

Finding Leaks Using Hydrogeophysical Data and Numerical Models

al. et Stefan Finsterle

**Earth Sciences Division
Lawrence Berkeley National Laboratory
University of California, Berkeley, USA**

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- **Role of Modeling in Support of Leak Detection**
- **Hydrogeophysics**
 - **Identification of soil structure and system state**
 - **Modeling supporting geophysical imaging**
- **ASCEM**
- **Concluding Remarks**

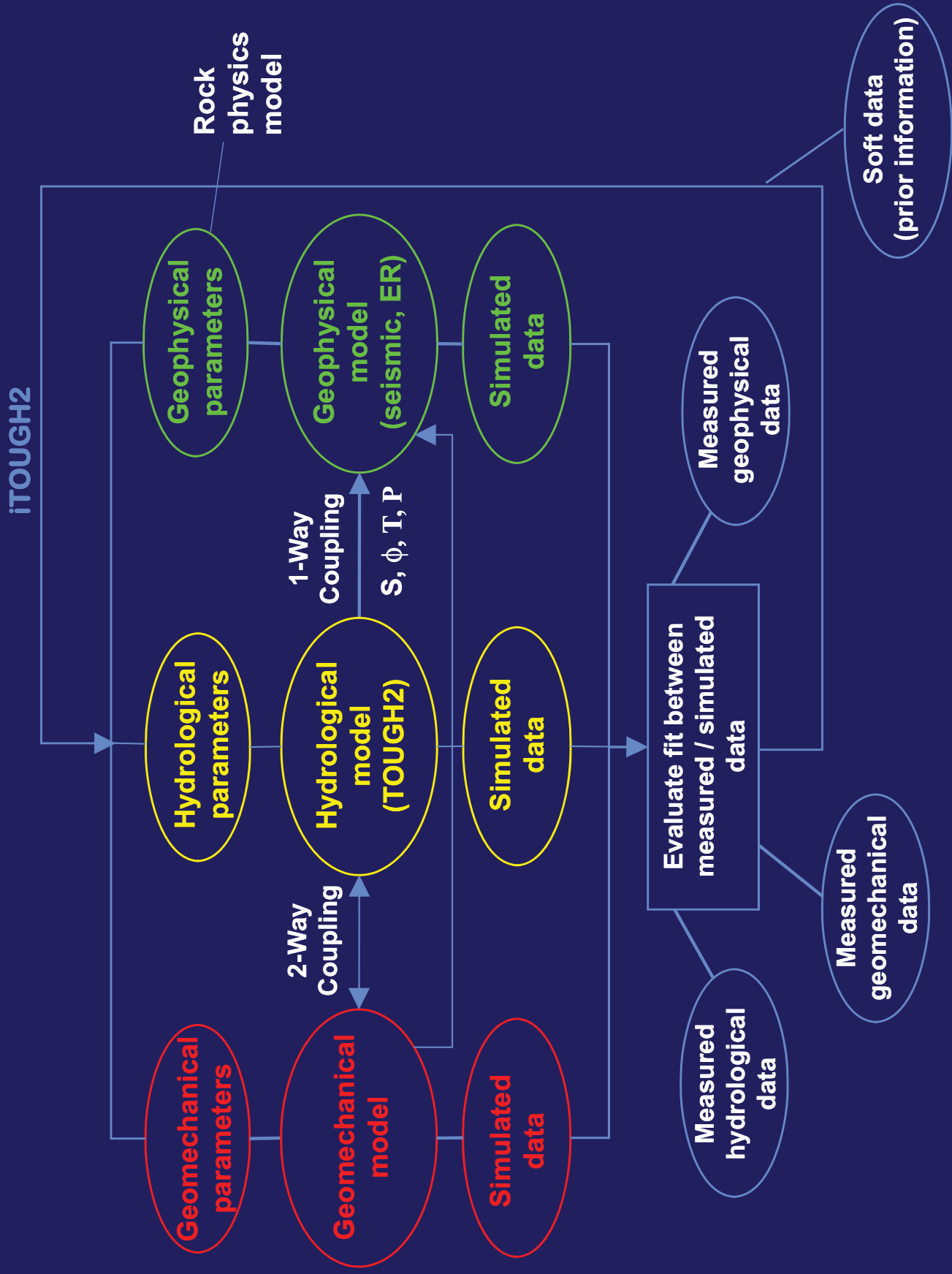


- Defect
- Failure scenario
- Conceptualization
- Pathway
- Characterization
- Parameter estimation
- Plume
- Monitoring
- Data analysis
- Impact
- Prediction
- Risk assessment
- Action
- Engineering
- Decision support

Modeling plays key role in all tasks related to leak detection and remedial actions

- **Geophysical** data provide **high-resolution** information on soil **structure** and state
- **Hydrological** data provide **process-specific** information on soil **properties** and state
- The hydrological forward model provides **physical regularization** to geophysical imaging
- Joint hydrogeophysical data analysis **reduces ill-posedness** of inverse problem
- **Joint** estimation of geometry and properties **reduces estimation and prediction bias**

Coupled Hydrogeophysical-Geomechanical Inverse Modeling

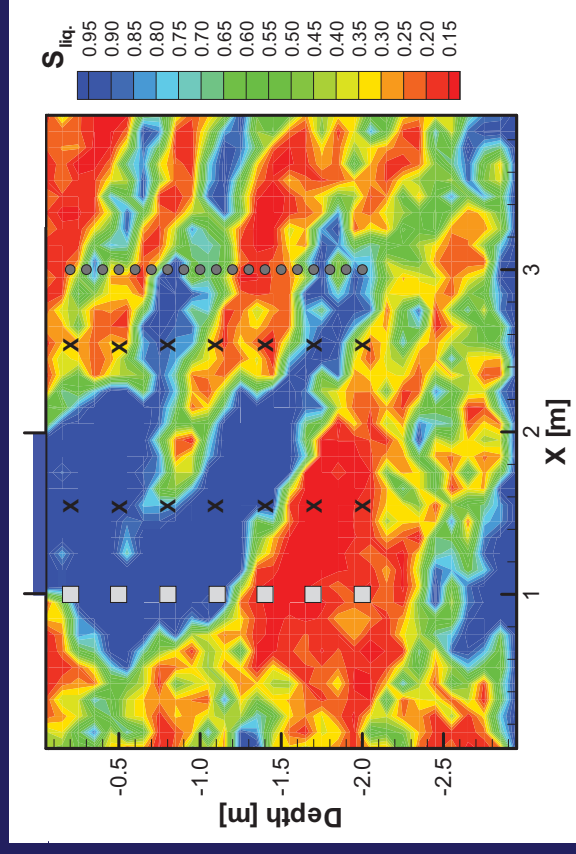
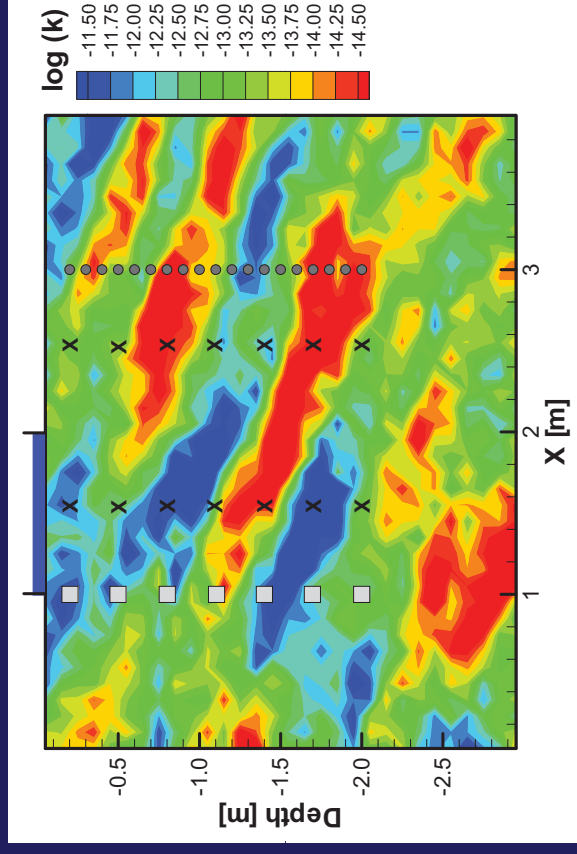


Identification of...

Soil Structure

and

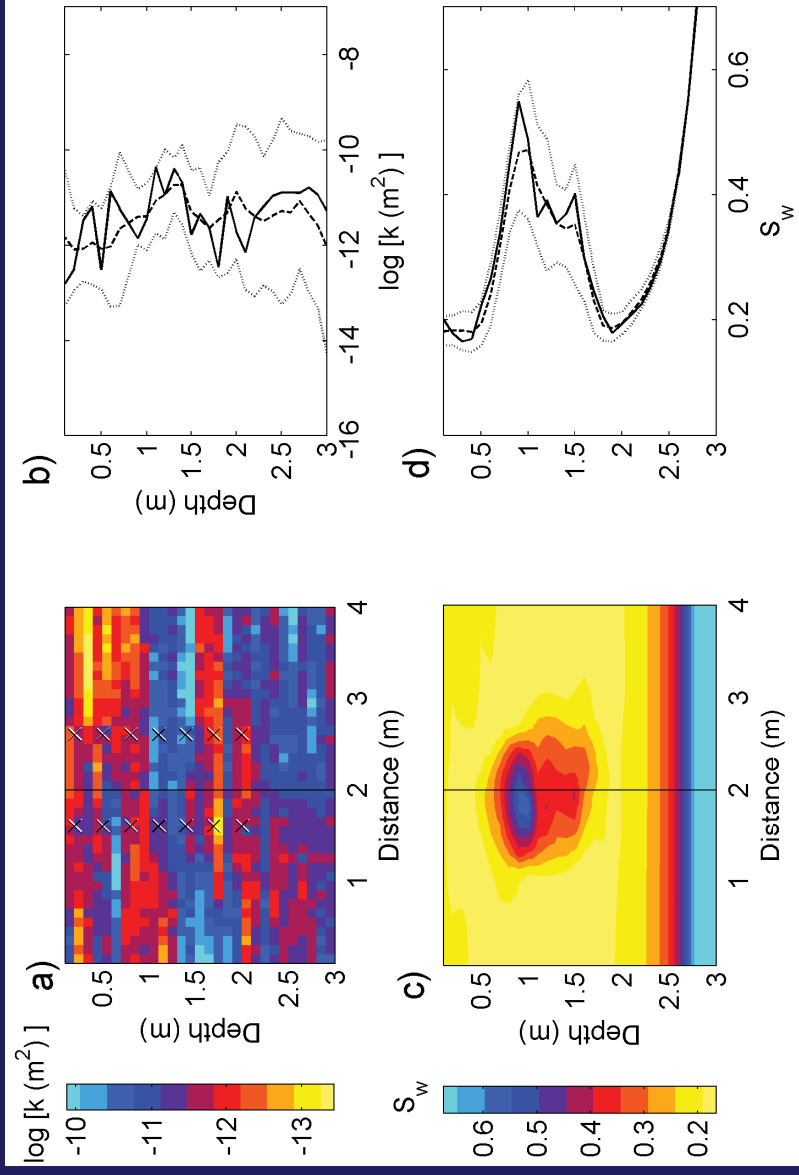
System State





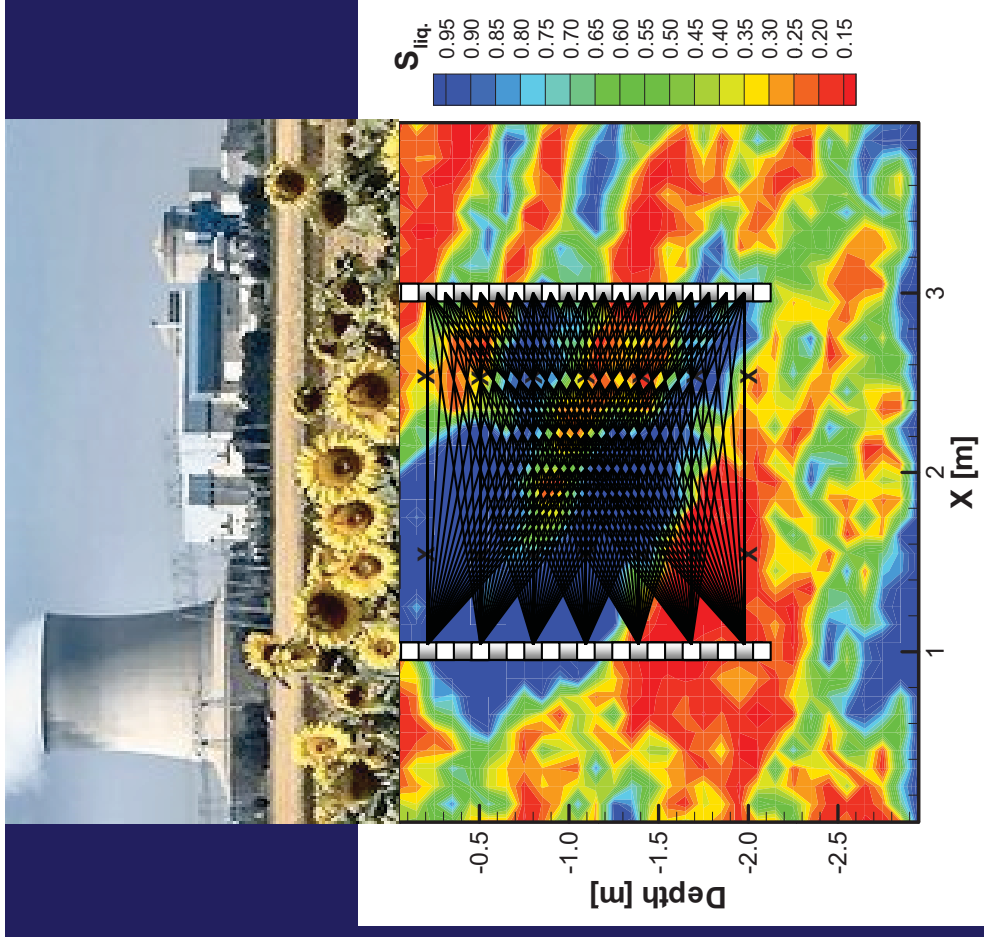
Joint Inversion

- *Geophysical data* contain high-resolution information about soil structure
- *Hydrogeological data* contain information about flow and transport processes
- *Jointly invert* geophysical and hydrogeological data
- Infer both *properties* and *system state*



Illustration

- Scenario:
 - 2 days leaking
 - 3 days redistribution
- 2 Boreholes:
 - Time-lapse GPR
 - Neutron probes
- Data (1 set every day):
 - 1 Infiltration rate
 - 40 Water content
 - 133 GPR travel times



($\sigma = 0.1$ L/day)

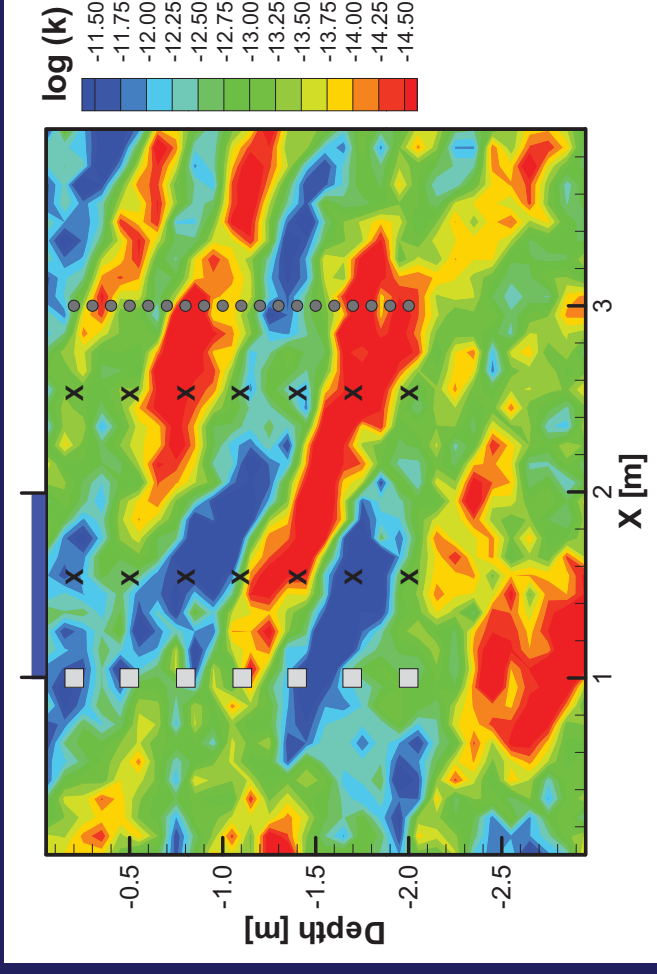
($\sigma = 0.02$)

($\sigma = 0.5$ ns)

Total: $6 \times 174 = 1044$ observations

Parameterization

- Soil structure:
 - Variance
 - Correlation length
 - Anisotropy
 - Orientation
- Petrophysical model:
 - Dielectric constant for solids κ_s
 - Mixing exponent n



$$\kappa = \left[(1 - \phi) \kappa_s^n + S_w \phi \kappa_w^n + (1 - S_w) \phi \kappa_a^n \right]^{\frac{1}{n}}$$

- Hydrogeological parameters:
 - Porosity: ϕ
 - Reference permeability: k_h, k_v
 - Permeability modifiers at 14 pilot points
 - Two-phase flow parameters: $\alpha, n, m, S_{lr,RP}, S_{lr,PC}, \varepsilon, \eta$

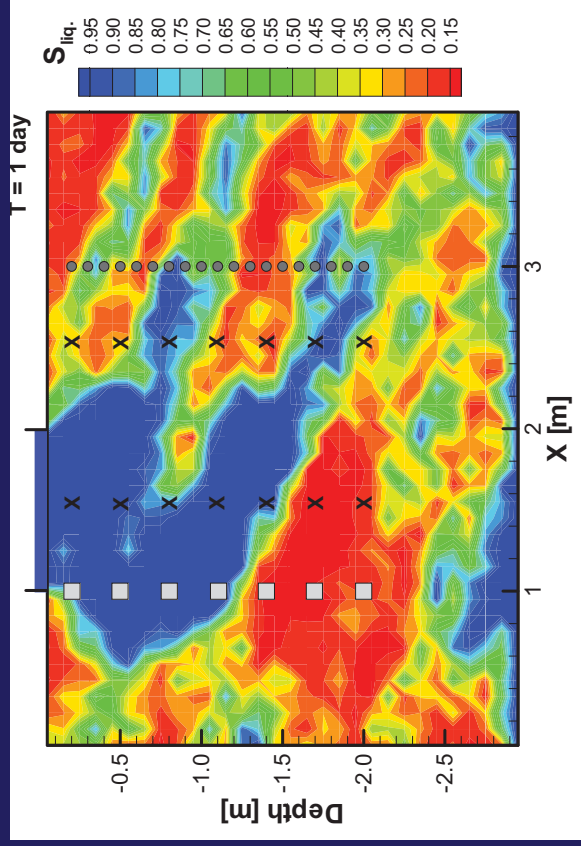
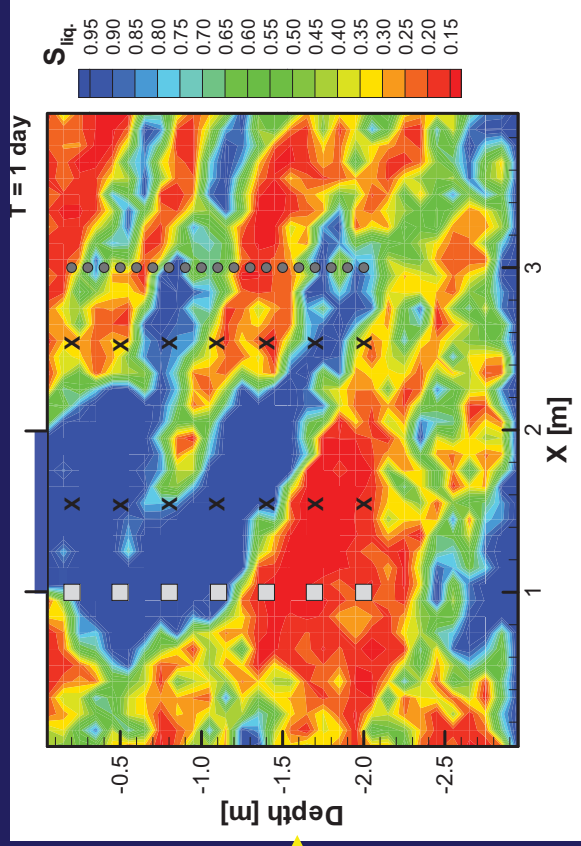
Total 30 parameters

True

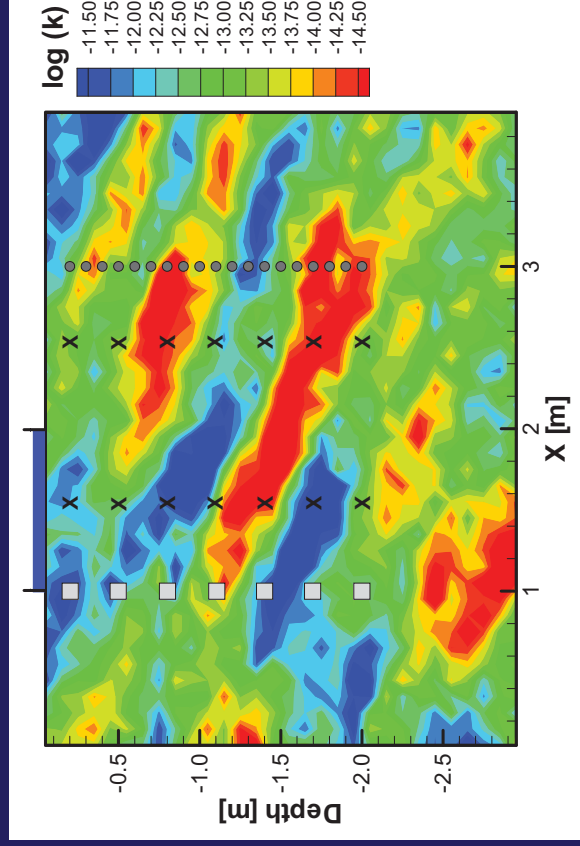
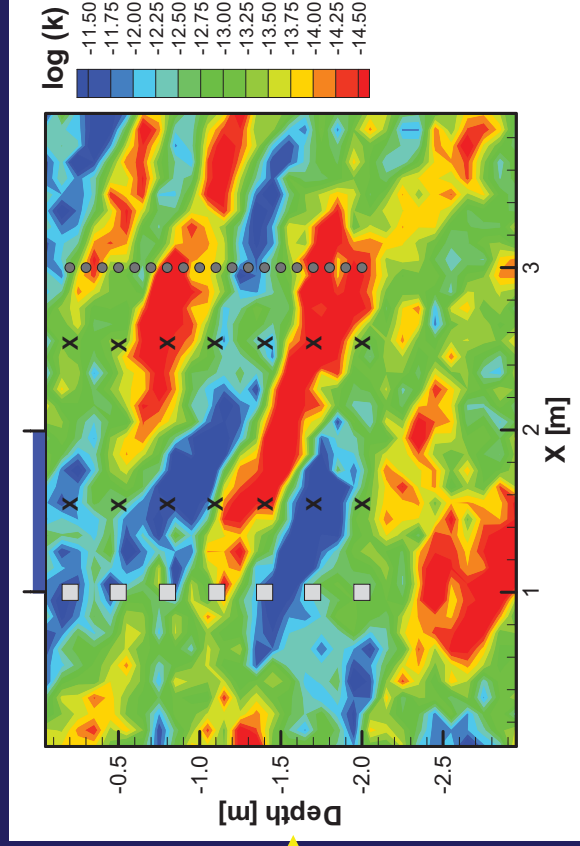
Estimated

Iteration 14 Obj. Fun.: 1,200

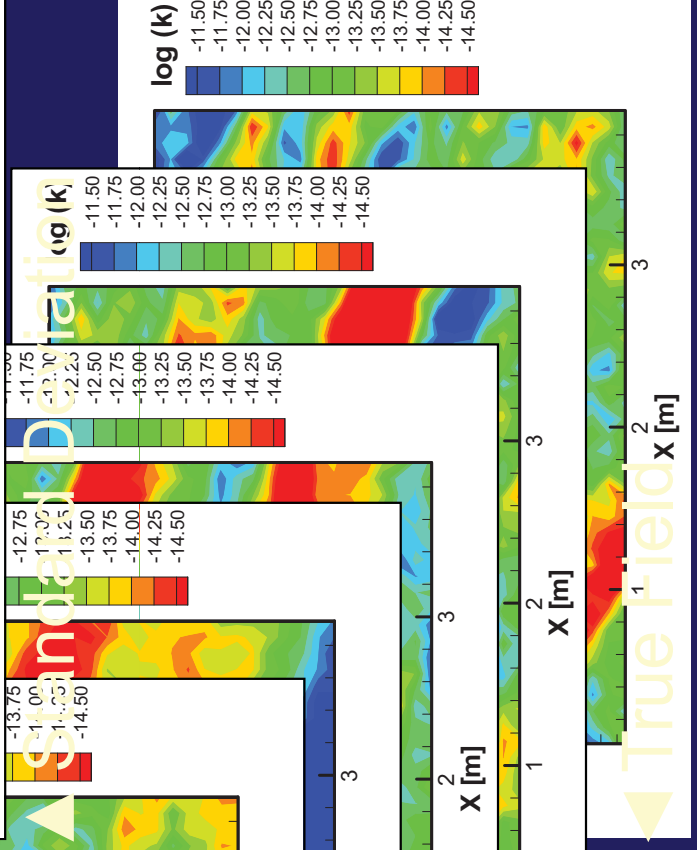
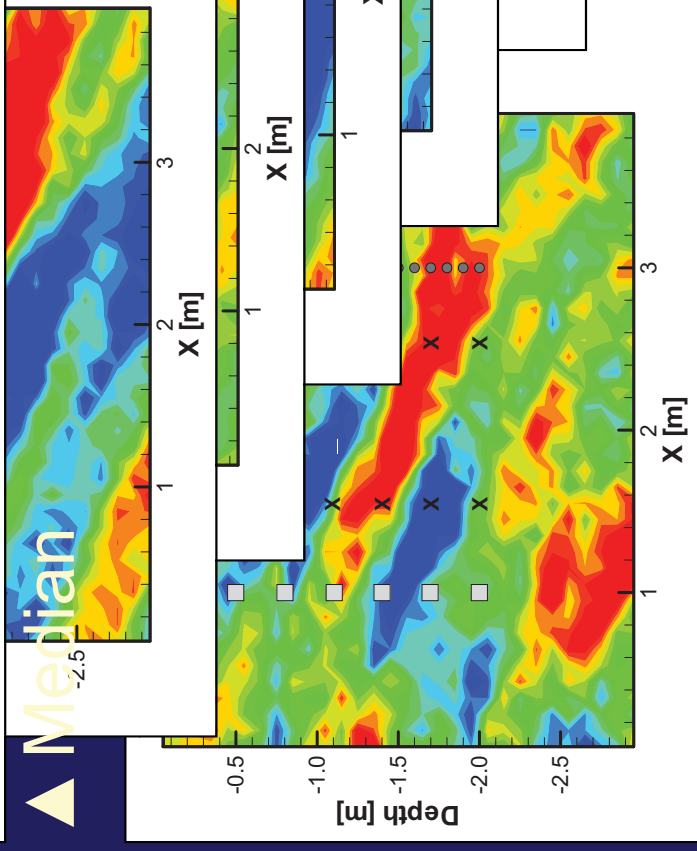
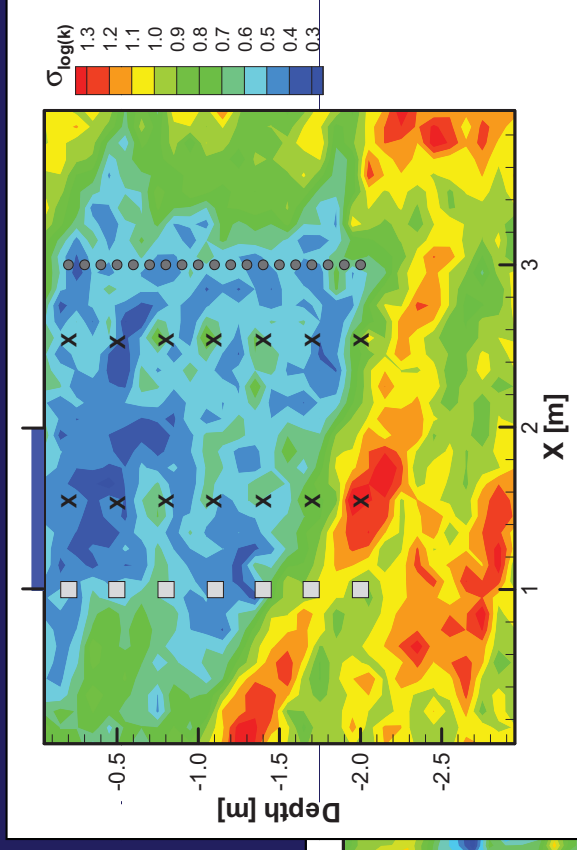
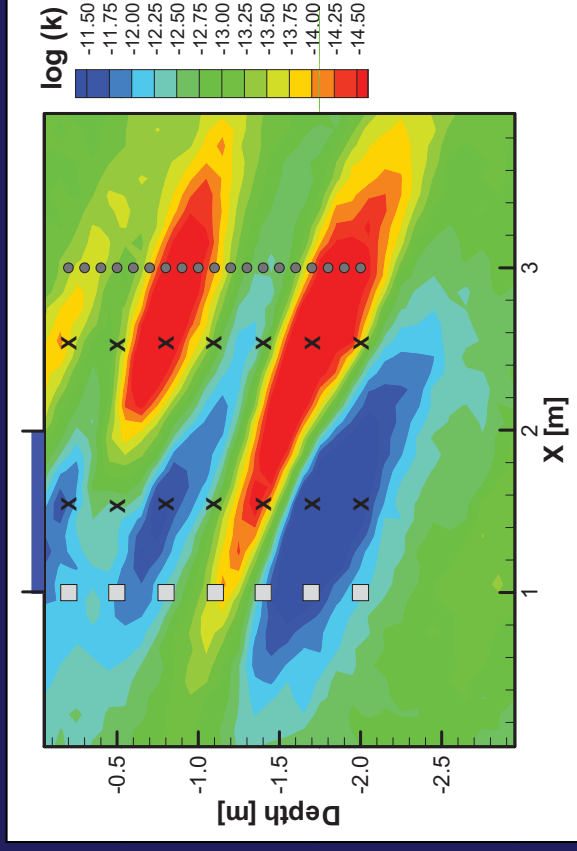
Saturation



Permeability



Ensemble Average



▲ Median

▲ Standard Deviation

▲ True Field

