

A Multi-Faceted Modeling Framework for Transforming Remediation Visions into Tangible Realities

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Aquifers are complex and heterogeneous

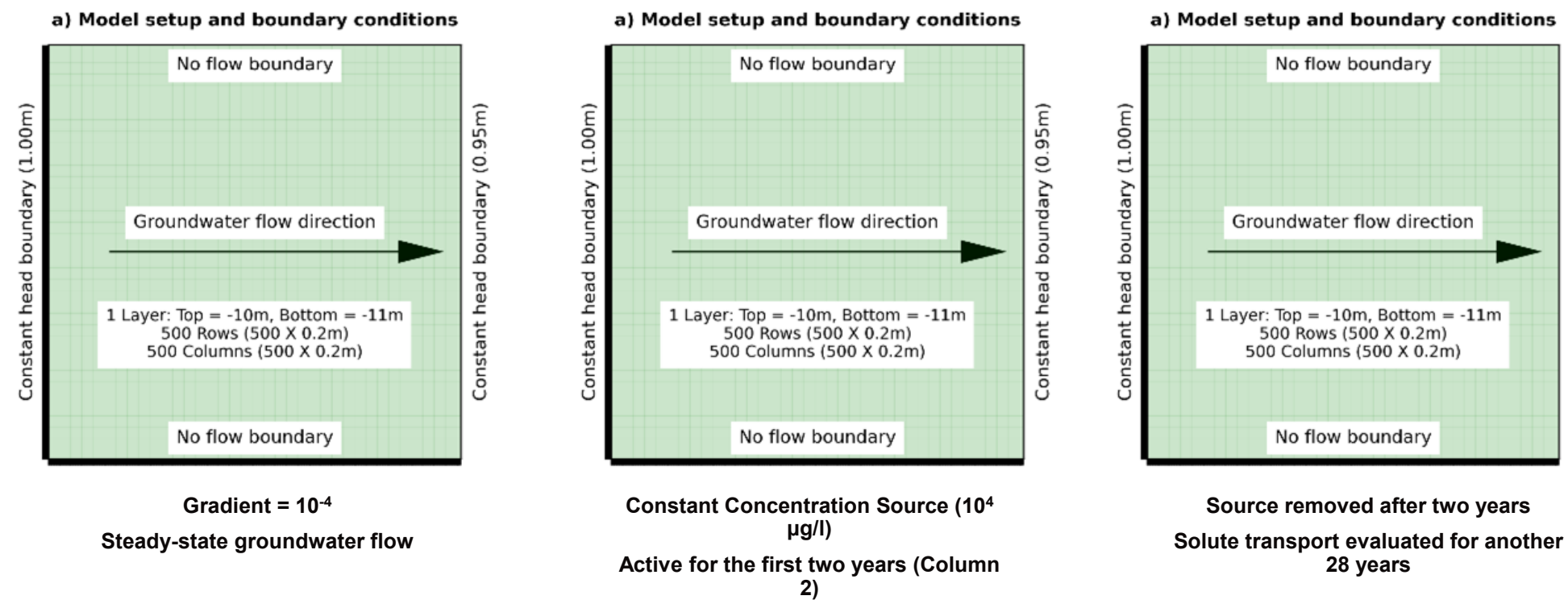
- Groundwater contamination remains above cleanup levels at hundreds of thousands of sites (NRC, 2013)
- Soil and groundwater cleanup at over 300'000 sites in the United States may exceed \$200 billion by 2033 (EPA, 2004)
- Emerging contaminants (PFAS) will significantly increase these costs



Can we make a difference ?

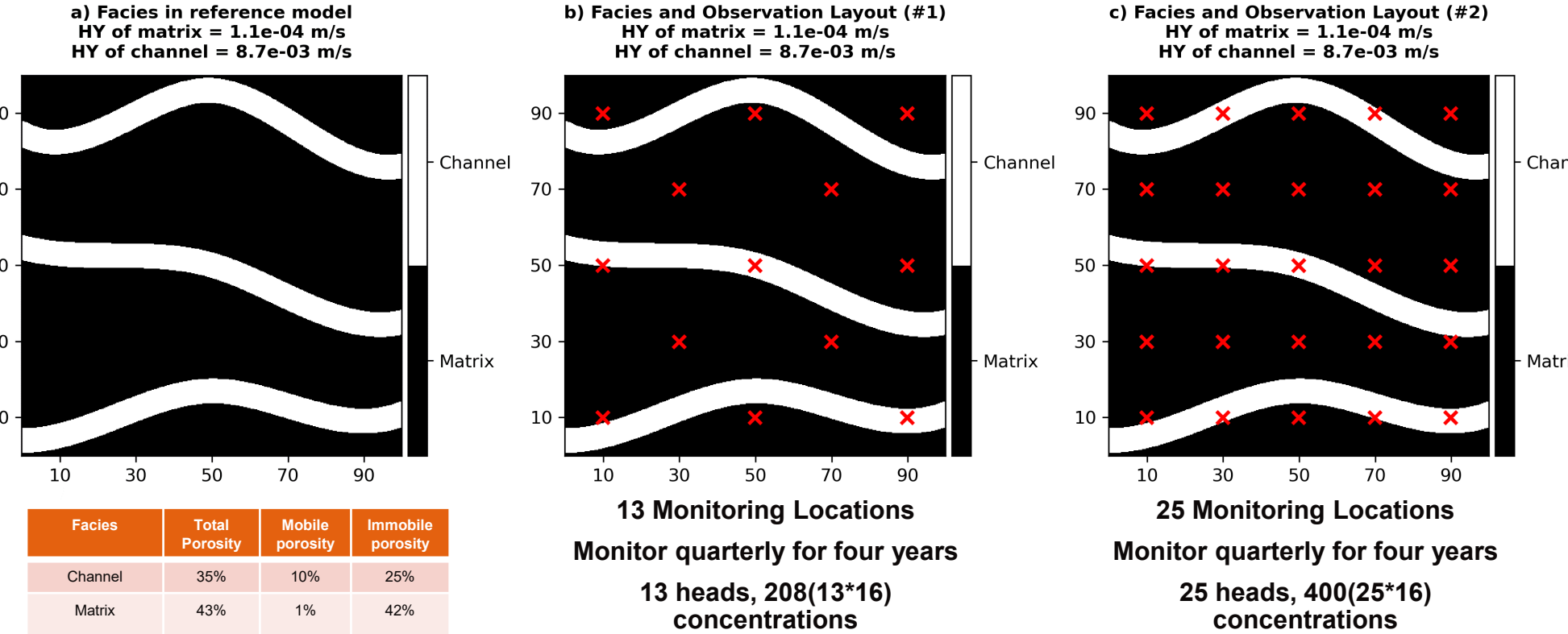
A Flow and Transport Example

- Infer categorical facies from groundwater heads and solute concentrations
- Quantify remedial uncertainty after 30 years



Transport Process and Monitoring Locations

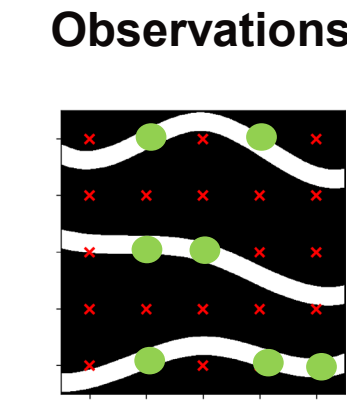
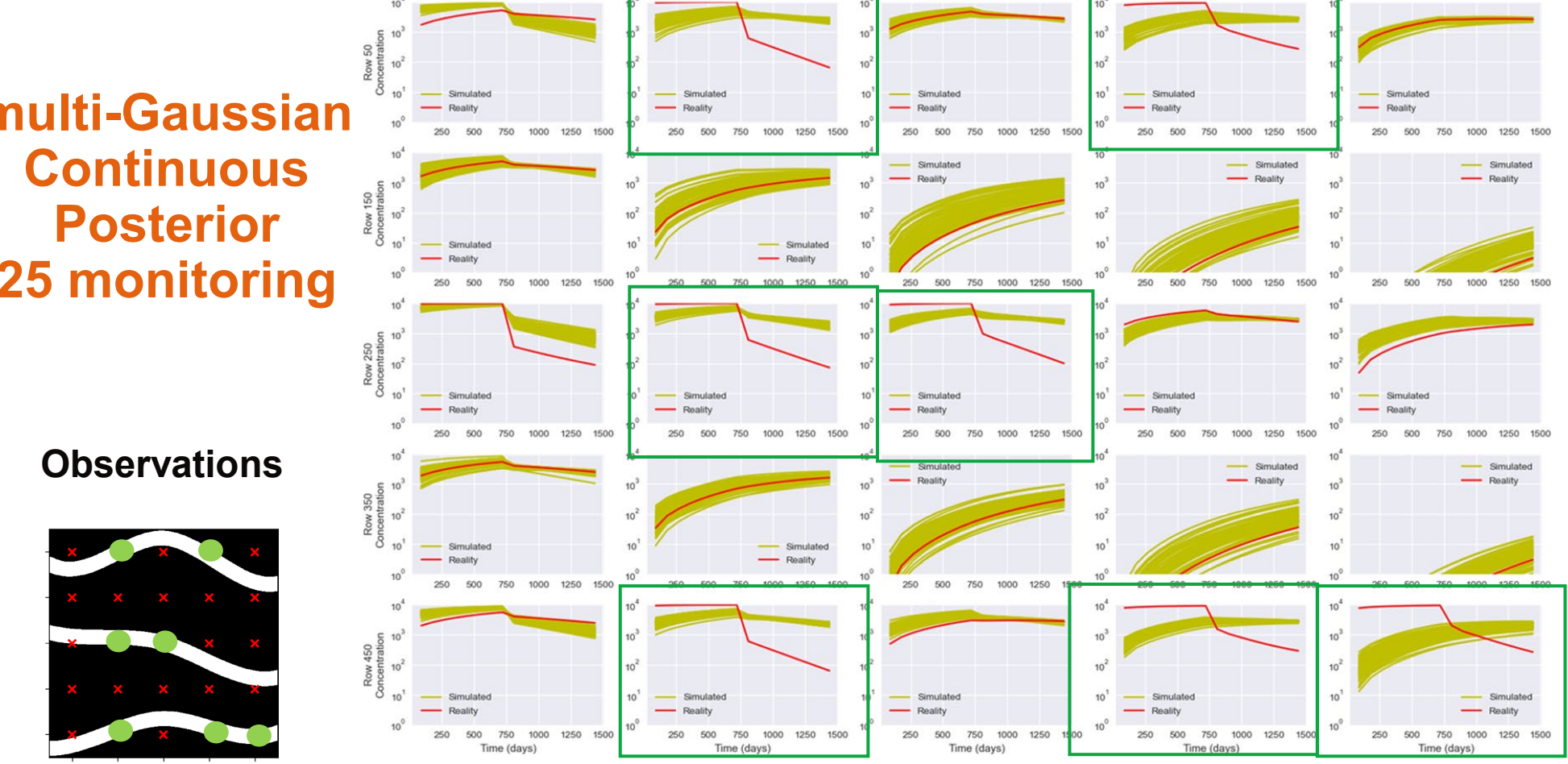
- Dual-domain(mobile/immobile) approach for simulating solute transport
- Dispersion/sorption/decay not simulated



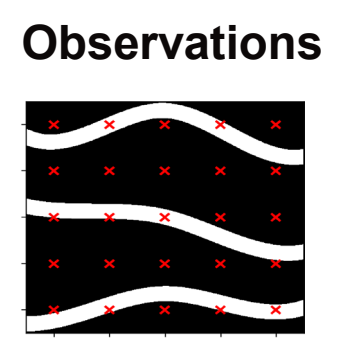
Heterogeneity Simulation Approaches

- Traveling /conceptual pilot point approach (15 TRIP locations)
- Continuous(multi-Gaussian) prior (simulate HY in every grid cell)

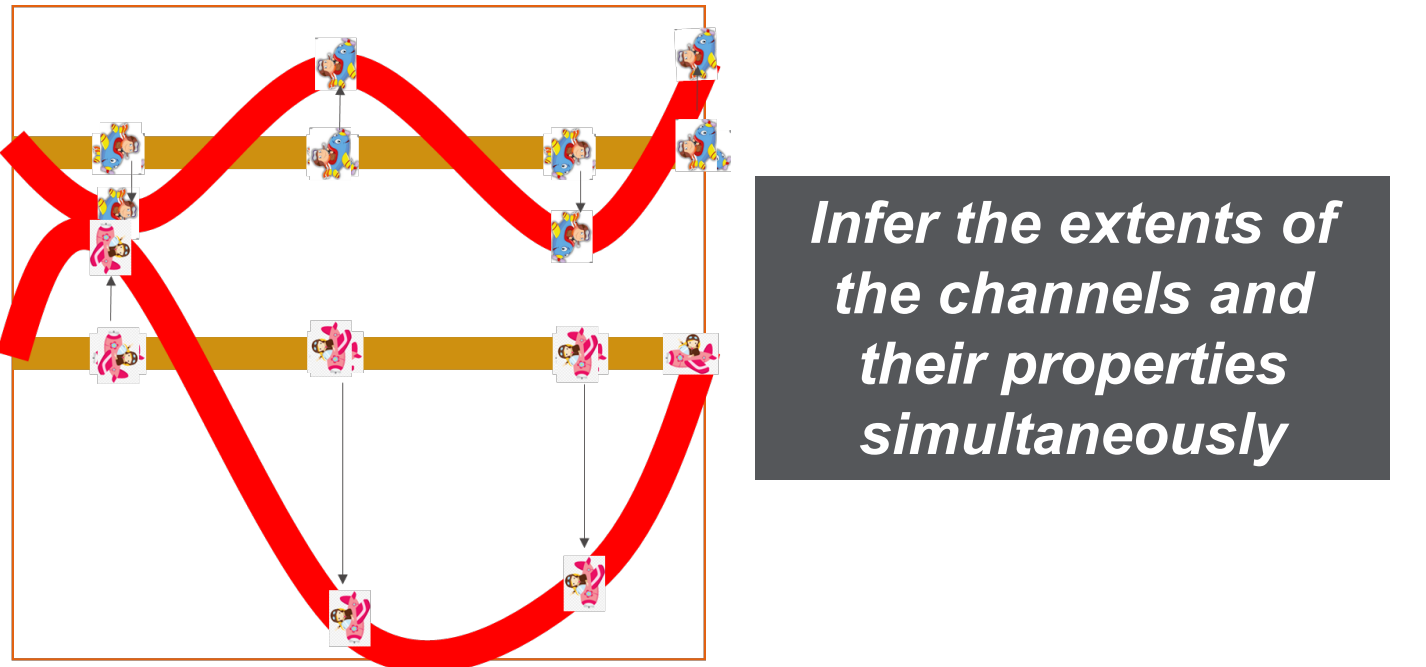
Simulated vs. Observed Concentrations



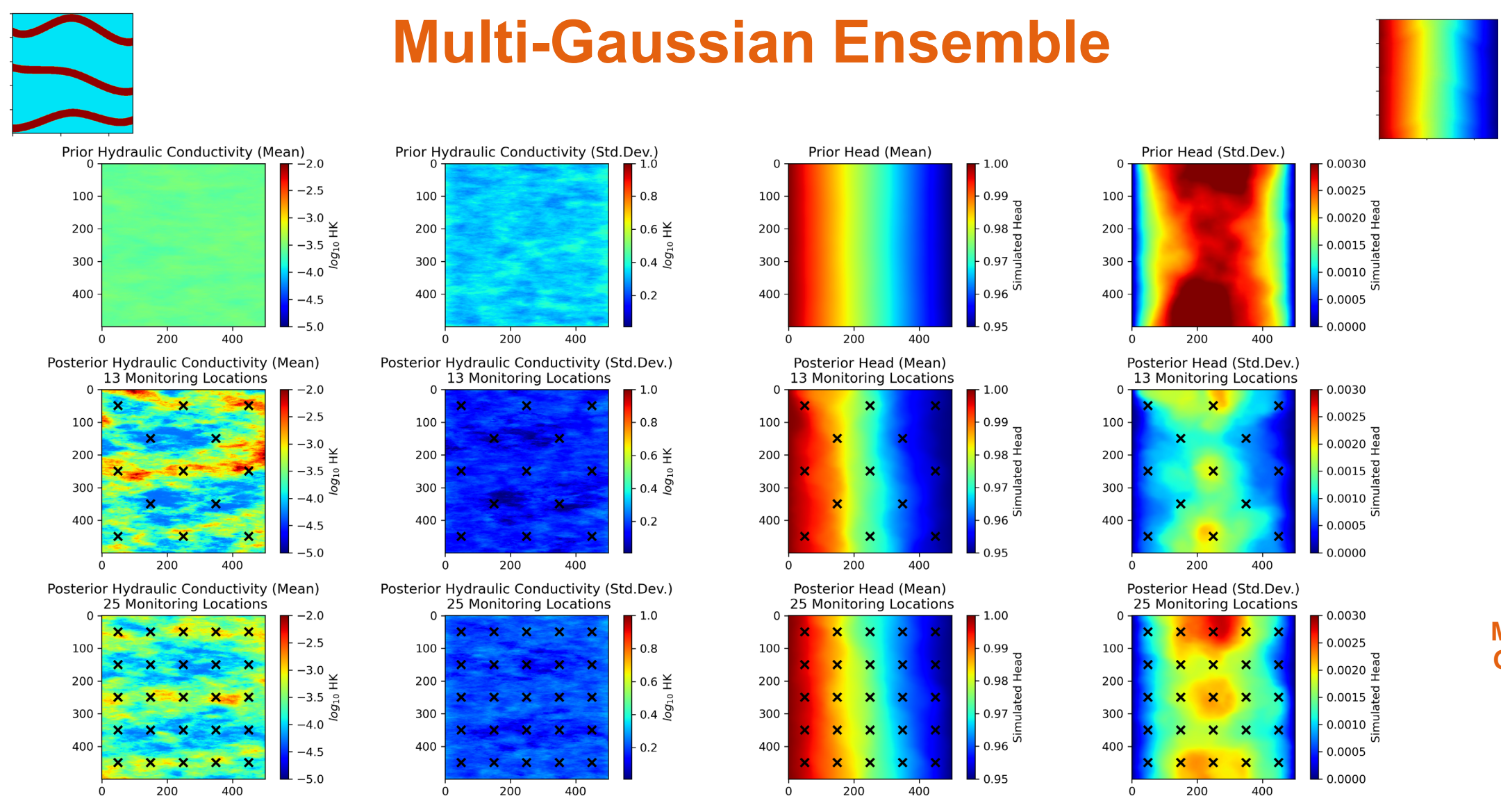
TRIPS Discrete Posterior 25 monitoring



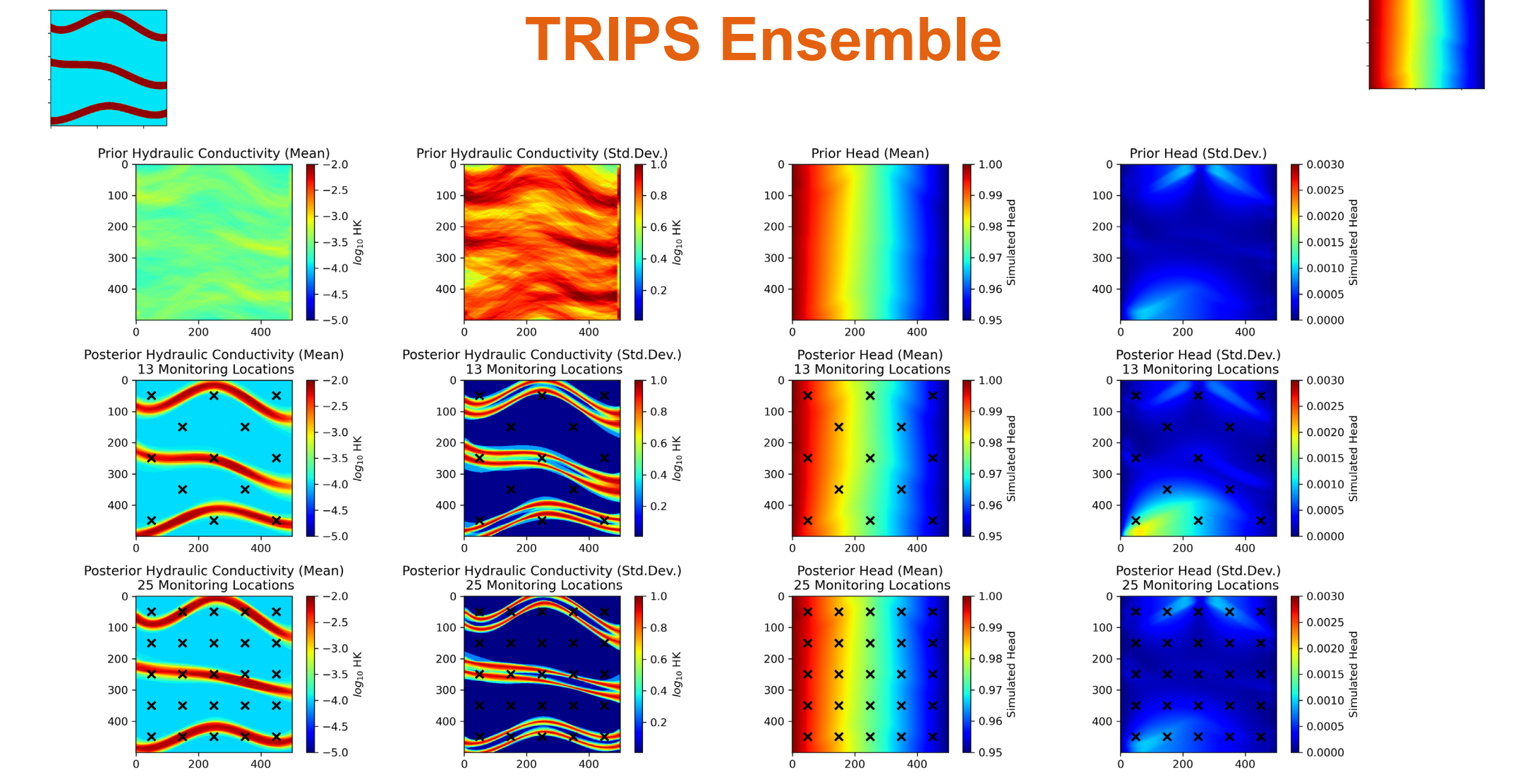
Traveling Pilot Points (TRIPS)



Multi-Gaussian Ensemble

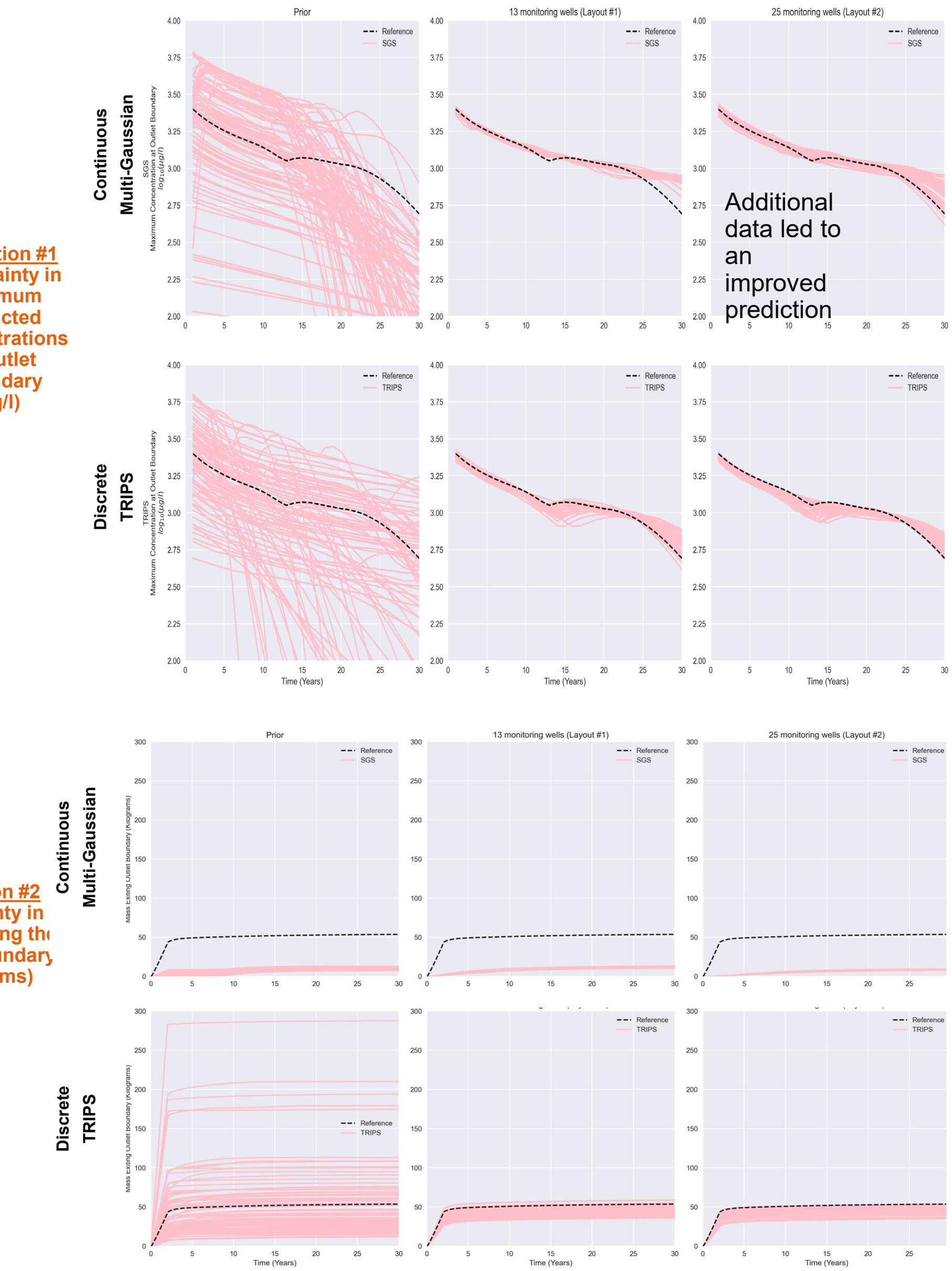


TRIPS Ensemble



Prediction #1 Uncertainty in Maximum Predicted Concentrations at Outlet Boundary (µg/l)

Prediction #2 Uncertainty in Mass leaving the Outlet Boundary (Kilograms)



Final remarks

- We present a multi-faceted modeling framework that combines dynamic parameterization through Traveling Pilot Points with ensemble smoothing to address aquifer heterogeneity.
- Data-driven updates using the Iterative Ensemble Smoother refine geological priors and improve predictive reliability for contaminant transport and remedial performance.
- For a synthetic case, we demonstrate how this integrated methodology reduces uncertainty and enhances decision-making for complex groundwater remediation challenges.

