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

RAPHAËL PÉRILLAT$^{1,2,5}$, 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 BERTIN Technologie, Saint-Aubin (France).
3 INRIA, Paris (France).
4 Japan Meteorological Agency, Meteorological Research Institute, Tsukuba (Japan).
5 now at Phimeca Engineering, Paris (France).
Context

In case of an accidental release

A deterministic approach is used

The uncertainties are very strong
- The model cannot predict some events

A reliable estimation of uncertainties is crucial

Forecast wind direction

« real » plume transport direction
- Release time
- Release height
- Wind direction change
- Orography...

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 field as a function of time

- Complex structures, spatial and temporal correlations
- Meteo and source term are the main sources of uncertainties
- 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-influential, negligible variables
- Quantify the proportion of output variance explained and the interactions

**Context**
Meteorological ensembles
Uncertainty propagation
Perspectives

**Sampling**
Crude perturbations (homogeneous factors...)

**Ensemble simulations**

**Perspectives**

R. PERILLAT - Using meteorological ensembles for atmospheric dispersion modeling of the Fukushima nuclear accident. HARMO18 October 12th 2017
How to quantify the uncertainty of data?

- Using meteorological ensembles ensures physical consistency!

### MRI (from Sekiyama et al) ensemble:
- High-resolution
- High-frequency assimilation
- Representative of analysis error (a posteriori)

### ECMWF ensemble:
- Crude resolution (horizontal & vertical)
- 24 hour-forecast (Assimilation at 00h each day, used between $T_0$ and $T_0+24h$)
- Representative of forecast error
- Representative of data used in an emergency?

<table>
<thead>
<tr>
<th></th>
<th>MRI data</th>
<th>ECMWF data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Members</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>Grid resolution</td>
<td>3 km</td>
<td>0.25°</td>
</tr>
<tr>
<td>Vertical levels</td>
<td>Sigma levels 15 levels below 2000 m</td>
<td>Pressure levels 5 levels below 5000 m</td>
</tr>
<tr>
<td>Time step</td>
<td>1 hour</td>
<td>3 hours</td>
</tr>
<tr>
<td>Assimilation time step</td>
<td>3 hours</td>
<td>24 hours</td>
</tr>
</tbody>
</table>

R. PERILLAT - Using meteorological ensembles for atmospheric dispersion modeling of the Fukushima nuclear accident. *HARMO18 October 12th 2017*
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)

---

R. PERILLAT - Using meteorological ensembles for atmospheric dispersion modeling of the Fukushima nuclear accident. HARMO18 October 12th 2017
How to validate the input data uncertainties?

- What is a rank histogram?

The rank of an observation is the number of ensemble members that are under this observation.

The rank histogram is a way to show how reliable an ensemble is compared to a set of observations.

Exemples of Rank histogram:

- Under-dispersed ensemble
- Well dispersed ensemble
- Over-dispersed ensemble
How to validate the input data uncertainties?

- Rank histogram

ECMWF ensemble is more widespread than the MRI ensemble

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

- Do we need to perturb these ensembles? (HARMO 2016)

These ensemble are worth to be used for uncertainty propagation

- The plume’s dispersion does not always depend on near-ground variables
- The uncertainties may accumulate along the plume trajectory
Uncertainty propagation

- IRSN’s Gaussian puff model pX (Korsakissok et al, 2013)
- MRI and ECMWF ensembles
- 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
  - 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 airborne measurement at the end of the emergency
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.

Some events are sometimes not well represented...
Ensemble + 7 source terms

Goal: to encompass Cs-137 deposition observations

The two ensembles underestimate the high values of deposition

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:

- 500 perturbed runs

Perturbations of the input:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Perturbation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meteorological fields</strong></td>
<td>Draw between the member of the ensemble</td>
</tr>
<tr>
<td>Stability calculation method</td>
<td>[Turner, LMO, Gradient]</td>
</tr>
<tr>
<td><strong>Source term</strong></td>
<td>[Mathieu, Stohl, Terada, Katata, Winiarek, SaunierECMWF, SaunierMRI]</td>
</tr>
<tr>
<td>Source term amplitude</td>
<td>LogNormal ($\times3$, $\div3$) at 95%</td>
</tr>
<tr>
<td>Source term time shift</td>
<td>Normal ($+3H$, $-3H$) at 95%</td>
</tr>
<tr>
<td>Source term altitude</td>
<td>Uniform [20, 150]</td>
</tr>
<tr>
<td>Dispersion method</td>
<td>[Doury, Pasquill, Similarity]</td>
</tr>
<tr>
<td>Deposition coefficient</td>
<td>LogNormal [0.5, 5] at 95%</td>
</tr>
<tr>
<td>Scavenging coefficient</td>
<td>LogNormal [0.005, 0.05] at 95%</td>
</tr>
</tbody>
</table>
Monte Carlo simulations:

- Goal: to encompass gamma dose rate observations

- The Monte Carlo results have a larger spread than the crossed simulations between the meteorology and the source terms.

- Some events are still not well represented.
Monte Carlo simulations

- Goal: to encompass Cs-137 deposition observations

- The ensemble results are a bit over-dispersed but embrace the observations

- There is a bias for the MRI ensemble

- Several simulations are under all observations in the two ensembles:
  - The inputs are over-dispersed
  - A threshold on the observation limits the rank histogram
The use of Monte Carlo simulations in emergency

The Monte Carlo results can be used to estimate the probability of an event to happen.

These tools could allow a better decision making in case of an emergency.
Conclusion and perspective

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

PhD of Ngoc Bao Tran LE (Poster H18-140)

In the future: Adaptation for operational purposes

Feel free to send me an e-mail for more discussion:
perillat@phimeca.com