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Title:	Identifying Heterogeneities in Subsurface Environment using the Level Set Method
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Identifying Heterogeneities in Subsurface Environment using the Level Set Method

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Outline

1. Motivation
2. Level Set Method (LSM)
3. Algorithms
4. Examples
5. Future Work

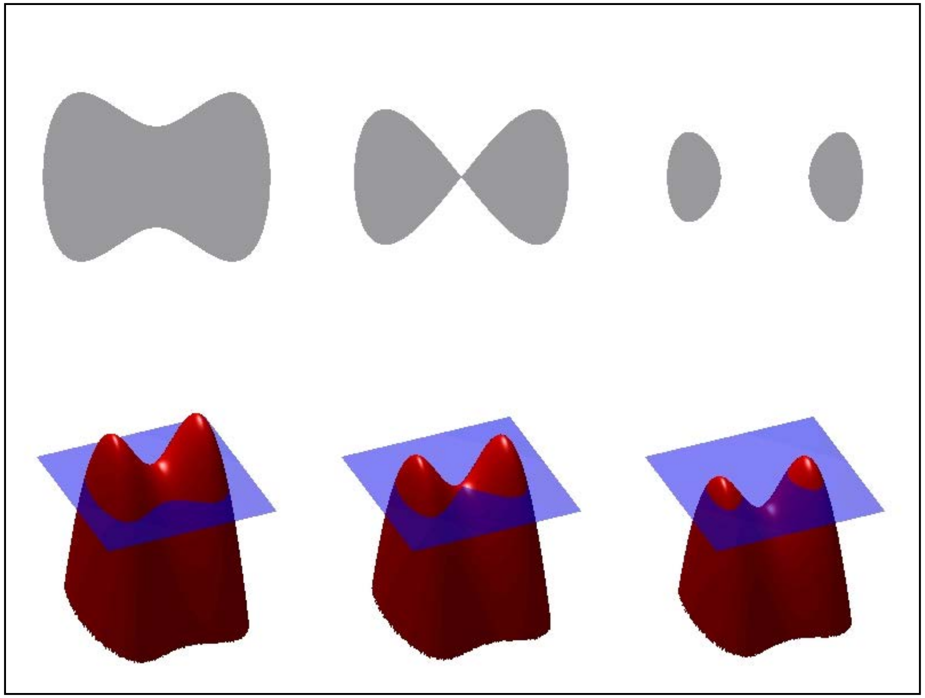
Identifying parameter zonation is difficult:

1. No information (or little information) regarding the shape, size, and locations of zones.

2. Existing inverse methods may not work or too time-consuming.

2. Level Set Method (LSM)

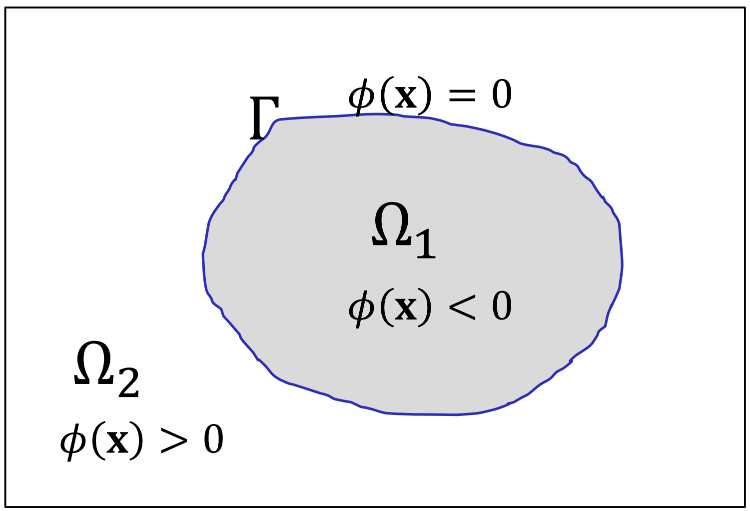
- Developed by Osher and Sethian in 1988.
- A great tool for solving problems that involve geometry and geometric evolution.
- Popular in:
  Image processing,
  Computer graphics,
  Computational geometry,
  Computational fluid dynamics,
  etc.



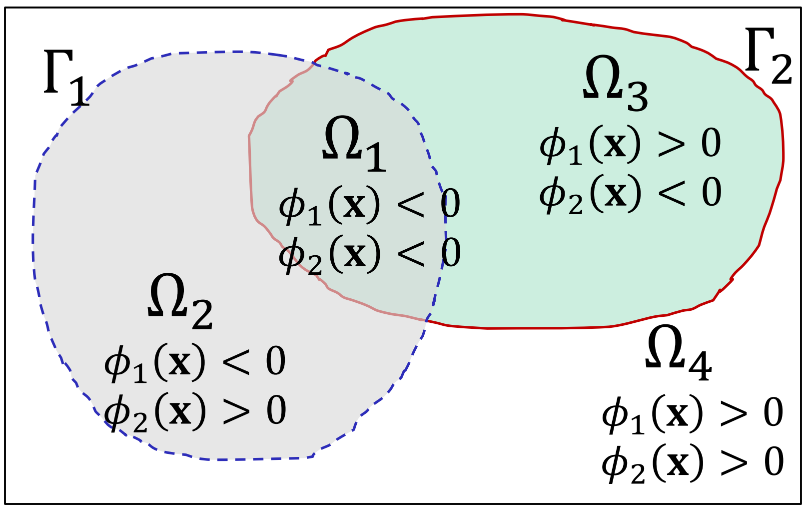
- Geometric boundaries Γ are represented by the zero level set of level set function ϕ, which is negative inside Γ and positive outside.

For two zone case below

$$\phi(\mathbf{x}) < 0, \text{for } \mathbf{x} \in \Omega_1,$$
$$\phi(\mathbf{x}) > 0, \text{for } \mathbf{x} \in \Omega_2,$$
$$\phi(\mathbf{x}) = 0, \text{for } \mathbf{x} \in \Gamma,$$



Two zone case



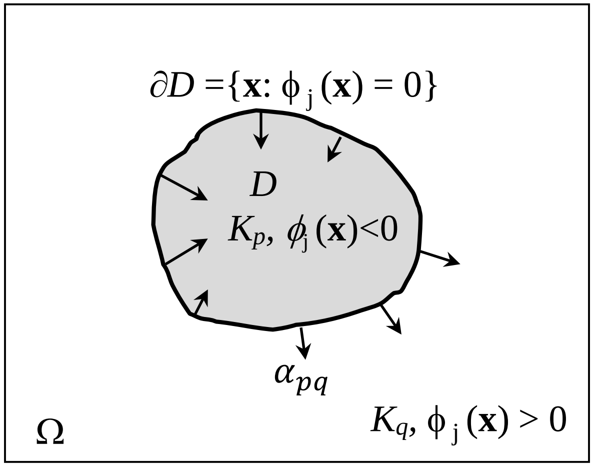
Four zone case

3. Algorithms

We try to minimize function

$$F(K) = \frac{1}{2}\|\boldsymbol{h}(K) - \boldsymbol{h}_m\|$$

where $\boldsymbol{h}_m$ is measured head and $\boldsymbol{h}(K)$ is simulated head.



Let the propagation of boundary ∂D

$$\alpha_{pq}(\mathbf{x}, t) = sign(K_q - K_p)\boldsymbol{J}^T(K)(\boldsymbol{h}(K) - \boldsymbol{h}_m)$$

where $\boldsymbol{J} = (d\boldsymbol{h}/dK)$ is the Jacobian matrix.

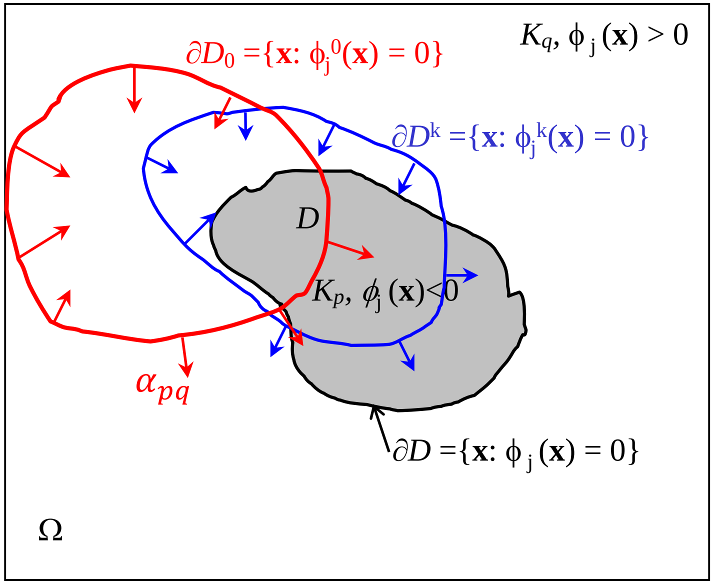
Then, the variation

$$\delta F(K) = -\sum_{p,q}\int_{\Omega_{pq}}\left[\alpha_{pq}(\mathbf{x}, t)\right]^2 d\mathbf{x} < 0$$

3. Algorithms

Level set function can be updated by solving

$$\frac{\partial \phi_j(\mathbf{x},t)}{\partial t} + \alpha_{pq}(\mathbf{x},t)\left|\nabla \phi_j(\mathbf{x},t)\right| = 0$$

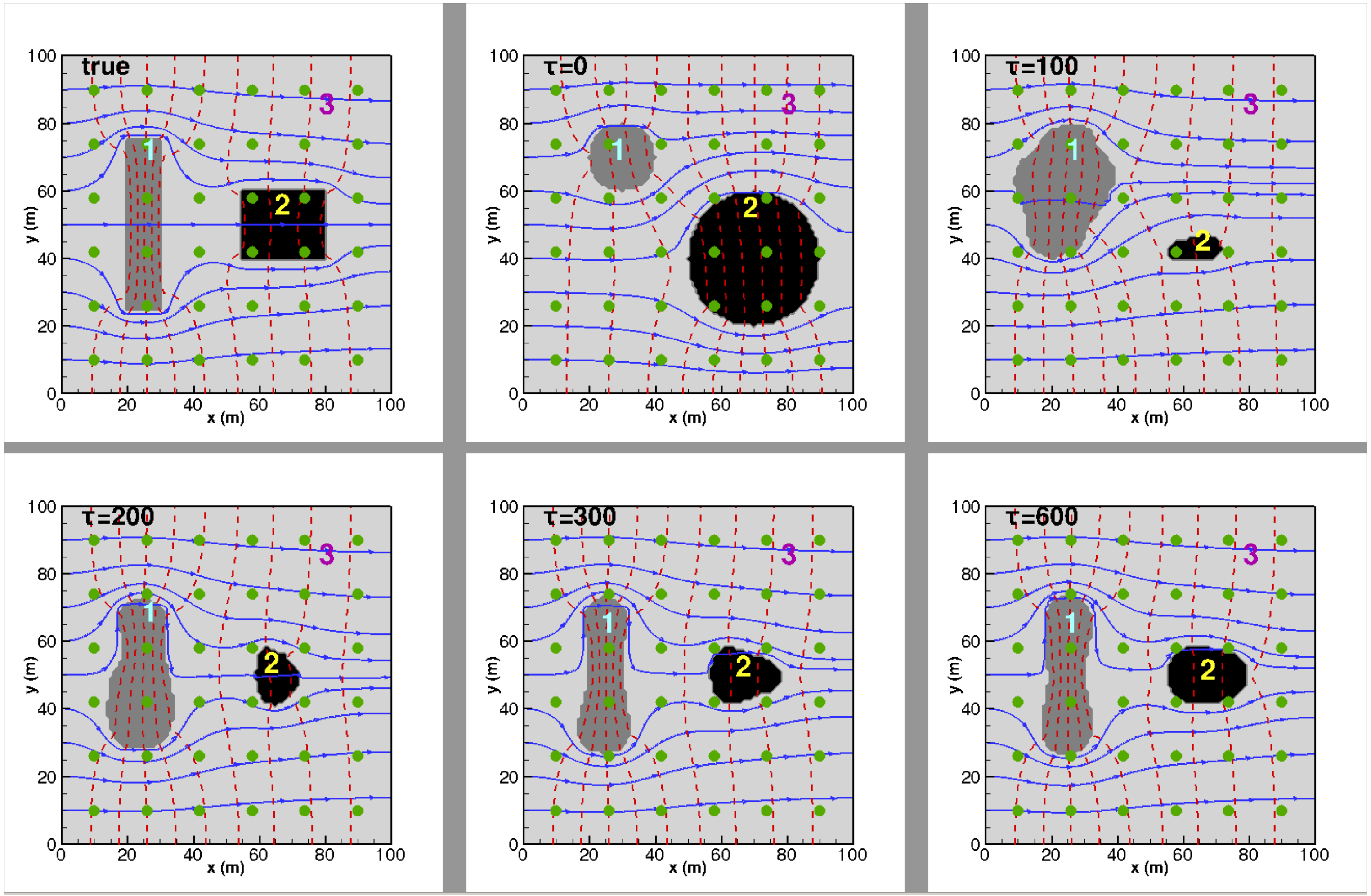


subject to initial condition

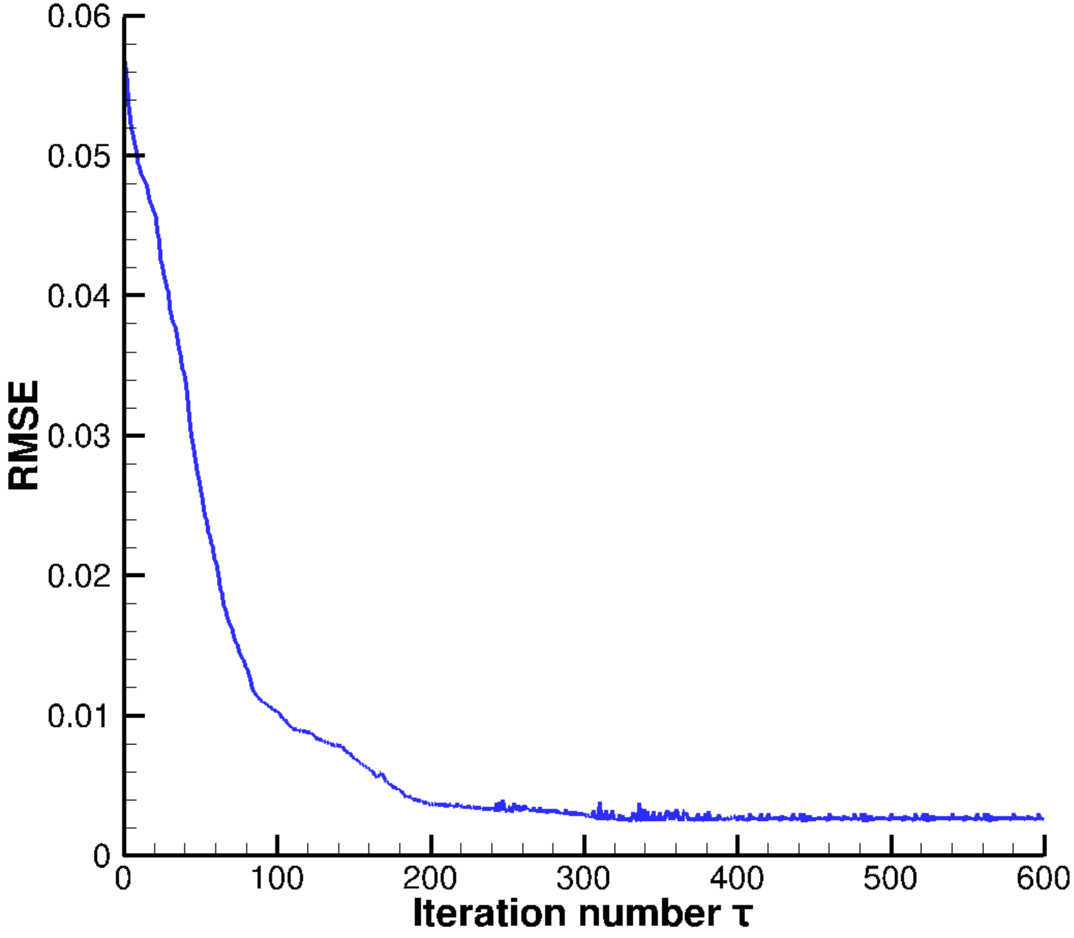
$$\phi_j(\mathbf{x},0) = \phi_j^0(\mathbf{x})$$

The set $\{x\text{: } \phi_j(x, t) = 0\}$ defines the boundary of D at time t.

4. Example

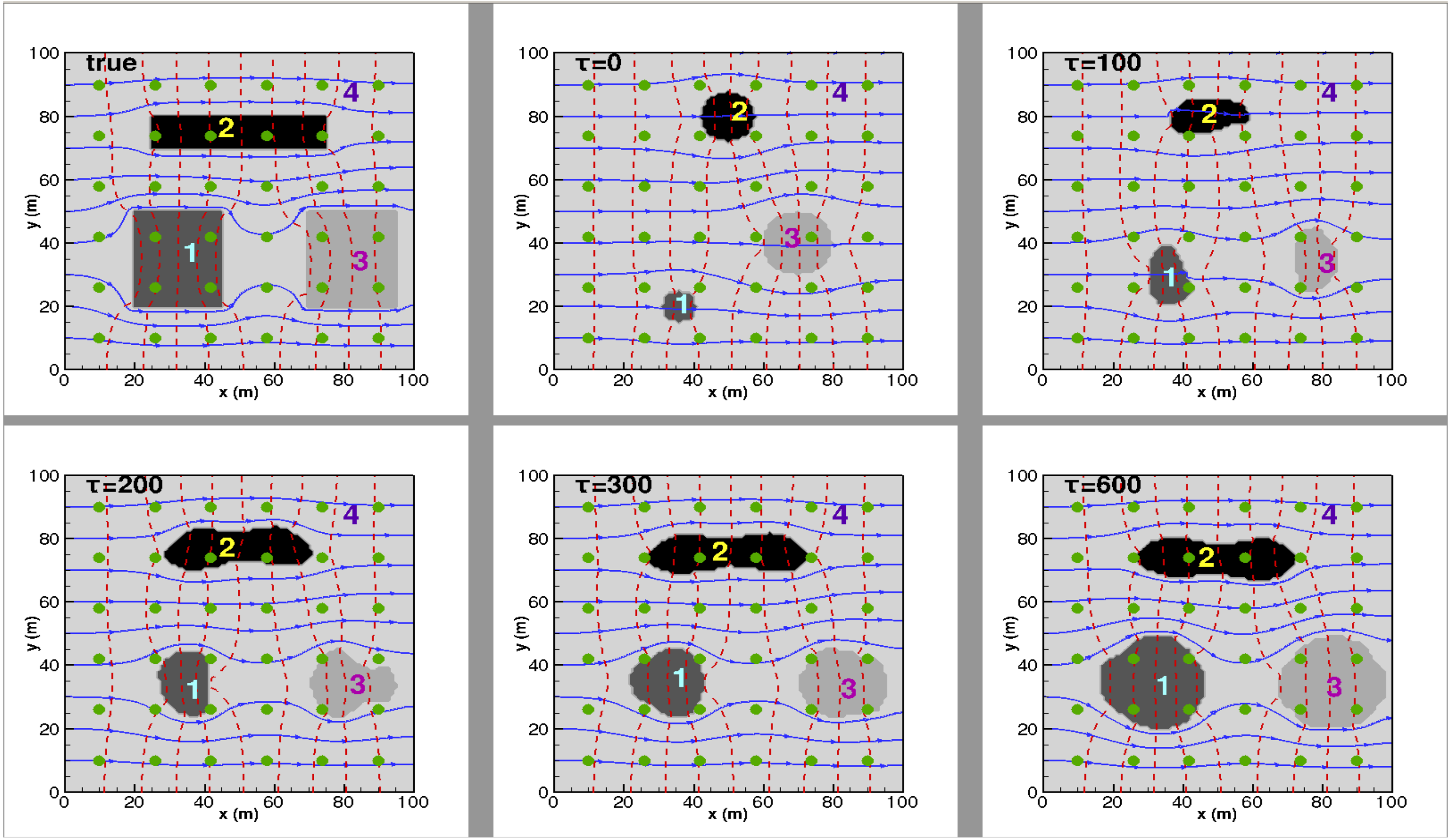


4. Example

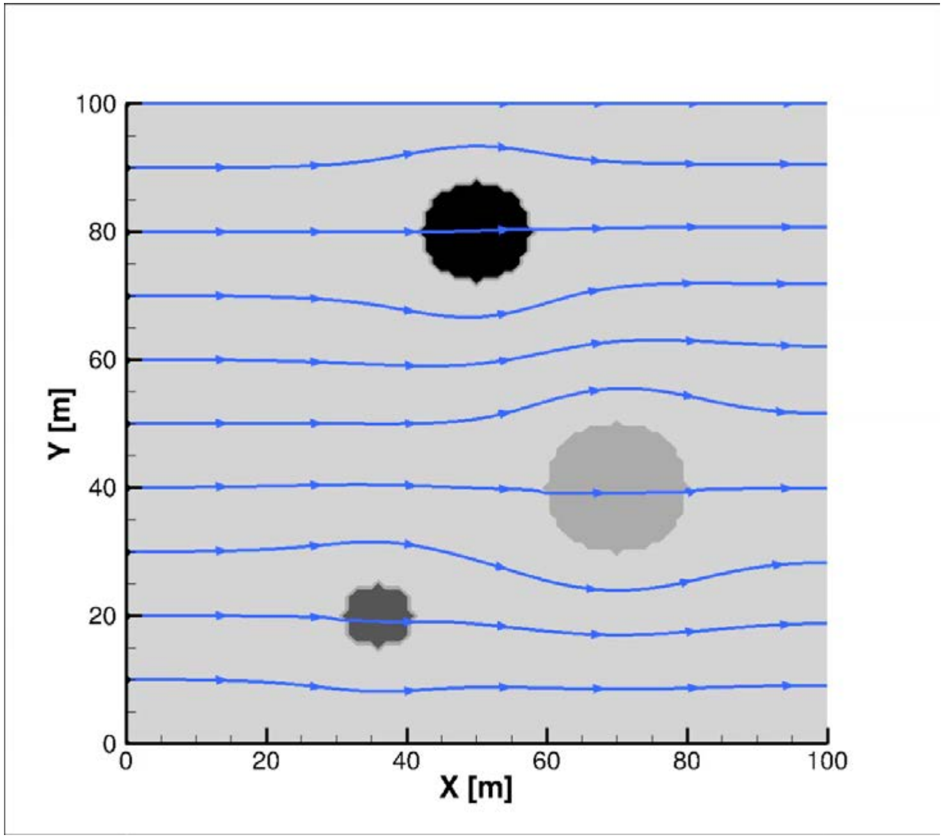


0.06
0.05
0.04
0.03
0.02
0.01
0
RMSE
0
100
200
300
400
500
600
Iteration number τ

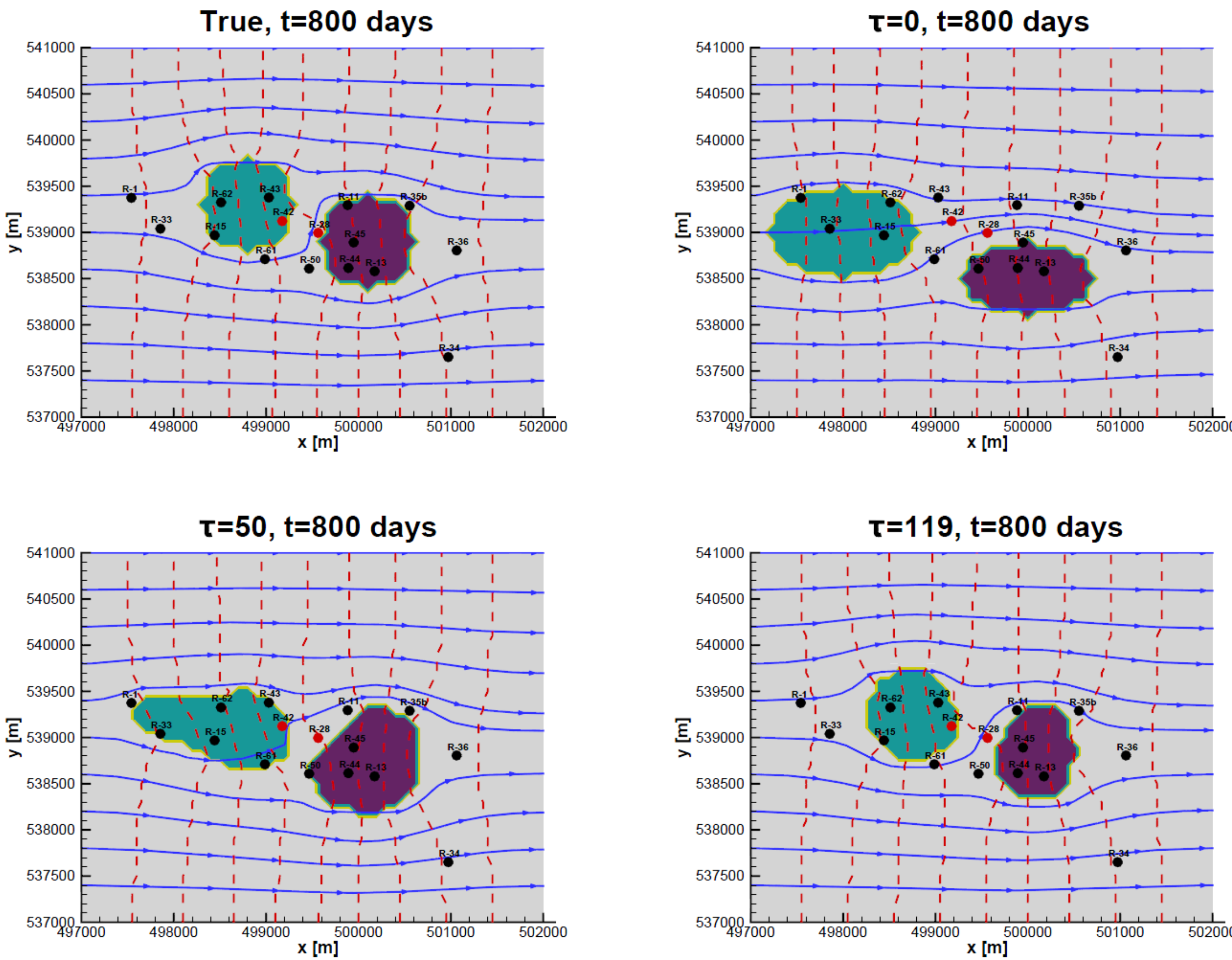
4. Example



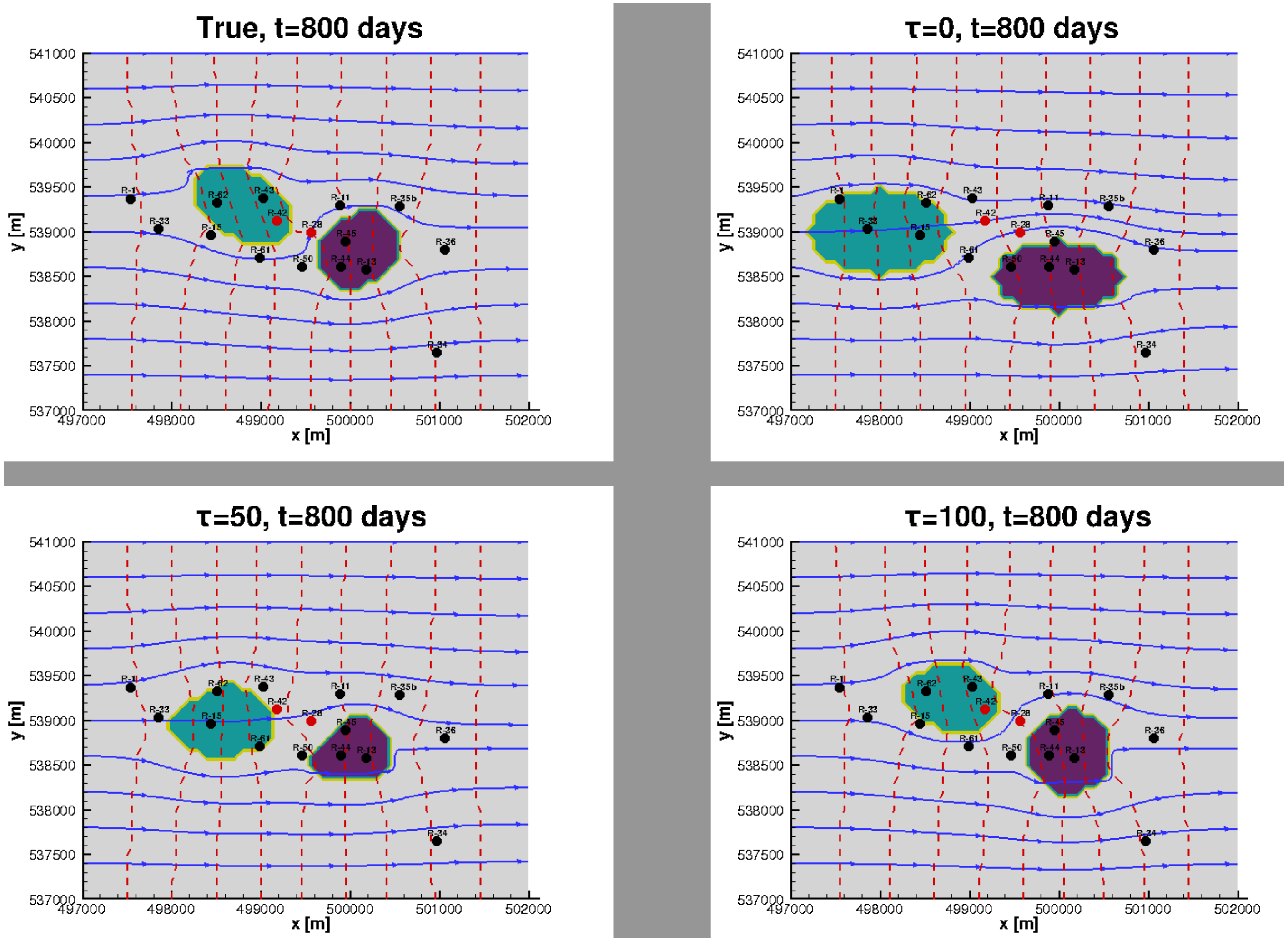
4. Example



4. Example (Transient)

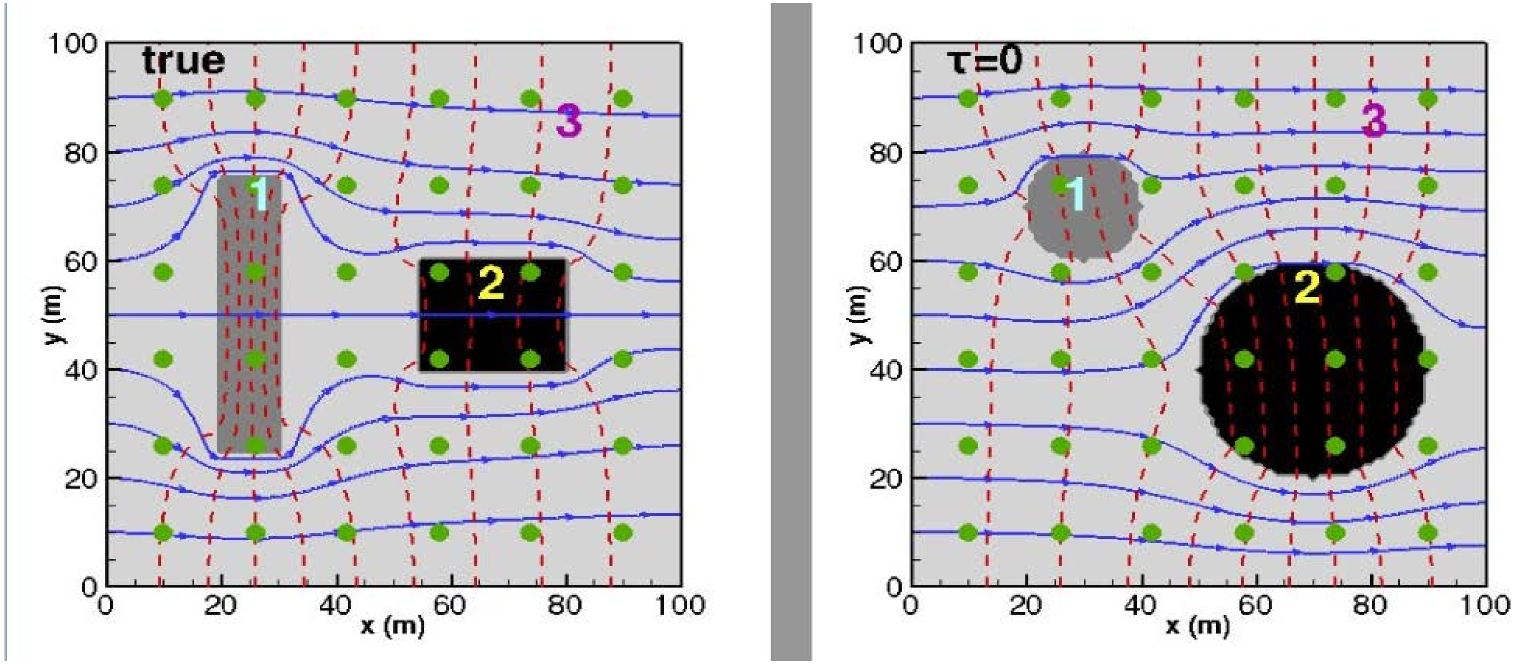


4. Example (Transient)



5. Future Work

1. Random initial material locations;
2. More initial materials;
3. Transient Flow.



Thanks!

Questions?