Simultaneous release rate estimation and modeled plume bias correction for atmospheric radionuclide emissions

Shuhan Zhuang and Sheng Fang
Institute of Nuclear and Energy Technology, Tsinghua University, Beijing, China (zhuangsh19@mails.tsinghua.edu.cn)

The atmospheric release of radionuclides is a crucial potential hazard to public health. Its release rate is vital in assessing the international environmental risk of atmospheric radionuclide leaks and conducting nuclear emergency preparedness. However, according to the radionuclide leaks such as the Fukushima Daiichi accident and the recent iodine-131 and ruthenium-106 releases in 2017, the release rate cannot be directly measured or derived in a forward way, but can only be inversely estimated by comparing the environmental measurements with a model-predicted plume, a technique often referred to as source inversion. However, such inversion is vulnerable to the inevitable plume biases, including the plume range (i.e. the area of positive model predictions) and transport pattern in radionuclide transport modeling, leading to inaccurate source estimates and risk assessment.

This paper describes an automated method that estimates the release rate while comprehensively correcting plume biases. By using the spatial correlation matrix, the predicted plume can spread over a broader area, thus covering the potential range of the true plume. Then, the difficult task of direct plume adjustment is simplified to tuning the predictions inside a correlation-adjusted plume. Based on this, the previous joint method can work efficiently to estimate the release rate while simultaneously refining the predictions inside the adjusted range, correcting both the plume range and the transport pattern. An ensemble-based algorithm is proposed to automatically calculate the spatial correlation in order to execute this method. With this algorithm, SERACT can accomplish realistic and robust source estimation without manual adjustment on any parameters.

The proposed method SERACT is validated with the two wind tunnel experiments based on a real Chinese nuclear power plant site, and the site features highly heterogeneous topography and dense buildings. In this paper, two radionuclide transport models with mild and severe plume biases respectively are used to assess the adjustment efficiency of SERACT, including source estimation and plume distribution. Its performance is compared with that of the standard approach and a recent state-of-the-art method. Its sensitivity to the number and quality of measurements, and the selection of autocorrelation scales is also investigated.

The results demonstrate that SERACT corrects the plume biases with high accuracy (Pearson's Correlation Coefficient=1.0000, Normalized Mean Square Error≤1.03×10^{-3}) and reduces the estimation error by nearly two orders of magnitude at best. In addition, SERACT exhibited stable performance in all the validation tests and gave the lowest error levels with various numbers and
quality of measurements. With fully automated parameterization, its performance is close to that obtained with the optimal autocorrelation scale in all test cases. These results indicate that SERACT is robust in various inversion cases and is able to serve as a general remediation to the long-standing imperfect modeling issue in source inversion.