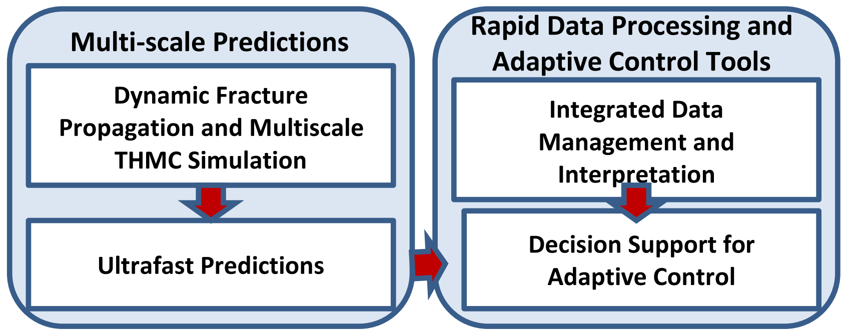
Fit-for-Purpose Simulation Capabilities

Introduction

Achieving adaptive control of subsurface fractures, reactions, and fluid flow in the subsurface requires game-changing improvements from scientific understanding through engineering applications. Advanced modeling and simulation that is fit-for-purpose, or targeted at the most important aspects of the problems, is essential for making a real difference in how the subsurface is engineered for both energy production, storage and waste disposal. Adaptive control of subsurface fractures, reactions, and flow requires understanding the complex, inter-dependent physical processes involved in dynamic fracturing and multi-phase fluid flow; rapidly assimilating, processing and interpreting large incoming data streams; and then representing the governing processes and responses at appropriate scales to provide decision support that allows real-time operational changes for enhanced production, or for risk reduction. These three components require individual capability advancements and are also mutually dependent. Tying them together will require new scaling techniques that utilize the full suite of signatures from geophysical, geochemical, and hydrologic observations. Ideally, these capabilities are embedded in a workflow that seamlessly integrates state-of-the-art algorithms for physical, chemical and biological processes within a platform that manages and interrogates data, enables model set-up and algorithm selection, and supports risk and uncertainty assessments as well as decision-making. Some of the capabilities required in this workflow exist, but currently lack integration, whereas others need to be developed or significantly improved.



Knowledge Gaps and Proposed Research

Multi-scale Predictions

One of the largest critical gaps in our simulation capabilities starts with the limited fundamental understanding of dynamic, mechanical damage and fracturing, and how the initiation, growth, and potential reactivation of natural and induced discontinuities (e.g., seismicity) is coupled to thermal-hydraulic-mechanical-chemical (THMC) processes, often with multiple fluids in multiple phases. We need better fundamental constitutive models to accurately represent how fractures form and grow, or heal and seal, in various lithological, structural, and stress conditions for complex, often far-from-equilibrium subsurface systems. High performance computing (HPC) will then allow us to mechanistically simulate these complex processes. For real-time adaptive control guiding operational decisions in field applications, fit-for-purpose simulation requires interplay between high-fidelity process-level simulation utilizing DOE's leadership HPC resources and ultrafast simplified, upscaled or abstracted prediction tools, such as reduced order models (ROMs). This interplay leads to two essential research components.

Dynamic Fracture Propagation and Multiscale THMC Simulation

Liberation of energy resources and isolation of wastes in the subsurface is highly dependent on coupled, dynamic properties of the rocks, fluids, and their exchange interfaces over a large range of scales (pore-grain, core, fracture-matrix, well to reservoir). We need efficient simulation tools for dynamic fracture propagation and fluid-flow to model fracturing initiation, growth, reactivation, and fluid resource interactions, but our current simulators for dynamic fracturing have only rudimentary capability, especially when applied to realistic lithological, structural, and stress conditions. We also need improved models for predicting the short-term and long-term behavior of natural and engineered materials interacting with fluids at elevated temperature and pressure, particularly for applications in drilling and well completion. Ongoing projects across the DOE complex are developing simulation methods for some aspects of coupled multi-physics processes, but have not yet achieved full coupling of THMC processes or integration of models at multiple relevant scales. The goal for the next generation of THMC models will be to provide information useful for identifying precursors to new fracturing or seismicity, and to be useful as a guide to provide better understanding, in advance, of the meaning of observables and how to react and adapt when signals that are potential precursors occur.

Ultrafast Predictions

Predictive models must be vastly more computationally efficient to support uncertainty assessments and decision-making in real time. Appropriate upscaling is one option, providing constitutive, dynamic stress-damage and flow/transport relationships that represent the dominant processes and structures at scales appropriate for decision modeling and adaptive control systems. Other options to achieve adaptive control in field settings include development of fit-for-purpose surrogates (ROMs) that capture the critical system behaviors and responses necessary to interpret specific data streams or inform specific decisions. Clearly, upscaling and validation of ROMs with next-generation THMC models is integral to building effective adaptive control simulation tools.

Rapid Data Processing and Adaptive Control Tools

The goal for modeling for adaptive control is to drive real-time operational changes to enhance production or reduce risk. This grand challenge will require rapid interpretation of incoming data streams integrated into a decision support system that evaluates alternatives and supports user-driven changes for fracture stimulation controls (pressures, volumes, locations), flow modification (injection of surfactants, engineered fluids to block fractures, etc.), or risk management (e.g., stress control, geosteering). Thus, the computational platform will need to serve the right information in real time in a format suitable for an informed expert to make operational choices to optimize a process. Such a capability does not exist today. Two essential components of this capability are highlighted below.

Integrated Data Management and Interpretation

Adaptive control will require development of integrated data management, processing, integration and visualization workflow/tools capable of rapidly handling large and heterogeneous data sets. New approaches are needed to assimilate direct and indirect measurements of geophysical, geochemical, mechanical and hydrological responses into fit-for-purpose models. This area is interwoven with the New Subsurface Signals topic. Advances in multi-stream data management, joint inversion capabilities, and their coupling to appropriate process models are needed to better decipher complex subsurface structures and interactions. A framework that integrates the data management tools and advanced inversion with multi-process simulators will allow predictive modeling for risk assessment and adaptive control decision support.

Decision Support for Adaptive Control

Adaptive control during either production or storage processes requires the ability to determine actions in response to the information contained in the data. Today, decision support algorithms typically involve extensive sampling of uncertain parameters and processes, including outliers and unanticipated events, and then incorporating them in a suite of scenario simulations with probabilistic outcomes; this can be a slow process, particularly for sparsely sampled subsurface systems. ROMS are currently preferred due to their low execution cost, but for some applications, higher fidelity models are needed to properly inform decisions. Therefore, a new paradigm for rapid decision support is needed: development of an approach to automatically assess and validate the appropriate level of abstraction that supports the relevant decisions most efficiently.