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Observability and analyses of volcanic ash emissions and their dispersion by two ensemble-based four-dimensional assimilation approaches applying remote sensing data

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Large amounts of accidentally emitted aerosols may cause serious impacts on health, climate, environment, and economy. Therefore, reliable forecasts of the released particulate matter are of societal need, whereas the uncertainties of emission source parameters impose characterizing impediments for skilful numerical simulations. Taking the most challenging case of volcanic eruption as prototype example for sudden aerosol injections, we developed and investigated new methodologies to assess the impact of observations on the analysis. The emphasis is placed on assimilation-based analyses applying both, initial value optimization within the EURAD-IM (European Air pollution Dispersion-Inverse Model) 4D-var assimilation system and emission factor optimization using the ESIAS-chem (chemical part of the Ensemble for Stochastic Integration of Atmospheric Simulations) particle smoother. As observational input, two entirely different satellite-borne remote sensing principles are exploited: firstly, vertically integrated SEVIRI (Spinning Enhanced Visible and Infrared Imager) volcanic ash column mass loadings and secondly, vertically resolved CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) particle extinction coefficient profiles. Appropriate observation operators and their adjoint realisations are constructed. The basic theoretical principles of observability in case of volcanic ash column mass loading observations are deduced from the viewpoint of the Kolmogorov-Sinai entropy. For volcanic ash dispersion forecasts, only at a few locations is the ash height directly observable by lidars or ceilometers. Passive satellite sensors like SEVIRI only give evidence of horizontal ash cloud extension, if not occluded by clouds. For the latter observational conditions the Kolmogorov-Sinai entropy manifests that the dynamically driven wind shear induces the separation of the volcanic ash and allows for the determination of volcanic ash cloud heights even for horizontally resolved observations only. Combining the research fields of observability and predictability enables to identify regions of high and low uncertainty in the dispersion simulation results and provides information on the concentration patterns, which are controlled by the appended knowledge of observations. The visualization of volcanic ash concentration isopleths in spaghetti plots provides guidance on the reliability of the forecast and information about the necessity of adaptive or targeting observations. The variable degree of reliability is shown as a consequence of cloud cover dependent observability from space for both, quasi-continuous SEVIRI data and sparse CALIOP overpasses.