FMM Petrel Plug-In
(Fast Marching Method)

Atsushi Iino, Hye Young Jung
April 28, 2017

MCERI

PETROLEUM ENGINEERING
TEXAS A&M UNIVERSITY

Outline

- Motivation
- Background
- FMM-plug in
  - FMM plug-in Features
  - Plug-in Workflow
- Demonstration

MCERI

Motivation

- Drainage volume and pressure depletion are important in unconventional reservoirs
- Quickly generalize the concept of drainage volume to account for complex geologic stratigraphy, reservoir heterogeneity and well/fracture geometry

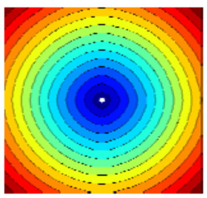
Background

Pressure Front Propagation

Radius of Investigation (ROI)
for homogeneous reservoir

$$r = \sqrt{\frac{4kt}{\phi \mu c_t}}$$

'Peak' arrival time
(Impulse source)

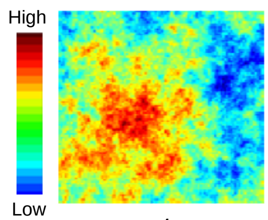


(Lee, 1982)

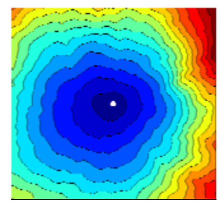
Generalization of ROI
for heterogeneous reservoir

Eikonal eq.: $$\sqrt{\frac{k(\mathbf{x})}{\phi(\mathbf{x})\mu c_t}}\left|\nabla \tau\right| = 1$$

Speed (diffusivity)



Diffusive Time-of-Flight



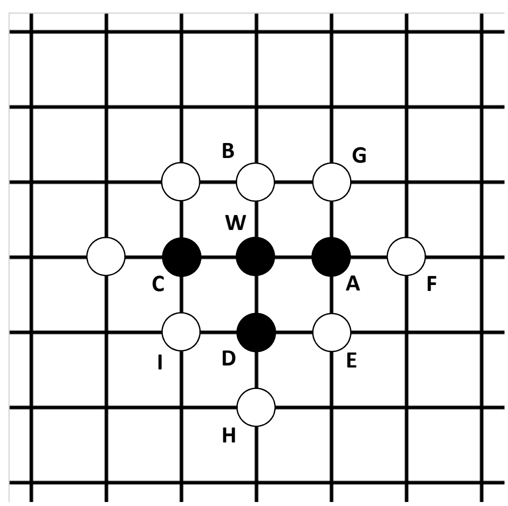
(Datta-Gupta et. al., 2011)

MCERI

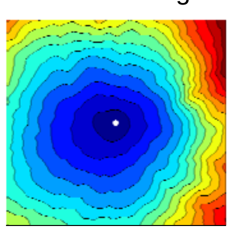
Travel Time Calculations by Fast Marching Method

Fast Marching Method (FMM)*

- Efficiently solves eikonal eq. for Diffusive Time-of-Flight τ (DTOF)
- Sequential calculation of shortest path from a source outwards



Diffusive Time-of-Flight Map

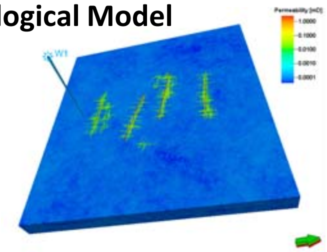


*Dijkstra (1959), Sethian (1996)

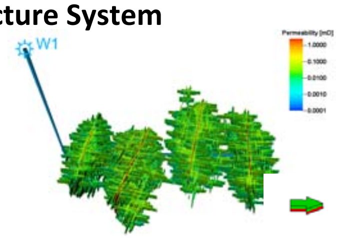
MCERI

Application to Unconventional Reservoirs: Drainage Volume Calculation Using Fast Marching Method

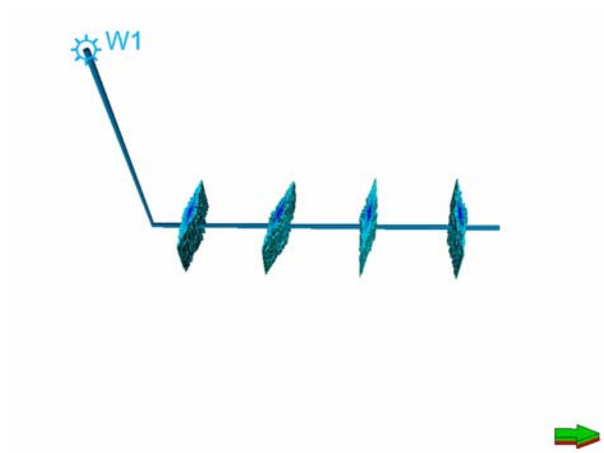
Geological Model



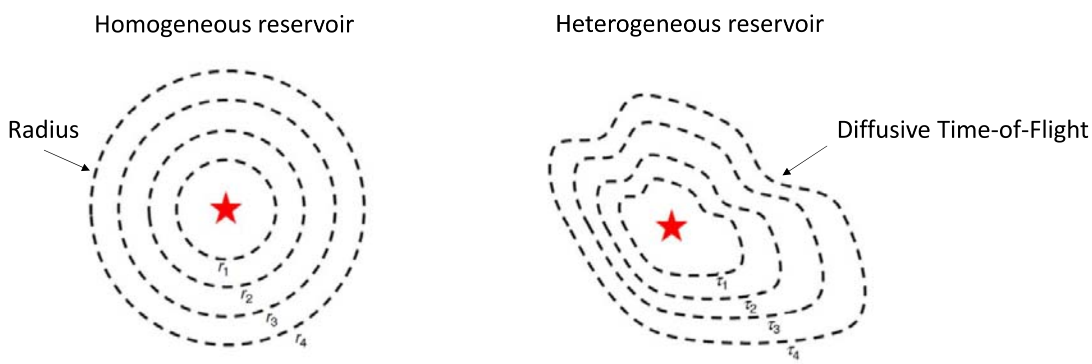
Fracture System



Drainage Volume



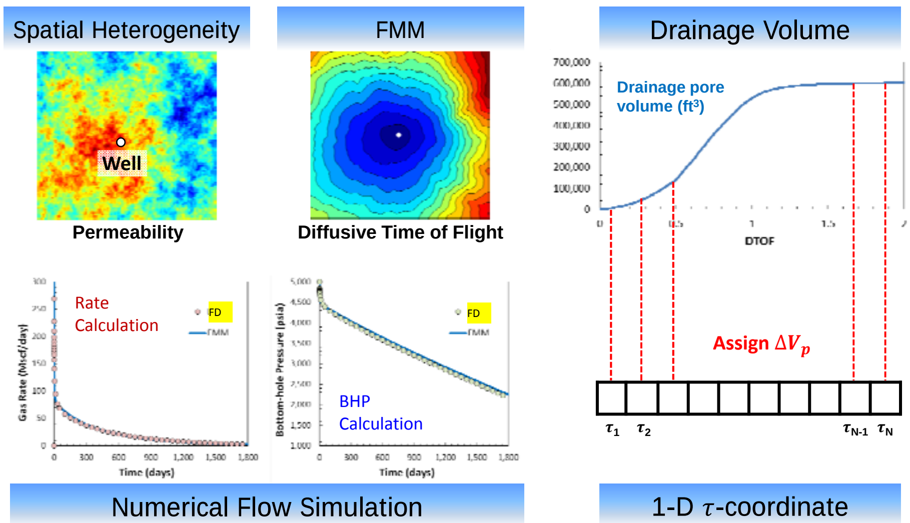
Generalization of Radial Diffusivity Equation Using Diffusive Time-of-Flight as a 1-D Spatial Coordinate



$$\frac{k}{\phi \mu c_t} \frac{1}{r} \frac{\partial}{\partial r}\left(r \frac{\partial P}{\partial r} \right) = \frac{\partial P}{\partial t} \xrightarrow{r \to \tau} \frac{1}{w(\tau)} \frac{\partial}{\partial \tau}\left(w(\tau) \frac{\partial P}{\partial \tau} \right) = \frac{\partial P}{\partial t}$$

$$w(\tau) = \frac{dV_p(\tau)}{d\tau}$$

Rapid Simulation of Unconventional Reservoirs: 3-D to 1-D Formulation

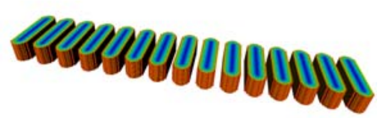


MCERI

CPU Time: Orders of Magnitude Faster Computation than Commercial FD Simulator

Significant gain in computational efficiency

- Dual Porosity Model, Horizontal well with 15 HFs
- BHP constraint
- 20 years forecast

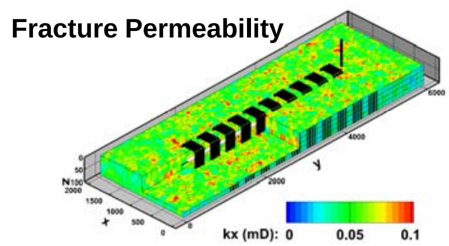


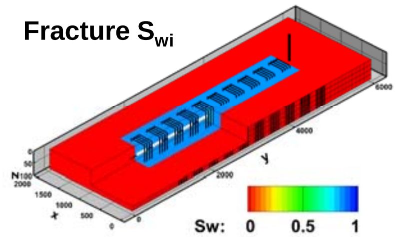
	Cell number (millions)	CPU Finite Difference(s)	CPU FMM (s)	Ratio
Base	1.03	574.7	13.1	43.87
High kf	1.03	557.9	13.1	42.59
High km	1.03	691.6	13.2	52.40
Long xf	1.03	586.2	13.4	43.75
More stages	1.23	628.0	16.4	38.29

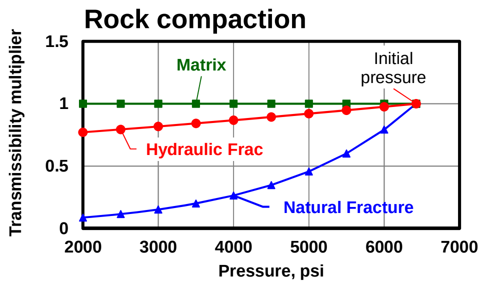
MCERI

Rapid Compositional Simulation Using Fast Marching Method

- 0.4 million cells with reservoir heterogeneity
- Multi-stage hydraulic fractures
- 3-phase and 7-component
- Dual-porosity
- High water saturation around well
- Permeability reduction due to compaction
- Primary depletion + CO_2 Huff-n-Puff (5-cycle)





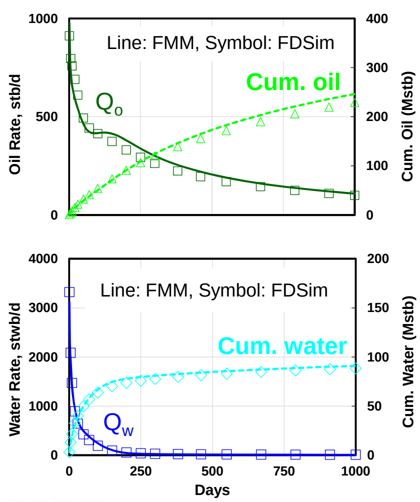


MCERI

Simulation Results

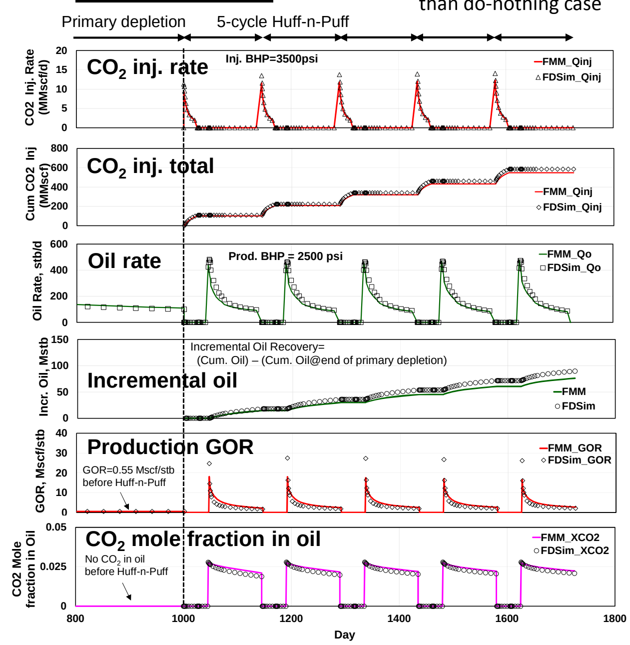
Speed-up factor x 320
(compared to commercial FD simulator)

Primary depletion



CO_2 Huff-n-Puff

32% increase in incremental oil than do-nothing case



FMM Petrel Plug-in

MCERI

FMM Plug-in Features

- Current version
  - Drainage volume calculation (single-phase)
  - 1-D simulation (single-phase)
- Future plan
  - Multi-phase black oil simulation
  - Compositional simulation

MCERI

FMM Petrel Plug-in Workflow

Drag and drop properties

⇩

Generate the simulation model

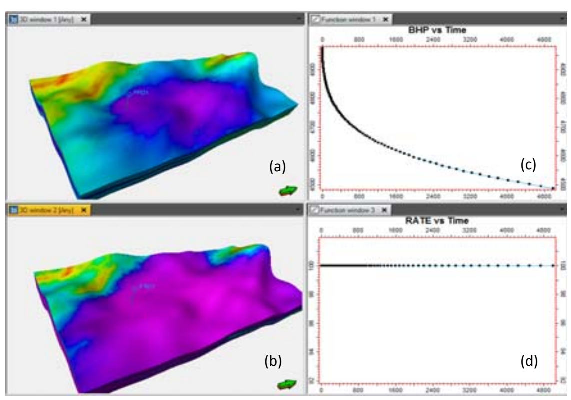
⇩

Run the FMM simulation

⇩

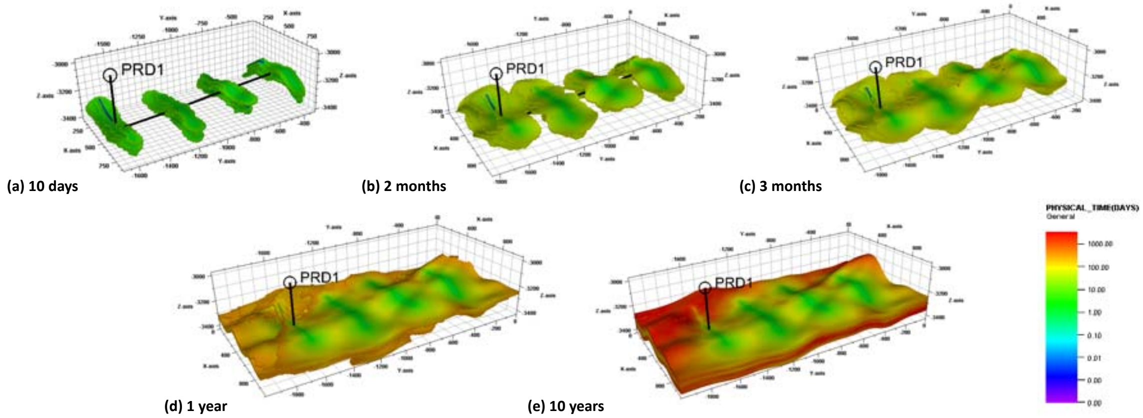
Import and visualize results

Visualizing Results in Petrel



(a) Diffusive Time of Flight; (b) Drainage Volume; (c) BHP; (d) Rate

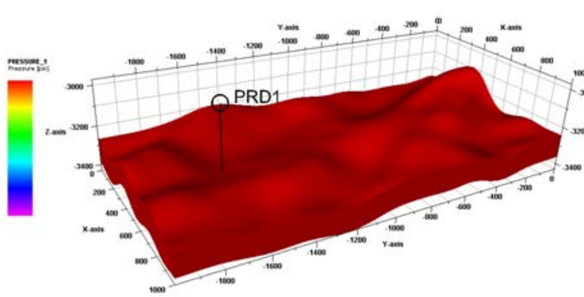
Evolution of Drainage Volume with Time



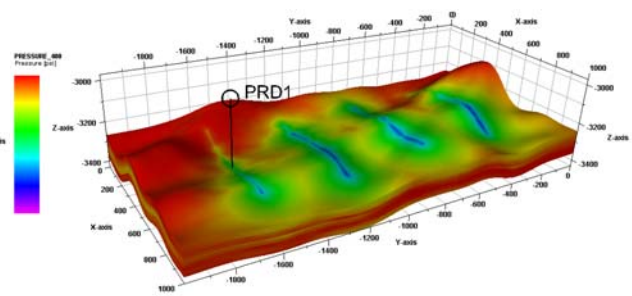
(a) 10 days (b) 2 months (c) 3 months

(d) 1 year (e) 10 years

Visualizing Pressure on the Grid



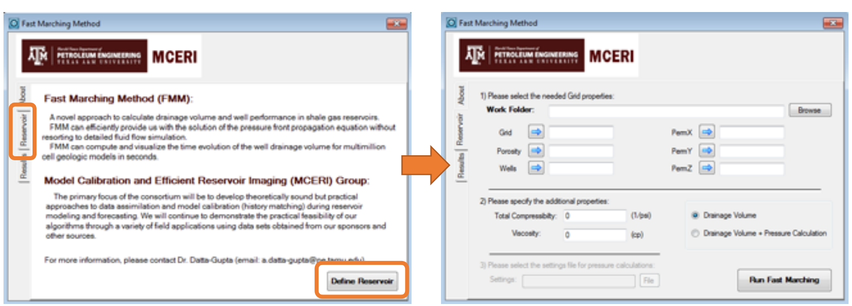
Initial Pressure = 4971 psi



Pressure at the last time step

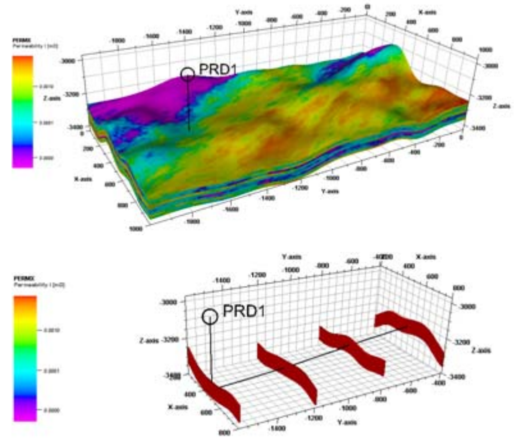
Training Session :
Petrel Plug-in

FMM Petrel Plug-in User Interface



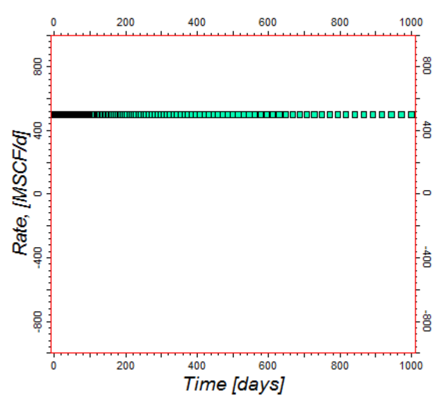
Model for Demonstration

Reservoir dimension	1000 ft x 2000 ft x 120 ft	
The number of grid blocks	100 x 200 x 10	
Well data	1 Producer Horizontal Well	Rate constrained : 500 MSCF/D
Hydraulic Fractures (4)	Half Length	300 ft
	Width	2 ft
Porosity	0.05	
Permeability	Matrix	Avg. k_h= 7.23e-4 md $k_x = k_y \; \frac{k_v}{k_h} = 0.1$
	Fracture	100 md

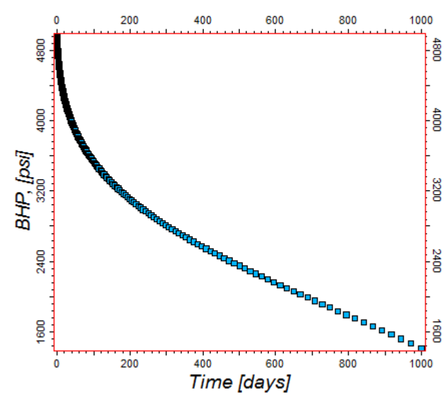


Results from Democase

Gas Rate

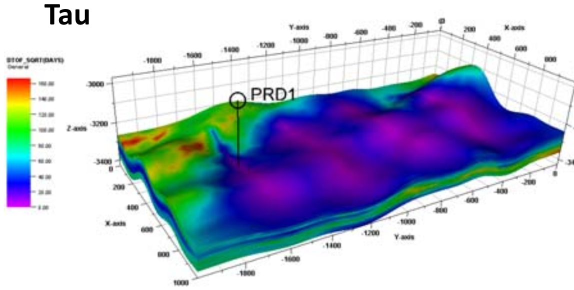


BHP

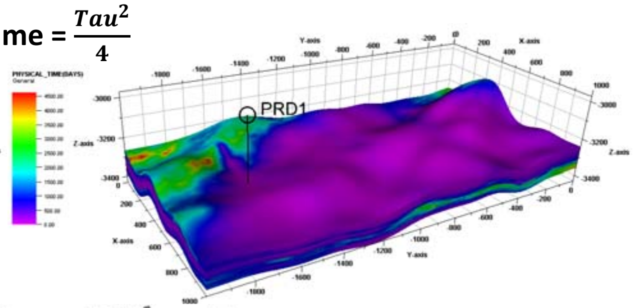


Results from Democase

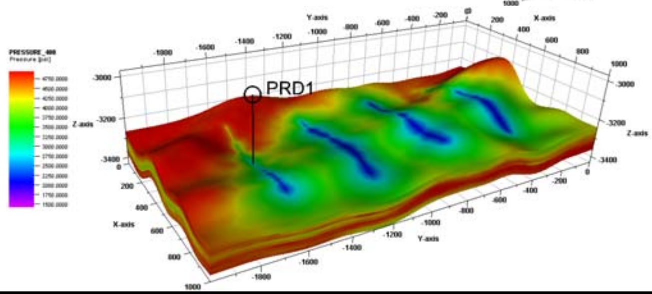
Tau



Time = $\frac{Tau^2}{4}$



Pressure



MCERI