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An accelerated data assimilation approach for volcanic ash forecast

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The 2010 Eyjafjallajökull volcano eruption had serious consequences to civil aviation. This has initiated a lot of research on volcanic ash forecast in recent years. Ensemble-based data assimilation uses the observation data to improve the parameter and state estimation and subsequently the volcanic ash forecast accuracy. Due to the computational complexity of ensemble-based algorithms and the large scale of real-life applications, application of these methods usually introduces a large computational cost, particularly in the analysis step of assimilation processes. Because the other time-consuming part in the single CPU case, the forecast step, can be efficiently and easily parallelized.

In this study, we focus on speeding up of the analysis step. For volcanic ash assimilation of aircraft-based measurements, the most time-consuming part in the analysis step has been shown to be the computation of the Kalman gain matrix. After a careful study on the characteristics of ensemble ash states, we propose a model-reduced Kalman gain (MR-Gain) approach which transforms the ensemble state matrix into a low-rank matrix by a multiplication with an index matrix which recorded the sparsity information of the ensemble state matrix, and thus the computational cost of all the ensemble-related matrix multiplications are reduced. After the computation of Kalman gain, using the previously recorded state index, the full analyzed ensemble states are reconstructed.

The result shows the MR-Gain approach is exact, which can be used to replace the original full matrix with a much low computation cost. Computer experiments show that the computing time for the analysis step with the new approach is a factor of ten times faster than the conventional analysis step. The result also shows that with the accelerated analysis step in volcanic ash assimilation system, the total amount of computing time for volcanic ash forecast can be significantly reduced by up to a factor of 5.