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Bayesian inference and uncertainty quantification for source reconstruction of radionuclides release: application to recent European radionuclide detection events

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In case of an accidental radioactive release, the Institute for Radiological Protection and Nuclear Safety (IRSN) uses atmospheric dispersion models to assess radiological consequences for human health and environment. The accuracy of the models' results is highly dependent on the meteorological fields and the source term, including the location, the duration, the magnitude and the isotopic composition of the release.

Inverse modelling methods have proven to be efficient in assessing the source term. Variational deterministic inverse methods have been used on the Fukushima accident and are suitable in operational use since they are able of quickly providing an optimal solution.
However the quantification of the uncertainties of the source term assessed is usually not easily accessible. In contrast, Bayesian inverse methods are developed in order to efficiently sample the distributions of the variables of the source, thus allowing to get a complete characterisation of the source.

In this study, we propose to tackle the Bayesian inference problem through two types of sampling methods: Monte Carlo Markov Chains methods (MCMC) with the parallel tempering algorithm and Stein variational gradient descent. The distributions of the control variables associated to the source and the observations errors are presented. To better quantify observations errors, different approaches based on the definition of the likelihood, the reduction of the number of observations and the perturbation of the meteorological fields and dispersion model parameters are implemented.

These different methods are applied on two case studies: the detection of Ruthenium 106 of unknown origin in Europe in autumn 2017 and the accidental release of Selenium 75 from a nuclear facility in Mol (Belgium) in May 2019. For both of these events, we present a posteriori distributions enable to identify the origin of the release, to assess the source term and to quantify the uncertainties associated to the observations, the dispersion model and meteorological fields. Finally, we show that the Bayesian method is suitable for operational use.