



## Ice nucleation properties of volcanic ash from Eyjafjallajökull

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The ice nucleation ability of two samples of volcanic ash collected during the April 2010 eruption of Eyjafjallajökull is investigated, using a differential scanning calorimeter (DSC), as well as the Zurich ice nucleation chamber (ZINC), and its vertical extension Immersion Mode Cooling Chamber (IMCA). Bulk measurements (DSC) exhibit a large variation in the freezing temperature when a well mixed suspension is used, which suggests the presence of very rare, moderately efficient (ice nuclei) IN. Both the variation in freezing temperature, as well as the freezing temperature itself decreases when the particles in the suspension are allowed to settle, providing further evidence for the rarity of the most efficient IN. A general dependence of freezing temperature on the surface area of ash in the suspension is found, with larger available surface areas leading to higher freezing temperatures. The highest freezing temperature measured in the DSC for the ash was at ca. 263K, with the median freezing temperature for un-settled 5 wt% ash suspension being 258.5K.

The immersion mode experiments which were carried out with IMCA/ZINC are sensitive to the average IN, in contrast to the DSC experiments which are only sensitive to the best IN in a sample. The IMCA/ZINC experiments show that in general, ash particles cause a ca. 2K-3K increase in the ice nucleation temperature with respect to homogeneous freezing of droplets produced by cloud condensation nuclei activation of ammonium sulphate particles within the same experimental setup.

The ZINC deposition freezing experiments show that at temperatures above the homogeneous freezing threshold of pure water, the volcanic ash is a much poorer deposition IN compared with mineral dusts. For temperatures of -45°C and -50°C, the activated fraction reaches almost its maximum value at a supersaturation with respect to ice of 20%. At these low temperatures, the volcanic ash indeed turns into deposition mode IN with efficiencies comparable to the ones of mineral dusts.

An analysis of seven days forward air parcel trajectories from the site of the eruption shows that for the longest period of the eruption when the ash was ejected to heights below 4-6 km, ash which reached saturation would mostly have encountered ice, and then water saturation at relatively warm temperatures (above 233K). Therefore, for the greatest part of this particular eruption, immersion freezing would have been the dominant influence of the ash. Further, it is likely that as the ash plume aged, the particles obtained a coating of sulphuric acid and water. This would further suppress deposition freezing.

In summary, while we find evidence for moderately good IN among the ash particles, 1-2 days downwind of the eruption they were not present in concentrations high enough to have an impact on atmospheric water vapour or cloud formation. Relatively poor IN, leading to freezing 2K-3K above temperatures required for homogeneous nucleation were present in high number concentrations a few days downwind of the eruption, and could have lead to modification of cloud formation. Immersion freezing would have been the most likely mechanism for ice nucleation.