Karlsruher Institut für Technologie

Institute of Meteorology and Climate Research (IMK)
Atmospheric Aerosol Research (IMK-AAF)

Aerosol composition, boundary layer dynamics, and air quality in the cities of Karlsruhe, Stuttgart, and Munich

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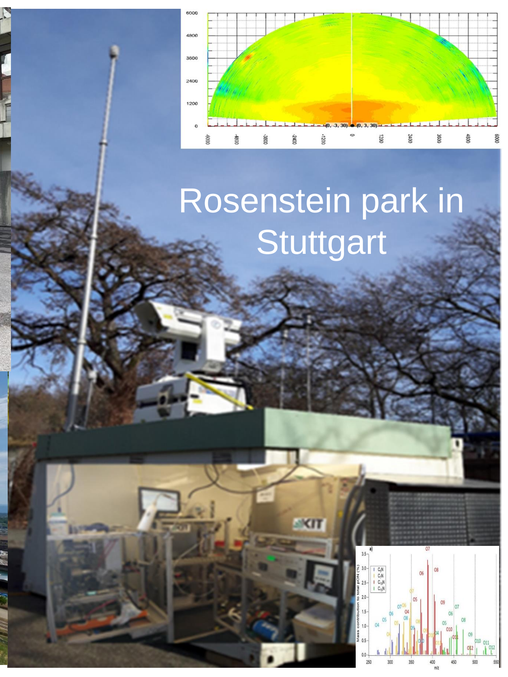
Motivation

Understanding primary and secondary sources, transformations, impact of meteorology and transport, characteristic optical and cloud formation properties for typical summer and winter conditions. Validation of models, low cost sensors, and mobile measurements.

Experimental

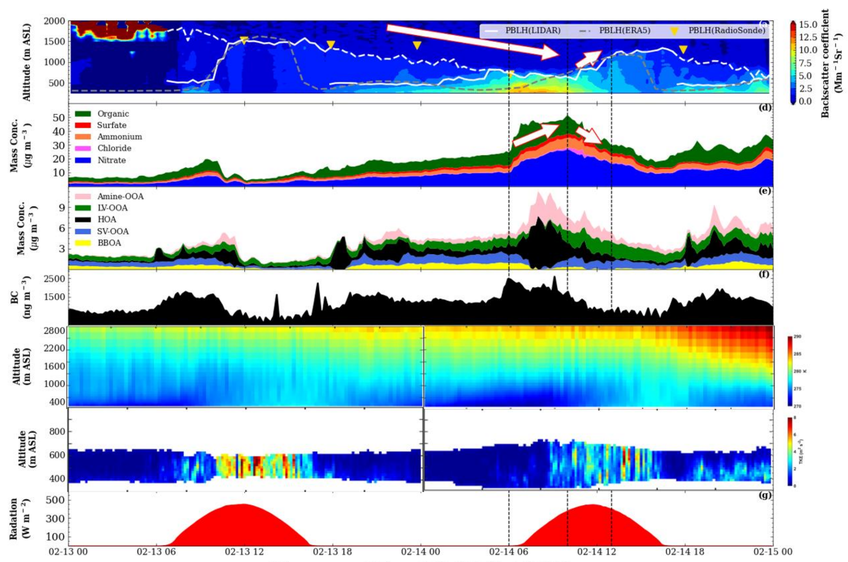
Measured parameters	Main Instruments
Particle composition, Non-refractory species, e.g. organics, inorganics, 70 nm – 2.5 µm	Aerosol mass spectrometer (HR-ToF-AMS) CHARON-PTR-MS
Oxygenated compounds in particle phase, volatility of particle phase compounds	Chemical ionization mass spectrometer (FIGAERO-CIMS, Iodide) (off-line)
Aerosol backscatter, N_2 Raman, and depolarization at 355 nm, also close to ground level (scanning)	Scanning depolarization Raman LIDAR[3]
Aerosol particle number, size	Various particle sizers and counters (CPC, OPC, SMPS)
Trace gases: O_3, NO, NO_2, NH_3, CO_2,	Various gas monitors
Meteorological parameters	Lufft WS700, radiosondes (DWD)

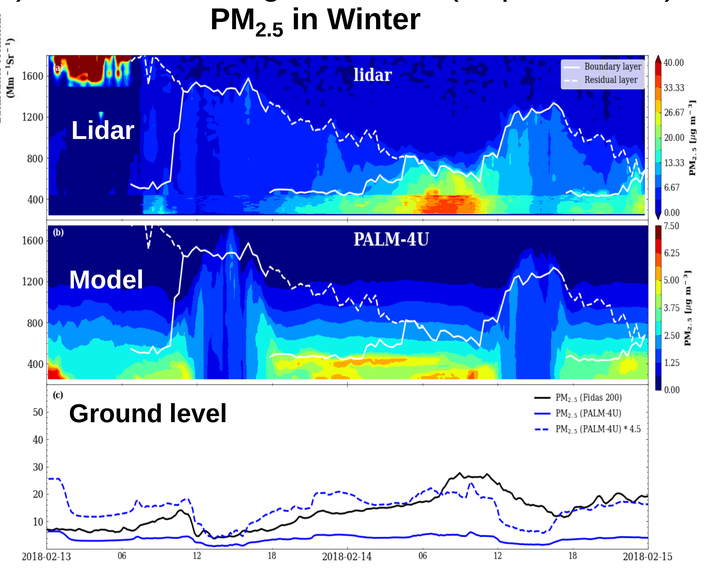


Measurement container at a park in the urban background of Stuttgart (Pop. 600.000) and overlooking Karlsruhe (Pop. 300.000).

Stuttgart 2017/20218

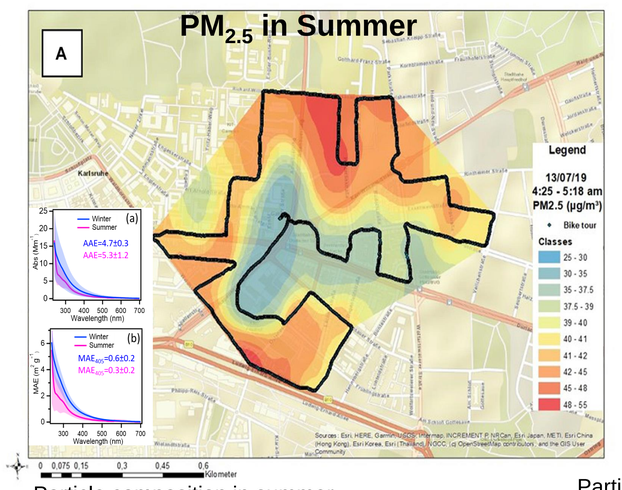
- Boundary layer heights (PBL) agree well for radiosonde and lidar measurements[2,3]
- Scanning lidar allows extinction measurements near ground level for comparison with in situ data
- Increased aerosol levels during morning and evening rush hours are related to the emission of traffic (HOA) and industry (Amine-OOA)[1]
- Decreasing pollution levels correlate with rising PBL height (vertical dilution)
- Nitrate and organics dominate the non refractory aerosol particle composition in winter and low-volatile oxidized organics dominate the organic fraction in winter
- Organics from biomass burning contribute most during evenings and nighttime in winter.

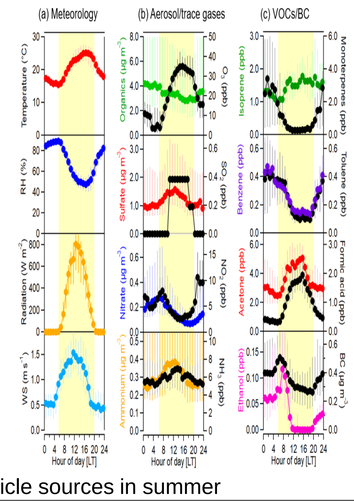


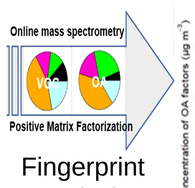


Karlsruhe 2019/2020/2022

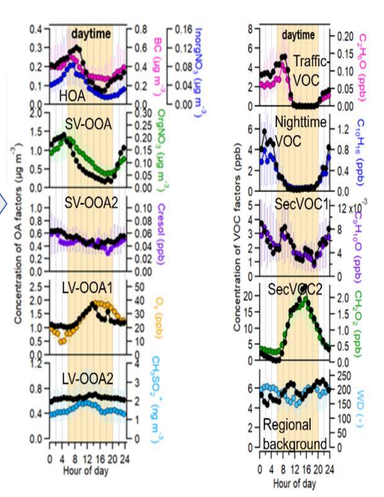
- Chemical fingerprints of VOCs and particles allow source identification[4]
- Brown carbon contributes only a small mass fraction but still substantial to aerosol absorption[5]
- Mobile measurements are suitable tools to identify heat islands and pollution hot spots[6]
- Scannig lidar measurements show aerosol inflow and plumes from industrial sources (power plants)
- Extreme weather events (heatwaves and storms) can dominate aerosol formation and wash out
- Heat wave night time particle growth rates[7] were 3-4 nm h^{-1} with formation of organonitrates.



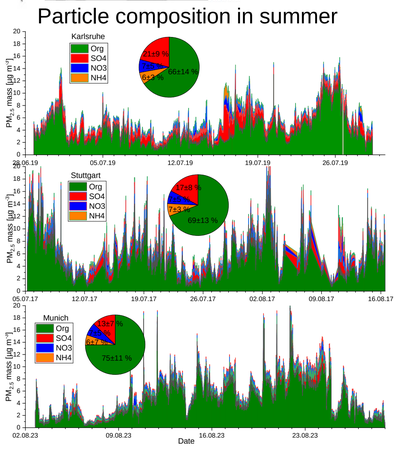




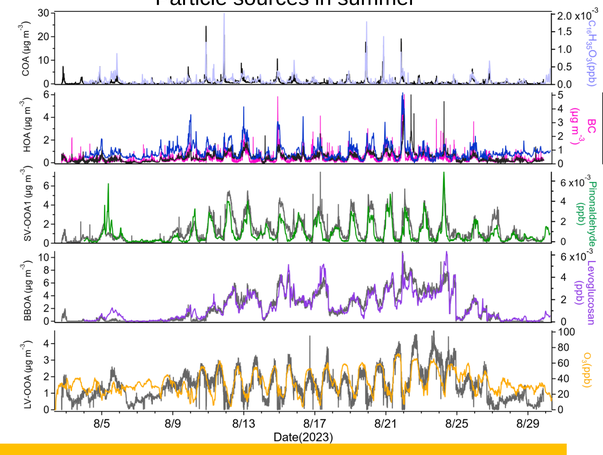
Fingerprint analysis

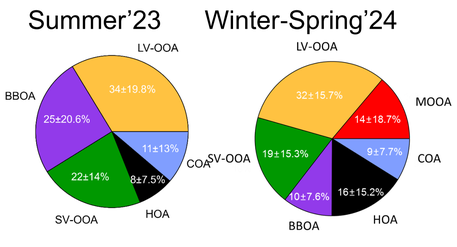


Particle composition in summer



Particle sources in summer





BBOA-Biomass burning organics
COA = Cooking organic aerosol
HOA = Hydrocarbon rich organics
LV-OOA = Low volatile oxid. organics
SV-OOA = Semi volatile oxid. organics
MOOA = More oxidized organics

Munich 2023/2024

- Chemical fingerprints of VOCs and aerosol particles, comparison of high resolution mass spectrometers with Harvard Univ.
- Comparison with low cost sensor network and mobile measurements
- Validation of scanning aerosol lidar data with reference station of Univ. of Munich
- Validation of models for air quality and urban climate prediction.

Conclusions and Outlook

- Secondary organic compounds of biogenic origin dominate $PM_{2.5}$ in all cities. In winter nitrate is higher but organics still dominate. Sulfate from industrial sources ranges between 13-20%.
- Shallow PBL with strong temperature inversion, stagnant winds, as well as increasing secondary inorganic and biomass burning particles are major reasons for higher air pollution levels in winter.
- The PALM-4U model predicts the boundary layer structure and $PM_{2.5}$ trends but still underestimates the aerosol mass[3]. Future validation of models, low cost sensors, and mobile measurements is required.

References

(1) Huang et al., (2019) Atmos. Chem. Phys.
(2) Zhang et al., (2022). Remote Sensing
(3) Zhang et al., (2024).ACPD.
(4) Song et al., (2022). Atmos. Environ.
(5) Jiang et al., (2022) Atmos. Chem. Phys.
(6) Norra et al., (2023) Front. Environ. Sci.
(7) Song et al., (2024) Atmos. Chem. Phys

PALM-4U

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