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Investigating ozone production regimes during a prolonged ozone episode over Europe in July 2022

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ABSTRACT

During a prolonged heat wave in July 2022, Europe faced a severe ozone episode, with stagnant atmospheric conditions causing ozone levels to exceed 200 µg/m³ in several regions. This study analyzed ozone production regimes using the formaldehyde-to-nitrogen dioxide ratio (FNR) from Sentinel-5P TROPOMI data. Significant shifts in the VOCs-to-NOx ratio were observed in France, Italy, Germany, Poland, the Czech Republic, and Austria. At the same time, other regions experienced a mix of NOx-limited and VOC-limited regimes. These shifts, driven by local emissions and weather, emphasize the need for tailored air quality management strategies during extreme events.

HEAT WAVE

In July 2022, Europe experienced a heat wave, primarily affecting the southern and western regions. The temperature anomaly pattern, depicted in Fig. 1, illustrates the progression from Western to Central Europe. This movement is likely driven by large-scale atmospheric patterns, such as the high-pressure systems that characterize summer heat waves.

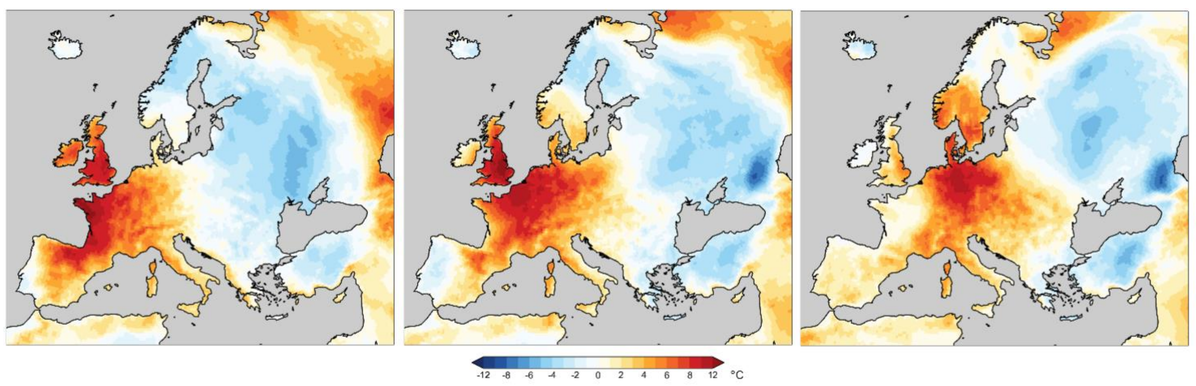

Figure 1: Surface temperature anomaly for 18, 19 and 20 July 2022
(Reference period: 1991-2020, Data: ERA5, Credit: C3S/ECMWF)

OZONE EPISODE

The heat wave was accompanied by a striking ozone episode with several locations in Spain, Portugal, France, and Italy, having encountered ozone levels surpassing 200 µg/m³, while the daily limits according to EEA (European Environment Agency), amount to 120 µg/m³.

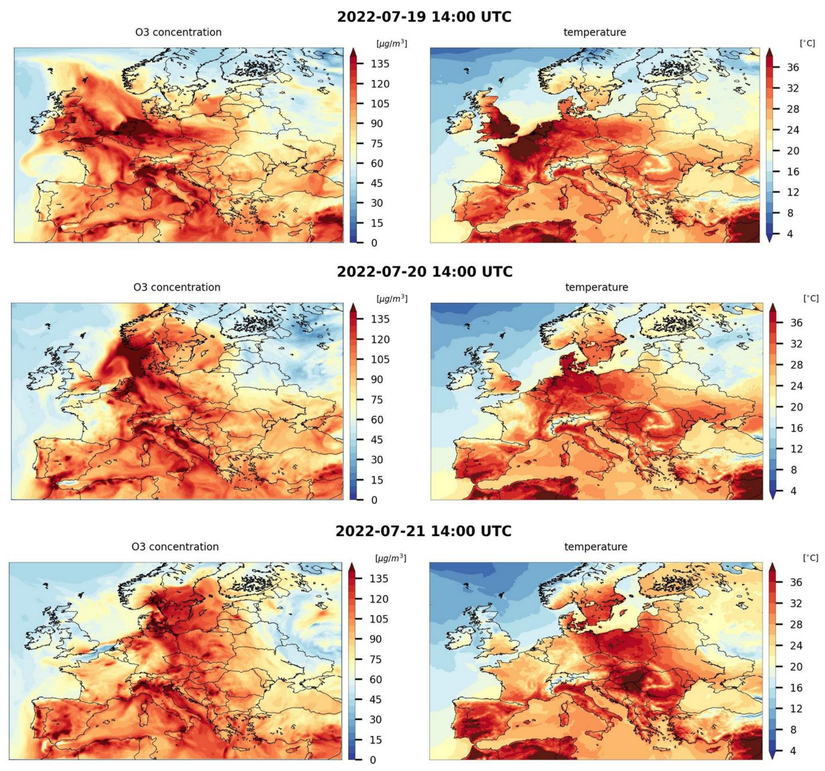

Figure 2: Model ozone concentration and surface temperature for 19, 20 and 21 July 2022
(CAMx model results)

The peak of ozone formation took place in mid-July, beginning more in the western parts of Europe (France, Spain, UK, Italy) on the 14-16 of July, and then shifting towards central Europe (Germany, Denmark, Poland, Czech Republic) around 19-21 July (Fig. 2). This progression suggests that transport of air masses played a role in spreading both heat and pollutants across the continent. As seen in Fig. 3, Central Europe experienced notably elevated ozone levels from July 19-21.

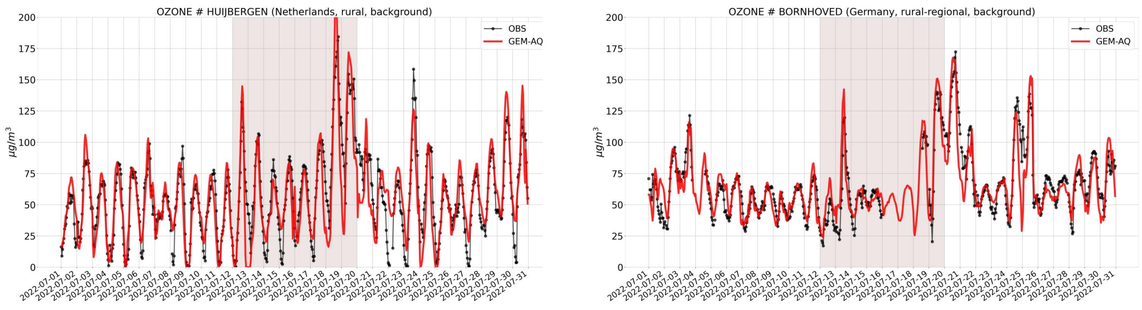

Figure 3: Model vs. observed ozone concentration for 2 stations
experiencing the July 2022 ozone episode (GEM-AQ model results)

VOC MEASUREMENT CAMPAIGN (TFMM IMP24)

Volatile Organic Compounds (VOCs) play a critical role as precursors in ozone formation, with highly reactive biogenic emissions being particularly significant. Fig. 4 shows isoprene observations in July 2022. Period of high maximum concentrations correlates well with heat wave evolution (Fig. 1, Fig. 2). When released, isoprene undergoes rapid oxidation, especially during periods of high temperature and sunlight, which leads to the formation of ozone and other secondary pollutants, including formaldehyde.

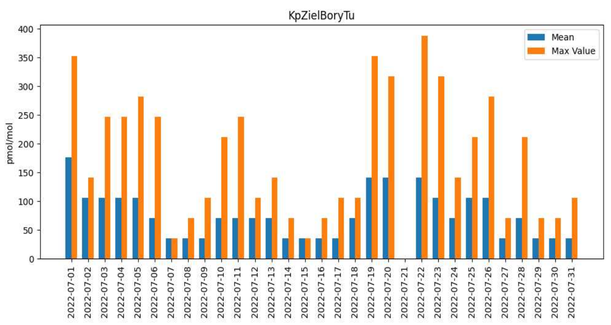

Figure 4: Isoprene observation in July 2022 (daily average and daily maximum)
in Poland (Zielonka, Bory Tucholskie)

DATA AND METHODOLOGY

The ratio of formaldehyde (HCHO) to nitrogen dioxide (NO_2), known as FNR, is widely used to assess ozone production regime. HCHO (as a representative VOC) and NO_2 (often used as a proxy for NO_x), can serve as indicators of VOCs and NO_x. A higher FNR value indicates a NO_x-limited condition, while a lower ratio points to VOC-limited environments. Thresholds between them vary across regions, depending on local emissions, meteorological conditions and chemical environments. Understanding this variability is key to designing effective air quality measures.

In this research, data from Sentinel-5P's TROPOMI spectrometer were filtered using Python, adhering to the guidelines provided in the product manuals and re-gridded to a 0.02° spatial resolution. For grid cells where both HCHO and NO_2 data coexisted after the process, the FNR was computed, and weekly averages (Mondays to Sundays, included) of the ratio were derived to analyse temporal and spatial trends in ozone production regimes.

RESULTS

Below (Fig. 5, Fig. 6) are weekly means of NO_2 and HCHO from the week when the shift occurred (19-21 July). For the 18-24.07 week, a sudden HCHO spread was observed compared to the week before (11-17.07), when increased formaldehyde levels could be observed mainly in Southern and Western Europe, with only wildfires' effect in Portugal standing out. The FNR means for three weeks of July are presented in Fig. 7, Fig. 8 and Fig. 9.

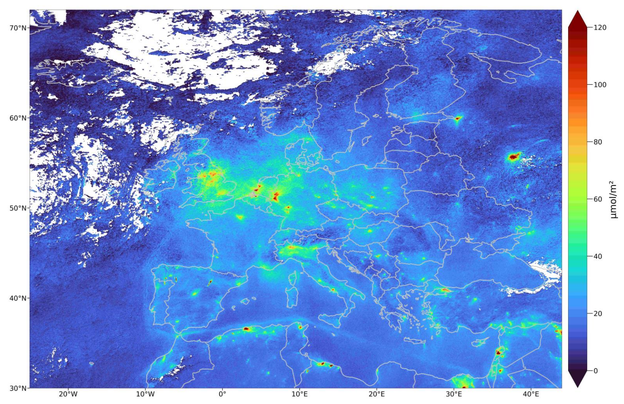

Figure 5: Tropospheric NO_2 mean between 18-24.07.2022

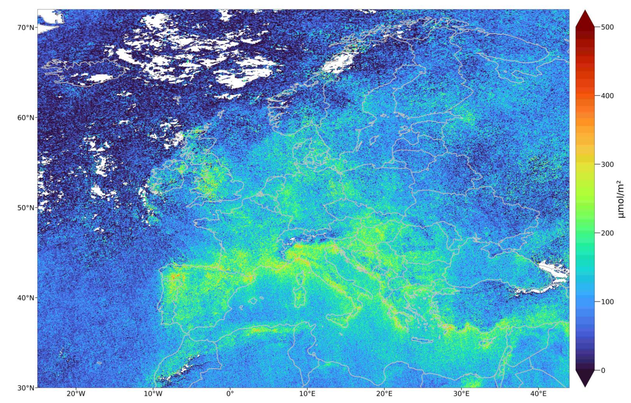

Figure 6: Tropospheric HCHO mean between 18-24.07.2022

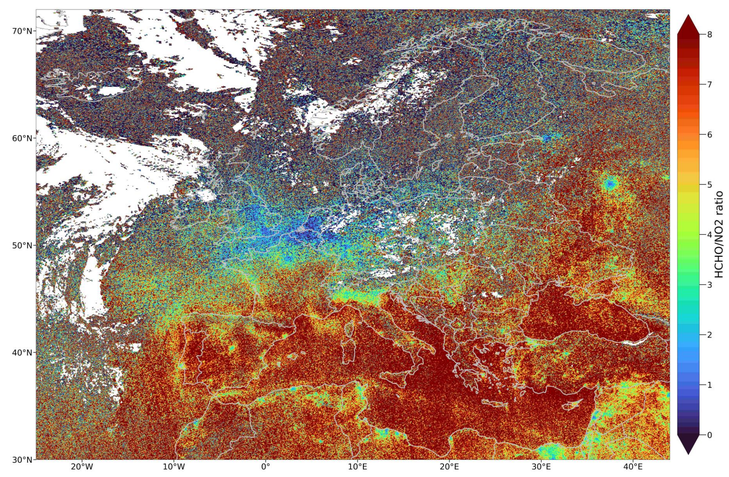

Figure 7: FNR (HCHO to NO_2 ratio) mean between 04-10.07.2022

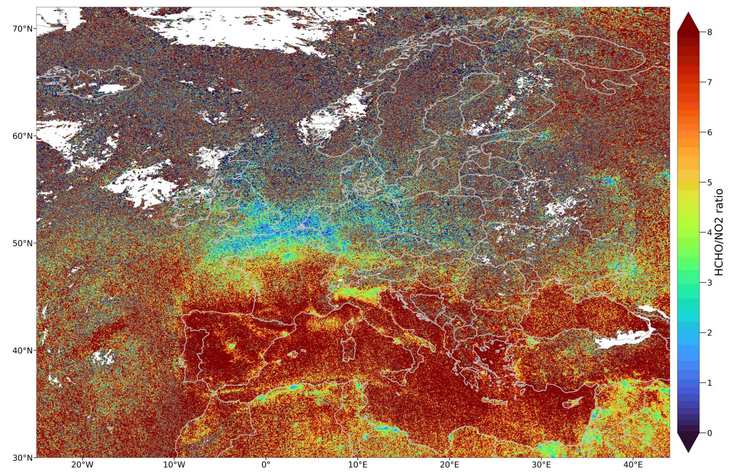

Figure 8: FNR (HCHO to NO_2 ratio) mean between 11-17.07.2022

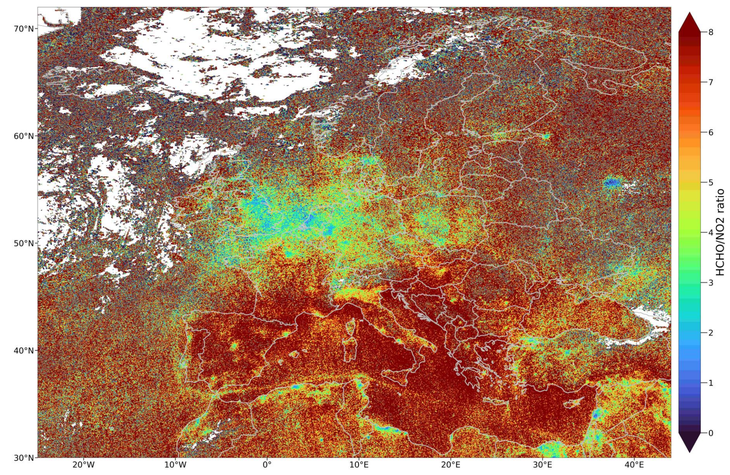

Figure 9: FNR (HCHO to NO_2 ratio) mean between 18-24.07.2022

The ozone episode that peaked in mid-July 2022 demonstrated an extensive shift in the VOCs-to-NOx ratio towards a NO_x-limited ozone production regime in some parts of France, Italy, Germany, Poland, Czech Republic and Austria – similar to the changes described before. Aside from that, the regimes in the other regions significantly affected by this ozone event remained similar, likely experiencing a mix of NOx-limited and VOC-limited regimes, with their specific ozone dynamics depending on local emissions and meteorological conditions. In VOC-limited areas, such as large urban centres with high NOx emissions from traffic and industry, ozone production would have been constrained by the availability of VOCs. The heatwave likely intensified these conditions by increasing the evaporation of VOCs and creating more stagnant air, which traps pollutants near the surface and allows ozone levels to rise significantly.

The spatial variability of ozone regimes observed in July 2022 underscores the importance of considering both local emissions and broader meteorological patterns when assessing and managing ozone pollution. By analyzing the FNR using satellite data, we can better understand how different parts of Europe responded to extreme weather conditions, helping to tailor air quality management strategies to specific regions.

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