UFZ HELMHOLTZ
Zentrum für Umweltforschung

From dynamic groundwater head measurements to regional aquifer parameters

Assessing the power of spectral analysis

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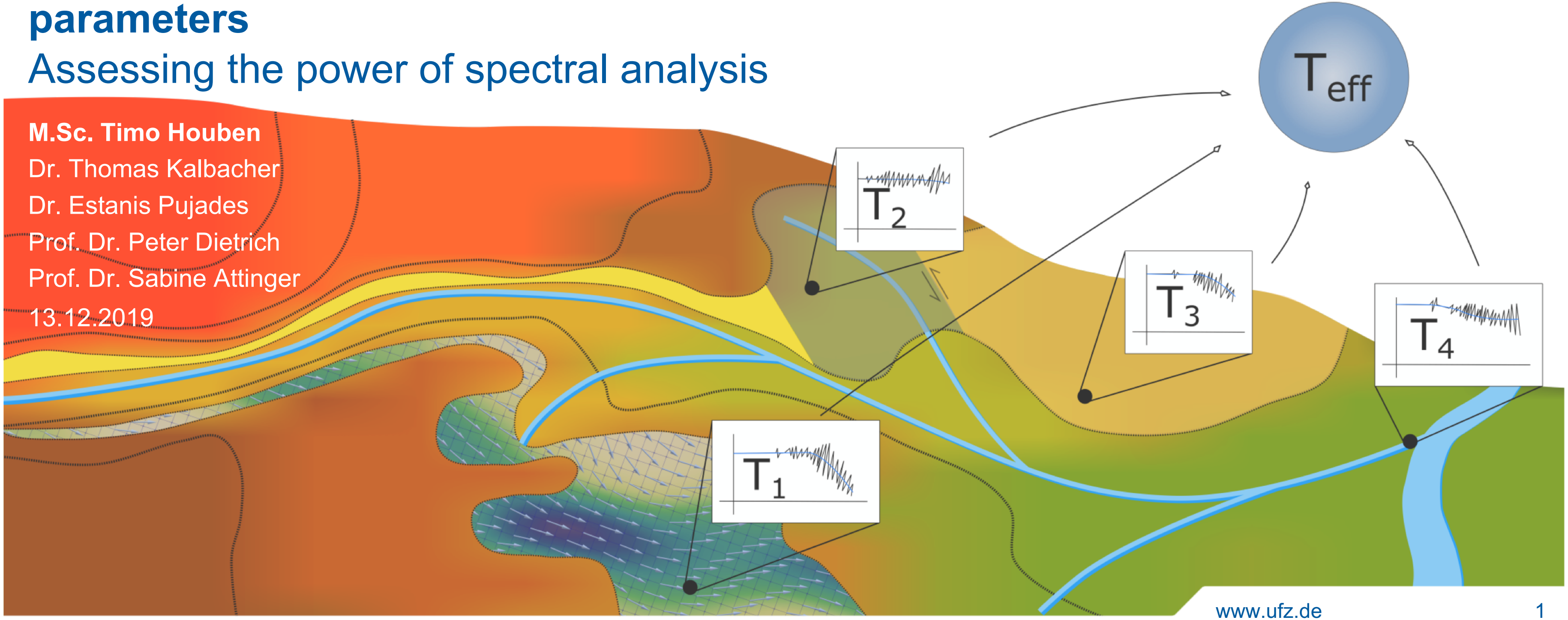
Prof. Dr. Sabine Attinger

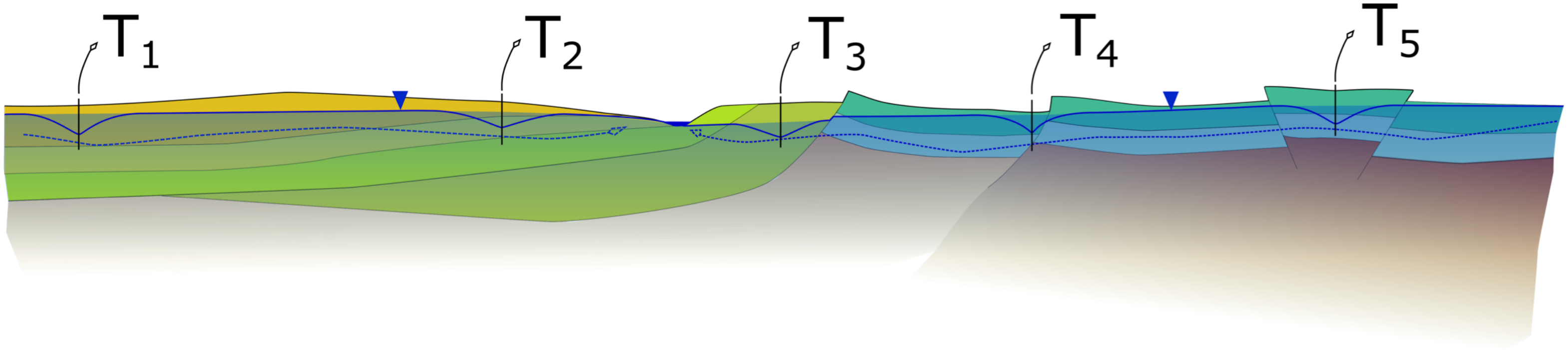
13.12.2019



Motivation

- Projecting the response of regional aquifer systems to strongly changing conditions is paramount.

We need regional GW models!

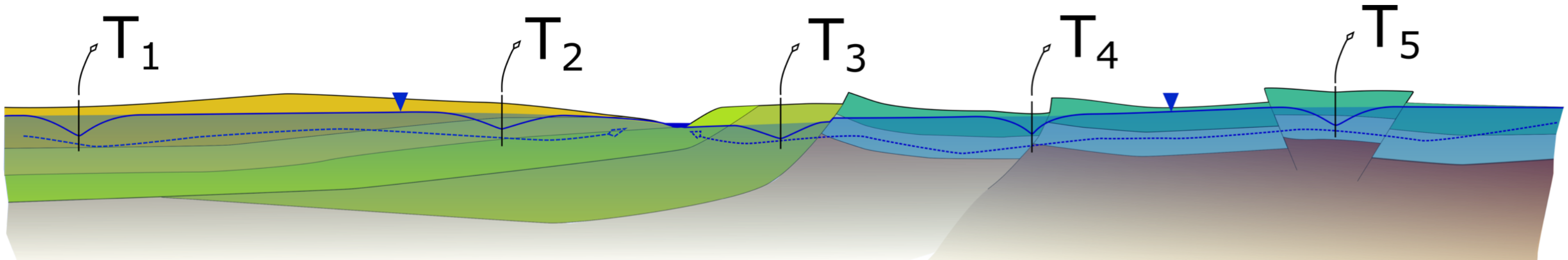


Motivation

- Projecting the response of regional aquifer systems to strongly changing conditions is paramount.

We need regional GW models!

- **Regional** groundwater models are **difficult to parameterize**!
- Usually aquifers are investigated through **pumping tests.**



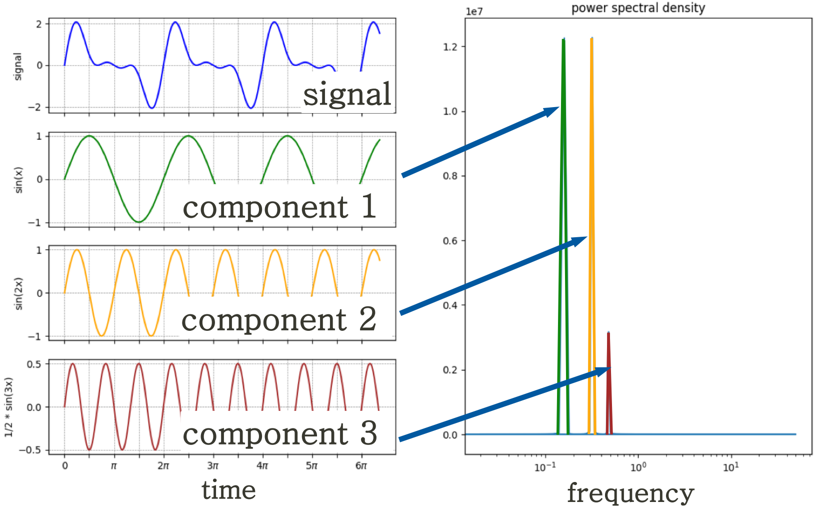
How to parameterize regional groundwater models?

Methodology
Spectral Analysis (SA)

Answer

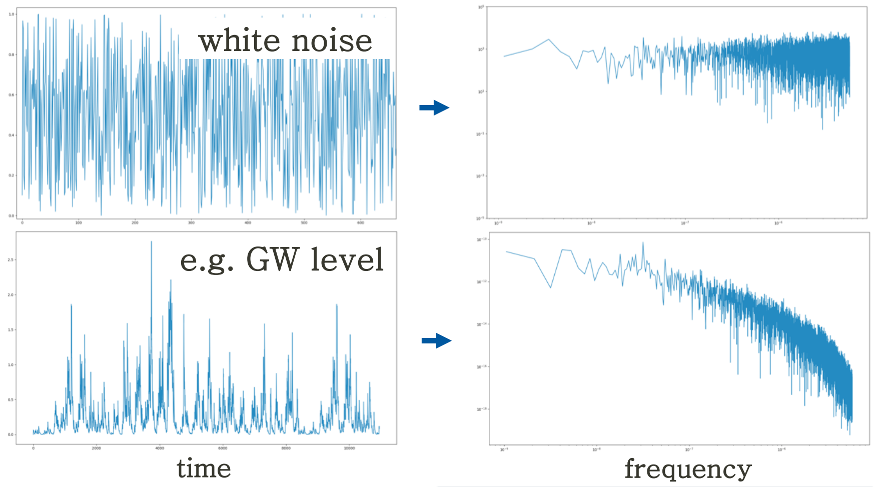
Take GW level time series and derive the aquifer parameters from the spectral response!

Example: disentangling a sinusoidal signal



time series

power spectrum



Previous Studies

Contents lists available at SciVerse ScienceDirect

Journal of Hydrology

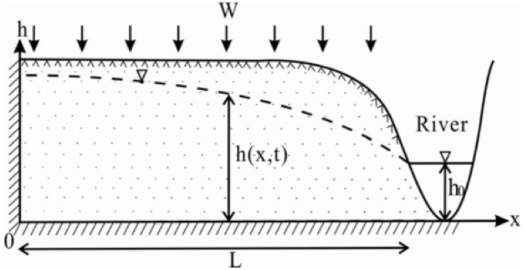
journal homepage: www.elsevier.com/locate/jhydrol

Temporal and spatial variation and scaling of groundwater levels in a bounded unconfined aquifer

Xiuyu Liang [a,b], You-Kuan Zhang [a,b,c,*]

Evoking the Dupuit-Assumptions:

$$S_{hh}(x',\omega) = \frac{16}{\pi^2 S_Y^2} \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \frac{(-1)^{m+n} B_m B_n S_{WW}}{(2m^2+2n^2+2m+2n+1)} \times \frac{(2m+1)^2}{(2m+1)^4/t_c^2 + \omega^2}$$

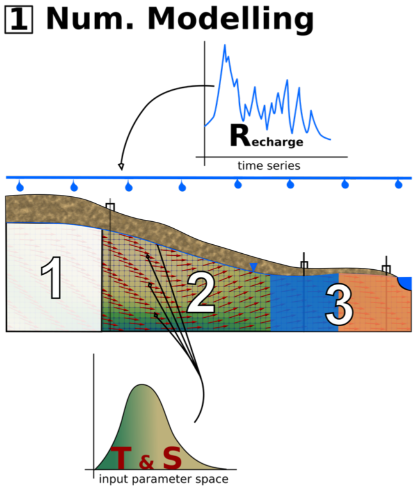


*S*torativity

*T*ransmissivity

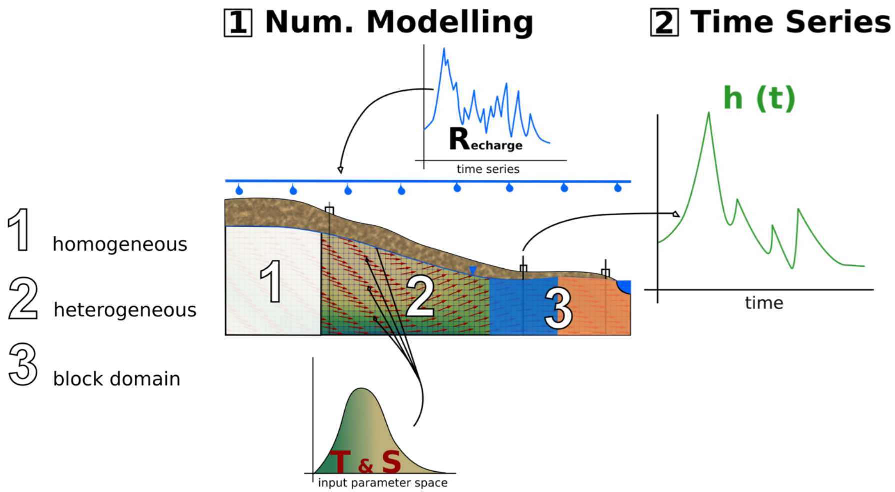
$$t_c = \frac{4 \cdot L^2 \cdot S}{\pi^2 \cdot T}$$

Our Approach
Schematized



1 homogeneous
2 heterogeneous
3 block domain

Our Approach
Schematized



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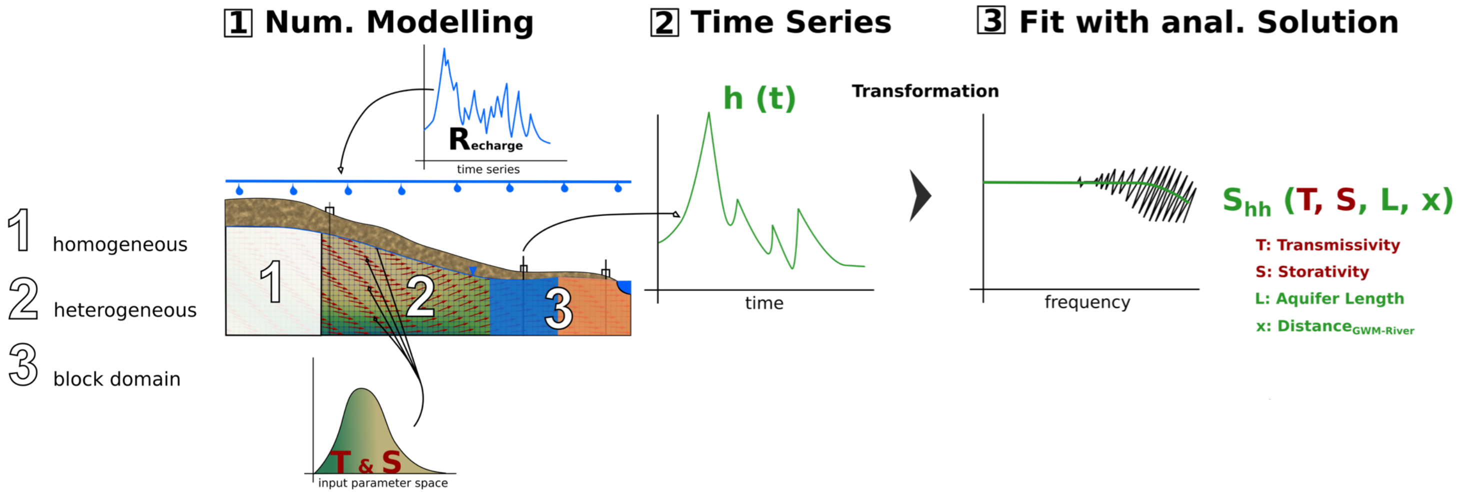

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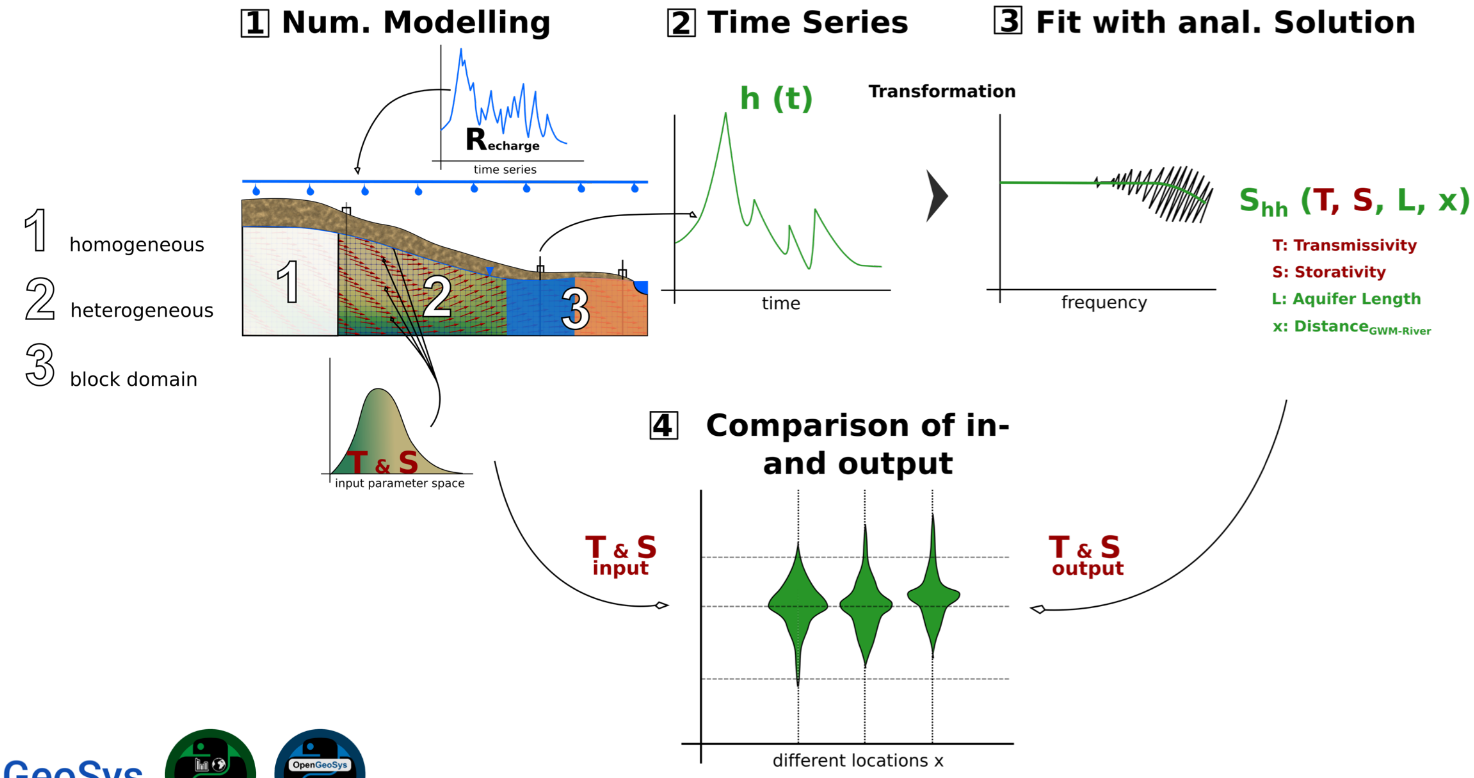

OpenGeoSys
OPEN-SOURCE MULTI-PHYSICS
GSTOOLS
OpenGeoSys OGS5PY

1 - Homogeneous Domain
Setup

Motivation

- Analytical solution of Dupuit-Eq. also **valid** for the **2D groundwater equation?**
- Does the **location** influence the **derived parameter**?
- What is the required **time step** and **length of the time series**?

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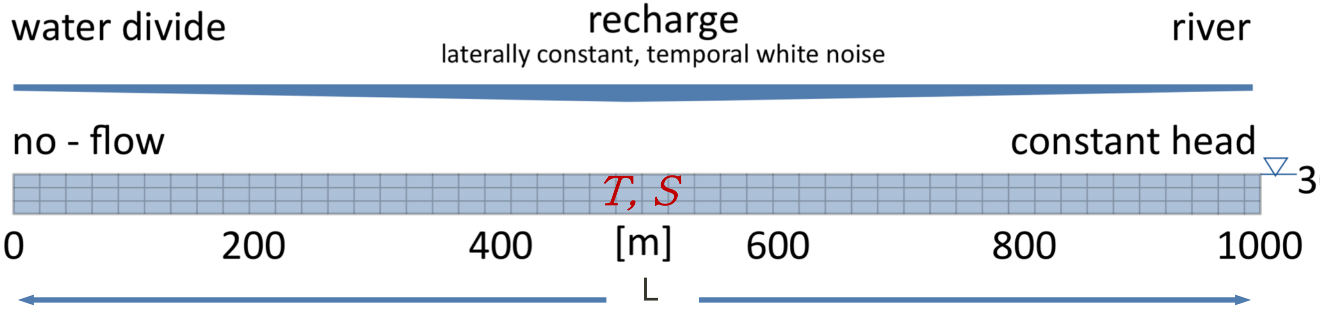
Setup

Input Parameter Space:

t_c = 10^{-1} ... 10^4 days

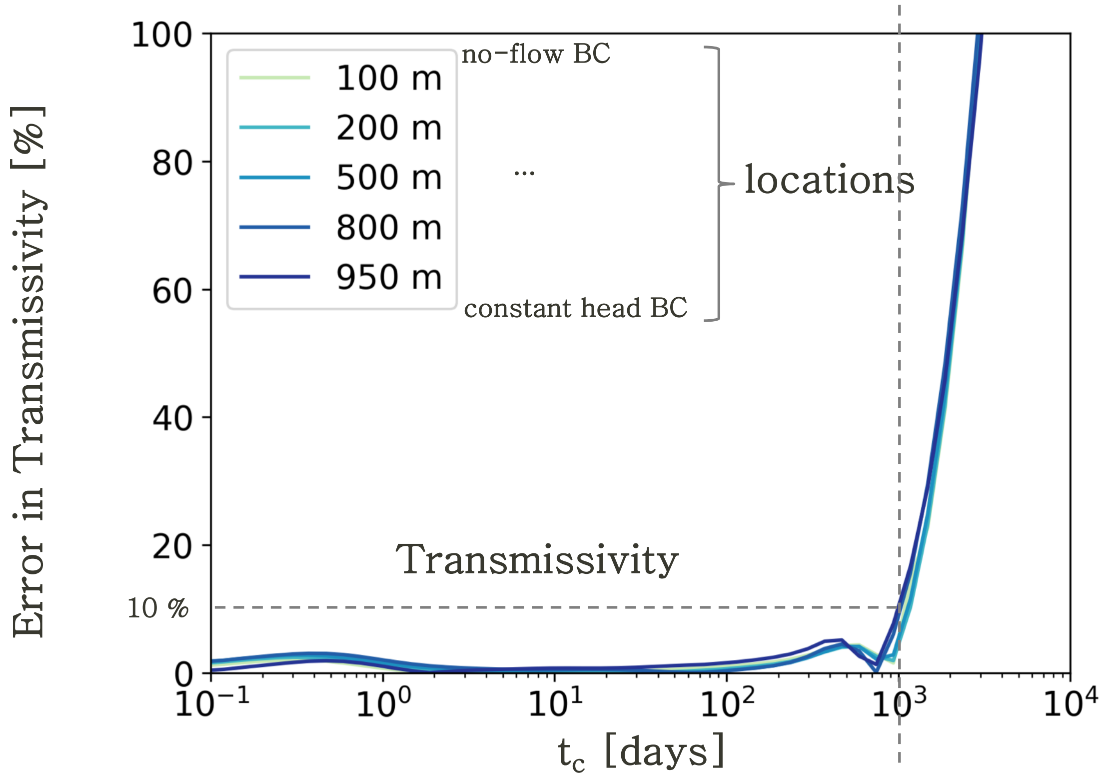
$$t_c = \frac{4 \cdot L^2 \cdot S}{\pi^2 \cdot T}$$

t_c : characteristic time



Recharge:	white noise
Time Step Size:	1 day
Time Steps:	10,950 (30 years)

1 - Homogeneous Domain
Results



The output transmissivity **matches** the input transmissivity almost **exactly!**

The error in transmissivity increases if the characteristic time is **larger than 1/10** of the length of the time series.

$$Error\ [\%] = \frac{|Input - Output|}{Input} \times 100$$

Motivation

- Aquifers are often considered as being homogeneous - **but they aren't!**
- What does the SA tell us when applying it to **heterogeneous media**?

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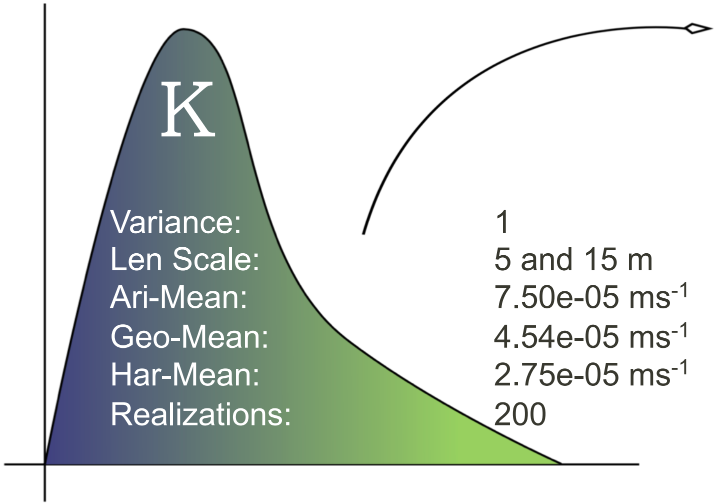
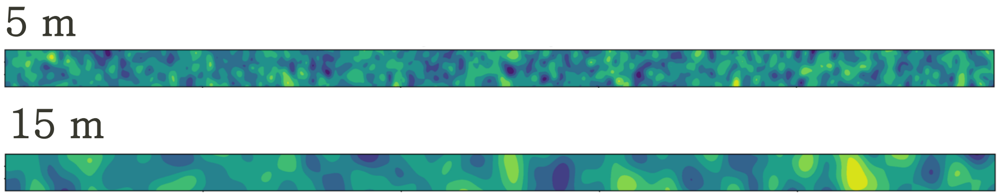
Setup

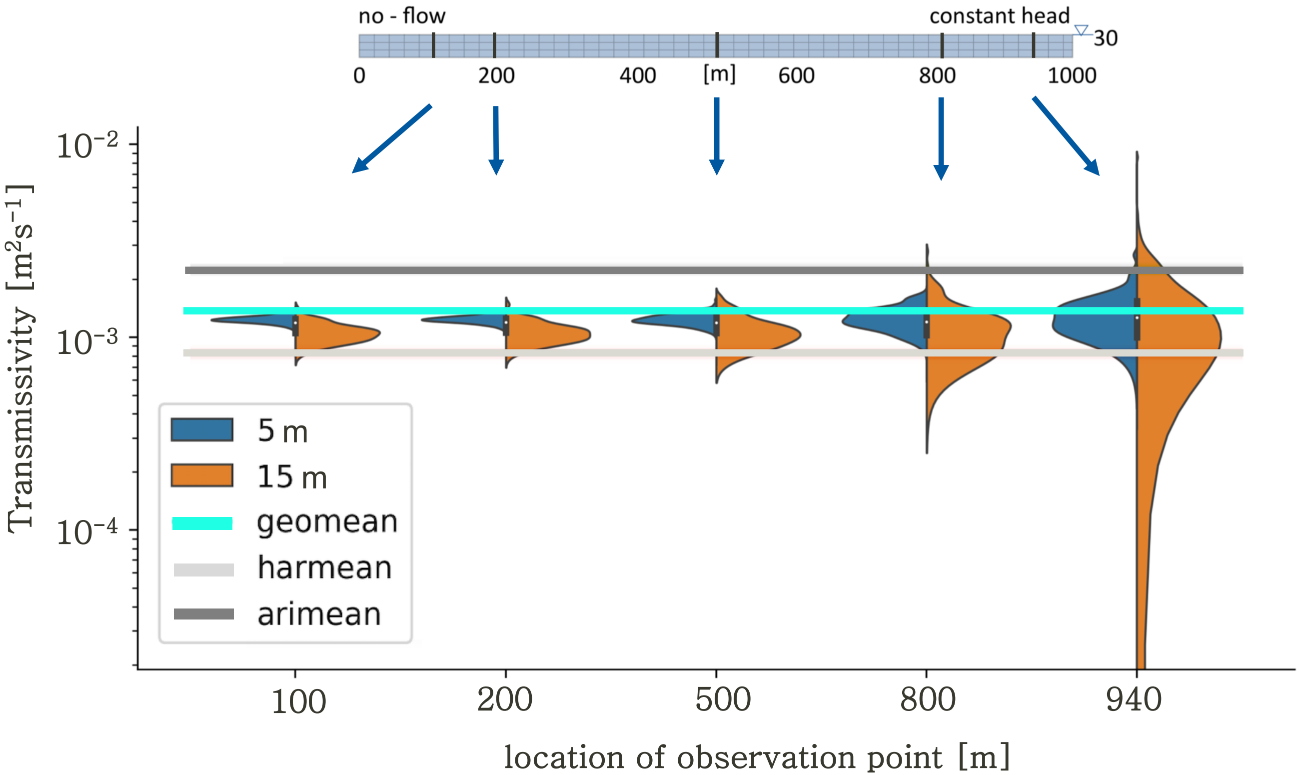


Variance:	1
Len Scale:	5 and 15 m
Ari-Mean:	7.50e-05 ms^{-1}
Geo-Mean:	4.54e-05 ms^{-1}
Har-Mean:	2.75e-05 ms^{-1}
Realizations:	200



Recharge:	white noise
Time Step Size:	1 day
Time Steps:	10,950
Spec. Storage:	0.001

2 - Heterogeneous Domain
Results



Motivation

- We have investigated homogeneous and log-normal domains > **works well!**
- Introduce an aquifer with different **hydraulic zones.**

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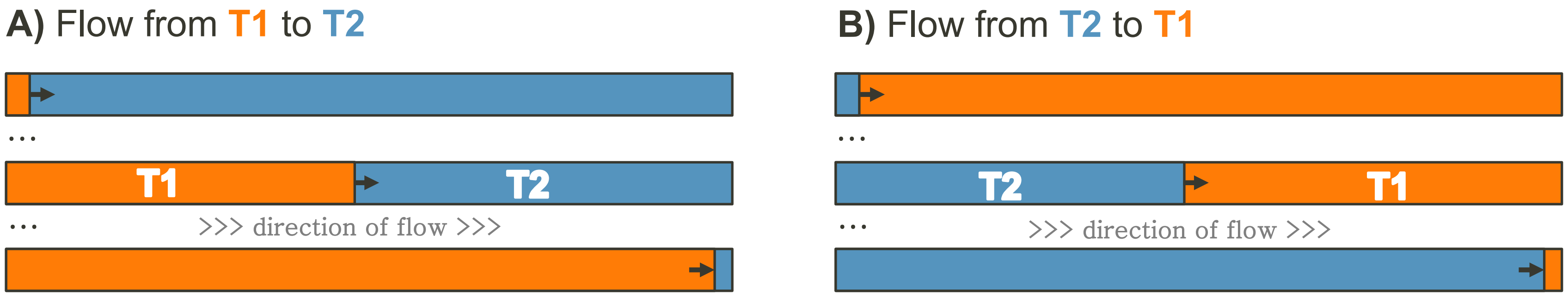
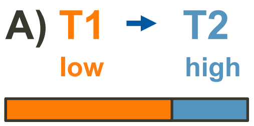


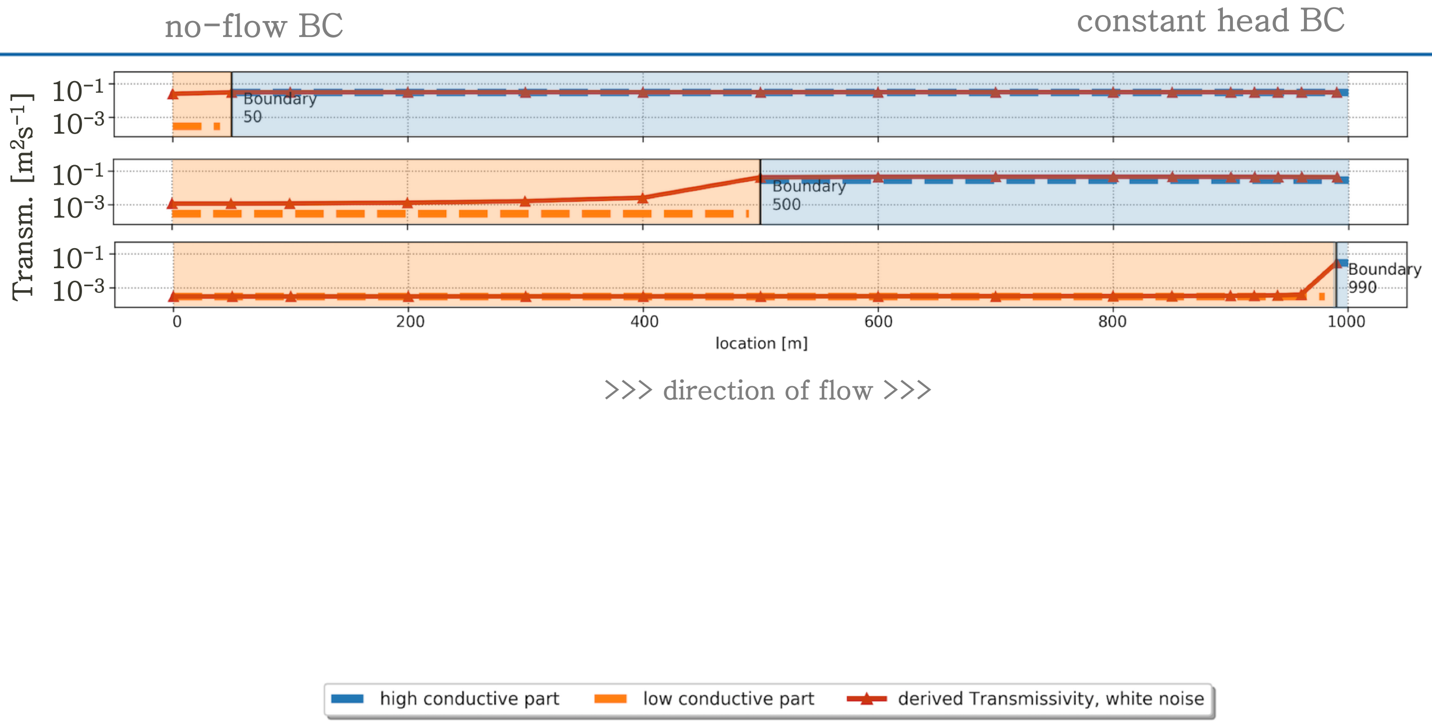
spec. storage: 0.0001
forcing & geometry: like previous examples

low conductive zone, T1 = **$3e^{-4}$ m²/s**
high conductive zone, T2 = **$3e^{-2}$ m²/s**

3 - Block Domain

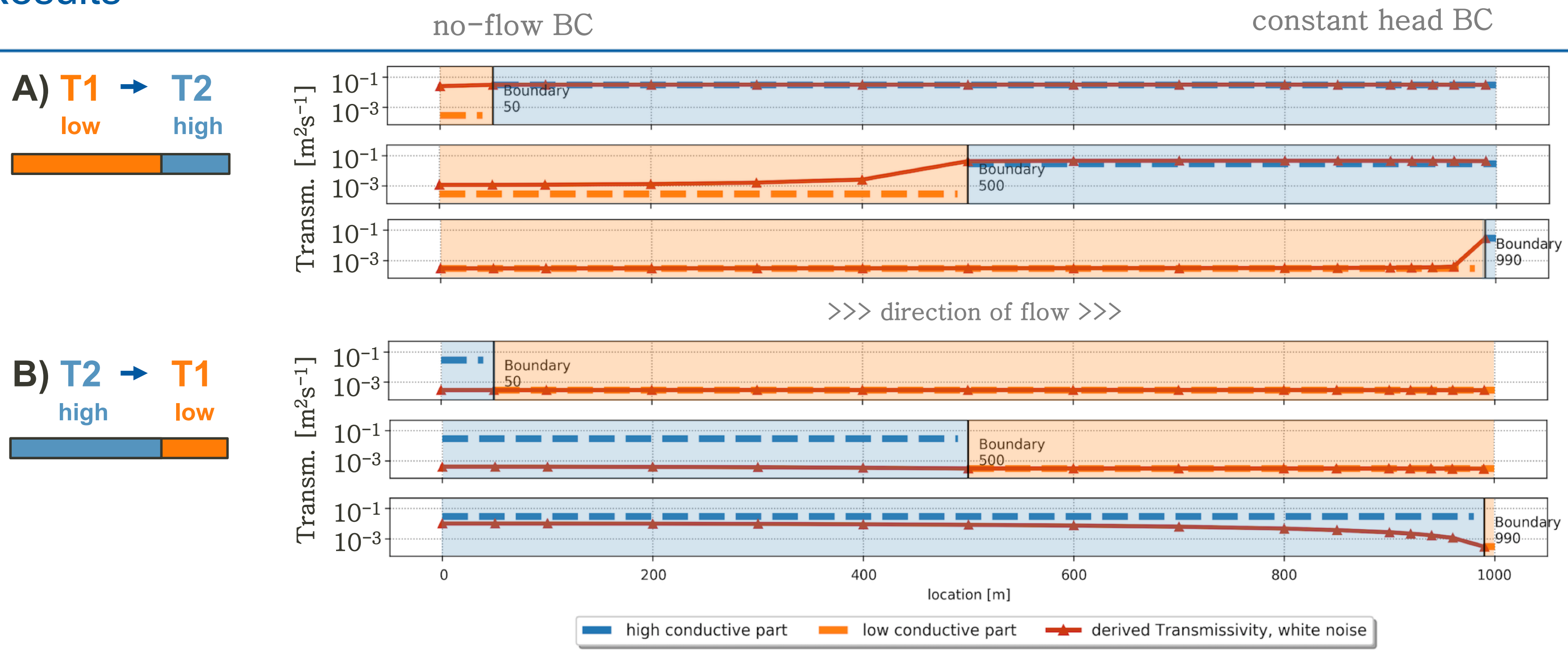
Results





> **High conductivities** at the outlet of the aquifer **slightly** affect lower transmissivities located upgradient.

3 - Block Domain
Results



> **High conductivities** at the outlet of the aquifer **slightly** affect lower transmissivities located upgradient.

> **Low conductivities** at the outlet dominate the entire flow regimes resulting in lower effective transmissivities upgradient.

To sum it up...
Conclusion

- The analytical solution for the head spectrum based on the linearized Boussinesq equation and evoking the Dupuit assumptions **is valid for the 2D GW equation** with mentioned constrains.
- Measure at least **~10 times** as long as your **expected t_c!**
- Spectral analysis reveals the **effective parameter**!

  > log-normal distributed conductivity domains: **geometric mean**

  > block domains: **low conductivities at the outlet dominate** the hydraulic regime

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Thank you
for your attention!

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geostat-framework.github.io

OpenGeoSys
OPEN-SOURCE MULTI-PHYSICS

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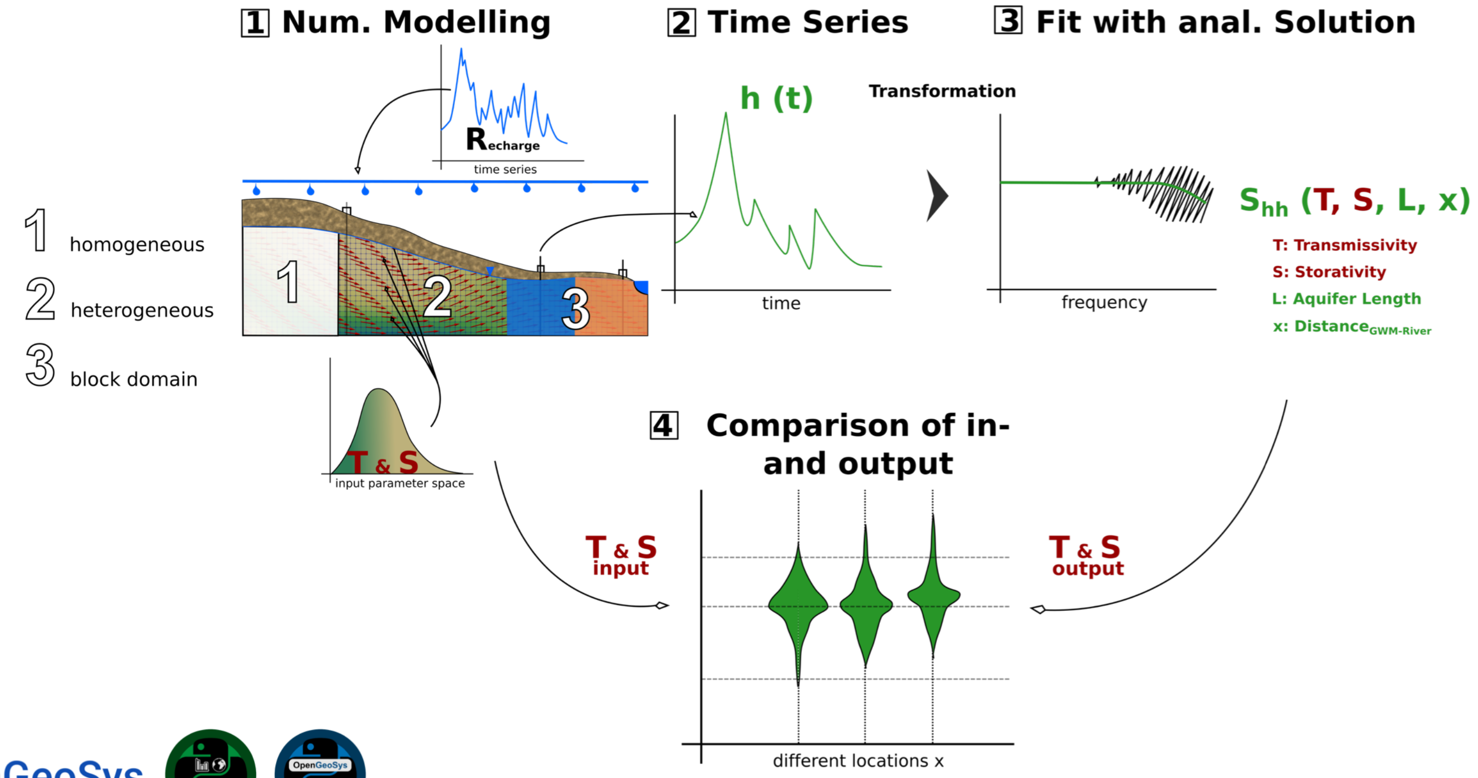
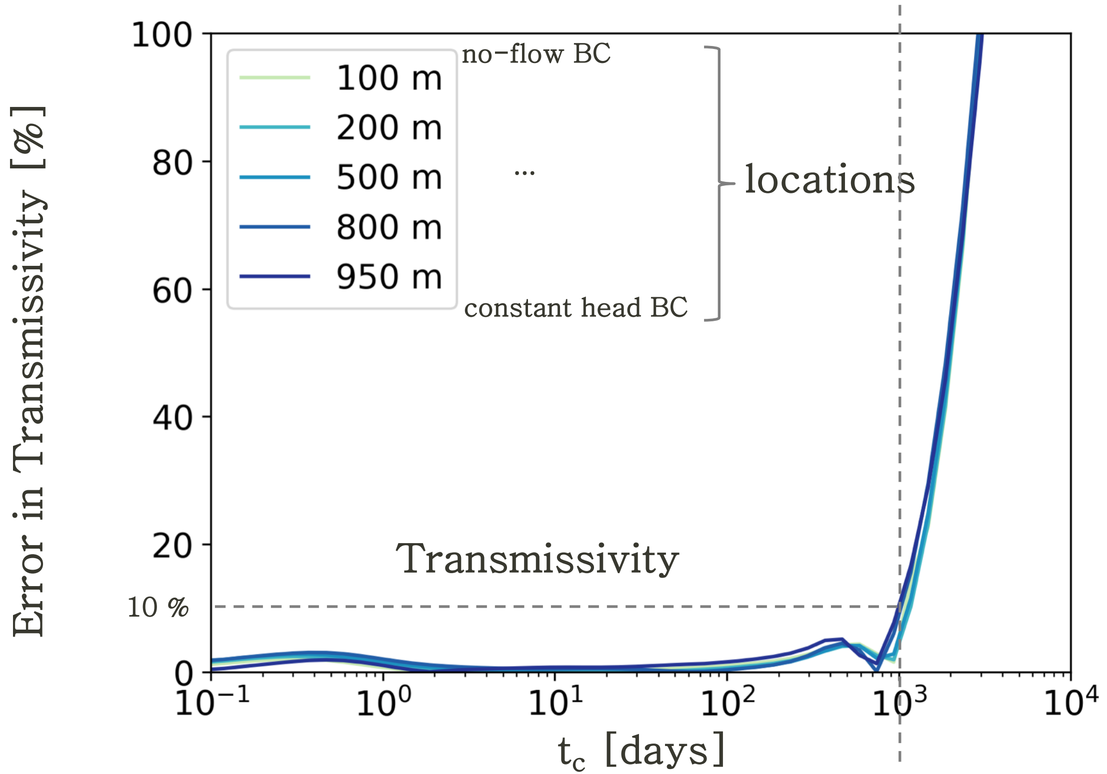


1 - Homogeneous Domain
Results



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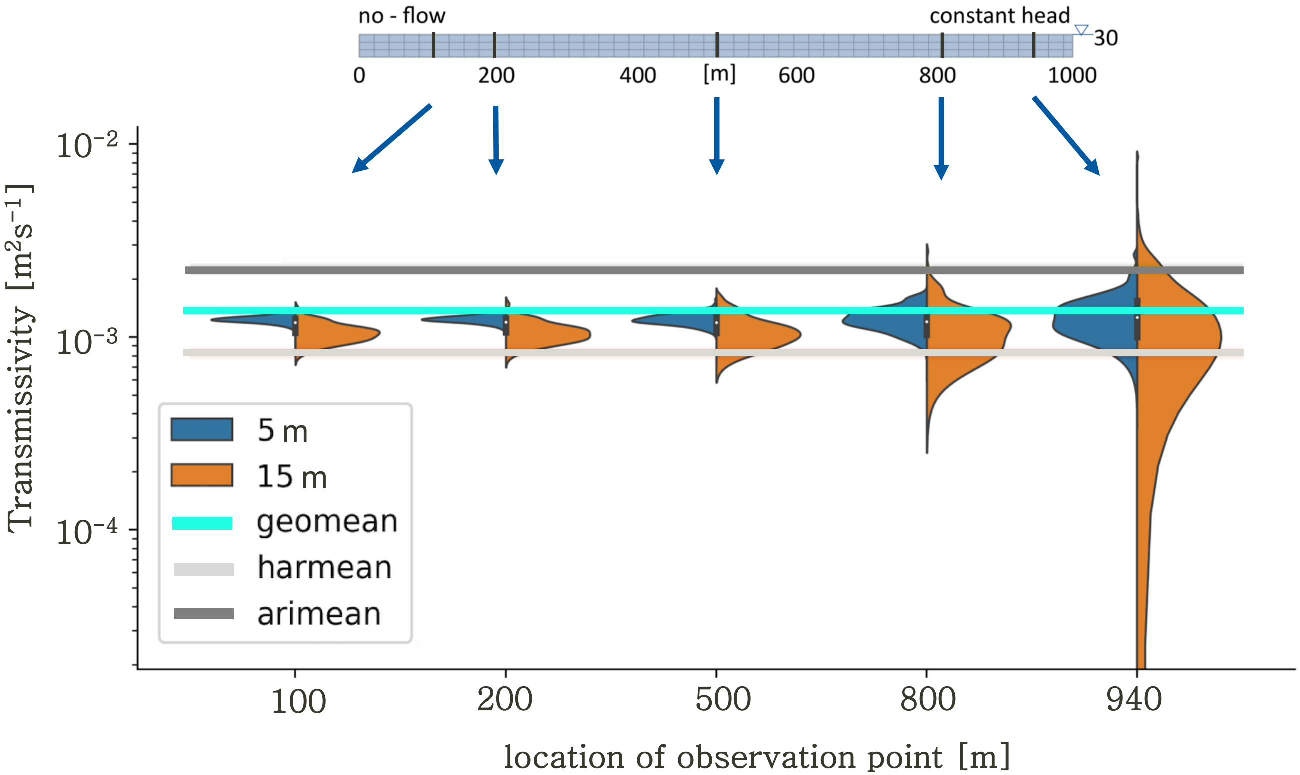
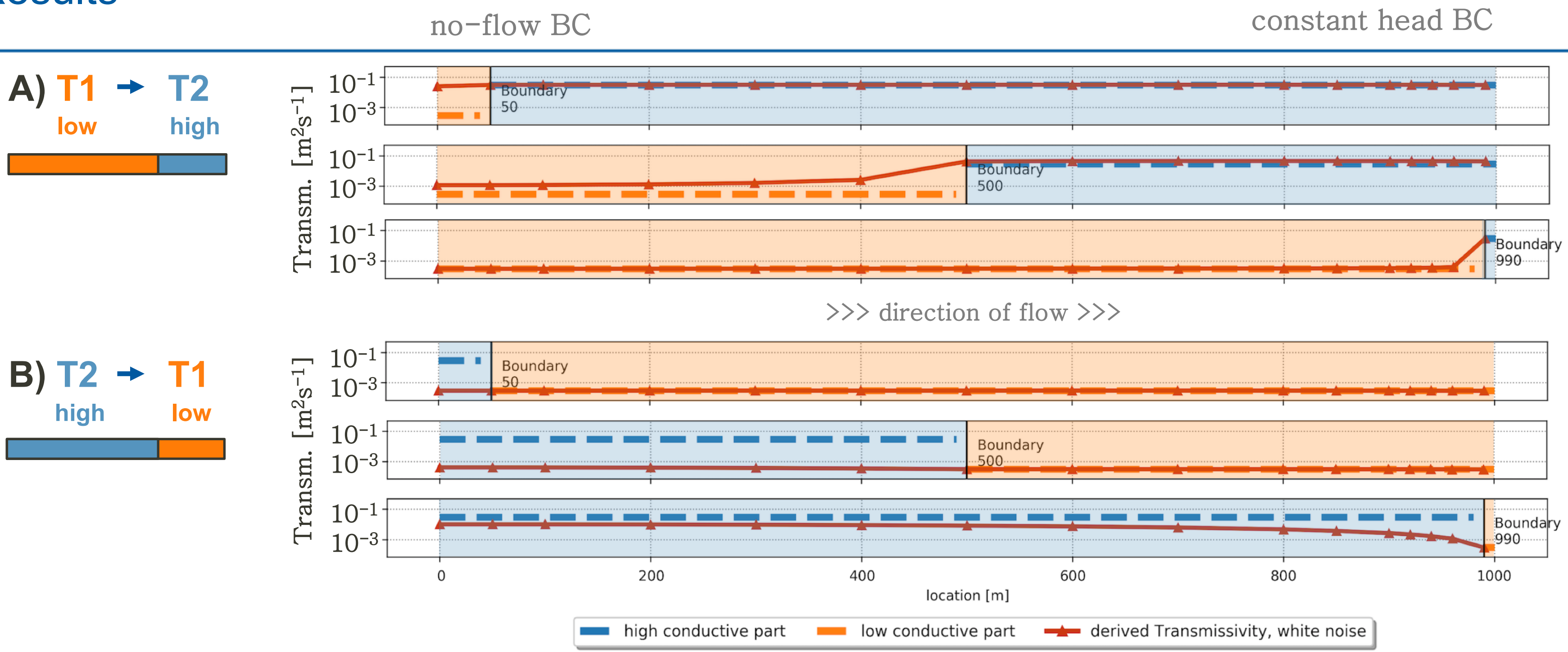


3 - Block Domain

Results



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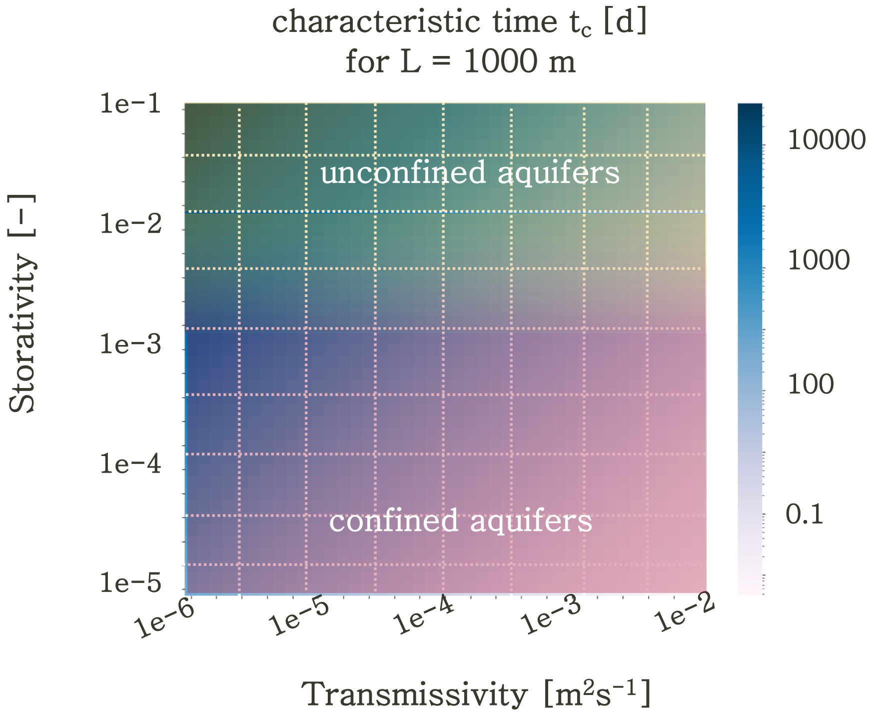
Homogeneous Domain
Setup



$$t_c = \frac{4 \cdot L^2 \cdot S}{\pi^2 \cdot T}$$

Example 1	Example 2
L = 1000 m	L = 1000 m
S = 0.1	S = 0.001
T = 1e-3 m^2s^{-1}	T = 1e-4 m^2s^{-1}
t_c = 469 d	**t_c = 46 d**

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Duffy, C. J., Gelhar, L. W. (1985): A Frequency Domain Approach to Water Quality Modeling in Groundwater: Theory. *Water Resources Research*, Vol. 21, No. 8, Department of Civil and Environmental Engineering and Utah Water Research Laboratory, Utah State University, Logan.

Molénat, J., Davy, P., Gascuel-Odoux, C., Durand, P., (1999): Study of three subsurface hydrologic systems based on spectral and cross-spectral analysis of time series. *Journal of Hydrology* 222.

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