UE Geophysical imaging

Level
Baccalaureate +5

ECTS
3 credits

Component
UFR IM2AG (informatique, mathématiques et mathématiques appliquées)

Semester
Automne

- **Teaching language(s):** English
- **Open to exchange students:** Yes
- **Code d'export Apogée:** GBX9AM27

Presentation

Description

In the current context of energy transition and fight against global warming, a precise knowledge of the crust, down to several km depth, has become a critical issue. The crust is the place where are to be found ore resources needed to build electric batteries (rare earth elements) as well as concrete resources for offshore and onshore wind turbines foundations. The crust is also the only place presenting sufficient volumes to store CO2 and H2 in a flexible way. CO2 storage will be a crucial component among industrial solutions to fight against global warming and reach neutral carbon emissions in the next decades.

To these ends, high resolution quantitative estimates of the mechanical parameters of the crust is essential. To perform such estimation, one has to rely on the interpretation of the mechanical waves which travel in the crust. The inference of the mechanical properties of the subsurface from local recording of the mechanical waves at the surface is a mathematical inverse problem. The aim of this course is to provide the mathematical background and the required theoretical tools to introduce high resolution seismic imaging methods to the students, complemented with practical numerical work on schematic examples.

The first main part of the course will be devoted to the theoretical and practical aspects of wave propagation in heterogeneous media. Beginning by some general consideration on hyperbolic partial differential equations, we will see how the elastodynamics equations, representing the propagation of mechanical waves in the subsurface, belong to this category of equations. We will show in particular an energy conservation result based on the symmetry of the underlying hyperbolic system. We will then discuss how to design absorbing boundary conditions for wave propagation problems, to mimic media of infinite extension. This will lead us to the question of numerical approximation to the solution of wave equations in heterogeneous media. We will discuss in details finite-difference schemes, and practical work will be dedicated to the implementation of a finite-difference scheme for the 1D and 2D acoustic equations, and potentially 2D elastic equations.

The second main part of the course will be devoted to the theoretical and practical aspects of seismic imaging using full waveform inversion. We will show how this method is formulated as a nonlinear inverse problem, controlled by partial differential equations representing wave propagation in heterogeneous media. We will discuss how this problem can be solved by local optimization strategies, and review such strategies, from 1st order gradient method to more evolved 2nd order Newton or quasi-Newton methods. The computation of the gradient of the misfit function through the adjoint state method, following optimal control theory, will be extensively presented, as well as its physical interpretation. This theoretical work will be supported by numerical experiments based on the finite-difference wave propagation code developed in the first part of the course. We will then discuss how full waveform inversion is applied in practice, supported by various field data applications examples. This will lead us to discuss current limitations of the method related to its ill-posedness and the lack of regularity of the solution, and give an overview of methodological work currently performed to mitigate these limitations.

Course outline

2 introductory session

- main introduction on seismic imaging (to do what?)
- main concepts related to general inverse problems

5 modeling sessions

- theoretical considerations on hyperbolic systems
- how to derive the elastodynamics equations from Newton and Hooke's law
- elastodynamics equations = symmetrizable hyperbolic system, energy conservation
- absorbing boundary conditions - *numerical approximation to the solution of wave propagation in heterogeneous media (finite-difference, finite element) - practical work : implement 1D and 2D acoustic, + 2D elastic if time allows*

5 inverse problem sessions

- imaging the crust= nonlinear inverse problem controlled by an hyperbolic PDE
- local optimization method
- gradient computation through the adjoint state strategy
- physical interpretation of the gradient and Hessian operators - *implementation of the gradient computation based on the modeling code designed in the first part*
- full waveform inversion in practice: hierarchical schemes
- review of applications - *review of current methodological developments*

Course parts

Lectures	Lectures (CM)	18h

Period : Semester 9

Useful info

Non-contractual information.
Last update on 16 October 2023

Contacts

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Campus

- Grenoble - University campus

Non-contractual information.
Last update on 16 October 2023