GREENPEACE

Behind the Smokescreen:

Satellite Data Reveal Air Pollution Increase in India's Eight Most Populous State Capitals

July 2021

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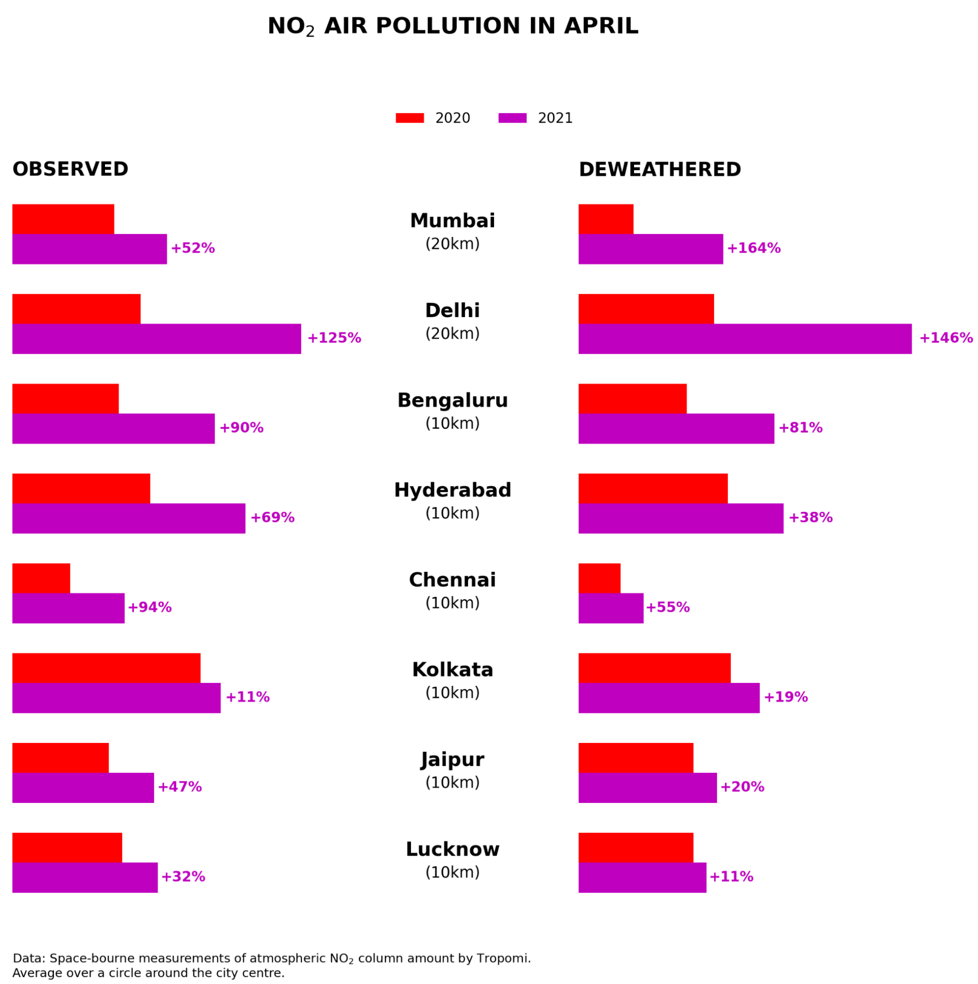
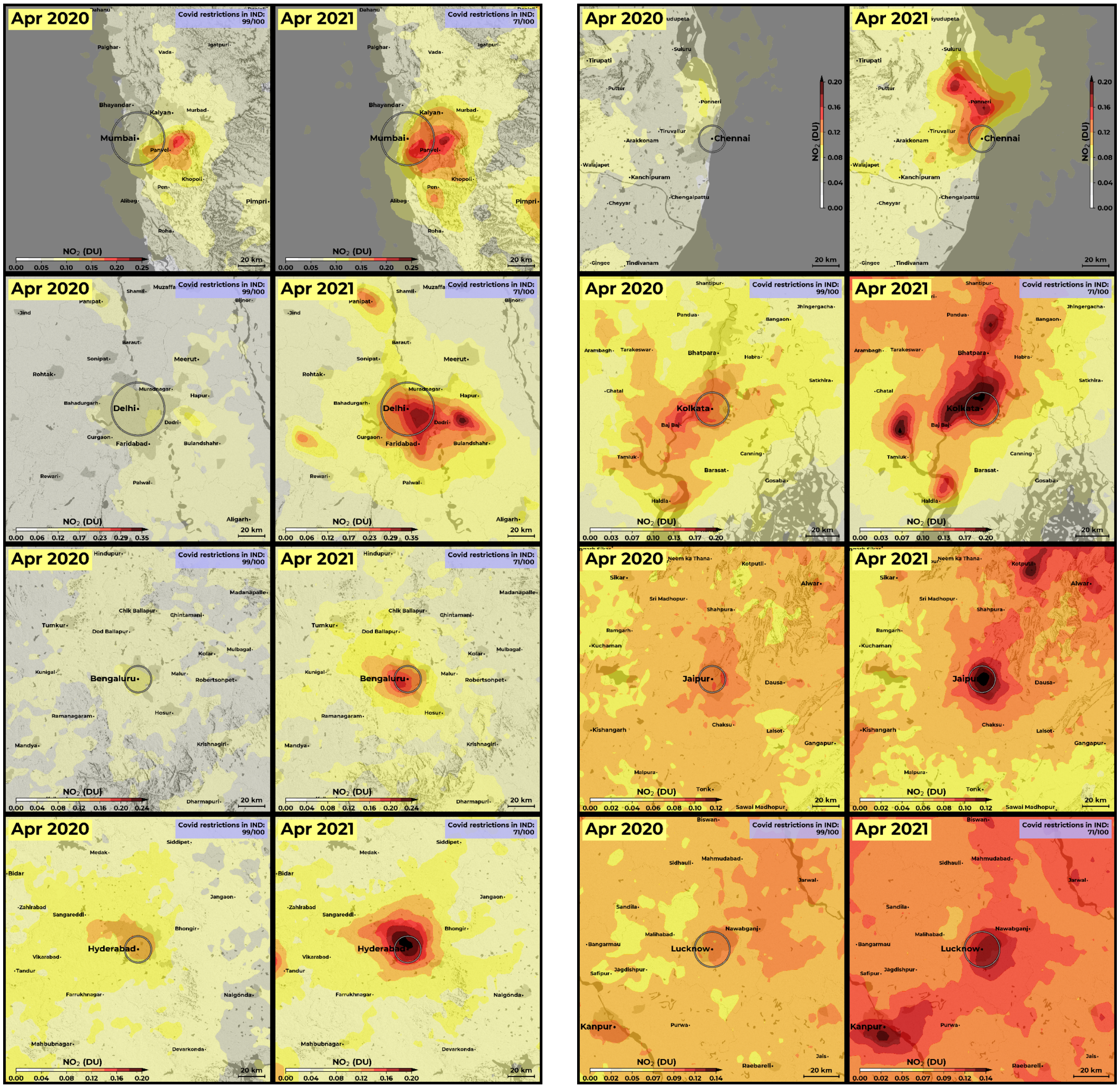
Key Takeaways

- NO_2 (nitrogen dioxide) is a dangerous air pollutant that is released when fuel is burned, including in motor vehicles, power generation, and industrial processes.
- Exposure to NO_2 can severely impact people's health, including the respiratory and circulatory systems, leading to increases in hospital admissions and mortality.
- One year after initial Covid-19 lockdowns reduced air pollution in many Indian cities, NO_2 pollution had increased in each of India's 8 state or union territory capital cities that have more than 2 million citizens. This result remains unchanged even when taking weather conditions into account.
- Ending fossil fuel use is essential for reducing NO_2 air pollution and the associated burden on our health. Governments and city authorities must accelerate the transition to renewable energy and invest in a green recovery, including a switch to wind and solar energy and building efficient public transport, cycling and pedestrian friendly, clean transport-oriented cities.





Maps: NO_2 column amount in April 2020 and 2021 around India's eight state capitals with >2 million citizens. Left from top to bottom: Mumbai, Delhi, Bengaluru, Hyderabad. Right from the top to bottom: Chennai, Kolkata, Jaipur, Lucknow.

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

Introduction

A side-effect of the initial responses to the Covid-19 pandemic in early 2020 was a dramatic reduction in air pollutant concentrations in many locations in India and 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 remained in the long-term after government restrictions are relaxed (e.g. Myllyvirta and Thieriot, 2020).

As the pandemic continues to have a severe impact in India during 2021, there is growing evidence that polluted cities suffer disproportionately more coronavirus cases (Rao, 2020). However, because there has been little change to our reliance on fossil fuels, including coal, oil and gas, increased economic activity is still largely coupled to the emission of toxic 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 – is responsible for an estimated 4.5 million deaths each year worldwide (Farrow et al., 2020). The same study estimated that 1.3 million children in India live with asthma due to chronic exposure to NO_2 and that NO_2 pollution from vehicles, power plants and factories is linked to roughly 350 thousand new cases of asthma in children each year (results unpublished; available upon request).

For this reason, a transition to much cleaner and more sustainable decentralised energy sources such as rooftop solar and clean and sustainable mobility must be central to recovery efforts across cities. The recovery from the pandemic must not come at the expense of a return to previous levels of air pollution. One of the main sources of NO_2 in major Indian cities is emissions from motor vehicles (Guttikunda and Calori, 2013). The governments and city officials need to initiate the transition from privately owned cars to an efficient, clean and safe public transport system that is run on clean energy and provides Covid-19 related safety measures.

In this report, we investigate nitrogen dioxide (NO_2) pollution data from satellite observations. The analysis compares air quality measurements made in April 2021 to those of April 2020, when Covid-19 related government restrictions in India started. 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 contribution of weather in the differences between the compared time periods.

Methods

We analyse satellite observations of the air pollutant NO_2 in the 8 capitals of Indian states or union territories with more than 2 million inhabitants in the 2011 census of India (Census of India, 2011).

Satellite Data

The satellite observations of NO_2 analysed in this study are monthly averages of measurements made by the Tropomi sensor on board the Sentinel-5P satellite, which has been operating since February 2018 (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 serves as a proxy for near-surface air pollution which can measure long term changes with reasonable confidence. However, determining actual pollutant concentrations close to the ground from satellite observations is not straightforward and we do not endeavour to do this.

The Effect of Weather

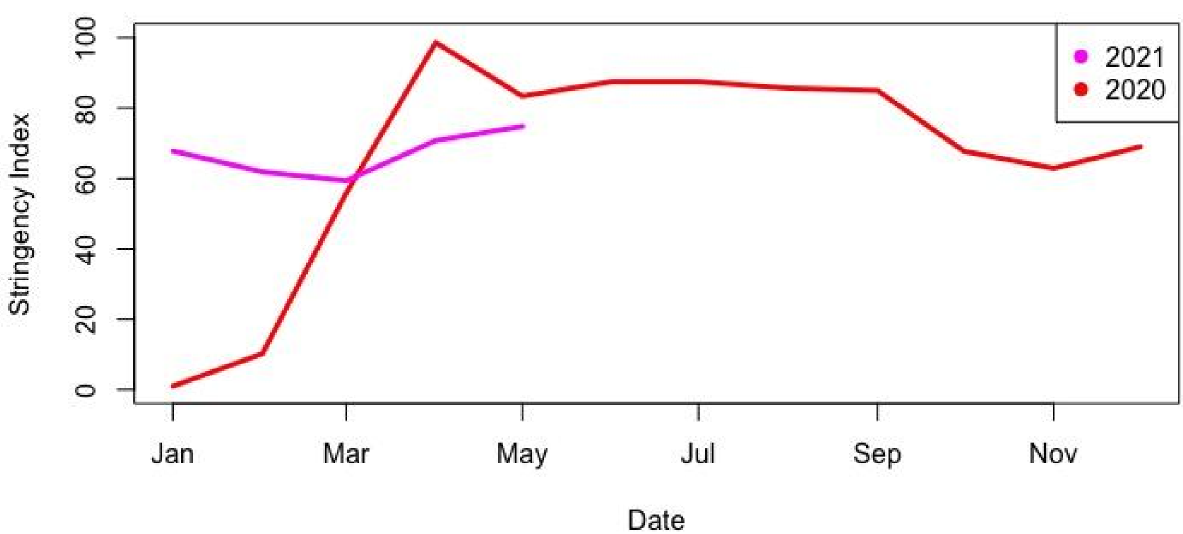
Air pollution is highly sensitive to weather conditions. Therefore, data are averaged to monthly means and compared to equivalent periods in different calendar years. Weather also has variations on time scales of months and longer, and thus temporal averaging only removes part of the influence of weather 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). Sentinel-5P/Tropomi overpasses each location on Earth once per day. These daily instantaneous observations were spatially averaged over a circle around the place of interest and then matched with hourly observations of air temperature, pressure, wind direction, wind speed, precipitation, relative humidity from the NOAA Integrated Surface Dataset (NOAA National Centers for Environmental Information, 2001) and diagnostics of the planetary boundary layer height from the NCEP Climate Forecast System (Saha et al. 2020, 2014). The 2018 and 2019 data of these variables were provided to the statistical deweathering model in the training phase. The model was then applied to the times of interest in the years 2020 and 2021.

Model performance. The deweathering models have been evaluated using historical data. Model predictions have a positive bias at all locations, the greatest bias is 30% in Bengaluru and smallest is 5% in Lucknow. In absolute terms bias ranges from 0.01-0.06 DU, the greatest bias occurs in Delhi. Willmott and coworkers' (2011) refined index of model agreement (IOA) is approximately 0.5 in each location, which means that model uncertainty is on average half as large as the spread in the observed data. Between 70-90% of model predictions are within a factor of 2 of observations (FAC2). The deweathering results are therefore not to be considered precise but nevertheless give a useful indication of the influence of weather on the observed changes in air pollution. Model evaluation statistics for all locations are provided in Appendix 1.

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 in the figure below. The tracker is only available at the country level and makes no distinction between types of restrictions that are likely to have little effect on air pollutant emissions and other types of restrictions where the effect could be significant. Nationally, April 2020 was the first month when the Government Response Tracker indicated significant restrictions were in place across India and therefore became the focus of this report.



Monthly average value of the Oxford Covid-19 Government Response Tracker stringency index for India (January 2020-May 2021)

Inter-annual comparisons

We present monthly average data and report changes in pollution between 2020 and 2021. 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 India. A time series of all monthly averages during 2020 and 2021 is also provided for each location.

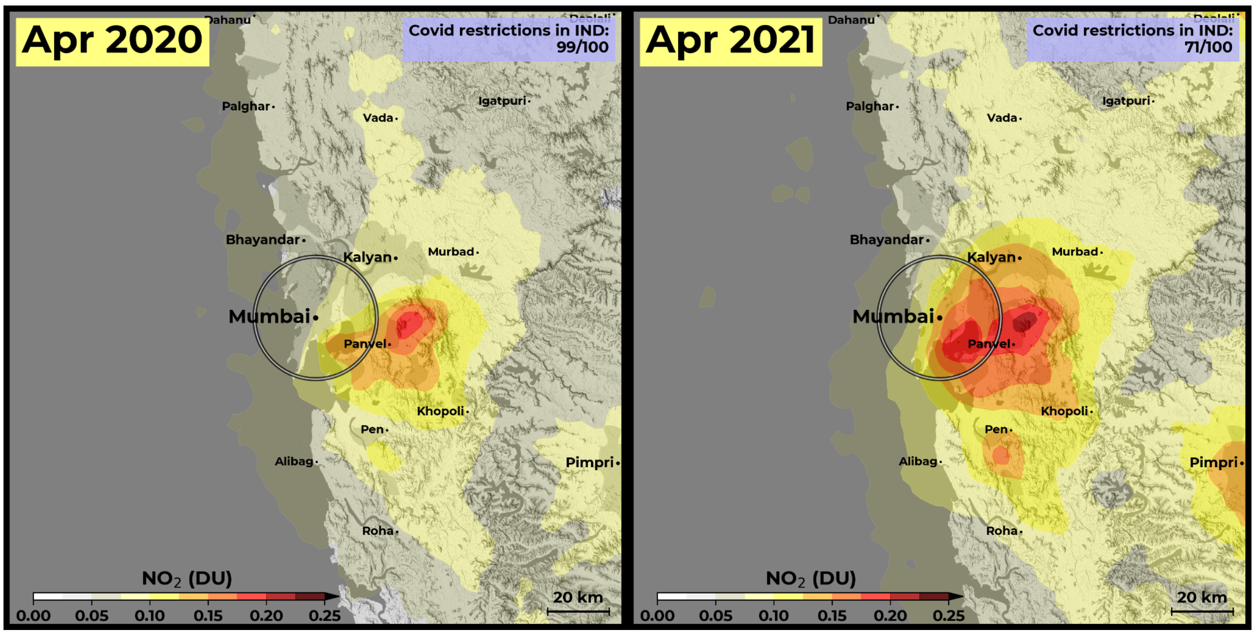
Results summary

- One year after initial Covid lockdowns went into effect, NO_2 pollution has increased in all 8 Indian cities studied.
- This result was supported even after weather conditions were taken into account. The results of the weather-correction analysis confirm that the observed increase in NO_2 pollution occurred primarily due to changes in emissions, while weather influence was only of secondary importance in most places.
- Delhi saw the most dramatic increase of all cities studied between April 2020 and April 2021. Satellite observations reveal NO_2 pollution increased to 125% of April 2020 levels. The analysis suggests the increase would have been even greater (146%) had weather conditions been similar to 2020.
- Despite India experiencing severe impacts from the Covid-19 pandemic during 2021, emissions of NO_2 appear to be driving the increased concentrations.

Results by Location

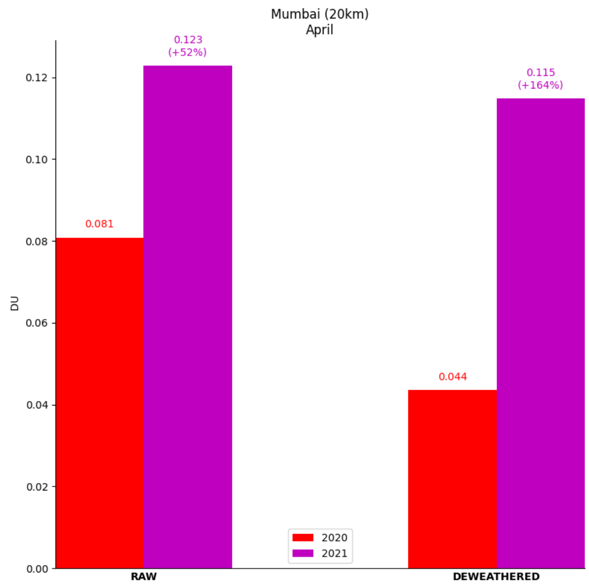
Mumbai

In Mumbai, NO_2 air pollution was 52% higher in April 2021 than in the same month of the previous year. The deweathering model suggests that 2020 air pollution was strongly influenced by weather conditions and that the increase would have been as much as 164%, had weather conditions been the same in both years. The deweathering model tended to overestimate NO_2 amounts in Mumbai, however a good correlation between model and observed provides some confidence in this result (Appendix 1).

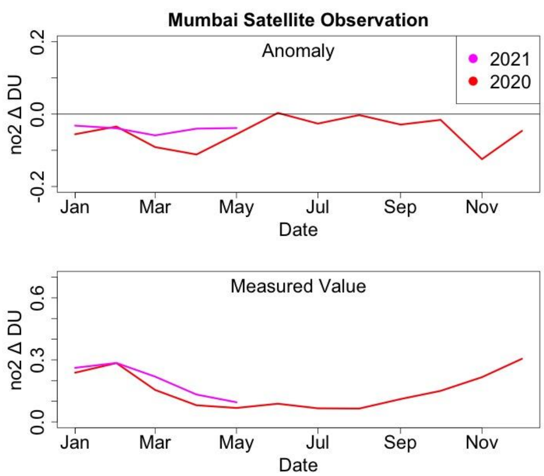


Maps: NO_2 column amount in April 2020 and 2021 in the Mumbai area. The circle has a 20km radius around the city centre.

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



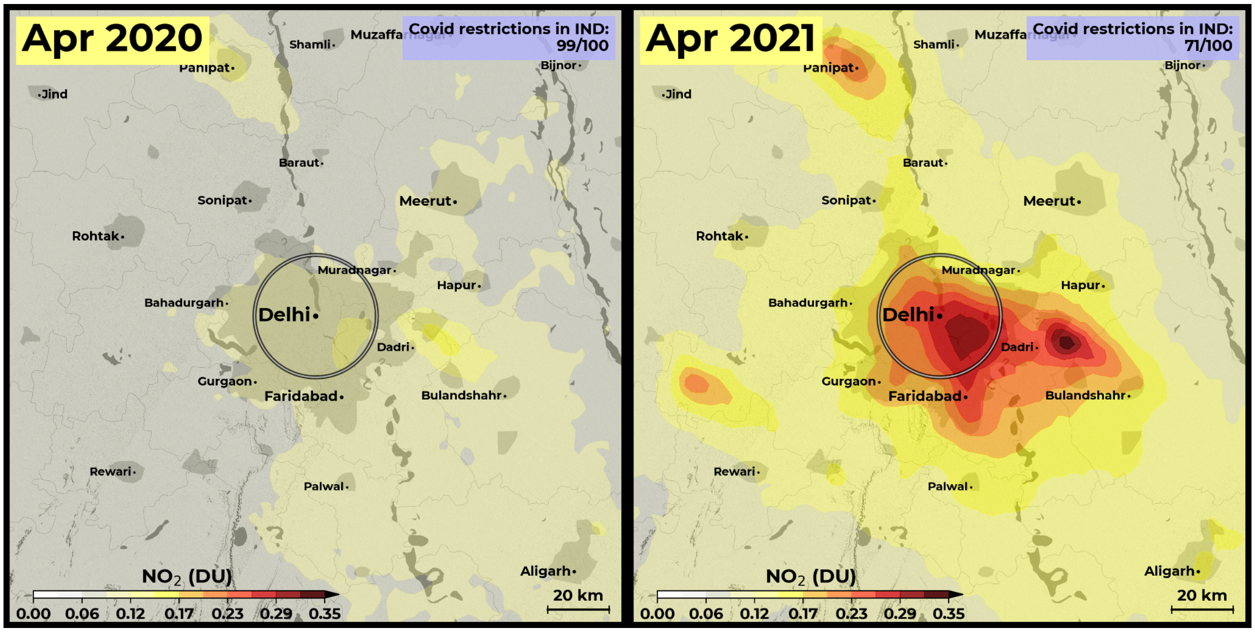
Bar chart: April NO_2 column amount for the circular area marked on the maps. Left: raw data. Right: NO_2 column amount after removing the effects of weather.



Line charts: Monthly average NO_2 column amount observed by satellite for the circular area marked on the maps and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (purple).

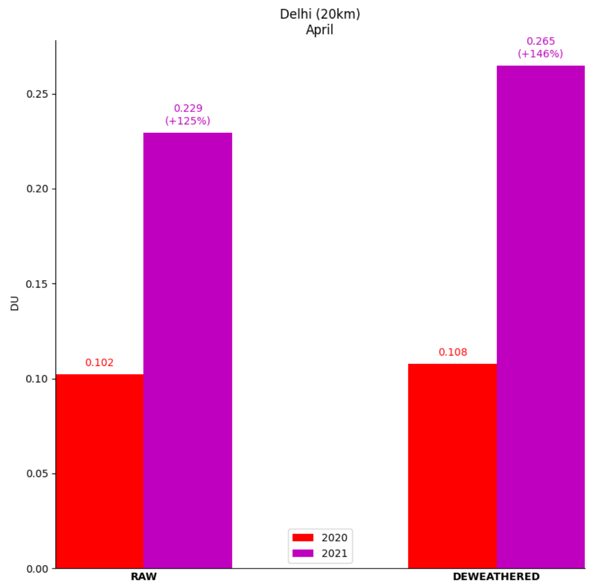
Delhi

In Delhi, NO_2 air pollution was 125% higher in April 2021 than in the same month of the previous year. There is relatively large uncertainty in the deweathering model results for Delhi. The model suggests that the increase would have been higher had weather conditions been the same in both years. Confidence in this result is not as strong as in other cities where the deweathering model showed greater agreement when compared with historical observations.

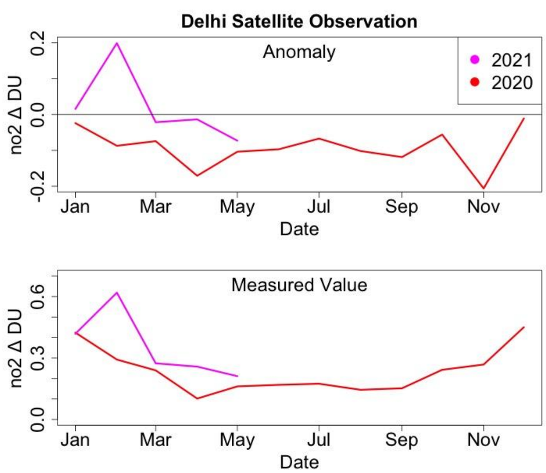


Maps: NO_2 column amount in April 2020 and 2021 in the Delhi area. The circle has a 20km radius around the city centre.

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



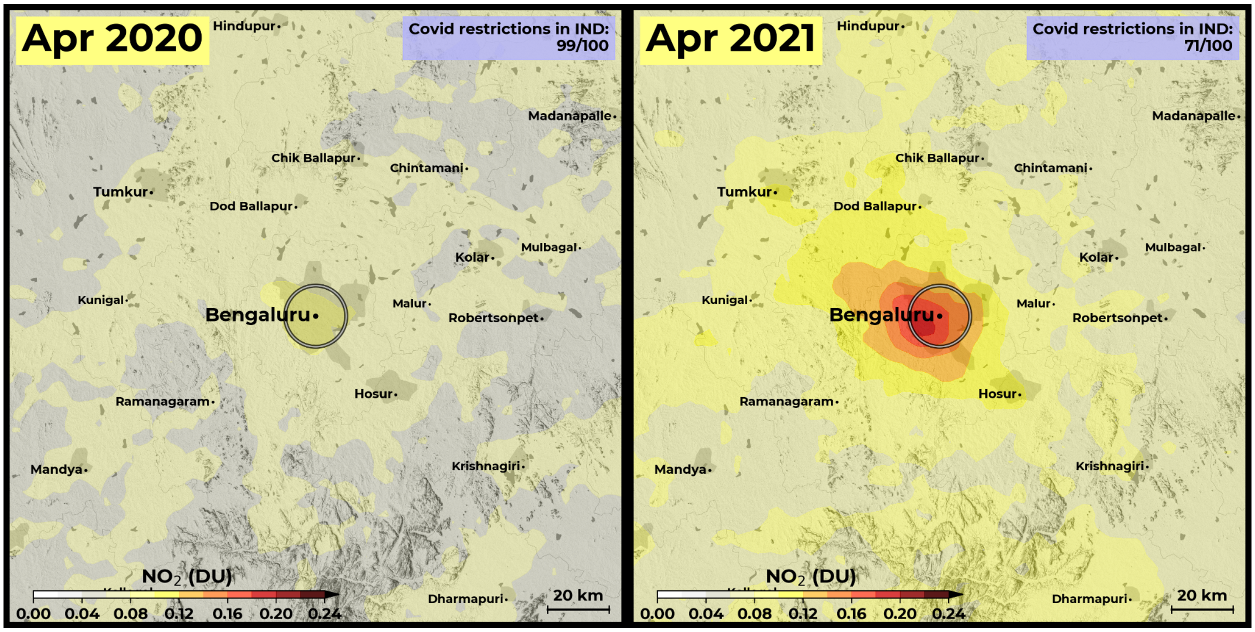
Bar chart: April NO_2 column amount for the circular area marked on the maps. Left: raw data. Right: NO_2 column amount after removing the effects of weather.



Line charts: Monthly average NO_2 column amount observed by satellite for the circular area marked on the maps and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (purple).

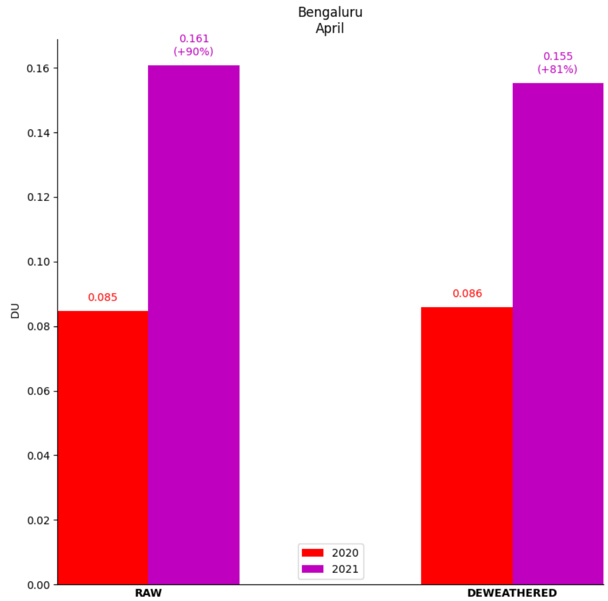
Bengaluru

In Bengaluru, NO_2 air pollution was 90% higher in April 2021 than in the same month of the previous year. Results of the deweathering analysis indicate that meteorology had only a little contribution to this change. Although the deweathering model tended to overestimate absolute NO_2 amounts in Bengaluru, model estimates correlated well with observed data providing confidence in this result.



Maps: NO_2 column amount in April 2020 and 2021 in the Bengaluru 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.



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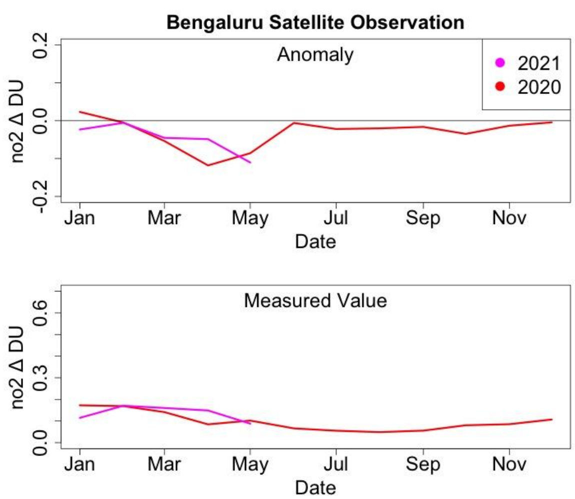
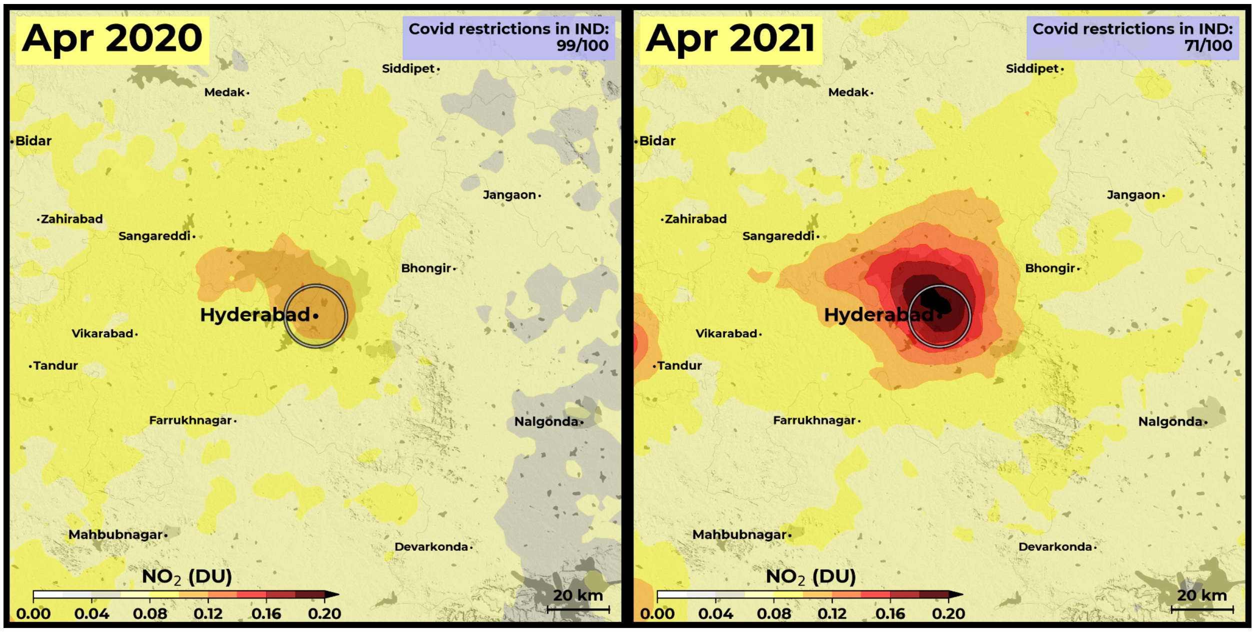


Line charts: Monthly average NO_2 column amount observed by satellite for the circular area marked on the maps and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (purple).

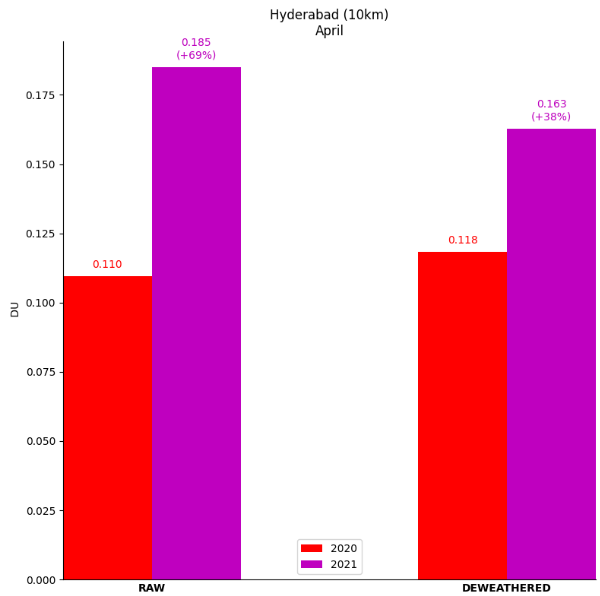
Hyderabad

In Hyderabad, NO_2 air pollution was 69% higher in April 2021 than in the same month of the previous year. Part of this difference is attributable to changing weather conditions. After removing the effect of weather, there is still an increase of 38% which is attributed to an increase in emissions.

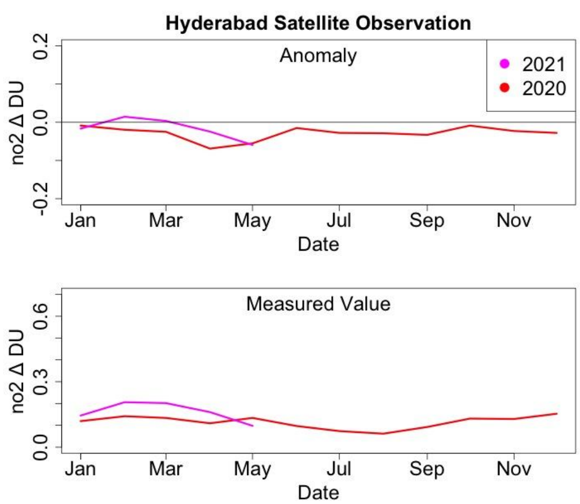


Maps: NO_2 column amount in April 2020 and 2021 in the Hyderabad area. The circle has a 10km radius around the city centre.

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



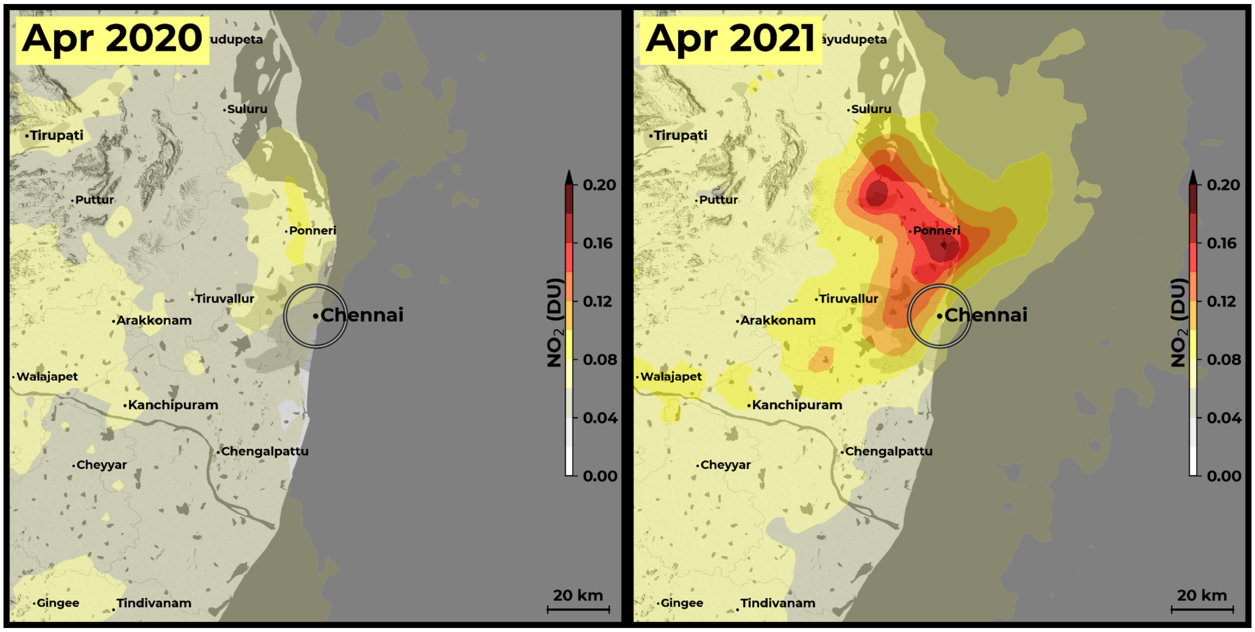
Bar chart: April NO_2 column amount for the circular area marked on the maps. Left: raw data. Right: NO_2 column amount after removing the effects of weather.



Line charts: Monthly average NO_2 column amount observed by satellite for the circular area marked on the maps and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (purple).

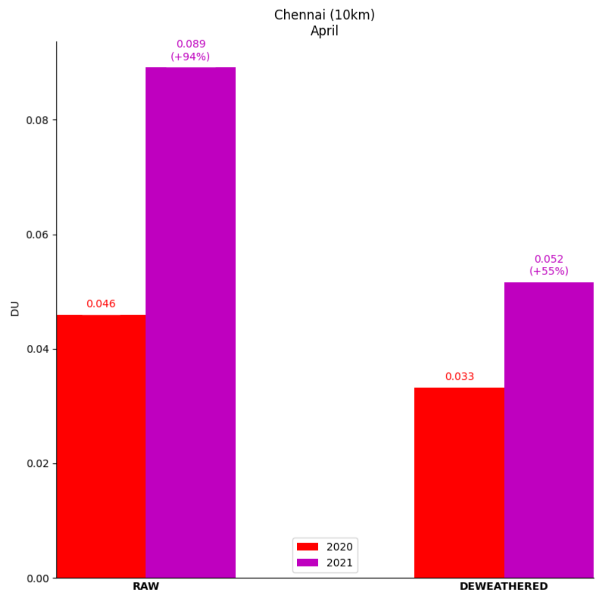
Chennai

In Chennai, NO_2 air pollution was 94% higher in April 2021 than in the same month of the previous year. Part of this difference is attributable to changing weather conditions. After removing the effect of weather, there is still an increase of 55% which is attributed to an increase in emissions. However, deweather model agreement with observations in Chennai is relatively low reducing confidence in this result.



Maps: NO_2 column amount in April 2020 and 2021 in the Chennai 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.



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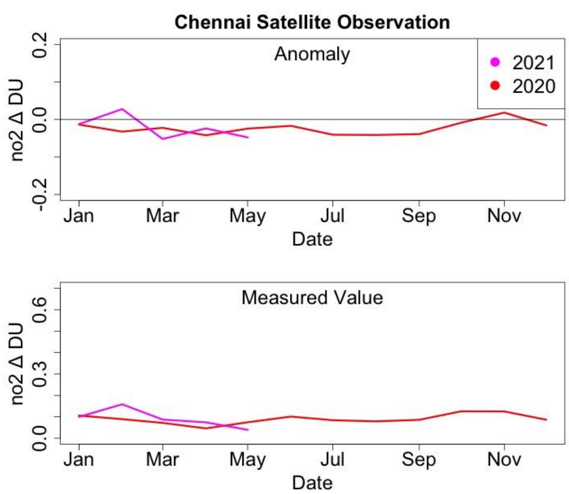
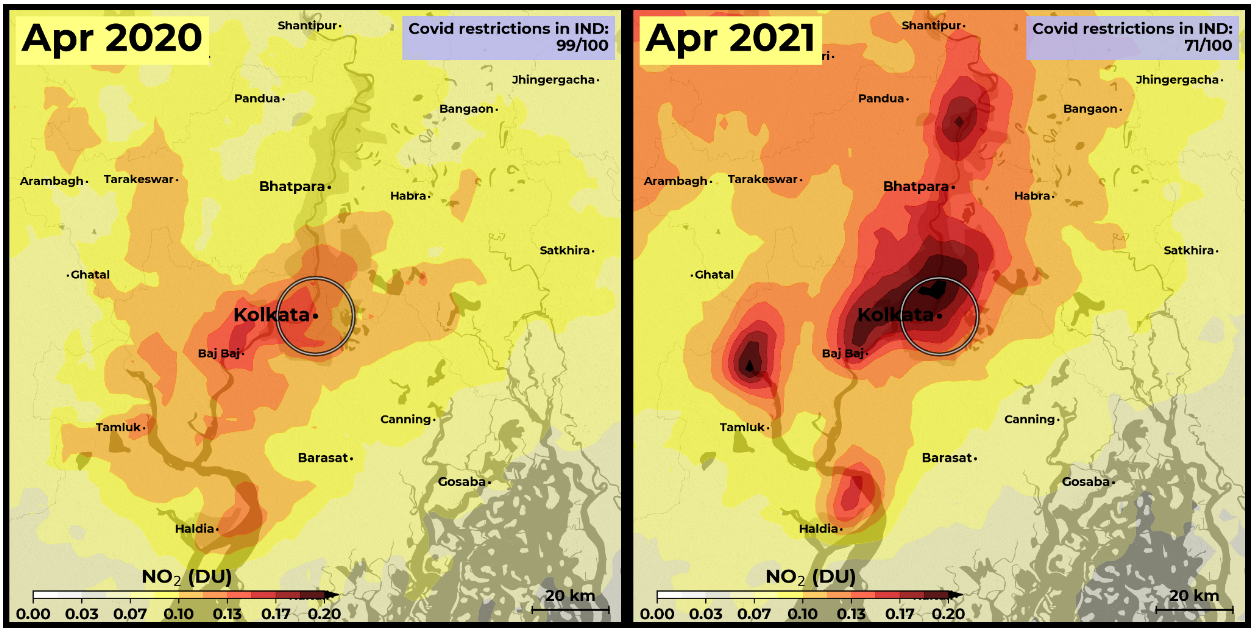


Line charts: Monthly average NO_2 column amount observed by satellite for the circular area marked on the maps and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (purple).

Kolkata

In Kolkata, NO_2 air pollution was 11% higher in April 2021 than in the same month of the previous year. If weather conditions had been the same in both years, this increase would be 19%. The deweathering model performed well in Kolkata.



Maps: NO_2 column amount in April 2020 and 2021 in the Kolkata area. The circle has a 10km radius around the city centre.

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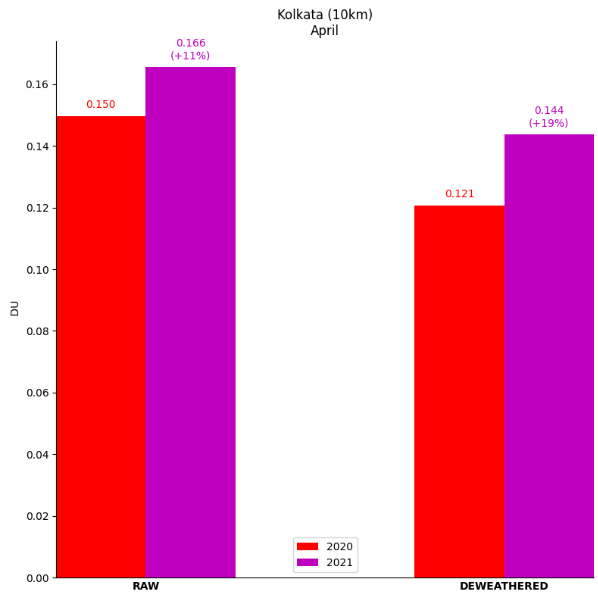

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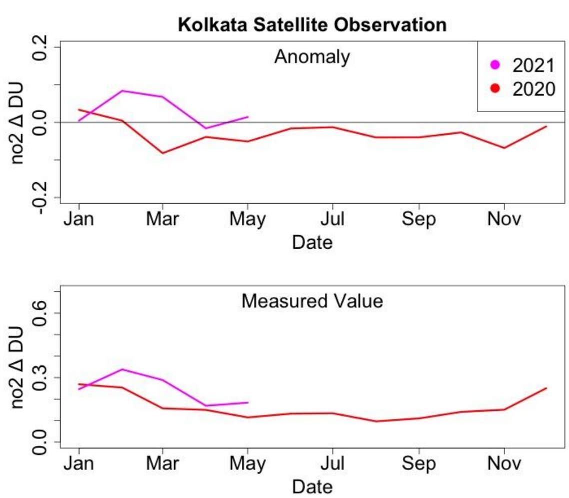
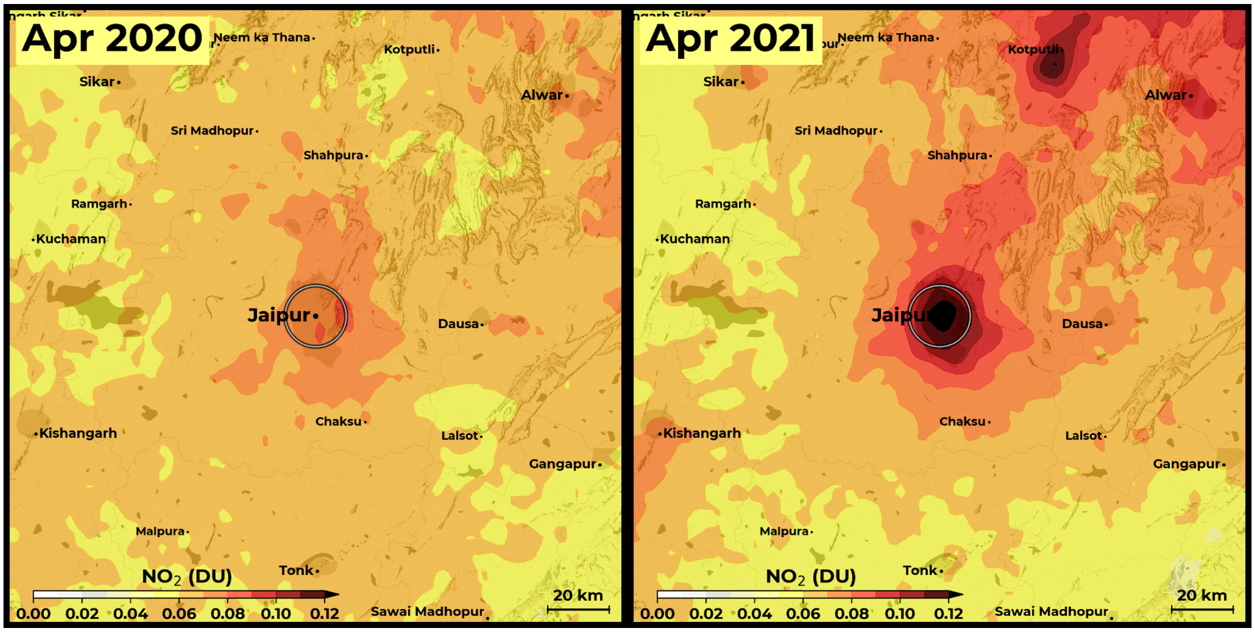


Line charts: Monthly average NO_2 column amount observed by satellite for the circular area marked on the maps and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (purple).

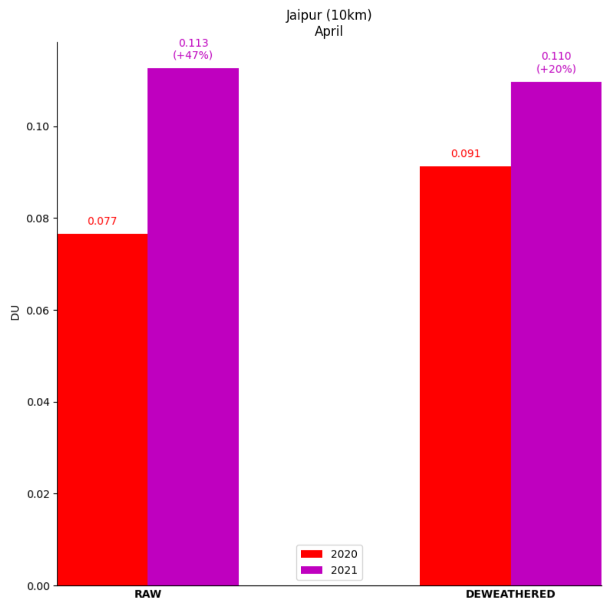
Jaipur

In Jaipur, NO_2 air pollution was 47% higher in April 2021 than in the same month of the previous year. Approximately half of this difference is attributable to changing weather conditions. After removing the effect of weather, there is still an increase of 20% which is attributed to an increase in emissions. The deweathering model performed well in Jaipur.

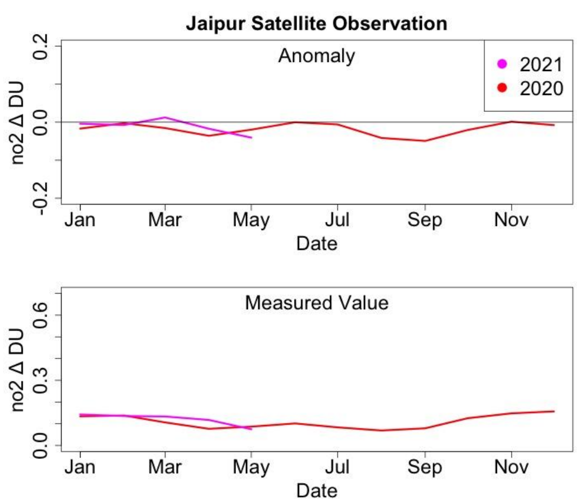


Maps: NO_2 column amount in April 2020 and 2021 in the Jaipur area. The circle has a 10km radius around the city centre.

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



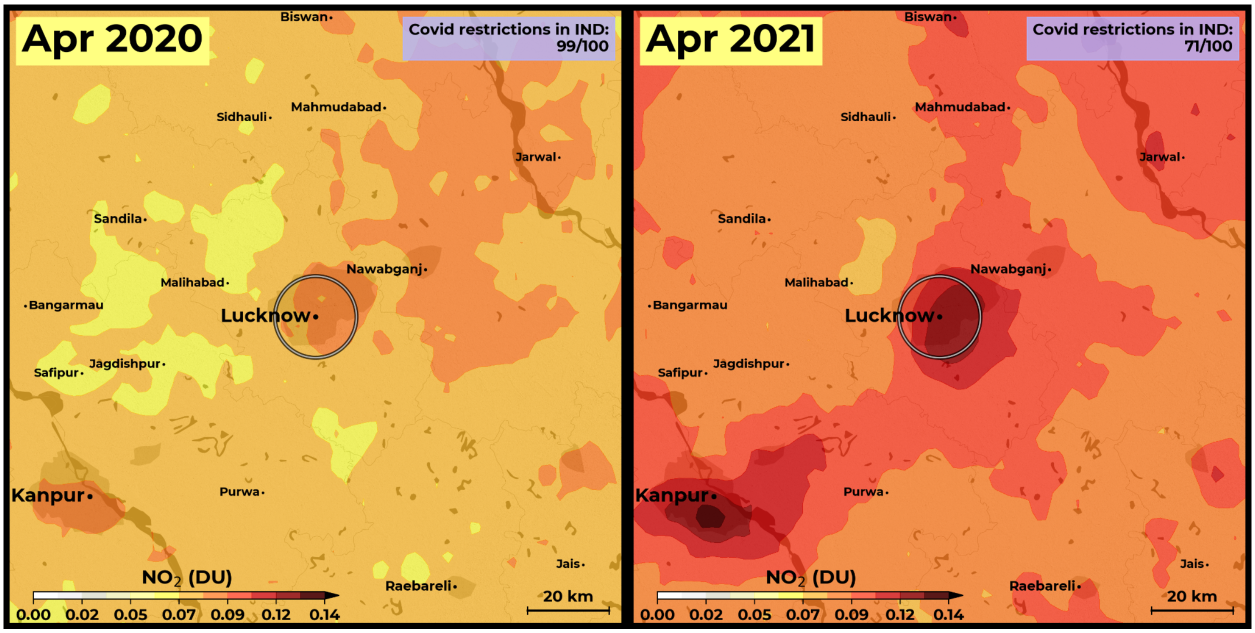
Bar chart: April NO_2 column amount for the circular area marked on the maps. Left: raw data. Right: NO_2 column amount after removing the effects of weather.



Line charts: Monthly average NO_2 column amount observed by satellite for the circular area marked on the maps and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (purple).

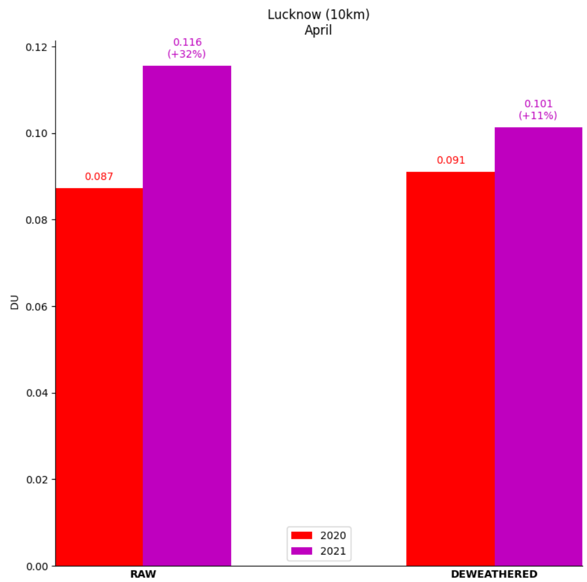
Lucknow

In Lucknow, NO_2 air pollution was 32% higher in April 2021 than in the same month of the previous year. Part of this difference is attributable to changing weather conditions. After removing the effect of weather, there is still an increase of 11% which is attributed to an increase in emissions. The deweathering performed well in Lucknow.

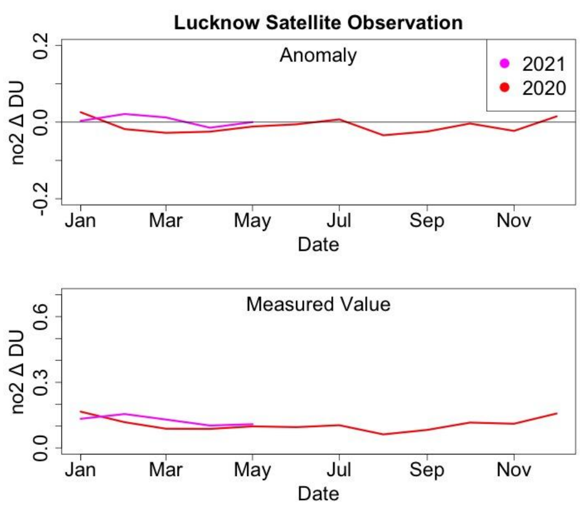


Maps: NO_2 column amount in April 2020 and 2021 in the Lucknow area. The circle has a 10km radius around the city centre.

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 for the circular area marked on the maps and the anomaly between deweathered NO_2 column amount prior to the pandemic and during 2020 (red) and 2021 (purple).

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].

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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

Appendix 1: Deweathering model evaluation

Table: Model performance metrics for the deweathering model in each of the locations studied. n: number of samples in the training phase (days with observation). FAC2: Fraction of model predictions within factor 2 of the observation. r: Pearson correlation coefficient. IOA: Willmott's refined index of agreement (Willmott et al., 2012). mean_obs (DU): mean of the observation values in Dobson units. bias: mean difference between model prediction and. observation.

City (radius)	n	FAC2	r	IOA	mean_obs (DU)	bias (DU)	bias/mean_obs
Mumbai (20km)	400	80%	0.73	0.62	0.167	0.048	29%
Delhi (20km)	394	73%	0.52	0.51	0.269	0.061	23%
Bengaluru (10km)	396	78%	0.56	0.50	0.109	0.033	31%
Hyderabad (10km)	388	86%	0.53	0.54	0.131	0.023	18%
Chennai (10km)	380	70%	0.37	0.45	0.092	0.022	24%
Kolkata (10km)	392	86%	0.55	0.59	0.188	0.012	6%
Jaipur (10km)	401	90%	0.55	0.56	0.113	0.014	13%
Lucknow (10km)	389	90%	0.46	0.56	0.113	0.006	5%

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