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Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic

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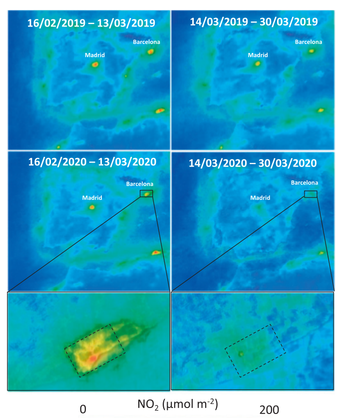
HIGHLIGHTS

- NO_2 and BC concentrations were reduced by half during the lockdown (more windy and wet) period.
- PM10 decreased but in a much lower proportion, causes for the lower abatement are still unknown
- O_3 concentrations increased by around 50%

GRAPHICAL ABSTRACT



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ABSTRACT

Lockdown measures came into force in Spain from March 14th, two weeks after the start of the SARS-CoV-2 epidemic, to reduce the epidemic curve. Our study aims to describe changes in air pollution levels during the lockdown measures in the city of Barcelona (NE Spain), by studying the time evolution of atmospheric pollutants recorded at the urban background and traffic air quality monitoring stations. After two weeks of lockdown, urban air pollution markedly decreased but with substantial differences among pollutants. The most significant reduction was estimated for BC and NO2 (−45 to −51%), pollutants mainly related to traffic emissions. A lower reduction was observed for PM10 (−28 to −31.0%). By contrast, O_3 levels increased (+33 to +57% of the 8 h daily maxima), probably due to lower titration of O_3 by NO and the decrease of NOx in a VOC-limited environment. Relevant differences in the meteorology of these two periods were also evidenced. The low reduction for PM10 is probably related to a significant regional contribution and the prevailing secondary origin of fine aerosols, but an in-depth evaluation has to be carried out to interpret this lower decrease. There is no defined trend for the low SO_2 levels, probably due to the preferential reduction in emissions from the least polluting ships. A reduction of most pollutants to minimal concentrations are expected for the forthcoming weeks because of the more restrictive actions implemented for a total lockdown, which entered into force on March 30th. There are still open questions on why PM10 levels were much less reduced than BC and NO_2 and on what is the proportion of the abatement of pollution directly related to the lockdown, without meteorological interferences.

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1. Introduction

The first confirmed cases of SARS-CoV-2 in Spain were identified in late February 2020 (Saglietto et al., 2020). Since then, Spain became, by the end of March, the third most affected country worldwide after the United States and Italy, and recorded the second-highest number of deaths due to the SARS-CoV-2 pandemic after Italy (Our World in Data, 2020). Since March 14th, lockdown measures were in place in Spain, restricting social contact, reducing public transport, and closing businesses (MPRCMD, 2020a). The restriction measures have been mainly oriented on flattening the epidemic curve, but at the same time confinement of the population, reduction of public transport, and most of the economic activity let to a considerable decrease in road traffic, and consequently, in levels of urban air pollution. We aimed to assess the changes in air quality during the implementation of the lockdown measures in the city of Barcelona (Spain) one month into the SARS-CoV-2 epidemic.

2. Methods

Data have been collected from February 16th to March 30th, 2020 on the particulate matter with a diameter of less than 10 (PM10), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and ozone (O_3) for the city of Barcelona, provided by the Xarxa de Vigilància i Previsió de Atmospheric Pollution (XVPCA), of the Generalitat de Catalunya (XVPCA, 2020). In this study, we select one traffic station (TR, located within the urban center and directly affected by traffic emissions) and one urban background station (UB, far from emission sources and representative of the levels of contamination of the urban background). Additionally, a second urban background station, the research supersite co-located with the XVPCA Palau Reial, was used to collect data on black carbon (BC). Daily averages (24 h) have been calculated for the periods before (February 16th to March 13th) and during the lockdown (March 14th to March 30th), assessing the variation in the mean concentration (μg/m^3) between both periods, and their relative change (%). Days with African dust outbreaks over the study area were identified from the Spanish Ministry for the Ecological Transition (MITECO, 2020). The Meteorological Service of Catalonia (Meteocat) supplied meteorological data recorded at Fabra Observatory.

Remote sensing NO_2 data, measured by the Copernicus Sentinel-5 Precursor Tropospheric Monitoring Instrument (S5p/TROPOMI) developed by the European Space Agency (ESA), has been used to assess tropospheric NO_2 background levels in a high resolution (3.5 × 7 km) continuous area (Veefkind et al., 2012). To this end, a script has been written to retrieve, calculate mean levels, and plot over a map the NO_2 data using Google Earth Engine (Gorelick et al., 2017).

3. Results

Relevant meteorological differences were evidenced for the February 16th to March 13th and March 14th to 30th. Thus with the data of the Fabra Observatory, it is evident that the first period had less marked fluctuations in temperature, wind speed, relative humidity and insolation, and without rainy days (0.2 mm). In contrast, a high variability occurred in the lockdown period. With low, but higher rainfall (3 mm), and colder, more humid and less sunny days (−1.5 °C, +6.6% RH, and −655 W/m^2) (Fig. S1 and Table S1). Furthermore, during the lockdown, maximal daily insolation values were recorded during the lockdown, and windy days reached averages of 8 m/s (max of 5.5 m/s in the prior period). African dust outbreaks of moderate intensity affected Barcelona before (February 28th to March 1st) and during the lockdown (March 18th to 24th).

After two weeks of lockdown, urban air pollution decreased with substantial differences among pollutants (Fig. 1). PM10 averaged concentrations decreased by −28% and −31% in the traffic and urban background stations, respectively (Table 1). In the lockdown period, the World Health Organization Air Quality Guideline (WHOAQG) daily reference value of 20 μg/m^3 was not exceeded at the UB site and slightly exceeded at the TR. For BC, the reduction was larger, −45% in the urban background, and similar to the one of NO_2 (−47 and −51% for UB and TR sites, respectively). The low SO_2 concentrations recorded (around 1.0 to 2.6 μg/m^3 as averages of the different sites) in the study period and the slight changes (−0.2 and +0.1 μg/m^3, for UB and TR sites, close to the detection limit) does not allow evidencing a definite trend. Concentrations of O_3 markedly increased (+29 and +58%, and +33 and +57% of the daily averages and 8 h average daily maxima concentrations for the UB and TR sites, respectively). In this case, and considering that we did not reach the usual high O_3 period (May–

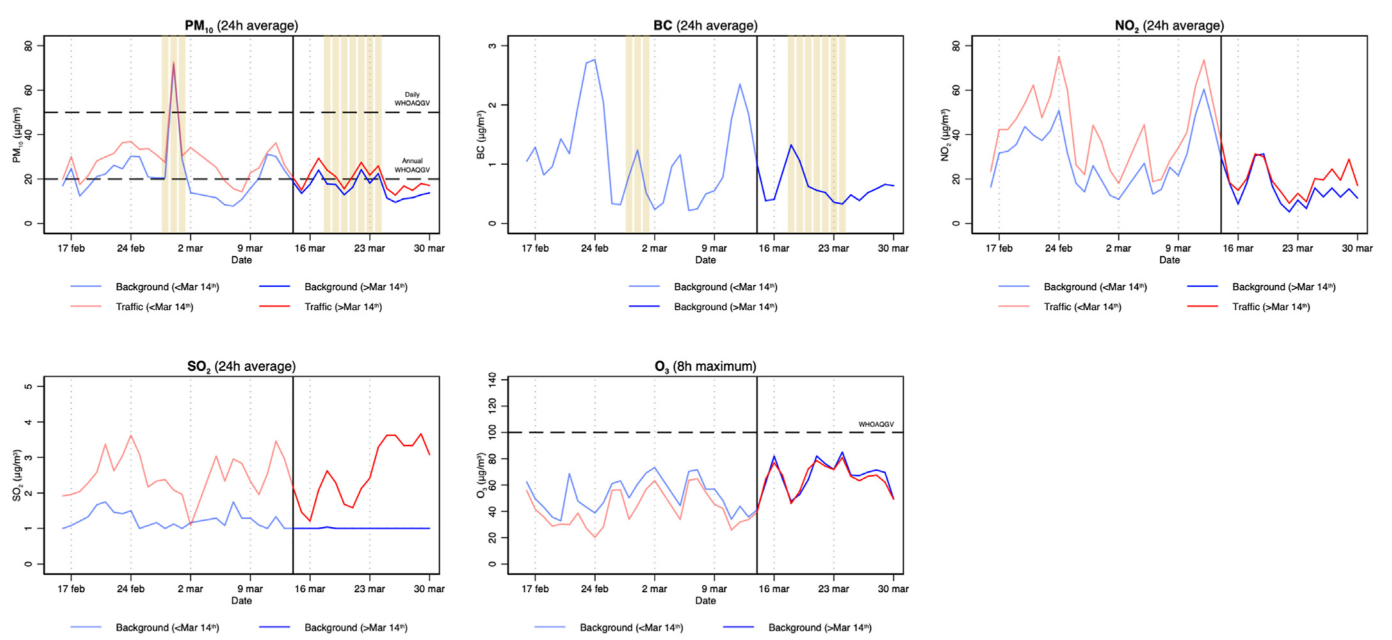

Fig. 1. Daily (24 h) average concentrations of PM10, BC, NO_2, SO_2, and 8 h average daily maxima of O_3 between February 16th and March 30th (with lockdown on March 14th) in Barcelona, Spain (in highlighted shadow those days with Saharan intrusion).

Table 1
Mean concentrations and variation of PM10, BC, NO_2, SO_2 and O_3 between February 16th to March 13th (before the lockdown) and March 14th to March 30th (during the lockdown) in Barcelona, Spain.

Type of station/air pollutant	Before lockdown	During lockdown	Variation	
			μg/m^3	(%)
Urban background				
PM10	22.4	16.2	−6.2	(−27.8)
BC	1.1	0.6	−0.5	(−45.4)
NO_2	30.0	15.9	−14.1	(−47.0)
SO_2	1.2	1.0	−0.2	(−19.4)
O_3	52.4	67.3	14.9	(+28.5)
Traffic				
PM10	29.2	20.2	−9.1	(−31.0)
NO_2	42.4	20.6	−21.8	(−51.4)
SO_2	2.5	2.6	0.1	(+1.8)
O_3	41.8	65.9	24.1	(57.7)

August), relatively high 8 h average daily maxima were recorded during the lockdown period (56–73 μg/m^3), although lower than the WHOAQG (100 μg/m^3), compared with the pre-lockdown (27–57 μg/m^3).

The major changes described above for NO_2, are clearly shown by satellite measurements of background tropospheric NO_2 concentrations supplied by TROPOMI-ESA (in this case not only in and around cities but also in the major highways) when comparing the before and during the lockdown and the later with the same period of 2019 (Fig. 2). Averaged TROPOMI NO_2 loads over the Barcelona Metropolitan Area (2000 km^2 with Barcelona city in the center, Fig. 2) decreased during the lockdown by −57% compared with the reference period. The same comparison has been made for the same periods for 2019, and −22% was reduced in the second period, in this case, by meteorological effects.

4. Discussion

As it could be expected, the lockdown, including restricted social contact, closing of restaurants, shops, and a large number of companies and administrative centers, temporarily reduced levels of specific air pollutants, mostly the primary dominated ones. The role of the meteorology is also evident and not quantified in this study. The most significant variation was observed for NO_2. Urban NO_2 is emitted from combustion processes, mostly road traffic in urban areas, especially

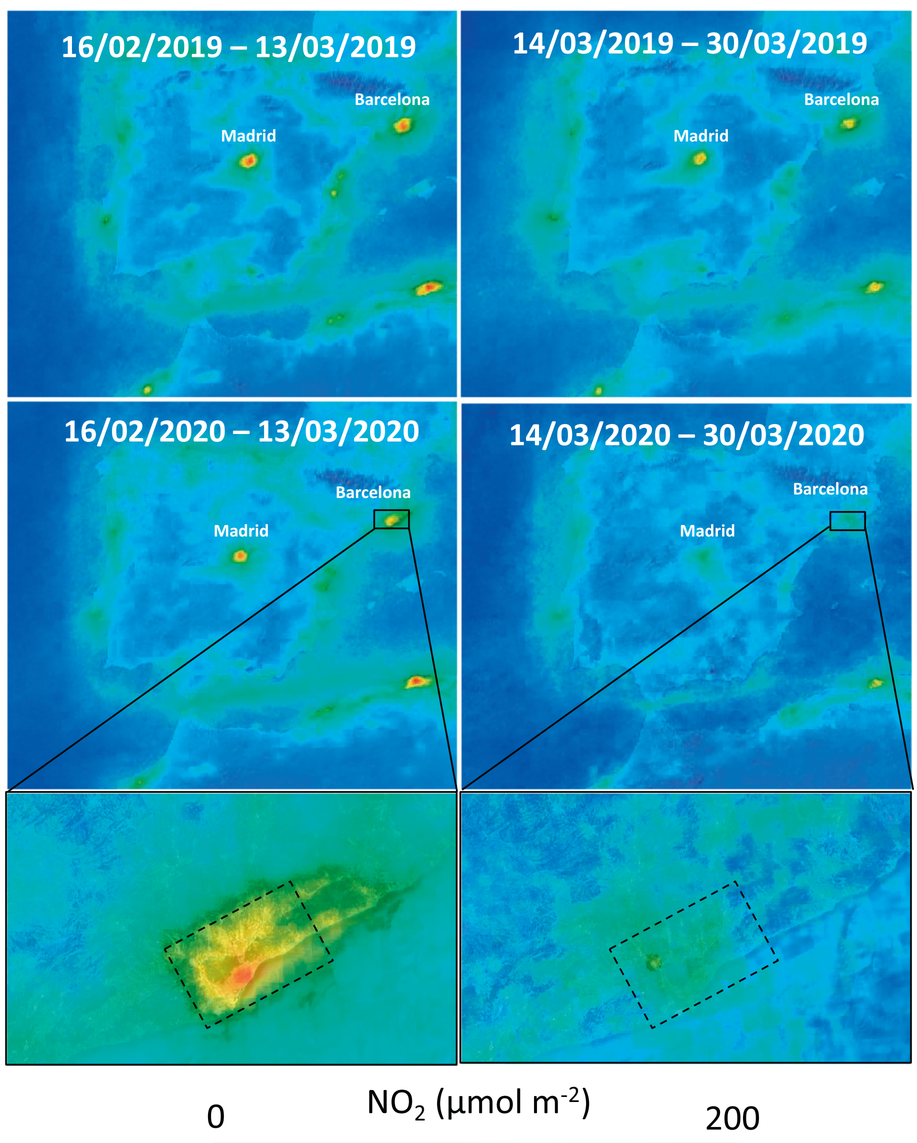

Fig. 2. Average levels of background tropospheric NO_2 measured by TROPOMI-ESA in the Iberian Peninsula. Bottom-left panel: between February 16th to March 13th, 2020 (before the lockdown); bottom-right: March 14th to March 30th, 2020 (during the lookdown). Top panel: equivalent time periods in 2019.

diesel and, to a lesser extent, gasoline, vehicles, industry, power generation, and shipping. Although the main source of PM10 in the urban background of Barcelona is road traffic (around 30% of the annual mean) (Amato et al., 2016), other important sources are industrial sources, harbor emissions, construction works, dust resuspension, and Saharan dust episodes. The latter occurred before and during the lockdown period, from February 28th to March 1st and March 18th to 24th, respectively, and this has influenced the variation of PM10. This might have reduced the decrease of PM10 when compared with that of NO_2, but in addition, other causes could also contributed. Thus, a relevant proportion of PM10 has a regional background-origin, mostly of secondary PM, and regional air mass transport might have influenced PM10 to the point of reducing the effects of local emission abatement.

Barcelona is a low SO_2 city, with most of this pollutant arising from shipping emissions. These are large cargo ships, ferries, and cruises. The low reduction observed might be due to the detection limit of the instruments, but also to the low SO_2 emissions from cruises, the type of ships most reduced in the lockdown period.

Finally, levels of O_3 markedly increased into the city as a consequence of three possible combined causes. Firstly, the decrease of NOx in a VOCs-limited environment (as most urban areas of Europe are) might cause urban O_3 to increase, as opposed to the behavior at the rural-regional background, which is mainly NOx-limited (Monks et al., 2015); secondly, the decrease of nitrogen oxide (NO) reduces the O_3 consumption (titration, $NO + O_3 = NO_2 + O_2$), and causes an increase of O_3 concentrations; and thirdly, the usual increase of insolation and temperatures from February to April leads to an increase in O_3, especially during Saharan dust episodes (from March 18th to 24th), when the maximum O_3 was recorded.

In any case, by staying at home, personal NO_2 exposure is expected to be reduced by 40% in comparison to outdoor exposure, as a study carried out for 39 schools in Barcelona evidenced (Rivas et al., 2014). Thus, in addition to the abatement of outdoor NO_2 levels, this exposure reduction should be taken into account.

Unfortunately, the current lockdown was not able to stop the rising of the SARS-CoV-2 epidemic. For this reason, more restrictive actions were implemented for a total lockdown, which entered into force on March 30th (MPRCMD, 2020b).

Finally, we would like to express that here we characterized the changes produced on air quality during the lockdown. We do not pretend to attribute specifically, neither quantifying the effects of the lockdown since other factors might have influenced the changes, such as meteorology and regional and long transport of pollutant. An in-deep analysis is required to obtain this information accurately.

In conclusion, we expect that air quality will keep improving for PM10, PM2.5, BC, and NO_2 down to minimal levels during forthcoming weeks because of the more restrictive actions to reduce the population's mobility and shut down of a large number of industries. The air pollution effects of the lockdown will be a unique opportunity to evaluate the effects of the reduction of different emission sources and to assess further air quality policies. However, we should clearly state that air quality policy is a long-distance race and that the effects of past emergencies (e.g., the 2008 financial crisis) for further air quality and climate policies have always been adverse.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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