

Forum

TERATEC

20 - 21 OCTOBRE 2026

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From Deep Uncertainty to Enlightened Decisions: Where Data, Physics, and AI Meet to Shape the Dynamics of Territories

Romain Chassagne, BRGM

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Tasks are not expertise!

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« ..AI would be able to do all of the things radiologists can do within five years.. »

« ..should stop hiring them.. »

Geoffrey Hinton, 2016.

2025 radiologists increased by 13% in the US.

Later on, Geoffrey Hinton acknowledge his mistake.

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Tasks are not expertise!

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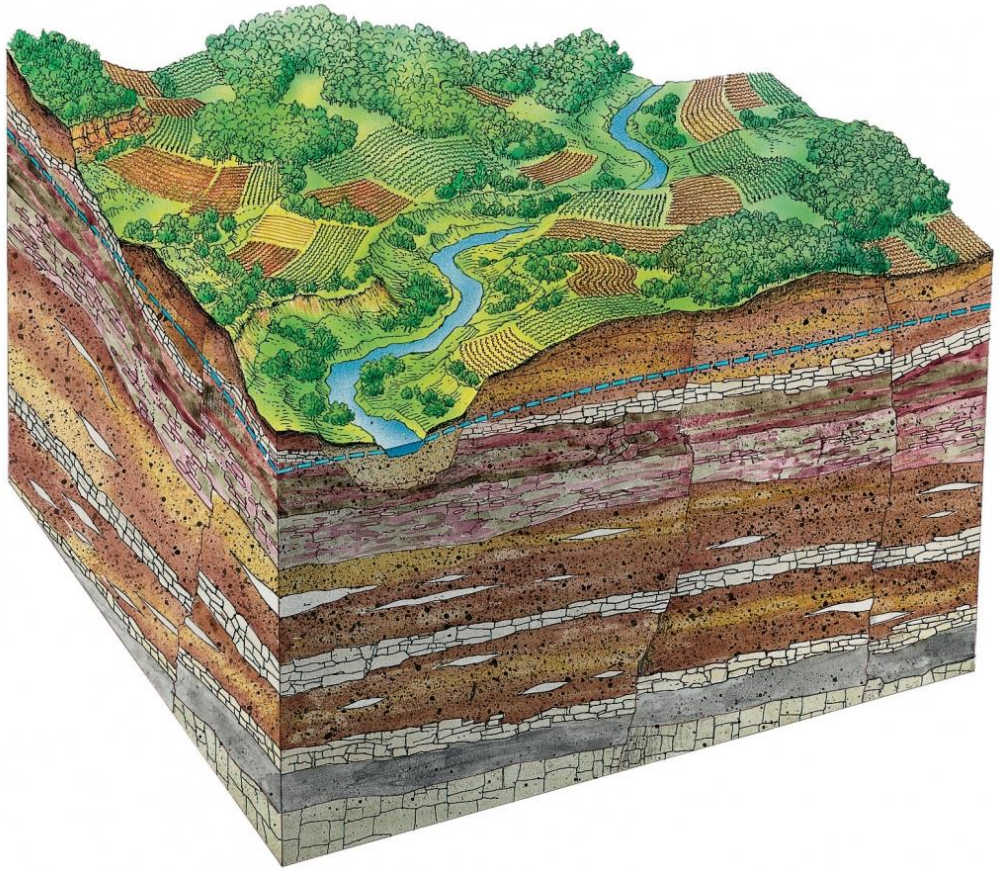
- A radiologist is not just analysing scans.
- His judgment is based on scan analysis but also on other information knowledge and experience (*The Tacit dimension, M. Polanyi, 1966*).

- AI expert is not a thematic expert. Both are needed to achieve successfully.
- I approach AI as a tool to **speed up and guide decision** making process, not an end to its own right.

Focus on the (uncertain) subsurface,

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- Water management
- Heat storage
- Shrinkage and swelling of soil clay
- Aquifer contamination
- Salt intrusion in coastal areas



- Geotechnics and soil stability
- Geothermal
- Nuclear waste and CO_2 storage site integrity
- Karst and cavities
- Mining

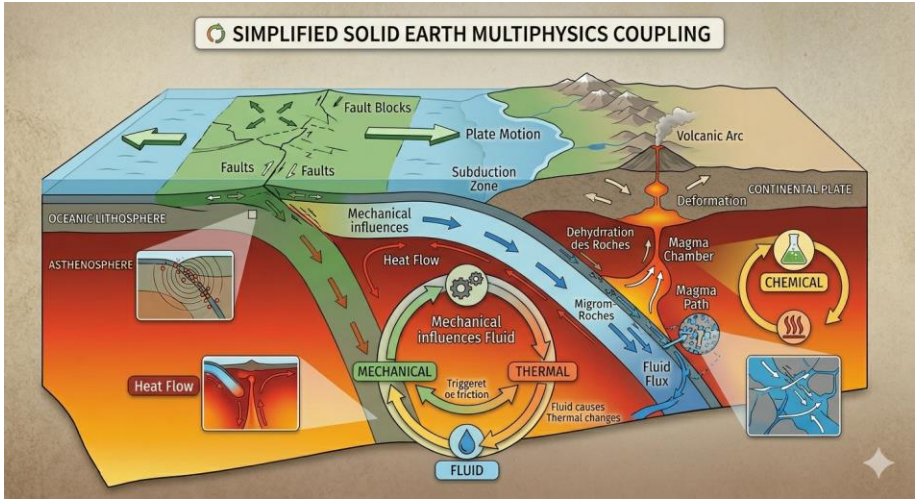
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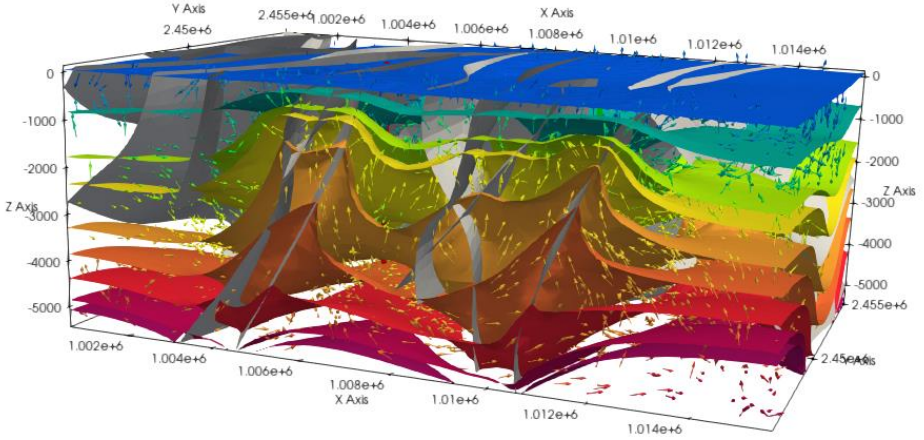
Challenges in the subsurface, modelling

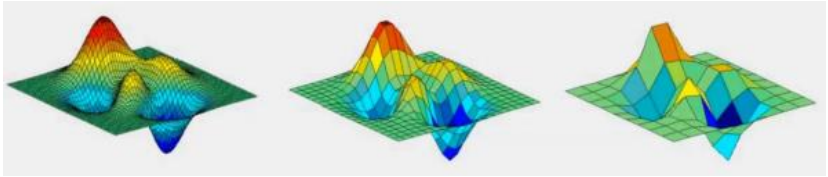
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Multiphysics:

- **Thermodynamics** (Heat)
- **Chemistry** (Reaction)
- **Structural Mechanics** (Stress/Strain)
- **Fluid Dynamics** (Gas / Water flow)
- **Electromagnetics** (Electricity/Magnetism)







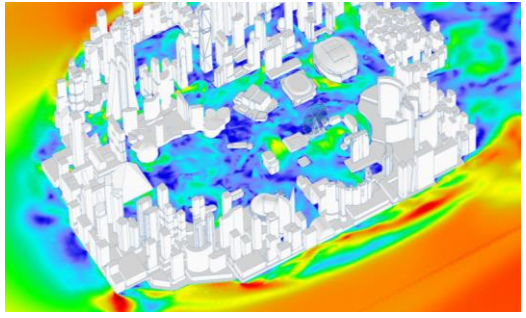
Multifidelity modelling

Challenges in the subsurface, multisource data

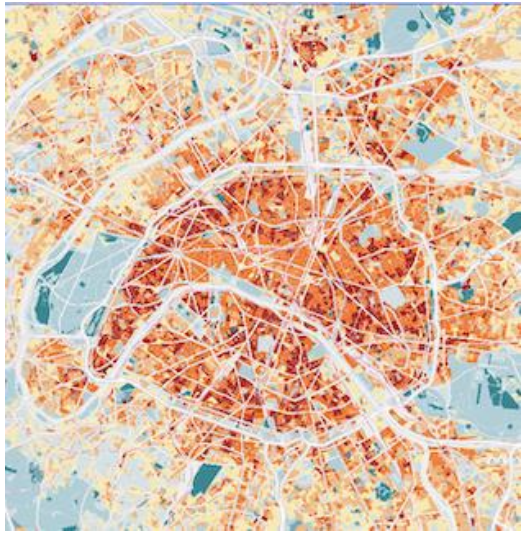
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A multisource data (for the surface)

- Surface data are for instance: Ground temperature, humidity, wind speed, .. Often punctual but not only.
- Surface data are independently “OK” to handle.
- Surface **data fusion** could inform better and enhance prediction and then decision making. Need to deploy **data integration** tools.

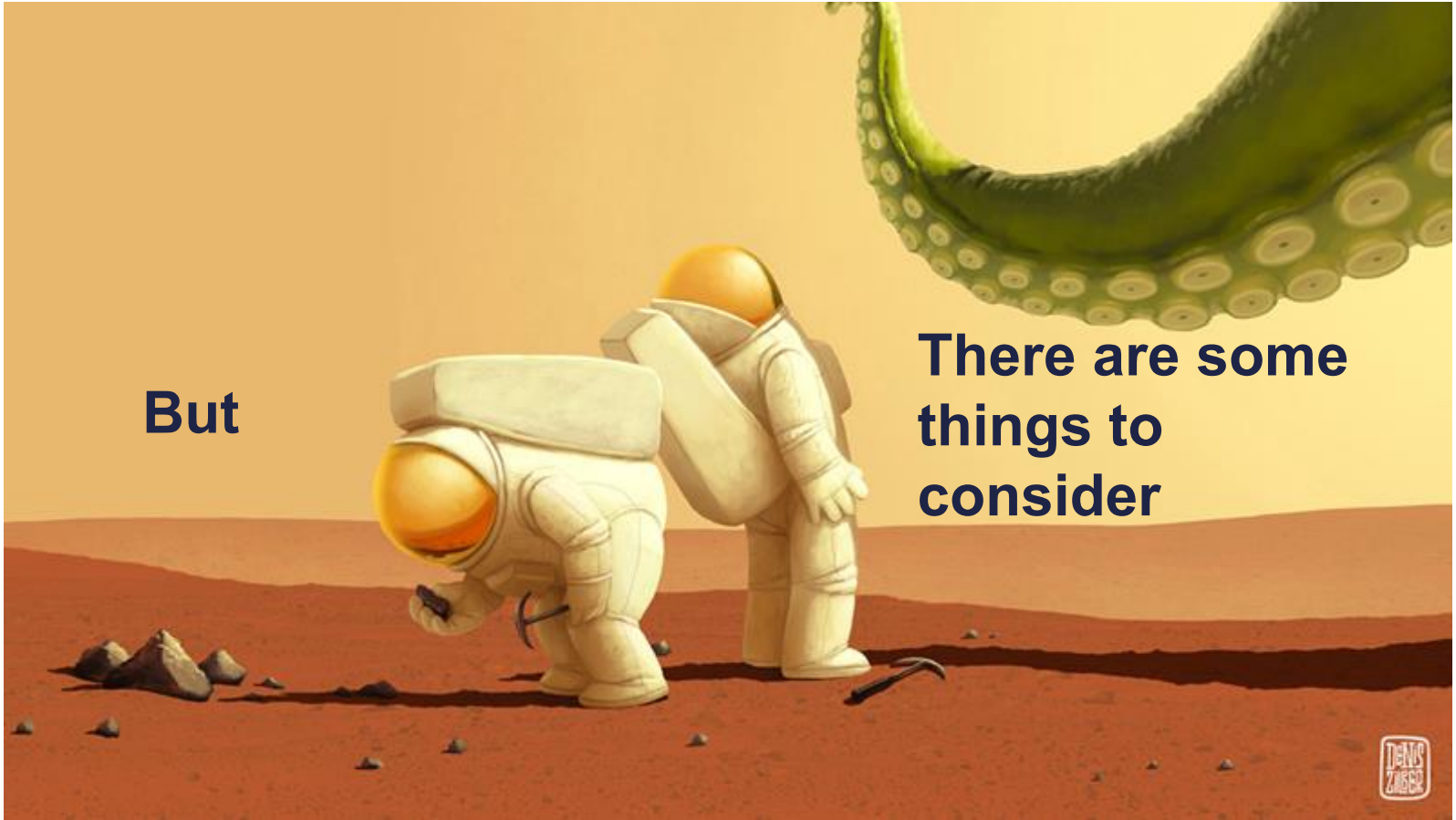


Dlubal.com



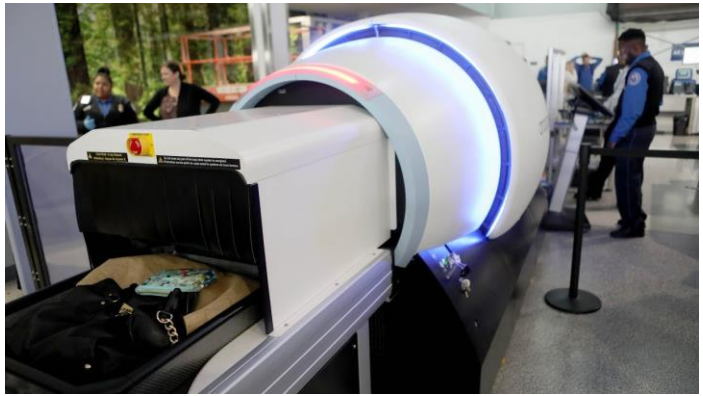
Source : L'Institut Paris Region

Challenges in the subsurface, multisource data



Focus on the subsurface, no 3D scan

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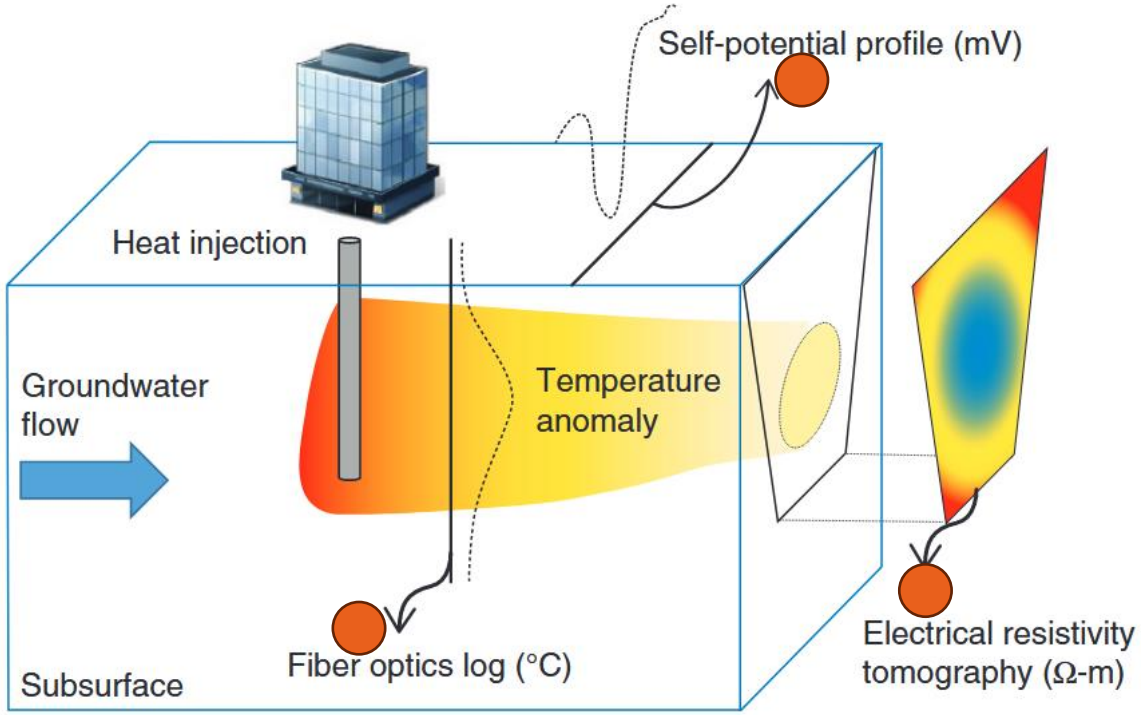




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Challenges in the subsurface, indirect measurements

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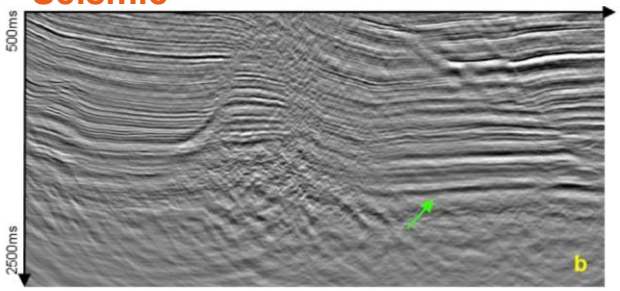
The use of electrical resistivity tomography in the design of shallow geothermal systems. From Hermans et al. [2014]

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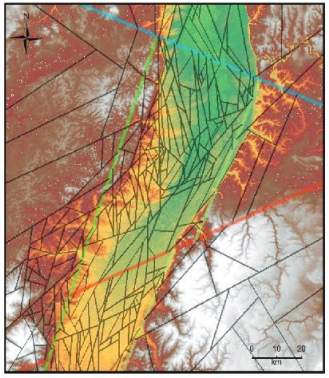
Challenges in the subsurface, multisource data

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Seismic

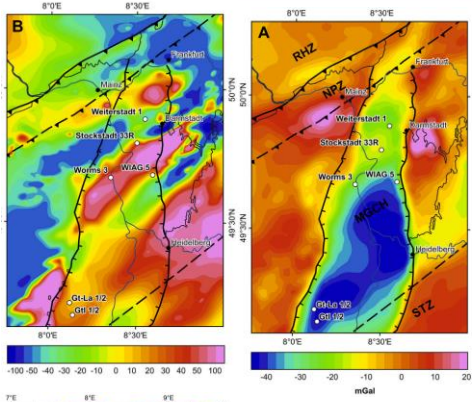


Faults network

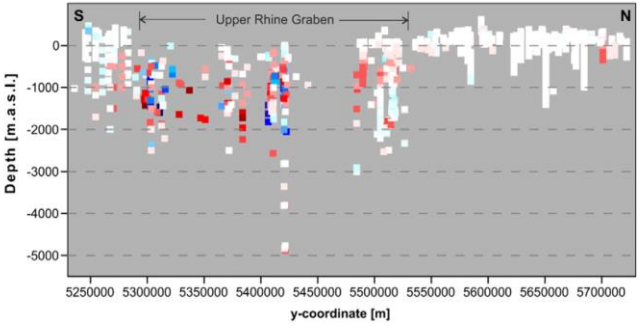


Armandines Les Landes et al., 2019

Magnetic anomalies



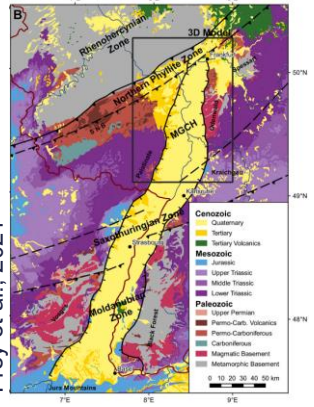
Temperature



Freymark et al., 2017

Petrophysical data

Mean density [g/cm^3]	Mean magnetic susceptibility [SI]
2.65 ± 0.028	0.0020 ± 0.0043
2.72 ± 0.062	0.0017 ± 0.0020
2.80 ± 0.052	0.0062 ± 0.0094
2.90 ± 0.068	0.0221 ± 0.0284
2.73 ± 0.088	–
2.65 ± 0.055	0.0012 ± 0.0041
2.91 ± 0.125	0.0089 ± 0.0114



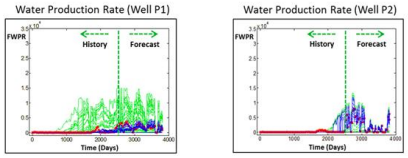
Frey et al., 2021

Geological knowledge

Geochemical

Well	Depth m	Fluid sampling date	pH	Na g/l	K g/l	Ca g/l	Mg mg/l	Cl g/l	SO_4 mg/l
n°5	2310–2699	1983		85.2	43.4	54.0		314	traces
C-1–1 - initial	960–3219	1975	8.5	63.6	21.4	0.043	12	37.0	91,010
C-1–2 - initial	960–3219	1975	8.5	78.9	48.4	0.106	17	42.9	163,290
C-1–3 -	960–3219	1982	7.9	61.0	88.0	0.070	12	28.0	191,000

Sanjuanet al., 2022



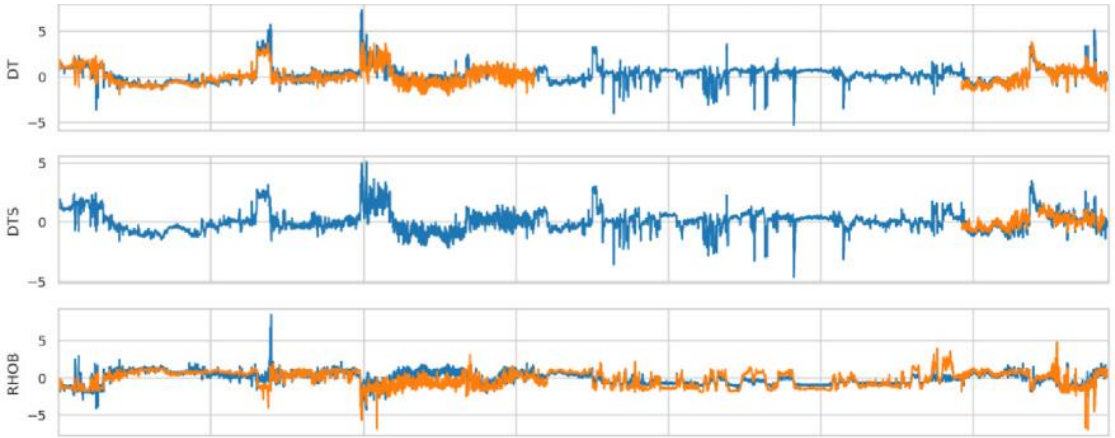
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Challenges in the subsurface, where AI is now “commonly” used

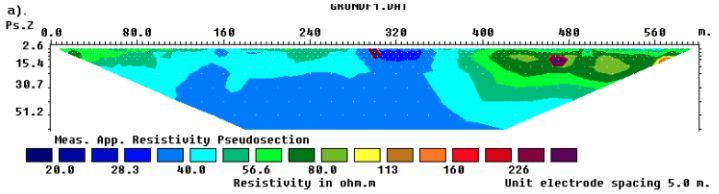
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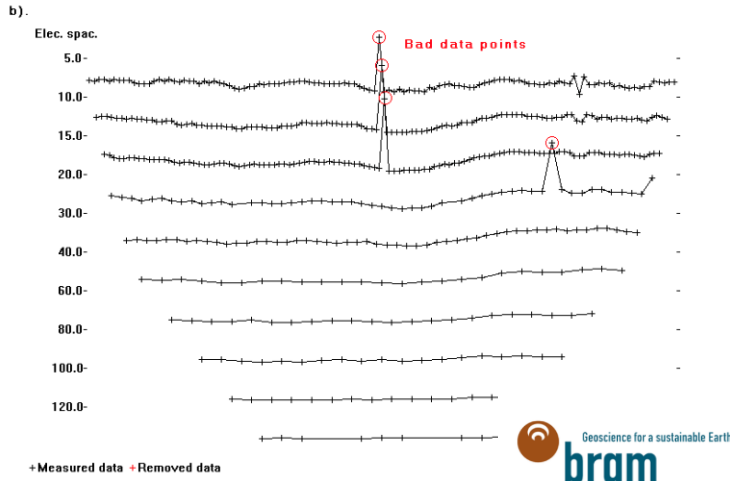
Data cleanning, remove duplicates, correct errors, manage missing values, remove outliers

- Outlier detection (DBSCAN, Autoencoders, etc..)
- Imputation (RF, SVR, LSTM, U-NET, GAN, PINNs, etc..)



Hallam et al.2022

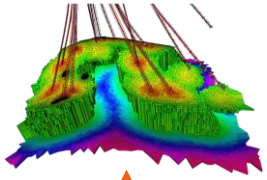




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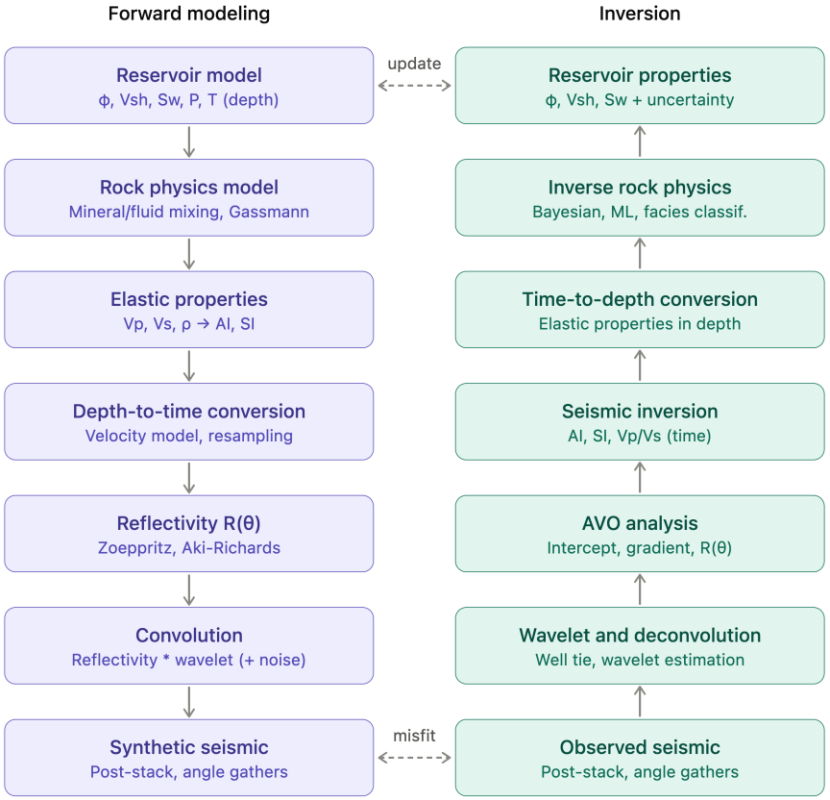
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Domain transfer





Seismic workflow example

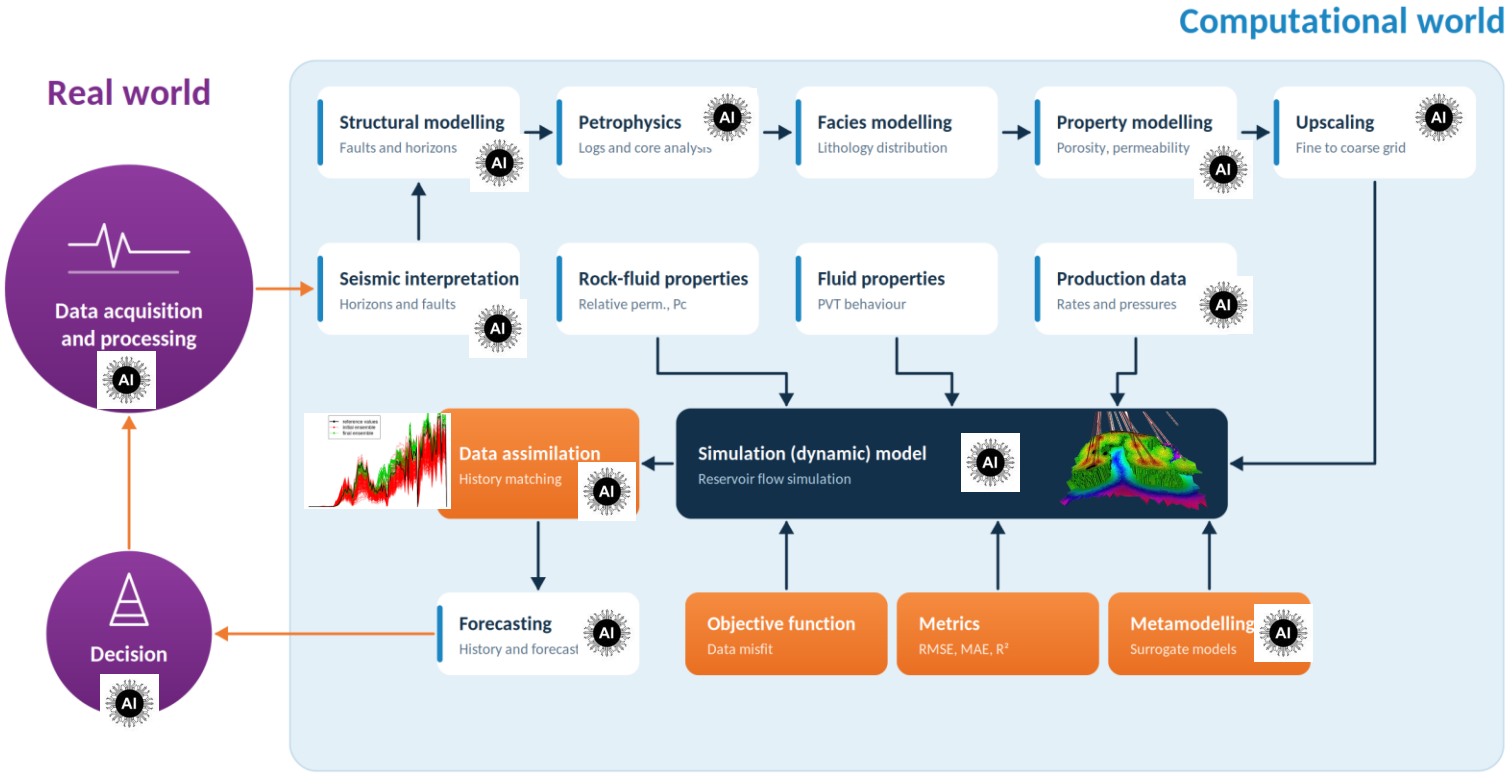
Interpretation, processing, inversion, modelling

PINNs, XGBoost, CNN, U-NET, FNO, IA-assisted FWI etc..

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Model update, multisource data, multiphysics, multiscale problem

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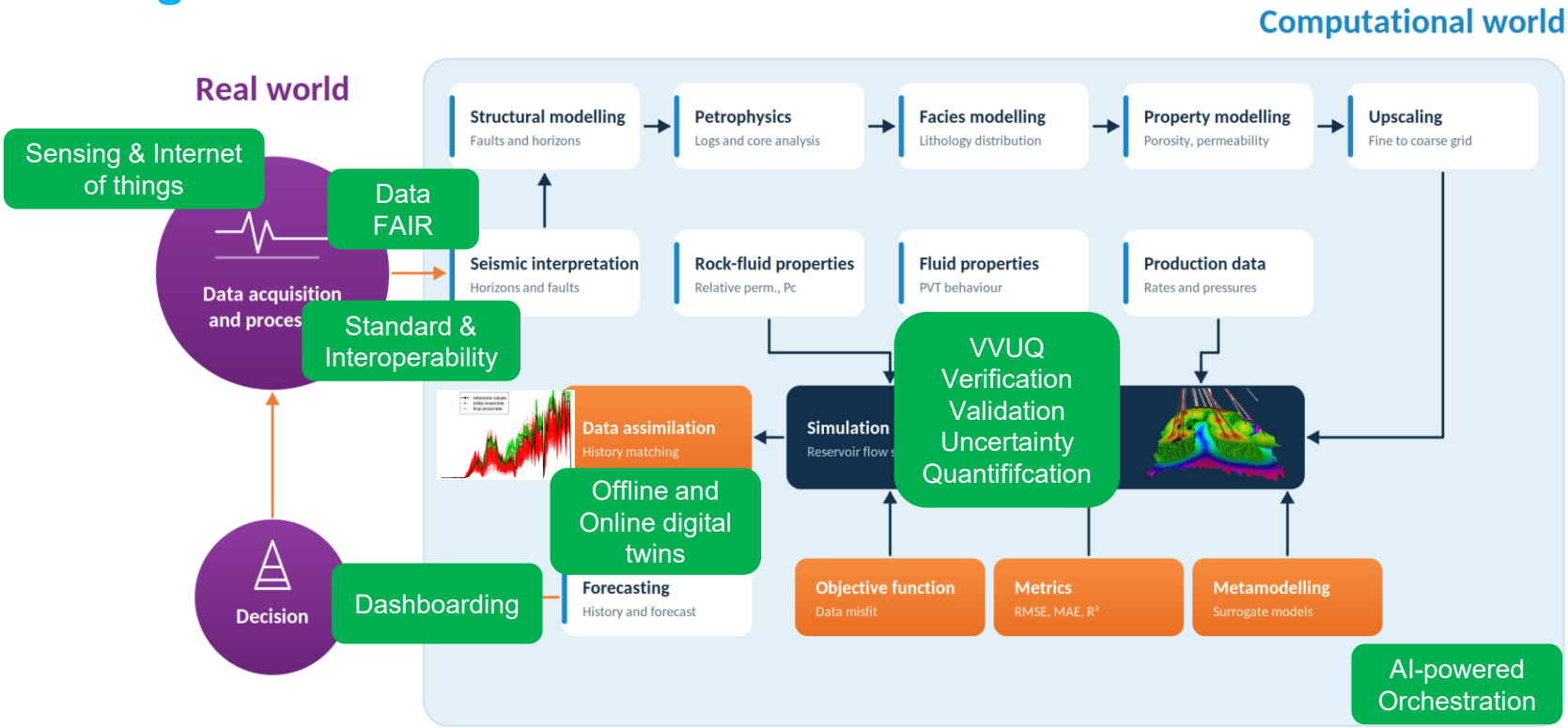


- Metamodelling
- Time-series
- Predictive mapping
- Data fusion
- Agentic AI
- UQ
- Interpolation
- Topological Data Analysis

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The full Monty, from model update, to a digital twin

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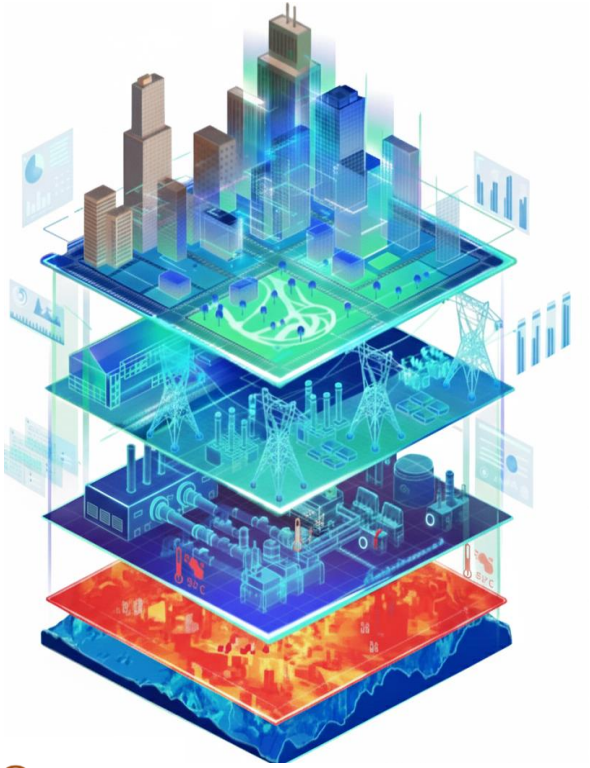
The full Monty, from model update, to a digital twin

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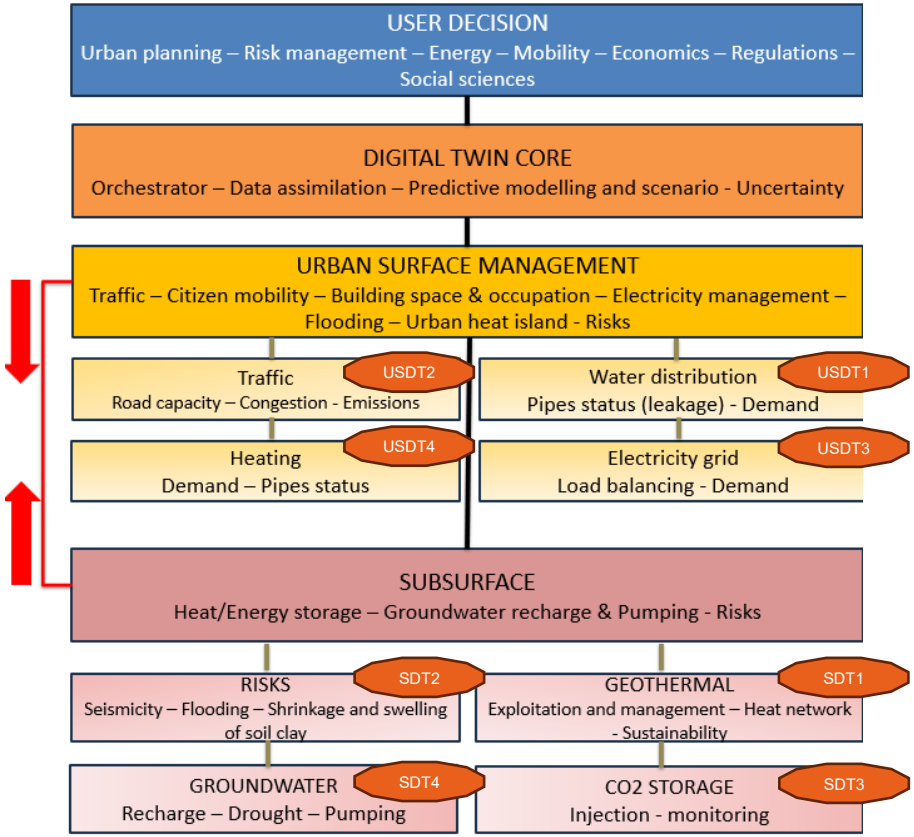


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Digital Twins for Territories, a digital envelope to rule them all

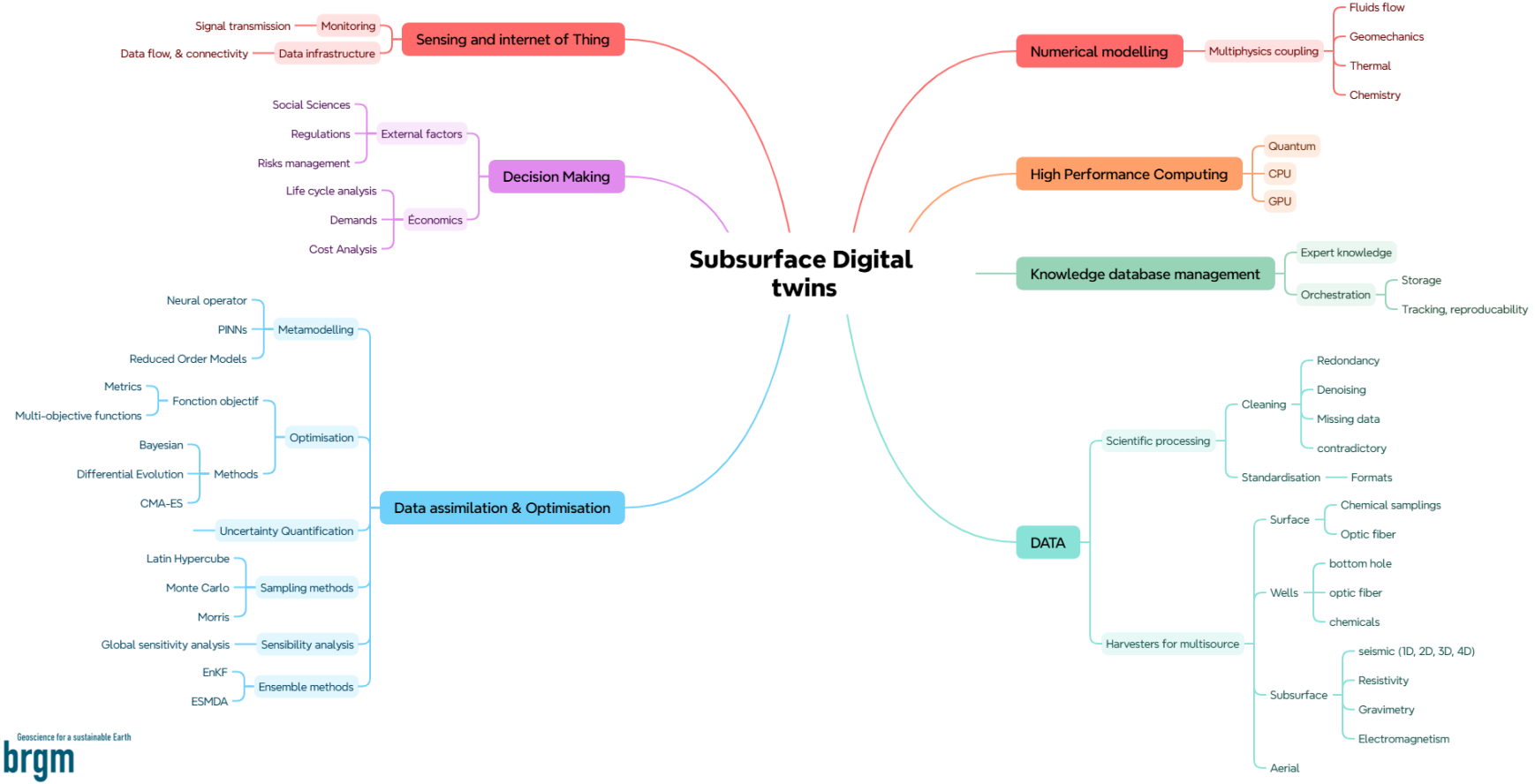


AI-powered orchestration & story telling



Digital Twins for Territories, a multidisciplinary problem

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The recurrence of the three states in life

- What we want

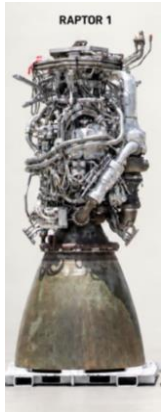


The recurrence of the three states in life

- What we want



- What we can



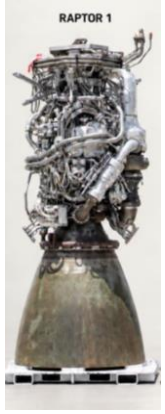
The recurrence of the three states in life

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- What we want



- What we can



- What we have



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The recurrence of the three states in life

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- What we want



Maturity level (complexity) for Subsurface Digital Twins

Spanning from the full monty to a single piece of useful-enough information

- What we can

- What we have

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Subsurface DT and AI in perspective

- Platform towards digital envelopes:
  - (AI-powered) **Orchestrators**
  - Seamless integration (multisoftware, able to plugin any physics simulator).
  - **Modularity** of many digital twins (generalisation versus thematic, Multiphysics)
  - Integrating anything **FAIR standard** in an **interoperable way.**

- Trustworthiness:
  - Comprehensive **uncertainty quantification verification and validation results** (Fundamentals* & human in the loop),
  - Real-time monitoring and dataflow tracking (where, who, how).
  - Algorithms and methods **benchmarking.**

- Cross-disciplinary joint research (AI and multimétier experts), **building DT is mainly a human challenge**.

- **Cybersecurity**, Cybercrime is expected to skyrocket *(source: Statista market insights).*

Different level of complexity for a digital twin exist. A simple one, enlightening decision is a success.

*Fundamentals of Verification and Validation by P, Roache.