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Source release-rate estimation of atmospheric pollution from a non-steady point source at a known location

Padmanathan Kathirgamanathan [a], Robert McKibbin [b] and Robert I. McLachlan [a]

[a] *Institute of Fundamental Sciences, Massey University, Private Bag 11 222, Palmerston North, New Zealand*
E-mail: {P.Kathirgamanathan,R.McLachlan}@massey.ac.nz

[b] *Institute of Information and Mathematical Sciences, Massey University, Albany campus, Private Bag 102 904 North Shore Mail Centre, Auckland, New Zealand*
E-mail: R.McKibbin@massey.ac.nz

The goal is to build up an inverse model capable of finding the release history of atmospheric pollution by using measured gas concentration data at just one location on the ground and identify the factors which affects the accuracy of the model predictions. The problem involves a non-steady point source of pollution at a known location in the atmosphere. This problem of finding the release rate is an ill-posed inverse problem and its solution is extremely sensitive to errors in the measurement data. Special regularisation methods, which stabilise the process of the solution, must be used to solve the problem. The method described in this paper is based on linear least-squares regression and Tikhonov regularisation, coupled with the solution of an advection-diffusion equation for a non-steady point source. The accuracy of the method is examined by imposing normally-distributed relative noise into the concentration data generated by the forward model as well as some real experimental data.

Keywords: release rate estimation, inverse air pollution model, ill-posed problems

1. Introduction

Post-accident management plans are considered necessary for public protection from potential accidents resulting from dangerous gas leakages. In the event of accidental gas releases, the determination of the release rate and location are important since forecasting of the concentration of gas in the atmosphere is totally dependent on them. Therefore the estimation of release rate and location is very useful for post-accident management staff to prioritise off-site evacuation actions.

The analysis process for accidental releases of gas from a single point source can be categorised as follows.

1. Instantaneous release from a known location.
2. Instantaneous release from an unknown location.
3. Extended release over a period of time from a known location.
4. Extended release over a period of time from an unknown location.

Therefore methods for assessing environmental consequences of accidental gas releases must incorporate all of the above situations. Case 1 is very simple since only a single parameter is to be estimated; we do not consider it further. In our previous paper [3], we presented an inverse model for case 2. The approach taken was to formulate a non-linear least squares estimation problem associated with an advection-diffusion equation for an instantaneous point source. We found that reliable estimates of the source location and amount released could be obtained even with the partial capture of the plume data, provided pollution concentration measurements were taken at a minimum of 3 non-collinear points on the ground. This is a well-posed problem and the source location and the amount released can be calculated with reasonable accuracy.

The novel concept of this paper is to develop an inverse model for case 3 using the methods available in groundwater modelling literature and identify the factors affect the accuracy of the inverse model prediction. To do so we consider the problem in which the transport properties of the medium and source location are known but the source release history is not known. The accuracy of the model is examined by using simulated concentration data (generated by the forward model) to which normally-distributed relative noise has been added, as well as some real experimental data. We formulate the inverse model as a least squares minimisation problem associated with the solution of an advection-diffusion equation for a non-steady point source. We show that this is a linear ill-posed problem and solve it using Tikhonov regularisation and the properties of L-curve and generalised cross validation. The number of measurement locations for this problem is not crucial. Even with the concentration measured at one location on the ground, we find that the source history can be reconstructed with reasonable accuracy provided the whole plume data sequence is captured.

Case 4 combines both of the difficulties of cases 2 and 3. It is both nonlinear and ill-posed. We plan to address this case in a forthcoming paper. Table 1 summarises the different situations.

This application in the field of atmospheric pollution has not been widely-studied in the literature. But in the field of groundwater modelling, many researchers (e.g., [5,8–10])