Responses to interactive comments

Journal: Atmospheric Chemistry and Physics

Manuscript ID: acp-2020-903

Title: "Impact of reduced anthropogenic emissions during COVID-19 on air quality in India"

Dear Referee #2,

We appreciate your comments to help improve the manuscript. We tried our best to address your comments and detailed responses and related changes are shown below. Our response is in blue and the modifications in the manuscript are in red.

Comments: The manuscript presents a topical research, i.e. to understand the air quality change in India during the COVID-19 lockdown period. The reported ozone and PM changes from the ground-based observations reveal the sensitivity of major pollutions to the drastic emission reduction in India which is one of the most polluted regions in the world. The WRF-CMAQ model simulations further shed light on the relative contributions from primary emissions and secondary formation of aerosols. The manuscript is easy to follow and fit to the scope of ACP very well. I recommend its publication with ACP, while I also have comments below for the authors to address.

Response: Thanks for the recognition of our study. Below is the response to each specific comment.

Comments: The major results of this study are based on the comparison between the Lockdown and Pre-lockdown periods. Figs. 1-3 show observed changes in PM and ozone. I'm wondering how different the meteorological conditions are during those two periods? The recent COVID-19-related studies (e.g. Le et al., 2020, Science) have stressed the importance of ventilation conditions and relative humidity in regulating the air pollution at the short time scale. Since the authors have obtain the meteorological data and conducted WRF simulations, it should be a low-hanging fruit to perform a more comparative analysis of meteorology (precipitation, winds, PBL height, etc.), in addition to the present Fig. S2 of temperature comparison. The outcome of this analysis should be also discussed in the context with the recent studies focusing on the air quality changes during the COVID-19.

Response:

Thanks for the comments. Considering the important influence of meteorological conditions, we added more analysis on their differences between pre-lockdown and lockdown periods including temperature (T), relative humidity (RH), planetary boundary layer (PBL) height, the average daily precipitation, and wind fields in below Fig. 1 (also added as Fig.S3 in the revised supplement). We also explained the impacts of these meteorological conditions on air quality in the Results and Discussion section.

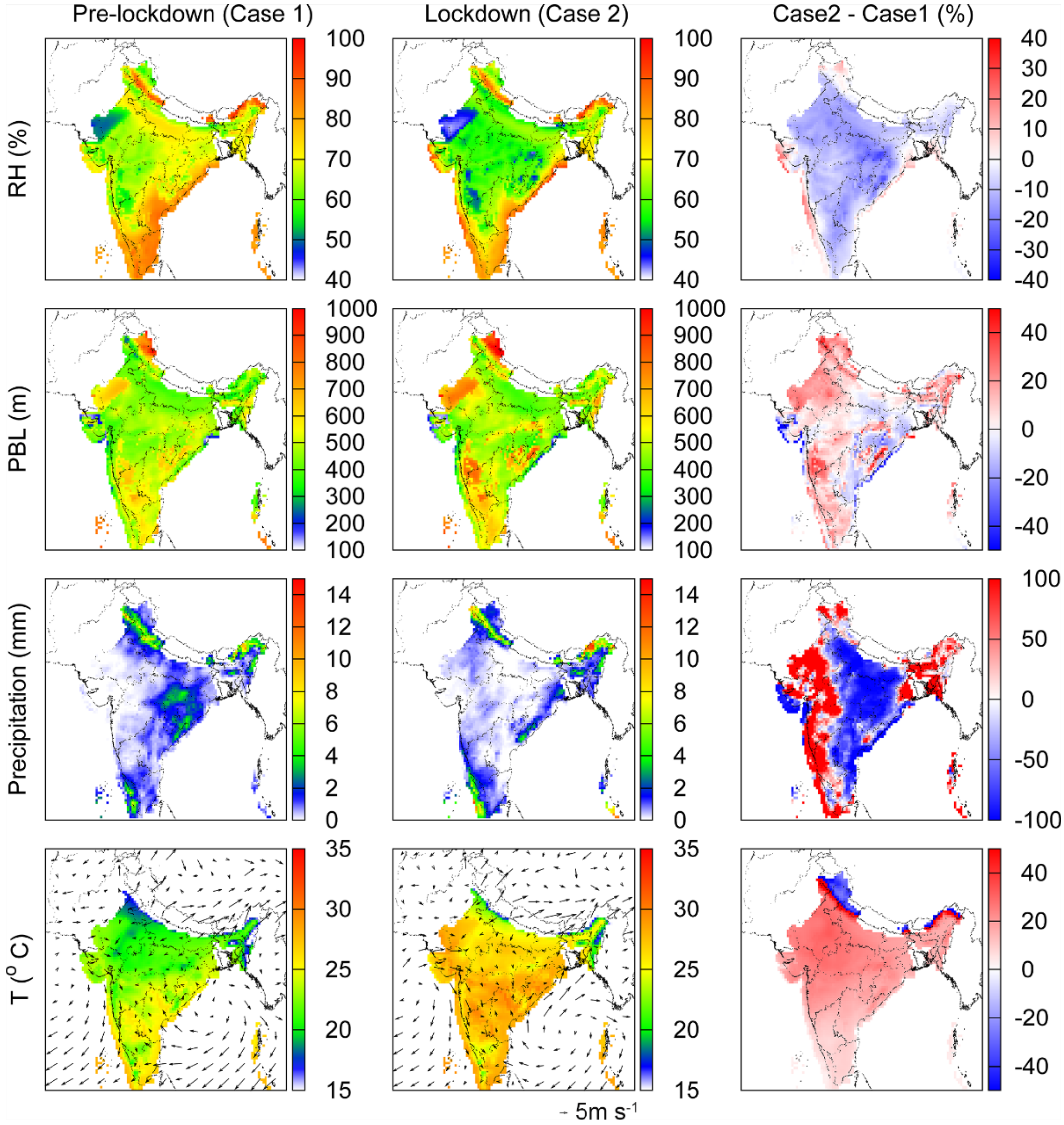

Figure 1: Distribution of simulated temperature (T), relative humidity (RH), planetary boundary layer (PBL) height, the average daily precipitation, and wind fields in India before and during the lockdown period. "Case2 - Case1" indicates (Case 2 – Case 1)/Case 1, reported as %.

Changes in manuscript:

Results and discussion (Lines 199-203 in the revision): "Variations in near-surface meteorological factors during lockdown also play an important role in $PM_{2.5}$ changes. As is shown in Fig. S3, lower $PM_{2.5}$ in urban areas during lockdown (Fig. 4) may attribute to the decrease of RH and increase of planetary boundary layer (PBL) height, while the decrease of precipitation and WS allows $PM_{2.5}$ to accumulate in some rural areas (Schnell et al., 2018; Le et al., 2020)."

Results and discussion (Lines 207-211 in the revision): "Although significant reductions are found in O_3 precursor emissions throughout India during the lockdown, the MDA8 O_3 has not shown comparable decreasing trends, which is affected by the meteorological conditions such as an increase of temperature and decrease of RH (Fig. S3). Higher temperature speeds up photochemical processes that produce O_3, while higher RH reduces them (Chen et al., 2019; Zhao et al., 2017; Ali et al., 2012)."

Comments: There is no doubt that HCHO is closely linked with VOCs, but it is unclear to me how well the HCHO can be used to represent the total VOCs in a quantitative manner. Can the authors show their correlations based on the CMAQ model results?

Response:

As one of the most abundant oxygenated VOCs, HCHO is one of the major contributors to total VOCs reactivity (Zhang et al., 2012; Steiner et al., 2008). Therefore, it is used to show the model performance on VOCs due to the lack of VOCs observations. Figure 2 (added as Fig.S4 in the revised supplement) shows scatter plots comparing the simulated average daily HCHO and the total VOCs at all 117×117 grids during the study period. It can be seen from the results that HCHO has a high correlation with VOCs, and R^2 reaches 0.93. We added explanations in the manuscript to make it clear.

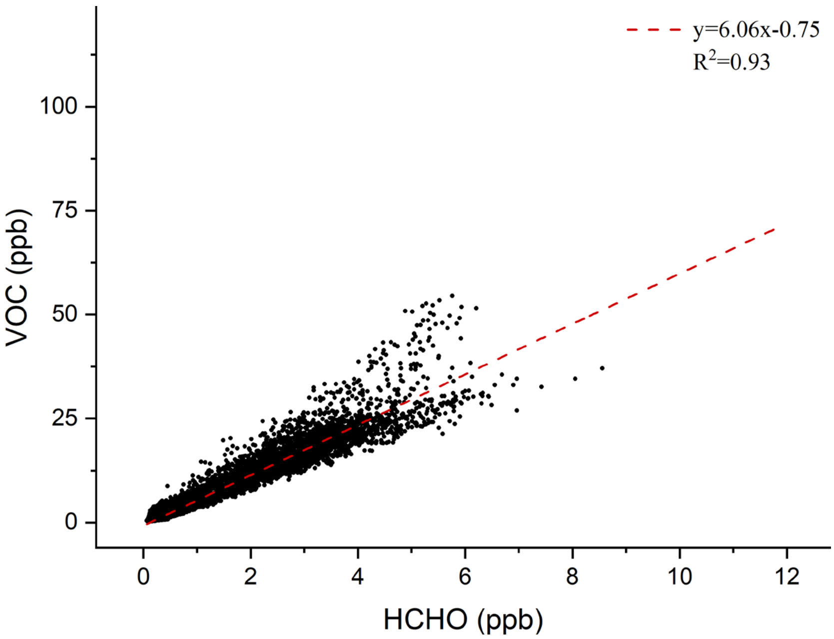

Figure 2: Scatter plots comparing the simulated average daily HCHO and the total VOCs at all 117×117 grids from February 21 to April 24, 2020.

Changes in manuscript:

Results and discussion (Lines 267-269 in the revision): "We investigated the changes of MDA8 O_3 and its major precursors NO_x and HCHO that is one of the major contributors to total VOCs reactivity (Zhang et al., 2012; Steiner et al., 2008) during the lockdown period. Figure S4 shows that HCHO has a strong correlation with total VOCs (R up to 0.93)."

Comments: Spaceborne measurements of HCHO and NO_2 are available from the latest satellites, such as TROPOMI. There are near-real-time products. The authors may want to explore those data and validate the modeled HCHO and NO_2 and see their changes in observations.

Response:

Thank you for this good suggestion. To validate the modeled HCHO and NO_2, we compared our simulated results with satellite-observed NO_2 and HCHO column number density datasets from TROPOMI during pre-lockdown and lockdown periods (Fig. 3, added as Fig. S1 in the revised supplement). As shown in Fig. 3, the predicted regional distribution of NO_2 and HCHO column number densities is similar to satellite-observations. Overall, HCHO and NO_2 are higher in eastern and northern India than in other regions. And their variation trends from CMAQ and TROPOMI are consistent that NO_2 decreases while HCHO increases during the lockdown.

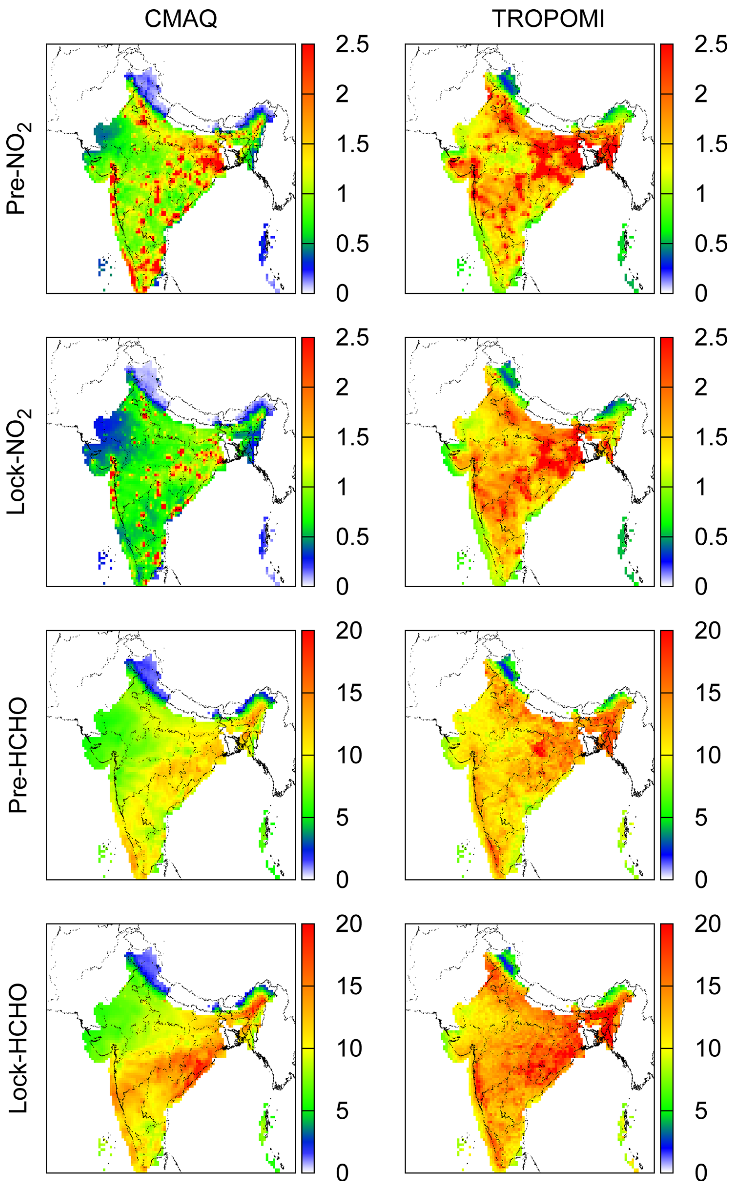

Figure 3: Comparison of the simulated and satellite-observed NO_2 and HCHO column concentrations before lockdown and during the lockdown in India. The unit is 10^{15} molec cm^{-2}.

Changes in manuscript:

Methodology (Lines 85-89 in the revision): "The satellite-observed NO_2 and formaldehyde (HCHO) column number density datasets are from the Sentinel-5 Precursor TROPOspheric Monitoring Instrument (S-5P TROPOMI) (https://scihub.copernicus.eu). Besides, we filter the satellite data under the recommended criteria of QA values greater than 75% for tropospheric NO_2 column number density datasets and 50% for HCHO (Apituley, 2018)."

Results and discussion (Lines 158-163 in the revision): "To further validate modeled HCHO and NO_2, we compared our simulated results with satellite-observed data during pre-lockdown and lockdown periods (Fig. S1). The tropospheric column densities of NO_2 and HCHO were calculated by summing their concentrations of 17 vertical layers in the CMAQ model (H. J. Eskes, 2020). The predicted regional distribution of tropospheric column NO_2 and HCHO is similar to satellite-observations. Overall, HCHO and NO_2 are higher in eastern and northern India than in other regions. And their variation trends from CMAQ and TROPOMI are consistent that NO_2 decreases while HCHO increases during the lockdown."

Reference

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