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TOWARDS THE OPERATIONAL APPLICATION OF INVERSE MODELLING FOR THE SOURCE IDENTIFICATION AND PLUME FORECAST OF AN ACCIDENTAL RELEASE OF RADIONUCLIDES

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Abstract: In the event of an accidental atmospheric release of radionuclides from a nuclear power plant, accurate real-time forecasting of the activity concentrations of radionuclides is required by the decision makers for the preparation of adequate countermeasures. Yet, the accuracy of the forecast plume is highly dependent on the source term estimation. Inverse modelling and data assimilation techniques should help in that respect.

In this presentation, a semi-automatic method is proposed for the sequential reconstruction of the plume, by implementing a sequential data assimilation algorithm based on inverse modelling, with a care to develop realistic methods for operational risk agencies. The performance of the assimilation scheme has been assessed through the intercomparison between French and Finnish frameworks. Three dispersion models have been used: Polair3D, with or without plume-in-grid, both developed at CEREA, and SILAM, developed at FMI. Different release locations, as well as different meteorological situations are tested. The existing and newly planned surveillance networks are used and realistically large observational errors are assumed. Statistical indicators to evaluate the efficiency of the method are presented and the results are discussed. In addition, in the case where the power plant responsible for the accidental release is not known, robust statistical tools are developed and tested to discriminate candidate release sites.

Key words: Inverse modelling, Data assimilation, Atmospheric dispersion, Radionuclides

INTRODUCTION

In the event of an accidental atmospheric release of radionuclides from a nuclear power plant, decision-makers need to know the trajectory and the pattern of the radioactive plume in order to take adequate countermeasures, and alert the targeted populations. It has been demonstrated (Politis and Robertson, 2004; Bocquet, 2007; Abida and Bocquet, 2009) that the main forcing of the plume was the source. In this aim, inverse modelling and data assimilation methods have already shown, at least at an academic level, their capacity to give accurate results. For instance, they were used successfully on the real ETEX data (Bocquet, 2007; Krysta et *al*., 2008), on the Algeciras dispersion incident (Krysta and Bocquet, 2007) and on the Chernobyl accident (Davoine and Bocquet, 2007). The objective of this work is to evaluate the performance of an inverse modelling and data assimilation system, simple enough to be used in an operational context, but still efficient. In particular, the situations where such a tool may fail are investigated and solutions are proposed.

In a first section the French and the Finnish contexts, as well as the dispersion models which were used are presented. The second section describes a semi-automatic sequential data assimilation system, whose methodology is mainly based on the assumption that the accidental release comes from a nuclear power plant and that this power plant is known. This assumption should be realistic as the management of nuclear power plant at risk should immediately raise an alert to authorities in charge. However, history has shown that this is not always the case. Besides the accident may occur on a location abroad. It is therefore necessary to implement statistical tests that would assess the probability of a site to be responsible for the release. Such Bayesian statistical tools are presented in the third section of the presentation.

FRANCE AND FINLAND CONTEXTS – SETUP OF THE MODELS

For the French context, the whole nuclear facilities are monitored – i.e. 19 nuclear power plants and a nuclear fuel reprocessing plant located at La Hague. The monitoring network that we used is the one that has been proposed in (Saunier et al., 2009). It is built with 100 stations, which measure volumetric activity concentrations over a range of 10^{-5} – 10^{9} Bq.m^{-3}.

For the Finnish context, we have decided to monitor 6 sites. Two of them are located in Finland (one of them, Olkiluoto, potentially stands for two power plants as a third generation European pressurized reactor is under construction there); two others are in Sweden and the last two ones are in Russia. The monitoring network is the actual Finnish ambient rate dose monitoring network (Uljas) of 255 stations. As a simplification, we have hypothesised that the stations of the Finnish and the French networks are measuring activity concentrations instead of ambient dose. This assumption simplifies the method since the assimilation of ambient dose would require a spatial model integration, and would require to properly take into account contamination effects of dose instruments.

The Finnish power plants are located on the shores, and the Swedish and Russian power plants are quite far from the Finnish monitoring network. This situation can lead to difficulties in the inverse modelling process. This is an important difference with the French setup where all monitored power plants are in the national territory and therefore well surrounded by the measuring stations.

For each situations (France or Finland, different meteorological situations, etc.), three models are tested : First, two Eulerian atmospheric dispersion models : Polair3D, developed by the CEREA (Quélo et *al*., 2007), and SILAM, developed by the FMI (Sofiev et *al*., 2006). In both cases, the horizontal resolution is 0.25° x 0.25°. The meteorological fields are computed from the reanalysis sets computed by the European Centre for Medium-Range Weather Forecasts (ECMWF) at the same horizontal resolution and with a temporal resolution of three hours. The study is focussed on ^{137}Cs. Dry deposition and wet scavenging are modeled. In addition, a plume-in-grid model, developed by CEREA and based on Polair3D as the Eulerian part of the model, is also tested.

THE SEMI-AUTOMATIC SEQUENTIAL DATA ASSIMILATION SYSTEM

The objective of such a tool is to give accurate real-time forecasting of the activity concentrations of radionuclides. As mentioned earlier, the accuracy of the forecast plume is highly dependent on the source identification. In a general context, the identification of the source concerns both geographical localization and temporal profile retrieval and implies to solve for a high number of unknown parameters. In this case, inverse modelling methods can be delicate to carry out. As a simplification, our methodology assumes that the geographical origin of the source, one of the monitored power plant, is known. As a consequence, the aim is to retrieve the temporal rate profile. For a time resolution of one hour, this may represent a few hundreds parameters to solve for. This number is small compared to the potential number of observations regularly available from the French or the Finnish monitoring networks, which will allow us to sequentially update the Jacobian source-receptor matrix using the forward selected model. This method avoids the derivation of the adjoint model, which is of utter importance in the frame of an operational context since deriving the adjoint model can sometimes be a technological challenge.

In broad outline, our semi-automatic sequential system consists of three main steps :

- Data assimilation

At time $t = t_{obs}$, the Jacobian source-receptor matrix has been built up from sequential computations from initial time t_0, to t_{obs}. This is the time when a new set of observations is available and data assimilation is processed.

- Inverse modelling

Inverse modelling is then performed and gives a retrieved temporal profile for the source between t_0 and t_{obs}.

- Forecasting

The source-receptor matrix is updated, containing now information on the period of desired forecast, i.e. between t_{obs} and $t_{obs} + t_{forecast}$. During this time period, the source is assumed to be persistent, and the forecast of the concentrations field at $t_{obs} + t_{forecast}$ is performed.

To evaluate the efficiency of this system, we have generated several sets of synthetic experiments with our models, using lognormally distributed errors, whose amplitudes are taken significant and realistic for an atmospheric tracer dispersion event. Then, the sequential data assimilation method is performed, assuming that errors are normally distributed with an error standard deviation proportional to the measurements.
With this methodology, we have realized several studies, varying the context : France or Finland, Polair3D or SILAM, the meteorology for a fixed power plant, the power plants for a single meteorological set of conditions, etc.

To compare the reference and the retrieved field (the source rate profile as well as the concentration field of radionuclides), we use several statistical indicators that will be indicated and discussed in the presentation. The visual pattern of the plume can also be interesting in an operational situation.

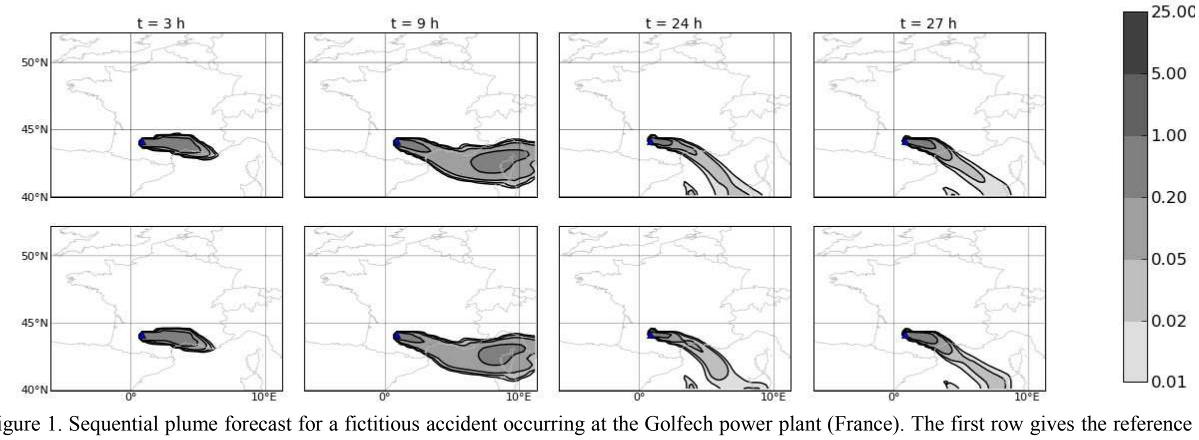

Figure 1. Sequential plume forecast for a fictitious accident occurring at the Golfech power plant (France). The first row gives the reference plume knowing the true source term. The second row gives the forecasted plume, using the data assimilation scheme, not knowing the source. The indicated time is the time of observation. The forecast time extend is 3h after the time of observation. The unit is Bq.m^{-3}.

BAYESIAN TESTS FOR THE DISCRIMINATION OF SOURCES

In the case where the site of the accidental release is unknown, at least two alternative solutions exist. First, one can complement the operational data assimilation system with a more complex system that does not assume that the location of the source is known (such as in Bocquet, 2007). Another solution consists in implementing some statistical tests that would calculate the probability for a site to be responsible for the accidental release. In the same constant quest for easily implementable tools, the second option was chosen in this study. We have implemented different Bayesian tests to help discriminating which site is responsible for the release. These tests mainly differ from each other by the prior assumption that is made on the source rate profile. These tests generally give accurate results, even in situations where the inverse modelling, knowing the release location, was difficult. Figure 2 shows a Bayesian test in such a critical case.

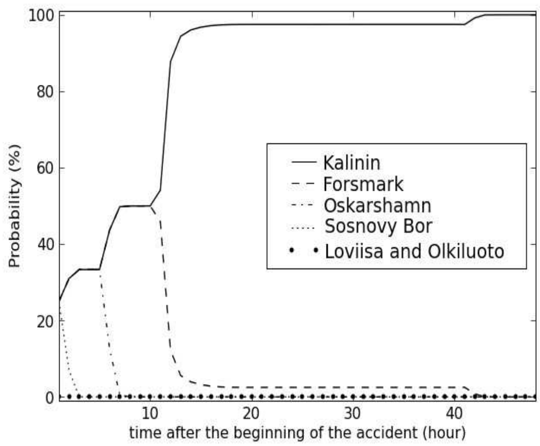

Figure 2. Sequential evolution of the likelihood for each site to be responsible for the release, according to one of our Bayesian indicators. The actual release occurs at the Kalinin power plant.

CONCLUSION

In this study, a semi-automatic data assimilation system is implemented to sequentially forecast radioactive plumes in the event of accidental releases of radionuclides. The constant objective is to propose tools easily implementable in an operational situation, and still efficient. The system presents very good average performances. Nevertheless, the situations where the system may fail (critical situations in an operational aspect) have been carefully investigated, and alternative complementary solutions have been implemented to help in these cases. Additionally, some Bayesian statistical tests have also been proposed to help identifying the site responsible for the release, giving very accurate results in most of the situations.

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