IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

USING METEOROLOGICAL ENSEMBLES FOR ATMOSPHERIC DISPERSION MODELING OF THE FUKUSHIMA NUCLEAR ACCIDENT

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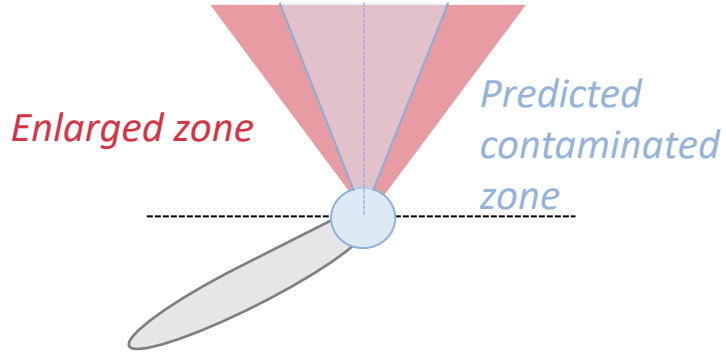
Context

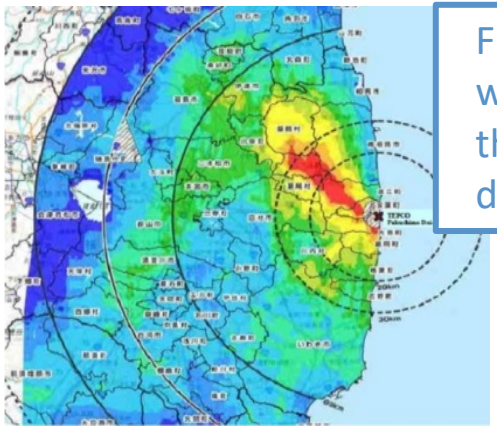
In case of an accidental release:

- **A deterministic approach is used to estimate the consequences**
- **Coupled to a practical method to "encompass" uncertainties**
  - Anticipating wind direction changes,
  - Using penalizing scenarios,
  - Impacted zone of 360° in case of large uncertainties (complex orography…)

↗ **To take into account the uncertainties is crucial**

↗ **To use probabilistic approaches**

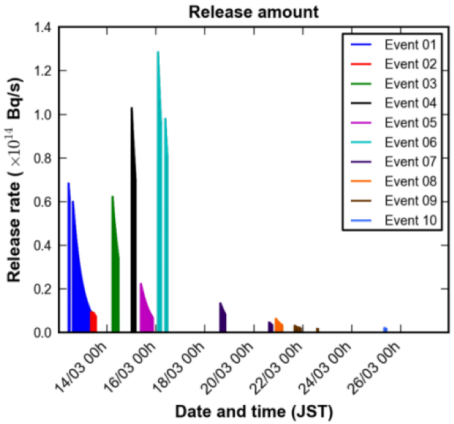


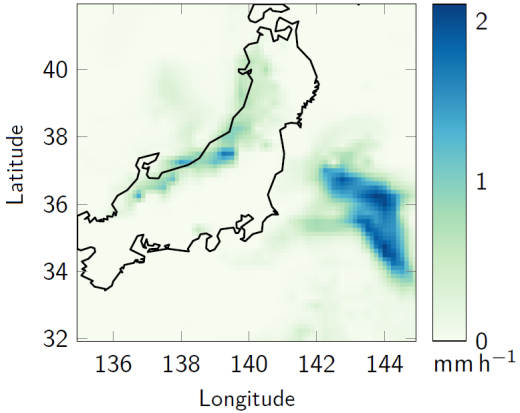


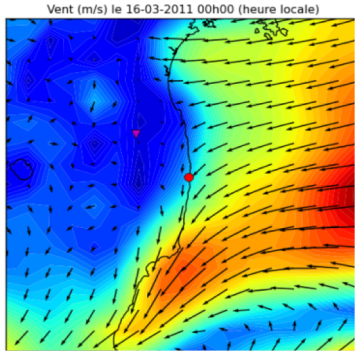
Fukushima: no model was able to predict the north-western deposition area !

What are the uncertain input variables ?

- Deposition velocities and scavenging coefficients: 1 scalar per species
- Source term: release height, kinetics (emitted quantity as a function of time) for each species, composition (isotopic ratios)
- Meteorological fields: Wind, rain, stability… 2D or 3D fields as a function of time



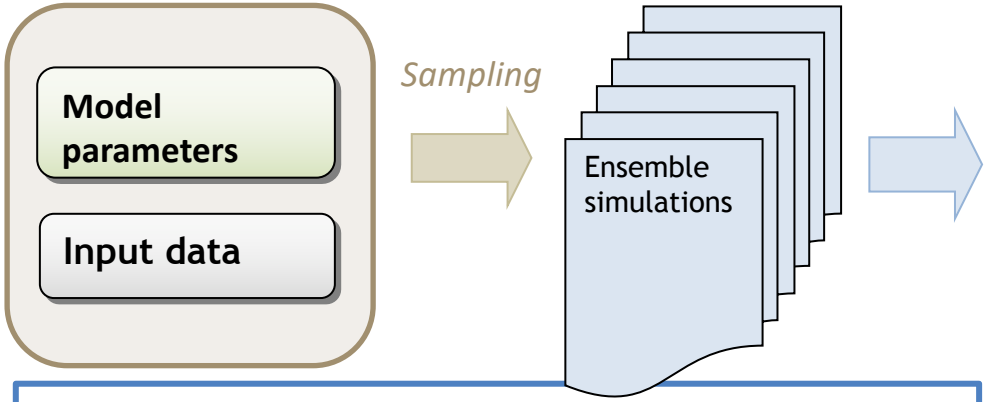


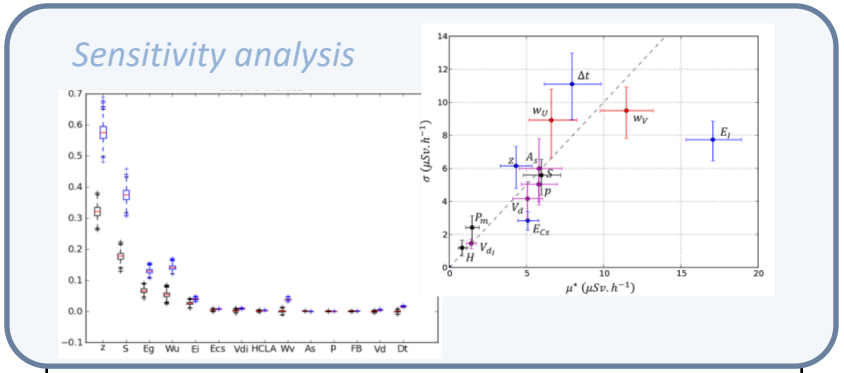


- **Meteo and source term are the main sources of uncertainties**
- **Complex structures, spatial and temporal correlations**
- **How to determine a realistic distribution ?**

What is the influence of input variables ?

First step: global sensitivity analysis methods of *Morris, Sobol*

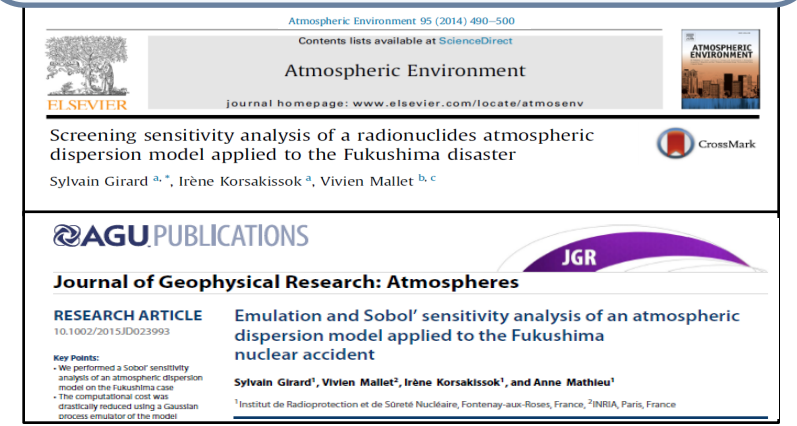




Goals:

- ✓ Classify variables as a function of their influence
- ✓ Discriminate non-influent, negligible variables
- ✓ Quantify the proportion of output variance explained and the interactions

↗ **Meteo and source term are the main sources of uncertainties**



How to quantify the uncertainty of data ?

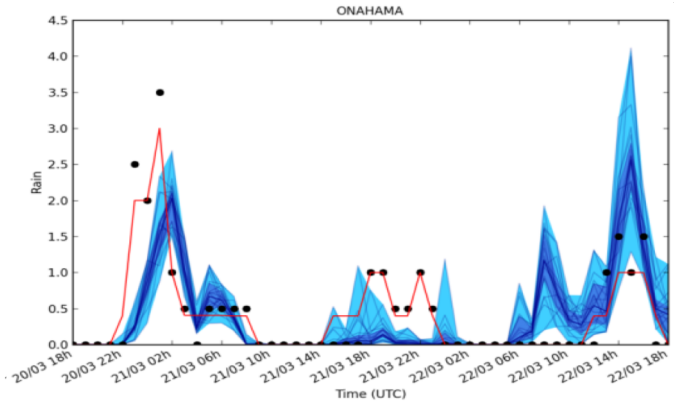
- Using meteorological ensembles ensures physical consistency !
- Is the ensemble is representative of the uncertainties *propagated in our model?*
- Comparison to 10-m wind and rain observations (AMEDAS network)

MRI (from Sekiyama et al) ensemble:

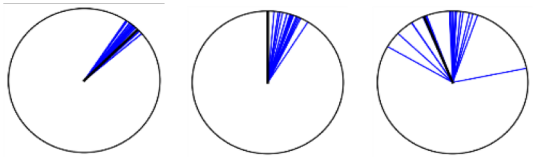
- High-resolution
- High-frequency assimilation
- Representative of analysis error (a posteriori)

10-m wind speed

rainfall



10-m wind direction



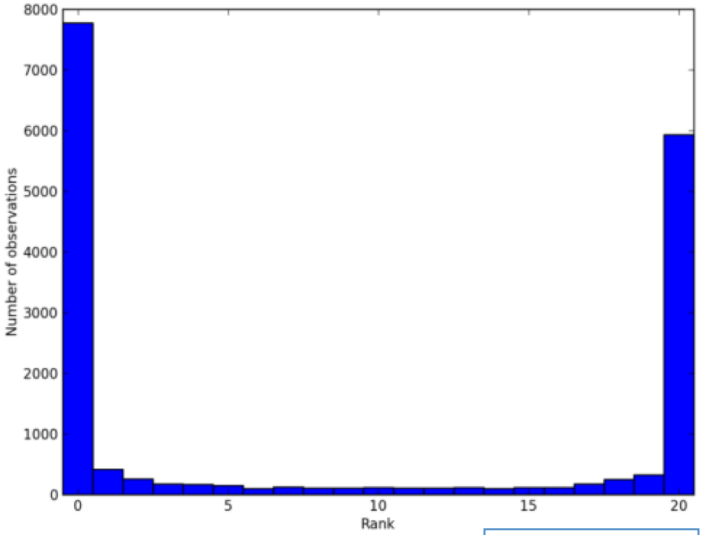
21/03 09h | 21/03 09h | 21/03 15h

How to validate the input data uncertainties?

➢ Rank histogram

- The observations are often outside the ensemble: the ensemble may under-estimate the meteorological variability close to the ground

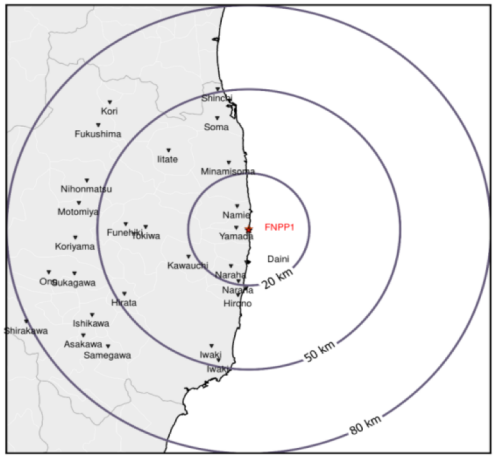
- These ensemble are worth to be used for uncertainty propagation
  - ➢ The uncertainties may accumulate along the plume trajectory
  - ➢ The plume's dispersion does not always depend on near-ground variables

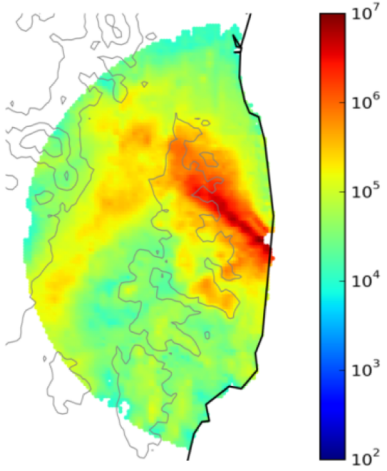


10-m wind speed

Uncertainty propagation

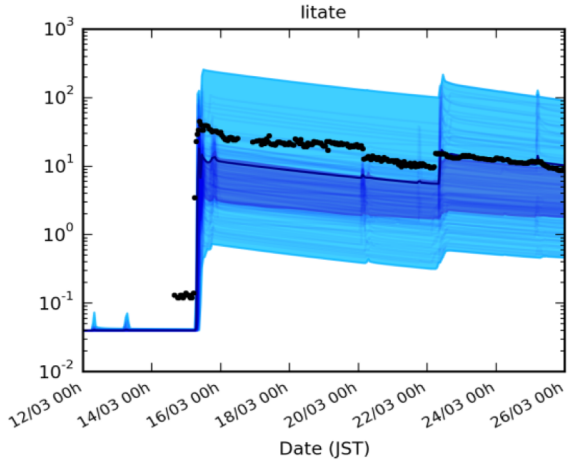
- IRSN's Gaussian puff model pX (Korsakissok et al, 2013)
- MRI ensemble
- Seven source terms from the literature
  - Mathieu et al, 2012
  - Terada et al, 2012
  - Saunier et al, 2013
  - Katata et al, 2015
  - Stohl et al, 2011
  - Winiarek et al, 2012
  - Saunier et al, 2016
- No additional perturbation on source term
- No perturbation of physical parameterizations
- Comparison to **gamma dose rate stations** in the Fukushima prefecture, and to **^{137}Cs deposition** measurements from airborne measurement at the end of the emergency

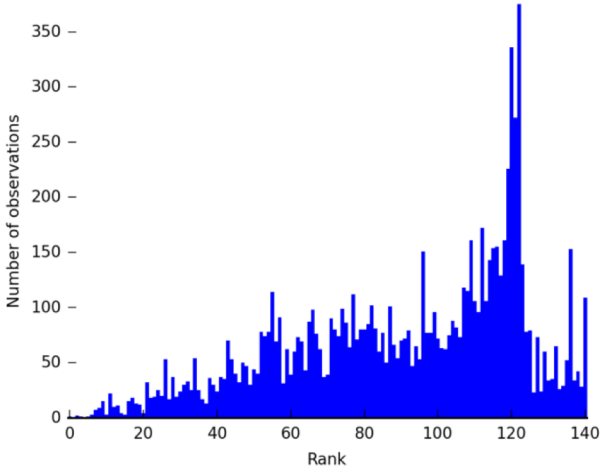




Ensemble + 7 source terms

- Goal: to encompass gamma dose rate observations





- The spread of the simulations ensemble is quite large compared to the observation variation. The small variability of the meteorological data allows to create large variability in the dispersion results.
- These rank diagrams are obtained by using only the ensemble and 7 source terms, which means that several uncertainties are not taken into account

  ↗ **Next step: full Monte Carlo with all uncertainties**

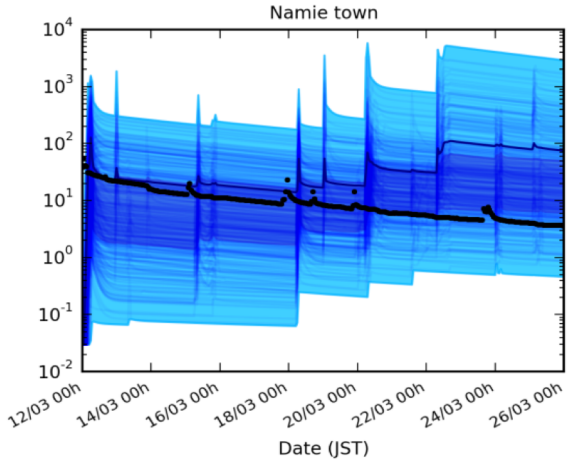
Monte Carlo simulations :

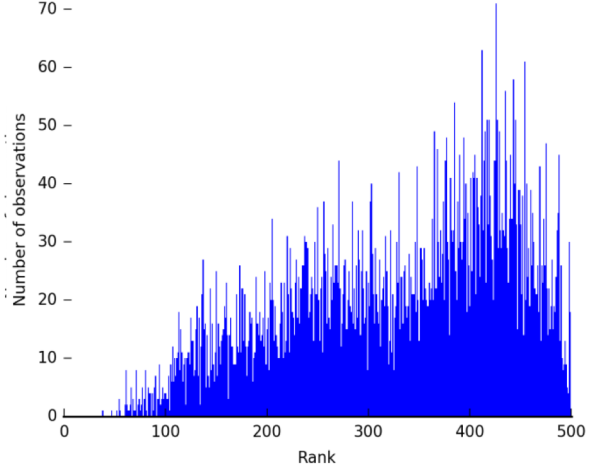
Perturbations of the input :

Variable	Perturbation
Meteorological fields	Draw between the member of the ensemble
Stability calculation method	[Turner, LMO, Gradient]
Source term	[Mathieu, Stohl, Terada, Katata, Winiarek, SaunierECMWF, SaunierMRI]
Source term amplitude	LogNormal $(\times 3, \div 3)$ at 95%
Source term time shift	Normal $(+3\mathrm{H}, -3\mathrm{H})$ at 95%
Source term altitude	Uniform $[20, 150]$ m
Dispersion method	[Doury, Pasquill, Similarity]
General deposition coefficient	LogNormal $[5\times10^{-4}\ ,\ 5\times10^{-3}]\ \mathrm{m.s^{-1}}$ at 95%
Iodine deposition coefficient	LogNormal $[5\times10^{-4}\ ;\ 2\times10^{-2}]\ \mathrm{m.s^{-1}}$ at 95%
Scavenging coefficient	LogNormal $[1\times10^{-5}\ ;5\times10^{-3}]\ \mathrm{h.mm^{-1}.s^{-1}}$ at 95%

Monte Carlo simulations :

- Goal: to encompass gamma dose rate observations





- The Monte Carlo results have a larger spread than the cross simulations
- There is a bias on the results, but it is quite correct for such simulations
- Several simulations are under all observations in the two ensembles :
  - the inputs are over-dispersed
  - Possibility of ensemble calibration
  - A threshold on the observation limits the rank histogram

Conclusion and perspectives

Monte Carlo results

- The small variability of the meteorological data allows to create large variability in the dispersion results
- The ensemble results are a bit over-dispersed but embrace the observations
- Importance of taking into account all uncertainties (Monte Carlo)

Improvement of the results

- Calibration of the inputs uncertainties
- Taking into account the observation error

Adaptation for operational purposes

- Forecast error (more than 24-hour forecast), a priori source term error, …
- During an emergency , more uncertainties due to other factors (partial information, human errors…)