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Reconstruction of Atmospheric Tracer Releases with Optimal Resolution Features: Concentration Data Assimilation

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The fast growing urbanization, industrialization and military developments increase the risk towards the human environment and ecology. This is realized in several past mortality incidents, for instance, Chernobyl nuclear explosion (Ukraine), Bhopal gas leak (India), Fukushima-Daichi radionuclide release (Japan), etc. To reduce the threat and exposure to the hazardous contaminants, a fast and preliminary identification of unknown releases is required by the responsible authorities for the emergency preparedness and air quality analysis. Often, an early detection of such contaminants is pursued by a distributed sensor network. However, identifying the origin and strength of unknown releases following the sensor reported concentrations is a challenging task. This requires an optimal strategy to integrate the measured concentrations with the predictions given by the atmospheric dispersion models. This is an inverse problem.

The measured concentrations are insufficient and atmospheric dispersion models suffer from inaccuracy due to the lack of process understanding, turbulence uncertainties, etc. These lead to a loss of information in the reconstruction process and thus, affect the resolution, stability and uniqueness of the retrieved source. An additional well known issue is the numerical artifact arisen at the measurement locations due to the strong concentration gradient and dissipative nature of the concentration. Thus, assimilation techniques are desired which can lead to an optimal retrieval of the unknown releases. In general, this is facilitated within the Bayesian inference and optimization framework with a suitable choice of a priori information, regularization constraints, measurement and background error statistics.

An inversion technique is introduced here for an optimal reconstruction of unknown releases using limited concentration measurements. This is based on adjoint representation of the source-receptor relationship and utilization of a weight function which exhibits a priori information about the unknown releases apparent to the monitoring network. The properties of the weight function provide an optimal data resolution and model resolution to the retrieved source estimates. The retrieved source estimates are proved theoretically to be stable against the random measurement errors and their reliability can be interpreted in terms of the distribution of the weight functions. Further, the same framework can be extended for the identification of the point type releases by utilizing the maximum of the retrieved source estimates. The inversion technique has been evaluated with the several diffusion experiments, like, Idaho low wind diffusion experiment (1974), IIT Delhi tracer experiment (1991), European Tracer Experiment (1994), Fusion Field Trials (2007), etc. In case of point release experiments, the source parameters are mostly retrieved close to the true source parameters with least error. Primarily, the proposed technique overcomes two major difficulties incurred in the source reconstruction:

(i) The initialization of the source parameters as required by the optimization based techniques. The converged solution depends on their initialization.

(ii) The statistical knowledge about the measurement and background errors as required by the Bayesian inference based techniques. These are hypothetically assumed in case of no prior knowledge.