2021-03453 - PhD Position F/M Advanced numerical schemes to understand SeismoElectric Effects and improve the characterization of geological reservoirs

Type de contrat : CDD  
Niveau de diplôme exigé : Bac + 5 ou équivalent  
Fonction : Doctorant  
Niveau d'expérience souhaité : Jeune diplômé

A propos du centre ou de la direction fonctionnelle

Makutu proposes a research program to develop numerical software packages for retrieving shapes and/or physical properties of the Earth and its natural reservoirs. In particular, the team is collaborating with experimental geophysicists to assess the impact of parameters on the wave propagation. In addition to geophysical setting, the team is working on solar imaging and musical acoustics. The team is shared by the University of Pau and Pays de l’Adour (UPPA) and Inria. The company Total is the main industrial partner of Makutu with whom the team develops activities on energy transition.

Contexte et atouts du poste

The SEE4GEO (Seismoelectric Effects for Geothermal Resources Assessment and Monitoring) project brings together an international team composed of researchers from Lawrence Livermore National Laboratory (LLNL, USA), the University of Hawaii at Manoa (UHM, USA), NORDIC (Norway), TUL Geothermics (France), and the University of Pau et des Pays de l’Adour (UPPA, France). The objective of the project is to develop a subsurface imaging technique based on seismoelectric effects. The purpose is to provide an innovative approach for geothermal subsurface imaging and monitoring at reservoir scale. We will assess SEE in terms of data acquisition, cost, and quality, and determine its capability in comparison with classical imaging and monitoring techniques, particularly decoupled seismic and electromagnetic methods. We will focus on developing new numerical tools for forward and inverse modeling, and to design an optimized field survey, data acquisition, and processing for deployment in many other exploration projects in case of success.

In the framework of this project, UPPA proposes two PhD positions:

- Numerical analysis: the PhD student will be involved in developing a fast, true 3D numerical package, handling SEE modeling imaging and subsurface properties characterization, including resistivity and permeability. Identified scientific and technical challenges will be related to the diffusive and attenuated nature of SEE signals. Numerically, this will imply extra care for stabilizing our algorithms for forward and inverse calculations.
- Experimental analysis: the PhD student will be involved in developing laboratory experiments. The goal of the study will be defining the best experimental setup for detecting permeable zones in geothermal systems. It will be led with a geophysical approach, including theoretical and instrumental analyses.

Mission confiée

Seismoelectric effects are a pore-scale phenomenon relying on electric charge separation created by streaming currents generated by pressure gradients, which occur when a seismic wave propagates (Ivanov, 1959). This defines seismic-to-electric conversion. The propagating seismic wave generates an electrical current, which induces an electrical field. This electrical field, which is in turn deduced to define a cosseismic field, propagating with the seismic wave. When this cosseismic field is disrupted by a heterogeneity (due to, e.g., a mechanical, electrical, or pore-fluid contrast), an electric dipole is created. Once an electrically diffuse EM field that is instantaneous detectable and provides information at depth, and is referred to as the so-called interface response field. Although the signal-to-noise ratio of the converted seismic-to-electric signals can be challenging, SEE dataset can capture unique information on important geothermal reservoir properties and heterogeneities, such as resistivity, salinity, degree of saturation and viscosity (e.g., Smeluders et al., 2014), as opposed to purely seismic or purely electromagnetic records. Moreover, the SEE interface response fields created at changes in properties can detect thin layers and other fine-scaled structural features such as fractures beyond the seismic resolution (e.g., Gobre and Slob, 2016).

The objective of the thesis is to design an imaging technique based on SEE and to develop an imaging software on top of our direct simulation tool. In Luo et al. (2009) and Zhu et al. (2009), the authors show how an impedance kernel based on seismic signal measurements, can be used to generate an image of the subsurface and help identify material discontinuities and salt dome boundaries. This first-order, direct use of seismic Fréchet derivatives is closely related to the popular imaging principle introduced by Caerbout (1977) in exploration geophysics. However, thin fluid-saturated layers or highly permeable fractures are difficult to detect using seismic imaging. Likewise, EM-based full waveform inversion is unable to infer high resolution structural features due to the low-frequencies required for geothermal reservoir scale imaging, and predominantly provides smooth, low-resolution images of subsurface fluid distribution.

Principales activités

The host team has developed a software able to model SEE in frequency domain, which allow for the consideration of a wide variety of parameters, and more importantly, to take full account of the seismoelectric effects. The mathematical model combines Biot's and Maxwell's equations following Pride's theory (Pride 1994). It is discretized using Discontinuous Galerkin (DG), which have proven their efficiency to solve wave problems in complex media (Bonnaire-Gahot et al. 2018, Barucq et al. 2021). Besides being easy to implement in a massively parallel environment, they are h-p-adaptive, which allows to reduce the computational costs while keeping a high-level of accuracy. This is of great interest, particularly since the problem to be solved is multi-scale, combining electromagnetic and...
The first step will be to work on solving the forward problem with the aim of reducing the associated computational costs. This one uses computational resources that must be optimized before moving on to the resolution of the inverse problem in 3D. For that, we propose to investigate the following ideas:

- The computational costs can be reduced by having a coarse mesh and it is well-known that large high-order cells perform better than small low order cells. However, the geometry of the geophysical domain along with the heterogeneities of the physical properties do not always allow to consider coarse elements. Regarding the heterogeneities, they can be considered with physical parameters varying as polynomials inside each cell. As far as the topography is concerned, hp adaptivity of 3D discretizations is an interesting asset. As a first milestone of the workplan, all these approaches will be combined to guarantee to the forward problem both accuracy and rapidity of execution. This is mandatory for performing 3D inversions.
- Domain decomposition is a key ingredient in the solution of large-scale wave problems in the frequency domain. In same time, domain decomposition is a natural candidate for solving wave problems with a very large number of sources that do not create disturbances on the whole domain but rather in a truncated domain defined by their propagation cone. Domain decomposition will be implemented by taking advantages of the DG framework that provides natural transmission conditions between subdomains.
- The host team has developed a full waveform inversion (FWI) piece of software which is based on the adjoint method. Here, the question is to figure out if this piece of software can be extended to PoroElastic equations in 3D. This development will benefit from the already installed framework for 3D elastic equations. This part of the workplan requires a lot of work that will be done in a team effort. A first step will be to carry out 2D imaging and inverse capability based upon adjoint method and assess the ability of the code to retrieve parameters of interest (e.g., permeability, resistivity, etc.) on synthetic cases. This study will help determine optimized monitoring configurations for SEE full waveform inversion. Then the possibility of having 3D versions will be addressed. This is a crucial question: FWI requires the solution of a huge linear system which might be prohibitive to conduct in 3D poroelastic media. Hence, it will be necessary to decide, by conducting some numerical experiments, if time-harmonic FWI can be used for 3D inversion or if a time-domain strategy should be preferred. This will be done in collaboration with LLNL.

Compétences

Particular skills are sought in:

- Programming skills: Fortran and/or C++, MPI, Openmp.
- Languages: Fluency in English is mandatory. Basic French is necessary (free French courses are available).
- Other valued appreciated: Interest in teaching. The PhD student might be involved as teaching assistant in our bachelor and master programs (32h/week). Bachelor of Mathematics is taught in French. Part of master of Mathematics, Modeling and Simulation is taught in English. The teaching assistant will have to manage exercises and practical sessions in general mathematics, basic computing, numerical analysis.

Avantages

- Subsidized meals
- Partial reimbursement of public transport costs
- Possibility of teleworking (after 6 months of employment) and flexible organization of working hours
- Professional equipment available (videoconferencing, loan of computer equipment, etc.)
- Social, cultural and sports events and activities
- Access to vocational training
- Social security coverage

Rémunération

1982€ / month (before tax) during the first 2 years, 2085€ / month (before tax) during the third year.