Empa
Materials Science and Technology

# The impact of COVID-19 lockdowns on air quality in European urban areas

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Presented online on May 11, 2021 in the "Impact of COVID-19 2020 lockdown on European air quality" session

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# Introduction

- The first COVID-19 lockdowns imposed unprecedented restrictions on the mobility of the European population between March and May, 2020
- The lockdowns had many positive environmental effects, including the reduction of $CO_2$ and air pollutant emissions[1,2]
- Here, the changes on air quality throughout European urban areas will be explored
  - Nitrogen dioxide ($NO_2$), primarily a road traffic-sourced pollutant and ozone ($O_3$), a secondary pollutant will be focused on

[1] Le Quéré et al. 2020, *Nature Climate Change*

[2] Shi et al. 2021 *Science Advances*

# Mobility changes

- The mobility of the European population was dramatically altered during the periods when lockdowns were applied
- Such changes in mobility should be clearly visible in air quality monitoring data

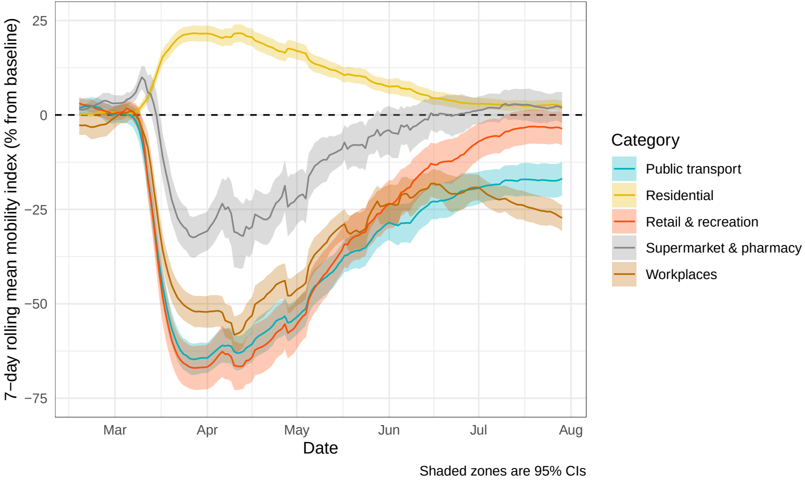


**Figure 1:** Google mobility data[1] for Europe between mid-February and July, 2020.

[1] Google, COVID-19 Community Mobility Reports

# A note on the weather

- The analysis of the effect of the lockdown on air quality is complicated by the unusual weather situation in the first few months of 2020 – this is a classic air quality data analysis issue and needs careful management

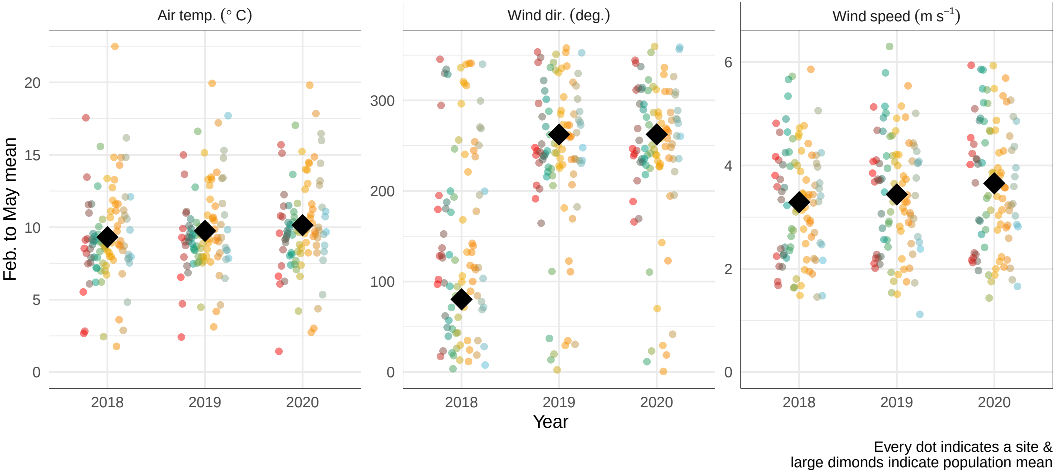


**Figure 2:** Mean meteorological variables for all urban areas included in the analysis between February and May for 2018, 2019, and 2020.

# Analysis approach

- The concentrations experienced in the first half of 2020 could be compared to an estimate of “what would have been” if the lockdowns did not occur
- An estimate of what would have happened can be called a business-as-usual (BAU) scenario or a *counterfactual*
- The observed and predicted concentrations can be readily compared

# Methods

- Random forest models[1,2] were trained to explain $NO_2$, $O_3$, and total oxidant ($O_x = NO_2 + O_3$) concentrations using surface meteorological variables
- 246 ambient air pollution monitoring sites in 102 urban areas and 34 countries were included in the analysis
- After training and checking of the models' skill, these models were used in predictive-mode to create a counterfactual which the observed concentrations could be compared with
- Change point models based on Bayesian inference[3] were used to identify the timing and magnitude of changes

[1] Grange et al., 2018, *Atmospheric Chemistry and Physics*

[2] Grange & Carslaw, 2019, *Science of the Total Environment*

[3] Lindeløv, 2020, **mcp**

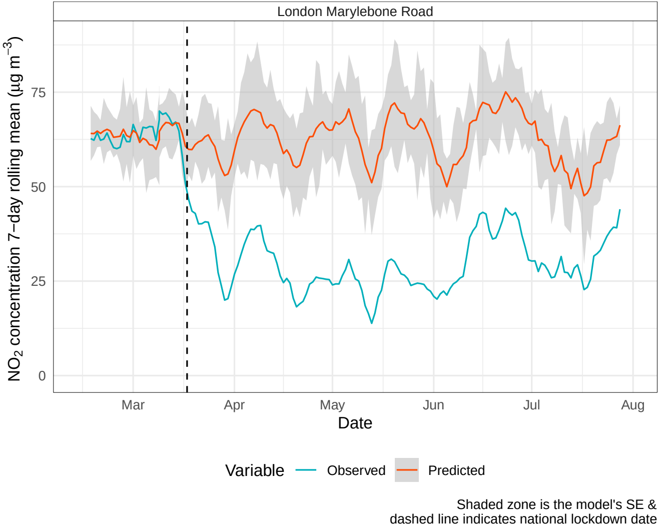


**Figure 3:** Observed and predicted $NO_2$ concentrations for London Marylebone Road between mid-February and July 31, 2020.

# Results

- $NO_2$ decreased by about a third across European urban areas
- The reduction in $NO_2$ was equal to 7.6 years of reduction, based on the mean European trend between 2010 and 2019
- $O_3$ increased between 21–31 % based on site type (background and traffic sites respectively)
- $O_x$ did not change, but there was some reduction at roadside sites which was probably due to decreases in traffic-sourced primary $NO_2$ emissions

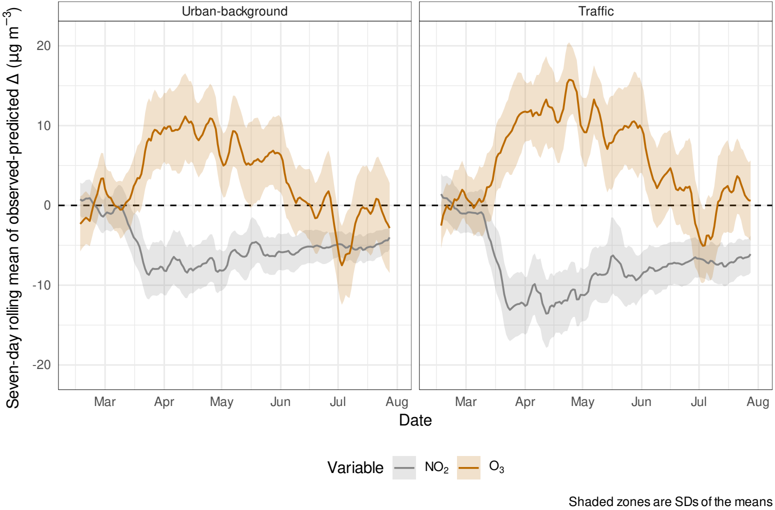


**Figure 4:** Seven-day rolling means of the observed-predicted concentrations deltas for $NO_2$ and $O_3$ for all European sites analysed between February 14 and July 31, 2020

| | | $NO_2$ | | $O_3$ | | $O_x$ | |
|---|---|---|---|---|---|---|---|
| Country | Site type | $\Delta$ ($\mu g\,m^{-3}$) | % change | $\Delta$ ($\mu g\,m^{-3}$) | % change | $\Delta$ (ppb) | % change |
| Austria | Traffic | -7.6 | -24.5 | – | – | – | – |
| Austria | Urban-back. | -5.2 | -23.1 | 11.3 | 19.5 | 4.3 | 11.2 |
| Belgium | Traffic | -10.8 | -45.3 | 5.0 | 10.5 | -2.2 | -6.5 |
| Belgium | Urban-back. | -9.5 | -38.4 | 8.9 | 19.2 | 2.4 | 6.5 |
| France | Traffic | -20.3 | -54.2 | – | – | – | – |
| France | Urban-back. | -11.2 | -44.1 | 13.9 | 35.0 | -4.9 | -12.1 |
| Germany | Traffic | -10.5 | -29.3 | 15.1 | 37.3 | 3.0 | 7.5 |
| Germany | Urban-back. | -4.9 | -21.6 | 8.8 | 16.6 | 3.5 | 9.1 |
| Greece | Traffic | -12.3 | -37.1 | NC | NC | -1.1 | -0.4 |
| Greece | Urban-back. | -9.5 | -43.9 | NC | NC | -3.8 | -8.5 |
| Italy | Traffic | -17.3 | -31.9 | – | – | – | – |
| Italy | Urban-back. | -12.5 | -32.7 | 3.8 | 14.1 | -1.5 | -2.2 |
| Spain | Traffic | -22.8 | -57.2 | 21.0 | 61.9 | -1.5 | -2.8 |
| Spain | Urban-back. | -16.4 | -55.7 | 15.9 | 37.5 | -2.2 | -5.4 |
| Switz. | Traffic | -5.5 | **-17.2** | 10.9 | **22.1** | 5.1 | 13.0 |
| Switz. | Urban-back. | -3.3 | -10.1 | 11.7 | 21.7 | 5.2 | 14.4 |
| UK | Traffic | -14.4 | **-50.8** | 14.4 | **45.8** | -3.8 | -8.3 |
| UK | Urban-back. | -8.1 | -36.8 | 8.0 | 16.4 | 0.0 | 0.1 |

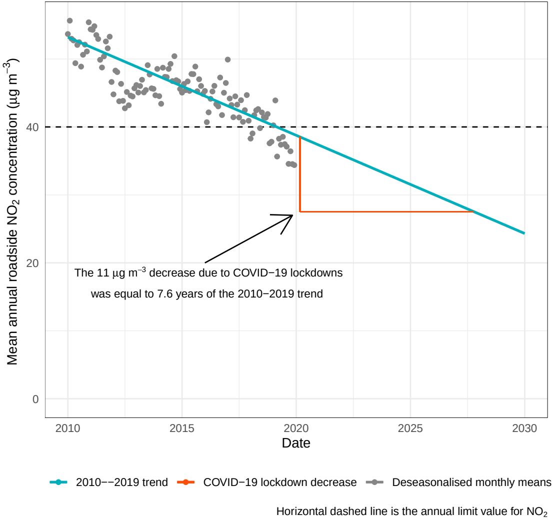


**Figure 5:** Mean European roadside $NO_2$ trend with the reduction of $NO_2$ concentrations attributed to the COVID-19 lockdowns put in context.

# Results continued

- The dates when concentrations diverged from the counterfactual were consistent with the dates of when nationwide lockdowns were applied
- For $NO_2$, the dates were very clear, but for $O_3$, this was a bit weaker, probably due to the different generation, lifetime, and spatial-scale characteristics of this gas

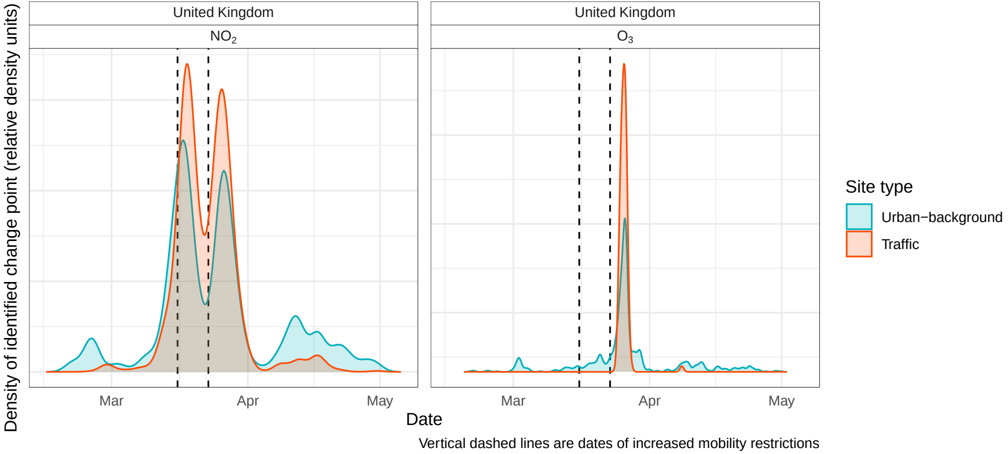


**Figure 6:** Densities of detected change points for $NO_2$ and $O_3$ in the United Kingdom between March and May, 2020. Note the double peak for $NO_2$.

# Implications

- The analysis approach of using machine learning derived models to calculate counterfactuals and Bayesian change point analysis was powerful
- The reductions of $NO_2$ by about a third were almost completely supplanted by increases in $O_3$
- This pattern represents the general trend of what has occurred in the last couple of decades, but the COVID-19 lockdowns exacerbated the trends for a few months in 2020
- The near-complete replacement of $NO_2$ with $O_3$ is somewhat surprising and indicates that urban European atmospheres are VOC limited in respect to $O_3$ generation
- The analysis gives a glimpse of a likely future situation where fewer vehicles powered by internal combustion engines are in use and highlights future issues with urban $O_3$ management

# To-do

- What has occurred in rural locations throughout Europe?
- How did particulate matter (PM) concentrations respond? This is a harder pollutant to investigate due a more diverse suite of sources and processes
- Many European countries have seen second, or third, less severe lockdowns in 2020 and 2021, the pollutant responses for these periods have not been investigated yet

# The publication

I thank my co-authors from Empa, University of York, and Ricardo Energy & Environment for their contributions.

For additional information, please see the paper:

Grange, S. K., Lee, J. D., Drysdale, W. S., Lewis, A. C., Hueglin, C., Emmenegger, L., and Carslaw, D. C. (2021). COVID-19 lockdowns highlight a risk of increasing ozone pollution in European urban areas. *Atmospheric Chemistry and Physics*. 21.5. https://acp.copernicus.org/articles/21/4169/2021.

**Figure 7:** You can find these presentation slides here.