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Physically rigorous reduced-order flow models of fractured subsurface environments without explosive computational cost

G. Didem Beskardes (PI), Kyle Jones (PM)
Chester J Weiss
Kyung Won Chang
Bart van Bloemen Waanders

Objective

To develop a computational capability to model fluid flow in large-scale geologic environments that possess geometrically-complex fractures and man-made infrastructures without explosive computational cost.

Multiple spatial scales of the models

<u>*mm-scale*</u> **fractures**
<u>*cm-scale*</u> **infrastructures**   **Fine mesh**
<u>*km-scale*</u> **field of interest**   **Extensive computational resources**

Fractured media   **Complex well geometries**   **Other man-made structures**
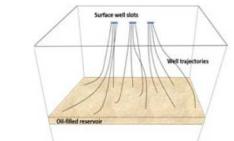
https://www.earthimagegallery.com
https://drillingsiberia.wordpress.com
http://www.cedmagazineng.com

How to model *all* in one simulation?
How to optimize the multi-scale domain?

Optimize the computational efficiency and realism for fluid flow models incorporating both *realistic, explicit* fracture and infrastructure *geometries*
by
- *embracing full-physics of fluid flow*
- *preserving model size and geometry*
- *retaining surrounding rock*
- *maintaining affordable computational costs*

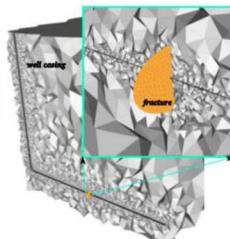### Science questions to be addressed in this work

Better understand the ***limits of homogenization*** and test how microstructures in transport phenomena upscale to the observable field scale.
At what point can simplified flow models be acceptable?
What is the response of the fully realistic model?

Approach

Hierarchical Finite Element Method (HiFEM)

Novel parametrization of physical properties

Material properties can be defined
for each dimensional component of
the volumetric finite element (3D tetrahedron
2D facets
1D edges)

3D tetrahedron   2D facet   1D edge
$\sigma_e \mathrm{diag}(1,1,1)_e$ $s_e \mathrm{diag}(0,1,1)_e$ $t_e \mathrm{diag}(1,0,0)_e$

Weiss, Geophysics 2017;
USPTO application 15/871,282

Geometric hierarchy within unstructured tetrahedral mesh

fractures → **2D planes**   *wellbores* → **1D lines**

aperture (h) —Hi-FEM→   conductivity (σ) conductance (Δσ·h)

Area (A) —Hi-FEM→   conductivity (σ) conductivity · cross-sectional area

Reduces insignificant dimensions mesh refinement computational cost
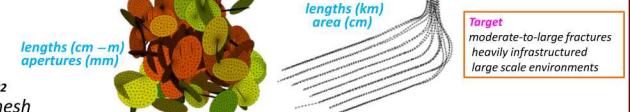
lengths (cm − m)
apertures (mm)

lengths (km)
area (cm)

Target
moderate-to-large fractures
heavily infrastructured
large scale environments

Research Outline
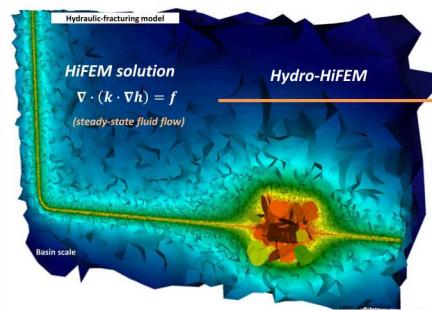
HiFEM solution   **Hydro-HiFEM**
$$\nabla \cdot (k \cdot \nabla h) = f$$
(steady-state fluid flow)

Basin scale

Milestones

Completion of Hydro-HiFEM code for transient flow

Expand Hydro-HiFEM code for other flow processes (advection, diffusion etc.)

Develop Hi-FEM based optimization (inversion, least squares, design)

Many energy and national security related engineering applications require **high fidelity**, **realistic** and **computationally efficient** modeling.

Applications in Global Security, Nuclear Deterrence, Energy and Homeland Security

- Nuclear waste isolation
- CO_2 sequestration
- environmental protection
- groundwater and solute management
- geothermal reservoir enhancement
- hydrocarbon reservoir management
- Underground facility characterization
- Engineered material monitoring and corrosion
- Engineered fracture system monitoring
- Suspected nuclear tests

Solve the transient flow in frequency domain
$$\nabla \cdot (\kappa \cdot \nabla h) = S_s \frac{\partial h}{\partial t} \longrightarrow \nabla \cdot (\kappa \cdot \nabla \bar{h}) = q \bar{h}$$

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