Air quality change during the COVID-19 pandemic lockdown over the Auvergne-Rhône-Alpes region, France

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Abstract

Under the rapid spread of coronavirus diseases (COVID-19) worldwide, a complete lockdown was imposed in France from March 17th to May 11th, 2020 to limit the virus spread. This lockdown affected significantly the atmospheric pollution levels due to the restrictions of human activities. In the present study, we investigate the evolution of air quality in the Auvergne-Rhône-Alpes region, focusing on nine atmospheric pollutants (NO2, NO, PM10, PM2.5, O3, VOC, CO, SO2, and isoprene). In Lyon, center of the region, the results indicated that NO2, NO, and CO levels were reduced by 67%, 78%, and 62%, respectively, resulting in a decrease in road traffic by 80%. However, O3, PM10, and PM2.5 were increased by 105%, 23%, and 53%, respectively, during the lockdown. The increase in ozone is explained by the dropping in NO and other gases linked to human activity, which consume ozone. Thus, the increase of solar radiation, sunshine, temperature, and humidity promoted the O3 formation during the lockdown. Besides, rising temperature enhances the BVOC emissions such as isoprene. In addition, volatile organic component (VOC) and SO2 remain almost stable and oxidation of these species leads to the formation of ozone and organic aerosol, which also explains the increase in PM during the lockdown. This study shows the contribution of atmospheric photochemistry to air pollution.

Keywords COVID-19 • Air quality index • Pollution • Lockdown • Auvergne-Rhône-Alpes • Lyon

Introduction

The new coronavirus discovered in Wuhan in China in late December 2019 has spread easily and sustainably. This infectious virus has caused many effects in almost all countries around the world. Because of the high propagation rate of COVID-19 between people, several countries have taken measures of safety to limit the spread of the virus. Accordingly, several human activities were suspended including industrial activities, tourism, and transport, while all scientific and cultural meetings were postponed across the globe. On 15th June the number of COVID-19 confirmed cases in Italy has reached 236,989; in Spain 243,928; in The UK 295,893; in India 332,424; in the USA 2,057,838; in Brazil 850,514; and in France 152,767 (WHO 2020).

The coronavirus disease has reached France on 24, January 2020 and the first imported cases in Europe were also detected in France (Bernard et al. 2020). The number of confirmed cases was progressively increased which lead to the announcement of limited safety measures on February 28th. While on March 17th, 2020, the French authority has implemented a nationwide lockdown as a response to the rapid spread of COVID-19 (Pullano et al. 2020). These strict safety measures have impacted negatively almost all economic activities in the whole world. In contrast, the environment has taken advantage of lockdown as the activities generating pollutants were reduced or suspended such as industrial activities, local transport and travel in and out the home country, and population mobility (Lal et al. 2020). Accordingly, several studies were carried out to evaluate the impact of imposed lockdown on the environment (Agarwa et al. 2020; Mandal and Pal 2020; Kerimray et al. 2020; He et al. 2020a, b; Bao and Zhang 2020; Zhu et al. 2020; Yao et al. 2020; Chu et al. 2020; Shakoor et al. 2020; Gautam 2020; Pata 2020).
The present study investigates the impact of imposed lockdown on air quality using the main atmospheric pollutants including the nitrogen dioxide (NO₂), ozone (O₃), particulate matter (PM₁₀ and PM₂.₅), volatile organic component (VOC), sulfur dioxide (SO₂), and carbon monoxide (CO), retrieved from 79 air quality monitoring stations of Auvergne-Rhône-Alpes region, France. This will allow identifying the principal sources of pollution and helping regulators to set pollution reduction targets at a level that would minimize the risk to the health of the exposed population. This study was focused more precisely on Lyon city (center of Auvergne-Rhône-Alpes region), as it is considered to be the most urbanized area with a high vehicle density (Anzivino and Venzac 2018) and which was largely affected by air pollution.

Methodology

Study area

Auvergne-Rhône-Alpes region is one of the most populated regions in Europe and the leading French industrial region. It is characterized by high population density and the large expansion of its territory combining large agglomerations of 5 metropolises: Lyon (1,622,331; region prefecture), Grenoble (510,368), Saint-Etienne (372,308), Clermont-Ferrant (264,704), and Chambéry (186,355), and 12 departments namely: Ain, Allier, Ardèche, Cantal, Drôme, Isère, Loire, Haute-Loire, Puy-de-Dôme, Rhône, Savoie, and Haute-Savoie (Fig. S1). It is located in the southeastern quarter of France, bordering on Switzerland and Italy. Auvergne-Rhône-Alpes occupies an area about 69,711 km², and a population of 8,037,059 inhabitants, with a density of 115 inhabitants/km². It is bordered by five other administrative regions: Bourgogne-Franche-Comté to the north, Centre-Val de Loire to the northeast, Nouvelle-Aquitaine to the west, Occitanie to the south-west, and Provence-Alpes-Côte d’Azur to the south-east. It is also bordered by Italy (Aosta Valley and Piedmont) to the east and Switzerland (Cantons of Geneva, Valais, and Vaud) to the north-east.

The average annual temperatures for this region are ranged from 5 to 15 °C, while the highest average annual temperatures are characterizing the south part of the region, which is under the Mediterranean influence. Auvergne Rhône-Alpes region is the sunniest French region (1976 h/year), it is characterized by very variable climate, the summers are pretty hot and quite humid because of some Mediterranean influences. Besides, the winters are very cold due to the presence of the mountains and dry in the south. Because of the different climates around the region, the vegetation is miscellaneous, there are numerous regional and national parks and lush forests but also southerner plants.

Pollution data sources

The data covering the whole area of the Auvergne-Rhône-Alpes region were analyzed, in terms of mass concentration of the different pollutants between 3rd February and 15th June 2020. The daily average mass concentrations of several air pollutants, including nitrogen oxides (NOx, NO, and NO₂), sulfur dioxide (SO₂), particulate matter (PM₁₀ and PM₂.₅), carbon monoxide (CO), ozone (O₃) (8 h diurnal average, from 08:00 AM until 16:00 PM), and volatile organic component (VOC) from 79 monitoring stations spread over the region were extracted and used (Fig. S1). Data used in the present study is available in Atmo-Auvergne-Rhône-Alpes online portal for air quality data dissemination (Atmo 2020a).

Meteorological conditions

The meteorological conditions strongly influence the formation and the evolution of many atmospheric pollutants (Zhang 2019; Chen et al. 2020a, b). Meteorological conditions data used in the present study including maximum and minimum temperatures, relative humidity, wind speeds, solar radiation, sunshine duration, and rainfall, for the period extending from 3rd February to 15th June in the Lyon, were downloaded from the weather station of Lyon-Bron (Info climat 2020).

Meteorological parameters influencing air pollution

The wind is a fundamental element for the dispersion, dilution, and orientation of pollutant plumes. Under high wind speed, the dispersion of the pollutant is greater, while, in the lower wind speed is likely for air pollution accumulation. Strong winds can direct a plume to a specific area, thereby concentrating pollution. Rain cleans the atmosphere from several pollutants because the falling water interacts with the pollutants present during its fall and then transform or deposit them on the ground. For nitrogen oxides, leaching is an efficient phenomenon permitting the decrease of NOx concentrations; however, chemical interaction between NO₂ and water leads to the formation of acid rain. Likewise, the particle matter (PM) can be cleaned from the air by the rain. Concerning ozone, despite his very low soluble in water, leaching contributes also to reduce its concentrations. Both high and low temperatures influenced the air atmospheric pollution emissions, formation, and evolution, for example, the volatility of organic species like VOC increase with temperature, which may increase their ratio in the gas phase and thus their condensation and conversion especially into particles (Kourchov et al. 2016). Sunshine duration, solar radiation, and relative humidity (RH) can strongly affect atmospheric photochemistry such as O₃ and OH radical formation, and also particle process formation including nucleation, condensation, and growth (Li et al. 2018; Lu et al. 2019a, b).
Results and discussion

The normal situation of NO\textsubscript{2}, O\textsubscript{3}, PM\textsubscript{10}, and PM\textsubscript{2.5} mass concentration over Auvergne-Rhône-Alpes region

Figure 1 shows the mapping of the normal situation of NO\textsubscript{2}, O\textsubscript{3}, PM\textsubscript{10}, and PM\textsubscript{2.5} mass concentration distribution over Auvergne-Rhône-Alpes. The highest NO\textsubscript{2}, PM\textsubscript{2.5}, and PM\textsubscript{10} levels are recorded in the middle at Rhône and Loire departments, which are characterized by high population and car densities (Anzivino and Venzac 2018). Nevertheless, only NO\textsubscript{2} levels exceed European limit values (40 μg/m\textsuperscript{3}), especially in Rhône and Loire departments and in the north of the Ain department. The industrial activities located in the south of the Lyon metropolis contribute significantly to the increase in PM level, either by direct emissions or by VOC conversion via photochemical reactions (Kourtchev et al. 2016; Palm et al. 2016; Sbai et al. 2020). Thus, sulfate particles can represent a significant amount of PM in the center of the region due to the SO\textsubscript{2} emission by industrial activities located in several areas in the Rhône department (Fig. S2). The moderate ozone mass concentration observed in Rhône and Loire departments can be especially due to its consumption by NO\textsubscript{2} because this area is characterized by high levels of NO\textsubscript{2} (Fig. 1). The departments affected by the highest O\textsubscript{3} mass concentration are Allier, Cantal, and Puy de Dôme; they are characterized by low population and car density. Moreover, higher solar radiation and sunshine in this area promote the formation of ozone (O\textsubscript{3}), but stay below European Limit values (120 μg/m\textsuperscript{3} daily 8 h mean) (European Commission 2019).

Spatial changes for main air pollutions (NO\textsubscript{2}, O\textsubscript{3}, PM\textsubscript{2.5}, and PM\textsubscript{10}) affecting the air quality during COVID-19 pandemic lockdown

Spatial pattern of nitrogen oxides (NO\textsubscript{2}) mass concentration

The NO\textsubscript{2} mass concentration before, during, and after lockdown is presented in a form of maps in Fig. 2. The

![Fig. 1 Normal spatial distribution for NO\textsubscript{2}, O\textsubscript{3}, PM10, and PM2.5 mass concentrations for March 10th, 2020](image-url)
reduction of road activities during lockdown reached 80% in the Auvergne-Rhône-Alpes region (Fig. S3); hence, atmospheric level of NO\textsubscript{2} may be affected. On March 10th, the NO\textsubscript{2} mass concentrations were high in the center (Rhône and Loire departments) and medium in the west of the region. Since the lockdown was implemented by the French authority on March 17th, 2020 (Pullano et al. 2020), the NO\textsubscript{2} level has decreased by 67.9% (at Saint Etienne) and 53.6% (at Annecy) during the lockdown (Table 1), because almost all the human activities were halted except power generation. It is also noticed that the NO\textsubscript{2} levels tend to increase, which is due to the beginning of easing the imposed lockdown restrictions on 11th and May 27th. Thus, these results indicate the improvement in air quality and prove that human activities are the main source for nitrogen dioxide rather than natural events and that lockdown some time will be mandatory to reduce pollution and improve air quality.

Several studies were carried out around the worldwide cities and have provided the positive impact of enforced lockdown as a response to the COVID-19 outbreak on air quality. In 44 cities located in the northern part of China, the NO\textsubscript{2} values were decreased by 24.7% because of the drop in human mobility by 69.8% and suspension of industrial activities (Bao...
and Zhang 2020). The same case is observed in Almaty (Kazakhstan), where the NO$_2$ levels were reduced by 35% (Kerimray et al. 2020) while in Barcelona (Spain), it was reduced by half during the lockdown period (Tobías et al. 2020). In the whole world, the restriction of human activities has led to an apparent reduction of nitrogen dioxide (Dantas et al. 2020; Bao and Zhang 2020; Ogen 2020).

**Spatial pattern of ozone mass concentration**

Figure 3 represents the spatial evolution of the ozone mass concentration over the Auvergne-Rhône-Alpes region from March 10th to May 27th, 2020. The results indicate an increase of O$_3$ levels from the beginning of the lockdown (March 17th) and this increase has become clearer on May 18th, especially in the center and south of Auvergne-Rhône-Alpes region. The results show that ozone mass concentration increased by 120.7, 109.5, 105.7, 102.6, 94.4, and 75.9% in Saint Etienne, Annecy, Lyon, Grenoble, Chambéry, and Valence, respectively (Table 1). This behavior could be attributed to the drastic drop in NO levels (Fig. S4), which leads to the reduction of the O$_3$ consumption (Sharma et al. 2020). The ozone destruction flux via the main NOX photochemical reactions has been calculated (Table 2); the flux has been reduced from $1.51 \times 10^{23}$ (molecule cm$^{-3}$ s$^{-1}$) before the lockdown to $6.28 \times 10^{22}$ (molecule cm$^{-3}$ s$^{-1}$) during the lockdown, which represent a reduction of 40% of O$_3$ destruction. This partially explains the increase in ozone during the lockdown. Similar results were found in almost all studies done in worldwide cities (Mahato et al. 2020; Siciliano et al. 2020). Besides, the significant ozone levels

| Pollutant | Cities          | Station                     | Average mass concentration ($\mu$g/m$^3$) Before lockdown | Difference (%) | Average mass concentration ($\mu$g/m$^3$) During lockdown |
|-----------|-----------------|-----------------------------|-----------------------------------------------------------|---------------|----------------------------------------------------------|
| NO$_2$    | Lyon            | Lyon center                 | 36.8                                                      | -67.4         | 12.0                                                     |
|           | Grenoble        | Grenoble les Frenes         | 28.0                                                      | -62.1         | 10.6                                                     |
|           | Saint Etienne   | Saint-Martin d’Heres        | 34.0                                                      | -67.9         | 10.9                                                     |
|           | Annecy          | Annecy Loverchy             | 27.4                                                      | -53.6         | 12.7                                                     |
|           | Chambéry        | Chambéry Pasteur            | 28.4                                                      | -60.2         | 11.3                                                     |
|           | Valence         | Valence urbain center       | 26.1                                                      | -64.4         | 9.3                                                      |
| PM$_{2.5}$| Lyon            | Lyon center                 | 12.1                                                      | 52.9          | 18.5                                                     |
|           | Grenoble        | Grenoble les Frenes         | 12.5                                                      | 32.8          | 13.4                                                     |
|           | Saint Etienne   | Saint-Martin d’Heres        | 11.6                                                      | 35.3          | 15.7                                                     |
|           | Annecy          | Annecy Loverchy             | 9.4                                                       | 20.7          | 11.8                                                     |
|           | Chambéry        | Chambéry Pasteur            | 6.7                                                       | 97            | 13.2                                                     |
|           | Valence         | Valence urbain center       | 11.6                                                      | 32.8          | 15.4                                                     |
| PM$_{10}$ | Lyon            | Lyon center                 | 20.0                                                      | 22.5          | 24.5                                                     |
|           | Grenoble        | Grenoble les Frenes         | 17.5                                                      | 14.9          | 20.1                                                     |
|           | Saint Etienne   | Saint-Martin d’Heres        | 20.0                                                      | 4.5           | 20.9                                                     |
|           | Annecy          | Annecy Loverchy             | 18.6                                                      | 11.3          | 20.7                                                     |
|           | Chambéry        | Chambéry Pasteur            | 9.8                                                       | 77.6          | 17.4                                                     |
|           | Valence         | Valence urbain center       | 16.6                                                      | 24.7          | 20.7                                                     |
| O$_3$     | Lyon            | Lyon center                 | 33.5                                                      | 105.7         | 68.9                                                     |
|           | Grenoble        | Grenoble les Frenes         | 30.3                                                      | 102.6         | 61.4                                                     |
|           | Saint Etienne   | Saint-Martin d’Heres        | 27.9                                                      | 120.7         | 61.6                                                     |
|           | Annecy          | Annecy Loverchy             | 31.6                                                      | 109.5         | 66.2                                                     |
|           | Chambéry        | Chambéry Pasteur            | 32.4                                                      | 94.4          | 63.0                                                     |
|           | Valence         | Valence urbain center       | 37.8                                                      | 75.9          | 66.5                                                     |

$^a$ Average mass concentration for 1 month before lockdown period  
$^b$ Average mass concentration during lockdown period before consecutive rainy days
detected in rural areas can be explained by the transport of air masses over long distances from urban areas. In addition, the presence of methane (CH₄), an important ozone precursor with a long chemical lifetime (about 9 years), contributes significantly to O₃ formation in rural areas (Atmo 2020b).

### Table 2

| Reaction                        | Rate constant (molecule⁻¹ cm³ s⁻¹) | Flux (molecule cm⁻³ s⁻¹) |
|---------------------------------|------------------------------------|-------------------------|
|                                 |                                    | Before lockdown (high NOx level) | After lockdown (low NOx level) |
| NO₂ + hv ≥ NO + O(3P)           | 5.0 × 10⁻³                          | 3.28 × 10⁹               | 6.05 × 10⁸                   |
| O(3P) + O₂ ≥ O₃                 | 1.5 × 10⁻¹⁴                         | 4.04 × 10¹²               | 4.04 × 10¹²                   |
| NO + O₃ ≥ NO₂ + O₂              | 2.0 × 10⁻¹⁴                         | 1.51 × 10²³               | 6.28 × 10²²                   |
| NO₂ + O₃ ≥ NO₃ + O₂             | 3.2 × 10⁻¹⁷                         | 8.05 × 10⁻⁶               | 4.03 × 10⁻⁶                   |
| Net flux                        |                                    | 1.51 × 10²³               | 6.28 × 10²²                   |

**Fig. 3** Spatial distribution for O₃ mass concentrations before (March 10th), during (March 17th, 19th, and 26th), and after lockdown (May 18th and 27th)
Spatial pattern of particulate matter PM$_{10}$ and PM$_{2.5}$ mass concentration

Figures 4 and S5 show the spatial distribution of PM$_{2.5}$ and PM$_{10}$ mass concentrations. Conversely to the most pollutants, the PM$_{2.5}$ and PM$_{10}$ have increased during the lockdown and show the same trend while the lower concentrations were registered on March 10th (before lockdown), May 18th and 27th (after lockdown), and the higher levels were recorded during the lockdown on March 17th, 19th, and 26th. The results show also that the PM$_{2.5}$ mass concentration increased by 97, 52.9, 35.3, 32.8, and 20.7% in Chambery, Lyon, Saint Etienne, Grenoble and Valence, and Annecy, respectively. Furthermore, the PM$_{10}$ mass concentration increased by 77.6, 24.7, 22.5, 14.9, 11.3, and 4.5% in Chambery, Valence, Lyon, Grenoble, Annecy, and Saint Etienne, respectively (Table 1).

Residential wood heating which is the main emitter of PM$_{10}$ and PM$_{2.5}$ in cold weather can contribute to 80% of total particle emissions in this region (Atmo 2020c). Thus, domestic housing could contribute to emissions of PM during the lockdown where the people spent more time confined in their homes, which increases the consumption of wood heating and consequently much PM emission. In addition to primary sources (heating, vehicles exhaust, and industrial activities), numerous secondary sources can also contribute to the PM emission, such as the atmospheric photochemistry (Ortega et al. 2016; Huang et al. 2015; Sbai and Farida 2019a). The SOA formation is enhanced during the lockdown period.

Fig. 4 Spatial distribution for PM$_{10}$ mass concentrations before (March 10th), during (March 17th, 19th, and 26th), and after lockdown (May 18th and 27th)

10 MARCH

17 MARCH

19 MARCH

26 MARCH

18 MAY

27 MAY

PM$_{10}$ concentration (µg/m$^3$)

High : 51,9
Low : 1

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because of the increase in $O_3$ that can produce the OH radical in the presence of humidity, according to the two reactions $O_3 + h\nu \rightarrow O_2 + O(1D)$ and $O(1D) + H_2O \rightarrow 2OH$ (Peng et al. 2015).

In the Rhône department, which is characterized by high levels of PM$_{10}$ and PM$_{2.5}$ (Figs. 4 and S5), industrial activities were not significantly affected by lockdown, since VOC levels in three areas of this region (Fayzin ZI, Saint-Fons ZI, and Vernaison ZI) remain almost stable (Fig. 5e). This clearly shows that $O_3$/OH oxidation of VOCs is an important secondary source of PM$_{10}$ and PM$_{2.5}$ in the metropolitan Lyon. In addition, in the Auvergne-Rhône-Alpes region, there are several parks and important forest areas (Fibois 2018), which may represent an important source of biogenic VOCs (BVOC), which can contribute to the PM formation. In our previous study, we found that urban air in Lyon can effectively contribute to the SOA formation via OH oxidation and ozonolysis (Sbai et al. 2020). Moreover, Sea salt especially iodine can contribute also to PM formation via OH and $O_3$ oxidation mainly under high $O_3$ levels (Saiz-Lopez and Plane 2004; Gómez Martín et al. 2013; Sbai and Farida 2019b). These particles could be transported by the wind towards the urban environment during the lockdown.

These results indicate that this region has experienced spatial PM$_{10}$ and PM$_{2.5}$ level increase during the lockdown period, in contrast to the similar studies carried out in other cities around the world where the PM$_{2.5}$ and PM$_{10}$ levels were declined during the enforced lockdown (Chauhan and Singh 2020; Dantas et al. 2020; Zambrano-Monserrate et al. 2020).

**The evolution of air pollutions (PM$_{10}$, PM$_{2.5}$, NO$_2$, O$_3$, CO, and VOC) affecting the air quality in Lyon**

Figure 5 summarizes the evolution of the PM$_{10}$, PM$_{2.5}$, NO$_2$, O$_3$, CO, and VOC in Lyon (center of the Auvergne-Rhône-Alpes region) between February 3rd and June 15th, 2020, to assess the effects of lockdown on air quality. We noticed a strong decrease in NO$_2$ during the first 2 weeks of lockdown.
However, a slight upward trend has emerged since the start of progressive removal of lockdown from May 11th. It should be noted that the NO\textsubscript{2} level dropped since February 23th, due to decreased road densities a week before strict lockdown (Fig. 5a). The O\textsubscript{3} levels have increased steadily since February 23th and remain almost stable during the lockdown (Fig. 5b). However, a significant decrease in ozone was observed after April 18th due to the consecutive rainy days and moderate sunshine (Fig. 6 b and d). The atmospheric oxidation of VOCs can represent an important source of ozone in Lyon since the VOC levels remained almost stable during lockdown (Fig. 5e) (Zhang et al. 2020).

Meteorological conditions such as solar radiation, humidity, temperature, sunshine, rainfall, and wind speed can affect ozone formation through modulating the rate of chemical kinetics reaction, the partitioning of reaction pathways, and efficiency of dry and humid deposition (Lu et al. 2019a, b). Lyon region is very sunny and characterized by a hot continental climate, which is more sensitive to ozone pollution. Solar radiation has increased regularly from 3rd February to 15th June (Fig. 5c), which can lead to an increase of atmospheric photochemistry and ozone formation. Figure 5a shows a continuous increase in temperature, which can lead to an increase in natural emissions of BVOC, in particular isoprene (Fig. S6). The atmospheric oxidation of BVOC contributes to the formation of ozone (Allison 2020). On other hand, despite the reduction in the carbon monoxide mass concentration (Fig. 5f), the O\textsubscript{3} formation may be influenced by CO reactivities, because under low NOx level, ozone depletion can occur; however, under high NOx level, CO can contribute to ozone formation according to the reaction mechanism depicted in Table 3.

Figures 5 c and d show the evolution of PM\textsubscript{10} and PM\textsubscript{2.5}, respectively, in Lyon between 3rd February and 15th June. PM\textsubscript{10} and PM\textsubscript{2.5} present the same trend and show a continuous increase during the lockdown. However, this trend was perturbed by successive rainy days from 25th April (Fig. 6d), which removed all the suspended particles (Info climat 2020). The decrease of ozone, solar radiation, and the sunshine between 25th April and 11th May (Fig. 6 a, b, and c) can limit the formation of secondary particles resulting in the decrease of PM levels. Chen et al. (2020a, 2020b) show also an increase in PM during lockdown; they have found two pollution episodes with PM\textsubscript{2.5} exceeding 100 \(\mu\text{g/m}^3\) in Shanghai, China.

**Air quality index change during lockdown in Lyon**

Air quality index (AQI) has been used in several cities around the world to quantify the presence of certain pollutants in ambient air. Their main purpose is to inform the public about air pollution and the associated potential health risk (Atmo 2020d). The AQI calculation is defined at the national level on the basis of regulatory thresholds (Table 4). Three
pollutants were considered for AQI estimation, including NO2, O3, and PM10. These species are considered as the main indicators of air pollution. For each of these pollutants, a sub-index is determined using daily mass concentration between February 3rd and June 15th, the final index corresponding to the highest sub-index. The air quality sub-index associated with O3, NO2, and PM10 at Lyon downtown shows that PM10 represents the main pollutant and the AQI is often attached to the PM10 mass concentration (Fig. S7). In addition, the AQI of the region generally varies between good and moderate, which indicates that there is no possibility of affecting public health. Despite the decrease of NO2 level, the AQI level is not reduced during the lockdown due to a notable increase in PM. However, other studies have shown a drop in AQI; this decrease has been explained as a consequence of halting the human activities (Mahato and Ghosh 2020; Bao and Zhang 2020; He et al. 2020a, 2020b) (Table 3).

### Air pollution in 2020 vs 2019

We have performed a comparison with data for main air pollution (NO2, O3, PM10, and PM2.5) of previous year 2019 and this year 2020 over the same period (17th March to 11th May) corresponding to the lockdown period for six cities in the region (Lyon, Saint Etienne, Grenoble, Annecy, Gaillard, and Valence) (Fig. S8). The results show that for all the cities, the NO2 decreased whereas O3 and the particles (PM10 and PM2.5) increased. The difference between the level of pollutants in 2019 and 2020 changes depending on each city; this can be explained by the meteorological conditions and the industrial activities of each zone and also the lockdown measures (strict or loose).

### Conclusion

In order to assess the air quality status of Auvergne-Rhône-Alpes during the lockdown period, we explored data related to atmospheric pollutants extracted from 79 air quality monitoring stations covering the whole region. The daily and hourly concentrations of air pollutants including PM2.5, PM10, NOx (NO2 and NO), CO, O3, SO2, VOC, and isoprene have been obtained from the online portal for air quality data dissemination.

The results revealed a substantial change in all studied atmospheric pollutants except the VOC and SO2 during the lockdown, as NO2, NO, and CO have decreased, owing to restriction of road traffic. However, O3, PM2.5, and PM10 have increased during the lockdown. The increase in ozone is attributed to the decrease in its titration by NO because the flux of ozone depletion via a photochemical reaction involving NO decreased by 40%. On the other hand, the reduction in ozone consumption by other gases is of anthropic origin. Moreover, weather conditions (temperature, solar radiation, RH, sunshine) have favored the formation of ozone during the lockdown. Thus, the oxidation of VOC and BVOC also can contribute significantly to O3 and PM formation, because they have not been reduced during the lockdown. The AQI which represents good and moderate categories remains almost stable despite the decrease of NOx because PM and O3 increase. It is noted that AQI shows that PM10 is the main pollutant in this region.

### Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s11869-020-00965-w.

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### Data availability

All the data used in this study are freely available on the Internet. Air quality data can be obtained through Atmo Auvergne Rhône Alpes website.

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