EGU21-10637
https://doi.org/10.5194/egusphere-egu21-10637
EGU General Assembly 2021


# Validation of Sentinel-5P TROPOMI tropospheric $NO_2$ with airborne imaging, ground-based stationary, and mobile DOAS measurements from the S5P-VAL-DE-Ruhr campaign

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Airborne imaging DOAS and ground-based stationary and mobile DOAS measurements were conducted during the ESA funded S5P-VAL-DE-Ruhr campaign in September 2020 in the Ruhr area. The Ruhr area is located in Western Germany and is a pollution hotspot in Europe with urban character as well as large industrial emitters. The measurements are used to validate data from the Sentinel-5P TROPOspheric Monitoring Instrument (TROPOMI) with focus on the $NO_2$ tropospheric vertical column product.

Seven flights were performed with the airborne imaging DOAS instrument, AirMAP, providing continuous maps of $NO_2$ in the layers below the aircraft. These flights cover many S5P ground pixels within an area of about 40 km side length and were accompanied by ground-based stationary measurements and three mobile car DOAS instruments. Stationary measurements were conducted by two Pandora, two zenith-sky and two MAX-DOAS instruments distributed over three target areas, partly as long-term measurements over a one-year period.

Airborne and ground-based measurements were compared to evaluate the representativeness of the measurements in time and space. With a resolution of about 100 x 30 $m^2$, the AirMAP data creates a link between the ground-based and the TROPOMI measurements with a resolution of 3.5 x 5.5 $km^2$ and is therefore well suited to validate TROPOMI's tropospheric $NO_2$ vertical column.

The measurements on the seven flight days show strong variability depending on the different target areas, the weekday and meteorological conditions. We found an overall low bias of the TROPOMI operational $NO_2$ data for all three target areas but with varying magnitude for different days. The campaign data set is compared to custom TROPOMI $NO_2$ products, using different auxiliary data, such as albedo or a priori vertical profiles to evaluate the influence on the TROPOMI data product. Analyzing and comparing the different data sets provides more insight into the high

spatial and temporal heterogeneity in $NO_2$ and its impact on satellite observations and their validation.

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