RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité

Forum TERATEC 24
Unlock the future

CLUSTERING METHODS FOR DECISION-MAKING

Application to Flood Risks and Radiological Emergencies

I. Korsakissok, Y. Richet

Institut de Radioprotection et de Sûreté Nucléaire

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Crédits F. Dubray / Ouest France 2021

Crédits IRSN

DECISIONS
FACING NATECH RISKS

RISKS MANAGEMENT

NATURAL AND/OR TECHNOLOGICAL (NATECH)

- Crisis situations
  - High **uncertainties** are intrisic to accidental situations
  - **Anticipation** : numerical simulations are a mandatory to predict potential consequences and protect population
  - Strong **time constraints**
- *Operational* decisions
  - Need for **clear and concise** information
  - Communication of **evaluation products** to **decision makers** *should* account for uncertainties

L'Aquila earthquake scientists win appeal

Six seismologists and official had been convicted over reassurance issued to residents before fatal quake in 2009

Orages en Corse : Météo-France invoque une situation « difficilement prévisible »

L'activation tardive de la vigilance orange, alors que les rafales ont atteint 200 km/h par endroits, illustre la difficulté à traduire les probabilités de phénomènes météo en un système d'alerte crédible.

Le Monde avec AFP

Publié le 18 août 2022 à 21h34, modifié le 24 juillet 2023 à 16h29 · Lecture 3 min.

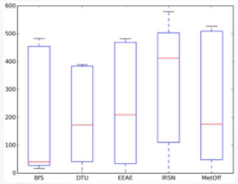
→ Crisis : **quick** decisions under **uncertainties**

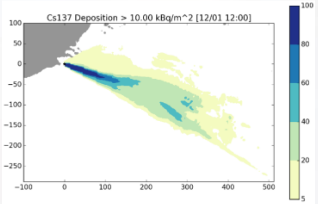
UNCERTAINTY ANALYSIS & INTERPRETABILITY

Uncertainty models for quantitative analysis or decision-making

- Quantification of input / model uncertainties
- Sensitivity analyses/indices (Sobol, Shapley, HSIC, ...)
- "Envelope" of trust, probability of threshold exceedance...
- Confidence level in evaluations
- **Identification of representatives/prototypes**

✓ Should be decision-oriented, incl. practical information (e.g. population, agriculture...)
✓ If possible, avoid interpretation bias

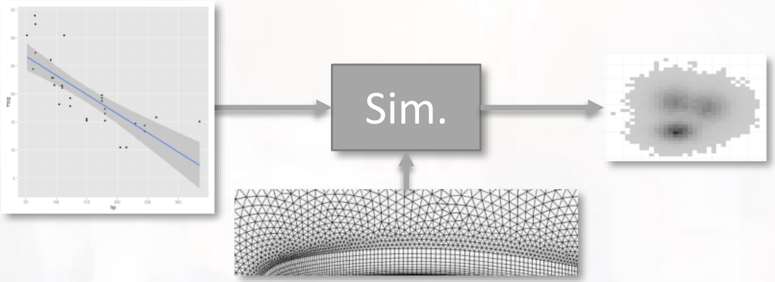




Simplicity / Interpretability

UNCERTAINTIES QUANTIZATION

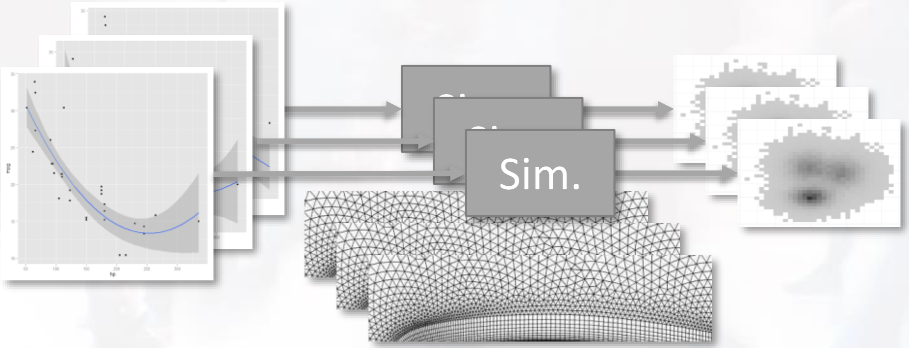
Simulations:



… a suitable support for propagation of uncertainties

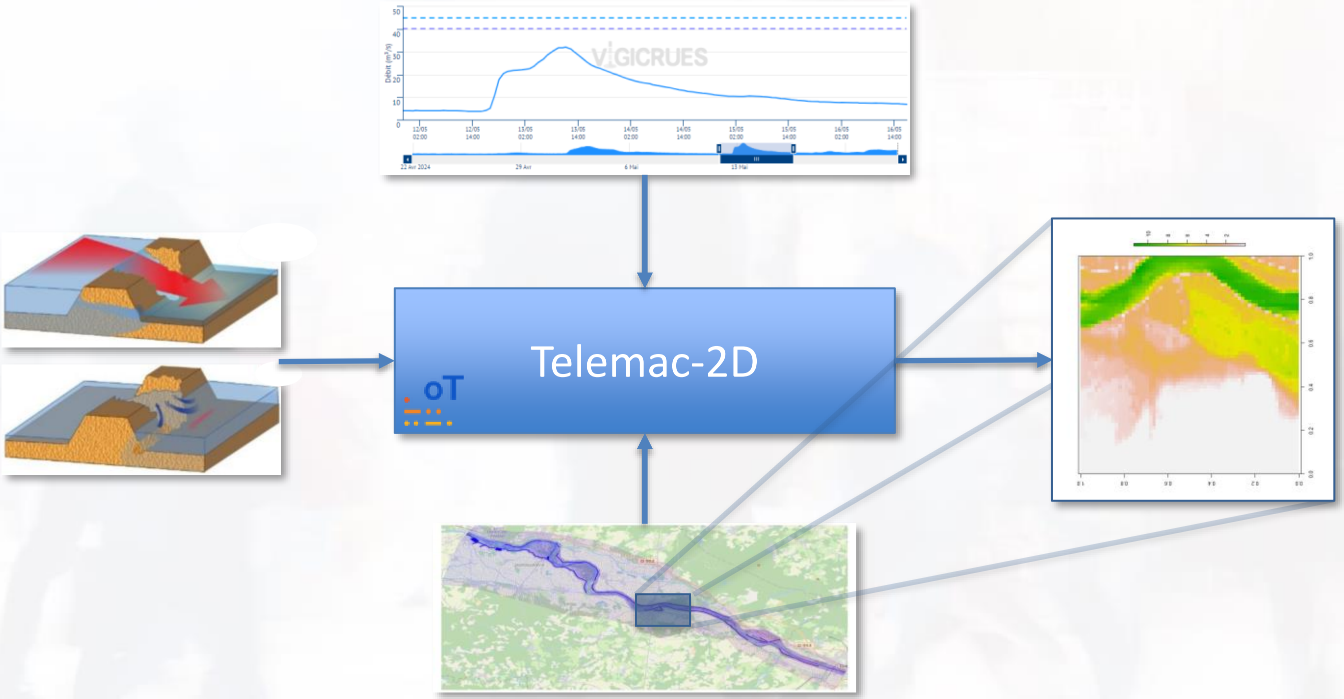
Ex. :

- Monte Carlo / random sampling
- Sets
- Quantiles / delta
- [Fuzzy logic]
- [Experimental Calibration]



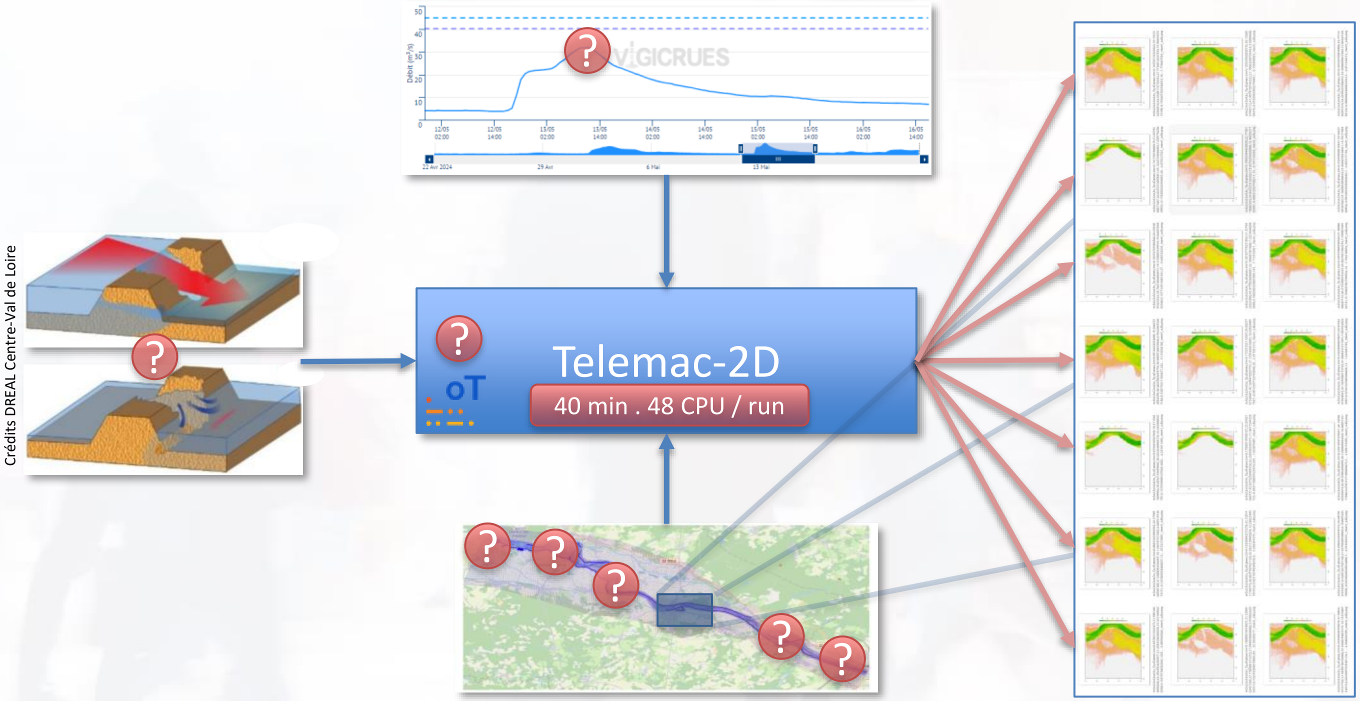
MODELLING HIGH-DIMENSIONAL DATA

[Ex.] Flooding



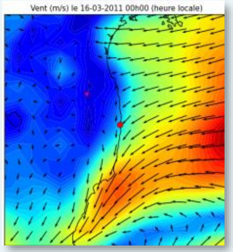
Crédits DREAL Centre-Val de Loire

[Ex.] Flooding

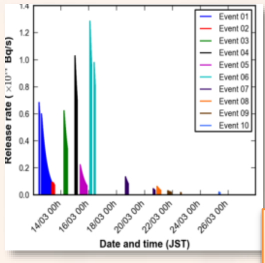

Crédits DREAL Centre-Val de Loire
VIGICRUES
Telemac-2D
40 min . 48 CPU / run

[Ex.] Radiological emergency response

Meteorology
- Observations
- 3D forecasts

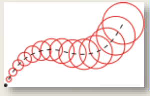


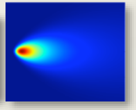
With Météo France

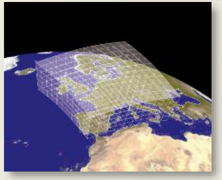


With operator

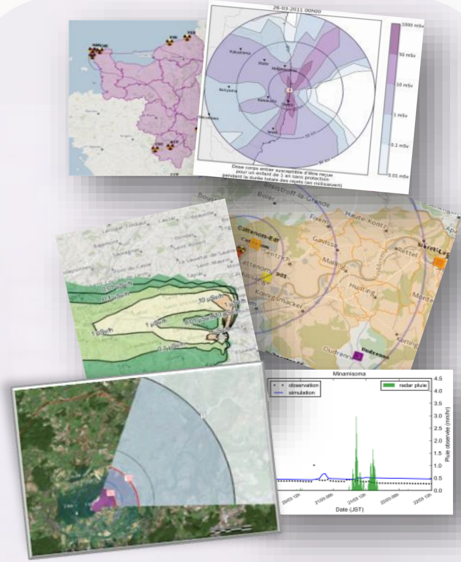
Release
- Diagnosis
- Prognosis





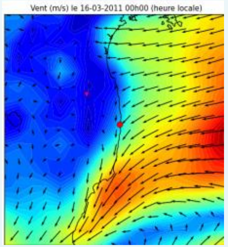


Dispersion models
- Gaussian puff (pX)
- Eulerian (IdX)

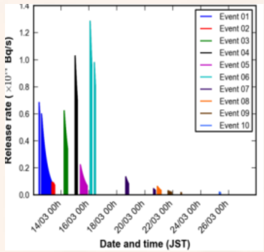


Radiological consequences
- Air concentrations, dose…
- Maps, time evolution
- Zones of threshold exceedance

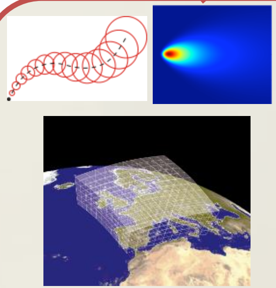
[Ex.] Radiological emergency response



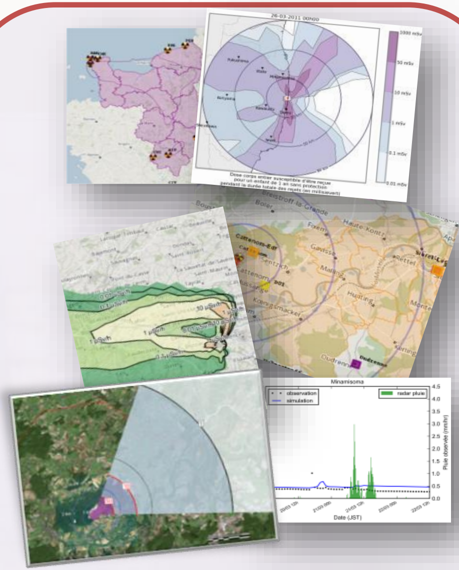
Epistemic
Stochastic
Modelisation



Epistemic
Human errors, ambiguities
Lack of information
Modelisation



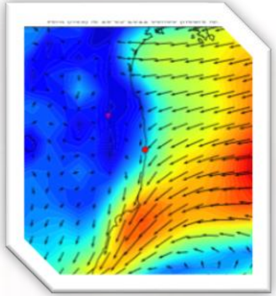
Physical and
numerical errors
User's decisions

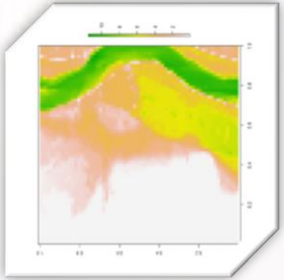


Choice of indicators and
output visualization
Interpretation
Decision making

How to include uncertainties in decision making ?

Challenge 1: high-dimension inputs / outputs



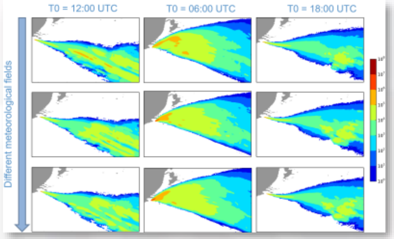


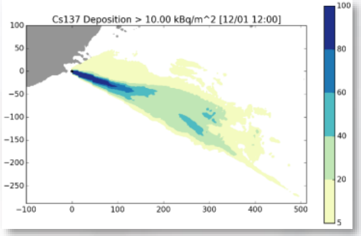
- Spatio-temporal physical fields
- Interactions / correlations between variables
- Use of appropriate dimension reduction methods

Challenge 2: Computational cost of physical models

- Use of meta-models or surrogate models

Challenge 3: interpretability of outputs





- Postage stamp ? Too many maps
- Probability maps ? Complex interpretation
- Scenario-based approach: “best estimate” vs. “worst case”

➡ Use of clustering methods

SURROGATE MODELLING

Parametric modelling to assess physical behaviour:

- High Performance Computing
- Numerical design of experiments
  (… but still curse of dimensionality)
- Agnostic response surface

… Training of a **surrogate model**
(Gaussian Process Regression)

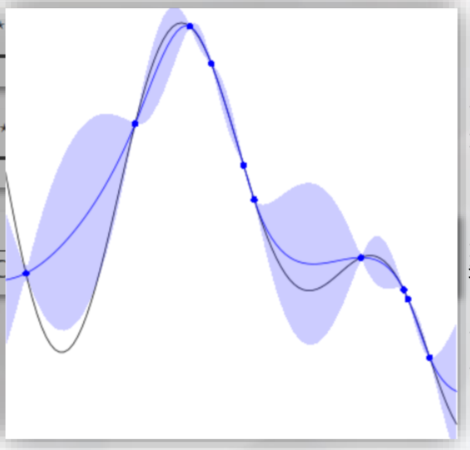
$$\mathbf{y}(\mathbf{x}_i) = \underbrace{\mathbf{f}(\mathbf{x}_i)^\top \boldsymbol{\beta}}_{\text{trend}} + \underbrace{\zeta(\mathbf{x}_i)}_{\text{smooth GP}}$$

$$C_\zeta(\mathbf{x}, \mathbf{x}'; \boldsymbol{\theta}, \sigma^2) = C_\zeta(\mathbf{h}; \boldsymbol{\theta}, \sigma^2) = \sigma^2 \prod_{\ell=1}^{d} \kappa(h_\ell/\theta_\ell)$$

$$\mathbb{E}[\mathbf{y}^\star \,|\, \mathbf{y}] = \underbrace{\mathbf{F}^\star \widehat{\boldsymbol{\beta}}}_{\text{trend}} + \mathbf{C}^\star$$

$$\mathsf{Cov}[\mathbf{y}^\star \,|\, \mathbf{y}] = \underbrace{[\mathbf{F}^\star - \widehat{\mathbf{F}}^\star]\, \mathsf{Cov}(\widehat{\boldsymbol{\beta}})\, [\mathbf{F}^\star}_{\text{trend}}$$

$$L(\psi, \boldsymbol{\beta}; \mathbf{y}) = \frac{1}{[2\pi]^{n/2}} \; |\mathbf{C}$$



Credits: https://libkriging.readthedocs.io

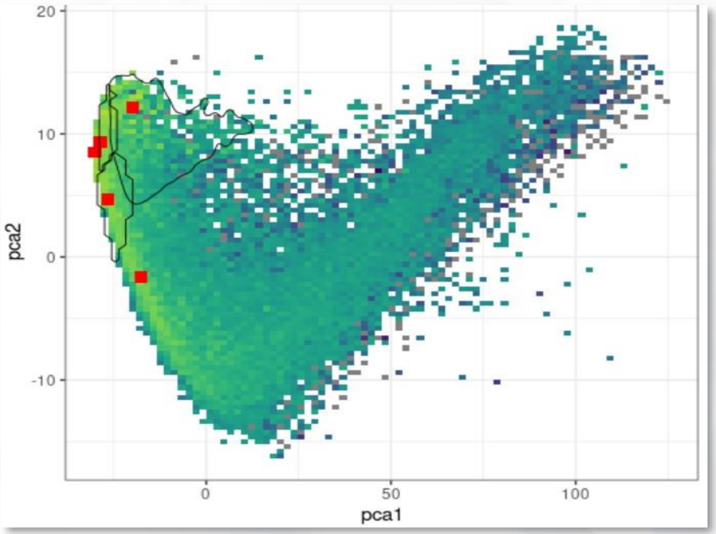
OUTPUTS PROJECTION

Complex numerical results:

- Physical quantities: spatial (lat,lon), temporal (t)
- Non-linear operational consequences

… supported by a **dimension reduction**:

- Supervised (prob. of occurrence) / unsupervised
- Non-significant "latent" space
- Desirable mathematical properties

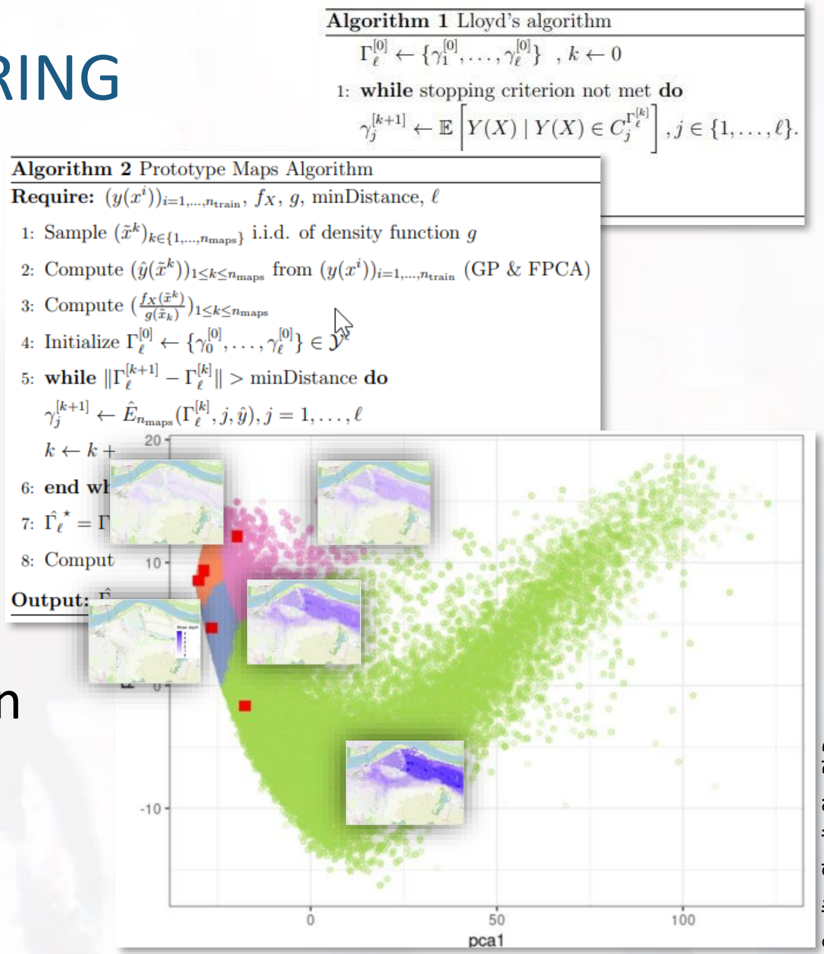


Credits: Charlie Sire PhD

Clustering

Objective:
sparse & synthetic sampling

- Some **prototypes** / centroids
- Weighted / probabilistic classes
- "Real" <-> "Latent" space projection



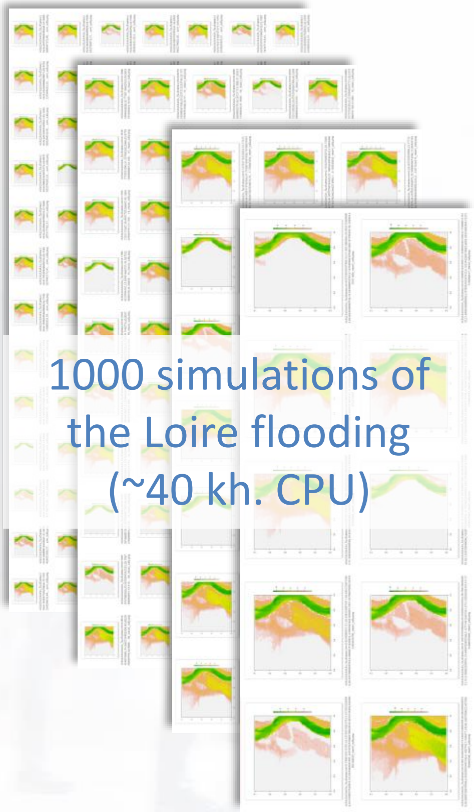
Credits: Charlie Sire PhD

… INTERPRETING FOR DECISION-MAKING

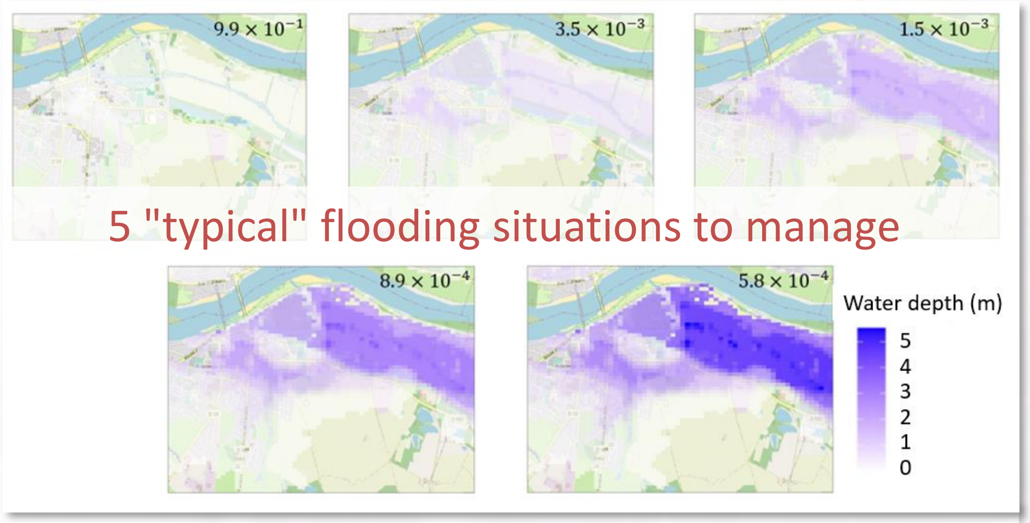
[Ex.] Flooding risk

Géosciences pour une Terre durable
brgm

IRSN
INSTITUT DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

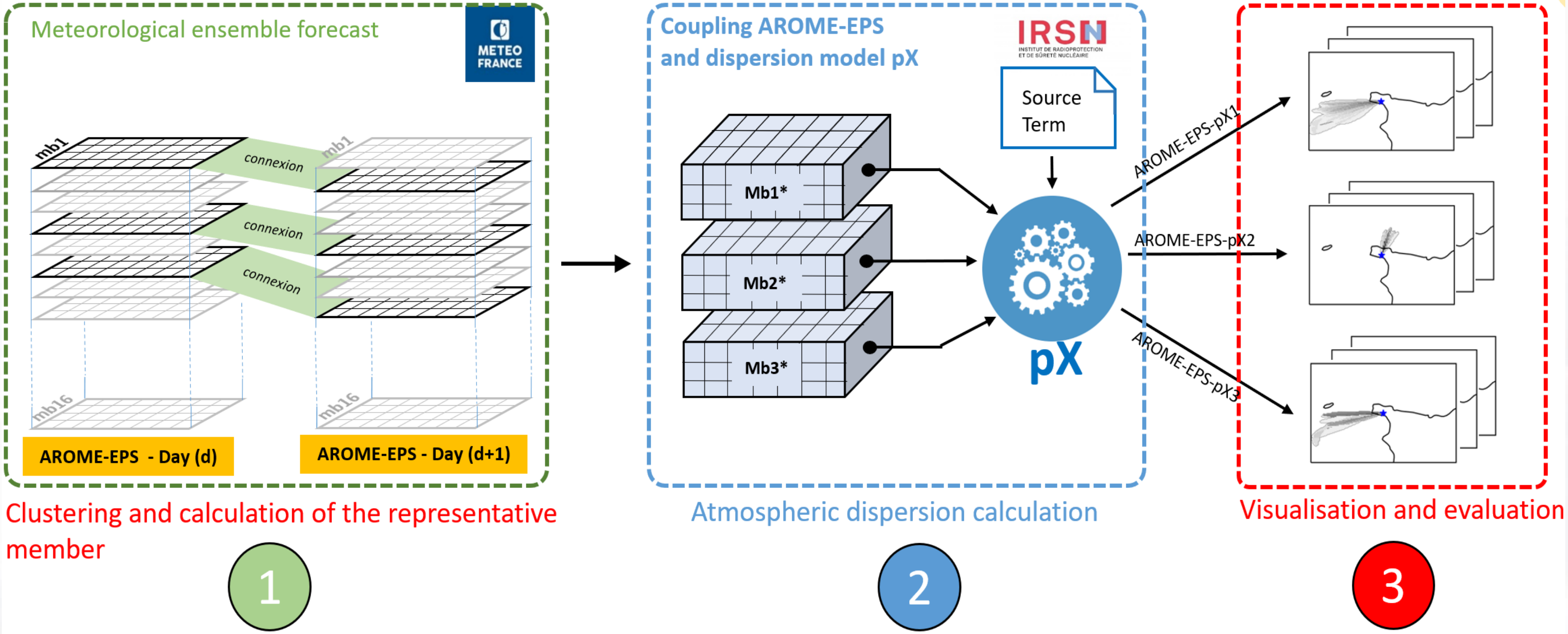


1000 simulations of the Loire flooding (~40 kh. CPU)

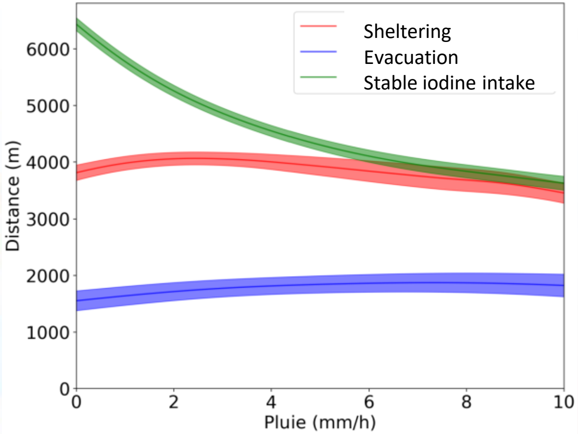


5 "typical" flooding situations to manage

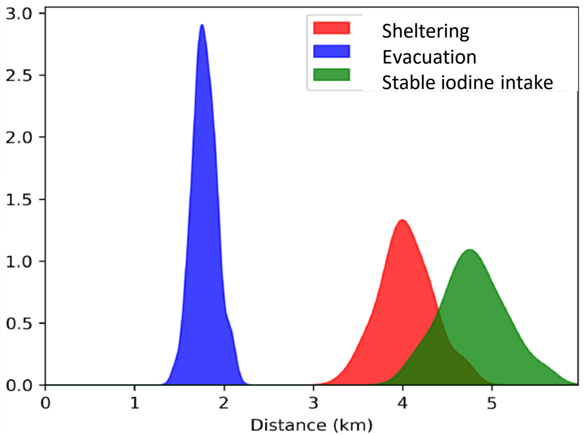
[Ex.] Radiological emergency response



[Ex.] Radiological emergency response

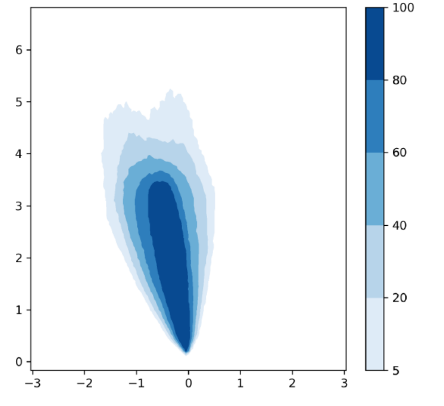


Sensitivity to input parameters (~20s)

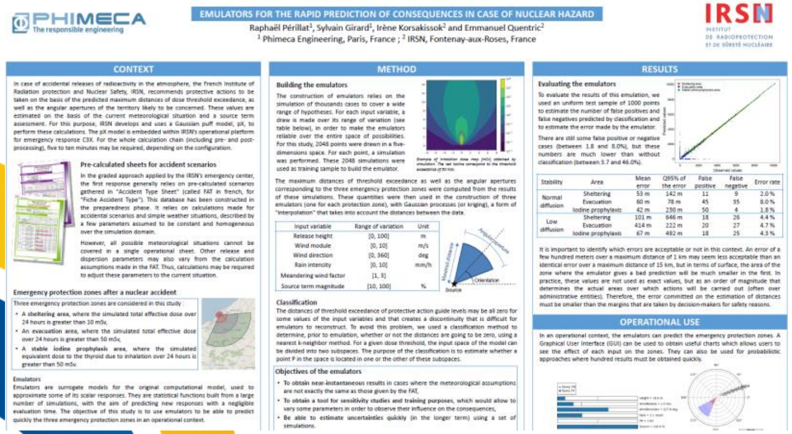


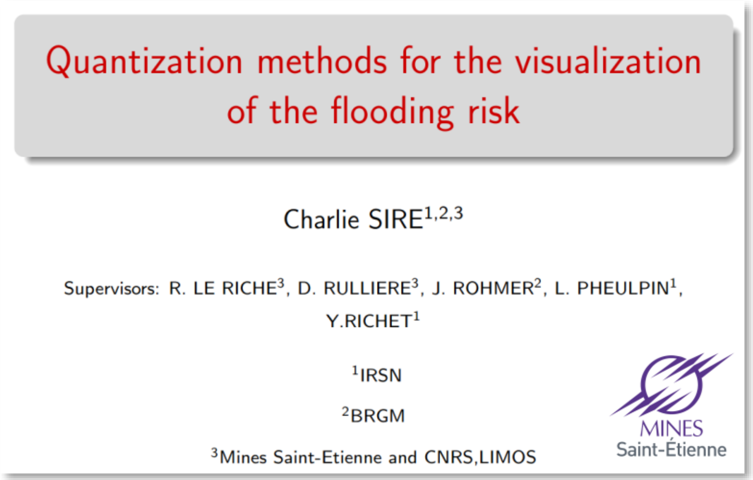
Probabilistic assessment of distance and aperture (~20s)

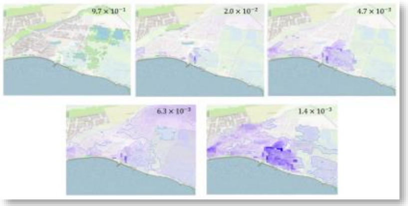
Probability of threshold exceedance (%)
Stable iodine intake

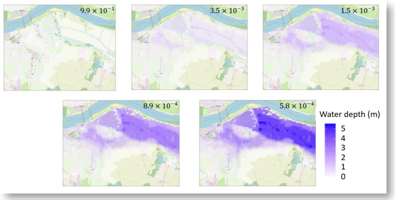


Probability map of threshold exceedance (~2-4 min)









Unlock the future

WHAT'S NEXT ?

Major challenges remain in

- **communicating uncertainties** to decision makers
- **integrating operational constraints** early in expertise

Bridging the gap between social sciences and geoscience / risk assessment and between different kinds of risks

→ Ambition of PEPR RISQUES, work on Natech scenarios