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Spatiotemporally-separated framework for the source reconstruction of atmospheric radionuclide releases

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Determining the source location and release rate is critical in assessing the environmental consequences of atmospheric radionuclide releases, yet this task remains challenging due to the vast multi-dimensional solution space. To address this, we propose a spatiotemporally-separated two-step framework that reduces the dimension of the solution space in each step and enhances the reconstruction accuracy, which is applicable to radionuclide releases. The separating process involves applying a temporal sliding-window average filter to the observations, thereby reducing the influence of temporal variations in the release rate and ensuring that the features of the filtered data are dominated by the source location. Initially, candidate source locations are pre-screened using a correlation-based method. To establish the relationship between the filtered data and candidate source locations, time- and frequency-domain features are extracted from the filtered data and an eXtreme Gradient Boosting algorithm is employed for fitting. The features are further screened out by the Recursive Feature Elimination with Cross-Validation. Utilizing the features of filtered observations, the source location can be determined without the knowledge of the release rate. Subsequently, the release rate is determined using projected alternating minimization with the L1-norm and total variation regularization algorithm.

The proposed method was rigorously tested on two field experiments: the SCK-CEN experiment, featuring local-scale ^{41}Ar releases over two days, and the ETEX-I experiment, involving continental-scale PMCH releases. Validation on the SCK-CEN experiment showed that the lowest source location error fell below 1% and the mean source location error remained under 5%, with temporal variations and peak release rate being accurately reconstructed. Similar accuracy was also observed in the ETEX-I experiment. Compared to traditional correlation-based method and Bayesian method, our method exhibited superior accuracy and a reduced uncertainty range.

Furthermore, comprehensive sensitivity tests were conducted on the SCK-CEN experiment to evaluate the influence of pre-screening range, sliding-window length, feature types, and combinations of observation sites. The results indicated that our method achieved consistent performance across various parameters and conditions, maintaining low error levels even with only a single observation site.