

Interactive comment on “Sudden changes in nitrogen dioxide emissions over Greece due to lockdown after the outbreak of COVID-19” by Maria-Elissavet Koukouli et al.

Anonymous Referee #2

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We thank Reviewer #2 for offering us the possibility to enrich our article. Point-by-point replies to all comments are given in maroon colour below.

Major comments

1) The decreases along the shipping lanes are interesting but not sufficiently discussed. How does the model perform along the major lanes and how does it compare to the observed decrease? What do shipping activity data tell us about the changes in traffic during the shutdowns? Can you provide a map of the column differences between March 2019 and March 2020 over the sea? From Figure S2, it is clear that a large hot spot located to the east of Athens in March 2019 disappears in March 2020. Is this due to a reduction of ship activity or to meteorological changes? A detailed model-data comparison along ship tracks should be presented. Figure S2 should also be moved to the main manuscript.

Since we composed this article, we have worked separately on the topic of shipping emissions and we indeed realized that there are a lot of interesting findings that can be extracted for this activity. We have hence decided to remove all shipping references from this article in favour of the autonomous work on the subject of shipping activities we are currently preparing for publication.

2) The comparisons with in situ stations are important for validating your results and should be part of the main text. These comparisons could help to interpret the changes sensed by TROPOMI. Although these comparisons should be taken with caution, it is very important to compare the satellite-based changes with the changes measured locally.

We have enriched our work by showing a more comprehensive analysis of what air quality stations around Athens have reported, both in the main text (Figure 8 and discussion thereof) as well as in the supplementary material (Figures S3 & S4.) Furthermore, our work in comparing the LOTOS-ERUROS simulations to TROPOMI, MAXDOAS and in situ stations around Greece has been published in Skoulidou et al., 2020, and references/discussions to the validation/comparison of the model runs used also in this work have been added to the flow of this text (see Section 2.2)

Skoulidou, I., Koukouli, M.-E., Manders, A., Segers, A., Karagiozidis, D., Gratsea, M., Balis, D., Bais, A., Gerasopoulos, E., Stavrou, T., van Geffen, J., Eskes, H., and Richter, A.: Evaluation of the LOTOS-EUROS NO₂ simulations using ground-based measurements and S5P/TROPOMI observations over Greece, Atmos. Chem. Phys. Discuss., <https://doi.org/10.5194/acp-2020-987>, in review, 2020.

3) I have serious doubts about the derived strong emission decrease (-37%) in Patra (Figure 5). Possible reasons for such a change should be analysed and discussed. Is this change expected based on in situ observations? Another concern is the 26% increase in emissions in Athens during the last week of April (Figure 7). Is this increase due to increased

anthropogenic emissions (traffic, energy or industrial sectors) or can this be attributed to modelling uncertainties and/or noise in the data?

Following suggestions by both referees, we have updated our model runs using the convolution of the satellite averaging kernels for the production of the columnar NO₂ estimates by the CTM. As expected, some numerical results are now different [such as the high negative decrease you mention] while the main findings, such as the relative levels and reductions, were not altered. It became apparent that for the cases of low monthly mean levels, such as those over the smaller Greek cities, the variability within the standard deviation introduced large absolute and relative differences between the satellite 2020/2019 difference and the CTM 2020/2019 difference. As a result we have added a discussion in Section 3.1, as well as altered the abstract & conclusions.

4) At the end of Section 2.3, the authors claim that TROPOMI NO₂ averaging kernels are not needed because only relative column changes are considered. This argument is not entirely correct. The averaging kernels could very well be different in 2019 and 2020, and their effects should not be overlooked. I strongly recommend their use in the revised manuscript, or, some demonstration that their effects can be ignored.

In order to be absolutely certain that not using of the AKs does not introduce differences in our main findings, we have repeated the entire analysis convolving the CTM profiles to the TROPOMI AKs. While for the locations with the smaller NO₂ loads the convolution did bring some differences in the resulting percentage values, the main findings remain and are indeed strengthened in this manner.

5) Sampling problems are not adequately discussed. Some of the model-data discrepancies could be due to sampling issues. For how many days are data available per month and per city? Is this taken into account in the comparisons with the model?

All findings in this work depend on the collocation of the satellite dataset to the CTM results, hence the exact same pixels are used for both datasets and this type of sampling issue is not expected. Sampling might be an issue if between years the number of collocations varies dramatically. The difference in number of available pixels for the monthly mean comparisons are added to Section 3.1 and the number of available days for the case of the weekly analysis over Athens was added to Section 3.2 .

6) The column decreases in March are more important than in April, as turns out from Table 2. This is at odds with the full lock-down period that you mention in Section 1.4 (23 March to 4 May). One would expect the decrease to be more significant in April than in March. How can we explain this? Do we have evidence that the lockdown was not (or less) enforced in April? As a matter of fact, the in situ data (Figure S1) indicate that the decreases are stronger in April than in March. A discussion is warranted. Moreover, there is inconsistency between the values for Heraklion of Table 2 and Figure 4.

Finally, thank you for spotting the differences for the mean levels of Heraklion between table and Figure, it led us to note that the calculation for Patras was also not performed properly. This is simply due to the fact that we were examining different pixels as representative for each of these locations and this led to the errors in the numerics of the table.

As to the well spotted point that the differences in March are stronger than in April. This was indeed curious to us as well, which is why we followed advice and studied the climatological mean 2005-2018 and the deviations of years 2019 and 2020 sensed by the OMI/Aura satellite sensor (see Figure 7 and discussion in Section 3.2). The OMI/Aura observations agree with TROPOMI, in that larger differences are found for the months of March than the months of April between 2019 and 2020. Furthermore, the ground-based Multi-Axis Differential Optical Absorption Spectroscopy, MAXDOAS, station in Athens also reported higher columns in March 2019 than April 2019, which again leads to smaller differences for April 2020 than for March 2020. See Section 6.3.4, page 52, of the official quarterly validation report of the TROPOMI Mission Performance Center, <https://mpc-vdaf.tropomi.eu/ProjectDir/reports/pdf/S5P-MPC-IASB-ROCVR-08.01.01->

[20200921_FINAL.pdf](#). These findings are also discussed in our new manuscript in Sections 2.1 & 3.2.

Minor comments

There is a recurrent problem with the format of citations. The authors should follow the journal guidelines for literature citations. Footnotes should be removed. Consider adding them in the reference list or insert them in the text (e.g. for URLs). The article needs to be corrected for typos and language mistakes. Consider a careful reading before resubmission.

We have removed all references previously given as footnotes to match the ACP guidelines and re-read the article to weed out typos and language mistakes.

- l.24: "second largest sector", which is the first one?

The first one is industry, we have added the clarification in the abstract.

- l.31: "we aim to show the quantifiable and beyond doubt decline", rephrase e.g. as: "we aim to quantify the decline"

Text altered as suggested.

- l.33: read "hereafter"

Text altered as suggested.

- l.36: "we enumerate the improvement", do you mean "we quantify the improvement"?

Text altered as suggested.

- l.51: remove "among others"

Text altered as suggested.

- l.53: remove "issues"

Text altered as suggested.

- Section 1.2: Too many details that are not used afterwards. Consider rewriting to ease readability.

As requested by yourself later on in this review, and the fact the more publications have appeared since we composed this section, we added a paragraph of reported findings in the end of this Section.

- In l.73, do you mean "by 2.1%" lower?

Yes, the minus sign was getting left behind in the previous line, text altered as suggested.

- in l.77, remove 'the work of'.

Text altered as suggested.

- In l.80, "If we assume that years 2019 and 2020 were not exceptional": what do you mean by exceptional?

- In l.82: "will not bare a significant of the emission", something is missing here. Reread carefully.

[both points above refer to the same sentence]

True, well spotted. Phrase now reads: *If we assume that years 2019 and 2020 were not exceptional in their temperature levels for the spring months, then it follows that changes in central heating emissions will not be bare a significant part of the emission changes observed.*

- l.92: read 'reductions'

Text altered as suggested.

- l.95: '25% decrease'

Text altered as suggested.

- l.98: update reference

Reference updated.

- l.103: Add more references for other regions of the world where lockdown effects on air quality have been studied.

References added as suggested.

- Section 1.4 is very long and too much detailed. This information is not used later on in the discussion. To interpret the results, one needs to know the beginning and end of the lockdown per city. Was the lockdown nationwide? You could replace this section by a table including this information for easy reference.

The details provided in this section aimed to show that during March, and well before the total lockdown of March 23rd, numerous sectors of normal life were being shut down one by one which resulted in the anticipated restriction of movement and hence possibly lower exhaust fumes.

- l.111: "coffee shops"

Text altered as suggested.

- l.121: remove "discreet".

Text altered as suggested.

- l.121-122: The sentence can be removed. In fact, hardly any dates have been used afterwards.

Text altered as suggested.

- l.133: read "point"

Text altered as suggested.

- Figure 2 is mentioned before Figure 1 in the text. What is the benefit of showing Figure 1?

Since we submitted this article before the article of Skoulidou et al., 2020, which presents the LOTOS-EUROS set up and first results over the region, we thought the add a figure for demonstrational purposes indeed. Since the Skoulidou et al., 2020, article is now online we have deleted the figure and added model information from that work.

- Figures 1 and 2 are not easy to read. Can you improve the scale? We cannot even see higher columns in Patra or Heraklion.

I tried a number of colour tables/colour scales but it was not possible to both view the hotspots that rise above $8-10 \times 10^{15}$ molec/cm² and at the same times cities with NO₂ loads between $1-2 \times 10^{15}$ molec/cm² around the big domain [new Figure 1]. This is why in [new] Figure 2 [zoom-in figures around the cities] the colour bars are not the same for all locations.

- In Figure 2, could you add additional panels with the column differences?

Differences panel added as suggested.

- l.169: "distinct", do you mean "specific"?

Text altered as suggested.

- l.173: explain what MAX-DOAS stands for

Acronym added.

- l.182: This is repeated elsewhere, reread carefully to avoid repetitions.

Indeed, well spotted.

- l.197: read "wind speed"

Text altered as suggested.

- Table 1, Figure 3 and l.249-259 have a lot of repetitions.

We have moved the (previous) Table 1 to the supplement, as TableS1, and re-wrote parts of this section.

- Why do you show the month of March in Figure 3? From Section 1.4 it looks like March was for only half affected by the measures. Wouldn't it be more interesting to show April

As discussed in the text, the NO₂ levels reported by TROPOMI over the entire country in April 2019 were lower than in March 2020, seen also by OMI/Aura and the ground-based MAXDOAS of Athens. This fact hinders the methodology chosen for this analysis, for the locations with already low tropospheric NO₂ load. We have added the April maps in the supplement, as Figure S1, where the decline for April 2020 is of course still evident.

- l.312-317: the discussion should be extended, see point 1 above.

See discussion under point #1 above.