17th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
9-12 May 2016, Budapest, Hungary

INVERSE DISPERSION MODELLING FOR IDENTIFICATION OF MULTIPLE-POINT SOURCE EMISSIONS IN ATMOSPHERE

Raj Rani, Sarvesh Kumar Singh, Gregory Turbelin, Pramod Kumar, Amir-Ali Feiz, Pierre Ngae

LMEE, Universite d'Evry-Val d'Essonne, 40 Rue du Pelvoux, 91020 Evry Cedex

Abstract: The paper deals with a complex situation of dispersion events where multiple releases are simultaneously emitting a common tracer and a merged set of atmospheric concentrations is recorded to identify these releases. The identification, here, refers to the estimation of locations and strengths of a known number of simultaneous point releases. The source-receptor relationship is described in the framework of adjoint modelling by using an analytical Gaussian dispersion model. A least-squares minimization framework, free from an initialization of the release parameters (locations and strengths), is presented to estimate the release parameters. This utilizes the distributed source information observable from the given monitoring design and number of measurements. The technique leads to an exact retrieval of the true release parameters when measurements are noise free and exactly described by the dispersion model. The inversion algorithm is evaluated using the blind data from multiple (two, three and four) releases conducted during Fusion Field Trials in September 2007 at Dugway Proving Ground, Utah. The accuracy of source retrieval is subjected to the retrieved resolution features by the monitoring network.

Key words: *Fusion field trials, Inverse dispersion modelling, Least-squares, Multiple source identification*

INTRODUCTION

In the atmospheric dispersion events, fast and accurate identification of unknown releases is one of the major concerns to advance the emergency assessment capabilities and to minimize the threat of exposure to the environment. The dispersion events might involve one or more releases simultaneously emitting the contaminants. In case of simultaneous releases emitting the same contaminant, the field of plumes may overlap significantly and the sampled concentrations may become the mixture of the concentrations originating from all the releases. The other uncertainties may arise as, (i) the sources are seen from the same angle but are located at different distances, (ii) the receptors near to a weak source will report same concentration as the receptors far away from a strong source, etc. In such cases, it is challenging to separate the influence of each source and to correctly identify each source from a set of merged concentration measurements. In local scale dispersion events, the unknown releases are often formulated as point type and their identification is addressed by estimating a fixed set of parameters, for instance, ground level coordinates of the release location, height, strength, etc,.

Fusion Field Trials (FFT07) refer to a series of short range diffusion tests conducted at Dugway Proving Ground, Utah during September 2007 (Storwald, 2007). The dataset corresponds to the instantaneous/continuous single as well as multiple (two, three and four) point releases. The experiment is designed and distributed widely for evaluating the performance and capability of several source estimation algorithms. In this study, an inversion technique is proposed to efficiently address the retrieval of continuous multiple point releases using real measurements from FFT07 datasets. The objective is to highlight the capability and efficiency of the inversion technique in identifying the parameters (mainly, locations and strengths) corresponding to the continuous multiple point releases in a real scenario. The bold symbol denotes vector/matrix and italic denotes scalar.

MULTIPLE-POINT SOURCE IDENTIFICATION

The inversion technique is based on an adjoint source-receptor relationship between measurements μ_i, $i = 1,2,\ldots,m$ and unknown emissions vector $\mathbf{s}$ of dimension *N* (number of discrete cells in the discretized domain) which is given as (Pudykiewicz, 1998),

$$\boldsymbol{\mu} = \mathbf{A}\mathbf{s} + \boldsymbol{\eta} \tag{1}$$

where $\boldsymbol{\eta}$ is the residual vector of dimension m including noise in the measurements and model, $\mathbf{A} = [\mathbf{a}_1, \mathbf{a}_2, \ldots, \mathbf{a}_N]$ is the $m \times N$ matrix of adjoint elements and $\mathbf{a}_i$ is a m-dimension adjoint vector representing sensitivity with respect to m measurements. Assuming that the measurements are generated from k point sources such that $s_i = q_{oi}\,\delta(\mathbf{x} - \mathbf{x}_{oi})$, $i = 1,2,\ldots,k$ where q_{oi} and $\mathbf{x}_{oi}$ are the release strength and location, respectively. Accordingly, the equation (1) is modified as,

$$\boldsymbol{\mu} = \mathbf{K}\mathbf{q}_o + \boldsymbol{\eta} \tag{2}$$

in which $\mathbf{K}$ is $m \times k$ matrix expressing sensitivity of m measurements with respect to k unknown release locations and $\mathbf{q}_o = [q_{o1}, \ldots, q_{ok}]$ is k-dimension vector of unknown strength. For the estimation of release locations and strengths, a cost function J is formulated as $J = \frac{1}{2}\boldsymbol{\eta}^{\mathrm{T}}\boldsymbol{\eta}$. First, the function J is minimized with respect to q_{oi} which provides a critical estimate as,

$$\hat{\mathbf{q}}_o = \left(\mathbf{K}^{\mathrm{T}}\mathbf{K}\right)^{-1}\mathbf{K}^{\mathrm{T}}\boldsymbol{\mu} \tag{3}$$

The estimate $\hat{\mathbf{q}}_o$ is a local minimum of J provided $\mathbf{K}^{\mathrm{T}}\mathbf{K}$ is invertible and positive definite. Further using equation (3), function $\hat{J}$ is simplified as,

$$\hat{J} = \frac{1}{2}\left(\boldsymbol{\mu}^{\mathrm{T}}\boldsymbol{\mu} - \boldsymbol{\mu}^{\mathrm{T}}\mathbf{K}\left(\mathbf{K}^{\mathrm{T}}\mathbf{K}\right)^{-1}\mathbf{K}^{\mathrm{T}}\boldsymbol{\mu}\right). \tag{4}$$

In equation (4), $\boldsymbol{\mu}^{\mathrm{T}}\boldsymbol{\mu}$ is constant and minimum of $\hat{J}$ is equivalent to maximum of $\omega = \boldsymbol{\mu}^{\mathrm{T}}\mathbf{K}\left(\mathbf{K}^{\mathrm{T}}\mathbf{K}\right)^{-1}\mathbf{K}^{\mathrm{T}}\boldsymbol{\mu}$. Accordingly, an algorithm is constructed as showed in figure (1) (Singh and Rani, 2015).

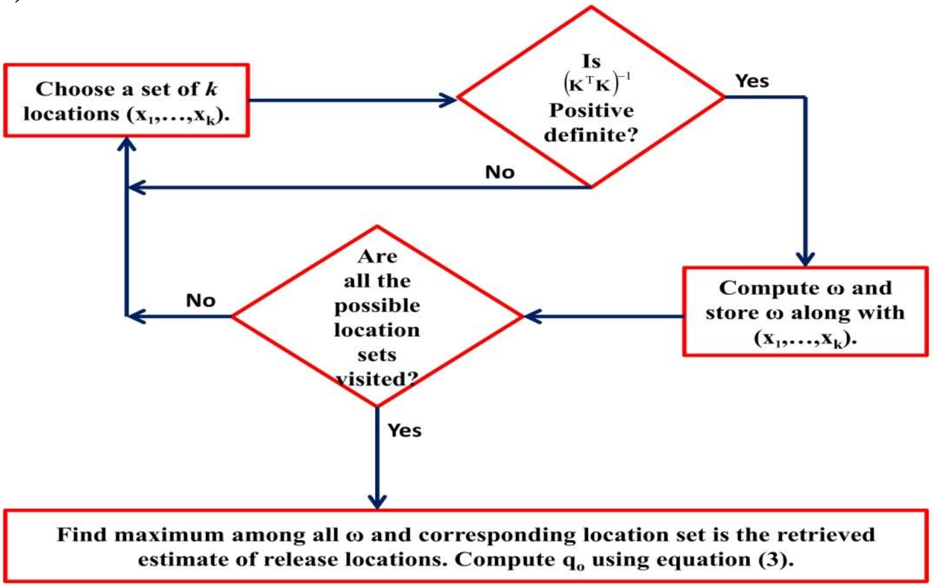

Figure 1. Multiple source identification algorithm.

FUSION FIELD TRIALS

The inversion methodology is evaluated by using the real data obtained from multiple release trials in FFT07 experiment (Storwald, 2007). The dispersion experiment involved release of a tracer gas propylene (C_3H_6) from multiple locations at constant flow rates for approximately 10 min per trial. A total of 100 concentration samplers were arranged in a rectangular staggered grid of area 475 m × 450 m at 50 m apart and 2 m above the ground (figure 2). The true releases are located, at the South-East end of the sampling grid, approximately within 30-50 m Euclidean distance from the last line of the receptors (91-100, see figure 2). The height of the releases was 2 m above the ground. In general, the release locations vary in each experimental trial, however, for representation, the release locations (S1, S2, S3 and S4) are exhibited for four release trials in figure 2. The concentration measurements considered from continuous point releases corresponding to the two, three and four sources. These measurements were mainly based on 4 or 16 samplers and considered as "*blind data*" distributed during the first phase of the release for the evaluation of several source estimation algorithms.

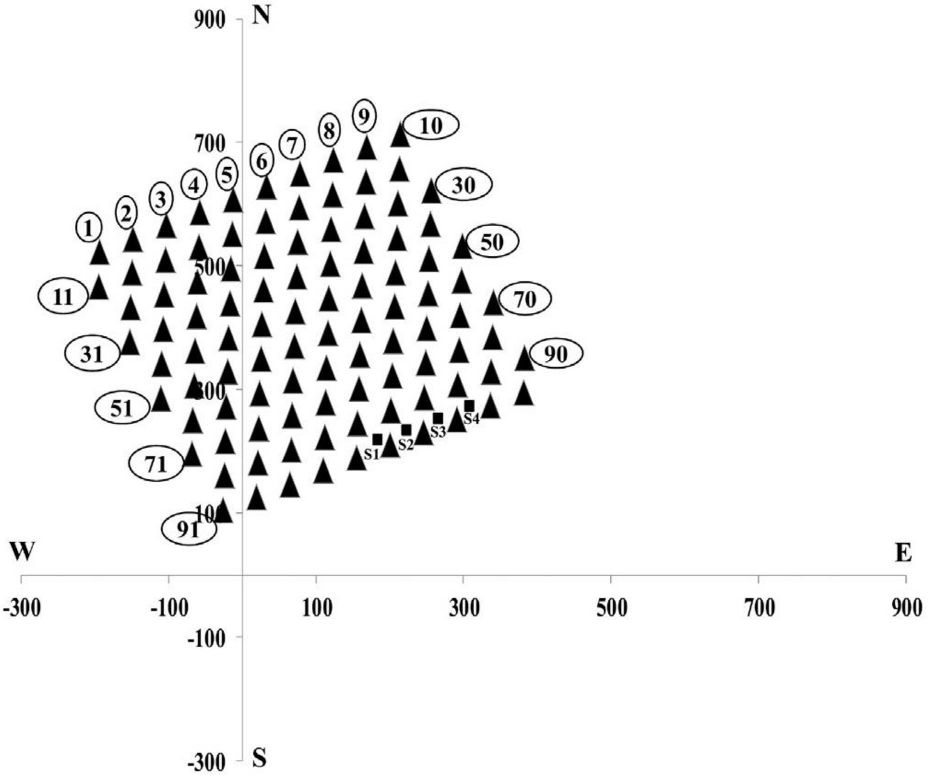

Figure 2. Layout of the computational domain (Singh and Rani, 2015). Black triangles denote position of receptors and their index numbers are mentioned in the circles. Black filled squares denote representative locations of the true releases (S1, S2, S3 and S4) in four release trials.

NUMERICAL IMPLEMENTATION

An implementation of the inversion algorithm requires a discretized domain. Accordingly, a domain of size 1200 m × 1200 m, discretized into 399 × 399 cells, is chosen. The sensitivity matrix (**A**) is computed as plumes originated from receptors backward in space with unit emission rate. For this, an analytical dispersion model by Sharan et al. (1996) is established in the adjoint mode by inverting the wind direction and taking receptor cells as source locations emitting unit amount of tracer per unit time. Further, the inversion algorithm is applied to retrieve the source locations and strengths.

RESULTS

The distributed source information, given by estimate ω, can be utilized to discriminate between the well or poorly resolved source regions (figure 3). In figure (3), the global or local maxima region describes the source information while upwind extensions away from the monitoring network are artifacts (Singh and Rani, 2015).

In two releases trials, all the source locations were retrieved within 200 m of the true source (table 1, figure 3). The average distance and standard deviation are 55 ± 61 m. In trials 19, 40 & 62, both the releases are retrieved far (> 100 m) from the true releases. The source strengths are retrieved within a factor of five in all the trials. In three releases trials, the average and standard deviation of the location error are obtained as 121 ± 71 m. All the release locations are retrieved within 255 m from the true release locations. The source strength are retrieved within a factor of six to the true release rate. In four releases trials, the average distance from the predicted source to the true source is observed as 146 m, with a standard deviation of 79 m. The source locations are retrieved within 250 m of the true source. In four release trials, two of the four releases locations are retrieved close to the true releases whereas the other two releases are predicted far upwind/downwind of the true releases. In most of the trials, the source strengths are retrieved within a factor of five to the true release rate. However, the factor increases up to ten (mostly under predicted) when the locations are retrieved upwind of the true releases.

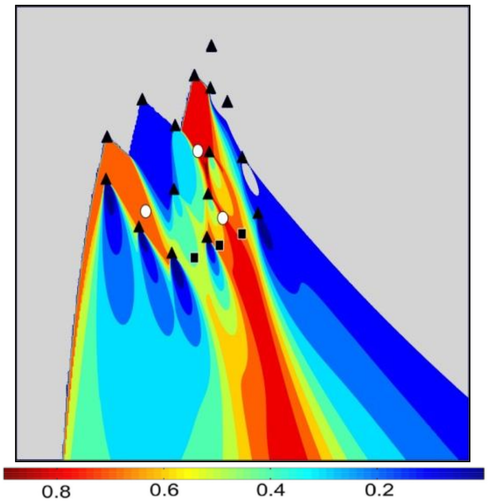

Figure 3. The isopleths of ω/max(ω) in three simultaneous release trial 61. The black filled squares were the true releases whereas the white filled circles are the retrieved release locations.

With blind data, the releases are retrieved both upwind as well as downwind of the true releases subjected to the available source information in the region. In two and four release trials, the release locations are mostly retrieved in the downwind of the true release whereas in three release trials, release locations are retrieved mostly upwind of the monitoring network. With few measurements, inversion technique mostly retrieves the releases downwind of the true releases towards the receptors. When receptors are located only along the plume centerline, the releases are retrieved close to each other or along a line in the upwind direction of the true releases (figure 4). This is interesting to observe in trial 55 that the inversion technique is able to retrieve the four releases with only four measurements, however, the retrieval errors are relatively large (figure 4). The present technique is shown to retrieve the releases within a reasonable accuracy as mentioned in other studies. However, the accuracy in source estimation is also subject to the accurate depiction of the plume features by the utilized dispersion model.

Table 1. Source retrieval using blind data. The maximum location error (in meters) and, mean and standard deviation (Std) of the location error, are shown in two, three and four release trials.

	Two releases		**Three releases**		**Four releases**	
	Maximum	Mean ± Std	Maximum	Mean ± Std	Maximum	Mean ± Std
Location error	200	55 ± 61	255	121 ± 71	250	146 ± 79

CONCLUSION

An inversion algorithm is presented here for identifying the release parameters (mainly, locations and strengths) of multiple point releases continuously emitting the same tracer from limited set of merged concentration measurements. The inversion algorithm is free from initial guess of the release parameters and only requires that the number of point releases is known. The inversion algorithm is evaluated with several trials of continuous multiple point releases from FFT07 experiment. It is observed that the inversion algorithm successfully retrieves the release locations within an average Euclidean distance of 150 m from the true release locations. The source strengths are also retrieved mostly within a factor of five. Overall, the retrieval errors are minimized with the addition of measurements.

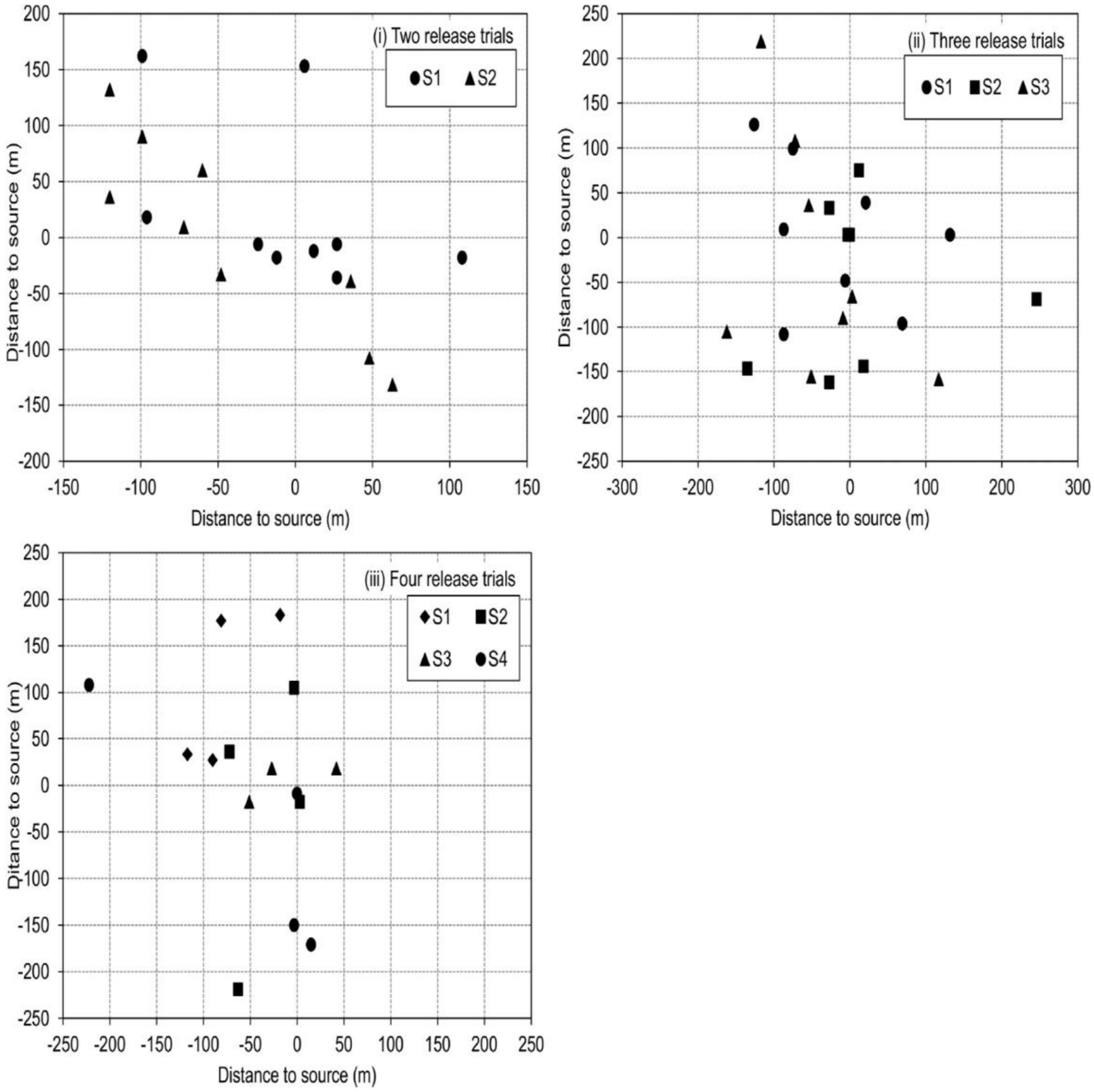

Figure 4. Location errors (or Euclidean distance from the corresponding true source) for the source retrieval in two, three and four release trials using blind data. S1, S2, S3 and S4 represent source location. The true source in each case is located at the axes origin and each retrieved source is paired with a true source for the calculation of the location error.

REFERENCES

Pudykiewicz, J., 1998. Application of adjoint tracer transport equations for evaluating source parameters. *Atmospheric Environment* **32**, 3039-3050.

Sharan, M., A. K. Yadav, M. P. Singh, P. Agarwal, and S. Nigam (1996), A mathematical model for dispersion of air pollutants in low wind conditions, *Atmospheric Environment*, **30**, 1209–1220.

Singh, S. K. and Rani, R., 2015. Assimilation of concentration measurements for retrieving multiple point releases in atmosphere: A least-squares approach to inverse modelling. *Atmospheric Environment* **119**, 402-414.

Storwald, D.P., 2007: Detailed test plan for the fusing sensor information from observing networks (Fusion) Field Trial (FFT-07), Tech. Rep. Document No. WDTC-TP-07-078, Meteorology Division, West Desert Test Center, U.S. Army Dugway Proving Ground WDTC, Salt Lake, Utah.