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COMPARISON OF ENSEMBLES OF ATMOSPHERIC DISPERSION SIMULATIONS: LESSONS LEARNT FROM THE CONFIDENCE PROJECT ABOUT UNCERTAINTY QUANTIFICATION

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Abstract: Work Package one (WP1) of the EU-funded project CONFIDENCE (COmping with uNcertainties For Improved modelling and DEcision making in Nuclear emergenCiEs) is dedicated to uncertainties during the early phase of a radiological accident. More specifically, it consists of propagating input uncertainties through atmospheric dispersion models to generate a results ensemble in which radiological endpoints can be analysed, for example by threshold exceedance of dose reference levels.

The first step of any uncertainty propagation study consists of identifying and quantifying input uncertainties. Meteorological data (e.g. wind, rain fields' forecasts) and source term (i.e. released rate of radionuclides as a function of time) are the key uncertainties during a nuclear crisis. The former was dealt with by using meteorological ensembles. For the latter, several scenarios were designed, from the most simple (a short release with crude perturbations on quantities, height and beginning time) to an ensemble of source terms, designed with the severe accident code ASTEC, including uncertainties. Finally, a significant literature review was undertaken to identify and characterise uncertainties linked to atmospheric dispersion models. Guidelines for ranking uncertainties in atmospheric dispersion were produced (Mathieu et al. 2017).

The second step was an uncertainty propagation exercise through atmospheric dispersion and radiological models, for both historical events and hypothetical scenarios. During this stage, participants from eight countries (Denmark, France, Germany, Greece, Hungary, the Netherlands, Norway and the UK) used the

meteorological ensembles and release scenarios to propagate the uncertainties through their operational tools (Korsakissok et al. 2019). The level of uncertainties taken into account depends on the participant; some only propagated the meteorological ensemble, others used Monte Carlo methods to take into account all the identified uncertainties.

This exercise led to a tremendous amount of data: fields of atmospheric concentrations and deposition as a function of time, and associated doses, for a large number of simulations. Some lessons learnt relate to dealing with high-dimensional inputs (meteorological ensembles, source terms) and outputs, from very practical issues to more theoretical ones. This abstract aims at presenting a synthesis of the exercise, with a focus on issues related to the analysis and visualization of uncertainties, including statistical and graphical indicators to compare ensemble results.

INTRODUCTION

One of the aims of the CONFIDENCE project is to understand, reduce and cope with the uncertainty of meteorological and radiological data and their further propagation in decision support systems, including atmospheric dispersion, dose estimation, food-chain modelling and countermeasure simulation models. Work package 1 (WP1) is focused on modelling uncertainties during the emergency phase, from meteorological and source term inputs, and applied to atmospheric dispersion and dose estimates. This abstract presents the ensemble dispersion simulations performed by WP1 participants for a hypothetical accident scenario at Borssele nuclear power plant (Netherlands).

The first part summarizes very briefly the release scenario and the meteorological conditions considered. Then, the second part presents the results with the short release and 10 meteorological members, with and without additional perturbations on the source term and/or physical parameters.

THE BORSSELE CASE STUDY

The Borssele nuclear power plant (NPP) is located at a latitude and longitude of 51.43 and 3.71 decimal degrees, respectively (cf. Figure 1).

Release scenarios and associated uncertainties

In WP1 of CONFIDENCE the Borssele case is studied, for which two release scenarios are defined. Here, we show the “short release” which has a duration of 4 hours. This is based on an accident which is anticipated to start in 24 hours with +/- 6 hours uncertainties on the release start. The Borssele NPP was scaled to a 900MWe reactor. The effective release height is 50 meters, with an uncertainty of 50 meters. Finally, the released quantities are given in Table 1, with an uncertainty factor of 1/3 to 3. The particulate diameter is 1µm and the iodine partitioning is 1/3 particulate, 2/3 elemental.

Table 1: released quantities for the short release scenario, for the 8 selected radionuclides (Bq).

Radionuclide	Xe-133	I-131	I-132	Te-132	Cs-134	Cs-136	Cs-137	Ba-137m
Activity(Bq)	3.51E18	2.25E16	2.84E16	1.37E16	2.69E15	6.37E14	2.06E15	2.78E14

Meteorology

The meteorology for the Borssele case study was provided by KNMI. The Harmonie-AROME model was used, with a horizontal resolution of about 2.5 km and a temporal resolution of one hour. The time-span of the data is 72 hours. The domain provided was 300 km x 300 km. The selected scenario applies to a release on 11 Jan 2017. It was labelled “easy case”, since the wind direction is well established (Figure 1). Rain adds uncertainty to the scenario (depending on the release time, the plume may or may not be scavenged by rain) and higher consequences as far as deposition is concerned. KNMI constructed a Harmonie-AROME ensemble from 2 different versions of the meteorological model, with different turbulence schemes, and combined successive deterministic forecasts to create a hybrid lagged ensemble. The ensemble is a hybrid in the sense that two different model versions are used; and lagged in the sense that successive forecasts are used. Each model version was used to construct 5 ensemble members with a forecast length of 72 hours (Geertsema et al. 2019).

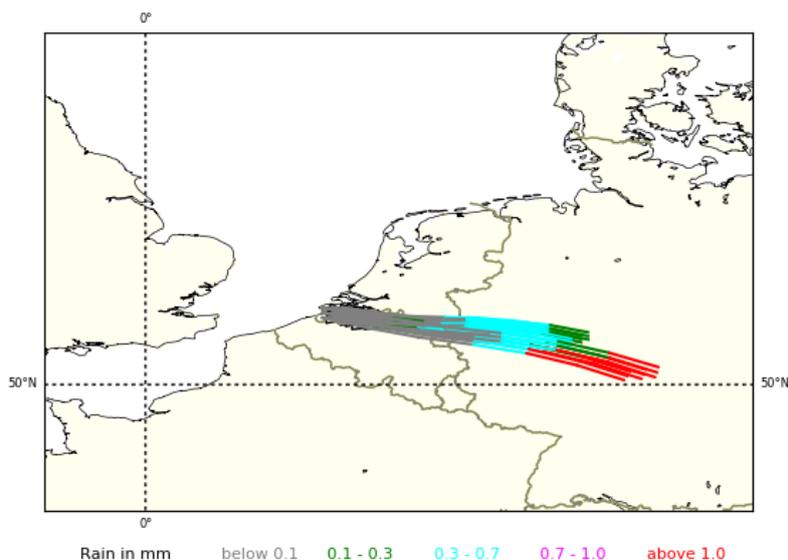


Figure 1 : Indicative plume trajectories based on analysed weather as a function of height (between 10m and 500m), for a release at 12 UTC 11/01/17, and associated rain (cumulated on one hour).

Endpoints

The outputs proposed here are maps of probability of threshold exceedance. Instead of a single contour showing the impacted area (based on a single deterministic simulation), the probability maps are based on an ensemble of simulations and correspond to the probability that a given zone is contaminated above a given level. Several levels were considered for Cs-137 deposition, for effective dose and inhalation thyroid dose for 1-year old child. In the following, the 37 kBq/m² threshold for Cs-137 deposition is presented (post-Chernobyl reference level). All variables are computed 24 hours after the reference release date. The results were computed on the input meteorological grid, with 2.5 km resolution. Useful outputs for decision making are the maximum distance and surface area affected by the threshold exceedance.

Modelling set-up

Table 1 : source perturbations used with the 10 meteorological members by each participant. Only IRSN used a Monte Carlo sampling, adding other uncertainties on diffusion and deposition coefficients.

Participant	Number of simulations	Source perturbations		
		Release height	Release time	Released quantity
IRSN	100 (Monte Carlo)	[0, 100m] uniform	[-6h, 6h] uniform	[1/3, 3] uniform
BfS	150	[0m, 50m, 100m]	T0 + [-6h, -3h, 0h, +3h, +6h]	
MetOffice/ PHE	90	[50m]	T0 + [-6h, 0h, +6h]	[x1/3, x1, x3]
EEAE	50	[50m]	T0 + [-6h, -3h, 0h, +3h, +6h]	
MTA EK	150	[0m, 50m, 100m]	T0 + [-6h, -3h, 0h, +3h, +6h]	
RIVM	650	[0m, 25m, 50m, 75m, 100m]	[-6h, +6h] with a time step of 1 hour (13 steps)	
DTU	10	-	-	-

The ensemble results from seven participating countries have been processed. Different types of atmospheric dispersion models were used: there is one Eulerian model, two Lagrangian particle models, and four Gaussian puff models. In addition, all models had different set-ups and physical parameterizations concerning the values of deposition velocities and scavenging coefficients.

The perturbations associated with the source term are listed in Table 1. All participants carried out “cross” simulations, that is, the number of simulations is equal to [number of source terms] X [number of meteorological members], except IRSN, who did Monte Carlo simulations and added perturbations of deposition and diffusion parameters, as recommended in (Mathieu et al. 2017).

RESULTS WITH THE SHORT RELEASE

Distance above a given threshold

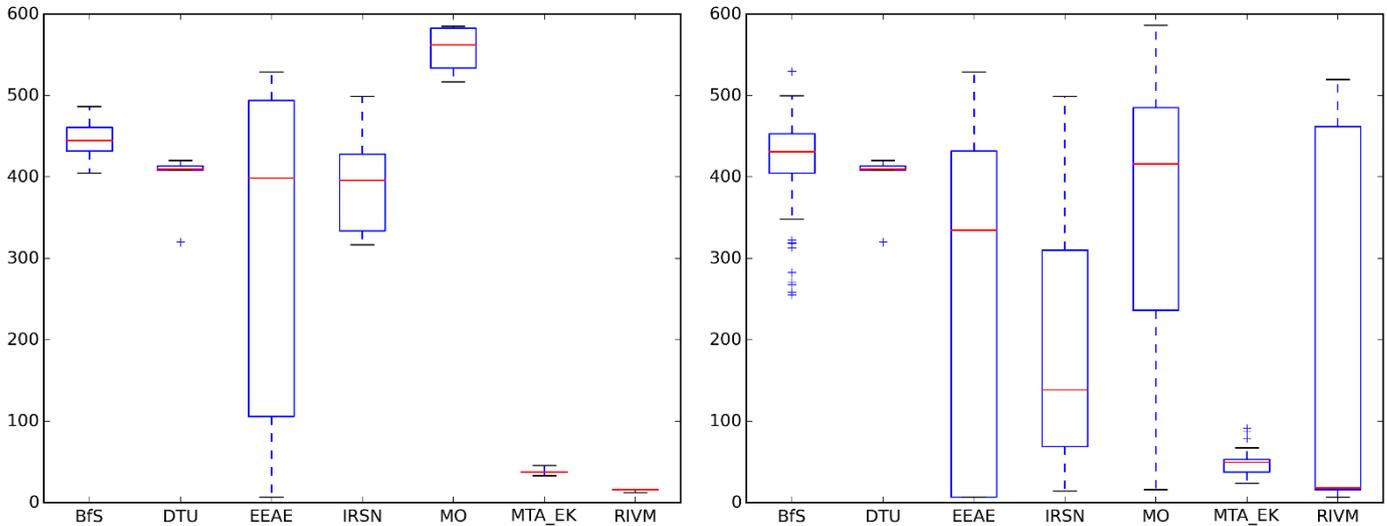


Figure 2 : Box plots for the maximum distance (in km from the source) of threshold exceedance of 37 kBq/m^2 for Cs-137 deposition: with the unperturbed source term and 10 meteorological members (left) and with the perturbations given in Table 1 (right).

Figure 2 shows the box plots for the maximum distance above the 37 kBq/m^2 threshold for Cs-137 deposition. The red line is the median over the ensemble, the box gives the limits of 25 and 75 percentiles. In the left figure, only 10 simulations per participant are considered, representing the meteorological uncertainties without any source term perturbation. Most participants' ensembles have a small spread, which is consistent with the small variability of the meteorological scenario (cf. Figure 1). Consequently, the inter-participant variability is quite large in comparison. This variability comes from the different model types and wet deposition schemes (the maximum distance is particularly sensitive to the wet deposition scheme since the threshold is exceeded in patches of wet deposition).

The variability between the estimated uncertainties using all simulations (i.e. the boxes' sizes) is highly influenced by the source term perturbations applied (Figure 2, right). For instance, the DTU ensemble's spread remains small due to the lack of source term perturbation. For most ensembles, the ensemble variability is very large and the variations between the participants may be encompassed within the overall uncertainties.

It should be noted that the maximum distance may be influenced by a few spots of contamination far from the main contamination area, which may appear in the case of rain. The surface above threshold may be more reliable (not shown). In addition, taking into account physical model uncertainties by perturbing diffusion and deposition coefficients, as done by IRSN, does not seem to lead to a higher ensemble's spread than the other participants', which hints that they are of a second order compared to source term and meteorology.

Figure 3 shows the maps of probability of threshold exceedance for the 37 kBq/m^2 threshold of Cs-137 deposition for one participant. It illustrates again that the variability (i.e. ensemble's spread) is much smaller when only the meteorological uncertainties are considered (right) than when the source term perturbations are added (left). By adding more variability, the average distance of threshold exceedance is lower. Indeed, by perturbing the release time, some simulations result in a change in the main plume direction, which results in a smaller proportion of simulations above a given threshold in a particular cell. Taking into account more uncertainties thus results in smaller average distances; on the other hand, the surface potentially impacted by the plume, that is, above a low threshold (e.g. 5%) is higher. This illustrates that such outputs and indicators have to be handled carefully to avoid misinterpretations.

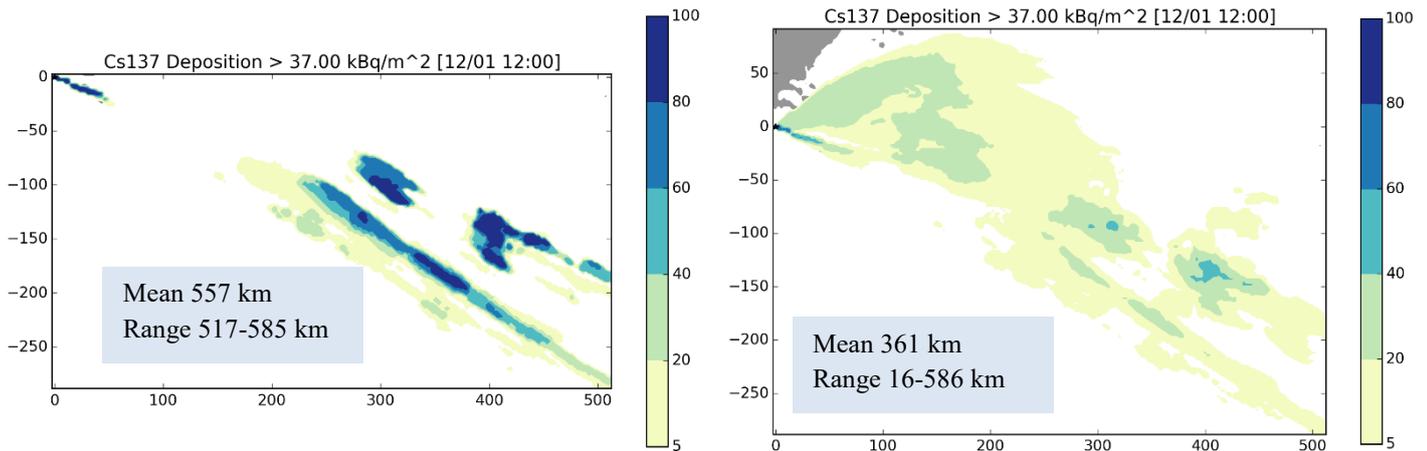


Figure 3: Maps of probability of exceeding the threshold of 37 kBq/m² of Cs-137 deposition with the unperturbed source term and 10 meteorological members (left) and with the perturbations given in Table 1 (right). The maximum distance of threshold exceedance is also given (mean over the ensemble, minimum and maximum values). The results shown here are from UK MetOffice.

CONCLUSIONS

We have illustrated the inter-model variability, compared to the uncertainty associated to meteorology and source term. In this scenario, the meteorological variability is small. A new inter-comparison is ongoing on another Borssele meteorological situation with a larger wind direction and rain variability. We have illustrated the importance of taking into account the source term uncertainties. The importance of the chosen output variable, threshold and percentile are also highlighted. In particular, for decision making, “probability maps” should be associated with examples of outputs such as “worst case” or “likely case”.

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