Stochastic Data Integration to model Quaternary Aquifers: Application on the Aare Valley, Switzerland

Alexis Neven[1] and Philippe Renard[2]

[1]University of Neuchâtel, Centre for Hydrogeology and Geothermics
[2]University of Neuchâtel

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Abstract

Nowadays, the centralization of subsurface-related observation is more and more common. Databases constituted of an ensemble of geophysical, hydrological, or borehole measurement forms a unique source of information for subsurface hydro-geological modeling. However, the increasing amount of data and the importance of being able to update the model when new data becomes available creates a huge need for automatic workflow for such data integration, hopefully reeling on open-source technology. Quaternary deposits are complex to model due to the high heterogeneity they present. Over the last 2.5 Ma, multiple cycles of glacial and inter-glacial phases deposited complex intertwining of sedimentary pattern, with high contrast in parameters (e.g. : permeability, porosity, nature of sediment) and space. Nevertheless, these deposits are some of the most extensively used for water resources, shallow geothermal exploitation, or construction material exploitation. In this study, we propose a new method based on a flipped stochastic joint inversion, and applied it on complex Quaternary deposits. Geophysical, boreholes and hydrological observations are inverted together. Boreholes are used to generate stochastic geological models, populated with parameters. The inversion tune the geological model in order to fit the field data. Our method allows not only to integrate boreholes, geophysical and hydrological data, but also conceptual models, with a robust uncertainty estimation. The method was applied on some areas of the Upper Aare Valley (Switzerland), a valley covered by more than 58'000 geophysical measurement points, 1'500 boreholes and 100 of hydrological observations. Our method showed promising results in combining these data. Comparison with existing geological models proves that our automated method not only show realistic underground structures, but also significantly improved the regional knowledge of the underground by combining all the existing data, and will therefore lead to better decision making while being based on open-source technology.

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Alexis Neven[1], Philippe Renard[1,2]

1 Centre of Hydrogeology and Geothermics, University of Neuchâtel, Switzerland
2 Hydrogeology departement, University of Oslo, Norway

AGU FALL MEETING
New Orleans, LA & Online Everywhere
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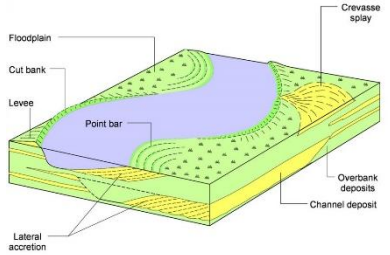
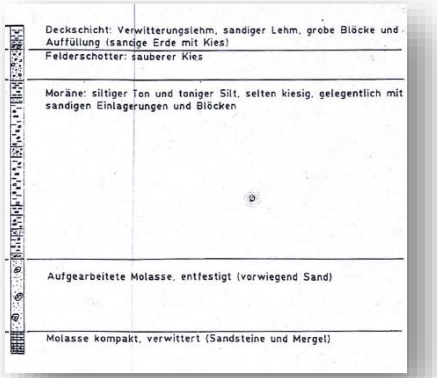
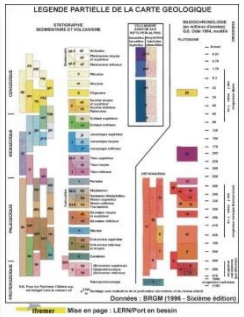
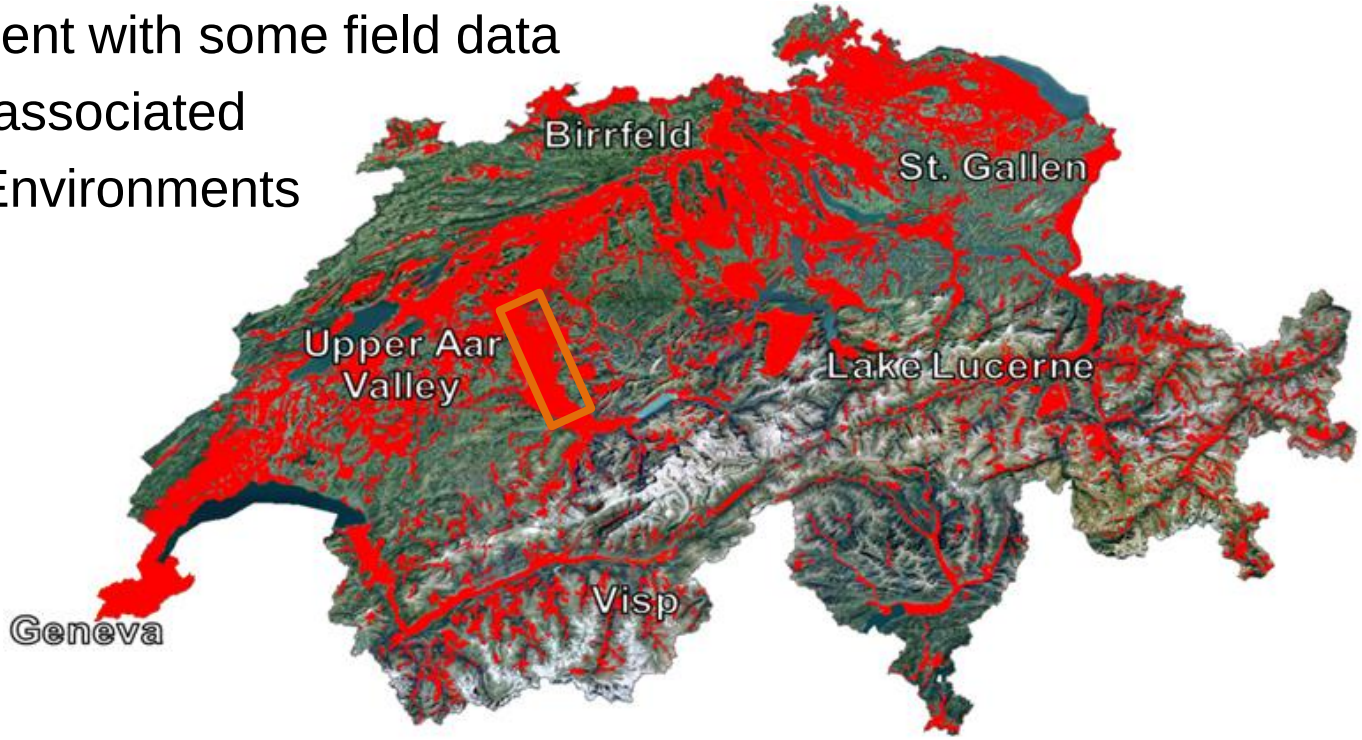
DATA

- In most countries, digitalization of data is growing.
  (mandatory to send new boreholes data)
- Too much data to manually interpret them
  - No uncertainty analysis
  - The final model might be in disagreement with some field data
  - Only boreholes based models can be associated with high uncertainties in Quaternary Environments





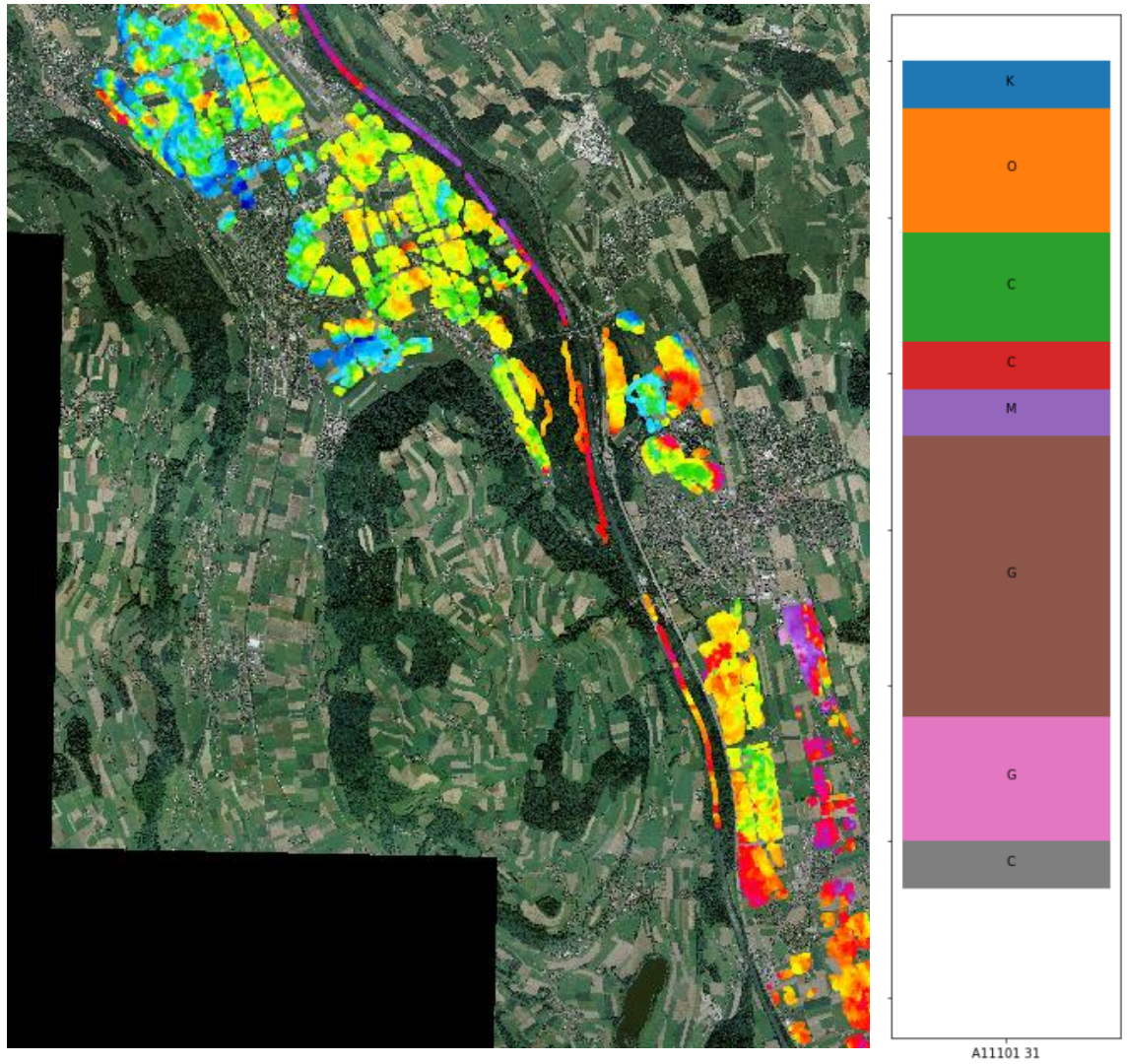




DATA

- What data do we usually have on site ?
  - Described boreholes (usually lithological)
  - Pumping test, or groundwater heads monitoring
  - Geophysical data (seismic, DC, EM, …)

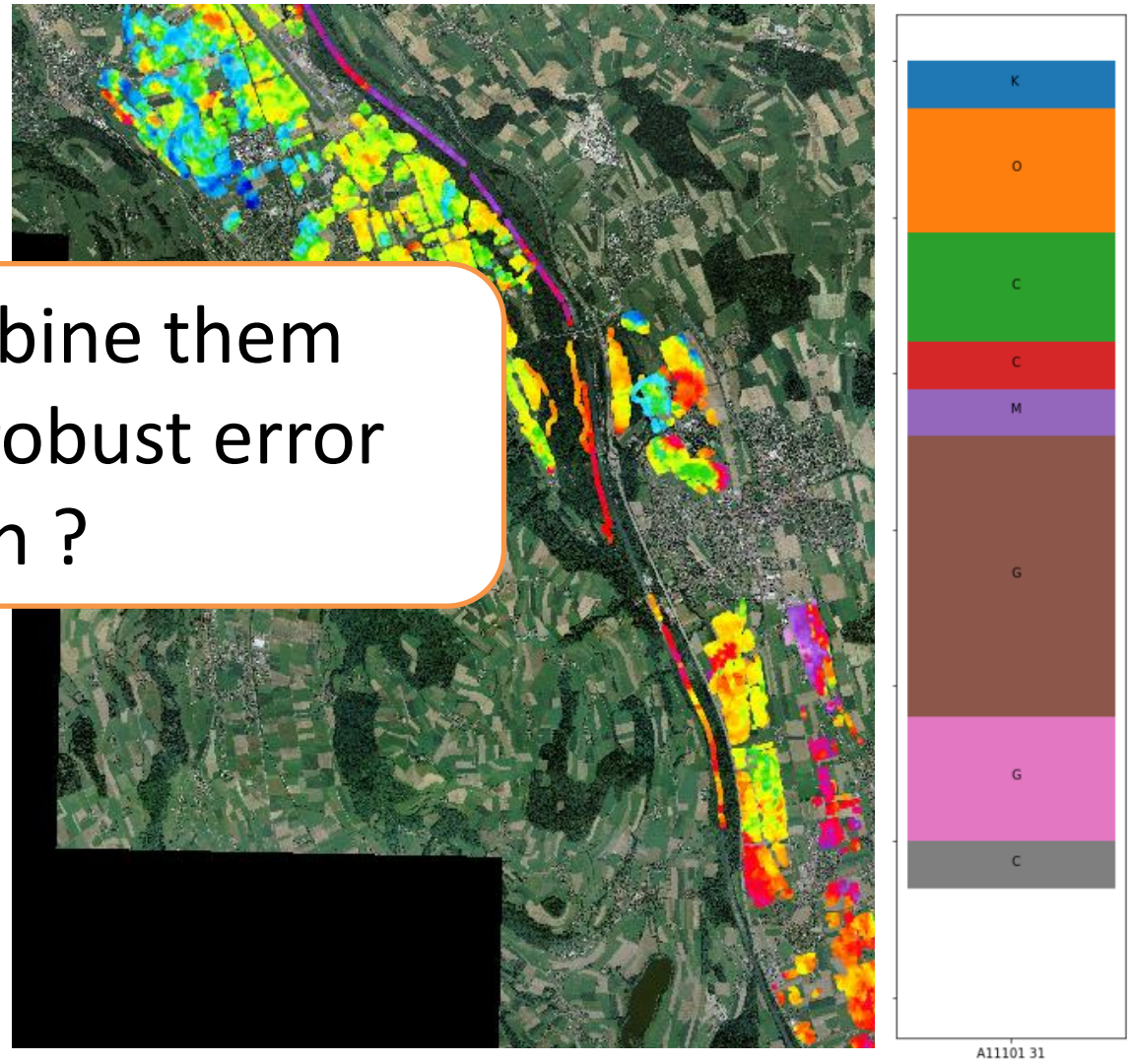
  - Conceptual idea



DATA

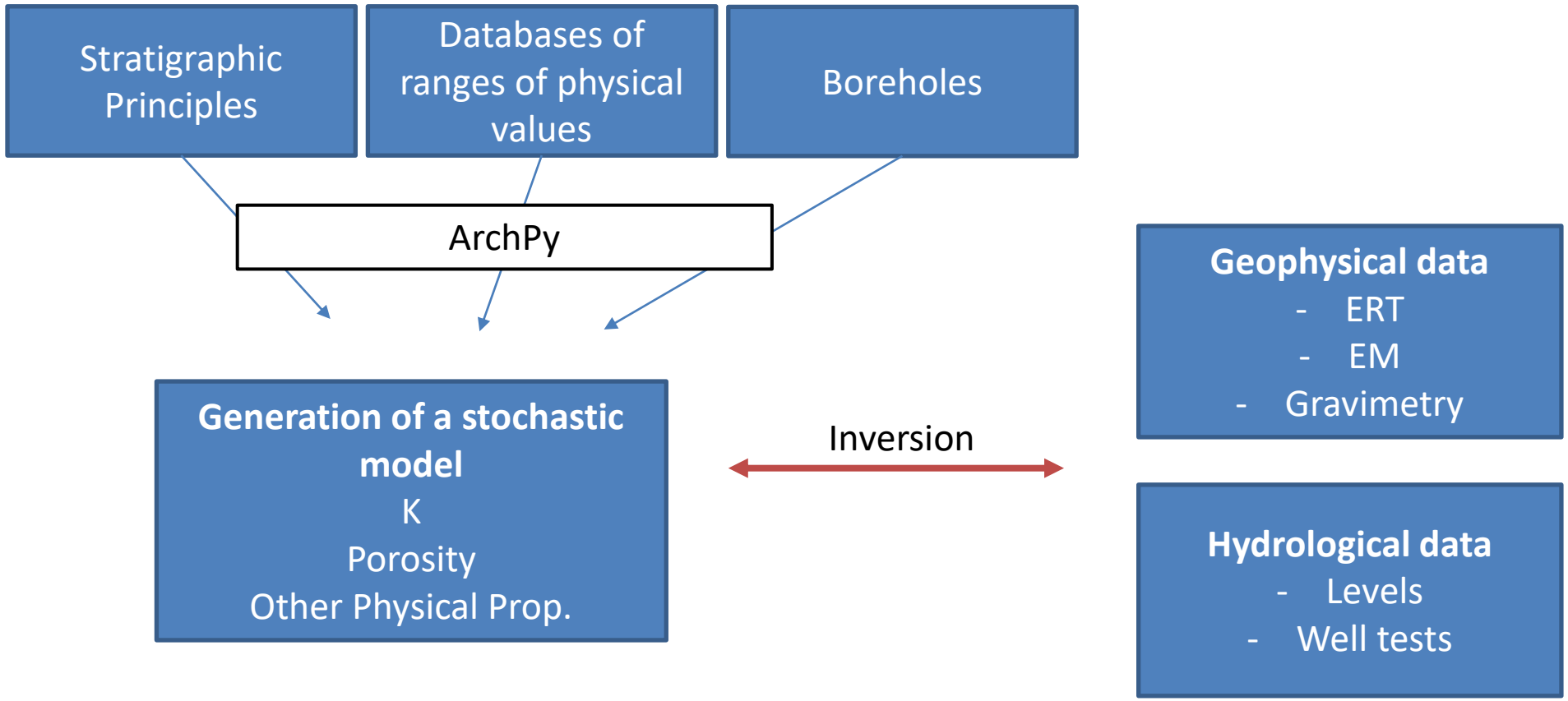
- What data do we usually have on site ?
  - Described boreholes (usually lithological)
  - Pumping te
    heads mon
  - Geophysica
    EM, …)
  - Conceptual idea

How can we combine them efficiently, with a robust error estimation ?



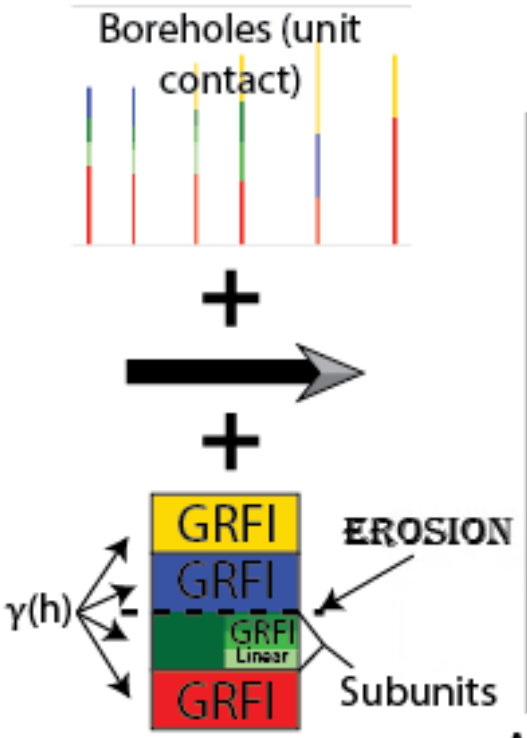
WHAT NEXT ?

– We need to be able to give some kind of geological principles !



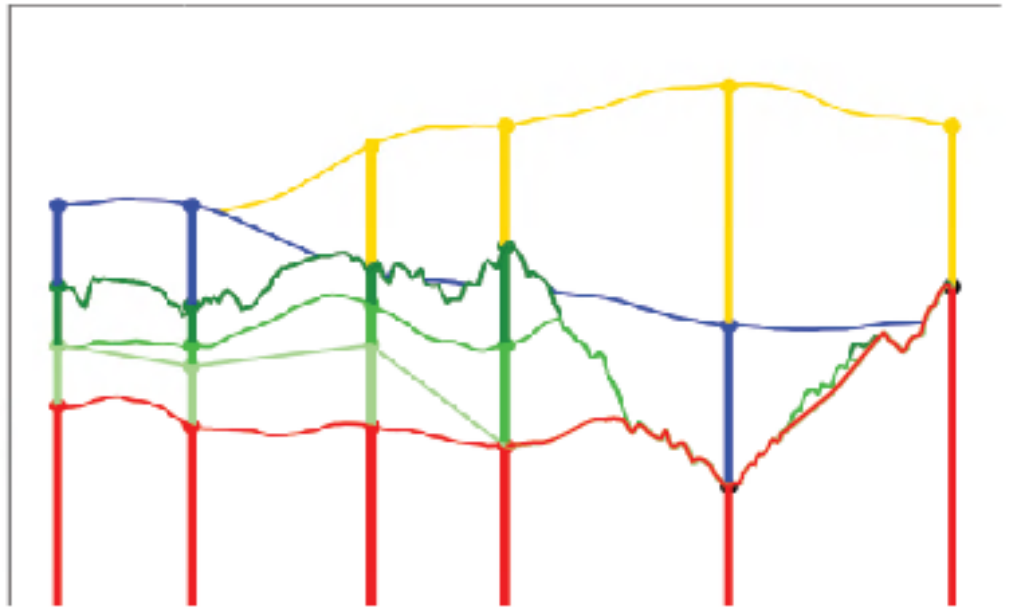
WHAT NEXT ?

Stratigraphic Principles



Stratigraphic pile and interpolation method/parameters (variograms (γ(h))

1. Computing units surface elevation



Available interpolation methods are : Kriging (OK, SK), Gaussian Random, function with (GRFI)/without (GRF) inequalities , basic splines and nearest neighbour and soon Multiple Point Statistics (MPS).

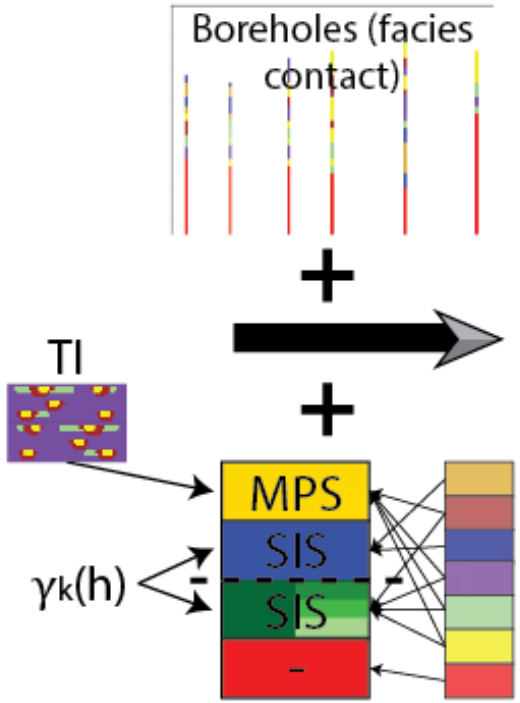
WHAT NEXT ?

Stratigraphic Principles

Databases of ranges of physical values

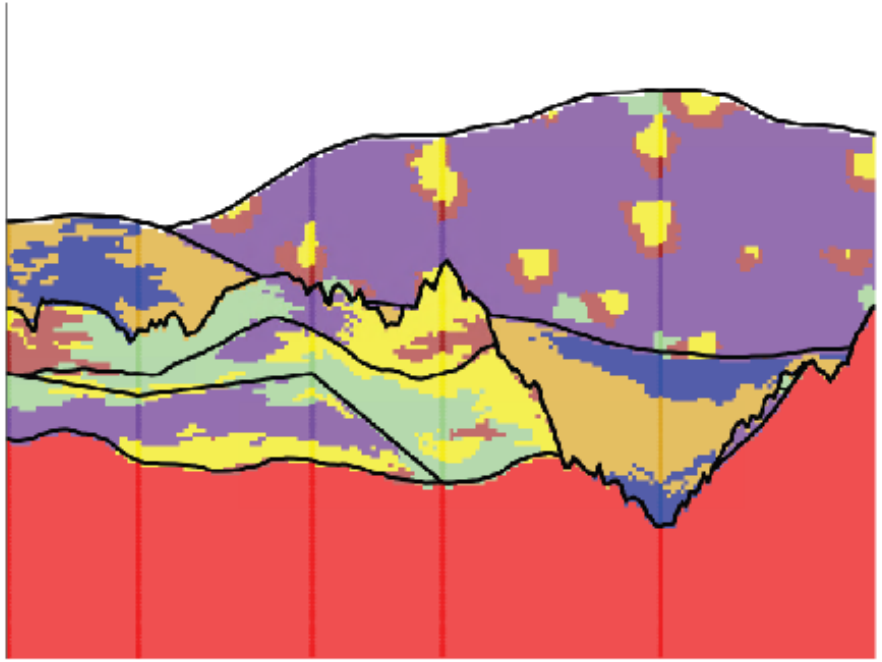
ArchPy

Generation of a stochastic model
K
Porosity
Other Physical Prop.



Facies relation to units and filling method/parameters (Training images, indicator variograms ($\gamma_k(h)$, etc.)

2. Filling units with associated lithologies/facies (sand, clay, ...)



Filling operates only inside unit given the method used. The available ones are : MPS, Sequential Indicator Simulations (SIS), Truncated PluriGaussians (TPGs) and homogenous (-).

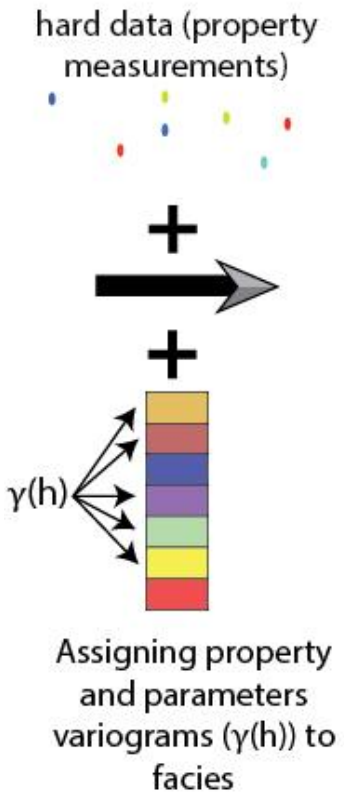
WHAT NEXT ?

Stratigraphic Principles

Databases of ranges of physical values

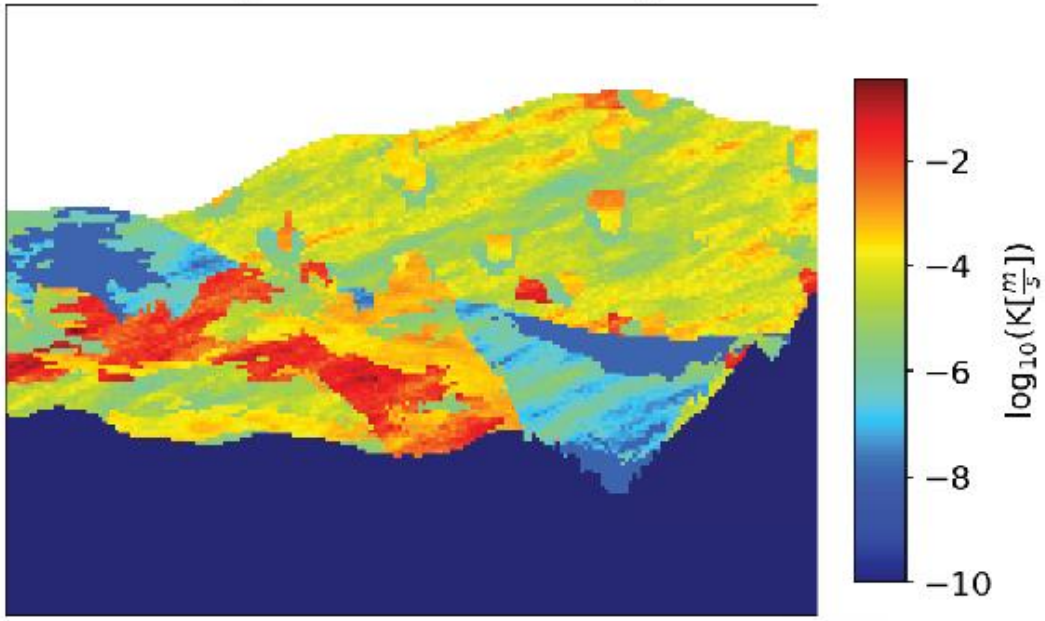
ArchPy

Generation of a stochastic model
K
Porosity
Other Physical Prop.



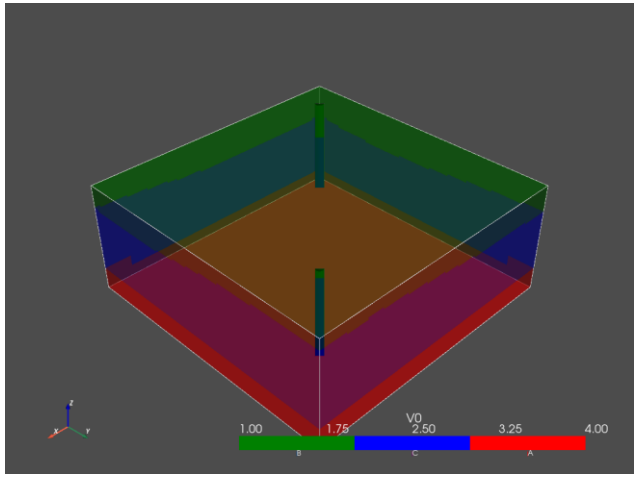
Assigning property and parameters variograms (γ(h)) to facies

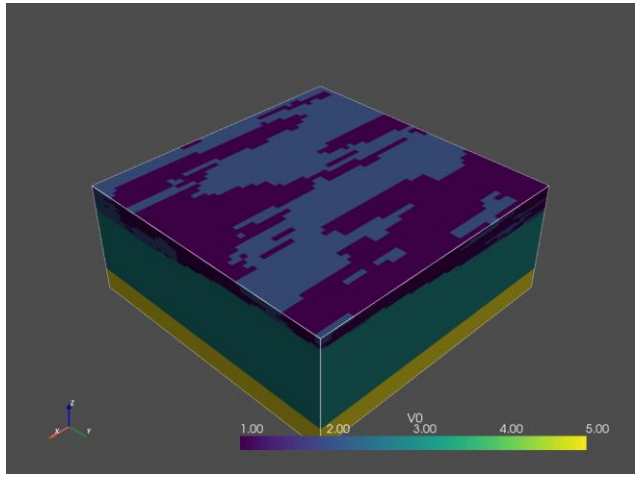
3. Computing physical models (e.g. hydraulic conductivity)

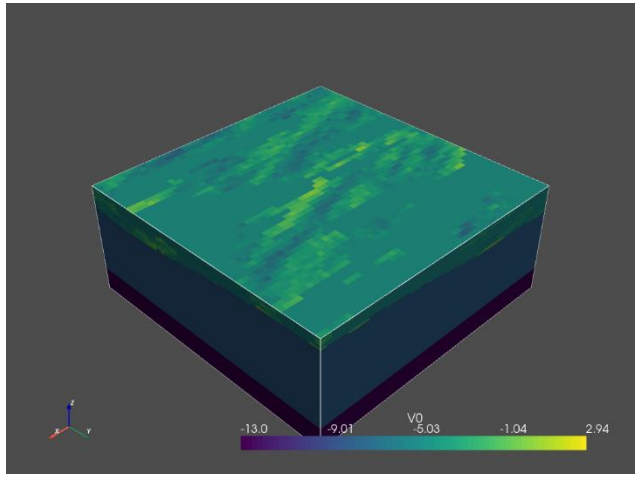


The desired properties are simulated inside each facies using GRFs or are simply set homogenous. Any number of properties can be assigned.

SUMMARY

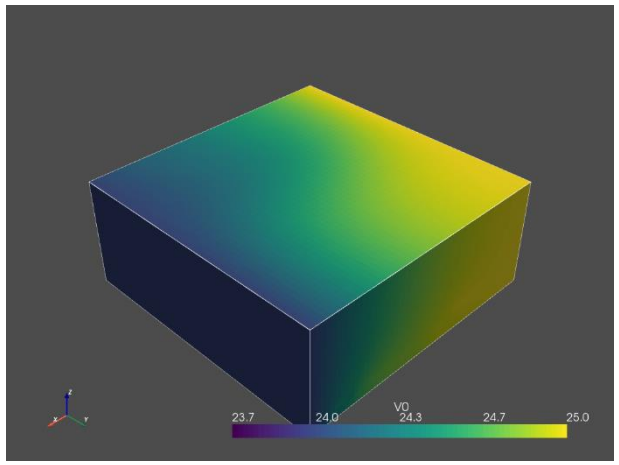


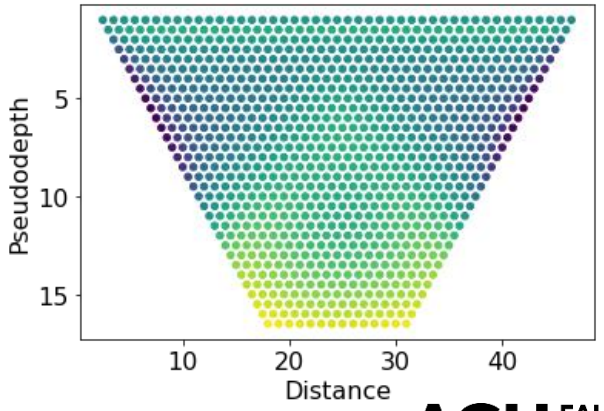


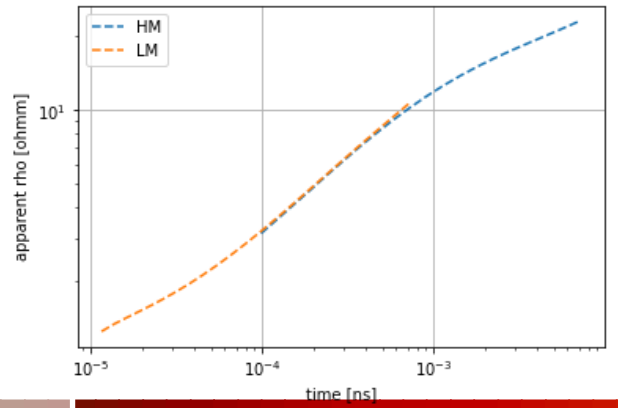


Units → Facies → Parameters

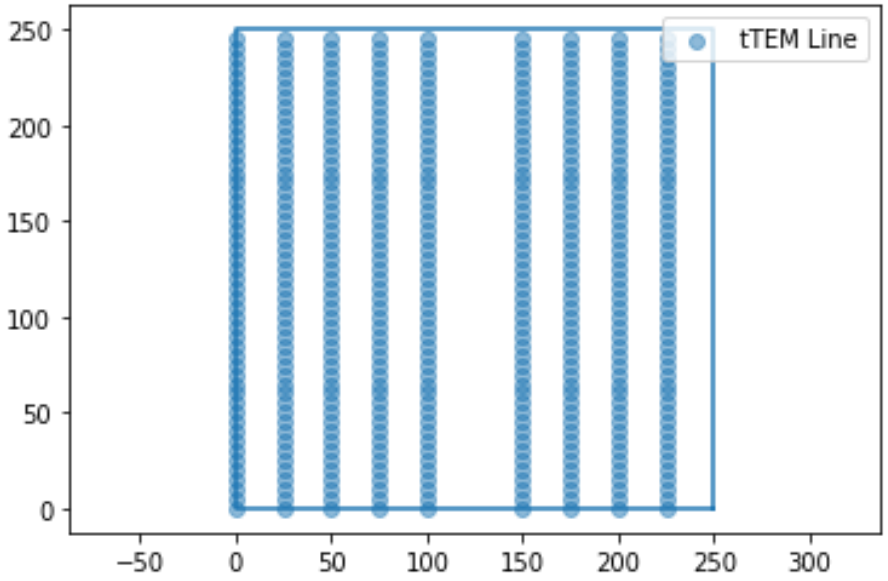
Any Physical Forward

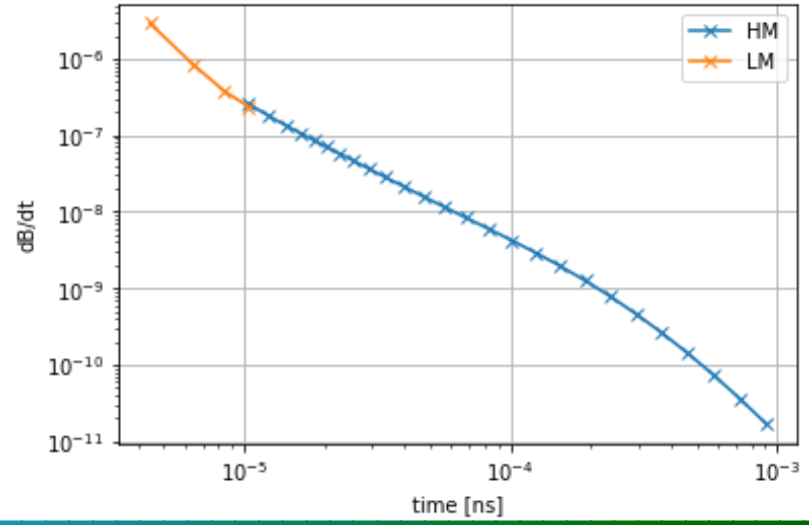






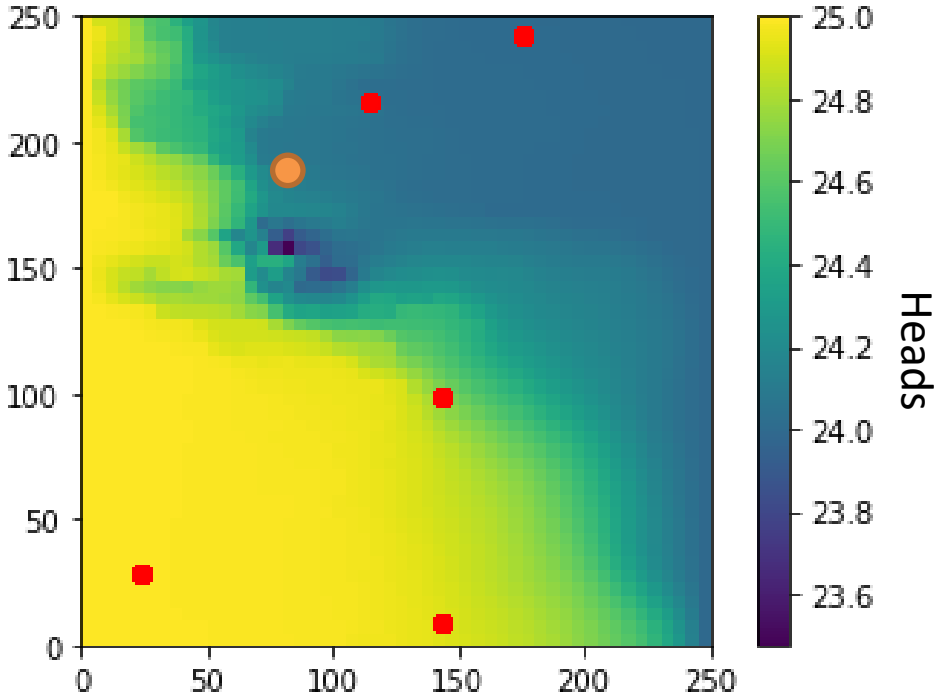
SYNTHETIC EXAMPLE - DATA





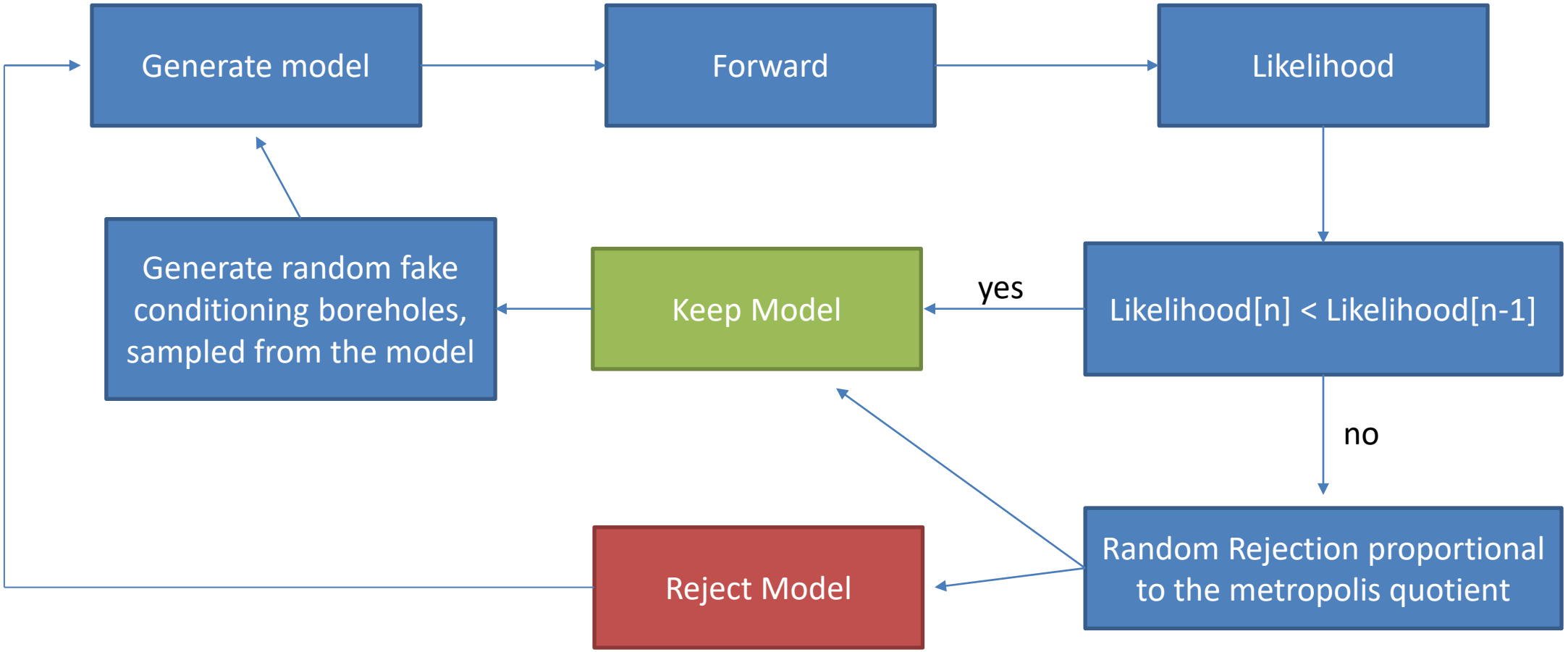
Geophysical data – random noise added
Towed TEM measurements

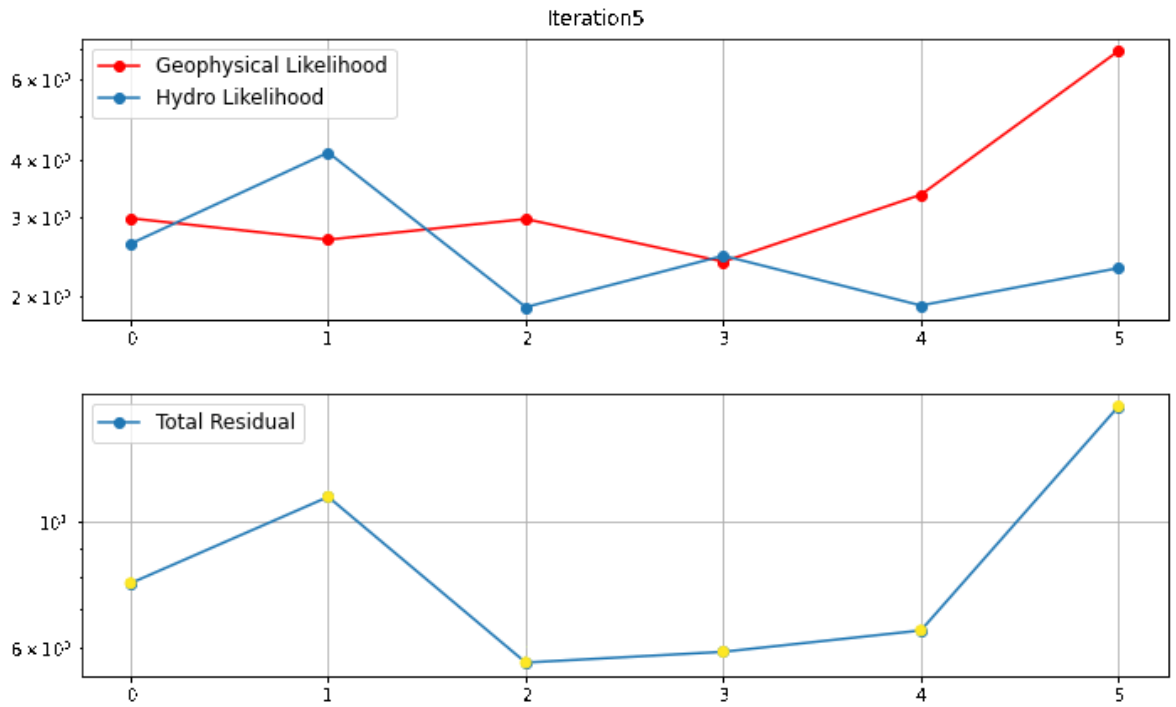
1 pumping well – constant rate
5 monitoring wells
2 wells are lithologically described

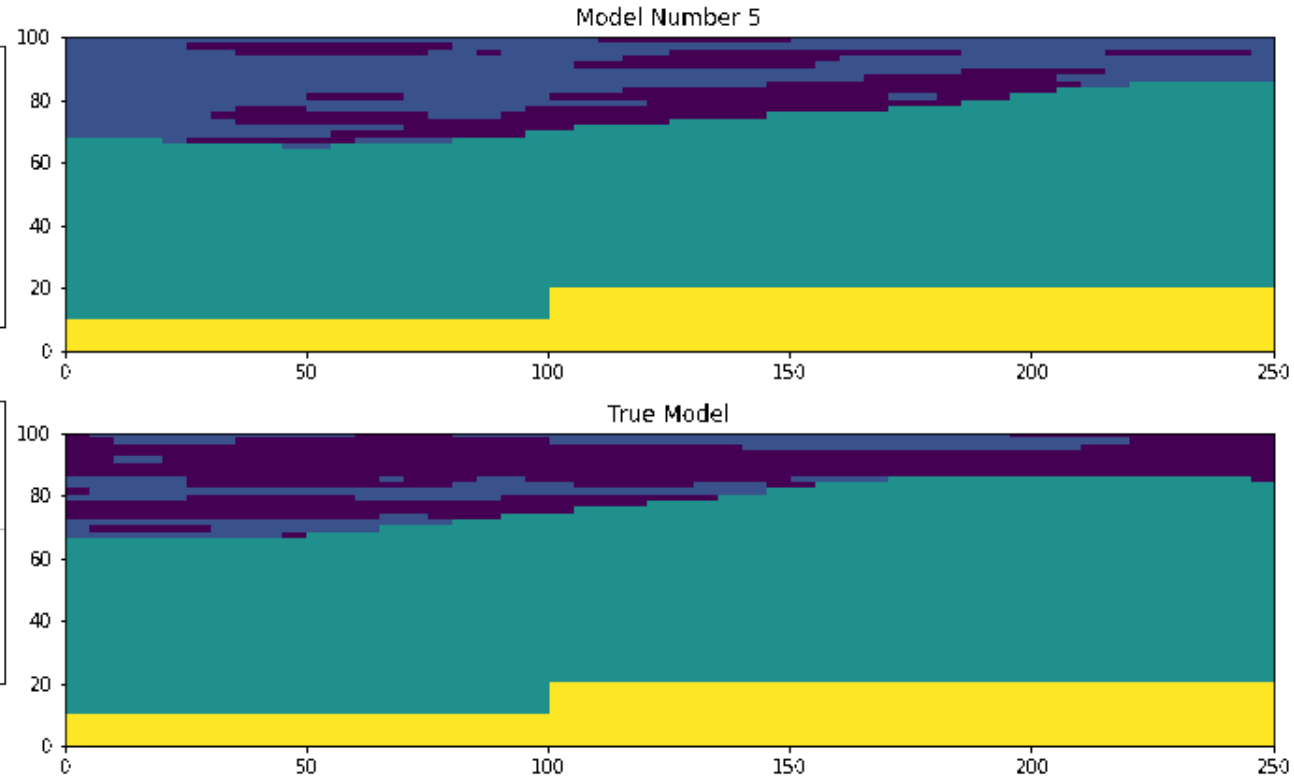


METROPOLIS HASTINGS

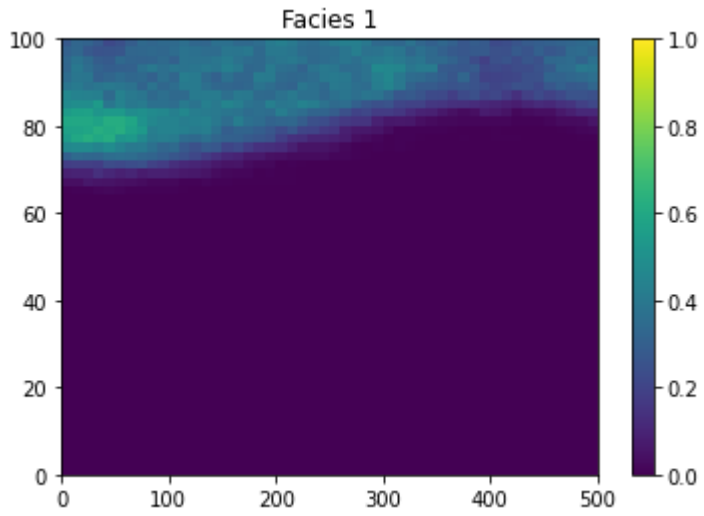
– Simplest stochastic inversion



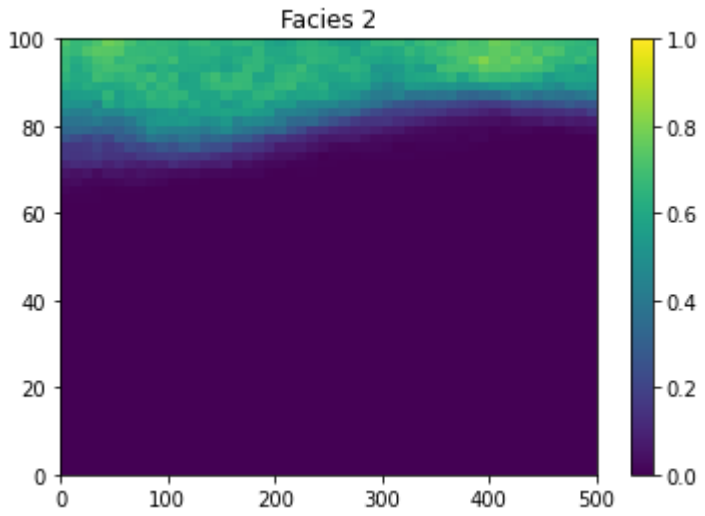

Iteration5
Geophysical Likelihood
Hydro Likelihood
Total Residual


Model Number 5
True Model

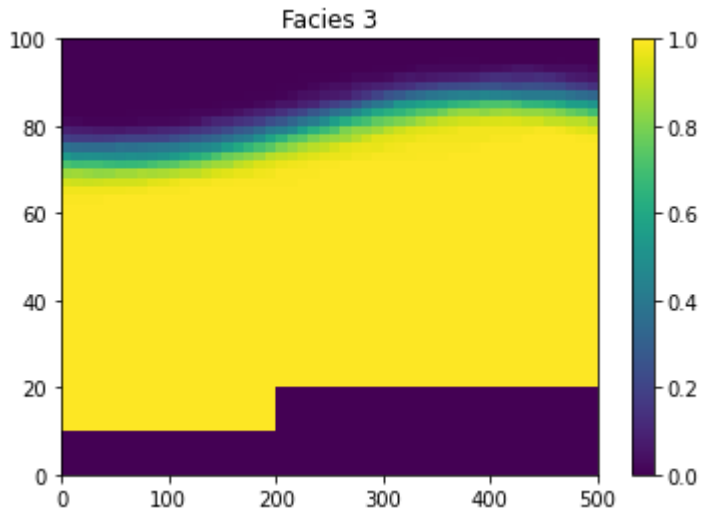
RESULTS OF THE SYNTHETIC



P(gravel)

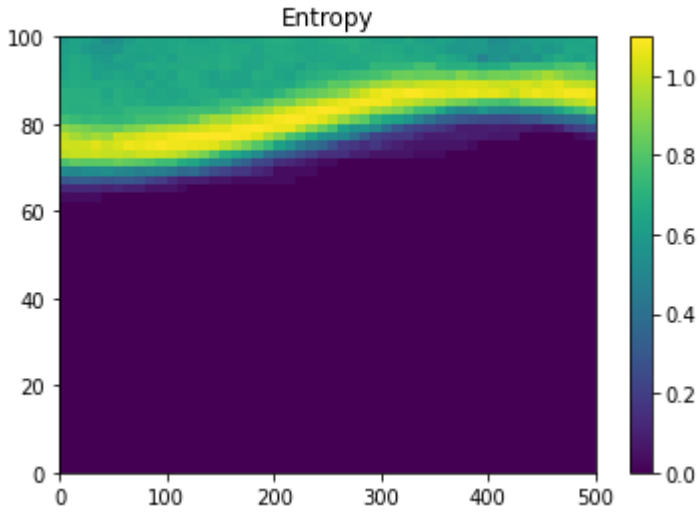


P(sand)

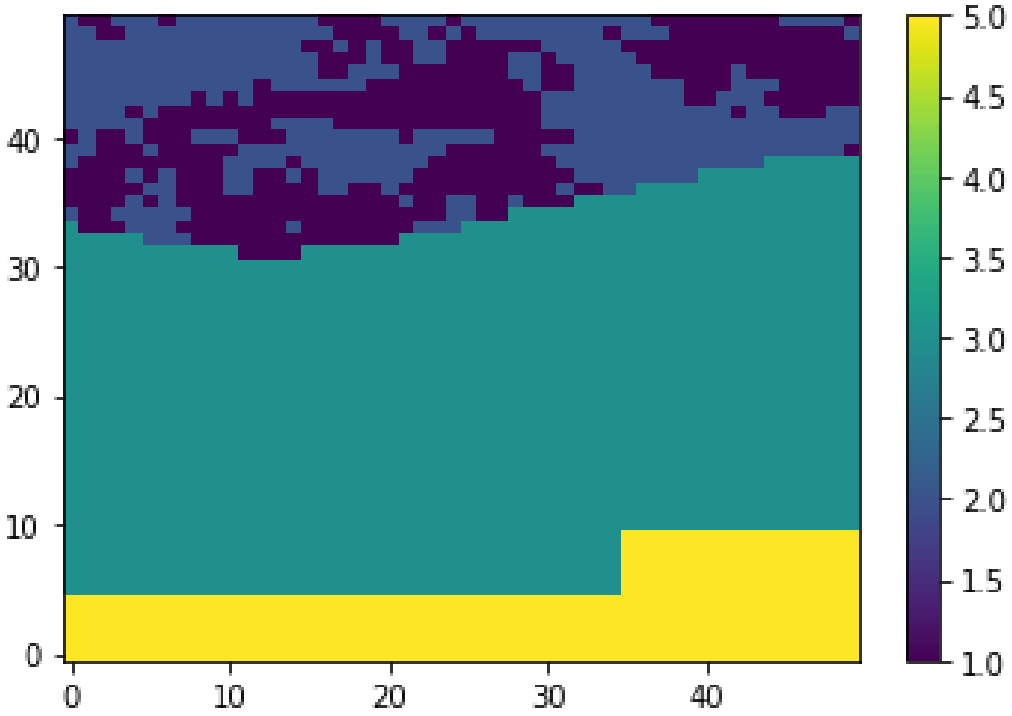


P(clay)

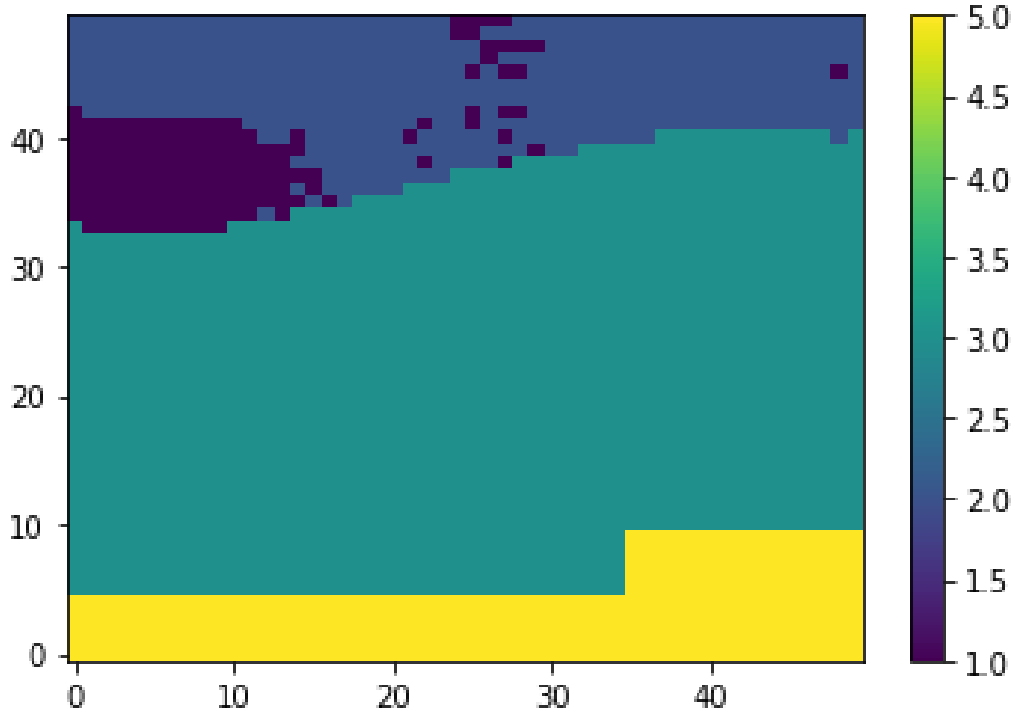
Based on 3000 iterations



True Model



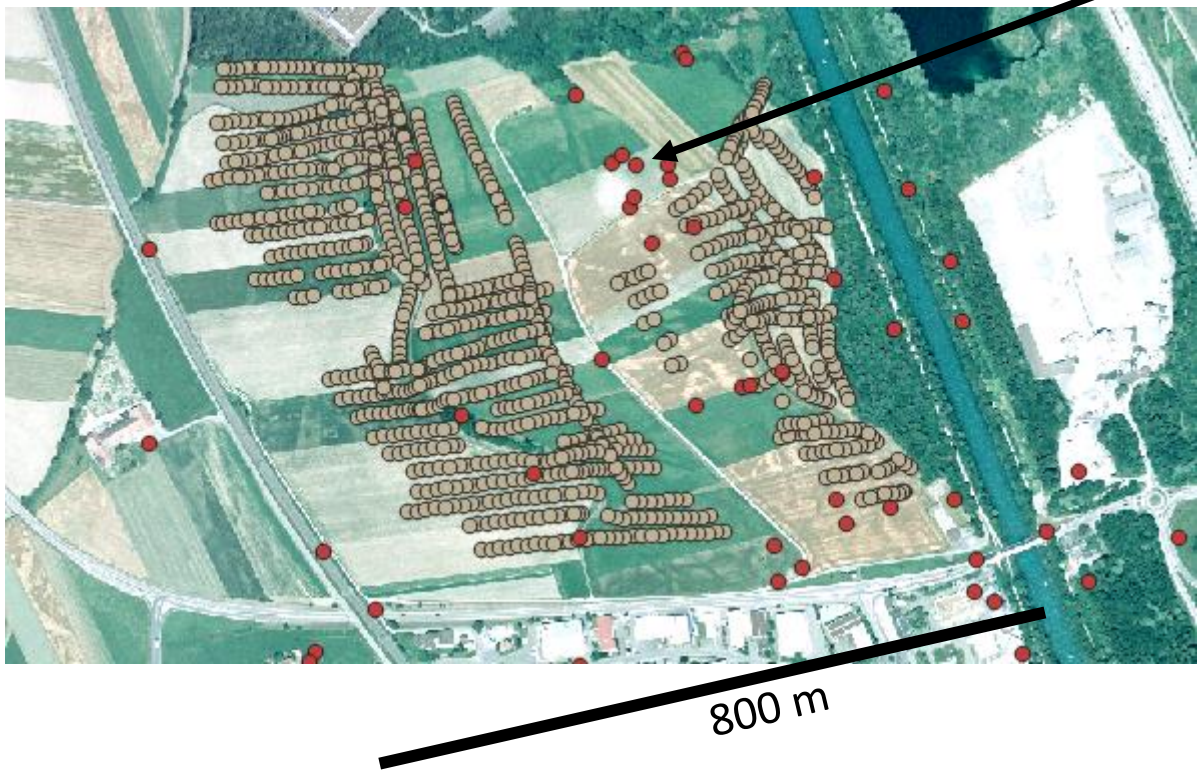
Most probable model



It works ? Yes but…

The real statistical models are known
The TEM data are in their “best scenario”

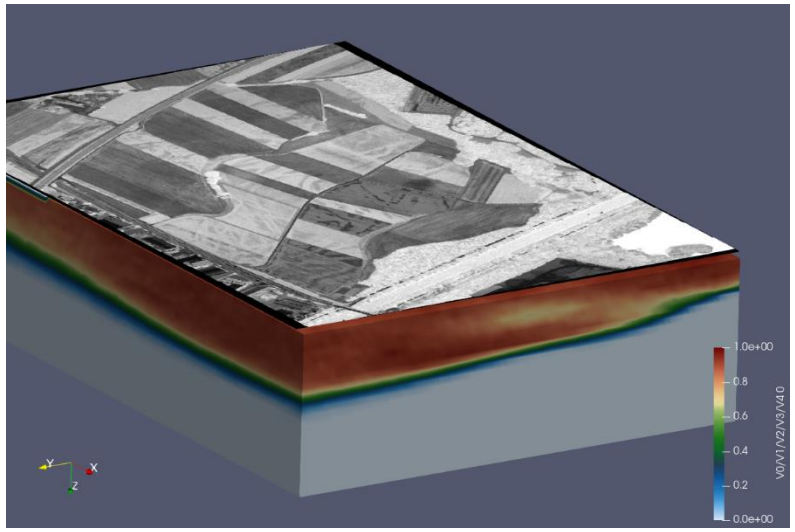
AMERIKAEGGE TEST SITE



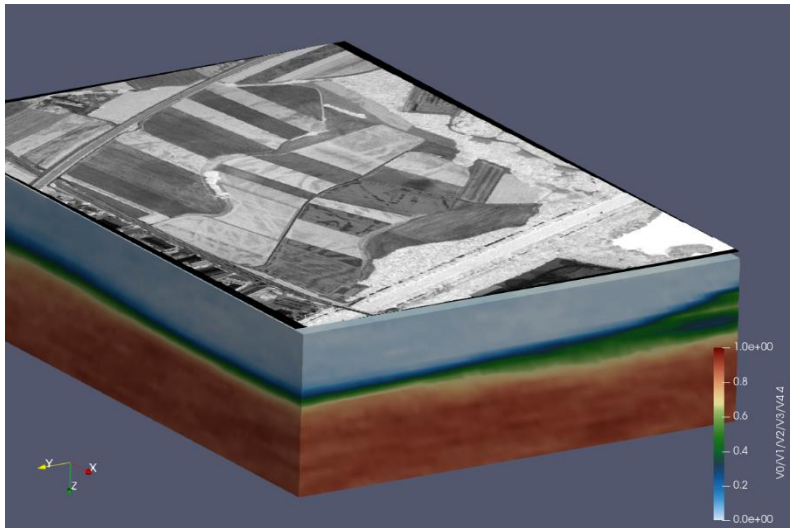
4000 iterations
5 Boreholes considered
No flow model (yet)

Let’s have a look with some real field data

AMERIKAEGGE TEST SITE

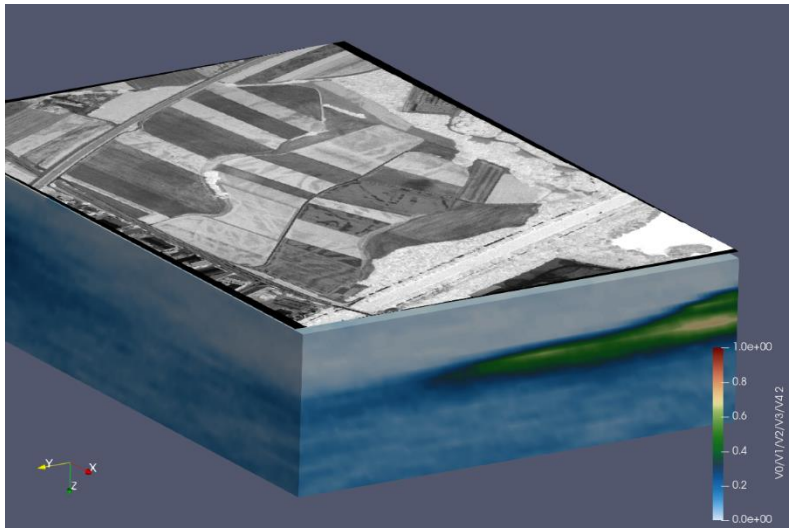


P(gravel)

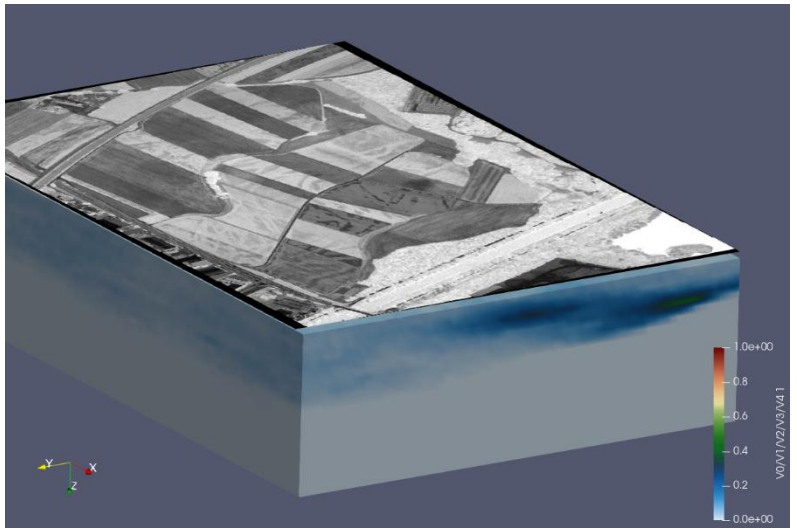


P(clay)

Based on 3000 iterations

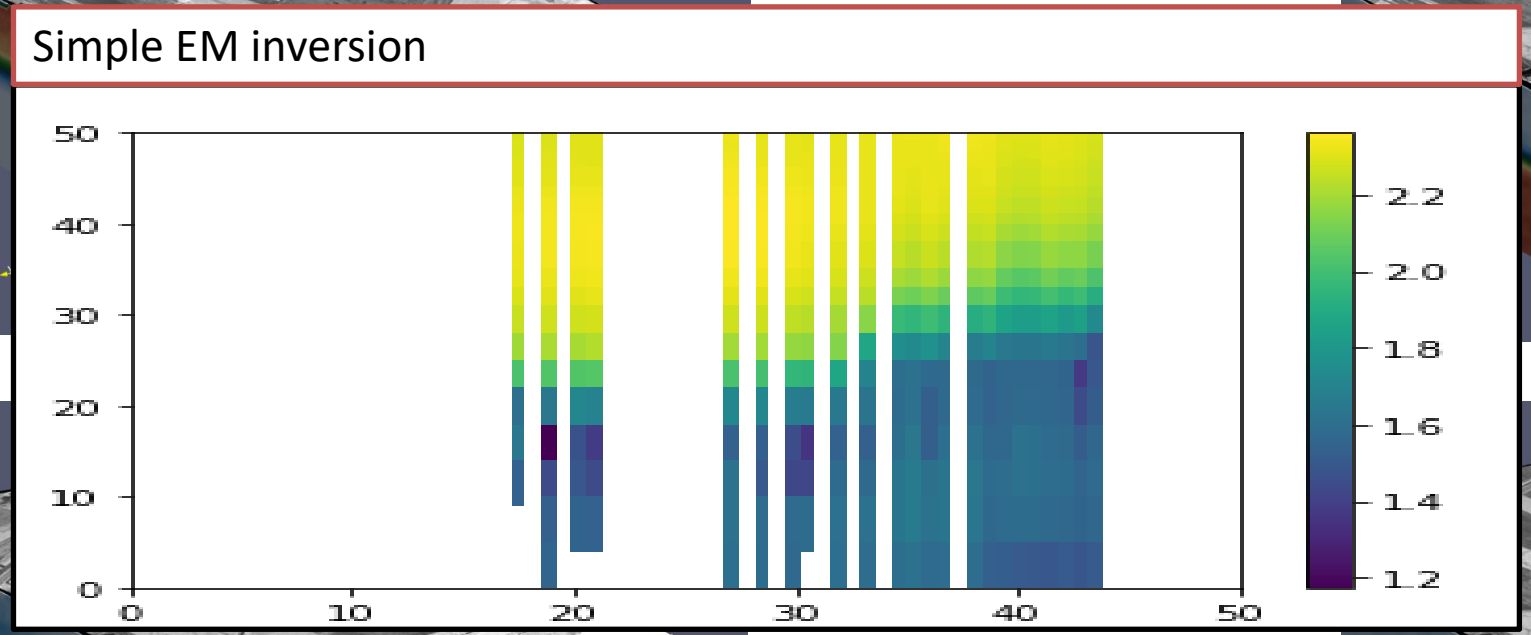


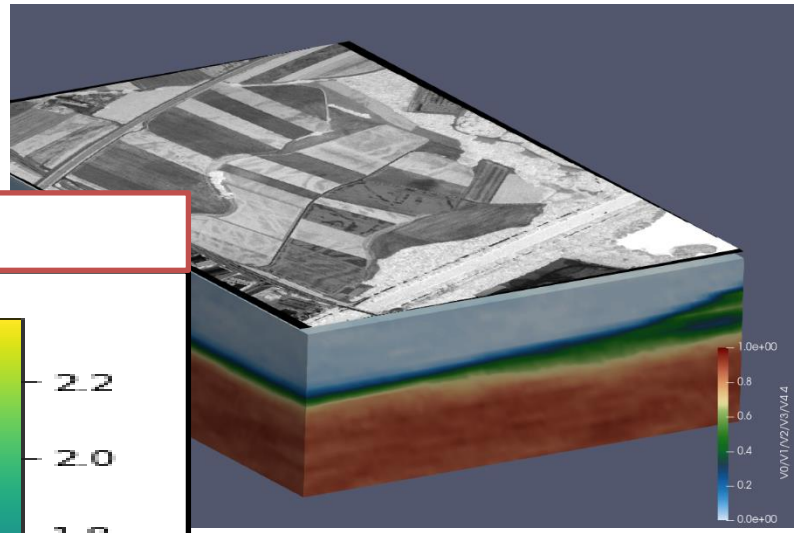
P(sandy clay)

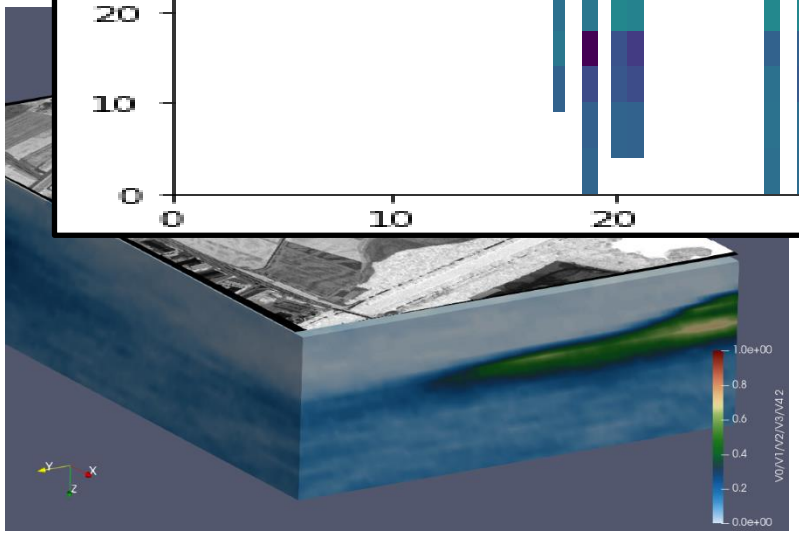


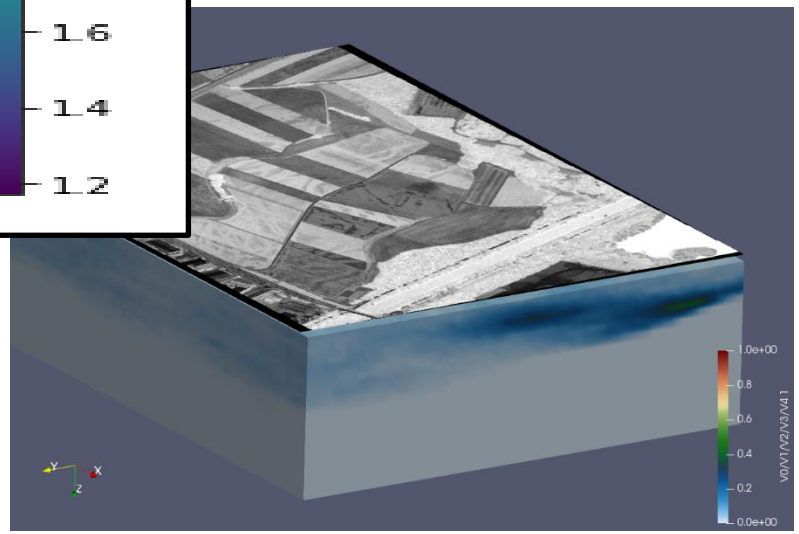
P(sand)

Simple EM inversion









CONCLUSION

- Promising approach
- This methodology :
  - Directly integrates multiple data types, and generates models in agreement with all of them
  - Is agile and easy to update

- Publish them open source
- Complete benchmark
- Other stochastic inversion strategies

THANKS FOR YOUR ATTENTION

Alexis Neven
Stochastic Hydrology Lab
CH-2000 Neuchâtel
Alexis.Neven@unine.ch
www.unine.ch