

# ***Interactive comment on “Changes in black carbon emissions over Europe due to COVID-19 lockdowns” by Nikolaos Evangeliou et al.***

**Anonymous Referee #2**

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In this work the changes in black carbon emissions (BC) due to the restrictions imposed in response to the global pandemic are estimated through inverse modeling. Absorption measurements from the Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) and the networks European Monitoring and Evaluation Program (EMEP) are used in a Bayesian inversion system to estimate weekly emissions over Europe for a given a priori emission inventory. Estimated posterior BC emissions are compared against dependent observations first to examine the optimal prior inventory to conduct the study. Then, concentrations computed with the estimated emissions were compared against two ARCTIS stations not considered in the inversion and therefore representing independent observations. Additionally, comparison was also conducted against reanalysis dataset of BC from MERRA-2 (Modern-Era Retrospective Analy-

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sis for Research and Applications Version 2). The results of this study suggest that BC emissions during the lockdown period were 10% smaller than for the same period of the previous five years. In addition, emissions decreased 10% over Europe when compared to the period before the lockdown. Although the study and the results are interesting, I find the article not well written. Before I can recommend it for publication it needs to be improved in terms of clarity and analysis. In what follows I'll present the general comments supporting my evaluation.

### General comments

1. Section 2 (Methods) is a description of different pieces used in the study without explaining the links between them and how they contribute to achieve the goal. The methodology was made clear while reading the Results. This should not happen; the full methodology should be clear to the reader while reading section 2. I suggest that an introductory paragraph should be included at the beginning of section 2 explaining the general methodology applied in the study and pointing to the individual sections where more information is provided. I believe it would also contribute if the inversion system is presented after all other elements used in the system have been presented.
2. The authors provide an incomplete description of the inversion system. It is not clear from the text what the size of the state vector is? Are the emissions estimated for each grid illustrated in Figure 1 or are these grids aggregated to larger regions? Furthermore, how are the B and R matrices defined? Are the uncertainties of the prior considered not to be spatially correlated and thus the B matrix defined as a diagonal matrix? What about the R matrix is it also considered to be a diagonal matrix? The authors describe how they validate the chosen values but do not present the values used in either matrix. This is relevant information that should be provided by the authors. If it is provided in another study it should nevertheless be summarized in the paper.
3. The authors use 6 emission inventories as prior for the inversion and from those one (ECLIPSE v6) is chosen to conduct the study. Most, if not all, of these inventories

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do not provide yearly estimates but for larger intervals. ECLIPSE for instance provides estimates every 5 years. How do the authors deal with this? Do they linearly interpolate between the available years to have yearly estimates? Furthermore, while 2015 in ECLIPSE correspond to an actual estimate, the emission for 2020 correspond to a projection. None of the priors for 2020 are an actual estimate but a projection of some kind. Do the authors attribute larger uncertainties to the prior of 2020 because of this? In other words is the B matrix defined differently for 2020? If not, why? What is the impact on the results due to this difference between emissions before 2020 and the projected emissions for 2020?

4. Different set of stations were used for the period 2015-2019 and 2020. As the authors state in sections 3.3, changing observations can have drastic impact on the posterior emissions. Why were different stations used for the two periods? How many stations would be available for the inversion if only stations with data for both periods were used? How do the results change if only these stations are used in the inversion? The authors should discuss how the fact of using different set of stations impact the results. Ideally, the authors should demonstrate that the results are not impacted by using different set of observations between both periods.

#### Specific comments

Lines 50-52: The two periods considered in the analysis should be included.

Lines 59-62: The formulation of this sentence can be improved. The sentence is started with “Except” and then continued with “also”. What is the point of using “Except”?

Line 74: Is “distancing” missing after “strict social”.

Line 120: Acronym MAC needs to be defined.

Lines 148-149: The reference corresponding to the study mentioned on this sentence should be provided. Furthermore, this work also examines the impact on the emissions

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of the strict restrictions between the lockdown period and before, so how do the results presented in this study differ or complement the other study? Additionally, how do the estimated emissions compare between both studies.

Line 178: the weighted sum of squares of what? Please clarify.

Line 182: Where is this number coming from? Are those the total number of observations for the period 2015 to 2020?

Line 267: Is the B matrix changed for each test according to the prior used or are the uncertainties of the prior emissions considered the same for all prior emissions? If not, how does the  $\chi^2$  statistic change for each test with a different prior?

Line 283: Although country emissions might have decreased, figure 4 also shows an increase of emissions in center-south France. Also, please explain the geometry of the region with increased emissions over Poland. How can these straight lines be explained? What does it say about the inversion system?

Line 289: The authors should clearly state the difference in the number of stations used for the period 2015-2019 and the year 2020.

Lines 302-303: Does this mean that the inversion was also conducted for each year since 2015 using the same stations as used in 2020? Doesn't this contradict what is said at the beginning of this section. Please clarify.

Line 353: I suppose that by "before" the authors refer to previous studies presented in the provided references. What do these results show? Is the impact associated to these other sources small compared to MAC? The authors should summarize the impact of the other sources on the inversion compared to the results obtained in this study?

Line 354-355: Which period is considered in this analysis? Is it the entire period (2015-2020)? According to Figure 1, the network used changes between 2020 and the rest of the period. Given the uncertainty obtained it should be clarified which period is used.

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Line 356: How much does “increases dramatically” represent? Please reformulate.

Line 357: I do not think that "Accordingly" is the correct word to be used here. I suppose the tests were conducted independently by fixing the other parameters (ie, fixed emissions when testing uncertainty due to MAC).

Line 363: Why were only two stations left out for the independent validation? Furthermore, both stations are located close to a station actually used in the inversion and since uncertainty "increases dramatically" far from the observations, using two “nearby” stations for validation represents the “best scenario” case. How independent are these two stations actually? How does the performance changes if isolated independent stations are used for validation?

Line 367, Figure 7: Since the uncertainty is not included in the analysis below, I would suggest to remove the illustration from the error (MAC & Prior) in order to make the figure easier to read. In it's present state, it is difficult to identify the different lines.

Lines 384-385: I have to admit I'm confused here. Figure 3 in the supplement shows that in all countries (except Scandinavia), MERRA-2 concentrations during lockdown in 2020 were not the lowest ones. How is this compatible with saying that and improved air quality was seen over Europe during lockdown based on MERRA-2 data?

Figure 8c: In figure caption please indicate the color used for each station.

Lines 414-421: I do not entirely agree with this analysis, Although the emissions were reduced in most selected countries, for France emissions for 2016 and 2018 were smaller than for 2020, at least for the first half of the lockdown period. Similarly, for Italy emissions in 2015 and 2017 were lower than for 2020. This is consistent with what is said at the beginning of section 4, where it is stated that increase light absorption measurement are observed at the beginning of the lockdown due to increased residential emission. Isn't it contradictory what is stated at the end of section 4 with what is said at the beginning of the same section?

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