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The significance of segregation and clustering of ash particles for ash aggregation in volcanic plumes and clouds

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Volcanic plumes and clouds transport volcanic ash in a turbulent suspension, and the spatial distribution of ash in these suspensions on scales from microns to kilometers is structured. Both clustering of particles and segregation of clusters are produced by coupling of the particles with the turbulent structure of the flow. Several decades of research in gas-particle suspensions shows that coupling depends primarily on particle size and concentration, with shape and density playing secondary roles. Our study examines two aspects of this coupling: (1) how solid particles change the energy scaling and structure in turbulent suspensions, and (2) how the turbulent structure affects the formation of ash aggregates. For particle-laden atmospheric clouds, dissipation of turbulent kinetic energy typically defines Kolmogorov scales between 0.1 mm and 1.0 mm. As fine micron-size ash is added to a volcanic plume, energy dissipation increases at scales less than a few hundred microns, causing clusters of particles tens of microns in diameter to form and be trapped within and between small eddies. Much larger (mm-size) particles, if present, are transported by much larger eddy structures and take separate paths. This segregation of different aggregate sizes and paths, a consequence of the turbulent structure of the suspension, produces collisions between different size clusters on different paths, and can quickly build aggregates hundreds of microns or more in diameter. These interactions within the turbulent structure of a plume explain the observed differences between core and rim structures in well-preserved ash aggregates from Redoubt volcano in 2009. Here cores rich in clusters of large particles have multiple rims of much finer particles. Additional evidence for segregated clusters comes from the 2011 eruption of Grimsvotn, in which clear hailstones several mm in diameter that fell from the volcanic plume were photographed. These photos show randomly distributed, irregular clusters of fine ash up to 200 microns in size trapped in each hailstone. The irregular distribution of clusters of different sizes within the hailstones demonstrates that the distribution of ash in the plume was neither random, nor homogeneous, but rather was segregated into clusters by the turbulent structure of the plume.