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Volcanic ash remote sensing by ground-based microwave weather radar

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The detection and quantitative retrieval of volcanic ash clouds is of significant and increasing interest both for environmental and social effects. As a matter of fact, ash fallout can cause substantial hardship and damages in volcano's surrounding area and represents a serious hazard to aircraft as well. Among the remote sensors, ground-based microwave weather radars have become an important tool to mitigate the hazard from the ash clouds, even though their potential and quantitative retrieval techniques are still the object of research. The possibility of monitoring 24 hours a day, in all weather conditions, at a fairly high spatial resolution (less than a kilometer) and every few minutes after eruptions occur are the major advantages of using ground-based meteorological radar system. Of even greater importance, ground-based radar systems represent the best known method for determining the ash volume, the total mass and the height of eruption clouds. In spite of this potential, there are still open issues about microwave weather radar capabilities to detect and quantitatively retrieve volcanic ash cloud parameters. The potential of using ground-based weather radar systems for volcanic ash cloud detection and quantitative retrieval is here evaluated. In order to do this, both the forward and the inverse problem are examined taking into account various operating frequencies such as S, C, X and Ka bands. After a summary on evidence of weather radar sensitivity to ash clouds, a microphysical characterization of volcanic ash is carried out. Particle size-distribution (PSD) functions are derived both from sequential/fragmentation/transport (SFT) theory of pyroclastic deposits, leading to a scaled Weibull PSD, and from more conventional scaled gamma PSD functions. Best fitting to PSD available measured data at ground are carried out. The radar backscattering from spherical-equivalent ash particles is simulated under Rayleigh approximation up to Ka band and its accuracy is assessed by using a T-matrix code. Besides, the relationship between radar reflectivity factor, ash concentration and fall rate is statistically derived for various eruption regimes and ash median sizes by randomizing key microphysical parameters. In order to quantitatively evaluate the ash detectability by weather radars, a systematic sensitivity analysis is carried out by varying ash concentration and regimes as function of the range for some available radar systems at S, C and X band. The received power is calculated taking into account path attenuation and the spatial extension of a hypothetical ash cloud. As a final stage, a prototype algorithm for volcanic ash radar retrieval (VARR) is discussed. Starting from measured single-polarization reflectivity, the Bayesian estimation of ash concentration and fall rate is based on two steps: i) a classification of eruption regime and volcanic ash category; ii) estimation of ash concentration and fall rate. Expected accuracy of the VARR algorithm estimates is evaluated on synthetic data sets. Results show that considered weather radars can detect mainly medium to gross ash particles, sized between 0.1 and few millimeters, for distances larger than even 100 kilometeres. Smaller ash particles (less than 0.001 mm) could be detected only for distances less than few tens of kilometeres from radar stations. A discussion on limitation and potentiality of the proposed technique is finally carried out.