To: Editor, ACP

Subject: Author Comments of Manuscript, acp-2022-270

Dear Dr. Jianping Huang,

Upon the recommendation, we have carefully revised the manuscript entitled "*Future dust concentration over the Middle East and North Africa region under global warming and stratospheric aerosol intervention scenarios*" after considering all the comments and suggestions made by the Referees; all the changes made in the revised manuscript are highlighted in yellow. The following is the point-to-point response to all the comments (the reviewers' comments are rewritten in black color and the replies in blue). We appreciate the opportunity to revise our paper. We believe that the manuscript is much improved after positively addressing all the requested revisions. In the following we provide answer of Anonymous Referee #1, and Anonymous Referee #2 respectively. The main changes have been made in the new version based on the referee's comments/suggestions are as follows:

- we have hatched significant regions instead of the insignificant regions in the contour plots (Fig. 3 to Fig. 8), to give better sense to reader.
- We used the detrended annual time series, for calculation of the correlation coefficient in Table3 and Fig. 9
- We performed statistical significance test on the annual time series to determine the confidence level of the correlations.
- we have added some sentences to explain the statistical analysis t-test in detail
- We have replaced all the contour plots (Fig. 3 to Fig. 8), that show the percentage of changes for different scenarios (instead of relative change in the previous version).
- We organized the rows of the Fig. 9, 10, 11, S1 and Table3, with the same order of parameters to increase readability.

Notice: The line and page numbers refer to the pdf file of "Revised Manuscript".

Response to the Anonymous Referee #1:

We thank the reviewers for the comments and suggestions. We think that by implementing the reviewers' comments and suggestions, the revised version has significantly improved.

Major points:

1) I am confused about the statistical significance and the way it is shown in the figures. In line 161 it is stated that the hatched areas are not significant. This choice is also mentioned in the caption to Fig. 3. But then in Fig. 3 there are areas with little change (shown with white) that are significant while some areas with large change (blue) don't seem significant. The same holds for the other figures except for Fig. 4 where it makes sense that the 'SAI - CTL' is not significant. In line 208 the differences in Fig. 5 are described as significant across the whole region while almost everything is hatched in that figure.

I also think the t-test should be described in more details. For example, what is the number of independent points used. And I think it would make more sense to hatch the significant regions instead of the insignificant regions.

Reply: Considering to the referee's suggestion, in the new version of the manuscript, the areas with significant difference have been hashed.

The white color in the contour plots indicate the areas in which the two scenarios have a small difference (less than 1% or 5% in the new figures). In other words, the color bar shows the differences between the means of the two scenarios. While the significance of the difference is defined by the t-value. and it depends on the means and variabilities of the two datasets (i.e., means, variances and the number of samples). Depending on the confidence level, the obtained t-value can be lower or higher than the statistical analysis threshold value. A brief explanation of the t-test statistical method has been added to the manuscript as a below

Lines 165-178: In this study, the independent t-test analysis has been used for comparing the statistical difference between scenarios for considered parameters. The t-test analysis is a statistical test that is used to determine the statistically significant difference of two samples. Depending on the confidence level, the obtained t-value can be lower or higher than the statistical analysis threshold (t-value). If the t-value is lower than the critical value, there is no statistically significant difference between samples, and if it is higher than the critical value there is a statistically significant difference between them. The t-value depends on the means and variabilities of the two datasets (i.e., means, variances, and the number of samples in different scenarios). In this investigation, the t-test is performed for 20 years (60 months for seasonal and 240 months for annual difference). The t-test formula is given in equation 2, where $\overline{X_1}$ and $\overline{X_2}$ are the means, S_1^2 and S_2^2 are the variances and n_1 and n_2 are the number of samples,

$$t - value = \frac{|\overline{X_1} - \overline{X_2}|}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

For more detail about statistical analysis reader, the readers are encouraged to see (Miller. J. N. and Miller. J. C., 1998).

2) I am also in doubt about the interpretation of the correlations in Fig. 9 and Table 3. If the time-series are not detrended you will mix the signals from trends and from faster variability. The correct way would be to make correlations from detrended series and see if these correlations 'predicts' the size and sign of the trends. I am also in doubt of what and how you conclude about the drivers of the larger reduction in dust in the SAI compared to RCP8.5.

Reply: As requested, detrended annual mean values have been used to calculate the correlation coefficient in Table 3 and Fig. 9. and also, all related sentences are rewritten in the new version of the manuscript.

Minor points:

l20: while for -> except for.

Reply: is implemented.

l150: Is the meaning of the last part of this sentence that you also focus on dust hotspots. I think the sentence is unclear.

Reply: in the new version of the manuscript, these sentences are rewritten.

Fig. 3: In the title to panel f it says 'Seasonal trend'. I think it should be 'Seasonal time-series'. It is not the trend that is shown.

Reply: is implemented.

Fig. 4: In the caption it writes 'd) The annual mean of the dust concentration ..' I think you mean the surface temperature.

Reply: is implemented.

Fig. 5: There are no numbers on the colorbar.

Reply: is implemented.

L209: I think there should be a full stop before 'seasonal cycle plots ..

Reply: is implemented.

I am unsure if the hatching in Fig. 9 shows the significance of the correlations or the regions with large dust concentrations as it says in the caption. The authors should definitely show where the correlations are statistically significant.

Reply: As requested, the statistical analysis test has been performed over the time series, and the significance of the correlation is shown on contour plots using the regions without hatch lines with a 99.5% confidence level. The dashed line contours show dust hotspots (R1 to R5) regions

Response to the Anonymous Referee #2:

We thank the reviewers for the comments and suggestions. We think that by implementing the reviewers' comments and suggestions, the revised version has significantly improved.

Major comments:

The most surprising result of this work is how little difference there is between the two scenarios RCP8.5 and SAI for most of the parameters considered, Figs. 2, 6, 7, 10, 11; except temperature and TLAI, and temperature is a given considering the added stratospheric aerosol. This is an important point and should be emphasized more.

Reply: Due to the vastness and climatic diversity of the MENA region, it is hard to accurately talk about the annual and monthly time series which averaged across the whole MENA region. However, the third column of Figures 3–8 (i.e., SAI-RCP8.5), show the differences between these two scenarios over the dust hotspots region with more detail. These figures show a 15-50% change for different parameters in the different areas of the MENA region (i.e., up to 15% for dust concentration, up to 30% for surface temperature, up to 35% for leaf area index, up to 20% for wind speed, up to 25% for precipitation, and up to 50% for soil water).

There is ambiguity with the use of the word significant. In statistics it has a very specific meaning, which is used in this paper some of the time. When describing differences it may be used, e.g. a significant difference, to imply a large difference. This is confusing in many places below and only very late in this review did I realize that the authors may be using the first definition, while I was assuming the second.

This leads to the complication of describing differences amongst the scenarios for the different parameters. Words like significant, considerable, large, small, … are subjective and readers and authors may differ on their meaning. In contrast words like larger, smaller, higher, lower, or more preferably percent differences, are objective and not as prone to misinterpretation. That is part of the reason, to suggest in my first review, that the authors present their results in terms of percent difference/change. They did this for some variables, but not all. The whole text should be gone through to make the comparison sentences more objective. Many of the comments below are related to confusion about these words, and disagreements with the authors interpretation/description of the figures.

Reply: As requested, new contour plots are depicted based on the percent of changes, all related sentences are rewritten based on the new figures, and the referee's suggestions are included in them. The percentage of changes has been used to depict the difference between the scenarios, and also all sentences have been rewritten as more objective comparison sentences.

Contour plots for changes in temperature, surface wind speed, and soil water are depicted with the percentage of change related to the current climate. In some areas of the MENA region, precipitation and TLAI parameters have zero or near zero values, and any changes in the future climate will eventuate an infinite positive or negative value for the percentage of changes compared to the current climate. To overcome this problem and for showing the difference based on the percentage of changes, we calculated the percentage of changes relative to the maximum value in the current climate in the MENA region. Also, to investigate dust concentration changes, and to better show the intensity and importance of changes in dust hotspots, the percentage of changes has been calculated compared to the maximum value of dust in the current climate in the MENA region (the maximum value for the mentioned parameters is written in the manuscript to give a sense about the quantity and intensity of change by the reader).

18-21 "This reduction in dust over the MENA region is stronger under the SAI scenario, while for the dry season (e.g., summer with the strongest dust events), more reduction has been projected for the global warming scenario." What is this statement based on, which figures? If anything Fig. 3e, d, g, h) might just suggest the opposite.

Reply: in these sentences, we talked about the higher reduction of dust over most of the dust hotspots, during the summer time. The sentences have been rewritten as below!

Lines 19 - 22: This reduction in dust over the whole MENA region is stronger under the SAI scenario, except over dust hotspots and for the dry season (e.g., summer with the strongest dust events), which more reduction has been projected for the global warming scenario compared with the SAI.

110-115 The amount of annual sulfur injections under the SAI scenario are not specified. Are they known? Text should be added how the SAI scenario is used to maintain 2020 temperature conditions. Is sulfur dioxide injected into the model? Or is the model just artificially nudged to keep the temperature at 2020 levels? If that is the case then aren't the SAI scenarios and the control close to the same, or how do they differ? The authors should explain more fully how the SAI scenario is created.

Reply: The amount of annual sulfur injection and related references are added to the manuscript. Also, the model is not artificially nudged. It is a fully interactive ESM, please see Tilmes et al, 2018 for more detail. Please see more detail about the SAI scenario (e.g., the location of injections, objects of the SAI simulations, the model components, and related references) in the lines 101-122.

180-181. Incomplete sentence. Maybe delete "that".
Reply: is implemented.

183 Northeastern
Reply: is implemented.

Figures 3, 5, … When gray and white are included in the color scheme, and then stippled over in gray, it is difficult/impossible to separate the color contours from the stippling. For example Fig. 5n), is most of the region the central color, white, or is there some gray factored in? Also on Fig. 5, TLAI, there is no quantitative information on the color bar. What for example indicates no change?
Reply: As mentioned before, the changes are drawn based on the percentage of changes, and these issues have been modified in the figures.

207 "The TLAI under the RCP8.5 scenario shows some significant reduction compared to the CTL across the whole region,…" Here is a case in point from the comment above. What constitutes significant? The gray shades are difficult to separate from the stippling, compare Figs 5d) and e). Without numbers on the color bar how is the reader to know that gray is significant? Why doesn't Fig. 5p) support the above statement. This panel shows that RCP8.5 and CTL are the same except for Jan – May which seems inconsistent with Figs 5g) j), unless the white is not apparent in these figures.
Reply: As requested, all related sentences are rewritten based on the new figures, and the referee's suggestions are included in them. In the new version of the manuscript, the color bar has been modified. Furthermore, as mentioned before, the vastness and variety of the MENA's climate, could be a reason for some inconsistency of the annual and monthly trends with seasonal contour plots. The annual and monthly trends (Fig.10, 11 and S1) over dust hotspots decrease this uncertainty and would give more accurate result for annual and monthly time series (compared with time series for the whole MENA region). The sentences are written as a below. Lines 224-226: The TLAI under the RCP8.5 scenario shows 5-30 % reduction compared to the CTL across the different area of MENA region, except the region between the Mediterranean and Caspian Seas (Fig. 5a, d, g and j).

214-215 "On the contrary, under the SAI scenario compared to the CTL, the TLAI shows a significant increase both spatially and temporally (Fig. 5b, e, h, k, p and q)." Same problem as above. The color under the stippling (indicating significance) seems to be white, right in the middle of the color bar, which should mean 0/no change, but without a quantitative color bar it

is unknown. The only place with positive colors are Spain and Eastern Europe. Changes shown as percent may help this presentation.

Reply: In the new version of the manuscript, this figure has been replaced with a new one, the color bar has been modified and related sentences have been rewritten according to the new figure presented as a percentage of change.

200-220 TLAI is difficult for any but an expert to understand. Perhaps a few words of explanation would help the reader understand what it means physically. Is it the fraction of a unit area covered by leaves, or??

Reply: the following sentences are included in the manuscript.
Lines: 339- 341: The Leaf area index (LAI) is a quantity to characterize the plant canopies (e.g., the aboveground portion of trees, crops, etc.). LAI is a dimensionless quantity and is defined as $LAI = (one-sided\ leaf\ area\ (m^2)\ /\ ground\ area(m^2))$.

226 "and in the Middle East with two major dust hotspots, the reduction is even stronger" This seems to be splitting hairs for the contour plots. This reader does not see a stronger reduction in the Middle East comparing the left and center set of panels. Perhaps the authors are emphasizing Figs 6p) and q), but calling these differences strong is a stretch. Plotting the differences as a percent would show a small percent difference, barely exceeding the uncertainty bounds.

Reply: As requested, new contour plots are depicted based on the percent of changes, and all related sentences are rewritten based on the new figures, what we meant by saying this sentence is that there is a greater decrease in dust hotspots (shown with black contours) than in its neighboring areas. The sentences rewritten as a below:
Lines 243-245: SAI also shows reductions in the wind speed compared to the CTL during all the seasons, notably in the Middle East with two major dust hotspots, it shows a 5 to 20 % reduction (Fig. 6b, e, h, k, n, p and q).

222-232 A 0.2 m/s wind change is 5% for a 4 m/s wind. Seems pretty close to the uncertainty limit. Still not sure why percent isn't used throughout as suggested in the first review.
Reply: In the new version of the manuscript, this figure has been replaced with a new one (using percent of change), and related sentences have been rewritten according to the new figure please see lines 240-251.

238-241 "The box plot and monthly mean values of the precipitation from different scenarios (Fig. 7p) show that under the RCP8.5 scenario (compared to the CTL), precipitation is projected to significantly increase during the summer season, and under the SAI scenario (compared to the

8

CTL), this region would experience more precipitation during the spring and summer." It is difficult to see that this statement is supported by Fig. 7p) where the three means of the scenarios are barely outside the 25th/75th quartiles. Perhaps the percent differences are on the order of 10% in some months. Thus why the claim of significant? What do the authors consider is meant by significant, just that statistically the difference of the means is significant, or that physically the difference is significant? The different intent of this word needs to be clarified by the authors.

Reply: In the new version of the manuscript, this figure has been replaced with a new one, and related sentences have been rewritten according to the new figure. The sentences rewritten as a below:
Lines 259-262: The box plot and monthly mean values of the precipitation from different scenarios (Fig. 7p) show that under the RCP8.5 scenario (compared to the CTL), precipitation is projected to almost a 20% increase during the summer season, and under the SAI scenario (compared to the CTL), this region would experience 5 to 25% more precipitation during the spring and summer.

250-254. This language is much improved by discussing the differences as "higher/lower, moderate positive trend", rather than putting a value on the difference, e.g. significant.
Reply: Considering referee suggestion, all sentences have been rewritten as objective comparison sentences.

258 "over the MEAN region (Fig. 9h) and caption Fig. 9", and text following. Where is the MEAN region and why is Figure 9h singled out to illustrate it? Fig. 9 shows the same MENA region shown on Figures 3-8.
Reply: This study was done for MENA region and it was written here as a reminder. This sentence has been corrected in the new version.

260 "columnar dust concentration lower than 35 (µg/m3) are depicted with hatch-line in the Fig 9." Once again the hatching obscures any of the contours except the brightest ones at the ends of the color bars, and in many panels the dust hotspots cannot be identified. Thus the discussion about these hotspots cannot be followed. Plus almost the entirety of each panel is hatched. It would make more sense to hatch the regions where dust concentrations are > 35 ug/m3. Also why is this number chosen? What is its significance?
Reply: This figure has been modified according to the referee's suggestion, and dust hotspot regions are shown using black dashed contour lines in Fig. 9. Also, the statistically significant correlations are shown using statistical analysis with a 99.5% confidence level.

Fig. 9 and Table 3. If the authors wish to compare these two they should be organized in the same way. Table 3 starts with precipitation and ends with wind speed. Fig. 9 is organized in reverse order to Table 3. Plus the dust hotspots are either not included on Fig. 9 or included in such a way that they cannot be seen. This makes it impossible to confirm, or follow the discussion from lines 260-272.

Reply: The order of the variables was modified based on the referee's suggestion.

Fig. 10 The rows of this figure should be organized so that they follow the same pattern as Fig. 9 and Table 3, once they are synced. The order of the parameters at present is somewhat random. Here temperature is at the bottom. In Fig. 9 it is at the top. This just makes more work for the reader to understand the paper.

Reply: The order of the variables was modified based on the referee's suggestion.

274-275. There is almost no change in dust in Fig. 10a3). So how do the authors claim just a lesser than strong reduction here?

Reply: The slight change (approximately 10%) is seen for the SAI scenario and there is no change for RCP8.5. The sentences were rewritten as a below.

Lines 297-300: Although, the dust concentration over the R2 and R3 hotspots has no considerable change by the end of the century for RCP8.5, an approximately 20% and 10% reduction is projected for the SAI scenario over the R2 and R3 hotspots respectively (Fig. 10a2 and 10a3).

283 "considerable reduction of dust concentration between the control and the two future scenarios for both regions" This is a reasonable statement for R5, but not R4. Again stating the differences as percent change is a quantitative statement which is objective. Words like considerable and significant are subjective and can be interpreted many ways.

Reply: in the new version of the manuscript, these sentences are rewritten as a referee's suggestion. please see below lines.

Lines 303 – 305: Figure 11 included error bars for monthly mean values of all considered parameters for R4 and R5 regions, and shows a reduction of dust concentration between the control and the two future scenarios (up to 25%) for R4 and (up to 35%) for R5 regions in spring to fall (Fig. 11a and b).

283-290 The authors frame the discussion as cause and effect. The reduction in wind speed is "controlled by the lower wind speed and higher leaf area index." But that's more than the model can determine. All that can really be said is that they are correlated.

Reply: in the new version of the manuscript, these sentences are rewritten as a below.

Please see lines 303-311: Figure 11 included error bars for monthly mean values of all considered parameters for R4 and R5 regions, and shows a reduction of dust concentration between the control and the two future scenarios (up to 25%) for R4 and (up to 35%) for R5 regions in spring to fall (Fig. 11a and b). Differences between RCP.85 and SAI are however not statistically significant. The monthly mean values with error bars of all considered parameters for R1, R2 and R3 regions are also shown in Fig S1. It seems that the reduction of dust concentration over the R4 region (Fig. 11a) has affected by the lower wind speed (Fig. 11c), and higher precipitation (Fig. 11d) and leaf area index (Fig. 11j) under both RCP8.5 and SAI scenarios. Furthermore, the reduction of the monthly mean value of dust concentration over the R5 region (Fig. 11b) could be a result of the decrease in wind speed (Fig. 11d) and increase in leaf area index (Fig 11j). The results of Fig. 10 and Fig. 11, are in good agreement with the results and correlation coefficients in Table 3.

307-308 "reduction rate of the dust concentration is about 5-40% for the RCP8.5 scenario (compared to CTL), where it is stronger from March to September" Where does 40% come from. The maximum difference in Fig. 2a) is about 4 ug/m3 which is about 16% of the CTL at maximum.

Reply: The stated values are related to the difference between the two scenarios in spring, summer, and autumn for the R4 and R5 dust hotspots (Fig. 3d, g, and j). in the new version of the manuscript, these sentences are rewritten. please see lines 330-334:

The reduction rate of the dust concentration is about 5-35% for the RCP8.5 scenario (compared to CTL), where it is stronger from March to September, especially for the dust hotspots in the Middle-East region (Fig. 3d, g, and j). Similarly, the dust concentration is also found to decline 5-30% under the SAI scenario compared to CTL over the dust hotspots in the MENA region (Fig. 3b, e, h, and k).

314-315 Here the authors suggest the increasing temperature is the reason for decreasing dust, but again all that can really be said is that they are correlated. The cause and effect is difficult to ascertain.

Reply: In the new version of the manuscript, these sentences are removed.

330 "While this increase in the TLAI is found to be small over the dust hotspots" Why is this considered small? TLAI increases in R4/5 by more than 100% and in R2 by this much for SAI.

Reply: it is small compared to the threshold of the TLAI for dust generation. The following sentences are written in the manuscript.

Lines 351-355: Although, more than 100% increase of TLAI is projected in R4 and R5 region for both RCP8.5 and SAI scenarios (Fig. 10e4, e5, Fig. 11i and j), the TLAI mean values over R4 and R5 are still lower than the threshold of the dust emission in the dust generation model (i.e., $TLAI_{mean} < 0.3$). However, this small increase may help to decrease the dust concentrations, since based on correlation coefficients in Fig. 9, and Table.3, there is a negative correlation between the dust and TLAI in these regions.

370-372 "We further conclude that, over the coming 80 years, the dust mass concentration generally decreases with an increase in the precipitation, soil water, and leaf area index, and a decrease in temperature and 10m wind speed over the MENA region" Is this the case for both RCP8.5 and SAI. If so this should be stated.

Reply: In the new version of the manuscript, these sentences are rewritten as a below.

Lines 389-393: We further conclude that, over the coming 80 years, the dust mass concentration generally decreases under the both RCP8.5 and SAI scenarios with an increase in the precipitation, soil water, and leaf area index, and a decrease in 10m wind speed over the MENA region, particularly across the Middle East, and also over the dust hotspots, the near surface wind speed and precipitation have the most impact on this reduction.