Adding geological knowledge in transport models to improve their predictive capacity for risk mitigation in heterogeneous aquifers

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Challenges for predictive transport modeling

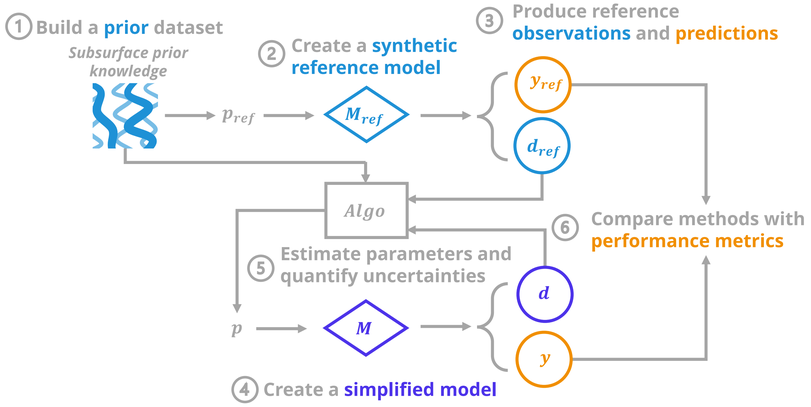
Heterogeneous aquifer = Host material + Discrete structures

Transport models need to account for these geological structures to provide reliable predictions used for decision-support.

? Can we integrate information about subsurface heterogeneities while still being able to assimilate observed data?

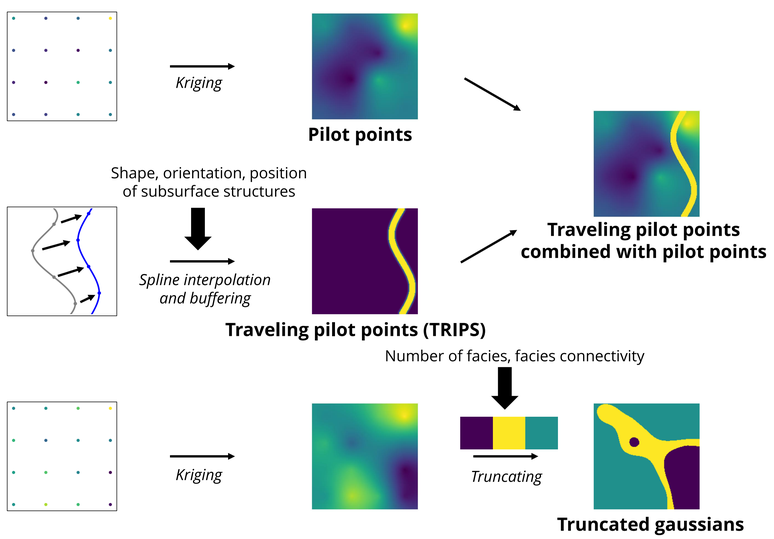
Robust predictions of solute transfer in alluvial systems

Workflow



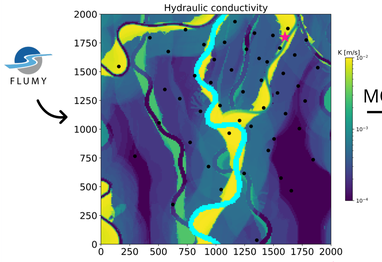
We adopt an inverse modeling approach and compare different parameterization strategies on their ability to use reference observations and geological knowledge to deliver reliable predictions.

Parameterization strategies

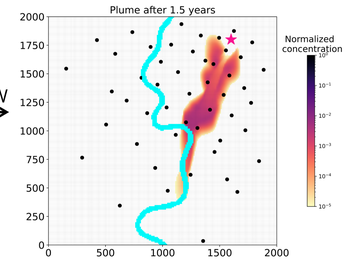


Reference model

A single layer alluvial aquifer



Steady-state flow and transient solute transport simulation



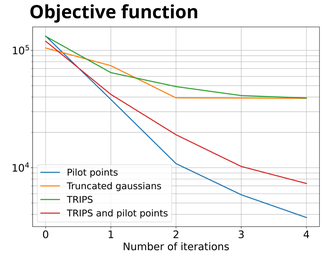
River ★ Solute source ● Observation point

How well can we predict the solute mass flow to the river, total mass in the river and peak arrival time using the different parameterization strategies?

Results of parameter estimation

① Data assimilation using PEST++ IES

Objective function

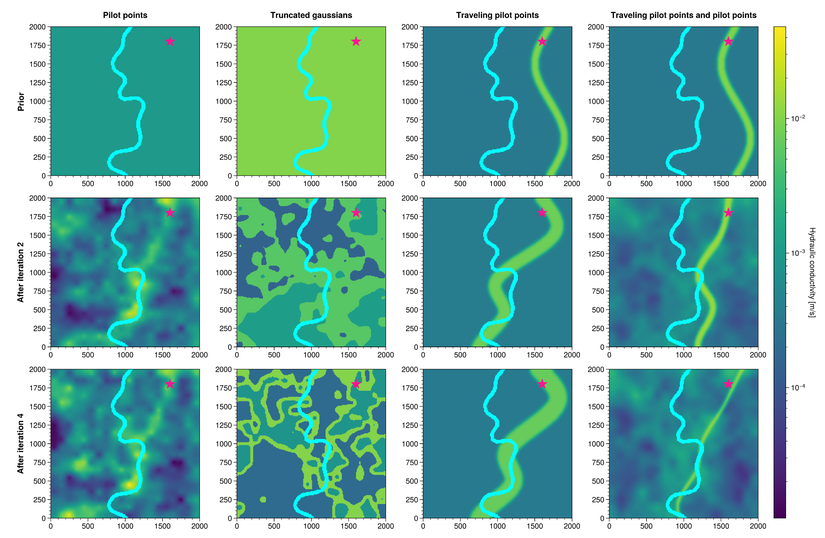


We used 400 realizations and calibrated them against head and log of concentration data, with weights adjusted so that each observation type represents half of the objective function.

Pilot points assimilate data the best. Using truncated gaussians impedes IES performances as it introduces additional non-linearities and discontinuities in the process.

② Parameter fields

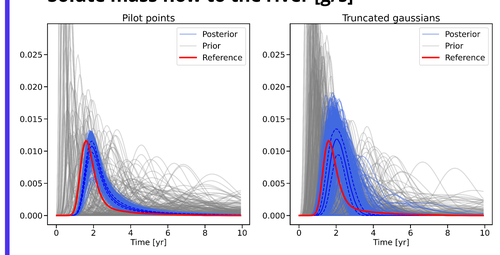
Evolution of hydraulic conductivity for base realization



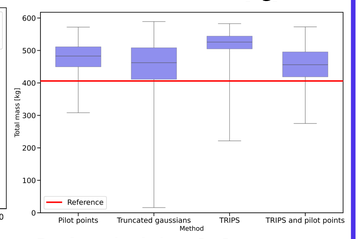
All methods show a connected, permeable flow path between the source and the river.
Pilot points identified the presence of a permeable channel through the observation data but show bullseyes in other parts of the domain.
With traveling pilot points, a connected path is included directly in the prior, which helps fit the concentration data and creates a smoother-looking field than with pilot points alone.

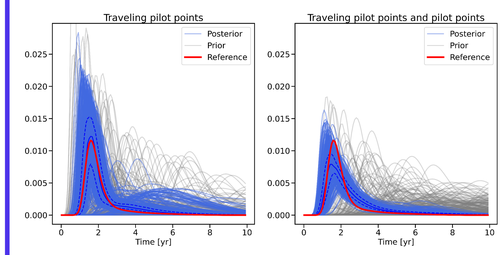
③ Predictions

Solute mass flow to the river [g/s]

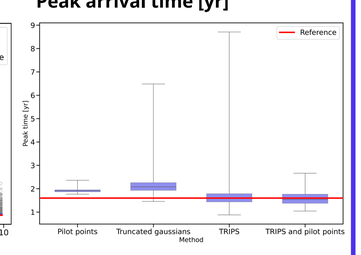


Total mass in the river [kg]





Peak arrival time [yr]



The shape of the mass flow is well predicted with pilot points, but the speed of the solute migration is underestimated.
The arrival and peak times are better predicted with traveling pilot points, because they create a direct connection between the source and the river.
Using traveling pilot points alone or truncated gaussians lead to high uncertainties on the mass flow, as IES struggle to fit the observations with those two methods.

Conclusion

We tested three different parameterization strategies to better integrate geological knowledge in a parameter estimation framework.

	Pilot points	**Truncated gaussians**	**Traveling pilot points**
Representation of the subsurface	Multigaussian	Discrete and facies-based	Object-based
⊕	Robust and flexible	Can render facies connectivity and sharp variations of properties	Can integrate information about permeable structures
⊖	Hardly integrates any geological knowledge	Harder to assimilate observations data	Simple representation of subsurface structures

Overall, using traveling pilot points to draw a permeable channel and pilot points to represent the host material seems to be a good strategy, as it keeps the flexibility of pilot points while better accounting for connectivity of permeable structures.

References

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