In-situ observation of Liquid Layers on Ice Crystal Surfaces Induced by Hydrogen Chloride Gas

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Surface melting of ice crystals forms quasi-liquid layers (QLLs) on ice surfaces, and affects a wide variety of natural phenomena. Since QLLs enhance various chemical reactions in ice clouds, the formation of QLLs by atmospheric gases has been studied intensively. However, such studies were performed using spectroscopy techniques, which have low spatial resolution. Here we show the first direct visualization of QLLs on ice basal faces in the presence of hydrogen chloride (HCl) gas (model atmospheric gas) by advanced optical microscopy, which can visualize individual 0.37-nm-thick elementary steps [1] and QLLs [2] on ice crystal surfaces. We found that the HCl gas induced the appearances of QLLs with a droplet shape in the temperature range of -15.0 ~ -1.5˚C, where no QLL appears in the absence of HCl gas [3]. This result indicates that HCl gas adsorbed on ice crystal surfaces probably changed the surface structure of ice crystals and then induced the subsequent melting of ice surfaces. We also observed the movement, shape change, and splitting of the droplet QLLs when water vapor was undersaturated. The long-term (one-hour) existence of the droplet QLLs under the undersaturated conditions strongly suggests that the droplet QLLs were thermodynamically-stable HCl solutions. In addition, we found that the HCl induced droplets were embedded into ice crystals by growth of ice crystals and the embedded droplets appeared again by evapolation of ice crystals. These results shows the possibility that ice crystals can store large amount of gas components as fluid inclusions.

[1] Sazaki et al. (2010) PNAS 107, 19702.
[2] Sazaki et al. (2012) PNAS 109, 1052.
[3] Nagashima et al. (2016) Cryst. Growth Des. 16, 2225.

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