Isatis applications for soil pollution mapping and risk assessment

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Objective & key aspects

To illustrate on real cases the current use of geostatistics for soil pollution mapping and risk assessment on contaminated volumes.

Key points:

- Recent Isatis projects.
- Nowadays: almost no data analysis, mapping and estimation on contaminated volumes based on deterministic approaches.
- Added value of geostatistics: spatial structure, uncertainty quantification, scientific, rigorous…

Contents

- State of the art & Methodology
- Presentation of the main case study
- Data analysis
- Soil pollution mapping
- Risk analysis & contaminated volumes
- Perspectives

State of the art & Methodology

- Common issues when attempting to characterize soil pollutions:
  - Limited number of samples
  - Lack of spatial representativity of samples (heterogeneity)

- Geostatistics starts to be applied to map soil pollutions and estimate contaminated soil volumes:
  - Data QC and analysis
  - Evaluation of pollutant's spatial structure
  - Integration of all available information
  - Soil pollution mapping (2D or 3D)
  - Estimation of soils to be remediated, depending on health risk evaluation.

- French association ***GeoSiPol*** created in 2004
  - Promote the use of geostatistics in soil characterization & remediation projects
  - Founding members: Ecole des Mines de Paris, FSS, Géovariances
  - More than 25 members: institutions, consultancy offices, industrials involved in soil remediation issues
  - http://www.geosipol.org

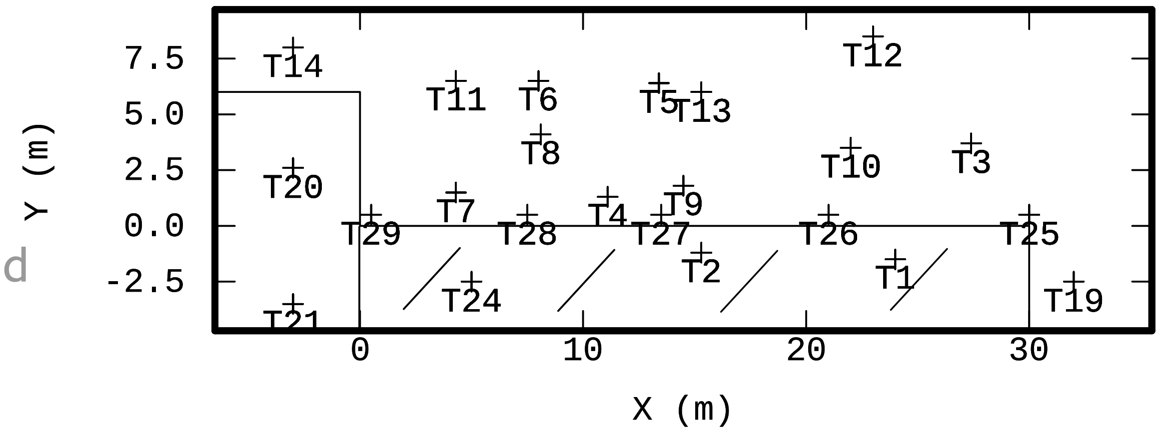
Case Study: HCT pollution

Objective:

- Owner: Charbonnages de France
- Organic contamination by hydrocarbons revealed on a former coal-fired power station under remediation.
- Contamination expected to be due to an hydrocarbon leak from an old building towards the adjacent backfill.
- Additional sampling in order to delineate in 3D the extension of the contamination and to evaluate contaminated volumes.

Sampling:

- Classical lab. analysis of total hydrocarbon grade (1-3 samples per borehole),
- Continuous record of lithology and presence/absence of visual indication of pollution.



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Data Analysis

- ## Sampling approaches:
  - Focus on historical information
  - Systematic sampling plans more and more frequent

- ## Common issues:
  - Erroneous data (locations, concentrations)
  - No analysis on clean samples (see case study)
  - Varying support sizes, common from various sampling campaigns

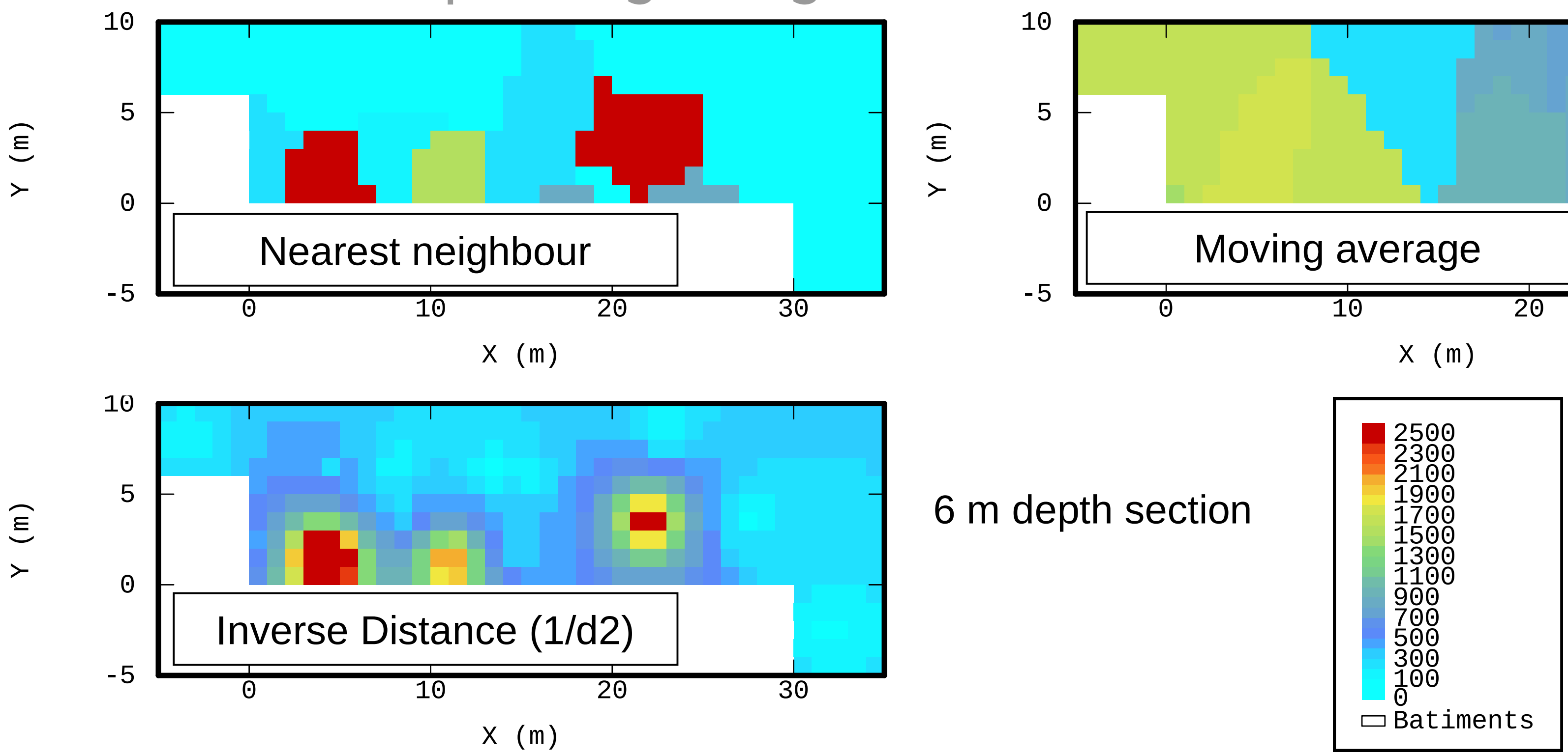
- ## Data QC & EDA Tools:
  - Basemaps
  - Histograms
  - H-scatter plots
  - Variogram cloud & variogram analysis

Soil pollution mapping

- Organic pollution by total hydrocarbons (THC)
  - 32 samples analyzed in THC (in 3D)
  - Values ranging from detection limit (DL) up to 14 000 mg/kg
  - High values preferentially located at 5-6m depth (consistent with the assumption of leak from the adjacent building)
- Auxiliary information:
  - Lithology,
  - Visual indication of contamination

Soil pollution mapping

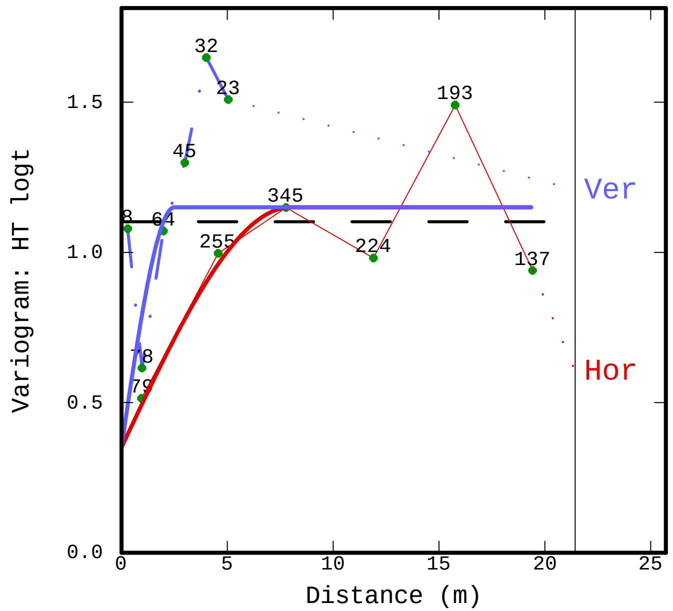
- Usual interpolation techniques: nearest neighbour, moving average, inverse distance, etc.
  - Correspond to a different weighting of the available samples when interpolating at a given location

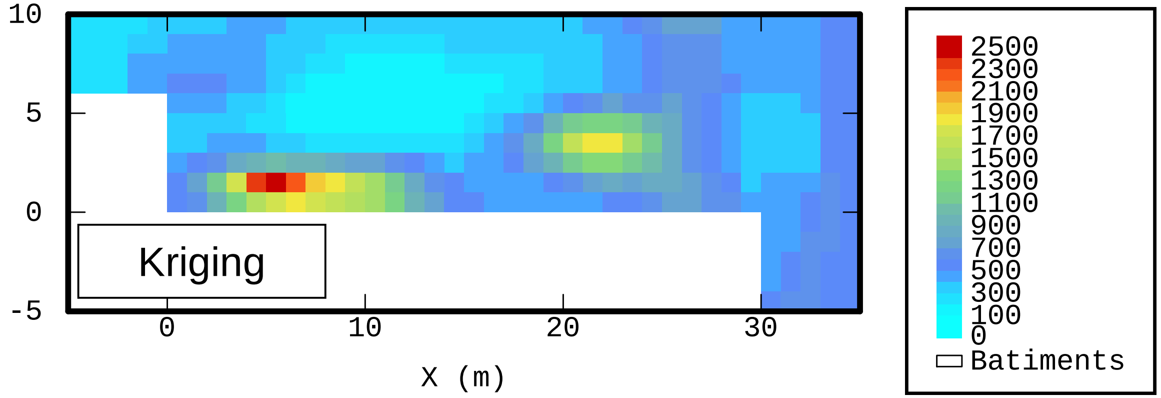


⇒ Which map shall we choose?

Soil pollution mapping

- **3D Kriging**
  - Weights depend on the spatial structure (variogram)

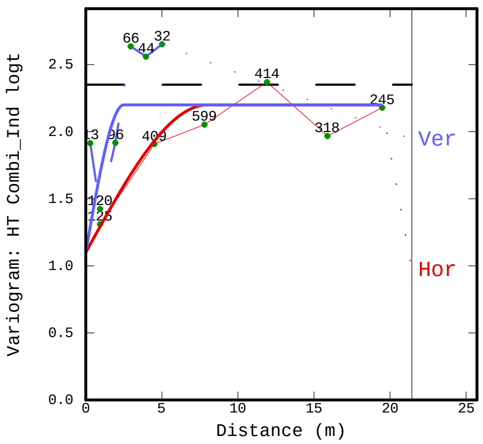


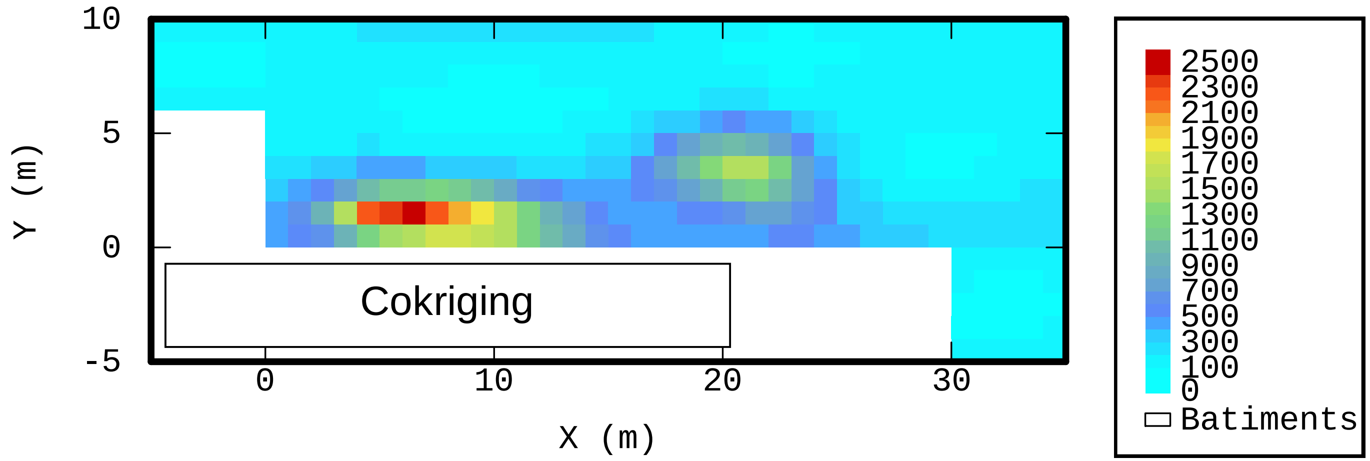


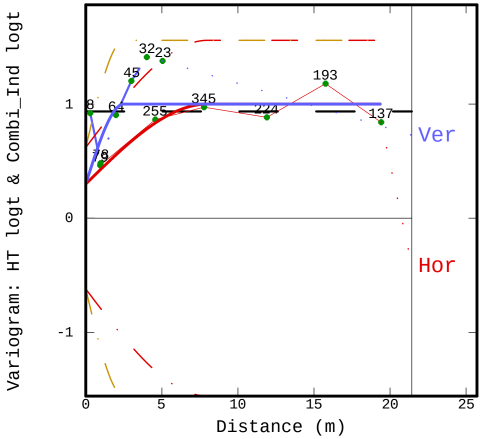
  - Large uncertainty in extrapolation

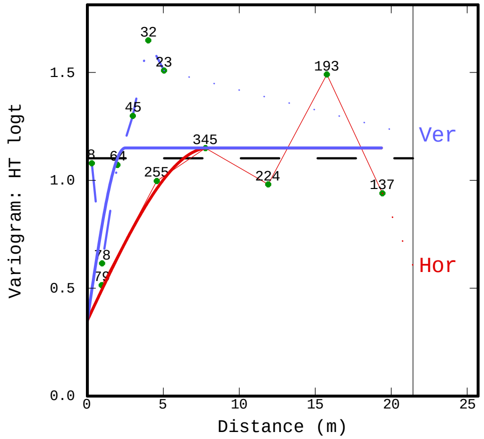
Soil pollution mapping

- Integration of auxiliary information
  - Lithology and visual indication of pollution are integrated through a cokriging approach



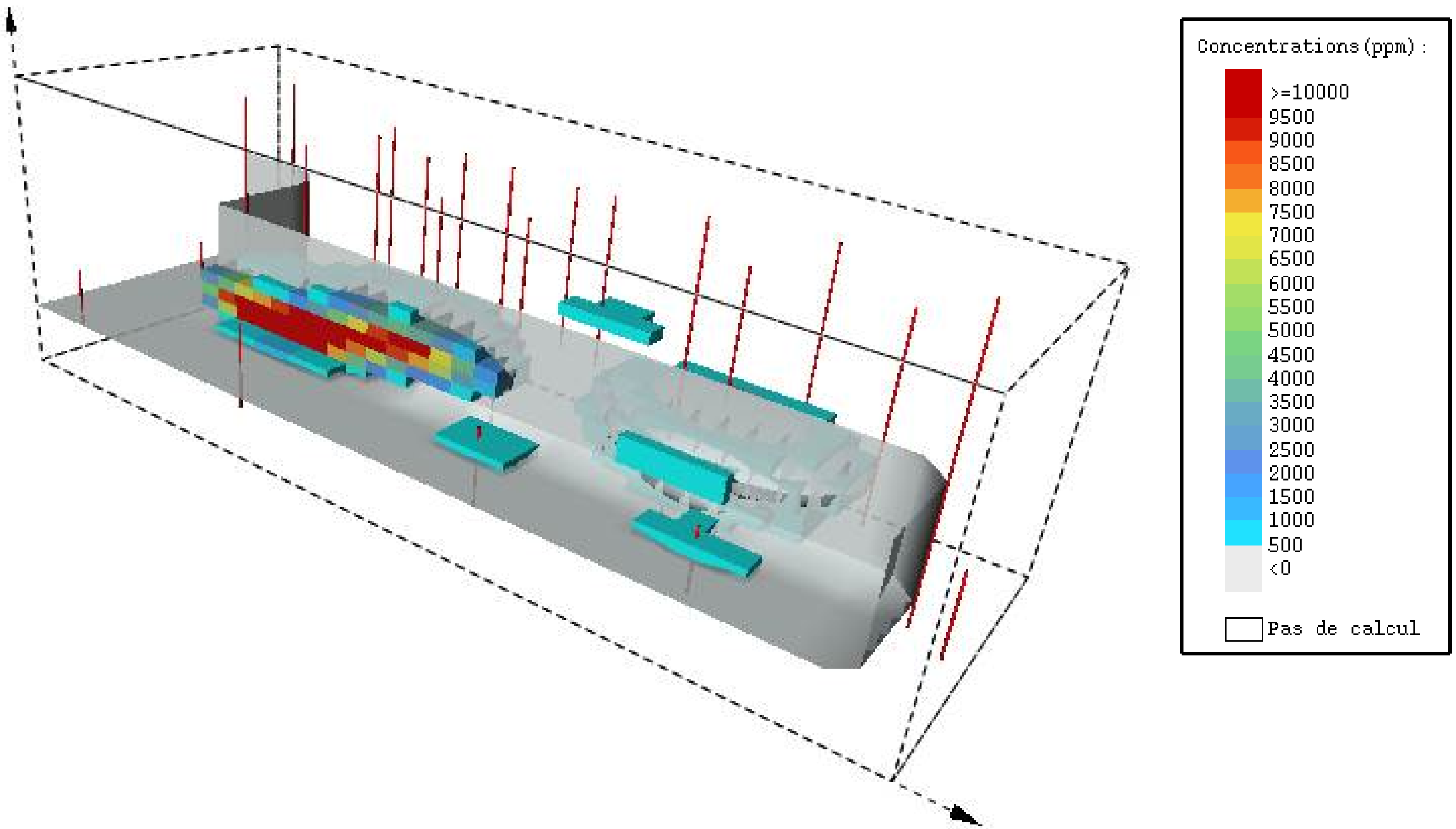






Soil pollution mapping

- 3D Visualization



Isatis - 3D Viewer

Soil pollution mapping: other examples

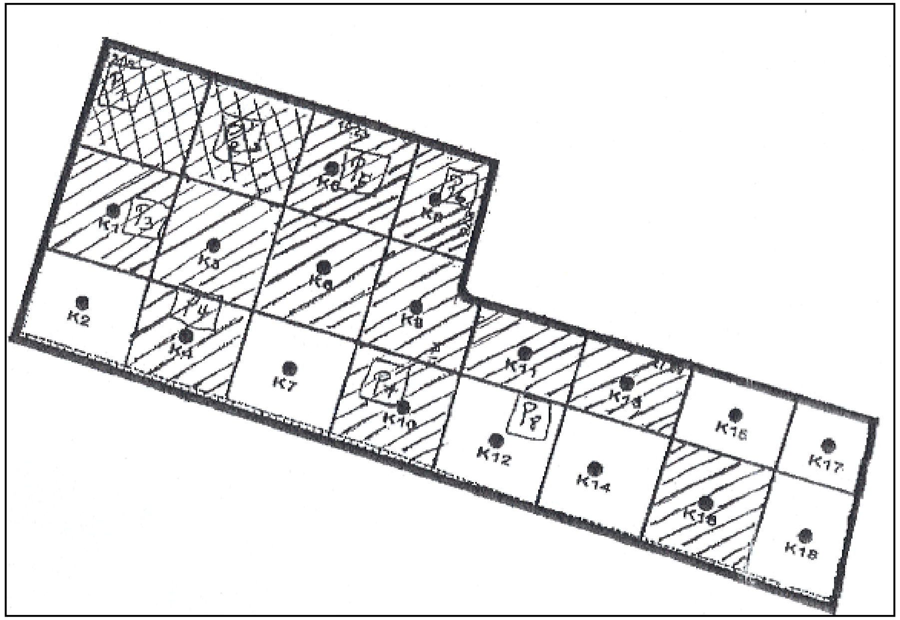
- Mapping radioactive compounds on contaminated parcels (soils) or former reactors (concrete)

CEA is developping of an in-house mapping sofware (Kartotrak) using Isatis in batch for automated geostatistical applications

Risk analysis and contaminated volumes

Usual way to evaluate contaminated volumes:

Hatched blocks: At least one compound exceeds the remediation threshold



- Gives a result… without any indication of uncertainty.
- Assumptions:
  - Remediation volume = sample
  - Sample representative of the entire block
  - Estimation is perfect, without uncertainty…
  - No sample = no pollution…………

Risk analysis and contaminated volumes

- Once the remediation threshold is defined, two questions:
  - How much soil should be remediated?
    - ⇒ Global question
  - Where should we excavate?
    - ⇒ Local question
- Difference between the estimation of:
  - what is really contaminated (volume),
  - and what should be excavated in order to avoid unacceptable risk to let in place contaminated soils!

Risk analysis and contaminated volumes

- Volumes should not be calculated on kriged maps!
  - Smoothing effect of kriging: the kriged map does not reproduce extreme values

    $\Rightarrow$ Risk of important bias on contaminated volumes!

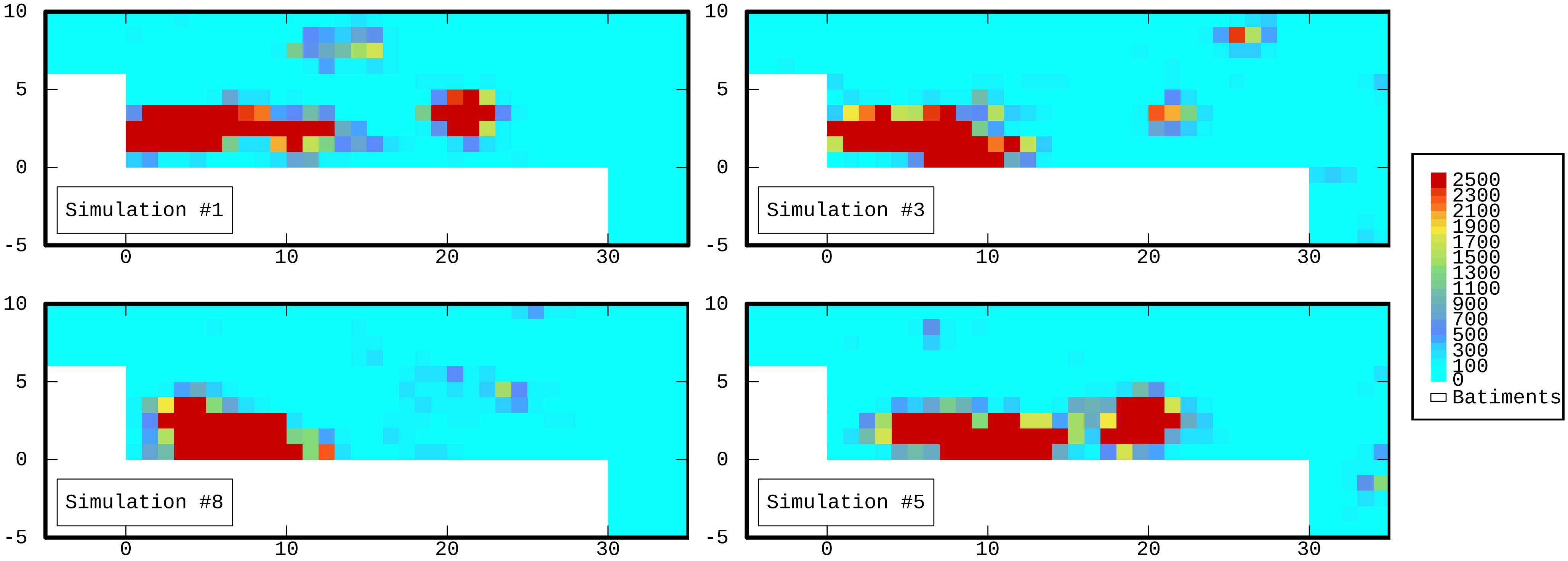
  - Need of an alternative way to represent the phenomenon, that give access to « possible » images of the pollution: same distribution, same spatial structure

  - Conditional Simulations: illustrate the degree of freedom left between the data

Risk analysis and contaminated volumes

Examples for THC grades

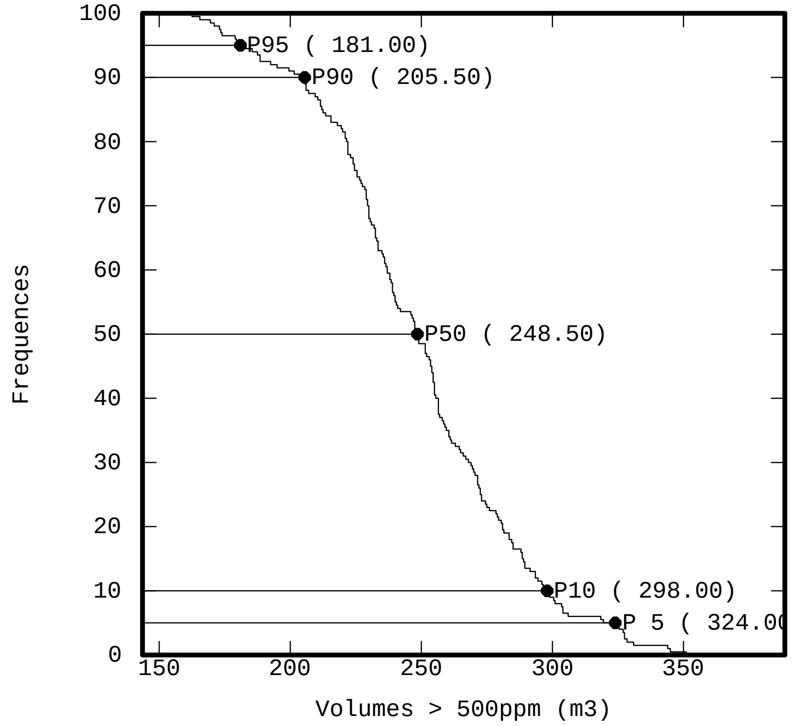
- Average grades on 1m x 1m x 0.25m blocks



- For each simulation, computation of the volume where [THC]>500mg/kg

Risk analysis and contaminated volumes

- Estimation of contaminated volumes ([THC] > 500 mg/kg) :



- Interesting tool to support decision making:
  - Most probable volume of contaminated soils: 250 m^3 (initial estimation 500 m^3)
  - 95% probability that the volume does not exceed 325 m^3

Conclusions & Perspectives

- Geostatistics : a tool with an important added value during investigation and remediation of contaminated sites.

- Up to now:
  - First of all, focus on data analysis and spatial structure!

    For instance, local delineation of contamination should be definitively avoided when there is no spatial structure (pure nugget effect, heterogeneity) ⇒ Global decision!
  - 2D and 3D mapping, use of auxiliary information
  - Risk analysis using conditional simulations (volumes) or equivalent techniques to produce probability maps (probability from conditional expectation)

- In the future:
  - Feedback on the actual added value of geostatistics
  - Develop the integration of auxiliary variables (in situ measurements)
  - Integration of other geostatistical tools in the methodology:

    Grade Tonnage Curves to support the choice of appropriate remediation support sizes, Plurigaussian simulations for large sites with complex lithology (backfill with different materials), etc.