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Using picosatellites for 4-D imaging of volcanic clouds: proof of concept using ISS photography of the 2009 Sarychev Peak eruption

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One of the biggest challenges for improving volcanic ash dispersion forecasts is to reduce the uncertainties associated with estimates of initial conditions of erupted ash above the volcano. Here, we explore the potential of upcoming picosatellite formations (e.g. the Telematics Earth Observation Mission) to provide frame camera imagery from which structure-from-motion (SfM) photogrammetry can be used to derive parameters such as the eruption rate and vertical ash distribution. Using photogrammetric simulations, we show that simultaneous image acquisition from three picosatellites should enable ash cloud heights to be determined with a precision (∼30–140 m depending on configuration) comparable to that of lidar observations (30–180 m depending on the cloud height). To support these estimates with real imagery, we processed photographs taken from the International Space Station of the 2009 Sarychev Peak eruption, as a proxy for picosatellite images. SfM-photogrammetric software successfully reconstructed the 3-D form of the ascending ash cloud, as well as surrounding cloud layers. Direct estimates of the precision of the ash cloud height measurements, as well as comparisons between independently processed image sets, indicate that a vertical measurement precision of ∼200 m was achieved. Image sets acquired at different times captured the plume dynamics and enabled a mean ascent velocity of 14 m s^{-1} to be estimated for regions above 7 km. In contrast, the uppermost regions of the column (at a measured cloud top height of 11 km) were not ascending significantly, enabling us to constrain a 1-D plume ascent model, from which estimates for the vent size (∼50 m) and eruption mass flux (2.6×10^{6} kg s^{-1}) could be made. Thus, we demonstrate that picosatellite imagery has the potential for substantially reducing uncertainties in ash dispersion models by providing valuable information on eruptive conditions.