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Modeling seismic wave propagation across the European plate: structural models and numerical techniques, state-of-the-art and prospects

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Together with the building and maintenance of observational and data banking infrastructures — i.e. an integrated organization of coordinated sensor networks, in conjunction with connected data banks and efficient data retrieval tools — a strategic vision for bolstering the future development of geophysics in Europe should also address the essential issue of improving our current ability to model coherently the propagation of seismic waves across the European plate. This impacts on fundamental matters, such as correctly locating earthquakes, imaging detailed earthquake source properties, modeling ground shaking, inferring geodynamic processes. To this extent, we both need detailed imaging of shallow and deep earth structure, and accurate modeling of seismic waves by numerical methods. Our current abilities appear somewhat limited, but emerging technologies may enable soon a significant leap towards better accuracy and reliability. To contribute to this debate, we present here the state-of-the-art of knowledge of earth structure and numerical wave modeling in the European plate, as the result of a comprehensive study towards the definition of a continental-scale reference model. Our model includes a description of crustal structure (EPcrust) merging information deriving from previous studies – large-scale compilations, seismic prospection, receiver functions, inversion of surface wave dispersion measurements and Green functions from noise correlation. We use a simple description of crustal structure, with laterally-varying sediment and cristalline layers thickness, density, and seismic parameters. This a priori crustal model improves the overall fit to observed Bouguer anomaly maps over CRUST2.0. The new crustal model is then used as a constraint in the inversion for mantle shear wave speed, based on fitting Love and Rayleigh surface wave dispersion. The new mantle model sensibly improves over global S models in the imaging of shallow asthenospheric (slow) anomalies beneath the Alpine mobile belt, and fast lithospheric signatures under the two main Mediterranean subduction systems (Aegean and Tyrrhenian). We validate this new model through comparison of recorded seismograms with simulations based on numerical codes (SPECFEM3D). To ease and increase model usage, we also propose the adoption of a common exchange format for tomographic earth models based on JSON, a lightweight data-interchange format supported by most high-level programming languages, and provide tools for manipulating and visualising models, described in this standard format, in Google Earth and GEON IDV. In the next decade seismologists will be able to reap new possibilities offered by exciting progress in general computing power and algorithmic development in computational seismology. Structural models, still based on classical approaches and modeling just few parameters in each seismogram, will benefit from emerging techniques – such as full waveform fitting and fully nonlinear inversion – that are now just showing their potential. This will require extensive availability of supercomputing resources to earth scientists in Europe, as a tool to match the planned new massive data flow. We need to make sure that the whole apparatus, needed to fully exploit new data, will be widely accessible. To maximize the development, so as for instance to enable us to promptly model ground shaking after a major earthquake, we will also need a better coordination framework, that will enable us to share and amalgamate the abundant local information on earth structure — most often available but difficult to retrieve, merge and use. Comprehensive knowledge of earth structure and of best practices to model wave propagation can by all means be considered an enabling technology for further geophysical progress.