USING RANDOM CIRCULAR MODELS IN AQUIFER FLOW SIMULATION

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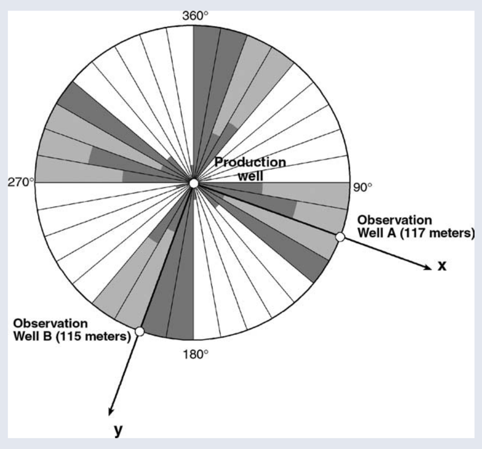
FRACTURES AND HYDRAULIC CONDUCTIVITY

The water flow in many aquifers is driven by strong anisotropy created by preferential flow features such as fractures and faults. We modeled this anisotropy hydraulic conductivity (AHC) in our poroelastic model.

From Heilweil and Hsieh, 2006

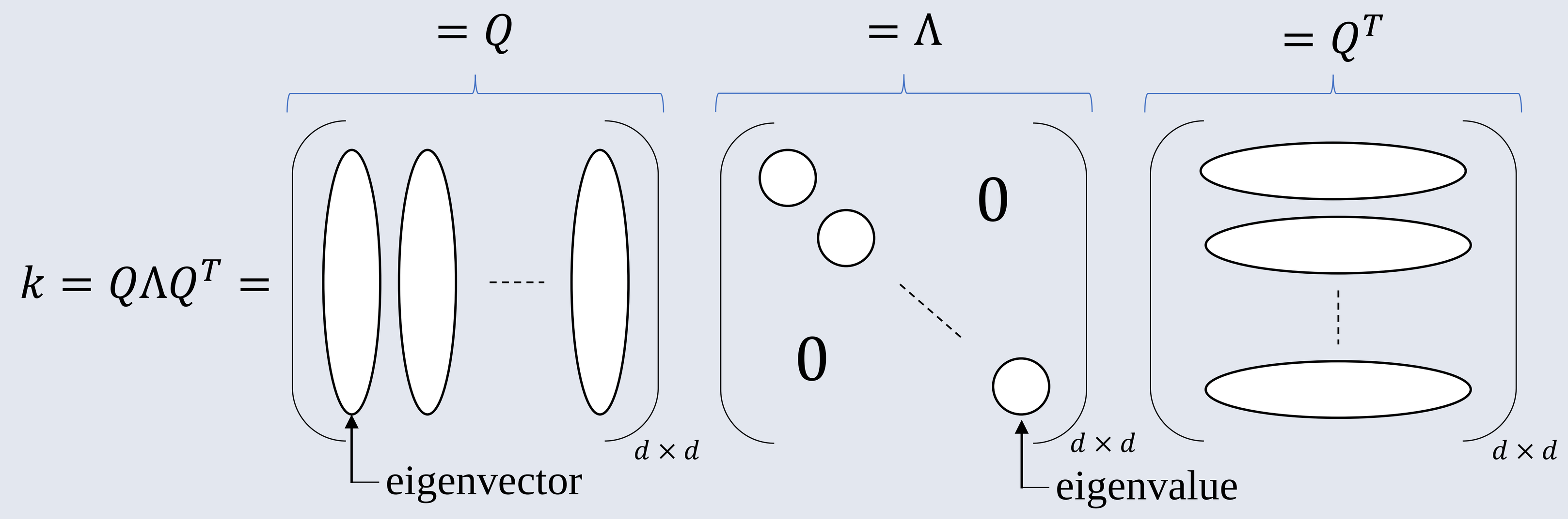


OBJECTIVE

- **Overall goal**: assimilate InSAR data into an aquifer model.
- **In this work**: develop a flexible stochastic prior model of the AHC tensor that respects its underlying symmetry and positive definiteness.

UNCERTAINITY IN AHC TENSOR

- Because of reported ≈ 20% uncertainty in Heilweil's AHC results,
- Assuming AHC's principal direction aligns with the fracture direction.
- Introducing a stochastic model, accounting for random variance in both the direction and magnitude of AHC using spectral decomposition (Shivanand, Rosić, and Matthies, 2024).



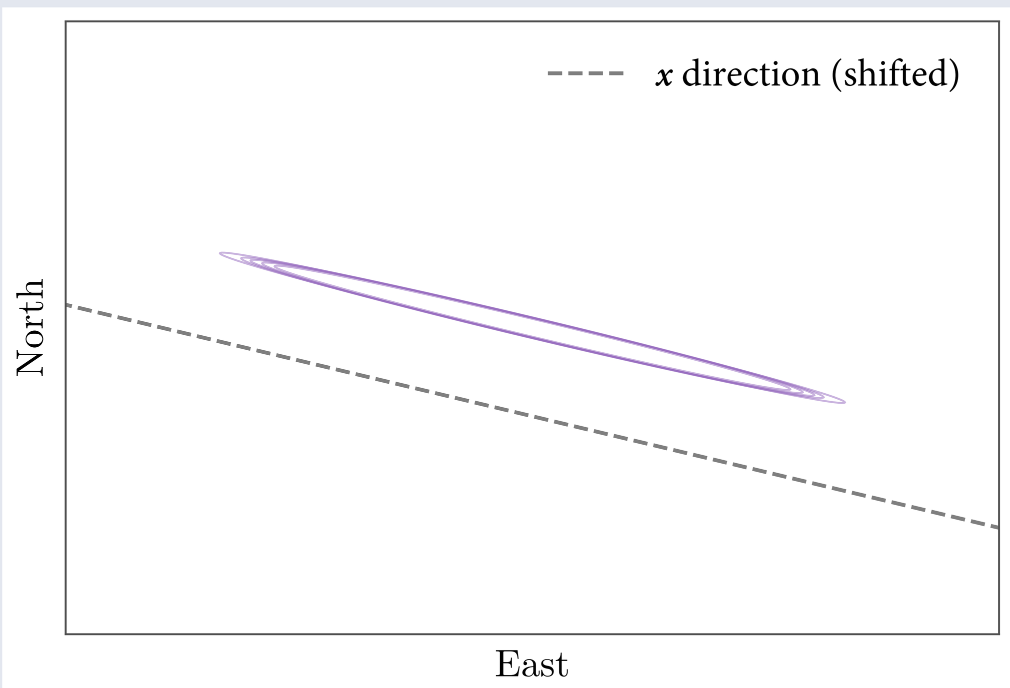
STEP 1: RANDOM SCALING

$$k_s(\omega_s) = \hat{Q}\Lambda_s(\omega)\hat{Q}^T$$

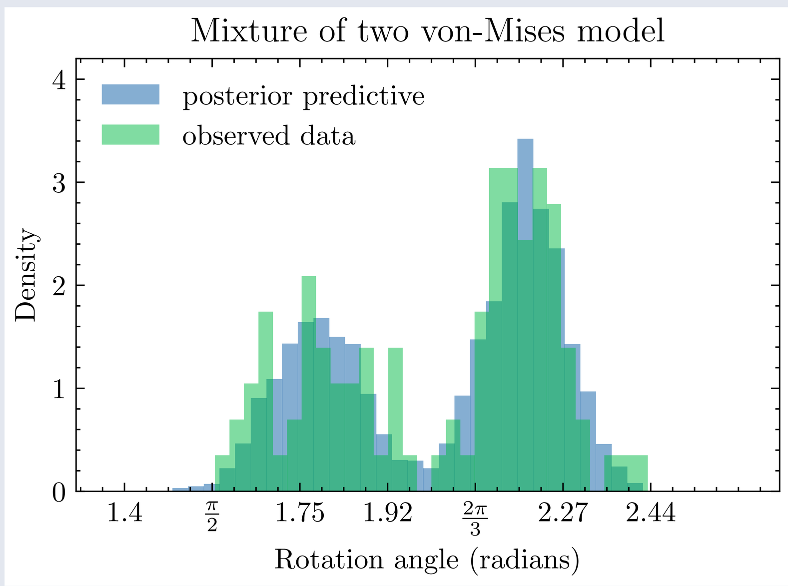
$$\Lambda_s = \begin{bmatrix} \lambda_x & 0 \\ 0 & \lambda_y \end{bmatrix}$$

$$\lambda_x = \text{lognorm}(k_{xx}, 0.2)$$

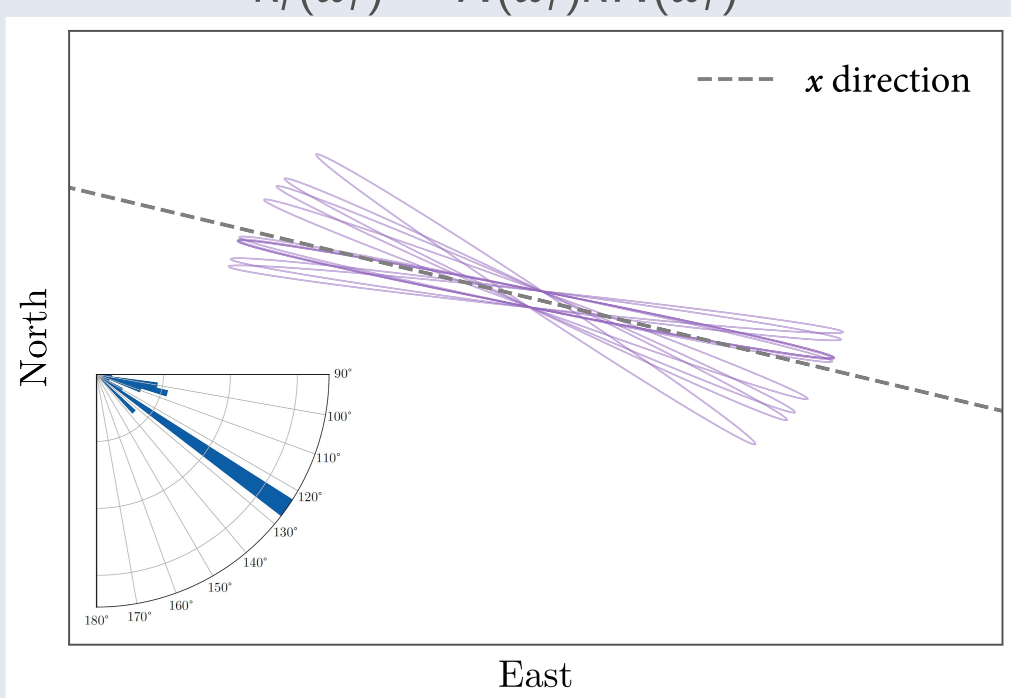
$$\lambda_y = \text{lognorm}(k_{yy}, 0.2)$$



STEP 2: RANDOM ROTATION



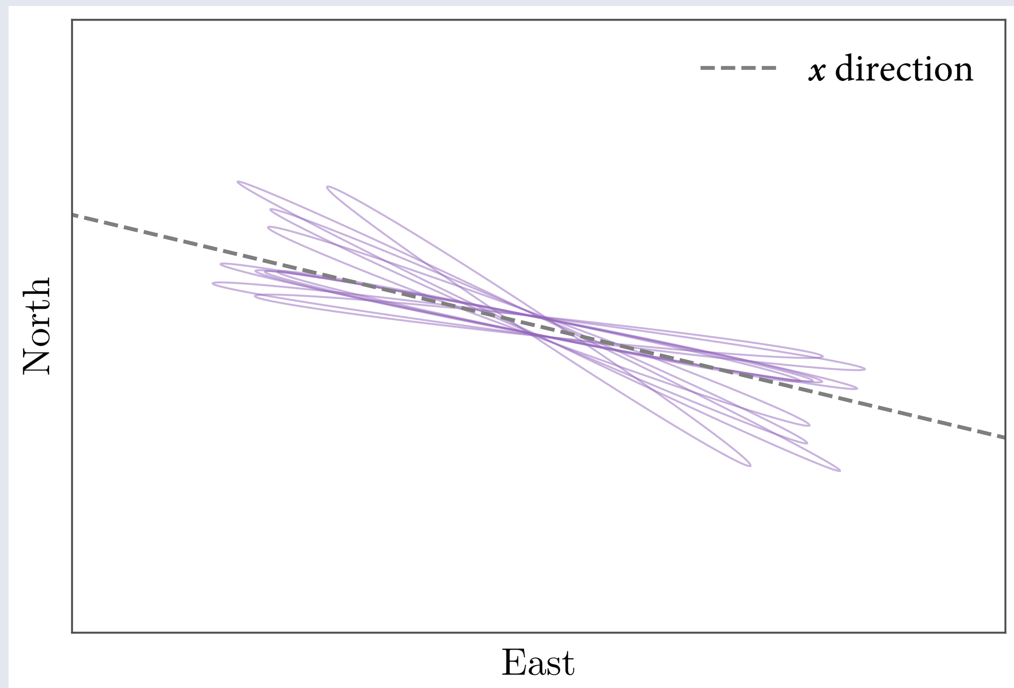
$$k_r(\omega_r) = R(\omega_r)\hat{k}R(\omega_r)^T$$



STEP 3: RANDOM BOTH

We consider these two approaches (fixed orientation and fixed scaling) independent, so we can combine them.

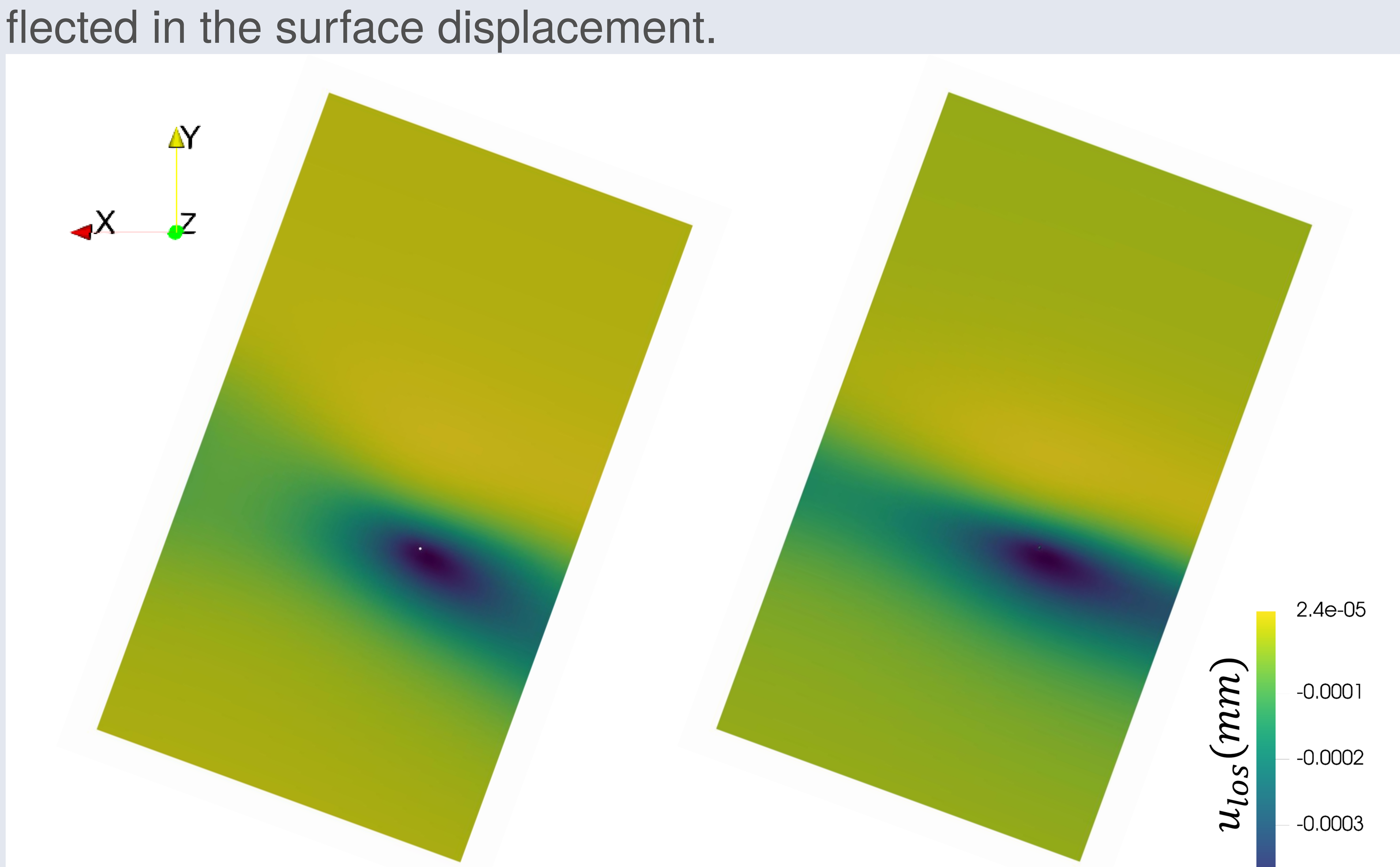
$$k_{rs}(\omega_{rs}) = R(\omega_r)k_s(\omega_s)R(\omega_r)^T$$



Random Hydraulic Conductivity Tensor ($k_{rs}(\omega_{rs})$) → Running Parallel Poroelastic Finite Element Model in HPC → Outputs (line of sight deformation) → Statistical Analysis (mean, standard deviation, ...)

DISPLACEMENT OF AQUIFER MODEL

The results show that the randomness in hydraulic conductivity is reflected in the surface displacement.



a) LOS surface displacement of random scaling and rotation

b) LOS surface displacement of fixed AHC

TAKE-HOME MESSAGE

Regenerating rotation angles using a mixture of two von Mises models and employing them to model random symmetric and positive definite (SPD) tensors were addressed in this study. The focus is on modelling uncertainties in such a way as to have a fine control independently over the scaling and directional attributes of the tensor—given that the material symmetry is fixed.

ACKNOWLEDGEMENTS

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Shivanand, Sharana Kumar, Bojana Rosić, and Hermann G. Matthies (2024). *Stochastic Modelling of Symmetric Positive Definite Material Tensors*. arXiv: 2109.07962 [math.NA].