2142-Presentation

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Asi-Sisma Presentations

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Present-day deformation field in the Central Mediterranean region revealed by the coupled use of thermomechanical modelling and geodetic data

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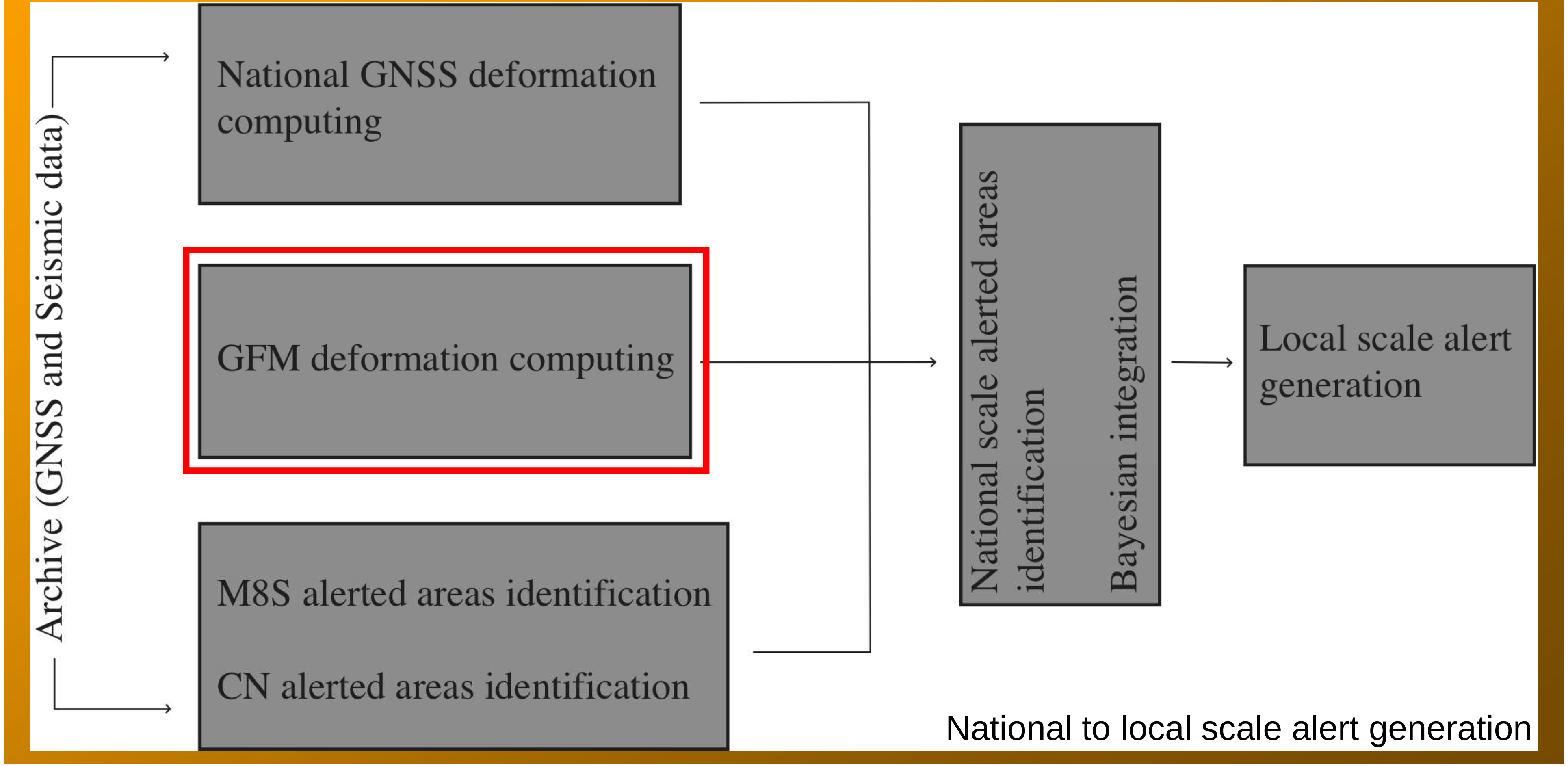
Project SISMA

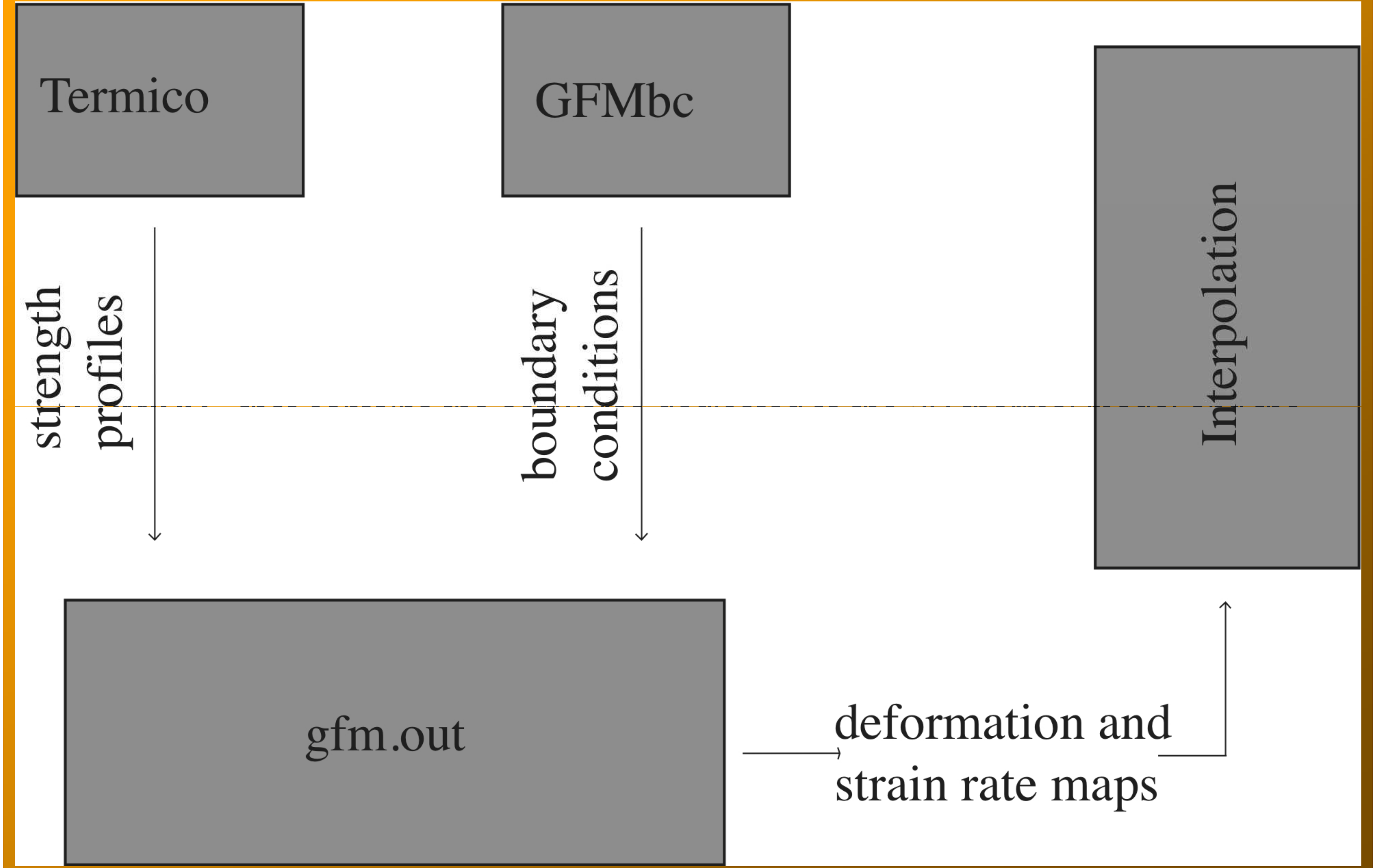
SISMA (Seismic Information System for Monitoring and Alert) is is a pilot project for the seismic hazard monitoring in Italy, funded by ASI (Italian Space Agency).

SISMA is a multiscale and multidisciplinary approach to the analysis of the seismic risk on the Italian Peninsula, that combines probabilistic methodologies with deterministic techniques in order to evaluate the hazard in a more consistent way.



National to local scale alert generation

GFM modulus



Termico

GFMbc

Interpolation

strength profiles

boundary conditions

gfm.out

deformation and strain rate maps

Numerical Model

Numerical model contains two different finite element model:

- *Finite element 2D <u>tectonic model</u>*, with “Thin Sheet” approach and spherical coordinates in which rheological heterogeneities, computed by a thermal model, are considered:
    - Tectonic velocity field (intermediate product)
    - Deformation map (GFM product)
    - Strain-rate map (GFM product)

- *Finite element 3D <u>thermal model</u>*:
    - Litospheric temperature vertical profiles (intermediate product)
    - Strength profiles, and effective viscosity (intermediate product)

Tectonic model

Tectonic model solves the momentum equations in spherical coordinates on a bidimensional grid, computing the horizontal velocities:

$$\frac{\partial}{\partial\theta}\left[2\overline{\mu}\left(\frac{\partial}{\partial\theta}u_\theta-\frac{1}{2}\left(\frac{\partial u_\theta}{\partial\theta}+\frac{1}{\sin\theta}\frac{\partial u_\Phi}{\partial\Phi}+u_\theta\cot\theta\right)\right)\right]+\frac{1}{\sin\theta}\frac{\partial}{\partial\Phi}\left[\overline{\mu}\left(\frac{1}{\sin\theta}\frac{\partial}{\partial\Phi}u_\theta+\frac{\partial}{\partial\theta}u_\Phi-u_\Phi\cot\theta\right)\right]$$

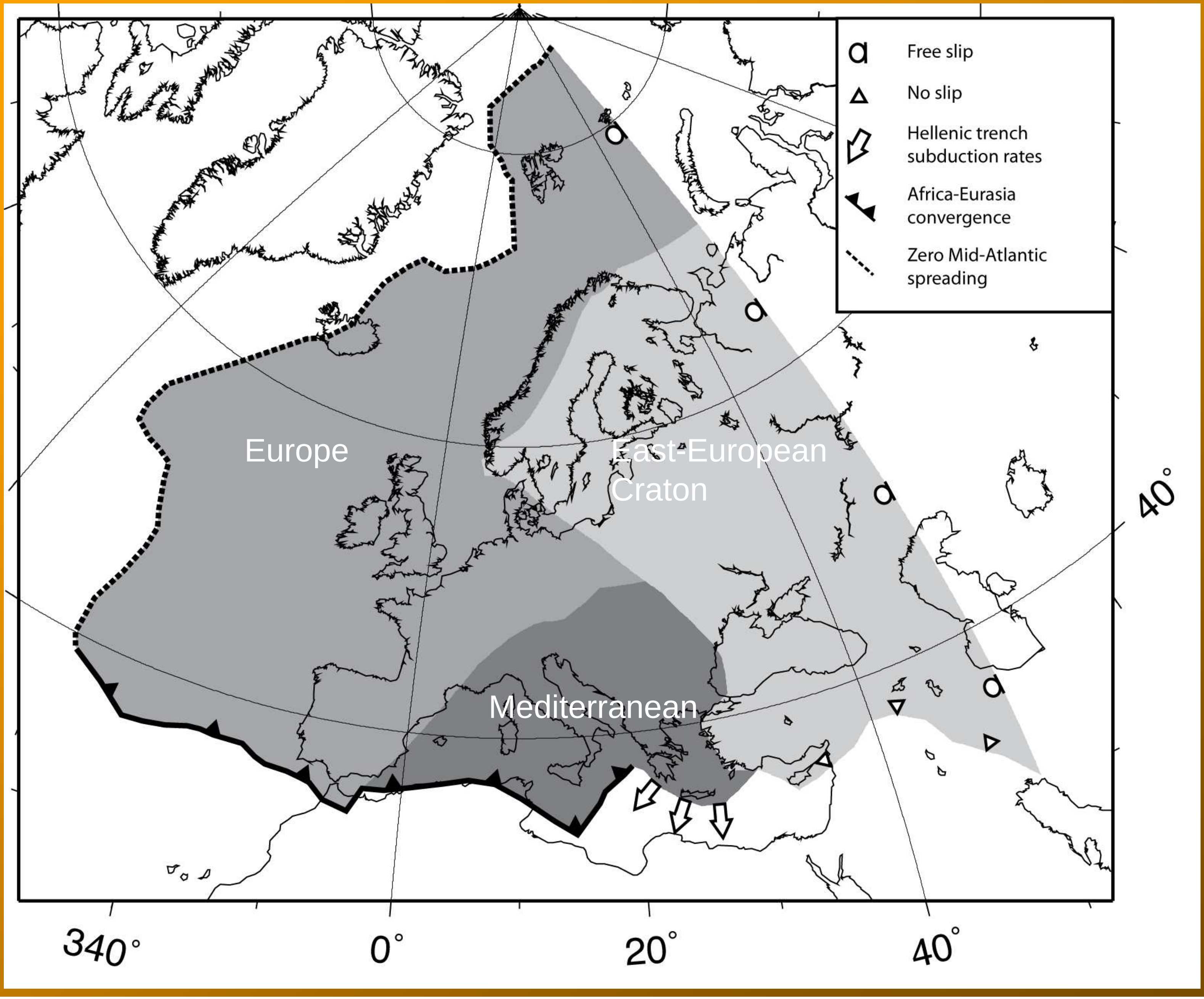
$$+\left[2\overline{\mu}\left(\frac{\partial}{\partial\theta}u_\theta-\frac{1}{\sin\theta}\frac{\partial}{\partial\Phi}u_\Phi-u_\theta\cot\theta\right)\right]\cot\theta=\frac{g\rho_c R}{2L}\left(1-\frac{\rho_c}{\rho_m}\right)\frac{\partial}{\partial\theta}S^2 \qquad (1)$$

$$\frac{\partial}{\partial\theta}\left[\overline{\mu}\left(\frac{1}{\sin\theta}\frac{\partial}{\partial\Phi}u_\theta+\frac{\partial}{\partial\theta}u_\Phi-u_\Phi\cot\theta\right)\right]+$$

$$\frac{1}{\sin\theta}\frac{\partial}{\partial\Phi}\left[2\overline{\mu}\left(\frac{1}{\sin\theta}\frac{\partial}{\partial\Phi}u_\theta+\frac{\partial}{\partial\theta}u_\Phi-u_\Phi\cot\theta\right)\right]\cot\theta=\frac{g\rho_c R}{2L}\left(1-\frac{\rho_c}{\rho_m}\right)\frac{1}{\sin\theta}\frac{\partial}{\partial\Phi}S^2 \qquad (2)$$

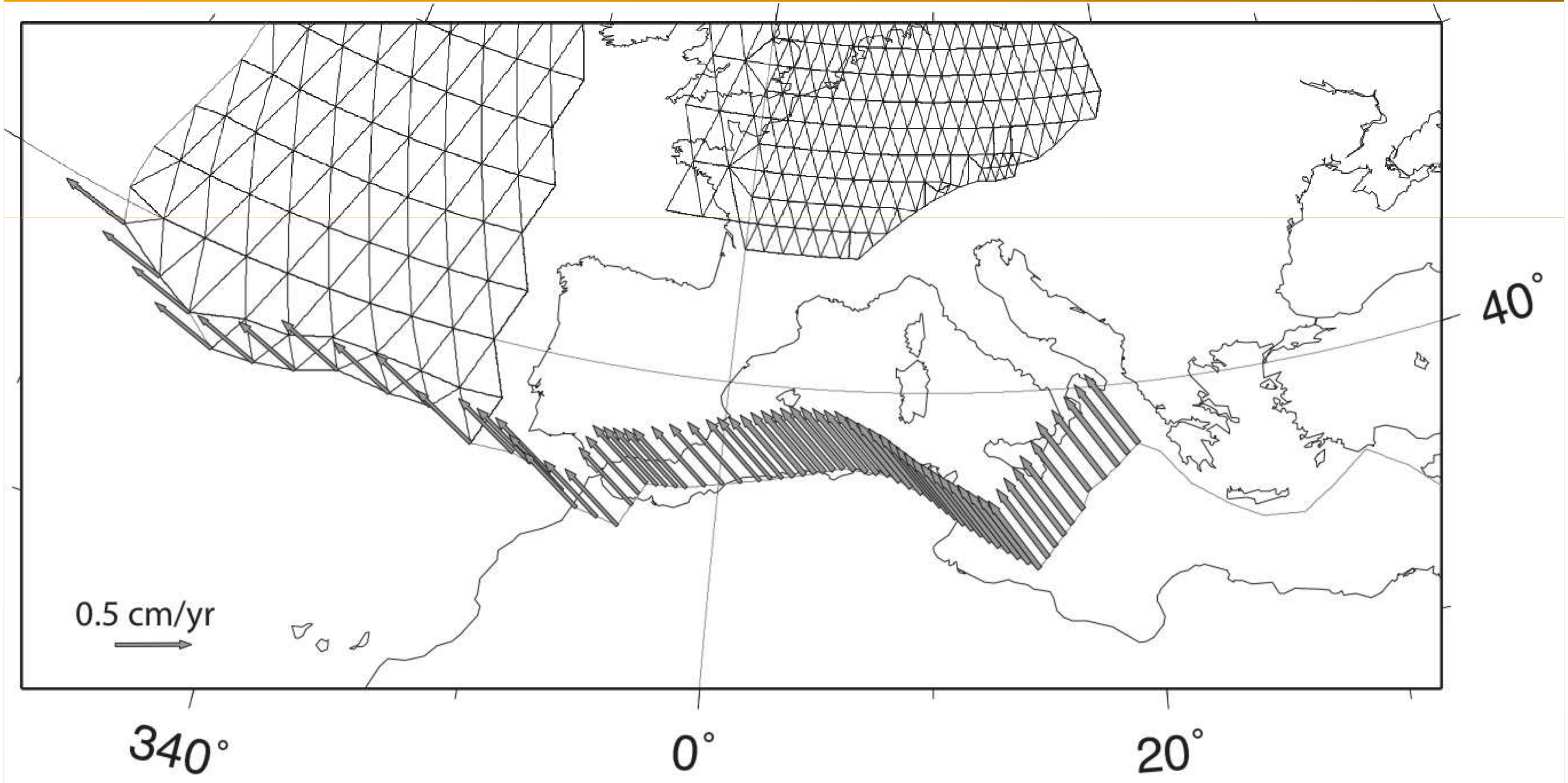
Starting from the horizontal velocity components, horizontal *strain rate* is predicted using the procedure described in Devoti et al. (2002)

Tectonic Model: Computation Domain



Tectonic model: mesh and boundary conditions

Boundary conditions (Africa-Eurasia convergence) are computed starting from ITRF 2005 solutions (Altamimi et al., 2007) through the Eulerian poles estimation (Noquet et al., 2001).



Tectonic model: boudary conditions computation

Tectonic model: effective viscosities

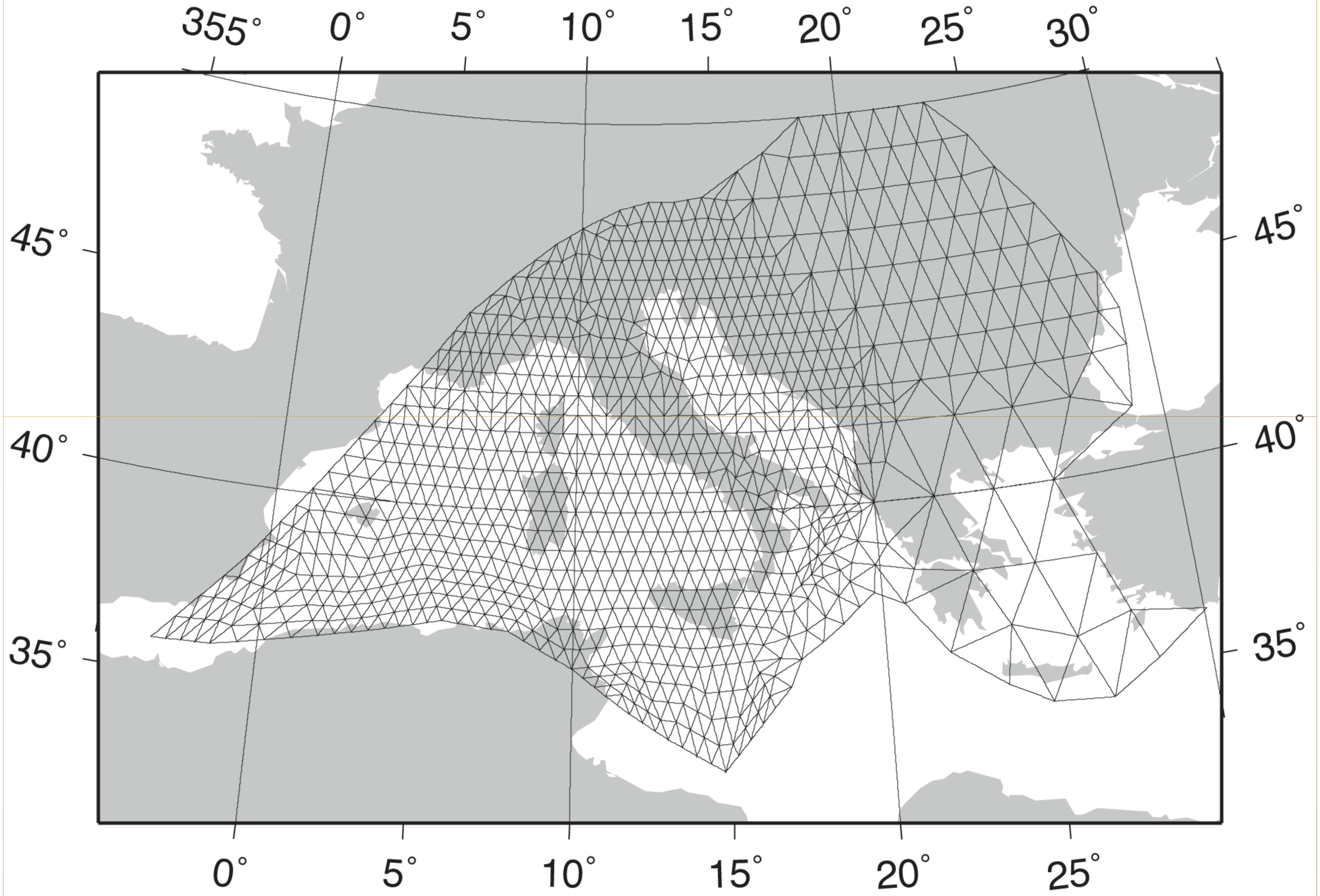
Model computation domain is made of 3 rheologically differentiated blocks, 2 with fixed effective viscosity:

- Europe: effective viscosity $=10^{25}$ Pas
- East-European craton: effective viscosity $=10^{27}$ Pas

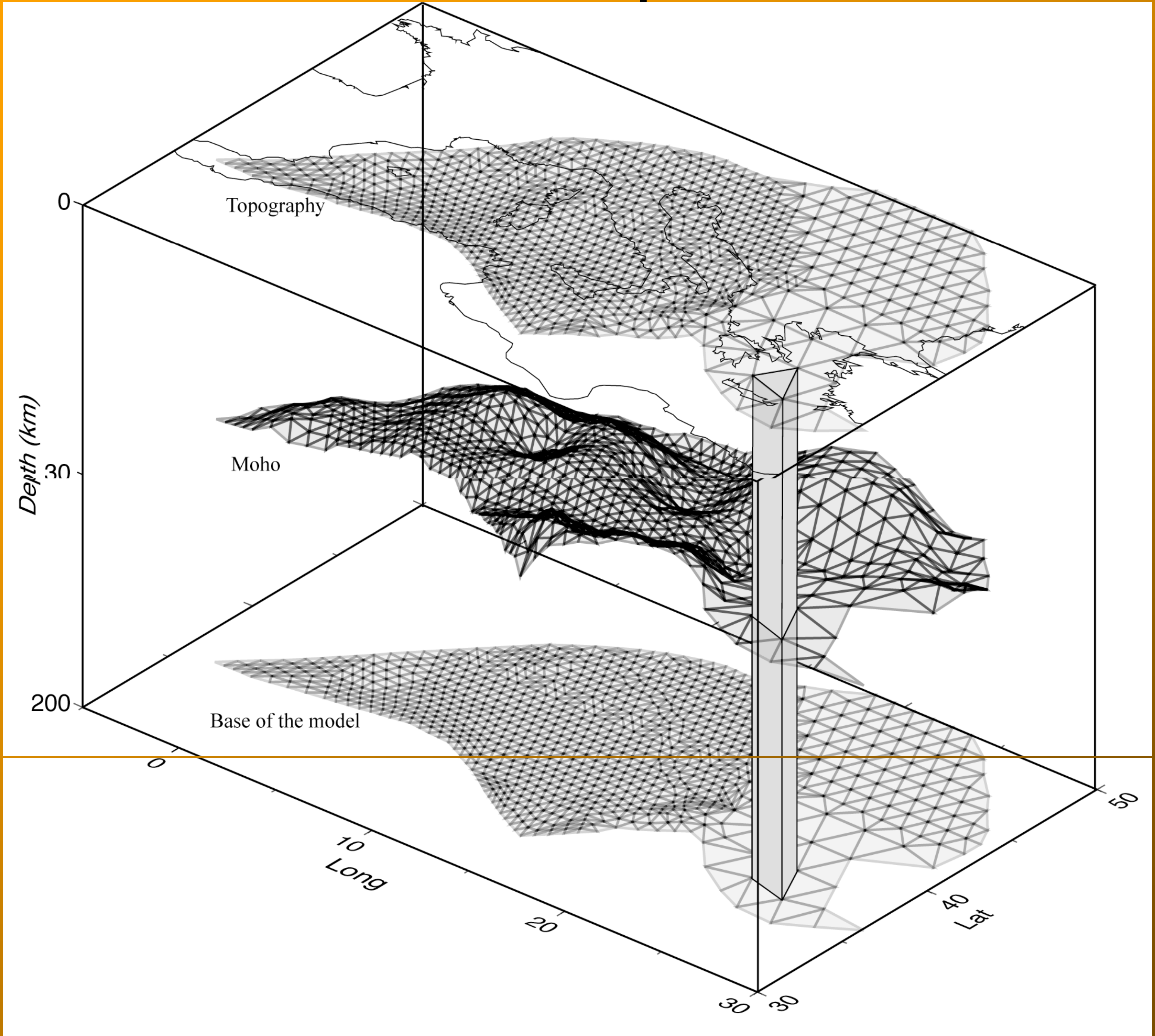
And one with calculated effective viscosity:

- Mediterranean: effective viscosity=calculated by finite element 3D thermal model coupled with a rheological analysis

Thermal model: computation domain



Thermal model: computation domain



Thermal model: equations and boundary conditions

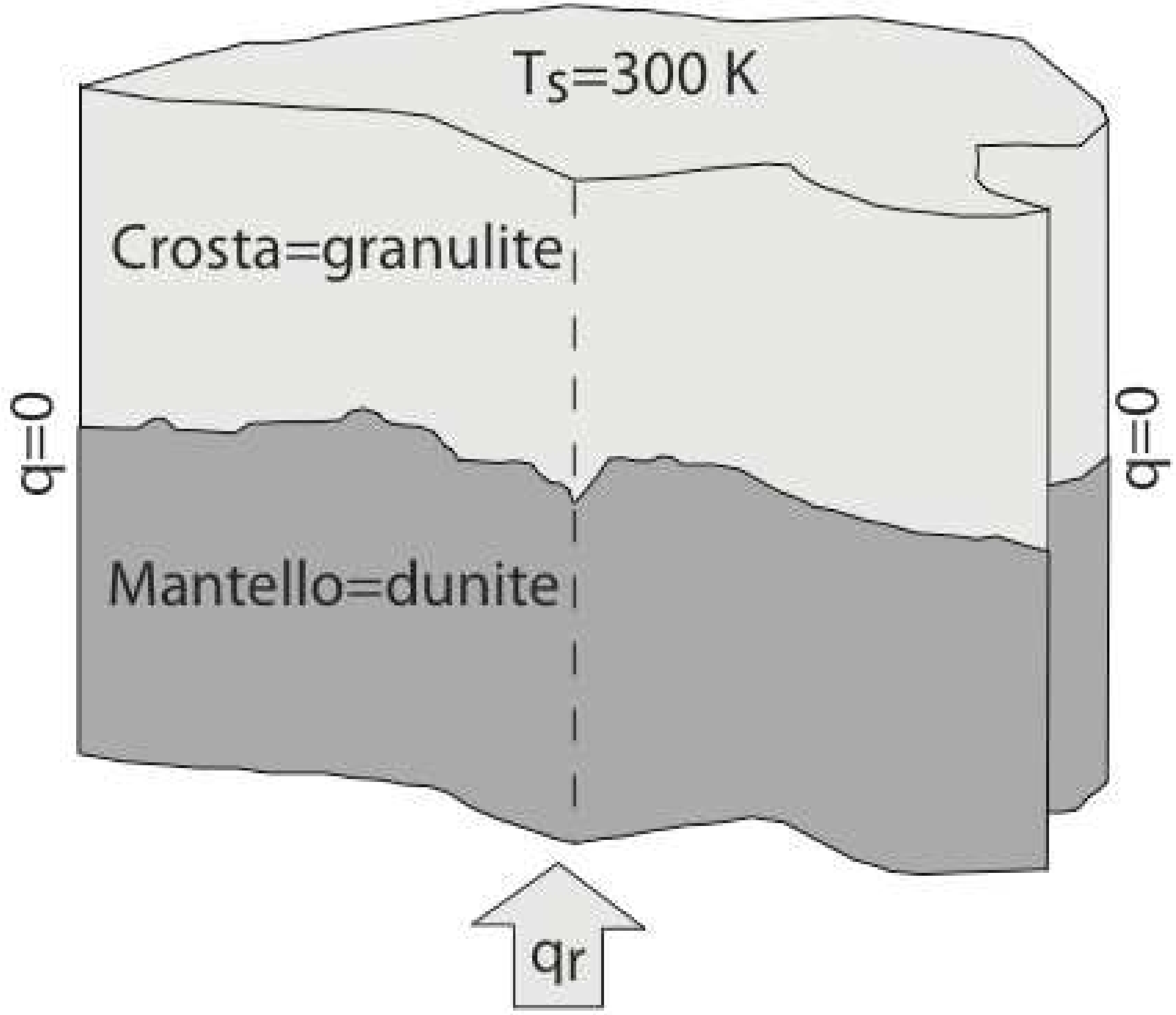
Thermal model solves the conduction equation on a 3D stratified grid, computing the vertical temperature profiles of the lithosphere:

$$\nabla \cdot \left(k \nabla T\right) + \rho H = 0$$

Model boundary conditions are:

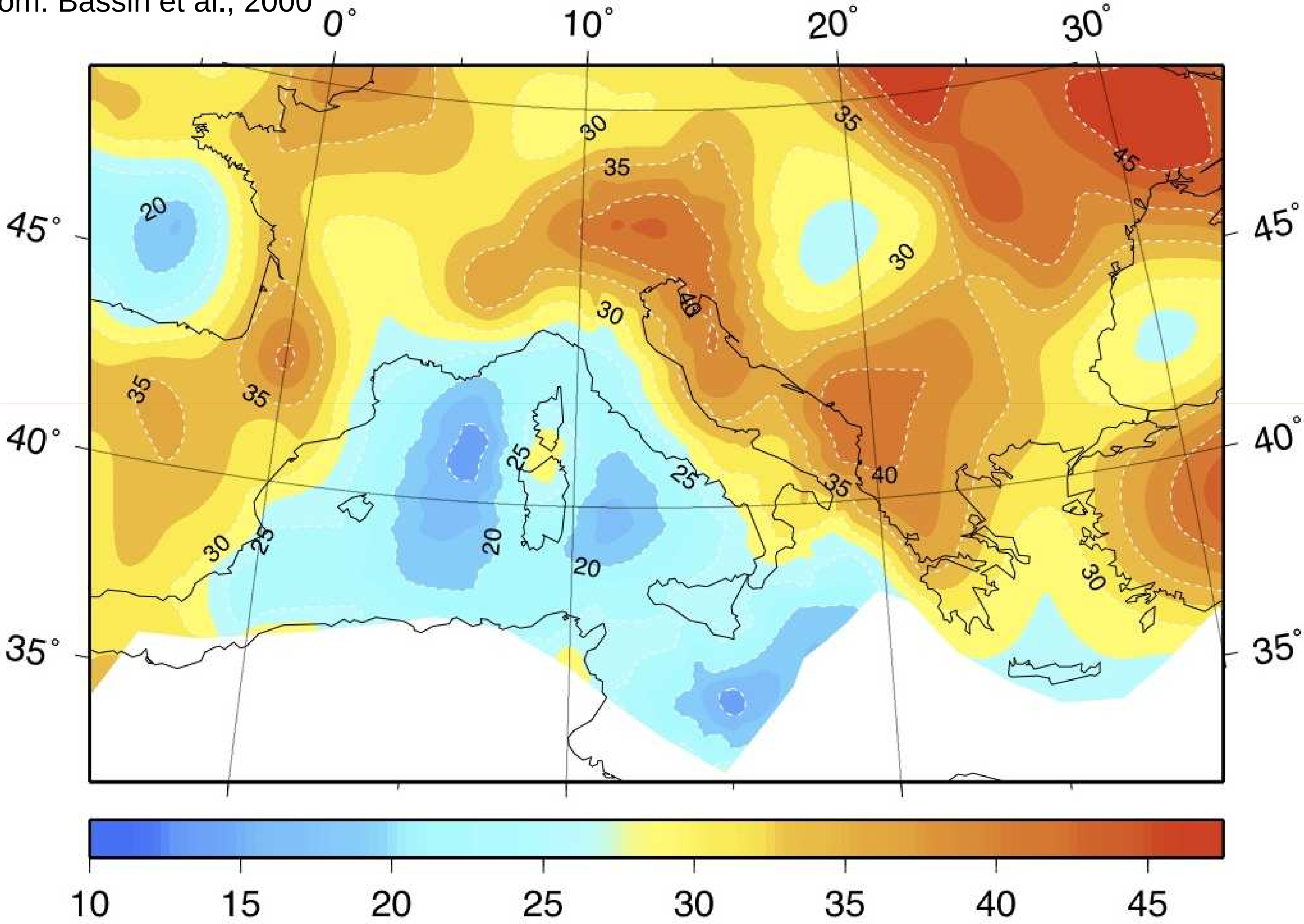
- Surface temperature of 300 K
- Zero heat flow at the lateral boundaries of the mesh
- Residual heat flow at the base of the model, calculated starting from the surface heat flow $q_r = 0.6 q_s$ (Pollack & Chapman, 1977).

Thermal model: equations and boundary conditions



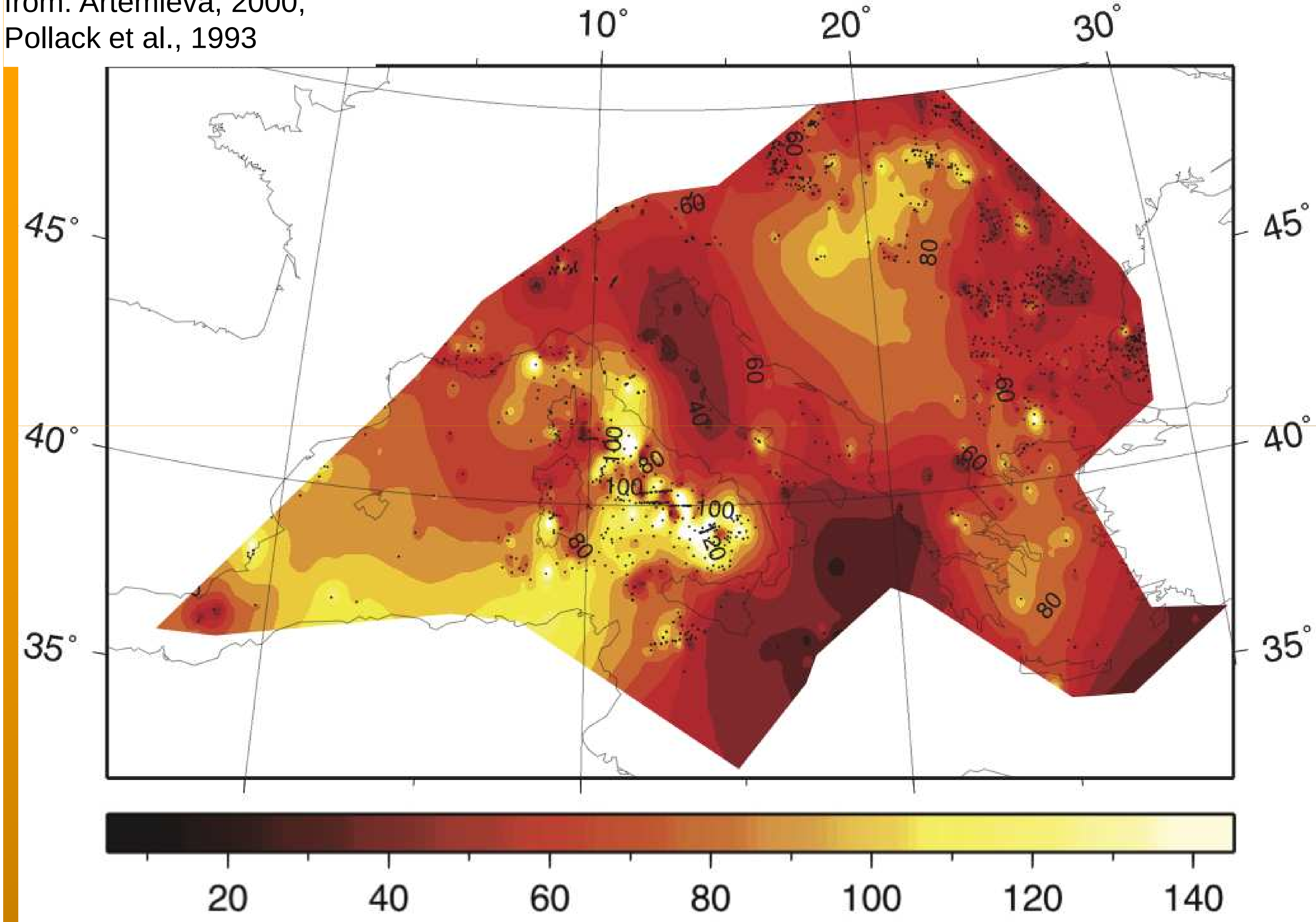
Models database: crustal thickness (km)

From: Bassin et al., 2000

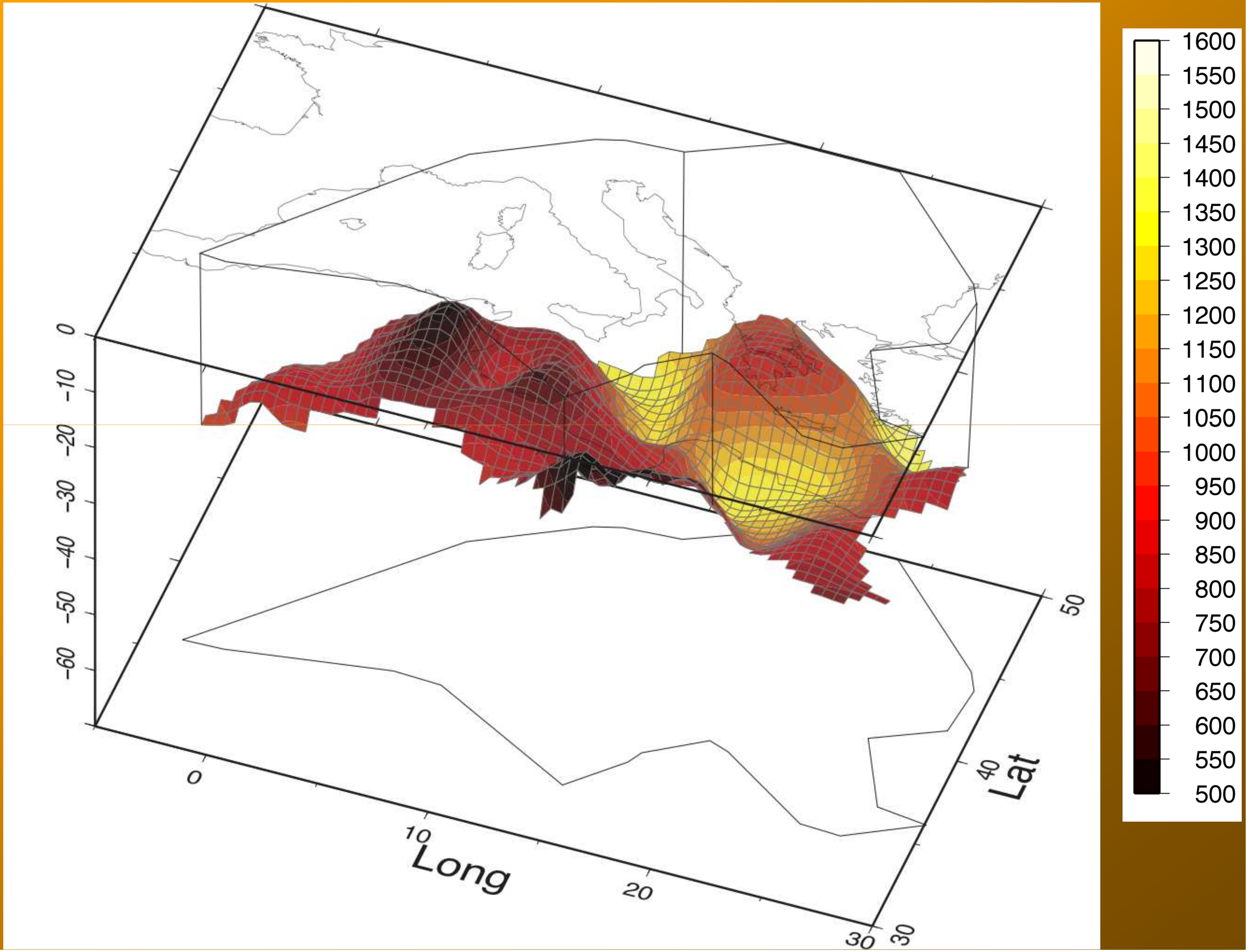


Models database: surface heat flow (mW/m²)

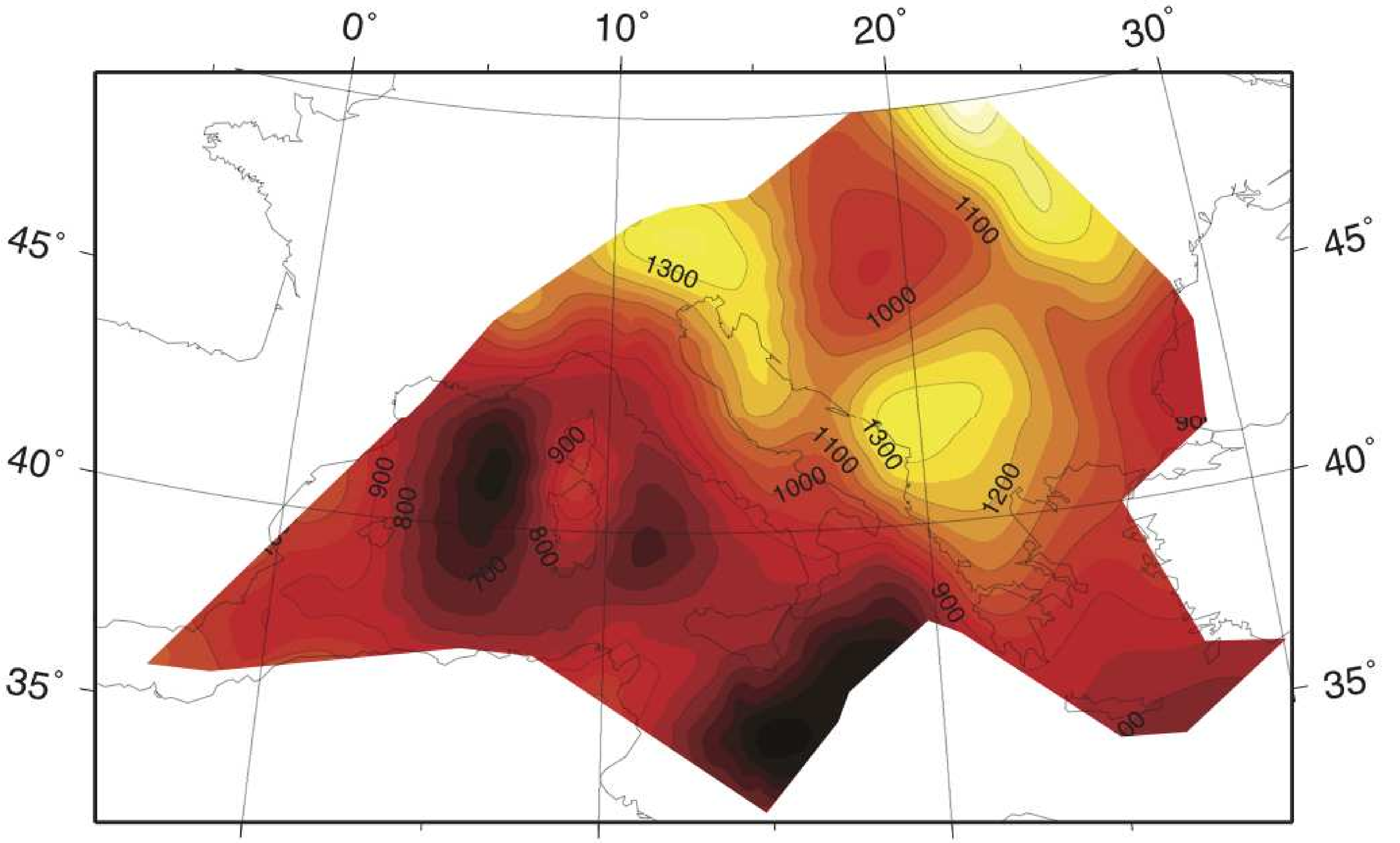
from: Artemieva, 2000;
Pollack et al., 1993



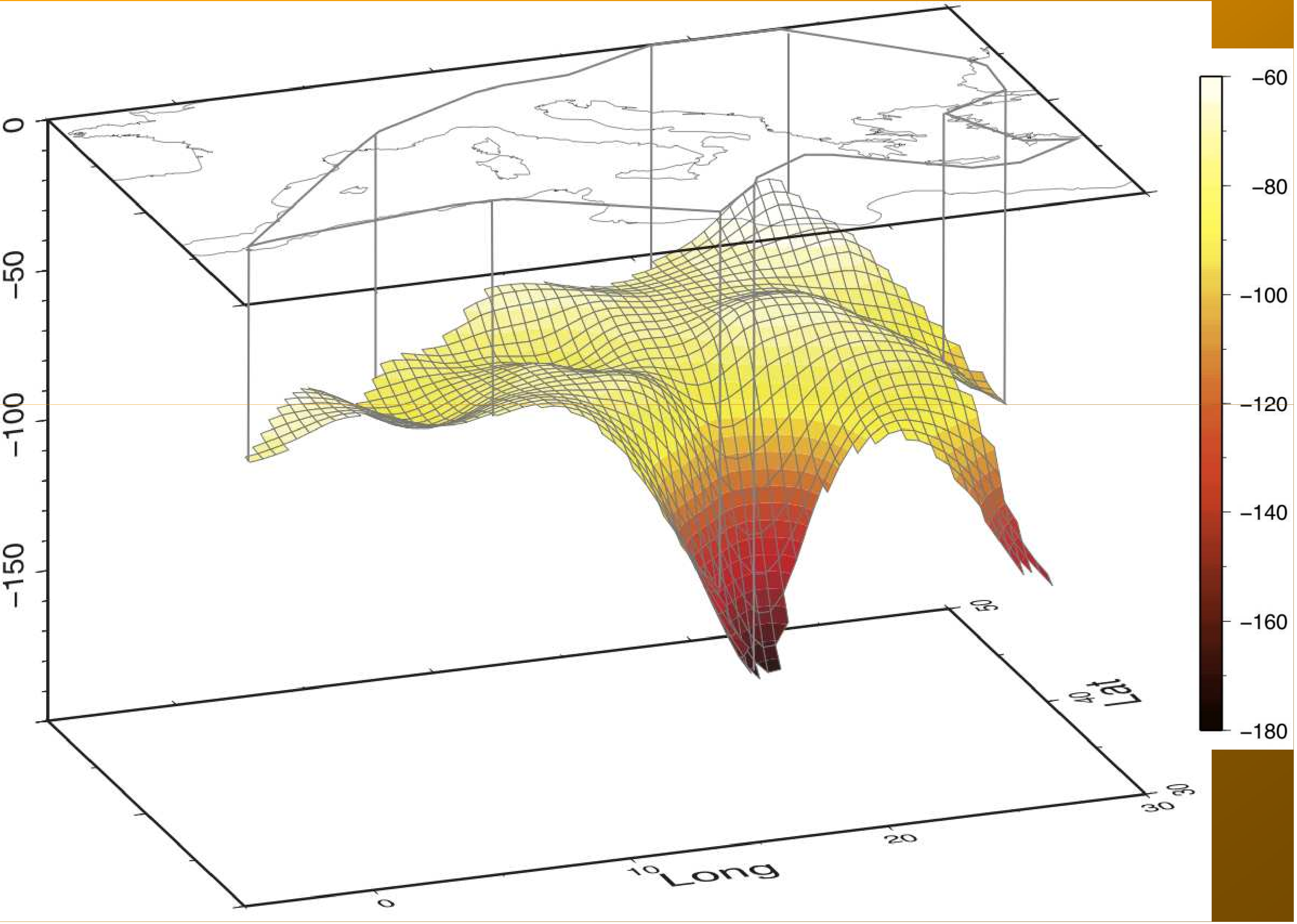
Thermal model: temperature at the Moho depth (K)



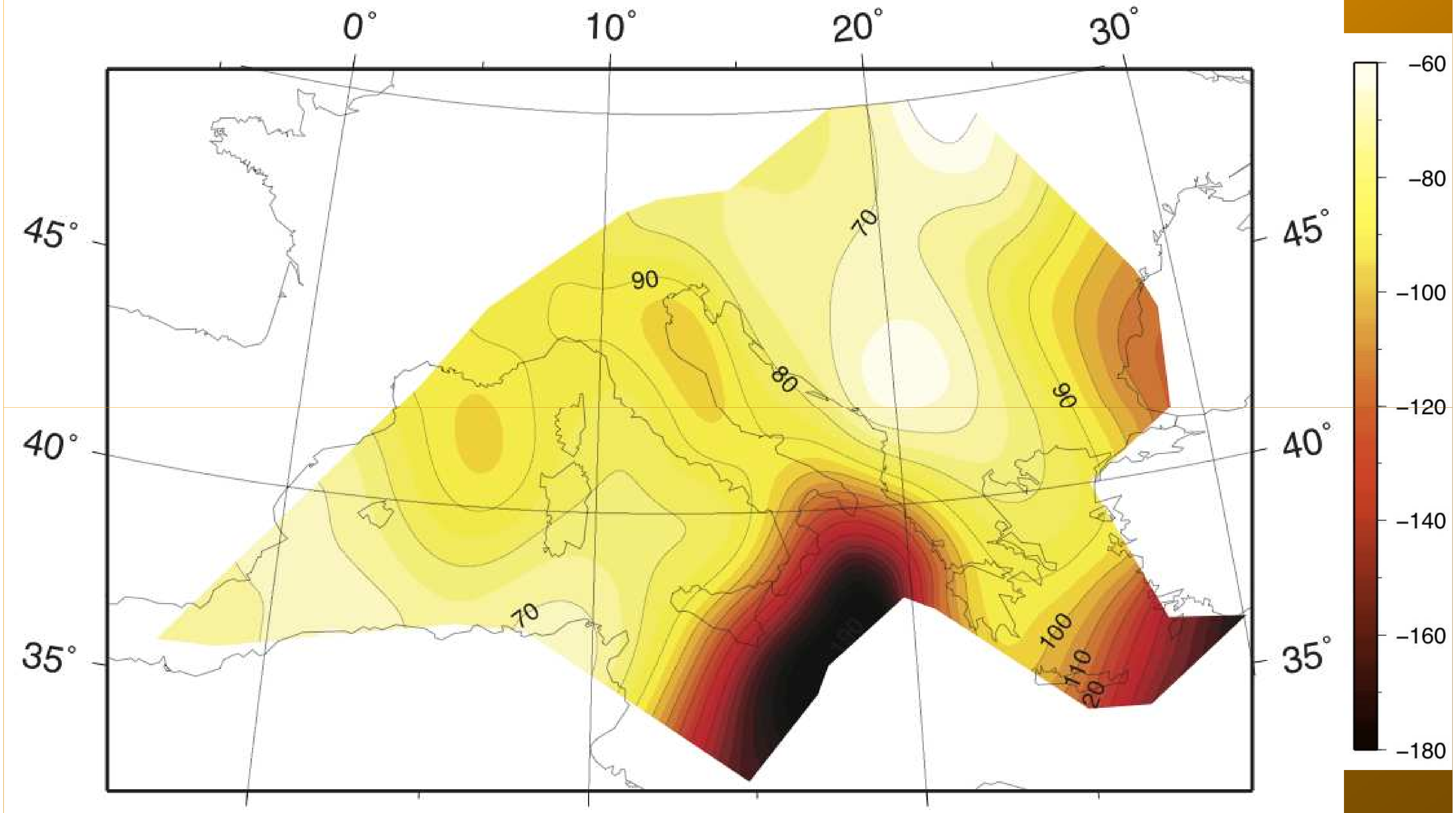
Thermal model: temperature at the Moho depth (K)



Thermal model: thermal lithosphere depth (km)



Thermal model: thermal lithosphere depth (km)



Rheological analysis

Starting from temperature profiles, strength profiles are computed:

<u>Fragile behavior</u> *(Ranalli & Murphy, 1987)*:

$$\sigma_B = (\sigma_H - \sigma_V)_B = \beta \cdot r \cdot \rho \cdot g$$

With $\beta=3$ for compressive regime, $\beta=1.2$ for strike slip regime and $\beta=0.75$ for normal regime.

<u>Ductile behavior</u> *(Weertman & Weertman, 1975)*:

$$\sigma_D = \left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_o}\right)^{\frac{1}{n}} \cdot \exp\left(\frac{E_a}{nRT}\right)$$

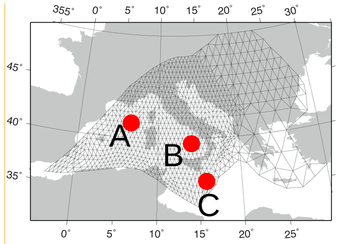
With reference strain rate $\dot{\varepsilon} = 10^{-16}$ s^{-1}

<u>Strength profiles:</u>

$$\sigma_y = \min\{\sigma_B, \sigma_D\}$$

<u>Effective viscosity:</u>

$$\mu_{eff} = \frac{1}{\dot{\varepsilon}}\frac{1}{L}\int_0^L \sigma_y \, dy$$

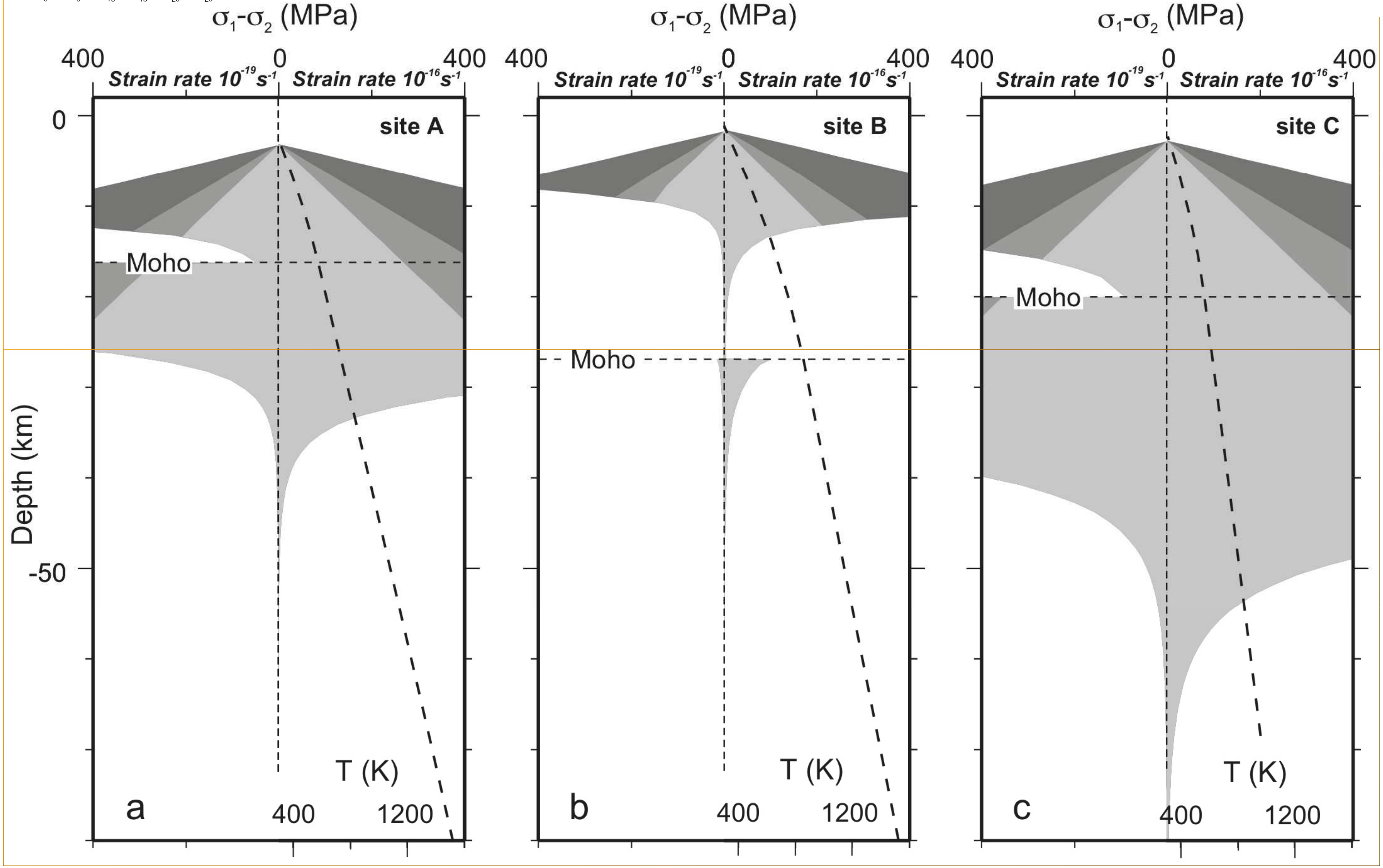


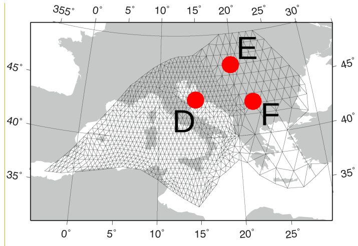
Strength profiles

▨ thrust

▨ strike slip

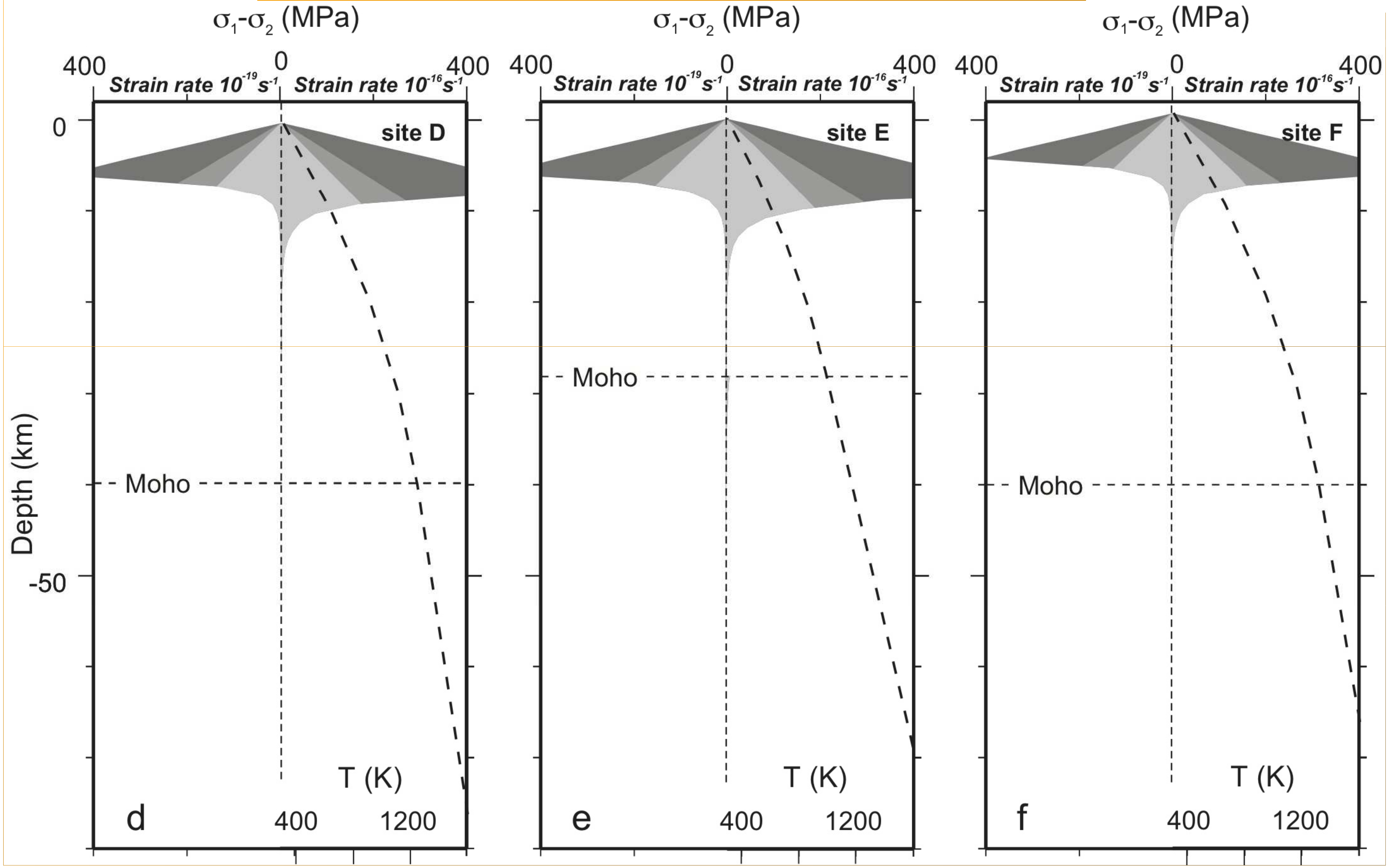
▨ normal



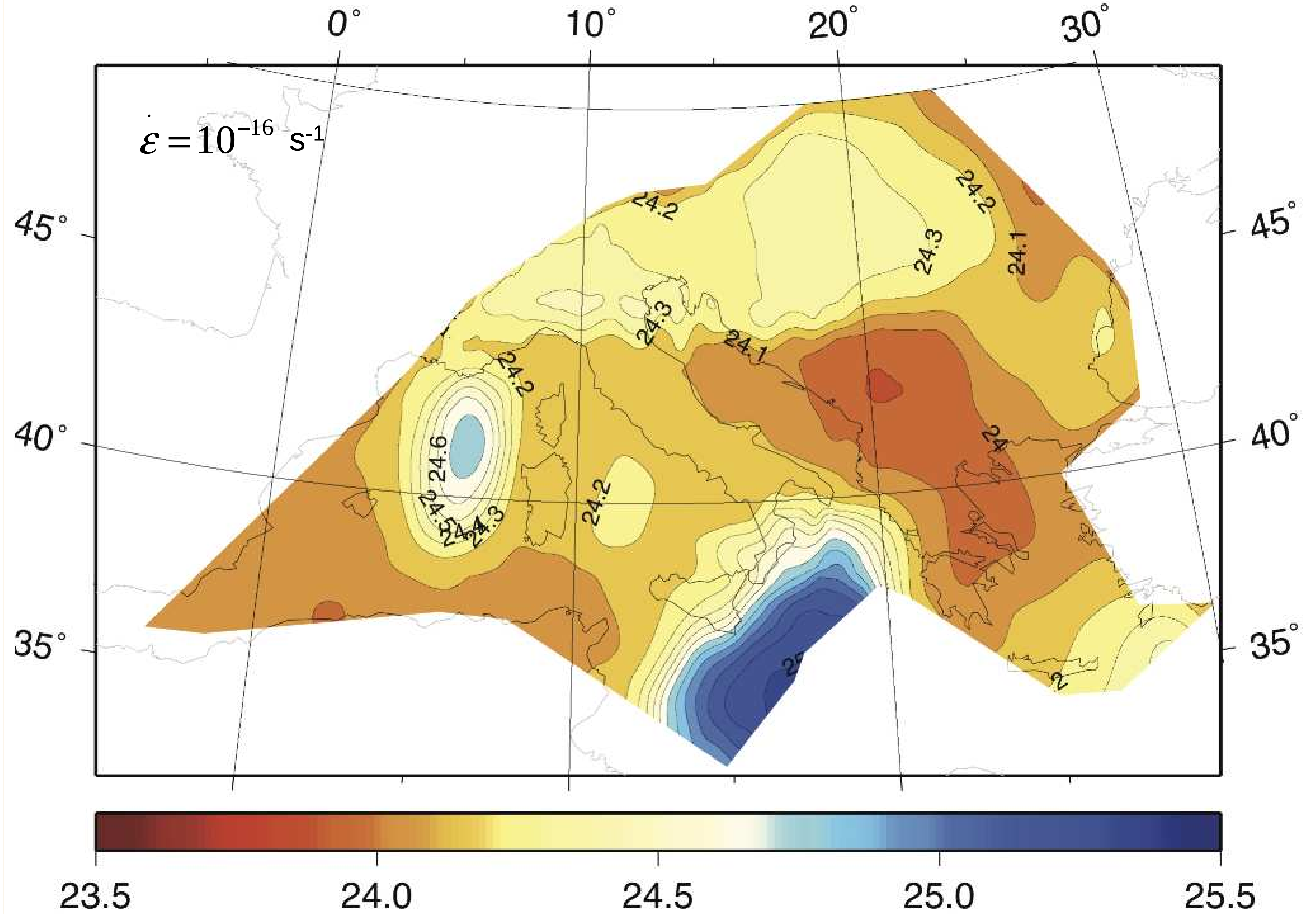


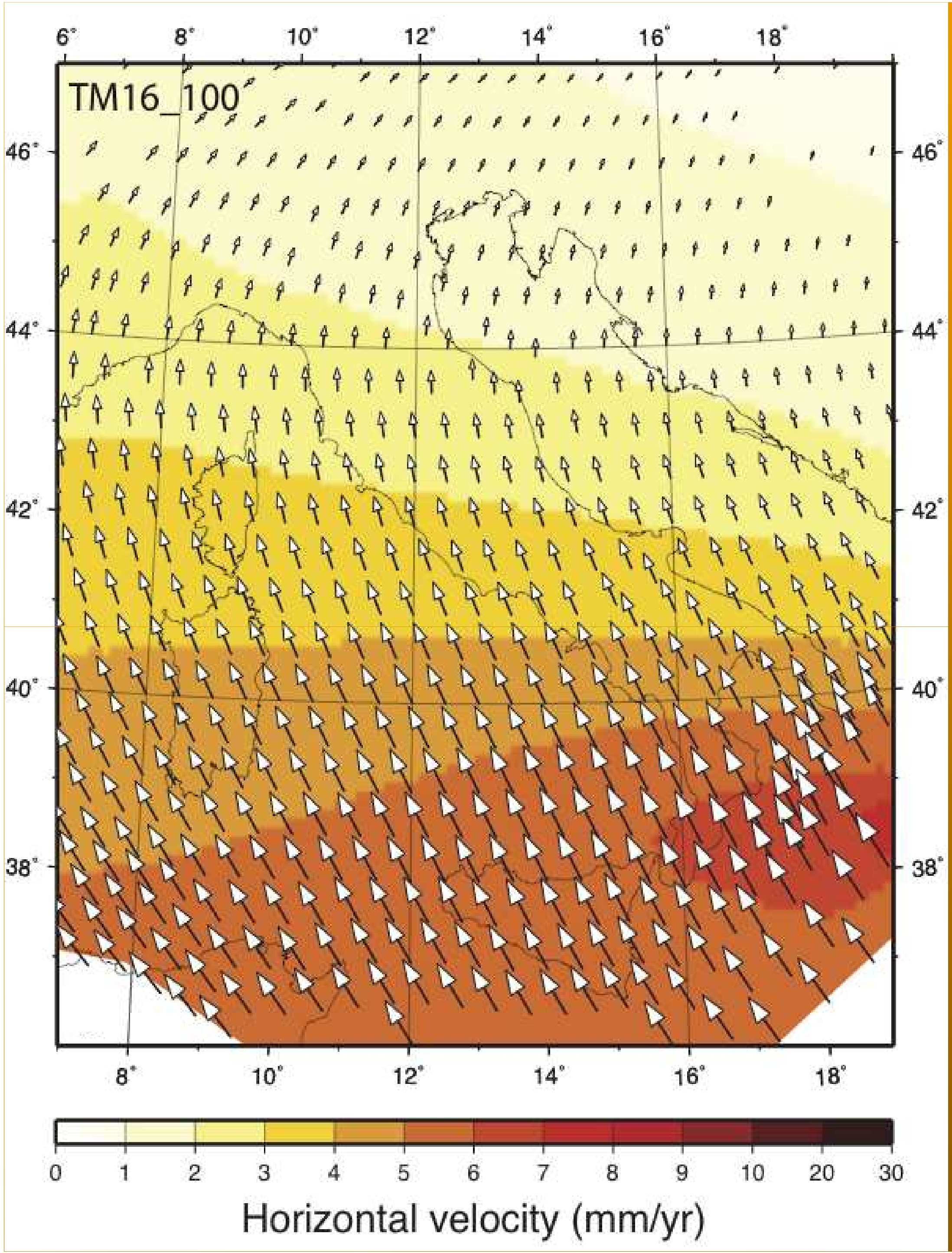
Strength profiles

- ■ thrust
- ▨ strike slip
- □ normal



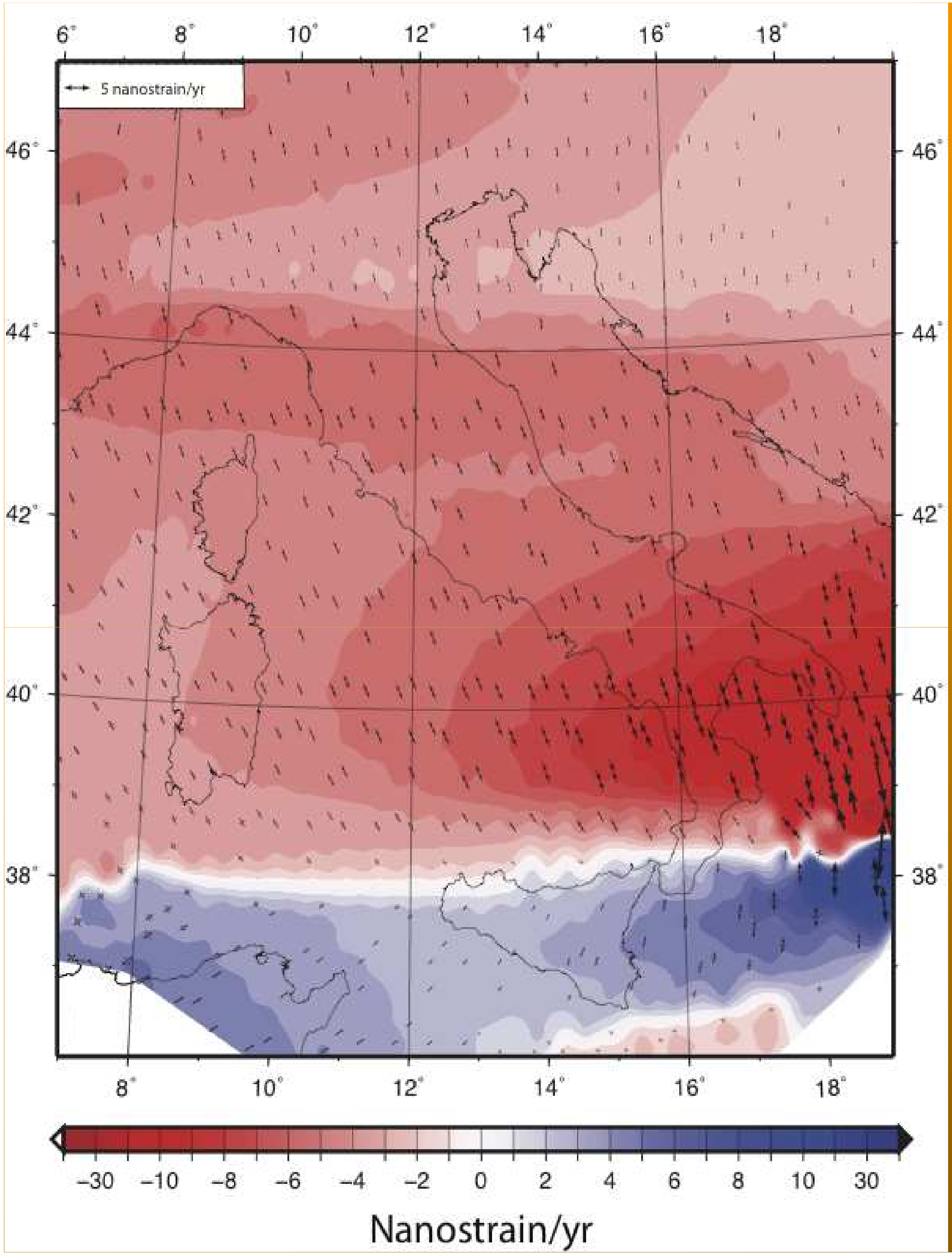
Effective viscosity ($\log_{10}\mu_{eff}$(Pas))





Model results: velocity field

Tectonic model computes the horizontal components of velocity for each node of the reference mesh (both logitudinal and latitudinal components).

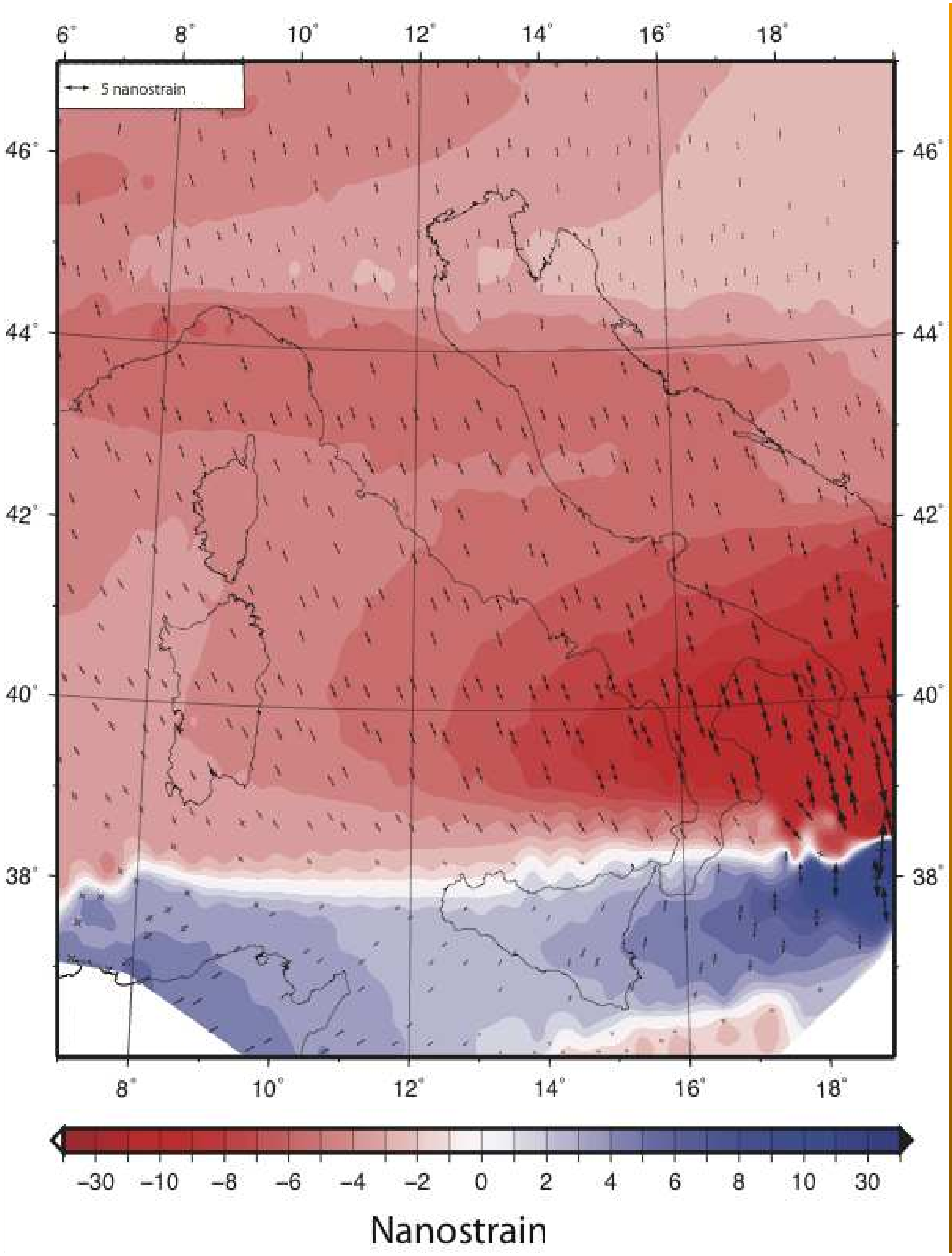


GFM products: Strain-rate field

Starting from the computed velocity field, strain-rate is calculated for each element of the reference mesh, using the procedure descripted in Devoti et al. (2002) for triangular elements.

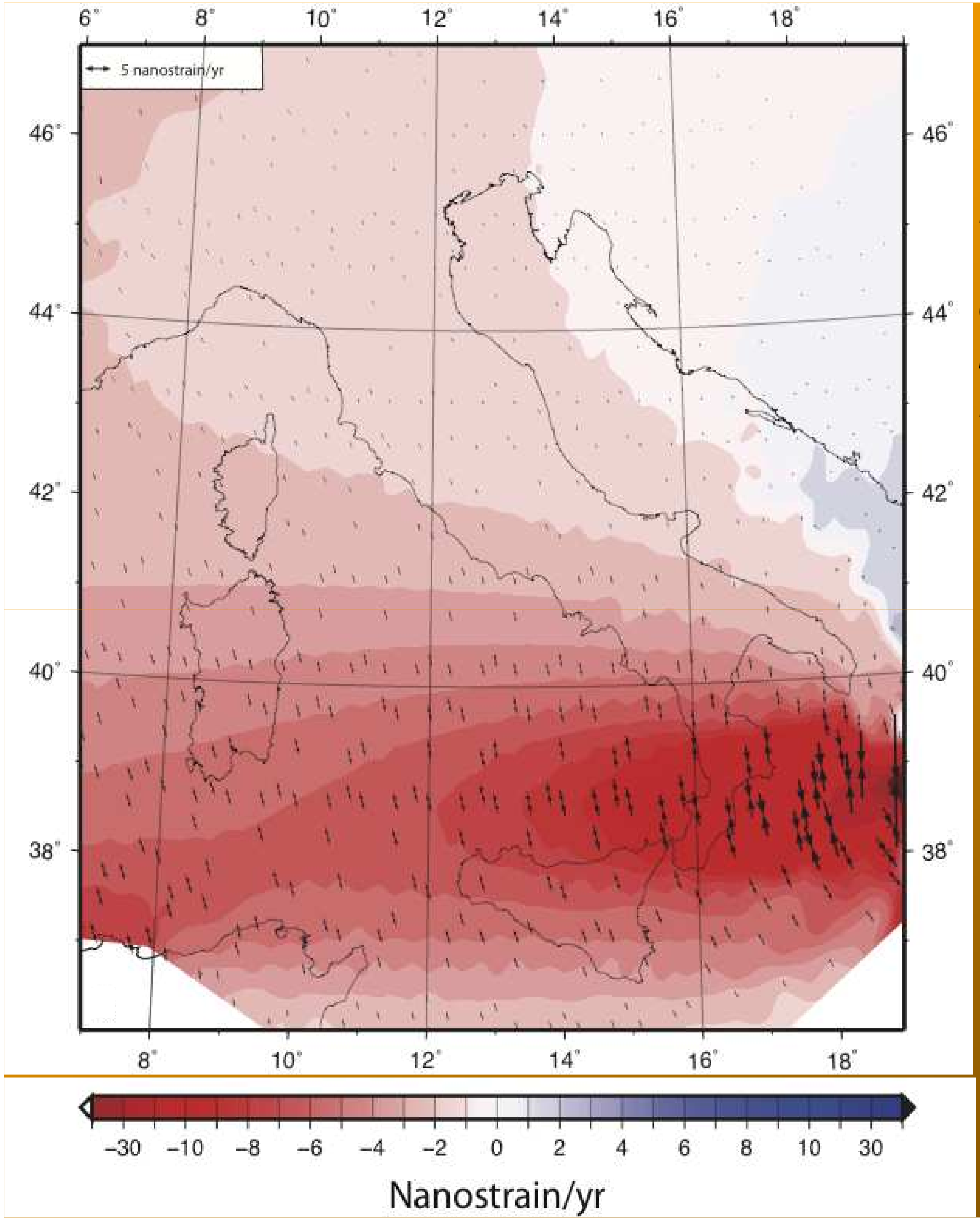
Negative strain-rate indicates compression (red), while positive train-rate indicates extension (blue). In the map strain-rate eigenvalues are also shown (black arrows).

GFM products: Deformation field



Starting from the strain-rate field, deformation is calculated for each element of the reference mesh.

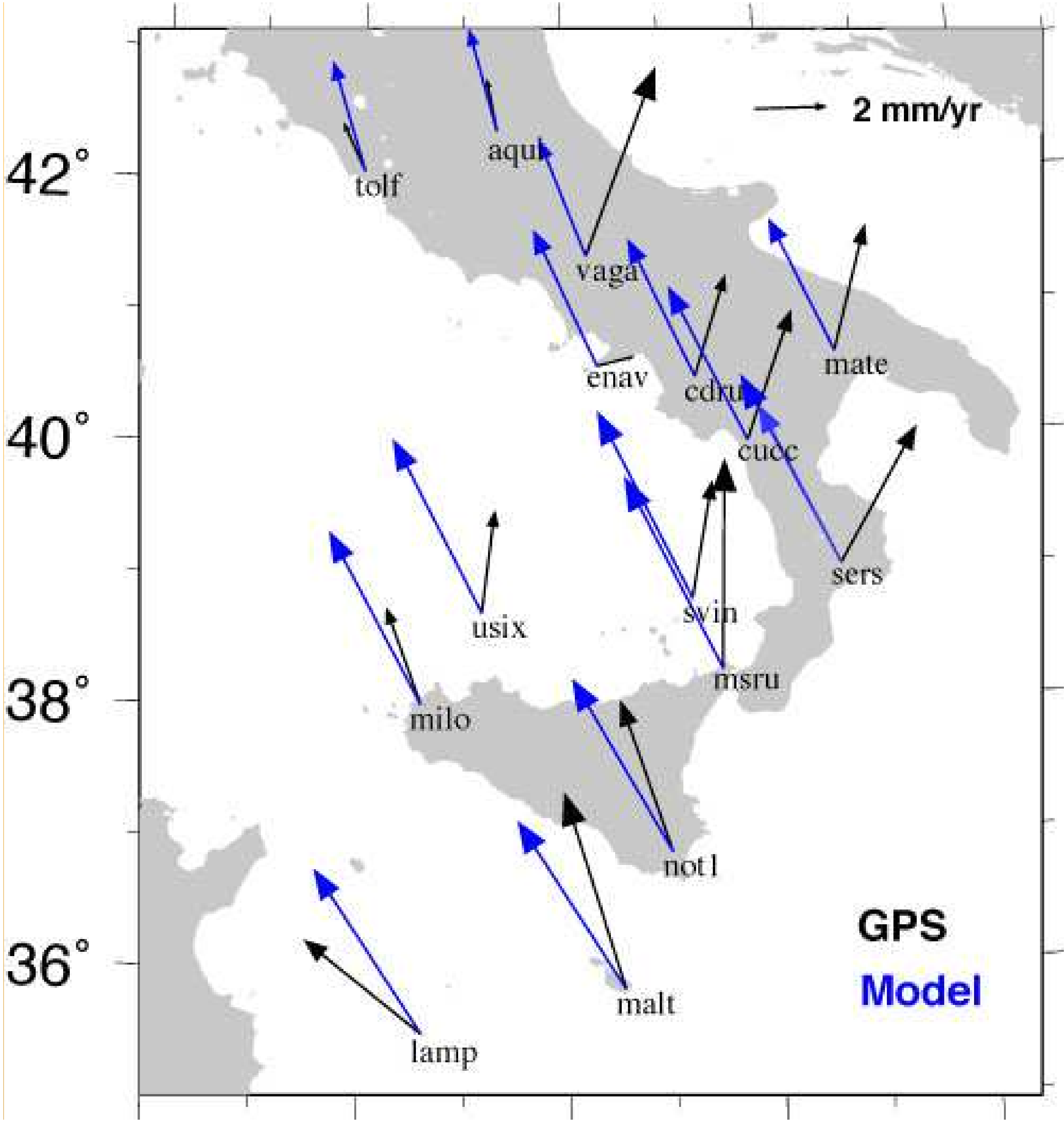
Negative deformations values indicate compression (red), while positive deformations values indicate extension (blue). In the map deformation eigenvalues are also shown (black arrows).



Tectonic deformation
Fixed vicosity

Horizontal strain-rate computed by the tectonic model without considering rheological heterogeneities in the Mediterranean domain (effectiv viscosity is fixed=10^{24} *Pas*

Interpolation modulus



Moreover the tectonic velocities computed by the model are interpolated on the net formed by GPS permanent stations, in order to statistically compare model results with GNSS data.

Products validation strategy

Products validation procedure is based on the model stability control, namely on its capacity of tolerate boundary conditions variations (boundary velocities changes in modulus and azimuth).

Procedure:

Increasing:

a. Modulus of the fixed velocities on the southern boundary of the model (+50%)
b. Azimuth of the fixed velocities on the southern boundary of the model (+30°)

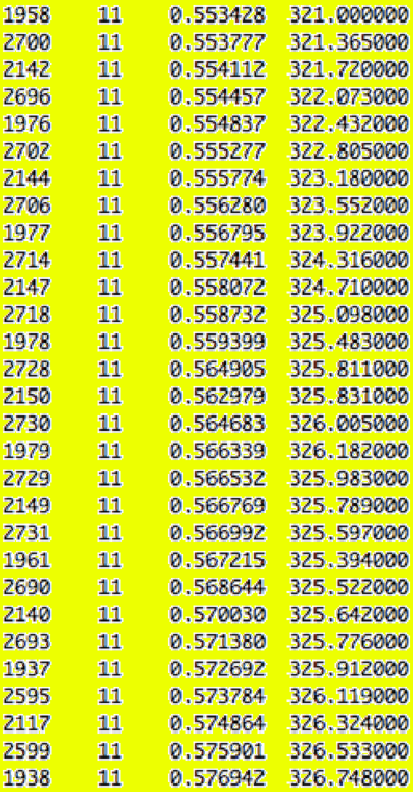
Model must remains stable, namely:

1. Maps must still contain real numbers
2. The order of magnitude of deformation and strain-rate values must remain 10^2 nanostrain and 10^2 nanostrain/yr, respectively

Validation procedure: BC variations

Boundary conditions (BC)

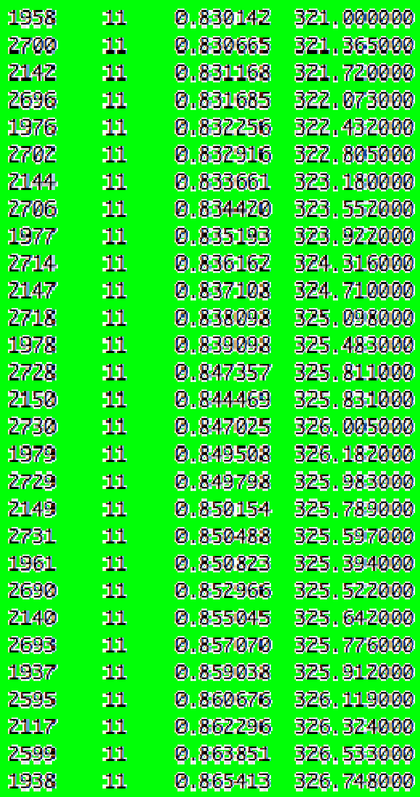
Modulus=M_o ; Azimuth=θ_o



```
1958     11     0.553428  321.000000
2700     11     0.553777  321.365000
2142     11     0.554112  321.720000
2696     11     0.554457  322.073000
1976     11     0.554837  322.432000
2702     11     0.555277  322.805000
2144     11     0.555774  323.180000
2706     11     0.556280  323.552000
1977     11     0.556795  323.922000
2714     11     0.557441  324.316000
2147     11     0.558072  324.710000
2718     11     0.558732  325.098000
1978     11     0.559399  325.483000
2728     11     0.564905  325.811000
2150     11     0.562979  325.831000
2730     11     0.564683  326.005000
1979     11     0.566339  326.182000
2729     11     0.566532  325.983000
2149     11     0.566769  325.789000
2731     11     0.566992  325.597000
1961     11     0.567215  325.394000
2690     11     0.568644  325.522000
2140     11     0.570030  325.642000
2693     11     0.571380  325.776000
1937     11     0.572692  325.912000
2595     11     0.573784  326.119000
2117     11     0.574864  326.324000
2599     11     0.575901  326.533000
1938     11     0.576942  326.748000
```

BC Variations

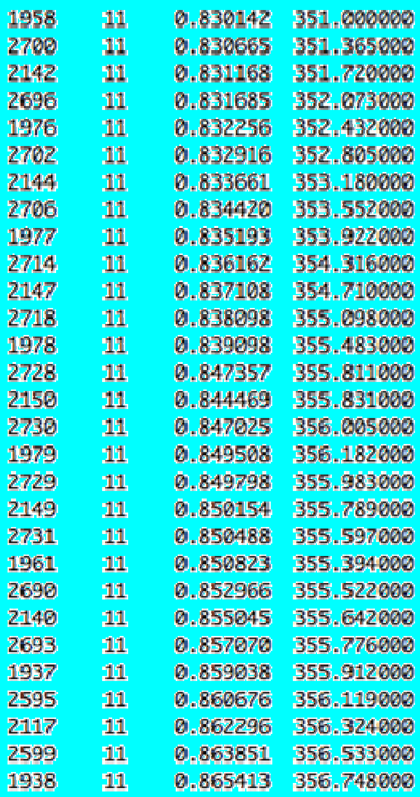
Modulus=M_o+50%



```
1958     11     0.830142  321.000000
2700     11     0.830665  321.365000
2142     11     0.831168  321.720000
2696     11     0.831685  322.073000
1976     11     0.832256  322.432000
2702     11     0.832916  322.805000
2144     11     0.833661  323.180000
2706     11     0.834420  323.552000
1977     11     0.835193  323.922000
2714     11     0.836162  324.316000
2147     11     0.837108  324.710000
2718     11     0.838098  325.098000
1978     11     0.839098  325.483000
2728     11     0.847357  325.811000
2150     11     0.844469  325.831000
2730     11     0.847025  326.005000
1979     11     0.849508  326.182000
2729     11     0.849798  325.983000
2149     11     0.850154  325.789000
2731     11     0.850488  325.597000
1961     11     0.850823  325.394000
2690     11     0.852966  325.522000
2140     11     0.855045  325.642000
2693     11     0.857070  325.776000
1937     11     0.859038  325.912000
2595     11     0.860676  326.119000
2117     11     0.862296  326.324000
2599     11     0.863851  326.533000
1938     11     0.865413  326.748000
```

BC Variations

Modulus=M_o+50%+Azimuth=θ_o+30°



```
1958     11     0.830142  351.000000
2700     11     0.830665  351.365000
2142     11     0.831168  351.720000
2696     11     0.831685  352.073000
1976     11     0.832256  352.432000
2702     11     0.832916  352.805000
2144     11     0.833661  353.180000
2706     11     0.834420  353.552000
1977     11     0.835193  353.922000
2714     11     0.836162  354.316000
2147     11     0.837108  354.710000
2718     11     0.838098  355.098000
1978     11     0.839098  355.483000
2728     11     0.847357  355.811000
2150     11     0.844469  355.831000
2730     11     0.847025  356.005000
1979     11     0.849508  356.182000
2729     11     0.849798  355.983000
2149     11     0.850154  355.789000
2731     11     0.850488  355.597000
1961     11     0.850823  355.394000
2690     11     0.852966  355.522000
2140     11     0.855045  355.642000
2693     11     0.857070  355.776000
1937     11     0.859038  355.912000
2595     11     0.860676  356.119000
2117     11     0.862296  356.324000
2599     11     0.863851  356.533000
1938     11     0.865413  356.748000
```

Validation procedure:

Surface strain-rate map

Boundary Conditions (BC)

Modulus=M_o ; Azimuth=θ_o

```
LONG      LAT      S1         S2          AZI2
9.26      74.7     0.249      -0.277E-01  -27.4
9.90      74.3     0.354      -0.773E-01  -25.0
10.5      74.7     0.225      -0.606E-01  -22.7
11.0      74.3     0.255      -0.810E-01  -23.8
11.5      74.7     0.183      -0.716E-01  -21.6
12.0      74.3     0.240      -0.989E-01  -22.7
12.5      74.7     0.171      -0.894E-01  -19.8
13.0      74.3     0.201      -0.110      -21.5
13.5      74.7     0.161      -0.104      -19.2
14.0      74.3     0.165      -0.116      -20.7
14.5      74.7     0.154      -0.114      -19.3
15.0      74.3     0.134      -0.117      -20.6
15.5      74.7     0.148      -0.119      -20.6
16.0      74.3     0.153      -0.131      -22.0
16.5      74.7     0.113      -0.124      -19.1
17.0      74.3     0.954E-01 -0.126       -20.3
17.5      74.7     0.108      -0.129      -20.3
18.0      74.3     0.114      -0.140      -21.8
18.5      74.7     0.748E-01 -0.133       -18.2
19.0      74.3     0.817E-01 -0.145       -20.2
19.5      74.7     0.945E-01 -0.147       -20.2
20.0      74.3     0.552E-01 -0.138       -20.3
20.5      74.7     0.665E-01 -0.140       -20.3
21.0      74.3     0.737E-01 -0.152       -22.0
21.5      74.7     0.596E-01 -0.149       -20.2
22.0      74.3     0.453E-01 -0.150       -21.0
22.5      74.7     0.309E-01 -0.147       -18.5
23.0      74.3     0.393E-01 -0.159       -20.6
23.5      74.7     0.497E-01 -0.161       -20.9
```

BC Variations

Modulus=M_o+50%

```
LONG      LAT      S1         S2          AZI2
9.26      74.7     0.363      -0.402E-01  -27.4
9.90      74.3     0.520      -0.114      -24.9
10.5      74.7     0.338      -0.906E-01  -22.7
11.0      74.3     0.407      -0.129      -23.6
11.5      74.7     0.288      -0.113      -21.2
12.0      74.3     0.333      -0.142      -22.5
12.5      74.7     0.273      -0.134      -20.4
13.0      74.3     0.316      -0.164      -22.0
13.5      74.7     0.257      -0.156      -19.9
14.0      74.3     0.251      -0.169      -21.3
14.5      74.7     0.219      -0.164      -19.5
15.0      74.3     0.214      -0.177      -21.0
15.5      74.7     0.208      -0.177      -20.1
16.0      74.3     0.204      -0.189      -21.5
16.5      74.7     0.171      -0.184      -19.4
17.0      74.3     0.168      -0.197      -21.0
17.5      74.7     0.161      -0.196      -20.0
18.0      74.3     0.158      -0.208      -21.3
18.5      74.7     0.126      -0.202      -18.9
19.0      74.3     0.124      -0.214      -20.5
19.5      74.7     0.116      -0.213      -19.3
20.0      74.3     0.927E-01 -0.215       -20.2
20.5      74.7     0.111      -0.218      -20.2
21.0      74.3     0.109      -0.231      -21.7
21.5      74.7     0.753E-01 -0.224       -19.0
22.0      74.3     0.546E-01 -0.225       -19.8
22.5      74.7     0.706E-01 -0.228       -19.8
23.0      74.3     0.708E-01 -0.240       -21.4
23.5      74.7     0.617E-01 -0.239       -20.1
```

BC Variations

Modulus=M_o+50%+Azimuth=θ_o+30°

```
LONG      LAT      S1         S2          AZI2
9.26      74.7     0.346      -0.320E-01  -25.9
9.90      74.3     0.493      -0.900E-01  -23.2
10.5      74.7     0.286      -0.695E-01  -20.9
11.0      74.3     0.365      -0.102      -21.6
11.5      74.7     0.299      -0.960E-01  -20.2
12.0      74.3     0.323      -0.115      -21.2
12.5      74.7     0.257      -0.108      -19.4
13.0      74.3     0.307      -0.135      -20.7
13.5      74.7     0.212      -0.125      -17.8
14.0      74.3     0.237      -0.144      -19.3
14.5      74.7     0.231      -0.144      -18.3
15.0      74.3     0.203      -0.148      -19.6
15.5      74.7     0.193      -0.148      -18.7
16.0      74.3     0.193      -0.159      -20.1
16.5      74.7     0.156      -0.154      -17.8
17.0      74.3     0.157      -0.166      -19.4
17.5      74.7     0.146      -0.166      -18.3
18.0      74.3     0.147      -0.177      -19.8
18.5      74.7     0.139      -0.176      -18.5
19.0      74.3     0.115      -0.179      -19.6
19.5      74.7     0.104      -0.178      -18.3
20.0      74.3     0.106      -0.189      -19.9
20.5      74.7     0.962E-01 -0.187       -18.4
21.0      74.3     0.749E-01 -0.190       -19.4
21.5      74.7     0.893E-01 -0.193       -19.6
22.0      74.3     0.917E-01 -0.204       -21.1
22.5      74.7     0.558E-01 -0.198       -17.8
23.0      74.3     0.367E-01 -0.200       -18.7
23.5      74.7     0.753E-01 -0.208       -20.7
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Thank you for your attention…