Inverse modelling of radionuclide release rates using atmospheric dispersion modelling

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Motivation

Severe accidents in nuclear power plants such as the historical accident in Chernobyl 1986 or the more recent disaster in the Fukushima Dai-ichi nuclear power plant in 2011 have drastic impacts on the population and environment. One of the most significant uncertainty in the evaluation of such nuclear accidents is the estimation of the source term. That is, the time dependent quantification of the released spectrum of radionuclides during the course of the nuclear accident. We present an inverse method to determine the source term using Lagrangian dispersion modelling and evaluate it's sensitivity towards the a priori term, observations, and meteorological fields.

Dispersion modelling

To simulate radionuclide dispersion, we used the Lagrangian particle dispersion model FLEXPART (Stohl et al., 2005). FLEXPART was driven with three-hourly operational meteorological data from two different sources. Data from the European Centre for Medium-Range Weather Forecasts (ECMWF) had a horizontal resolution of 1°x1° on 91 vertical levels and data from National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) analyses had a horizontal resolution of 1°x1° on 26 vertical levels.

Inversion

The applied inversion method uses a Bayesian formulation considering uncertainties for the a priori term and the observations. n unknown radio nuclide emissions, i.e. the source term, are put into a vector $\mathbf{x}$. For each of the unknown n emissions a unit amount of radio nuclides was emitted and its dispersion was modelled with FLEXPART. The model results were matched with m observation values. Modelled values $\mathbf{y}$ corresponding to the observations can be calculated as $\mathbf{y}=\mathbf{Mx}$ where $\mathbf{M}$ is the $m \times n$ matrix of the source-receptor relationships calculated with FLEXPART.

The problem is typically ill-conditioned because the observations are often insufficient to fully constrain the source term. Therefore, a priori information is necessary to obtain a meaningful solution. The detailed solution of the problem is described and was successfully applied in e.g. Eckhardt et al., 2008, Seibert et al., 2011, Stohl et al. 2012.

A hypothetical test case

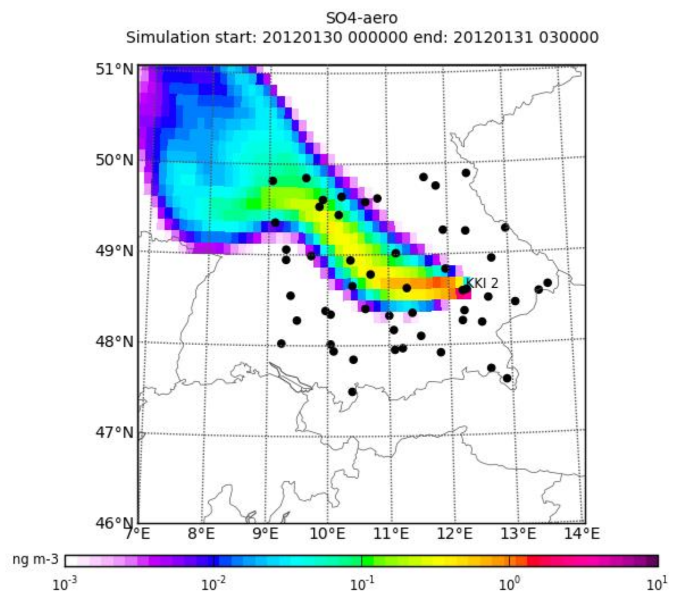
A hypothetical test case was set up to evaluate the inversion method. Radio nuclide activity concentrations of Cs-137 (and Xe-133, not shown here) are used in the evaluation process.

The fictitious accident

A fictitious accident in the Isar 2 Nuclear Power Plant (KKI 2) was assumed as test case. A hypothetical release of 16 radio nuclide species was compiled for a period of 3 weeks and serves as the "true" source term.

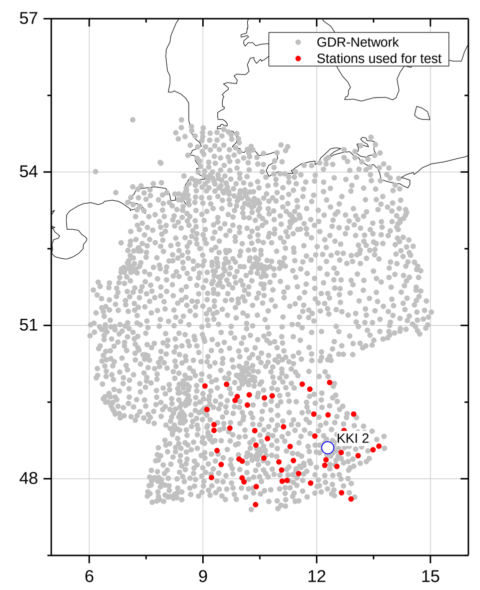
The modelled measurement data

Pseudo observations of radio nuclide activity concentrations were modelled at 52 sites of the German gamma dose rate (GDR) observation network using the FLEXPART model and the given source term.



FLEXPART simulation using an unity release of an aerosol type tracer (possibility of wet and dry deposition). Aerosol bound radionuclides like Cs-137 are scaled according to the simulated release rates.

Outlook



The gamma dose rate (GDR) observation network offers a densely populated network of observational data. The presented inversion method is currently extended from radio nuclide activity concentrations to gamma dose rates to take benefit from the existing GDR network.

A predefined spectrum of radio nuclides according to the inventory of the nuclear power plant is used to determine the modelled data which will be matched with the observations

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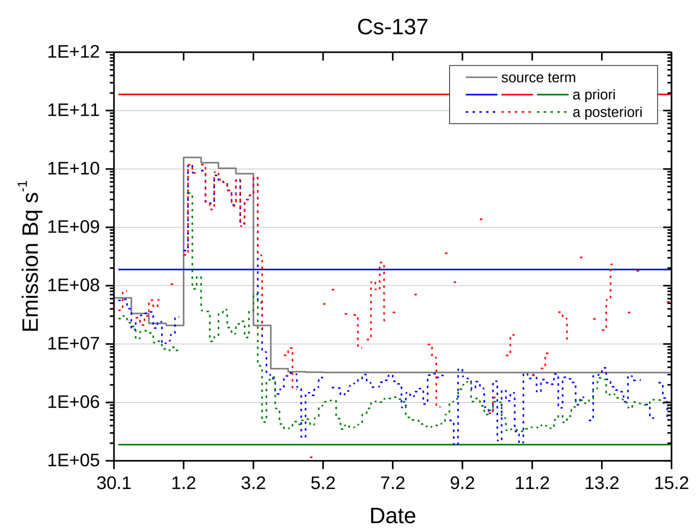
Sensitivity tests

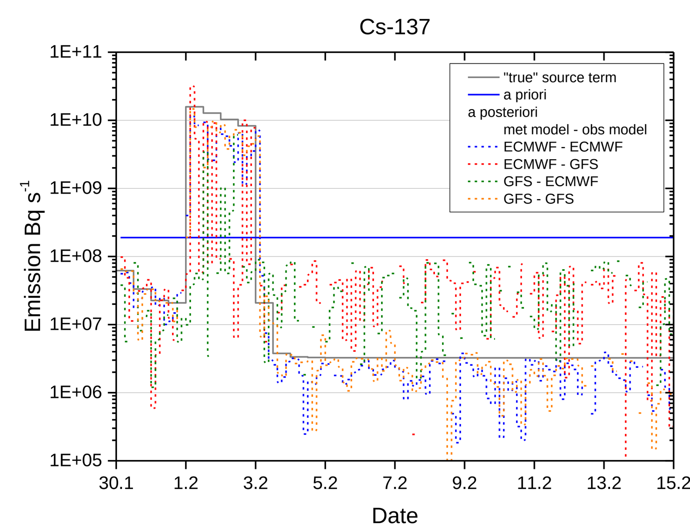
A priori source term

Three constant a priori source terms were assumed.



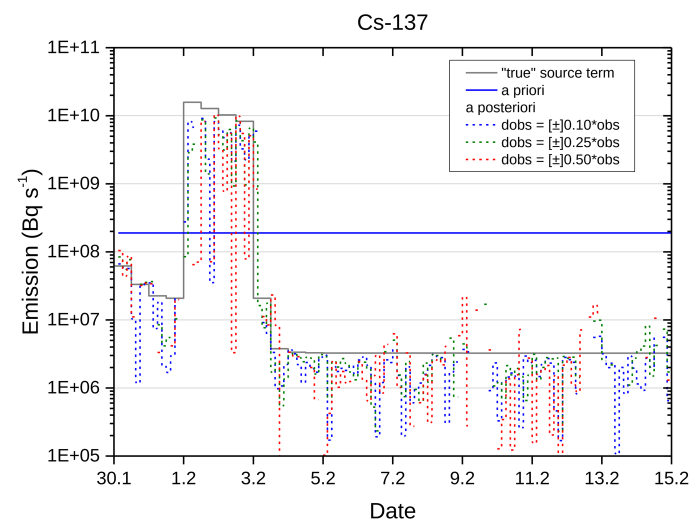
Meteorological fields

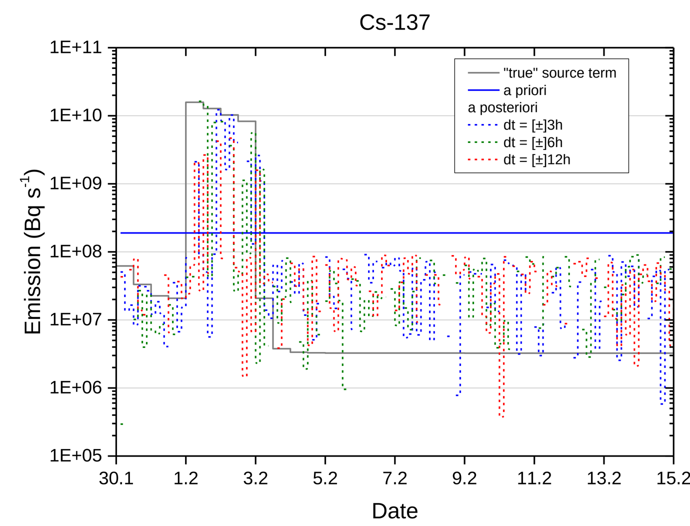
Permutation of ECMWF and GFS data (observations and inversion).



Observations

The observational data was modified in magnitude and time. The deviation was set randomly up to a maximum as given in the figures.





Results

The presented inversion method is most sensitive to the applied a priori source term. However, the sensitivity towards the a priori source term depends on its estimated error, as well (not shown here), and has to be kept in mind. Changes in the meteorological fields – which might also lead to temporal shifts within the source-receptor relationships – can also significant deviations.

Acknowledgements

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