



## **Ensemble Kalman smoother and ensemble Kalman filter approaches to the joint air quality state and emission estimation problem**

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The purpose of this paper is to present some ensemble based statistical estimation methods for inverting modeling of pollution emissions. Previous studies using advanced sequential method to the joint air quality state and emission estimation problem focus on the ensemble Kalman filter (EnKF) or the discrete Kalman filter (DKF). However at each assimilation time, EnKF and DKF cannot update the emissions at the previous times, though their information is contained in the present observations. This is a major drawback, especially in the case of the time variant emissions. Therefore it is necessary to investigate other methods that can overcome this drawback. Starting from Bayes theorem, we present the ensemble smoother (ES), the ensemble Kalman smoother (EnKS) and the ensemble Kalman filter for the joint air quality state and emission estimation problem and derived their detailed mathematical formulations. The introduction of ES and EnKS, the emission estimation at previous time can be updated by assimilating observation at the later time. A simple model is used to demonstrate the feasibility of the methods. Also, issues of the impacts of observational error and the prior error of the emission on estimation results are discussed based on the experiments using the simple model. The results show that EnKS can estimate the time-variant emission well at every time steps when the observations are not available at every time steps, while the EnKF can only estimate the emission well at the observation time. When observations are available at every time step, EnKF and EnKS perform similarly. The larger observational errors can affect estimation results of emission, but not very sensitively. It is also shown that over-estimation or under-estimation of the prior emissions uncertainty can bring larger estimation errors of emissions.