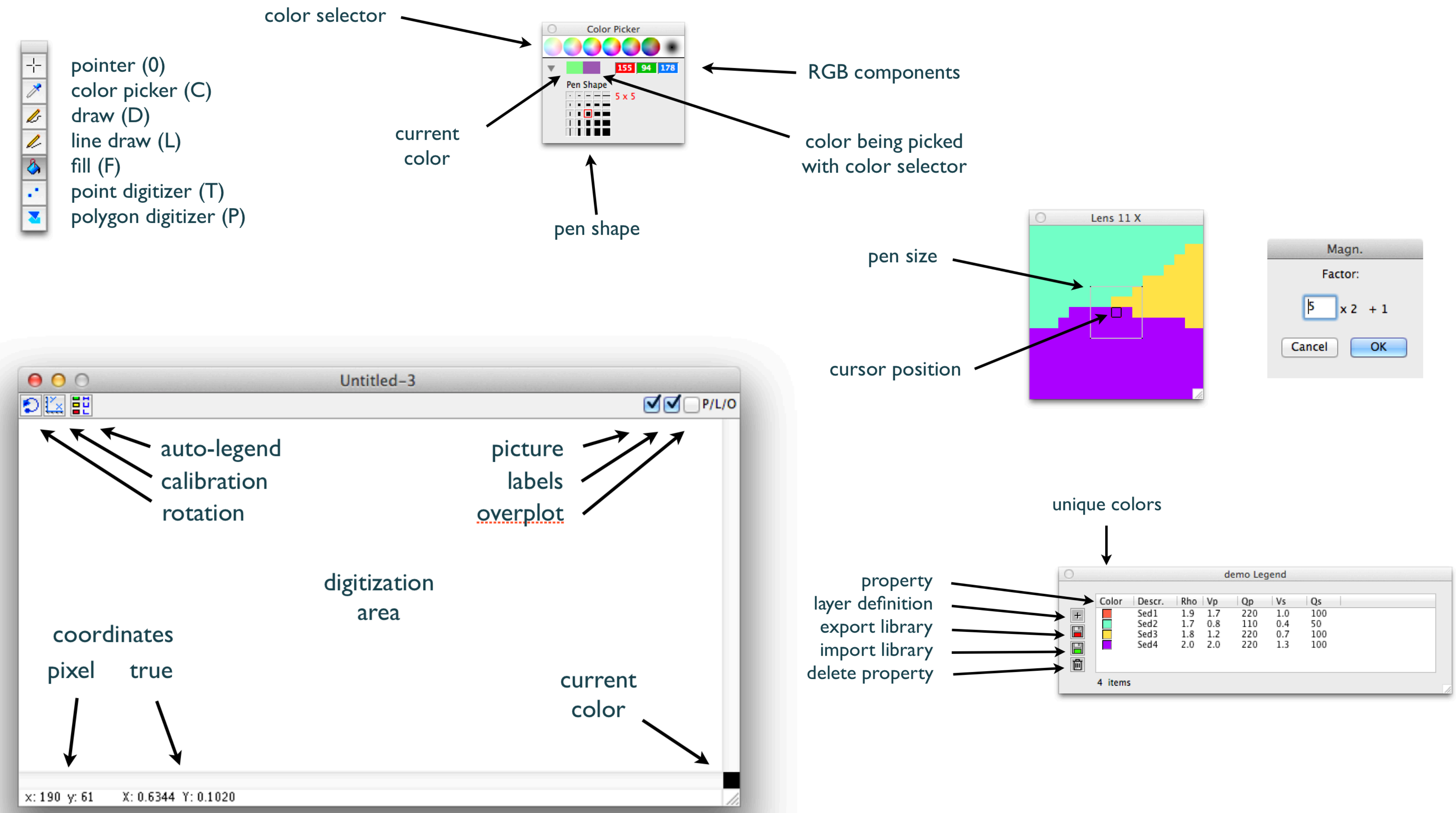
Local Scale - Choice of Profiles

- Drawing of the profile with XDigiMac



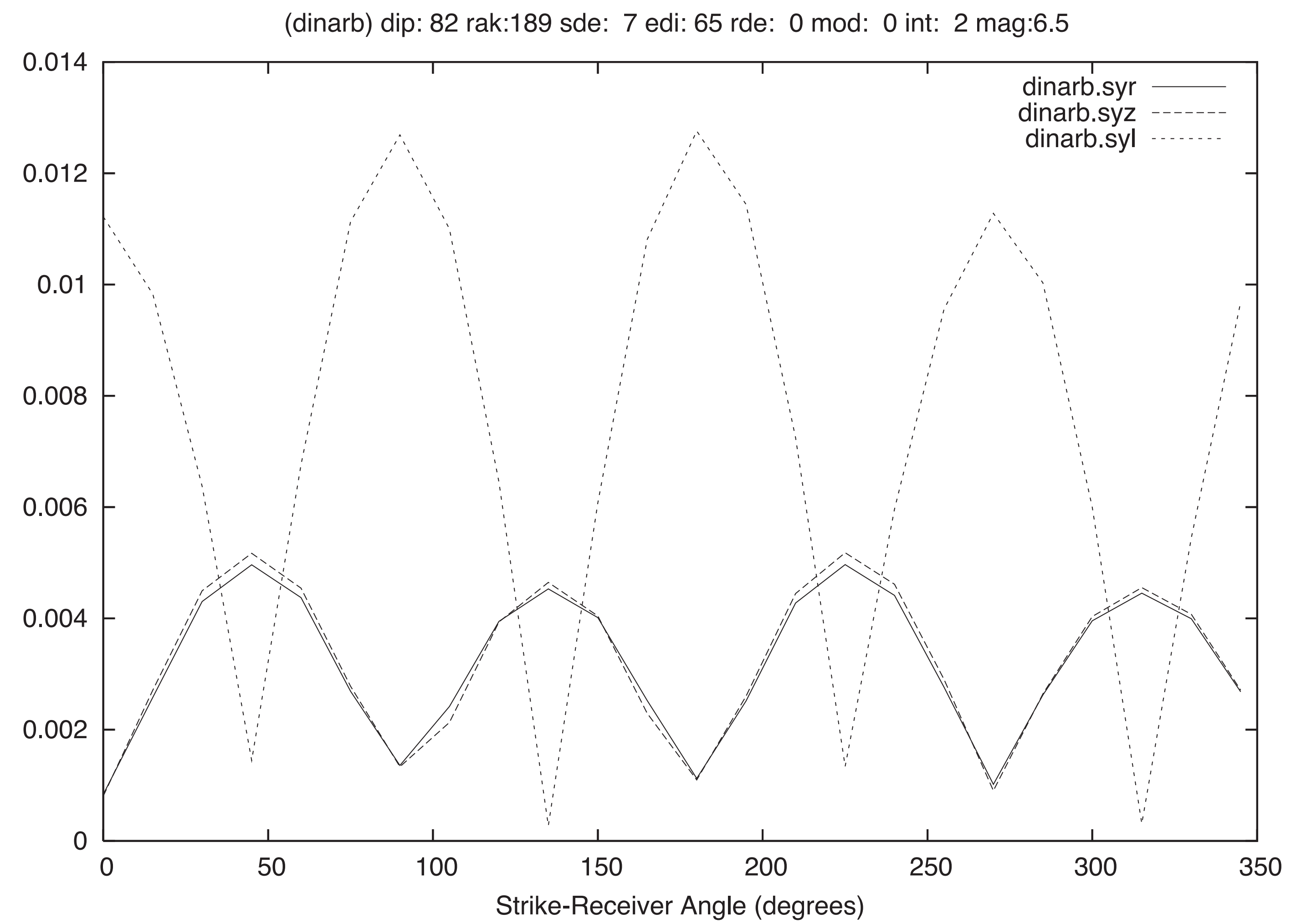
Local Scale - Choice of Profiles

Main elements of XDigiMac user interface

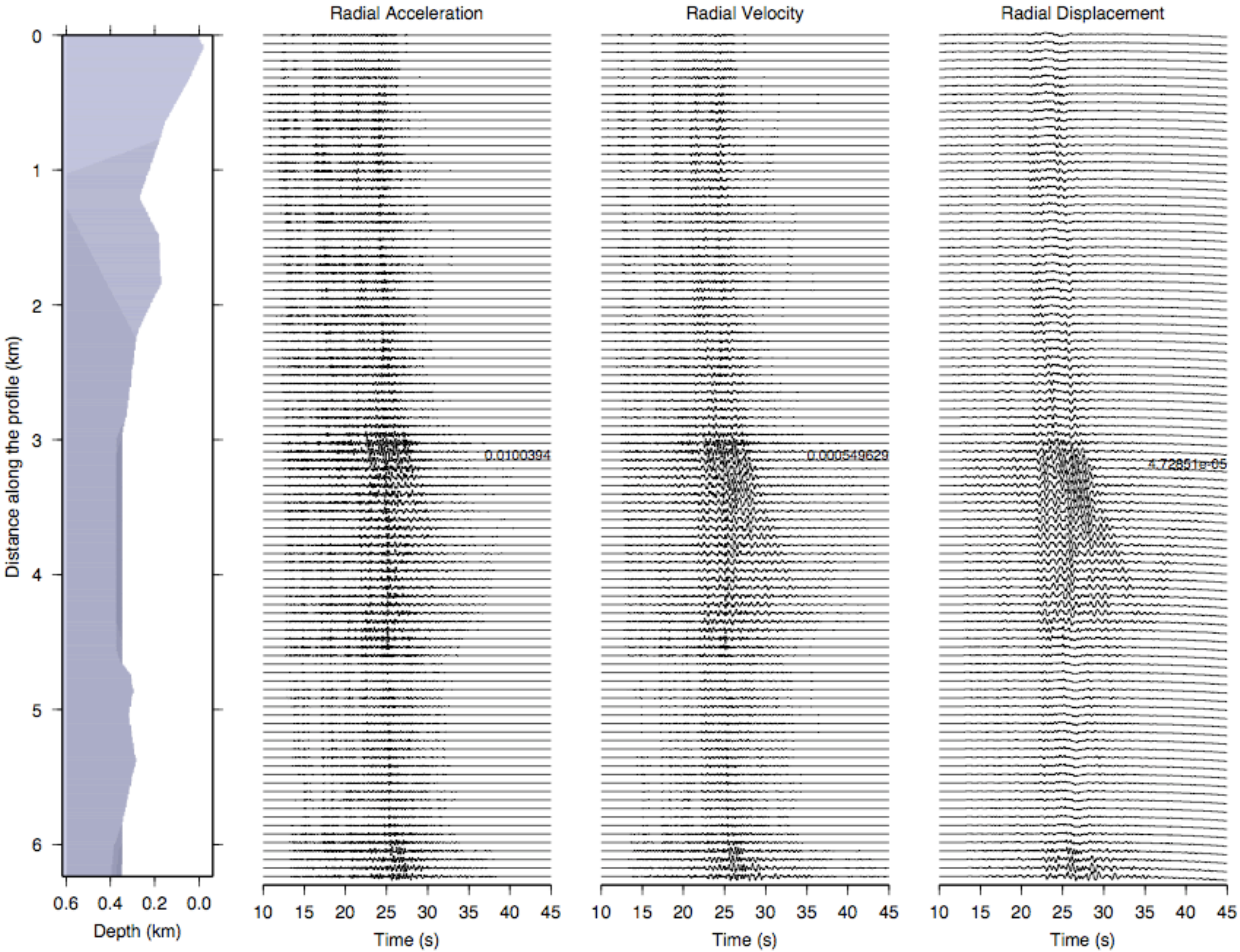


Local Scale - Preliminary Parametric Test

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

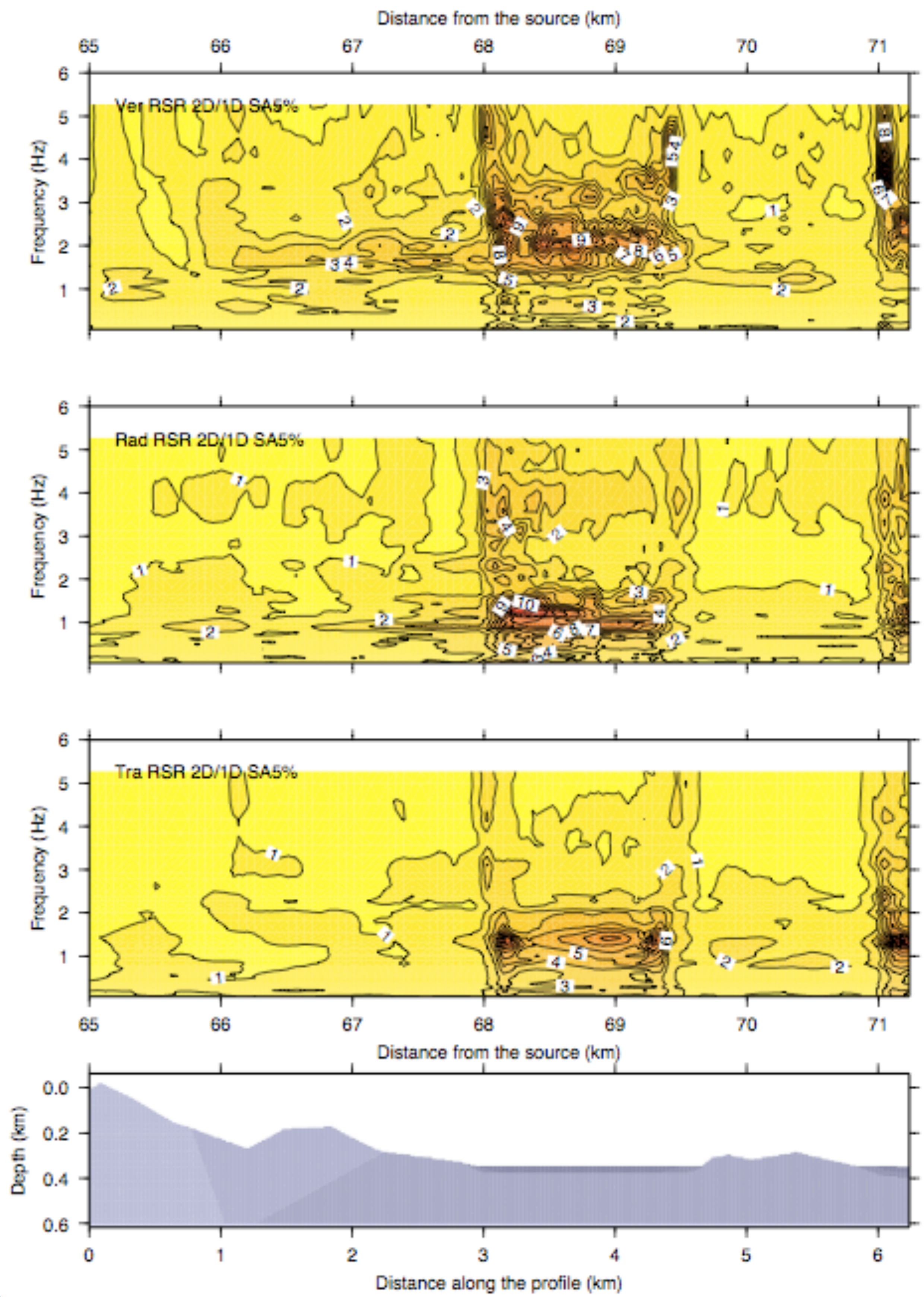


Local Scale - Synthetic Seismograms 2D



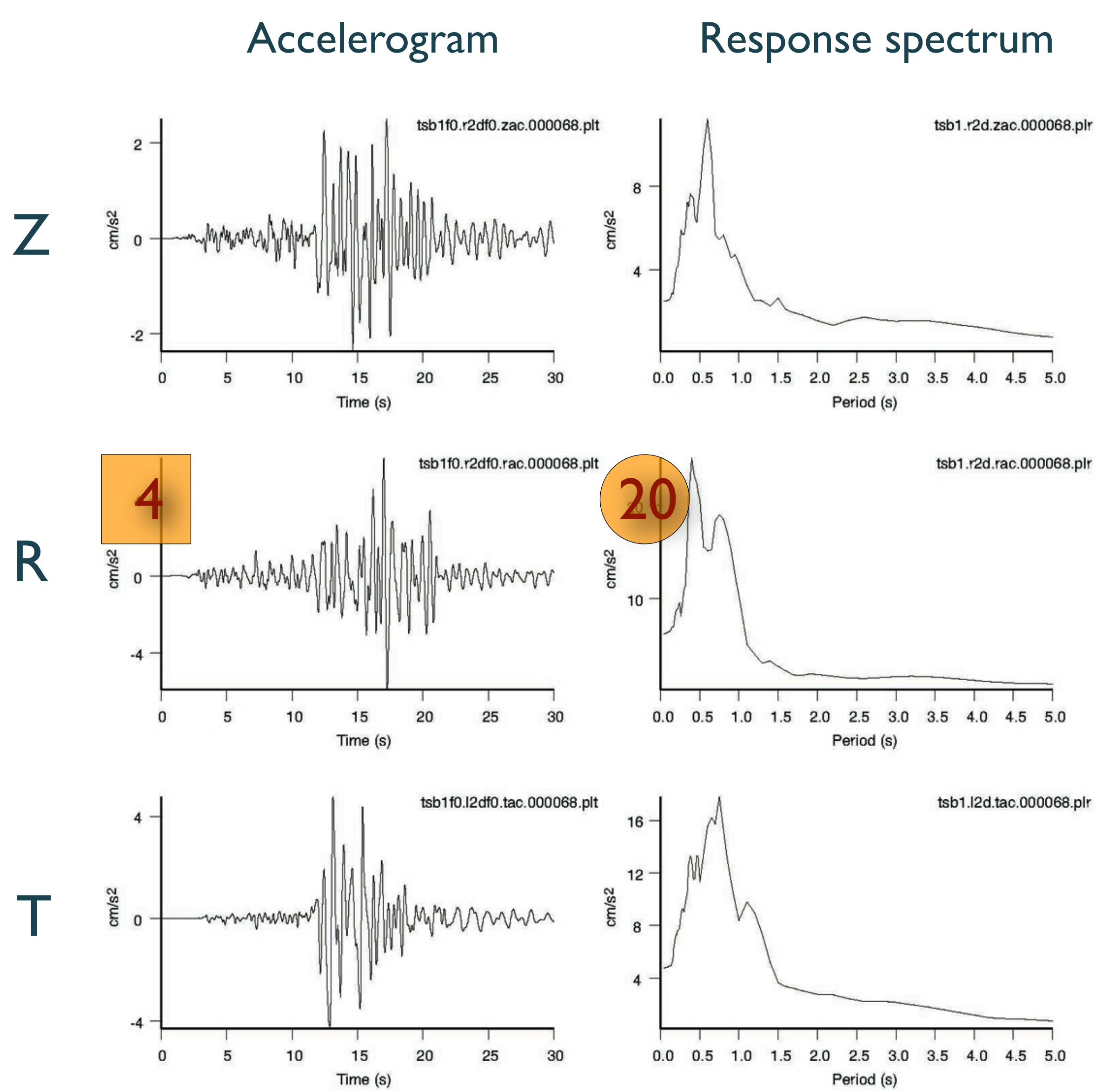
Local Scale - Response Spectra Ratios

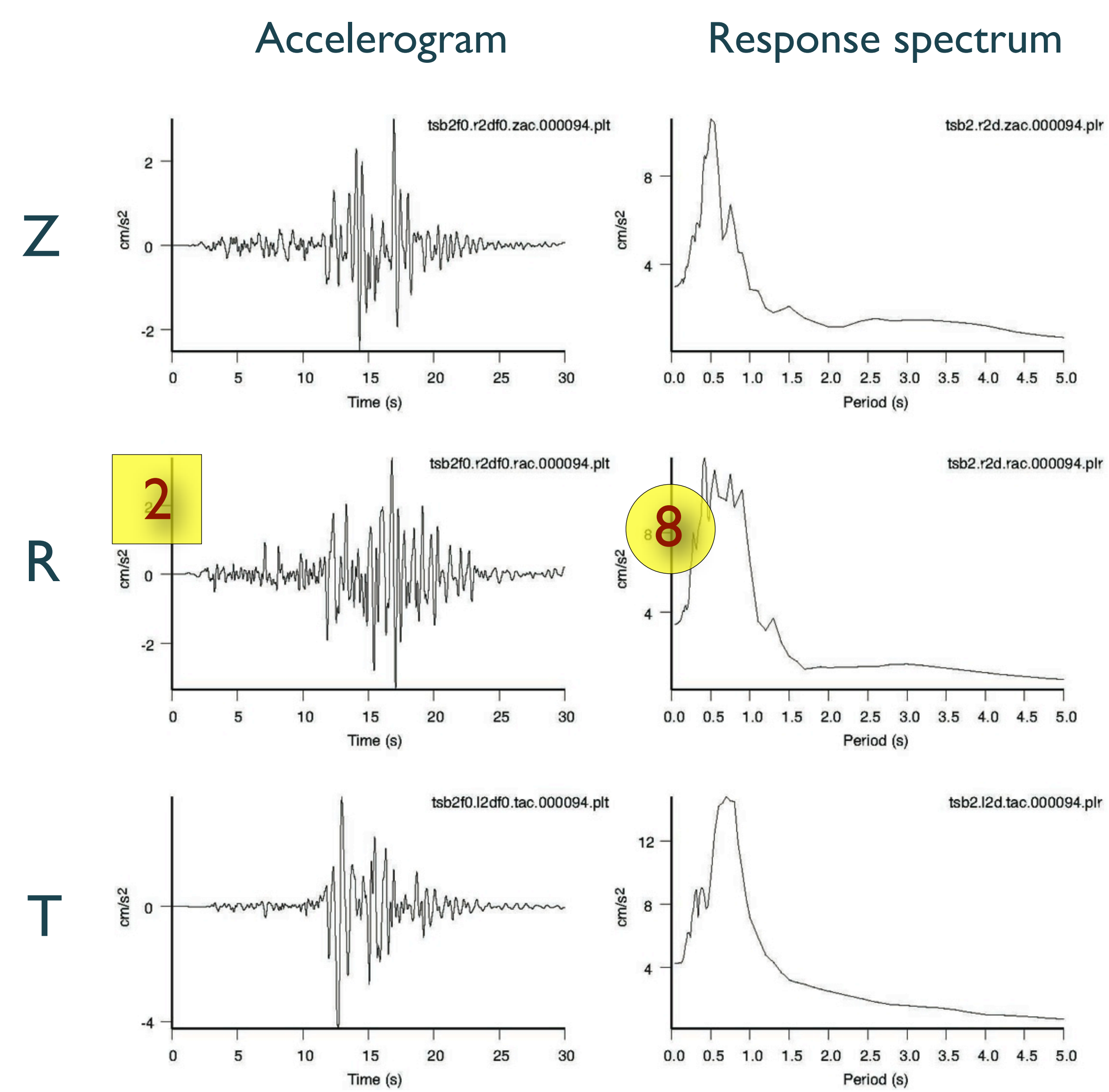
- 2D/1D RSR

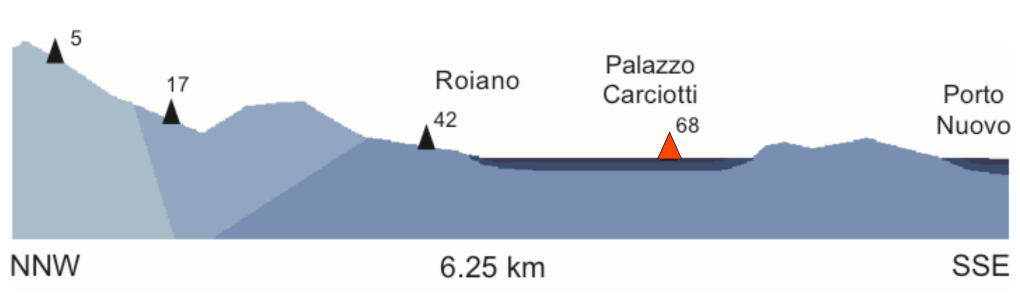


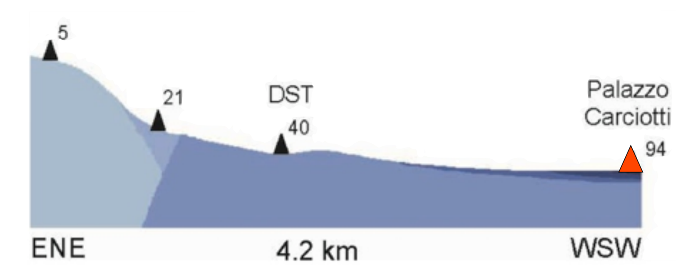
Local Scale - Seismograms and Response

- Same site at the intersection of two profiles (red triangle)



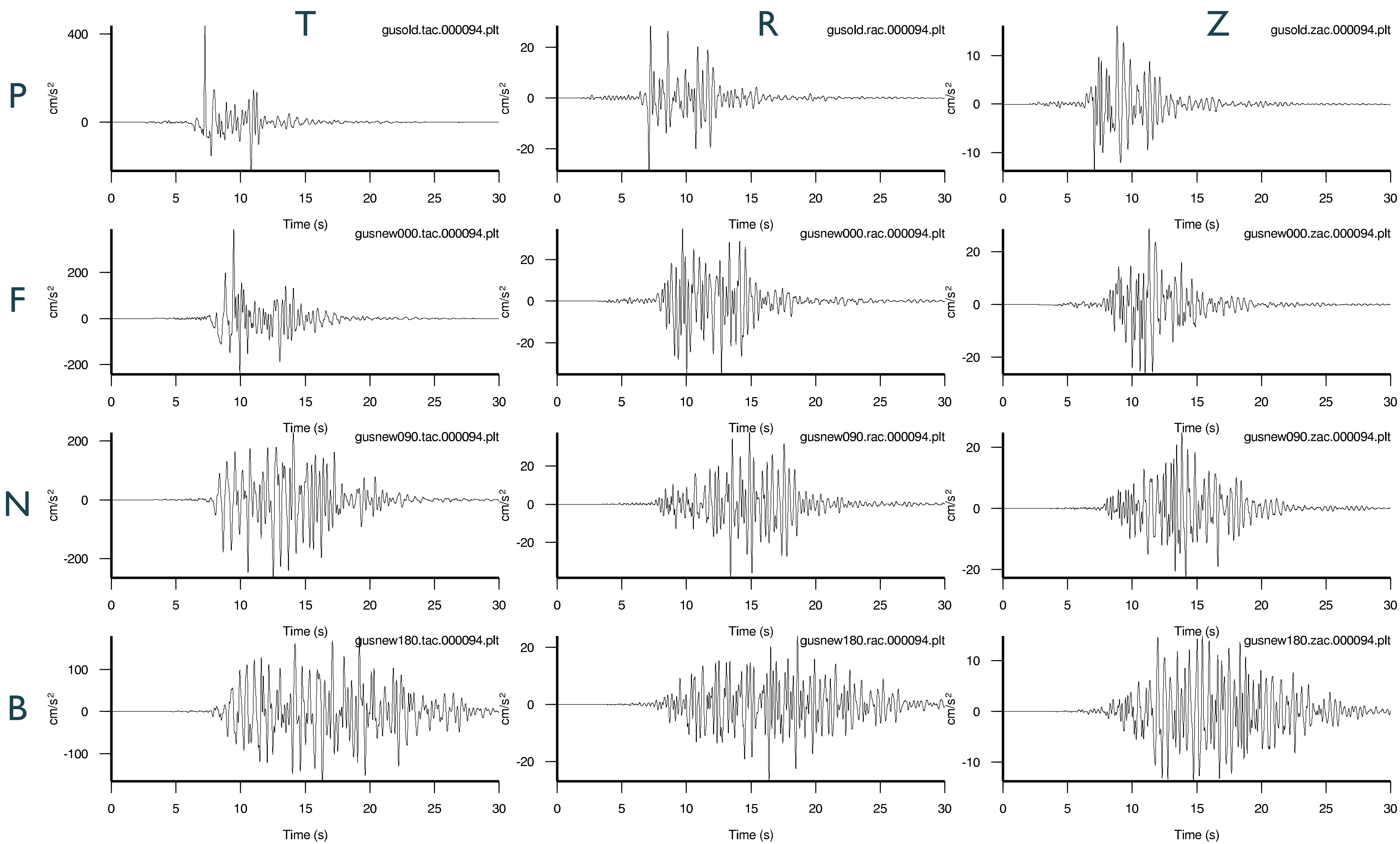






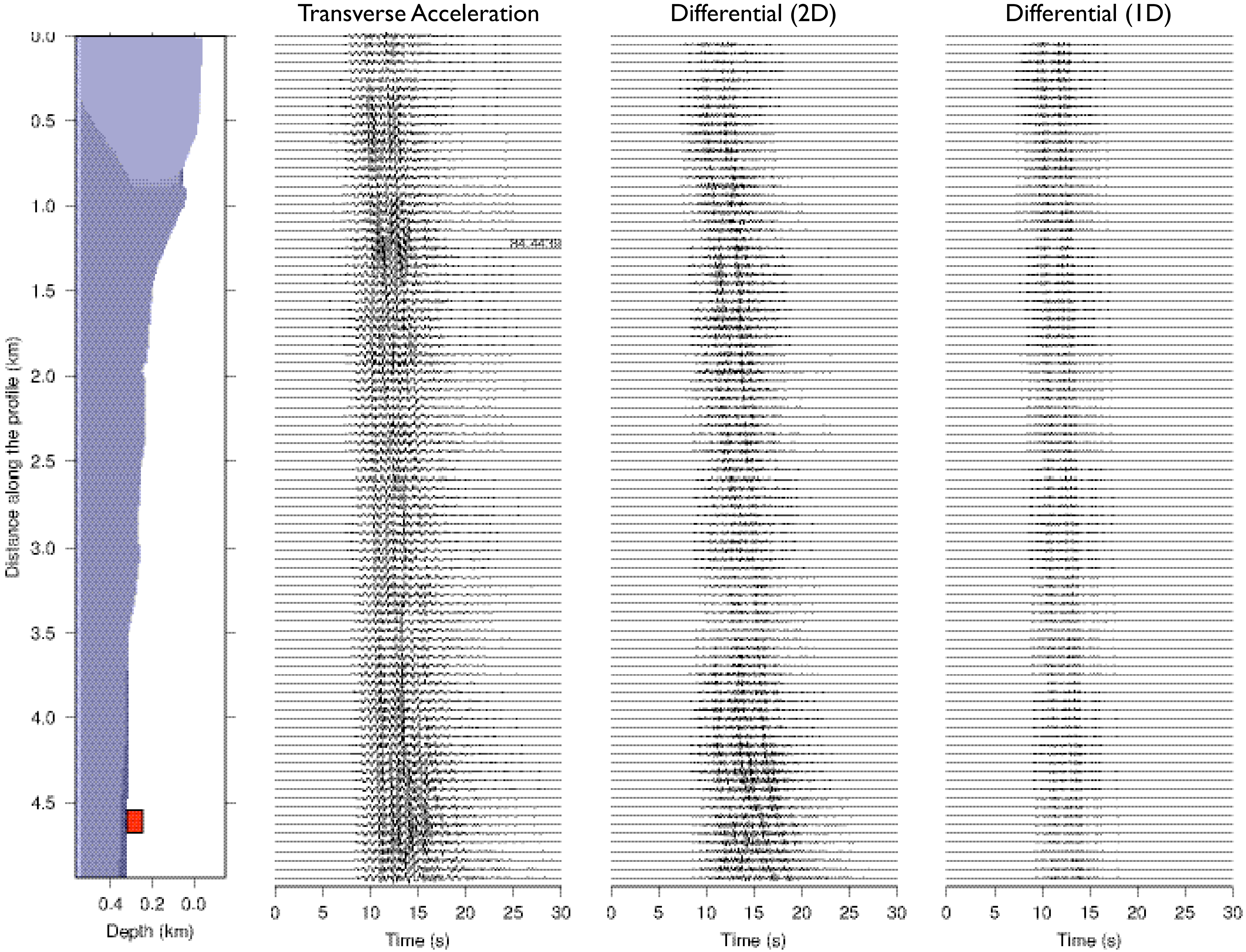
Local Scale - Source Model

- Seismic Source of finite dimension and complicated rupturing process



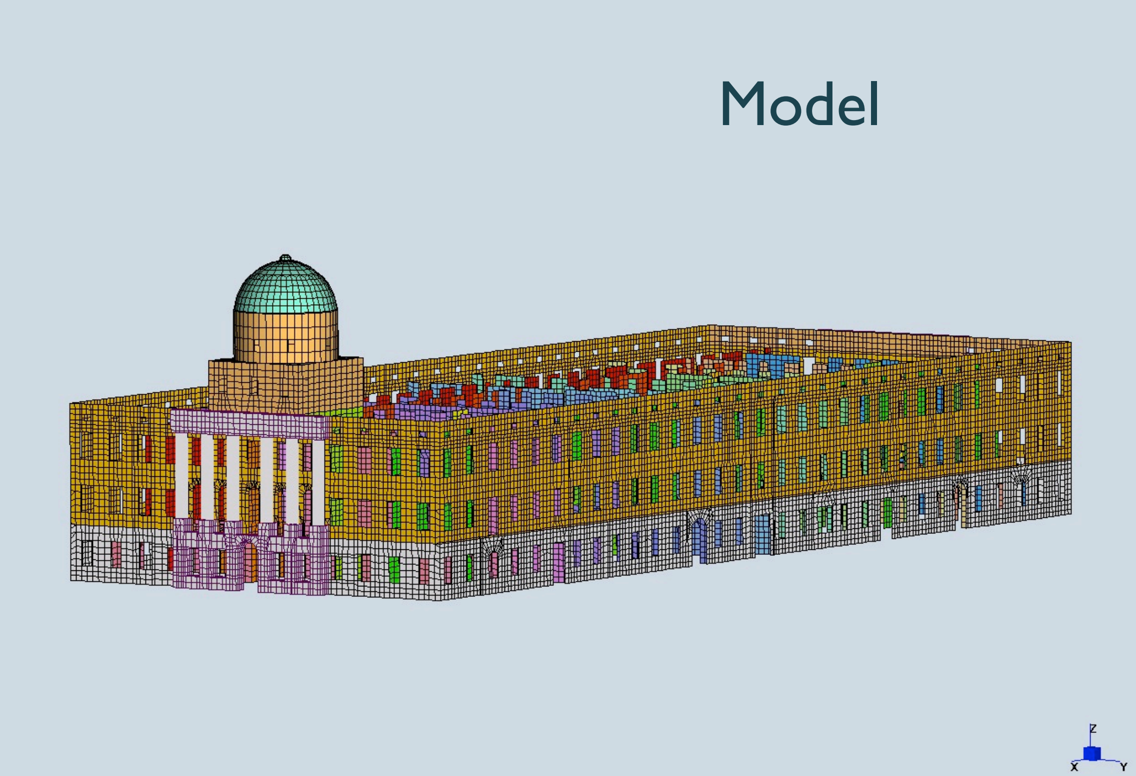
Local Scale - Differential Motion

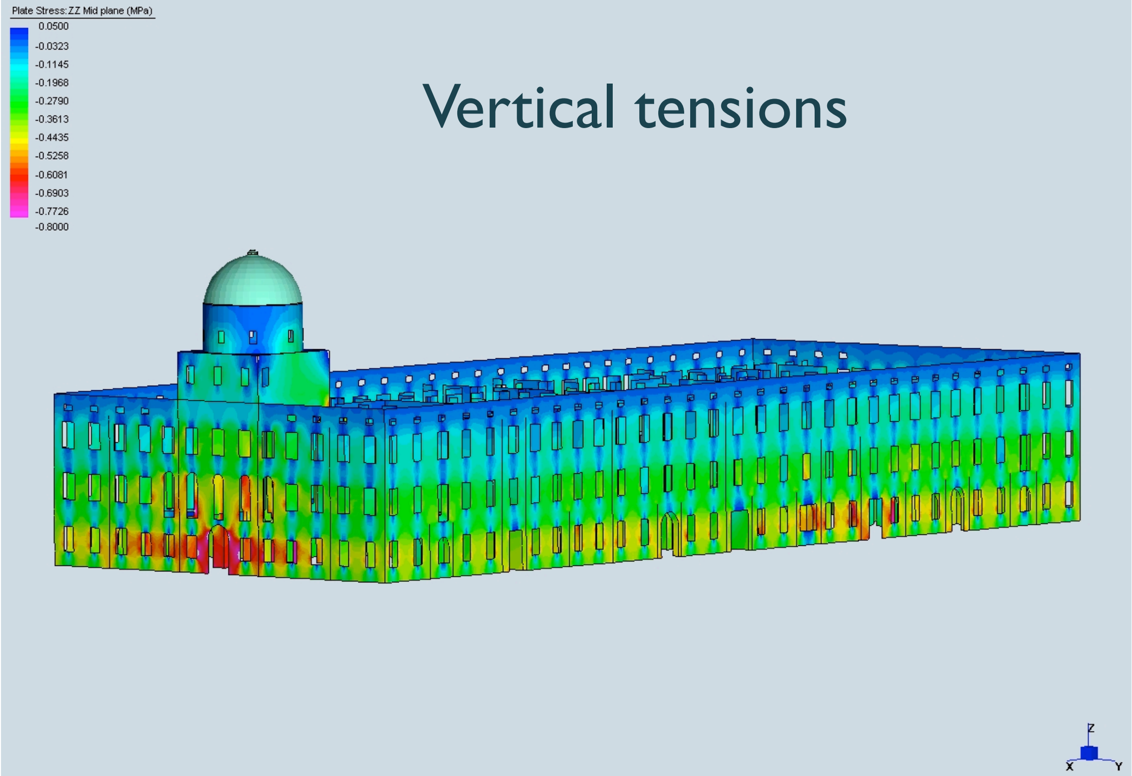
- Significant for elongated structures (bridges, lifelines etc)



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





Then what?

Then what?

- Not fully satisfied with shell scripts

Then what?

- Not fully satisfied with shell scripts
- How to reach the potential adopters?

Then what?

- Not fully satisfied with shell scripts
- How to reach the potential adopters?
- Web application!

Web Application developed in the framework of the Project:
Definition of seismic hazard scenarios and microzoning by means of Indo–European e–infrastructures
Sponsored by Regione Friuli Venezia Giulia
Version 0.16.0 hosted on VacRBook.local, connected from IP 127.0.0.1

UNIVERSITÀ DEGLI STUDI DI TRIESTE

REGIONE AUTONOMA FRIULI VENEZIA GIULIA

eXact

User: [ ] Enter

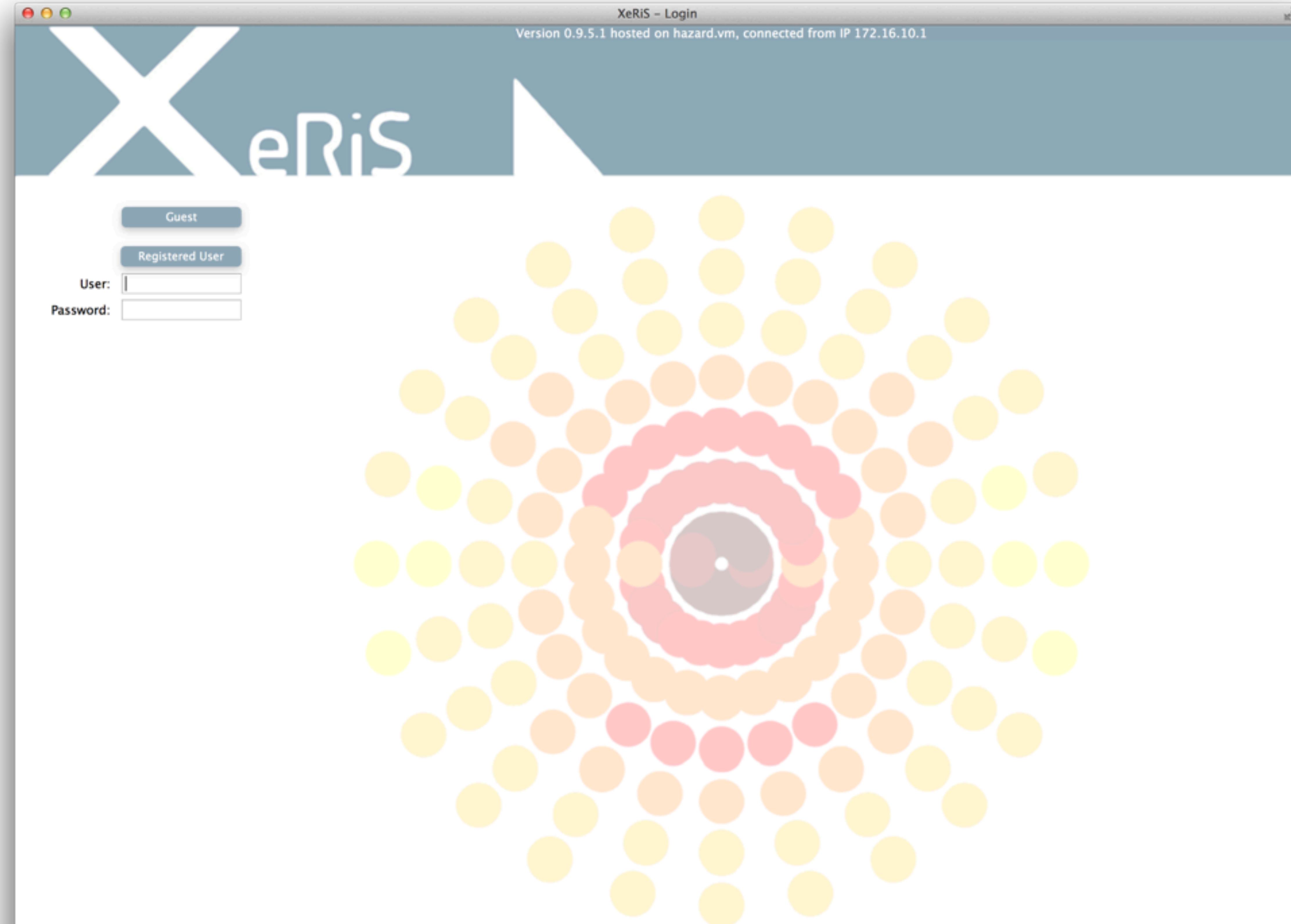
Password: [ ]

The Web Application

See you at the computer exercise session!

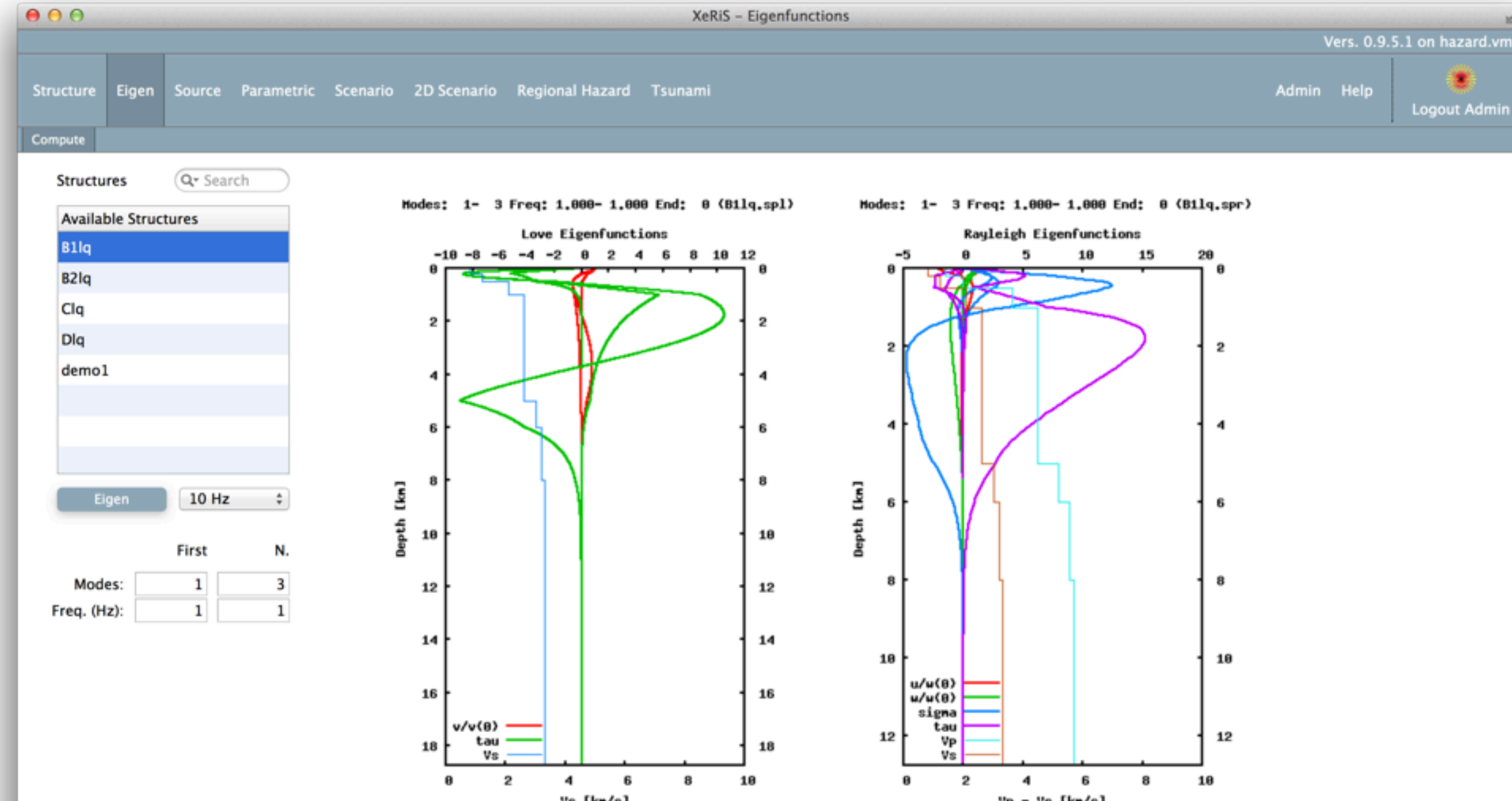
🙂

The Web Application



The Web Application

The Web Application

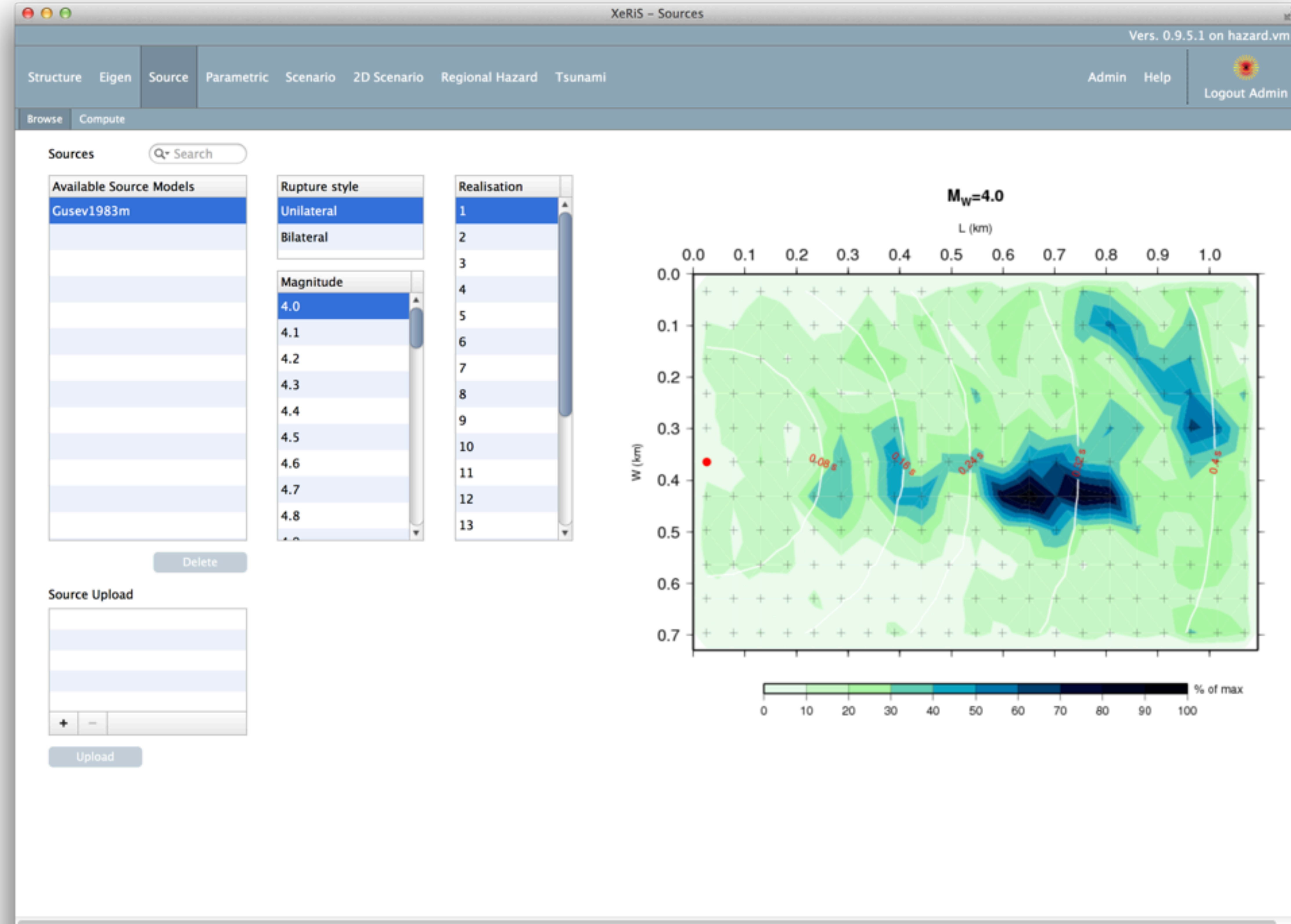


$$u_y^L(x,z,\omega)=\sum_{m=1}^{\infty}\frac{e^{-i3\pi/4}}{\sqrt{8\pi\omega}}\frac{e^{-ik_m x}}{\sqrt{x}}\frac{\left(\chi_m^L(h_s,\omega)\right)}{\sqrt{c_m v_m I_m}}\frac{\left(F_y(z,\omega)\right)}{\sqrt{v_m I_m}}$$

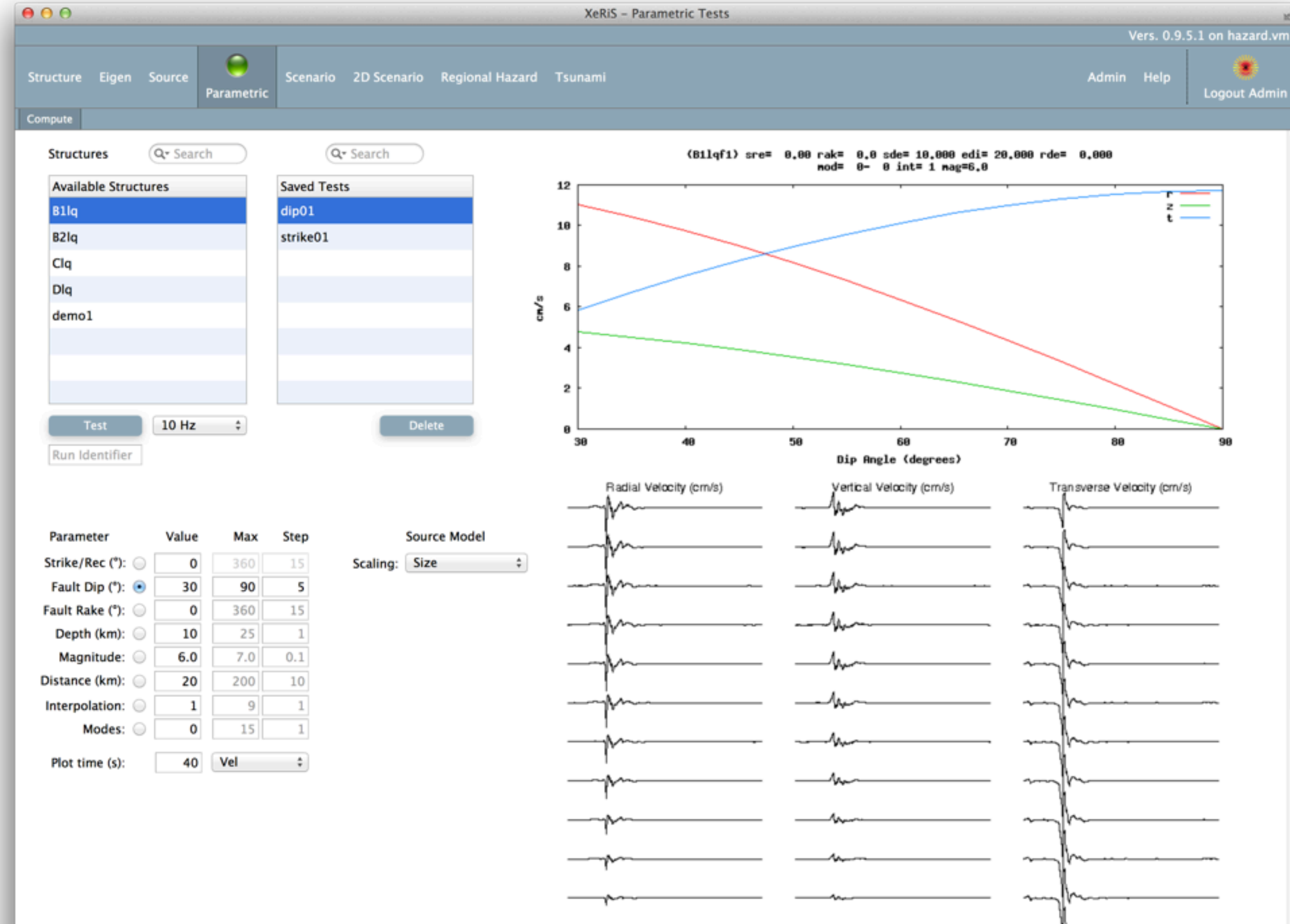
$$u_x^R(x,z,\omega)=\sum_{m=1}^{\infty}\frac{e^{-i3\pi/4}}{\sqrt{8\pi\omega}}\frac{e^{-ik_m x}}{\sqrt{x}}\frac{\left(\chi_m^R(h_s,\omega)\right)}{\sqrt{c_m v_m I_m}}\frac{\left(F_x(z,\omega)\right)}{\sqrt{v_m I_m}}$$

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

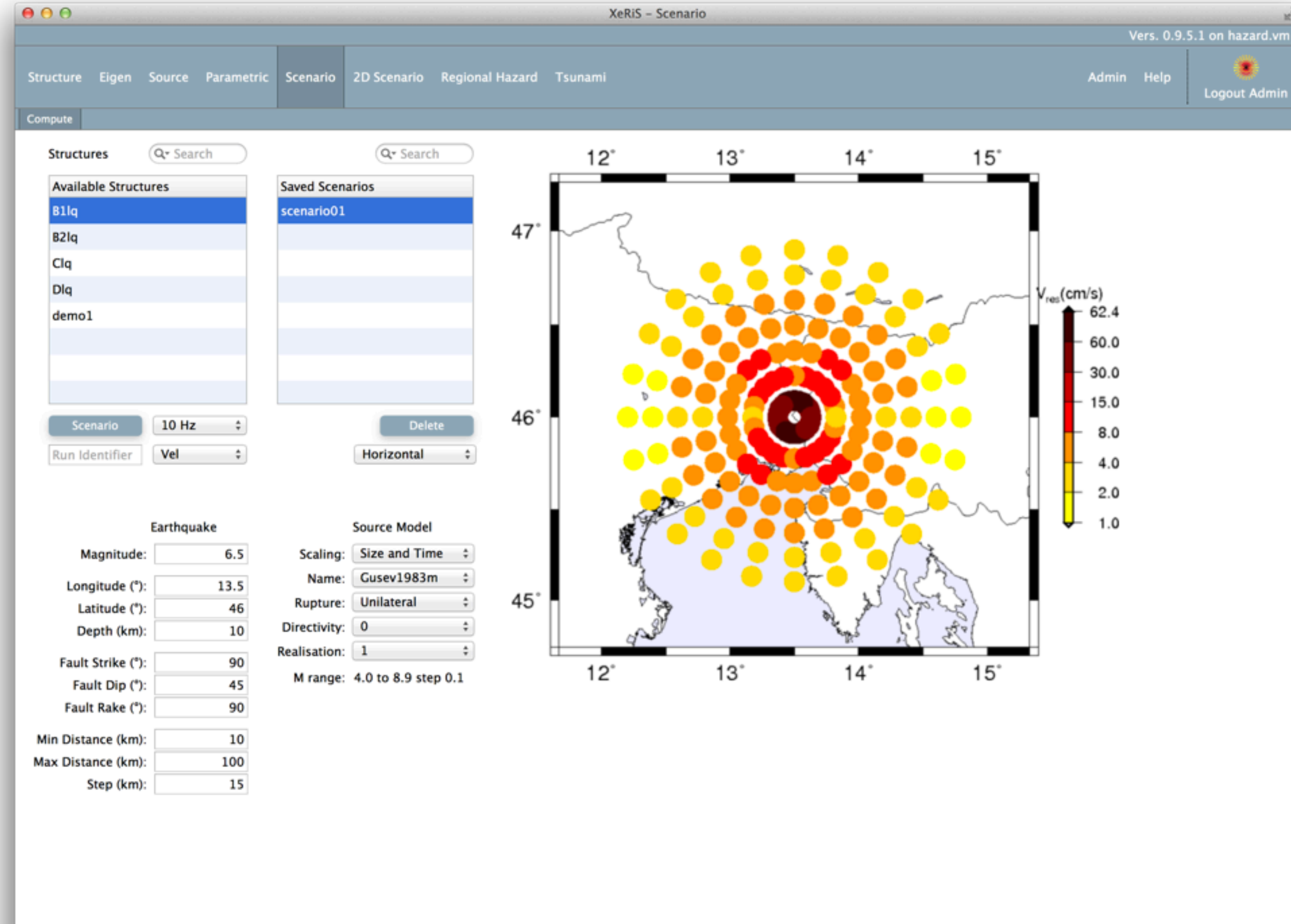
The Web Application



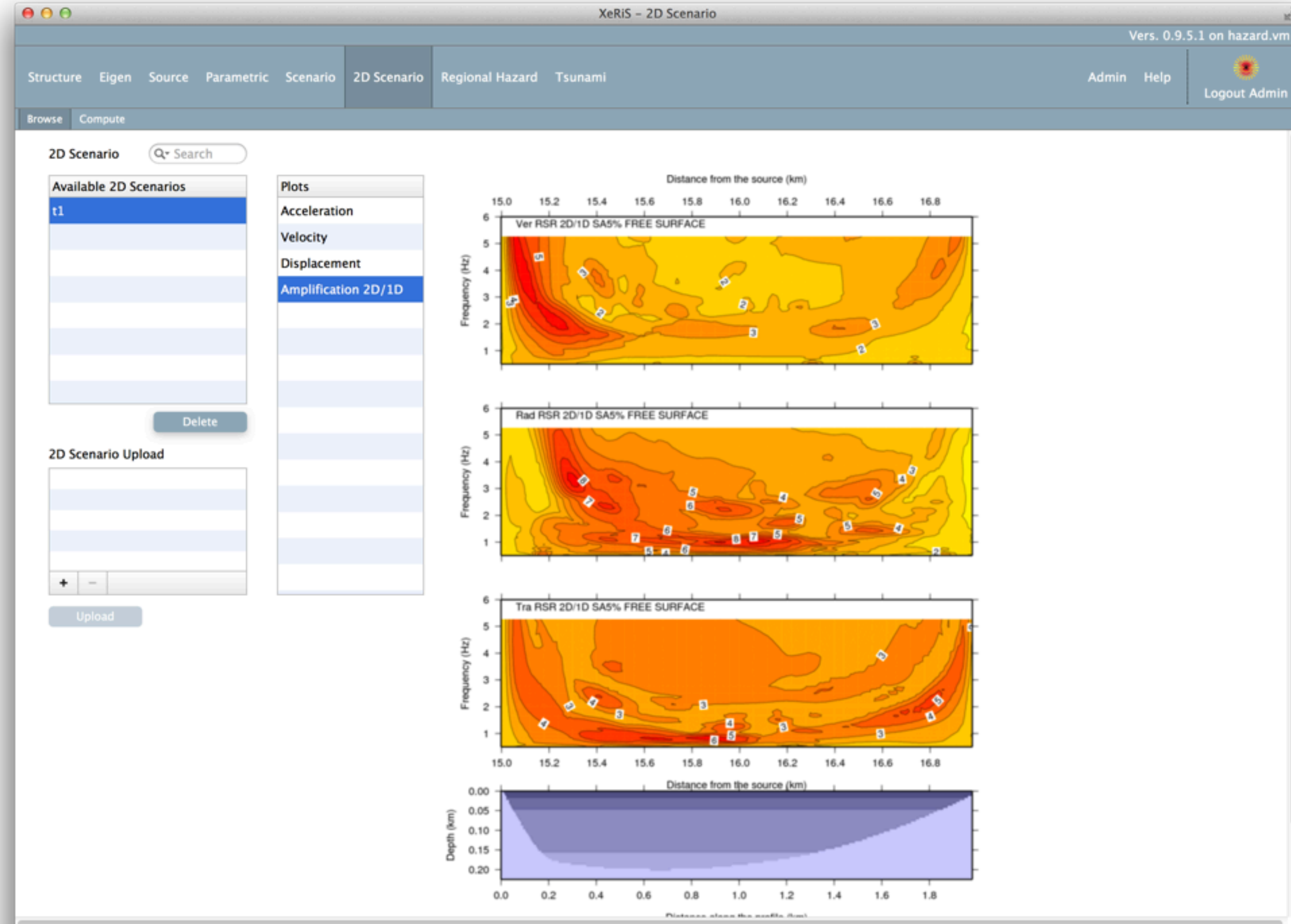
The Web Application



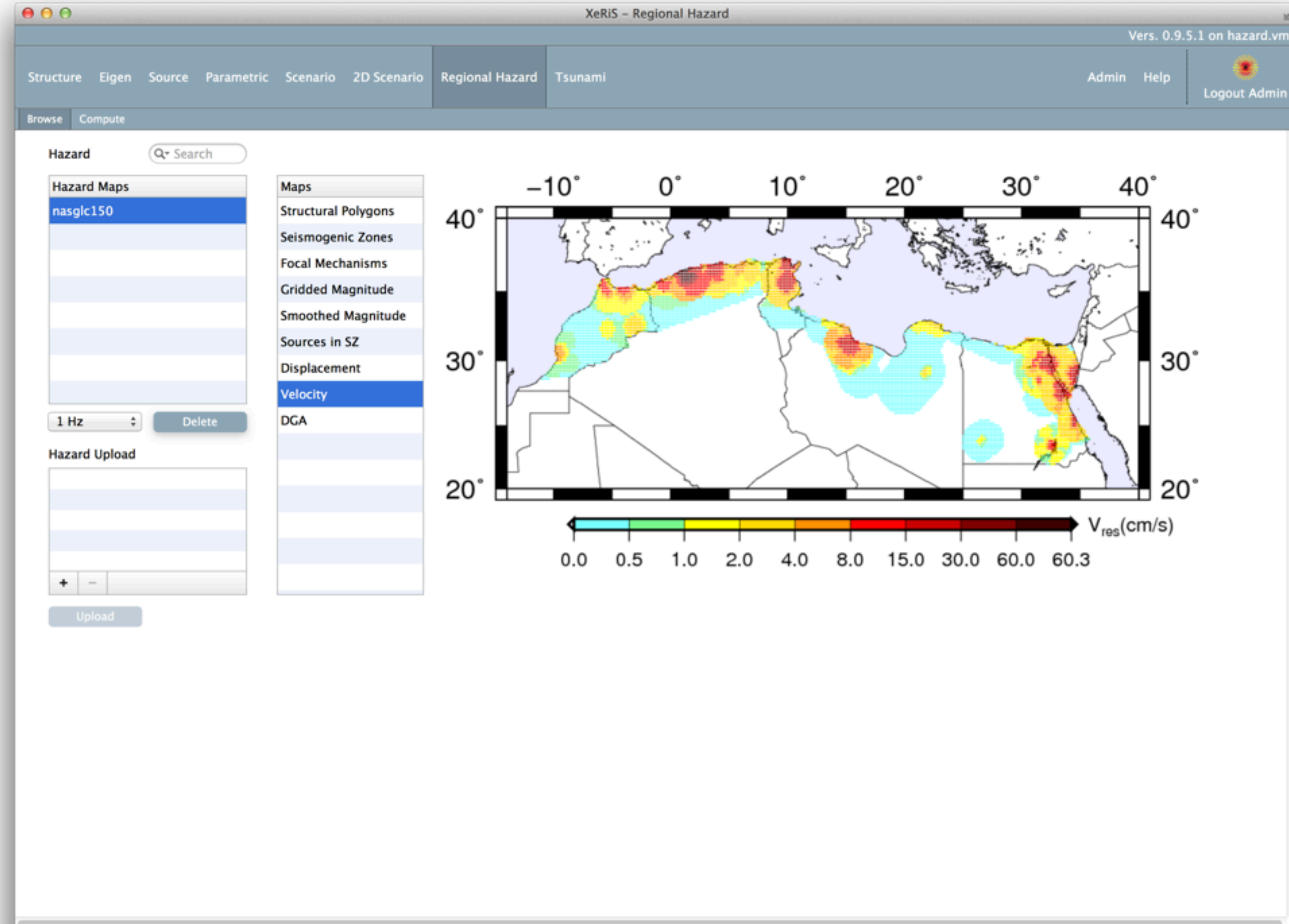
The Web Application



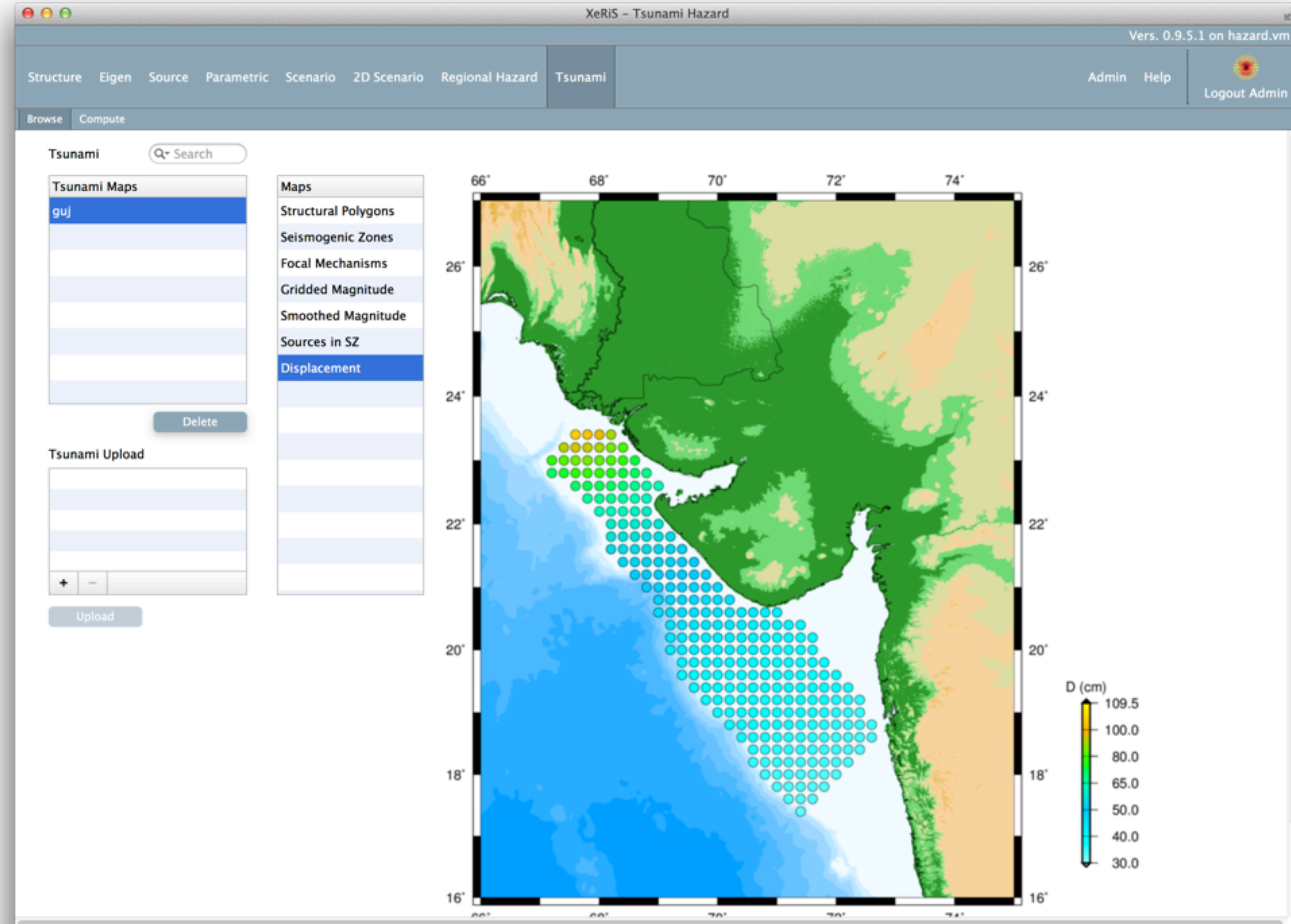
The Web Application



The Web Application



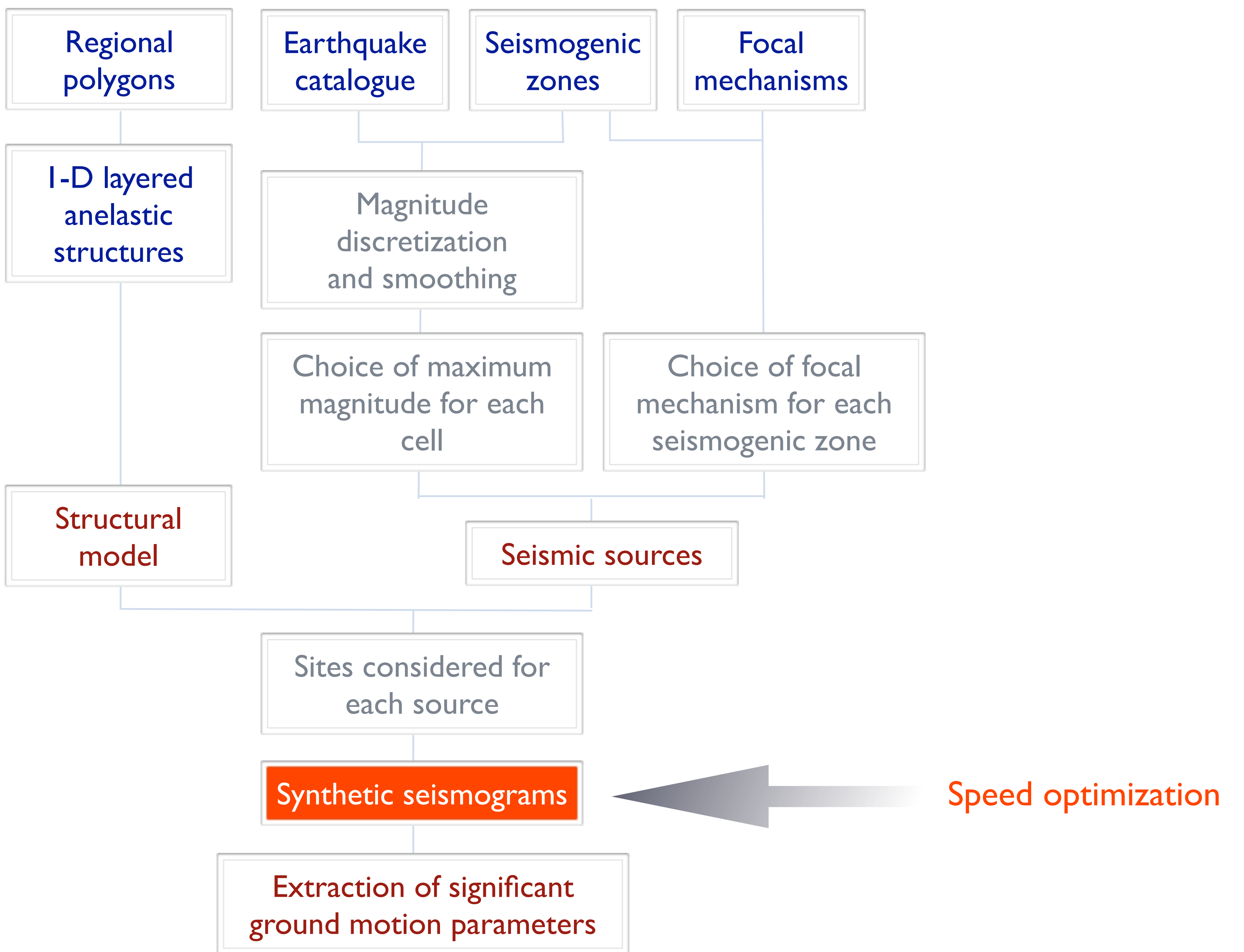
The Web Application



Computational tasks

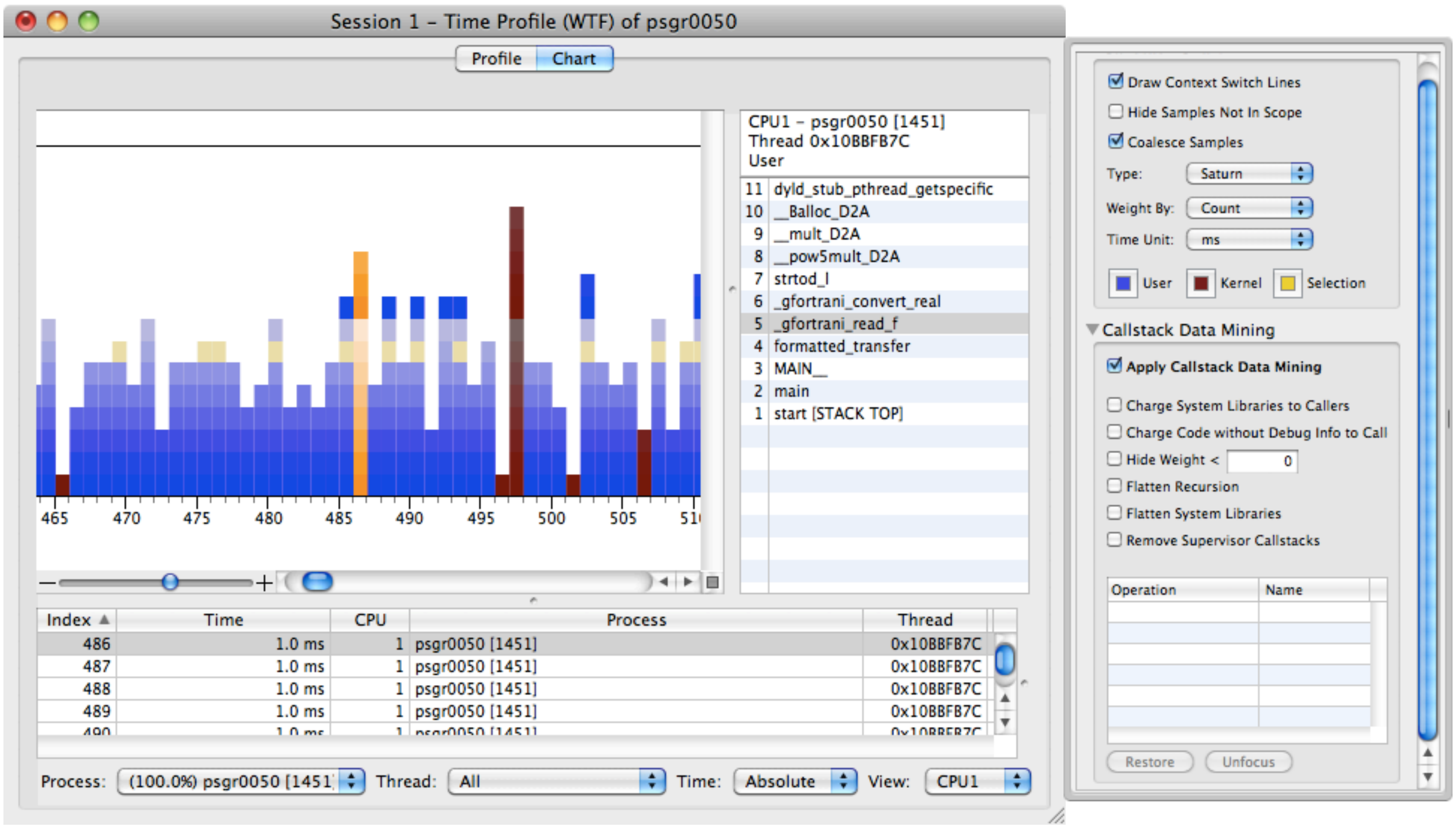
- Optimization
  - Identification of critical package programs
  - Identification of hot spots within programs
- Porting to grid or cloud infrastructure
  - Parametric runs
  - Data management

Flow chart of the package - Optimization



Optimization - Profiling

2011/04/15	13:01:55	esgr0050	computing	74 seismograms for structure n. 1 (index 0010)
2011/04/15	13:02:14	esgr0050	radial components computed and rotated to NS and EW	
2011/04/15	13:02:14	esgr0050	OK - Execution terminated	



Optimization - Seismogram computation

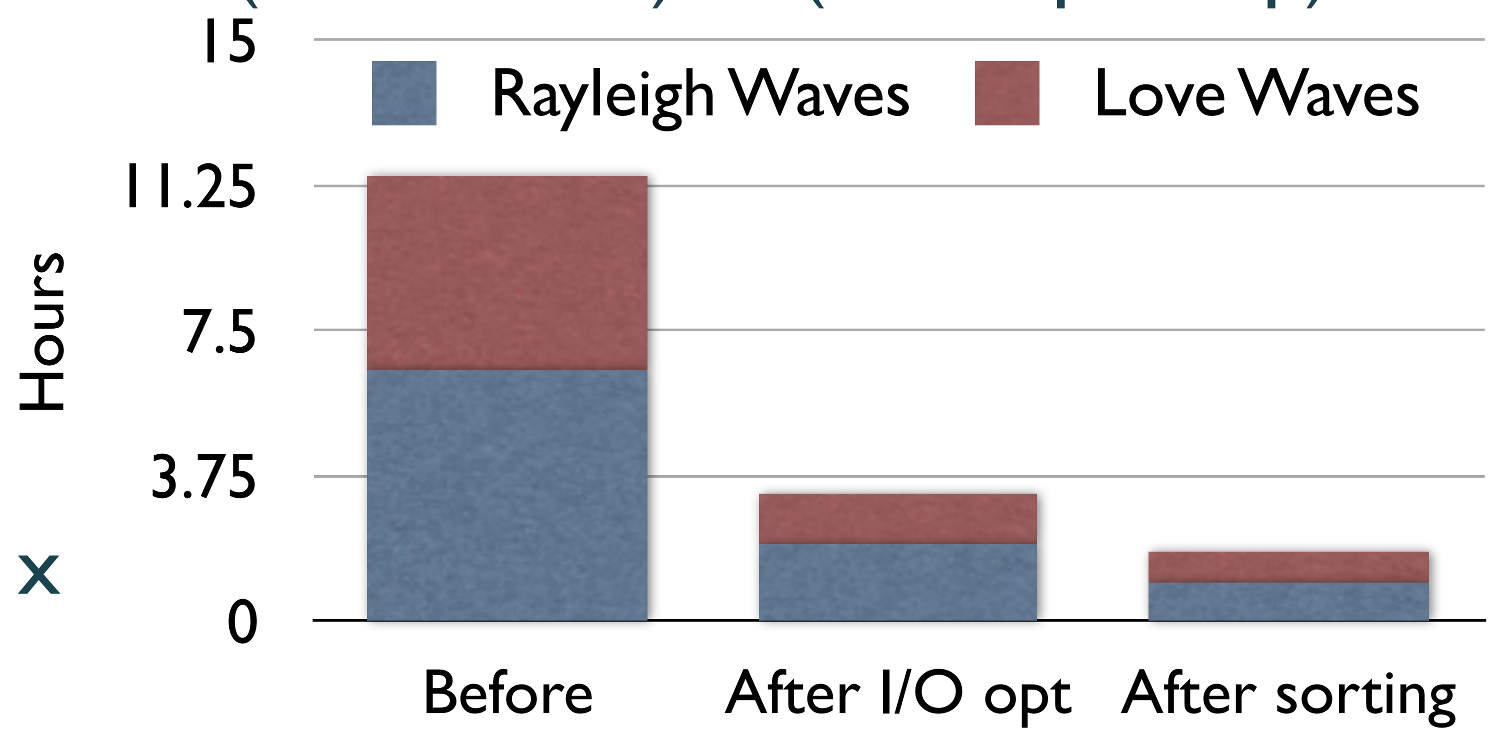
- Removed repeated formatted disk I/O, defined new arrays instead

6.5 hours → 2 hours (Rayleigh waves) (3.25 x speedup)
5 hours → 1.3 hours (Love waves) (3.8 x speedup)

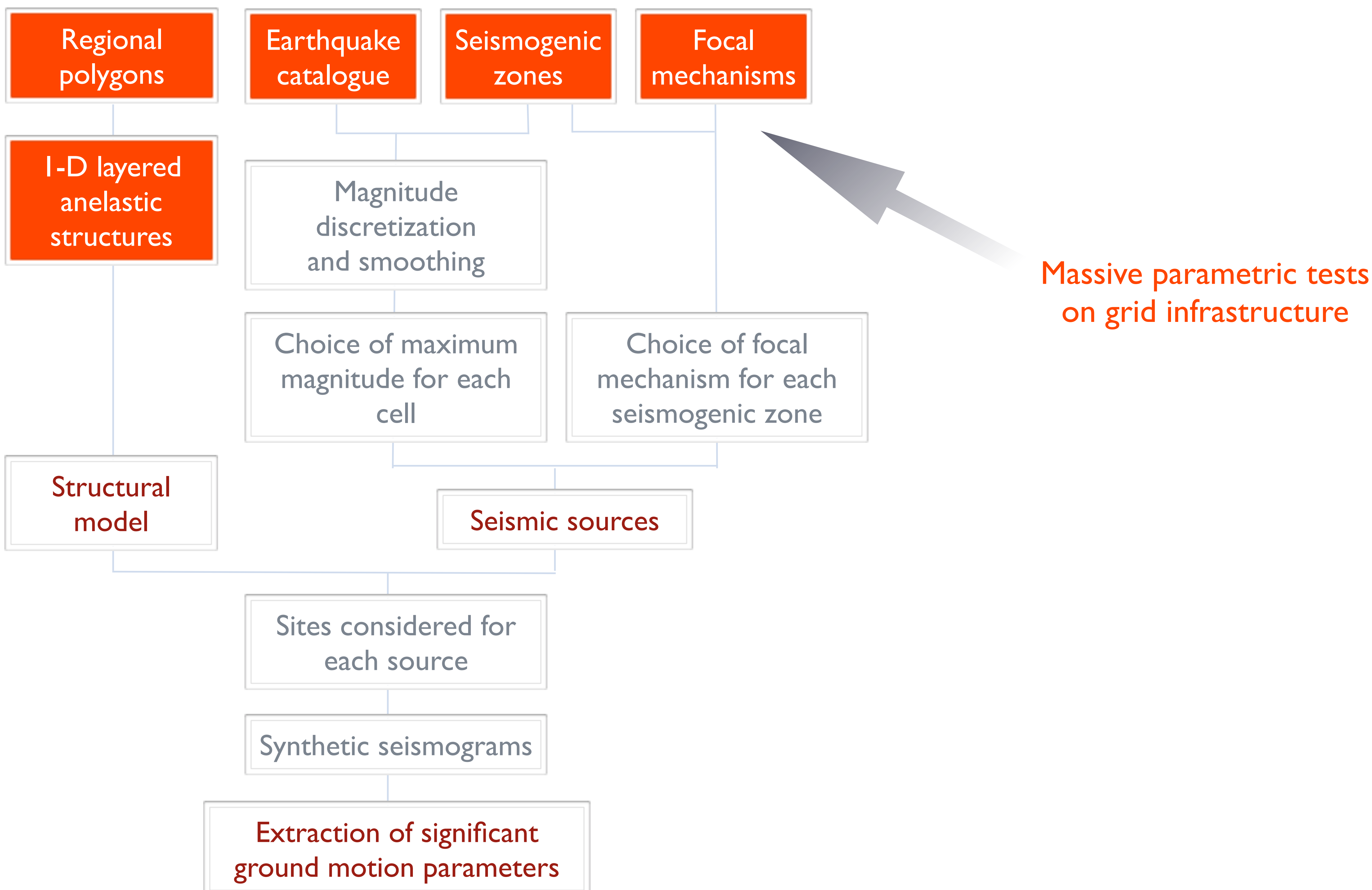
- Tested further optimization: sorting seismograms by source depth

2 hours → 1.0 hours (Rayleigh waves) (2.0 x speedup)
1.3 hours → 0.8 hours (Love waves) (1.6 x speedup)

- Total speedup: ~6.5 x



Flow chart of the package - Grid



Project tasks - Grid

- Add to the package a FORTRAN program that perturbs the properties of the earthquake source (orientation and depth, four parameters changed in loops)
- Prepare a shell script to generate as many JDL scripts as the combinations of parameters are, and submits all the combinations to the grid in a single command
- Improve the job submission
- Manage data retrieval

Further possible optimization...

- Vectorization and parallelization
  - FFT routines
  - modal summation technique

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

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

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

source | structure | receiver

The Web Application

See you at the computer exercise session!