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

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Abstract: Dispersion models are used in response to an accidental release of radionuclides of the atmosphere, to infer mitigation actions, and complement field measurements for the assessment of short and long term environmental and sanitary impacts. However, the predictions of these models are subject to important uncertainties, especially due to input data, such as meteorological fields or source terms (Korsakissok et al. (2013), Girard et al. (2014),).

In the framework of the SAKURA project, an MRI-IRSN collaboration, a meteorological ensemble of 20 members designed by MRI (Sekiyama et al. (2013)) was used with IRSN's atmospheric dispersion models. Another ensemble, retrieved from ECMWF and comprising 50 members, was also used for comparison. The MRI ensemble is assimilated every 3 hours, with a 3-kilometer resolution, designed to reduce the meteorological uncertainty in the Fukushima case. The ECMWF is a 24-hour forecast with a coarser grid, and is supposed to be representative of the uncertainty of the data available in a crisis context.

First, it was necessary to assess the quality of the ensembles for our purpose, i.e. to ensure that their spread was representative of the uncertainty of the meteorological fields. Using meteorological observations allowed characterizing the ensembles' spreads, with tools such as rank histograms. Then, the ensemble simulations were carried out with atmospheric dispersion models. The underlying question is whether the output spread is larger than the input spread, that is, whether small uncertainties in meteorological fields can produce large differences in atmospheric dispersion results. Here again, the use of field observations was crucial, in order to characterize the spread of the ensemble of atmospheric dispersion simulations. In the case of the Fukushima accident, ambient gamma dose rates, air activities and deposition data were available. Based on these data, selection criteria for the ensemble members were designed. Finally, the total uncertainty, including from the source term and the model formulation, was propagated in time. The results were compared with the meteorological-induced uncertainty, and between the two sets of meteorological data.

Key words: *Uncertainty, Fukushima, Monte Carlo, meteorological ensemble*

INTRODUCTION

Atmospheric dispersion simulations made in case of nuclear accidents rely on meteorological fields provided by meteorological models. The strong uncertainties in these data have an impact on the computed plume's trajectory. A good knowledge of this uncertainty is necessary for a good decision making in case of an emergency. Since meteorological data are 2D or 3D-fields varying in time and space, perturbing them in a physically consistent way is not trivial. Using meteorological ensembles seems therefore a good alternative to coarse perturbation, as homogeneous additive or multiplicative perturbations. A meteorological ensemble is constituted of several equiprobable forecasts on the same region and on the same period of time. It is evaluated for meteorological forecasts, and the spread of the members is supposed to represent the forecast uncertainty.

The aim of this study is to evaluate the use of meteorological ensembles for uncertainty studies in the case of the Fukushima disaster. The two ensembles used are presented and compared to meteorological observations. Then, dispersion results at local scale are shown with a set of source terms, using the meteorological ensembles with and without an additional perturbation.

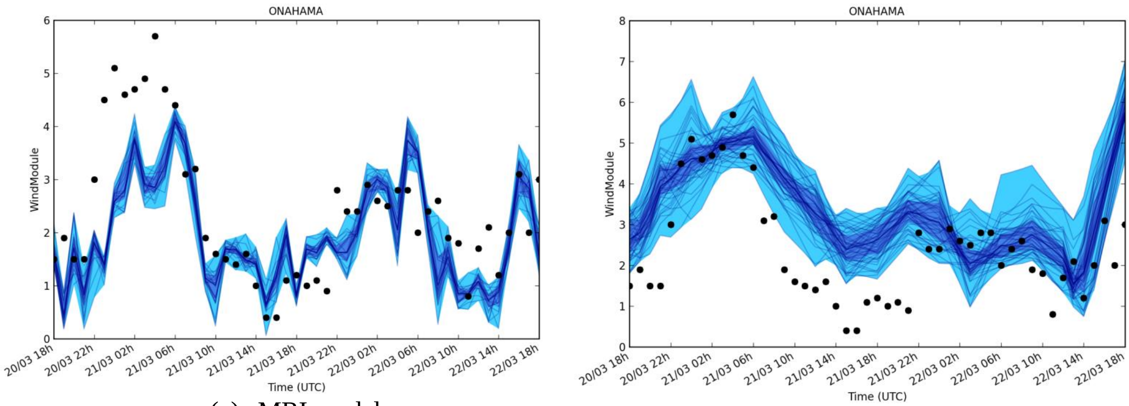
METEOROLOGICAL ENSEMBLES

In this study, we use two meteorological ensembles. The first one is from the Meteorological Research Institute (MRI) of the Japan Meteorological Agency (Sekiyama et al. (2013), Sekiyama et al. (2015)). It is built with 20 members on a 3-km horizontal resolution with an hourly time step. These data come from a posteriori assimilation of the AMeDAS[1] observations of the wind and temperature, every three hours. This ensemble is representative of the a posteriori analysis error, i.e. the meteorological uncertainty with our best knowledge of the target times on forecast. The second meteorological ensemble used here is from the European Centre for Medium-Range Weather Forecasts (ECMWF). It is built with 50 members on a horizontal resolution of 0.25°, with a three-hour time step. These data come from 24-hour forecasts and are representative of the uncertainty of data available during a crisis. These two ensembles were available on pressure levels and were interpolated on vertical levels.

Table 1. Property of the meteorological ensembles

Ensemble	Spatial resolution	Time resolution	Vertical levels (m)	Assimilation frequency	Domain
MRI	3 km	1h	10, 20, 50, 100, 120, 250, 500, 1000	3h	207km x 207km
ECMWF	0.25°	3h	10, 100, 250, 500, 1000	24h	300km x 300km

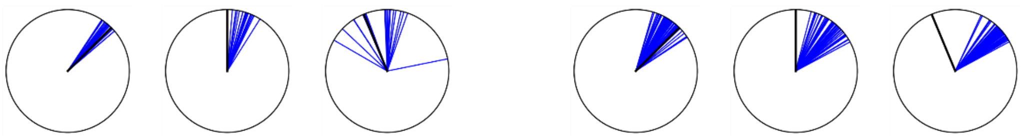
To study the behaviour of the two meteorological ensembles, we compared them to AMeDAS observations of the wind, the rain precipitation and the temperature, available at more than 60 stations in our simulation domain. The model-to-data comparison was carried out using time series of each variable, scores and rank histograms.



(a) MRI model

(b) ECMWF model

Figure 1. Wind module (m.s^{-1}) of the meteorological ensembles (in blue) compared to the AMeDAS observations (in black) for the Onahama station.



21/03 09h 21/03 12h 21/03 15h

(a) MRI model

21/03 09h 21/03 12h 21/03 15h

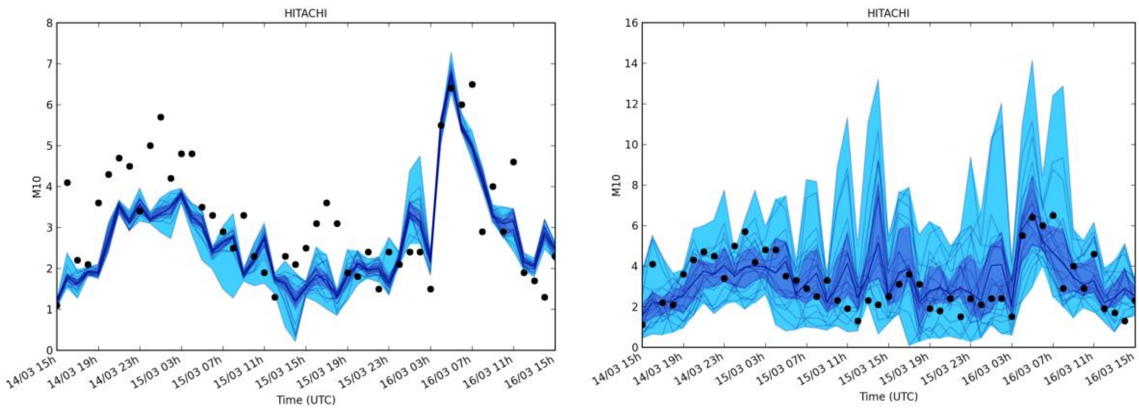
(b) ECMWF model

Figure 2. Wind direction of the meteorological ensembles (in blue) compared to the AMeDAS observation (in black) for the Onahama station.

[1] Automated Meteorological Data Acquisition System (http://www.jma.go.jp/en/amedas/)

It appears on Figures 1 and 2 that the members of the ECMWF ensemble are more spread compared to the MRI ensemble, which is consistent with the larger assimilation time. According to the scores, the MRI members are closer to the observations, with a root mean square error (RMSE) around 1.5 $m.s^{-1}$ for the wind module of MRI against 2.1 $m.s^{-1}$ for ECMWF. For the rain precipitation, the RMSE is around 0.68 $mm.h^{-1}$ for all the members of the MRI ensemble against 0.71 $mm.h^{-1}$ for the ECMWF. However, these two ensembles are not spread enough to encompass the observations. In a lot of cases, the AMeDAS observations are above or under all the members, which leads to a rank histogram in U-shape. A rank histogram is a way to assess an ensemble spread using a set of observations. For each observation we compute the rank which is the number of ensemble members that forecast less than the observation. The rank histogram shows the total number of observations of a given rank against the rank. If the ensemble is representative of the uncertainty, the rank histogram tends to be flat. The U-shaped rank histogram found for the two ensembles means that they underestimate the meteorological uncertainty. They were built to represent the uncertainty of large-scale variables that are used for meteorological forecast. The 10 meters variables are not considered for the construction of the ensemble, while the forecast error in the boundary layer is much more important than in the large scale variables, because of the direct interactions with the ground.

Therefore, we decided to apply an additional perturbation on wind and rain fields, to expand the spread of the ensembles and better represent the amplitude of the uncertainty on 10-meters variables. For that, we added a homogeneous, time-dependent, perturbation to each ensemble's member. The perturbation was chosen so as to obtain a flat rank diagram of these fields, compared to AMeDAS observations, while keeping the same ensemble mean (see Figure 3). While the physical consistency of the resulting fields can be questioned, this allowed us to verify whether a wider meteorological ensemble was sufficient to represent the output uncertainty. A better approach, in the future, would be to construct adequate meteorological ensembles, representative of the boundary layer uncertainties.



(a) Original MRI model

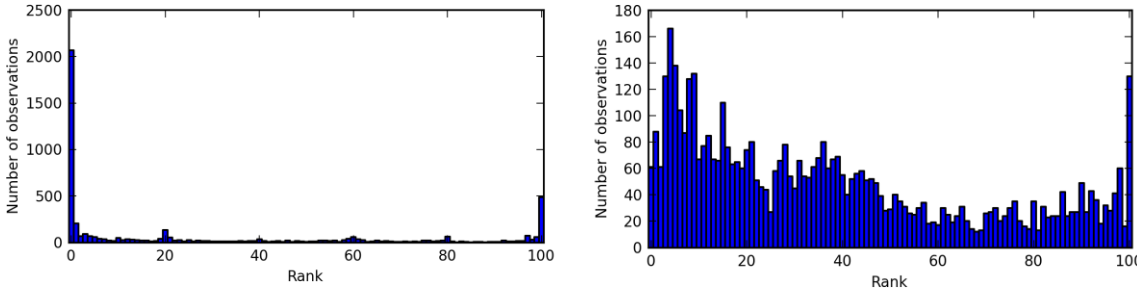
(b) Perturbed MRI model

Figure 3. Wind module ($m.s^{-1}$) of the meteorological ensemble (in blue) compared to the AMeDAS observations (in black) for the Hitachi station.

SIMULATION OF THE DISPERSION

For atmospheric dispersion computation at local scale, we used the pX model, which is a Gaussian puff model developed and used in the IRSN (Korsakissok et al. (2013)). In order to add more variability to the computation, we used the meteorological ensemble in the pX model with different source terms. The five source terms used are those from Mathieu et al. (2012), Saunier et al. (2013), Terada et al. (2012), Katata et al. (2015), and a new IRSN source term that was evaluated with inverse modelling, using the same methodology as in Saunier et al. (2013), with IRSN's large scale model and MRI's deterministic meteorological fields. As we expected, the results are really different depending on the source term.

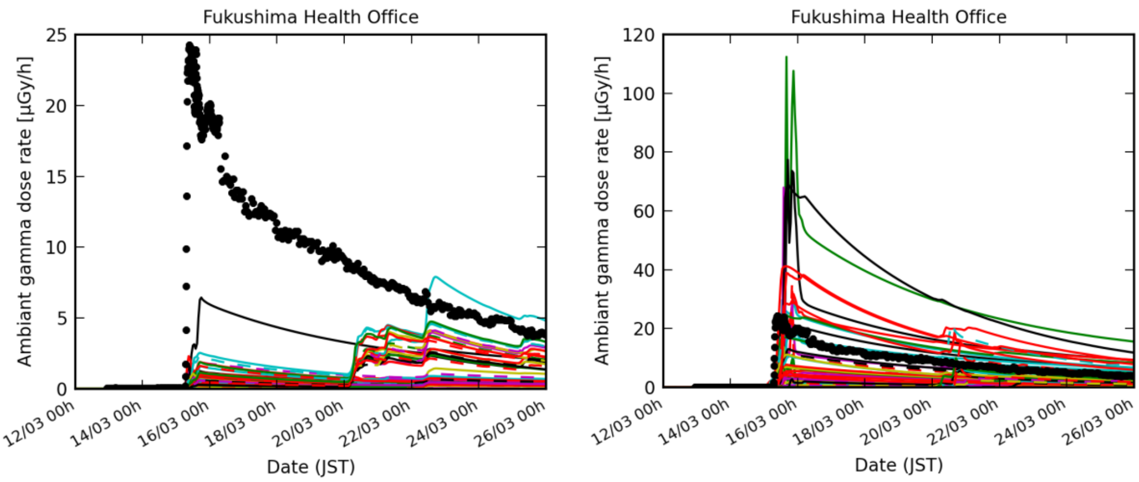
Comparing the results with the ambient gamma dose rate observations available in the Fukushima prefecture, the two ensembles do not embrace the observations, even if we include all source terms for more variability. The rank histograms are in U-shape, which means that in a lot of cases the observations are above or under all the simulations. The results are shown for MRI ensemble (Figure 4(a)), but are similar when using ECMWF ensemble, even though the ensemble's spread was larger. When using the additional perturbation on meteorological fields, the rank diagram of the simulation outputs is greatly improved (Figure 4(b)). There is still not enough spread in the simulations, but they clearly embrace the observations much more. This kind of perturbations creates more variability on the simulations and can, for instance, allow representing a peak that the previous meteorological data missed (see Figure 5).



(a) Original MRI model

(b) Perturbed MRI model

Figure 4. Rank histograms of the ambient gamma dose rate for the pX out, calculated with all source terms, compared to the observations.



(a) Original ECMWF model

(b) Perturbed ECMWF model

Figure 5. Gamma dose rate of each outputs of the meteorological ensemble compared to the observation for the Fukushima Health Office station.

CONCLUSION

Two meteorological ensembles were used for atmospheric dispersion computations in the Fukushima case, along with five up-to-date source terms. The aim was to propagate the input's uncertainties through the model, and evaluate their impact on dispersion results. The resulting ensemble simulations were compared to gamma dose rate observations. When using a non-perturbed meteorological ensemble, the output spread is not sufficient to encompass the observations. If an additional perturbation is added to the input fields, so as to be better representative of the 10-meter variables' uncertainty, the dispersion results are much better in terms of rank histogram.

However, the physical consistency of this perturbation is questionable. A more satisfactory approach, in the future, would be to construct adequate meteorological ensembles, representative of the boundary layer uncertainties.

Other uncertain parameters will also be perturbed. First, the source term uncertainty is also underestimated when using only five of them, and additional perturbations on the release times, the source altitude and the amplitude of the release should be applied. The modelling parameters are also uncertain, and deposition parameters such as the scavenging coefficient and the deposition velocity will be included in future uncertainty propagation study.

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