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

RAPHAËL PÉRILLAT[1,2], Ngoc Bao Tran LE[1,3]

Irène Korsakissok[1], Vivien Mallet[3], Anne Mathieu[1], Damien Didier[1],

Thomas Sekiyama[4], Mizuo Kajino[4], Kouji Adachi[4] and Yasuhito Igarashi[4]

1 IRSN - Institute of Radiation Protection and Nuclear Safety, Fontenay-aux-roses (France).

2 Phimeca, Paris (France).

3 INRIA, Paris (France).

4 Japan Meteorological Agency, Meteorological Research Institute, Tsukuba (Japan).

NERIS 2018

April 27th 2018, Dublin, Ireland

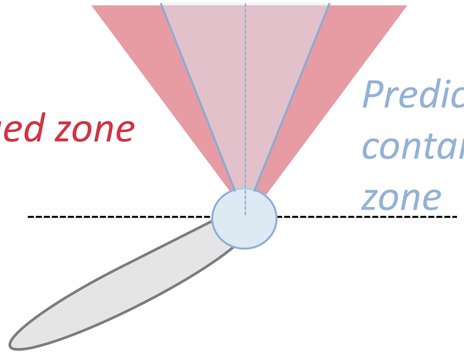
Context

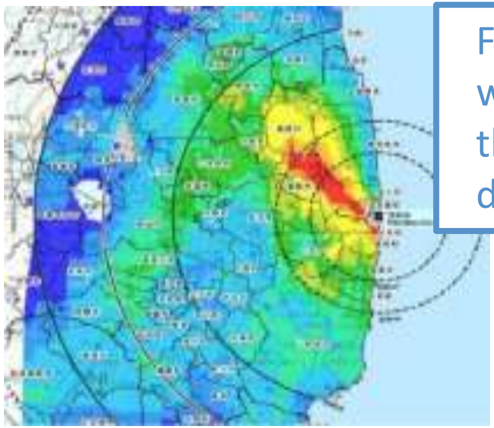
In case of an accidental release:

- **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

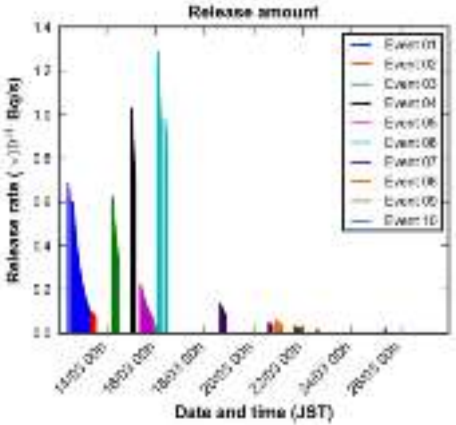


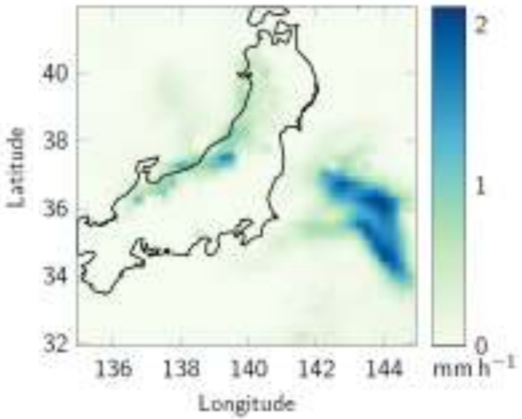


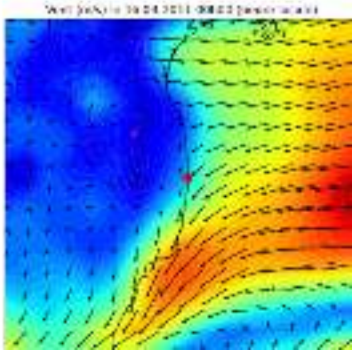
Fukushima: no model was able to predict the north-western deposition area !

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*

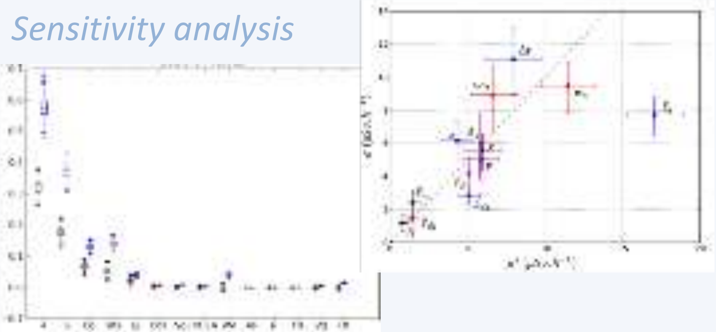
Model parameters

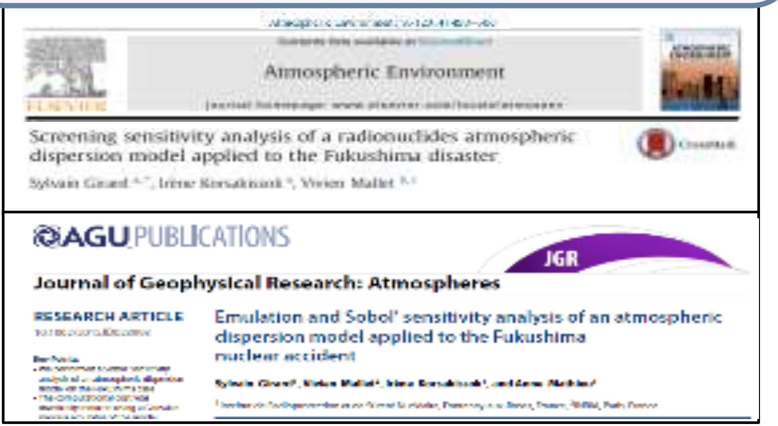
Input data

Sampling

Ensemble simulations

Sensitivity analysis




Atmospheric Environment

Screening sensitivity analysis of a radionuclides atmospheric dispersion model applied to the Fukushima disaster

AGU PUBLICATIONS

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

Emulation and Sobol' sensitivity analysis of an atmospheric dispersion model applied to the Fukushima nuclear accident

Goals:

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

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

How to quantify the uncertainty of data ?

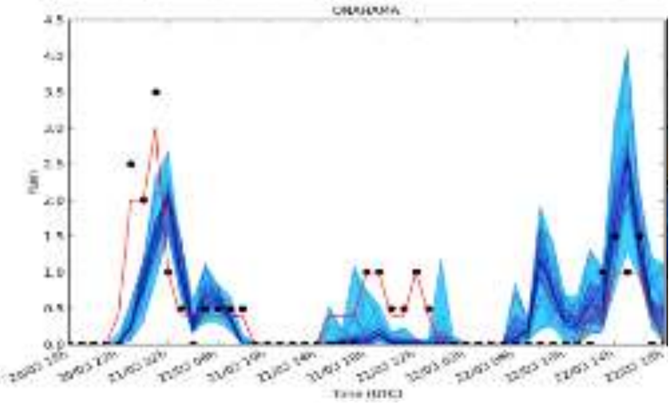
- Using meteorological ensembles ensures physical consistency !
- Is the ensemble is representative of the uncertainties *propagated in our model?*
- Comparison to 10-m wind and rain observations (AMEDAS network)

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

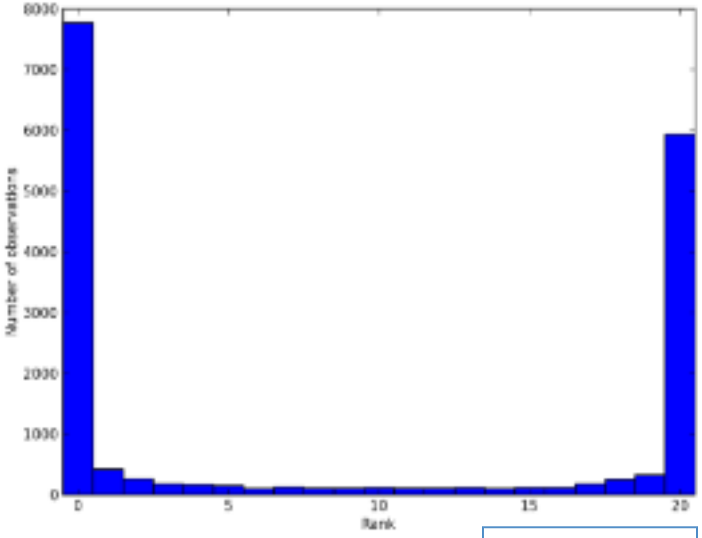
21/03 09h 21/03 09h 21/03 15h

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

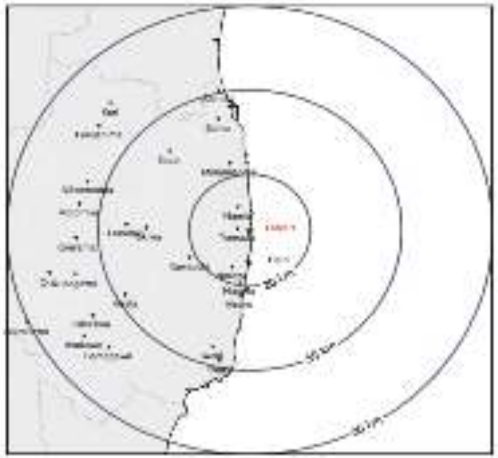
- These ensemble are worth to be used for uncertainty propagation
  - ➢ The uncertainties may accumulate along the plume trajectory
  - ➢ The plume's dispersion does not always depend on near-ground variables

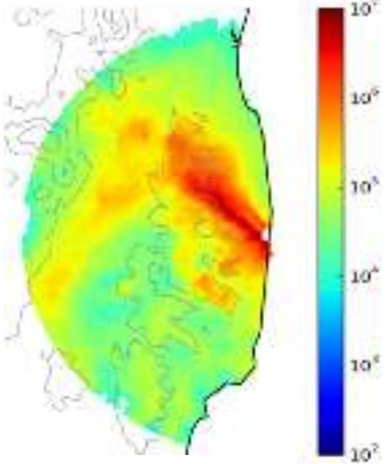


10-m wind speed

Uncertainty propagation

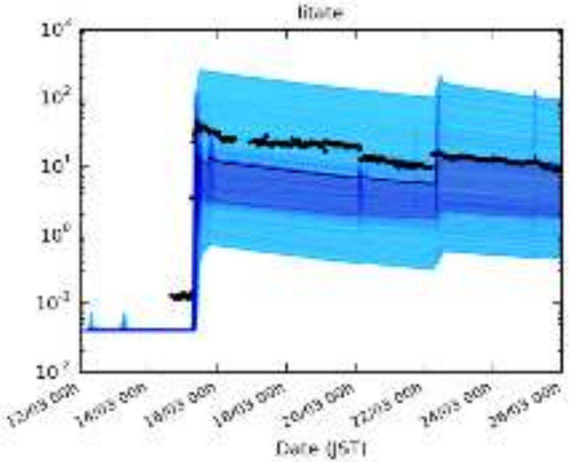
- IRSN’s Gaussian puff model pX (Korsakissok et al, 2013)
- MRI ensemble
- Seven source terms from the literature
    - Mathieu et al, 2012
    - Terada et al, 2012
    - Saunier et al, 2013
    - Katata et al, 2015
    - Stohl et al, 2011
    - Winiarek et al, 2012
    - Saunier et al, 2016
- No additional 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

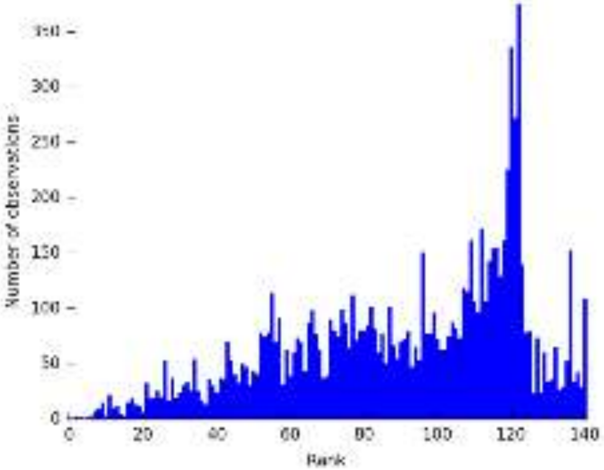




Ensemble + 7 source terms

➢ 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

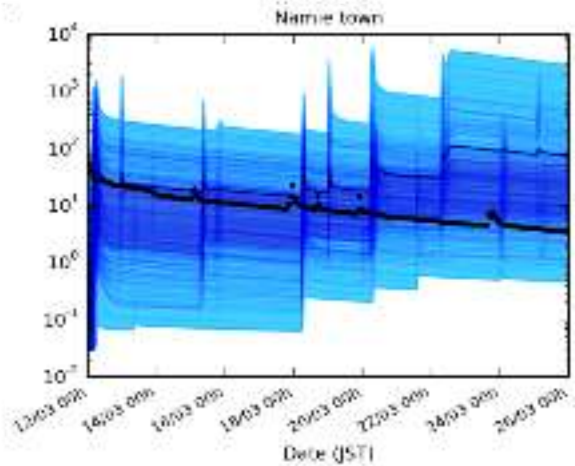
Monte Carlo simulations :

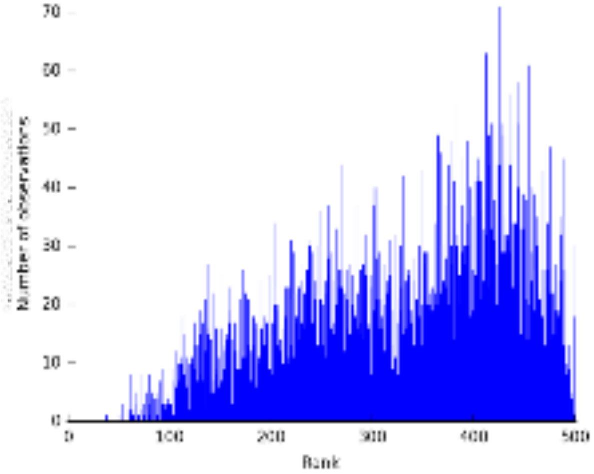
Perturbations of the input :

Variable	Perturbation
Meteorological fields	Draw between the member of the ensemble
Stability calculation method	$[\mathrm{Turner}, \mathrm{LMO}, \mathrm{Gradient}]$
Source term	$[\mathrm{Mathieu}, \mathrm{Stohl}, \mathrm{Terada}, \mathrm{Katata}, \mathrm{Winiarek}, \mathrm{SaunierECMWF}, \mathrm{SaunierMRI}]$
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 $[20, 150]\ \mathrm{m}$
Dispersion method	$[\mathrm{Doury}, \mathrm{Pasquill}, \mathrm{Similarity}]$
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 $[1\times10^{-5}\ ; 5\times10^{-3}]\ \mathrm{h.mm}^{-1}.\mathrm{s}^{-1}$ 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…)