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Data assimilation of volcanic aerosol observations using FALL3D+PDAF

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Abstract. Modelling atmospheric dispersal of volcanic ash and aerosols is becoming increasingly valuable for assessing the potential impacts of explosive volcanic eruptions on buildings, air quality, and aviation. Management of volcanic risk and reduction of aviation impacts can strongly benefit from quantitative forecasting of volcanic ash. However, an accurate prediction of volcanic aerosol concentrations using numerical modelling relies on proper estimations of multiple model parameters which are prone to errors. Uncertainties in key parameters such as eruption column height and physical properties of particles or meteorological fields represent a major source of error affecting the forecast quality. The availability of near-real-time geostationary satellite observations with high spatial and temporal resolutions provides the opportunity to improve forecasts in an operational context by incorporating observations into numerical models. Specifically, ensemble-based filters aim at converting a prior ensemble of system states into an analysis ensemble by assimilating a set of noisy observations. Previous studies dealing with volcanic ash transport have demonstrated that a significant improvement of forecast skill can be achieved by this approach. In this work, we present a new implementation of an ensemble-based data assimilation (DA) method coupling the FALL3D dispersal model and the Parallel Data Assimilation Framework (PDAF). The FALL3D+PDAF system runs in parallel, supports online-coupled DA, and can be efficiently integrated into operational workflows by exploiting high-performance computing (HPC) resources. Two numerical experiments are considered: (i) a twin experiment using an incomplete dataset of synthetic observations of volcanic ash and (ii) an experiment based on the 2019 Raikoke eruption using real observations of SO_2 mass loading. An ensemble-based Kalman filtering technique based on the local ensemble transform Kalman filter (LETKF) is used to assimilate satellite-retrieved data of column mass loading. We show that this procedure may lead to nonphysical solutions and, consequently, conclude that LETKF is not the best approach for the assimilation of volcanic aerosols. However, we find that a truncated state constructed from the LETKF solution approaches the real solution after a few assimilation cycles, yielding a dramatic improvement of forecast quality when compared to simulations without assimilation.