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

Raphaël Périllat[1,2,5], 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).

Abstract: Atmospheric dispersion simulations used in case of a radionuclides' accidental release have a lot of uncertainty. A sensitivity study on the Fukushima disaster with the short distance model pX (Korsakissok, I. et al. 2013) from IRSN has shown that the meteorological data and the source terms are the most influent inputs on the simulation results (Périllat et al, 2016). These variables are very uncertain and a minor change of one of them can change completely the simulation results. A realistic way to propagate the uncertainty of the meteorological data is to use ensembles.
Two meteorological ensembles were used in this study. The first ensemble was designed by the Meteorological Research Institute of Japan (MRI) (Sekiyama et al. 2013). This ensemble has been built to be representative of the a posteriori analysis error, i.e. the uncertainty of the meteorological fields after assimilating observations from the period of interest. The second ensemble is the forcast ensemble from the European Centre for Medium-Range Weather Forecasts (ECMWF) and is more representative of the uncertainty of the meteorological data that can be available in case of an accidental situation for emergency situations management.
First, it was necessary to assess the quality of the ensembles, namely to ensure that their spread is representative of the uncertainty of meteorological fields. Then, the uncertainty was propagated through atmospheric dispersion models with Monte Carlo simulations in order to obtain the best assessment of the output uncertainty. For these simulations, seven source terms from the literature were used and additional perturbations were applied to the release times, the source altitude and the amplitude of the release. Scavenging coefficients and deposition velocities were also perturbed. Several dispersion schemes were included. The resulting statistical model of uncertainty was assessed by comparison with gamma dose rate and airborne deposition observations using rank histograms.
The Monte Carlo sample issued from both ensembles are spread wider than the radiological observations, despite the ensembles themselves being under-dispersed compared to the meteorological observations. Both samples are biased relatively to the observations. Additionally, they both contain, especially the ECMWF one, simulations with values below all the observations. Adjustments of the input perturbations could possibly compensate for this discrepancies.

Key words: *Atmospheric dispersion, Fukushima, Uncertainty, Monte Carlo, Meteorological ensemble*

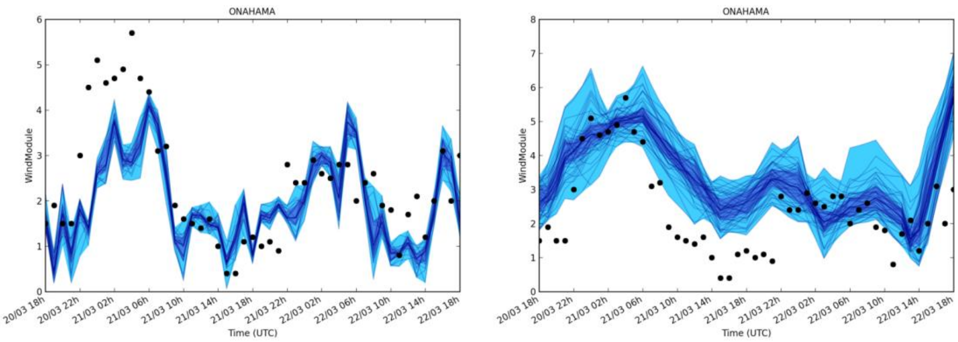
INTRODUCTION

At the Institute of Radiation Protection and Nuclear Safety (IRSN), in case of an accidental release of radionuclides in the atmosphere, dispersion simulations are used in the early stage of the accident for emergency management and after the release, to provide an evaluation of its consequences in complement to measurements with the pX model (Korsakissok, I. et al. 2013) from the C3X platform. In nuclear emergency management, dealing uncertain information on the current situation, or predicted evolution of the situation, is an intrinsic problem for decision making.
Our previous studies on the long distance model ldX (Girard, S., I. Korsakissok, et al. 2014) has shown that the meteorological data and the source terms are the most influents inputs on the simulation results. However, these variables are very uncertain and a minor change of one of them can change completely the simulation results. A realistic way to propagate the uncertainty of the meteorological data is to use ensembles.

EVALUATION OF METEOROLOGICAL ENSEMBLES

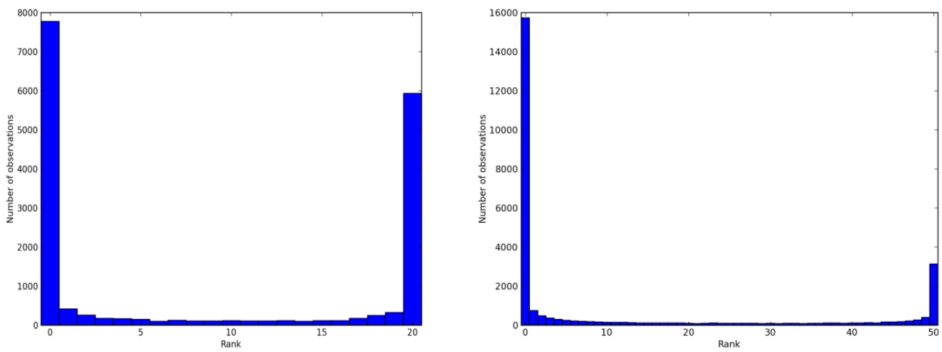
A meteorological ensemble is built from several numerical forecasts aiming to give indications of the possible future states of the atmosphere on the same region and same time period, the dispersion of the forecasts privide an estimation of the weather uncertainty. Usually, these ensembles are mostly used for meteorological forecast and the spread of the members is supposed to represent the uncertainty of this forecast. In this study, two meteorological ensemble where used. One from the Meteorological Research Institute (MRI) (Sekiyama et al. 2013) from Japan and one from the European Centre for Medium-Range Weather Forecasts (ECMWF). The MRI ensemble is built of 20 members on a 3km horizontal resolution grid, with 9 vertical levels under 1000 meters, a time step of one hour and a assimilation frequency of 3h. This ensemble has been built to be representative of the a posteriori analysis error. The ECMWF ensemble is made of 50 members on a 0.25° resolution grid, with 6 vertical levels under 5000 meters, and a time step of three hours. The assimilation frequency of the meteorological observations is of 24h. This frequency and the resolution are more representative of the uncertainty of the meteorological data that can be available in case of an accidental situation for emergency management.

Before using meteorological ensembles to forecast the uncertainty in dispersion models, it is useful to compare these data to the meteorological measurements on stations and the rank histogram is a good method to estimate if an ensemble is representative of the observed uncertainty. In this study, the meteorological observation data used in this study are from the Automated Meteorological Data Acquisition System (AMeDAS) which collects more than 1200 observation stations on Japan. The data used are the observations of temperature at 2 meters, wind speed and direction at 10m above the ground, and the 10-minutes cumulated precipitation from rain gauges. The goal would be to have an ensemble that embrace the meteorological observations and give a flat rank histogram.



(a) **(b)**

Figure 1. Wind module (in m/s) of the ensemble compared to the AMeDAS measurements on Onahama between the 20th of March at 18h UTC and the 22th of March at 18h UTC (a) for the MRI ensemble and (b) for the ECMWF ensemble.



(a) (a)

Figure 2. Rank histogram between the 12th and the 30th of Marsh 2011 for the wind module (a) of the MRI ensemble and (b) of the ECMWF ensemble.

The ECMWF ensemble is more widespread that the MRI ensemble (Figure 1) because of the larger frequency of assimilation and of the cruder spatial resolution. Since the 50 members are computed from 24-hour forecast, uncertainties can grow more than with a 3-hour assimilation window. Furthermore, the members of the ensemble give a value which is averaged on the cell, without taking into account the local variations due to subgrid processes, ground occupation effects or relief for instance. This representativeness error due to the grid resolution is larger on the ECMWF ensemble.

The observations are often outside the ensemble, which may indicate that the ensembles are under-dispersed, that is, they under-estimate the meteorological variability close to the ground. That can be due to lacks in the meteorological model and to representativeness error which prevent the model to correctly simulate the interactions with the ground surface. Thus, the uncertainties are probably bigger on the 10-meter-high-variables than above the boundary layer, whereas the ensembles' spread may be more representative of higher-levels uncertainty.

The rank of an observation is determined by counting how many members of the ensemble are below this observation. The rank histogram shows the number of observations of each rank, counted on all stations and time steps. Theoretically, a "perfect" rank histogram would be flat. However, for the ECMWF and MRI ensembles, the rank histograms of each variable are absolutely not flat (Figure 2). Indeed, the time series figures show that the ensemble members do not embrace the observations very often. Then, all the members are mostly above or under the observation, which cause the rank histogram to be in the typical under-dispersed U-shape. It seems the two ensemble under-estimate the meteorological uncertainty in the boundary layer. Moreover, the diagrams are not symmetric: the left bar is higher than the right, which indicates a bias with a tendency to overestimation.

It should be noted that the observation error is not taken into account in these comparisons. Measurements are considered to be perfect, which is not the case, especially in very stable, low-wind situations, which is often the case in the 3-weeks period studied here. If this observation error was taken into account (by specifying its standard deviation and perturbing the models outputs with it), the rank diagrams would be better, still not flat.

Although the meteorological ensembles are not perfect, when compared to 10-meter or ground observation data, it is worth trying to use them for uncertainty propagation through dispersion models. First, the meteorological uncertainties may accumulate along the plume trajectory and result in larger errors in dispersion than on meteorological variables. Moreover, the plume's dispersion does not always depend on near-ground variables but, as it grows larger on the vertical, the mass center of the plume moves upper within the boundary layer. Therefore, the dispersion depends rapidly on 500-meter wind or higher, which is probably better represented by the ensemble.

MONTE CARLO SIMULATIONS

Using the meteorological ensembles in the dispersion model pX is a way to observe if their uncertainty correspond to a use in case of an emergency.

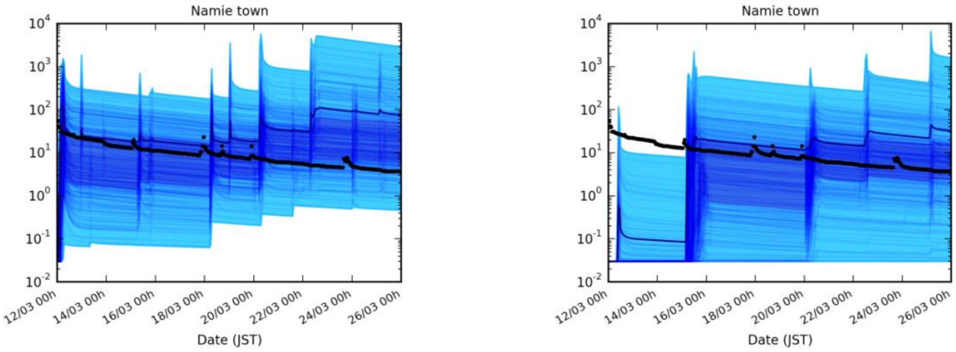
In the case of the Fukushima accident, the a priori uncertainty of the source term would be very difficult to quantify, but several source terms are available in the literature, which give an idea to quantify the *a posteriori* uncertainties. It should be noted that all these evaluations were conducted using radiological observations coupled with dispersion modelling, which means that they are not independent from meteorological and model-related uncertainties.

Both meteorological ensembles were used for the Monte Carlo simulations, to compare the result and see the effect of the meteorological fields on the uncertainty of the output. In addition, other sources of uncertainties are taken into account. Seven of them were used in this study, from Mathieu et al. (2012), Stohl et al. (2011), Terada et al. (2012), Katata et al. (2015), Winiarek et al. (2012), Saunier et al. (2013), and the source term obtain by the inverse modelling method of the IRSN with the deterministic MRI meteorological data. Additional perturbations are applied to the seven source terms used in the previous part, to better take into account uncertainties related to total quantities, release timing and height of emission. See Table 1 for the details of all the input perturbation.

Table 1. Perturbation of the model inputs for the Monte Carlo simulations.

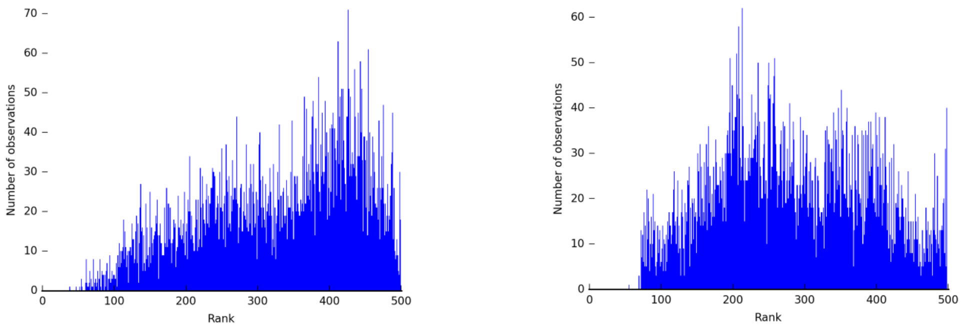
Variable	Perturbation
Meteorological fields	Draw between the member of the ensemble
Stability calculation method	[Turner, LMO, Gradient]
Source term	[Mathieu, Stohl,Terada, Katata, Winiarek, SaunierECMWF, SaunierMRI]
Source term amplitude	LogNormal (×3, ÷3) at 95%
Source term time shift	Normal (+3H, -3H) at 95%
Source term altitude	Uniforme [20, 150]
Dispersion method	[Doury, Pasquill, Similarity]
Deposition coefficient	LogNormal [0.5, 5] at 95%
Scavenging coefficient	LogNormal [0.005, 0.05] at 95%

The results from the Monte Carlo are very similar with the two ensembles. In both cases, the ensemble result is very large (Figure 3) and there are always several simulations that are under the observations, which means that there are no observations of rank zero to 30 or more (Figure 4), mostly because the deposition observations are available only above a threshold of 10 000 Bq/m^2, then the low value that would be under the ensemble are missing. Also, the rank histograms are not flat. There is a bias for the MRI ensemble, which tends to under-estimate deposition, but the rank histograms are quite correct for such simulations. These histograms are promising and they are significant of an over-dispersed input, which means that this can be corrected by changing the perturbation of the inputs.
Still, these histograms are obtained from an observation grid; therefore there is dependence in space between the observations, but not in time as for the gamma dose rate.



(a) (b)

Figure 3. Monte Carlo simulations compared to the gamma dose rate observation (in µSv/h) at the Namie town station between the 12th and the 26th of Marsh 2011 (a) for the MRI ensemble and (b) for the ECMWF ensemble.



(a) (b)

Figure 4. Rank histogram of the Monte Carlo simulations for the comparison to the Cs137 deposition observations (a) for the MRI ensemble and (b) for the ECMWF ensemble.

CONCLUSION

Monte Carlo simulations of the atmospheric dispersion model were computed by the use meteorological ensembles and the perturbation of the model inputs. Despite the small variability of the meteorological data used in this study, the dispersion results have a large variability compared to the gamma dose rate observations and deposition measurements. A large part of this variability is due to the source terms that are very different from each other.

The use of both meteorological ensembles gives over-dispersed results. The rank diagram obtain with the ECMWF meteorological ensemble is similar to the results of the MRI ensemble ensemble, despite the large difference of resolution and precision of the two meteorological ensembles, but the crude resolution meteorological ensemble is more likely to be unprecised compared to the observations.

Our futur studies will focus on the calibration of the inputs uncertainties and on a way to take into account the observation error.

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