What can we learn about urban air quality with regard to the first outbreak of the COVID-19 pandemic? A case study from Central Europe

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Table S1. Macrocirculation patterns and their seasonal and annual occurrences in the Carpathian Basin for years 1958–2010 (Maheras et al., 2018).

No.	Code	Description	Occurrence frequency (%)				
			Winter	Spring	Summer	Autumn	Annual
1	mCc	Cyclone with a cold front over NE Europe, N wind	7.3	11.3	12.1	8.0	9.7
2	AB	Anticyclone over the British Isles, N wind	5.6	7.1	8.6	6.4	6.9
3	CMc	Mediterranean cyclone with a cold front over S Europe, N wind	2.5	3.5	1.8	1.9	2.4
4	mCw	Mediterranean cyclone with a warm front over NE Europe, S wind	9.2	9.7	5.7	7.2	7.9
5	Ae	Anticyclone over E Europe, S wind	14.2	11.3	7.3	17.6	12.6
6	CMw	Mediterranean cyclone with a warm front over S Europe, S wind	8.9	8.7	3.7	8.3	7.4
7	zC	Highly developed cyclone over N Europe, W wind	5.0	3.2	2.7	2.9	3.5
8	Aw	Anticyclone over W Europe, W wind	13.1	11.2	20.8	12.8	14.6
9	As	Anticyclone over S Europe, W wind	7.0	4.4	2.9	5.6	4.9
10	An	Anticyclone over N Europe, E wind	10.9	12.8	11.3	10.1	11.3
11	AF	Anticyclone over Fennoscandia, E wind	2.8	5.2	5.9	3.7	4.4
12	A	Anticyclone over the Carpathian Basin, changing wind direction	11.8	7.3	13.3	13.3	11.4
13	C	Cyclone over the Carpathian Basin, changing wind direction	1.7	4.3	3.9	2.2	3.0

Pandemic phase	Date (dd-MM)	Day of week	Heating info	MCP code	Precipitation
Pre-emergency (71 d)	01-01	Wed	Heating season (106 days)	8	0
	02-01	Thu		9	0
	03-01	Fri		12	0
	04-01	Sat		1	1
	05-01	Sun		8	0
	06-01	Mon		12	0
	07-01	Tue		12	0
	08-01	Wed		12	0
	09-01	Thu		12	0
	10-01	Fri		9	0
	11-01	Sat		8	0
	12-01	Sun		12	0
	13-01	Mon		12	0
	14-01	Tue		12	0
	15-01	Wed		5	0
	16-01	Thu		5	0
	17-01	Fri		12	0
	18-01	Sat		5	0
	19-01	Sun		2	0
	20-01	Mon		2	0
	21-01	Tue		2	0
	22-01	Wed		2	0
	23-01	Thu		2	0
	24-01	Fri		9	0
	25-01	Sat		9	0
	26-01	Sun		12	0
	27-01	Mon		9	0
	28-01	Tue		1	8
	29-01	Wed		1	1
	30-01	Thu		13	0
	31-01	Fri		4	1
	01-02	Sat		7	1
	02-02	Sun		7	2
	03-02	Mon		7	1
	04-02	Tue		13	6
	05-02	Wed		6	0
	06-02	Thu		2	0
	07-02	Fri		10	0
	08-02	Sat		12	0
	09-02	Sun		9	0
	10-02	Mon		1	5
	11-02	Tue		13	0
	12-02	Wed		8	0
	13-02	Thu		9	2
	14-02	Fri		1	0
	15-02	Sat		12	0
	16-02	Sun		5	0
	17-02	Mon		5	0
	18-02	Tue		7	0
	19-02	Wed		4	1
	20-02	Thu		4	0
	21-02	Fri		5	0
	22-02	Sat		8	0
	23-02	Sun		7	0
	24-02	Mon		1	0
	25-02	Tue		4	2
	26-02	Wed		1	6
	27-02	Thu		1	1
	28-02	Fri		13	2
	29-02	Sat		9	0
	01-03	Sun		1	17
	02-03	Mon		13	2
	03-03	Tue		13	4
	04-03	Wed		13	0
	05-03	Thu		12	2
	06-03	Fri		13	11
	07-03	Sat		13	0
	08-03	Sun		8	0
	09-03	Mon		6	0
	10-03	Tue		6	1
	11-03	Wed		7	0
Pre-restriction (16 d)	12-03	Thu	Heating season (cont'd)	7	0
	13-03	Fri		7	0
	14-03	Sat		8	0
	15-03	Sun		12	0
	16-03	Mon		5	0
	17-03	Tue		5	0
	18-03	Wed		12	0
	19-03	Thu		12	0
	20-03	Fri		12	0
	21-03	Sat		5	1
	22-03	Sun		2	0
	23-03	Mon		10	1
	24-03	Tue		10	0
	25-03	Wed		10	0
	26-03	Thu		10	0
	27-03	Fri		10	0
Restriction (51 d)	28-03	Sat		5	0
	29-03	Sun		2	0
	30-03	Mon		2	0
	31-03	Tue		2	0
	01-04	Wed		2	0
	02-04	Thu		12	0
	03-04	Fri		12	0
	04-04	Sat		10	0
	05-04	Sun		10	0
	06-04	Mon		5	0
	07-04	Tue		5	0
	08-04	Wed		12	0
	09-04	Thu		12	0
	10-04	Fri		2	0
	11-04	Sat		10	0
	12-04	Sun		5	0
	13-04	Mon		5	0
	14-04	Tue		1	0
	15-04	Wed		2	0
	16-04	Thu	Non-heating season (107 days)	9	0
	17-04	Fri		9	0
	18-04	Sat		11	0
	19-04	Sun		13	0
	20-04	Mon		11	0
	21-04	Tue		11	0
	22-04	Wed		11	0
	23-04	Thu		11	0
	24-04	Fri		12	0
	25-04	Sat		1	0
	26-04	Sun		1	0
	27-04	Mon		1	0
	28-04	Tue		1	0
	29-04	Wed		1	3
	30-04	Thu		4	4
	01-05	Fri		1	1
	02-05	Sat		1	0
	03-05	Sun		1	0
	04-05	Mon		4	0
	05-05	Tue		13	0
	06-05	Wed		1	0
	07-05	Thu		2	0
	08-05	Fri		12	0
	09-05	Sat		9	0
	10-05	Sun		1	0
	11-05	Mon		6	0
	12-05	Tue		1	1
	13-05	Wed		1	0
	14-05	Thu		13	0
	15-05	Fri		13	0
	16-05	Sat		2	2
	17-05	Sun		2	3
Post-restriction (31 d)	18-05	Mon	Non-heating season (cont'd)	8	0
	19-05	Tue		6	0
	20-05	Wed		1	1
	21-05	Thu		11	0
	22-05	Fri		11	0
	23-05	Sat		4	1
	24-05	Sun		4	0
	25-05	Mon		2	1
	26-05	Tue		2	0
	27-05	Wed		2	3
	28-05	Thu		2	1
	29-05	Fri		11	1
	30-05	Sat		11	1
	31-05	Sun		11	2
	01-06	Mon		11	0
	02-06	Tue		11	0
	03-06	Wed		4	0
	04-06	Thu		1	0
	05-06	Fri		1	5
	06-06	Sat		1	0
	07-06	Sun		1	11
	08-06	Mon		1	0
	09-06	Tue		1	7
	10-06	Wed		13	4
	11-06	Thu		13	0
	12-06	Fri		13	0
	13-06	Sat		4	2
	14-06	Sun		4	24
	15-06	Mon		1	26
	16-06	Tue		4	4
	17-06	Wed		4	13
Post-emergency (44 d)	18-06	Thu		4	5
	19-06	Fri		1	0
	20-06	Sat		8	0
	21-06	Sun		8	1
	22-06	Mon		8	0
	23-06	Tue		8	0
	24-06	Wed		11	0
	25-06	Thu		11	0
	26-06	Fri		10	1
	27-06	Sat		5	0
	28-06	Sun		12	0
	29-06	Mon		1	6
	30-06	Tue		8	0
	01-07	Wed		9	0
	02-07	Thu		1	2
	03-07	Fri		1	0
	04-07	Sat		8	0
	05-07	Sun		8	0
	06-07	Mon		8	7
	07-07	Tue		8	0
	08-07	Wed		8	0
	09-07	Thu		12	0
	10-07	Fri		12	0
	11-07	Sat		1	7
	12-07	Sun		8	0
	13-07	Mon		8	0
	14-07	Tue		12	0
	15-07	Wed		12	0
	16-07	Thu		1	0
	17-07	Fri		1	2
	18-07	Sat		1	1
	19-07	Sun		10	7
	20-07	Mon		1	0
	21-07	Tue		1	1
	22-07	Wed		1	0
	23-07	Thu		1	1
	24-07	Fri		10	17
	25-07	Sat		13	0
	26-07	Sun		1	2
	27-07	Mon		1	0
	28-07	Tue		1	0
	29-07	Wed		1	0
	30-07	Thu		8	0
	31-07	Fri		12	0

Total number of days: 213

Figure S1. Survey on time intervals of interest with basic facts, daily macrocirculation pattern (MCP) codes and daily precipitation sum (mm) in Budapest from 1 January to 31 July 2020. The holidays are indicated in darker green, heating season in darker grey, non-heating season in lighter grey, Pre-emergency phase of the first COVID-19 outbreak in lighter blue, Pre-restriction phase in lighter yellow, Restriction phase in orange, Post-restriction phase in darker yellow and Post-emergency phase in darker blue colours. The cyclonic and anticyclonic MCP types are marked in lighter green and pink colours, respectively.

Motor road vehicles traffic was measured by the Budapest Public Roads Ltd., which is responsible for operation, control and maintenance of all roads, streets, bridges, tunnels, other structures and traffic engineering facilities in Budapest. The actual locations were 1) Szabadság Bridge, 2) Váci Road near its junction with Árpád Road, 3) Alkotás Road near its junction with Nagyenyed Street, 4) Margit Boulevard and Vérmező Street which both lead to Széna Square (and therefore the site is called here as Széna Square), where the monitoring station for the criteria air pollutants is located.

The Szabadság Bridge hosts quite complex events. The bridge was reserved for the pedestrians and was closed for motor vehicles on some summer weekends, namely on 17–18 June, 24–25 June, 5–6 August and 12–13 August in 2017, on 14–15 July, 21–22 July, 28–29 July and 4–5 August in 2018, on 6–7 July, 13–14 July, 20–21 July and 27–28 July on 2019. It was also partially or completely closed for vehicles in some other intervals due to urban running races or for its planned extended cleaning. The vehicle census data for these days and time intervals were included in deriving the time series of vehicular traffic but were excluded when calculating the average diurnal patterns and descriptive statistics to avoid their distortion due to these very specific or unusual circumstances.

For location no. 3 (Alkotás Road), the data coverage for year 2019 was poor (21%) and, therefore, this year was excluded from the averaging for the reference year. Similarly, there were larger scale traffic control arrangements and missing data in larger abundance for the site no. 4 (Széna Square), and, therefore, year 2019 was only maintained here.

Table S2. Ranges and medians of hourly mean *T* (°C), RH (%), absolute humidity (AH, in g m^{-3}), WS (m s^{-1}), GRad (W m^{-2}, for individual data ≥50 W m^{-2}), daily maximum planetary boundary layer height ($PBLH_{max}$, in km) in the average reference year of 2017–2019 (Y3Ref) and year 2020 (Y2020) together with their relative difference (RDiff) in % and their anomaly standardised to SD (SAly) for the overall state of emergency time interval (from 12 March to 17 June).

Interval/ Variable	Y3Ref			Y2020			RDiff	SAly
	Min	Median	Max	Min	Median	Max		
T	3.2	16	30	–0.4	15	31	–0.7[†]	–0.1
RH	19	56	92	12	50	100	–11	–0.4
AH	2.8	7.6	17	1.2	5.9	17	–22	–0.5
WS	0.3	1.7	7.0	0.2	1.6	6.5	–6	–0.1
GRad	51	407	913	50	397	977	–2	–10[‡]
$PBLH_{max}$	0.84	1.5	2.2	0.57	1.7	3.3	+10	+0.3

[†] Y2020–Y3Ref difference in median *T*s; in a unit of °C.
[‡] Anomaly not standardised to SD; in a unit of W m^{-2}.

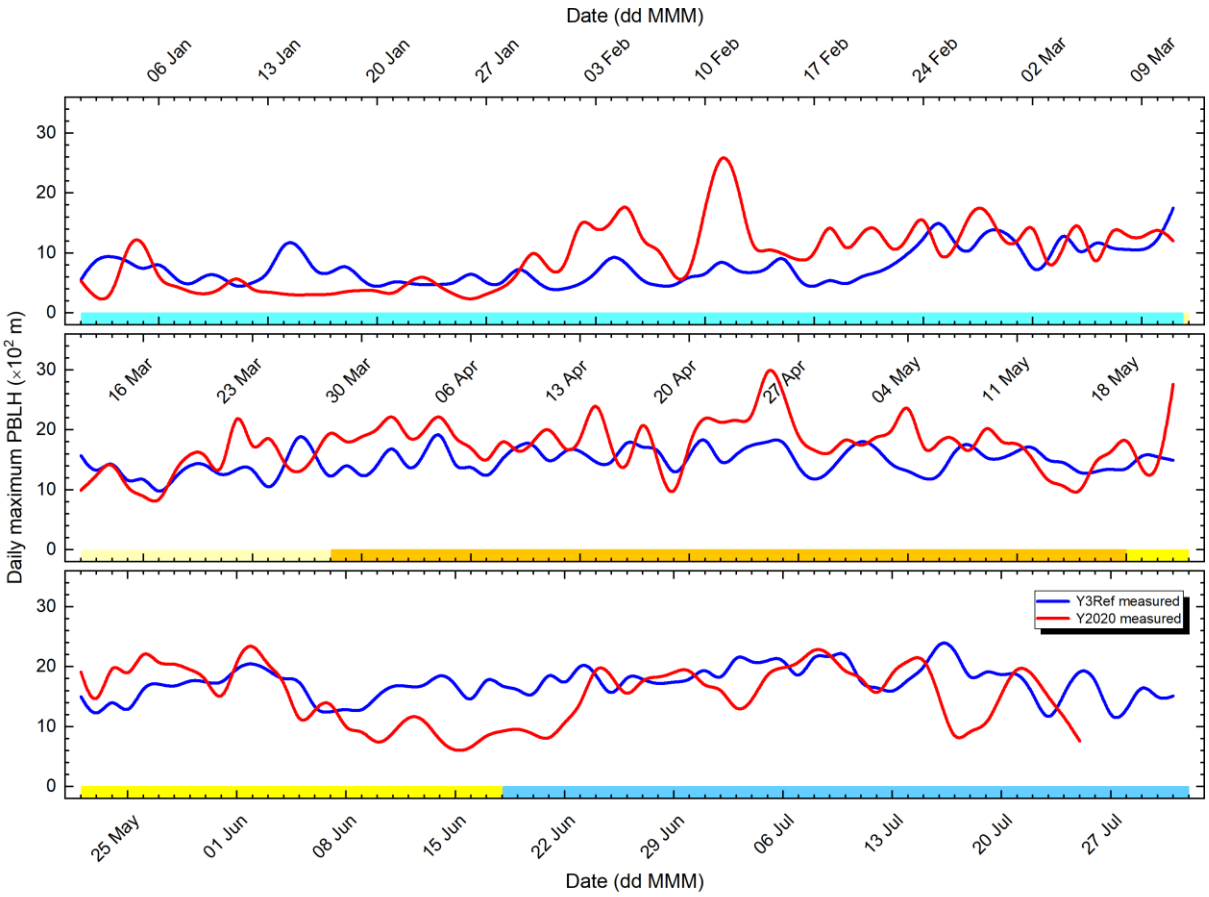

Figure S2. Time variation of the daily maximum of planetary boundary layer height ($PBLH_{max}$) in the average reference year of 2017–2019 (Y3Ref) and year 2020 over the five consecutive phases of the first COVID-19 outbreak. The phases are marked by the following colour codes: Pre-emergency phase lighter blue, Pre-restriction phase lighter yellow, Restriction phase orange, Post-restriction phase darker yellow and Post-emergency phase darker blue.

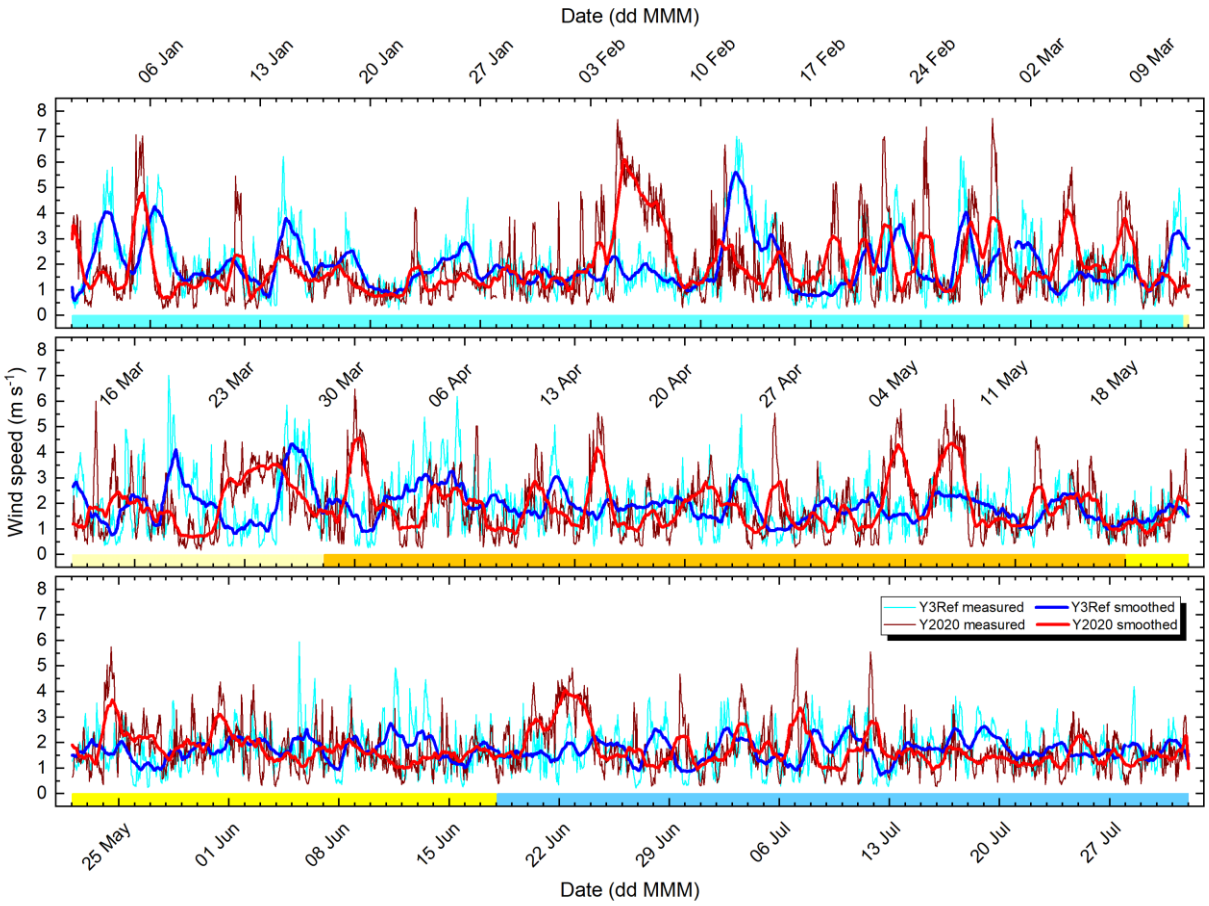

Figure S3. Time variation of wind speed in the average reference year of 2017–2019 (Y3Ref) and year 2020 together with their 24-h smoothed cures over the five consecutive phases of the first COVID-19 outbreak. The phases are marked by the following colour codes: Pre-emergency phase lighter blue, Pre-restriction phase lighter yellow, Restriction phase orange, Post-restriction phase darker yellow and Post-emergency phase darker blue. The tick labels of the abscissa indicate the Mondays in 2020.

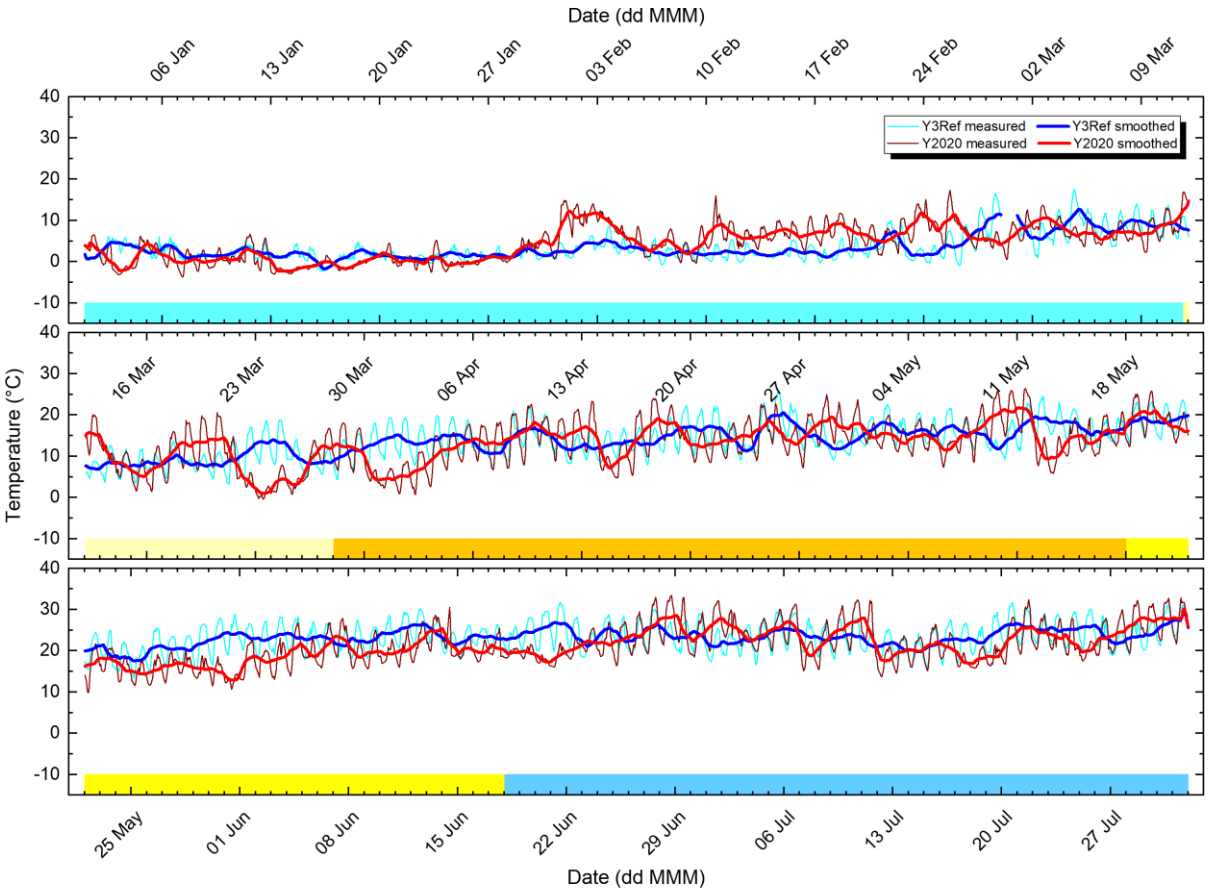

Figure S4. Time variation of air temperature in the average reference year of 2017–2019 (Y3Ref) and year 2020 together with their 24-h smoothed cures over the five consecutive phases of the first COVID-19 outbreak. The phases are marked by the following colour codes: Pre-emergency phase lighter blue, Pre-restriction phase lighter yellow, Restriction phase orange, Post-restriction phase darker yellow and Post-emergency phase darker blue. The tick labels of the abscissa indicate the Mondays in 2020.

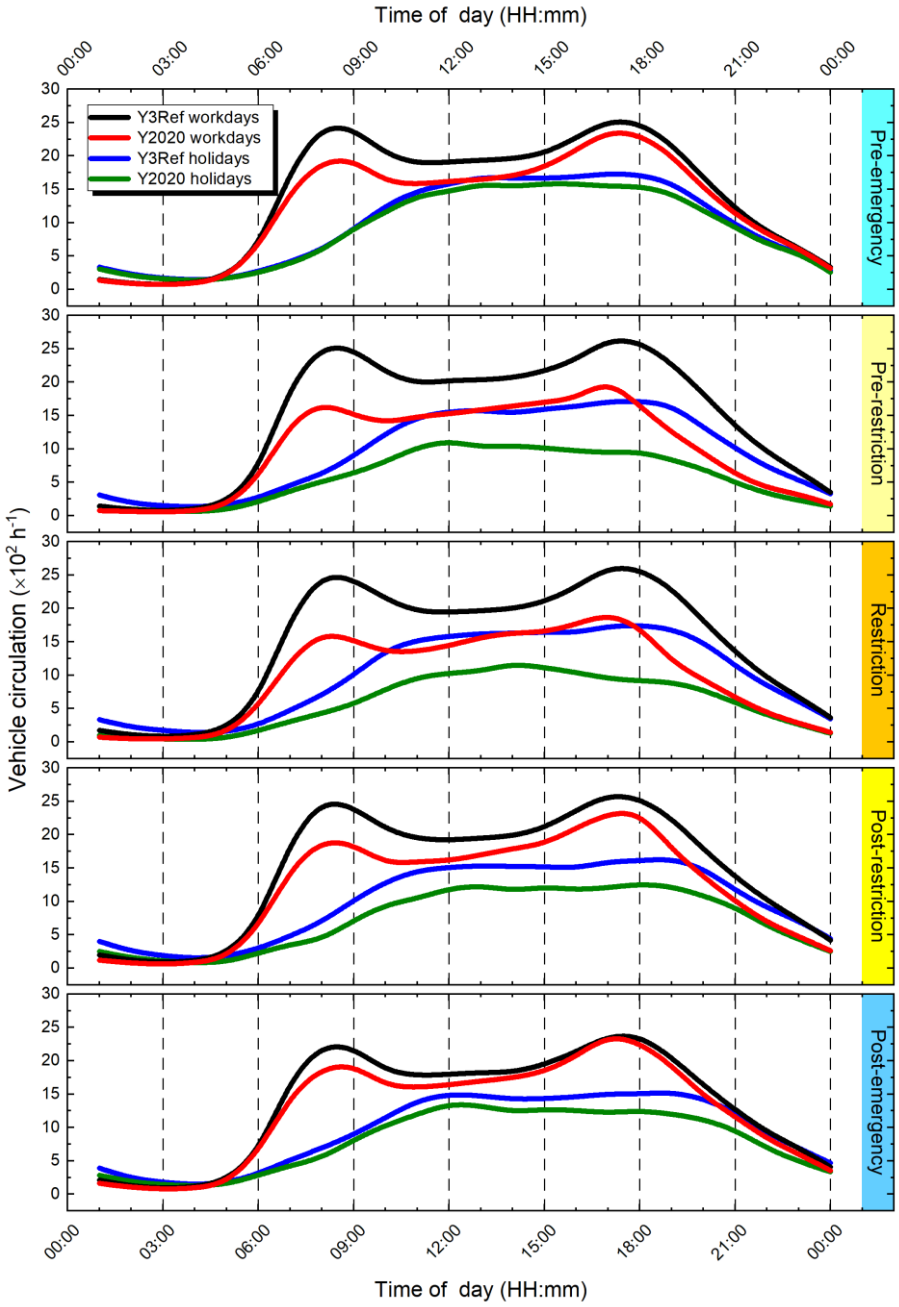

Figure S5. Average diurnal variations of motor vehicle road traffic in both directions on a major route (Váci Road) in Budapest separately for workdays and holidays in the average reference year of 2017–2019 (Y3Ref) and year 2020 over the five consecutive phases of the first COVID-19 outbreak. The phases are marked by the following colour codes: Pre-emergency phase lighter blue, Pre-restriction phase lighter yellow, Restriction phase orange, Post-restriction phase darker yellow and Post-emergency phase darker blue.

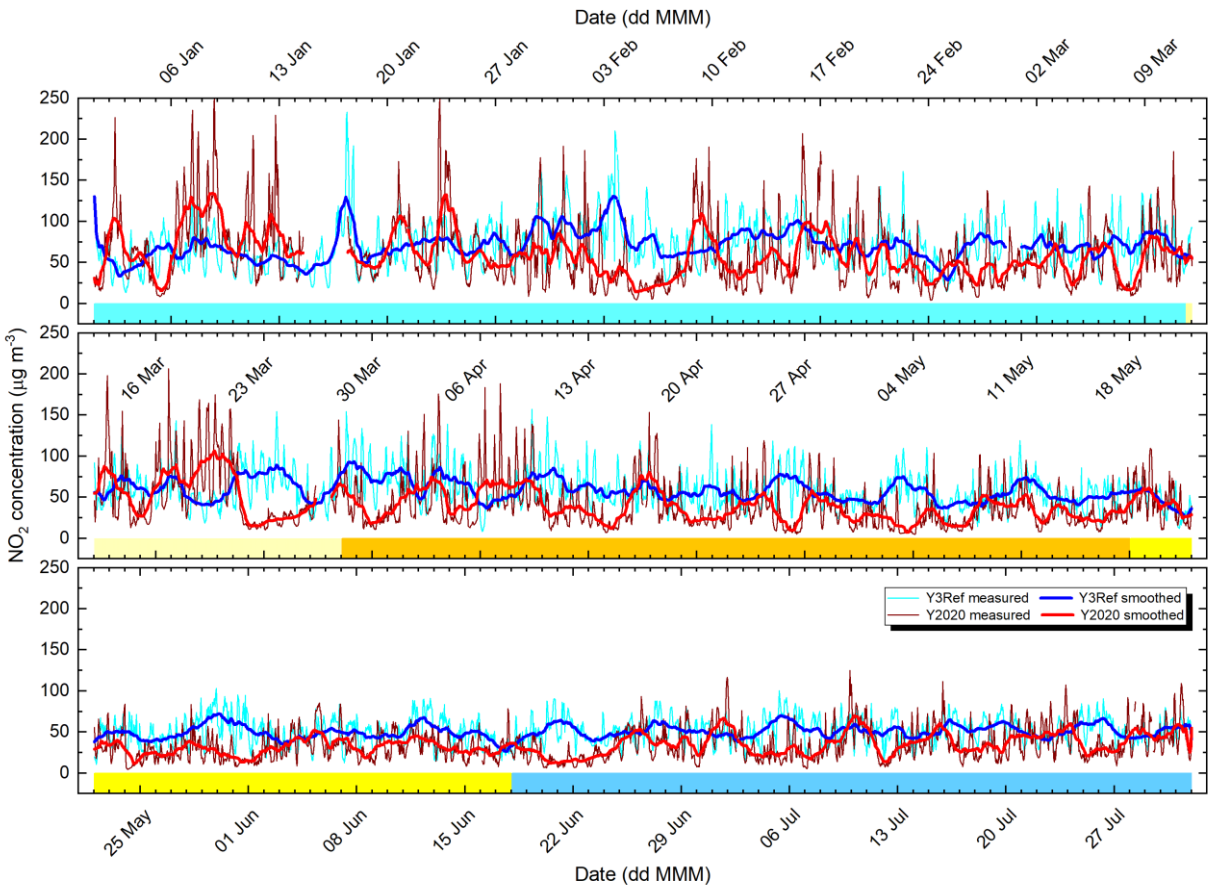

Figure S6. Time variation of NO_2 concentration in the average reference year of 2017–2019 (Y3Ref) and year 2020 together with their 24-h smoothed cures over the five consecutive phases of the first COVID-19 outbreak. The phases are marked by the following colour codes: Pre-emergency phase lighter blue, Pre-restriction phase lighter yellow, Restriction phase orange, Post-restriction phase darker yellow and Post-emergency phase darker blue. The tick labels of the abscissa indicate the Mondays in 2020.

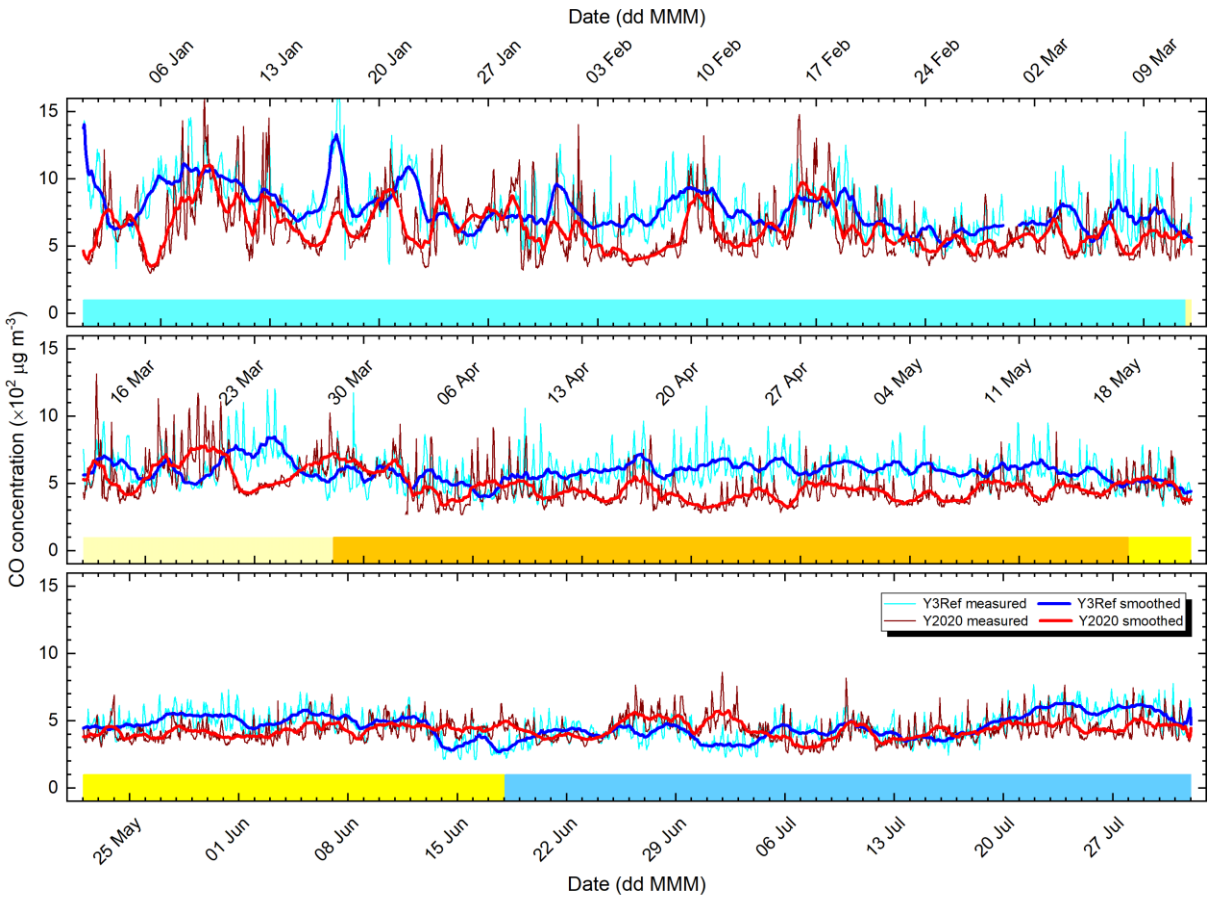

Figure S7. Time variation of CO concentration in the average reference year of 2017–2019 (Y3Ref) and year 2020 together with their 24-h smoothed curves over the five consecutive phases of the first COVID-19 outbreak. The phases are marked by the following colour codes: Pre-emergency phase lighter blue, Pre-restriction phase lighter yellow, Restriction phase orange, Post-restriction phase darker yellow and Post-emergency phase darker blue. The tick labels of the abscissa indicate the Mondays in 2020.

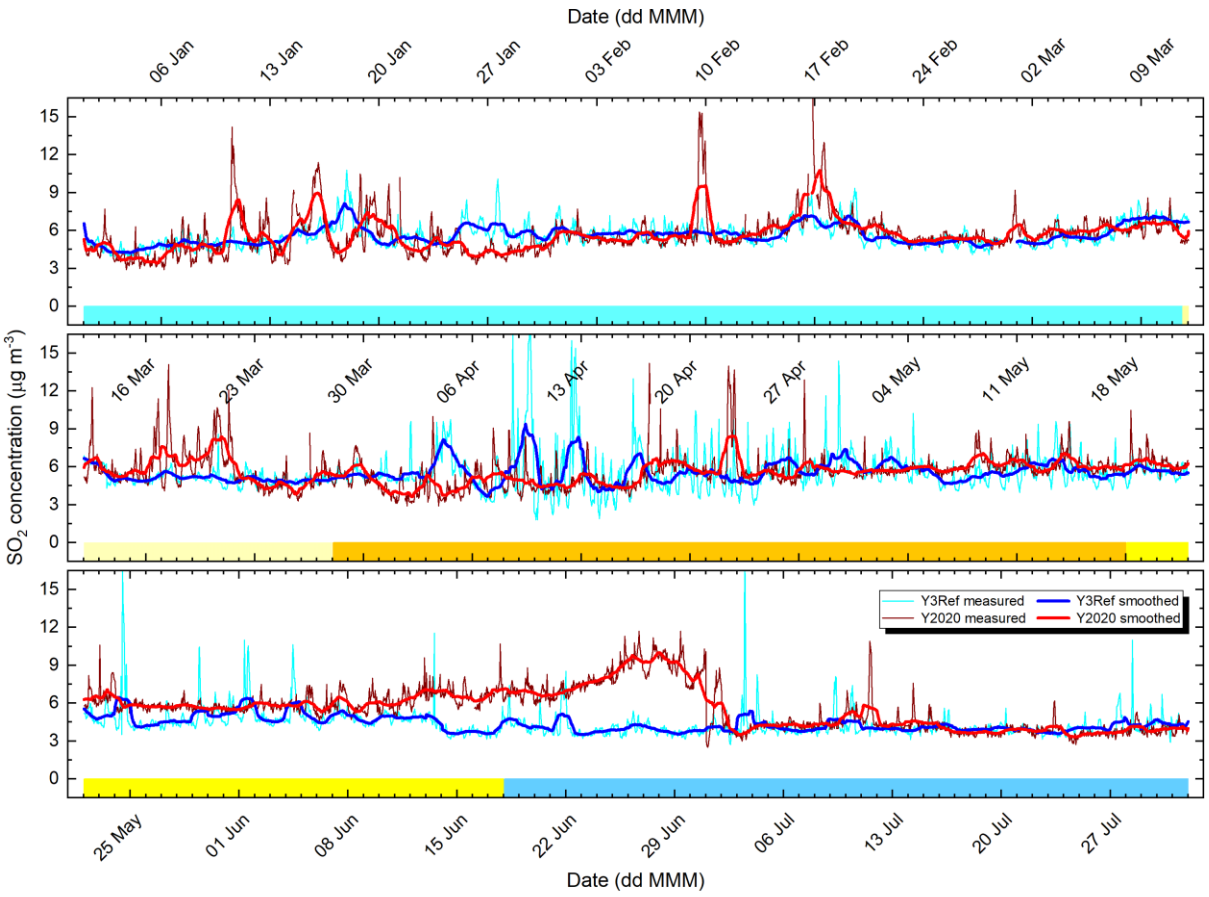

Figure S8. Time variation of SO_2 concentration in the average reference year of 2017–2019 (Y3Ref) and year 2020 together with their 24-h smoothed curves over the five consecutive phases of the first COVID-19 outbreak. The phases are marked by the following colour codes: Pre-emergency phase lighter blue, Pre-restriction phase lighter yellow, Restriction phase orange, Post-restriction phase darker yellow and Post-emergency phase darker blue. The tick labels of the abscissa indicate the Mondays in 2020.

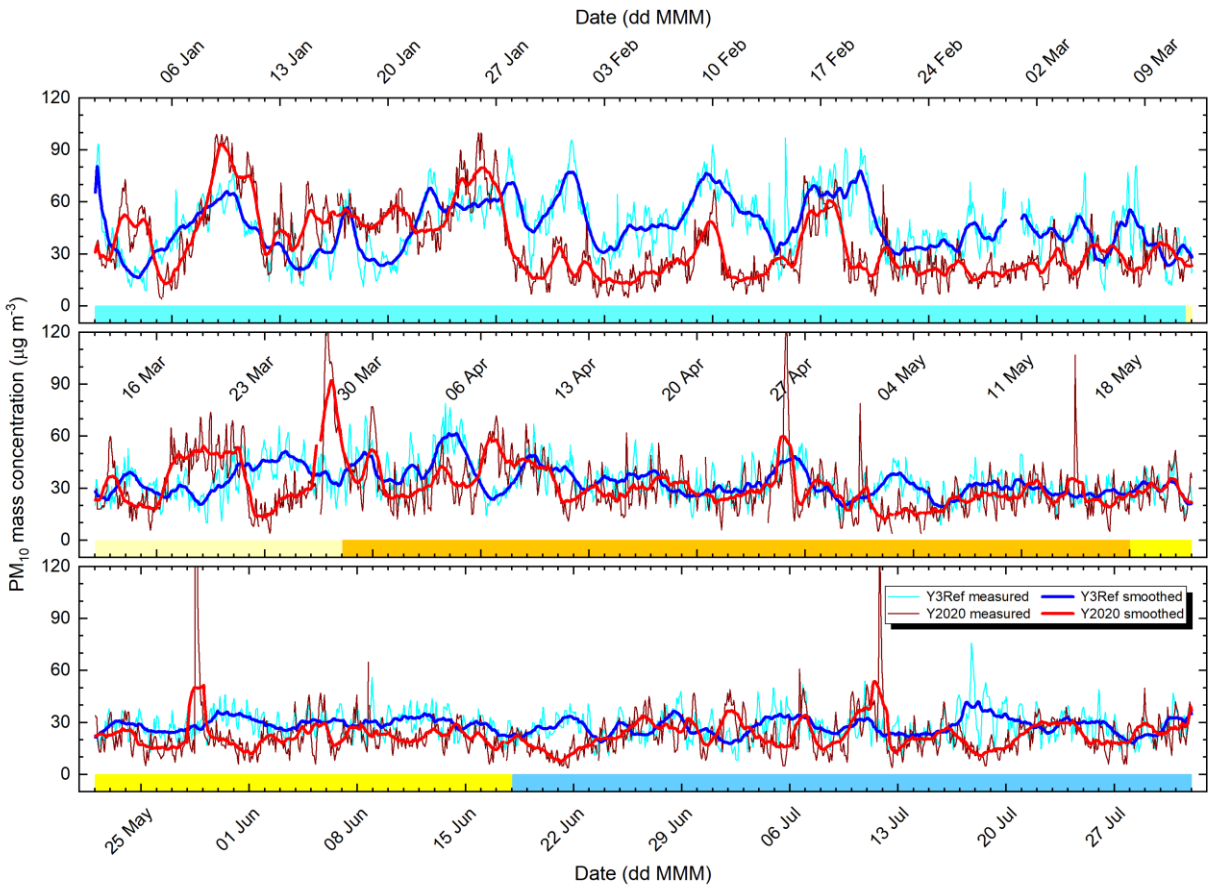

Figure S9. Time variation of PM_{10} mass concentration in the average reference year of 2017–2019 (Y3Ref) and year 2020 together with their 24-h smoothed curves over the five consecutive phases of the first COVID-19 outbreak. The phases are marked by the following colour codes: Pre-emergency phase lighter blue, Pre-restriction phase lighter yellow, Restriction phase orange, Post-restriction phase darker yellow and Post-emergency phase darker blue. The tick labels of the abscissa indicate the Mondays in 2020.

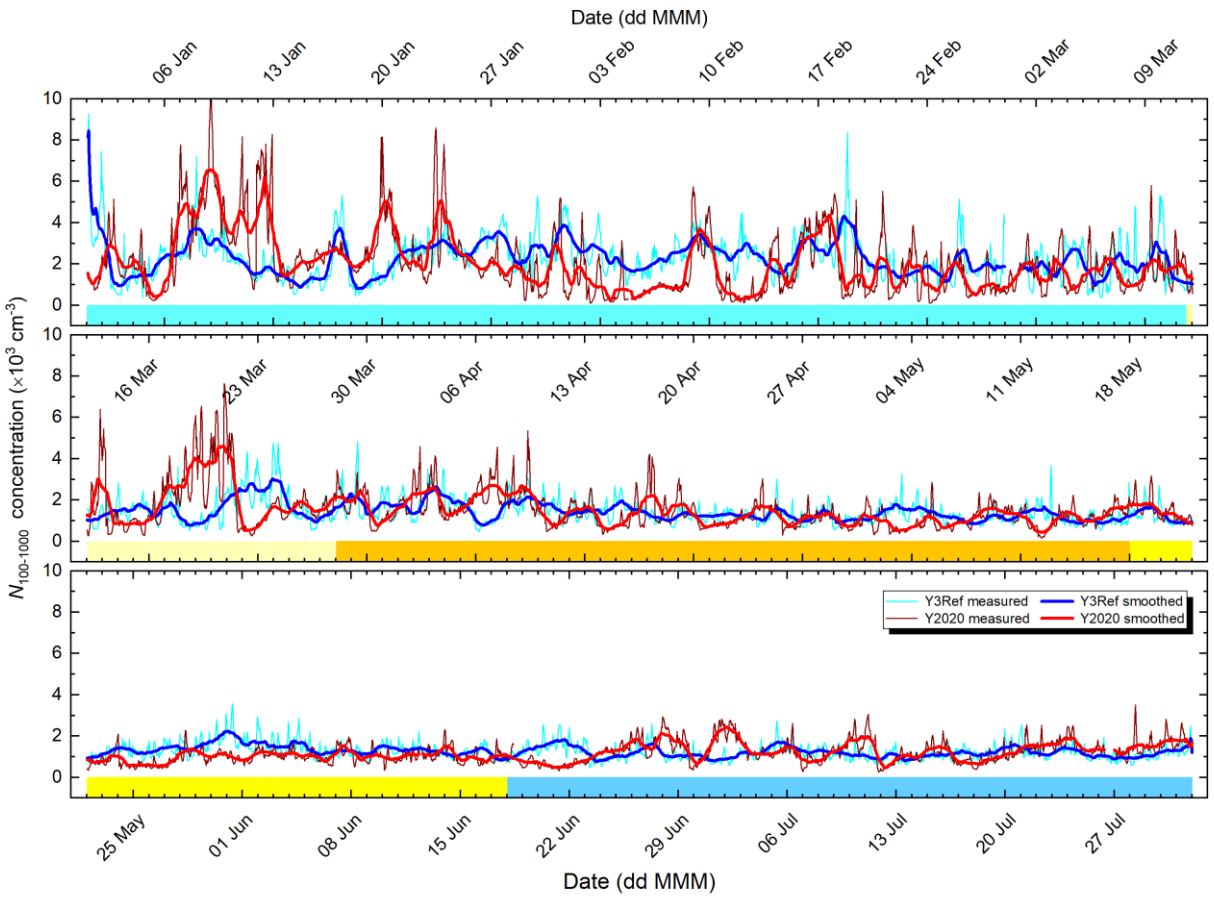

Figure S10. Time variation of $N_{100–1000}$ concentration in the average reference year of 2017–2019 (Y3Ref) and year 2020 together with their 24-h smoothed curves over the five consecutive phases of the first COVID-19 outbreak. The phases are marked by the following colour codes: Pre-emergency phase lighter blue, Pre-restriction phase lighter yellow, Restriction phase orange, Post-restriction phase darker yellow and Post-emergency phase darker blue. The tick labels of the abscissa indicate the Mondays in 2020.

Reference

Maheras, P., Tolika, K., Tegoulias, I., Anagnostopoulou, Ch., Szpirosz, K., Károssy, Cs., Makra, L.: Comparison of an automated classification system with an empirical classification of circulation patterns over the Pannonian basin, Central Europe, Meteorol. Atmos. Phys., https://doi.org/10.1007/s00703-018-0601-x, 2018.