OBJECTIFS DU PROJET

We propose to use modern numerical methods and computers to improve images of earthquakes and Earth’s interior based upon forward and inverse simulations of seismic wave propagation. The simulations are based upon a spectral-element method and account for heterogeneity in the crust and mantle, topography, anisotropy, attenuation, fluid-solid interactions, self-gravitation, rotation, and the oceans. On future exascale machines we will be able to reach frequencies well below 1 Hz in global simulations. Our objective is to go beyond classical travel time tomography, and to use information contained in entire seismic waveforms. By drawing connections between seismic tomography, adjoint methods popular in climate and ocean dynamics, and time-reversal imaging, we have demonstrated that one iteration in tomographic inversions may be performed based upon just two numerical simulations for each earthquake: one calculation for the current model and a second adjoint calculation that uses time-reversed signals at the receivers as simultaneous, fictitious sources. This has finally opened the door to solving the 3D inverse problem, namely the problem of using the remaining differences between the data and the simulations to improve images of Earth’s interior. The aim of our proposal is to use adjoint methods to image Earth structure on all scales.

MÉTHODOLOGIE ET RESULTATS

The adjoint method may also be used for kinematic source imaging, with a good rate of convergence of a conjugate gradient Centroid Moment-Tensor (CMT) inversion algorithm in which Fréchet derivatives are calculated based on an adjoint method. Within 4 or 5 iterations the algorithm usually converges on the right solution using three-component data recorded by a seismic network. We extend kinematic source inversions to investigate finite-fault effects associated with large earthquakes.

For earthquakes with magnitudes larger than ~7.5, the routine CMT point-source solution is no longer an adequate description of the rupture process. Previous finite-fault studies used 1D background models and ascribed waveform / travel time anomalies entirely to the rupture process, while we know that tectonically active regions are very heterogeneous. The adjoint formulation incorporates 3D background models in finite-fault inversions. With the use of 3D Green functions, we may iteratively resolve the earthquake rupture processes and improve our understanding of the physics of earthquakes.

CONCLUSIONS ET PRESPECTIVES

We have successfully applied adjoint seismic tomography to some regions, and we now plan to apply it to other tectonically interesting regions, such as Europe and China. The resulting detailed, high quality images of the crust and mantle will help address unresolved tectonic and geodynamical questions for these regions. But our most ambitious goal is to move towards adjoint tomography of the entire planet. Current global inversions are limited by ‘crustal corrections’, which involve first-order corrections to accommodate the effects of the Earth’s crust. Crustal thickness varies from less than 10 km underneath the oceans to more than 70 km underneath the Andes and Tibet; this order-of-magnitude variation cannot be properly accounted for based on perturbation methods, and one of our first goals is to properly account for the effects of Earth’s crust by jointly inverting for crust and upper mantle structure.

High-performance computing and the race to petaflops and exaflops have been a crucial tool for the successful completion of this project. The GENCI and PRACE infrastructures have been extremely useful towards this goal, and will remain so in the future.