Multiscale study of water condensation on aerosols using in-situ Environmental Scanning and Transmission Electron Microscopies

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Background incl. aims
Predicting cloud formation and the arrival of precipitation has always been a hot topic in meteorology. With global warming and the many ongoing drought events, this has become a major issue. Environmental scanning and transmission electron microscopy (respectively ESEM and ETEM) can provide valuable information to understand how clouds are formed by condensation of water on submicronic aerosol particles. Indeed, Environmental Electron Microscopy allows following the structural changes during the condensation of water droplets, while controlling the relative humidity, from the dry state up to fully hydrated conditions.

Methods
Sodium chloride particles are used as model marine aerosols. The deliquescence of crystals in the size range 100 nm – 1 µm is studied in ESEM (QuattroS from TFS) equipped with either a commercial Peltier stage (SE imaging) or a home-made tomographic stage (STEM imaging in both BF and DF modes) [1]. The deliquescence of smaller crystals is studied in ETEM (Titan ETEM from FEI/TFS) using either a commercial cryo-holder from Gatan/Ametek or a home-made system based on a Peltier micro-cooler [2]. More realistic aerosols, such as (non-hygroscopic) Arizona dust decorated with (hygroscopic) sodium chloride, are then studied.

Results
The evolution of the crystal facets and corners as a function of relative humidity is studied in ESEM in the SE mode, and is compared with the literature [3]. The measurement of the relative humidity allows a calibration of the other microscopy set-ups. Interestingly, oscillating behaviors at the beginning of deliquescence could be reproduced and followed in real time in STEM and TEM on smaller crystals (see Figure 1). They were found to match 2D simulations based on local fluctuations of the solute content. The

distribution of sodium chloride during hydration/dehydration cycles is also analyzed.
Electron tomography is also carried out at multi-scale, in ESEM and ETEM on hydrated samples and quantitative data can be extracted: crystal shape and size as well as water droplet shape, and the aggregate shape and compound distribution in the case of salted Arizona dust.

Conclusion

The multi-scale approach combining ESEM and ETEM enable the analysis of salt particles not only in 2D, but also in 3D, for different values of relative humidity. As irradiation damage can have large influence on the observed behavior and kinetics, the electron dose received by the sample is quantified and its effects discussed.

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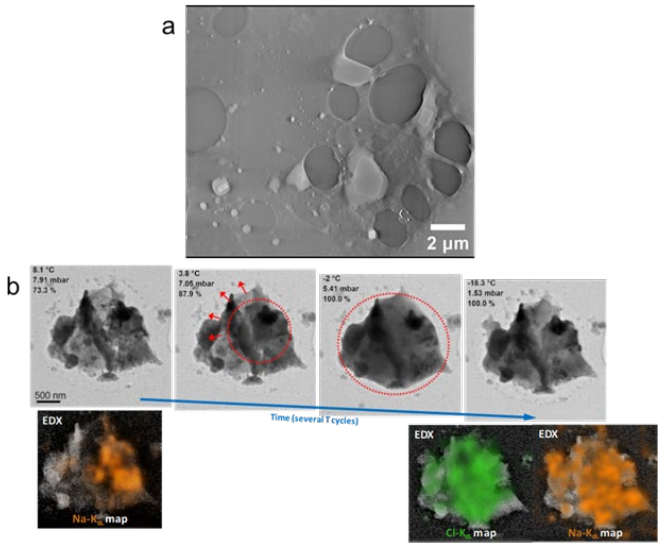
Figure caption

water condensation on aerosols.(a) XY slice of a tomogram obtained in ESEM, showing NaCl crystals within water droplets. (b) Hygroscopic behavior of realistic aerosol (mixed phase Arizona dust and NaCl) with spatial localization and chemical identification of soluble phases during hydration (several T cycles).

Graphic:



Keywords:

ETEM, ESEM, in-situ, liquid

Reference:

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