Satellite-based observations of ground-level particulate matter and comparison to a regional air quality model

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Project S-VELD

Motivation:

- Air pollutants (i.a. PM2.5) has strong and dangerous effects on human health
- Limit values for EU/Germany are regularly exceeded, especially in metropolitan and high-traffic areas

Idea and Goals:

- quantification of contributions from different emission sources to environmental pollution in Germany and better quantification of traffic-related emissions
- **monitoring of transnational air pollution and emission patterns using high resoluted data sets**
  - ➢ combination of satellite data, in-situ measurements, model data
- improving air quality model performances through data assimilation

➡ **1. Step**: Deriving ground-level PM2.5 concentrations from satellite column AOD measurements to produce high resoluted PM2.5 maps for Germany

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Partners:

DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

Freie Universität Berlin

TNO innovation for life
Netherlands Organization for Applied Scientific Research

IVU Umwelt GmbH
Umweltplanung - Informationssysteme

Method

Deriving ground-level PM2.5 concentrations from satellite column AOD measurements

Semi-empirical approach based on the physical relationship between optical and meteorological parameters (*Koelemeijer et al. 2006*)

$$PM = \tau \frac{4\rho r_{eff}}{3Hf(RH)Q_{ext,dry}}$$

Meteorological parameters

H Planetary boundary layer height

$f(RH)$ Function of relative humidity to include effects of hygroscopic growth

ECMWF Set1 forecasts (HRES)

Optical parameters

τ AOD 550nm

Satellite measured aerosol optical depth

MODIS Aqua - Collection 6.1 - 3km product

r_{eff} Effective radius

$Q_{ext,dry}$ Extinction efficiency

Assumptions for spherical particles and a constant aerosoltype

Method

Calibration with in-situ data

- ● Calibration stations (75%)
- ▲ Validation stations (25%)

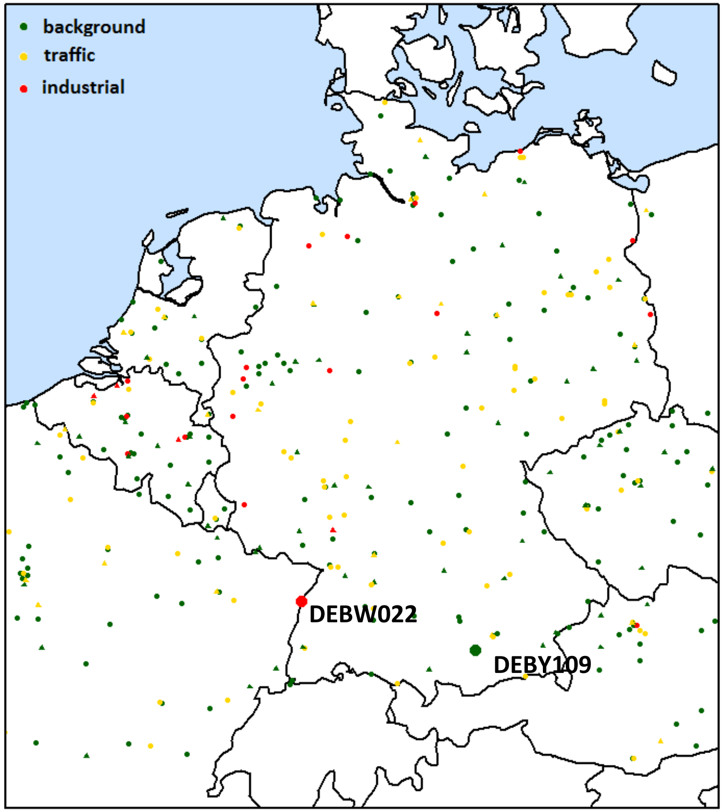


Fig. 1 Stations of the European Environmental Agency (EEA) with available PM2.5 measurements for the year 2018

$$PM = A * \tau \frac{4\rho r_{eff}}{3Hf(RH)Q_{ext,dry}} + B$$

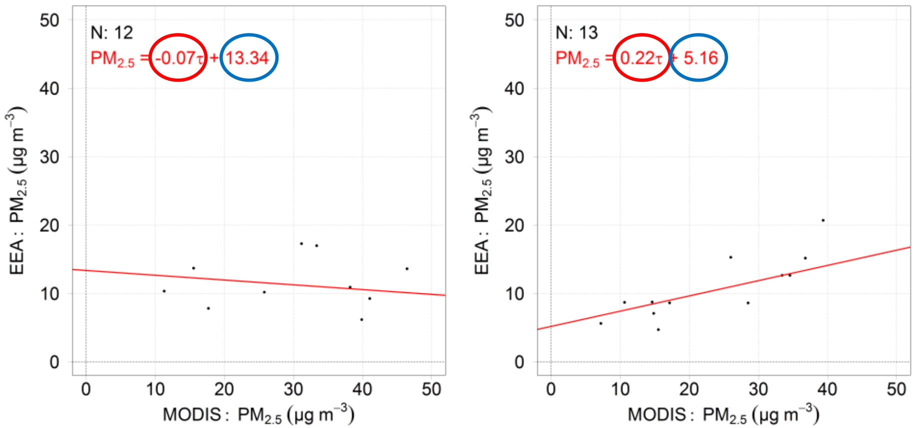


Fig. 2 Scatter plots and linear regression between satellite-derived and in-situ measured (EEA airbase dataset) PM2.5 concentrations for two example stations in Germany for July 2018

- Coefficients from linear regression between satellite-derived and in-situ measured PM2.5 concentrations are used as calibration parameters
- Calculation of calibration parameters per station (●) and month because of the strong seasonal and spatial variability

Results

$$PM = \tau \frac{4\rho r_{eff}}{3Hf(RH)Q_{ext,dry}}$$

MODIS AOD 550nm (2018)

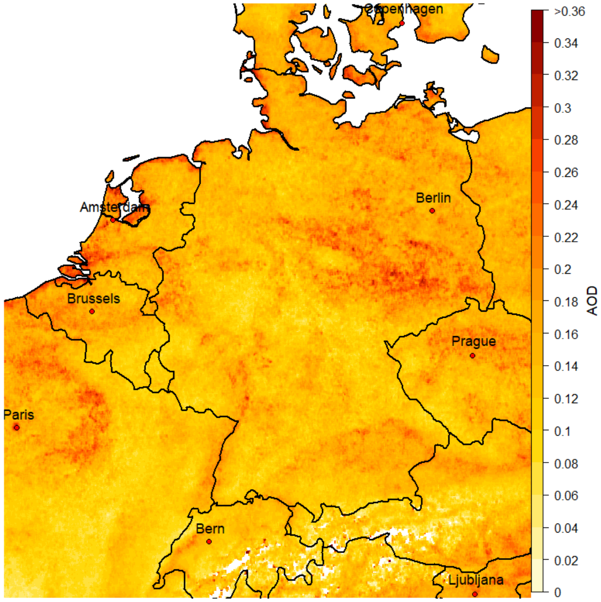
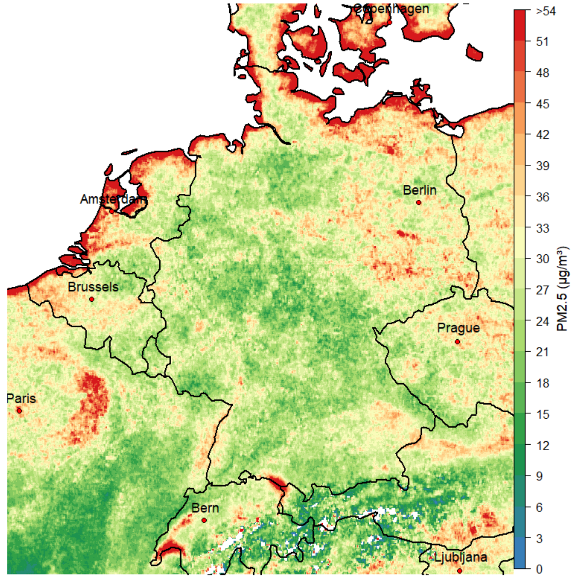
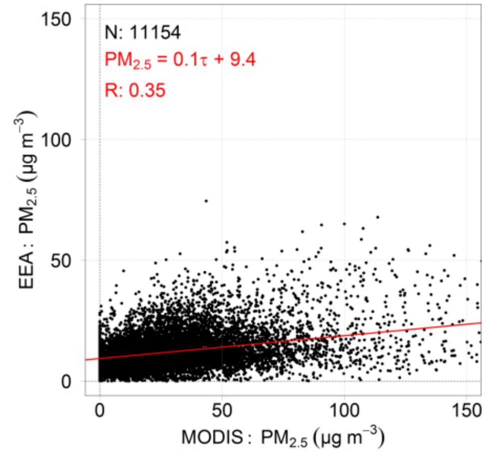


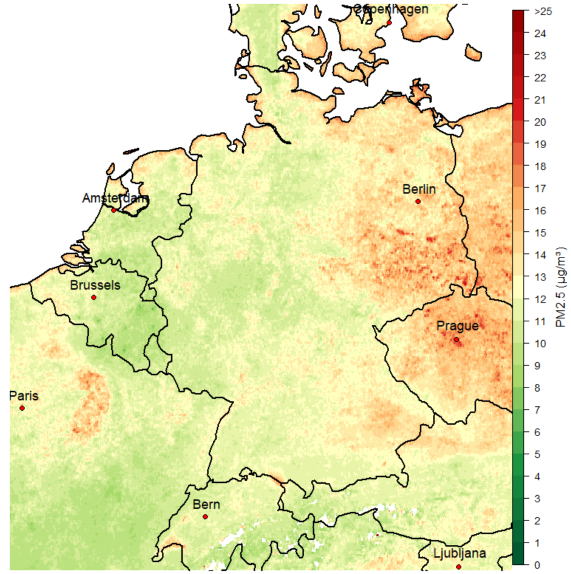
Fig. 3 *Mean AOD at 550nm for the year 2018 from MODIS Aqua (C6.1, 3km) regridded to 1 km resolution*

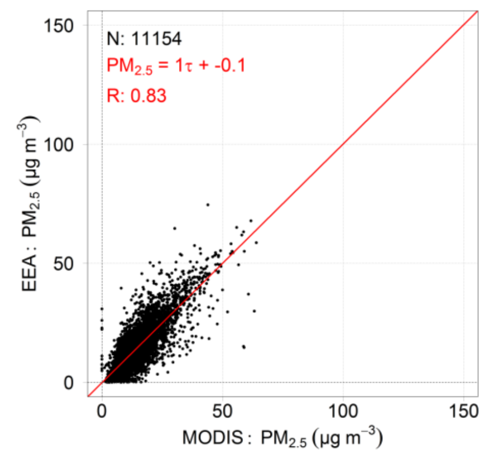




- ➢ **clear overestimation of PM2.5**

Fig. 4 *Mean MODIS-derived PM2.5 concentrations (uncalibrated) for 2018 and scatterplot/ correlations (R) with in-situ measurements (EEA airbase)*





- ➢ **slight underestimation of PM2.5**
- ➢ **high correlations with in-situ data**

$$PM = A * \tau \frac{4\rho r_{eff}}{3Hf(RH)Q_{ext,dry}} + B$$

Fig. 5 *Mean MODIS-derived PM2.5 concentrations (calibrated) for 2018 and scatterplot/ correlations (R) with in-situ measurements (EEA airbase)*

DLR

Comparison to model results

Simulations performed with the chemistry-transport-model POLYPHEMUS/DLR

Domain: Bavaria (southern Germany) 47.00-50.96 °N/ 9.3-13.74 °E

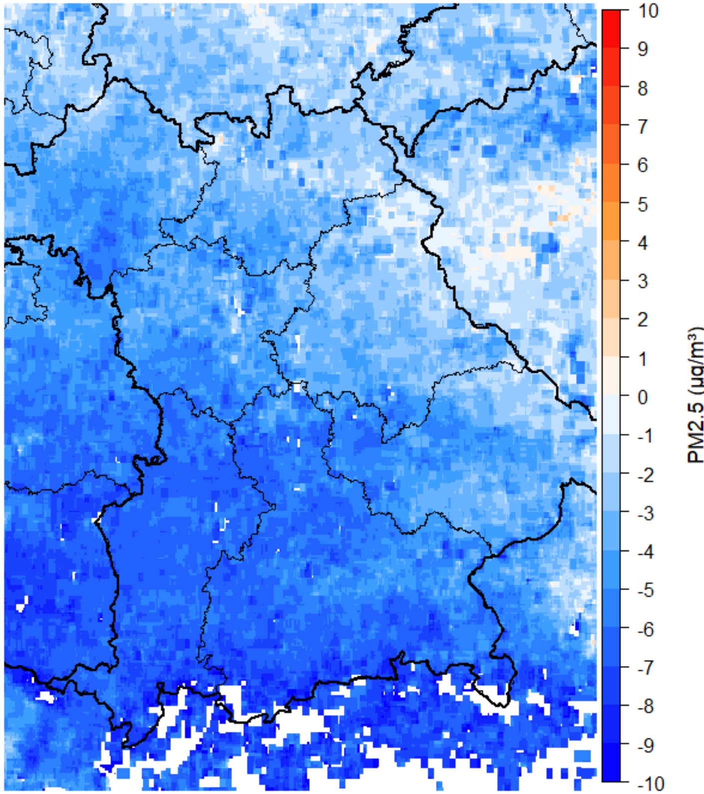
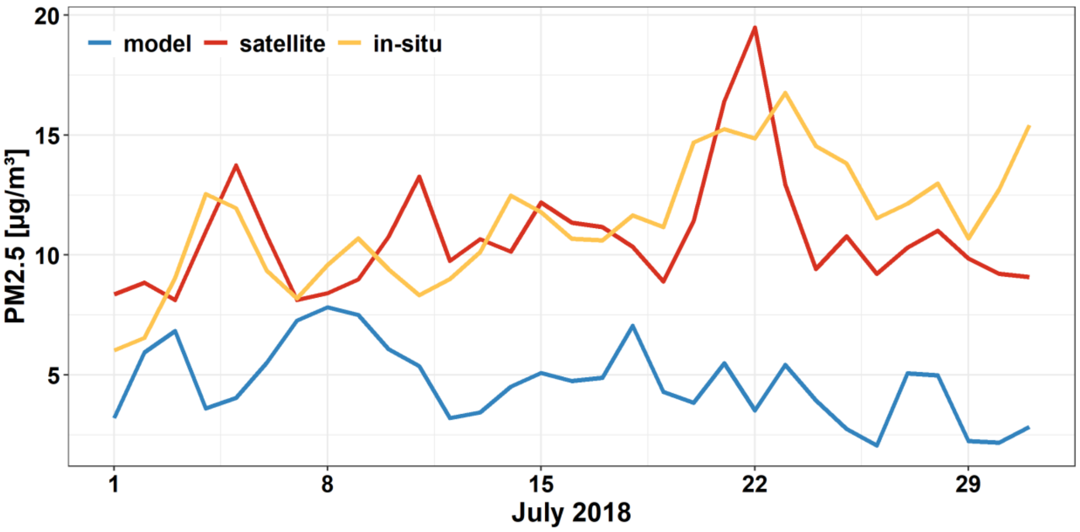


Fig. 6 *Difference between simulated and satellite-derived mean PM2.5 concentrations for July 2018*

Fig. 7 *Time series of PM2.5 concentrations from in-situ measurements, satellite measurements and model simulation for July 2018, spatial average for Bavaria, model-data filtered by valid MODIS pixels*



- Underestimation of PM2.5 concentrations by the model
- Partial anti-correlations with measurements

Summary

- Use of a semi-empirical method to derive ground-level PM2.5 concentrations from satellite column AOD for Germany
- Calibration with in-situ measurements improved results, correlations between satellite-derived and in-situ measured PM2.5 rose from 0.35 to 0.83
- we could produce detailed, reliable and almost gapless PM2.5 maps for Germany which can be used for identification and localization of emission sources
- First comparisons to model simulations (POLYPHEMUS/DLR) showed significant differences between measurements and model simulations of PM2.5

Next steps

- Deriving PM2.5 concentrations for Germany using AOD data from other satellite sensors (Sentinel-3, Sentinel-5p)
- Using satellite-derived PM2.5 data to improve model performance through data assimilation