Formation and transformation of atmospheric aerosols, and impact on health and climate

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Atmospheric aerosol particles are liquid or solid particles suspended in the atmosphere and are of interest mainly because of their effects on health and climate. Concerning health, many epidemiological studies, summarized e.g. in WHO (2013) have shown a link between increased mortality/morbidity and increased PM10 or PM2.5 (particulate matter with an aerodynamic diameter smaller than 10 and 2.5 μm, respectively). Concerning climate, aerosol particles scatter and absorb light (termed aerosol-radiation interaction by IPCC (2013)), and modify cloud properties (with a variety of effects termed aerosol-cloud-interaction by IPCC (2013)). These effects are influenced by the chemical and physical properties of the aerosol particles, which makes these properties important to be measured. Atmospheric aerosol particles are produced by a large variety of sources, and are either emitted as primary particles (i.e., they are directly emitted as particles into the atmosphere) or formed by secondary processes (i.e., by transformation of emitted precursor gases).

While the formation pathways of secondary inorganic aerosols such as nitrate and sulfate in general are reasonably well understood, the formation of secondary organic aerosol (SOA) is still an area of active research. A wide variety of gaseous precursors contribute to SOA, and their aerosol yields depend on a wide variety of conditions. Models typically underestimate the amount of measured organic aerosol. A major reason for this is that a large number of SOA precursors are not taken into account. As an example, Bruns *et al* (2016) simulated the aging of wood burning exhaust in a smog chamber. They showed that that SOA precursors traditionally included in models accounted for only ~20% of the observed SOA, whereas by inclusion of non-traditional precursors they were able to explain ~100% of the SOA.

In addition, it is still largely unknown to which extent and under which conditions oxidized organic molecules can contribute to nucleation, i.e., the formation of new particles. Until about 5 years ago it was believed that sulfuric acid alone is able to nucleate new particles at concentrations and temperatures observed in the planetary boundary layer. Kirkby *et al* (2011) then showed that sulfuric acid is by far not sufficient and other ingredients are needed to explain the observed nucleation rates. Riccobono *et al* (2014) showed that oxidation products of biogenic organic gases indeed enhance the nucleation rate of sulfuric acid by up to four orders of magnitude and that the nucleating clusters include such oxidized organic compounds. Kirkby *et al* (2016) recently showed that pure oxidation products of biogenic gases (e.g., α-pinene), termed HOMs (highly oxygenated molecules) are able to nucleate new particles, i.e., even in the absence of sulfuric acid. Bianchi *et al* (2016) confirmed, by measurements at the high-alpine research station Jungfraujoch in the Swiss Alps (3580 m asl), that nucleation by pure HOMs, without participation of sulfuric acid, indeed occurs in the ambient atmosphere. Tröstl *et al* (2016) formulated a growth model where, due to the Kelvin effect, only the least volatile HOMs participate in the initial growth while with increasing particle size also HOMs with increasing volatility can participate in the growth process.

In order to reduce air pollution efficiently the contributions of the individual sources need to be known. Instrumental advancements of the last decade such as the aerosol mass spectrometer, along with sophisticated statistical analyses such as positive matrix factorization have brought along hitherto unknown capabilities for such source apportionment (e.g., Crippa *et al*, 2014, and references therein). In this way a number of primary aerosol sources (e.g., traffic, biomass burning, cooking) can be identified, however, SOA can only be quantified in total, without discrimination of the individual sources contributing to SOA. As this SOA typically comprises the major part of the organic aerosol, also at air pollution hot spots such as in China (Huang *et al*, 2014) further development is required here.

The research of the impact of atmospheric aerosols on health is still at its infancy. New developments (such as e.g. in Künzi *et al* (2015)) are needed to elucidate health effects of different aerosol types.

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