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Editorial: Applications of wave propagation simulation in complex geological media

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Editorial on the Research Topic

Applications of wave propagation simulation in complex geological media

Earth models and seismic sources models can be inferred from waves recorded at the surface of the Earth or at depth in wells. Whatever the method used for this, it is necessary, at a recurring stage of the process, to model these waves, i.e., to solve a wave equation for a given source and a given medium. In some very simple cases, analytical solutions exist, but these cases rarely correspond to the geological complexity that we want to take into account in practice. Geological environments are indeed heterogeneous and 3D. Moreover, they can present behaviors much more complex than the simple linear elasticity. For lack of analytical solutions in such media, the resolution of the corresponding wave equation is done using numerical methods.

In addition to their implication in the construction of models, the numerical methods for modeling seismic wave propagation are essential to the evaluation of the seismic hazard, in particular the site effects which can amplify the energy of the waves on the surface and cause significant damage. These methods are also involved in seismic survey design in order to monitor or better image a given geological medium.

Whatever the application, most numerical modeling methods require a mesh, i.e., a discretization of the geometry of the medium. However, we have seen that geological environments are complex by nature: they are heterogeneous, 3D, multi-physics, and above all, they are multi-scale and discontinuous. These last two features pose major issues when modeling waves numerically, because the required mesh can be very difficult to generate and the computational cost of the simulation can increase dramatically. In many applications, these two features are set aside. This is the case in full waveform inversion (FWI) for instance. To remain above the seismic resolution and mitigate the non-uniqueness of the problem, FWI results are restricted to smooth models without any small scales. Nevertheless, geological environments contain some, and geological complexity should remain one of the guidelines of seismological research.

Forgetting the geological complexity, some seismologists say that the resolution of the seismic wave equation no longer is a problem. When claiming this, they probably also set aside the ambition to process the ever-increasing quantity of data at our disposal. Despite

the development of artificial intelligence algorithms and the increasing computational power, these data would benefit from innovative simulation methods in order to investigate deeper and extract further information on geological environments and seismic sources. There is an increasing amount of seismic data because of 1) new acquisition technologies such as distributed acoustic sensing and 2) new types of data such as rotational motion of particles, noise correlations and tremors from non-volcanic sources. Better using and understanding these data, with the help of better simulation methods and tools, is another guideline of seismological research.

The papers in this Research Topic cover a wide variety of aspects of numerical wave propagation and tackle some of the current challenges. [Hou et al.](#) analyze a multi-physics issue related to the exploration of geothermal reservoirs; namely, the effects of a temperature field in the elastic waves. They use a thermoelastic model based on the Biot and extended Lord-Schulman theories, and obtain the reflection and transmission coefficients for the P- and S-waves and an additional T-wave predicted by this model. [Yang et al.](#) propose a new finite-difference method for acoustoelastic wave propagation in prestressed media. Their method is based on the rotated staggered-grid finite-difference method and was developed with a particular interest in the exploration of deep oil- and gas-bearing formations. [Ajala et al.](#) are concerned with the application of numerical wave propagation to seismic hazard analysis. They perform numerical simulations using realistic rupture scenarios in the San Andreas fault in southern California, and analyze the effects of topography, near-surface layers and attenuation in the wavefield. Also with a keen interest in earthquake simulations, [Lehmann et al.](#) use state-of-the-art machine-learning techniques to investigate the variability in seismic response associated to random geological fluctuations. As a result, they show how condensing these fluctuations into a few components can help in performing uncertainty analyses. In a very similar context, [Celorio et al.](#) compare spectral element simulations and radiative transfer predictions of SH-waves in 2D random media. Relying on an

unprecedentedly large number of von Karman realizations, the authors find an excellent agreement between the two approaches for both the scattering mean free path and the mean intensities. In particular, they show how the ballistic peak evolves with propagation distance, which is crucial in seismic hazard evaluation. Finally, [Shen et al.](#) propose a method to improve hybrid simulations, i.e., when a wavefield computed in a large domain using a given simulation feeds another simulation in a more local domain. The improvement consists in a relevant space and time interpolation of the hybrid inputs. When the global and local meshing differs, the proposed interpolation method appreciably reduces the error of the hybrid waveforms caused by inaccurate hybrid inputs.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

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