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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Quantifying population exposure to airborne particulate matter during extreme events in California due to climate change" *by* A. Mahmud et al.

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R1C1: Is the PCM assumption of a 1% per year increase in CO2 sufficient to model the effects of climate change?

Response: The Parallel Climate Model (PCM) simulation was selected from an ensemble of GCM predictions used in the IPCC Fourth Assessment Report (AR4) (2007). PCM was one of the 23 models utilized in estimating the global climate change impact for future in the assessment report*. The scenario was judged to sufficiently represent climate change as part of that process. The simulations currently underway as part of AR5 consider increasing emissions of CH4 and changes to anthropogenic aerosols,

but these more sophisticated results were not available at the time of our analysis. The text of the manuscript will be revised to reflect this limitation in the study.

*Randall, D.A., R.A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R.J. Stouffer, A. Sumi and K.E. Taylor, 2007: Cilmate Models and Their Evaluation. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

R1C2: The authors mention on a few separate occasions within their model description that it has been assumed that population density, population, and emissions levels are held at 2000 levels. Why have the authors used this assumption?

Response: The goal of the current paper was to resolve the effects of climate change alone on conditions conducive to extreme PM2.5 concentrations in California. For this reason, the other variables including population, population density, and base-case emissions were held constant at 2000 levels. An interesting follow-up study would involve the comparison of climate effects vs. these other effects on extreme pollution events. This suggestion for future work will be included in the revised manuscript.

R1C3: If growth rates of species emissions are prescribed (and therefore known), could a study not then elucidate the effect of the climate change physics separately from the growth in emissions rates? Would statistical analysis, using these growth rates as independent variables, not be able to still provide some sense of total climate change forcing's effect on PM?

Response: Yes, this would be one method to weigh the effect of emissions changes vs. climate change. A separate method would involve directly simulating the present and future climate condition using future emissions to compare the relative strengths. We generally favor this second approach and will consider this in future work.

R1C4: Eventually, this method would predict some near-steady state (after all, CO2 is rising, but there may be a saturation point in its effect on PM), given a long enough simulation timeframe. Is there any evidence that the climate is approaching some steady-state in the context of the pertinent variables discussed in this work? Do the authors foresee any potential change in the nature of their results if growth was included? For example, does the growth in emission rate of some species x alter the nature of the predominant reactions in the atmosphere such that the reaction set enters a different "regime?"

Response: To the best of our ability to analyze the system, the direct effects of climate on stagnation appear to explain the change in extreme PM2.5 concentrations. The known potential non-linearity of the nitrate system with respect to NOx and VOC concentrations does not appear to be active in the winter stagnation events where background ozone is the dominant oxidant. Increasing background ozone concentrations in the future would compete with strongly decreasing NOx emissions in the future, leading to a net reduction in nitrate. These effects are both “linear” to first approximation, even though they act in different directions. This discussion will be added to the revised text.

R1C5: How realistic is this in the context of observable and expected growth? Can a regulatory agency make any recommendations based on an assumption of zero growth?

Response: The assumption of zero growth is obviously unrealistic for California moving into the future. The results of the current paper help quantify the heightened stagnation during extreme events in the future implying that additional controls would be needed to offset the “extreme PM climate penalty”. The exact magnitude of those additional controls given the existing control plans can be explored in future studies with more refined models that consider feedback effects between source-oriented aerosols and local meteorology. This point will be clarified in the revised manuscript.

R1C6: The results for shipping sources in Figure 2 are surprising in the context of current observable trends, especially in SoCAB. The industry expects major increases in the activity of the Ports of LA and Long Beach in the years included within this study. However, this work shows a major decrease in contribution of PM from this source. It is well-known that ships at the ports are major contributors to PM emissions, and CARB has found this emission to be predominantly PM2.5, putting these ideas at odds with the authors’ results. Can the authors provide any insight on this discrepancy?

Response: The assumption of constant year 2000 emissions for both present and future climate conditions explains the lack of emissions growth in the current study. The average population exposure to shipping is therefore determined exclusively by changes in meteorology during the 1008 days of present climate vs. the 1008 days of future climate. The coastal regions of California experience higher wind speeds during future climate on average, yielding increased dilution for emissions from shipping.

R1C7: The authors mention the 3rd and 4th Assessment Reports of the IPCC. Some quantitative comparison between the current work and these references would be helpful in understanding the new contribution of this work.

Response: The PCM simulations that act as the starting point for the current study were one of an ensemble of results from 22 GCMs included in AR4. The mean temperature response of PCM over California was lower than the ensemble mean temperature response. We selected the future climate period around the year 2050 (as opposed to 2030) to give PCM more time to resolve a realistic climate response.

R1C8: The authors mention stagnation events being stronger in the future scenario. This is not shown in the Tables or Figures. A more thorough discussion, and visual demonstration, of these events will solidify the connection for the reader. As currently written, the reader must simply take the authors’ word that these stagnation events occurred with greater severity in the future scenario. A further step would be for a statistical analysis to provide a quantitative measure between stagnation event severity

and maximum PM concentration (or whatever similar measures the authors feel most appropriate).

Response: The increased stagnation in the future California climate system has been documented thoroughly in a previous study (Zhao et al. 2011a,b). We have made greater reference to those findings in the revised manuscript, but have not reproduced the analysis entirely in order to focus on the air quality results that are central to the current study.

R1C9: The data in Figure 3 does not seem to be in agreement with S3. The maximum concentrations in S3 seem to be cut off at thresholds approximately 1/2 as high as those shown in Figure 3. Data seems to indicate that in worst regions, 50% increase in PM. Given uncertainties previously discussed by the authors, how should the 50% difference be interpreted (is it significant even with the wide limits on the 90% CI)? How does the smaller sampling (since this is only the top 1% of days now) affect the uncertainty and 90% CI?

Response: Response: Figure 3 shows the regional distribution of 24-hr average concentrations of PM2.5 for those days exceeding the 99th percentile value of the population-weighted 24-hr average (=16.2 μg m-3). The 24-hr average PM2.5 concentration on these extreme days is predicted to increase by $\sim$50% in the future in central California, with slight decreases predicted in southern California, but the reduced number of sample days make it difficult to directly interpret the statistical significance of this result. The entire point of the Extreme Value Analysis (EVA) presented in the remainder of the paper is to address this question of statistical significance in the framework of population exposure to PM2.5. Fig. S3 of the supplemental information illustrates the distribution of statewide population-weighted concentrations during the present and future 7-year analysis periods. It is difficult to compare the statewide population-weighted concentrations (Fig S3) to the regional distributions (Figure 2) because the underlying population density fields are not shown. The upper values in the future population-weighted distributions are shown more clearly in the revised ver-

sion of Figure S3, emphasizing the increase in statewide exposure to extreme PM2.5 concentrations in future climate.

R1C10: A fundamental question that the authors should address is the choice between comparing current climate impacts on PM to the effects either in the past or the future. As an implicit basis of the work is that the climate is (and has been changing). With this assumption, is it possible to develop a more statistically significant (possibly more accurate) comparison if observed climate conditions from the past are used instead of projections to future conditions? After all, given the assumptions of the work and the high uncertainty in the current work, it does not seem that the authors are trying to answer what future climate will do to PM. Rather, the aim seems to be whether or not climate change can have regional PM effects. If this is the case, then the authors have freedom to choose the past or future to investigate.

Response: The authors agree that the effects of climate on extreme pollution events can be analyzed by comparing past climate to present climate or present climate to future climate. We feel that the present climate vs. future climate comparison has more relevance for future policy decisions. The current paper is a step towards comparing the influence of climate vs. emissions controls on future extreme PM2.5 events. We prefer to maintain the present vs. future focus to build the foundation for future studies.

R1C11: The authors do not mention in their paper any possible feedback between PM emissions (dependent variable) and climate change (independent variable) itself. It is of course known that, depending on the composition of the PM, there can be a feedback provided to regional climate forcing. Do the authors have some evidence to show that this effect can be ignored in their work or in general?

Response: We suspect that PM may have strong feedback effects on local meteorology in the San Joaquin Valley and possibly in the South Coast Air Basin. We are planning to use a sophisticated source-oriented version of the WRF-CHEM model to perform the next round of simulations that compare climate vs. emissions controls.

The current paper builds a foundation for that work, but a full application of the model with feedbacks is beyond the scope of the current study.

Technical Comments 1. The authors have slightly differing versions of their paper's title in the full manuscript, the supplemental material, and the submission paperwork. Response: The title of the supplemental will be corrected.

2. Page 3, Line 10: The year is incomplete for the Samet et al. reference. Response: Reference will be corrected in the revised manuscript.

3. Page 3, Line 21: The phrase "trapping leading" seems to indicate a word or phrase is missing or one of these words is not intended. Response: This phrase will be corrected to read: "…. trapping emissions close to sources leading to reduced ventilation of pollutants…."

4. Page 3, Line 26: The reference for Kleeman has an extra digit in the publication year. Response: This typo will be corrected.

5. Page 4: Line 2: "United Stated" is a typo. Response: This typo will be corrected.

6. Page 4, Line 19: "El Nino" requires the proper ñ character. Response: Nino will be replaced with Niño in the manuscript.

7. Page 4, Line 21: It is early in the paper, but the authors would benefit from using a more technically precise terminology than "tails" to describe the limits of the statistical distribution. Response: The statement will be revised to read: "The large number of simulation days also provides enough information about the extreme values of the distribution to support a rigorous analysis of these extreme events."

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