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Estimation of volcanic ash emissions with satellite data: The inclusion of mass loading and plume height information in modified 4D-Var

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Volcanic ash forecasting is a critical tool in hazard assessment and operational volcano monitoring. Emission parameters such as injection height, total emission mass and vertical distribution of the emission plume rate are essential and important in the implementation of volcanic ash models. Satellite instrument is a powerful tool to monitor volcanic aerosol evolution and satellite total-column data has been integrated in the modeling process to achieve a better initial condition for the forecasting. However, the use of total-column data,which has no vertical resolution, usually leads to an ill-conditioned problem and ineffective estimation of emission parameters. Fortunately, techniques to retrieve the information of total ash mass loading and injection height from satellite data has been developed recently. It provides a new possibility to increase the accuracy of estimation results by integrating them into data assimilation systems.

In this work we propose a modified 4D-Var approach which seek the vertical emission distribution by observing ash cloud transport patterns from satellite total-ash-columns data, and two ways of including the information of mass loading and plume height in the assimilation process. The modified 4D-Var based on trajectory statistics forms a reformulated cost function which computes the total difference between observed ash columns and a linear combination of simulated ensemble columns coupled with a priori emission knowledge (‘background’ term). The ensembles are generated by a volcanic ash transport model with the tracer released form different layers. Experiment shows such straightforward method does not always guarantee the identification of injection height with a short assimilation time window, and additional information of injection height is needed to correct the solution.

We propose two tricks to incorporate the information: 1. add extra terms containing the information to the cost function as restriction term; 2. generate a new emission based on the information and substitute it for the ‘background’ term in the cost function. The results of twin experiments show that with the inclusion of emission parameter information both methods have great correction impact to recognize the injection height and produce more accurate emission estimation and reliable initial field of volcanic ash loading. Details of the correction effects of the two methods are discussed and different sets of weighting factors for the restriction term or ‘background’ term can be chosen according to specific situation. Furthermore, comparison is made with other methods such as inverse modeling and satellite image matching and analysis is given about the reliability and applicability of these methods.