» Strategy for data acquisition Data visualization, analysis and mapping with geostatistics

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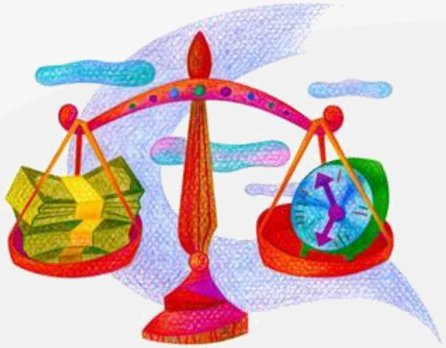
»Presentation key issues

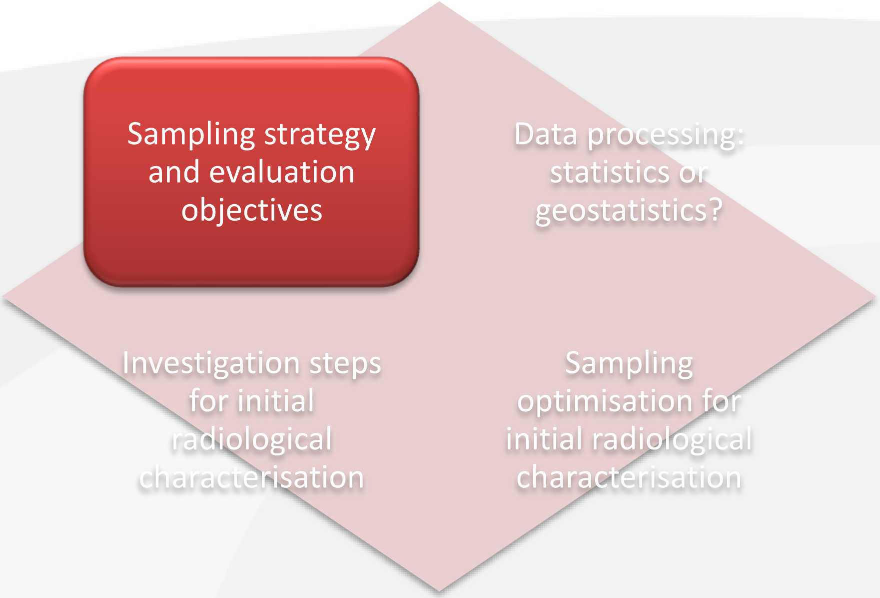
- Added value of geostatistics



  - How to optimize the investigation costs?
  - How to take auxiliary information such as historical inventory and radiation maps consistently into account?
  - How to quantify uncertainties in the remediation costs while computing contaminated surfaces or volumes?

»Outlines

- Sampling strategy and evaluation objectives
- Data processing: statistics or geostatistics?
- Investigation steps for initial radiological characterisation
- Sampling optimisation for initial radiological characterisation



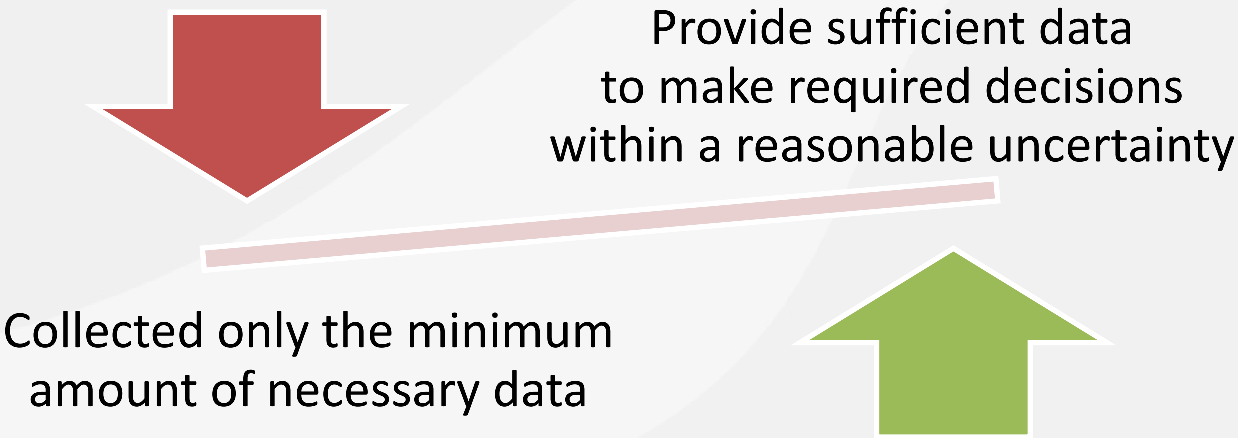
Part 1

» How to select the sampling strategy for an evaluation objective?

- Three legged stool theory
  - Three sound legs: stability and simplicity
  - Weakness of one leg: stool fall
  - Stable position but uncomfortable: not possible to sleep!

»Data Quality Objectives

- Methodological framework for characterisation



- Avoid losing time and money, collecting useless data, over-production of uncontaminated waste…

»Evaluation objectives

2D - Dose mapping

- Worker protection and prioritisation of area to be decontaminated
- **Removal of doubt** step (identification of punctual sources, hot spots, labile or fixed contamination…) and **surface mapping** step

3D - Categorisation of radiological wastes

- Characterisation of contaminated surfaces / volumes
- Setting up the **operational waste zoning** (radiological thresholds, decontamination support, migration profiles…) and **global estimation** (total activity, scale factors…)

0D - Final control

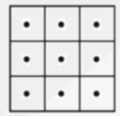
- Radiological characterisation of the final state
- Demonstration of **compliance with clearance levels** (statistical conformity tests), then estimation of **residual mean activity** for sanitary impact assessment

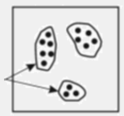
»Sampling strategy

- Minesweeper

Random

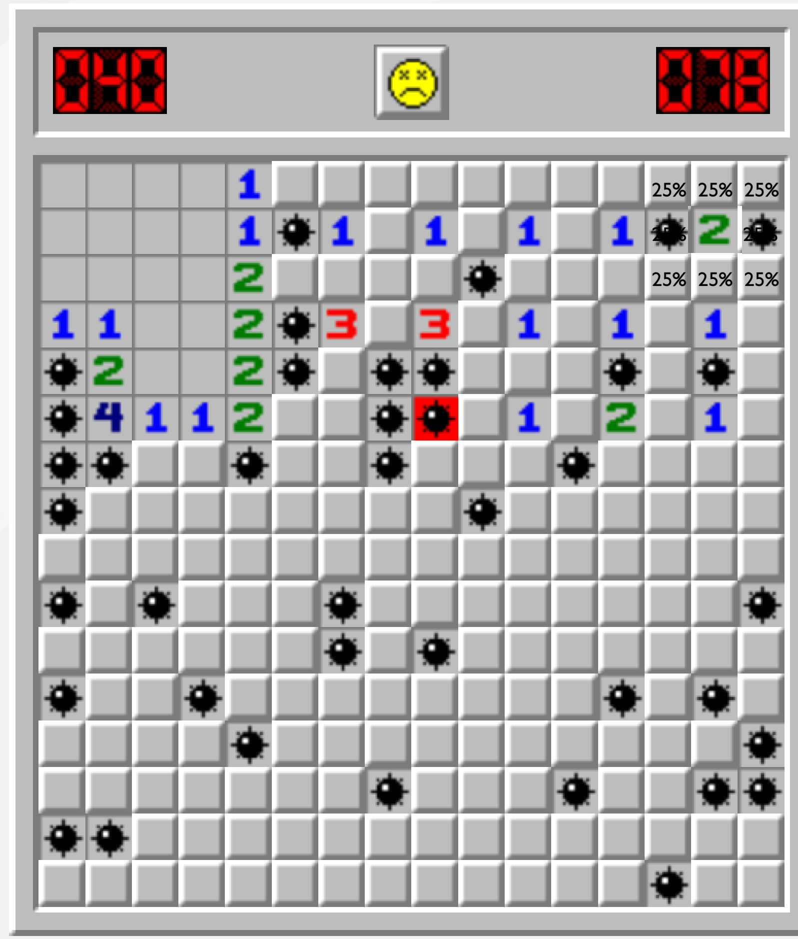
Systematic (regular mesh)





Cluster (iterative approach)
"0" in minesweeper

Judgement (expertise)

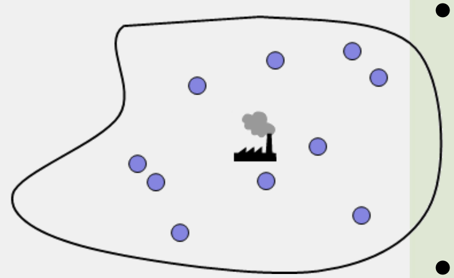


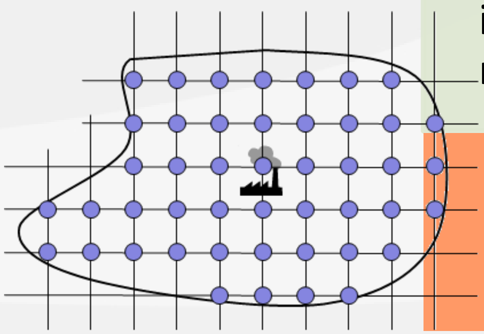
- Looking for hot spots
- Integrating neighbourhood
  - Observation scale
  - Spatial coherence
- Probabilistic schemes

»Sampling strategies

Probabilistic approaches

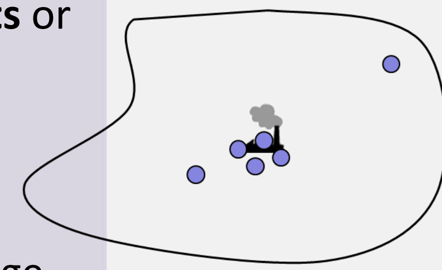
- **Statistical considerations of the sampling design** (uniform probability of selecting a point)
- Therefore, statistical inferences available for results interpretation



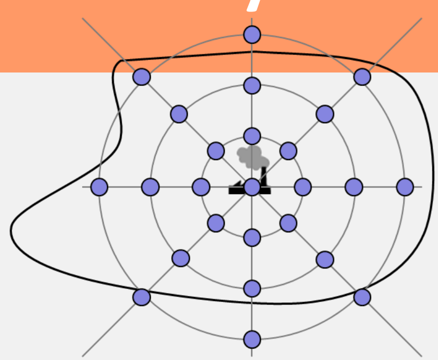


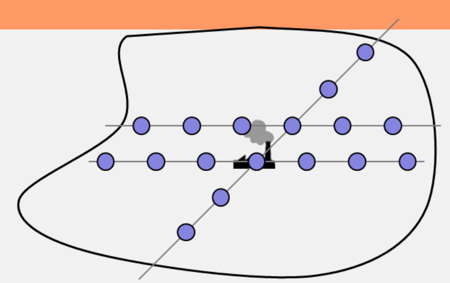
Preferential approaches

- Point number and locations resulting from **particular constraints** or **specific evaluation objectives**
- Generally, need of expertise advices or preliminary knowledge



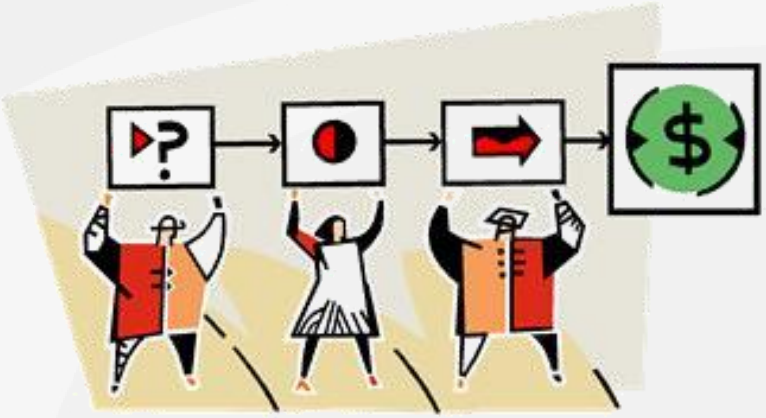
Hybrid approaches



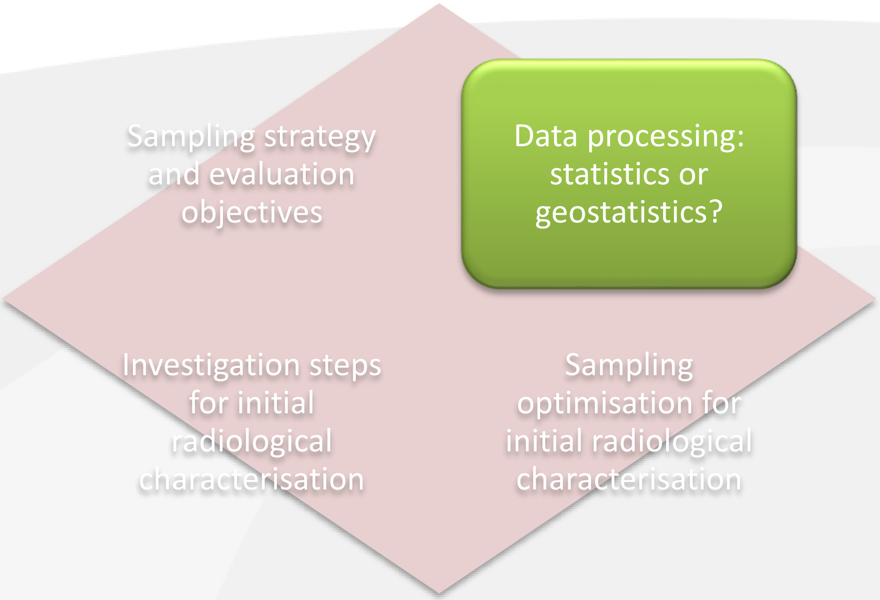


»Additional comments

- Essential dialogue between
  - Prime contractor (objective)
  - Collecting team (sampling)
  - Analyst (data processing)

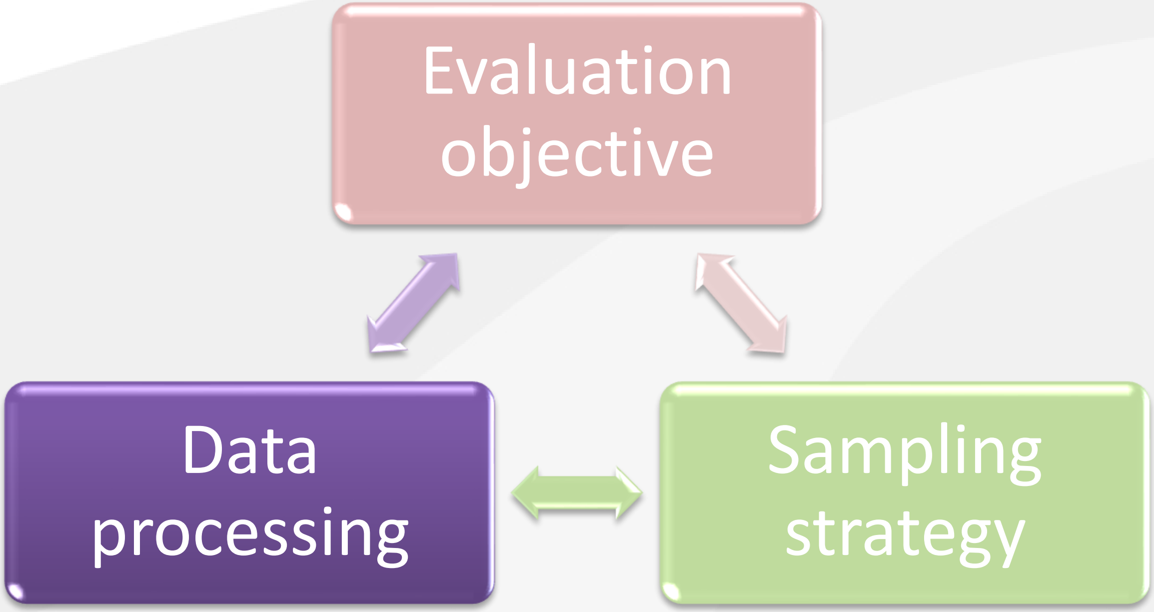


- Always simultaneous objectives
- Importance of preliminary information about the area to be characterized (historical records, physical characteristics, homogeneous areas…)
- Relevance of an adaptive approach (or iterative)



Part 2

» How to analyse and valuate collected data?



- Give value to collected information
- Data interpretation, analysis and processing
- Quantification of results uncertainties
- Answering the initial evaluation objective?
  → Back to the sampling strategy…

»Data processing

Removal of doubt

- Direct comparison to a threshold

Characterisation

- Numerical modelling
- Geostatistics

Decontamination

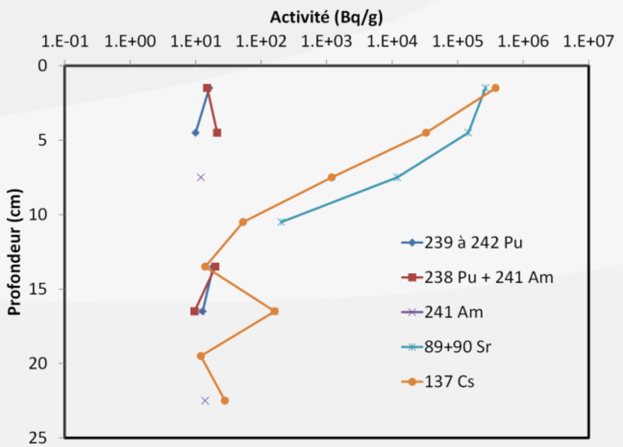
- Monitoring
- Package characterisation

Decommissioning

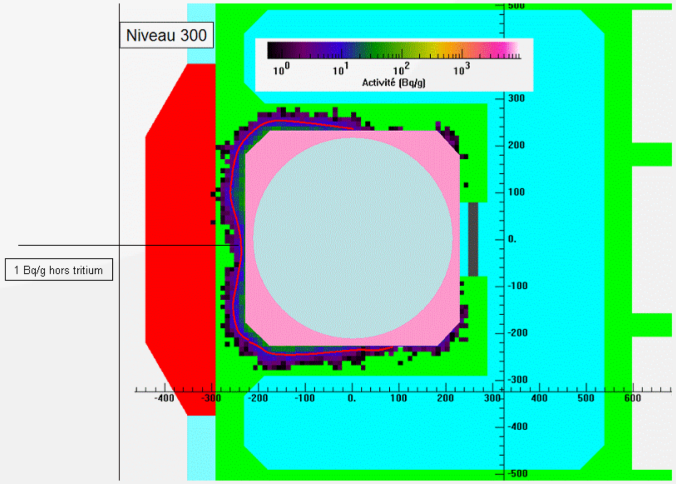
- Statistical tests
- Sanitary impact

»Modelling

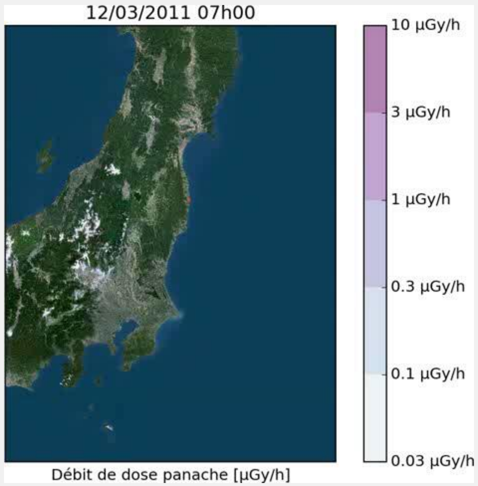
- Phenomenon that can be modelled
  - Mathematical formulae (determinism)
  - Physical modelling and simulations
  - Parameterisation / calibration (eventually by data)



Migration profiles



SILOE Reactor: Activation model of the concrete pool block
Source: DAPNIA

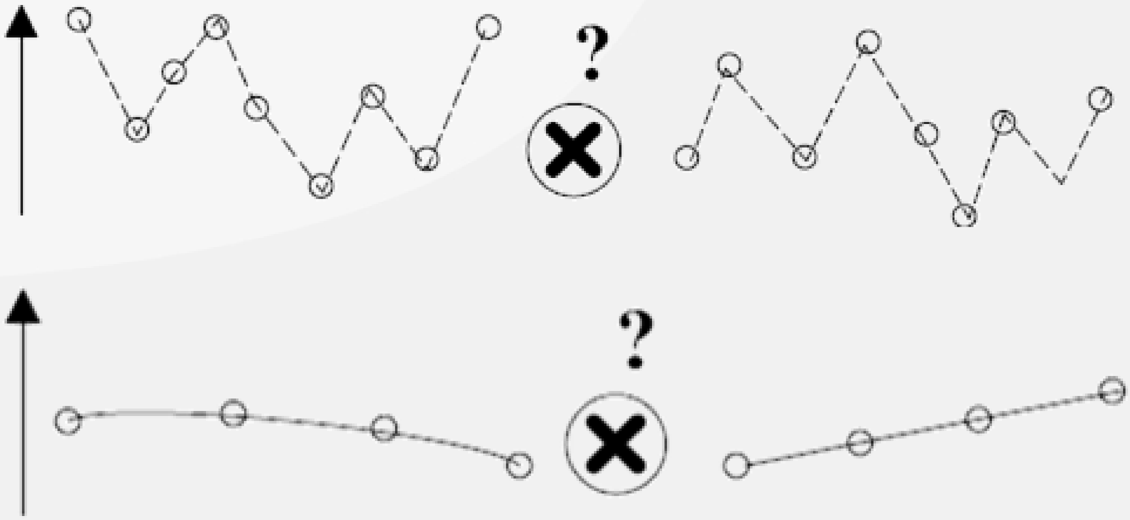


Atmospheric spreading Fukushima
Source: IRSN

»Geostatistical approach

- Difficulties to describe (model) / predict the phenomenon
- The model is within the data!

- Spatial estimation and related uncertainty



»Geostatistical approach

- Young science but a well-tried one (since 1950's in the mining industry, then in oil & gas field…)
- Geo + Statistics:

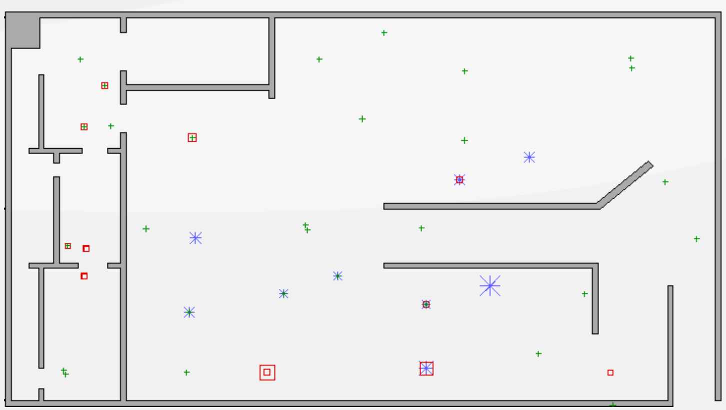
  Statistical processing of spatialised data

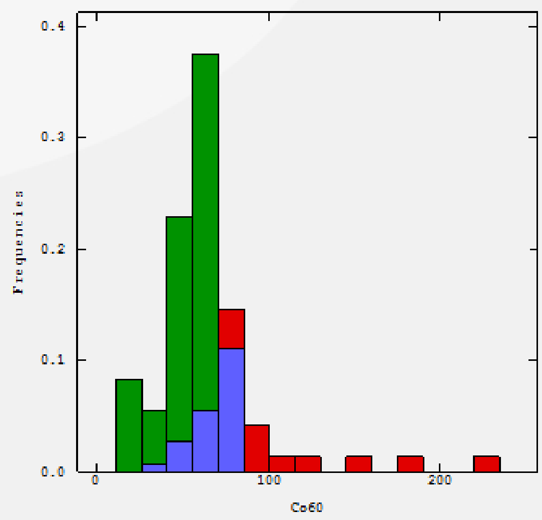
  but not only…

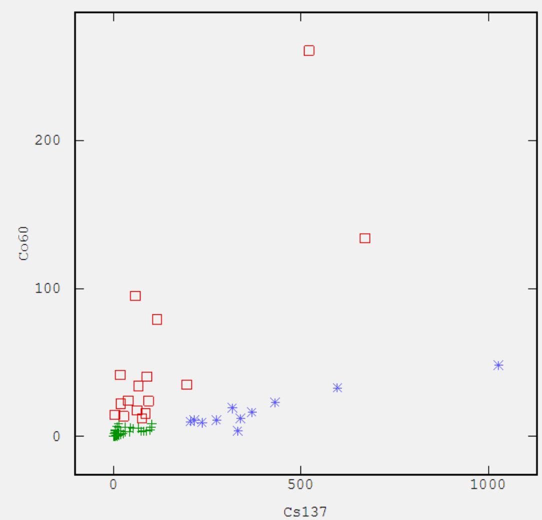
- Analysis, mapping and estimation tool
  - Suited to delineate the extension of the contamination: waste zoning assessment
  - Special emphasis on uncertainty quantification (contrary to other "classical" interpolators)
    → Enables risk analyses: decision-making tools, cost/benefit

»Exploratory data analysis

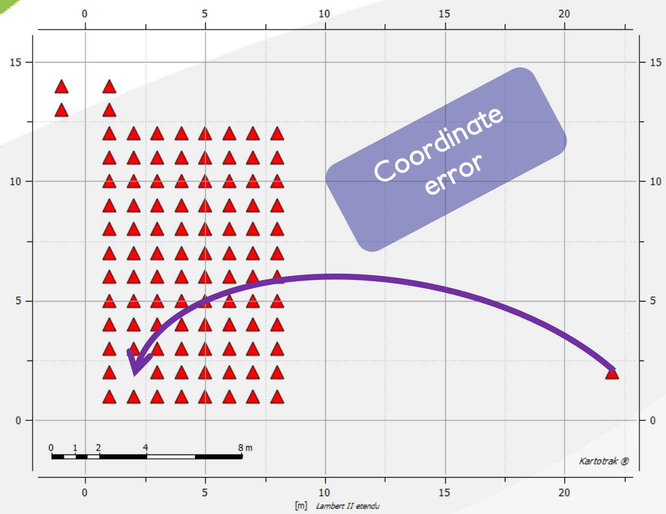
- Consolidation of the database (errors, different campaigns…)
- First spatial findings (base map)
- Statistical distribution (histogram)
- Similar behaviour (correlation cloud)

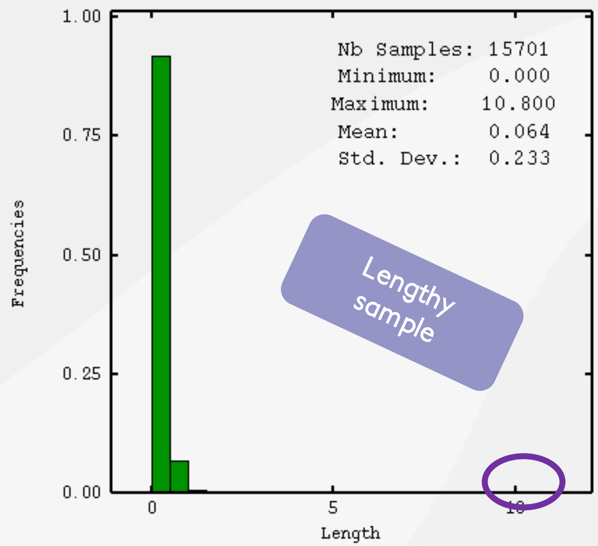


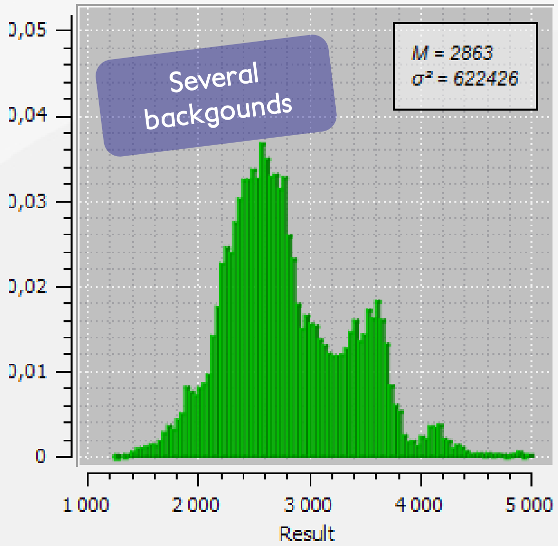


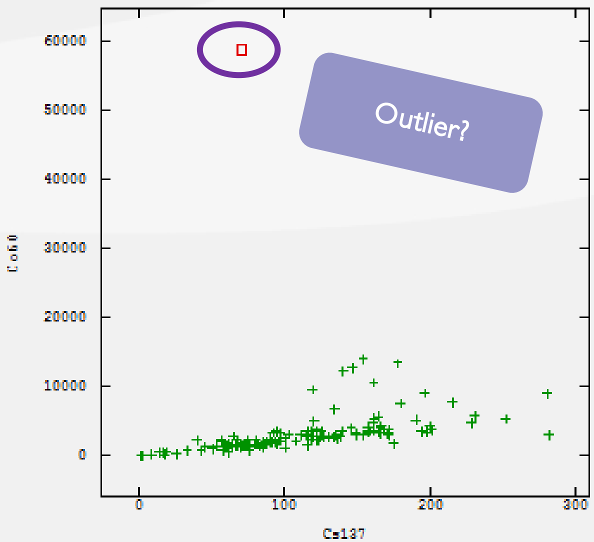


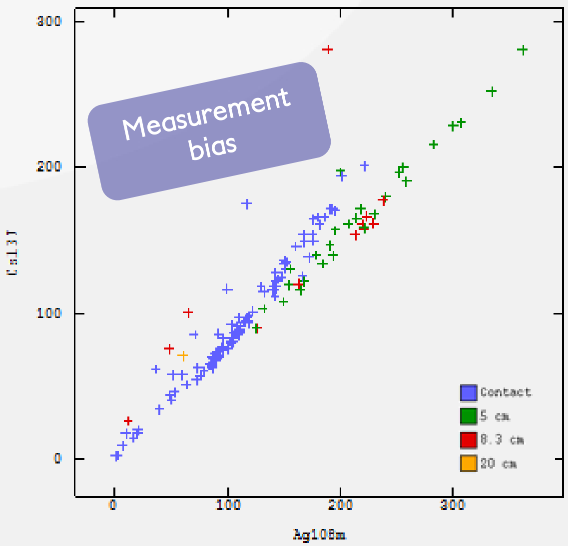
»In real life…

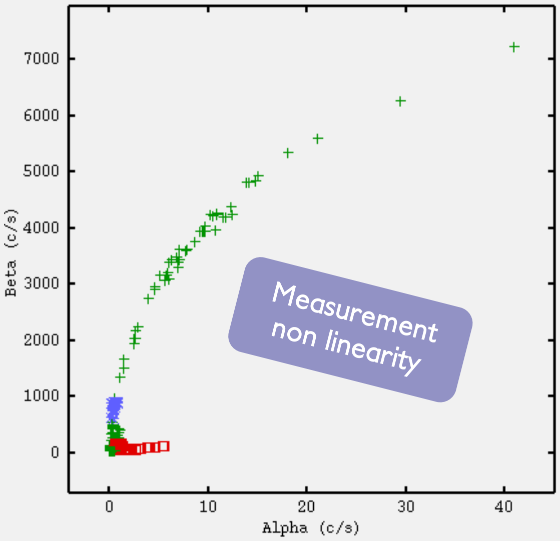

Coordinate error
Kartotrak ®
[m] Lambert II etendu


Nb Samples: 15701
Minimum: 0.000
Maximum: 10.800
Mean: 0.064
Std. Dev.: 0.233
Lengthy sample
Frequencies
Length


Several backgounds
M = 2863
σ² = 622426
Result


Outlier?
Co60
Cs137


Measurement bias
Contact
5 cm
8.3 cm
20 cm
Cs137
Ag108m


Measurement non linearity
Beta (c/s)
Alpha (c/s)

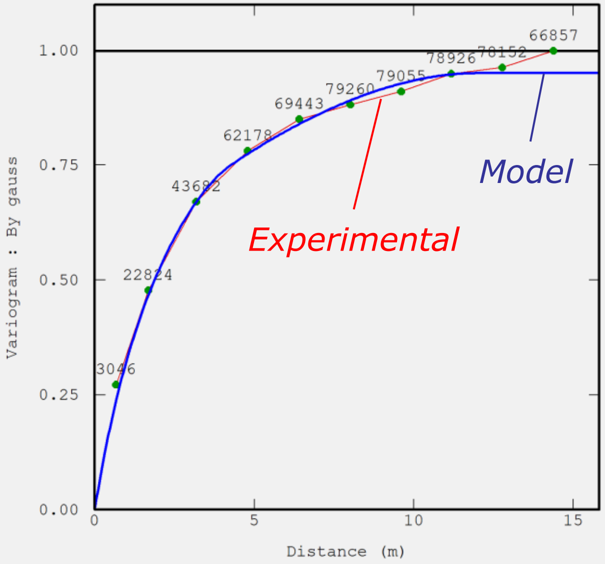
»Describing the spatial continuity

- Main tool of geostatistics:

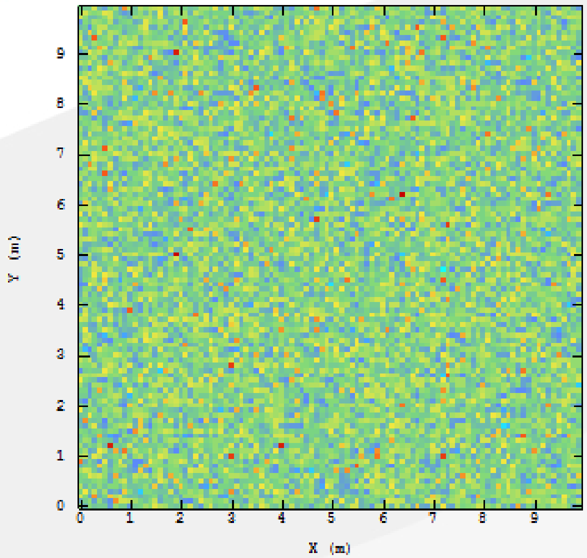
  the variogram

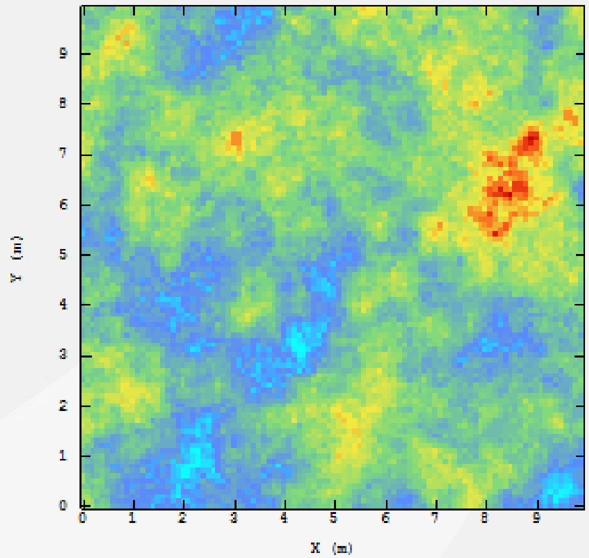
  - Description of the variability between 2 points
    - on average, the difference between two CLOSE measures is LOW
    - on average, the difference between two DISTANT measures is HIGH

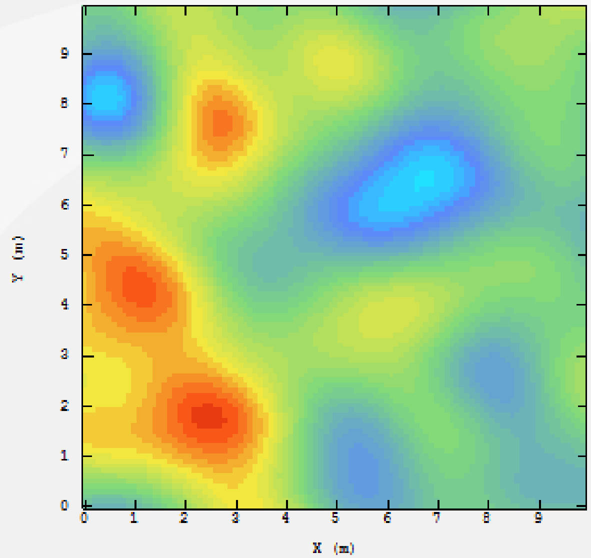
$$\gamma(h) = \frac{1}{2} E[Z(x) - Z(x+h)]^2$$

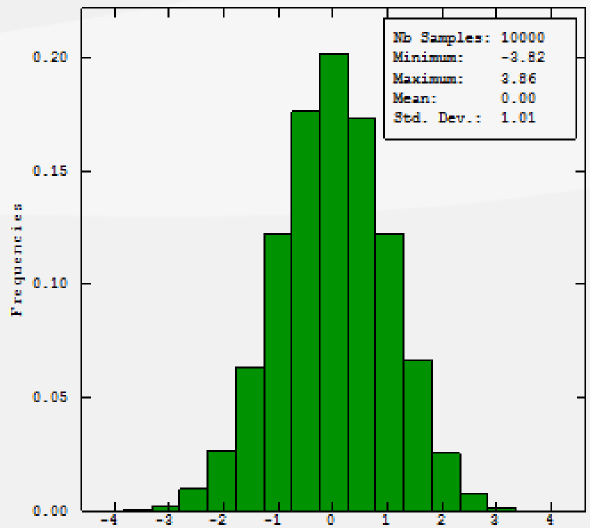


»Variograms of three examples



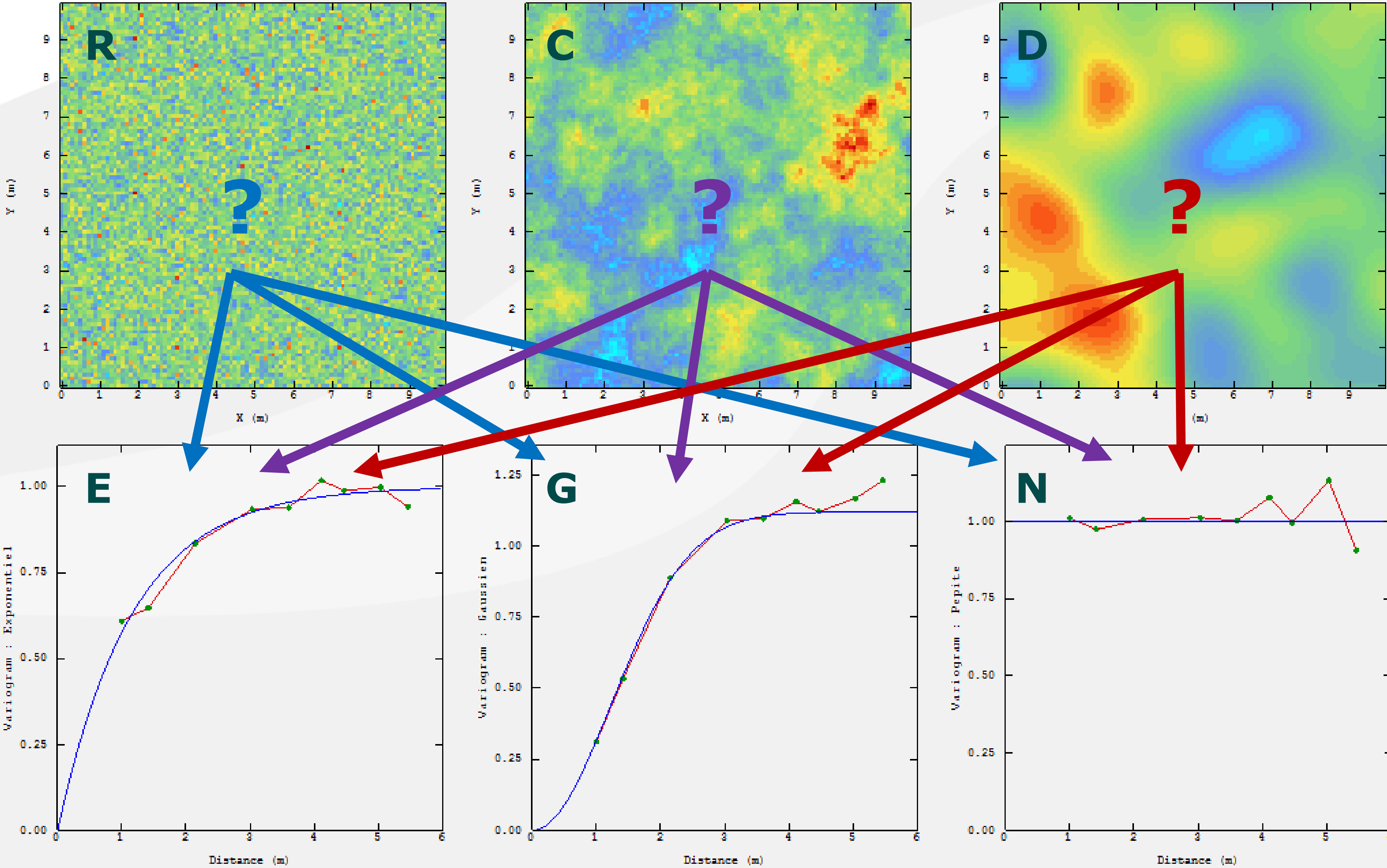




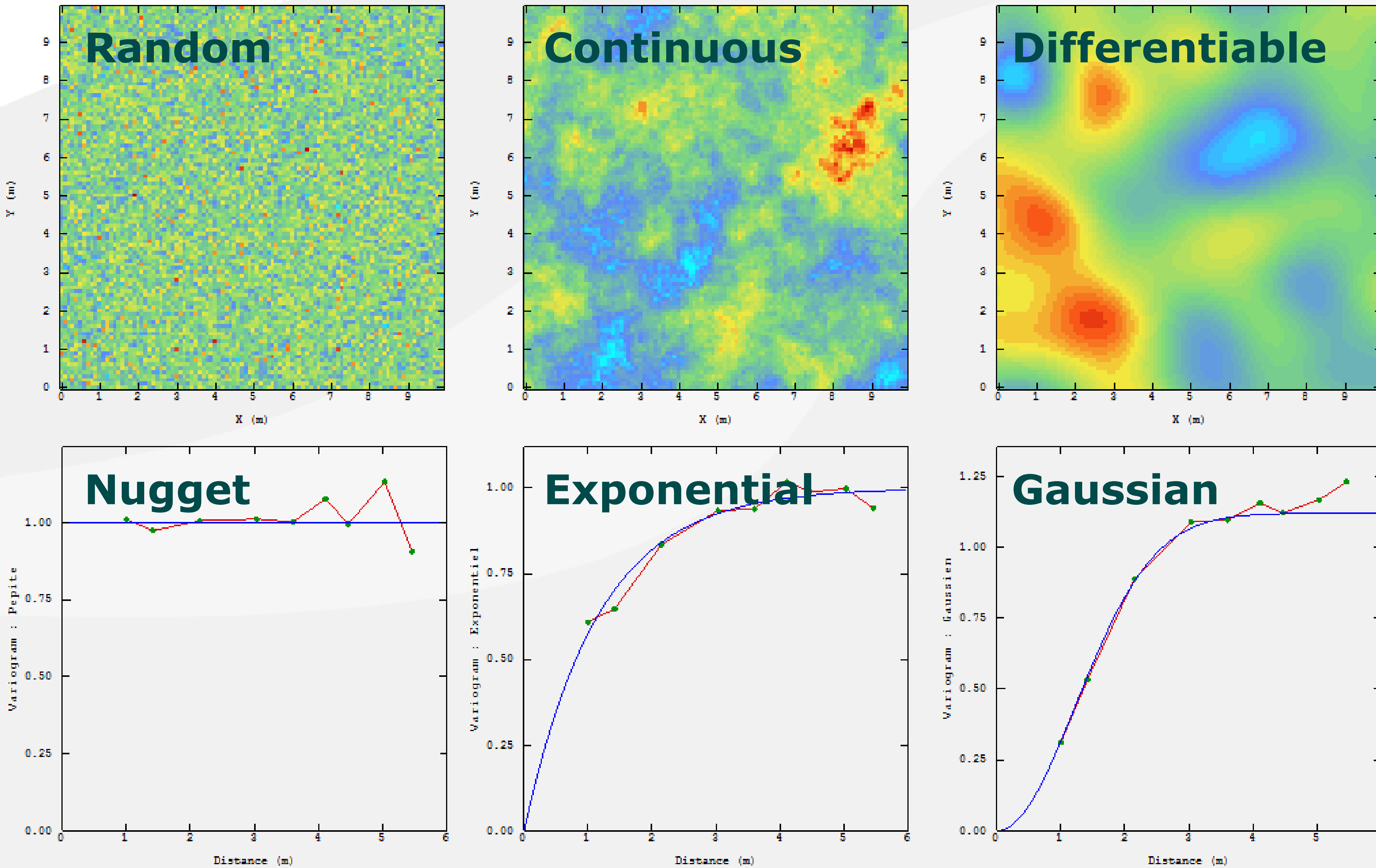


- Three spatial phenomena with the same statistical distribution
- Characterisation of the spatial structure thanks to a regular sampling grid

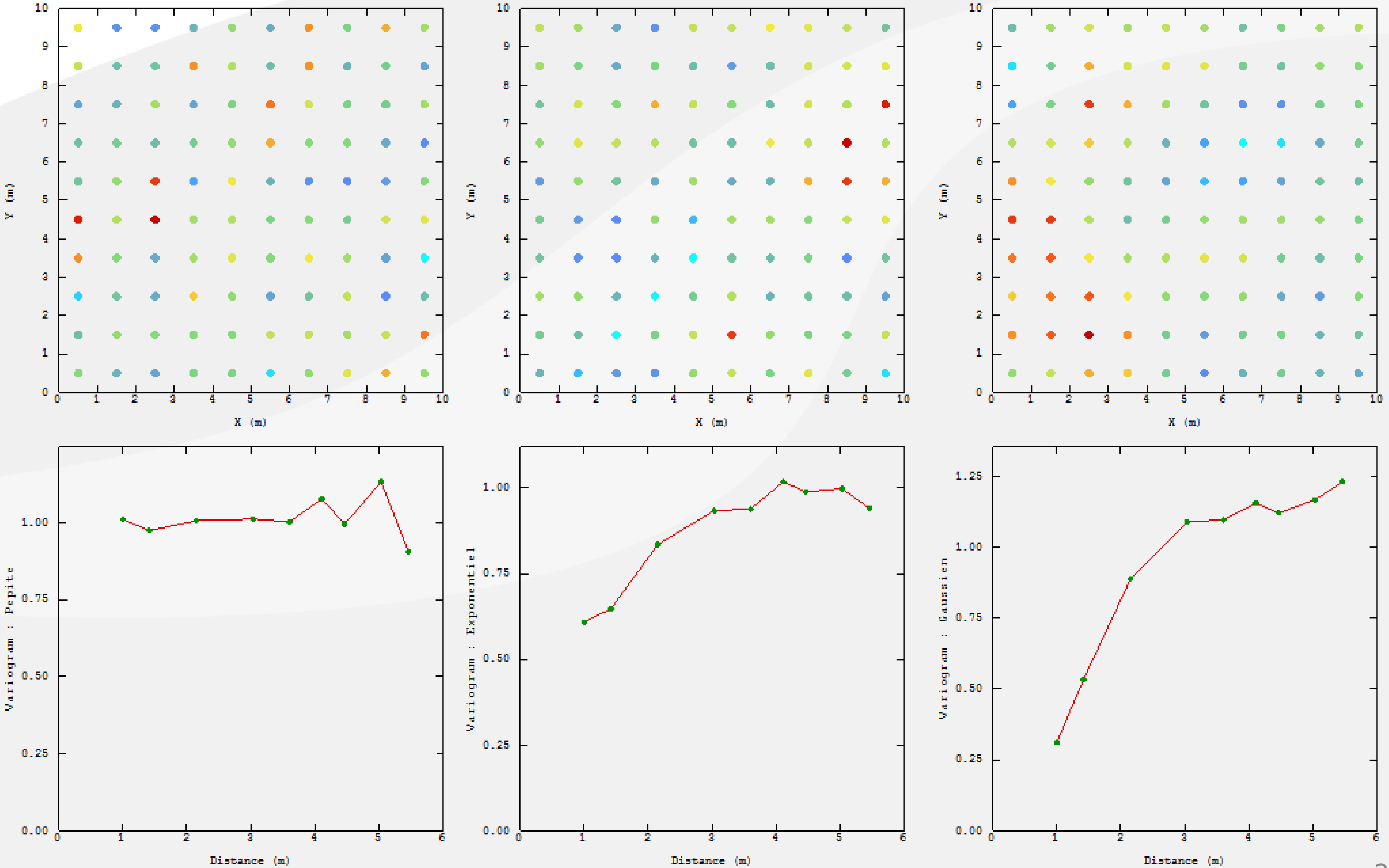
»Variograms of three examples



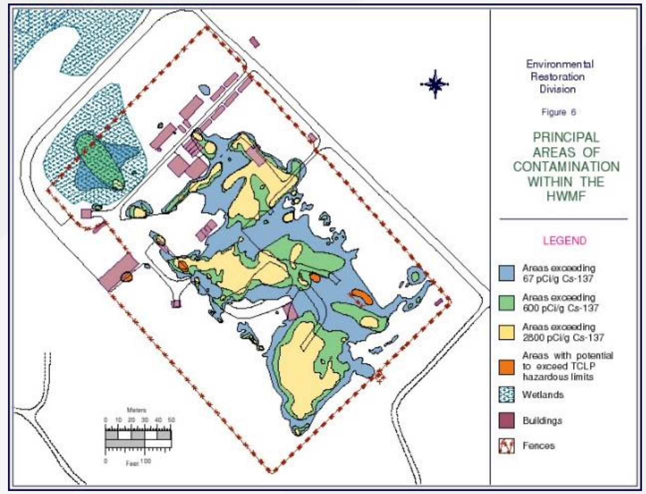
»Variograms of three examples

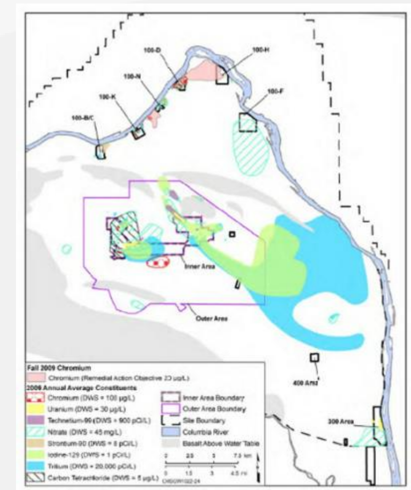


»Variograms of three examples



»In real life…





Trenches

Contaminated soils

Groundwater plume

Increasing of spatial continuity

»To sum up geostatistics

Understand

Exploratory data analysis

- Preliminary stage of geostatistics processing
- Data consolidation (cleaning errors and dealing with heterogeneities) and first spatial and statistical analyses (base map, histogram, correlation…)

Model

Spatial structure analysis (variography)

- Analysis and modelling of the phenomenon spatial continuity
- Integration of auxiliary variables to improve further estimates (multivariate, external drift…)

Interpolation (kriging estimates)

- Based on the variogram model, mapping of the phenomenon
- Kriging smoothing of the reality

Visualise

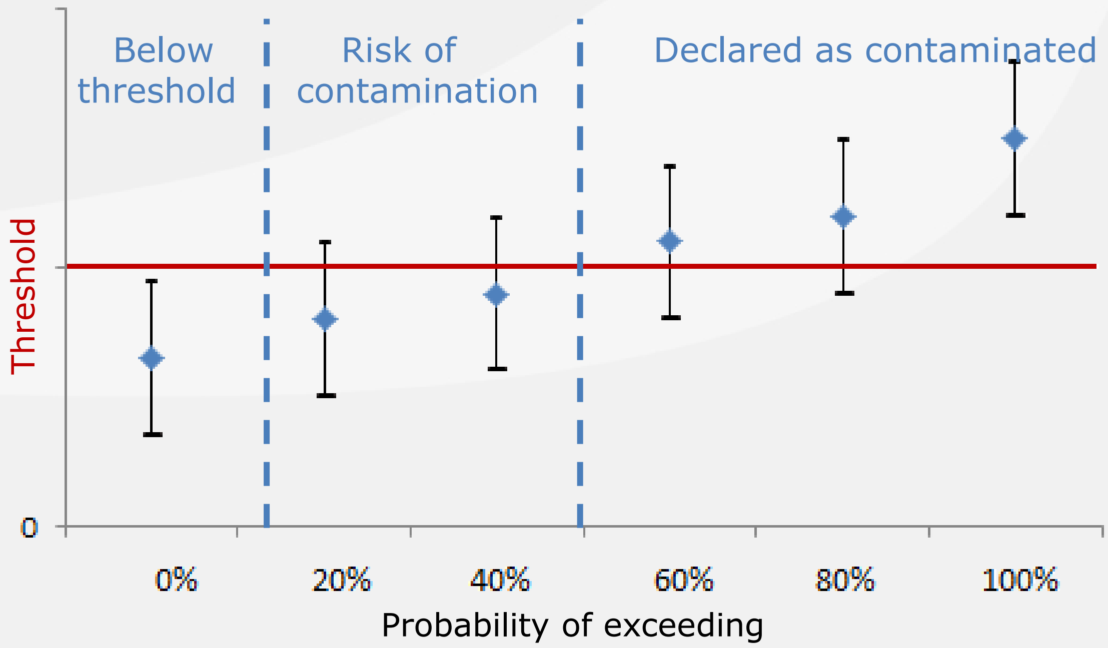
Risk analysis (uncertainty)

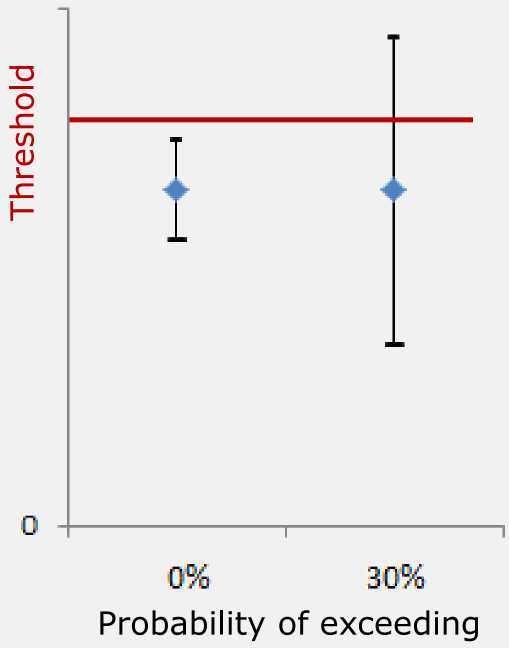
- Local mapping of the uncertainty
  - Geometric uncertainty
  - High variability areas
  - Probability of exceeding a threshold: waste classification
- Global estimates of total surfaces, volumes and accumulation (total activity)

Decide

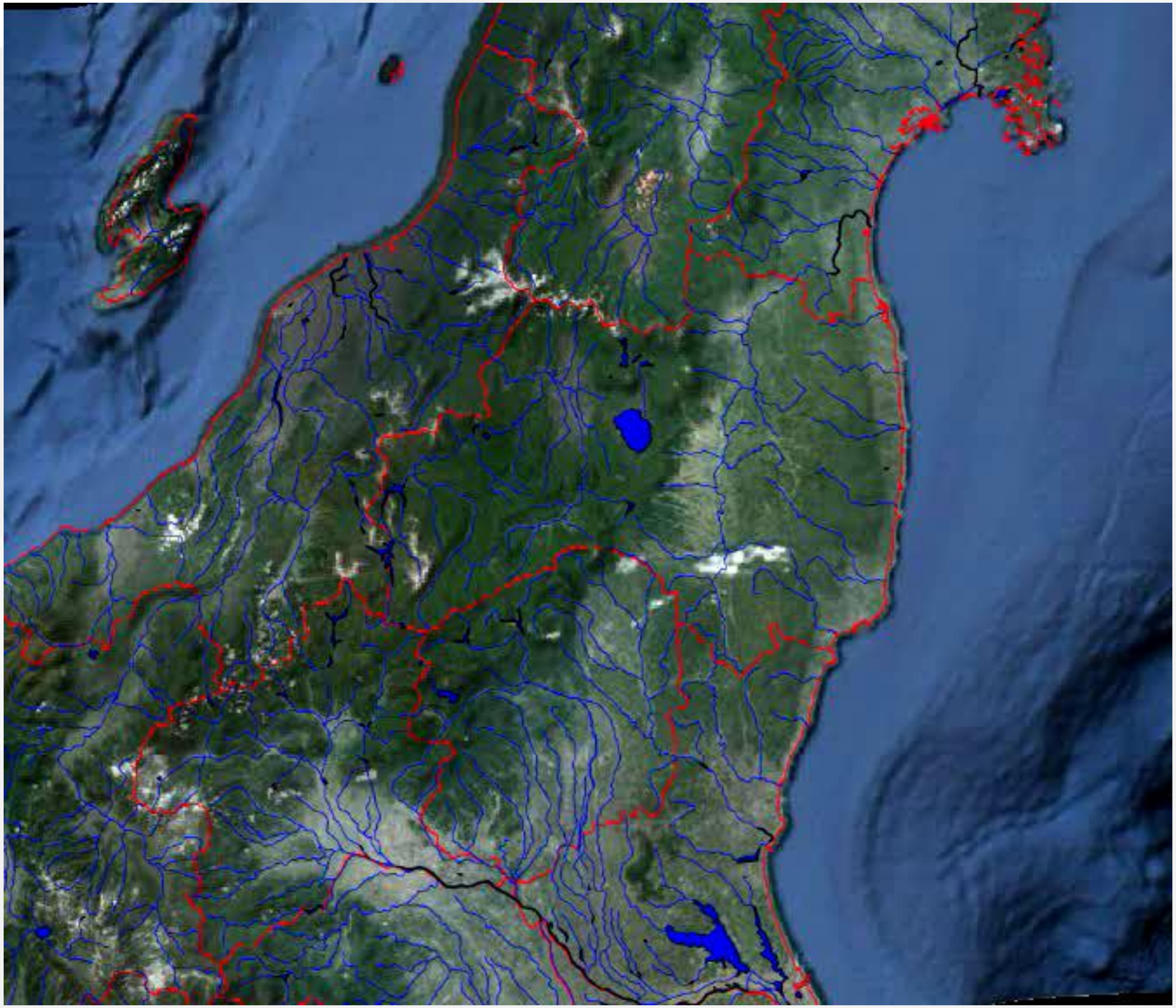
»Classification / Categorisation

- Use of probability of exceeding a threshold
  - Through a non linear estimation
  - Integration of estimation uncertainty





»Illustration case: Fukushima



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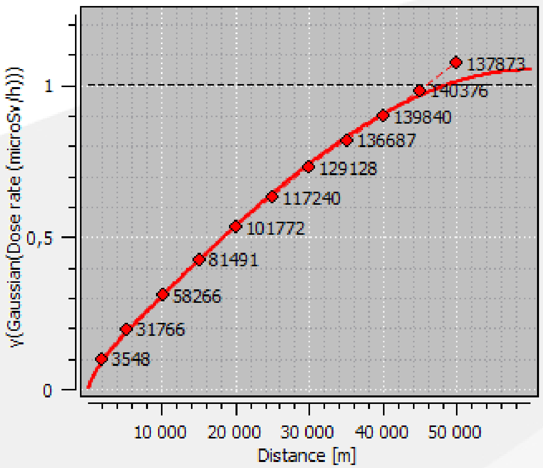
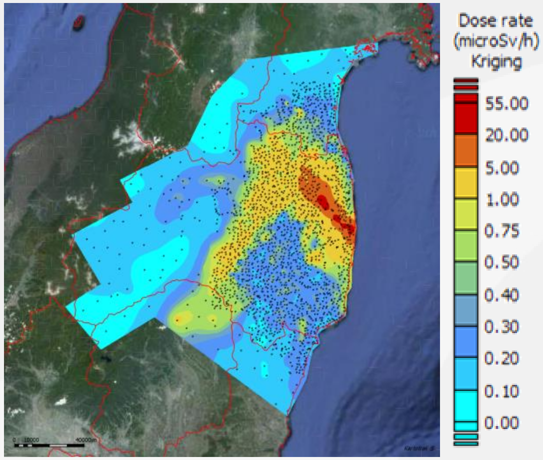
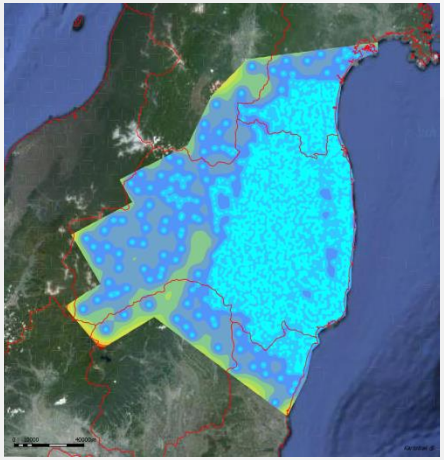
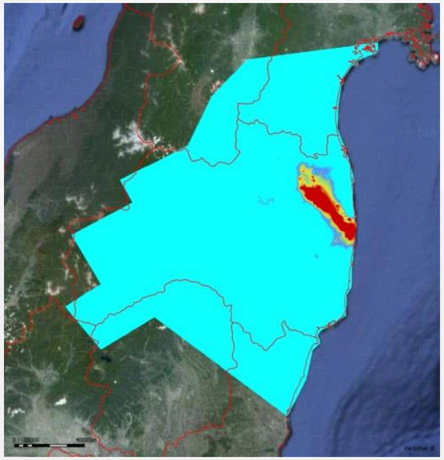


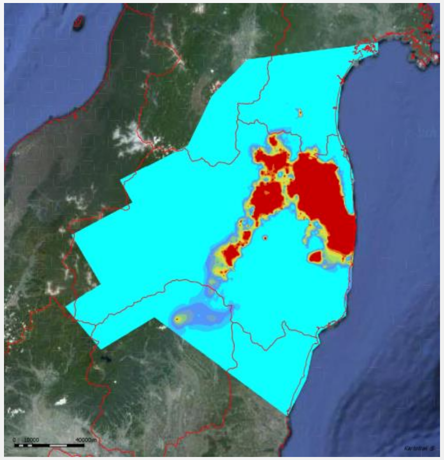
Spatial structure

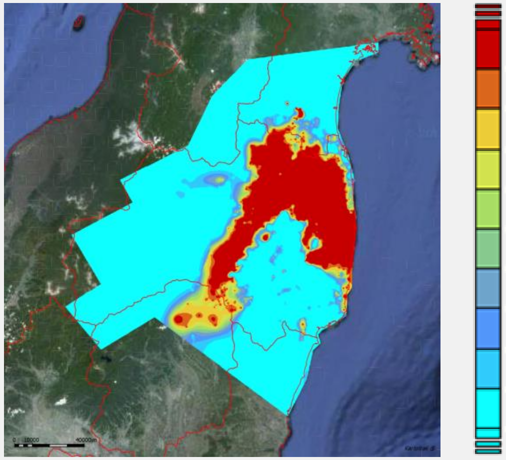


Kriging


Error variance

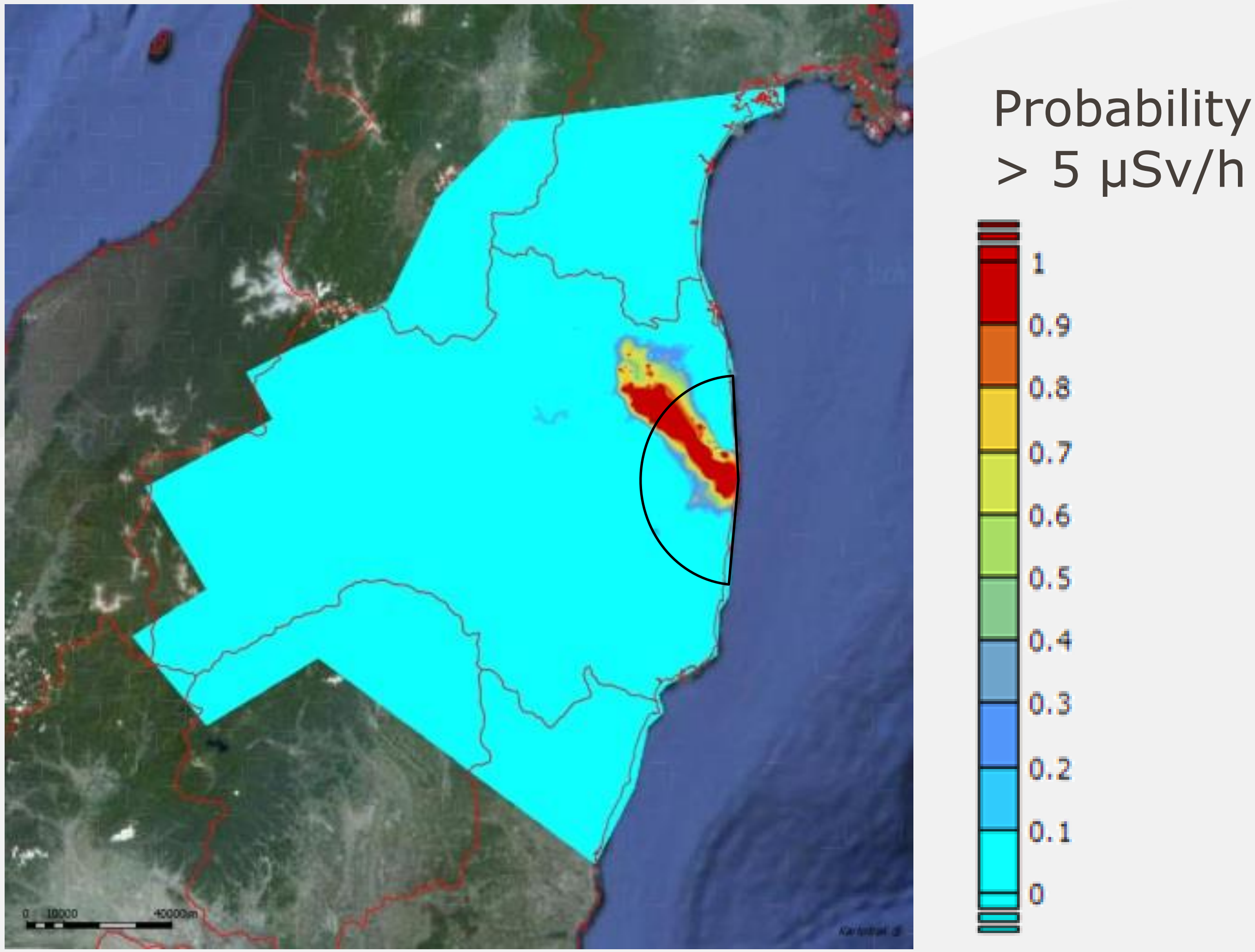

Probability > 5 μSv/h


> 1 μSv/h



> 0.5 μSv/h

»Illustration case: Fukushima

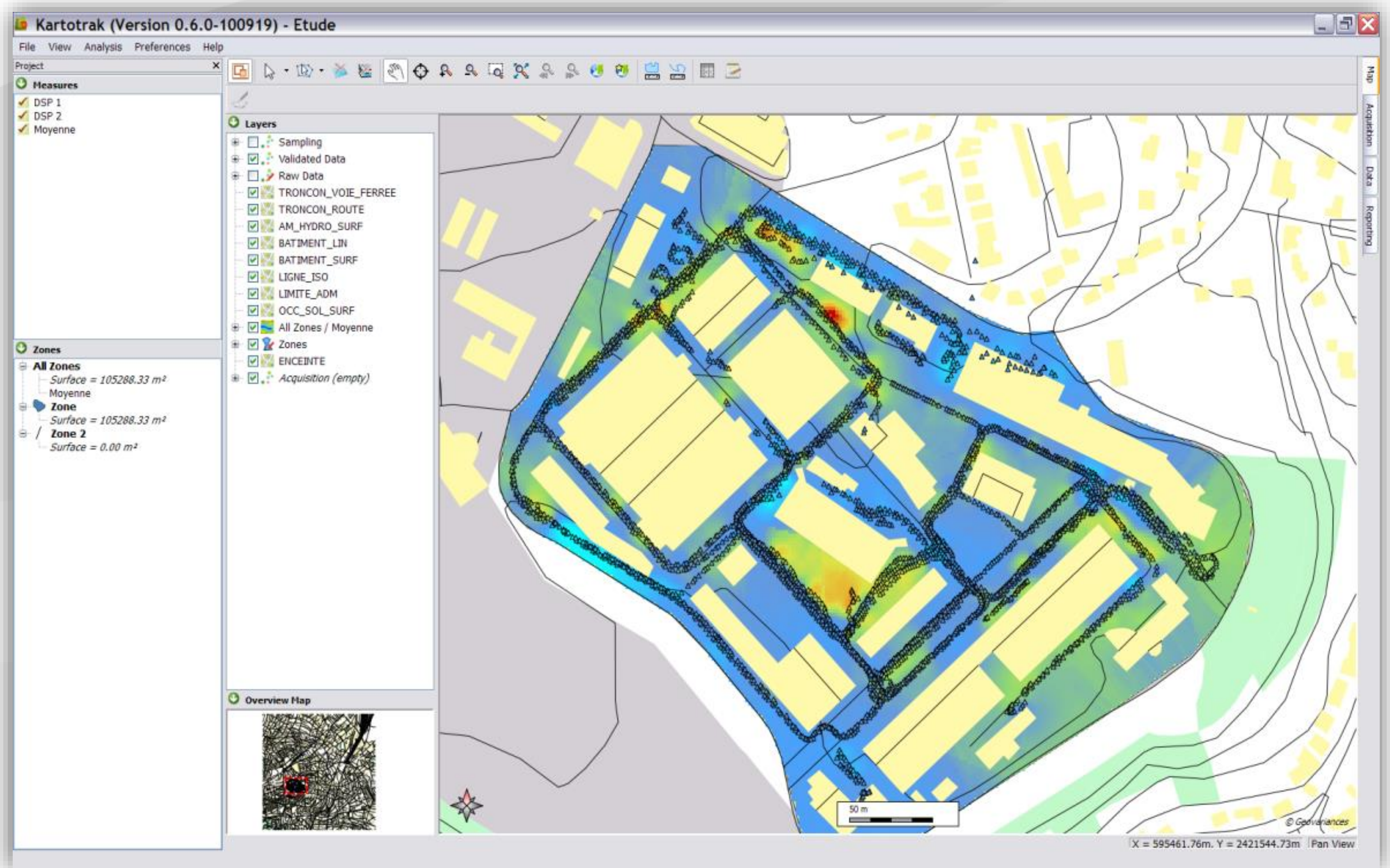


»Illustration case: Real-time

kartotrak

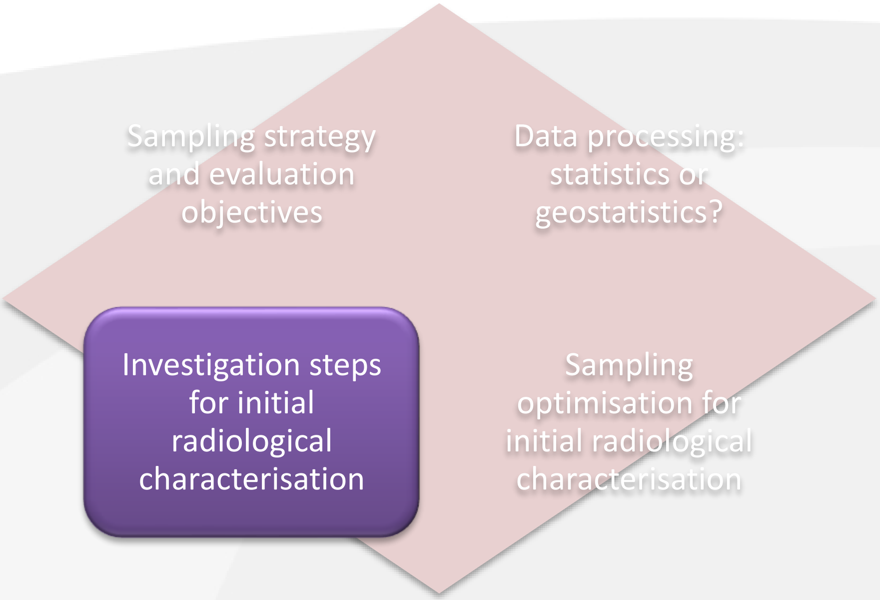
- On-site for streaming data acquisition connected to a GPS and several measuring devices
  - Quick contamination mapping
  - Real-time monitoring of covered areas
  - Additional investigation positioning
- At the office for:
  - Sampling plan preparation
  - In-depth data analysis
  - Risk evaluation

»Illustration case: Real-time



»Statistical approches

- Compliance with final radiological state
  - Statistical computations
    - Estimation of an average value, a proportion, a confidence interval…
  - Hypothesis testing
    - Compare average to a fixed value (regulatory threshold)
    - Compare average to a reference population (background)
  - Underlying hypotheses
  - Determination of the minimum required number of data
  - Uncertainties related to the result

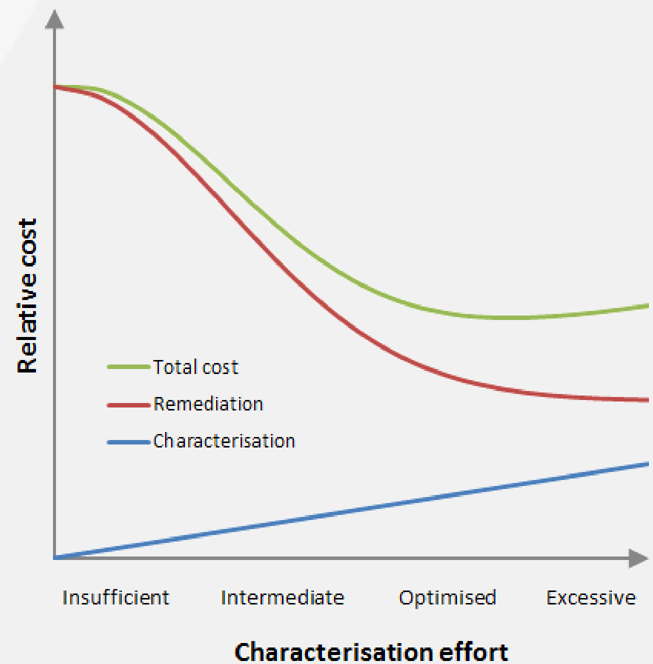


Part 3

» What are the investigation steps to assess the initial radiological state?

»Initial radiological characterisation

- Key issue for the success of decommissioning and dismantling projects
  - Radiological inventory and waste management
  - Decontamination technique selection / worker protection
  - Planning and budgets…



»Several objectives…

- Collecting and analysing data to:
  - Categorise radiological contamination
    - Scaling factors, activity levels, migration depth, total activity…
    - Operational waste zoning, waste route management optimisation
  - Define working conditions and worker protection
    - Fixed / labile contamination, hot spots, worker doses…
  - Foresee the final state
    - Cleaning objective, ALARA approach

»Characterisation methodology

Historical and functionnal analysis

- Fragmented data
- Qualitative analysis
- Identification of special areas

Surface radiation survey

- Regular grid + special areas
- Half-quantitative representation
- Limitation alpha and in-depth contamination

Radiological waste segregation

- Judgmental positioning
- Quantitative representation
- Activities and depths

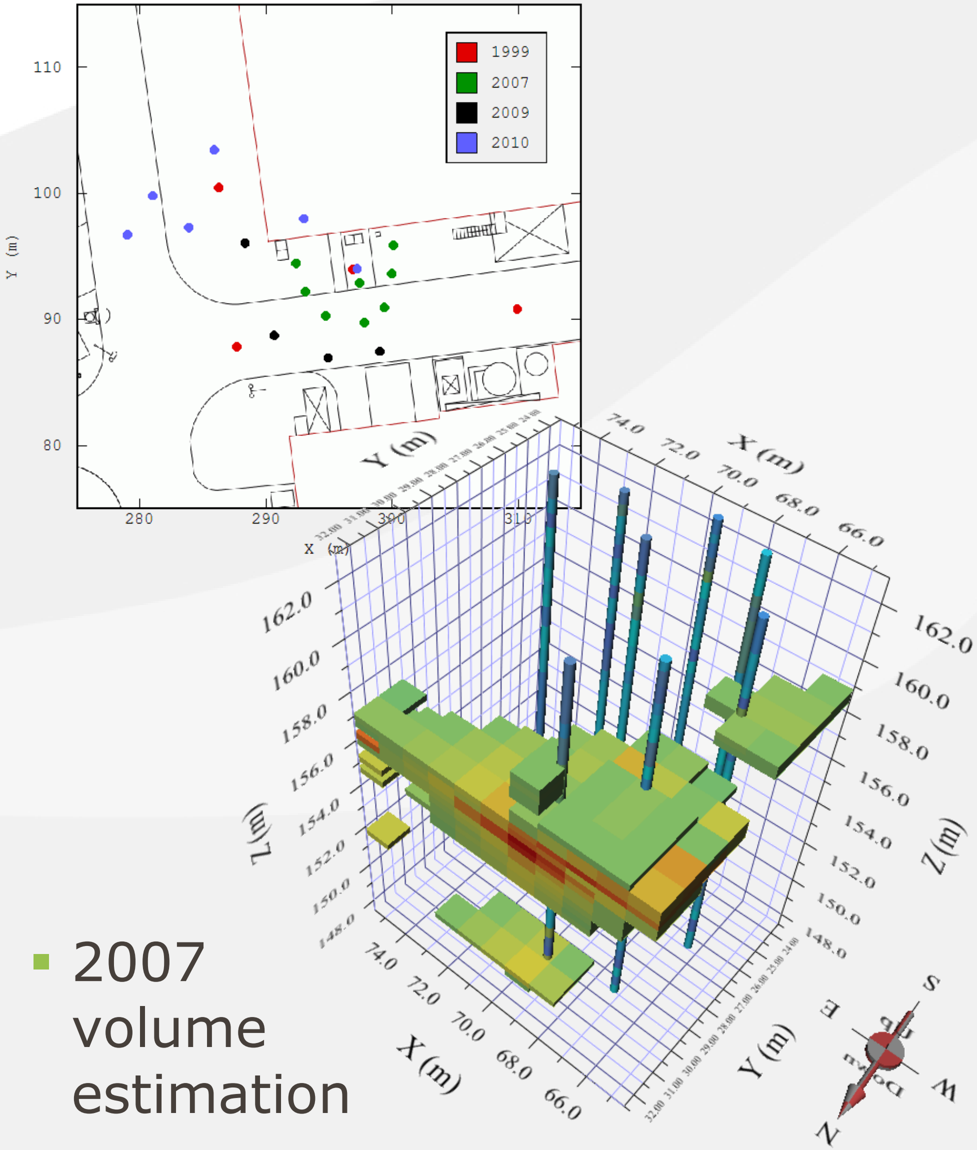
»Characterisation methodology

- Sequential characterisation / global approach
  - Multivariate geostatistical processing of the dataset
  - Reinforcement of the first defence level instead of a case by case approach (S3 classification in French NSA guide 14)
  - Characterisation, characterisation, characterisation!

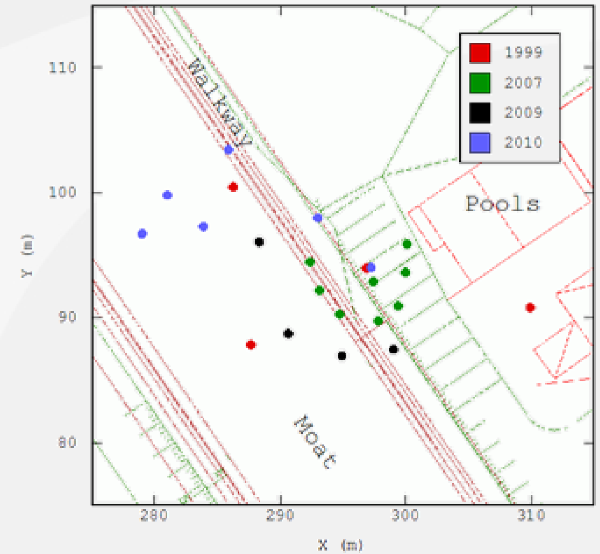
- Pitfall to avoid
  - Over-categorisation (excess of conservatism)
  - Bad surprises (unexpected nuclides or activity levels)

- Sampling optimisation

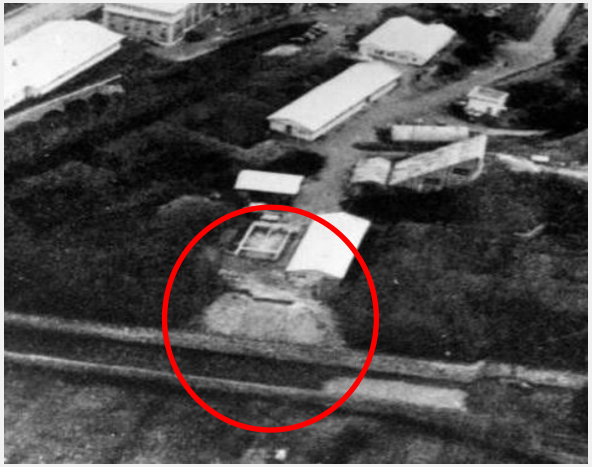
»Illustration case: 50 years old contaminated soil



- 2007 volume estimation



- Historical context



»Illustration case:50 years old contaminated soil

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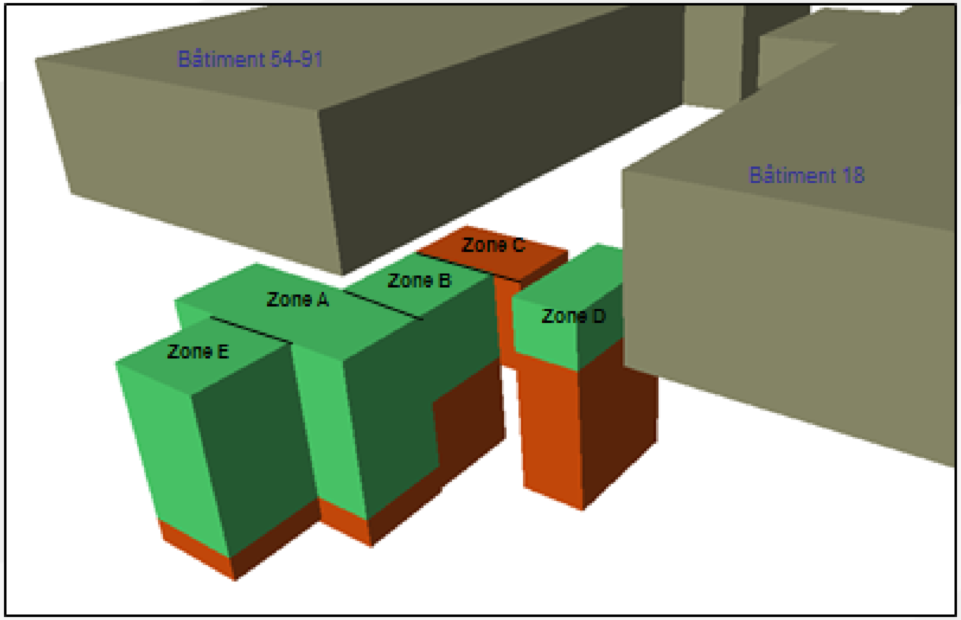
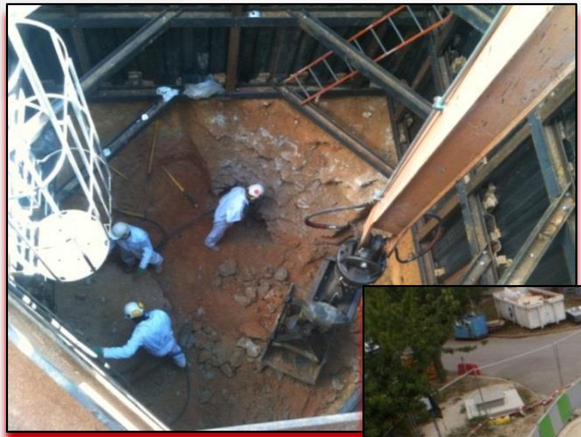
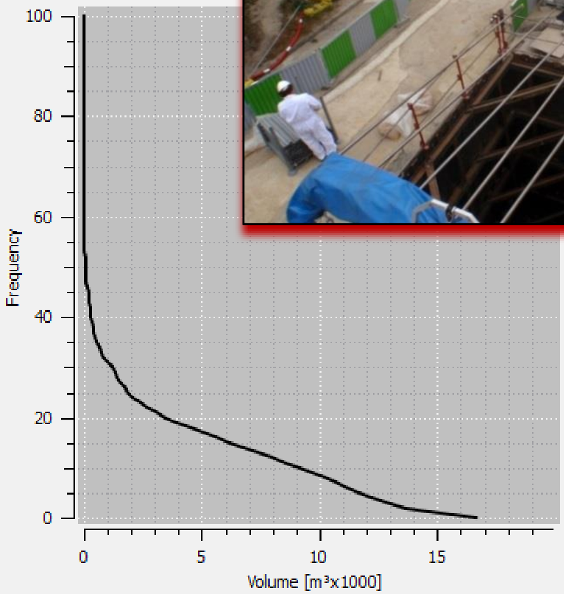
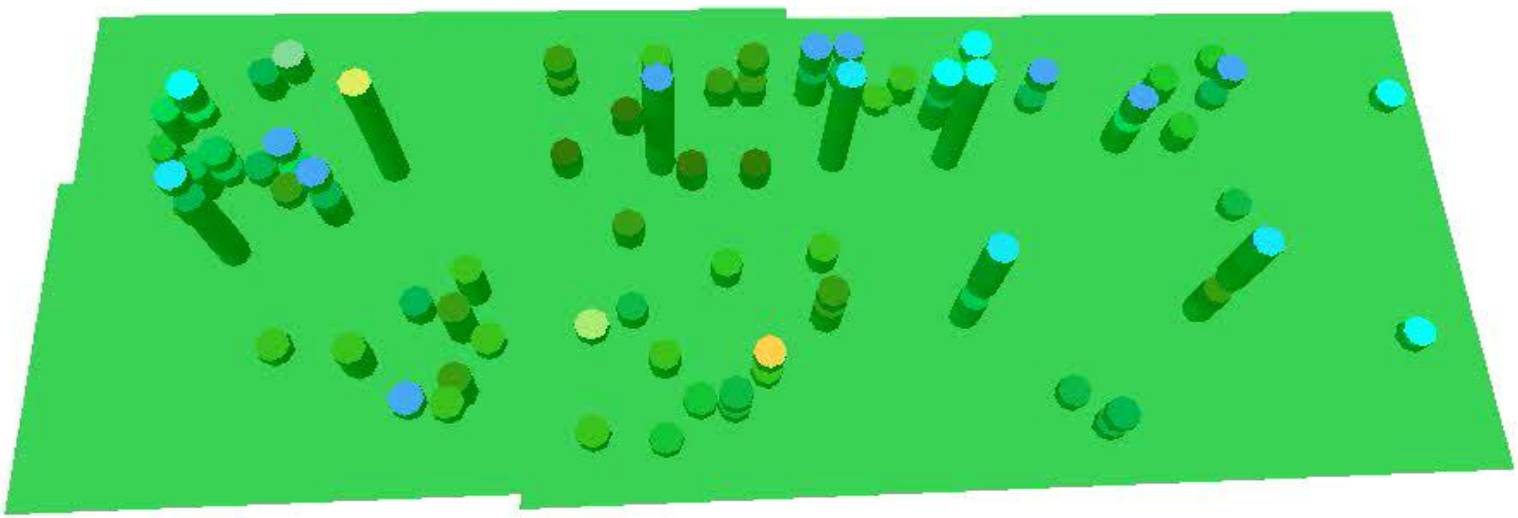


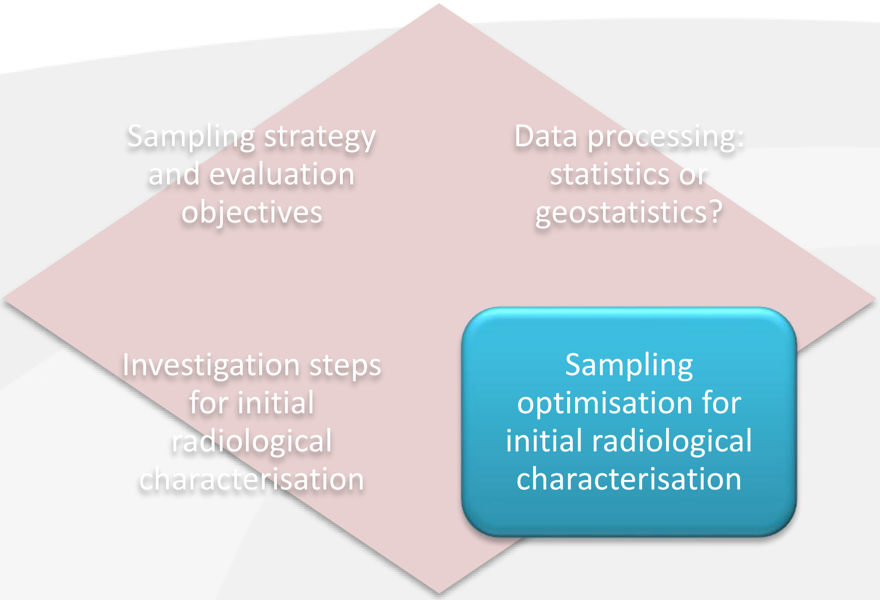




- 2000 m^3 of conventional waste
- 2000 m^3 of VLL waste

»Uranium conversion plant





Part 4

» How to optimise the investigations during the initial radiological characterisation?

Sampling optimisation

Initial mesh

- Integration of the historical and functional analysis
- Experience feedback on spatial structures
- Geometric objective: Probability of hitting a target

Adding extra measurements

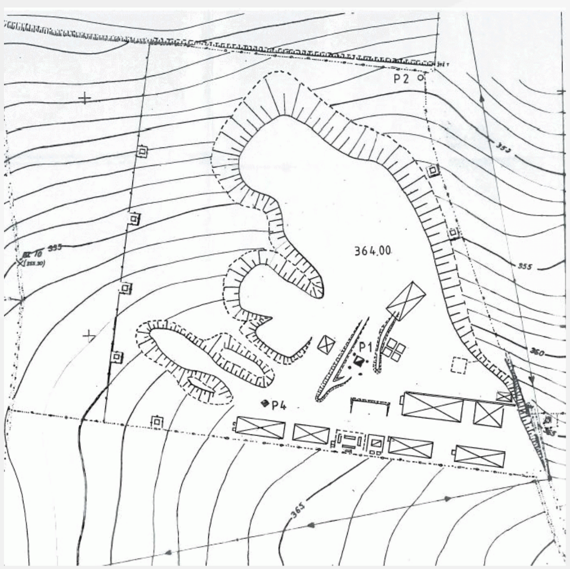
- Taking the risk analysis mapping into account
- Experimental approach and automation (objective function)

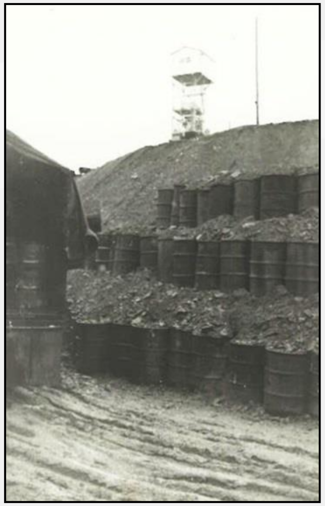
Sample positioning

- Based on 2D maps (correlation)
- Considerations for the vertical resolution

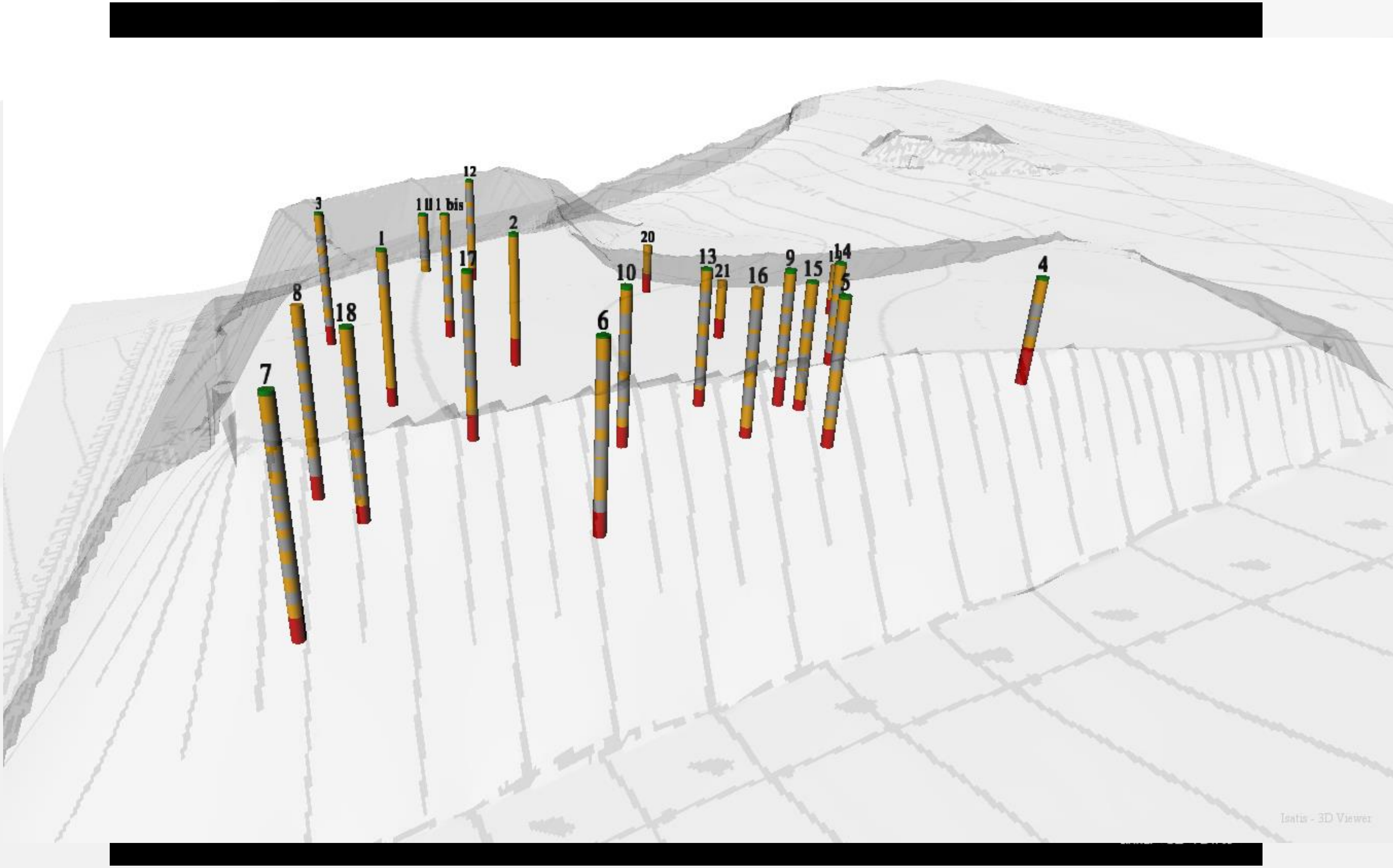
»Illustration case: Drum legacy site

- First French final disposal site
  - 80,000 drums on a former uranium mining pithead
  - Historical analysis based on numerous records…
  - Topographical data + aerial photos

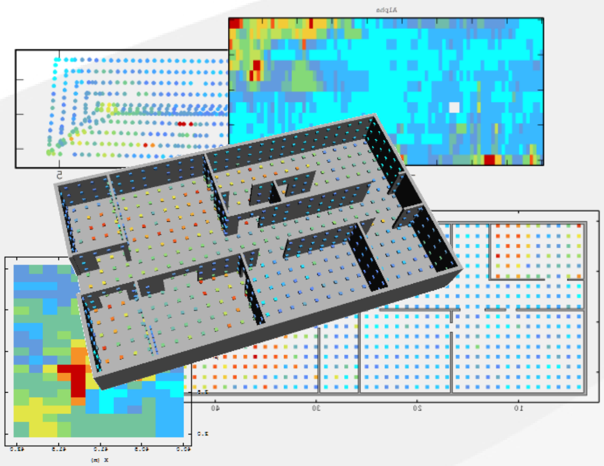




»Illustration case: Drum legacy site

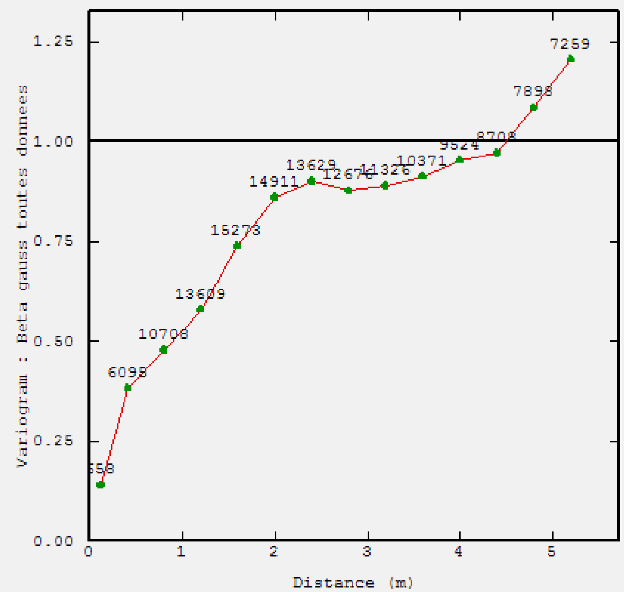


»Spatial structure synthesis



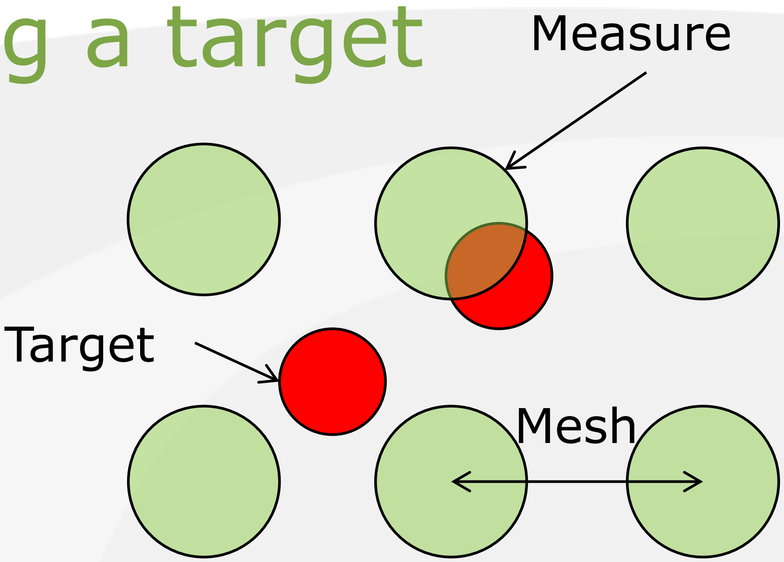
- A large amount of sites and buildings (history, surfaces, processes, measurements…)

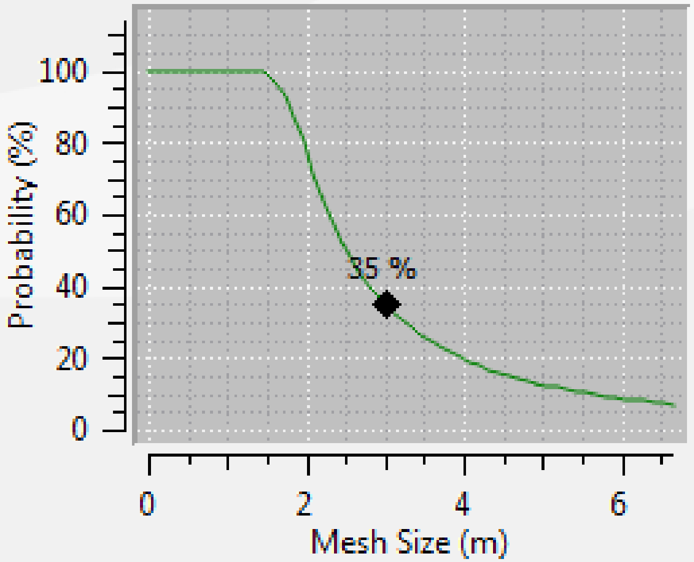
- Systematic presence of a spatial structure
  - Relevance of geostatistics
  - General trends
    - Main range 2-5 m
    - Limited nugget effect

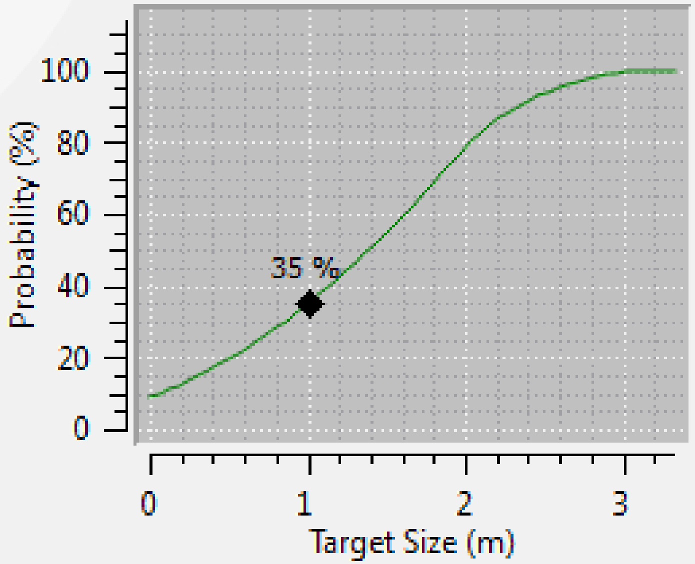


»Probability of hitting a target

- Geometric considerations
  - Size of the target
  - Size of the measurement
  - Size of the sampling mesh

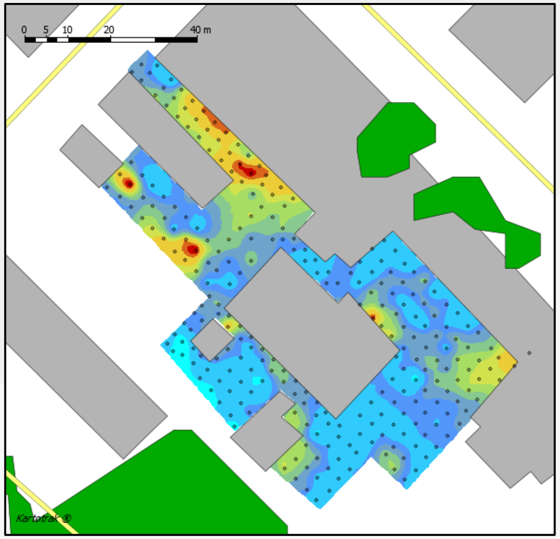




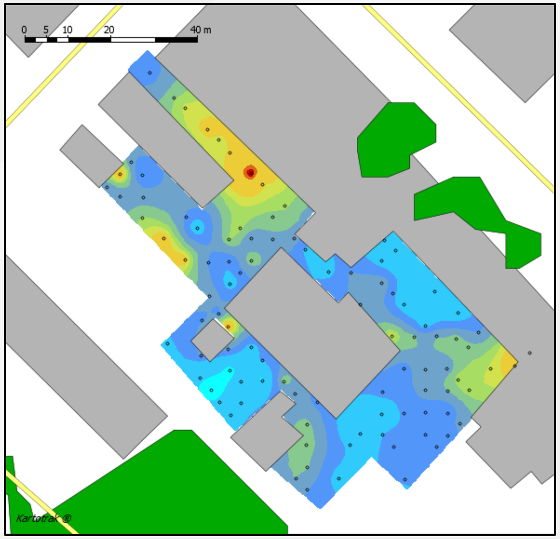


»Initial mesh resolution

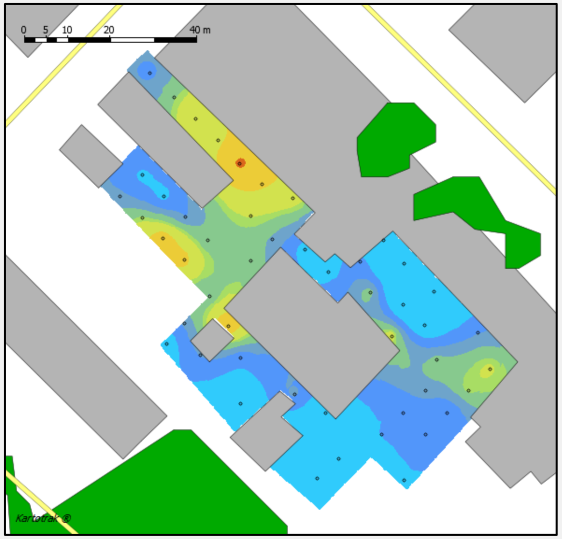
- Statistics and variographic robustness
- Impact on estimation map and uncertainty quantification



265 points



100 points

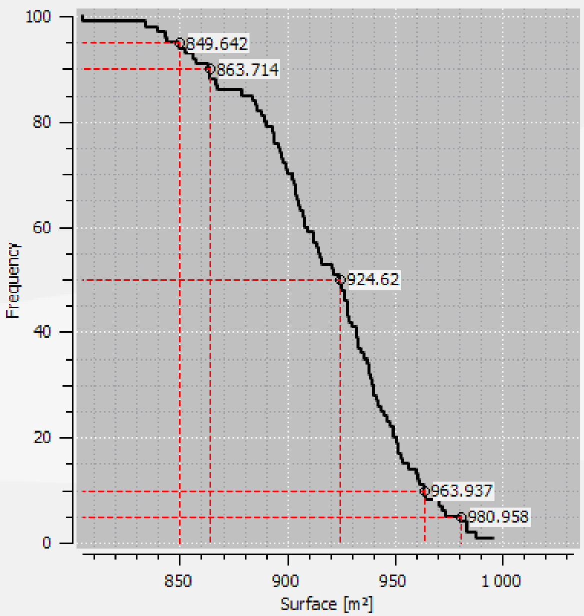


50 points

- What is the objective?
  - Hot spots / Trends / Waste zoning…

»Initial mesh resolution

- Impact on global risk analysis
  - Variability around the more precise scenario
  - Risk curve spreading → uncertainty increase



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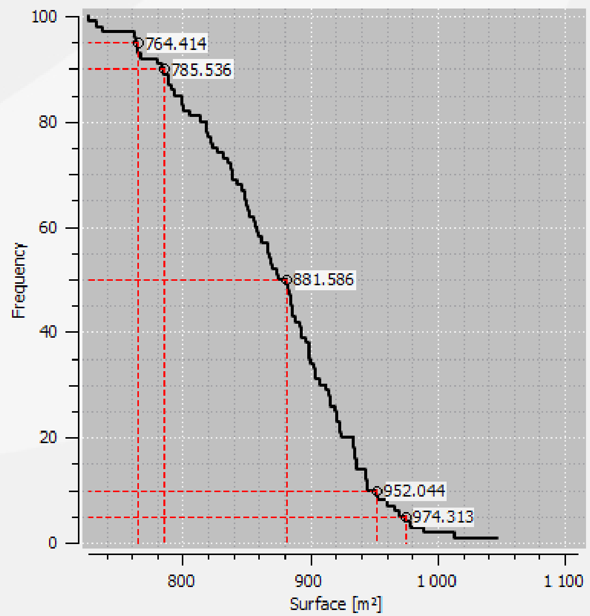
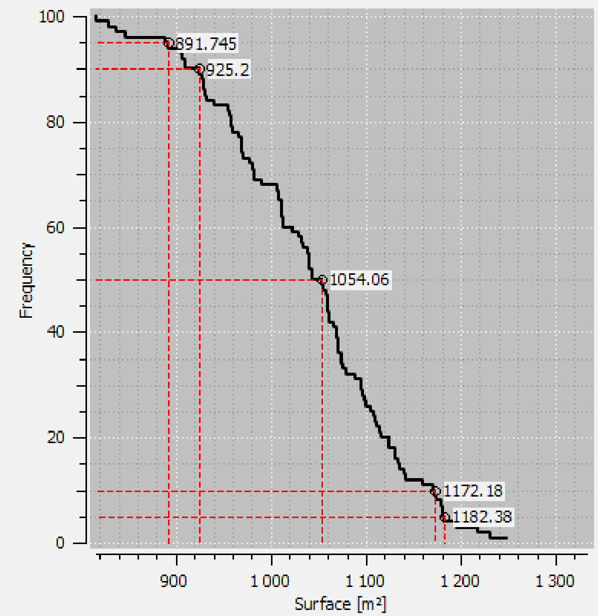


100 points



50 points

»Adding extra measurements

- Reducing uncertainties
  - Iterative approach
  - Real time adaptation
  - Selection of the criterion to be improved
  - Visually or with genetic algorithms

Kriging variance
- Under-sampled areas, spatial covering

Confidence interval
- High variability areas

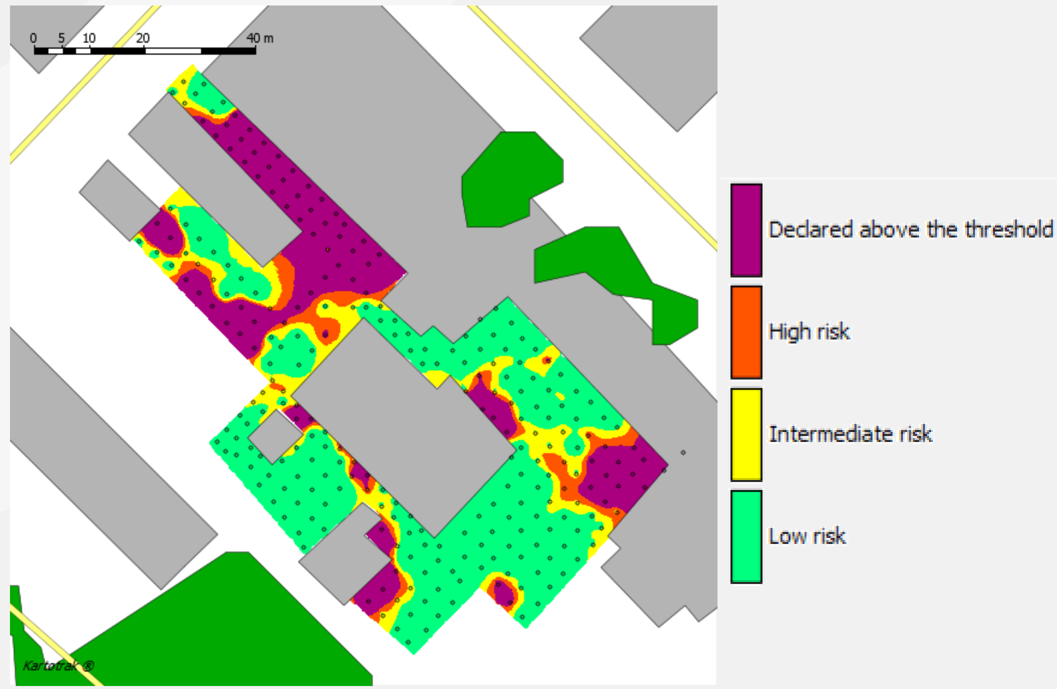
Ratio between confidence interval and estimate
- Homogeneous areas and transition zones in high variability areas

Risk of exceeding a threshold
- Uncertain areas according to the threshold

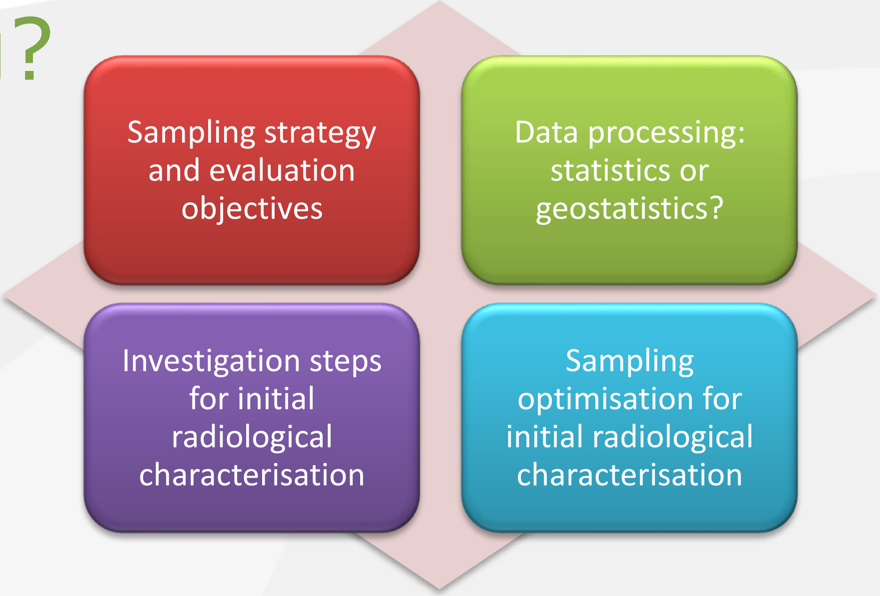
»Risk maps for extra points

- Confidence interval

- Misclassification risk (false negative)



»A better understanding?



- Added value of geostatistics
  - How to optimise the different sampling campaigns?
  - How to precisely assess the initial radiological state before starting the decontamination work?
  - How to estimate the waste volumes according to the different routes and the related uncertainties?

Thank you

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