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**Article title: $NO_x$ emissions changes from 2019 to 2021 in Eastern China as estimated through variational inversions and TROPOMI satellite data**

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- In black are the comments of the reviewer
- In blue are our answers

## Reviewer #1:

This study quantifies changes in NOx emissions over eastern China from 2019 to 2021, with particular attention to the reduction associated with the COVID-19 lockdowns and the Chinese Lunar New Year. A noteworthy aspect is that the authors derive total NOx emissions, encompassing both anthropogenic and biogenic contributions. Given the substantial reduction from 2019 to 2020, which is likely driven by government interventions associated with COVID-19 restrictions and the Lunar New Year slowdown, and considering the clear rebound in 2021, **the interannual pattern reported in the study appears reasonable. The manuscript provides useful insights and is, overall, clearly presented and well-structured.** However, certain critical details require clarification. I support the publication of this manuscript, provided that the following major comments can be addressed.

**Major comments:**

**Question 1:** In this study (line 214), the NOx emission estimates are reported in teragrams of nitrogen dioxide equivalent (Tg NO2) for both the prior and posterior datasets. **I am not fully familiar with this convention and would appreciate clarification on the rationale for adopting NO2-equivalent units, particularly in comparison with more conventional representations such as NOx expressed directly in tons.** Given that this study relies on TROPOMI observations with high spatial resolution and daily temporal coverage, rather than annual or monthly averaged emission inventories, it is not immediately clear whether expressing emissions in Tg NO2 offers advantages or disadvantages when dealing with such pronounced temporal and spatial heterogeneity.

**Answer 1:** We do not report the $NO_x$ emissions via the mass of actual $NO_2$ molecules emitted, we report the total $NO_x$ emissions as the mass of equivalent amount of $NO_2$ if all $NO_x$ molecules that have been emitted were emitted as $NO_2$ (as often done, in particular when the mass is given in "Tg" or "tons" without more details); as a result, our unit choice cannot have any impact on the spatial and temporal variations of the emissions. We rechecked a wide range of scientific articles and found that all of them use either $NO_2$[1–4] or N-equivalent[5–8] units. In some inventories, the $NO_x$ emissions are expressed as NO such as CAMS-GLOB-ANT[9]. Converting the total $NO_x$ emissions between $NO_2$, NO, and N-equivalent units is straightforward, so we routinely convert our emissions into all conventional units to enable comparison with other inventories; however, to maintain a consistent presentation in the article, we stick to a single unit. Lastly, the reason we do not show the emissions in tons instead of Tg is to avoid stating large numbers, since $NO_x$ emissions in China are among the highest globally (for example, 16 Tg of annual $NO_x$ emissions in 2019 corresponds to 16000000 tons).

**Question 2:** This study combines several emission inventories to represent different sectors and applies multiple downscaling approaches to convert monthly emission estimates into daily values. **A key issue arises in Figure 2 (line 217) and Figure S1 to S3, where prior emission values below 0.3 kt NO2 in February 2019 are set to zero when computing the relative difference in order to reduce noise in the figure.** It is well understood that extremely small values in prior fields often reflect numerical noise rather than actual emissions. **However, the manuscript only discusses this adjustment in the context of figure presentation and does not clearly explain how grids with prior values below 0.3 kt NO2 are treated during the inversion itself.** Specifically, it remains unclear whether these low-value regions are assimilated as noisy priors, masked out, or handled with any constraint in the retrieval process.

**Answer 2:** Values below 0.3 kt$NO_2$ are only filtered (set to zero) for the computation and display of relative differences; they are not filtered during the inversion itself. In relative terms, such small values behave like noise and produce large apparent changes over low-emission regions, which are not the focus of the analysis. To obtain a more meaningful graphical representation, all values lower than 0.3 kt$NO_2$ are therefore masked in the relative difference plots. We clarified this in the caption of Figure 2, now it reads as follows (we added the text in Bold and Italic): "[…] *Values below 0.3 kt $NO_2$ in the prior estimate for February 2019 are set to zero when calculating the relative difference (d)* ***only for display purposes; these are not filtered in the inversion itself.***"

**Question 3:** Figure 9 is discussed only briefly, **yet it shows a monthly trend that differs substantially from the posterior estimates. A deeper analysis is recommended** to clarify the potential drivers of this discrepancy and to explain the underlying causes of the observed emission pattern.

**Answer 3:** We believe that the monthly variability of the posterior estimates is different from that of the prior emissions due to an underestimation of biogenic emissions in the MEGAN inventory, and therefore an underestimation of biogenic emissions in our prior estimates. We briefly state this in the discussion of Figure 2 (lines 467 – 476). We tested this hypothesis by using CAMS-GLOB-SOIL instead of MEGAN in several sensitivity tests of the forward prior simulations (not shown in this work). However, performing a full additional analysis and including it in this scientific article would further divert the focus and make an already dense manuscript even longer, which is beyond the scope of the present work. That is why, in this article we choose to keep the explanation brief.

**Question 4: Although the study claims advantages in high temporal resolution, the daily emission variations are not clearly demonstrated**. Most results remain at monthly or seasonal scales, and even in Figure 11, the time series which is about two months for Henan is shown with a 14-day moving average, which overly smooths the data. This presentation does not effectively showcase the value of daily-scale emission information.

**Answer 4:** We show daily TVCDs (prior, posterior and TROPOMI TVCDs) in the supplementary materials, for the period 2019 – 2021, for Eastern China (Figures S4, S5 and S6). We added daily emissions in the supplementary materials for provinces (S13 to S40) and we show below one of them:

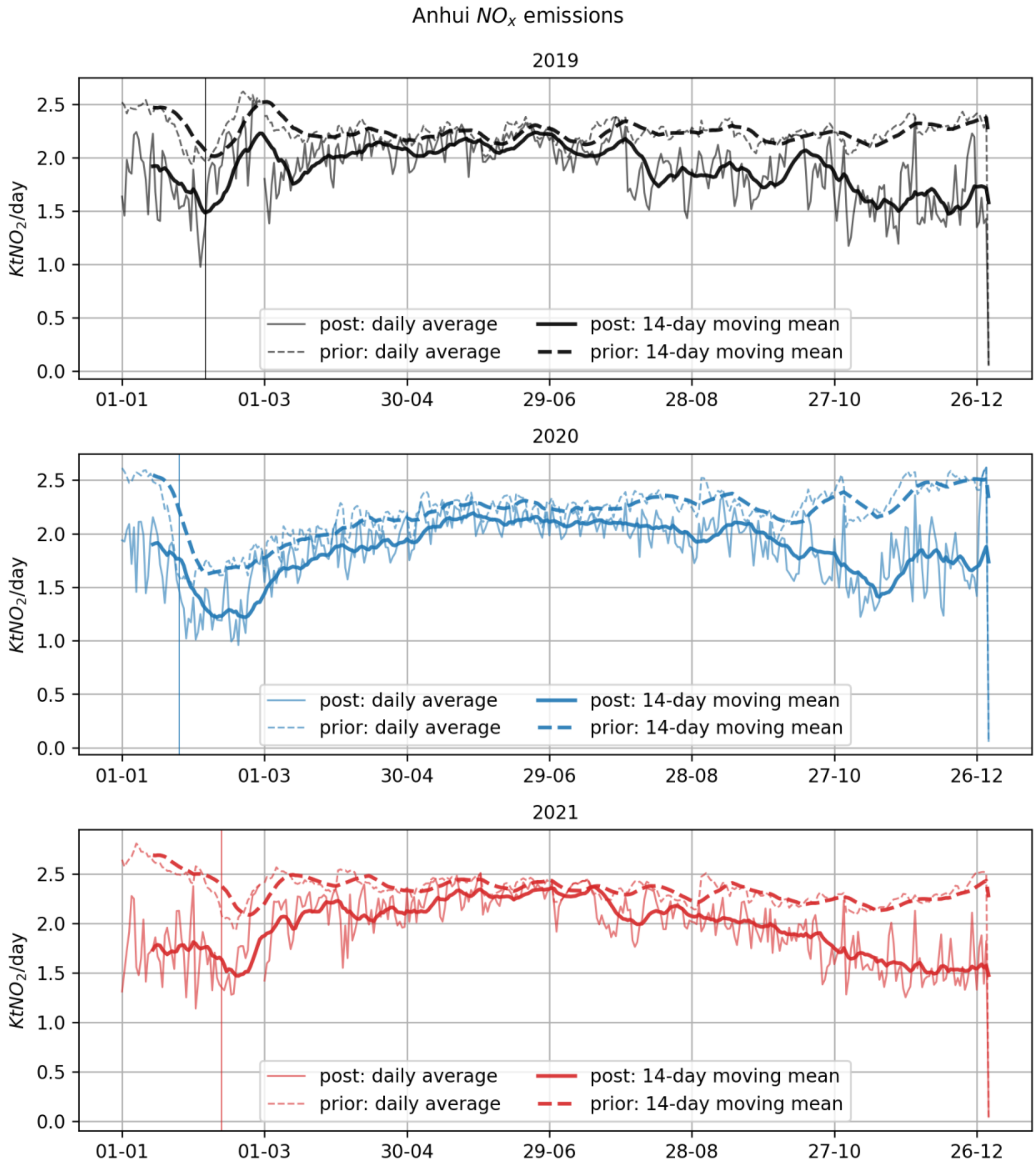


**Fig. S13.** $NO_x$ emissions presented as daily averages and 14-day moving averages for 2019, 2020 and 2021. The prior estimates are the dotted lines, and the posterior are the solid lines.

**Question 5:** As shown in Figures 13 and 14, the year 2020 marks not only the onset of the COVID-19 lockdowns but also the final year of China's 13th Five-Year Plan. Although many studies have reported substantial emission reductions during this period, **attributing these changes solely to the lockdown**

**measures is not appropriate, especially given the large spatial and socio-economic heterogeneity of the cities examined**. Broader policy-driven structural adjustments and long-term emission control measures likely contributed as well, and should therefore be considered in the interpretation. To avoid potential over-attribution, the authors are encouraged to either (1) clarify how the analysis distinguishes the lockdown-induced reductions from broader economic influences, or **(2) revise the discussion to reflect that the observed changes may result from both the lockdown measures and underlying economic conditions.**

**Answer 5: We do not attribute the changes in emissions during 2020 solely to the lockdown measures**, and we state this in section 3.3 (lines 493 to 495): "*Miyazaki et al. (2020a) showed that nearly 80% of the emission reductions, during the period 23 Jan – 29 Feb 2020, are due to the lockdown measures in each province*". Our analysis is therefore in alignment with the second suggestion.

In section 3.4, **we equally discuss the changes in import and export during March-April-May 2020** (lines 525 to 530): *"During March-April-May of 2020, emissions decreased by −20% along the China-Mongolia-Russia Economic Corridor (Figure 12a), one of the main economic belts connecting China through Inner Mongolia, then Mongolia and Russia (World Bank, 2019). This reduction in $NO_x$ emissions may be a result of the decrease in the Chinese exports in April and May 2020 by −15% (GACC, 2020), due to the lockdown measures applied by the Chinese government and to the decrease in Russian exports to China , from ~ $60 billion in 2019 to ~$50 billion in 2020 (GZERO, 2022; OEC, 2022)."* However, it is also important to note that most of these economic changes are in fact linked to the pandemic and the measures that were applied.

**Minor comments:**

**Comment 1: The title of Section 3.3, "Seasonal cycle of NOx total emissions in Eastern China" appears to reflect only the content associated with Figure 9**. However**, Figures 10 and 11** focus on the NOx emission changes around the **Lunar New Year** period, which does not fall under the concept of a seasonal cycle. To avoid confusion and more accurately represent the scope of this section, it would be clearer to revise the title of Section 3.3 to better encompass both the seasonal analysis and the LNY-related emission variations.

We changed the title of section 3.3 to "Seasonal cycle of $NO_x$ and the Lunar New Year contribution"

**Comment 2:** Line 477 contains only a single sentence presented as an independent paragraph. It would be clearer and more consistent with academic writing conventions either to merge this sentence with the preceding or following paragraph.

The sentence is now merged with the paragraph preceding it.

**Comment 3:** In Figure 10 and 11, the comparison of different weeks following the Lunar New Year provides useful insight into the holiday-related impact on NOx emissions in China. However, when comparing week-to-week trends across different years, is the underlying daily grid spatial coverage consistent among the three years**. If the number of valid emission grids in 2020 differs from (maybe much smaller than) those in 2019 and 2021, the conclusion regarding the pandemic-related disruption would not be fully robust.**

The number of valid emission grids in 2020 is the same as in 2019 and 2021, for all the provinces, during the first and second weeks of analysis. Here we show an example of two provinces. The title of each subplot includes the week studied (w1, or w2), the year, and the number of pixels (px = available emission grids per province, per week). Providing that the number of grids in 2020 is equivalent to those in 2019 and 2021, we believe that our conclusion regarding the pandemic-related disruption is robust.

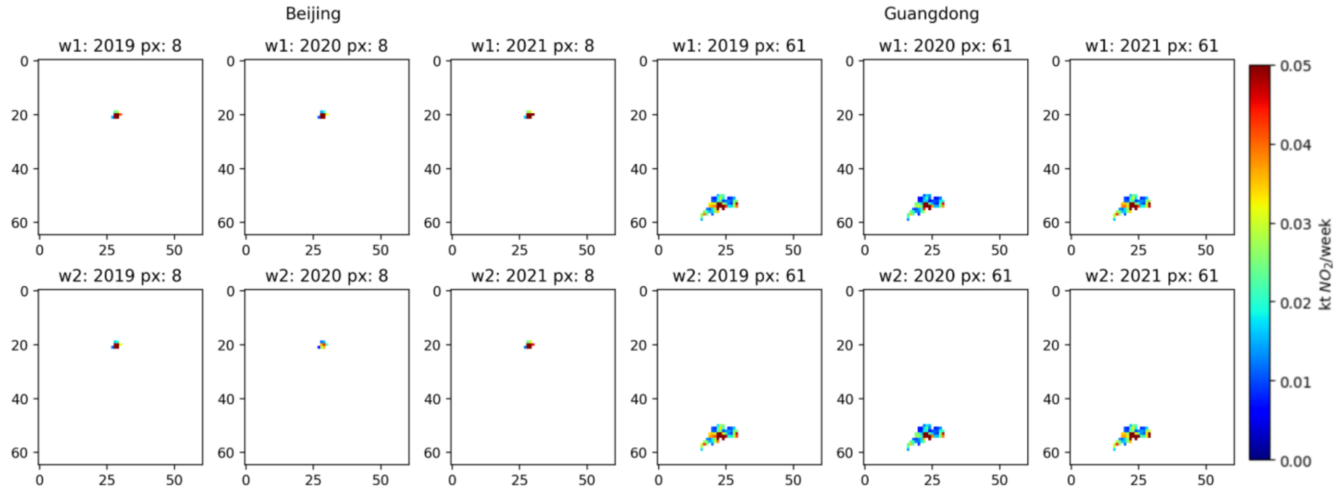


**Figure R1.1:** $NO_x$ emissions per week of LNY (w1 or w2), for two provinces (Beijing and Guangdong). Please note that the start date of w1 and w2 depends on the date of the Lunar New Year during the year of study (since it is different for each year). For instance, day1 of w1 is 05/02 for 2019, 25/01 for 2020, and 12/02 for 2021; and day1 of w2 is 12/02 for 2019, 01/02 for 2020 and 19/02 for 2021.

**Comment 4:** In Figure 10, connecting the data points for different provinces with lines adds little interpretive value. The key information lies in whether the relative changes are above or below zero, similar to the Figure 13. It is recommended to remove these lines and consider alternative ways to visually highlight the direction and magnitude of the changes, which would improve the clarity and readability of the figure.

We removed the line connecting the data points, and now the figure looks like that:

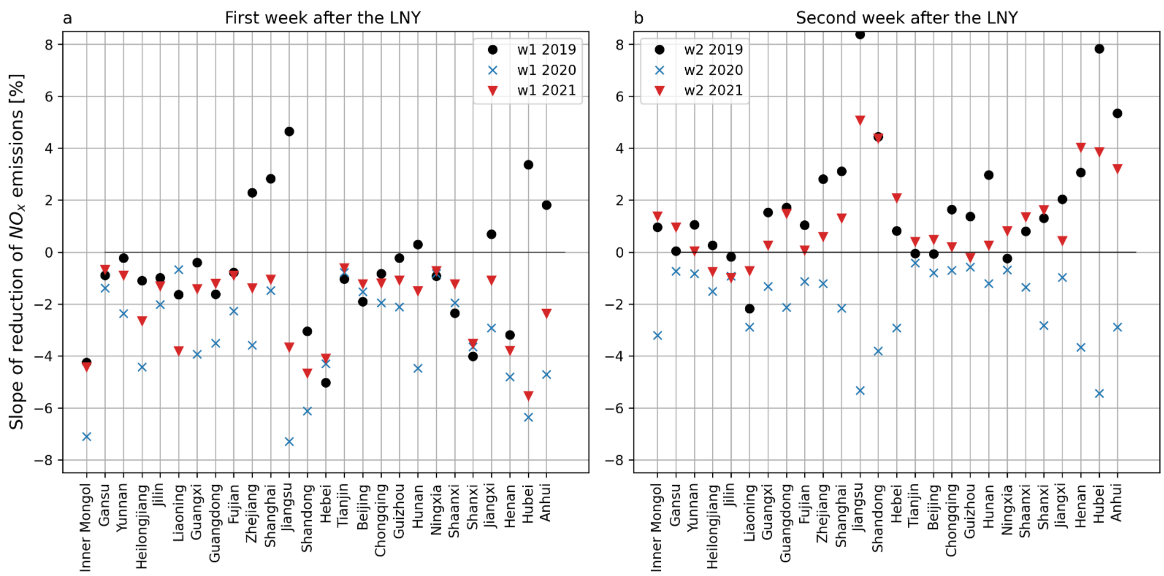


**Figure 10:** Slope of change in the posterior estimates of $NO_x$ emissions during the first (a) and second (b) weeks following the LNY dates, in 2019, 2020, and 2021 in the Chinese provinces. These slopes of change are calculated for each week separately by computing the slope of a line that connects the first and the last days of the week in question. Week1 of LNY starts on the first day of the New Year for the corresponding year (assigned day1), and week2 starts on day 8. Note that the LNY dates for each year are different; and they fall on 5 February 2019, 25 January 2020, and 12 February 2021; therefore, day 1 is assigned for each year based on the corresponding date, i.e. day1 for 2019 falls on 5 February, and for 2020 on 25 January.

**Comment 5:** The title of Section 3.4, "Impact of the COVID-19 lockdown in Eastern China", suggests that the analysis only focus on the effects of the lockdown. However, as indicated in lines 525 to 530, part of the observed emission reductions may also stem from concurrent economic downturns or other many factors which are not related with lockdown. **It is not sufficiently precise to use the current title and framing of Section 3.4 when other factors,** such as economic slowdown, also contribute to the observed emission reductions.

We changed the title of Section 3.4 and now it reads as follows: *"Impact of the COVID-19 lockdowns and economic changes on $NO_x$ emissions".*

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