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DISPERSION MODELING UNCERTAINTIES IN DISPERSION ENGINE (DE)

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Abstract: We have used a method called Latin Hypercube Sampling (LHS) to study uncertainties in dispersion modeling. The strength of the method is that it reduces the number of runs needed to estimate the uncertainties. Input to the dispersion runs are based on probability distributions. Most of them are set through expert judgement but for wind direction, weather prediction ensemble runs can be used to add information to the distribution. Individual weather prediction runs have forecast errors and here with suggest a way to combine information on ensembles and wind direction error distributions via the LHS approach. Results show that the ensembles perturbed with the error distribution seem to give a better representation of the uncertainties from a probabilistic point of view. However, in directions with few ensembles represented, the approach with one perturbation per one ensemble member gives too much of a plume-like behaviour. Further improvements of the approach involve studies of a correct sampling approach to handle both a cluster of ensemble runs and single outliers. Also, it remains to study the stability of the LHS-approach.

Key words: *LHS, ensembles, probability distributions, dispersion modeling*

INTRODUCTION

Uncertainties in dispersion modeling may sometimes be quite large, both concerning source terms and parameters controlling the dispersion itself. However, for decision makers it is becoming more and more important to also understand the uncertainties in relation to CBRN-releases. We have studied and implemented a method called Latin Hypercube Sampling (LHS) in order to reduce the number of numerical runs needed to estimate the uncertainties (Burman et al 2013, only in Swedish). In this stage of the implementation we have focused on developing the uncertainty calculations. One important part is however to suggest how the uncertainty calculations should be presented. Many times decision makers would like to have yes and no answers but uncertainties based on probability distributions only give solutions which are related to levels of probability. In this work we do not aim to develop presentation methods even though we have recognized that this is an important part if a decision maker should take full use of the calculations. Our goal is rather to explore how sensitive the solution is to different parameters and if there are any combinations which we need to pay extra attention to. Two of these parameters are wind speed and wind direction which determine the speed of the dispersed cloud and the main transport axis. The specific goal of this study is thus to investigate how the information of ensemble weather prediction runs can be combined with forecast error probability distributions in order to better describe the distributions of wind direction. The main scenario that we visualize is an accident where a release of a CBRN-substance may happen but does not occur immediately. Then decision makers may be interested in what happens if the release takes place now, in a couple of days or in five days. Information from an ensemble weather prediction system could be helpful in such a situation.

THE LHS METHOD

The LHS method requires knowledge about the probability distributions for the parameters used as input data to dispersion runs. The number of runs in this approach is independent of the number of input parameters and only determined by how many subintervals of the probability distributions are used. The main rule is to never use the same subinterval twice. We typically use 50 subintervals which also coincides with the number of ensemble runs in many numerical weather prediction systems.

The LHS approach is implemented in a framework called Dispersion Engine (DE) which is used by the Swedish rescue services for example. The DE framework takes care of source descriptions, dispersion calculations and effect calculations. It runs in a .NET environment with all the dispersion models set up as separate executables. DE was originally designed for training and simulation environments and is also currently used in a simulation tool for the Swedish armed forces stand-off detection instrument RAPID.

ENSEMBLES

Since the motions in the atmosphere are a part of a chaotic system the solutions are sensitive to the initial conditions. Therefore, a numerical weather prediction system is built-up both with so-called deterministic runs and runs where the initial conditions are perturbed (see for example Toth and Kalnay 1993). The runs using a perturbed initial condition defines the ensemble weather prediction solutions. Basically, for a specified location at a specified time we obtain approximately 50 different solutions which can be used to estimate the uncertainty of the deterministic weather forecast. Each ensemble run is said to be equally probable. The difference between the deterministic run and the ensemble runs is mainly that a lower resolution is used in the ensemble runs. Therefore, a control run is performed which is a part of the ensemble but with the same initial conditions as the high resolution deterministic run. The ensemble runs often coincides with the deterministic run the first days and it is not until day three into the forecast that you usually notice differences. At day five into the forecast and onward the differences are clearly seen. In this study we have not analyzed real ensemble weather forecasts but instead defined two academic realizations corresponding to how day three and five may behave in a weather prediction system. In summary, first a smaller spread is considered and then one where significant jumps consist in the ensemble solutions.

PROBABILITY DISTRIBUTIONS

Here, we have studied LHS-runs in DE where probability distributions are set for a number of parameters: wind direction, roughness, friction velocity, Brunt-Vaisala frequency (stability) and vertical velocity. All other parameters in this study, also those coupled to the source are set to specific values. The runs are based on an event where an accident with a train filled with Chlorine occurred. A release never took place but the Swedish rescue service needed to decide the best time to empty the tanks. Here, uncertainty runs could be an important input to decide the right time when to do this. The ensemble itself describes a distribution of likely parameter settings. However, wind direction is not easy to forecast and comparisons with observations show that a 3 day forecast has a mean error (bias) of approximately 5-10 degrees and a standard deviation of 50 degrees. This is the case for every individual forecast, both the deterministic as well as the ensemble runs. However, when using the ensemble to describe a distribution we argue that an overlap exist between information from the ensemble and the existing forecast errors. Therefore, it is reasonable to believe that a distribution described by the ensemble should employ an error distribution different from the individual one. We suggest that the error distribution for the whole ensemble is set to a mean error of zero degrees and a standard deviation of 10 degrees. However, wind direction errors are allowed out to 40 degrees when sampling is done from the distribution.

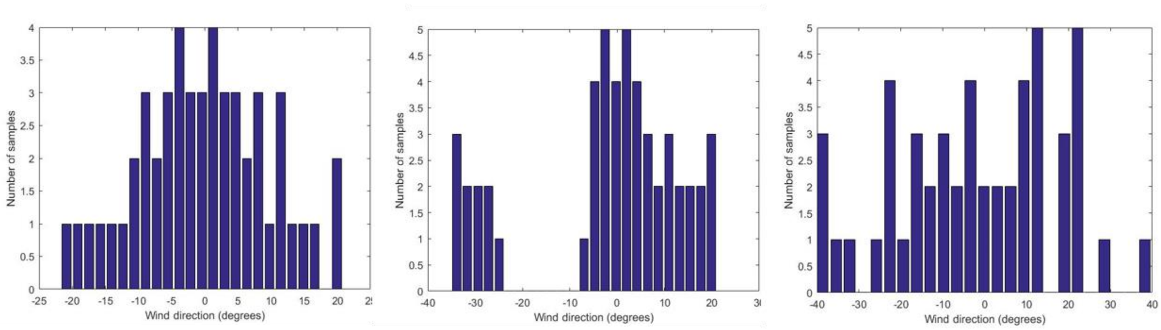

Figure 1. From left we have the error distribution, ensemble wind directions and the perturbed ensemble wind directions. Notice how the “hole” in the ensemble is filled with information when applying LHS sampling.

An example of the error distribution, ensembles and the resulting wind directions distribution is seen in Figure 1. In our approach we take one sample from the wind error distribution and add to one of the wind directions from the ensemble. The process is then repeated for every wind direction in the ensemble. This means that a broadening of the ensemble distribution takes place in a random procedure specified by the LHS-method. In this way we believe that we cover the wind direction parameter space more realistically. In summary, the input data to the runs consists of fixed (known) variables and the five parameters mentioned above are given uncertainties according to probability distributions. Roughness and Brunt-Vaisala frequency are sampled from uniform distributions while all the other parameters are sampled from normal distributions.

RESULTS

The runs are performed in DE with a lagrangian particle model. The results are presented using the dose calculations. All grid points which have a dose larger than zero are set to one. Then all dose fields are added and divided by the number of runs (fifty). Finally, we take the logarithm in order to easier visualize the features of the calculations. Thus, we get a probability of passage in all grid points and in grid points where all plumes passes the probability is of course hundred percent. We have done calculations using only the information from the ensemble and when the ensemble wind directions have been perturbed with the LHS error distribution as well. First, we consider the case with a smaller spread, corresponding to day three. The results from the idealized ensembles without any perturbations show a plume-like behavior, especially in one direction (Figure 2). This corresponds to the “hole” in the ensemble seen in Figure 1. Such a behavior could mislead a decision maker to believe that there is no risk in certain directions. When using ensemble information perturbed according to LHS we avoid this behavior and a more smooth transition is seen (Figure 3) which also reflect the forecast error better. In this case a decision makers can get a more realistic situational awareness

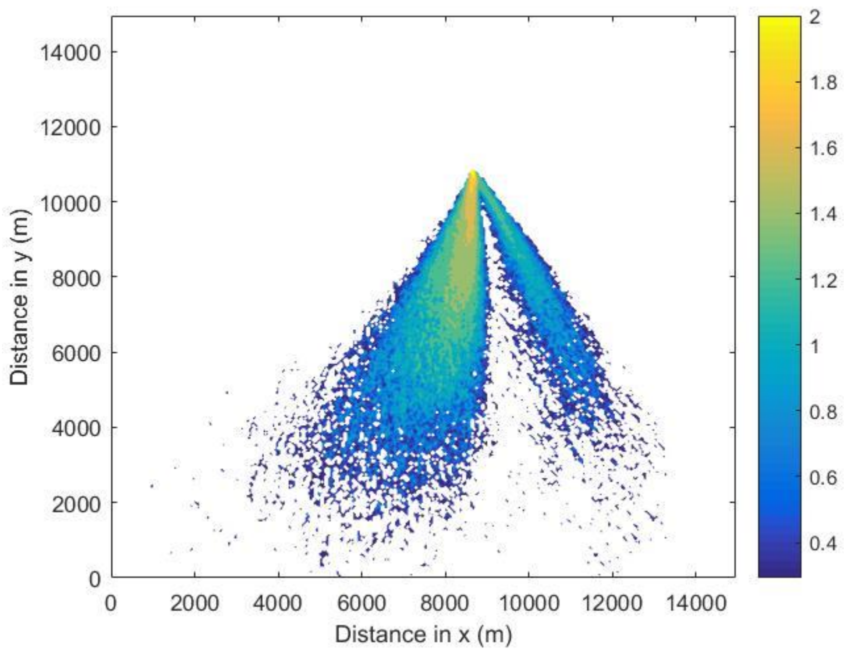

Figure 2. The probability in space of the plume-passage for the ensemble only plotted in a logarithmic scale. Hundred percent corresponds to 2 and ten percent to 1.

For the situation corresponding to day five we have set fifteen ensembles with a shifted wind direction to around 180 degrees. As seen in Figure 4 we will then get two main areas potentially influenced by a release. Clearly, when the ensembles are fewer a more plume-like behavior is present especially near the edges of the main probability area. However, this is usually the case in reality also. We also reduced the number of ensembles at the shifted direction to five (Figure 5). Then, we can almost identify every single run and this points out the weakness of the method that we have implemented so far. In directions with few ensembles we have to add more samples from the error distribution to the ensemble wind direction in order to represent the dispersion from a probabilistic view. This of course means more runs. However, in directions where many ensembles are present we can probably reduce the number of runs. We are therefore hopeful that by analyzing the ensemble and make a clever design of the distributions the number runs can stay at approximately fifty.

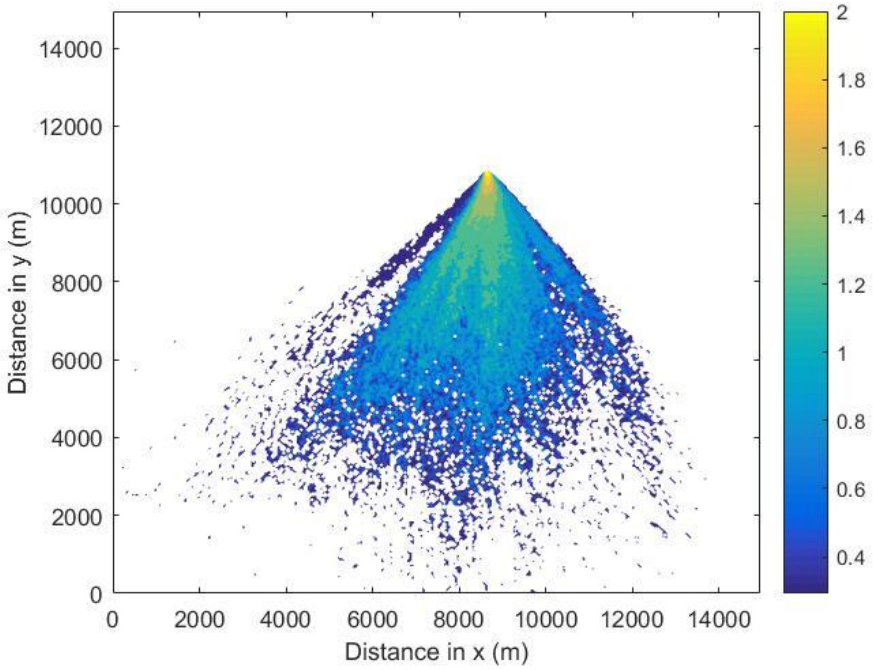

Figure 3. The probability in space of the plume-passage for the LHS-perturbed ensemble plotted in a logarithmic scale. Hundred percent corresponds to 2 and ten percent to 1.

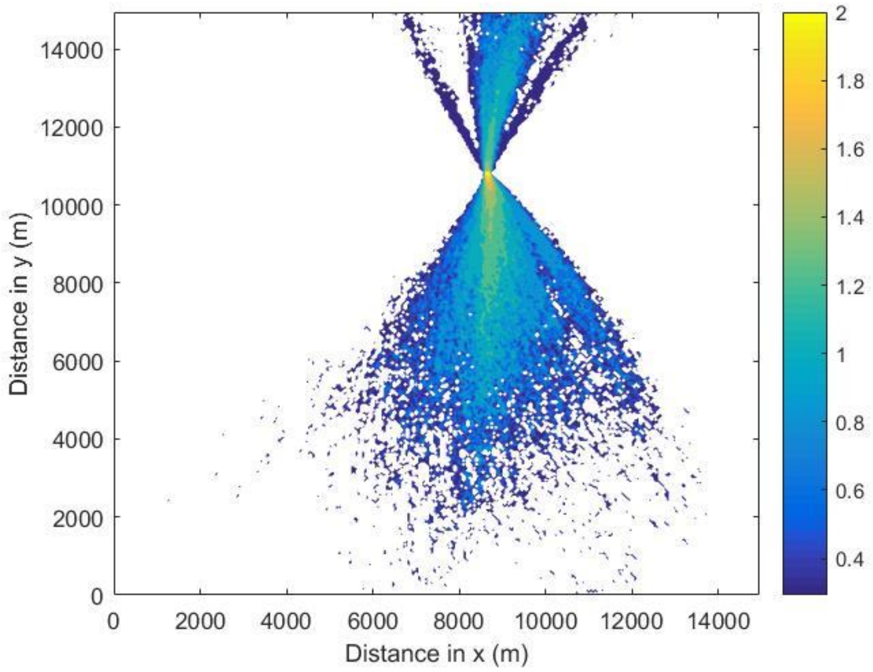

Figure 4. The probability in space of the plume-passage for the shifted LHS-perturbed ensemble plotted in a logarithmic scale. Hundred percent corresponds to 2 and ten percent to 1.

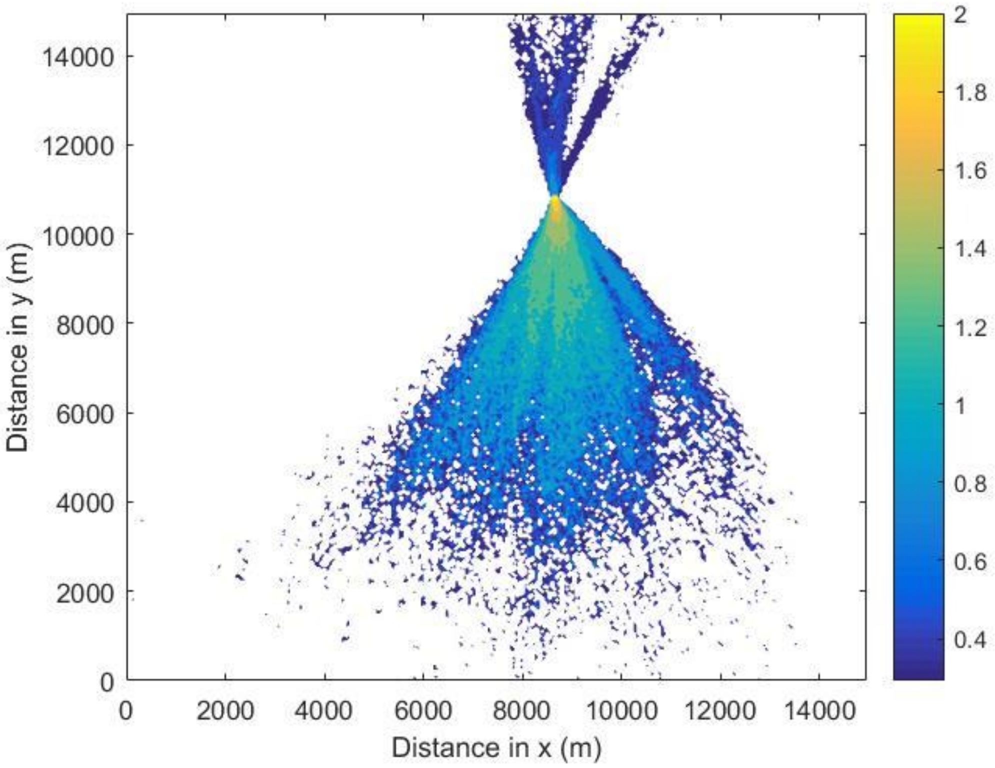

Figure 5. The probability in space of the plume-passage for the single-shifted LHS-perturbed ensemble plotted in a logarithmic scale. Hundred percent corresponds to 2 and ten percent to 1.

CONCLUSIONS

So far we have been working with idealized ensemble distributions and therefore analysis of real weather situations are necessary. Especially, we need to study the ensemble wind direction distributions in order to understand how to set appropriate error distributions. Initial runs with the LHS methodology show that the suggested error distribution together with the ensemble information seem to produce realistic results as we could anticipate the real world to look like from a probabilistic view. However, if only a few number of the ensembles have different main wind directions there is a need to add a proper amount of samples (more than one) from the error distribution to be able to reproduce real world uncertainties. Otherwise one can end up with too much of a plume behavior. Thus, the suggested one-sampling approach from the error distribution can fully work only where the overlap between ensemble information and the forecast error for one forecast is large enough. Thus, the error distribution depends on the behavior of the ensemble and we also have to choose a correct sampling approach to handle both a cluster of ensemble runs and single outliers. Also, it remains to study the stability of the LHS-approach. One should of course get more or less the same behavior if we design a new LHS-distribution. By using a multi-processer approach we could speed up the calculations and therefore we believe that uncertainty calculations could be a standard tool of rescue services in the future in the view of local scale dispersion.

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