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

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

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Context

In case of an accidental release of radionuclides

- Atmospheric dispersion models are used to *forecast* the sanitary impact
- A tool for decision making: countermeasures (evacuation, sheltering)…
- A complement to environmental measurements

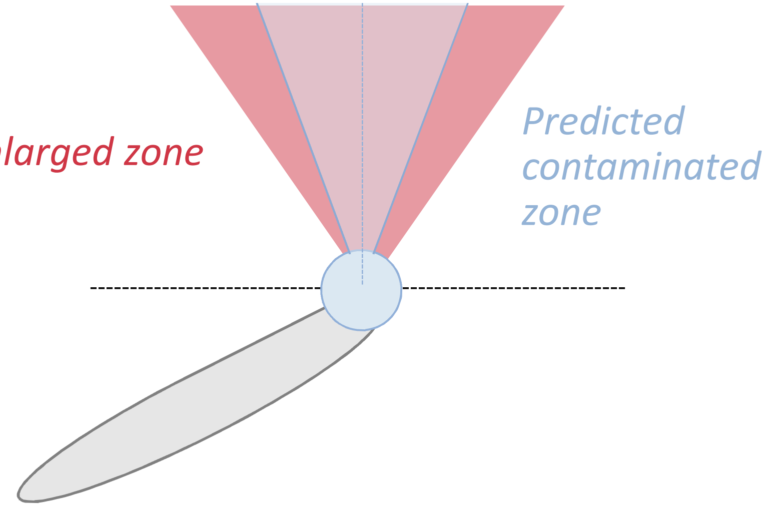
Results are subject to many uncertainties

Model-to-data discrepancy = Input data uncertainties + Model uncertainties + Representativeness error + Measurement error

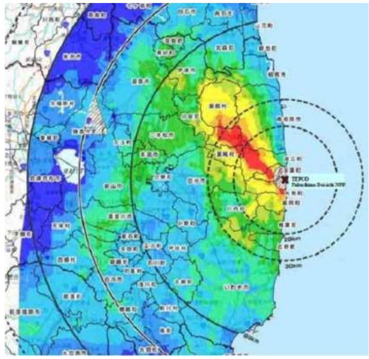
Uncertainty modeling

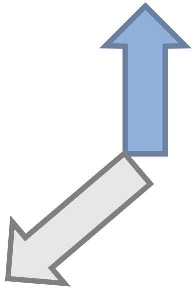
Context

A deterministic approach…



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





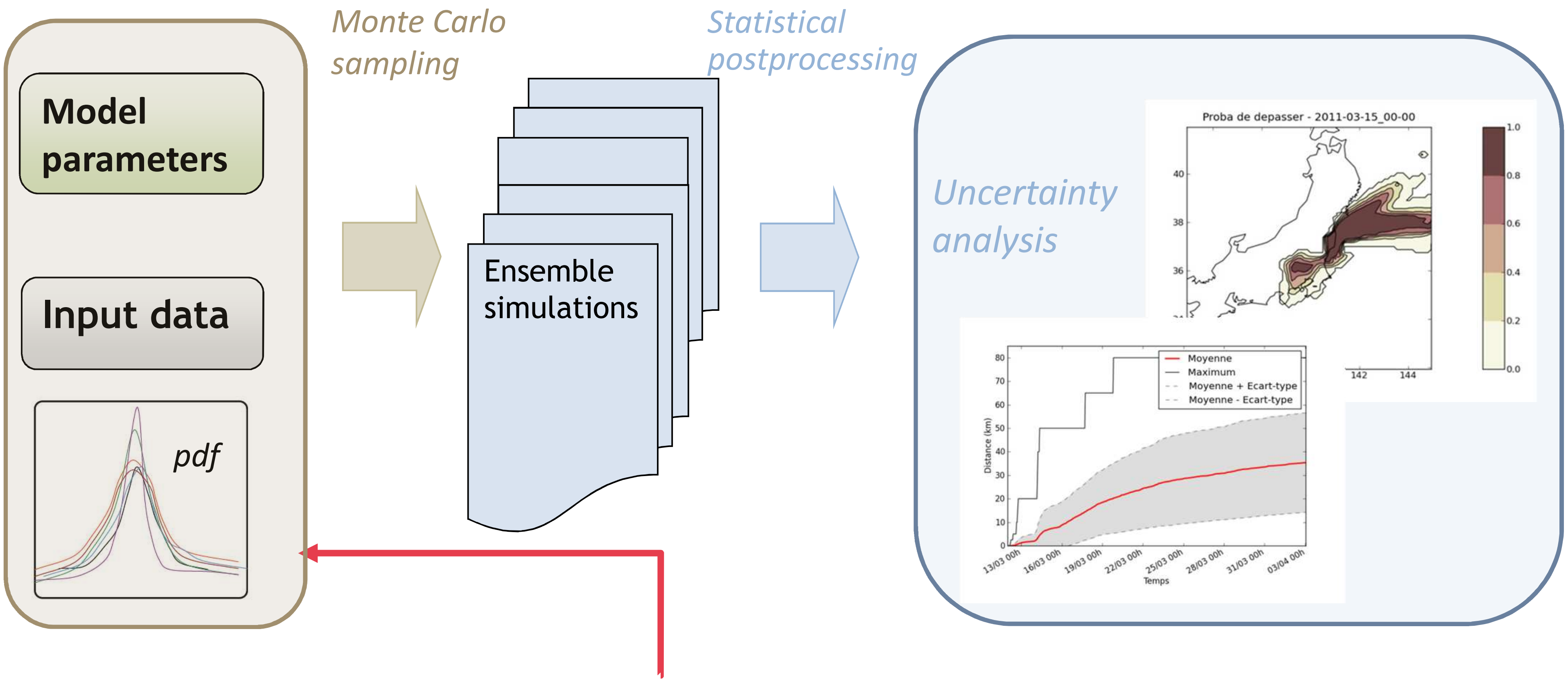
- Release time
- Release height
- Wind direction change
- Orography…

… 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…)

➚ A reliable estimation of uncertainties is crucial

Uncertainty analysis



Need to assess the uncertainty (i.e. probability distribution) of input data

Quantifying input data uncertainties…

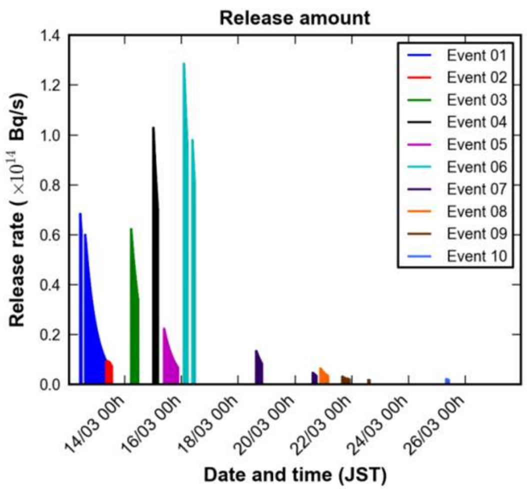
…The key issue !

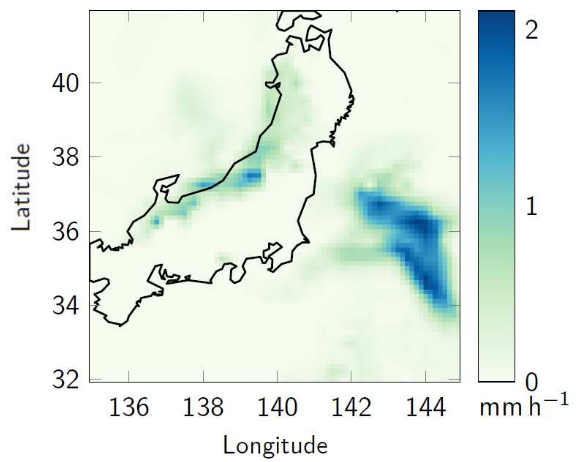
- What are the uncertain input variables ?
- What is the influence of input variables on outputs ?
- How to quantify the uncertainty of input data ?
- How to validate our uncertainty quantification, i.e. how to know if we have properly taken into account all the uncertainty associated to the variable ?

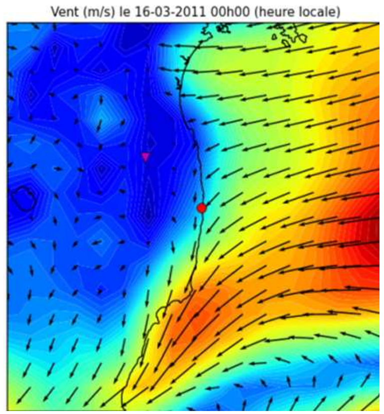
➚ Some part can rely on experts' judgment
➚ Using observation data is mandatory

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 field 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*

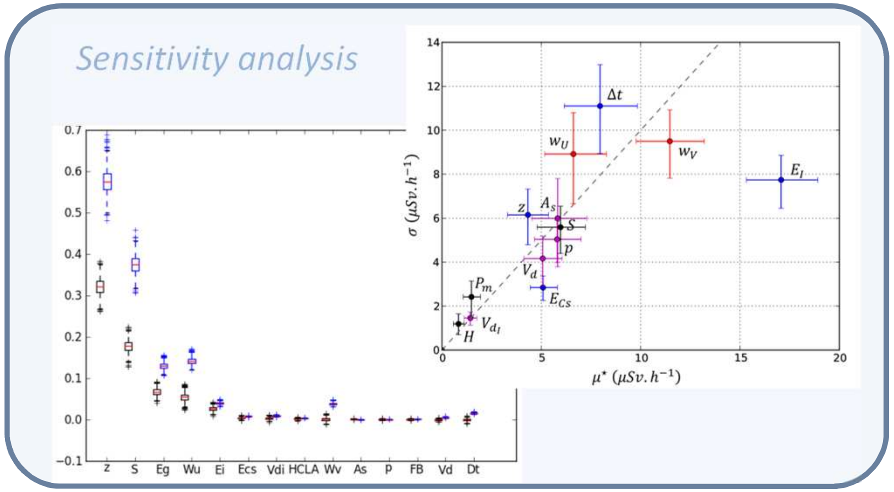
Model parameters

Input data

Crude perturbations (homogeneous factors…)

Sampling

Ensemble simulations



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

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

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Key Points:
- We performed a Sobol' sensitivity analysis of an atmospheric dispersion model on the Fukushima case
- The computational cost was drastically reduced using a Gaussian process emulator of the model

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>

How to quantify the uncertainty of data ?

➢ Using meteorological ensembles ensures physical consistency !

MRI (Japan meteorological agency) ensemble:

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

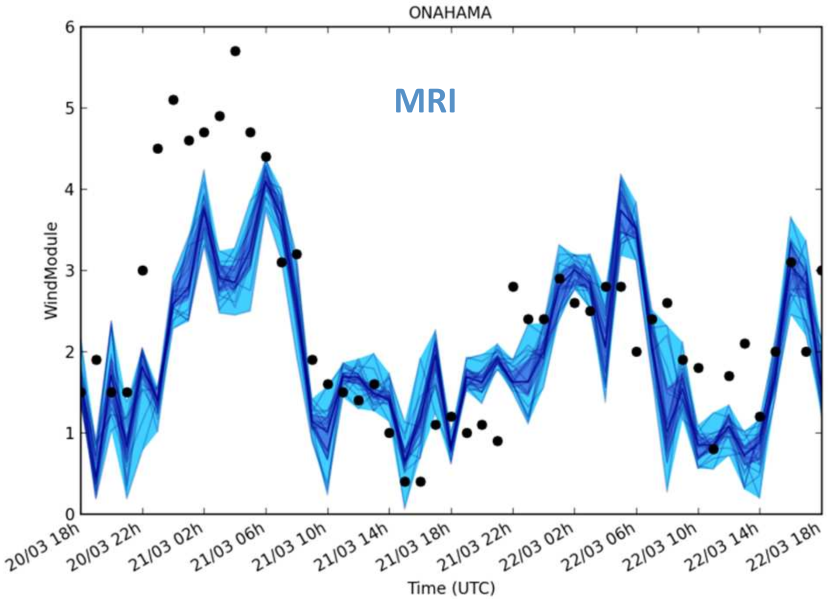
ECMWF ensemble:

- crude resolution (horizontal & vertical)
- 24 hour –forecast
- Representative of forecast error
- Representative of data used in a crisis ?

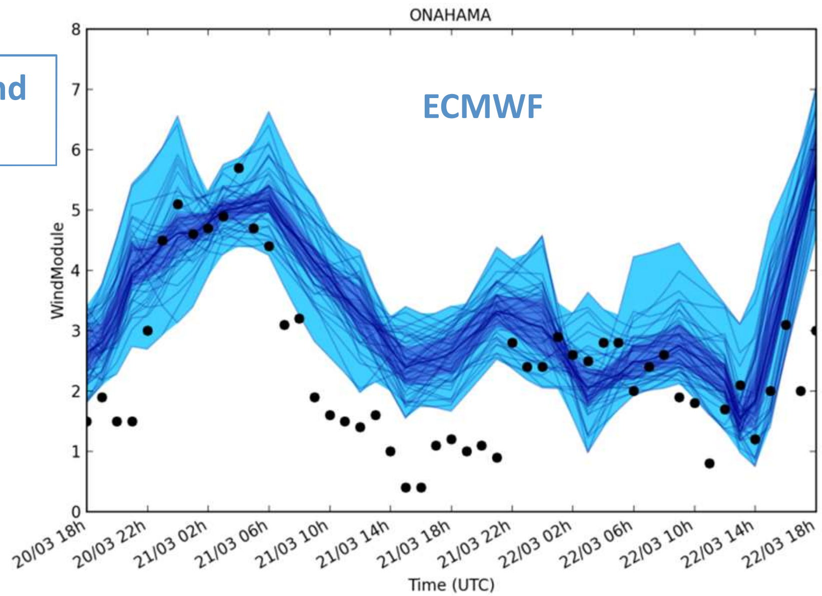
	MRI data	ECMWF data
Members	20	50
Grid resolution	3 km	0.25°
Vertical levels	Sigma levels 15 levels below 2000 m	Pressure levels 5 levels below 2000 m
Time step	1 hour	3 hours
Assimilation time step	3 hours	24 hours

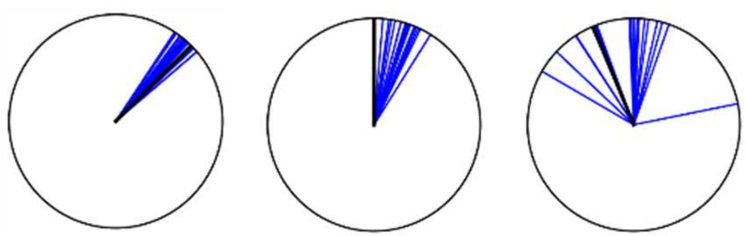
How to validate the input data uncertainties?

- Is the ensemble is representative of the uncertainties *propagated in our model?*
- Comparison to 10-m wind and rain observations (AMEDAS network)



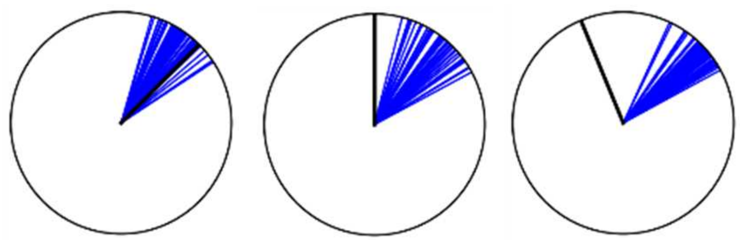
10-m wind speed





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

10-m wind direction



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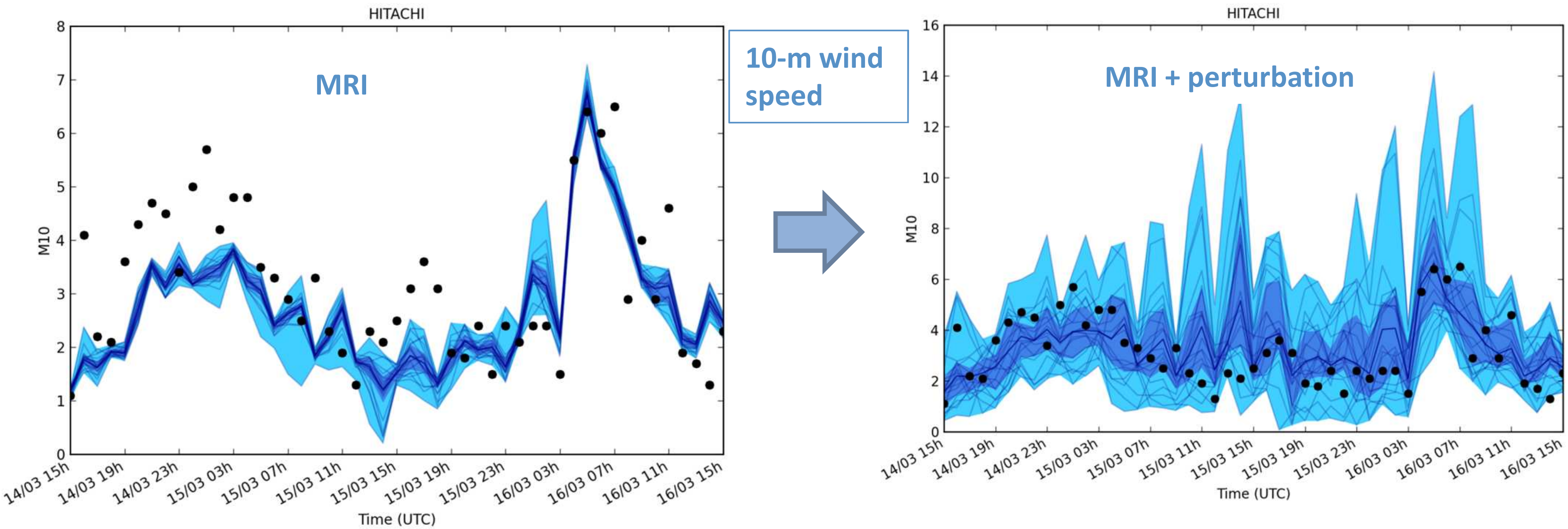
Additional perturbation to MRI ensemble

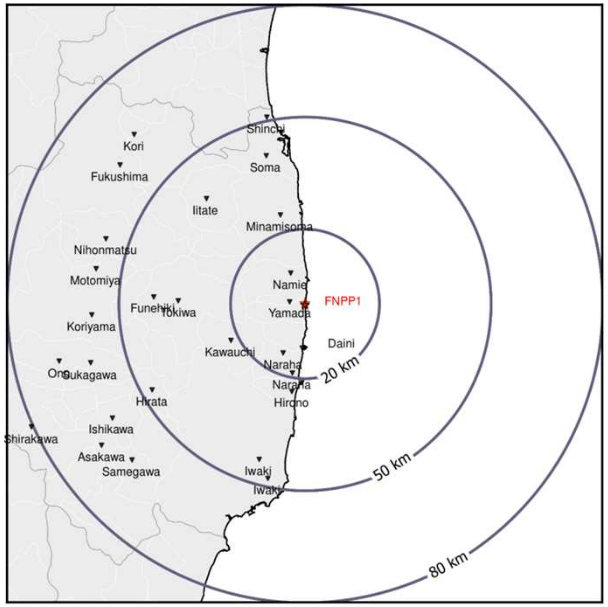
➢ The new ensemble is designed to encompass all meteorological observations

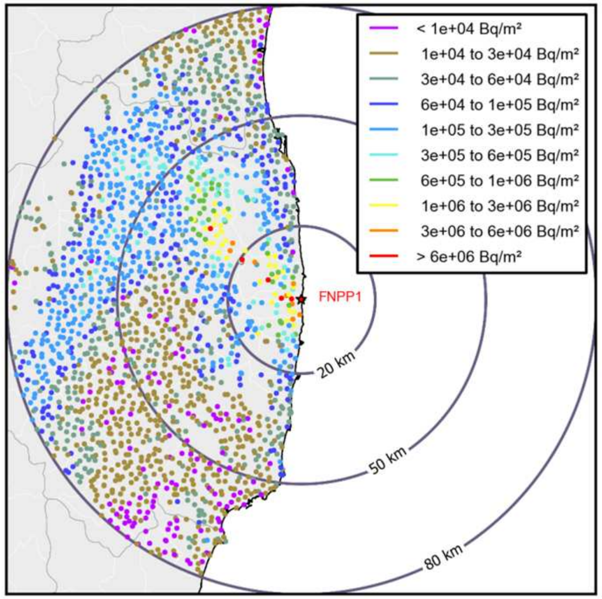


- Additional perturbation to wind fields (U,V) and rain fields
- Homogeneous, but depending on time and ensemble's member
- Calculated to get a flat rank diagram on meteorological observations

Uncertainty propagation

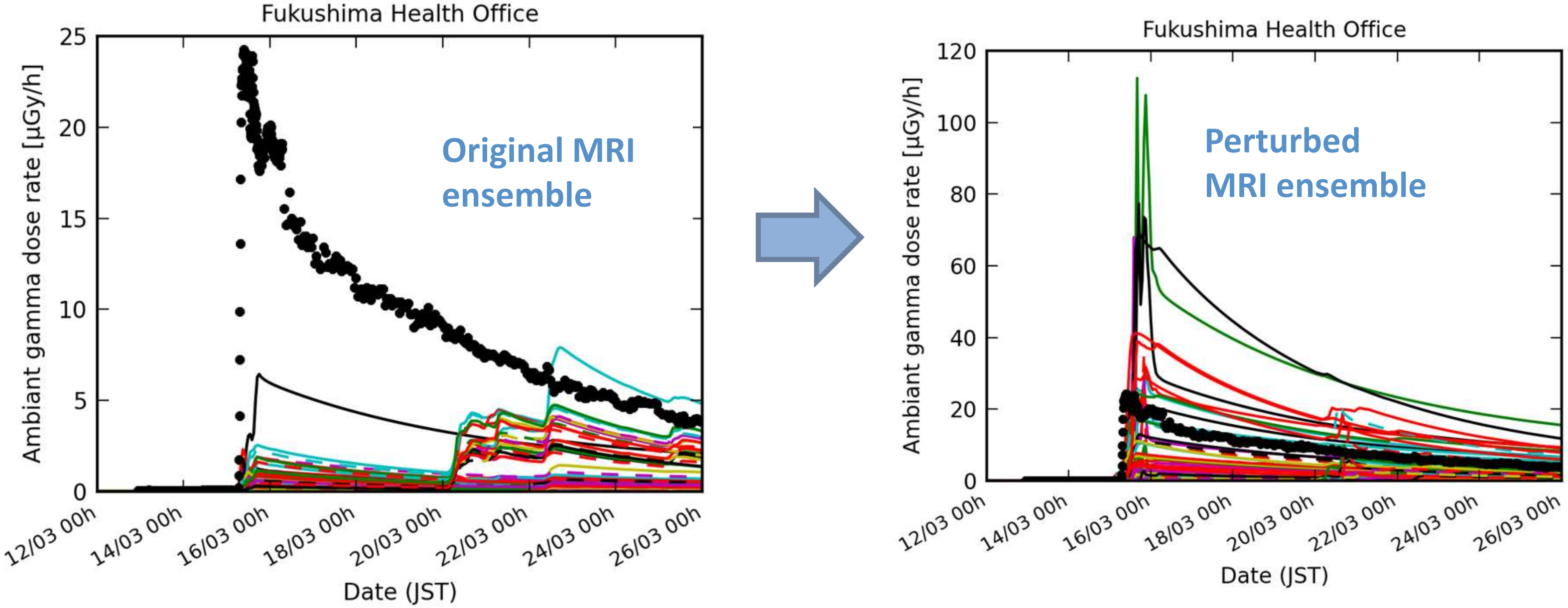
- IRSN's Gaussian puff model pX (*Korsakissok et al, 2013*)
- MRI and ECMWF ensembles with and without additional perturbation
- Five source terms from the literature
  - Mathieu et al, 2012
  - Terada et al, 2012
  - Saunier et al, 2013
  - Katata et al, 2015
  - IRSN's inverted source term with long-distance model and MRI deterministic meteorological data
- *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 MEXT sampling campaign





MRI ensemble + 5 source terms

- Goal: to encompass gamma dose rate observations

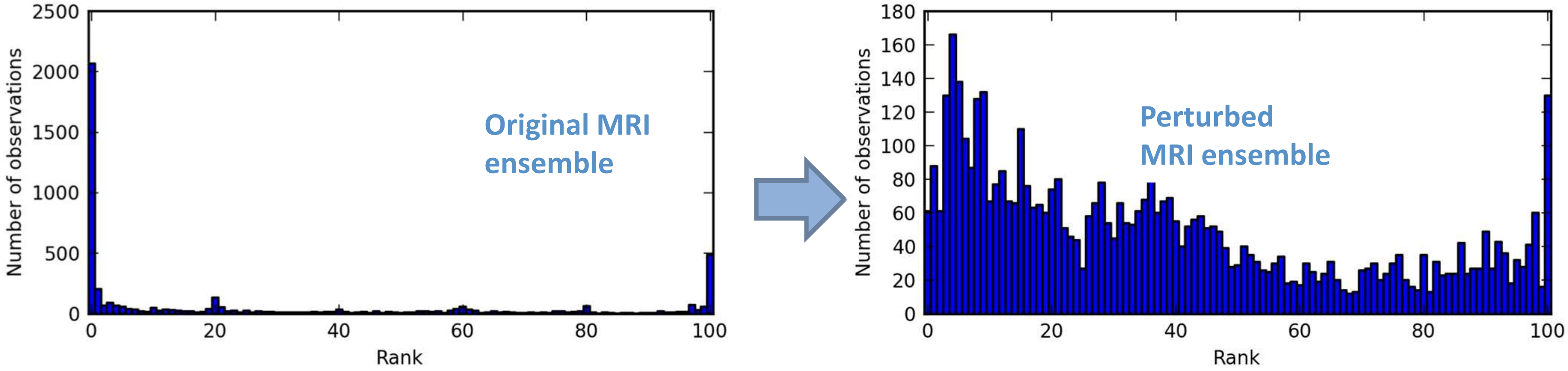


- Even with 20 meteorological members and 5 source terms, some stations are not well represented…

- With the additional perturbation on meteorological fields, the spread is larger!

MRI ensemble + 5 source terms

➢ Goal: to encompass gamma dose rate observations



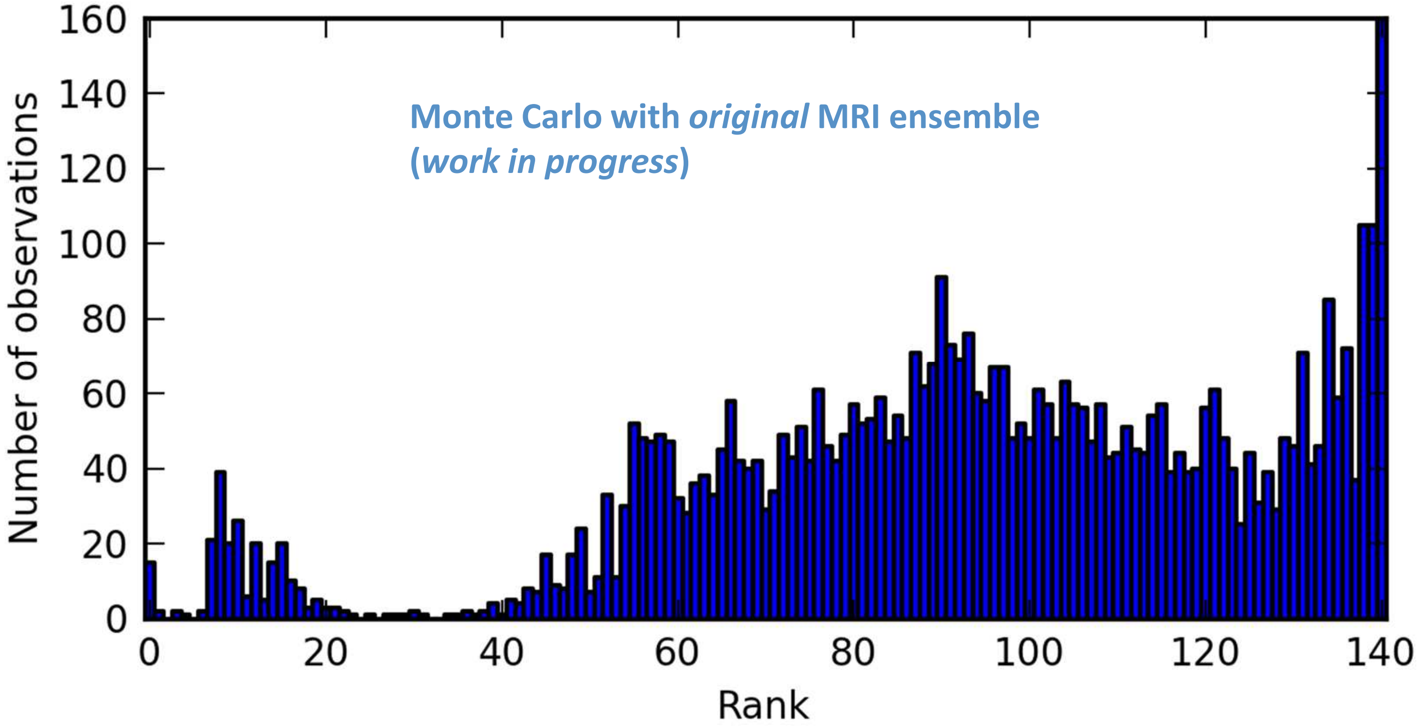
- The perturbed MRI ensemble was designed to encompass all wind/rain observations
- Using only the perturbed ensemble and 5 source terms, the rank diagram is much better than without perturbation, but not flat…

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

Monte Carlo simulations (in progress)

- Use of MRI ensemble and 5 source terms

- Other perturbed parameters: deposition velocities, scavenging coefficients, source height, released quantities, release time…



Perspectives

Improve our knowledge of input data uncertainties

- Deposition velocities and scavenging: use of experimental data…
- Construction of meteorological ensembles representative of boundary layer uncertainties!
- *Work with experts on source term uncertainties in a crisis context*

Quantification of uncertainties on the Fukushima case

- Using Bayesian inference to calibrate input uncertainties with observations
- Work on emulation (model reduction) to reduce computational time
- Work on output variables (not independent)…

Reflection for operational purposes

- What data do we have during a crisis ?
- Problem of computational time is crucial
- What do we want to communicate ?

Thank you…

Questions ?