



*Supplement of*

## **Assessing COVID-19 lockdowns' impacts on global urban PM<sub>2.5</sub> air quality with observations and modeling**

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## Tables S1-S2

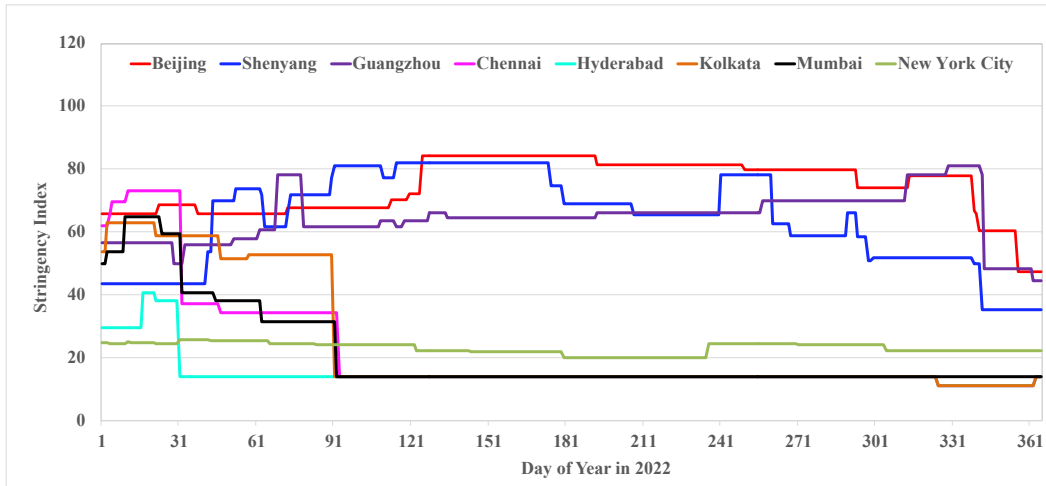
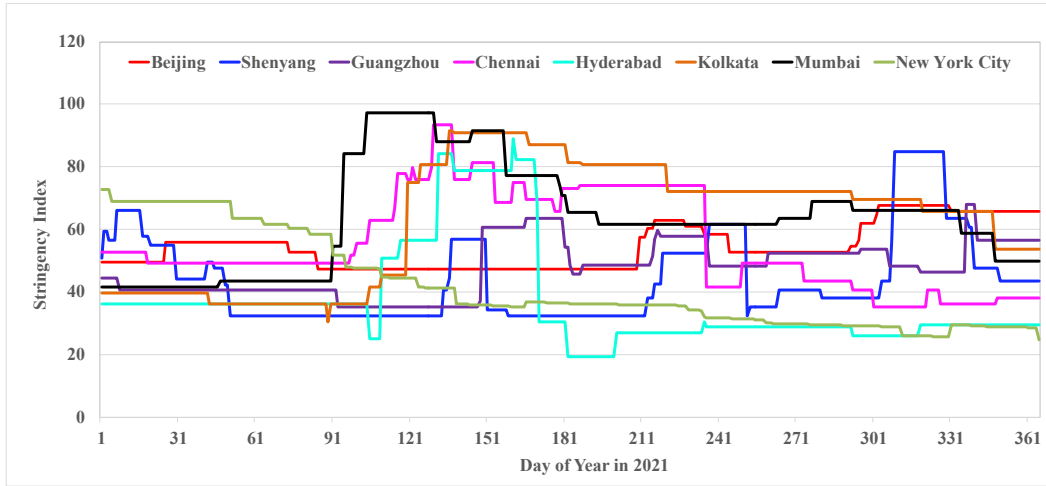
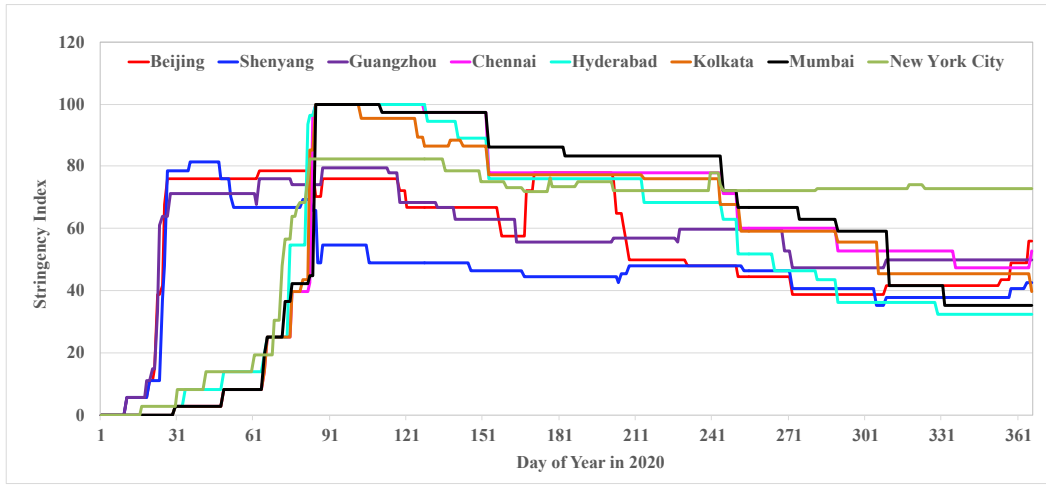
## Figures S1-S10

| <b>Table S1: Characteristics of PM<sub>2.5</sub> observations from 21 monitoring stations used in this study. The number of order is consistent with that illustrated in Figure 1.</b> |               |           |          |           |                                          |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|-----------|----------|-----------|------------------------------------------|
| No.                                                                                                                                                                                    | City          | Country   | Latitude | Longitude | Period of PM <sub>2.5</sub> observations |
| 1                                                                                                                                                                                      | Beijing       | China     | 39.95°N  | 116.47°E  | 2010-2022                                |
| 2                                                                                                                                                                                      | Shenyang      | China     | 41.78°N  | 123.43°E  | 2013-2022                                |
| 3                                                                                                                                                                                      | Shanghai      | China     | 31.21°N  | 121.45°E  | 2012-2022                                |
| 4                                                                                                                                                                                      | Guangzhou     | China     | 23.11°N  | 113.32°E  | 2011-2022                                |
| 5                                                                                                                                                                                      | Hanoi         | Vietnam   | 21.03°N  | 105.83°E  | 2015-2022                                |
| 6                                                                                                                                                                                      | Jakarta*      | Indonesia | 6.21°S°N | 106.85°E  | 2015-2022                                |
| 7                                                                                                                                                                                      | Chennai       | India     | 13.05°N  | 80.25°E   | 2015-2022                                |
| 8                                                                                                                                                                                      | New Delhi     | India     | 28.60°N  | 77.19°E   | 2015-2022                                |
| 9                                                                                                                                                                                      | Mumbai        | India     | 19.06°N  | 72.86°E   | 2015-2022                                |
| 10                                                                                                                                                                                     | Kolkata       | India     | 22.55°N  | 88.35°E   | 2015-2022                                |
| 11                                                                                                                                                                                     | Hyderabad     | India     | 17.44°N  | 78.47°E   | 2015-2022                                |
| 12                                                                                                                                                                                     | Addis Ababa   | Ethiopia  | 8.98°N   | 38.76°E   | 2016-2022                                |
| 13                                                                                                                                                                                     | Dubai         | UAE       | 25.20°N  | 55.27°E   | 2018-2022                                |
| 14                                                                                                                                                                                     | Kuwait City   | Kuwait    | 29.38°N  | 47.98°E   | 2017-2022                                |
| 15                                                                                                                                                                                     | Manama        | Bahrain   | 26.22°N  | 50.59°E   | 2016-2022                                |
| 16                                                                                                                                                                                     | Paris         | France    | 48.86°N  | 2.35°E    | 2013-2022                                |
| 17                                                                                                                                                                                     | Milano        | Italy     | 45.46°N  | 9.19°E    | 2013-2022                                |
| 18                                                                                                                                                                                     | Pristina      | Kosovo    | 42.60°N  | 21.16°E   | 2016-2022                                |
| 19                                                                                                                                                                                     | New York City | USA       | 40.71°N  | 74.00°W   | 2010-2022                                |
| 20                                                                                                                                                                                     | Los Angeles   | USA       | 34.05°N  | 118.24°W  | 2010-2022                                |
| 21                                                                                                                                                                                     | Lima          | Peru      | 12.10°S  | 76.97°W   | 2016-2022                                |
| *There were two PM <sub>2.5</sub> monitoring stations in Jakarta, Indonesia, namely Jakarta – Central and Jakarta – South.                                                             |               |           |          |           |                                          |

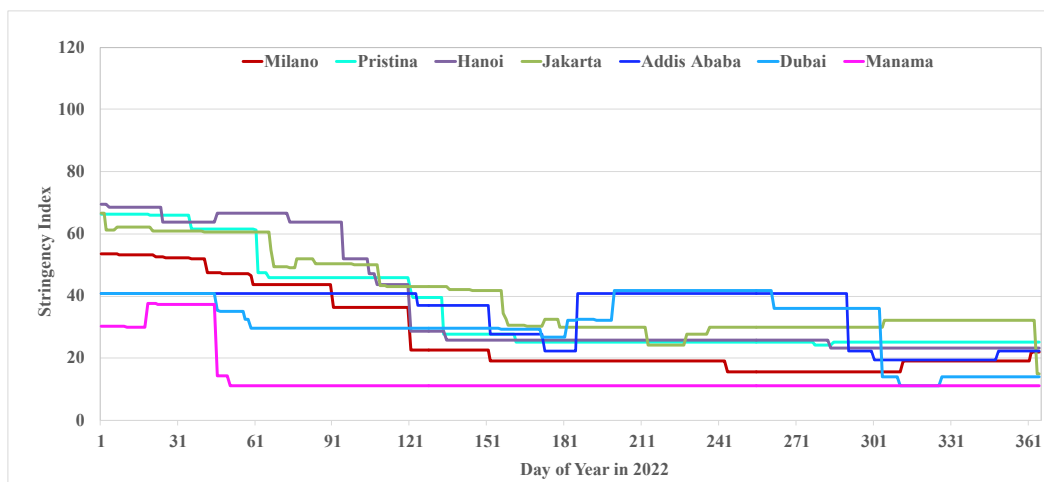
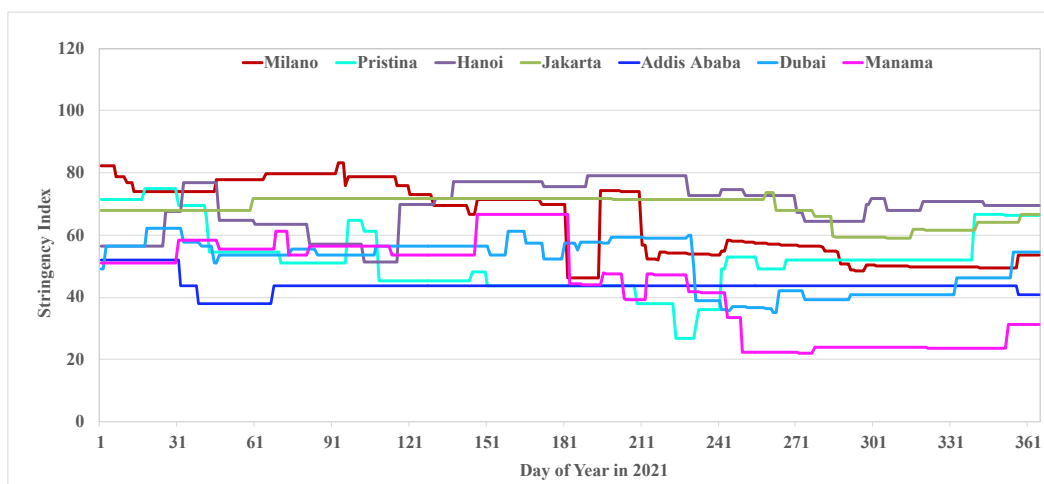
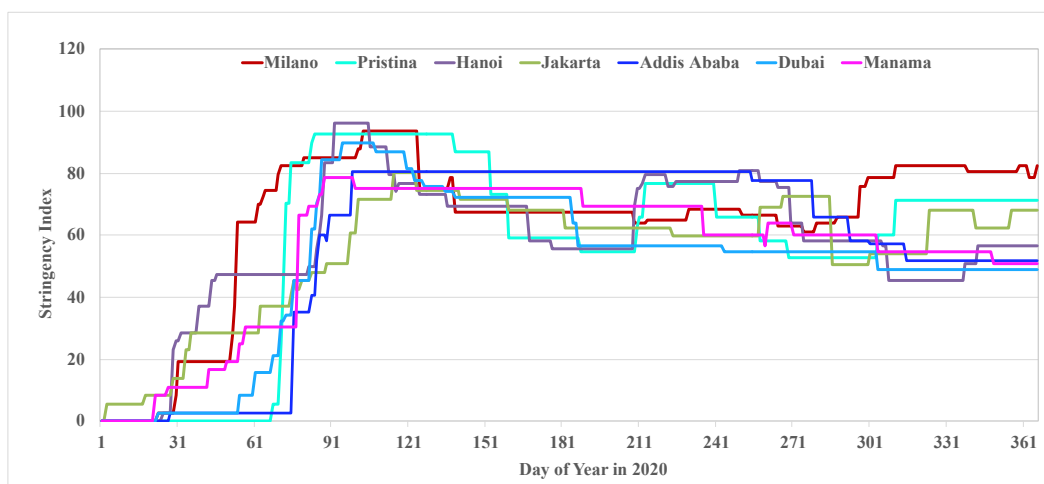
**Table S2: Comparisons of some major meteorological variables and fire-emitted OC between 2020 and 2019 on a basis of March and April average. The data are derived from GEOS simulations by averaging over 3°x3° box around 14 stations (Similar analysis for six other stations is summarized in Table 3)**

|                    | PBLH (m)     | 10m wind speed (m s <sup>-1</sup> ) | Precipitation (mm d <sup>-1</sup> ) | OC emissions from fires (g m <sup>-2</sup> d <sup>-1</sup> ) |
|--------------------|--------------|-------------------------------------|-------------------------------------|--------------------------------------------------------------|
| <b>Beijing</b>     |              |                                     |                                     |                                                              |
| 2019               | 919          | 0.92                                | 0.64                                | 4.1E-4                                                       |
| 2020               | 995          | 0.99                                | 0.74                                | 3.0E-4                                                       |
| 2020 vs 2019       | +76 (+8.3%)  | +0.07 (+8.4%)                       | +0.1 (+16.7%)                       | -1.1E-4 (-28.2%)                                             |
| <b>Shenyang</b>    |              |                                     |                                     |                                                              |
| 2019               | 850          | 1.58                                | 0.36                                | 4.7E-4                                                       |
| 2020               | 846          | 1.32                                | 0.37                                | 8.5E-4                                                       |
| 2020 vs 2019       | -4 (-0.4%)   | -0.26 (-16.2%)                      | +0.01 (+2.0%)                       | +3.8E-4 (+81.2%)                                             |
| <b>Guangzhou</b>   |              |                                     |                                     |                                                              |
| 2019               | 503          | 1.14                                | 6.60                                | 4.2E-5                                                       |
| 2020               | 519          | 1.01                                | 4.09                                | 1.3E-4                                                       |
| 2020 vs 2019       | +16 (+3.2%)  | -0.13 (-11.4%)                      | -2.51 (-38.0%)                      | +9.1E-5(+215.5%)                                             |
| <b>Hanoi</b>       |              |                                     |                                     |                                                              |
| 2019               | 439          | 1.55                                | 3.5                                 | 4.8E-3                                                       |
| 2020               | 459          | 1.22                                | 5.2                                 | 2.4E-3                                                       |
| 2020 vs 2019       | +20 (+4.6%)  | -0.33 (-20.8%)                      | +1.6 (+45.9%)                       | -2.4E-3 (-50.0%)                                             |
| <b>Jakarta</b>     |              |                                     |                                     |                                                              |
| 2019               | 569          | 0.92                                | 11.0                                | 7.2E-5                                                       |
| 2020               | 550          | 0.67                                | 14.4                                | 6.3E-5                                                       |
| 2020 vs 2019       | -19 (-3.4%)  | -0.25 (-27.5%)                      | +3.4 (+30.9%)                       | -9.0E-6 (-12.6%)                                             |
| <b>Chennai</b>     |              |                                     |                                     |                                                              |
| 2019               | 681          | 3.63                                | 0.25                                | 4.1E-4                                                       |
| 2020               | 703          | 3.14                                | 0.57                                | 1.6E-4                                                       |
| 2020 vs 2019       | +22 (+3.2%)  | -0.49 (-13.5%)                      | +0.32 (+132.0%)                     | -2.5E-4 (-60.7%)                                             |
| <b>Mumbai</b>      |              |                                     |                                     |                                                              |
| 2019               | 666          | 2.71                                | 0.07                                | 4.2E-4                                                       |
| 2020               | 719          | 2.54                                | 0.15                                | 2.1E-4                                                       |
| 2020 vs 2019       | +53 (+8.0%)  | -0.17 (-6.1%)                       | +0.08(+113.6%)                      | -2.1E-4 (-50.0%)                                             |
| <b>Kolkata</b>     |              |                                     |                                     |                                                              |
| 2019               | 824          | 2.28                                | 0.88                                | 4.9E-5                                                       |
| 2020               | 819          | 1.74                                | 1.78                                | 6.9E-5                                                       |
| 2020 vs 2019       | -5 (-0.7%)   | -0.54 (-23.8%)                      | +0.9 (+103.0%)                      | +2.0E-5 (+37.6%)                                             |
| <b>Hyderabad</b>   |              |                                     |                                     |                                                              |
| 2019               | 1359         | 1.69                                | 0.28                                | 2.3E-4                                                       |
| 2020               | 1237         | 1.83                                | 0.45                                | 3.0E-4                                                       |
| 2020 vs 2019       | -122 (-8.9%) | +0.14 (+8.4%)                       | +0.17(+60.9%)                       | +7.0E-5 (+31.7%)                                             |
| <b>Addis Ababa</b> |              |                                     |                                     |                                                              |
| 2019               | 937          | 1.77                                | 4.3                                 | 2.2E-4                                                       |

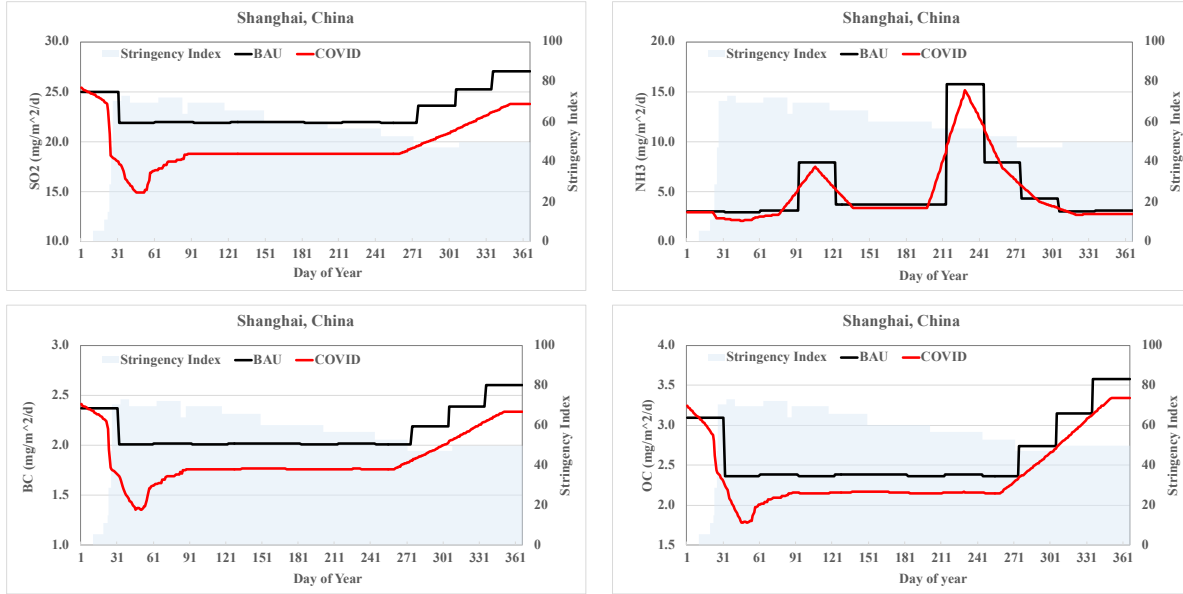
|                      |               |                |                |                  |
|----------------------|---------------|----------------|----------------|------------------|
| 2020                 | 861           | 1.59           | 6.3            | 1.9E-4           |
| 2020 vs 2019         | -76 (-8.1%)   | -0.18 (-10.2%) | +2.0 (+46.2%)  | -3.0E-5 (-12.6%) |
| <b>Dubai</b>         |               |                |                |                  |
| 2019                 | 654           | 1.63           | 0.63           | 1.1E-5           |
| 2020                 | 627           | 0.54           | 0.57           | 4.8E-6           |
| 2020 vs 2019         | -27 (-4.1%)   | -1.09 (-67.2%) | -0.06 (-9.7%)  | -6.2E-6 (-56.9%) |
| <b>Manama</b>        |               |                |                |                  |
| 2019                 | 583           | 2.01           | 0.80           | 2.9E-4           |
| 2020                 | 573           | 0.92           | 0.61           | 1.9E-4           |
| 2020 vs 2019         | -10 (-1.8%)   | -1.09 (-54.0%) | -0.19 (-23.5%) | -1.0E-4 (-36.3%) |
| <b>Milano</b>        |               |                |                |                  |
| 2019                 | 577           | 0.32           | 2.36           | 3.9E-4           |
| 2020                 | 470           | 0.41           | 2.04           | 1.3E-4           |
| 2020 vs 2019         | -107 (-18.6%) | +0.09 (+28.3%) | -0.32 (-13.7%) | -2.6E-4 (-66.3%) |
| <b>Pristina</b>      |               |                |                |                  |
| 2019                 | 639           | 0.47           | 1.7            | 2.2E-3           |
| 2020                 | 637           | 0.53           | 1.9            | 1.4E-3           |
| 2020 vs 2019         | -2 (-0.3%)    | +0.06(+13.5%)  | +0.2 (+12.2%)  | 8.0E-4 (-35.0%)  |
| <b>New York City</b> |               |                |                |                  |
| 2019                 | 684           | 0.94           | 3.0            | 5.6E-4           |
| 2020                 | 763           | 0.78           | 3.5            | 2.0E-4           |
| 2020 vs 2019         | +79 (+10.0%)  | -0.16 (-17.3%) | +0.5 (+13.7%)  | -3.6E-4 (-63.5%) |



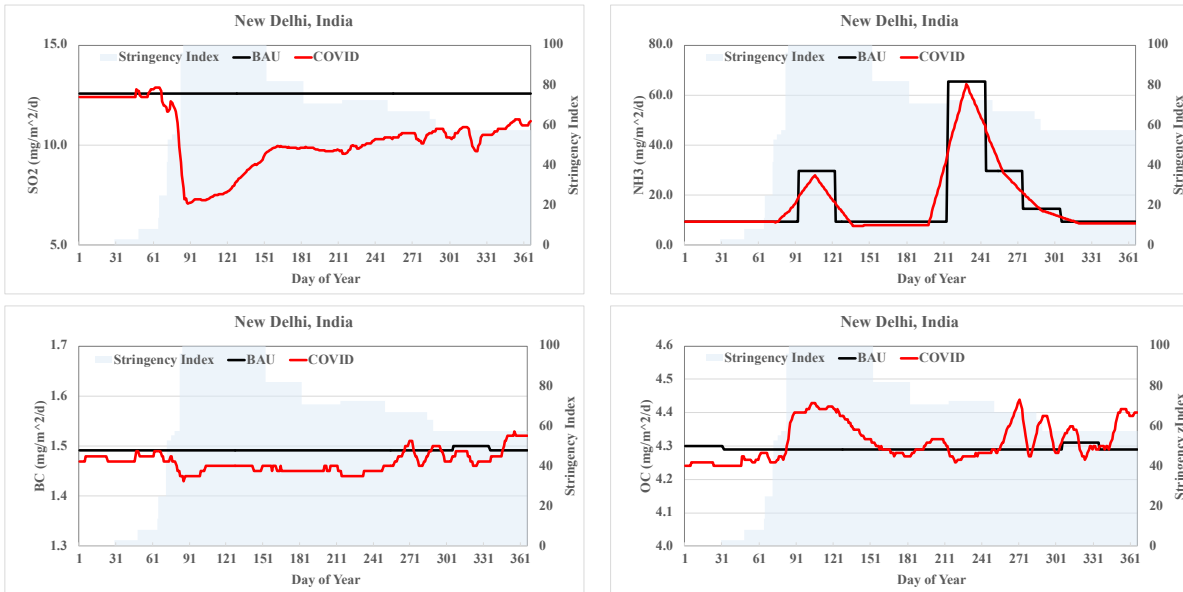
**Figure S1: Stringency index in 2020-2022 for Beijing, Shenyang, Guangzhou, Chennai, Hyderabad, Kolkata, Mumbai, and New York City.**



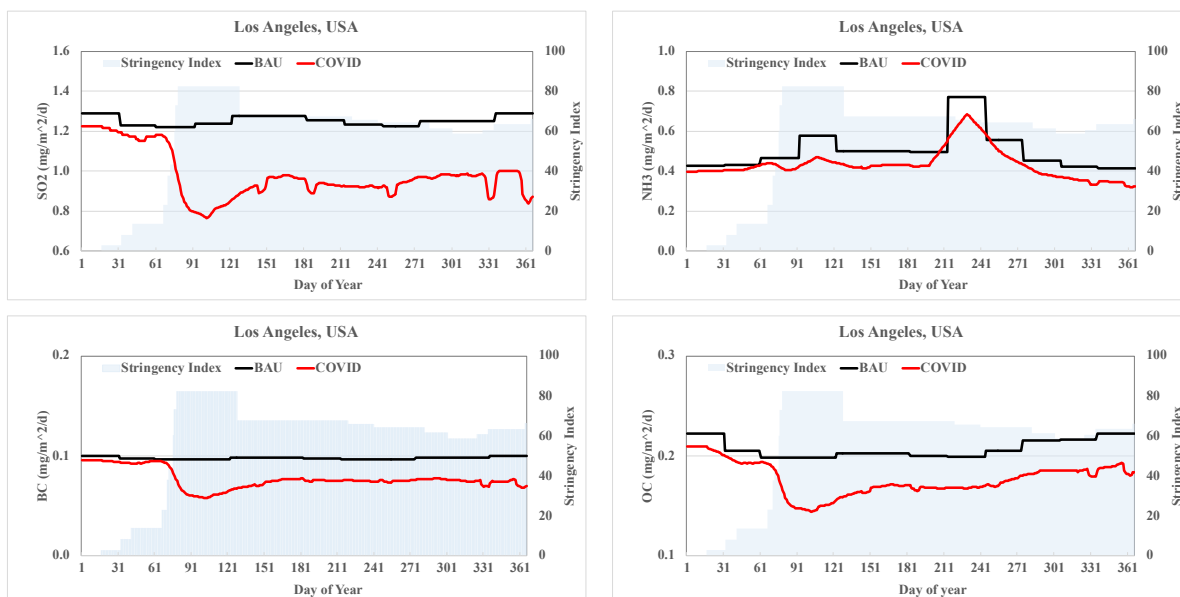
**Figure S2: Stringency index in 2020-2022 for Milano, Pristina, Hanoi, Jakarta, Addis Ababa, Dubai, and Manama.**



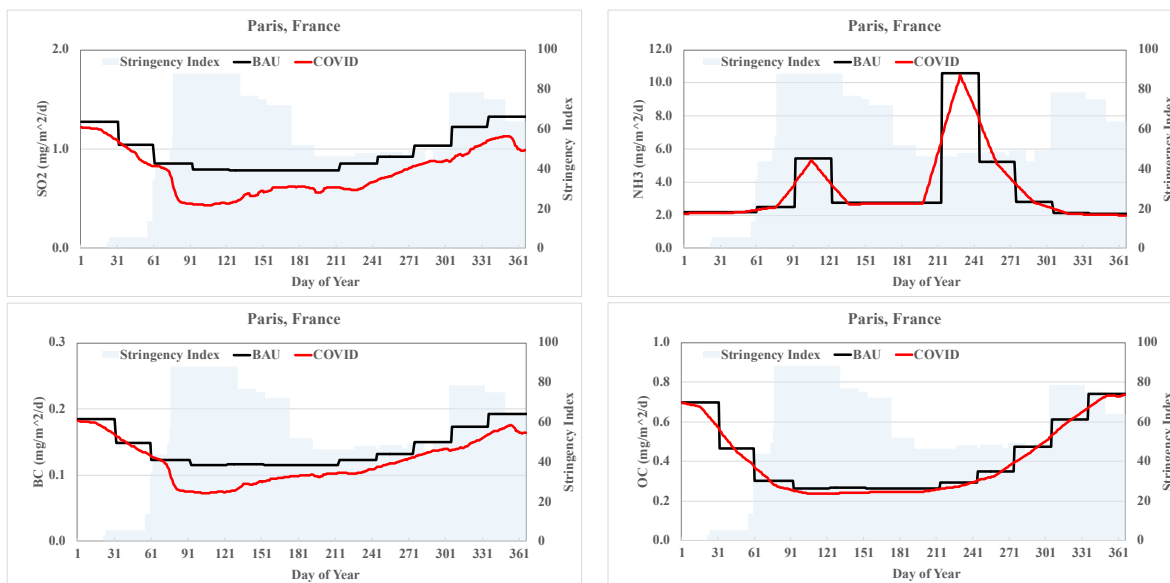
**Figure S3: 2020 anthropogenic emissions of SO<sub>2</sub>, NH<sub>3</sub>, BC, and OC in Shanghai, China used in the GEOS modeling for BAU (black) and COVID (red) scenarios, which is overlaid on the stringency index.**



**Figure S4: same as Figure S3 but for New Delhi, India.**

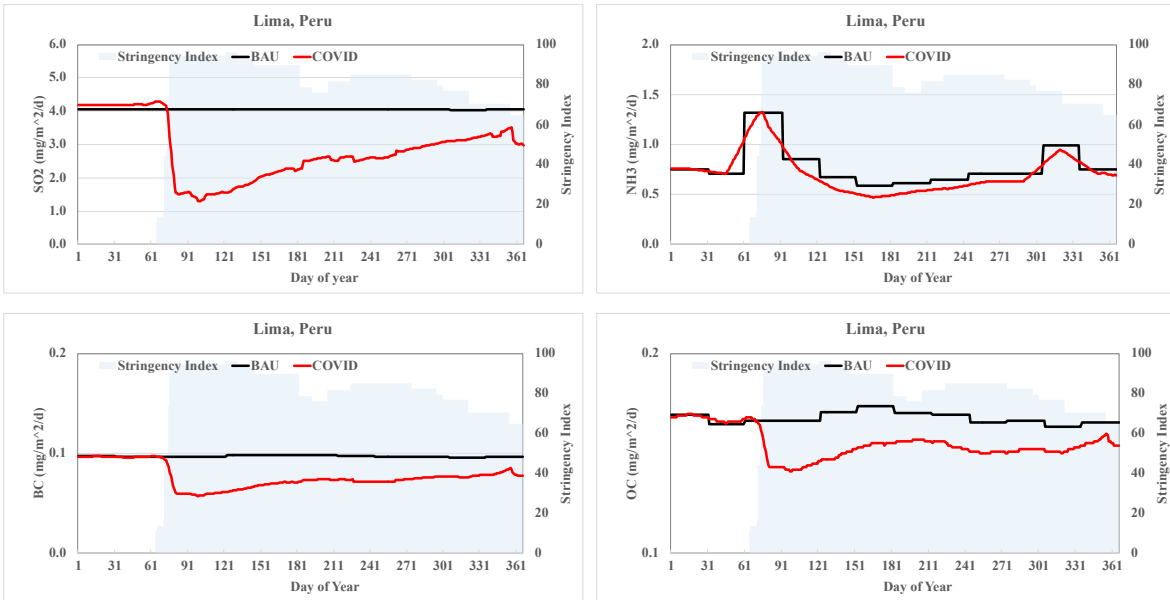


**Figure S5: same as Figure S3 but for Los Angeles, USA.**

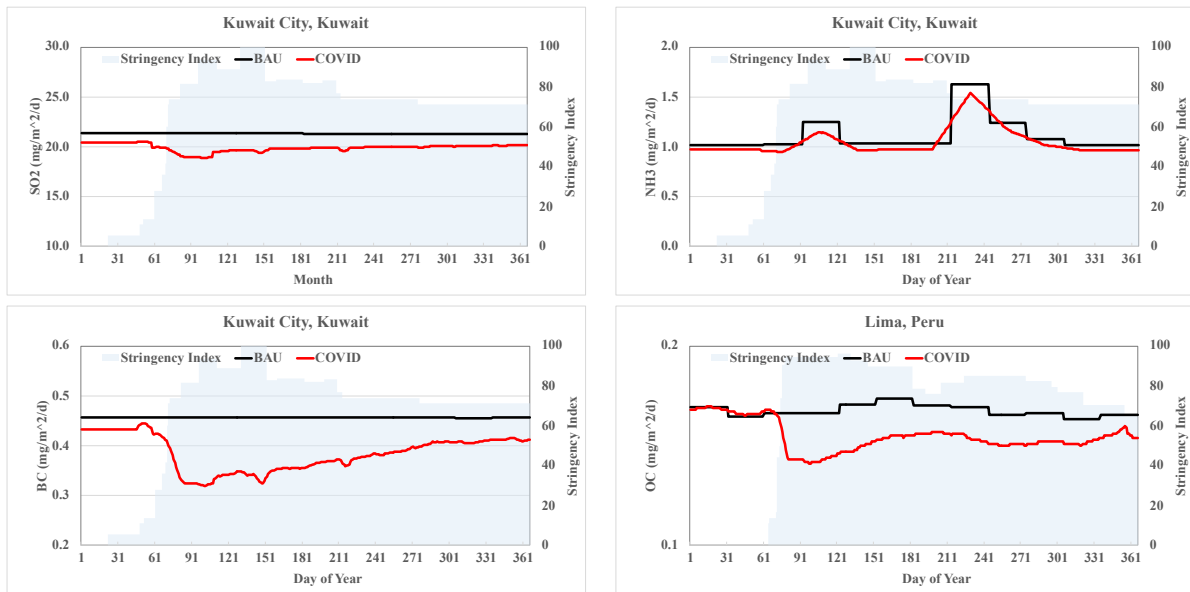


**Figure S6: same as Figure S3 but for Paris, France.**

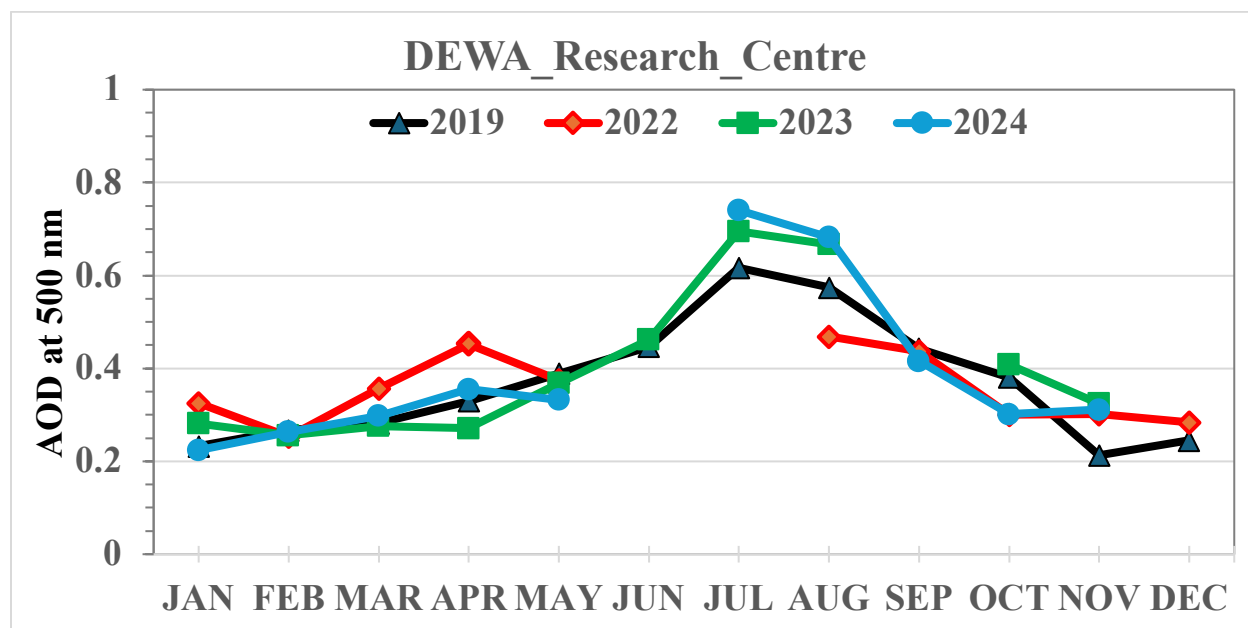




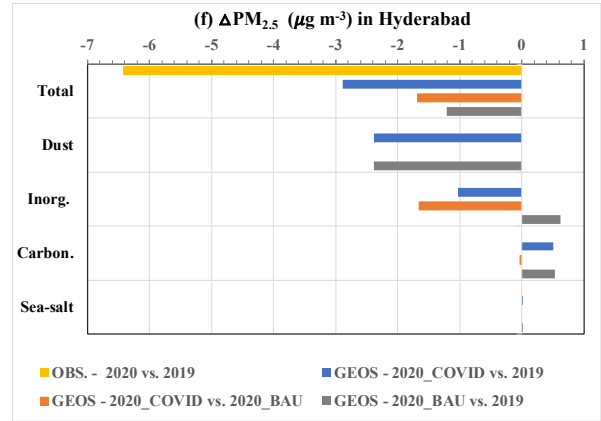
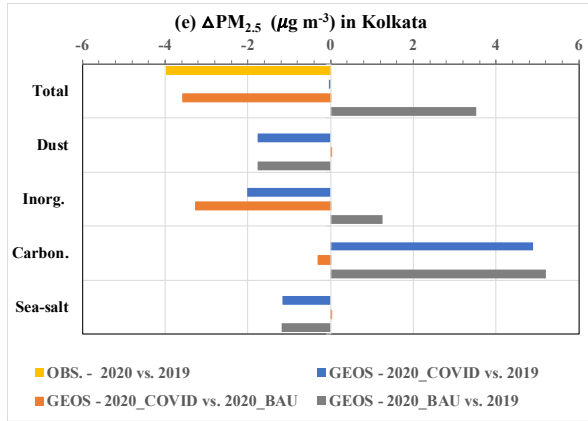
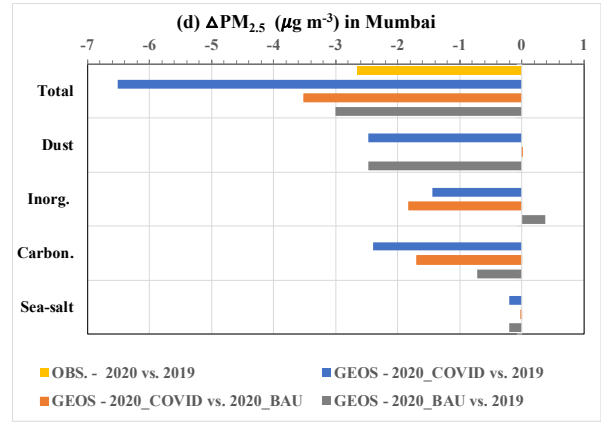
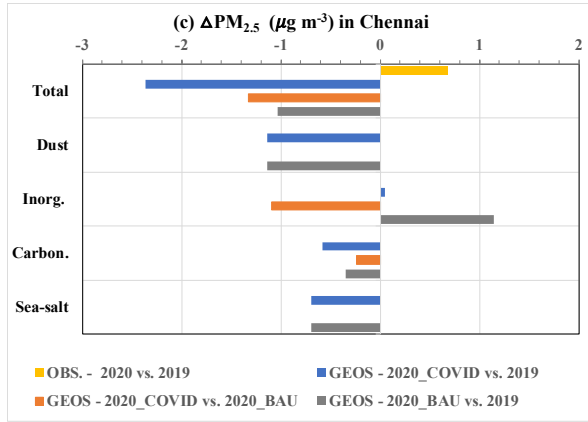
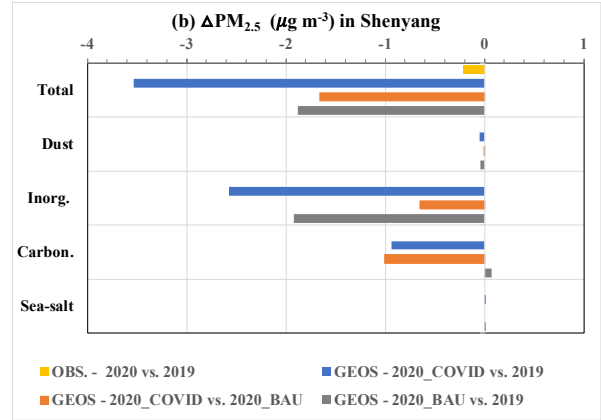
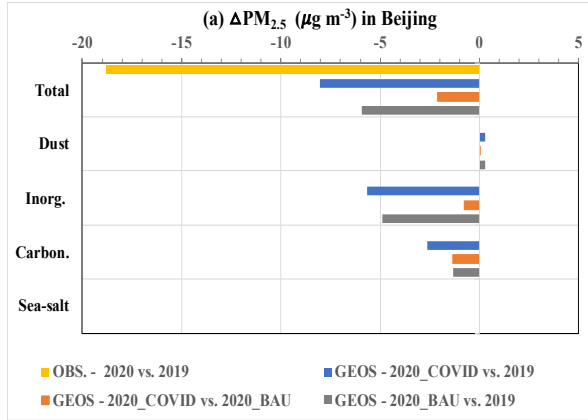
**Figure S7: same as Figure S3 but for Lima, Peru.**



**Figure S8: same as Figure S3 but for Kuwait City, Kuwait.**



**Figure S9:** Interannual variations of monthly AOD at 500 nm collected at an AERONET station in Dubai - DEWA\_Research\_Centre.





**Figure S10: Absolute differences ( $\mu g m^{-3}$ ) in March-April average  $PM_{2.5}$  between 2020 and 2019 (a negative value indicating that  $PM_{2.5}$  was smaller in 2020 than 2019) in Beijing, China (a), Shenyang, China (b), Chennai, India (c), Mumbai, India (d), Kolkata, India (e), Hyderabad, India (f), Addis Ababa, Ethiopia (g), Dubai, UAE (h), Manama, Bahrain (i), Milano, Italy (j), Pristina, Kosovo (k), and New York City, USA (l). Shown here include observed (yellow bars) and GEOS simulated (blue bars) changes in total and component  $PM_{2.5}$ . For both total and component  $PM_{2.5}$ , GEOS simulation is partitioned into GEOS  $PM_{2.5}$  change due to anthropogenic emission change (orange) and GEOS  $PM_{2.5}$  change due to differing meteorology (gray).**