Decision Support System (v 1.0) for Air Quality Management in New Delhi, India

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Reply to the reviewers

We thank the reviewers for their insightful comments on the manuscript. The comments/suggestions have certainly further improved the state of the manuscript. In this document, we have provided point by point reply to the comments/suggestion and have modified the manuscript wherever required. The reviewer's comments are written in black font, and the authors' replies are written in blue font.

General comments

Most of my comments have been addressed by the authors, which has improved this manuscript. I would suggest that the authors to implement some of the replies in the manuscript. I am impressed that the authors were able to correct the errors in the anthropogenic emissions and update the results. However, I have a few questions after reviewing the revised manuscript. Please see the specific comments listed below.

Specific comments

P4, Line 179: The authors use the anthropogenic emission inventory from TERI for the year 2016. Is there any increasing or decreasing trends of anthropogenic emissions from 2016 to 2022?

Regarding this question, I would suggest the authors to implement key points and citations in the manuscript based on their reply, such as the increases in emissions from transport and industrial sectors over the last a few years. This can provide more information to readers.

- We thank the reviewer for this important suggestion. In the revised version of the manuscript, we have included this discussion in the main text (line numbers 186–191).

P4-5, Line 190-208: I would suggest the authors to add a figure showing the timeseries of estimated daily fire emissions in the domain during the simulation period. I'm wondering if the authors evaluated their forecasted fire emissions using other available fire emission inventories such as GFED. I'm also wondering if this climatological method could generally capture the day-to-day variability of fire emissions in this region.

- We thank the reviewer for raising this critical concern. We have examined the prescribed fire emissions in the model domain, especially over the agricultural-fire-prone region (i.e., the states of Punjab and Haryana in the northwestern part of India). As suggested by the reviewer, we have compared the total prescribed daily fire emissions over these states for the period of October–November 2021 in our modeling framework (DSS) with the corresponding daily climatological emissions prepared using the FINN (Fire INventory from NCAR) dataset for the year 2022–2018. Additionally, we compare those with the corresponding emissions from the Copernicus Atmosphere Monitoring Service (CAMS) Global Fire Assimilation System (GFAS) (Kaiser et al., 2012) for the same period. Figure 1 depicts this comparison.

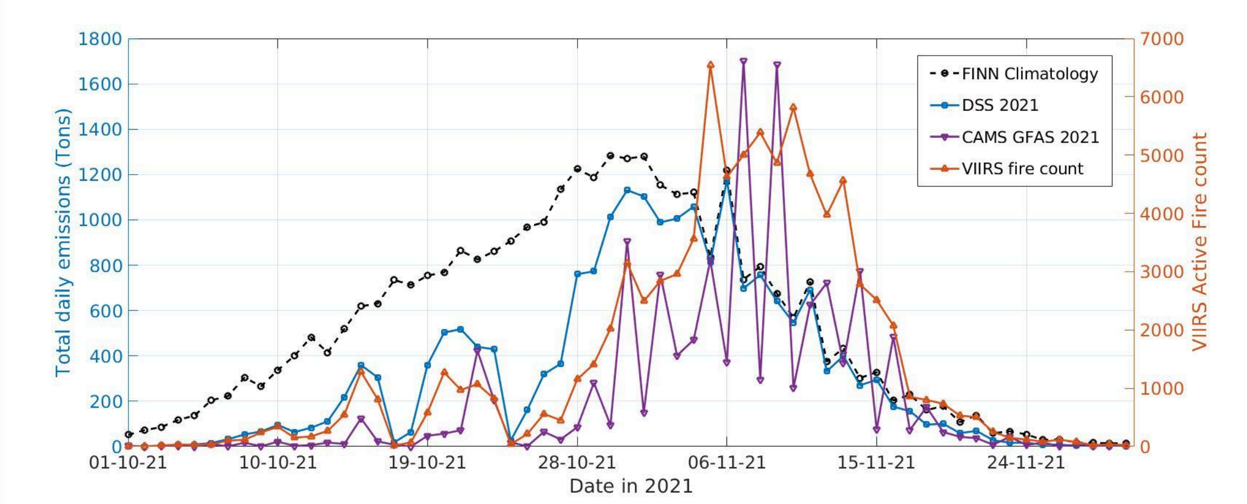

Figure 1: Daily emissions of Organic Carbon from fires over Punjab and Haryana states of India for the period of October 2021–November 2021 from a). FINN climatology prepared using the data from 2002–2018 (Dashed black line), b). DSS modeling framework (blue line), and c). CAMS GFAS emissions database (purple line). The units are tons of Organic Carbon. The Orange line depicts daily active fire counts over the same region retrieved by the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument onboard the NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP) satellite. The y-axis on the left side may be used for emissions, while that on the right side may be used for fire counts.

It may be noted from Figure 1 that the fire emissions employed in DSS differ substantially from its parent i.e., the daily mean climatological data of FINN. The primary reason for the difference is the availability of the active fire count data from VIIRS. It may clearly be seen from the plot that the daily variation in fire counts effectively decides the fire emissions in the DSS framework. It is particularly evident around 19th October and 28th October when VIIRS fire counts and the corresponding prescribed fire emissions in the DSS are zero, in spite of a non-zero FINN climatology. Thus, it can be clearly noticed that the prescribed fire emissions in DSS differ reasonably from the climatology, and they do vary on a day-to-day basis.

Upon comparing with the emissions from CAMS GFAS, it can be seen that the overall temporal variation of both datasets is roughly similar. Both of them depict zero values when fire counts are zero. Both datasets peak roughly during the same time. However, the DSS fire emissions show their primary peak towards the end of October, while that for GFAS exists in the first week of November. Similarly, the peak fire counts also are seen in the first week of November. Thus, the peak in DSS emissions of fires was reached almost a week earlier compared to GFAS and VIIRS fire count data. This behavior is likely to be linked with the FINN climatology employed in DSS. There have been a few recent studies (Jethva et al., 2019; Sembhi et al., 2020; Kant et al., 2022) that have shown that the fires in this part of the world have temporally shifted by roughly 1–2 weeks owing to a policy aimed at protecting the groundwater in the region. However, this shift in the emissions is not reflected in the FINN climatology which is computed for the period of 2002–2018. In the next version of DSS, we are aiming to revise the FINN climatology by using more recent FINN data to prepare the base emissions. Owing to the differences in fire emissions of DSS and GFAS during the month of October, the total fire emissions of organic carbon from Punjab and Haryana states come out to be 8311.80 tons for DSS and 2538.60 tons for GFAS. Nevertheless, the total estimates agree well in the month of November, with DSS giving 12653 tons of OC and GFAS showing 10447 tons. Another difference in the estimates is that the GFAS dataset shows more variability in day-to-day emissions from fires compared to that in the DSS framework. Such high variability is not seen in the VIIRS fire counts as well. Thus, the GFAS dataset generally depicts a higher day-to-day variability.

Thus, the fire emissions employed in the DSS framework do show day-to-day variability. They are not overly driven by long-term FINN climatology. However, the peak in the absolute magnitudes of the emissions in DSS looks to reach a week earlier compared to that in GFAS, and even in VIIRS fire counts data. In the next release of DSS, we will address this issue.

This description has been included in the main text (line numbers 207–216), and Figure 1 has also been added as Figure 2 in the supplementary material.

P15, Table 2: The authors mentioned that they corrected the prescribed anthropogenic emissions and re-ran the simulations. I'm wondering why the statistics for the "Poor" and "Very poor and above" categories increase significantly during the post-monsoon season in Table 2. It seems that the prescribed anthropogenic emissions contribute to the biases.

- We thank the reviewer for raising this concern. It may be noted from Figure 5 of the original manuscript and Figure 5 of the revised manuscript that the model fails to capture the high AQI values that occurred in the first week of November 2021. As mentioned in the main text, this underestimation is related to the limitations of the modeling framework in getting the correct prescription of the emissions of particulate pollutants from stubble-burning activities occurring in the neighboring states of Punjab and Haryana. Moreover, the pulse of fire-crackers during the day of the Diwali festival would have also played a role, as mentioned in the main manuscript. However, in the original manuscript with incorrect anthropogenic emissions in the following week the model overestimated the observations substantially. This overestimation negated the underestimation in the previous weeks, resulting in the cancellation of the biases and a net low bias in the $PM_{2.5}$ concentrations. However, upon correcting the anthropogenic emissions for the week following the Diwali festival, the large overestimation in the model gets corrected. This results in a net underestimation from the model side for the post-monsoon season, as the pre-Diwali underestimation dominates the performance statistics. Thus, the correction of emissions results in increased bias. However, it may be noted that the corrections reduce the mean error values, especially for the 'very-poor and above' categories. Thus, while the biases increase due to corrections, the errors actually reduce.

Technical corrections

P5, Line 197-199: Please directly use the acronyms “VIIRS” and “Suomi NPP”.

- We thank the reviewer for pointing this out. We have made this correction.

P14: Figure 5a: Please correct the label “Date in 2011”. I think it is supposed to “Date in 2021”.

- The corresponding correction has been made.

P25, Line 813: “…17.1% and 10.2…%

- The typo has been corrected.

P26, Line 816-819: Change the unit “ug/m3” to “µg m-3”.

- The units have been changed wherever they appear in the entire manuscript.

P33, Line 1125: please remove the repeated citation.

- The corresponding correction has been made.

P34, Line 1155: the font for this citation looks very different.

- The font has been corrected.

References:

Jethva, H., Torres, O., Field, R. D., Lyapustin, A., Gautam, R., & Kayetha, V. (2019). Connecting crop productivity, residue fires, and air quality over northern India. *Scientific Reports*, *9*(1), 16594.

Kant, Y., Chauhan, P., Natwariya, A., Kannaujiya, S., & Mitra, D. (2022). Long term influence of groundwater preservation policy on stubble burning and air pollution over North-West India. *Scientific Reports*, *12*(1), 2090.

Kaiser, J. W., Heil, A., Andreae, M. O., Benedetti, A., Chubarova, N., Jones, L., Morcrette, J.-J., Razinger, M., Schultz, M. G., Suttie, M., and van der Werf, G. R. (2012). Biomass burning emissions estimated with a global fire assimilation system based on observed fire radiative power. BG, 9:527-554.

Sembhi, H., Wooster, M., Zhang, T., Sharma, S., Singh, N., Agarwal, S. Boesch, H., Gupta,, S., Misra, A., Tripathi, S.N., Mor, S., Khaiwal, R (2020). Post-monsoon air quality degradation across Northern India: assessing the impact of policy-related shifts in timing and amount of crop residue burnt. *Environmental Research Letters*, *15*(10), 104067.