Bayesian Analysis of the Data Worth of Pumping Tests Using Informative Prior Distributions

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Motivation

The characterization of the subsurface is always burdened with large uncertainties. These uncertainties are caused by the general lack of data and the large spatial variability of many subsurface properties. Due to their comparably low costs and versatility, pumping tests are regularly applied for the characterization of groundwater aquifers.

Yet, their data worth has rarely been investigated within a Bayesian framework. This is particularly relevant since recent developments in the field of Bayesian inference facilitate the derivation of informative prior distributions for subsurface parameters. If this is the case, the actual data worth of pumping tests, as well as other subsurface characterization methods, may be lower than assumed.

Stochastic model

- Gaussian random field to represent log-hydraulic conductivity (transmissivity)
- Simple model with three paramters; mean, variance, correlation length
- Gaussian random field generator from the Python geostatitical project GSTools (https://github.com/GeoStat-Framework/GSTools)

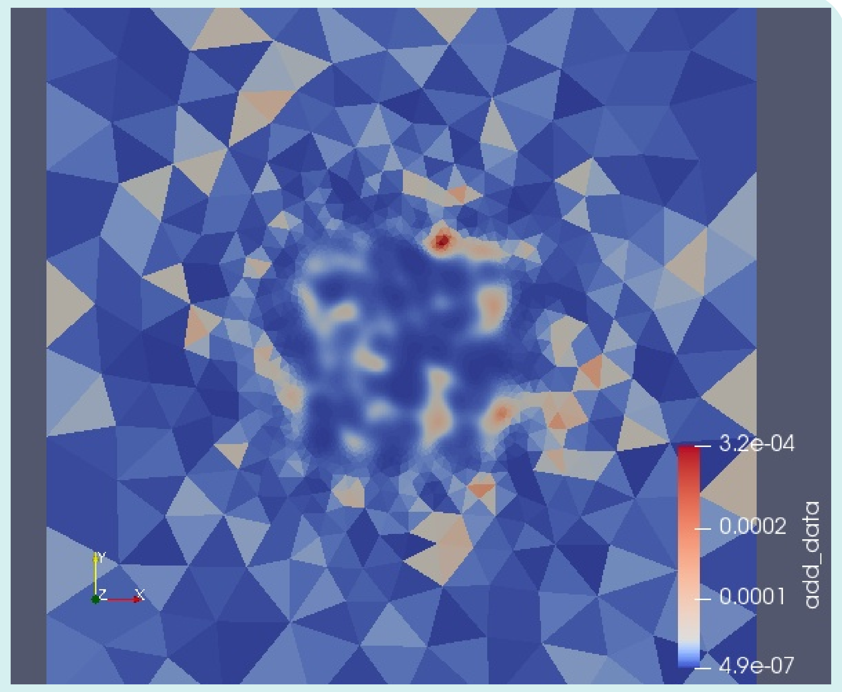

Fig. 1: Gaussian random field to represent the heterogeneous conductivity field.

Numerical model

- numerical steady-state pumping test using OpenGeoSys 5 (OGS)
- synthetic data from baseline pumping test
- inceasing mesh size toward outer regions of the domain
- twelve randomly placed observation wells
- fitting an analytical function to steady-state draw down from wells to reduce number of dimensions
- integrated work flow of GSTools and OGS using ogs5py (Müller et al.)

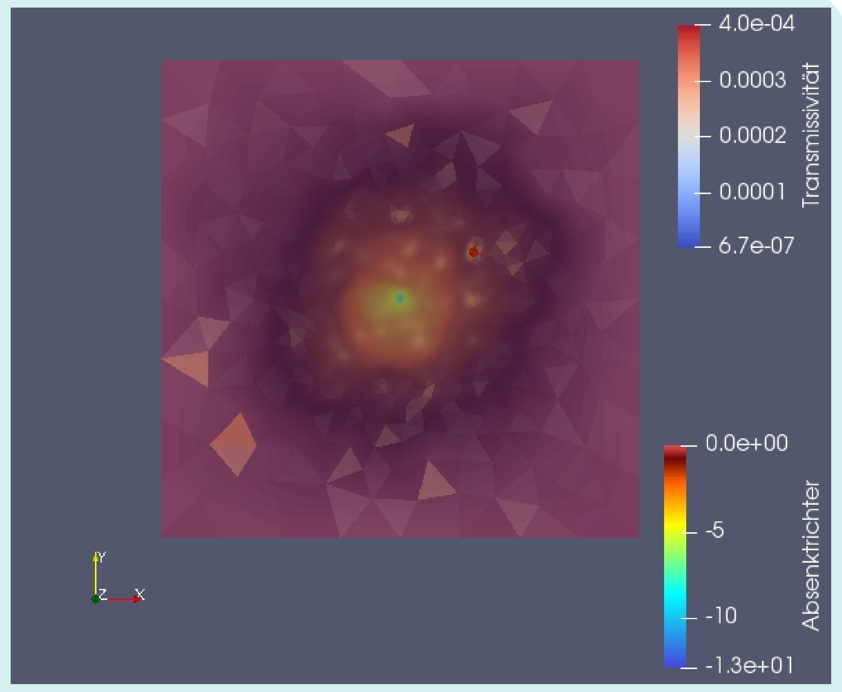

Fig. 2: Draw down from the pumping test in a heterogeneous field.

Results

Prior distributions

- Gaussian processes need at least three parameters; mean, variance and correlation length
- we took mean and variance from Cucchi et al. (2019)
- correlation length was estimated with data from the literature
- strong differences in information content
- we sampled from these priors and used ABC to compute the posterior

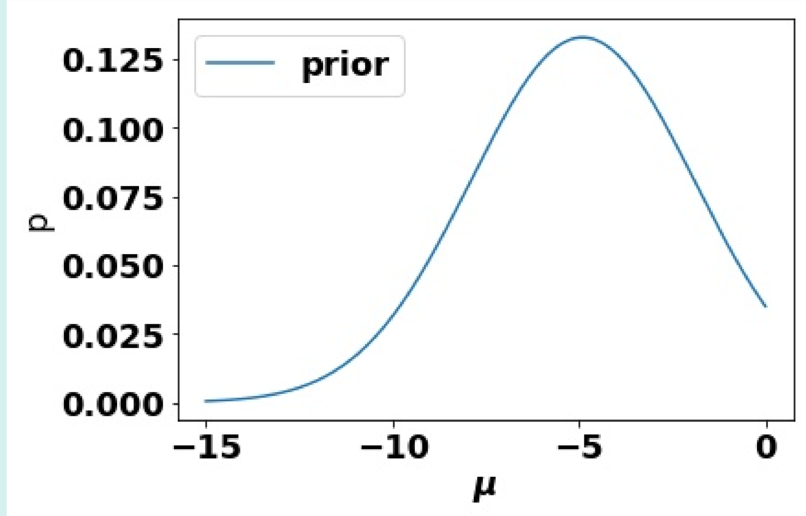

Fig. 3: Prior distribution of mean according to Cucchi et al.

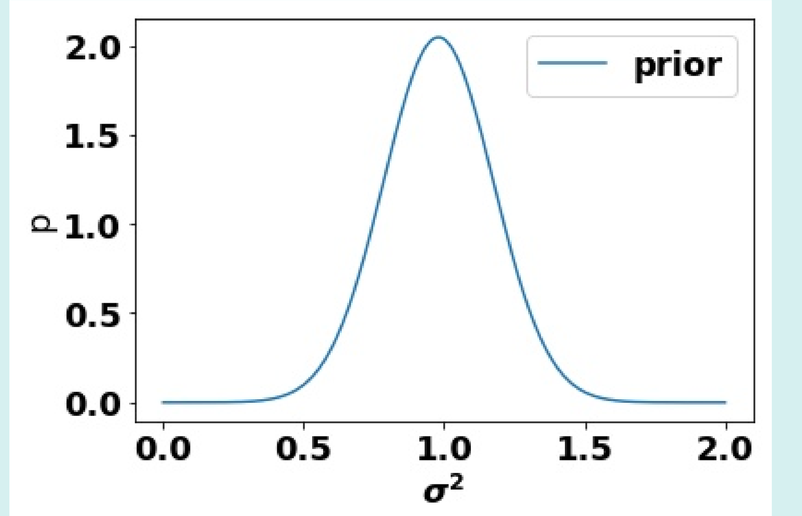

Fig. 4: Prior distribution of variance according to Cucchi et al.

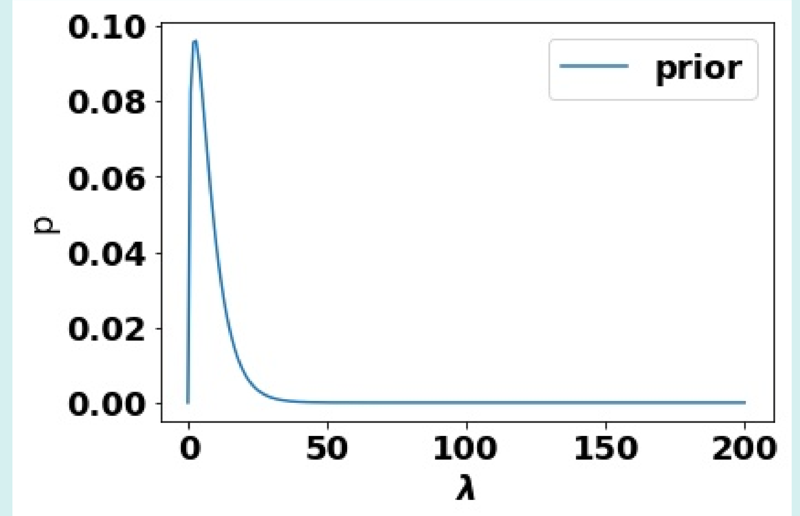

Fig. 5: Prior distribution of correlation length estimated from literature values

Posteriors for sand stone

- reduced uncertainty by focussing on sand stone only
- still strong impact of pumping test data on posterior of mean value
- almost no impact of pumping test data on posterior of variance
- little impact of pumping test data on posterior of correlation length
- overall reduced data worth

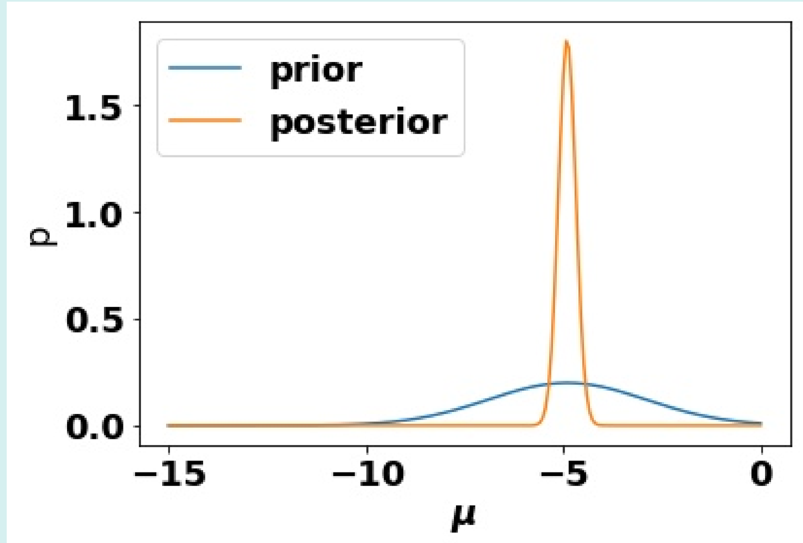

Fig. 6: Prior and posterior distribution of mean for sand stone

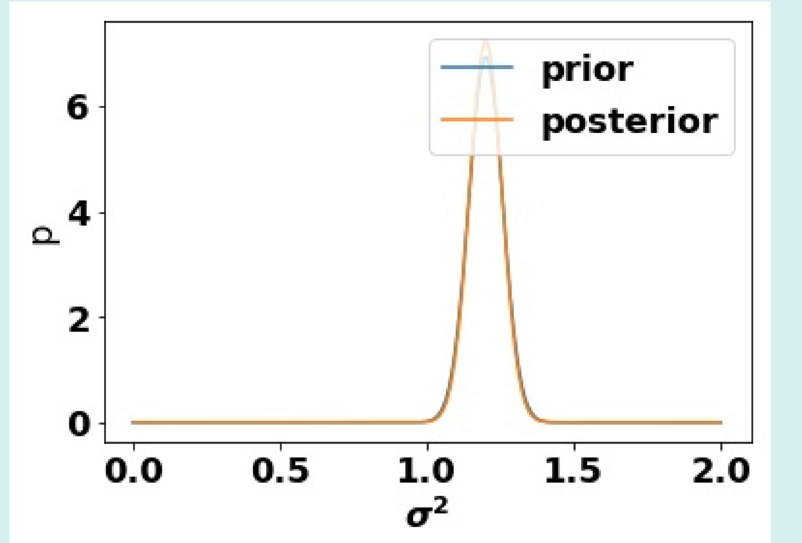

Fig. 7: Prior and posterior distribution of variance for sand stone

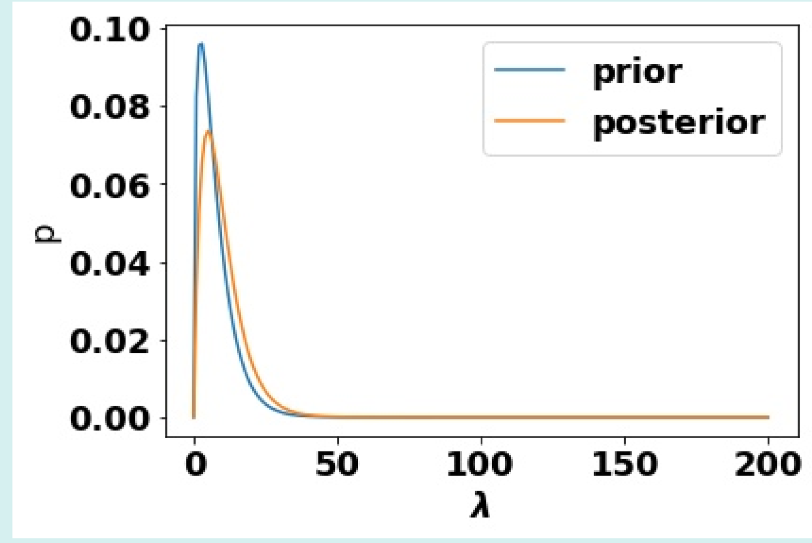

Fig. 8: Prior and posterior distribution of correlation length for sand stone

Posteriors for gravel

- reduced uncertainty by focussing on gravel only
- again strong impact of pumping test data on posterior of mean value
- again little to almost no impact of pumping test data on posterior of variance as well as correlation length
- almost the same overall reduction in data worth

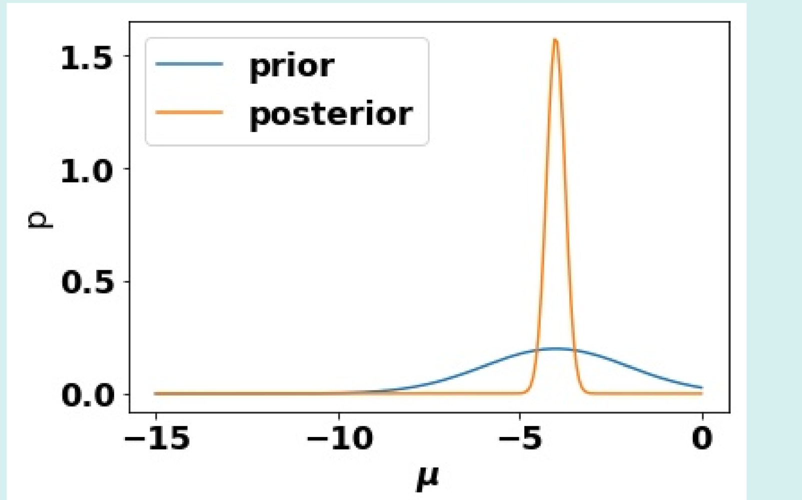

Fig. 9: Prior and posterior distribution of mean for gravel

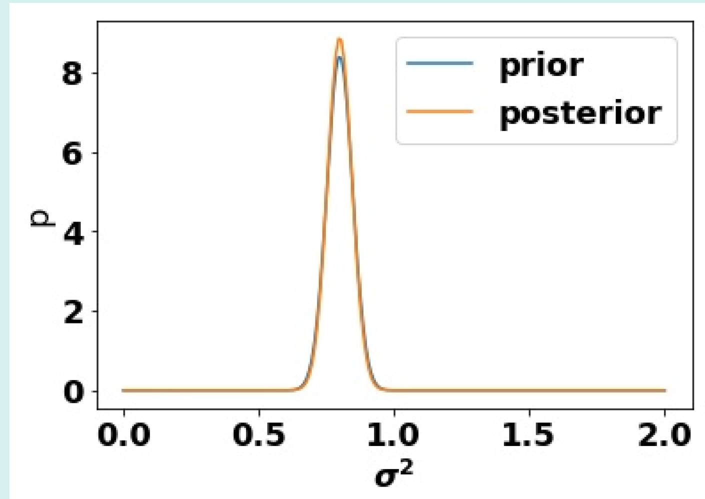

Fig. 10: Prior and posterior distribution of variance for gravel

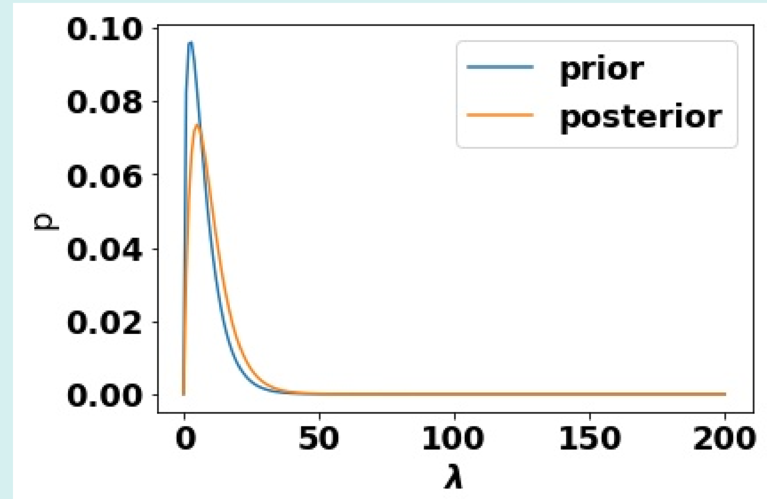

Fig. 11: Prior and posterior distribution of correlation length for gravel

Main conclusions

- Given the currently available background knowledge, we can already observe a significant drop in data worth for steady-state pumping tests. This situation was strongest for variance and lowest for corelation length.
- With more and more data becoming available, the data worth of pumping tests is going to decrease further.
- With this diminishing data worth of pumping tests, other methods for subsuface characterization, like hydraulic tomography, are going to become more important in the future.

References

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K. Cucchi, F. Heße, N. Kawa, Y. Rubin; Ex-situ priors: A Bayesian hierarchical framework for defining informative prior distributions in hydrogeology, ADWR, (2019)

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