A Novel Point Process Paradigm for Stochastic Modeling and Inversion of Microseismic Monitoring Data for CO$_2$ Storage

Accurate representation of the distribution and attributes of discrete microseismic monitoring events is critical for characterization of rock flow and mechanical properties. These properties, in turn, determine the changes in the subsurface stress and strain distributions due to CO$_2$ injection. The objective of this method is to establish physical correlations among rock mechanical properties and discrete microseismic events, a fundamental requirement for formulating and solving inverse problems to estimate rock physical properties from observed microseismic monitoring data.
Benefits:

The integration of microseismic monitoring data through coupled models of multi-physics processes is a necessary step for constraining the key properties of storage reservoirs and for predicting their responses, in particular, geomechanical deformation and/or rock failure that can lead to induced seismicity, during CO₂ injection. The point process model constitutes a measurement operator for coupled flow and geomechanics state-space models that relates microseismic events (model outputs) to important rock properties that are used as input into the simulator. Hence, the model can be used to enable systematic estimation of rock flow and mechanical properties from observations of microseismic clouds. The results showed that both ES-MDA and EnPPF data assimilation approaches had similar performance in assimilating microseismic data when the measurements are assumed to be independent, suggesting that the Gaussian assumption used in the ES-MDA does not result in major approximation errors. This observation implies that the advantage associated with point process filtering that are often related to high data resolution (in time and space) may not be present in processing low (spatial and temporal) resolution microseismic measurements. Therefore, while modification to the EnPPF can be performed to process measurements that are inter-dependence, the ES-MDA implementation can be conveniently applied to those cases without any additional efforts.

Accomplishments:

The team developed and tested both a point process inversion method (EnPP) and a data assimilation technique with Gaussian assumption (ES-MDA) for inference of rock properties from integration and interpretation of microseismic response events. The work resulted in development of a stochastic framework to simulate microseismic clouds based on coupled flow and geomechanical simulation and rock failure mechanism for a given set of parameters. In addition to the uncertainty in hydraulic and geomechanical rock properties, they accounted for the uncertainty in seismic modeling and source inversion that is used to locate microseismic events. After completing the forward modeling framework for prediction of microseismic events, performed sensitivity analysis, they developed and applied the inversion algorithms (ES-MDA and EnPPF). They investigated the issues related to implementation of the EnPPF and evaluated its main properties and possible advantages relative to ES-MDA. They applied the formulation to simple models for testing and fine-tuning prior to using it with the field-scale examples. They tested both ES-MDA and EnPPF by applying it to the Farnworth field model. The main product of this work are the computer codes that were written to implement the ES-MDA and EnPPF algorithms. These codes include the CMG-based coupled flow and geomechanical model, the flow-only model, as well as the implementation of the data assimilation algorithms in Matlab, which includes modules that interface with the CMG simulator to run coupled flow and geomechanical simulation and import the results for inversion analysis.

NETL Collaboration:

Collaboration with NETL was primarily on discussing the approach and assumptions in developing the geologic models for testing their methods. The researchers had a number of meetings with the NETL research personnel. Discussions led to making reasonable assumptions in constructing the models, including model dimensions, boundary conditions, and modeling rock property distributions. They identified important parameters, with appropriate description of their heterogeneity, which we included in our microseismic data integration formulation. They also discussed approaches for stochastic representation of microseismic data from rock failure maps, which were predicted using coupled flow and geomechanics simulation. Discussion was around the sources of uncertainty in processing microseismic data and how they can be accounted for in the team’s modeling approach. They also received published papers by NETL collaborators on topics that are closely relevant to this work. They worked with NETL to implement the developed method on a field model. They received the field model for Farnworth, which is related to a CO₂-EOR project, to test their developed methods. They adapted the model into a coupled flow and geomechanical simulation model and used it for testing algorithms.

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