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Centre for EXPLORATION TARGETING

MinEx CRC

Loop

6ias 2023 Perth

Loop 'Flow'

Fremantle, July 23rd 2023

6ias *3D modelling and Loop* workshop

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AngloAmerican

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HiSeis

IMDEX REAL-TIME SUBSURFACE SOLUTIONS

AMC DRILLING OPTIMISATION

REFLEX INTELLIGENCE ON DEMAND

McKAY DRILLING Setting the Standard

OLYMPUS Your Vision, Our Future

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wassara STRAIGHT FORWARD DRILLING

Australian Government Geoscience Australia

Geological Survey of Western Australia

SOUTH AUSTRALIA

Government of South Australia Department for Energy and Mining

NSW GOVERNMENT

Majors, METS and Survey Participants (16)

Loop

Research Participants and Affiliates (20)

What is LoopFlow ?

- A Python package authored by Mark Jessell and Guillaume Pirot, to:
  - Generate graphs from Loop models
  - Calculate flow parameters based on those graphs

- Available on GitHub:
  - https://github.com/Loop3D/LoopFlow

- With some example Python notebooks:
  - one derived from ‘Draw your own model’ example (6ias *map2loop* workshop)
  - the other hardwired to loading van der Wielen et al. Emmie Bluff *Gocad* surfaces

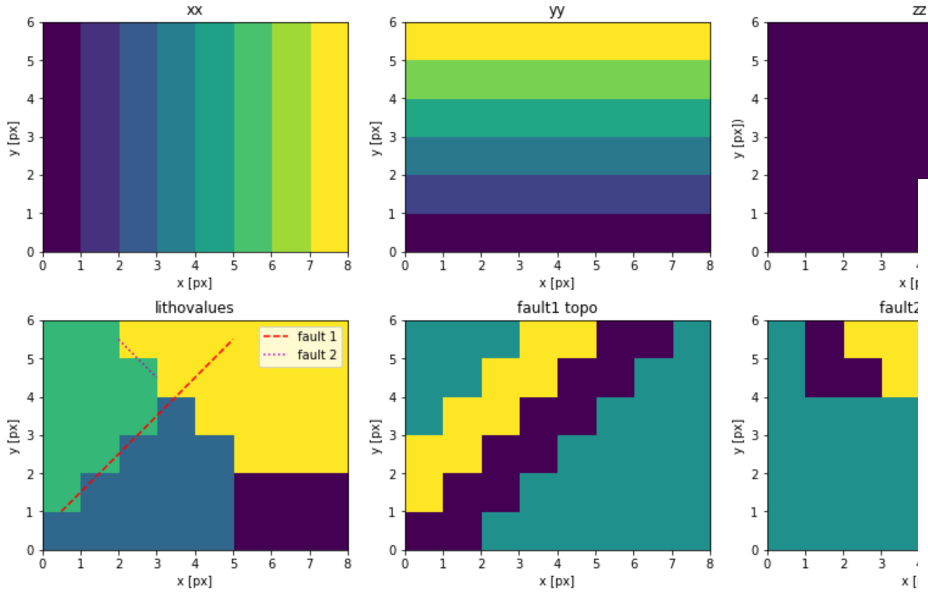
Motivations – part 1

- Understanding and Targeting Mineral Systems
  - Source
  - Path
  - Host
- Testing different scenarios
  - Source locations
  - Potential path or barriers
  - Potential hosts

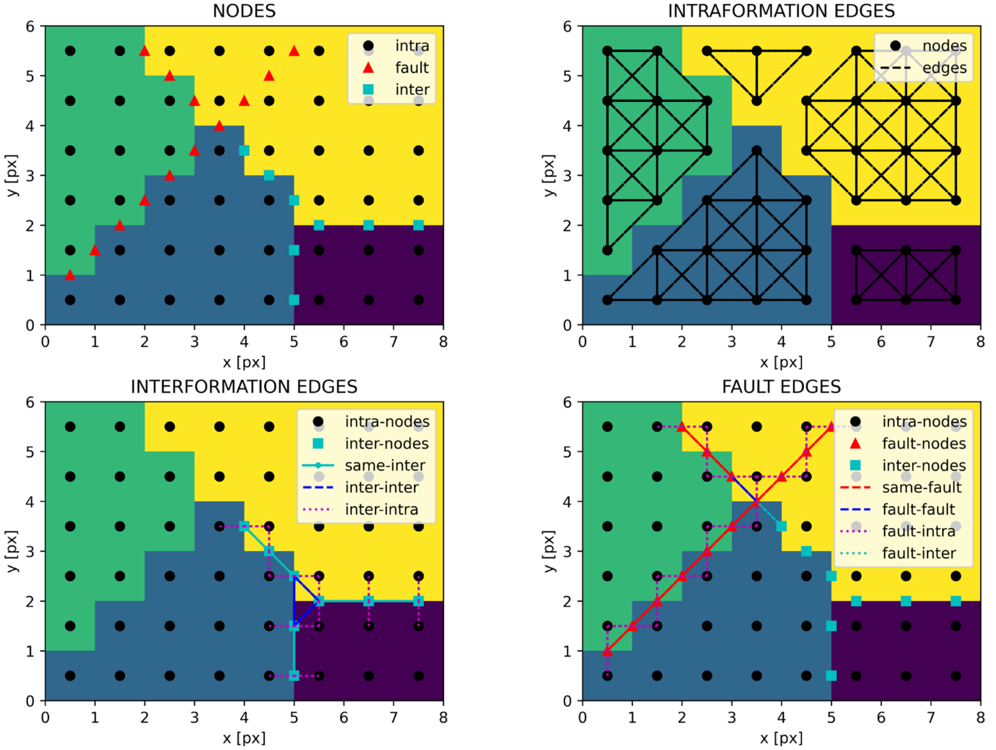
Motivations – part 2

- Groundwater management
- Subsurface characterization
- Inverse problem
  - Challenging computing costs of flow and transport simulations with finite element or finite difference solvers

From voxet to graph

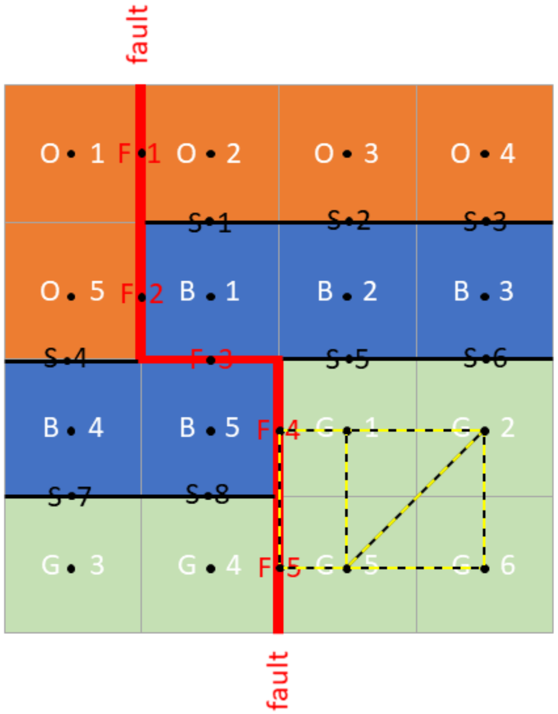


Voxet outputs from Loop Model

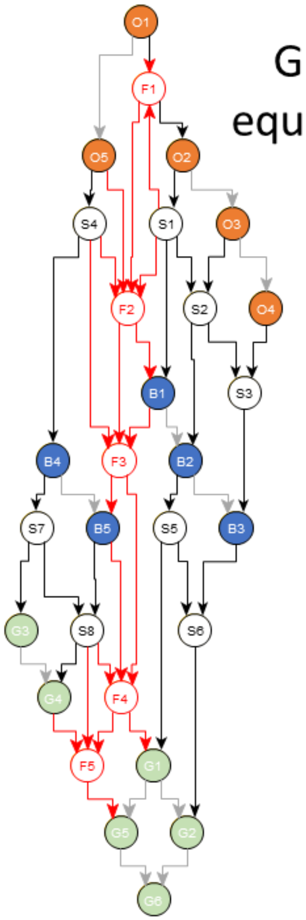


Graphs

Small slice through voxel model



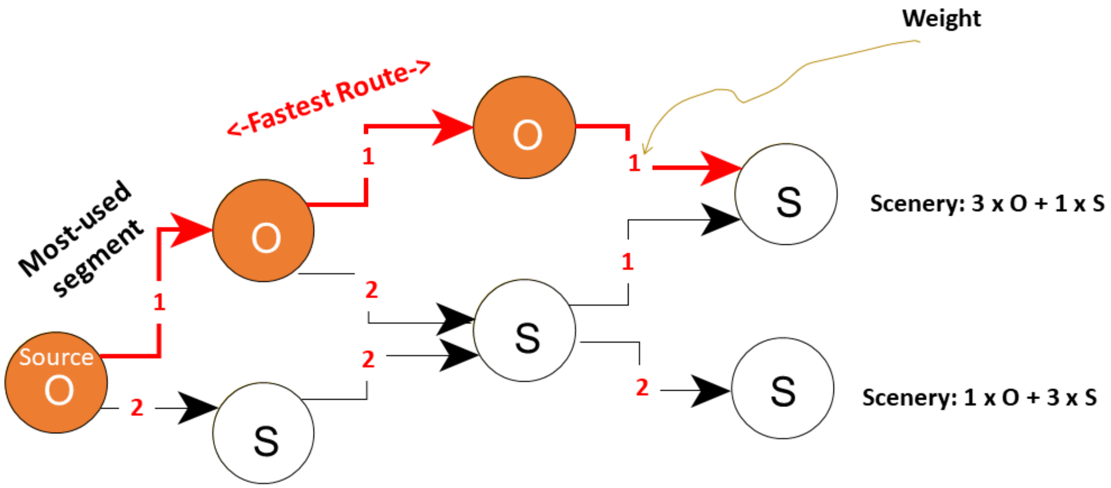
Graph equivalent



What is the fastest route home?

Possibilities

Distance, pathways, scenery…



Does it work to approximate flow and transport in aquifers with complex structures?

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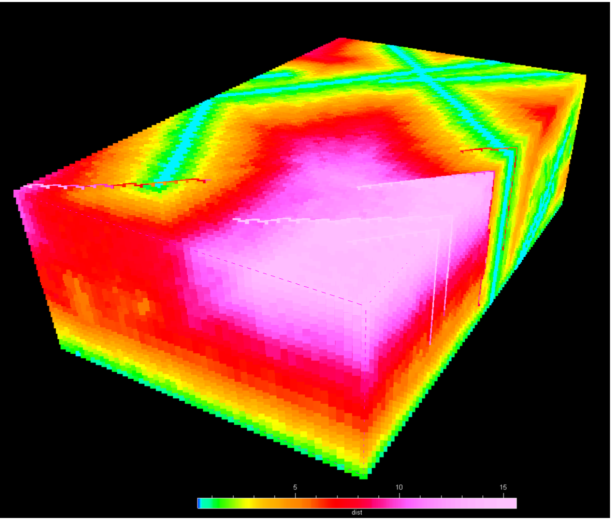
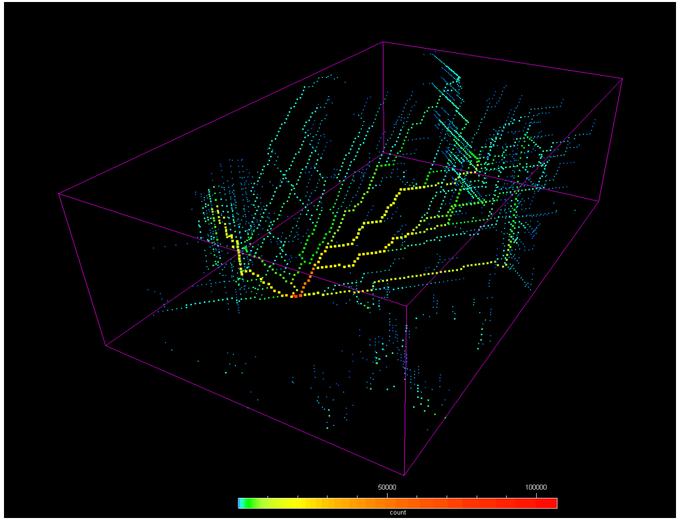
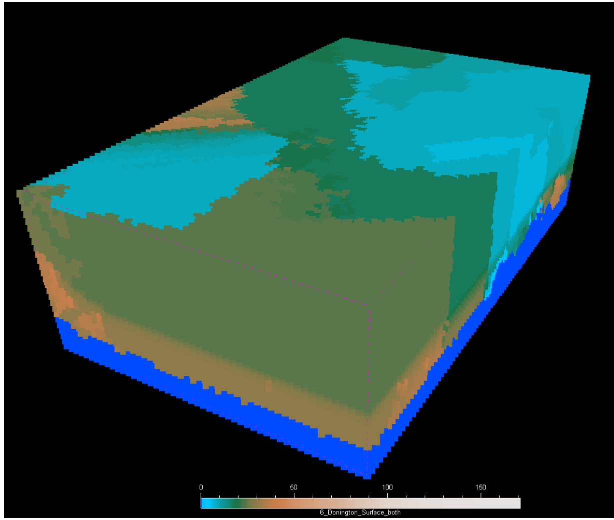
Mineral resources perspectives



Distance from source



Preferred pathways



Path scenery

- Mineralization halo
- Contaminant remobilization
- Chemical reaction paths

Python notebook: https://github.com/Loop3D/6IAS/blob/main/LoopFlow/2_m2l_wa_flow.ipynb

A groundwater application

- Can we approximate flow and transport simulations by computations through graph representations of subsurface models?

- Darcy's law

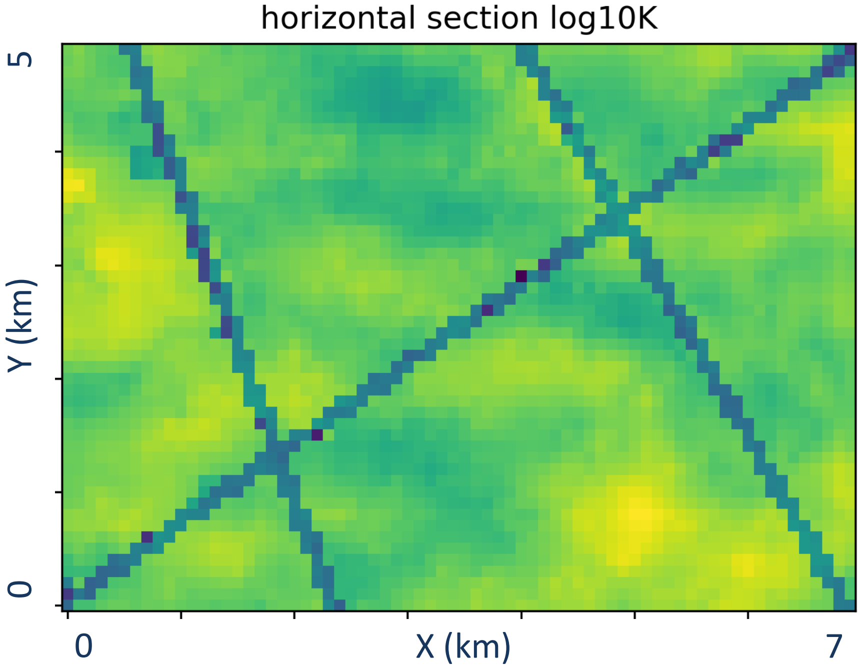
$$\vec{q} = -K\nabla h$$

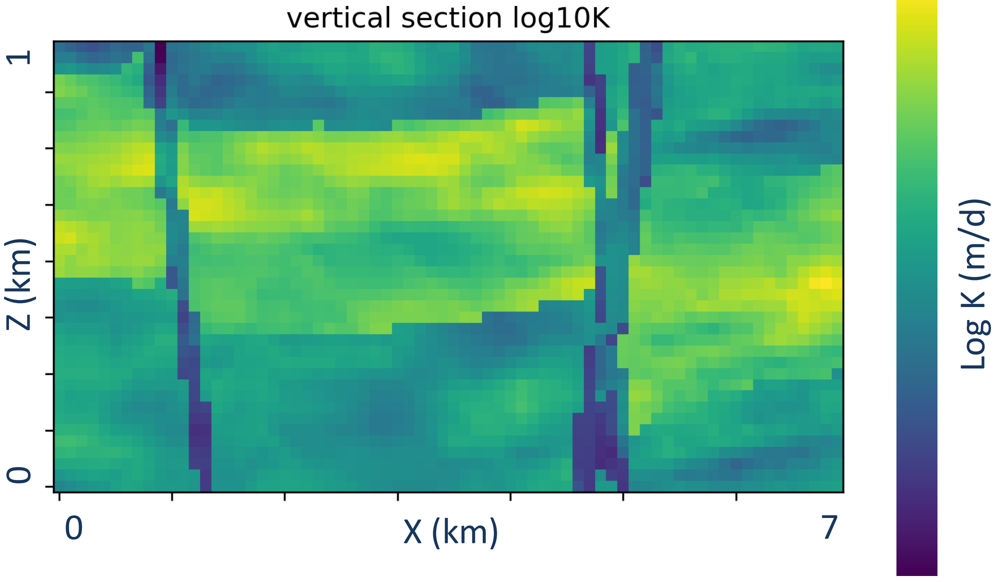
- Advection dispersion equation (ADE)

$$\frac{\partial c}{\partial t} = \underbrace{-\vec{q}\nabla c}_{\text{advection}} + \underbrace{D_m \nabla^2 c}_{\text{diffusion}}$$

Experimental setting

- 7km x 5km x 1km (x-axis,y-axis,z-axis)
- 70 x 50 x 40 cells
- 3 heterogeneous stratigraphic units
- 3 faults (fixed geometry)





Scenarios & boundary conditions

3 faults paths or barriers

2^3 = 8 possibilities

– path $\log_{10}K$ +2

– barrier $\log_{10}K$ -2

▲ injection well

Scenario 0

Scenario 1

Scenario 2

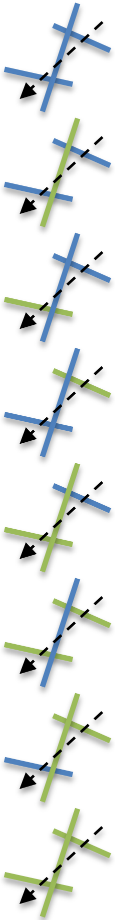
Scenario 3

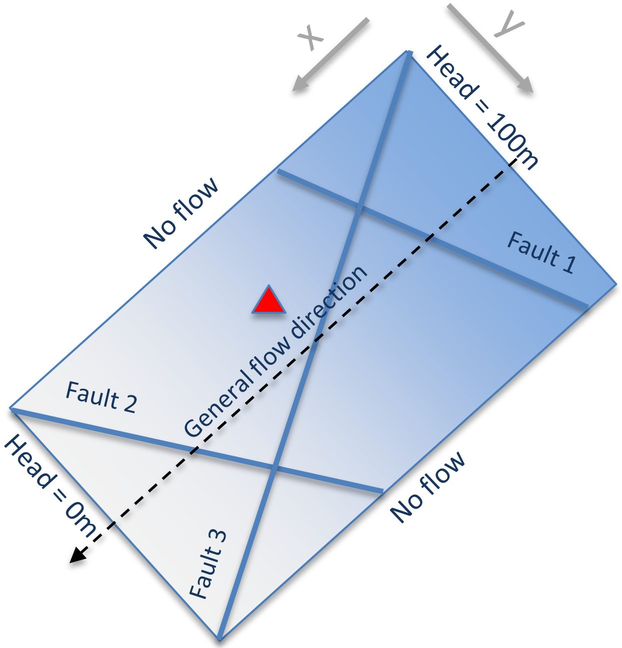
Scenario 4

Scenario 5

Scenario 6

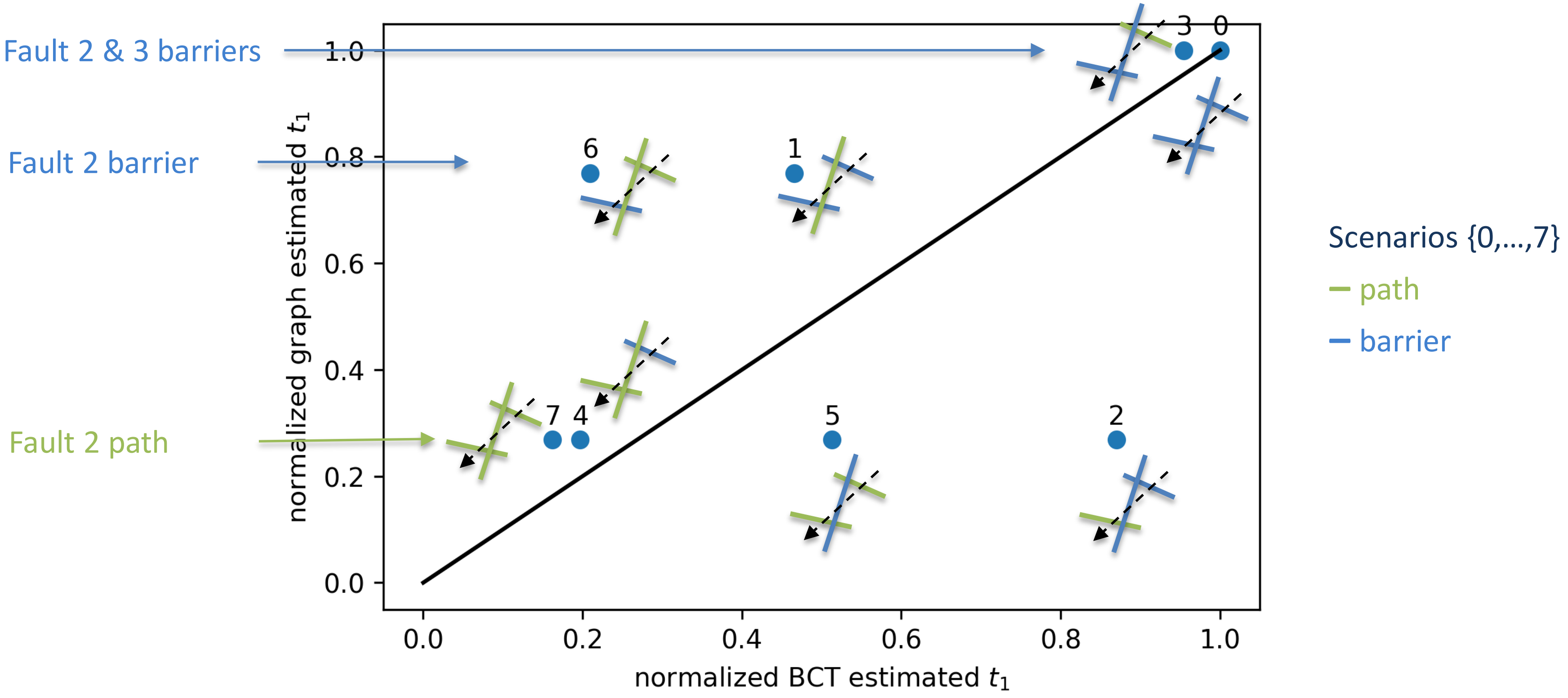
Scenario 7





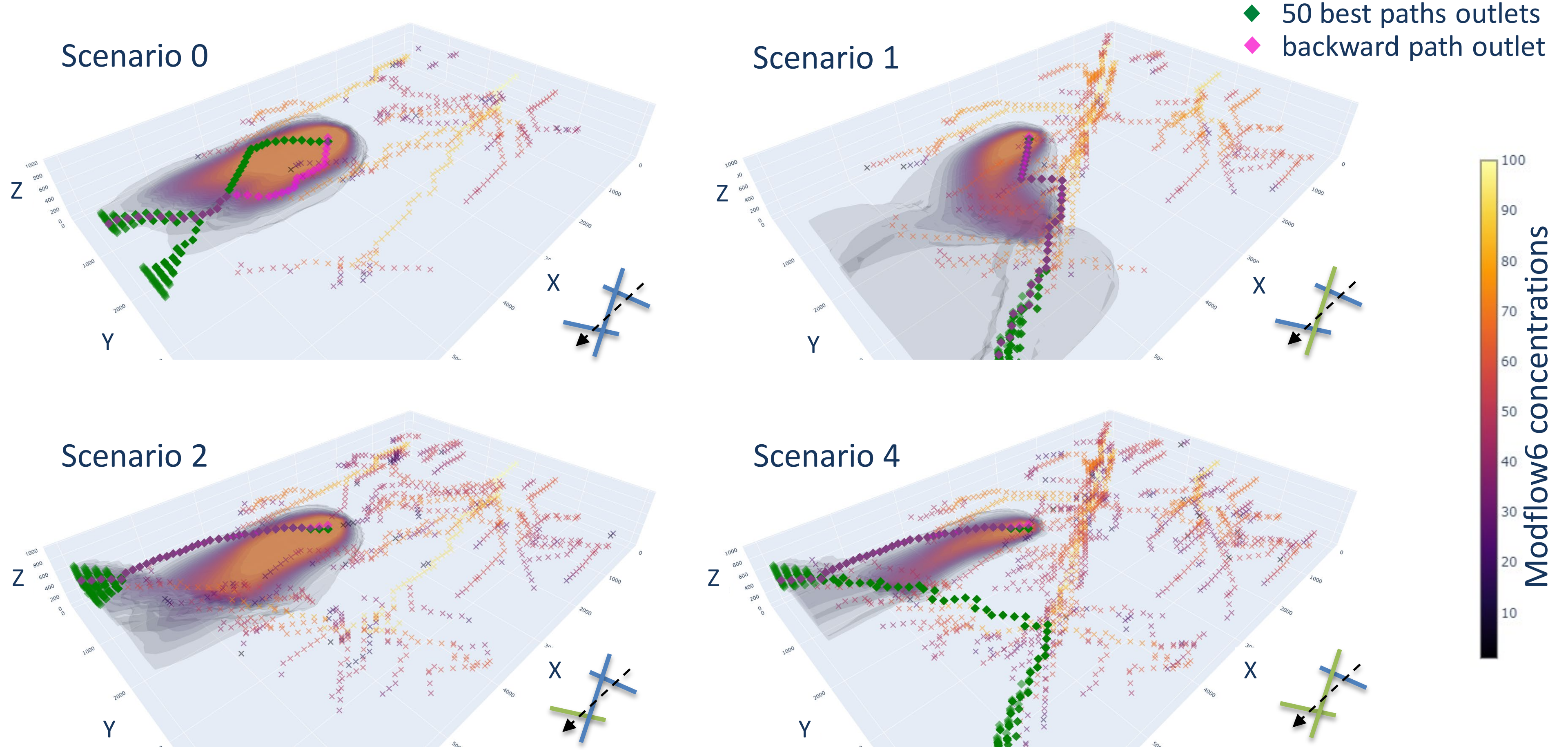
Steady state flow
Transient transport, advection and diffusion
10 years of simulation (timestep = 1 month)

First arrival travel times

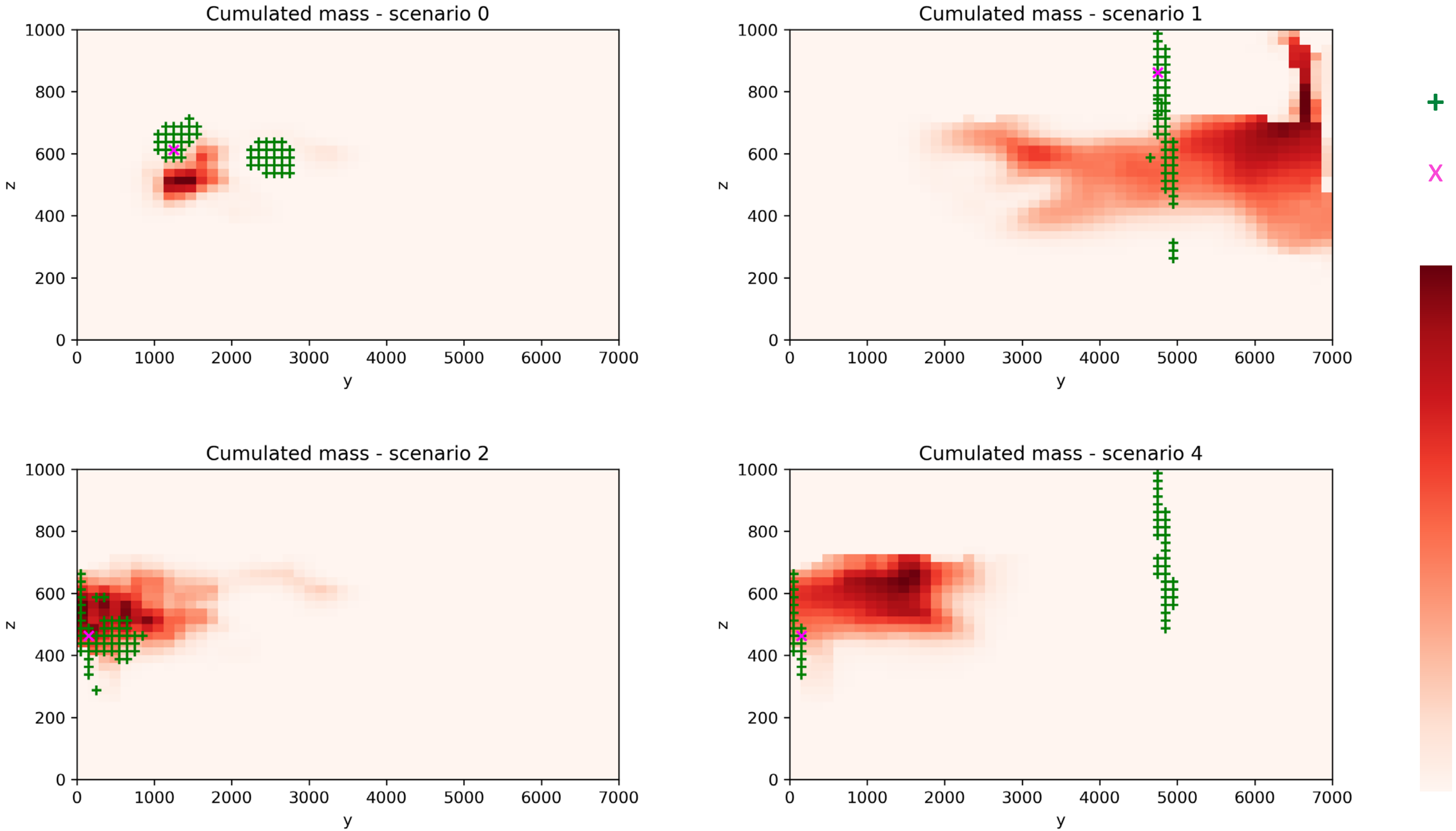


Fault 3 most influential, then Fault 2 then Fault 1

Transport results



Transport results

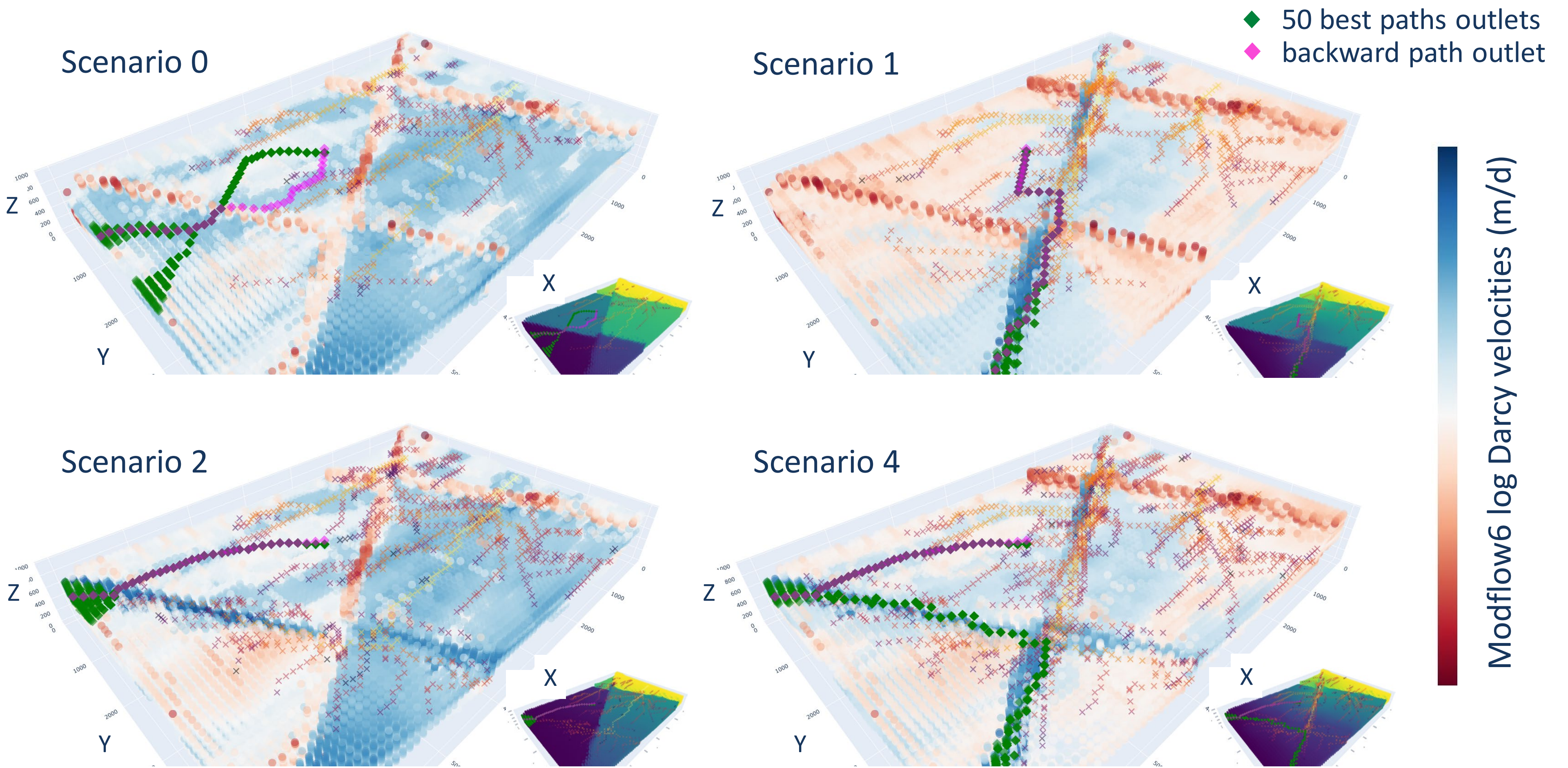


+ 50 best paths outlets

x backward path outlet

cumulated mass from Modflow6

Flow results



Computing requirements

From an existing voxet model (140k cells)

– Using Python libraries networkx and flopy

- Graph generation: ~30 seconds per graph
- Backward or forward distances from graphs: ~ 3 seconds per computation
- Modflow6 simulation (1 steady state + 120 timesteps for a total of 10 years): ~ 5 minutes per simulation

Groundwater application summary

- Graph approximations are blind to upstream flow conditions
- Backward path approximation seems more accurate
- Cumulative mass outlet locations are relatively coherent
- Least resistant paths are consistent with the field of Darcy velocity magnitudes

Future work

- Graph weight tuning
- First arrival time calibration
- Find alternative paths to see if we can approximate the plume shape
- What if we used the velocity field rather than the K field to build a graph
- Comparison with particle tracking simulations
- Unstructured mesh to better explore fault effects

- **Ideas for other applications and collaboration?**

THANK YOU

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Detailed parameters

- Upper hydro stratigraphic unit $\log_{10}K$
  - μ = -4.45 m/s
  - σ = 0.4 m/s
- Middle hydro stratigraphic unit $\log_{10}K$
  - μ = -3.10 m/s
  - σ = 0.5 m/s
- Lower hydro stratigraphic unit $\log_{10}K$
  - μ = -4.69 m/s
  - σ = 0.6 m/s
- $K_{xx}=K_{yy}=10K_{zz}$

- Porosity: 25%
- $Q_{well} = 50 \cdot 10^3\ m^3/d$
- α_L = 1 m (longitudinal dispersivity)
- α_T = 0.1 m (transvers dispersivity)

Estimation of first arrival travel time from breakthrough curves