# Neo-deterministic Seismic Hazard Assessment

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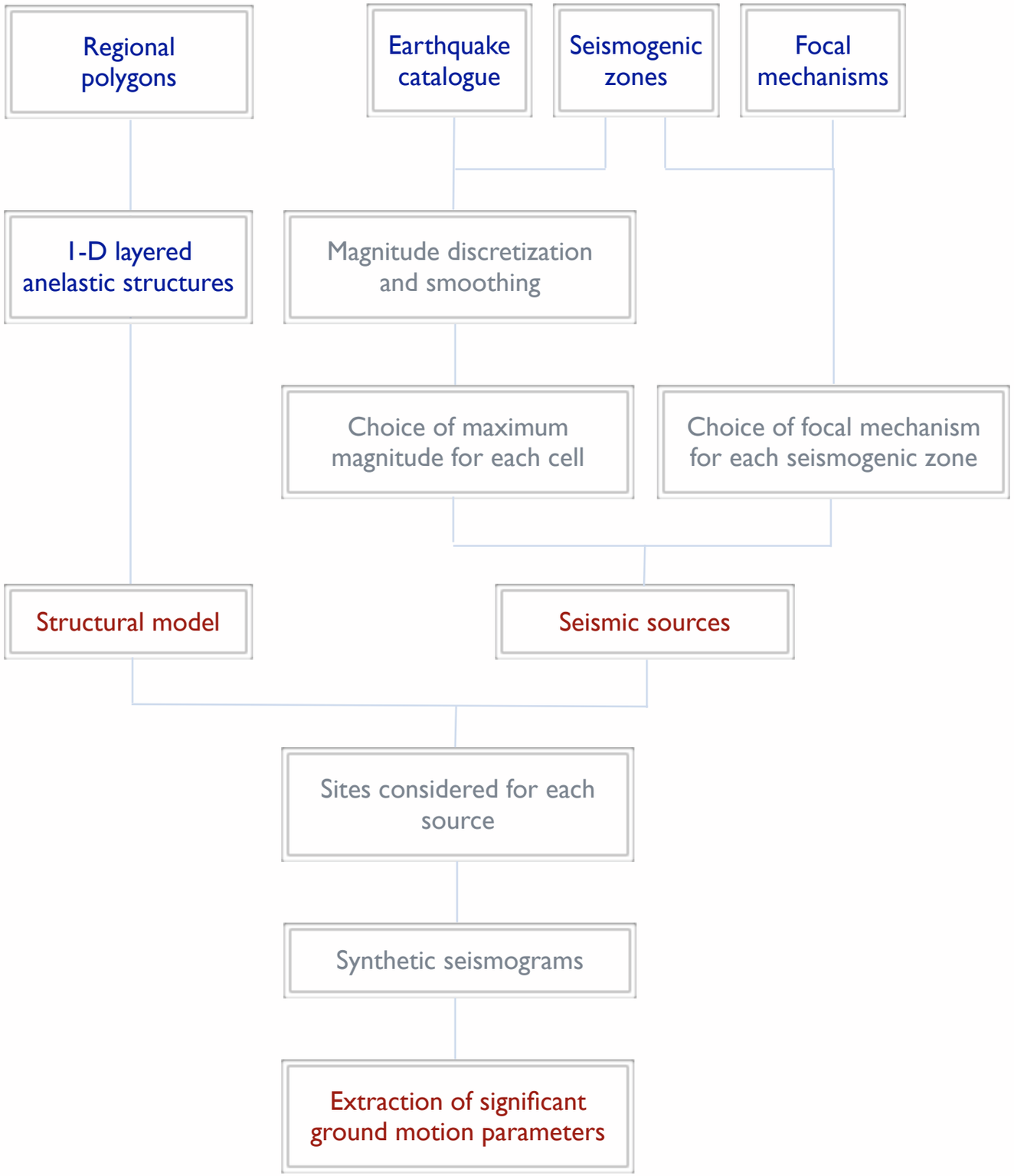
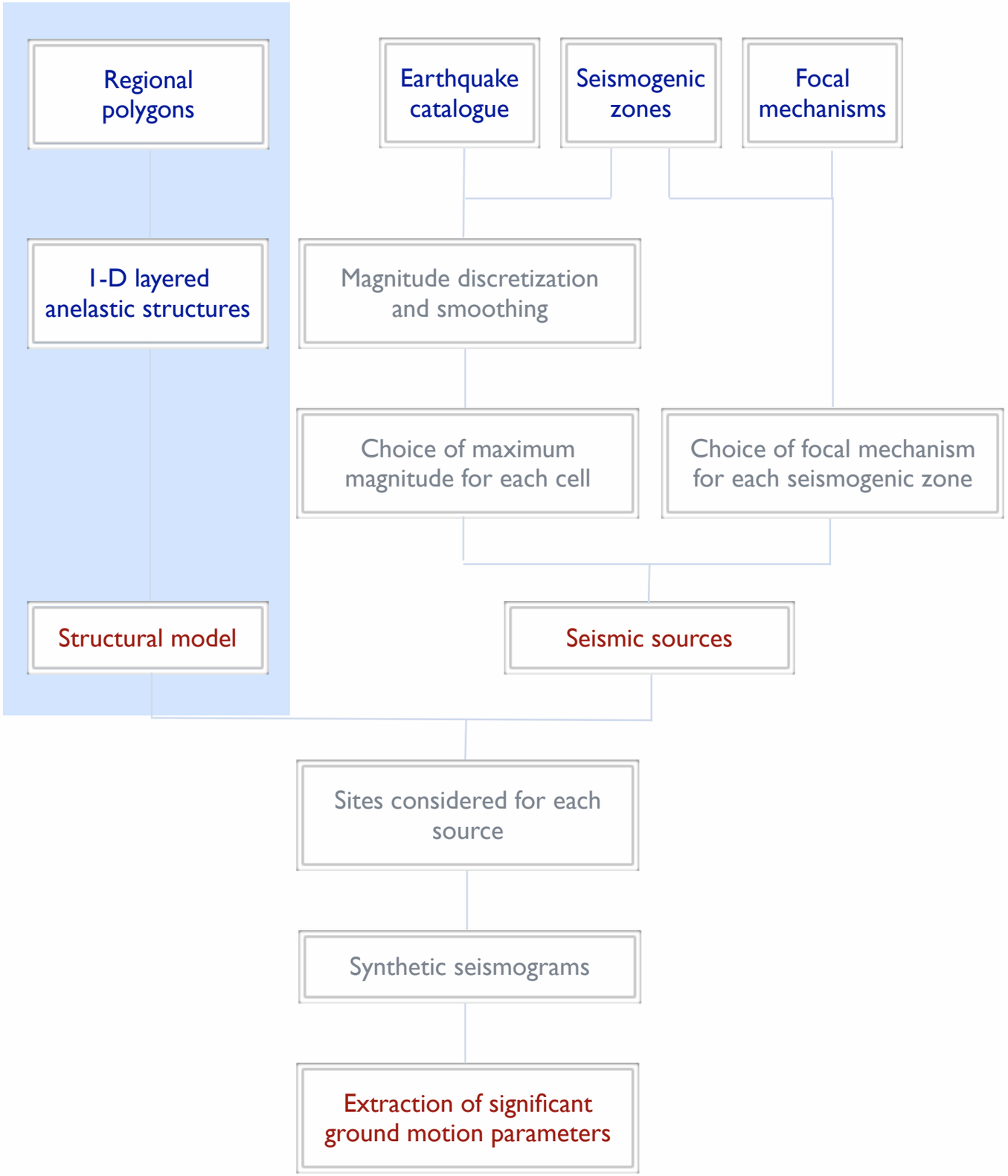
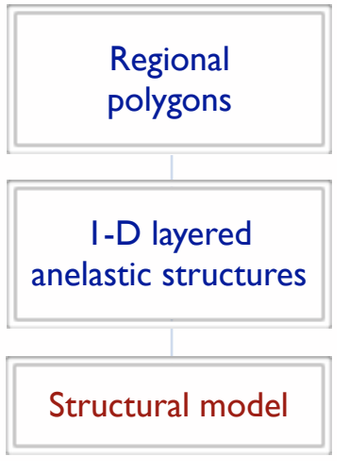
# Regional scale - Flow chart



# Regional scale - Structural model



# Regional scale - Structural model



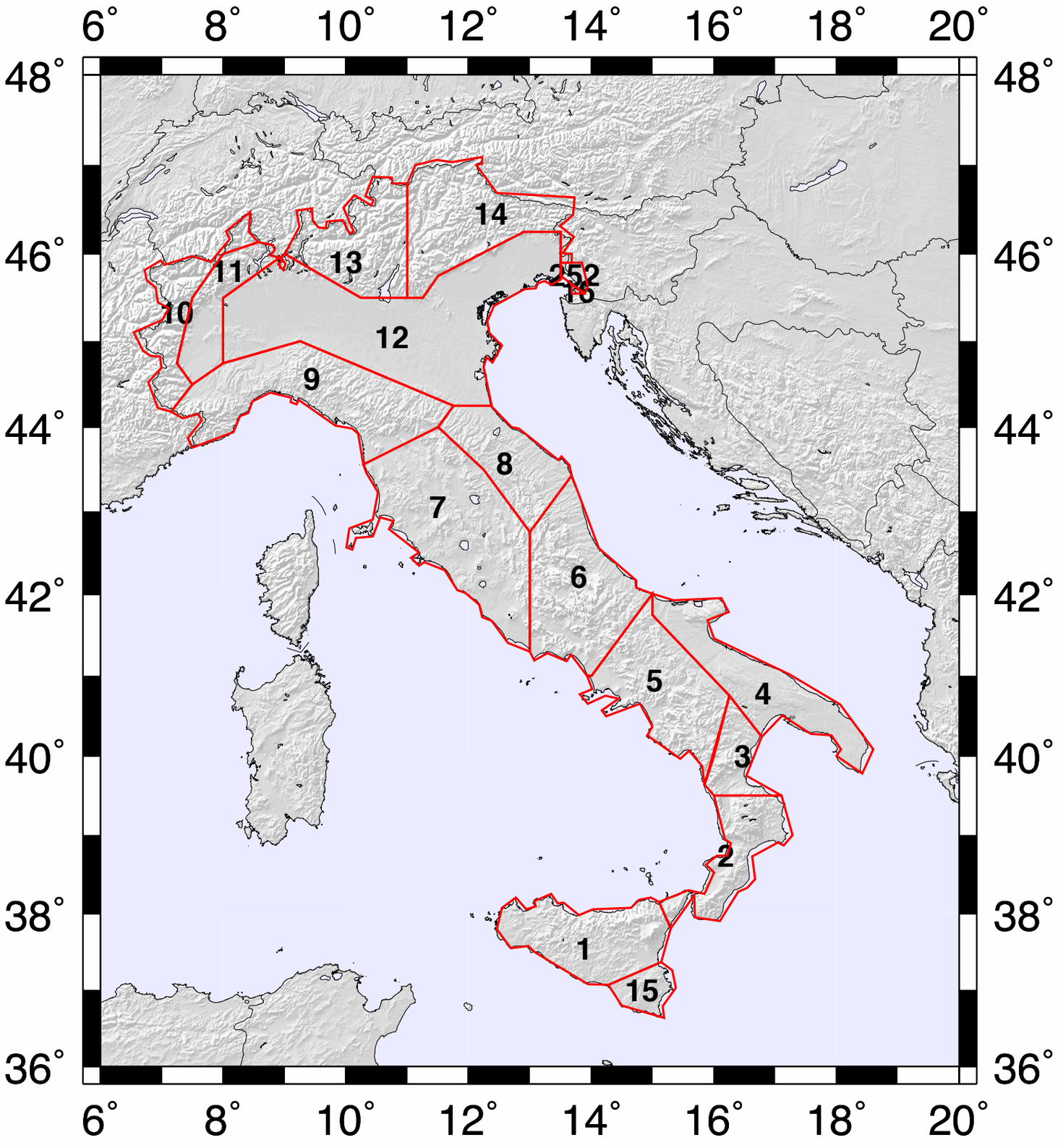
# Regional scale - Structural model

- 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
```

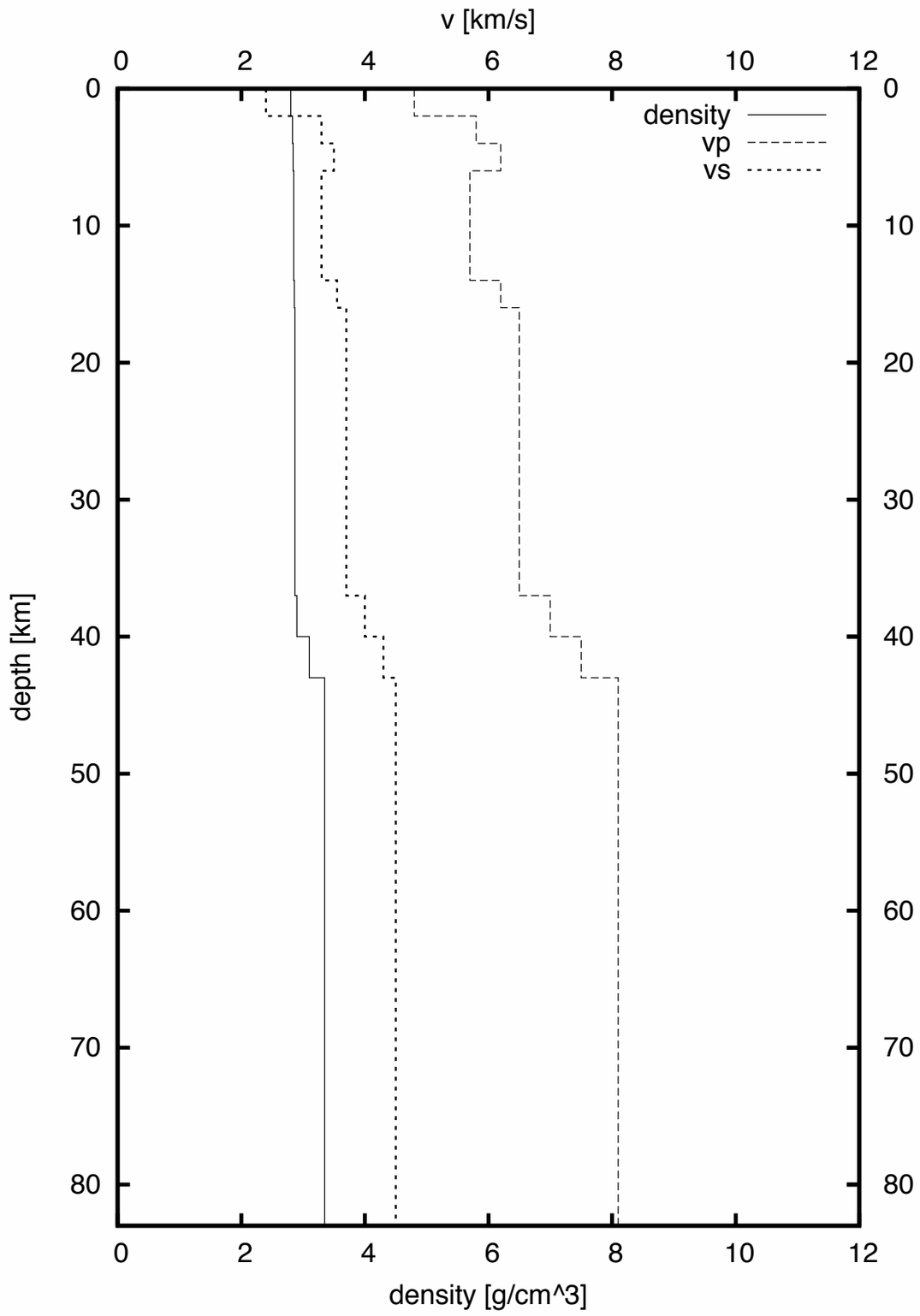
# Regional scale - Structural model

- Regional polygons
- 1-D layered anelastic structures
- Structural model



# Regional scale - Structural model

- Regional polygons
- 1-D layered anelastic structures
- Structural model



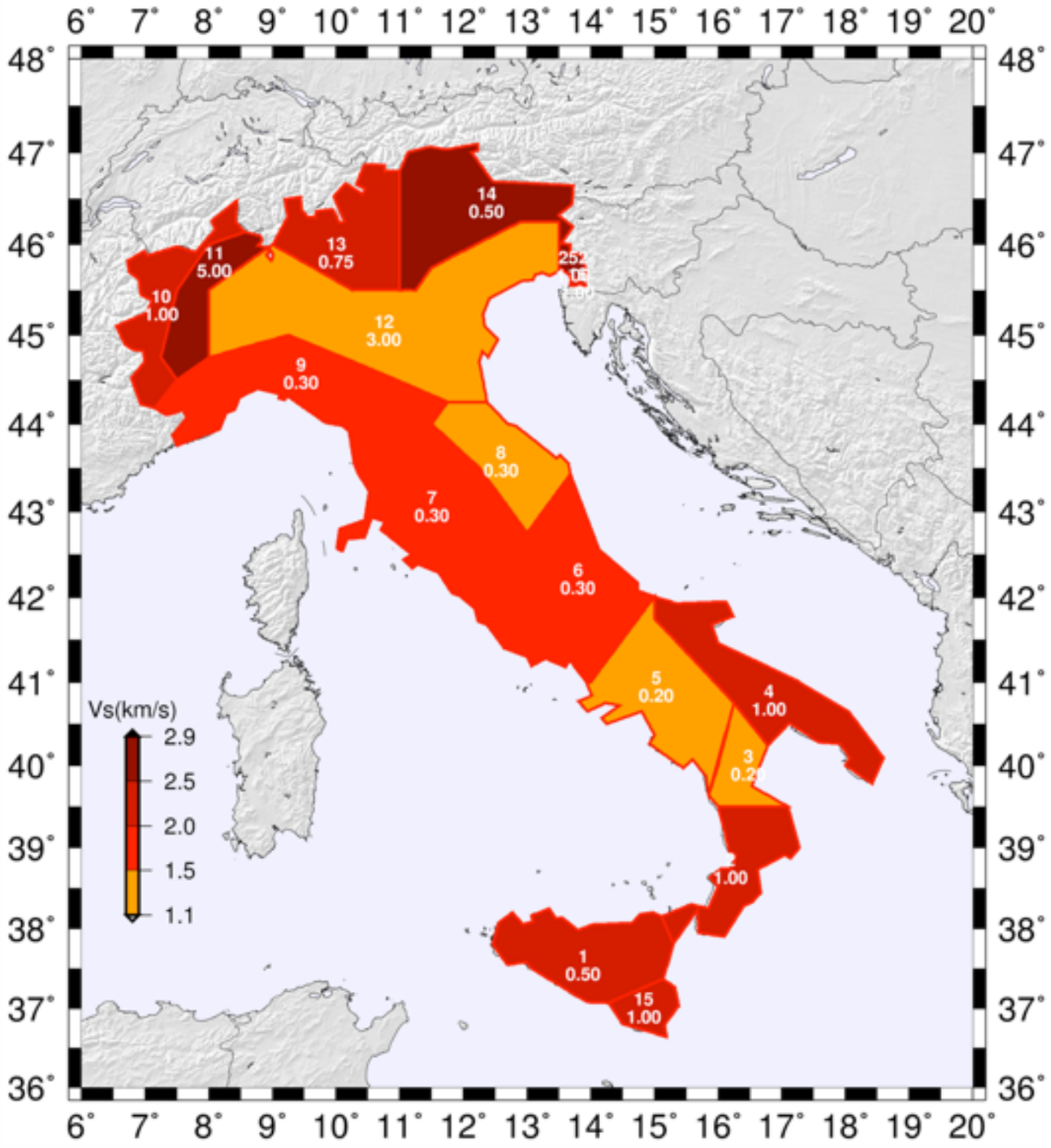
# Regional scale - Structural model

- Regional polygons
- 1-D layered anelastic structures
- Structural model

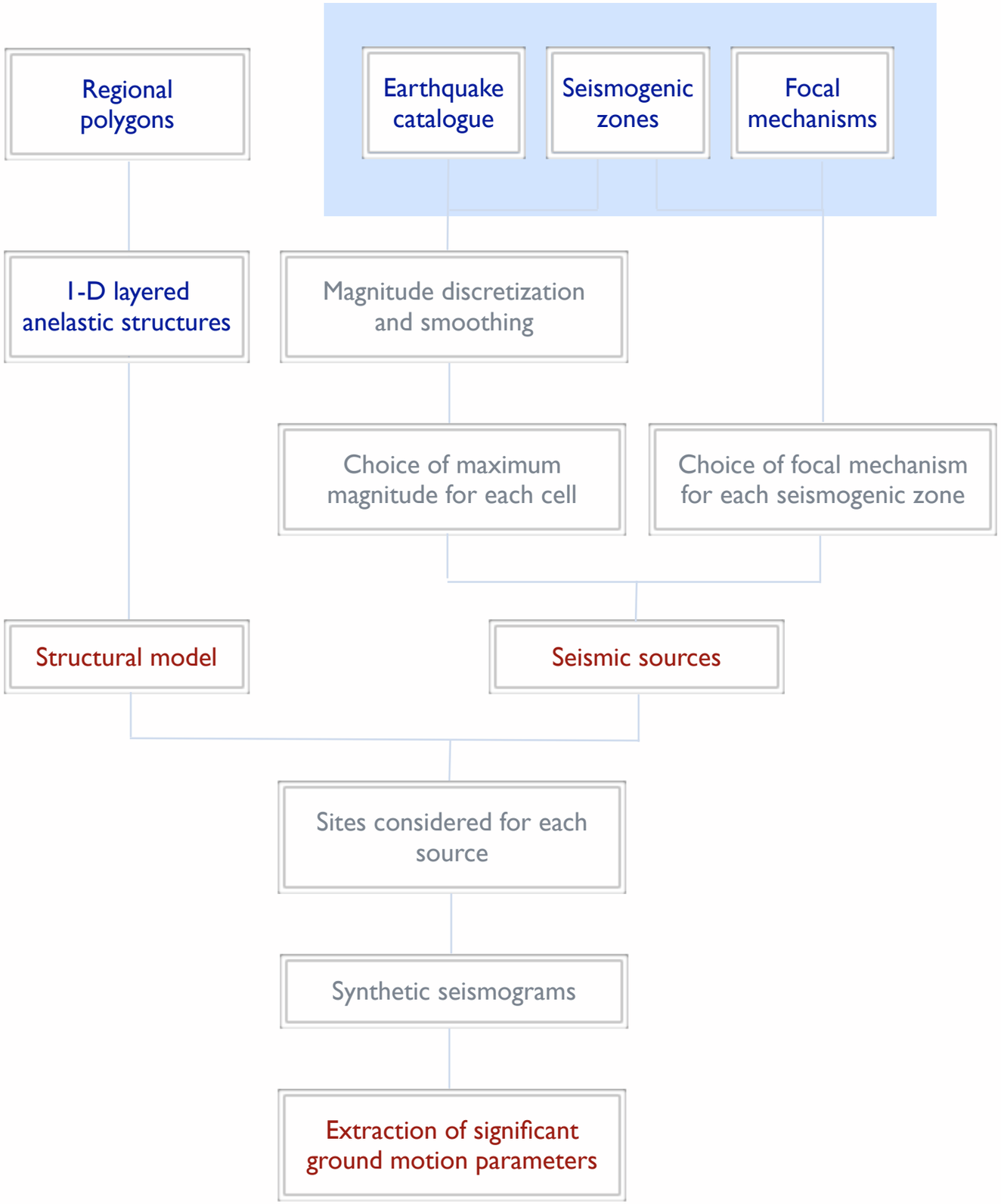
| thk(km) | rho | Vp(km/s) | Vs(km/s) | Qp | Qs | depth(km) | layer |
|---|---|---|---|---|---|---|---|
| 0.5000 | 2.300 | 3.800000 | 2.200000 | 660.00 | 300.00 | 0.50000 | 1 |
| 0.5000 | 2.300 | 3.900000 | 2.250000 | 660.00 | 300.00 | 1.00000 | 2 |
| 1.0000 | 2.450 | 4.000000 | 2.300000 | 660.00 | 300.00 | 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

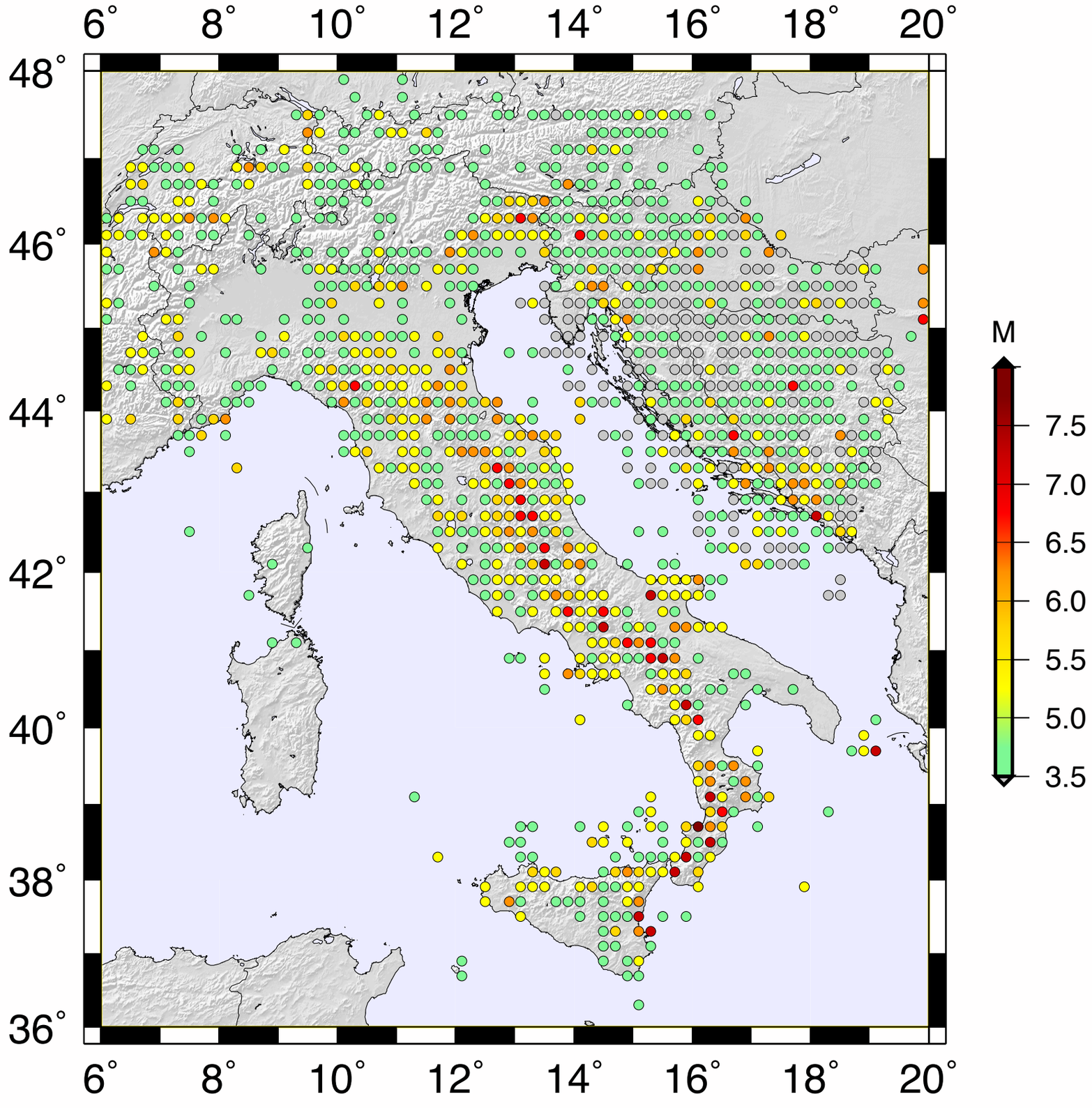
```
1005 0 0 0 0 0 4347  1188  0520520  05200
1005 0 0 0 0 0 4150  1375  0520520  05200
1065 32711 0 0 4553  1022  0520520  05200
1087 9 0 0 0 0 4125  1560  0500500  05000
1097 0 0 0 0 0 4560  1530  0620620  06200
1117 1 313 0 0 4545  1104  0640640  06400
1120 0 0 0 0 0 4142  1387  0550550  05500
11251011 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

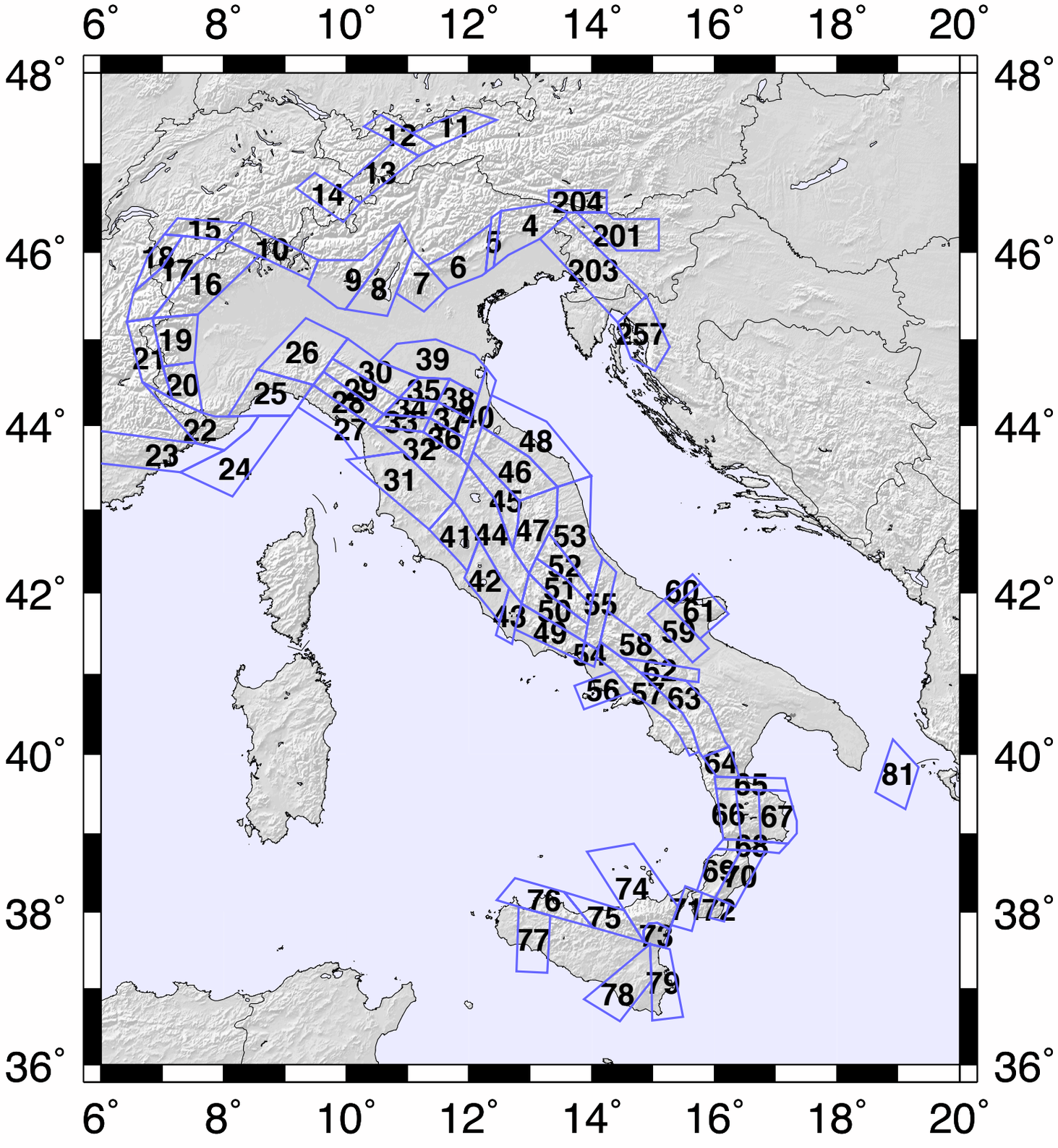
```
Polygons that define seismogenic zones (lon,lat)
seismo0257
                15.278  44.918
                15.036  44.635
                14.644  44.783
                14.422  45.193
                14.890  45.500
seismo0004
                12.520  46.468
                13.300  46.550
                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

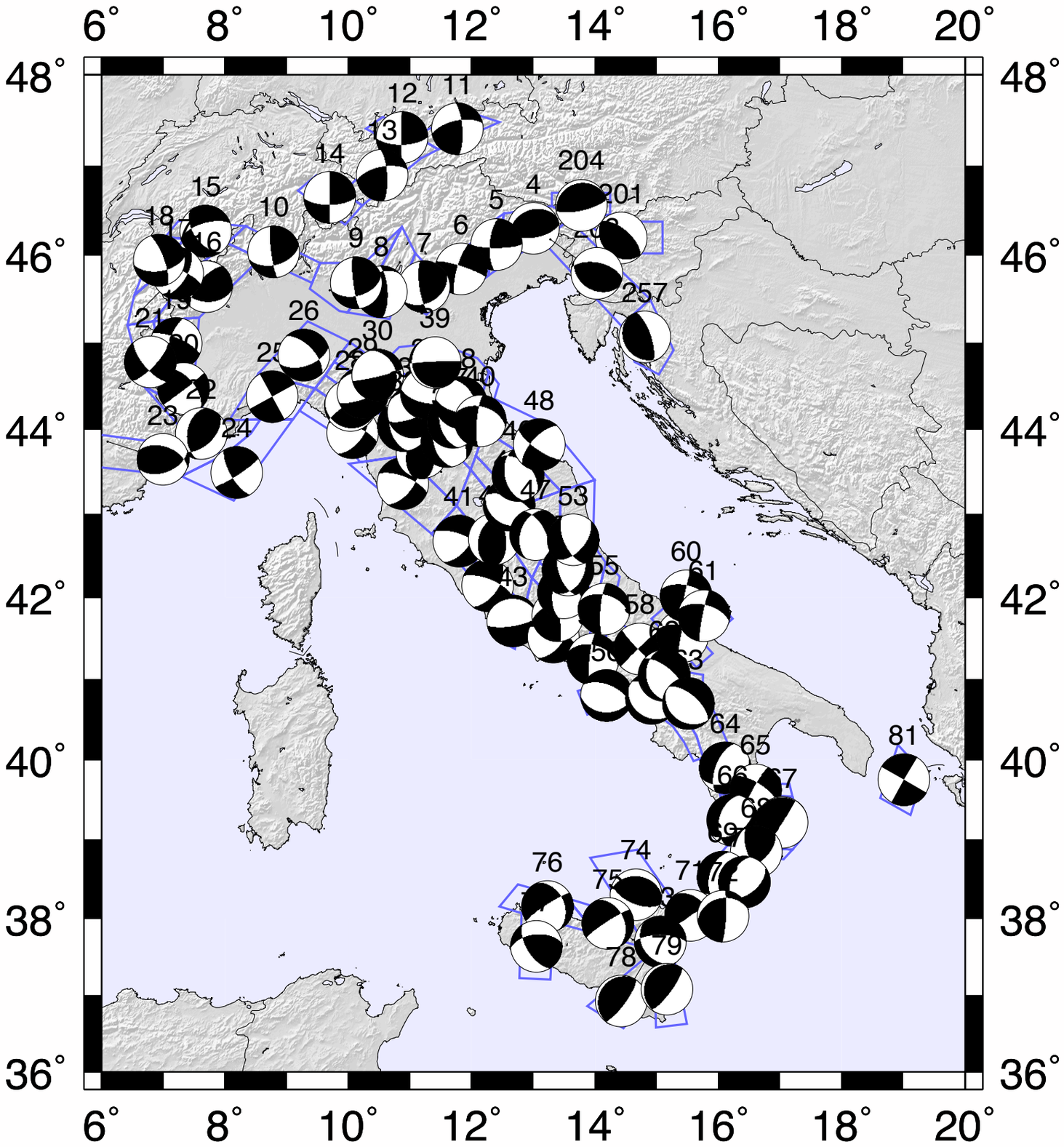
```
-------------------- FPGNDT.DAT --Revised- July 1, 1977 -----------------------
NUMBEA YEARMODY HRMISEC LA.TITN LON.GITE DEPT MLMDMSMBMA AGEN AREADESCRI
NUMBEF ST1 D1 RA1  ST2 D2 RA2   PDI PI  TDI TI  BDI BI Q REFE AREADESCRI
NUMBEM M00 SF REFE DURA F2 M0XX ER1 M0YY ER2 M0ZZ ER3 M0XY ER4 M0XZ ER5 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
...
...
...
```

# Regional scale - Sources

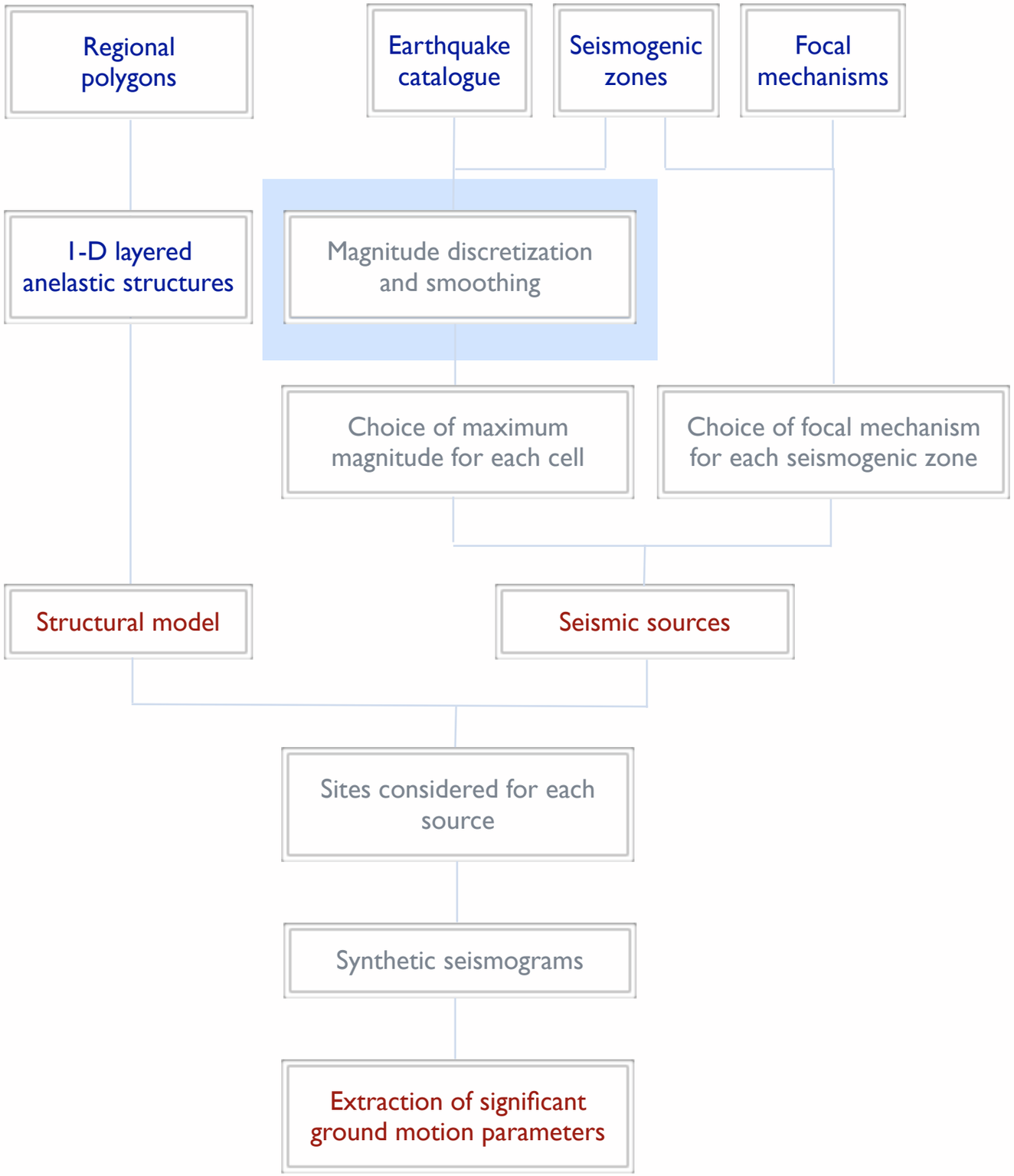
Earthquake catalogue

Seismogenic zones

Focal mechanisms

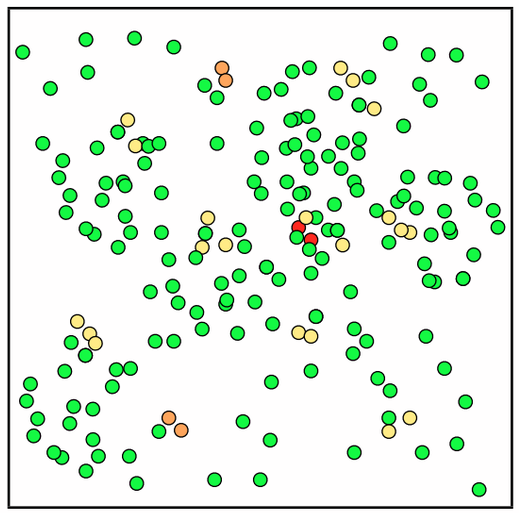


# Regional scale - Sources



# Regional scale - Sources

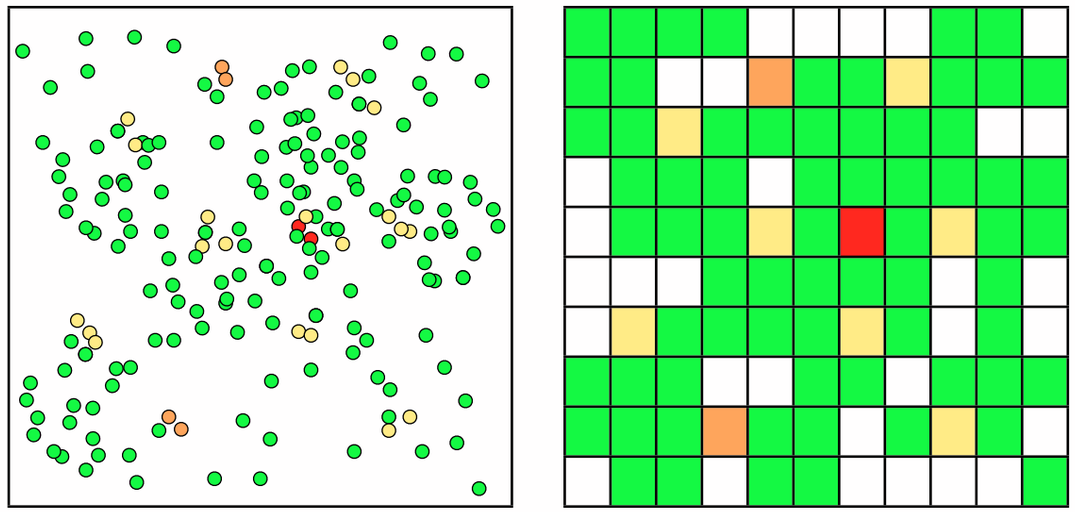
## Seismicity



Magnitude discretization and smoothing

# Regional scale - Sources

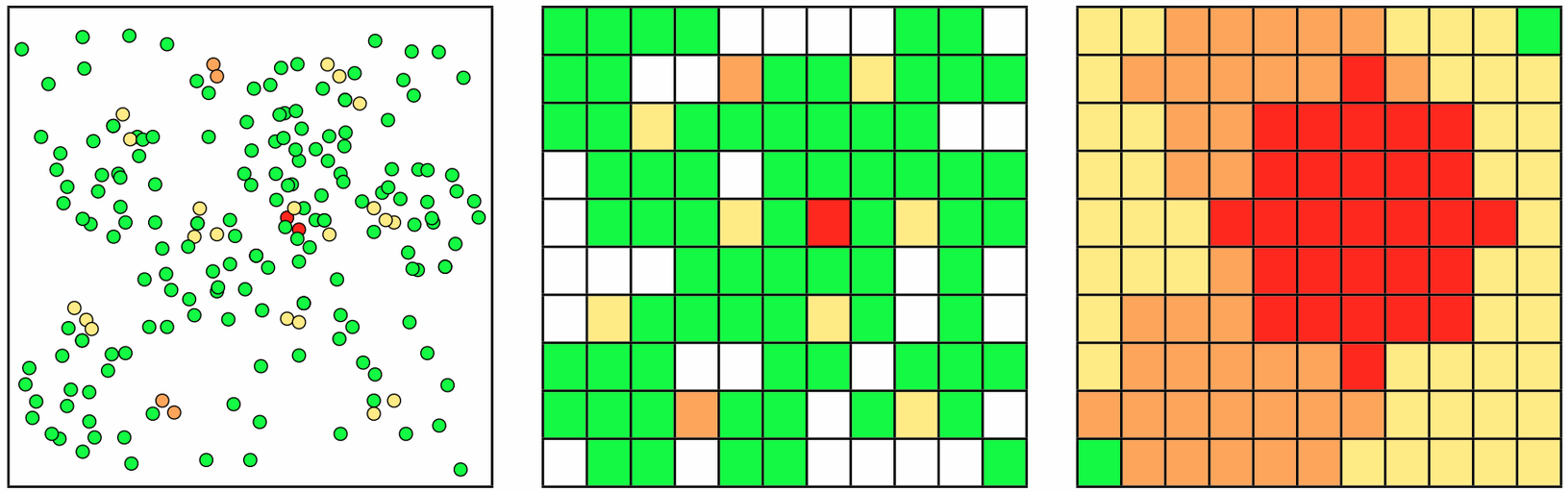
Seismicity ⟶ 1 - Discretization



Magnitude discretization and smoothing

# Regional scale - Sources

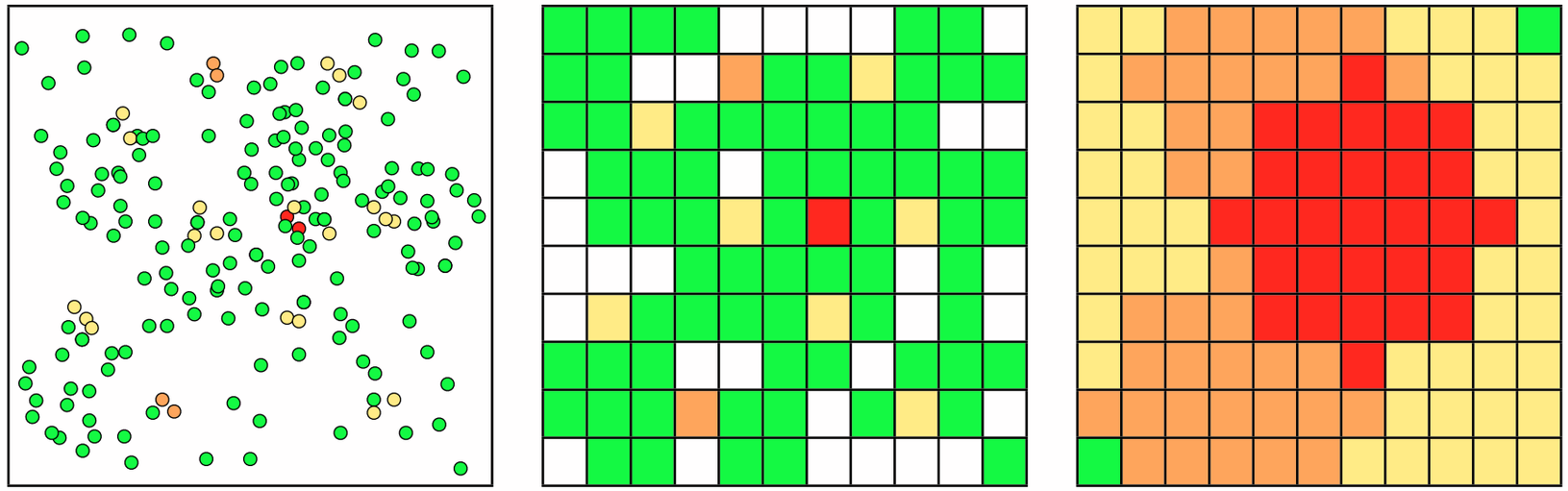
Seismicity → 1 - Discretization → 2 - Smoothing



Magnitude discretization and smoothing

# Regional scale - Sources

Seismicity → 1 - Discretization → 2 - Smoothing



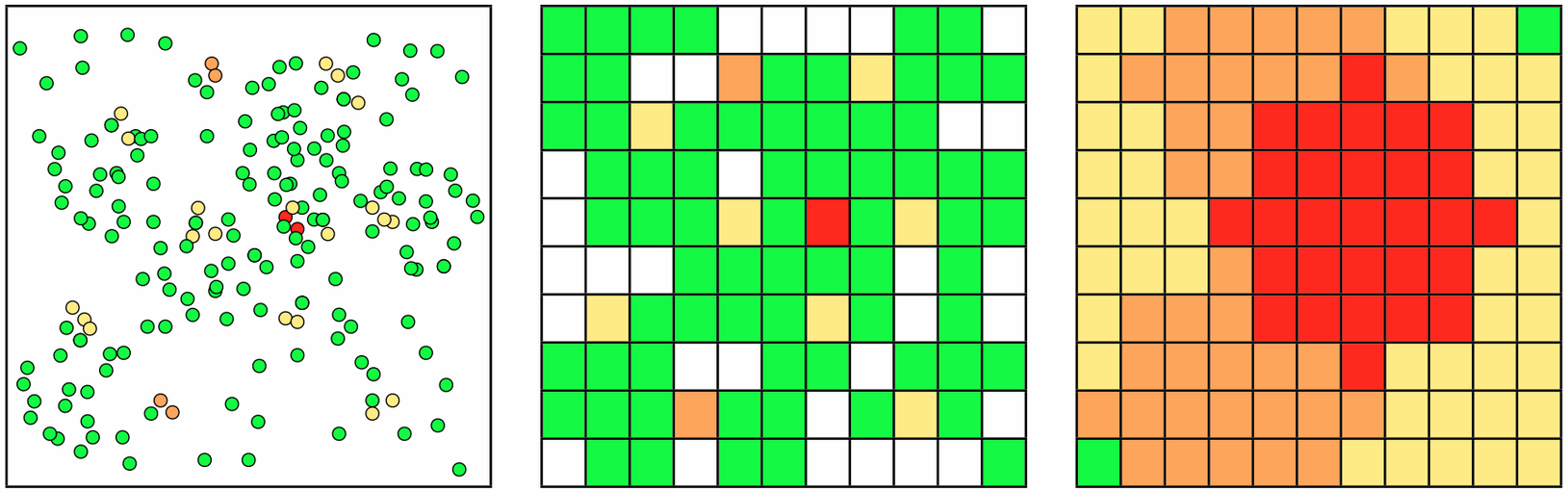
Magnitude discretization and smoothing

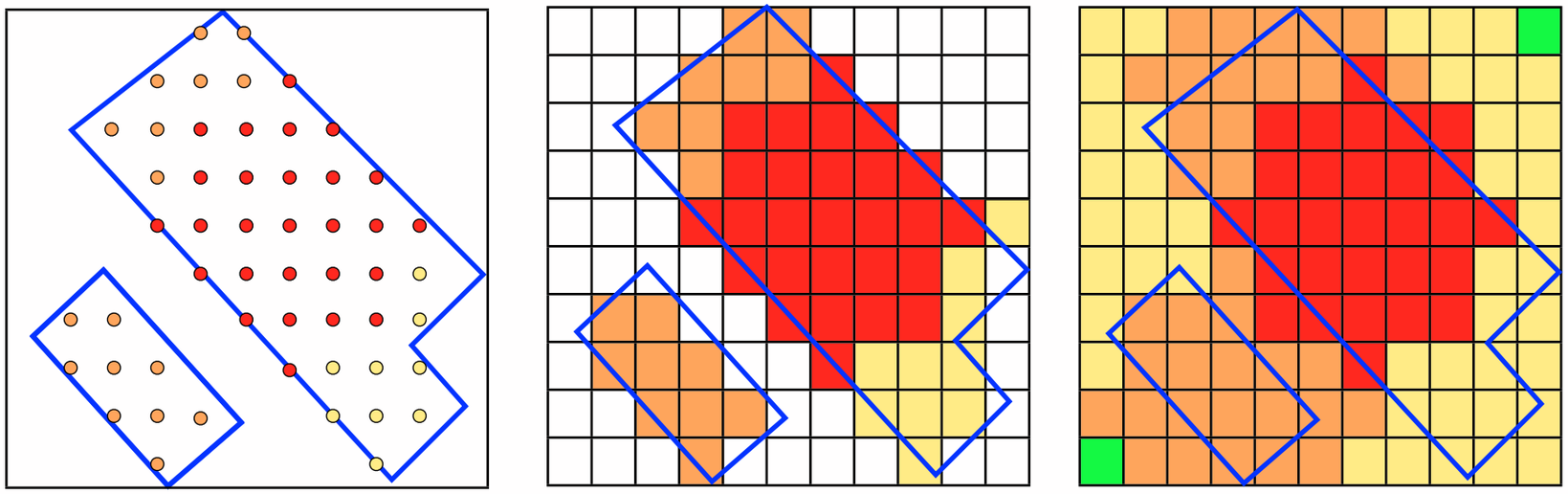
3 - Seismogenic zone

# Regional scale - Sources

Magnitude discretization and smoothing

Seismicity → 1 - Discretization → 2 - Smoothing

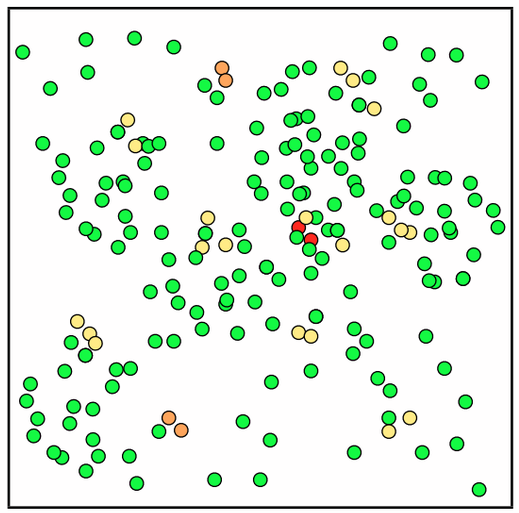


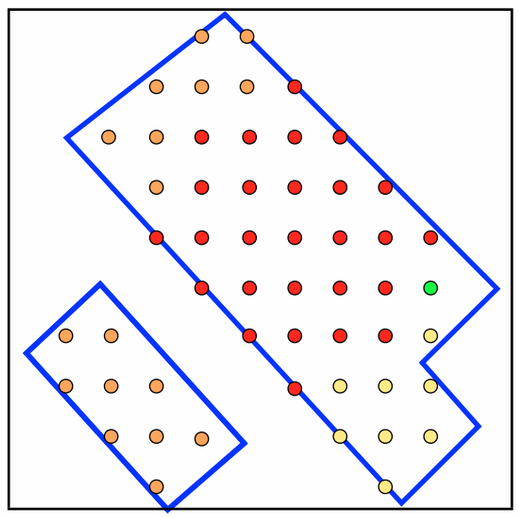


5 - Sources ← 4 - Truncation ← 3 - Seismogenic zone

# Regional scale - Sources

Seismicity



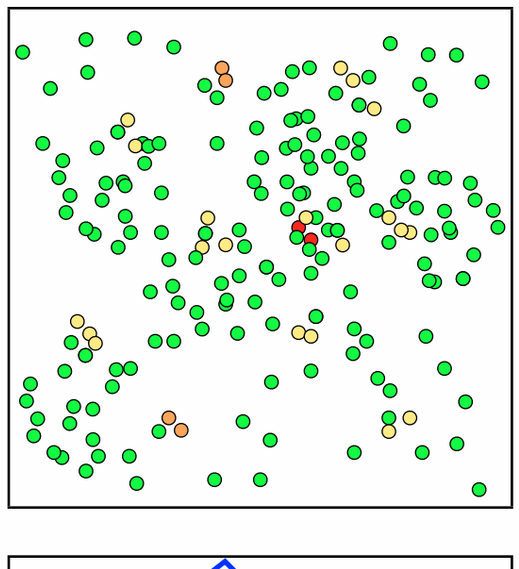


Sources

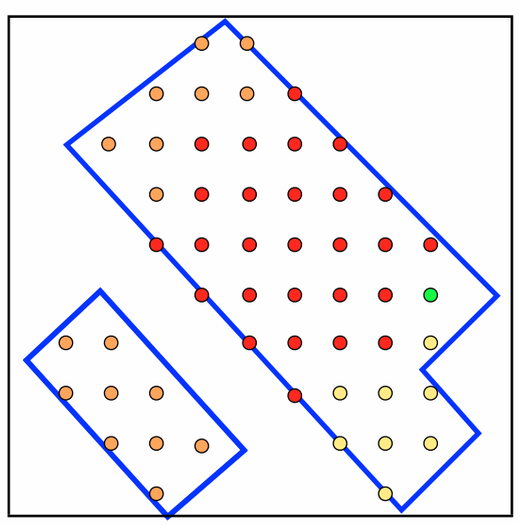
Magnitude discretization and smoothing

# Regional scale - Sources

Seismicity



Sources

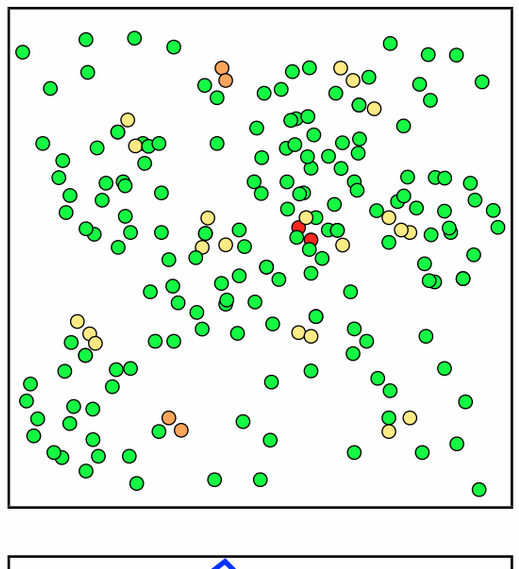


- Why do we do this?

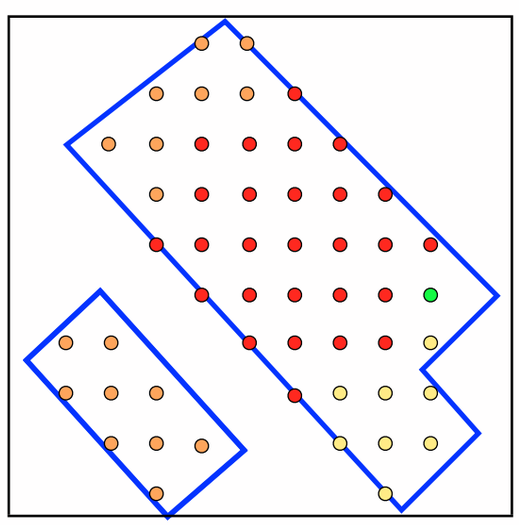
Magnitude discretization and smoothing

# Regional scale - Sources

Seismicity



Sources

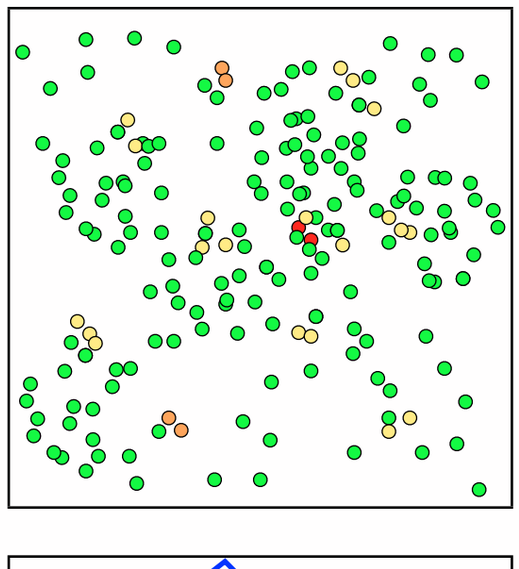


Magnitude discretization and smoothing

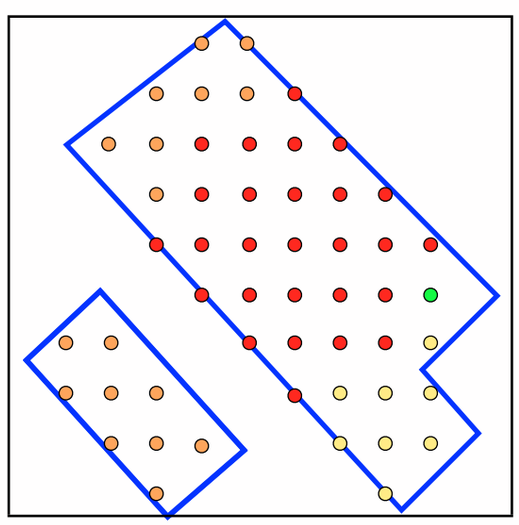
- Why do we do this?
  - To account for mislocations of events in the catalogue

# Regional scale - Sources

Seismicity



Sources

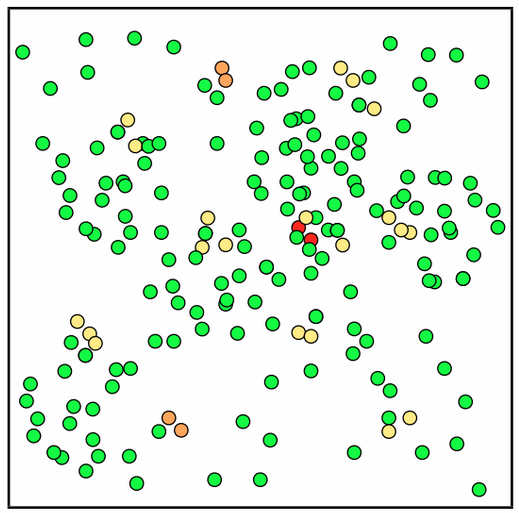


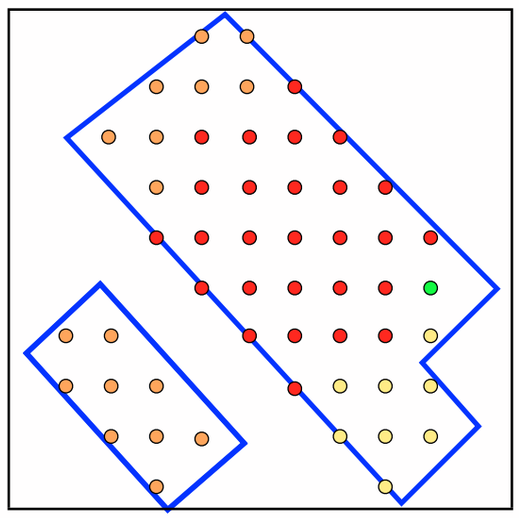
Magnitude discretization and smoothing

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

# Regional scale - Sources

Seismicity



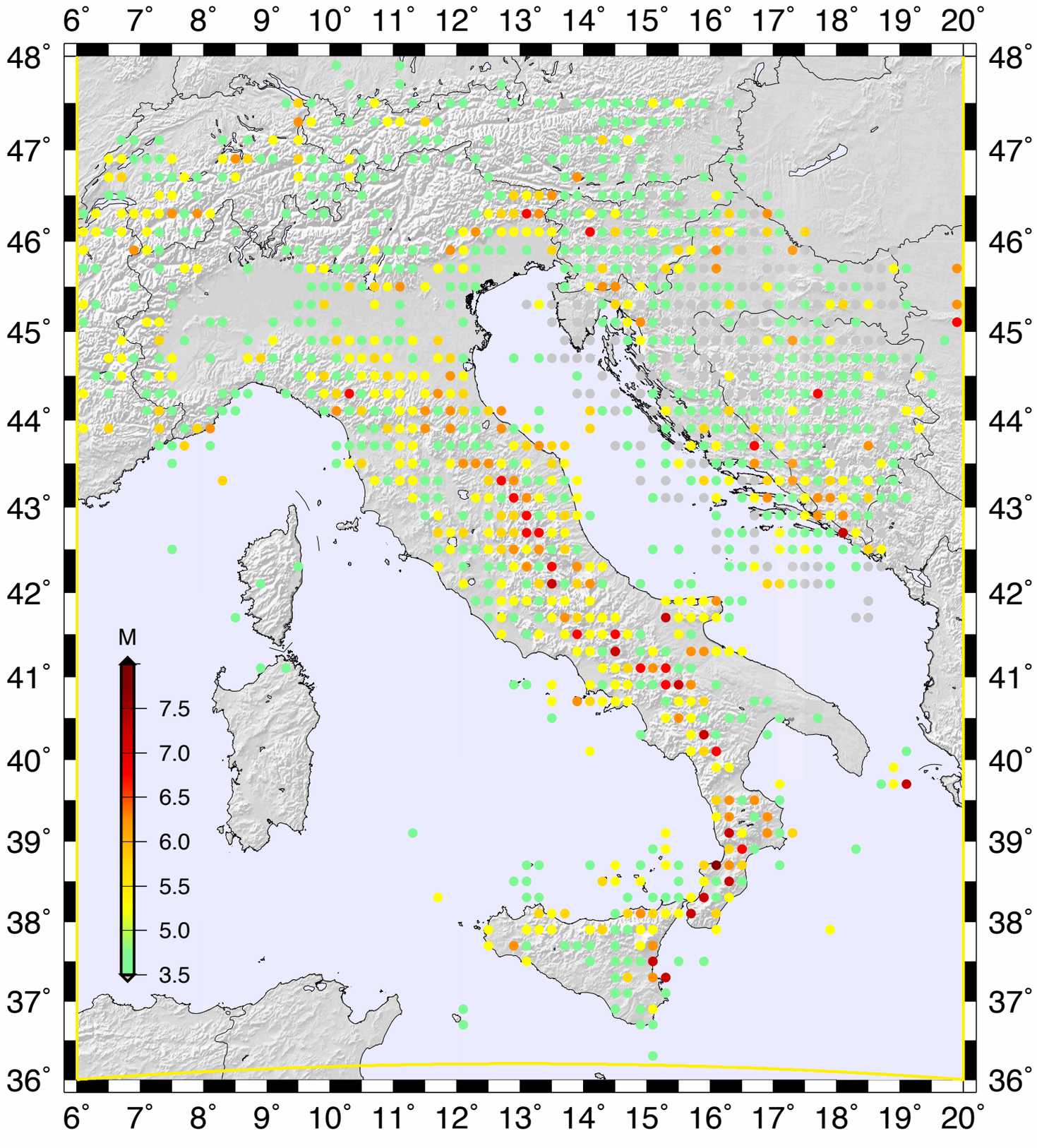


Sources

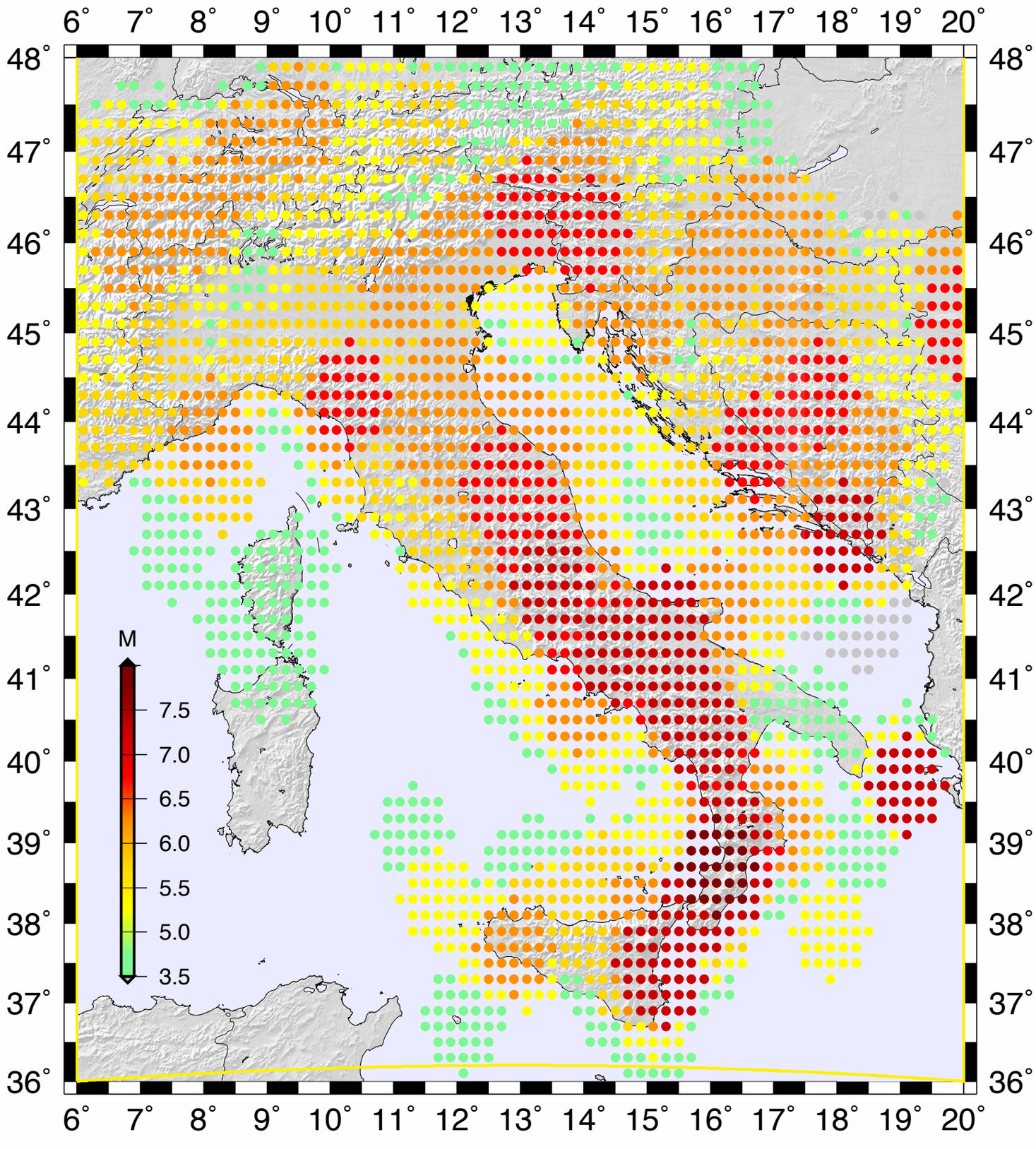
Magnitude discretization and smoothing

- 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
  - To be conservative...

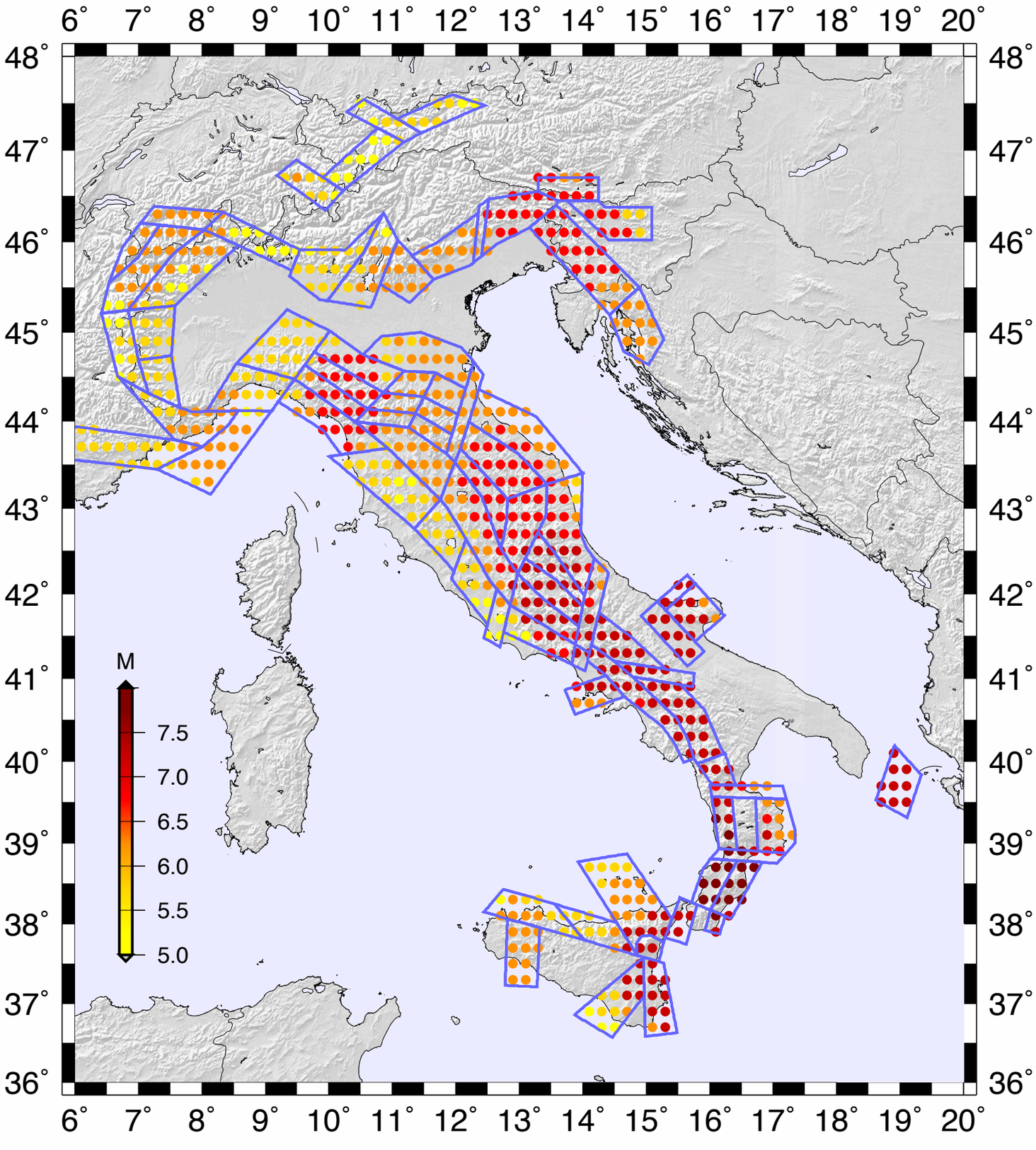
# Regional scale - Discretized Magnitude



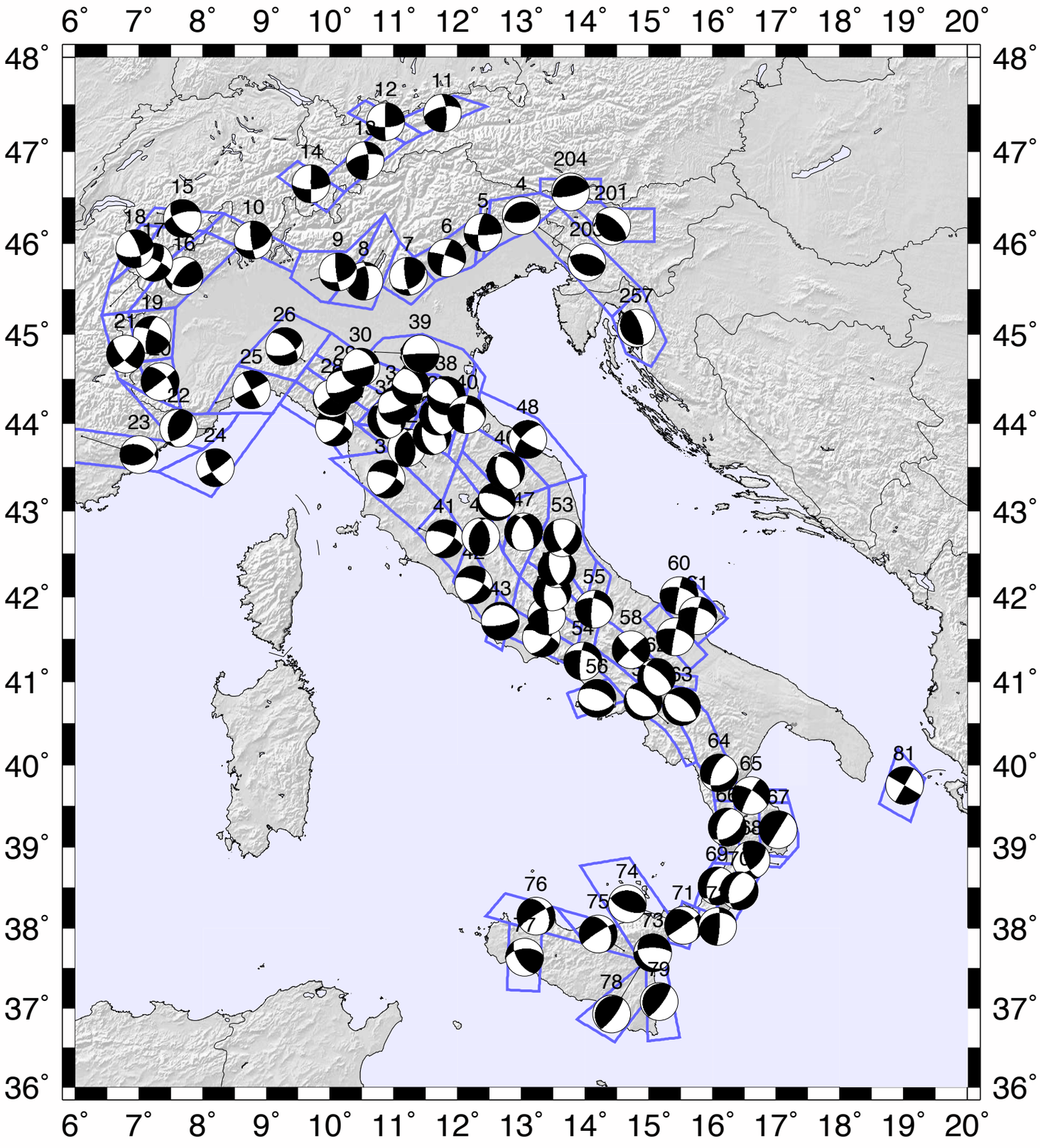
# Regional scale - Smoothed magnitude



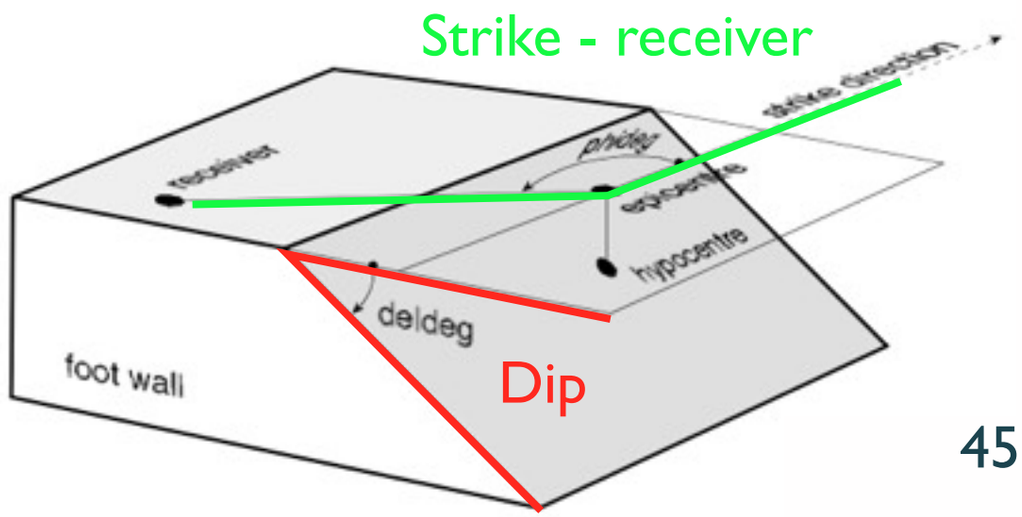
# Regional scale - Sources inside SZ

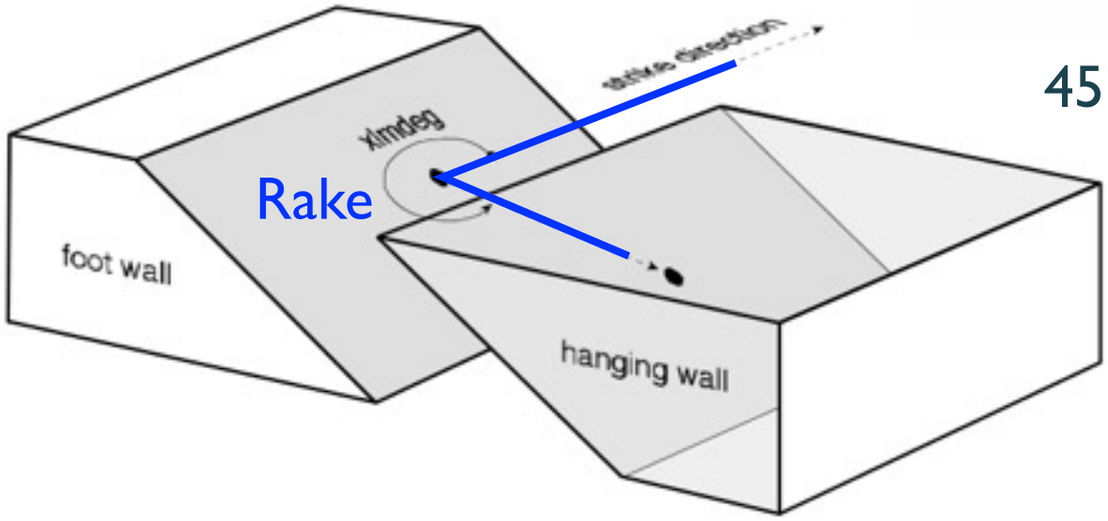


# Regional scale - Sources inside SZ



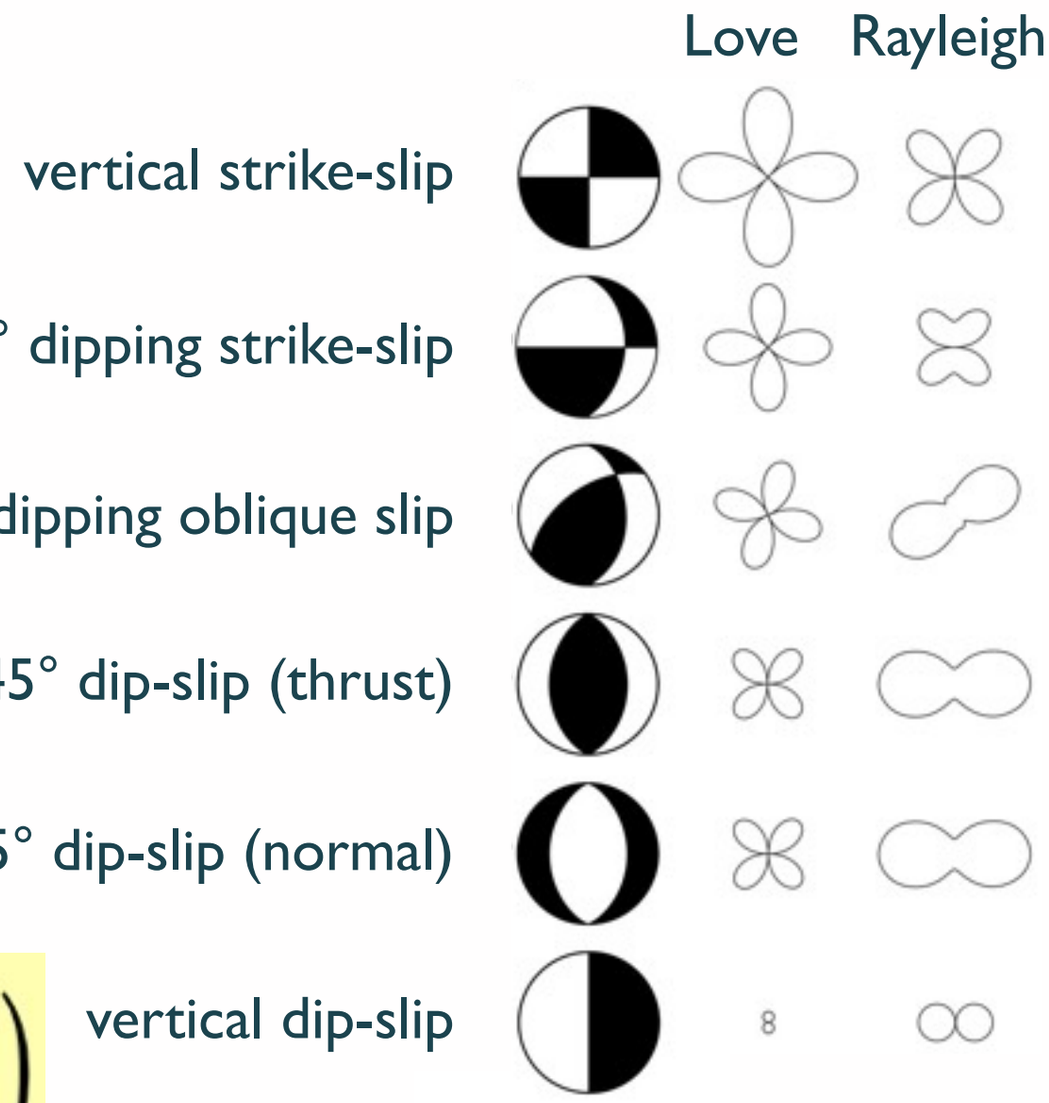
# Source definition - Radiation pattern



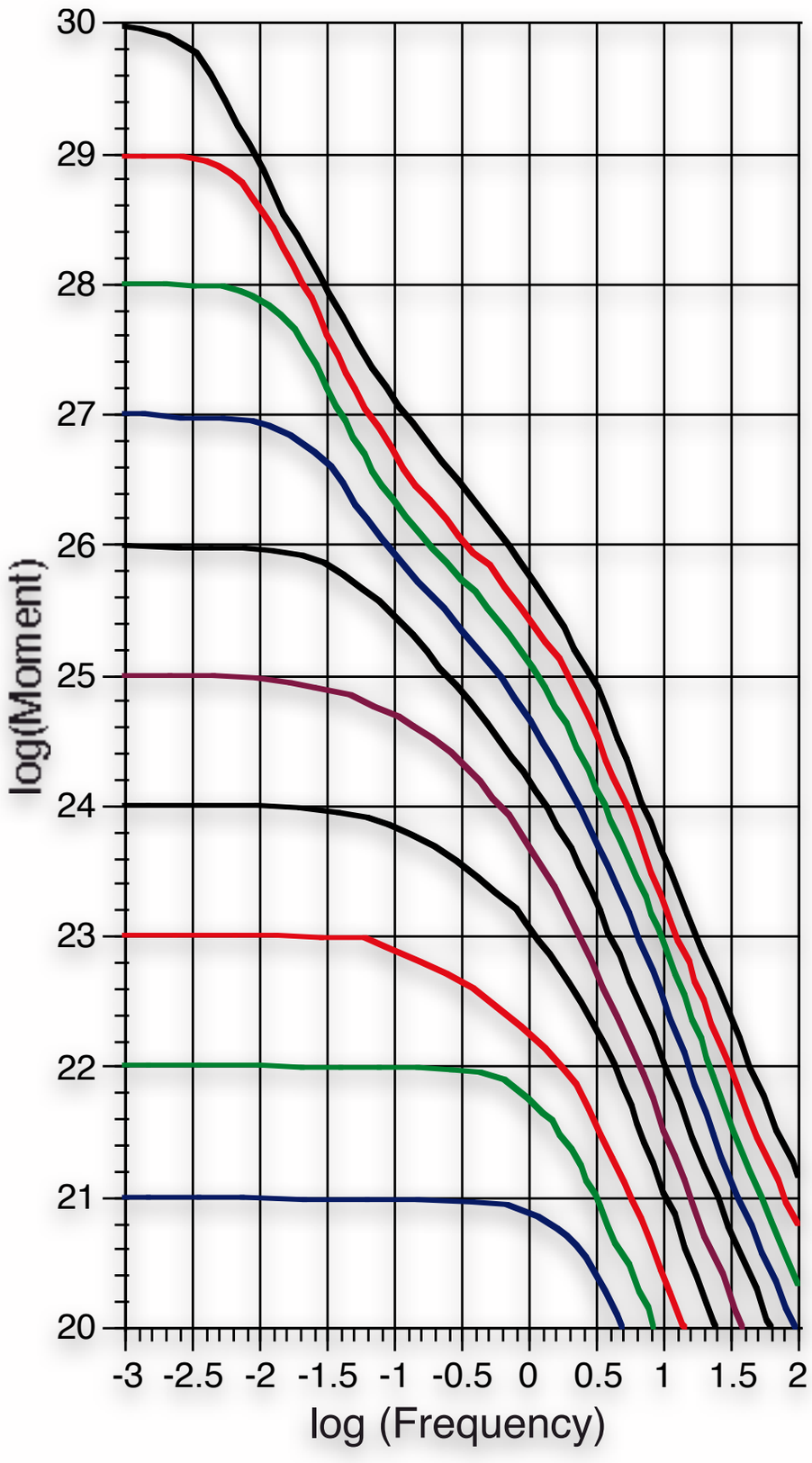

$$\left(\chi_m^L(h_s,\omega)\right)$$

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



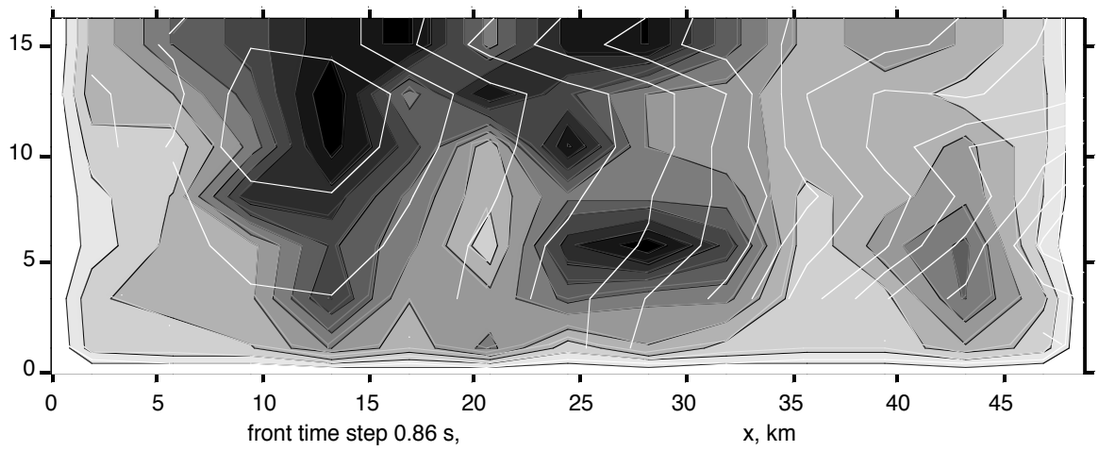
# Source definition - Scaled point source

- 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



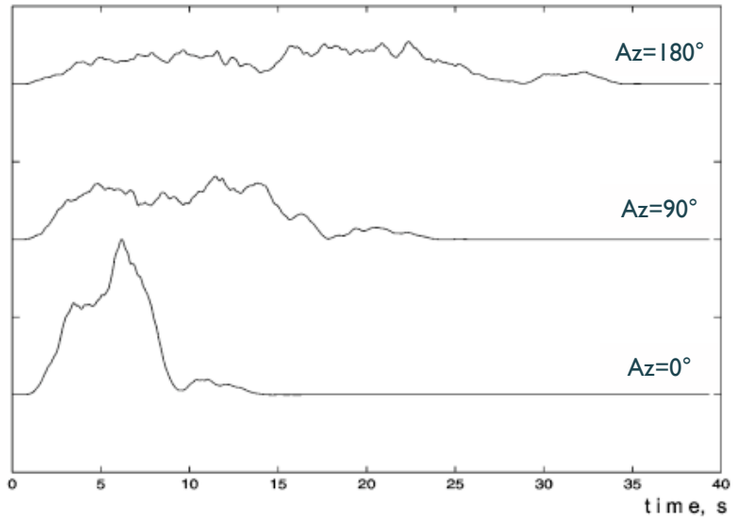

2-dimensional final slip distribution over a source rectangle, shown as a density plot (Mw=7.0).

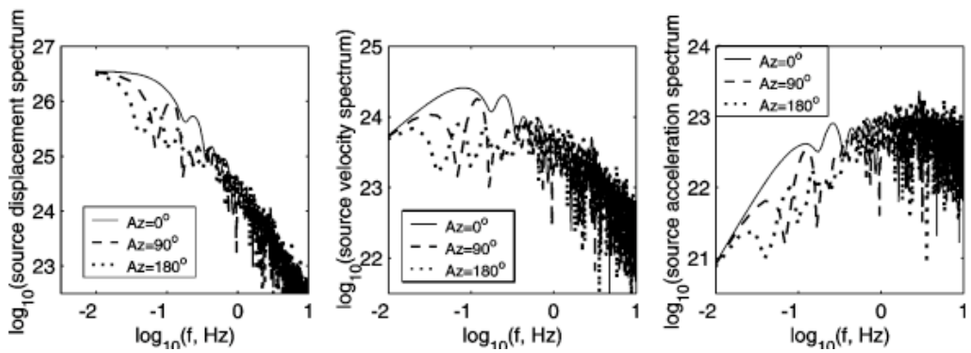
Rupture front evolution was simulated kinematically from random rupture velocity field.

(Gusev, 2011)

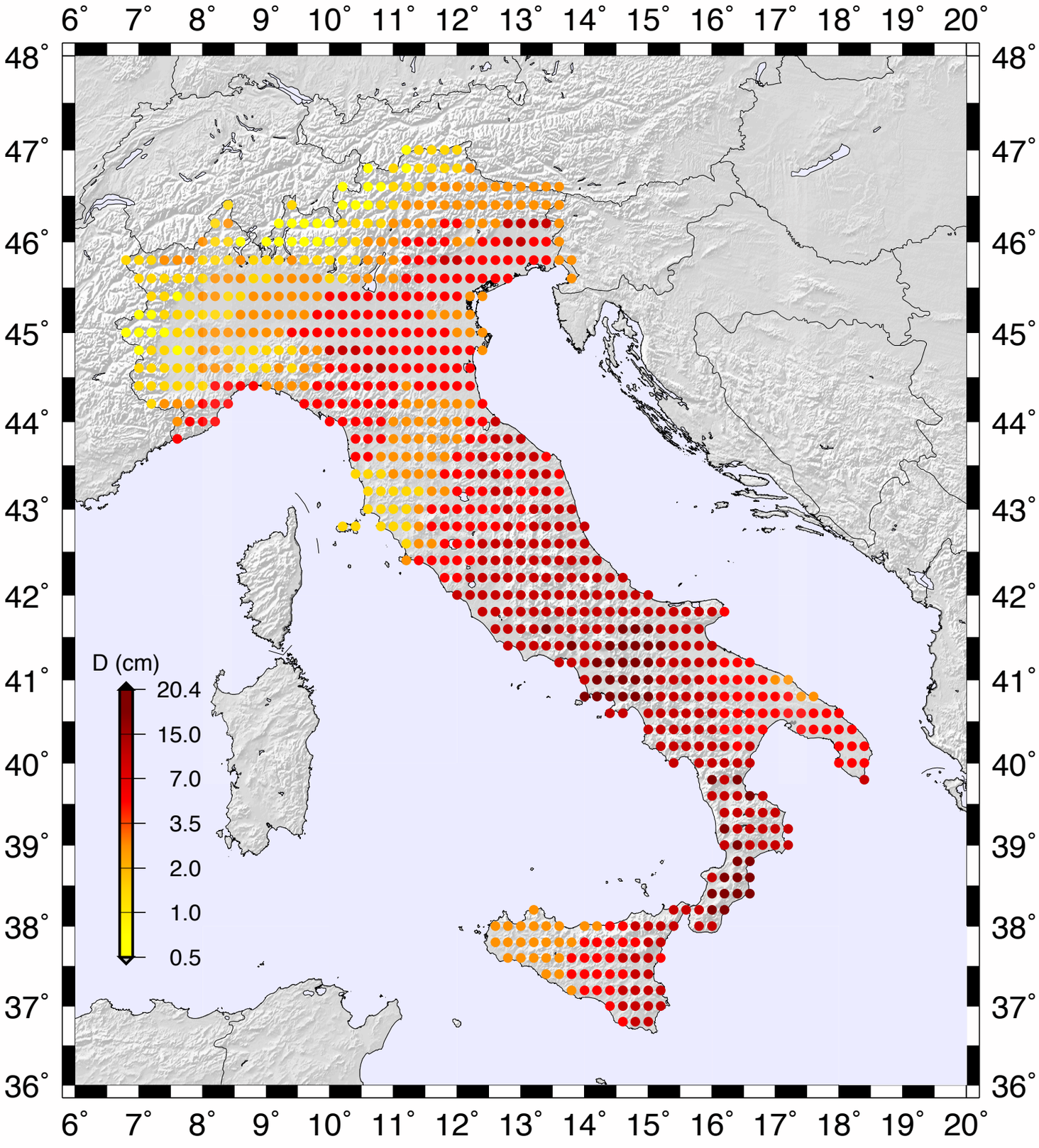
Far-field source time histories and their spectra.

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

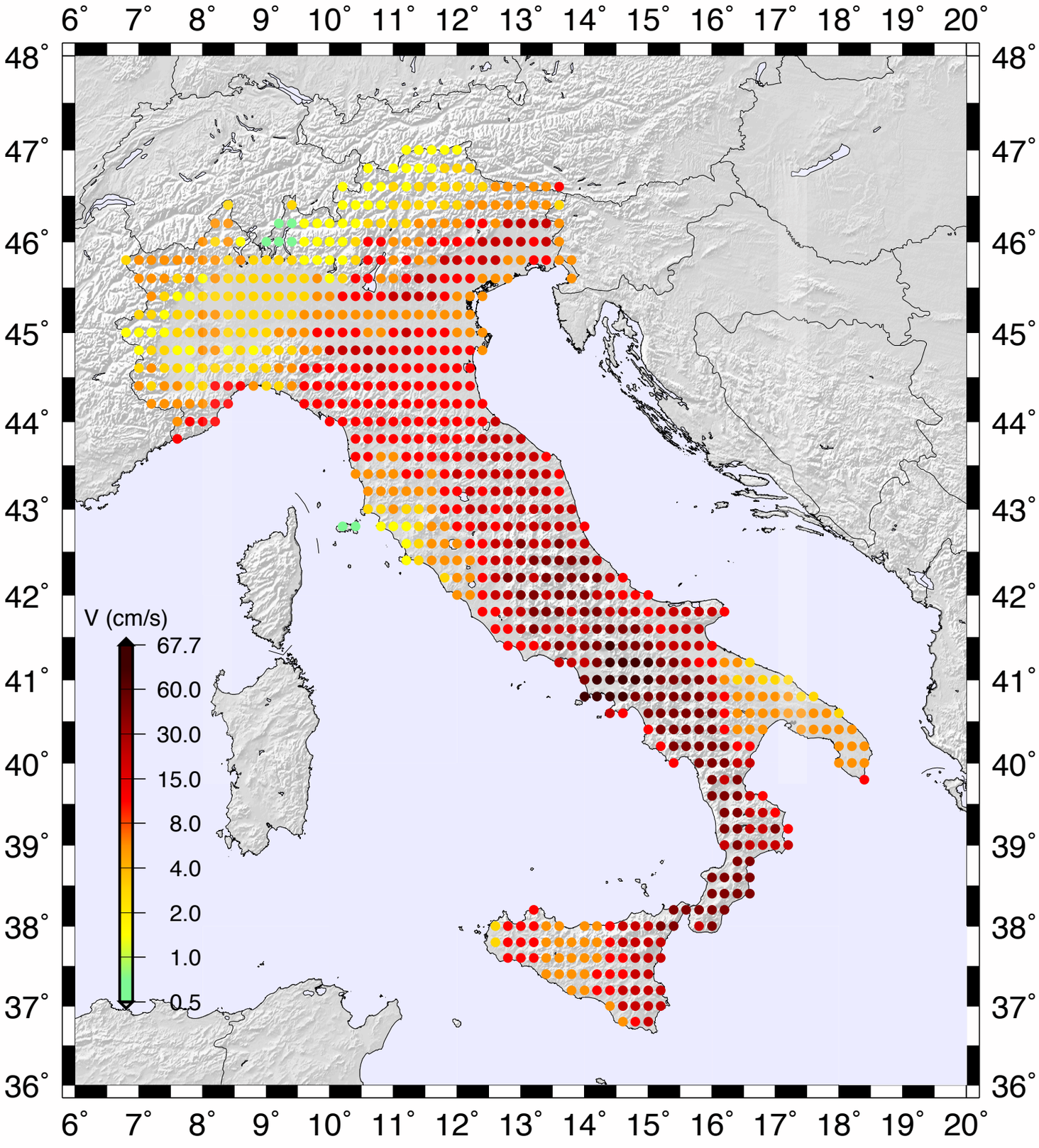


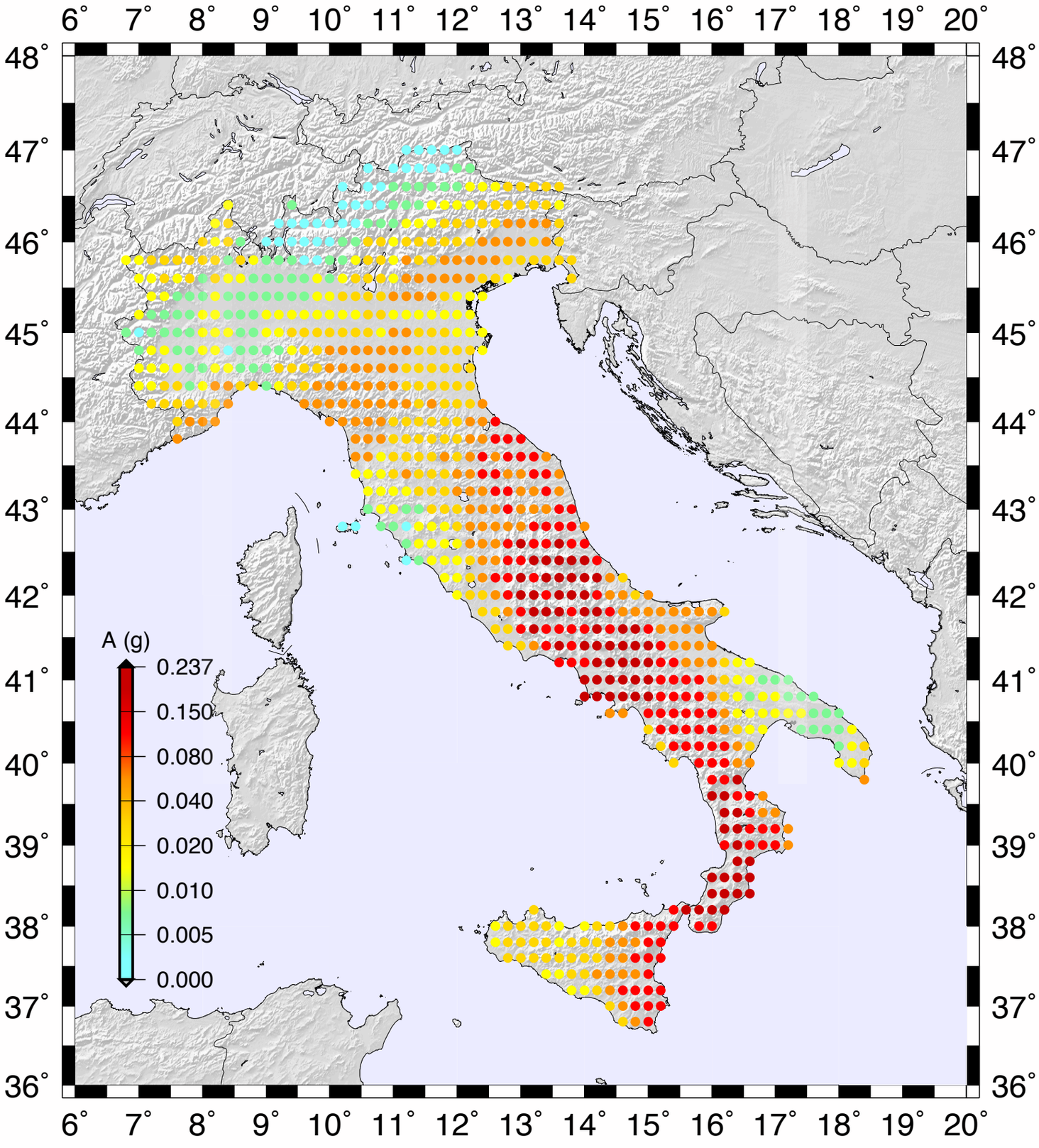
# Example computation - Ground shaking



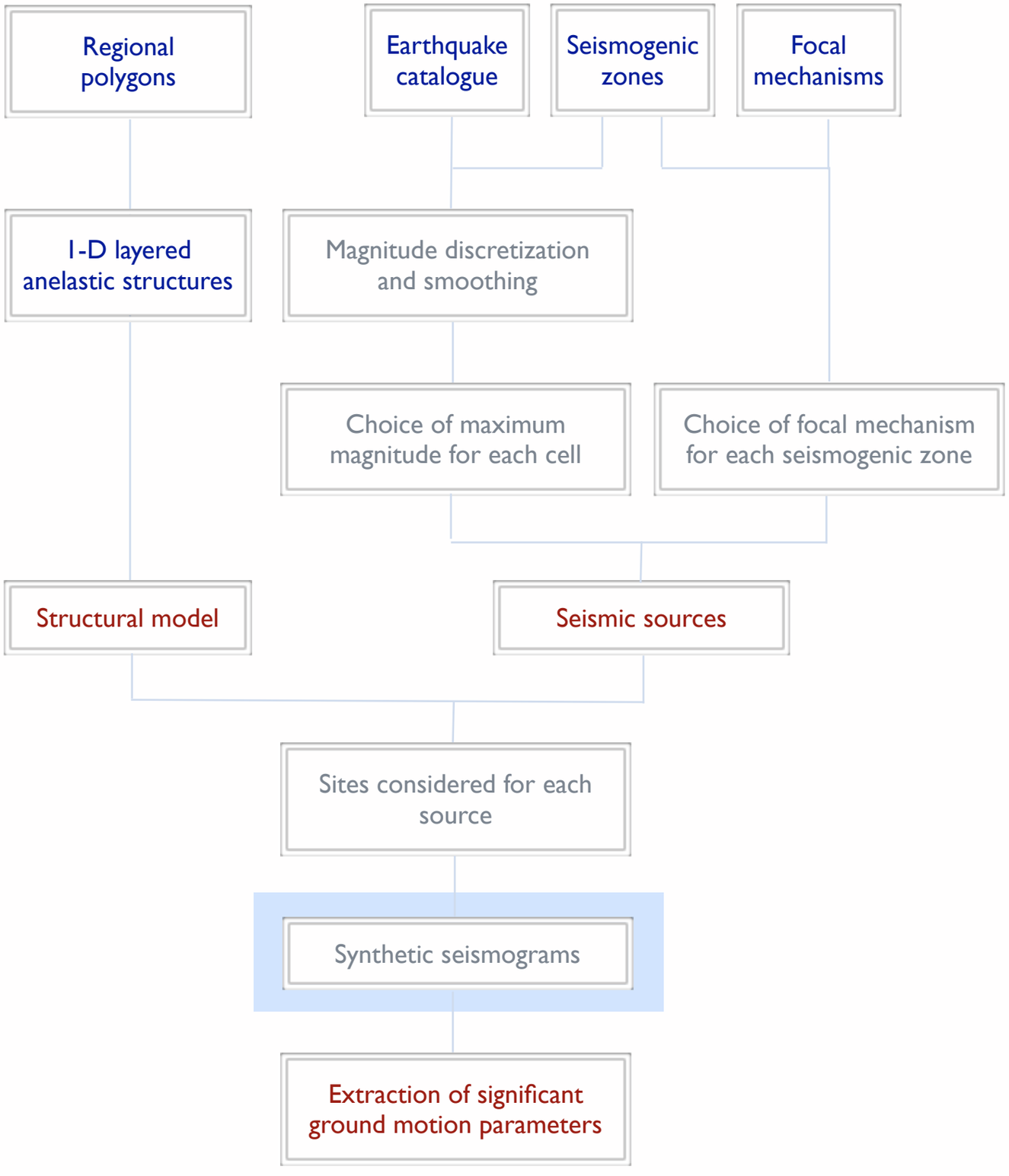
# Example computation - Ground shaking

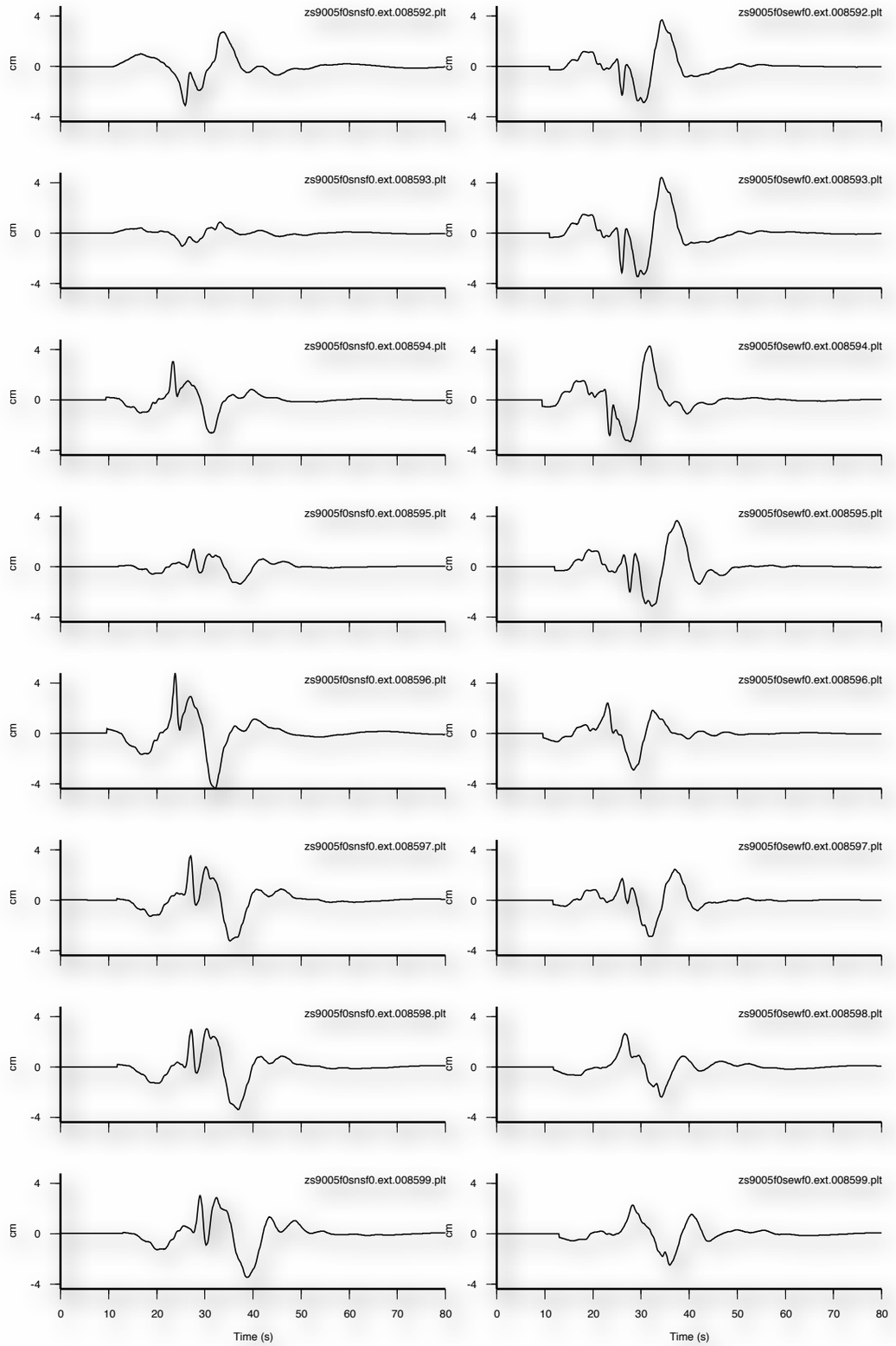


# Example computation - Ground shaking

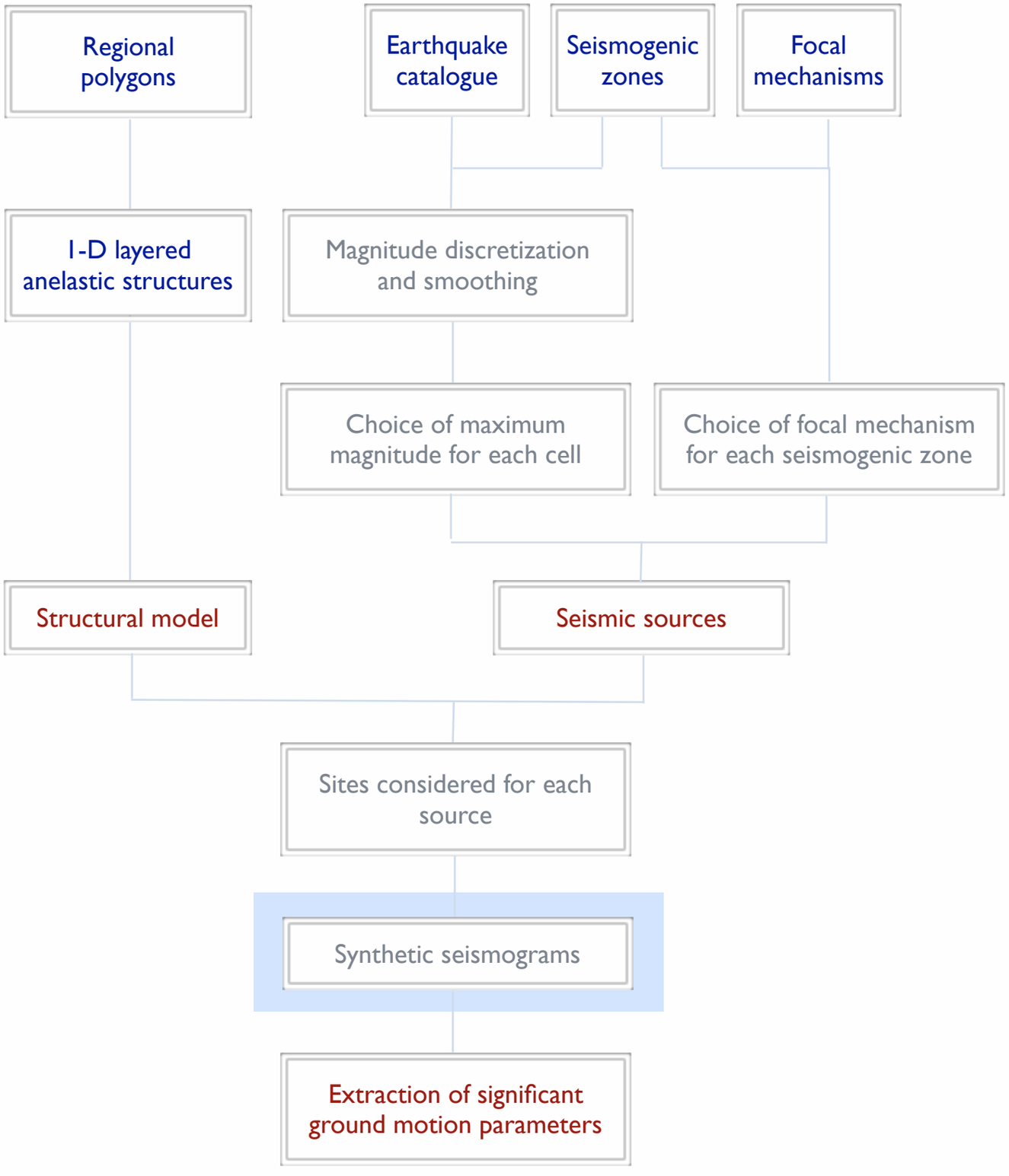


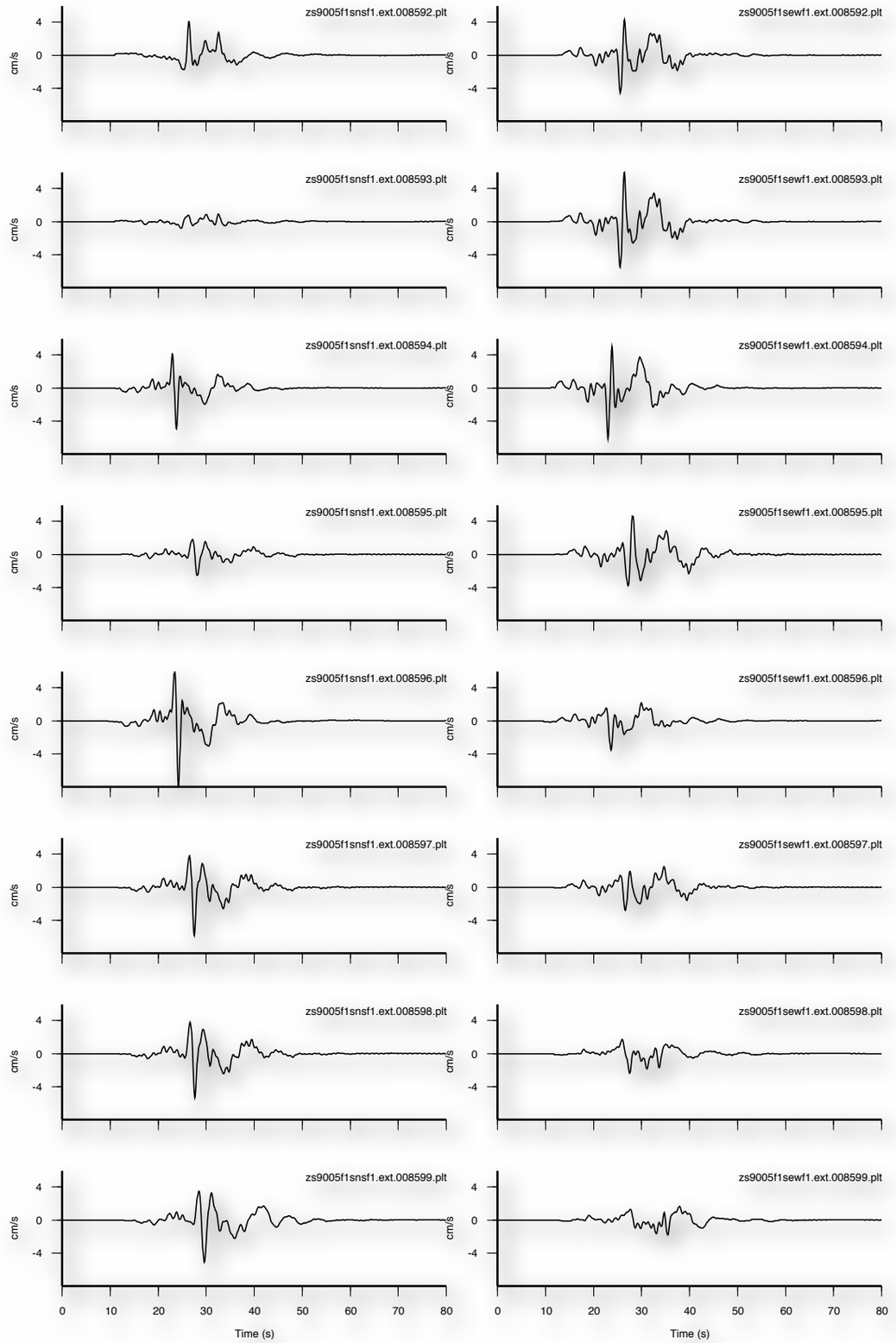
# Regional Scale - Displacement



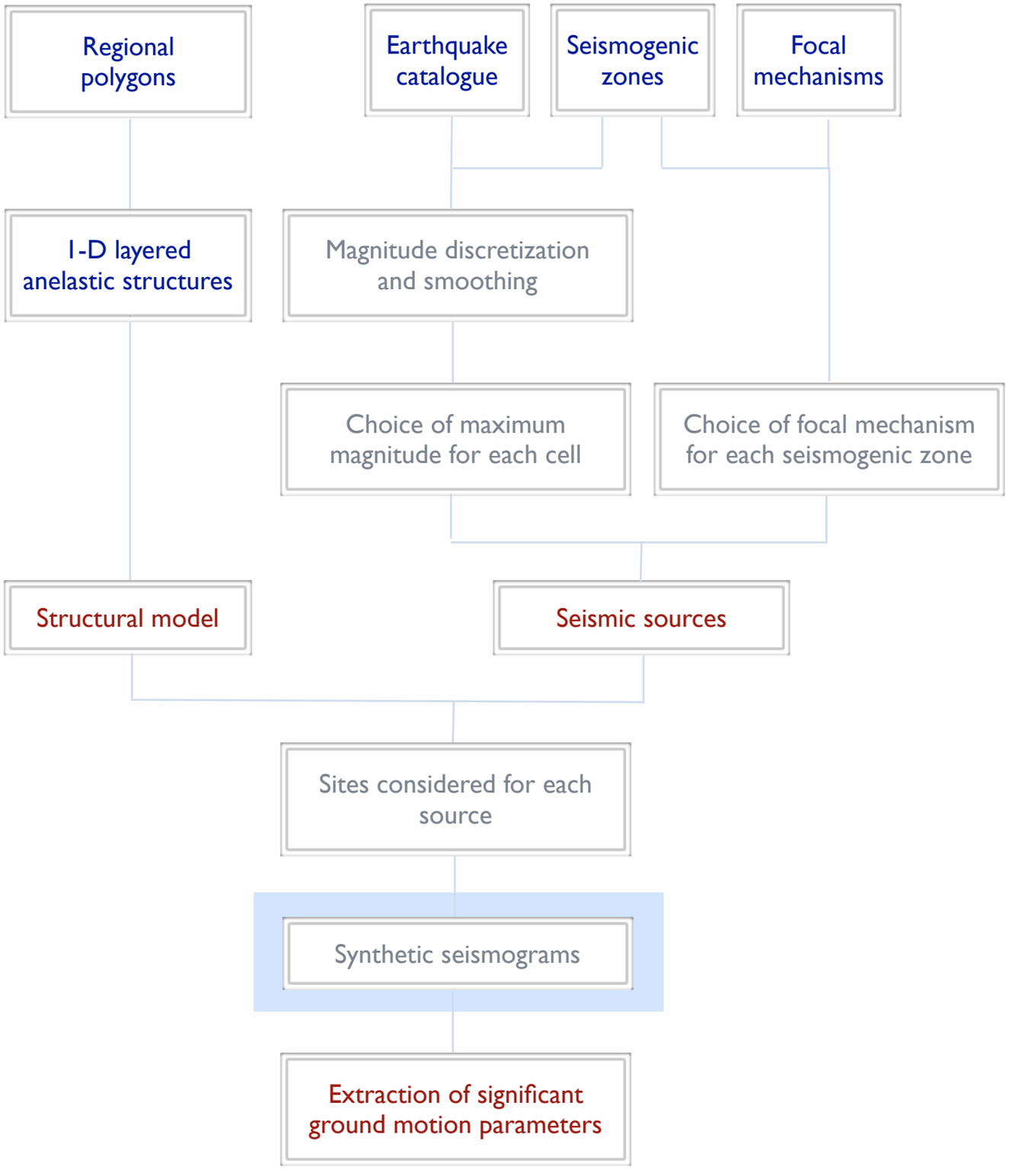



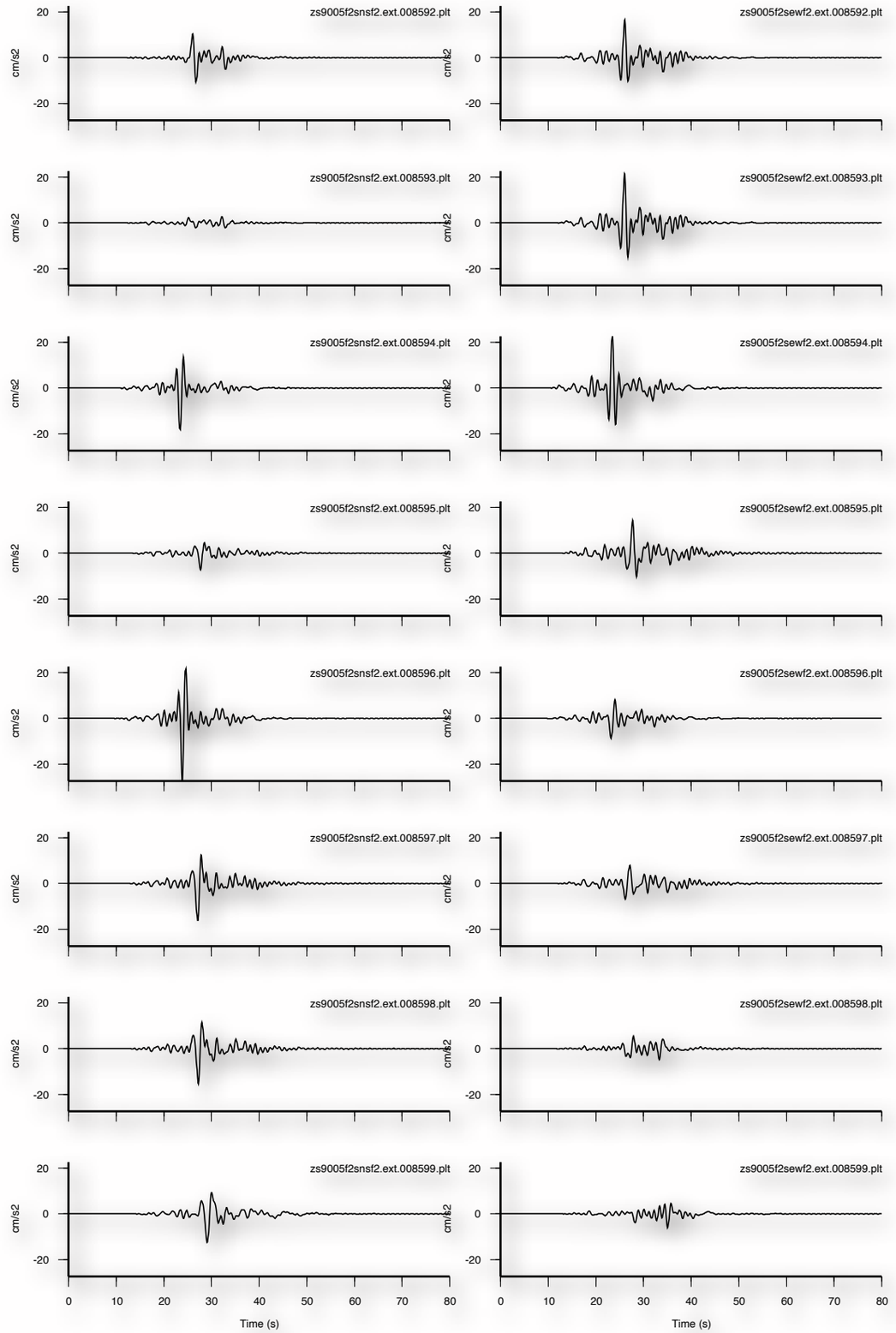
# Regional Scale - Velocity



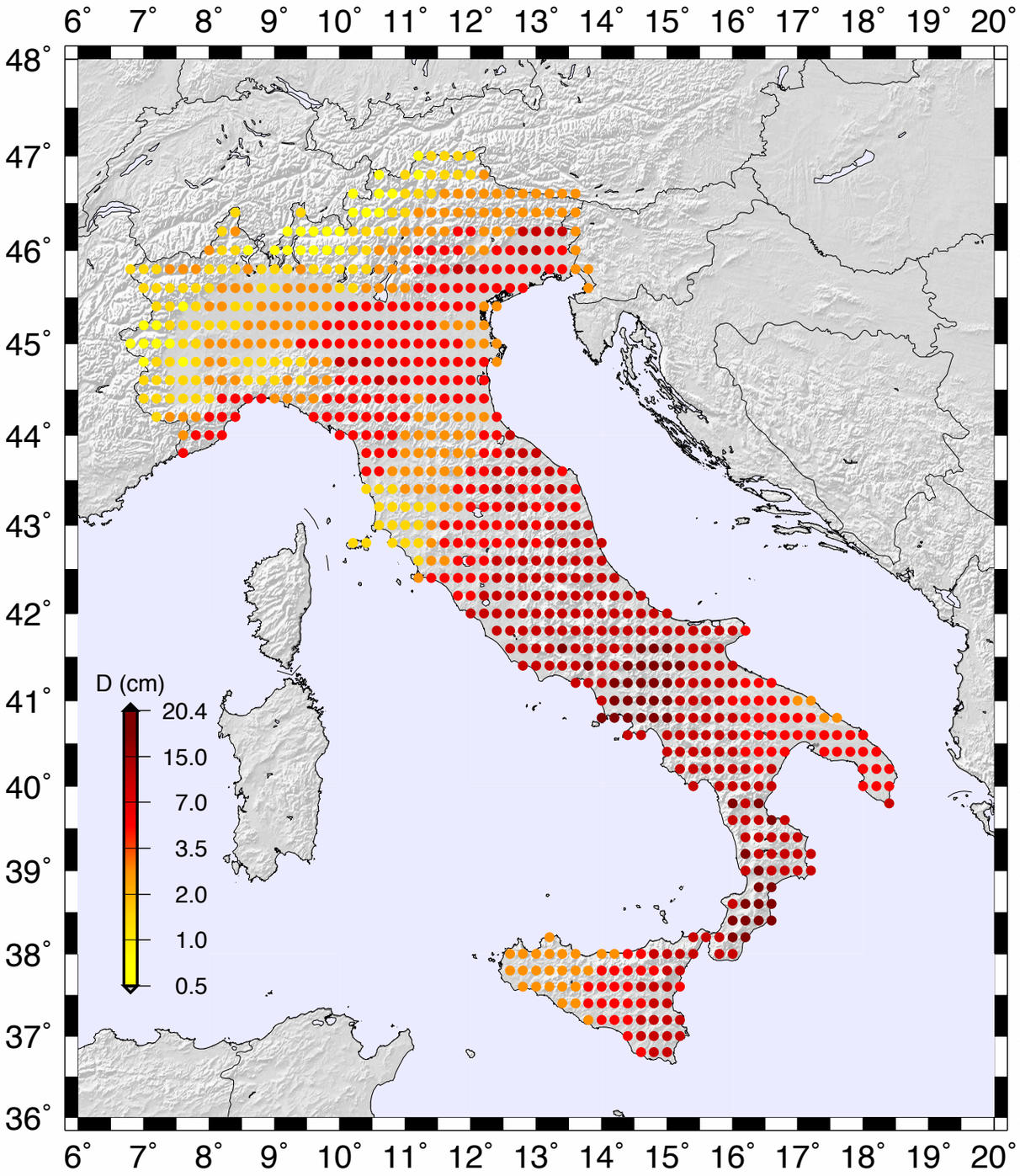
# Regional Scale - Acceleration



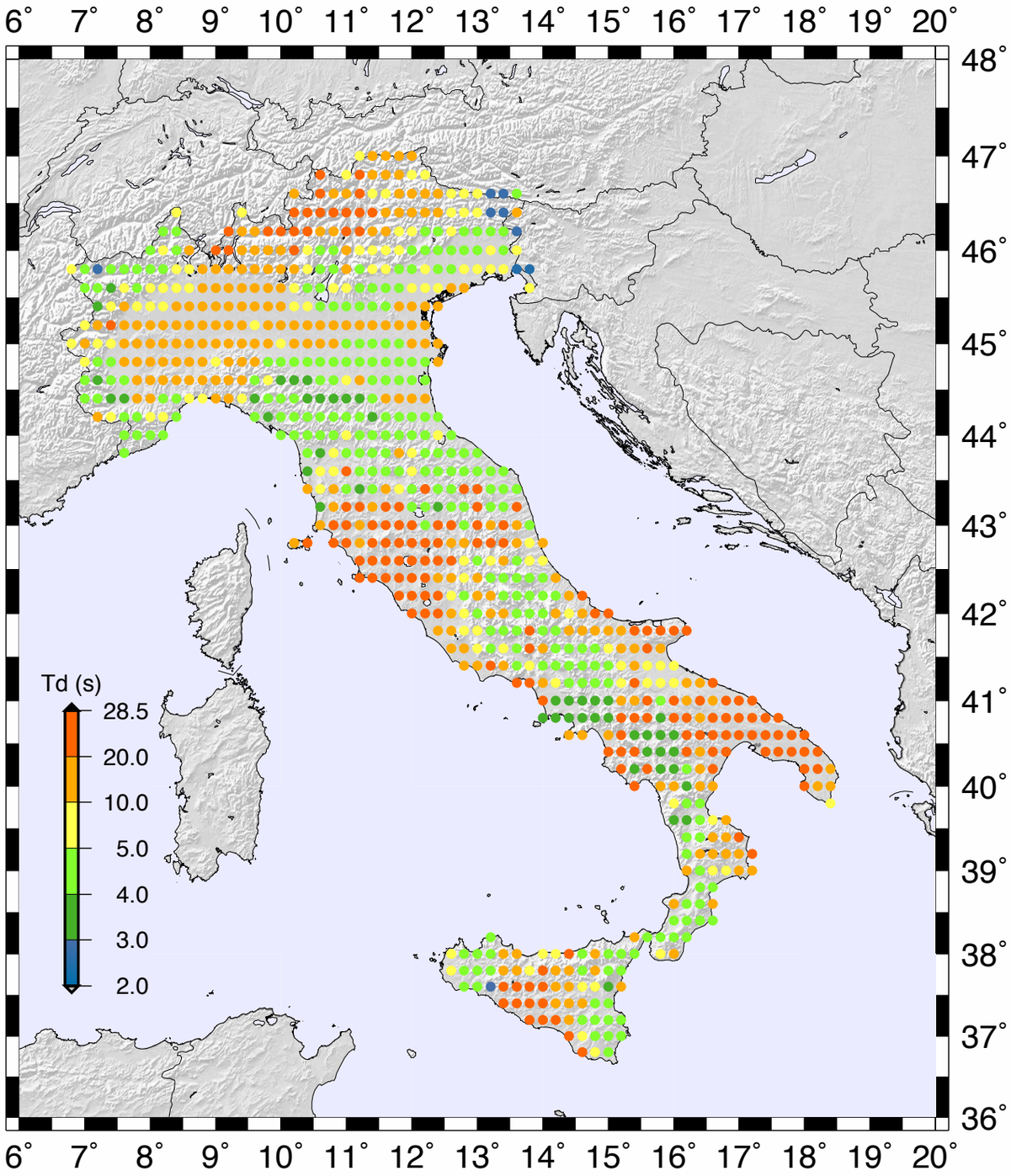



# Displacement

## Amplitude of Peaks from Time Series (1Hz)

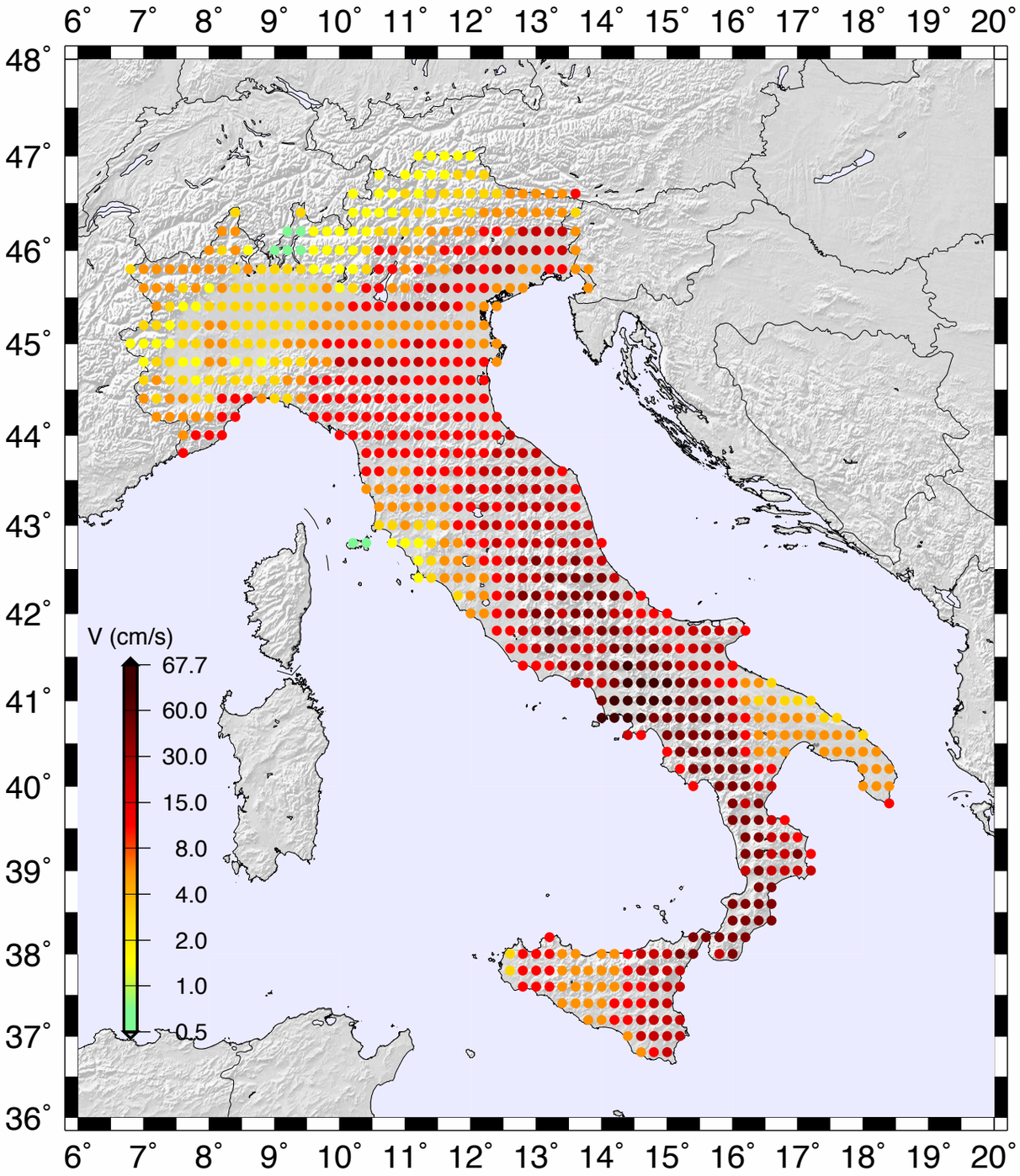



## T of Peaks from Fourier Spectra

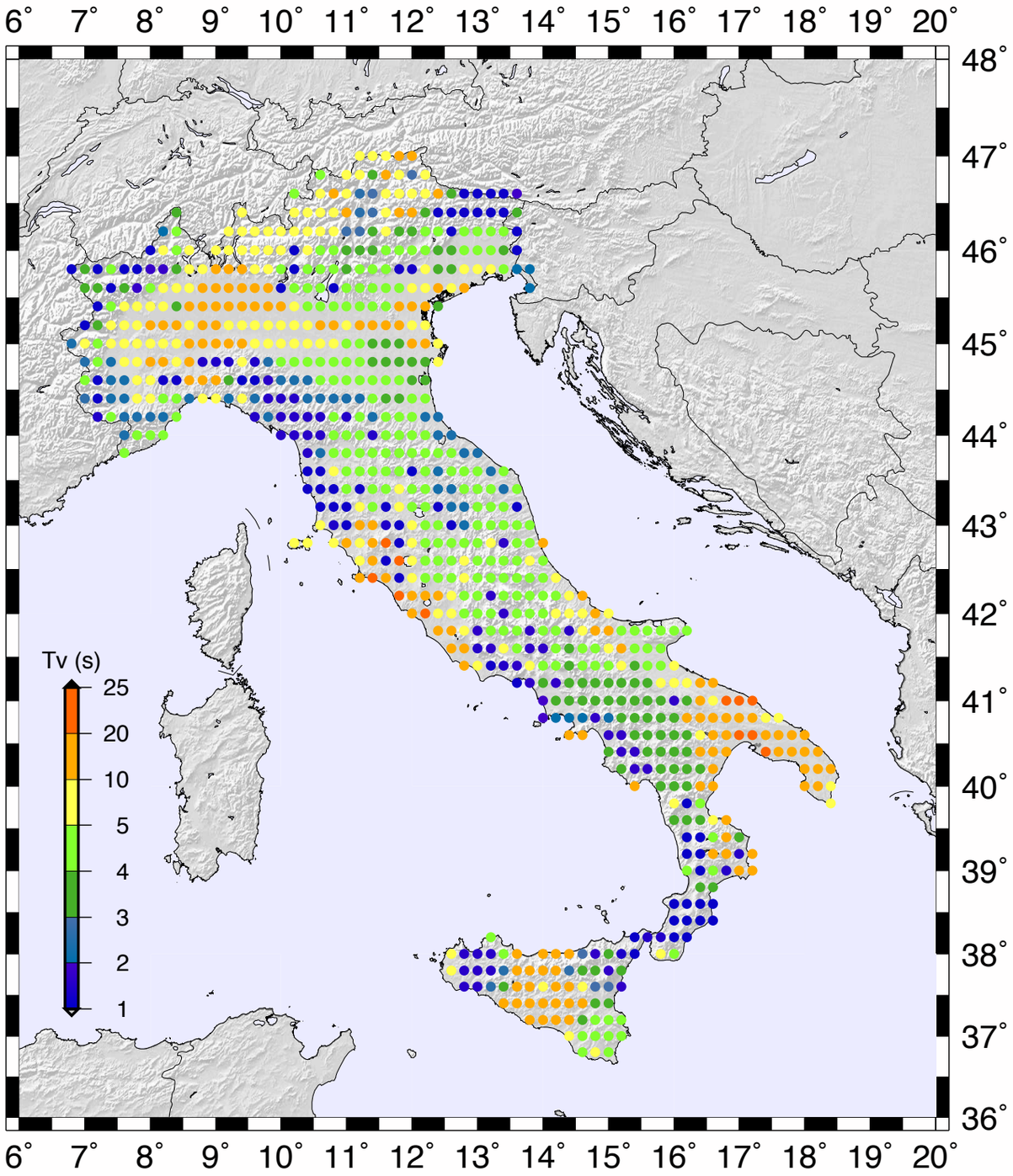


# Velocity

## Amplitude of Peaks from Time Series (1Hz)

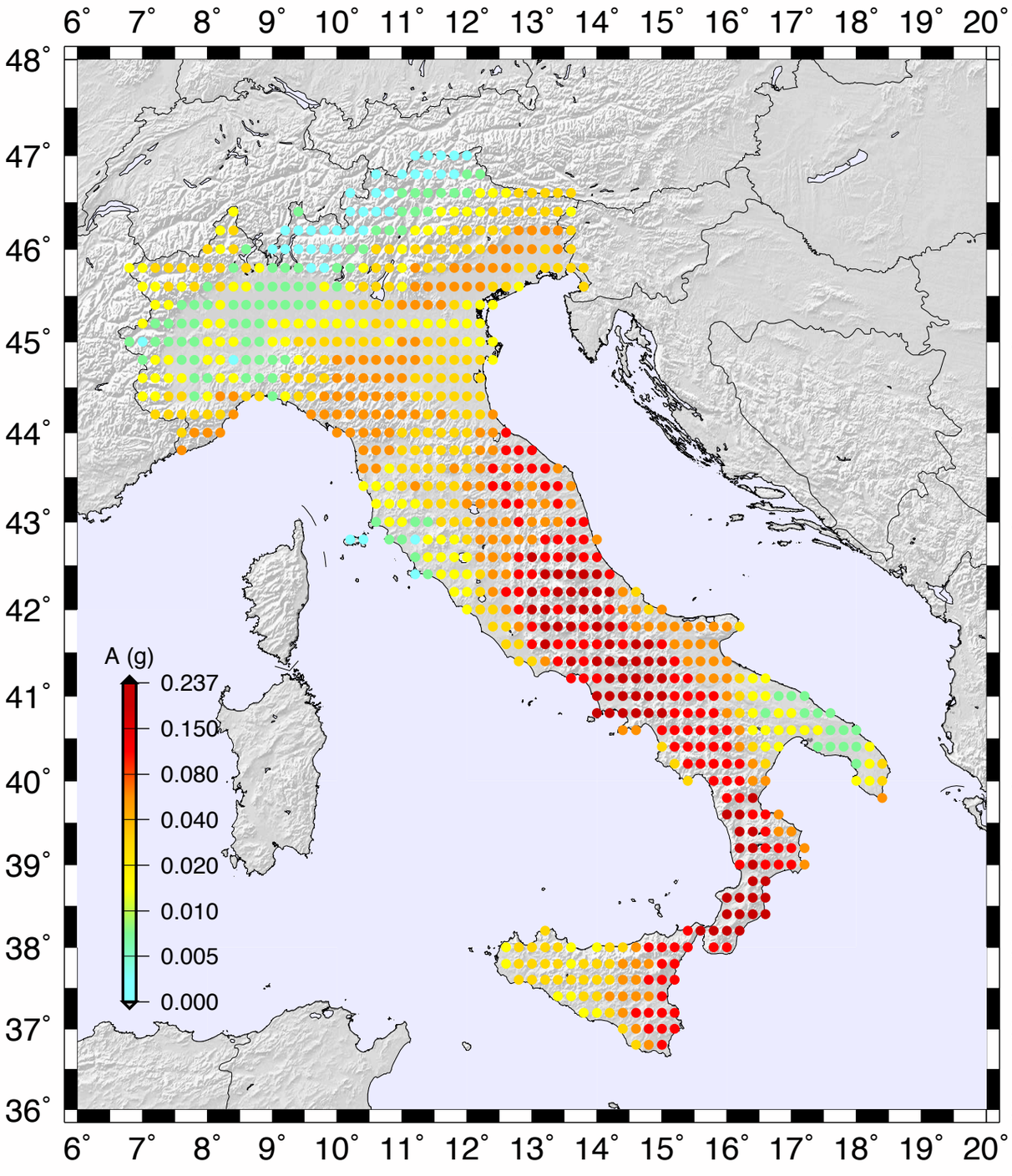



## T of Peaks from Fourier Spectra



# Acceleration

## Amplitude of Peaks from Time Series (1Hz)

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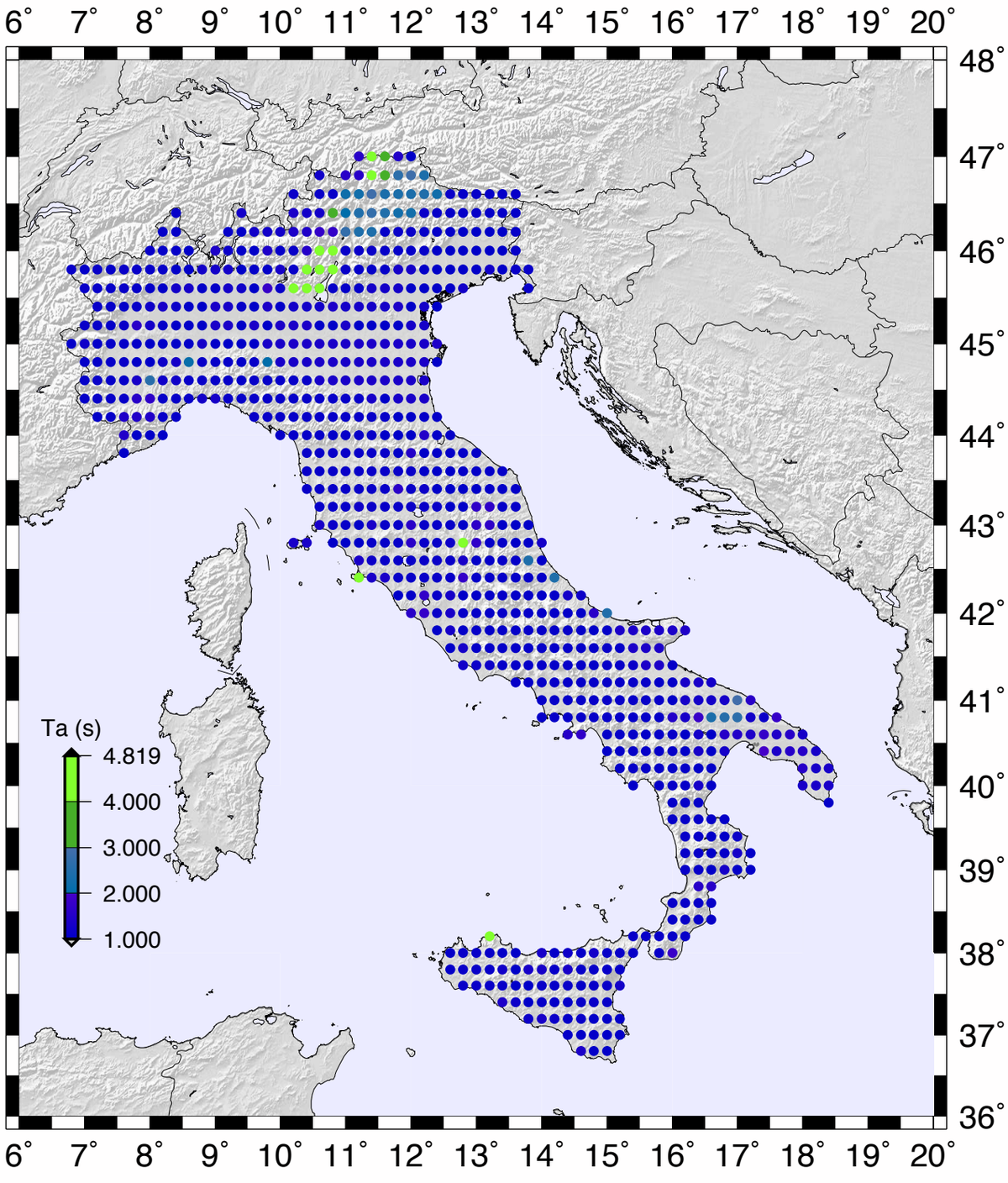
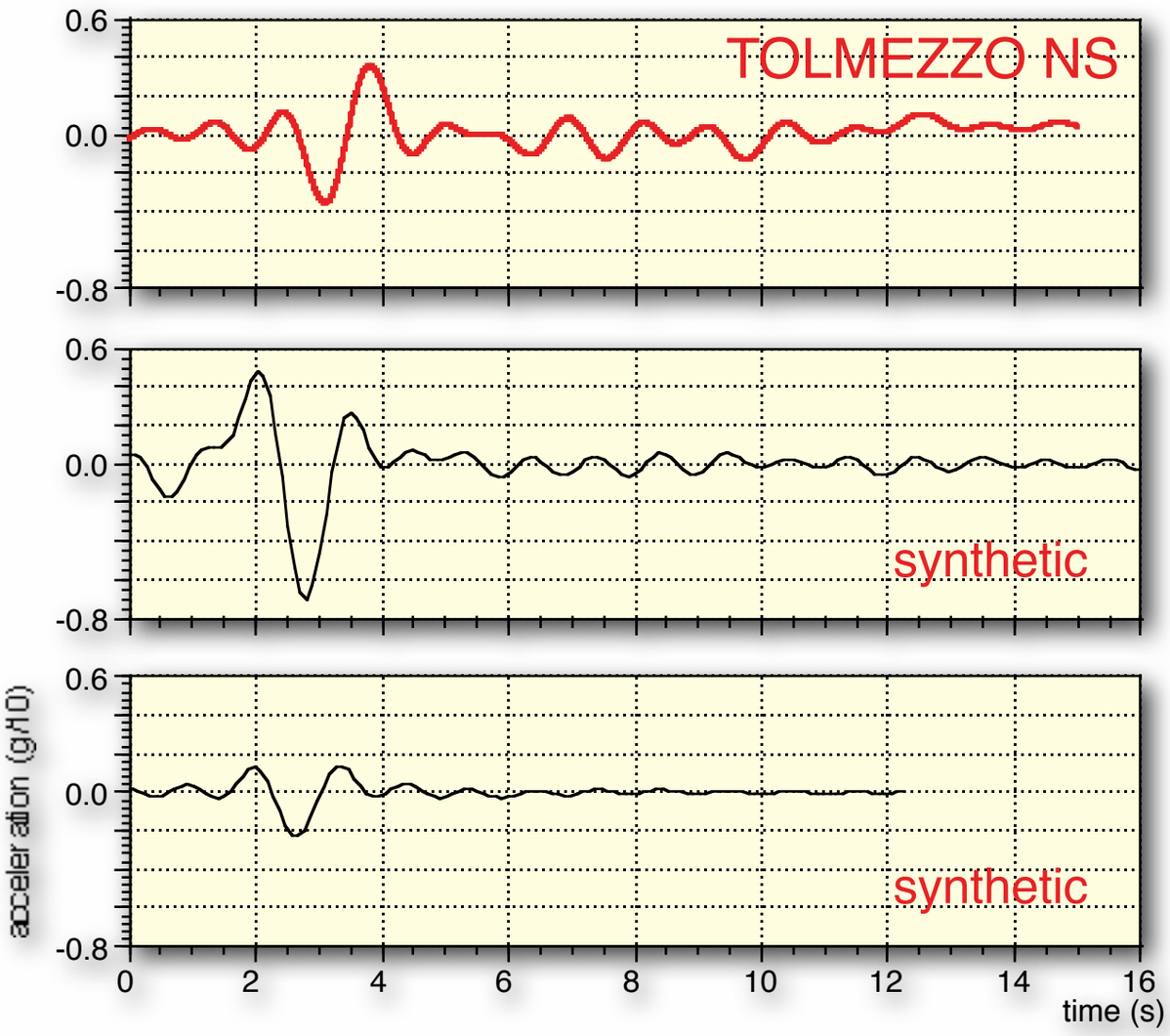


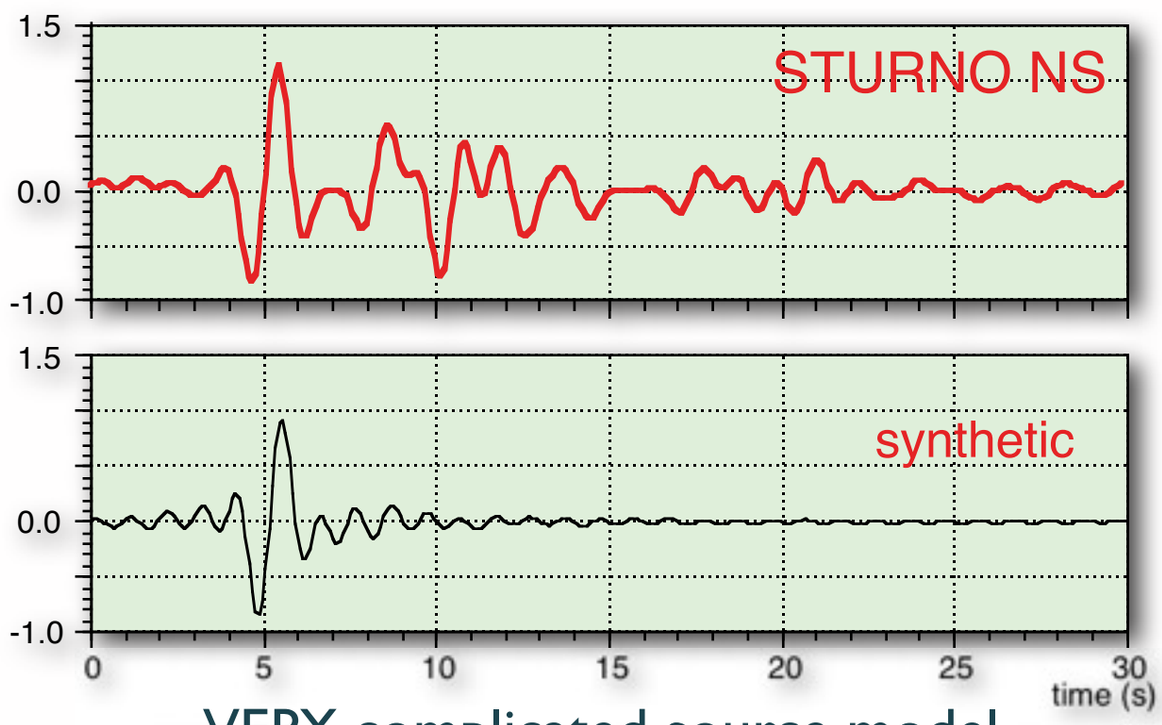
# Regional Scale - Check (1 Hz cutoff)

## 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)

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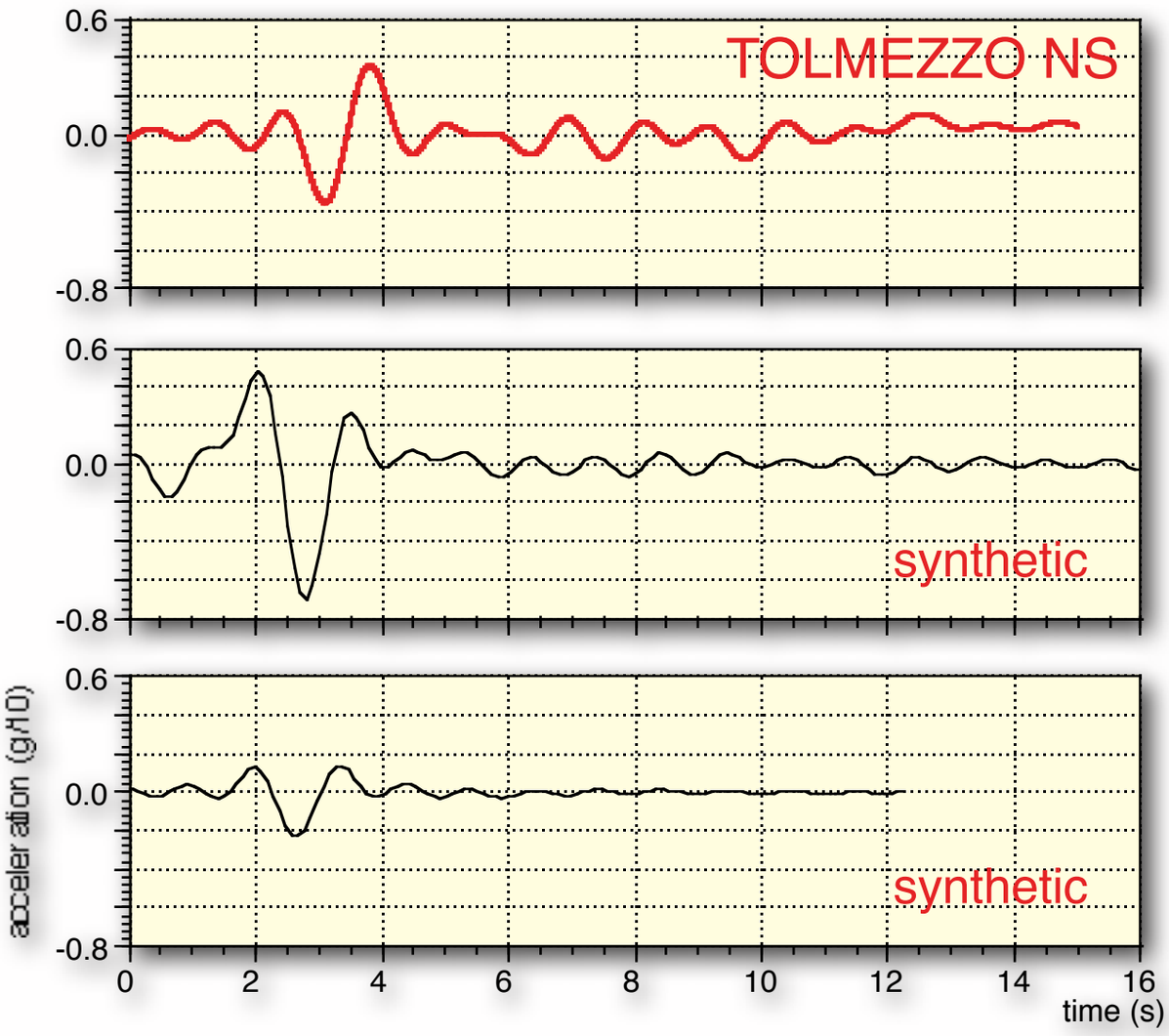


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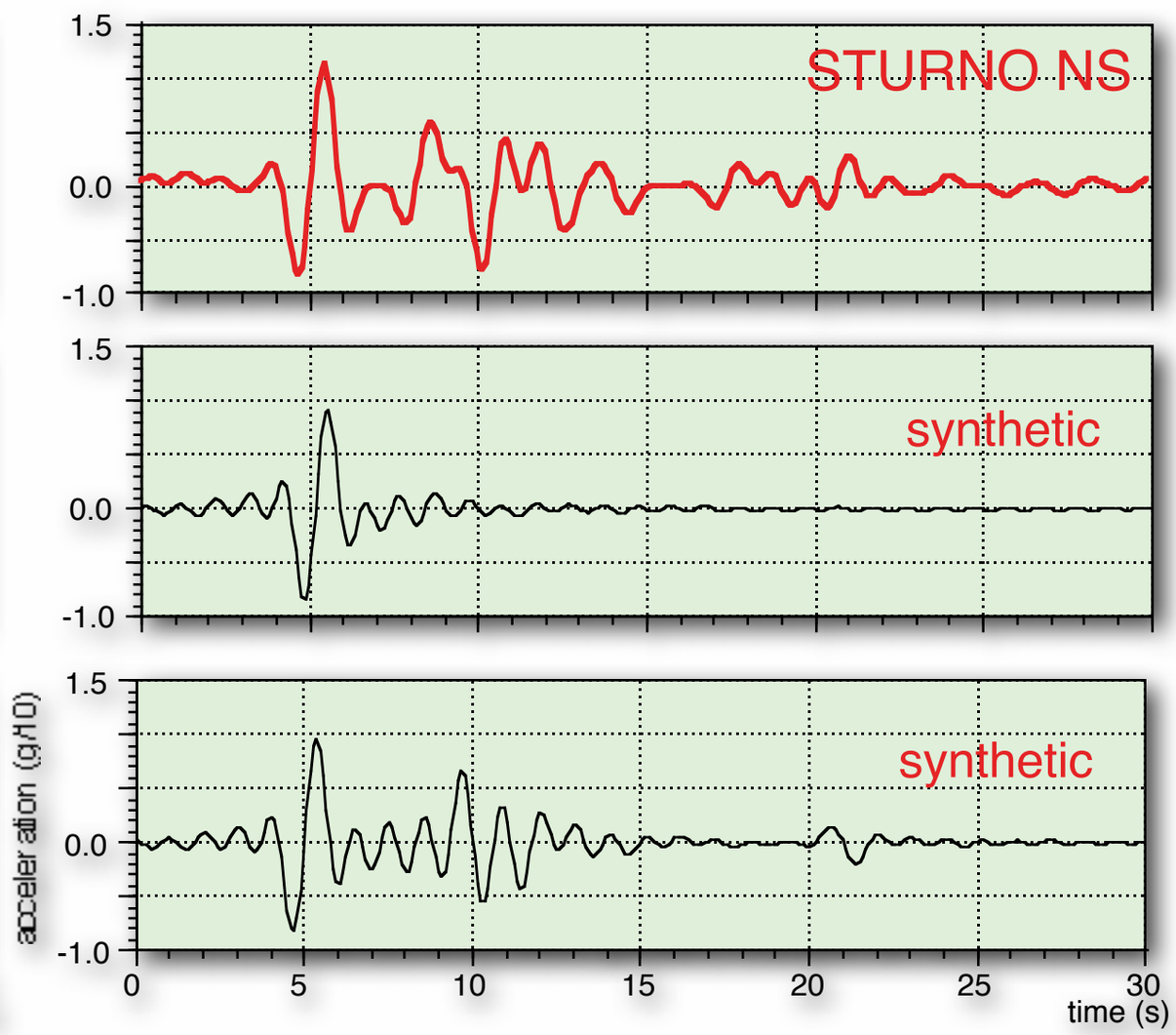
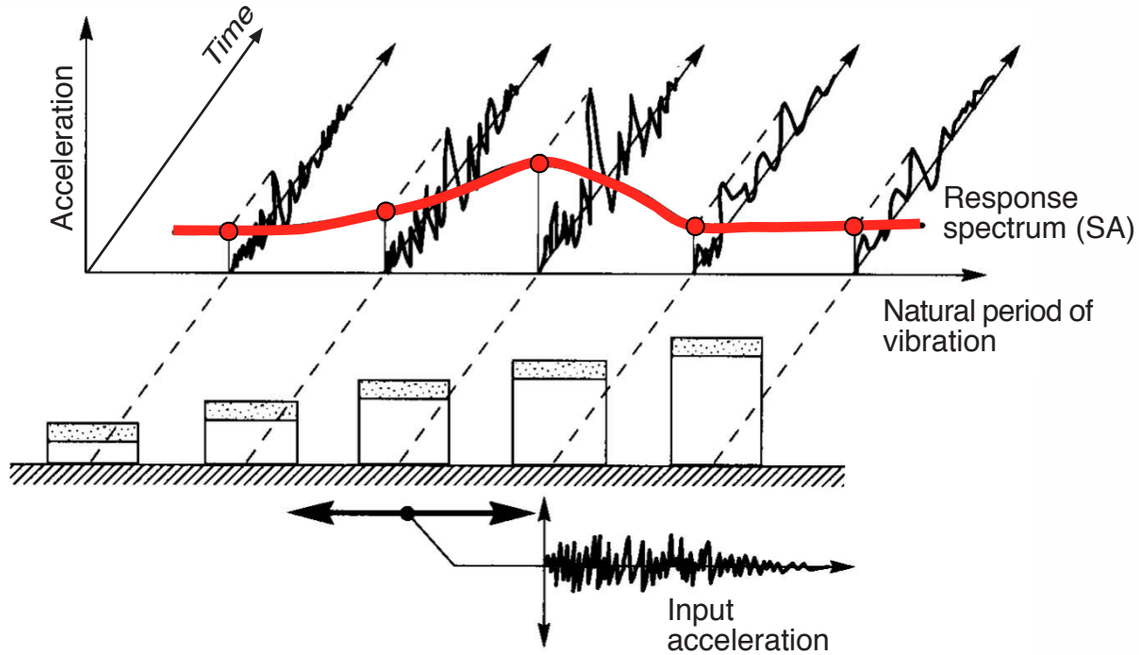



With a sequence of point sources the duration can be reproduced but this is deliberately neglected since rupturing process is not known a priori

# 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



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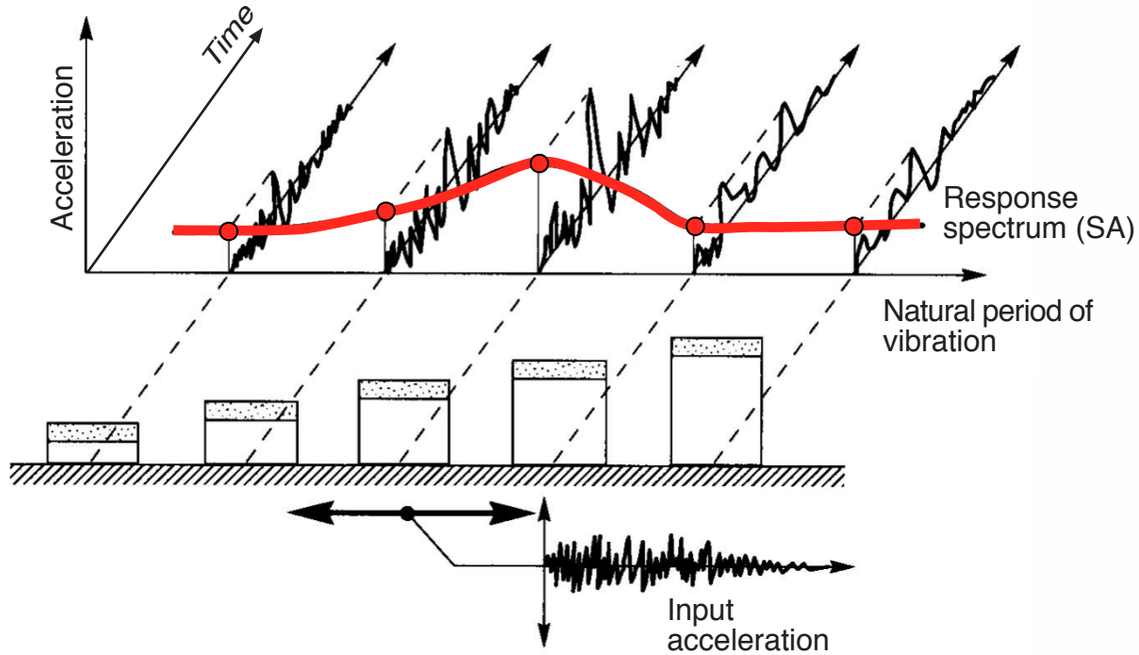
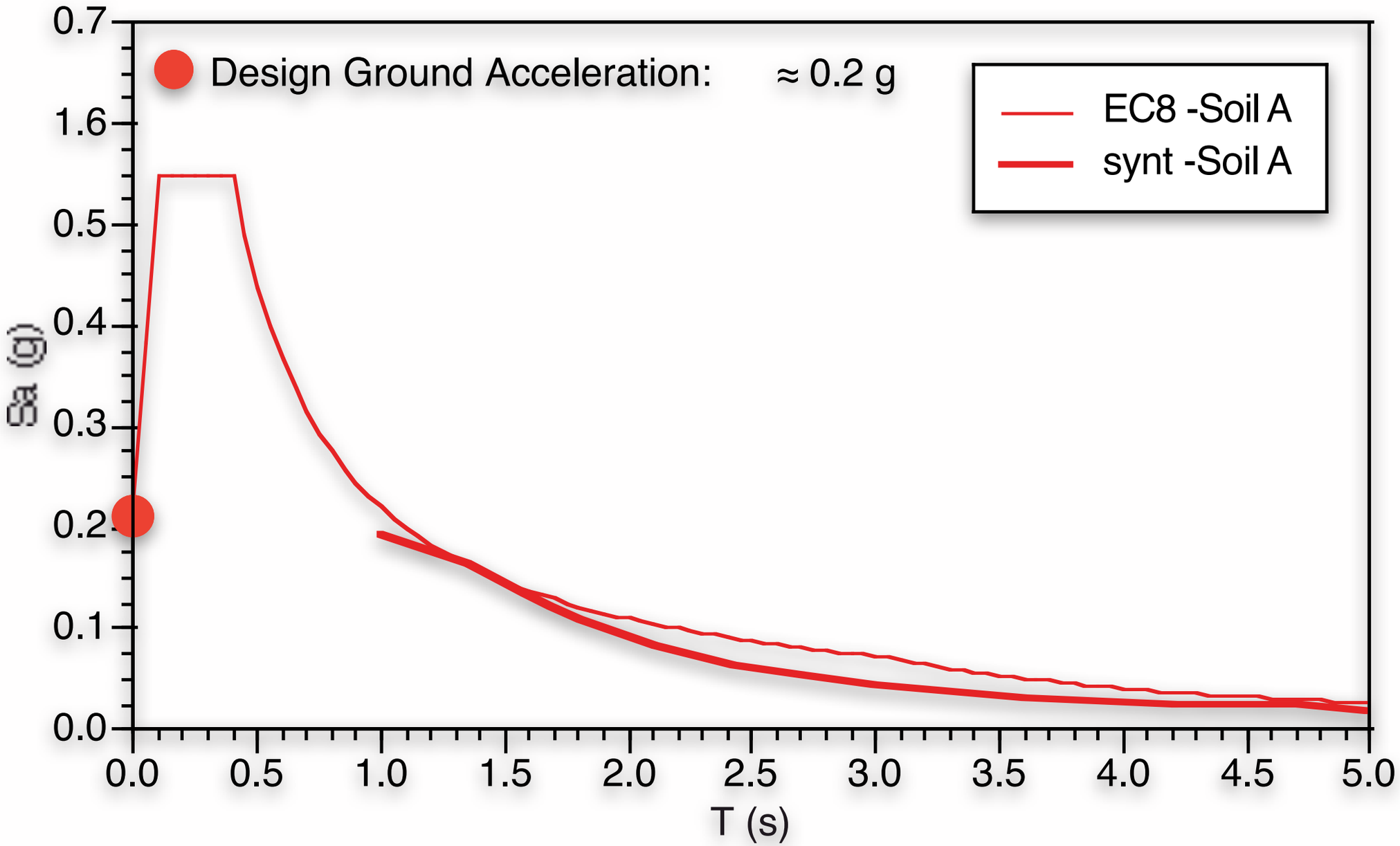
Response spectrum




- Rule of thumb for a rough estimate of the resonance period: T=1 s every 10 floors, but it strongly depends on the building characteristics (type of construction, geometry etc)

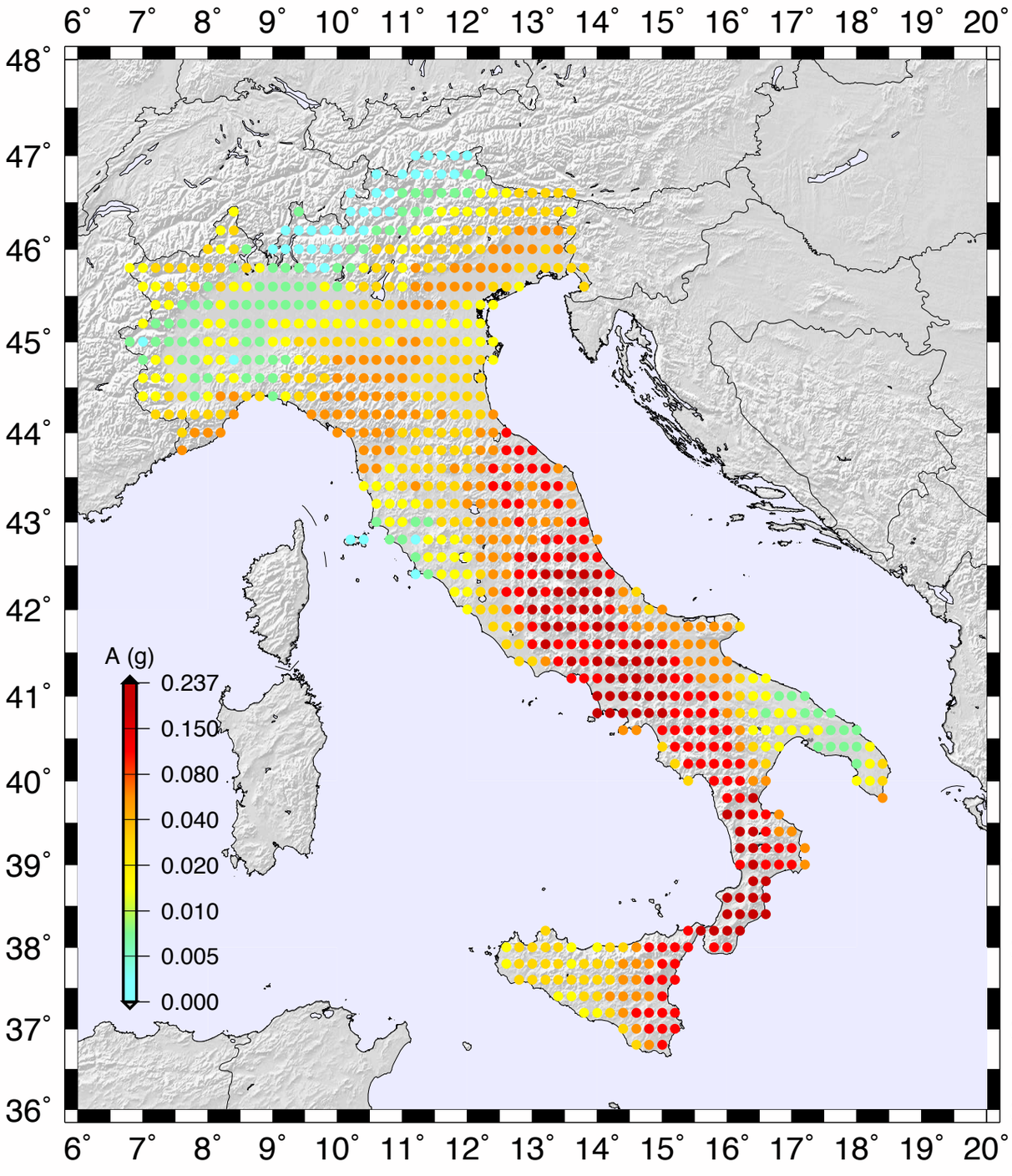
# Design Ground Acceleration (DGA)

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

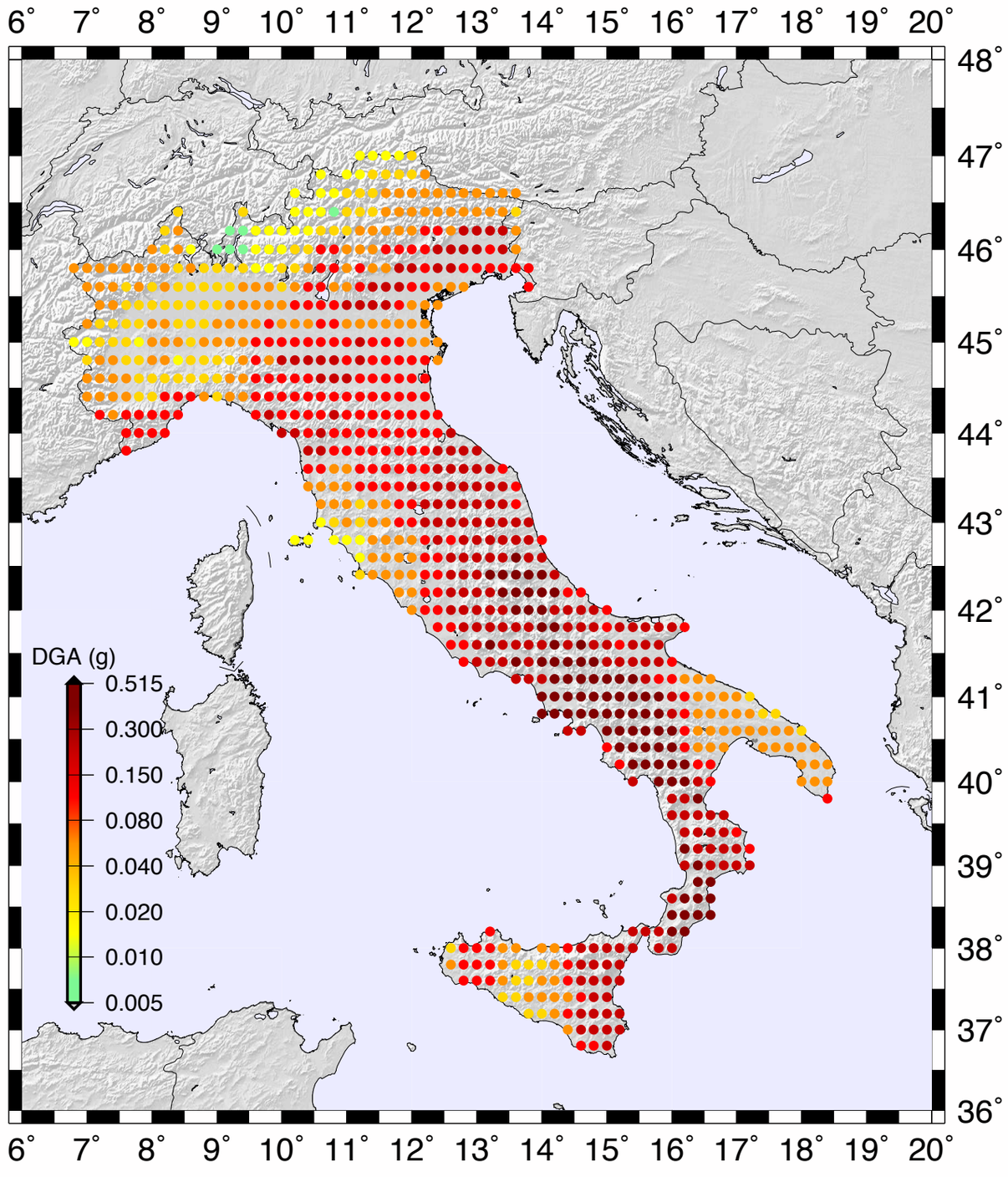


# Acceleration

## Amplitude of Peaks from Time Series (1Hz)

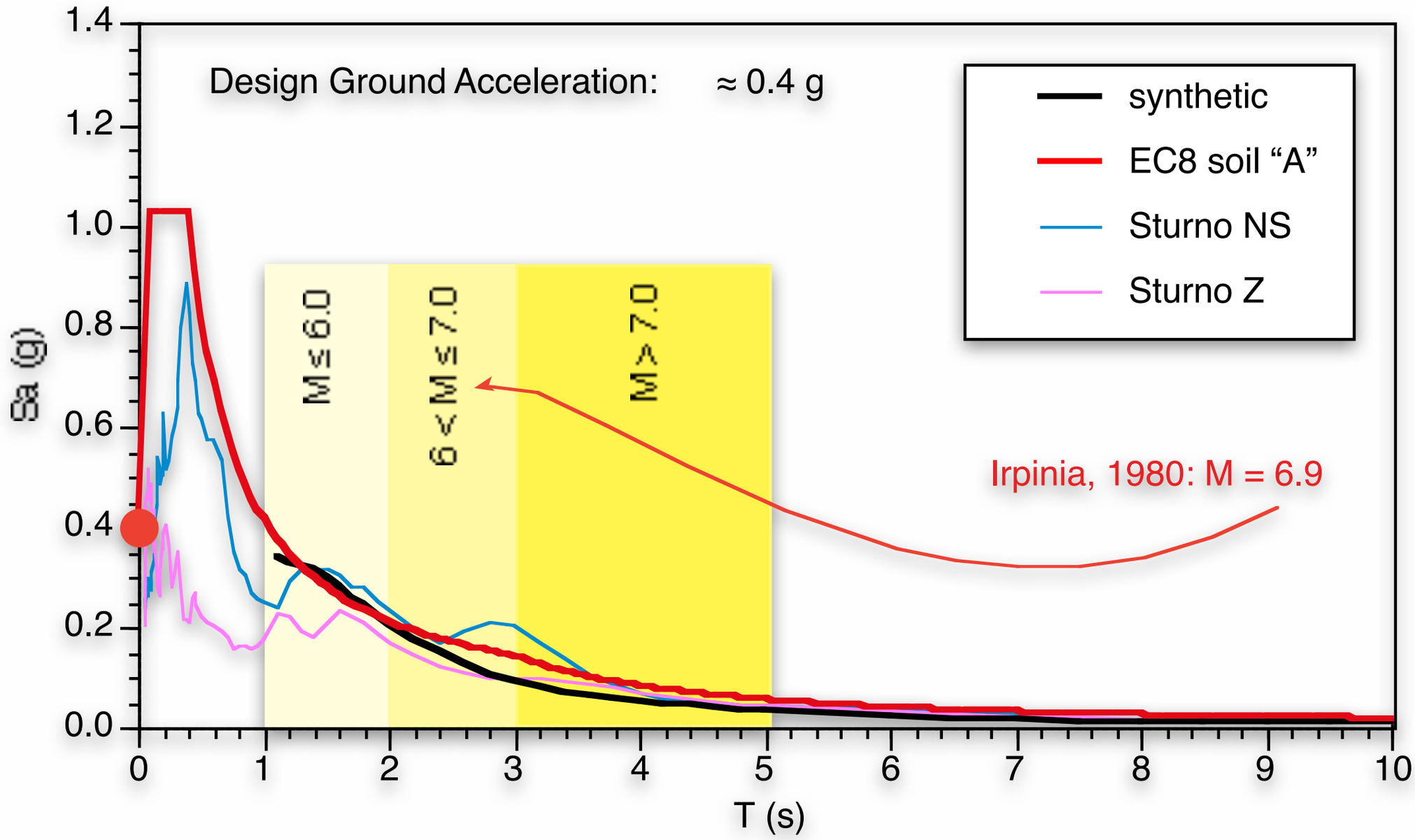



## DGA Extrapolated by Means of Design Spectrum



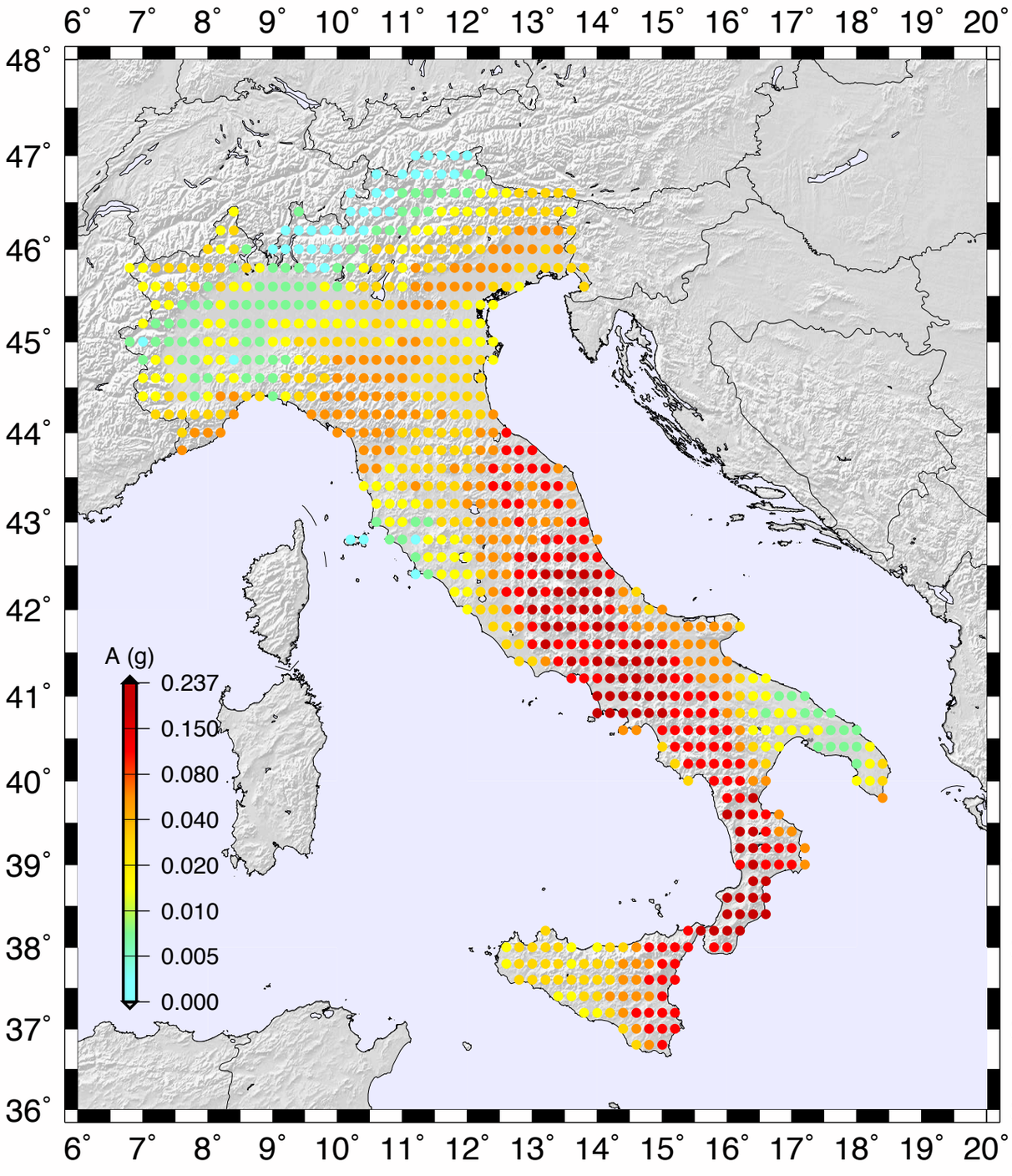
# Design Ground Acceleration (DGA)

- 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



# Acceleration

## Amplitude of Peaks from Time Series (1Hz)




## DGA Extrapolated by Means of Design Spectrum