Using freezing spectra characteristics to identify ice-nucleating particle populations during the winter in the Alps

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One of the least understood cloud processes is modulation of their microphysics by aerosols, specifically of cloud ice by ice-nucleating particles (INPs). To investigate INP impacts on cloud ice and subsequent precipitation formation, measurements in cloud environments are necessary but difficult given the logistical challenges associated with airborne measurements and separating interstitial aerosol from cloud residues. Additionally, determining the sources of INPs is important given the dependency of glaciation temperatures on the mineral or biological components and diversity of such INP populations. Here, we present results from a comparison of INP spectral characteristics in air, cloud rime, and fresh fallen snow at the High Altitude Research Station, Jungfraujoch. The goal of the study was twofold: (1) to assess variability in wintertime INP populations found in cloud based on wind and air mass direction during snowfall and (2) to evaluate possible INP sources between different sample types using a combination of cumulative INP (K(T)) and differential INP (k (T)) spectra. INP freezing temperatures and concentrations were consistently higher on average from the southeast as compared to the northwest for rime, snow, and especially aerosol samples, which is likely a result of air mass influence from predominantly boundary layer terrestrial and marine sources in southern Europe, the Mediterranean, and North Africa. For all three sample types combined, average onset freezing temperatures were -8.0 and -11.3 degrees C for southeasterly and northwesterly days, respectively, while K (T) were 3 to 20 times higher when winds arrived from the southeast. Southeasterly aerosol samples typically had a clear mode in the warm-temperature regime (i.e., >= -15 degrees C) in the k (T) spectra - indicating a putative influence from biological sources - while the presence of a warm mode in the rime and snow varied. Evaluating K (T) concert with k (T) spectra exhibited variable modality and shape - depending on the types of INPs present - and may serve as a useful method for comparing different sampled substances and assessing the possible relative contributions of mixed mineral and biological versus only biological INP sample populations.

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