GREENPEACE

Satellite Data Reveal Global Air Pollution Rebound One Year After First Covid-19 Lockdowns

June 2021

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Acknowledgements:

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Design:

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Published by:

Greenpeace Southeast Asia

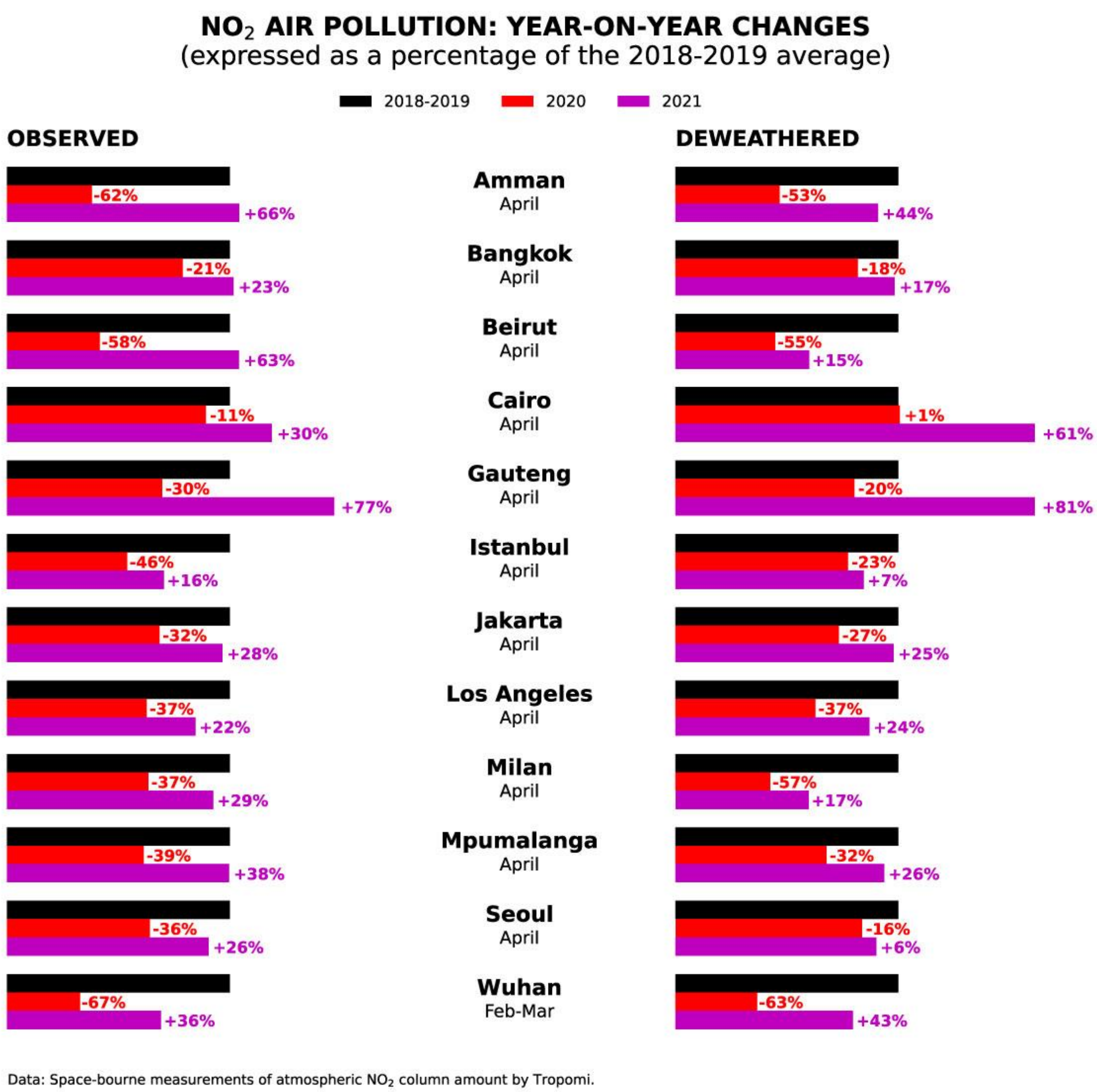
Suggested citation:

Farrow, A., Anhäuser, A. Satellite Data Reveal Global Air Pollution Rebound One Year After First Covid-19 Lockdowns. 37 pp. June 2021.

Contents

Key Takeaways

- NO_2 (nitrogen dioxide) is a dangerous air pollutant that is released when fuel is burned, including in vehicles, power generation, and industry.
- In many locations around the world, NO_2 air pollution was substantially lower in the first half of 2020 than during the same period of previous years.
- One year after initial Covid-19 lockdowns went into effect, NO_2 pollution had rebounded in all areas studied. This result was supported even after weather conditions were taken into account.
- Ending fossil fuel use is essential for reducing NO_2 air pollution and the associated burden on our health. Governments must accelerate the transition to renewable energy and invest in a green recovery, including a switch to wind and solar energy and building bike-friendly, clean transport-oriented cities.



Introduction

Early responses to the Covid-19 pandemic led to dramatic reductions in air pollutant concentrations in many locations worldwide (e.g. Shi et al., 2021, Hu et al., 2021, Beloconi et al., 2021). Research has suggested that significant health benefits could be realised if these air pollution reductions remain in the long-term after government restrictions are relaxed (e.g. Myllyvirta and Thieriot, 2020).

In this report, we investigate nitrogen dioxide (NO_2) pollution data from ground level monitors and satellite observations. The analysis compares air quality before the emergence of Covid-19 against pollution measurements made during different stages of the pandemic. Ground level measurements of fine particulate matter ($PM_{2.5}$) were also analysed in those locations where data were readily available. Weather conditions can hide or exaggerate the effect of changes in emissions on air quality; therefore a statistical technique is used to account for the effect of weather in different time periods.

The pandemic continues to have a colossal impact on public health, the economy and lifestyles in 2021. Despite the continuing threat and disruption, economic activity has rebounded in many locations, often with governmental support. However, because there has been little change to our reliance on fossil fuels, including coal, oil and gas, increased economic activity has been followed by increased air pollution in many cities. The health impact of fossil-fuel related air pollution is severe. A previous Greenpeace Southeast Asia study found that air pollution from burning fossil fuels – primarily coal, oil, and gas – was responsible for an estimated 4.5 million deaths each year worldwide (Farrow et al., 2020).

For this reason, a transition to clean energy sources such as wind and solar and clean and sustainable mobility must be central to recovery efforts worldwide. The recovery from the pandemic must not risk a return to previous levels of air pollution.

Methods

We analyse satellite observations of the air pollutant nitrogen dioxide (NO_2). This is supplemented with ground level measurements of NO_2 and fine particulate matter ($PM_{2.5}$) in those locations where data are available.

Satellite Data

The satellite observations of NO_2 included in this study have been retrieved by the Tropomi sensor on board the Sentinel-5P satellite (Copernicus, 2018). In contrast to ground-based sensors, Tropomi does not measure near-surface concentration, but instead atmospheric column amount, i.e. the amount of NO_2 over the entire thickness of the lower atmosphere (surface to ca. 10km above ground). This is a reasonable proxy for near-surface air pollution, but satellite observations alone do not allow us to determine pollution concentrations close to the ground. Tropomi has been operating since February 2018.

Ground Station Data

Where available, ground station data for the selected areas has been collated by the Centre for Energy and Clean Air (CREA). Ground station data are included for Istanbul, Los Angeles, Milan and Wuhan and have been retrieved from the following data providers: Republic of Turkey Ministry of Environment and Urbanity, Open AQ (https://openaq.org), and the People's Republic of China Ministry of Ecology and Environment. Where possible, data are included from 1 Dec 2016 to 20 May 2021, using the earliest available data when measurements are not available for the full period. An average was taken across all monitors within the selected area to give a single daily mean value.

The Effect of Weather

Air pollution is highly sensitive to weather conditions. Therefore, data are averaged to monthly or bi-monthly means and compared to equivalent periods in different calendar years. However, temporal averaging can only remove part of the influence of weather variations. To assess if the changes in air pollution are due to weather or changes in emissions, a statistical modelling process is applied to remove the effects of weather from the air pollution measurements. We refer to this process as ‘deweathering’ and the data it produces as ‘deweathered’ data. The deweathering analysis has been carried out in collaboration with the Centre for Energy and Clean Air (CREA) who applied the ‘counterfactual’ approach described in Thieriot (2021). Hourly observations of air temperature, pressure, wind direction, wind speed, precipitation, relative humidity and planetary boundary layer height have been included.

Planetary boundary layer height is taken from the NCEP Climate Forecast System (Saha et al. 2020, 2014) and all other meteorological variables are taken from the NOAA Integrated Surface Dataset (NOAA National Centers for Environmental Information. 2001). In the case of satellite data, daily Tropomi measurements were averaged over either the location's administrative domain or a circle around the place of interest, and measured data from 2018 and 2019 were used to construct the statistical models. In the case of ground station data, the models were constructed using observations from 2016 to 2019 or the earliest available data when measurements are not available for the full period. The performance of the deweathering model is not equal at all locations. Confidence in the deweathering results is reduced where there is poor correlation (r) or a low Index of Agreement (Willmott, Robeson, and Matsuura 2011) between model predictions and observations.

Covid-19 Restrictions

The government restrictions during the Covid-19 pandemic which led to reductions in air pollutant concentrations are complex. The *Oxford Covid-19 Government Response Tracker* has reported a daily *stringency index* describing current restrictions for each country since January 2020 (Hale et al 2021). The index provides a useful indication of government restrictions and is presented alongside pollution data in some figures below. The index has values from 1 (few Covid-related restrictions) to 100 (severe restrictions). The tracker is only available at the country level and makes no distinction between restrictions that are likely to have little effect on air pollutant emissions and restrictions where the effect could be significant.

Inter-annual Comparisons

We present monthly average data and report changes in pollution during 2020 and 2021 relative to pre-pandemic baseline conditions. Much of the analysis is focused on the month of April which was the first month during 2020 when the Government Response Tracker indicates significant restrictions were in place in all of the included locations. In this analysis the pre-pandemic baseline is defined as the average of the April 2018 and 2019 monthly mean. A time series of monthly averages during 2020 and 2021 is also provided for each location. The results of the deweathering analysis are presented as an anomaly with respect to the pre-pandemic baseline.

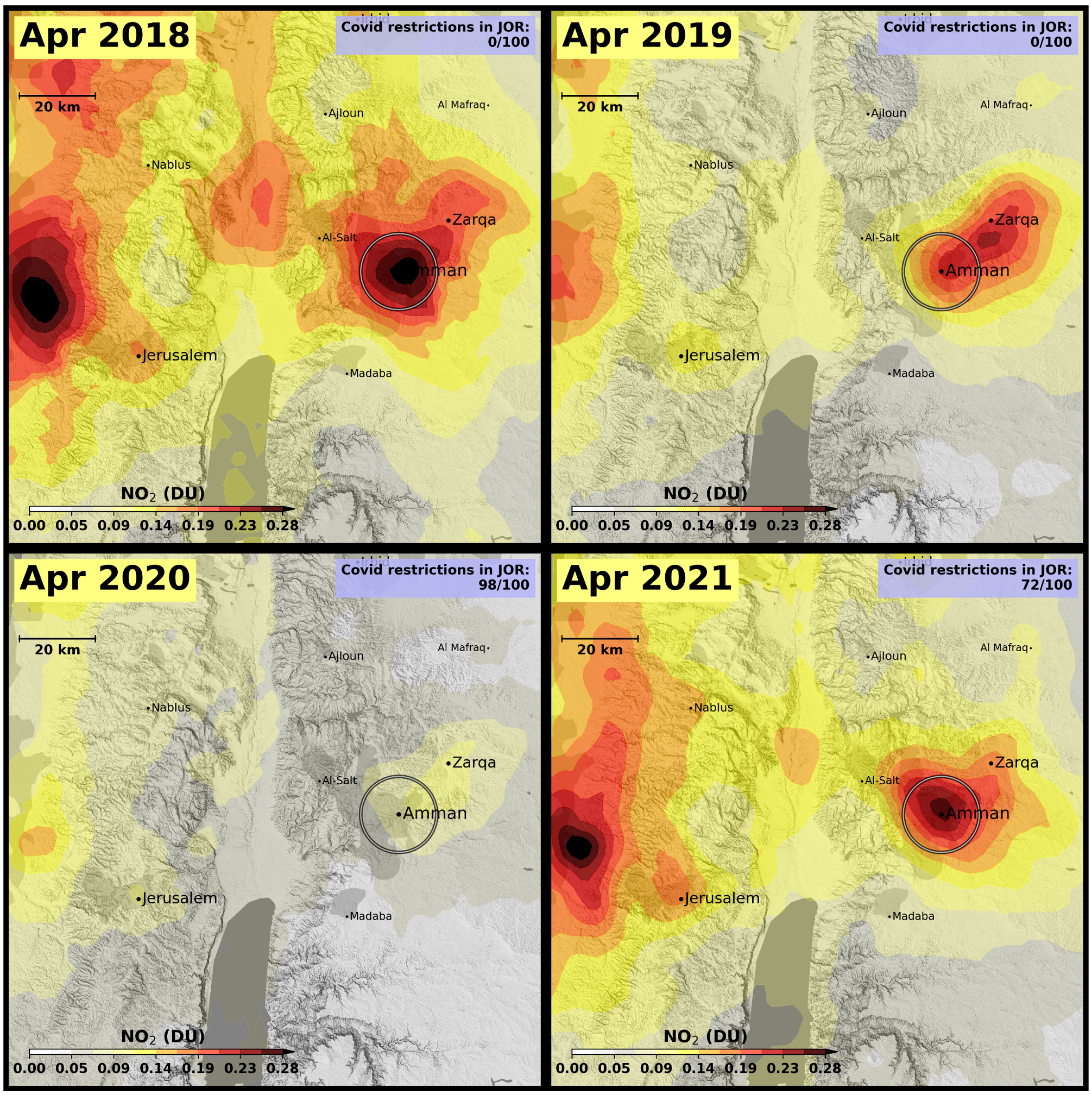
Results Summary

- Consistent with previous research findings, in many locations around the world we find that NO_2 air pollution was substantially lower in the first half of 2020 than during the same period of previous years.
- One year after initial Covid lockdowns went into effect, NO_2 pollution had rebounded in all of the areas studied. This result was supported even after weather conditions were taken into account.
- Air pollution did not fully return to pre-Covid levels in most areas studied, likely at least in part because many of the same restrictions on activity remained in place.
- The results of the weather-correction analysis confirm that the 2020 drop in NO_2 pollution and subsequent 2021 rebound occurred primarily due to changes in emissions, while weather influence was only of secondary importance in most places.
- Gauteng province, South Africa, where Johannesburg is located, saw the most dramatic increase relative to pre-Covid conditions. Satellite observations reveal NO_2 pollution fell by approximately 20% in April 2020, but pollution during the same period in 2021 had rebounded to values exceeding pre-pandemic levels by approximately 47% (a 77% increase from 2020).
- Despite major decreases in air pollution in early 2020, in a number of cities, including Bangkok and Jakarta, NO2 had returned to pre-Covid levels one year after initial lockdowns.
- Although all cities saw NO_2 pollution rebounds in April 2021, in some cities, including Los Angeles and Wuhan, NO_2 pollution remained below pre-COVID levels.

Results by Location

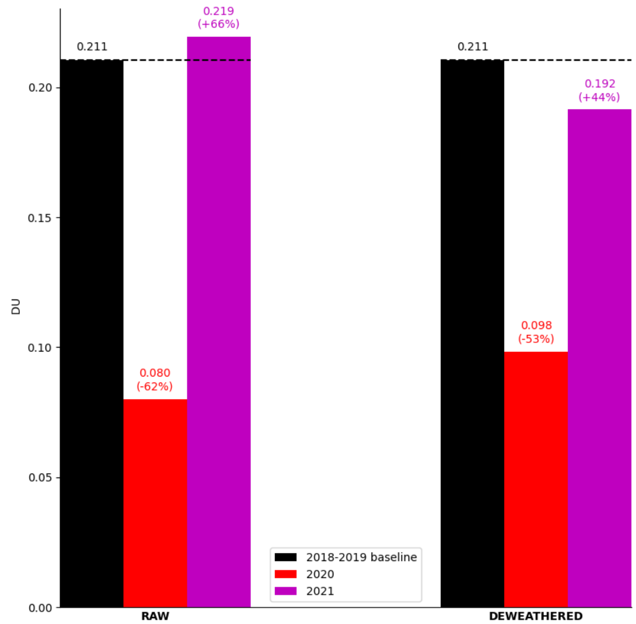
Amman (Jordan)

NO_2 air pollution around Amman dropped by about 60% in April 2020, as compared to the same period in the 2018-2019 average. There was a strong increase in April 2021, overshooting pre-Covid levels. Although confidence in the Amman deweather model is low, the results when accounting for weather agree with the raw data and suggest that the observed changes in NO_2 air pollution are related to a 2020 decrease and 2021 increase in pollutant emissions.

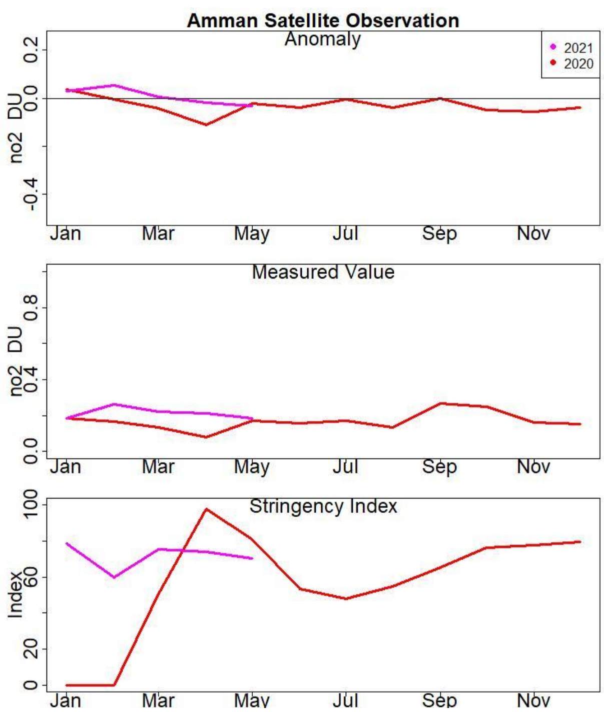


Maps: NO_2 column amount in April 2018 through 2021 in the Amman area. The circle has a 10km radius around the city centre.

Map data: © GADM 3.6, SRTM1, Digital Chart of the World, cities15000, OpenStreetMap contributors and wikipedia. See Map Acknowledgements for details.



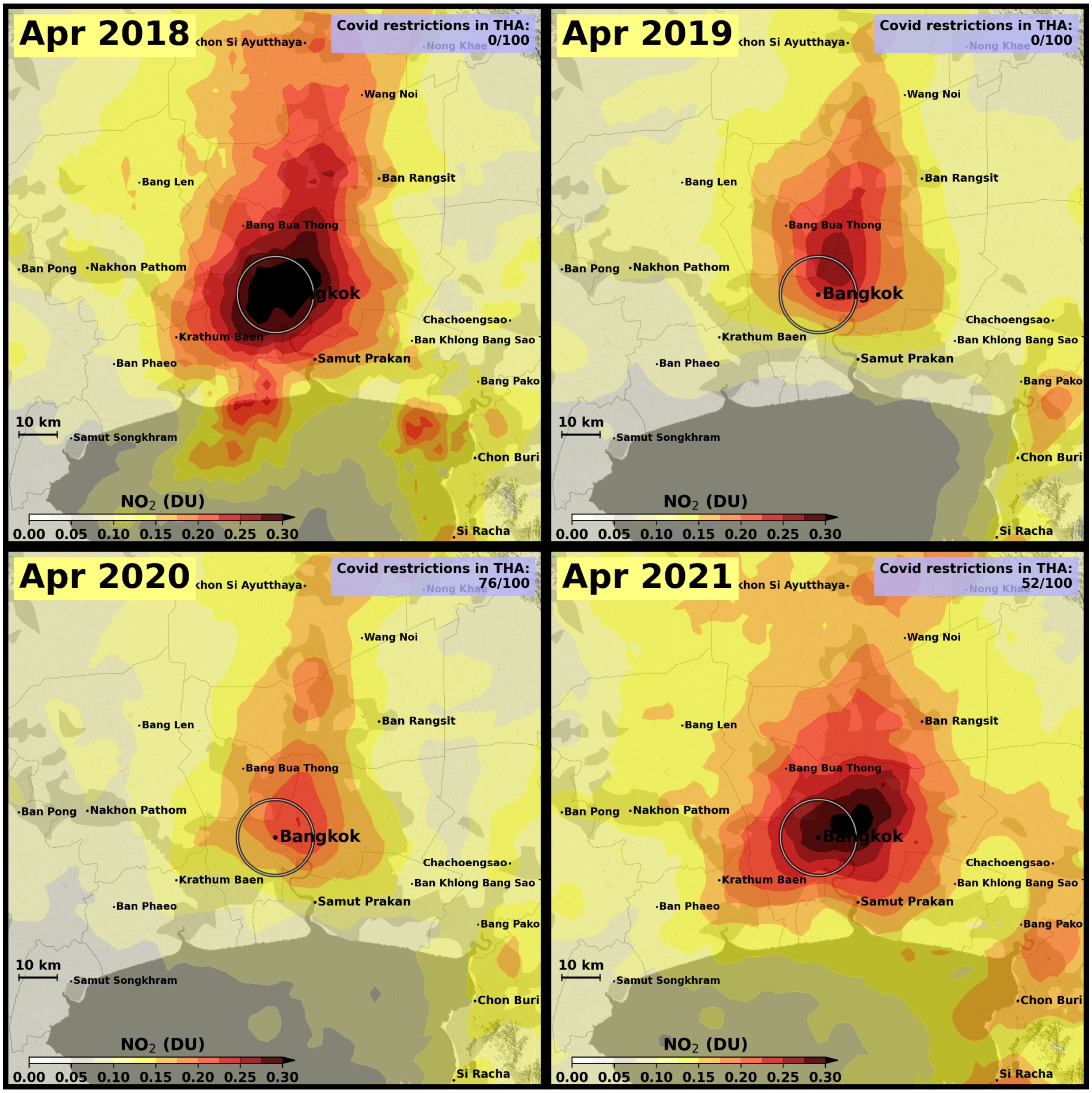
Bar chart: April NO_2 column amount for the circular area marked on the maps. Left: raw data. Right: NO_2 column amount after removing the effects of weather.



Line charts: Monthly average NO_2 column amount observed by satellite in a 10km radius around Amman shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (blue).

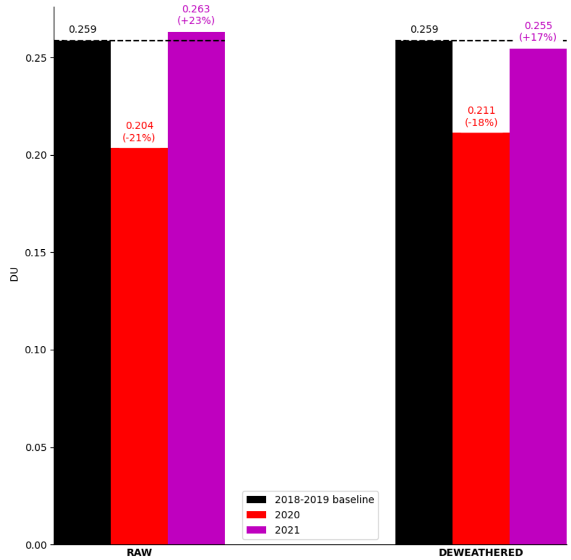
Bangkok (Thailand)

In Bangkok, NO_2 column amount in 2020 dropped by 21% compared to the 2018-2019 average. However in 2021, it returned back to pre-Covid levels, even when accounting for weather.

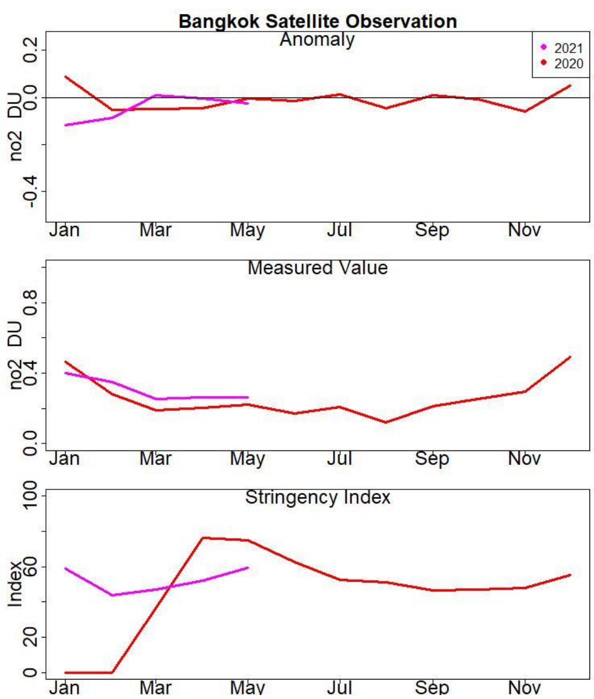


Maps: NO_2 column amount in April 2018 through 2021 in Bangkok area. The circle has a 10km radius around the city centre.

Map data: © GADM 3.6, SRTM1, Digital Chart of the World, cities15000, OpenStreetMap contributors and wikipedia. See Map Acknowledgements for details.



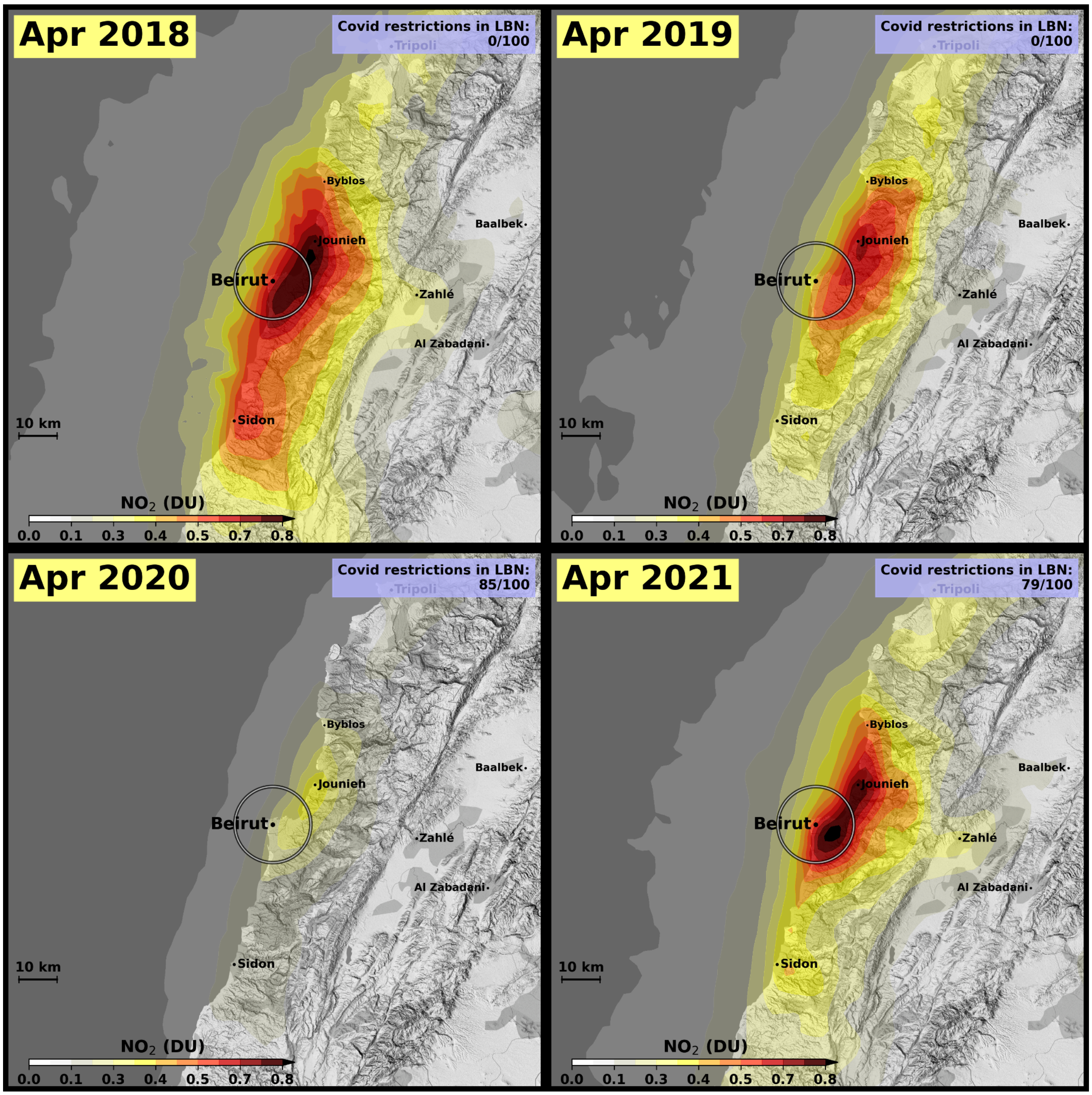
Bar chart: April NO_2 column amount for the circular area marked on the maps. Left: raw data. Right: NO_2 column amount after removing the effects of weather.



Line charts: Monthly average satellite-observed NO_2 column amount for Bangkok shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (blue).

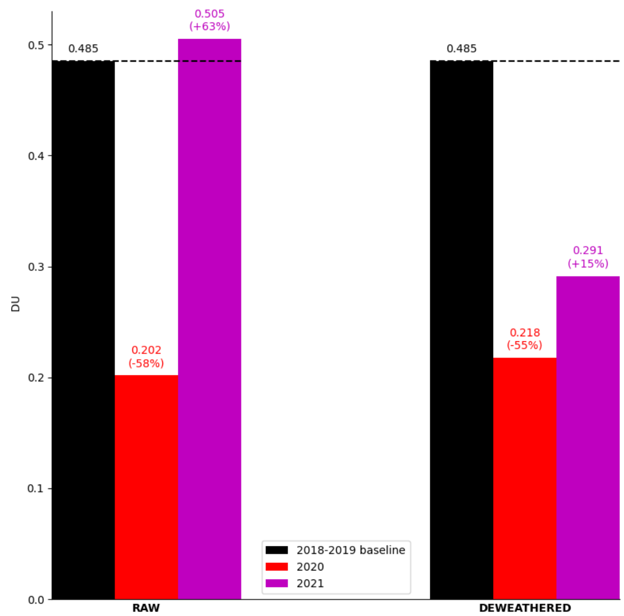
Beirut (Lebanon)

NO_2 air pollution column amount in Beirut dropped by more than 50% in April 2020 compared to the 2018-2019 average of the same month. Deweathering analysis indicates that weather was not the principal cause of this decrease. In April 2021 NO_2 air pollution column amount had rebounded to exceed pre-Covid levels. The deweathering analysis suggests that most of this rebound was driven by changes in weather conditions. The analysis suggests a rebound to 65% of pre-Covid levels is attributable to changes in emissions.

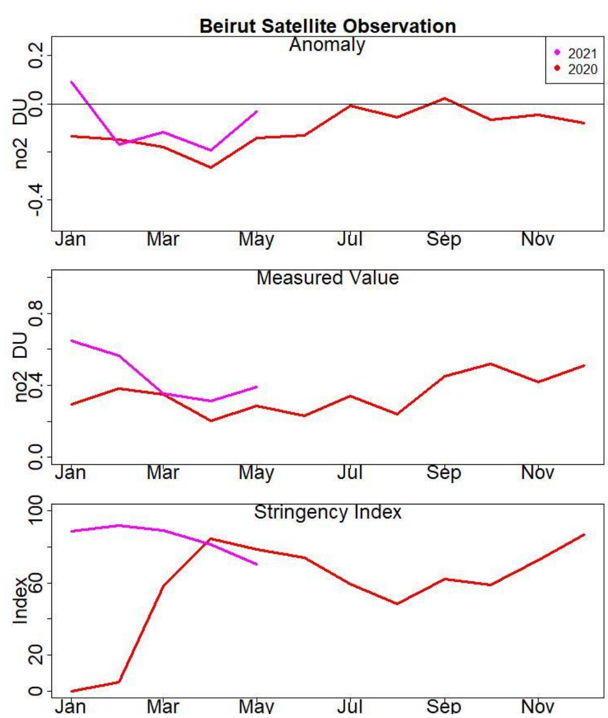


Maps: NO_2 column amount in April 2018 through 2021 in the region around Beirut. Circle has a 10km radius around the centre of Beirut.

Map data: © GADM 3.6, SRTM1, Digital Chart of the World, cities15000, OpenStreetMap contributors and wikipedia. See Map Acknowledgements for details.



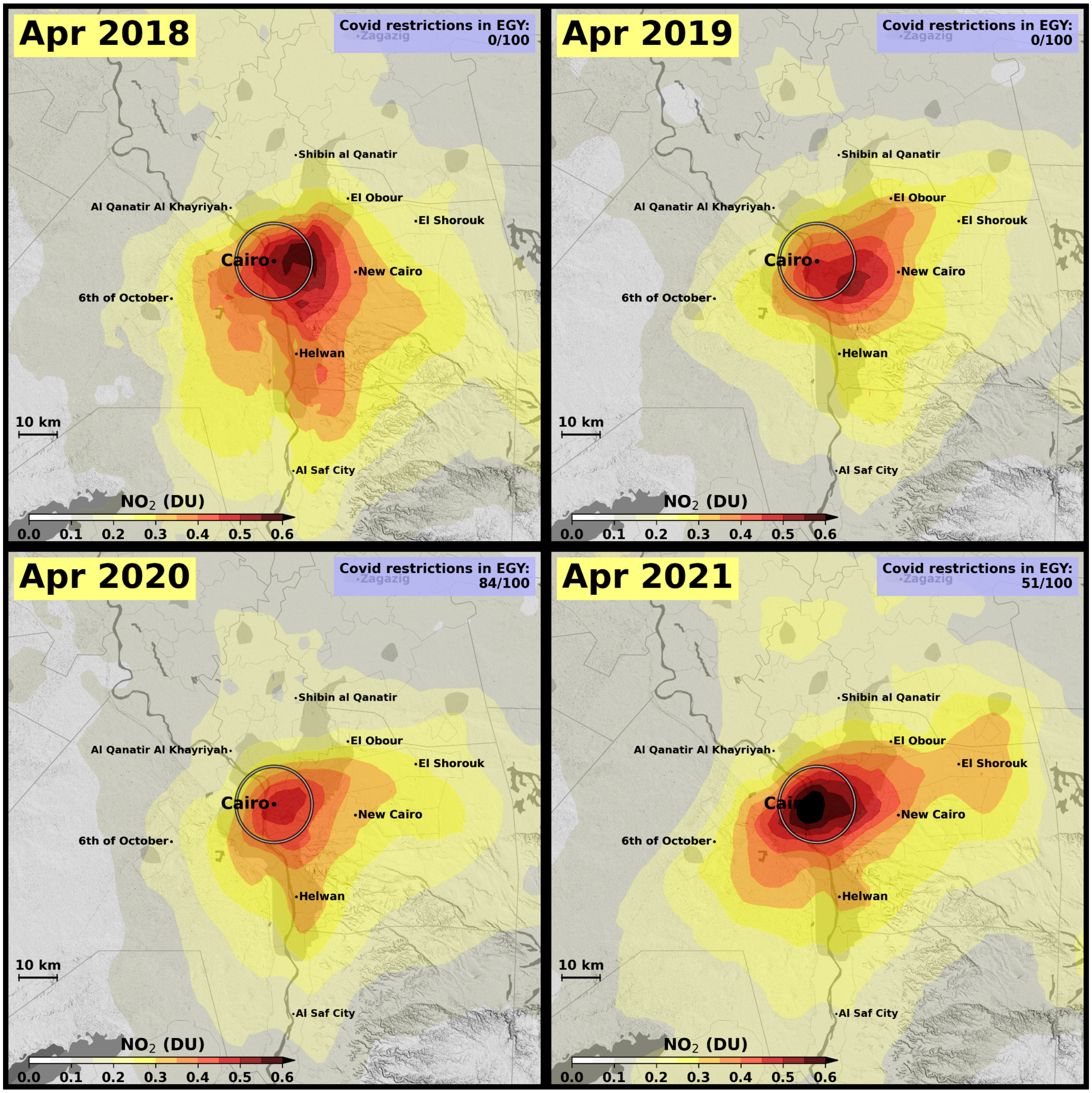
Bar chart: April NO_2 column amount in a 10km-radius around Beirut city centre (marked on the maps). Left: raw data, right: deweathered data.



Line charts: Monthly average satellite-observed NO_2 column amount for the Beirut region defined in the maps above (middle) shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (blue).

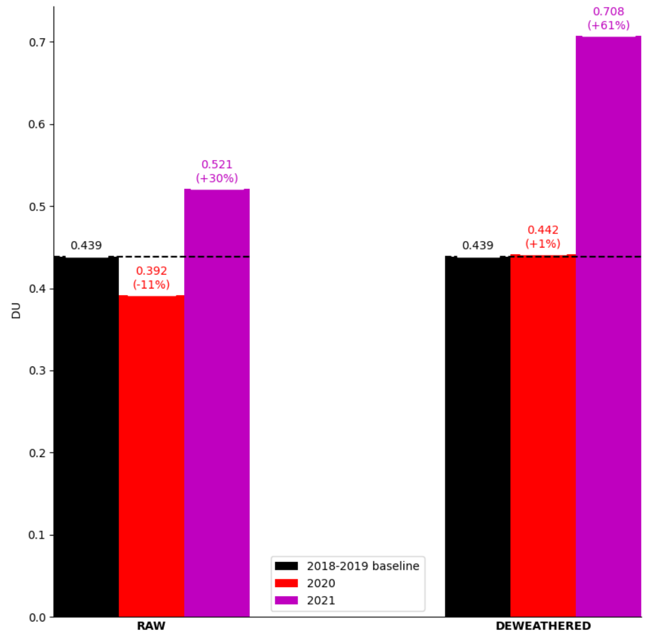
Cairo (Egypt)

In Cairo, the 2020 April average NO_2 column amount differed by only 10% from the 2018-2019 average. This small change cannot be differentiated from that attributable to changing weather conditions. In 2021, NO_2 levels overshot pre-Covid values by 30%. We estimated that NO_2 levels could have been as high as 60% above pre-Covid levels, had weather conditions been similar to 2018-2019.

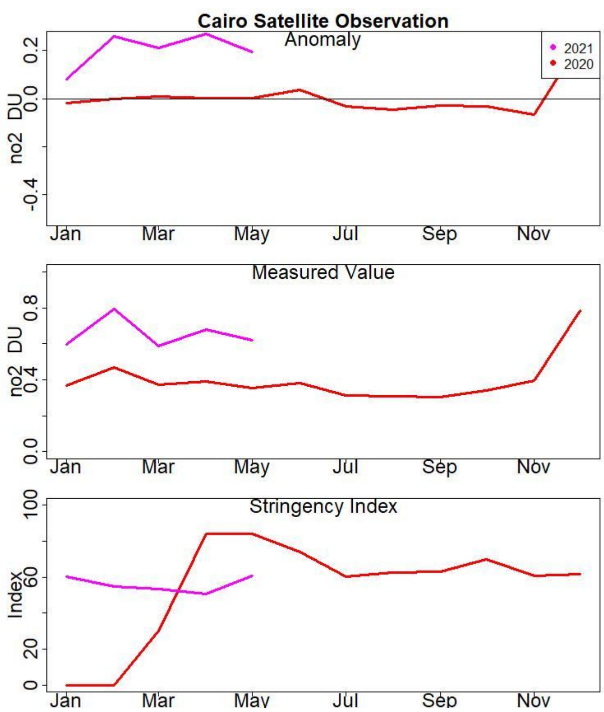


Maps: NO_2 column amount in April 2018 through 2021 in the region around Cairo. The circle has a 10km radius around the centre of Cairo.

Map data: © GADM 3.6, SRTM1, Digital Chart of the World, cities15000, OpenStreetMap contributors and wikipedia. See Map Acknowledgements for details.



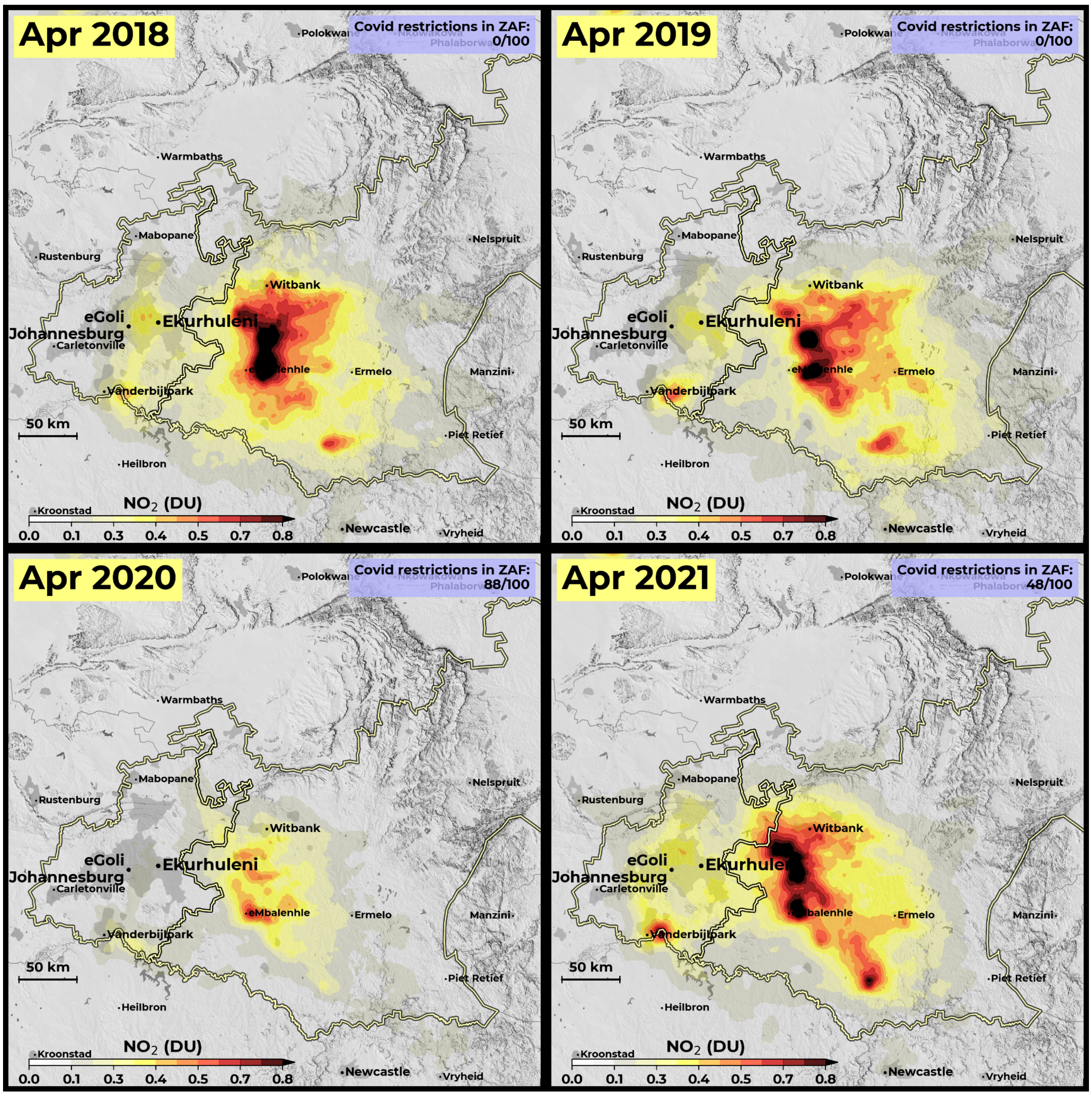
Bar chart: April NO_2 column amount in a 10km-radius around Cairo city centre (marked on the maps). Left: raw data, right: deweathered data.



Satellite observation line charts: Monthly average NO_2 column amount for the Cairo region defined in the maps above (middle) shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (blue).

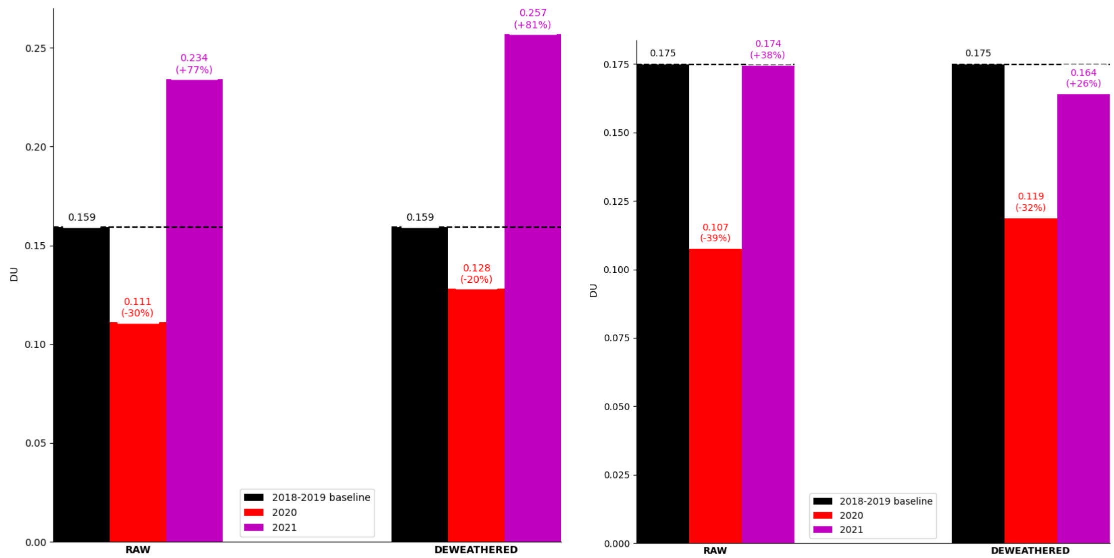
Gauteng & Mpumalanga (South Africa)

NO_2 pollution in Gauteng, the province in which Johannesburg is located, dropped by about 30% in April 2020 as compared to the average of 2018-2019. We estimate that about one-third of this drop is a result of changing weather conditions, and about two-thirds of the drop (i. e. a 20% reduction from 2018-2019 levels) can be attributed to changes in pollutant emissions. In April 2021, the measured NO_2 column amount overshot pre-Covid levels by about 47%. The deweathering analysis suggests that the overshoot would have been as high as 61%, had weather conditions in 2021 been similar to 2018-2019. In the heavily polluted Mpumalanga province east of Johannesburg, a similar drop was observed in April 2020, but NO_2 column amount levels did not overshoot in 2021.

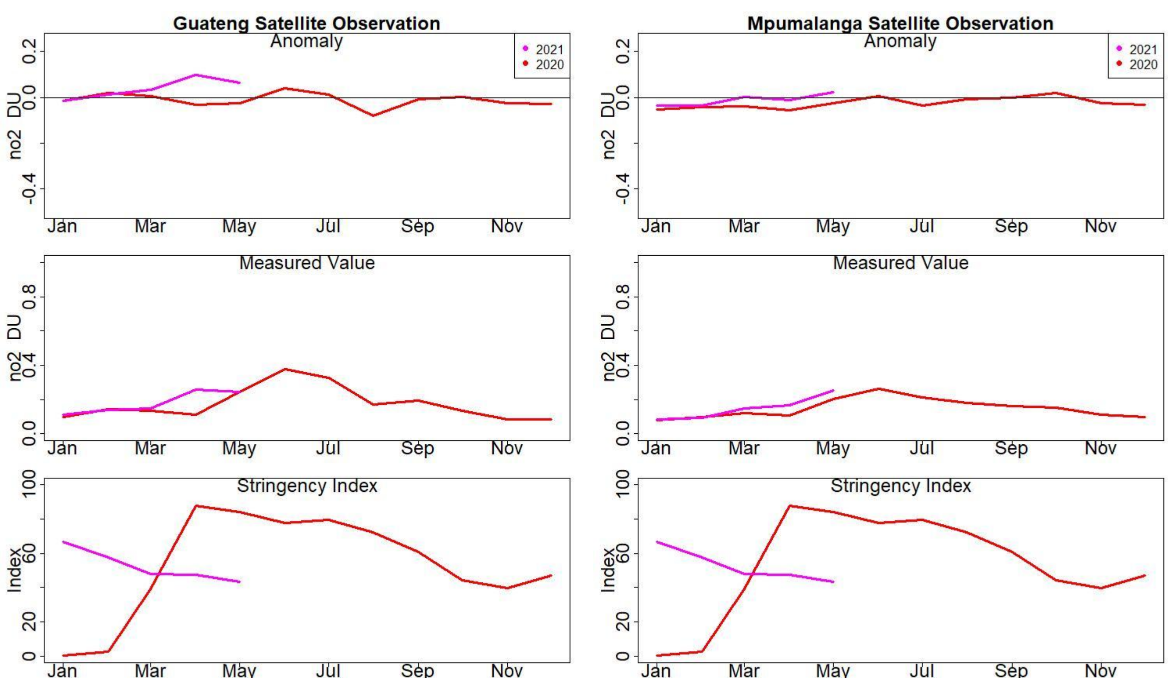


Maps: NO_2 column amount in April 2018 through 2021 in the region around Johannesburg. Polygons mark the Gauteng (west) and Mpumalanga (east) provinces.

Map data: © GADM 3.6, SRTM1, Digital Chart of the World, cities15000, OpenStreetMap contributors and wikipedia. See Map Acknowledgements for details.



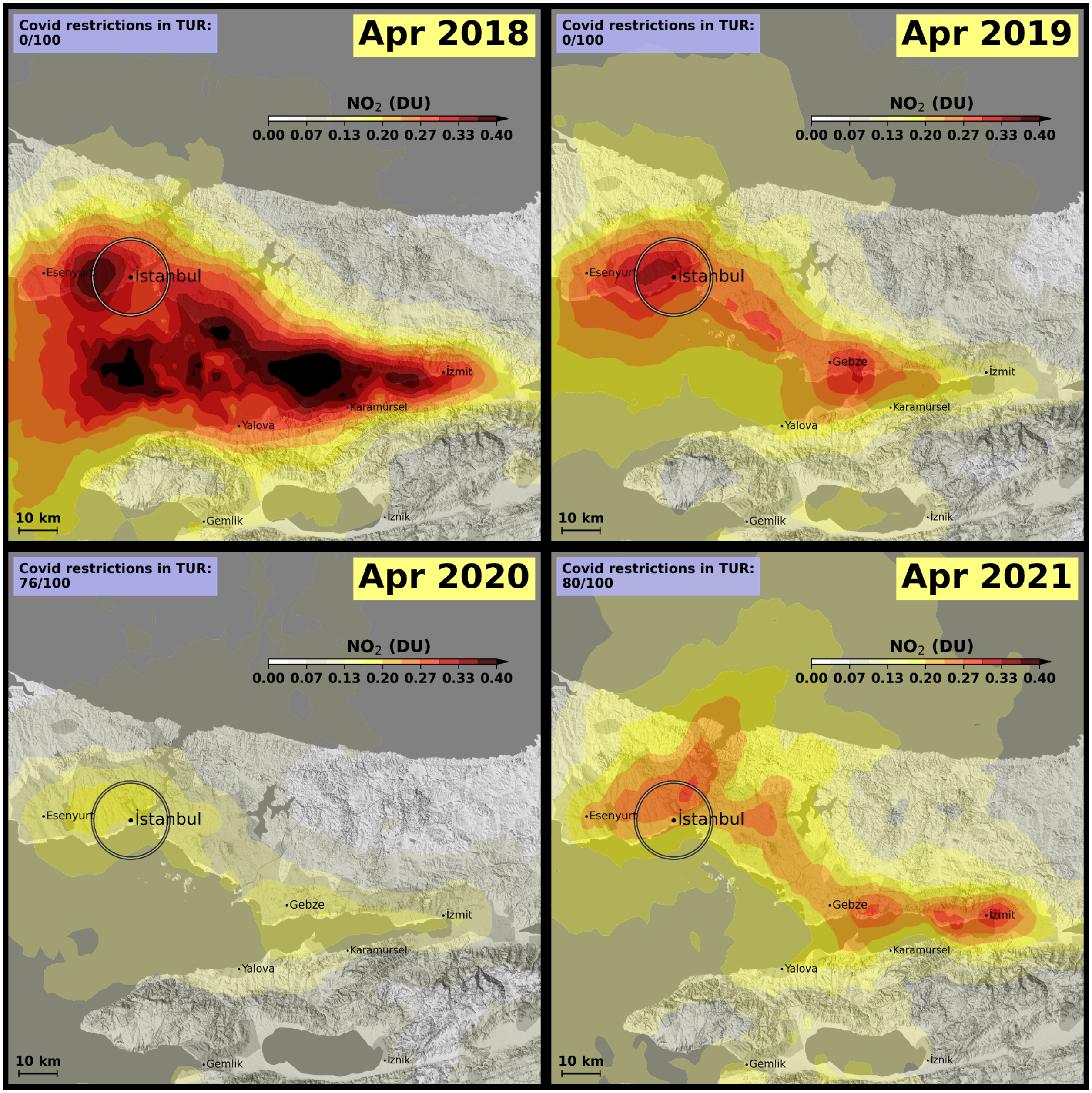
Left bar chart: April NO_2 column amount in Gauteng (left bars: raw data, right bars: deweathered data). **Right bar chart:** Same for Mpumalanga.



Line charts: Monthly average satellite-observed NO_2 column amount for the Gauteng and Mpumalanga provinces shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (blue).

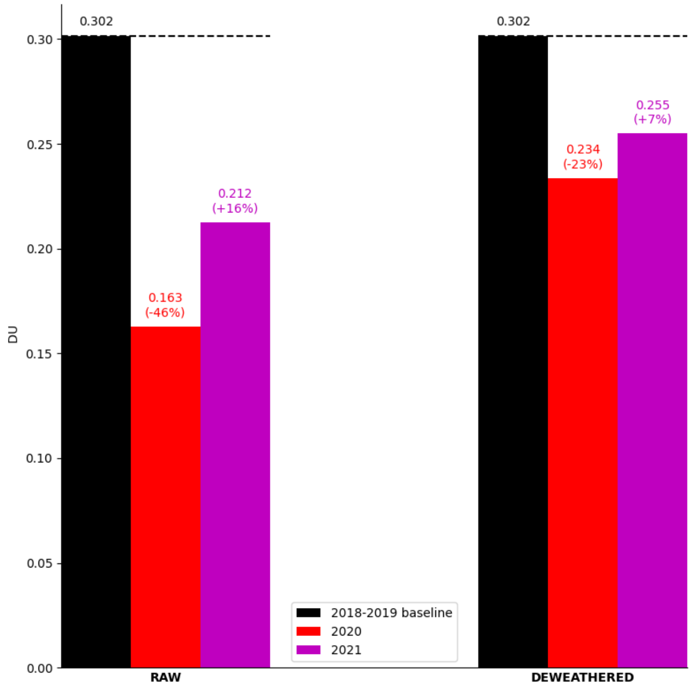
Istanbul (Turkey)

NO_2 air pollution around Istanbul dropped by about 46% in April 2020, as compared to previous years. About half of this decrease is found to be due to weather conditions, while the remainder (a decrease of 25% from 2018-2019 average) is attributed to a decrease in emissions. There was a slight rebound towards pre-Covid levels in April 2021, but the deweathered NO_2 column amount remained 16% below the 2018-2019 baseline.

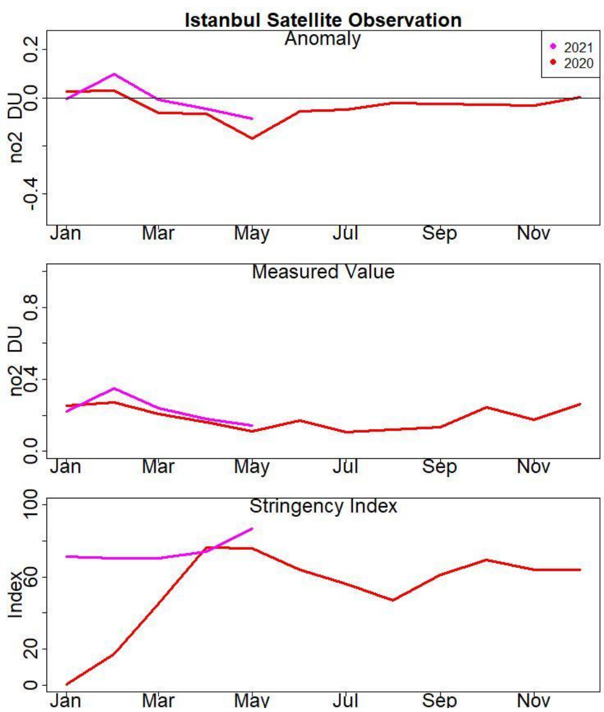


Maps: NO_2 column amount in April 2018 through 2021 in the greater Istanbul area.

Map data: © GADM 3.6, SRTM1, Digital Chart of the World, cities15000, OpenStreetMap contributors and wikipedia. See Map Acknowledgements for details.

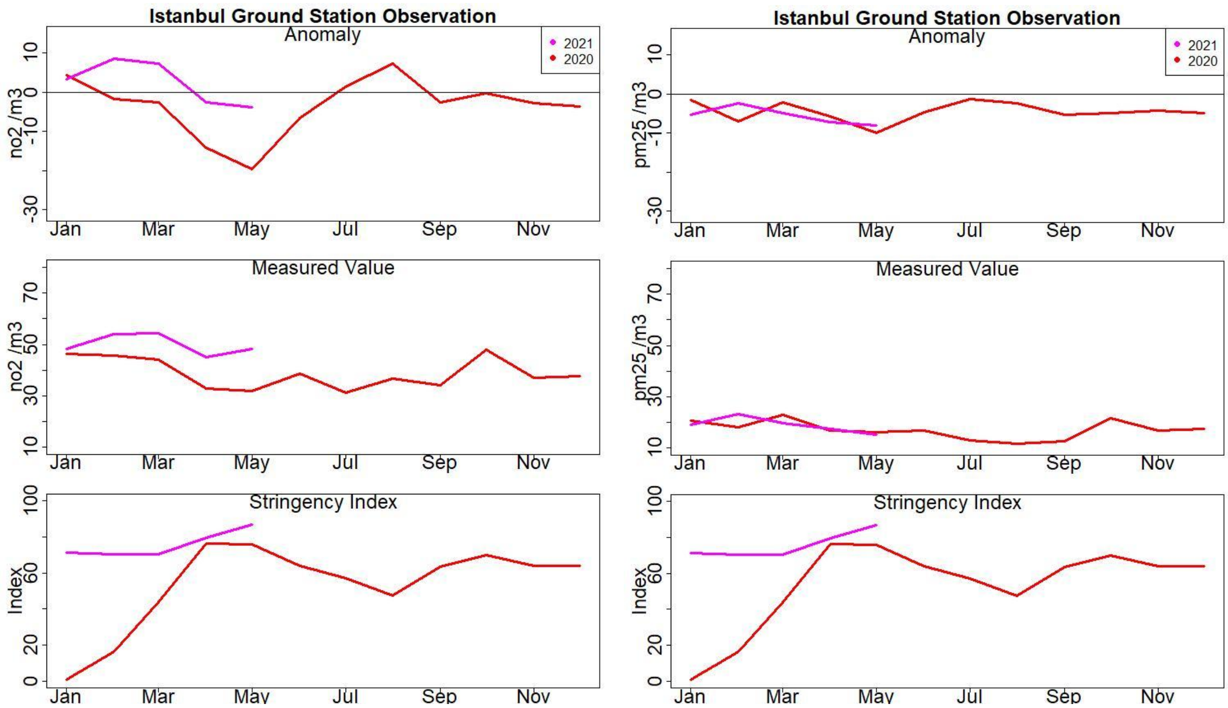


Bar chart: April NO_2 column amount in a 10km radius around Istanbul city centre (marked on the maps). Left: raw data, right: deweathered data.



Satellite observation line charts: Monthly average NO_2 column amount for the Istanbul region defined in the maps above (middle) shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (blue).

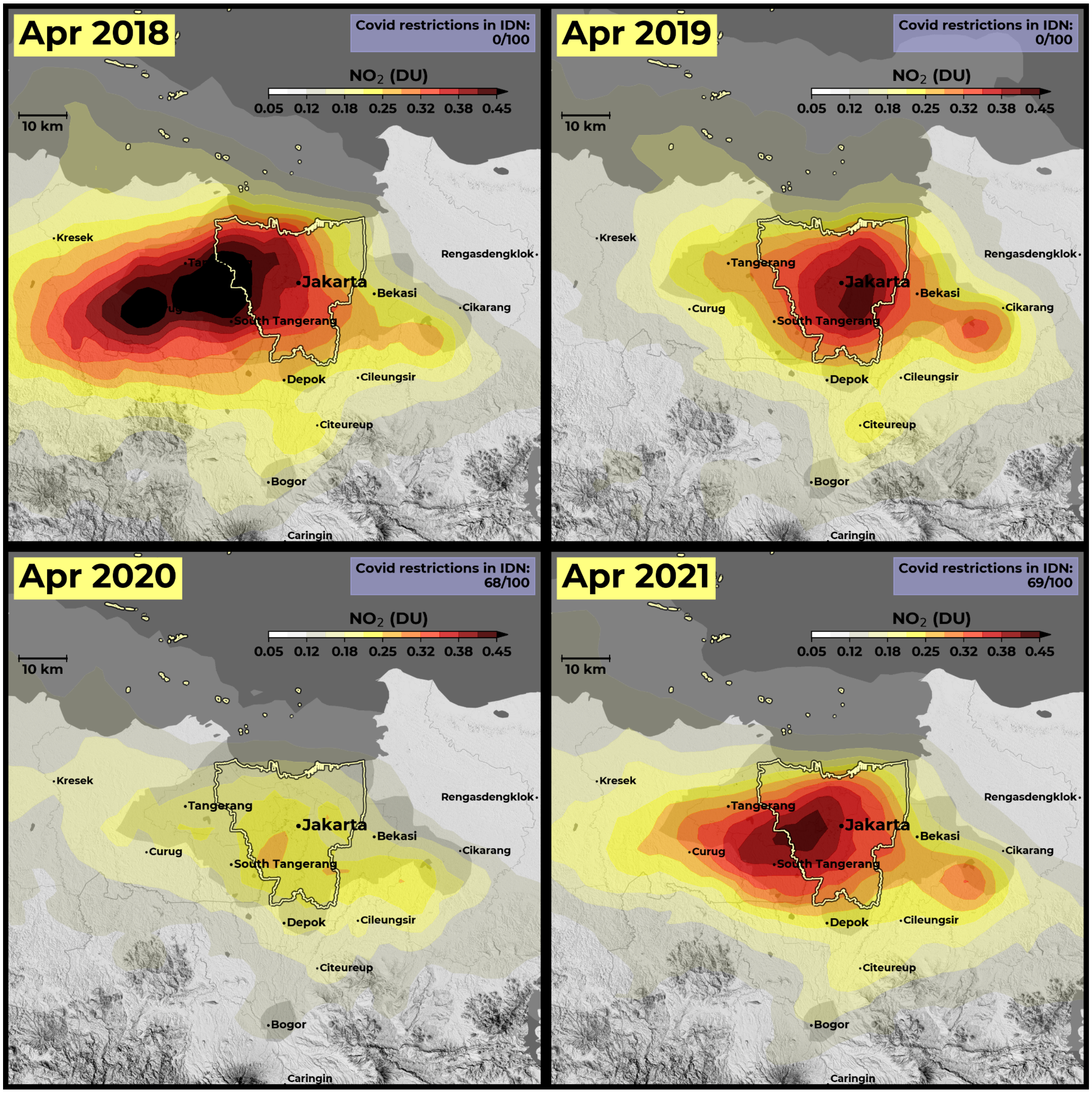
Ground station data:



Line charts: Monthly average pollution concentration as measured by ground-based monitoring stations in Istanbul (middle) shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered pollutant observations prior to the pandemic and during 2020 (red) and 2021 (blue). A simple arithmetic mean is used to combine observations from stations with available data. Left: NO_2. Right: $PM_{2.5}$

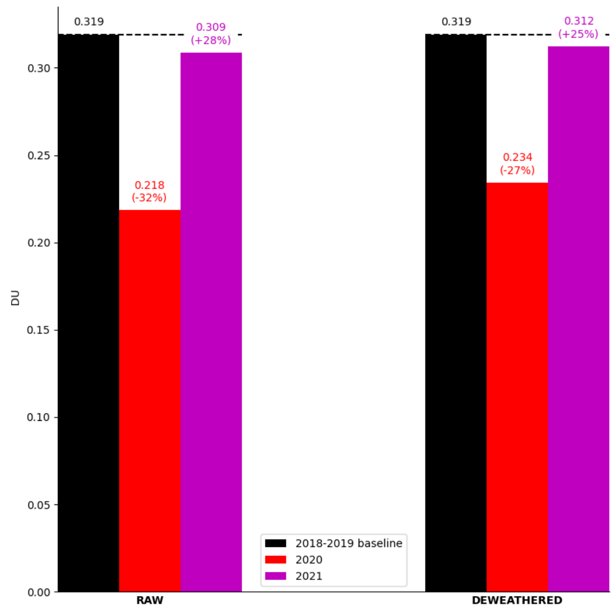
Jakarta (Indonesia)

In Jakarta, NO_2 air pollution dropped by around 30% in April 2020, compared to the average of previous years. In April 2021 the NO_2 column amount had rebounded. The model used to account for weather effects did not perform as well in Jakarta as it did in some other cities. This means that the results of the deweathering process are less certain in Jakarta. The deweathered data agrees with the observed data, cautiously suggesting that pollution level changes are driven by emissions changes.

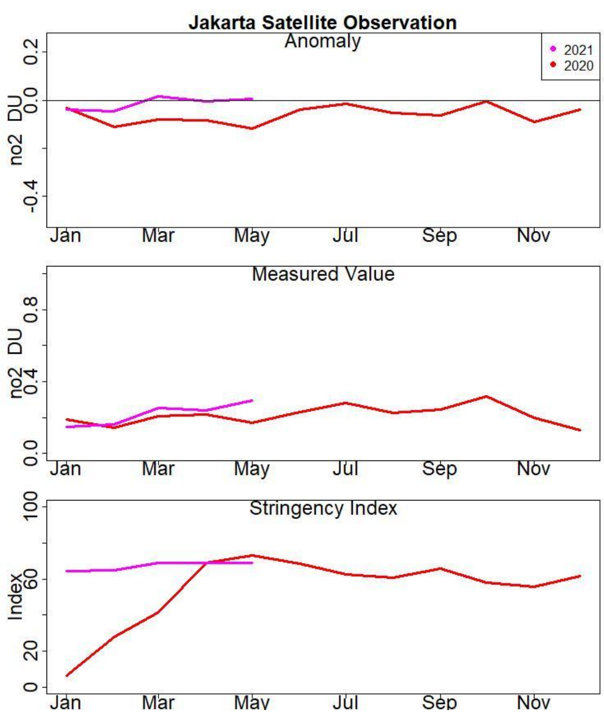


Maps: NO_2 column amount in April 2018 through 2021 around Jakarta. The polygon marks the Jakarta Special Capital Region.

Map data: © GADM 3.6, SRTM1, Digital Chart of the World, cities15000, OpenStreetMap contributors and wikipedia. See Map Acknowledgements for details.



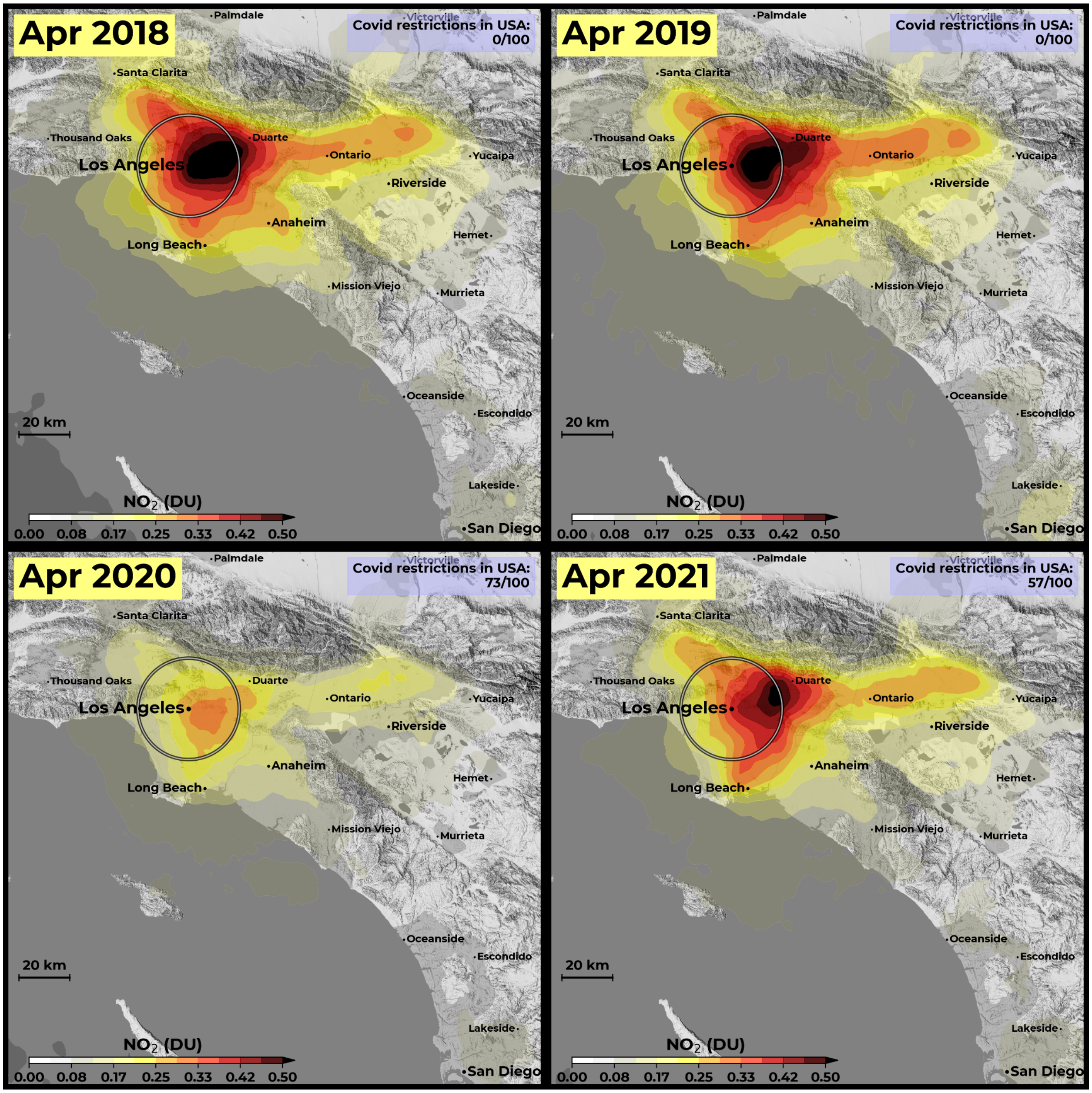
Bar chart: April NO_2 column amount in Jakarta SCR. Left: raw data. Right: NO_2 column amount after removing the effects of weather.



Line charts: Monthly average satellite-observed NO_2 column amount for the Jakarta region defined in the maps above (middle) shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (blue).

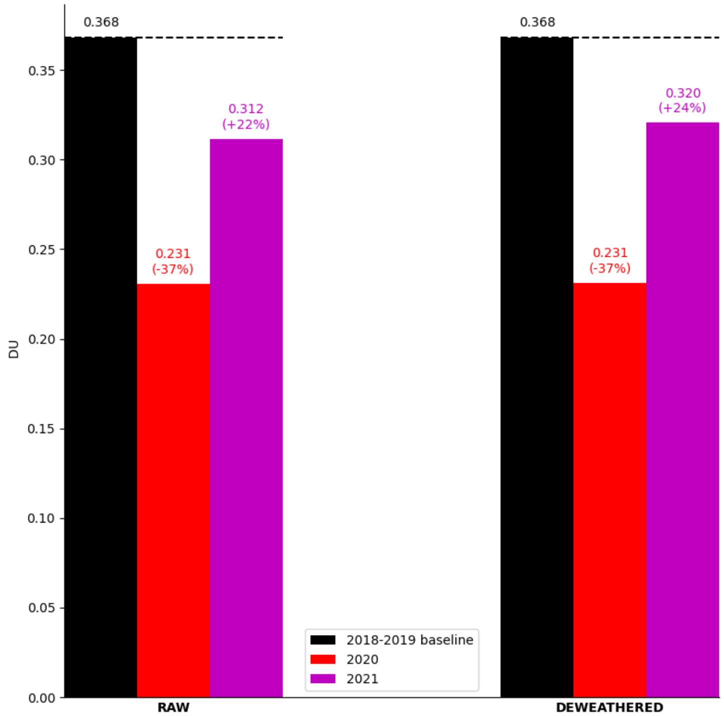
Los Angeles (USA)

Measured NO_2 pollution in April 2020 was almost 40% lower than in previous years. In April 2021 NO_2 column amount returned to around 85% of the pre-Covid levels. The deweathering analysis suggests that weather had little effect on these changes.

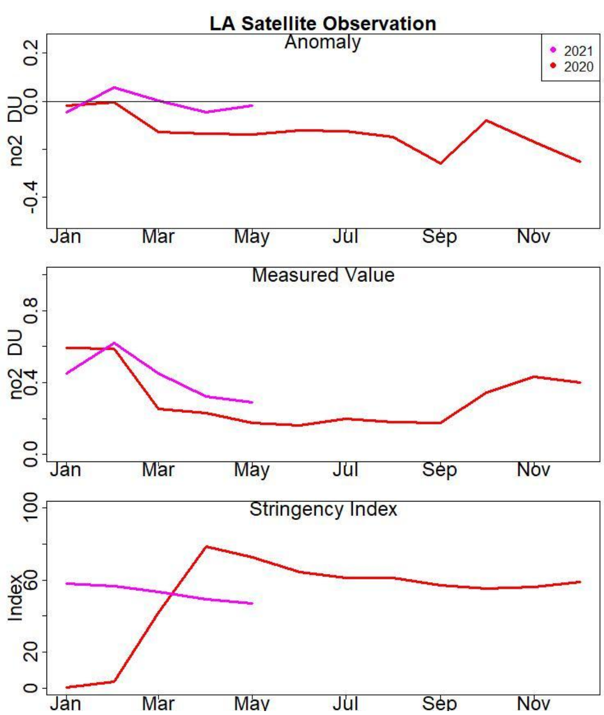


Maps: NO_2 column amount in April 2018 through 2021 in the area around Los Angeles. The circle has a 20km radius around the city centre.

Map data: © GADM 3.6, SRTM1, Digital Chart of the World, cities15000, OpenStreetMap contributors and wikipedia. See Map Acknowledgements for details.

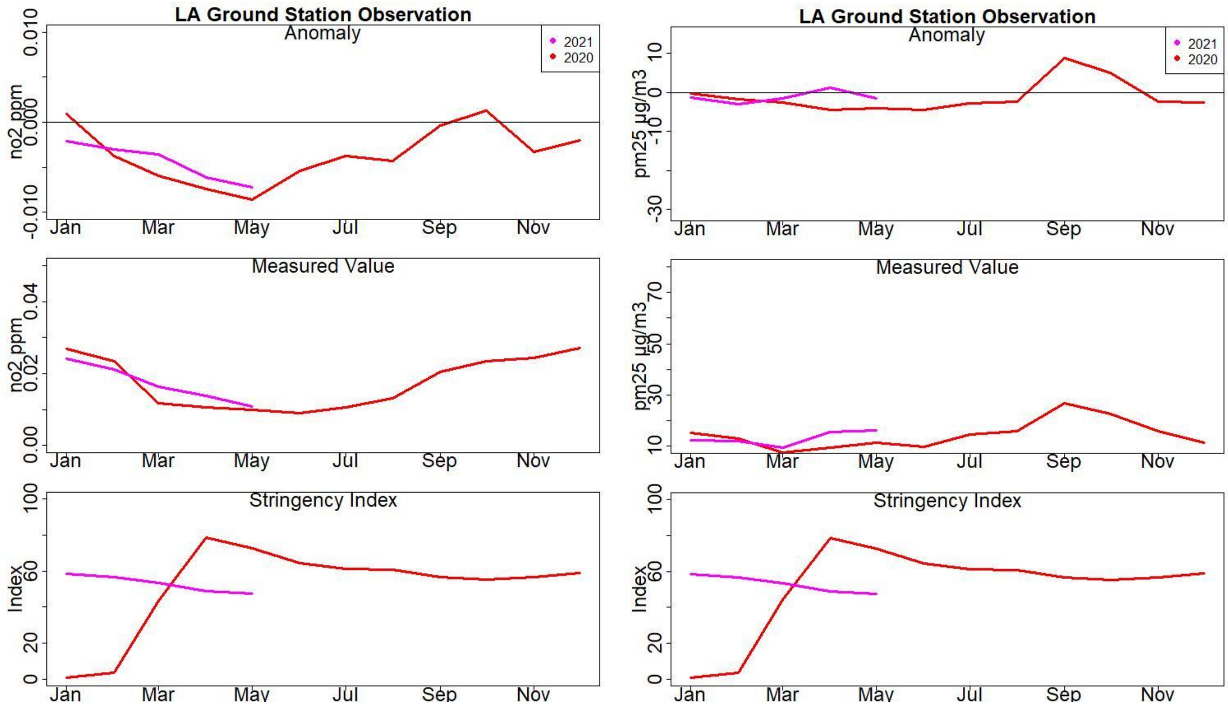


Bar chart: April NO_2 column amount for the circular area marked on the maps. Left: raw data. Right: NO_2 column amount after removing the effects of weather.



Line charts: Monthly average satellite-observed NO_2 column amount for the Los Angeles region defined in the maps above (middle) shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (blue).

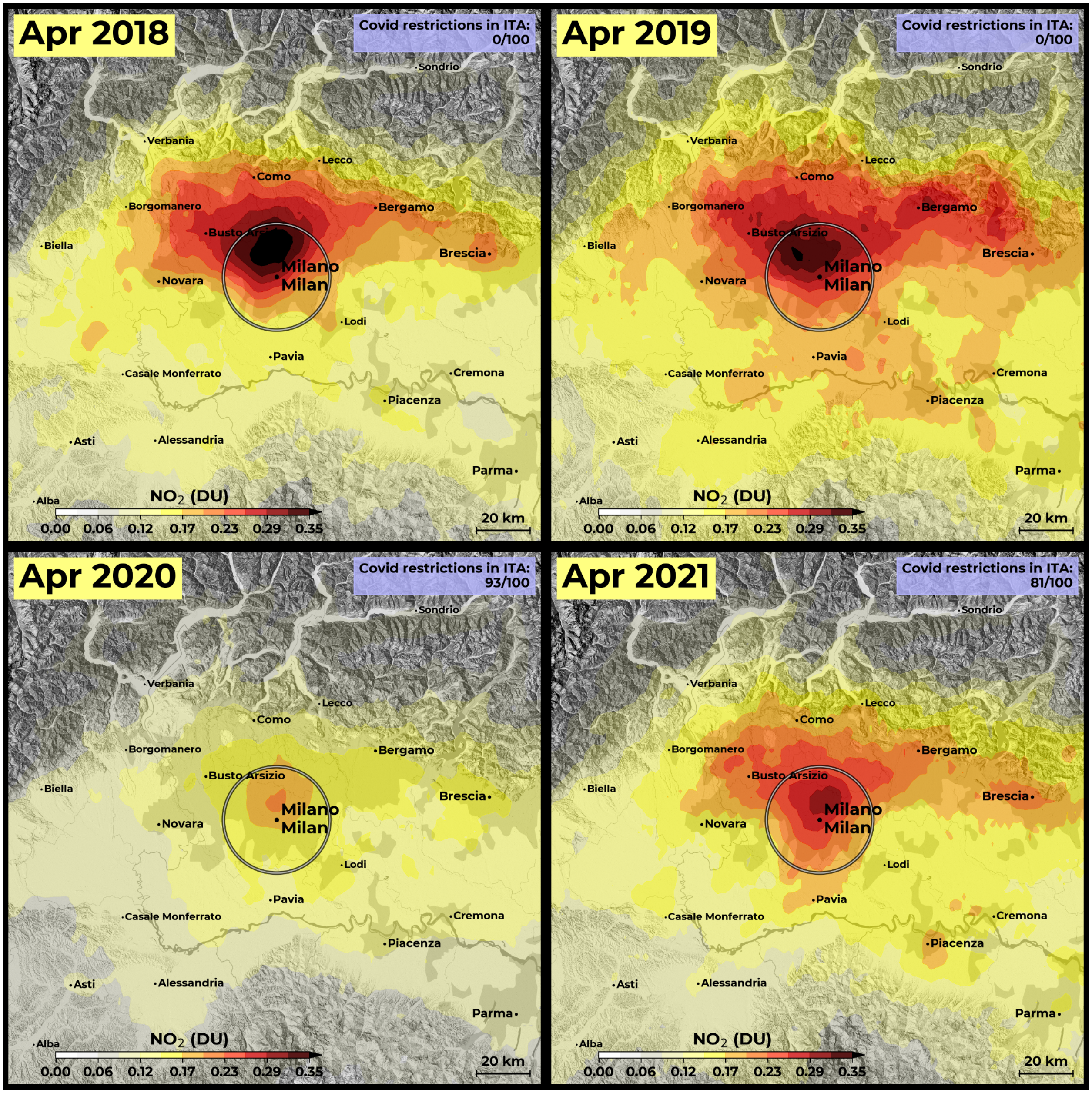
Ground Station Measurements



Line charts: Monthly average pollution concentration as measured by ground based monitoring stations in Los Angeles (middle) shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered pollutant observations prior to the pandemic and during 2020 (red) and 2021 (blue). A simple arithmetic mean is used to combine observations from stations with available data. Left: NO_2. Right: $PM_{2.5}$

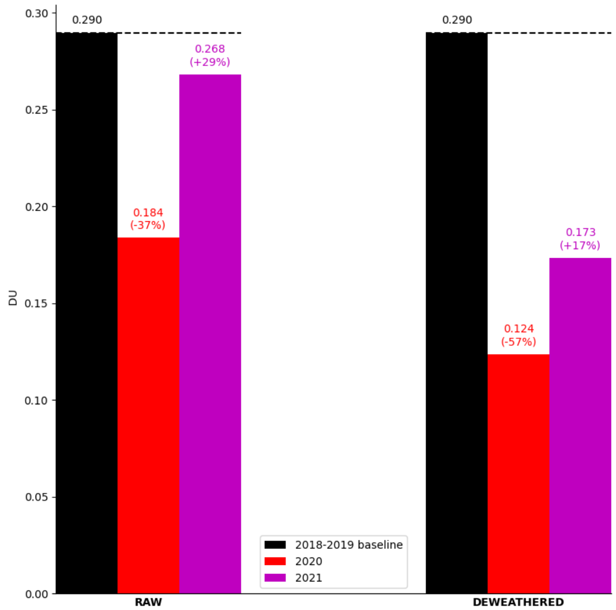
Milan (Italy)

Satellite-measured pollution NO_2 column amounts show NO_2 pollution in Milan was about 37% lower in April 2020 than in the 2018-2019 average. The deweathering analysis suggests that this reduction would have been as much as 57%, had weather conditions been similar to 2018-2019. In April 2021, NO_2 pollution increased to 92% of pre-Covid levels. However, when removing the effects of weather variation, there is a moderate rebound to about 60% of pre-Covid levels in April 2021.

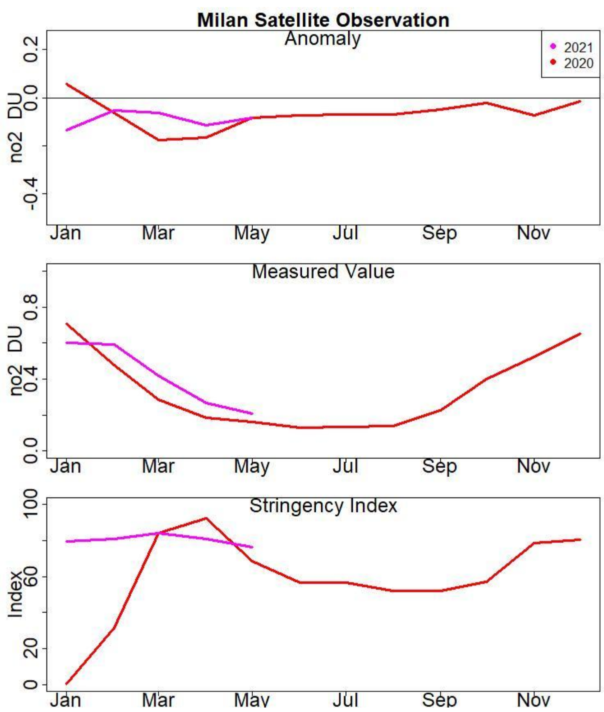


Maps: NO_2 column amount in April 2018 through 2021 in Milan and surrounding area. The circle has a 10km radius around Milan centre.

Map data: © GADM 3.6, SRTM1, Digital Chart of the World, cities15000, OpenStreetMap contributors and wikipedia. See Map Acknowledgements for details.

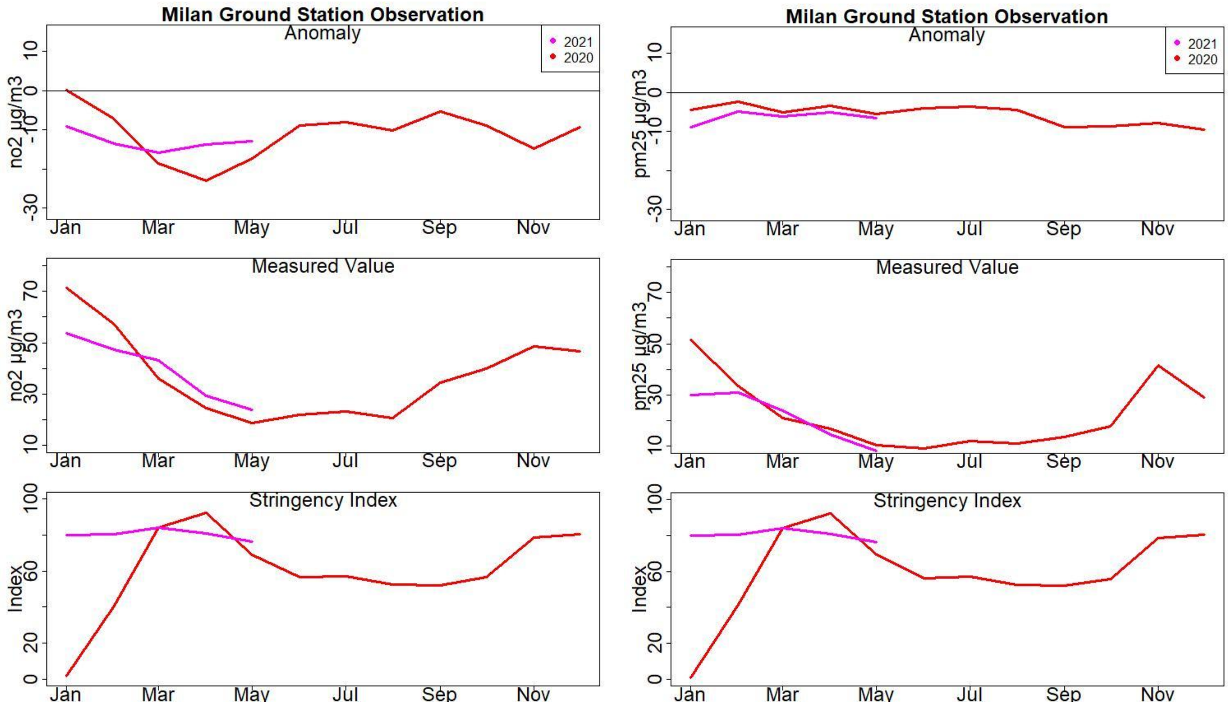


Bar chart: April NO_2 column amount in a 10km radius around Milan. Left bars: raw data. Right bars: Pollution NO_2 column amount after removing the effects of weather.



Line charts: Monthly average NO_2 column amount for the Milan defined in the maps above (middle) shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (blue).

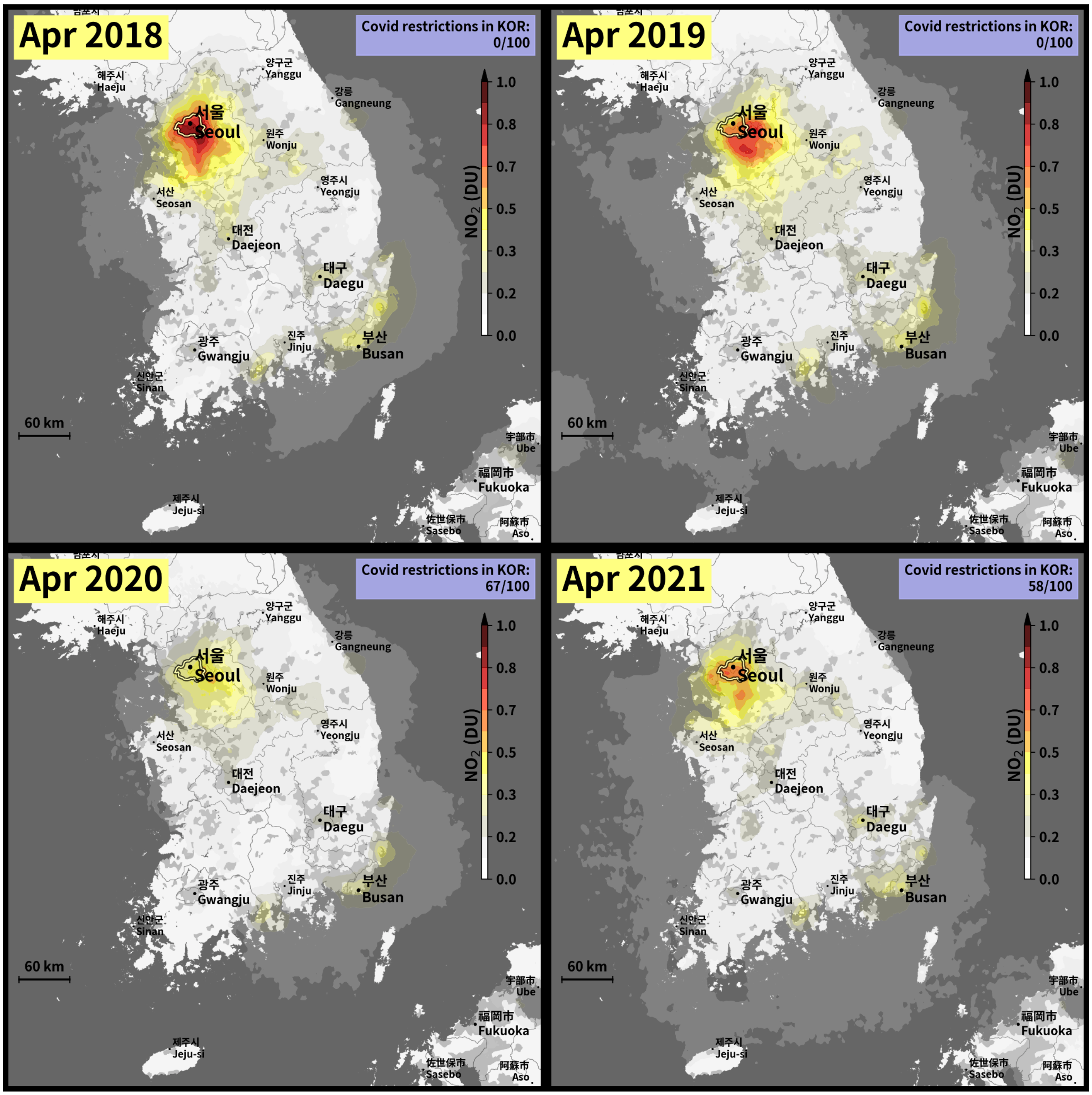
Ground Station Measurements:



Line charts: Monthly average pollution concentration as measured by ground based monitoring stations in Milan (middle) shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered pollutant observations prior to the pandemic and during 2020 (red) and 2021 (blue). A simple arithmetic mean is used to combine observations from stations with available data. Left: NO_2. Right: $PM_{2.5}$

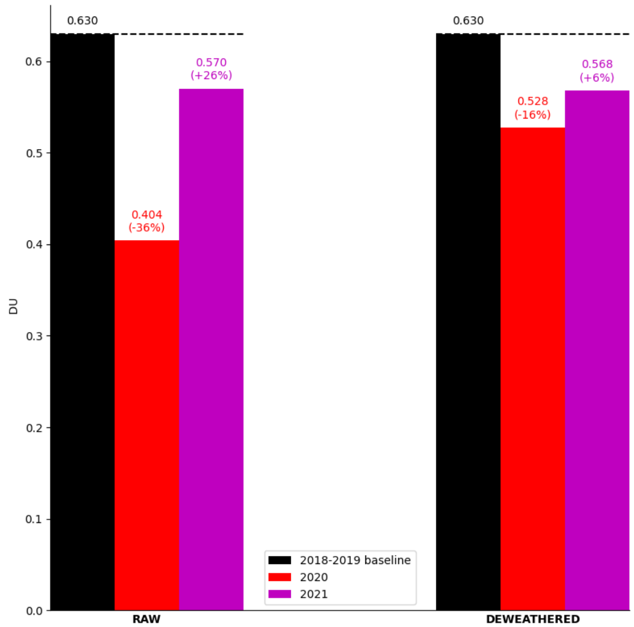
Seoul (South Korea)

NO_2 column amount in April 2020 were 36% lower in Seoul than the average of the same period in the 2018-2019 average, but more than half of this decrease is attributed to weather effects. After correcting the data for weather, NO_2 column amount in Seoul is found to be only 16% lower in April 2020 than in the 2018-2019 average. In April 2021, NO_2 levels rebounded to just 10% below the 2018-2019 average, with negligible influence of weather on this.

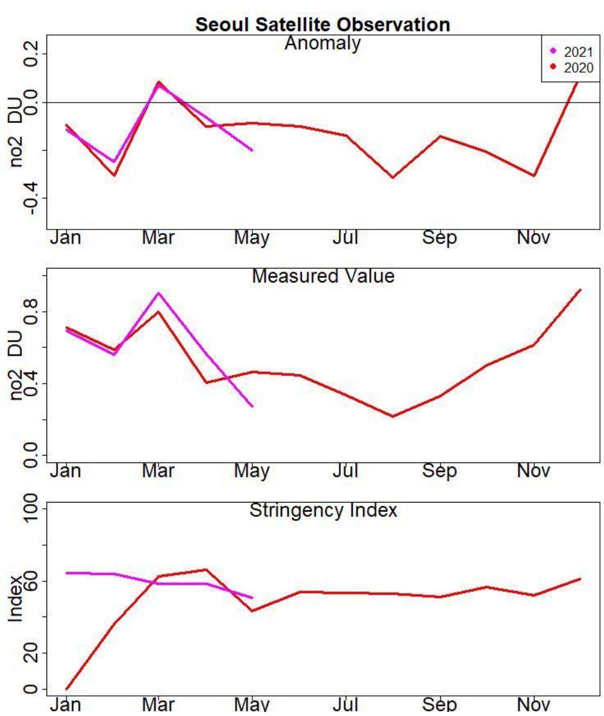


Maps: NO_2 column amount in April 2018 through 2021 in South Korea. The marked polygons show the administrative boundaries of the Seoul Special City.

Map data: © GADM 3.6, SRTM1, Digital Chart of the World, cities15000, OpenStreetMap contributors and wikipedia. See Map Acknowledgements for details.



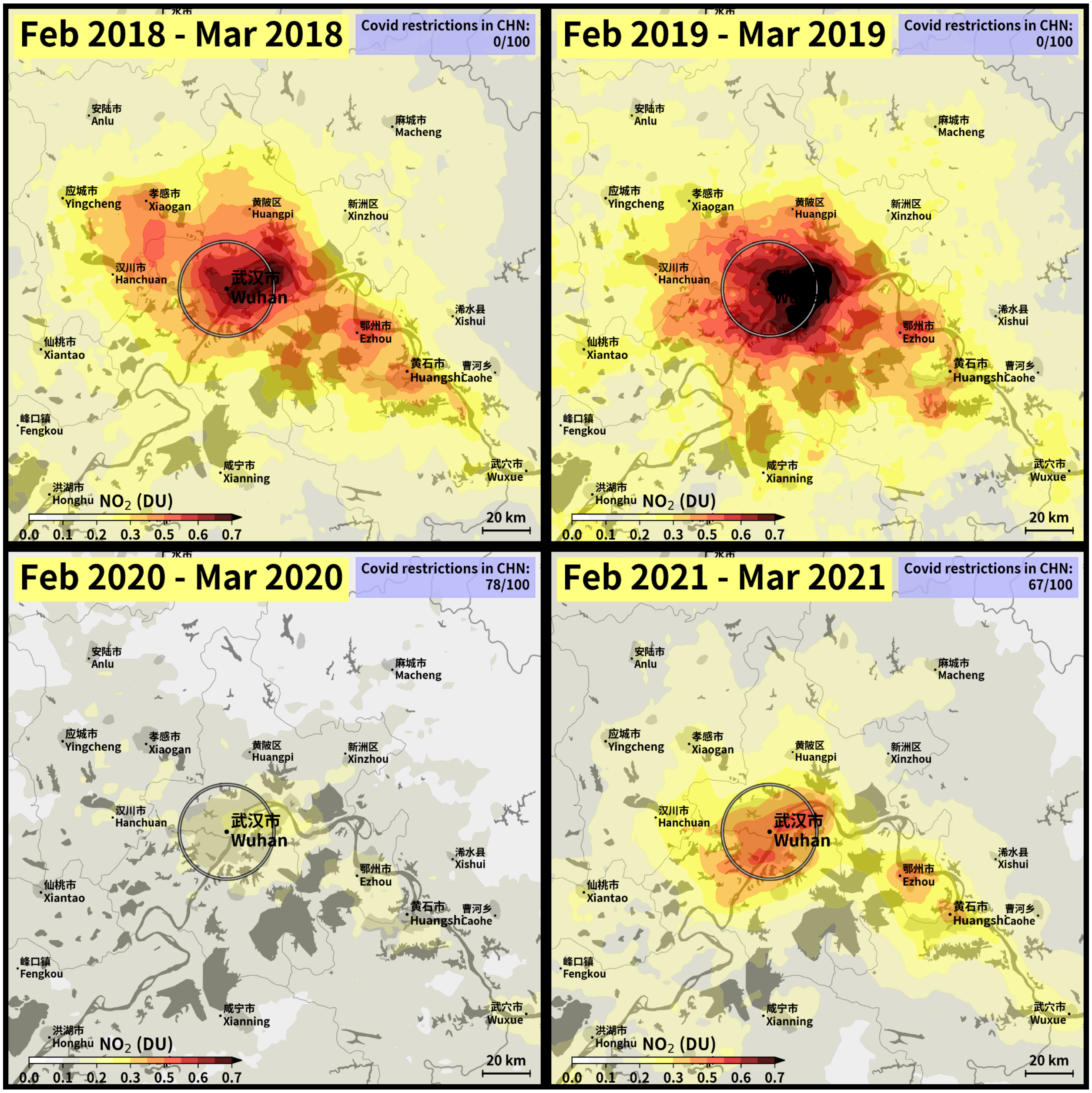
Bar chart: April NO_2 column amount in the city of Seoul.



Line charts: Monthly average satellite-observed NO_2 column amount for Seoul city (middle) shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (blue).

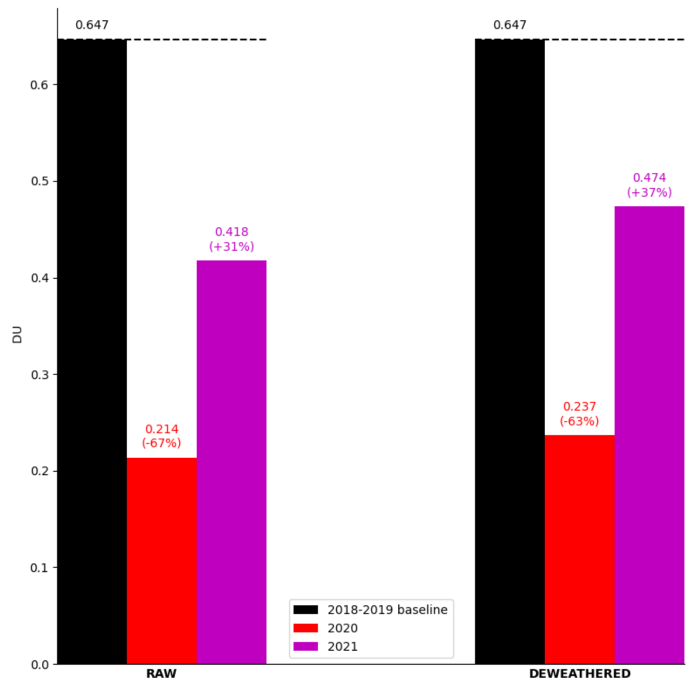
Wuhan (China)

NO_2 pollution in Wuhan dropped by around 65% in February through March 2020. In February through March 2021, NO_2 pollution returned to approximately 30% below pre-Covid levels. The model used to account for weather effects did not perform as well in Wuhan as it did in some other cities. This means that the results of the deweathering process are less certain in Wuhan.

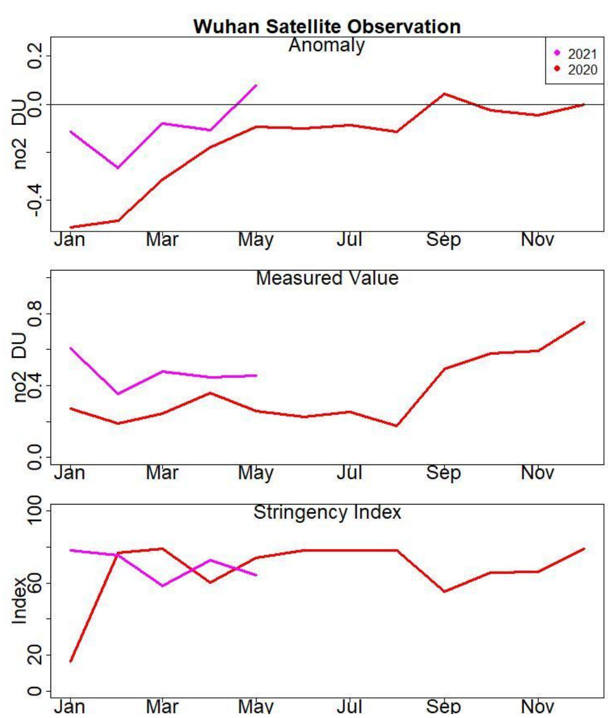


Maps: NO_2 column amount in Feb-Mar 2018 through 2021 around the city of Wuhan. The circle has a radius of 20km around the city centre.

Map data: © GADM 3.6, SRTM1, Digital Chart of the World, cities15000, OpenStreetMap contributors and wikipedia. See Map Acknowledgements for details.

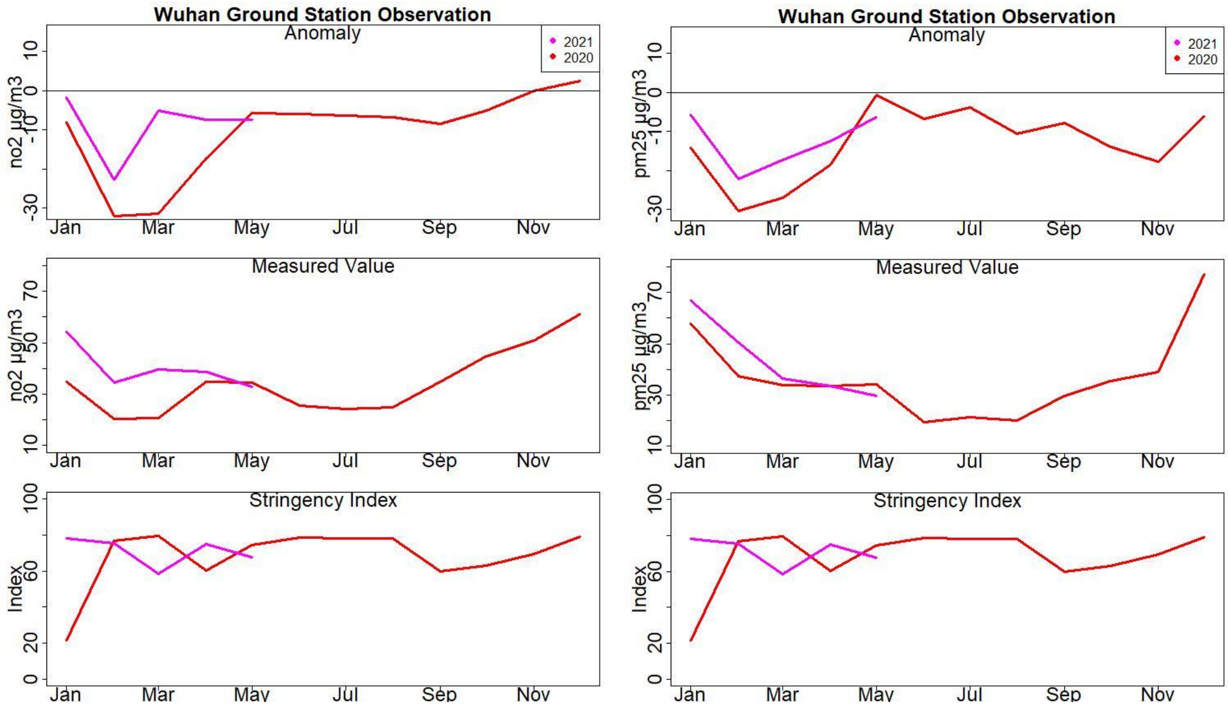


Bar chart: February-March NO_2 column amount in a 20km-radius around Wuhan (left bars: raw data, right bars: deweathered).



Line charts: Monthly average satellite-observed NO_2 column amount for the Wuhan region defined in the maps above (middle) shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (blue).

Ground Station Measurements:



Line charts: Monthly average pollution concentrations as measured by ground based monitoring stations in Wuhan (middle) shown against *Oxford Covid-19 Government Response Tracker stringency index* (bottom) and the anomaly between deweathered pollutant observations prior to the pandemic and during 2020 (red) and 2021 (blue). A simple arithmetic mean is used to combine observations from stations with available data. Left: NO_2. Right: $PM_{2.5}$

Disclaimer

Within this report "Greenpeace" refers to Greenpeace Southeast Asia unless otherwise indicated. Greenpeace is politically independent and does not take sides in territorial disputes. Boundaries on maps and place names on maps and in the text reflect the data sources used and do not imply any opinion by Greenpeace.

Map Acknowledgements

Maps presented in this report use data from the following sources. Boundaries and coastline data: GADM version 3.6.[1] Terrain data: SRTM1.[2] Inland waters: Digital Chart of the World.[3] Cities and towns: cities 15000[4], wikipedia[5] and openstreetmap[6].

[1] GADM version 3.6, retrieved from https://gadm.org/ on 2021-05-12.

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[6] OpenStreetMap contributors. Copyrighted OpenStreetMap contributors, retrieved from https://www.openstreetmap.org on 2021-05.12. Licensed: Open Database Licence www.openstreetmap.org/copyright

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