Title:	Long-term MAX-DOAS measurements of NO2, HCHO, and aerosols and evaluation of corresponding satellite data products over Mohali in the Indo-Gangetic Plain
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Abstract:	We present comprehensive long-term groundbased multi-axis differential optical absorption spectroscopy (MAX-DOAS) measurements of aerosols, nitrogen dioxide (NO2), and formaldehyde (HCHO) from Mohali (30.667° N, 76.739° E; ~310m above mean sea level), located in the densely populated Indo-Gangetic Plain (IGP) of India. We investigate the temporal variation in tropospheric columns, surface volume mixing ratio (VMR), and vertical profiles of aerosols, NO2, and HCHO and identify factors driving their ambient levels and distributions for the period from January 2013 to June 2017. We observed mean aerosol optical depth (AOD) at 360 nm, tropospheric NO2 vertical column density (VCD), and tropospheric HCHO VCD for the measurement period to be 0.63±0.51, (6.7±4.1) ×1015, and (12.1±7.5)×1015 molecules cm-2, respectively. Concerning the tropospheric NO2 VCDs, Mohali was found to be less polluted than urban and suburban locations of China and western countries, but comparable HCHO VCDs were observed. For the more than 4 years of measurements during which the region around the measurement location underwent significant urban development, we did not observe obvious annual trends in AOD, NO2, and HCHO. High tropospheric NO2 VCDs were observed in periods with enhanced biomass and biofuel combustion (e.g. agricultural residue burning and domestic burning for heating). Highest tropospheric HCHO VCDs were observed in agricultural residue burning periods with favourable meteorological conditions for photochemical formation, which in previous studies have shown an implication for high ambient ozone also over the IGP. Highest AOD is observed in the monsoon season, indicating possible hygroscopic growth of the aerosol particles. Most of the NO2 is located close to the surface, whereas significant HCHO is present at higher altitudes up to 600m during summer indicating active photochemistry at high altitudes. The vertical distribution of aerosol, NO2, and HCHO follows the change in boundary layer height (BLH), from the ERA5 dataset of European Centre for Medium-Range Weather Forecasts, between summer and winter. However, deep convection during the monsoon transports the pollutants at high altitudes similar to summer despite a shallow ERA5 BLH. Strong gradients in the vertical profiles of HCHO are observed during the months when primary anthropogenic sources dominate the formaldehyde production. High-resolution MODIS AOD measurements correlate well but were systematically higher than MAX-DOAS AODs. The ground-based MAX-DOAS measurements were used to evaluate three NO2 data products and two HCHO data products of the Ozone Monitoring Instrument (OMI) for the first time over India and the IGP. NO2 VCDs from OMI correlate reasonably with MAX-DOAS VCDs but are lower by ~ 30 %-50% due to the difference in vertical sensitivities and the rather large OMI footprint. OMI HCHO VCDs exceed the MAX-DOAS VCDs by up to 30 %. We show that there is significant scope for improvement in the a priori vertical profiles of trace gases, which are used in OMI retrievals. The difference in vertical representativeness was found to be crucial for the observed biases in NO2 and HCHO surface VMR intercomparisons. Using the ratio of NO2 and HCHO VCDs measured from MAX-DOAS, we have found that the peak daytime ozone production regime is sensitive to both NOx and VOCs in winter but strongly sensitive to NOx in other seasons
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