Heterogeneity in uranium mining by In Situ Recovery

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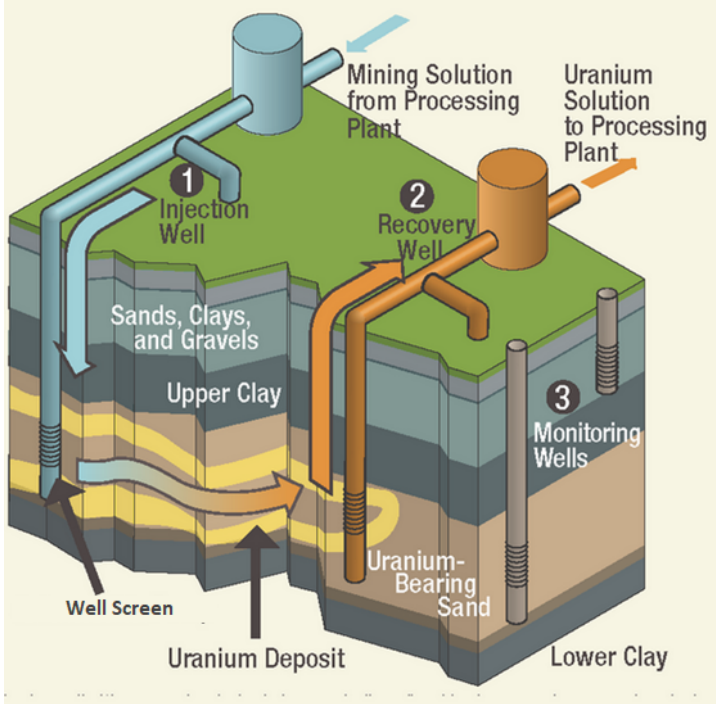
J.Langanay[1], T. Romary[1], V. Lagneau[1], G. Petit[2]

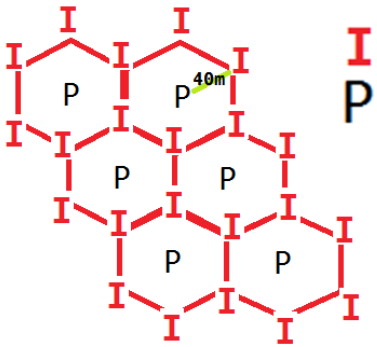
(1) Mines ParisTech, Geoscience Center - France
(2) Orano Mining - France

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

In Situ Recovery



[US NRC, 2013-2014]



I Injection well

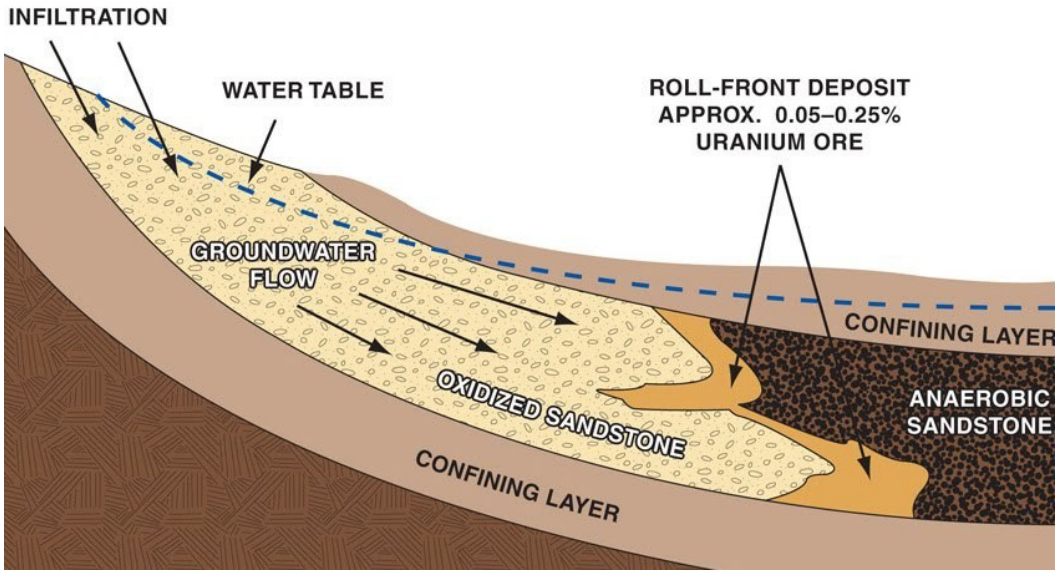
P Production well

ISR well field - Upper view [From M.Vergnaud]

- Fluid flow
- Transport
- Chemical reaction
- Complex medium
  - Heterogeneous properties

Reactive transport simulation

Roll front deposit characteristics



[Cauldron Energy website]

General specificities

-Low ore grades

-Highly permeable deposit

-Confined between two non permeable layer

Particular specificities

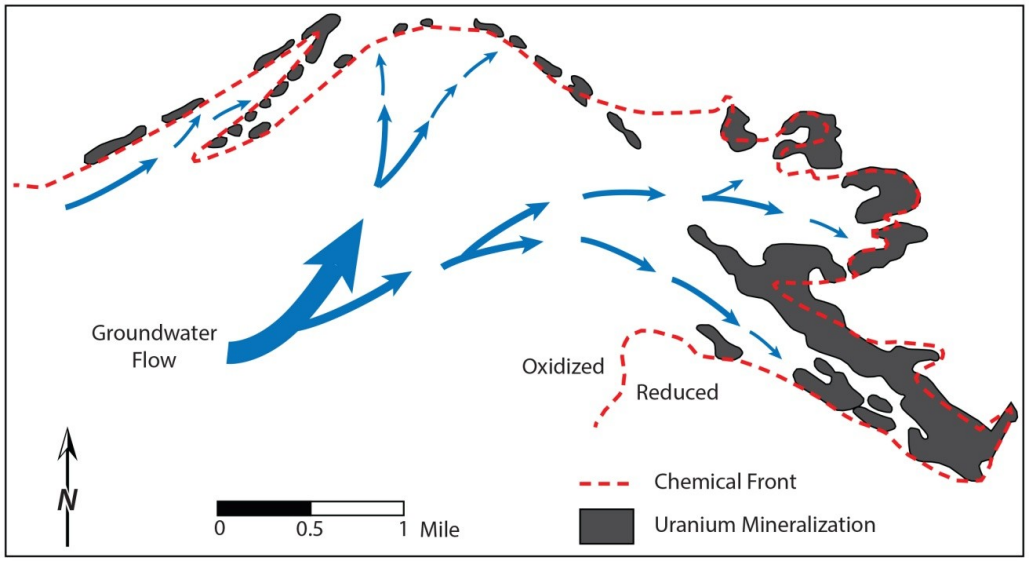
-Very heterogeneous

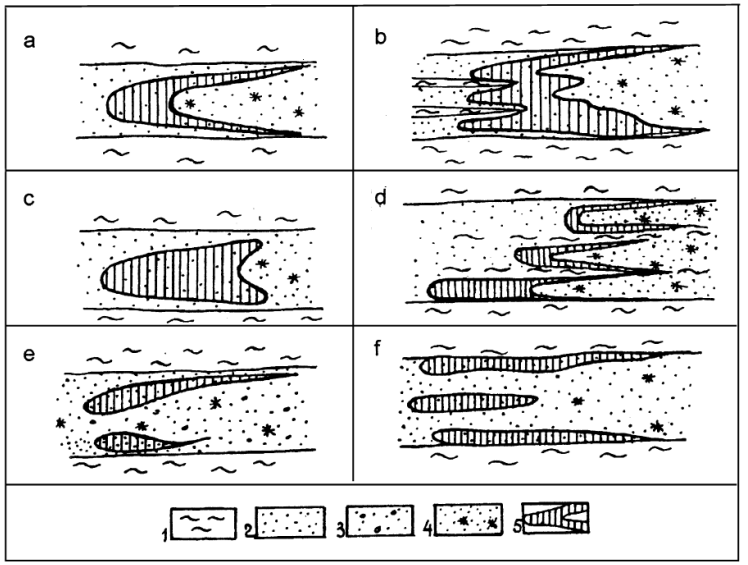
-deep

Roll front deposit variability

Example of map and cross sections of roll-front deposits

- Uranium mineralization depends on variable factors:
- Geological, Geochemical, hydrogeological





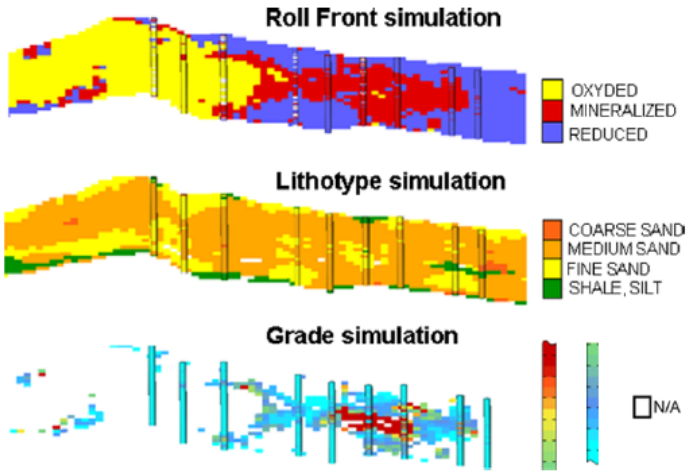
- Significant diversity of mineralized uranium geometry
- Elongated and more or less continue
- Lenticular or roll shapes

- **How can we model the <u>geological</u> uncertainty?**

Geological uncertainties modeling

Well data analysis → Conditioned geostatistical realizations

N realizations of three properties



[Petit et al, 2012]

One production block realization

-3D regular grid

-Hundreds of thousand cells

Reactive transport simulation with HYTEC

Input

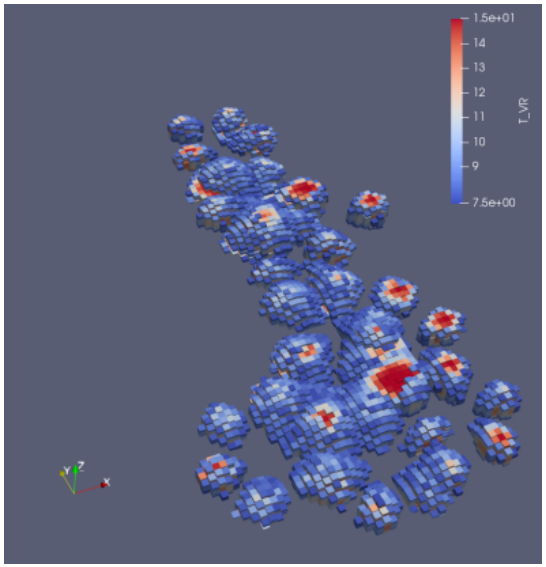
-Operational parameters
-Geological properties (3D grid properties)
-Geochemical properties

-Reactive transport simulation with HYTEC

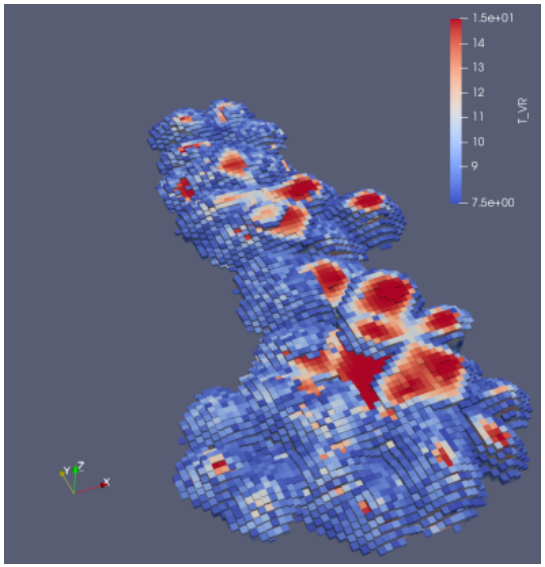
Output

Block exploitation behavior

t

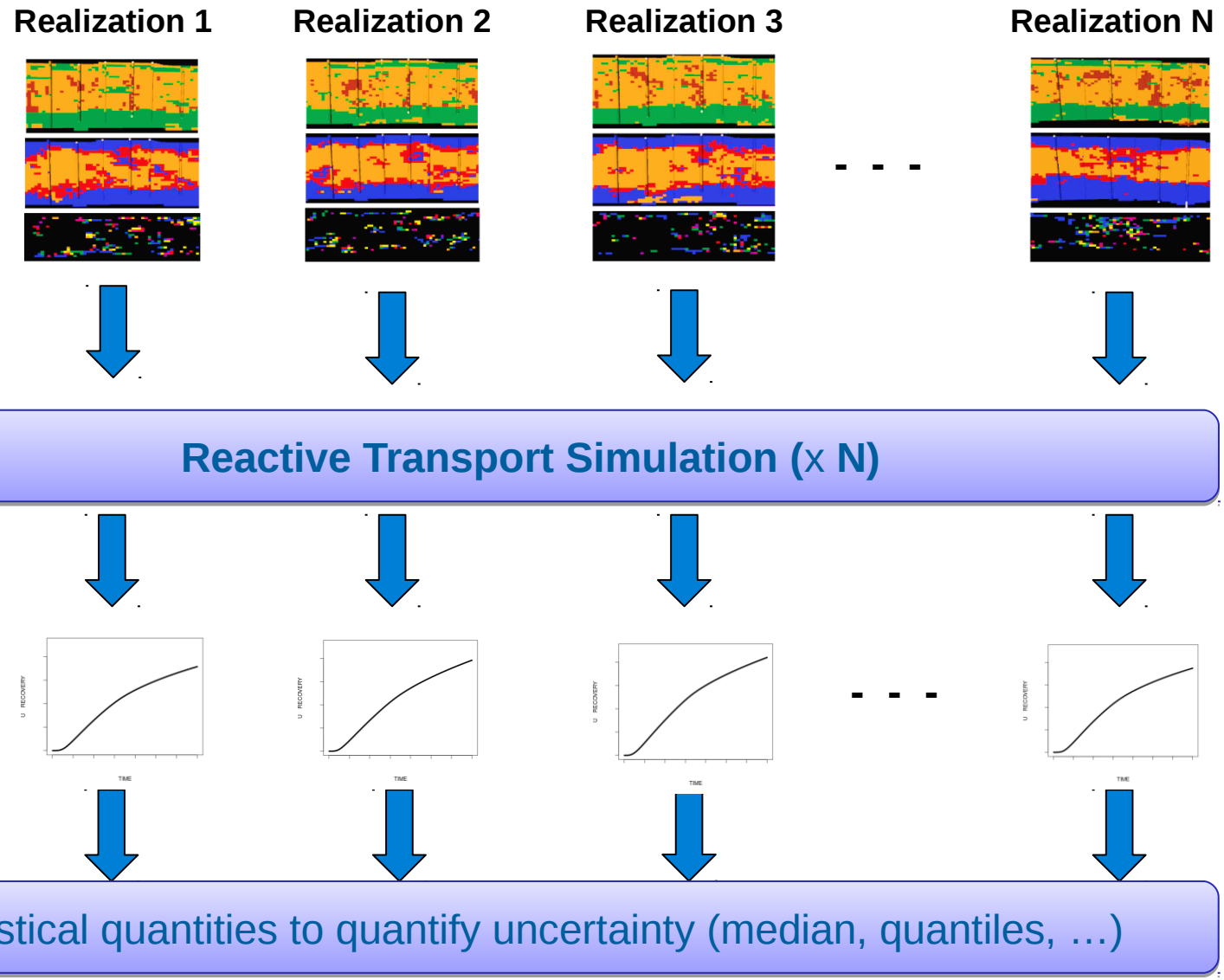


t+Δt



How can we predict the uranium recovery uncertainty?

Classical Uncertainty Quantification



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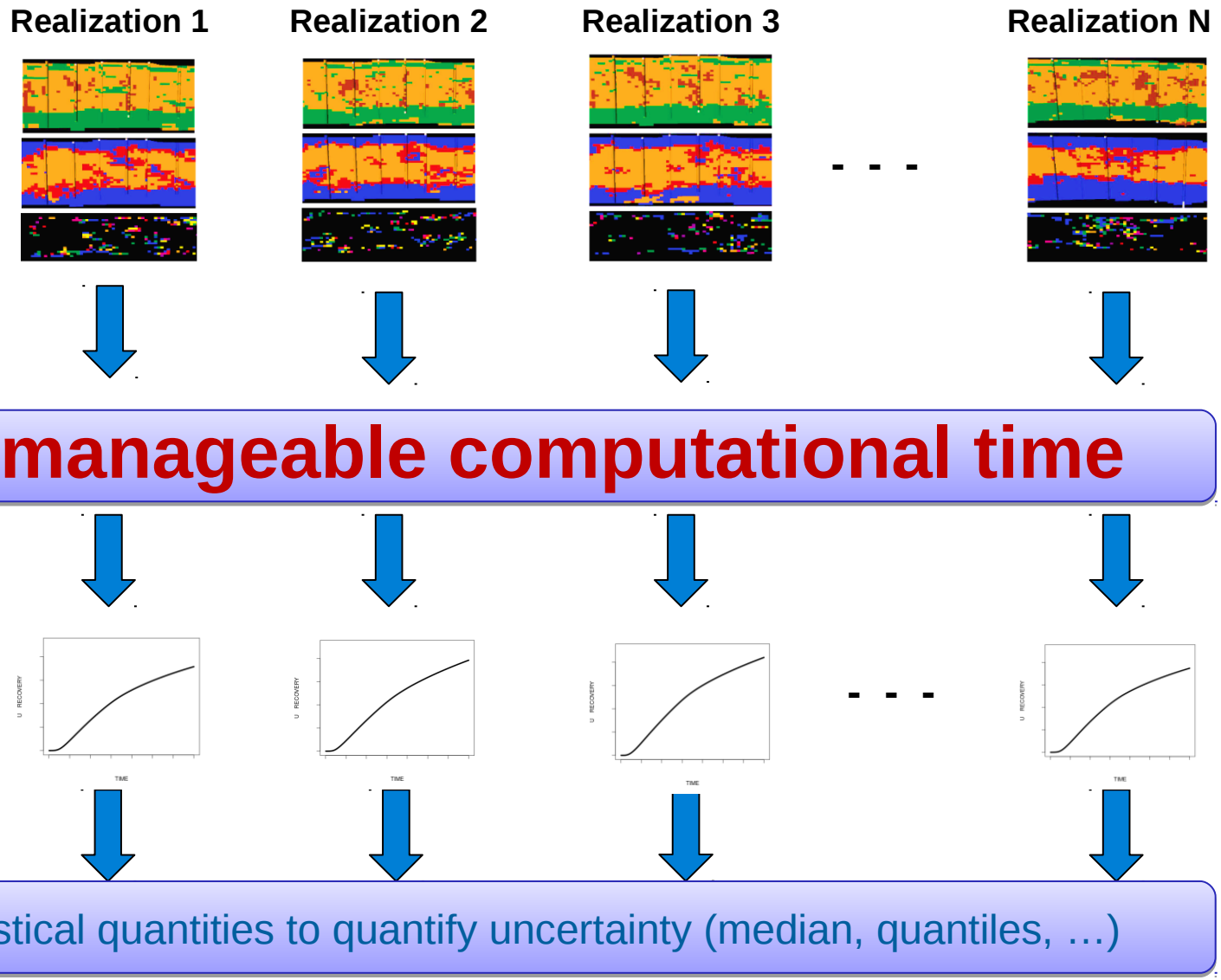
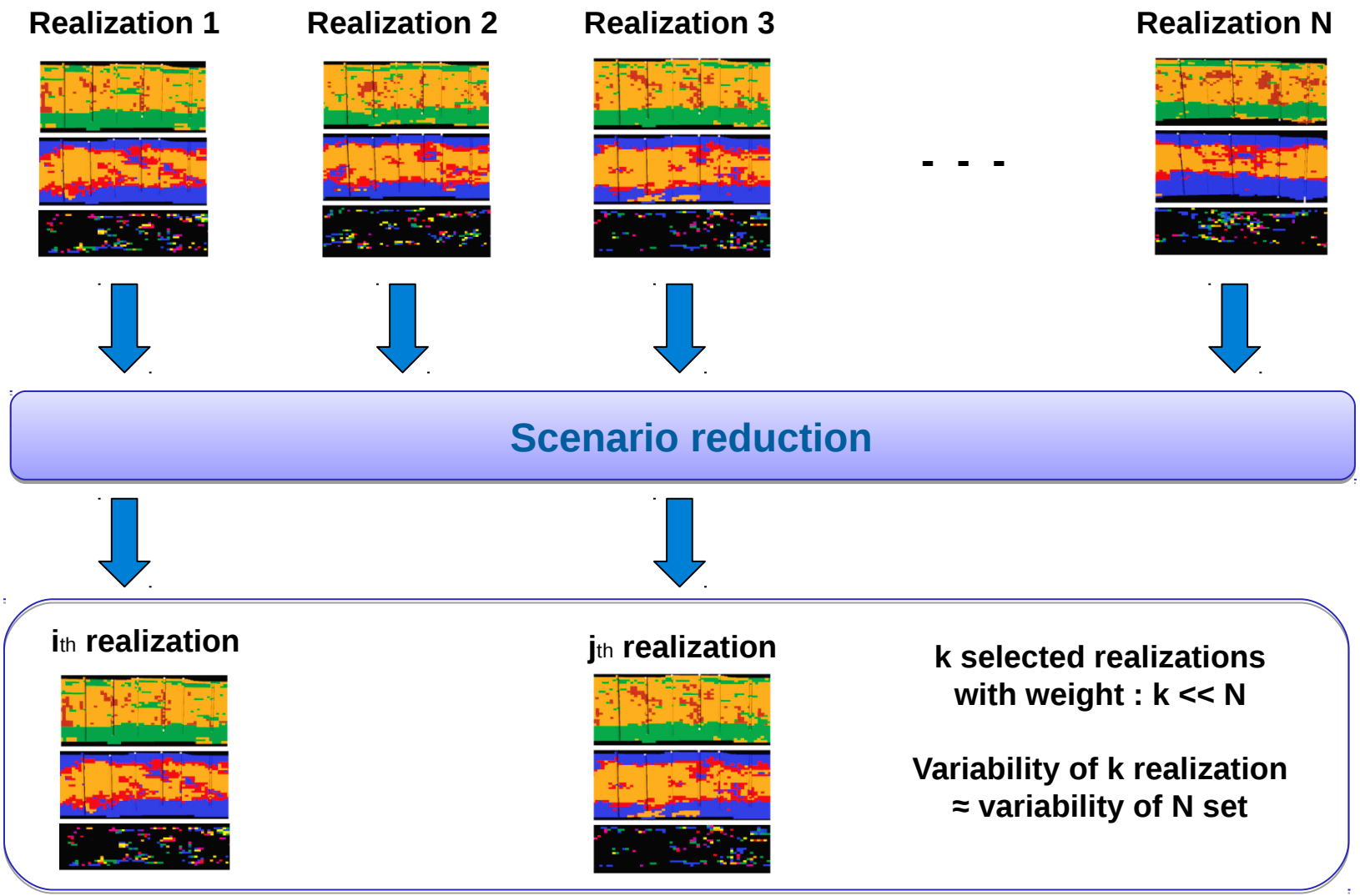


Uncertainty Quantification with scenario reduction



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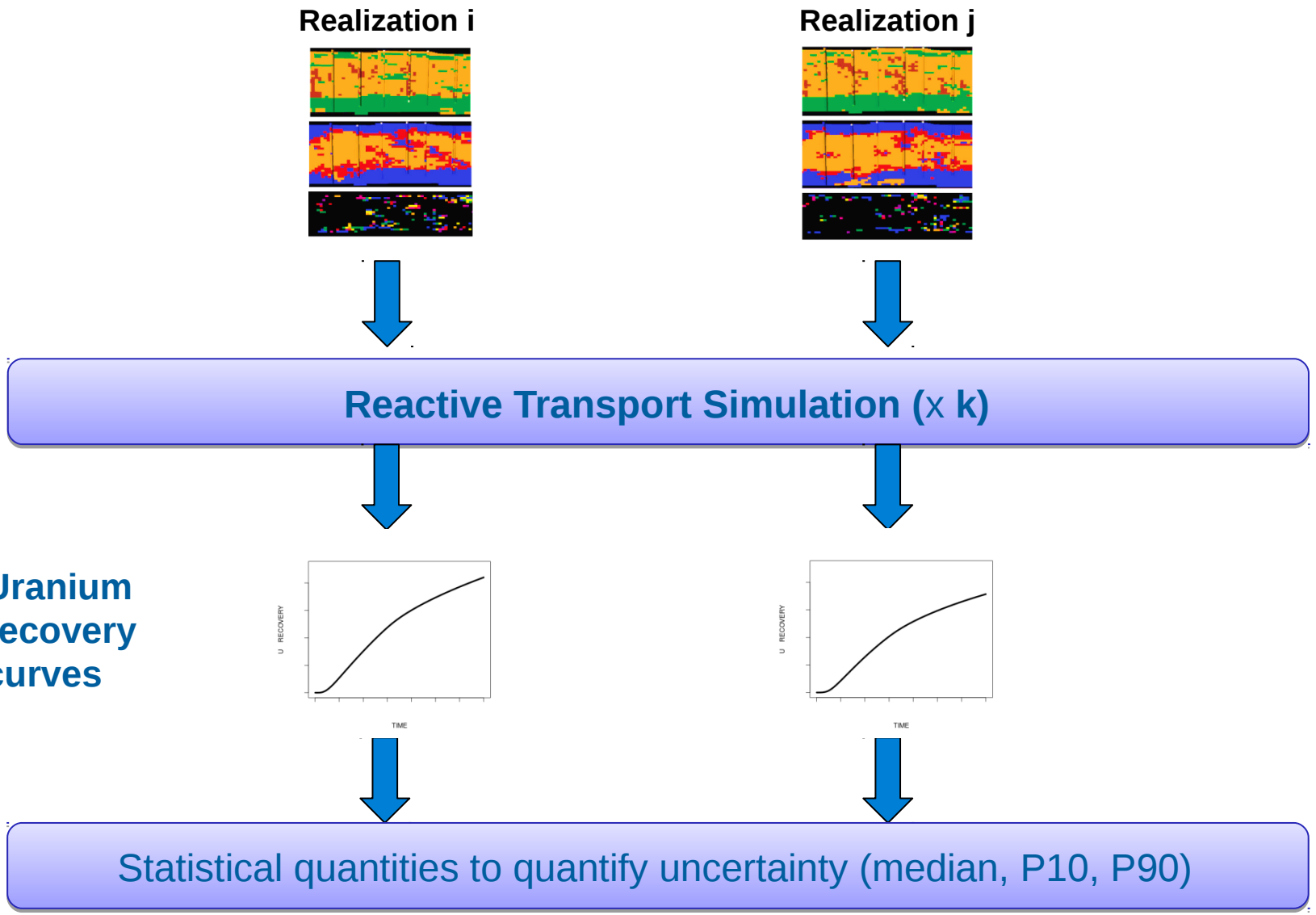


Scenario Reduction Method

- Step 1

Description of each realization using few quantities

- Step 2

Compute dissimilarities between realizations

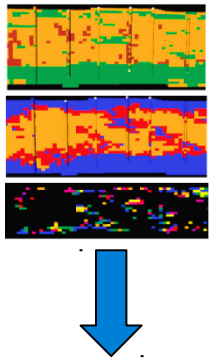
- Step 3

Clustering of the realizations set and representative realizations selection

1th step of scenario reduction

In each realization

- **Summarizing geological properties**



- Mineralization uranium volume
- Uranium grade proportion
- Uranium mass
- …

1th step of scenario reduction

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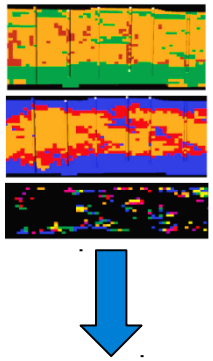

  - Mineralization uranium volume
  - Uranium grade proportion
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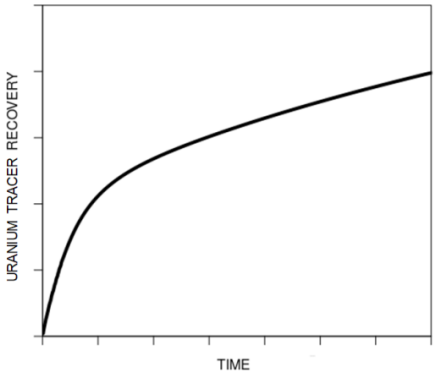
  - …

- **Performing TRACER transport simulations**
  - Fast simulations (without chemistry)
  - Tracer of uranium in place
  - Tracer production simulation try to approximate the uranium production



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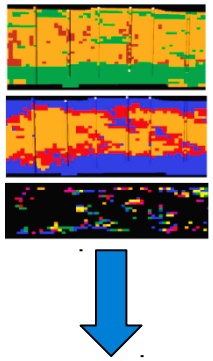

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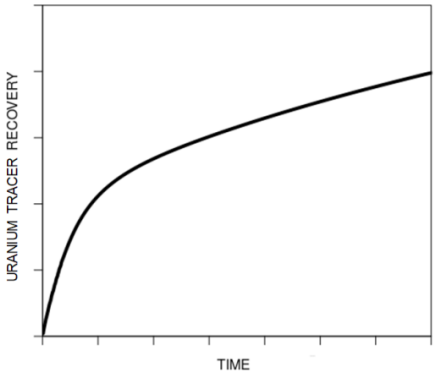


➔ Flow-based proxy result

➔ Geological properties descriptors

Realization description :

✓Quickly computed

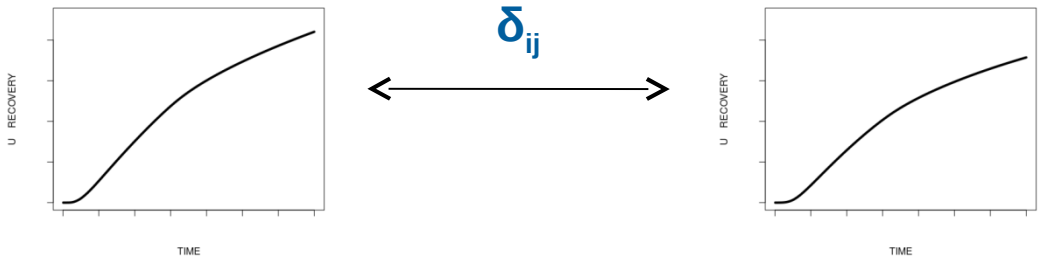
✓Vector of realization features

2nd step of scenario reduction

Realization dissimilarity distance computing

- Ideal dissimilarity (output dissimilarity)
- Practical dissimilarity (input dissimilarity)

Realization i $\quad\quad$ **Realization j**



δ_{ij}

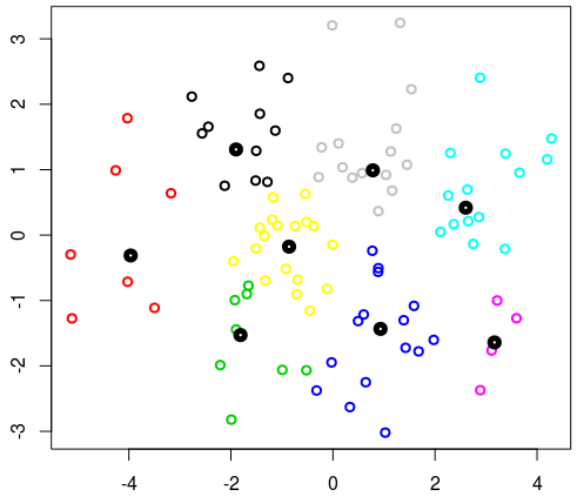
Feature vector X^i of the realization i $\quad$ D_{ij} $\quad$ **Feature vector X^j of the realization j**

$$D_{ij} = \sqrt{\sum_k (X^i_k - X^j_k)^2}$$

A dimensional reduction can be applied (complexity reduction, visualization, ...)

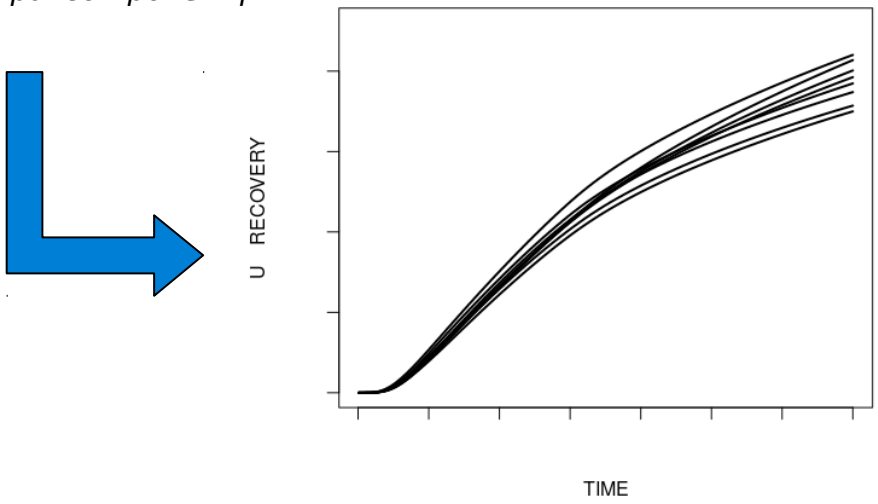
3rd step of scenario reduction

K-medoïd algorithm



Eight clusters of realizations and representative realizations (projected in the two first principal component plan)

- Realization segregation into cluster
- Representative scenario selection in each cluster
- Scenario weight ⇔ Realization proportion in the cluster

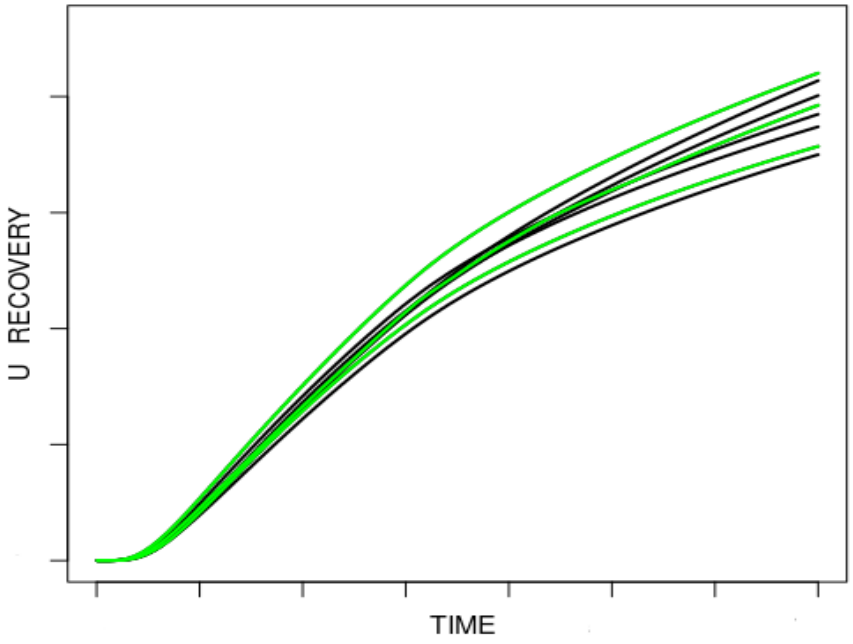


Uranium recovery of the eight selected realizations

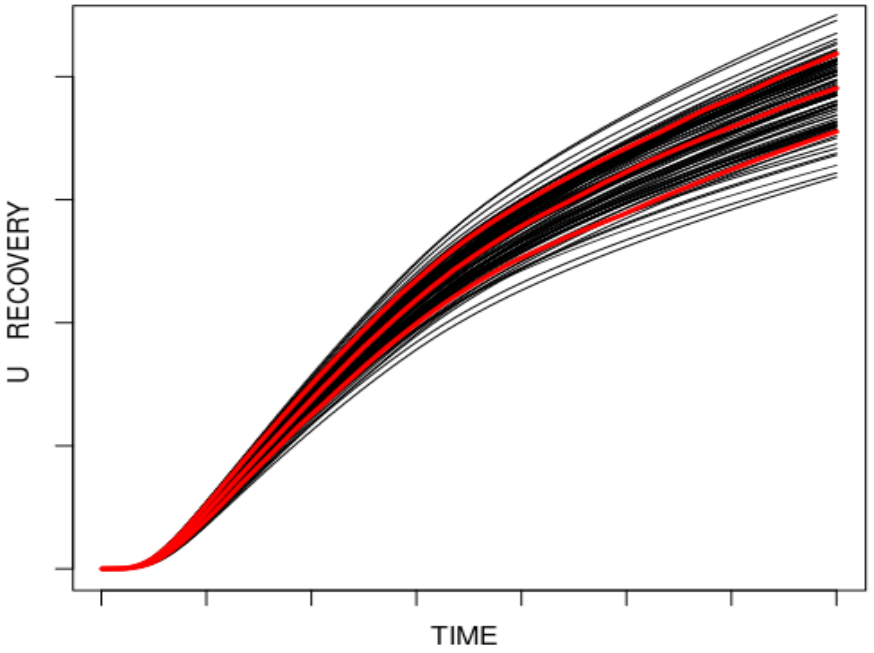
Validation of scenario reduction for uncertainty quantification

Uncertainty quantifications : P_{10}, P_{50} and P_{90} curves

UQ in eight selected and weighted realizations



UQ in a large set of realizations



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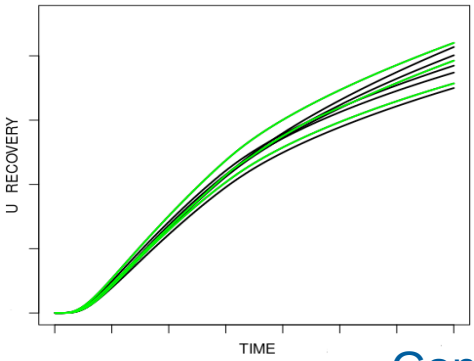
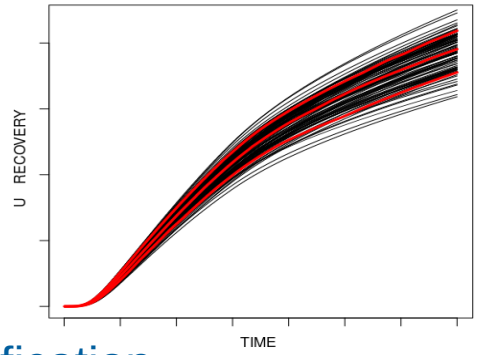
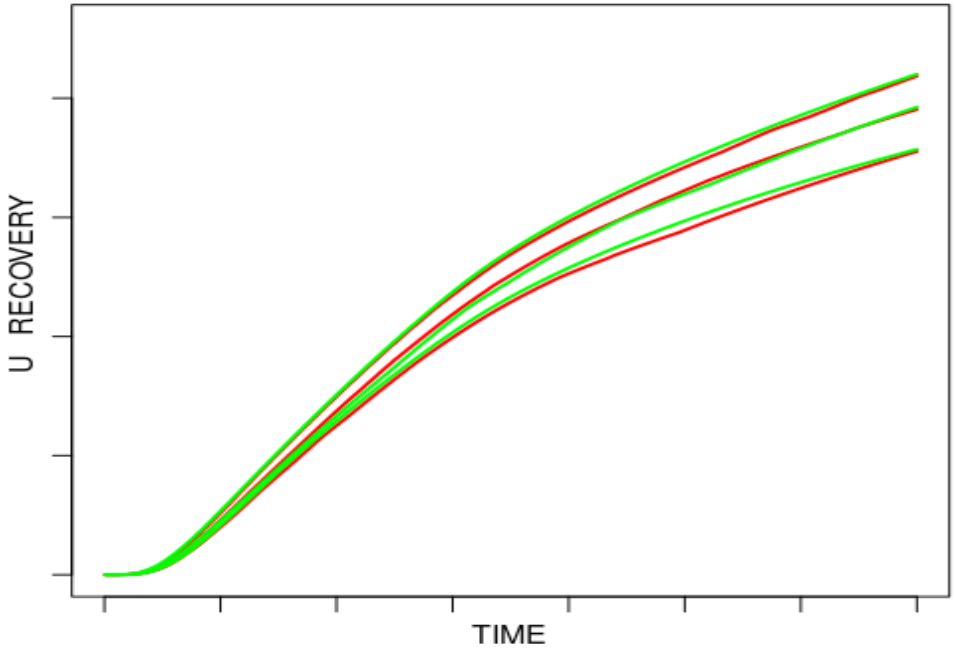




Comparison of uncertainty quantification



- Uncertainty quantification by simulating the ISR exploitation in the few selected and weighted realizations

Conclusion

- Complexity of the ISR exploitation ➔ Reactive transport modeling
- Heterogeneity of roll front deposits properties➔ Geostatistics modeling

- Selection of few realizations using scenario reduction method
  - Defining each geological realization in the space of descriptors
  - Distance between realization and dimensionality reduction
  - Clustering (representative realizations selection and weighting)

- Management of property heterogeneity to quantify their impact on uranium recovery

Perspectives

- Creation of more descriptive tracers of the uranium production
- Use meta-modeling of reactive transport simulation to gain computational time

Meta-modeling in Hytec

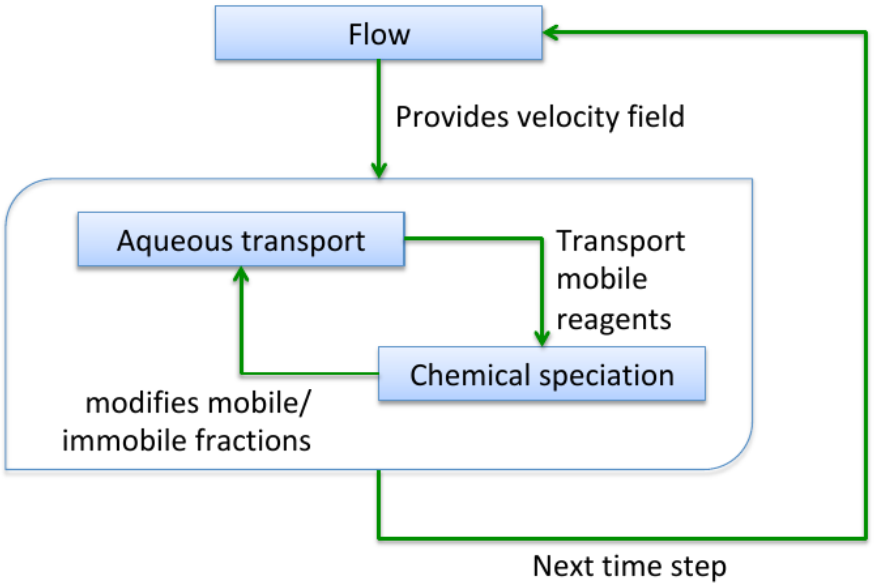
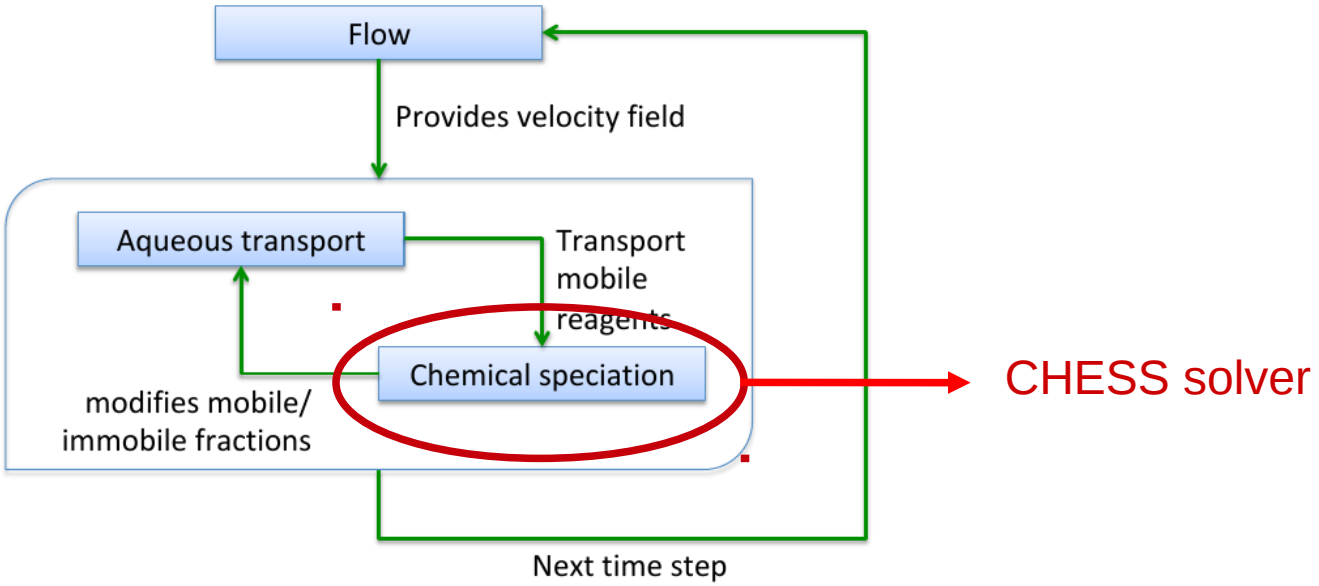


Figure 1: Resolution scheme of the HYTEC code.

Meta-modeling in Hytec



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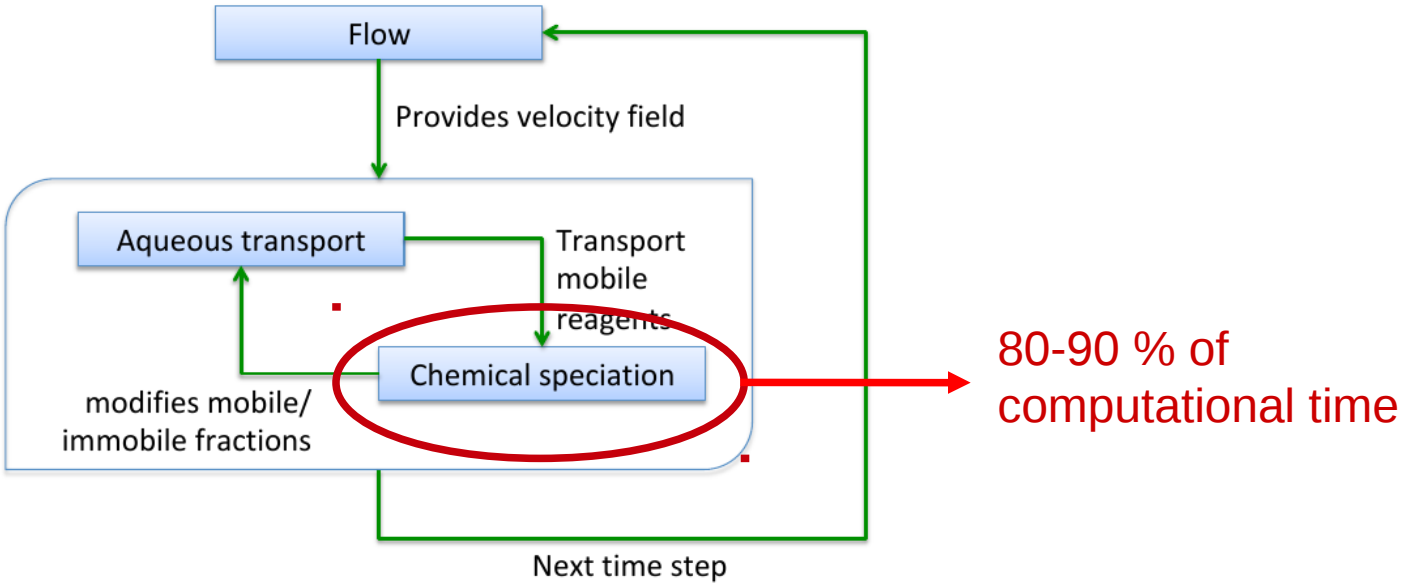

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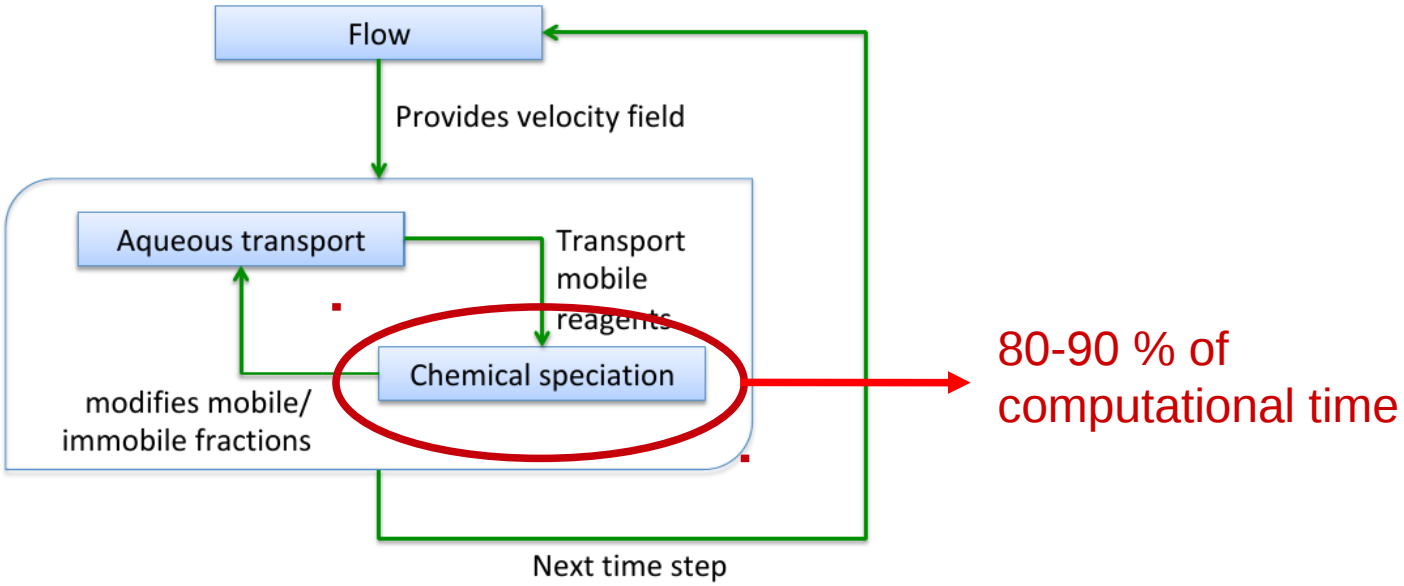
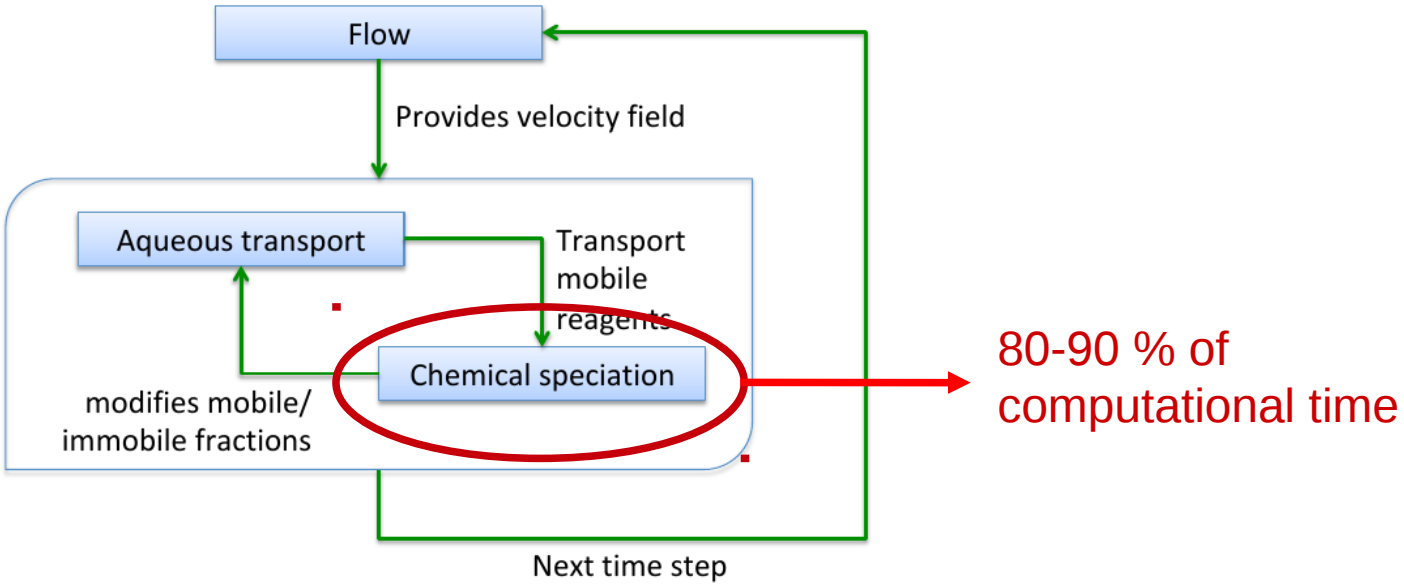


Figure 1: Resolution scheme of the HYTEC code.

- Objectives:
- Meta-model results have to be validated at the cell scale **AND** at the full simulation scale
- The gain in computational time has to be significant

Meta-modeling in Hytec



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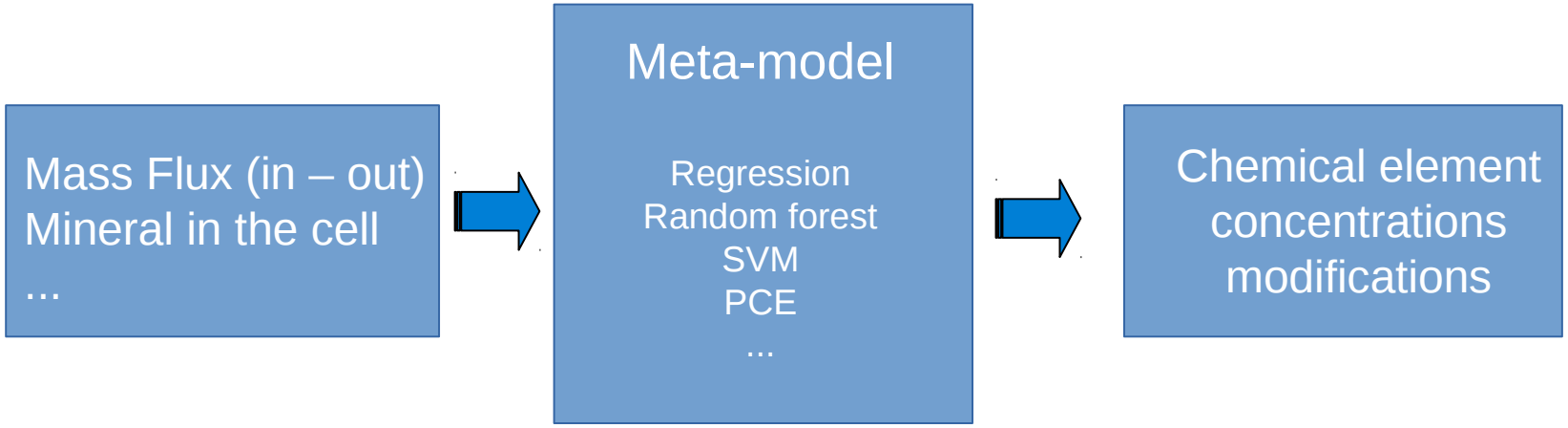
Meta-modeling in Hytec

- Training set : (cell number x time step number x convergence iteration number) CHESS results



- Test of different machine learning algorithms to find the most efficient one

Meta-modeling in Geosciences

- Several examples of Machine learning in geosciences
  - Construction of 3D porous media (pore scale) [L. Mosser, 2017]
  - Synthesis of 3D geological reservoir [A. Elsheikh, 2017]
  - Partnership between Total and Google to perform seismic data interpretation
  - ….

- Machine learning in the Geoscience Center, an interesting niche or a more popular future?

References

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Thank you for your attention !