This manuscript presents a modeling investigation of particulate matter (PM2.5) changes by the mid-21st century driven by changes in wildfire smoke emissions across North America. Based on simulations with and without wildfire emissions in a coupled fire-climate-ecosystem model (RESFire-CESM), the authors reveal elevated summertime wildfire-induced PM2.5 concentrations during 2050s over the entire North America, with most substantial increase in wildfire contribution to the total PM2.5 across the eastern United States. The authors further attribute this remote PM2.5 enhancement to smoke transport and positive climatic feedbacks on PM2.5. While this study provides insights on a timely issue, it seems this study could be improved in terms of its completeness. More specifically, the proposed mechanism underlying the remote effects of wildfire emissions on PM2.5 over southeastern US needs further verification or exploration. Therefore, I suggest to return the manuscript to the authors for major revision.

We are thankful to the reviewer for his careful reading and thoughtful suggestions. We have addressed all the concerns and provided our response to each of these points below (response in **blue** and revised text of manuscript in red font).

Main suggestions:

While the authors investigate the thermodynamical feedbacks associated with absorbing aerosols, it looks like neither the dynamical feedbacks or circulation changes under climate change are explored. Intuitively, one would expect the dynamical/circulation features to be important for the long-range transport of smoke; without a thorough analysis on the dynamical aspects, it is hard to believe that the thermodynamical feedbacks are the only or dominant mechanism underlying the projected enhancement of the remote smoke-induced PM5. I suggest to 1) analyze observational data to identify circulation features that are responsible for long-range transport of western North American smoke to the southeastern US region; 2) evaluate the historical representation of such circulation features in your model; 3) investigate changes in such circulation feature between 2050s and 2000s, with and without wildfire emissions. In terms of the currently analyzed climatic feedbacks to smoke, the current interpretation of Figure 5 does not seem to be complete or robust. For example, the authors argue that "lower-tropospheric stability is enhanced by wildfire aerosols in the future", but the changes in AAOD (Figure 5A) or stability (Figure 5C) are only significant in very small and inconsistent areas in the eastern US. In addition, how do you explain the lack of stability changes in western US despite the significant changes in AAOD? Are the changes in stability sensitive to vertical distribution of absorbing aerosols? It is even harder to believe that the changes in AAOD (Figure 5A) solely cause the changes in precipitation (Figure 5D), given their very distinct spatial patterns.

We are thankful for the reviewer's suggestion. Actually, we discussed about the transport of enhanced smoke emission in detail and also identified it as a key cause of more wildfire-enhanced pollution over EUS compared to WUS in future (before discussing the climate feedbacks in figure 5). However, the climate-induced changes in circulation was not discussed in the original version and we have now included the same in our revised manuscript as a new figure on dynamical feedbacks.

Figure R1 below compare the decadal mean wind circulation at 850 hPa over North America for JJA season (2001-2010) from a) NCEP reanalysis and b) CESM-Resfire simulated control run simulation. The comparison illustrate that the model is able to reasonably capture the westerly jets and broad west to east circulation patterns over North America during our study

season. A more detailed and comprehensive evaluation of simulated meteorology including dynamical/circulation features by the control run is illustrated in Zou et al., 2019, ACP and Zou et al., 2020, ACP.

As the background circulation is westerlies over Northern America during both present and future years, the wildfire emissions are advected from Canada and western US to eastern US. In future, the simulated speed of the westerly jet flows over Canada wildfire regions is reduced in both the scenarios (ALL and WEF). It indicates that the westerly-induced transported wildfire emissions from Canada boreal forests to the eastern half of Northern America and EUS will be slower in future compared to that in present era. On the one hand, it implies that the advection of smoke plumes will be slightly reduced in future. On the other hand, this phenomena can also contribute to the enhanced PM2.5 values at surface as these transporting plumes will be subject to relatively more boundary layer mixing over the EUS and dry deposition/settling enhances. At the same time, the westerly winds over western US below 40N is strengthened in future compared to present day which indicates more advection flux of wildfire emissions to EUS. Thus, in addition to the thermodynamical and precipitation changes, the dynamical changes in future also generates a positive feedback and provides a more solid explanation for the simulation of relatively more PM2.5 accumulation over the eastern US compared to western US in future under wildfire enhancement.

We agree with the reviewer that the elevational variation of wildfire plumes over eastern US and western US /Canada is the cause of the differences we see in lower tropospheric stability. The smoke plumes which reaches eastern US are at an elevated altitude due to self-lofting property of absorbing aerosols as they travel downwind but the smoke over western US is at near surface elevation as it is at its source region. This can explain the significant atmospheric stability simulated over the eastern US compare to the source regions in western US and boreal forests of Canada. We have accordingly included this explanation in our revised text (see below).

The difference between future and present run (due to wildfire emissions) also show that rainfall reduces in eastern US region and increases in western US region. We have revised the text to clarify that this is an additional effect on PM2.5 accumulation over Eastern US rather than the interpretation that the absorbing aerosols are causing this regional heterogeneity in precipitation change. We have added following texts and new figure in the revised manuscript.

In future, the simulated speed of the westerly jet flows over Canada wildfire regions is reduced in both the scenarios (ALL and WEF). It indicates that the westerly-induced transported wildfire emissions from Canada boreal forests to the eastern half of Northern America and EUS will be slower in future compared to that in present era. On the one hand, it implies that the advection of smoke plumes will be slightly reduced in future. But on the other hand, this phenomena can also contribute to the enhanced PM2.5 values at surface as these transporting plumes will be subject to relatively more boundary layer mixing over the EUS and dry deposition/settling enhances. At the same time, the westerly winds over western US below 40N is strengthened in future compared to present day which indicates more advection flux of wildfire emissions to EUS. Thus, the net effect is more removal of wildfire-emitted PM2.5 from WUS and more influx of wildfire-emitted PM2.5 in EUS.

Along with this dynamical changes, other climatic feedbacks simulated can also contribute to enhancement of EUS pollution. Specifically, the enhancement of wildfire-induced smoke

aerosols increases solar absorption and scattering in the future (Figure 6A). This reduces the incoming solar radiation reaching at the surface (Figure 6B) and induces surface cooling. With atmospheric warming and surface cooling, lower-tropospheric stability is enhanced by wildfire aerosols in the future (Figure 6C). The smoke plumes which reaches eastern US are at an elevated altitude due to self-lofting property of absorbing aerosols as they travel downwind but the smoke over western US is at near surface elevation as it is at its source region. This can explain the more significant atmospheric stability simulated over the eastern US compared to the source regions in western US and boreal forests of Canada. Relatively stronger atmospheric stability over eastern US impose a stronger thermal capping that traps more anthropogenic aerosols and particulate matter near the surface over EUS (already an emission hotspot). At the same time, future increase in wildfire emissions also leads to greater reduction of monthly rainfall (Figure 6D) over EUS, which may additionally strengthen the positive feedback to surface PM2.5 over EUS by reducing wet scavenging of transported wildfire smoke to EUS. Thus, wildfire-emitted aerosols induce positive feedback on the surface PM2.5 concentration over EUS through fire-climate interactions that vary on a regional scale. Moreover, the above discussed dynamical changes in future can also feedback these simulated thermodynamical and precipitation changes, exaggerating the enhancement in PM2.5 values over EUS in future. However, due to computational constrains, no direct quantification of the magnitude of these feedback (with aerosol-radiation and aerosol-cloud interactions turned off) on PM2.5 is performed and would be taken up in future studies.
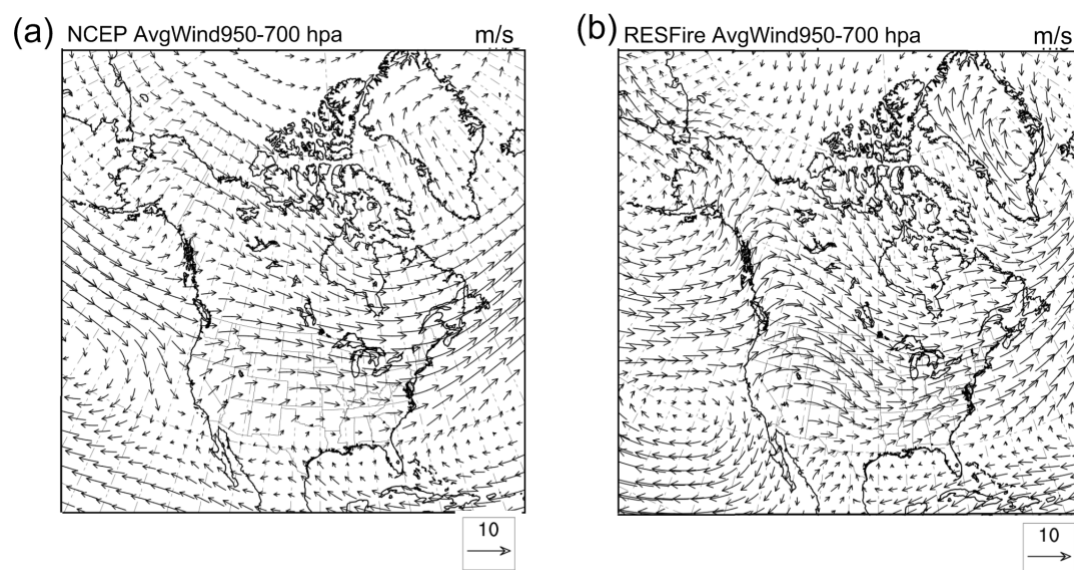
Figure R1: Spatial distribution of the decadal mean wind circulation at 850 hPa over North America for JJA season (2001-2010) from a) NCEP reanalysis and b) CESM-Resfire simulated control run simulation
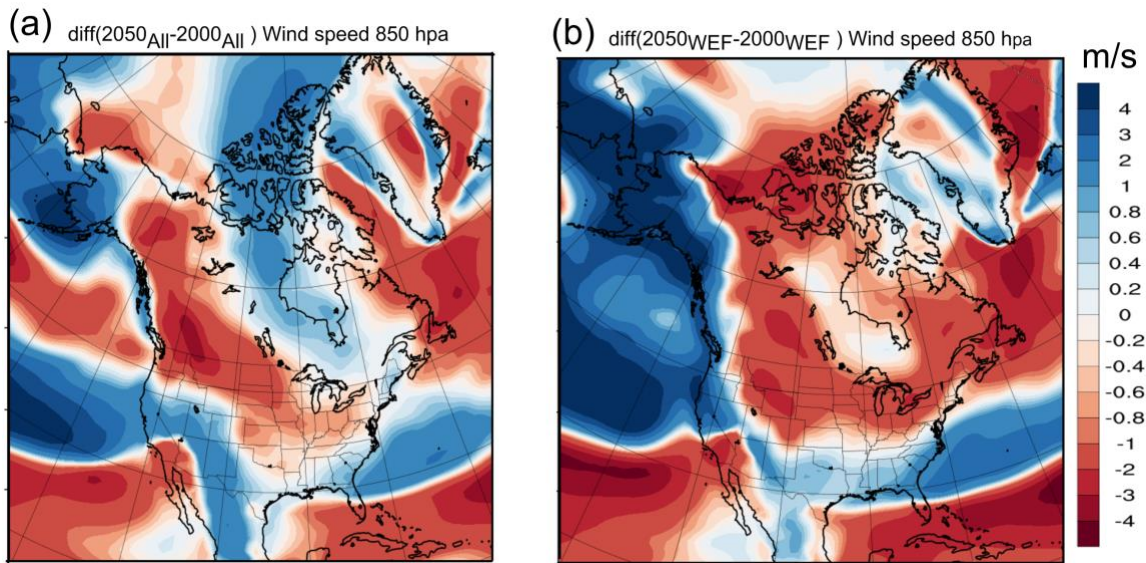
Figure 5a: Spatial distribution of decadal mean summer (JJA) wildfire-induced future changes [(2050$_{ALL}$-2050$_{WEF}$) – (2000$_{ALL}$-2000$_{WEF}$)]. A) Wind speed at 850 hpa for [(2050$_{ALL}$- – 2000$_{ALL}$], B) Wind speed at 850 hpa [(2050$_{WEF}$) – (2000$_{WEF}$)].
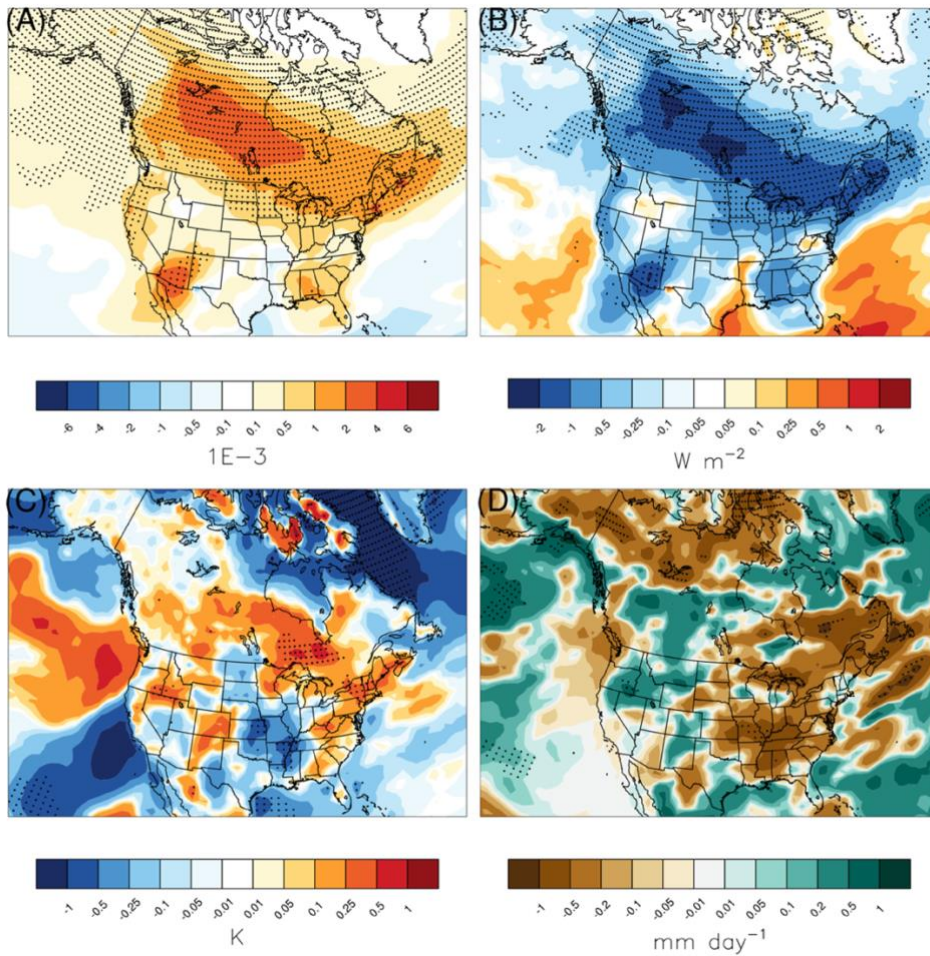
Figure 6: Spatial distribution of decadal mean summer (JJA) wildfire-induced future changes [(2050$_{ALL}$-2050$_{WEF}$) – (2000$_{ALL}$-2000$_{WEF}$)]. A) aerosol absorption optical depth at 550 nm, B)

While the authors focus their analysis on decadal mean changes and spatial distribution of such changes, the temporal variations in PM_5 are worthy of investigation too. A natural question would arise whether we will experience elevated occurrence of extreme $PM_{2.5}$ days. For example, it would be interesting to see something similar to Figure 6 but presenting the spatio-temporal PDF of $PM_{2.5}$ from all grid cells and all days in both the historical and future simulations.

In this experiment, our aim was to understand the changes at climatic scale, so we saved our simulated output values at monthly resolution only to reduce the huge expense associated with storage and file movement for analysis. Hence, we are not able to do daily scale analysis, although the reviewer's suggestion is valid.

Does your simulation include multiple ensemble members? Will an ensemble simulation enhance the robustness of your results?

No, our simulations do not include ensemble members. More details see Zou et al., 2019, ACP and Zou et al., 2020, ACP.

In our experiment, we aim at qualitative and annual mean scale analysis of what might happen in future under climate change induced wildfire enhancement. An ensemble simulation setup can help us towards reducing the uncertainty in quantitative forecasts/analysis in this experiment. But due to computational constrains simulating ensembles was not undertaken.

Finally, while the burnt area does not increase in the southeastern US, it is possible that smoke emission still increases. Does your model account for future biomass increase and possible smoke emission rate increase?

Yes, ResFire includes for future biomass increase and smoke emission rate.

Minor suggestions:

On line 217-218, the authors attribute the inconsistency between model and satellite-derived PM_5 to the bias in the pristine region, but the scatterplot does not seem to support such bias in the low-value region.

This sentence is meant for Figure 1C. We can distinctly see a cluster of low PM2.5 biased towards satellite measurement compared to observations. We have revised the sentence now as follows for clarity.

First, the satellite-derived data has a non-zero lower bound of $PM_{2.5}$ concentrations, so the ambient background concentrations for relatively cleaner regions such as the western US may be overestimated (Figure 1C), also the sampling frequency between these datasets are different.

On line 249, it is also useful to indicate sample size.

We have included the sample size in captions

On lines 315-316, please rephrase this sentence, it is not clear what this sentence means.

We have removed the mentioned statement.

On lines 396-398, you can actually test this hypothesis with your simulations, for example by compositing absorbing aerosols in the subsequent days following fire events in Canada.

As explained above, we don't have simulation outputs at daily resolution.

Figure 5, what statistical test did you use?

Students t-test was used.

All the data shown in Fig.5 are fire-induced differences between the 2050 scenario and the 2000 scenario as indicated in the caption. They are not temporal trends. We subtract the fire effects in the 2000s from the fire effects in the 2050s [(2050ALL-2050WEF) – (2000ALL-2000WEF)] to evaluate the fire-induced changes from the 2000s to the 2050s. The significance of these changes is calculated using the Student's t-test between the two simulations.

Around line 450, it is also helpful to report the percentage of grids with seasonal mean PM_5 exceeding 10 µg m^{-3}.

We have included in the text.