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Ultrafine Particles from Power Plants: Evaluation of WRF-Chem Simulations with Airborne Measurements

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Introduction

Ultrafine particles (UFP, particles with a diameter < 100 nm) are an acknowledged risk to human health. They can also potentially affect the number concentration of cloud condensation nuclei and therefore climate. Although UFPs may have hazardous effects, no regulations exist for this class of particles. Furthermore, UFPs are also not well described in common air quality models.

Despite their importance, information about the vertical distribution of UFP is still limited. This gap has been closed during the last years by regional-scale airborne surveys of UFP concentrations and size distributions over Germany (Junkermann et al., 2016). 'Clean' coal fired power stations with flue cleaning technology and refineries have been identified as a major source of 1 – 10 nm UFP in the atmospheric boundary layer.

Airborne Measurements

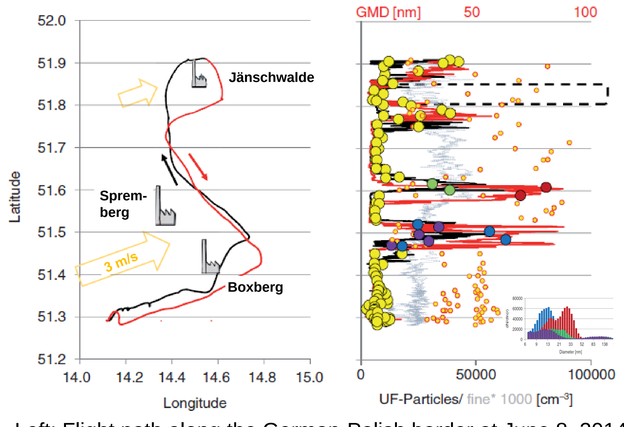
The airborne measurements were carried out in 2012 to 2014 during the summer months using a small slow flying open cell aircraft with a cruising speed of 25 m s^{-1}. A minimum flight height of 150 m for cross country flights permits flights within the atmospheric boundary layer.

Among others, the aircraft was equipped with a GRIMM condensation particle counter (total UFP number > 4.5 nm), a GRIMM scanning mobility particle size spectrometer (size distribution from 4.5 nm – 350 nm), and an optical particle spectrometer (particle size distribution 300 nm – 20 μm).

The ultralight aircraft

Main observational results

- UFP concentrations up to 90000 cm^{-3} in the plumes approximately 10 km downwind of power stations.
- The aerial survey has shown that UFP plumes were observed during 10% to 60% of the flight time within atmospheric boundary layer over Germany.
- A pronounced drop of the geometric mean diameter (GMD) of the particles to values below 10 nm was found when the aircraft crossed an UFP plumes.



Left: Flight path along the German-Polish border at June 8 2014. Right: Particle number concentrations (black and red lines line) and GMD (geometric mean diameter; small red/yellow points).

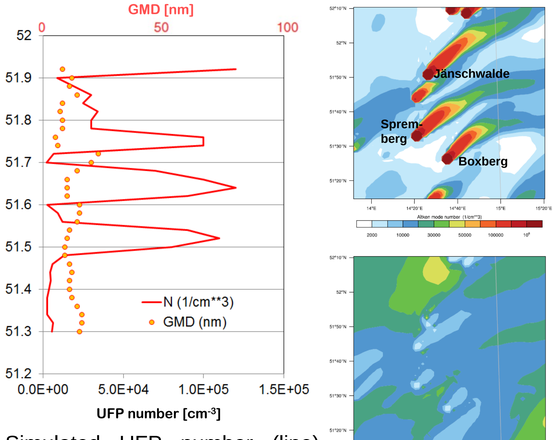
Reference:
Junkermann et al., 2016, TELLUS B, 68, 29250, http://dx.doi.org/10.3402/tellusb.v68.29250

WRF-Chem Simulations

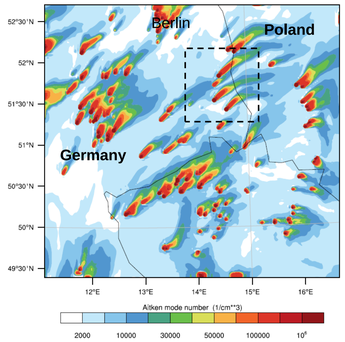
Nested simulations with WRF-Chem (v 3.8.1) with 2 km grid width of the innermost domain were carried out for Eastern Germany. The focus was on June 8 2014 when a flight was performed to investigate the emissions of several large coal-fired power stations near the border to Poland.

Although WRF-Chem offers different options for the description of aerosol physics and chemistry, none of the options included in the public version of WRF-Chem is optimized to describe ultrafine particles.

In this study, WRF-Chem's modal MADE-SORGAM aerosol module was applied, which describes the aerosol size distributions by log-normal distributions for the Aitken mode (< 100 nm), the accumulation mode (100 nm – 2 μm), and the coarse mode. For the Aitken mode, 2 % of the SO_2 emissions from energy industries and industrial combustion was assumed to contribute particulate sulfate.



Simulated UFP number (line) and GMD (dots) along the south-bound flight track.



UFP concentration at 500 m above ground level from a simulation with adapted mass to particle number conversion factor.

The dashed square (100 km x 100 km) indicates the area of interest. UFP number concentrations and GMD are shown below for this area.

Baseline simulation

- Aitken mode particle numbers within the plumes were underestimated by a factor of 2 to 3.
- The observed geometric mean diameters around 10 nm in the plumes cannot be reproduced with the standard model configuration.

Adapted UFP emissions

- The conversion factor for emitted primary sulfate to particle numbers was identified as a reason for the too large particles and consequently the too low particle number concentrations.
- Changing the mean diameter in the conversion of primary sulfate particles from 30 nm to 3 nm lead to more than 10 times higher particle concentrations and geometric mean diameters in the rage of 8 nm to 30 nm.

Conclusions

- Concentrated efforts are required to specify the relation between emitted sulfate and UFP emissions from coal fired power plant.
- Downward mixing of UPFs from elevated point sources contributed to near surface UFP loads.
- It is highly desirable to include an improved representation of UFPs in WRF-Chem's standard configuration.

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