Diagnosing long-term and short-term changes in ozone production sensitivity to precursor emissions: the view from space

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Ambient exposure to ground-level ozone (O$_3$) is estimated to cause more than 250,000 global premature deaths per year. O$_3$ is produced from photochemical reactions involving its precursors: nitrogen oxides (NO$_x$) and volatile organic compounds (VOCs). A major challenge in lowering ground-level O$_3$ in urban areas is to determine whether O$_3$ production is limited by NO$_x$ (NO$_x$-limited) or VOCs (VOC-limited) or both (transitional). While satellites cannot retrieve the abundance of ground-level O$_3$, they have provided continuous global observations of O$_3$ precursors, namely tropospheric columns of NO$_2$ and formaldehyde (HCHO, a proxy for VOCs), for over two decades. To assess the extent to which satellite retrievals of O$_3$ precursors can capture the non-linear chemistry of ground-level O$_3$, we pair daily satellite retrievals of NO$_2$ and HCHO from Ozone Monitoring Instrument (OMI) with ground-based observations of surface O$_3$ from the U.S. EPA Air Quality System (AQS) network. For urban areas, we find O$_3$ exceedances (> 70 ppbv) are more likely to occur with NO$_x$ reductions (NO$_x$-saturated or VOC-limited) when OMI HCHO/NO$_2$ is lower than 1.8, but less likely to occur with NO$_x$ reduction (NO$_x$-limited) when OMI HCHO/NO$_2$ is higher than 2.8. We further contrast how the O$_3$-NO$_x$-VOC sensitivity differs on high-ozone versus “average” ozone days. Next, we construct 20-year (1996 to 2016) time series of the O$_3$ sensitivity indicator ratio (HCHO/NO$_2$) using the state-of-art, harmonized multi-satellite products of tropospheric NO$_2$ and HCHO vertical columns from the Quality Assurance for Essential Climate Variables (QA4ECV) project that retrieves products consistently from four satellites, including GOME, SCIAMACHY, GOME-2 and OMI. We analyze the long-term trend in the ratio of HCHO to NO$_2$ over major cities across the world. Our study aims to demonstrate how satellite HCHO/NO$_2$ products can complement in-situ O$_3$ networks by providing information on the spatial heterogeneity and long-term evolution of O$_3$ chemical regimes.