

Integrating in situ Measurements and City Scale Modelling to Assess the COVID-19 Lockdown Effects on Emissions and Air Quality in Athens, Greece

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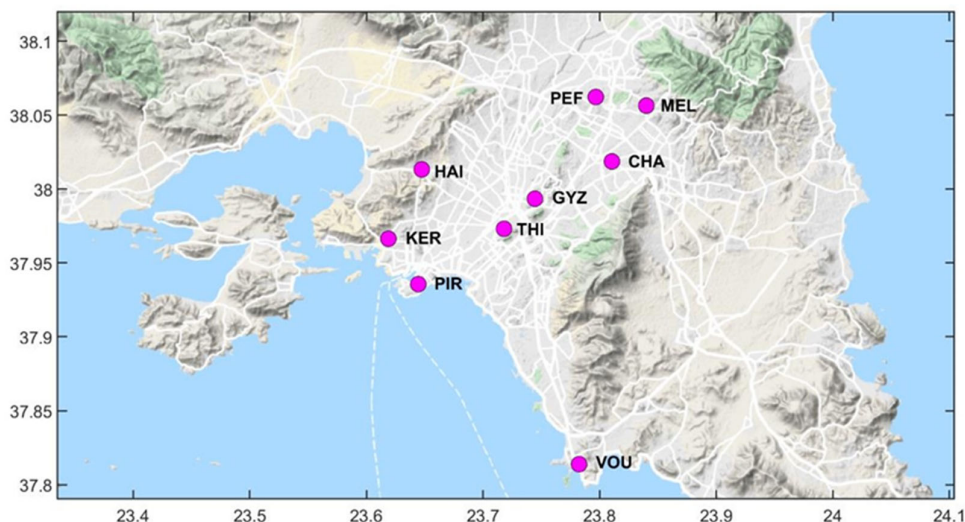


Figure S1. Map of the NOA/PANACEA low-cost PM_{2.5} monitoring network at residential urban/suburban background locations in the Athens basin. The central site at Thissio (THI) is also indicated.

Table S1. Mean (standard deviation for hourly values) values of meteorological parameters observed in Athens (Thissio), for years 2016-2020 and days corresponding to the pre-lockdown (March 1-22), lockdown (March 23 – May 10) and post-lockdown (May 11-31) periods of 2020. Displaying also the % difference of 2020 values compared to the mean of previous years. Statistical significance assessed by the Mann-Whitney non-parametric test.

	Temperature	Relative Humidity	Wind Speed	Precipitation
	Mean (SD)	Mean (SD)	Mean (SD)	Total
Pre-lockdown				
2016	13.5 (3.2)	63.5 (12.2)	3.01 (1.77)	33.8
2017	13.2 (2.9)	62.2 (14.4)	2.68 (1.65)	54.0
2018	15.3 (2.6)	58.0 (13.2)	3.00 (1.73)	6.4
2019	13.9 (3.2)	58.5 (13.3)	3.16 (2.13)	20.2
2016-2019 (mean)	14.0	60.6	2.96	28.6
2020	13.8 (3.5)	56.0 (13.5)	3.09 (2.32)	29.0
% difference (2020/2016-19)	-1.4%	-7.6% **	+4.4%	+1.4%
Lockdown				
2016	18.1 (3.9)	53.8 (14.0)	2.86 (1.85)	8.0
2017	17.6 (4.1)	47.9 (13.8)	2.80 (1.88)	3.0
2018	19.0 (4.1)	52.6 (14.1)	2.60 (1.73)	43.0
2019	15.5 (3.3)	56.5 (14.8)	3.45 (2.48)	95.6
2016-2019 (mean)	17.6	52.7	2.93	37.4
2020	15.9 (4.1)	53.5 (16.2)	3.14 (2.08)	47.4
% difference (2020/2016-19)	-9.7% **	+1.5%	+7.2% **	+26.7%**
Post-lockdown				
2016	22.1 (3.4)	55.7 (14.1)	2.73 (1.54)	1.4
2017	21.1 (3.8)	53.0 (15.2)	3.08 (1.91)	38.0
2018	23.7 (3.1)	53.6 (14.0)	3.32 (2.12)	10.2
2019	21.2 (3.1)	56.5 (14.2)	2.24 (1.39)	0.6
2016-2019 (mean)	22.0	54.7	2.84	12.6
2020	22.3 (4.9)	53.5 (15.2)	2.53 (1.62)	28.6
% difference (2020/2016-19)	+1.4%	-2.2% **	-10.9% **	+127.0%**

* significant at the 0.05 level

** significant at the 0.01 level

Table S2. Mean (standard deviation) concentrations of pollutants measured in Athens (Thissio), in 2020 during the pre-lockdown (March 1-22), lockdown (March 23 – May 10) and post-lockdown (May 11-31) periods. Statistical significance assessed by the Mann-Whitney non-parametric test. Standard deviations calculated from 1-h average values (3-h for PM_{2.5}).

	Pre- lockdown	Lockdown	Post- lockdown	Lockdown vs. Pre- lockdown (%)	Post- lockdown vs. Lockdown (%)
	March 1-22	March 23 – May 10	May 11-31		
CO ₂ (ppm)	433.6(23.4)	424.5 (12.4)	426.9 (18.9)	- 2.1% **	+ 0.6%
ΔCO ₂ (ppm) ¹	15.0 (23.4)	6.3 (12.4)	11.2 (18.9)	- 58.0% **	+ 77.8% **
CO (mg m ⁻³)	0.40 (0.32)	0.26 (0.12)	0.37 (0.28)	- 34.6% **	+ 42.3% **
NO ₂ (μg m ⁻³)	26.7 (17.4)	18.3 (11.8)	31.5 (22.3)	- 31.5% **	+ 72.1% **
PM _{2.5} (μg m ⁻³)	17.3 (10.4)	14.2 (7.3)	22.2 (7.6)	- 18.0% *	+ 56.7% **
BC (μg m ⁻³)	1.57 (1.62)	0.94 (0.84)	1.23 (1.18)	- 40.1% **	+ 31.1% **
BC _{ff} (μg m ⁻³)	1.02 (0.98)	0.68 (0.61)	1.04 (1.02)	- 33.4% **	+ 52.8% **

BC_{bb} ($\mu g m^{-3}$)	0.54 (0.77)	0.26 (0.32)	0.19 (0.18)	- 52.8% **	- 24.6% **
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* significant at the 0.05 level

** significant at the 0.01 level

¹ Calculated by subtracting the respective period-average regional-background values

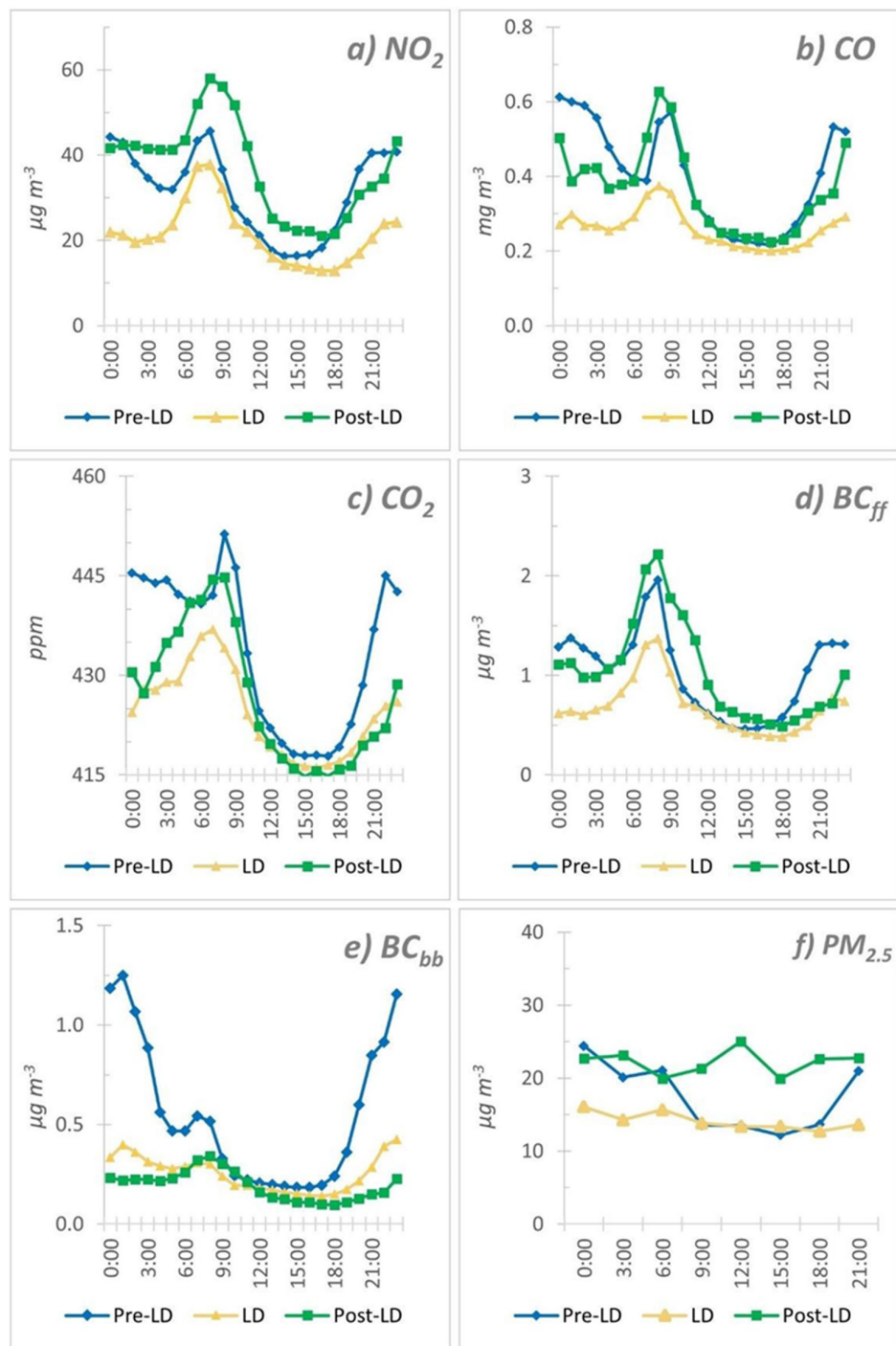


Figure S2. Mean diurnal variability of pollutant (gaseous: a-c; particle: d-f) concentrations during the lockdown (LD), pre-lockdown (Pre-LD) and post-lockdown (Post-LD) periods in Athens, Greece. Hourly values displayed for all pollutants except $PM_{2.5}$ (3-hour

averages). All displayed times on the x-axis in UTC+2:00. Time values correspond to the start of each sampling interval.

Table S3. Model performance metrics for NO₂ (March – April of 2019 and of 2020) and PM_{2.5} (March – April of 2020) concentration levels in Athens.

Air pollutant /site	Average (st. dev.) of 1-h observations (µg m ⁻³)	Average (st. dev.) of 1-h predictions (µg m ⁻³)	Mean Bias, MB (µg m ⁻³)	Normalized Mean Bias, NMB (%)	r^2 / IoA (d)***	No of pairs
NO₂ /THI						
Pre-lockdown*						
2019	30.5 (19.5)	34.3 (21.4)	3.7	35.90	0.28	528
2020	26.7 (17.4)	28.2 (19.6)	1.5	18.87	0.36	936
% difference	-12%	-18%				
Lockdown**						
2019	29.6 (21.7)	31.3 (23.5)	1.2	28.30	0.27	528
2020	18.4 (12.0)	18.1 (13.8)	-0.3	10.30	0.18	936
% difference	-38%	-42%				
mean	25.7 (18.6)	27.0 (20.6)	1.2	22.19	0.32 / 0.72	2928
PM _{2.5} / PEF	16.0 (8.1)	20.0 (10.7)	3.8	32.27	0.33	1420
PM _{2.5} / ATH	16.0 (8.1)	27.0 (17.8)	10.6	71.60	0.38	1418
PM _{2.5} / PIR	17.2 (8.1)	28.9 (21.2)	8.3	45.73	0.42	1148
PM _{2.5} / MEL	15.4 (7.1)	18.5 (9.5)	2.7	24.97	0.32	1383
PM _{2.5} / CHA	17.5 (10.6)	20.8 (11.3)	3.2	30.17	0.34	1421
PM _{2.5} / KER	15.8 (8.1)	22.6 (12.4)	6.4	48.65	0.48	1421
PM _{2.5} / HAI	15.2 (7.7)	22.3 (12.3)	6.7	56.80	0.31	1422
mean PM_{2.5}	16.1	22.9	6.0	44.31	0.37 / 0.63	

* March 1 – 22

** March 23 – April 30

*** IoA: Index of Agreement d (Willmott, 1982)

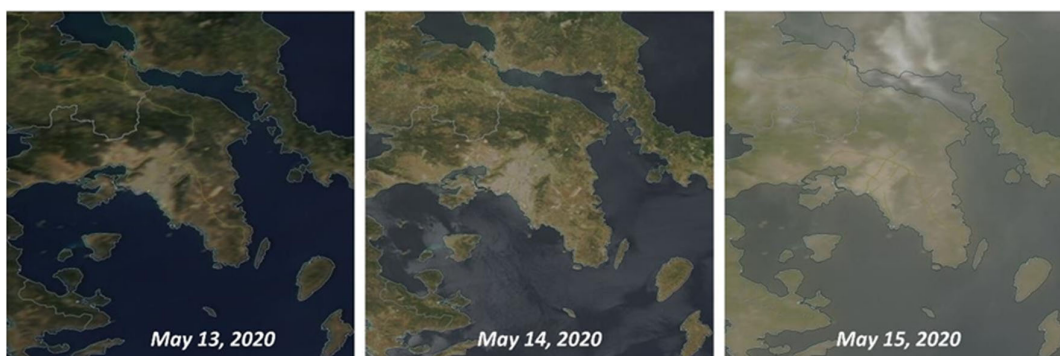


Figure S3. Satellite overview (Aqua/MODIS) of the Attica peninsula (true color reflectance), showing the settling in of the dust transport event in Athens during May 13-15, 2020.

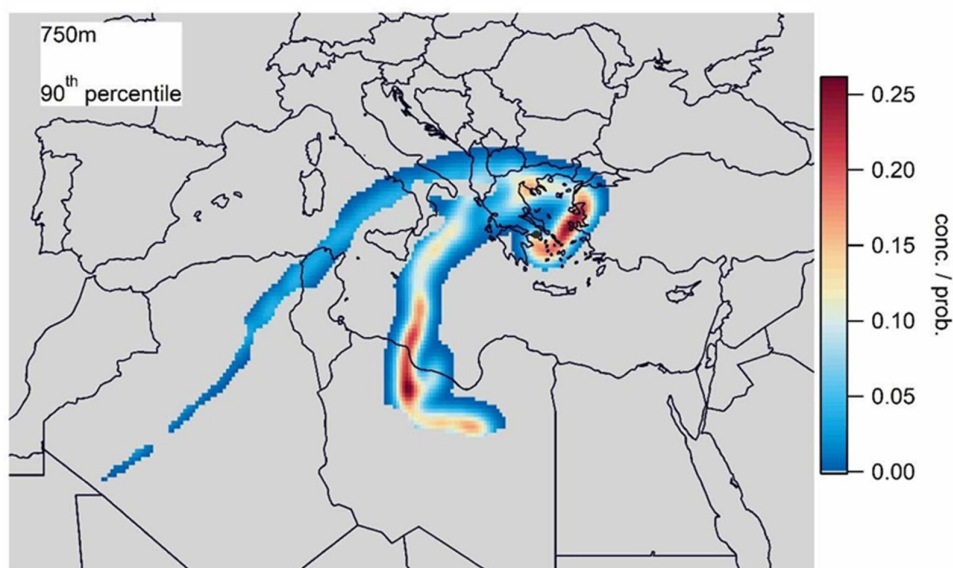


Figure S4. Potential source contribution (PSCF) plot for PM_{2.5}, calculated for five-day air mass back-trajectories that arrived at an altitude of 750 m in central Athens (Thissio) during May 15- 18, 2020, every 3 hours. The 75th percentile of measured PM_{2.5} concentrations during this period was set as the PSCF threshold. Trajectories were calculated using the HYSPLIT model (Stein et al., 2015) and GDAS1 meteorological data (1x1 degrees). Details on the theory and implementation of the PSCF methodology are provided by Petit et al. (2017). The plot was obtained using the Zefir toolkit of the IgorPro software.

Table S4. Mean (standard deviation for hourly values) values of NO₂, BC and BC components (BC_{ff} and BC_{bb}) measured in Athens (Thissio), for years 2016-2020 and days corresponding to the pre-lockdown (March 1-22), lockdown (March 23 – May 10) and post-lockdown (May 11-31) periods of 2020. Displaying also the % difference of 2020 values compared to the mean of previous years. Statistical significance assessed by the Mann-Whitney non-parametric test.

	NO ₂	BC	BC _{ff}	BC _{bb}
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Pre-lockdown				
2016	23.7 (15.0)	1.49 (1.67)	1.15 (1.18)	0.34 (0.58)
2017	32.5 (18.6)	1.98 (1.81)	1.44 (1.21)	0.54 (0.76)
2018	26.8 (18.4)	1.32 (1.42)	0.95 (0.98)	0.37 (0.51)
2019	30.5 (19.5)	1.51 (1.38)	1.09 (1.03)	0.43 (0.42)
2016-2019 (mean)	28.4	1.57	1.15	0.42
2020	26.7 (17.4)	1.57 (1.62)	1.03 (0.98)	0.54 (0.77)
% difference (2020/2016-19)	-6.0% *	-0.0%	-10.4% **	+ 29.0% *
Lockdown				
2016	29.0 (18.2)	1.62 (1.88)	1.39 (1.70)	0.23 (0.28)
2017	31.8 (20.4)	1.44 (1.32)	1.20 (1.16)	0.24 (0.20)
2018	36.1 (23.9)	1.87 (1.70)	1.53 (1.49)	0.35 (0.25)
2019	28.0 (20.6)	1.36 (1.39)	1.05 (1.11)	0.31 (0.33)
2016-2019 (mean)	31.2	1.57	1.29	0.28
2020	18.3 (11.8)	0.94 (0.84)	0.68 (0.61)	0.26 (0.32)

% difference (2020/2016-19)	-41.5% **	-40.2% **	-46.9% **	-9.9% **
Post-lockdown				
2016	28.5 (14.4)	1.00 (0.85)	0.87 (0.79)	0.11 (0.12)
2017	28.5 (18.3)	1.14 (1.14)	0.99 (1.02)	0.15 (0.14)
2018	25.2 (16.8)	1.18 (0.96)	1.00 (0.84)	0.18 (0.15)
2019	33.2 (20.6)	1.29 (1.19)	1.11 (1.08)	0.18 (0.14)
2016-2019 (mean)	28.9	1.16	1.00	0.16
2020	31.5 (22.3)	1.23 (1.18)	1.04 (1.02)	0.19 (0.18)
% difference (2020/2016-19)	+8.7%	+5.8%	+3.6% **	+20.6% **

* significant at the 0.05 level

** significant at the 0.01 level

Supplementary References

1. Stein, A.F.; Draxler, R.R.; Rolph, G.D.; Stunder, B.J.; Cohen, M.D.; Ngan, F. NOAA's HYSPLIT atmospheric transport and dispersion modeling system. *Bull. Am. Meteorol. Soc.* **2015**, *96*, 2059– 2077, <https://doi.org/10.1175/BAMS-D-14-00110.1>.
2. Petit, J.-E.; Favez, O.; Albinet, A.; Canonaco, F. A user-friendly tool for comprehensive evaluation of the geographical origins of atmospheric pollution: Wind and trajectory analyses. *Environ. Model. Soft.* **2017**, *88*, 183–187, <https://doi.org/10.1016/j.envsoft.2016.11.022>.
3. Willmott, C.J. Some comments on the evaluation of model performance. *Bull. Am. Meteor. Soc.* **1982**, *63*, 1309-1313.