Transition zone dynamics under Europe as deduced from two-dimensional wavelet analysis of high resolution seismic tomography

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1 Abstract

Wavelets have been developed recently in the last 15 years and are linear mathematical transformations, which can analyze signals at different scales. The wavelet transform can be likened to a mathematical microscope. Large-scale wavelets give an approximate image of the overall shape of the signal, while smaller-scale wavelets zoom in on the minute details. Until recently most of the applications of wavelets in solid-earth geophysics have been focused on the use of one-dimensional wavelets to analyze time-series of geophysical phenomena such as Chandler wobble or magnetic responses or one-dimensional spatial tracks, such as gravity, geoid anomalies or surface topography. Recently [*Bergeron et al.*, 1999; 2000] we have developed fast multi-dimensional wavelet transforms, based on higher order derivatives of the Gaussian function. We have employed them as a filter for constructing rapidly two- and three-dimensional wavelet transforms of geophysical fields, such as geoid anomalies, thermal fields in high Rayleigh number convection and the scalar field depicting the degree of heterogeneity in passive mixing driven by thermal convection.

The continuous wavelet transform $\tilde{f}$ of a 2D field $f(x, y)$ is given by

$$\tilde{f}(a, \vec{b}) = \frac{1}{a} \int \int f(\vec{x}) \psi \left(\frac{\vec{x} - \vec{b}}{a} \right) d^2\vec{x} \qquad (1)$$

where a is the scale and $\vec{b}$ is the position vector (x, y). We note that a is the quantity which allows us to zoom in and out of different length-scales and is an unique property associated with wavelets. The mother wavelet Ψ is the pth order derivative of the Gaussian function. We have used $p = 4$ throughout.

We will apply two-dimensional wavelets to horizontal layers extracted by the high-resolution ($0.5° \times 0.5°$) tomographic model of the top 1000 km of the mantle below Europe [*Piromallo and Morelli*, 1997; *Morelli and Piromallo*, 2000]. This model of P-wave seismic velocity anomalies (SVA) was obtained by inversion of P delay time data reported by the International Seismological Centre, using *sp6* global velocity model [*Morelli and Dziewonski*, 1993] as a reference.

Fig. 1 shows map views of P-wave SVA at three different depth layers above (400 km), inside (600 km) and below the transition zone (800 km). We observe that, at 400 km depth, positive (fast) velocity anomalies (in blue) are present underneath Greece and Italy. Negative (slow) anomalies are present under the Adriatic Sea (east of Italy) and southern Germany. Deeper down there is a large accumulation of fast material at a depth of 600km. There is a shift in the overall SVA pattern at 800 km depth and the large mass of fast anomalies from 600 km has mostly disappeared. One can discern that the length-scales of the SVA become smaller from those at 600 km depth.

In Fig. 2 we display the wavelet transforms of the SVA for a scale a of 130 km at the same three depths as in Fig. 1. Same color convention is used as in Fig. 1 with blue and red representing respectively fast and slow anomalies, which have been wavelet-transformed. We note that the color patterns on this map have spatial dimensions considerably greater than the sampling length-scale of the wavelet, which is 130 km. Thus the color maps represent the spatial distributions of fast and slow anomalies sampled by the wavelet filter with a width of the prescribed scale a. With wavelets the upwelling of slow (hot) material under the Adriatic Sea

is clearly delineated as a two-dimensional feature produced near 600 km depth and is constrained by the squeezing action due the two neighboring slabs (fast anomalies). This slow seismic anomalies (hot) upwelling becomes much weaker and is shifted at 800 km depth. Other upwellings in Germany and the Massif Central (France) can be observed clearly down to 600 km with some connection to 800 km depth.

It is clear the characteristic scales of the patterns at 600 km depth are larger than those at 800 km depth. This variation in the pattern suggests that the viscosity change instead of increasing under Europe, as is commonly assumed in geoid modelling of the whole Earth (e.g. *Ricard et al.*, 1984), should instead be decreasing under Europe. Such a scenario of a low viscosity zone under the 660 km has been proposed first by *Kido and Cadek* [1997] on the basis of non-linear inversion of the viscosity versus depth profile from regional geoid data. The depth variation of viscosity can affect the horizontal length-scales of mantle dynamics as shown first by *Gurnis and Hager* [1988]. We have conducted 3-D numerical simulations, using the spectral- finite-difference code of *Dubuffet et al.* [2000] and with 257^3 grid points. The depth of the mantle is 2000 km and the viscosity interface is set at 600 km depth. Viscosity profiles are shown in (a) and (d) panels of Fig. 3. In the first case with a viscosity jump of 30, we can see that the features become bigger across the viscosity interface. Fig. 3b and 3c are horizontal planes representing the thermal field at depths of 500 and 800 km, respectively. On the other hand with a viscosity drop (Fig. 3d) by a factor of 30 inside a well with a width of 200 km, smaller scale features are found inside the low viscosity zone (Fig. 3f).

Thus, using the combined tools of wavelet analysis of tomographic data and 3-D numerical simulations of a locally depth-dependent viscosity, we can place constraints on the sign of viscosity change across 670 km boundary under Europe. The low viscosity zone may have lower mantle origins from the megaplume from neighboring Africa and the Icelandic plume, as they may provide hot material to lower substantially the shallow lower-mantle viscosity under the 660 km boundary.

The main results of this work are:

(1) viscosity below 660 km boundary in Europe seems to be lower than the viscosity of the upper mantle immediately above;

(2) hot upwelling under Europe at least under the Adriatic may have upper-mantle origins;

(3) large accumulation of fast seismic anomaly (cold) material under Europe immediately above the 660 km boundary.

2 Reference

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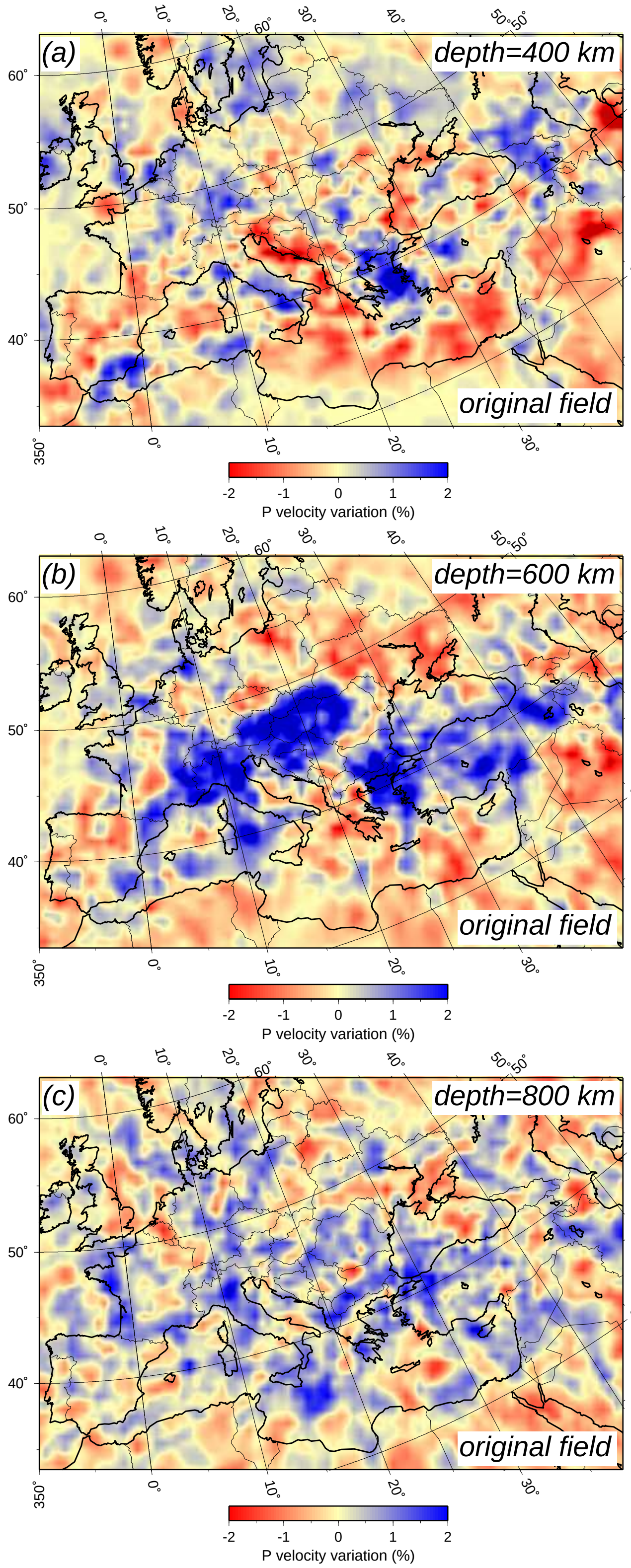

Fig. 1. Seismic velocity anomalies, at three different depths in the mantle below Europe, from high resolution tomographic model.

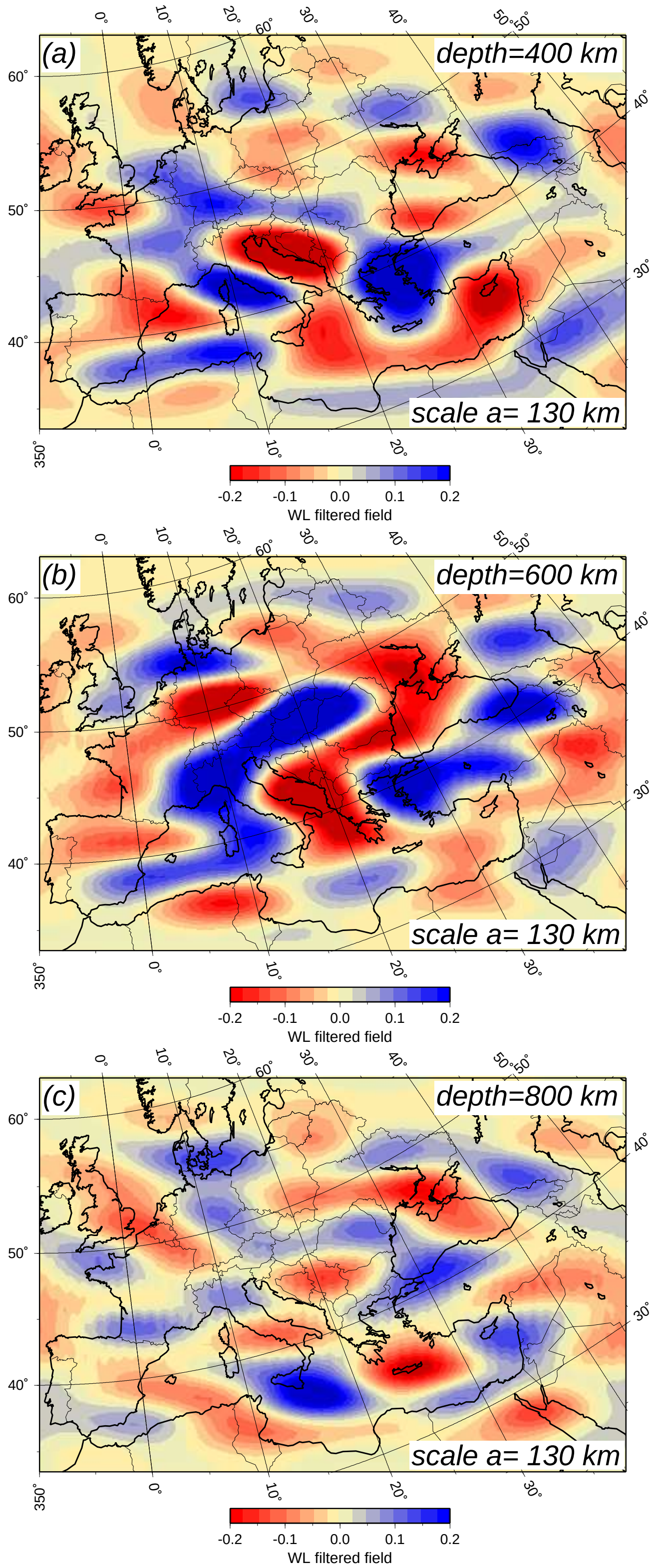

Fig. 2. Wavelet filtered images of the 2D seismic anomaly fields of Fig. 1. Sampling length-scale of the wavelet is $a = 130km$.

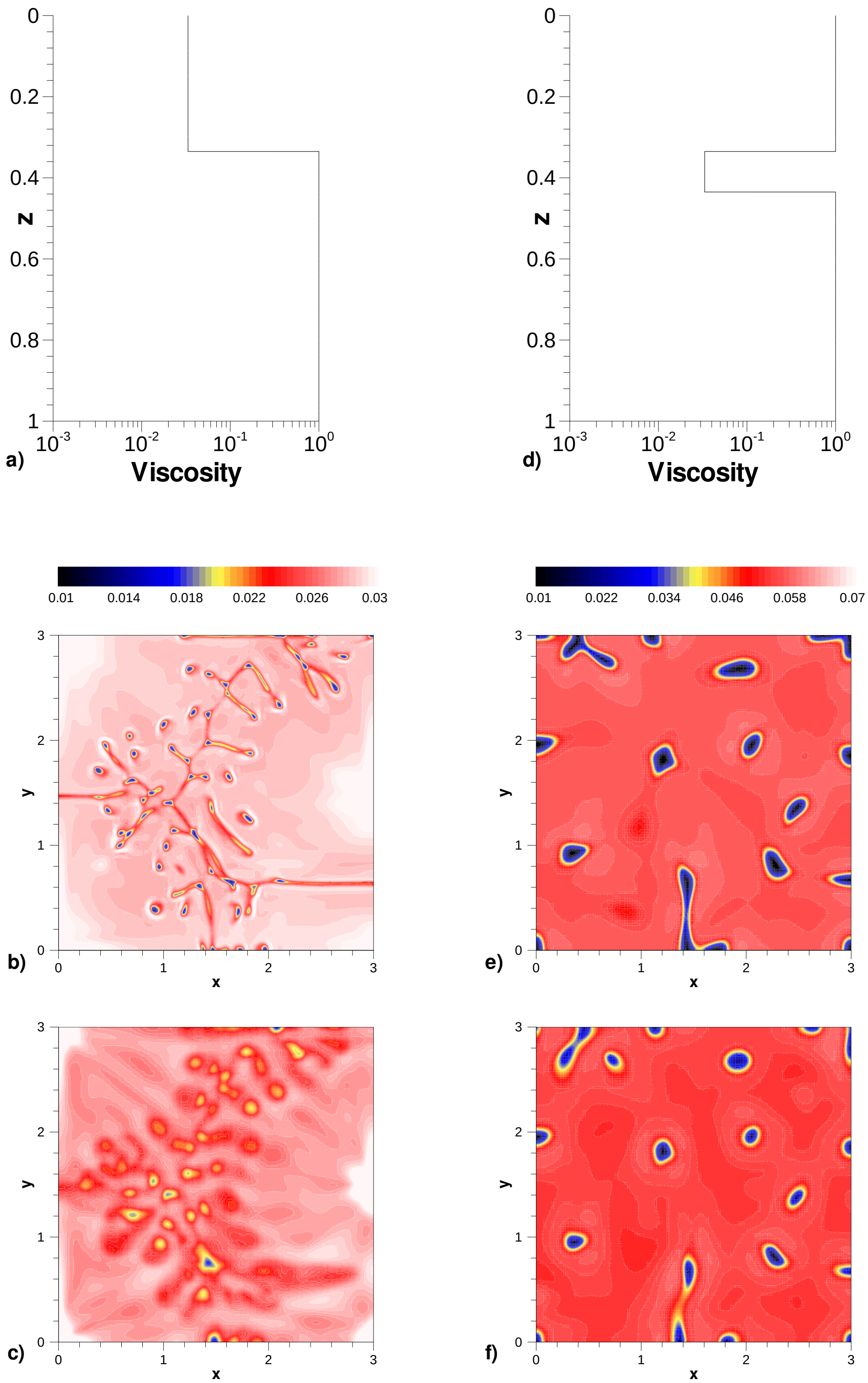

Fig. 3. Results from 3D numerical simulation with depth-dependent viscosity.