Response to the Anonymous Referee #1:

Major concerns:

a) The cross-coherence analysis:

I don't find that the method is very well explained in section 2. What are the connections to the axes in Fig. 2? How do you come from the equations to the quantities (amplitude, phase?) shown in the figure? More importantly, I am also confused about the physical interpretation. There are probably annual cycles in all meteorological variables. This means that there will always be coherence between them. As the annual cycle probably is different from a pure sinusoidal, there will also be a signal at 1/2-year. So what do we actually learn from Fig. 2? In the discussion section (l365) it says that the dust is 'substantially influenced' by the changes in the other fields. But I don't think you can conclude that from the analysis. What we learn is only that there is an annual cycle in all the fields including the dust but nothing about the physical interpretation. This manuscript presents projected changes of dust storms in the Middle East and North Africa region, which is very sensitive to climate change, under future scenarios, with (SAI) and without (RCP8.5) geoengineering, focusing on the stratospheric aerosol intervention effect but discussing both of them. Therefore, the title could be modified to reflect better the content.

Reply: 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.

As you mentioned correctly, Fig 2, mostly demonstrates the annual correlations between dust and considered variables. In new version of the manuscript, Fig. 2, has been replaced by two new plots (Fig. 9 and 10) to make correlations more understandable. In Fig. 9, we depicted the correlation coefficient of dust with considered parameters for all grids (i.e., cells with a horizontal resolution of 0.9° latitude by 1.25° longitude) over the MEAN region. The positive and negative correlations are shown as a contour plot for both RCP8.5 (left column) and SAI scenarios (right column). Moreover, the dust hotspots are specified using the climatology of dust concentrations in this figure (regions with no hatch-lines). The correlation coefficients for hotspots are listed in Table 3. Furthermore, annual trends of parameters over the dust hotspots are shown in Fig. 10, for both RCP8.5 and SAI scenarios. This figure depicted the intensity of annual changes for any parameter in any special region that would affect the dust change.

Regarding your suggestion about the title, as you mentioned MENA region is very sensitive to any changes in future dust. Although our focus in this study is on the stratospheric aerosol intervention geoengineering effect, in this paper we would like to give a perspective of future dust under both RCP8.5 and SAI scenarios, and we selected a title to reflect this issue (i.e., changes of future dust under both RCP8.5 and SAI scenarios). Moreover, the sections of the manuscript have been rewriting based on the new plots. The following lines and Figure were added to the new version of manuscript:

Lines 25-27 (Abstract): Detailed correlation analysis over dust hotspots indicates that lower future dust concentrations are controlled by lower wind speed and higher precipitation in these regions, under both RCP8.5 and SAI scenario.

Lines 163-169 (Data and Methods): We also calculate the correlation coefficient of dust with other considered parameters for all grids (i.e., cells with a horizontal resolution of 0.9° latitude by 1.25° longitude) over the MEAN region, for both RCP8.5 and SAI scenarios. The climatology of dust concentration is used to specify dust hotspots regions and regions with columnar dust concentration lower than 35 ($\mu g/m^3$) are depicted with hatch-line in the correlation coefficient figures. Moreover, the spatial average of annual time series over dust hotspots are used to calculate the correlation coefficients of atmospheric dust concentration with surface temperature, near-surface wind speed, total leaf area index, precipitation, and soil moisture for both RCP8.5 (2010-2097) and SAI (2020-2099) scenarios and are listed in Table 3.

Lines 256-281 (Results): Finally, to find the most efficient factors for reducing columnar dust concentration over hotspots, we calculated the correlation coefficient of dust with other considered parameters for all grids (i.e., cells with a horizontal resolution of 0.9° latitude by 1.25° longitude) over the MEAN region (Fig. 9h). The positive and negative correlations are depicted as a contour plot for both RCP8.5 (2010-2097) (Fig. 9, left column) and SAI (2020-2099) (Fig. 9, right column). Regions with columnar dust concentration lower than 35 (µg/m3) are depicted with hatch-line in the Fig 9. The correlations between dust and surface temperature are depicted in Fig. 9a and Fig. 9b. In Fig. 9c and Fig. 9d, the correlation between dust and wind speed is presented, and positive correlations are shown over the dust hotspots. Negative correlations between dust and TLAI can be seen for most hotspots in both scenarios (Fig. 9e and f). Furthermore, the correlation of dust concentration with soil water (Fig. 9g and h) and precipitation (Fig. 9i and j) show considerable negative mean values for the R4 region. Moreover, the spatially averaged correlation coefficients between dust and considered parameters for five dust hotspots over the MEAN region and under both RCP8.5 and SAI scenarios are listed in Table. 3. In this table, the most important variables for each region are highlighted in orange. According to this table, for all dust hotspots (i.e., R1 to R5), the wind speed is the main parameter that affects dust concentration change under both RCP8.5 and SAI scenarios, except for the R4 region under SAI scenario. In the R4 region the increase in precipitation and soil water under SAI scenario seems to control the reduction of dust respectively. In addition, under the SAI scenario, over dust hotspots with higher latitudes (i.e., R2 and R5), the vegetation cover is another important factor in controlling the change of dust concentration.

Moreover, to explore the annual trends of parameters over the dust hotspots, and to compare the annual mean values of different variables, we depicted the regional annual mean of considered parameters under both RCP8.5 and SAI scenarios over different hotspots regions (Fig. 10). Figure 10, indicates that the strong reduction of dust concentration for R4 and R5 and to a lesser extent for R3 under both RCP8.5 and SAI scenarios has been modeled (Fig. 10a4, a5, and a3). Although, the dust concentration over the R2 hotspot has no considerable change by the end of the century for RCP8.5, an approximately 30% reduction is projected for the SAI scenario (Fig. 10a2). Corresponding to the reduction of dust in R4 region (Fig. 10a4) under both RCP8.5 and SAI scenarios, an increase in precipitation (Fig. 10c4) and a decrease in wind speed (Fig. 10b4) are seen. Detailed analysis of annual trends for the R5 region indicates that the strong reduction of dust concentration in this region would be controlled by the decrease in wind speed and the considerable increase in leaf area index under both RCP8.5 and SAI scenarios (Fig. 10a5, b5, and e5).

Please see Fig. 1, Fig. 2, and Table 1 in the context (i.e., Fig. 9, 10 and Table 3 of the new version of the manuscript).

Table 1. The correlation coefficient of dust with considered parameters for all dust hotspots over the MEAN region. The most important variables for each region highlighted by orange color. The correlation coefficients are calculated using annual mean time series resulting from the average of all ensemble members, and spatially averaged over the corresponding dust hotspot region.

	RCP8.5 Scenario (2020-2097)					SAI Scenario (2020-2099)				
	R1	R2	R3	R4	R5	R1	R2	R3	R4	R5
Precipitation	-0.25	-0.11	-0.27	-0.54	-0.28	+0.02	-0.49	-0.46	-0.64	-0.21
Soil Water	-0.06	-0.22	-0.06	-0.48	+0.23	+0.18	-0.34	-0.18	-0.52	-0.09
Leaf Are Index	-0.18	-0.22	-0.09	-0.13	-0.40	-0.12	-0.52	-0.11	-0.36	-0.63
Surface Temperature	-0.04	+0.26	-0.29	-0.81	-0.76	-0.02	+0.38	-0.12	+0.44	+0.20
Wind Speed	+0.62	+0.64	+0.50	+0.59	+0.63	+0.70	+0.67	+0.84	+0.50	+0.84

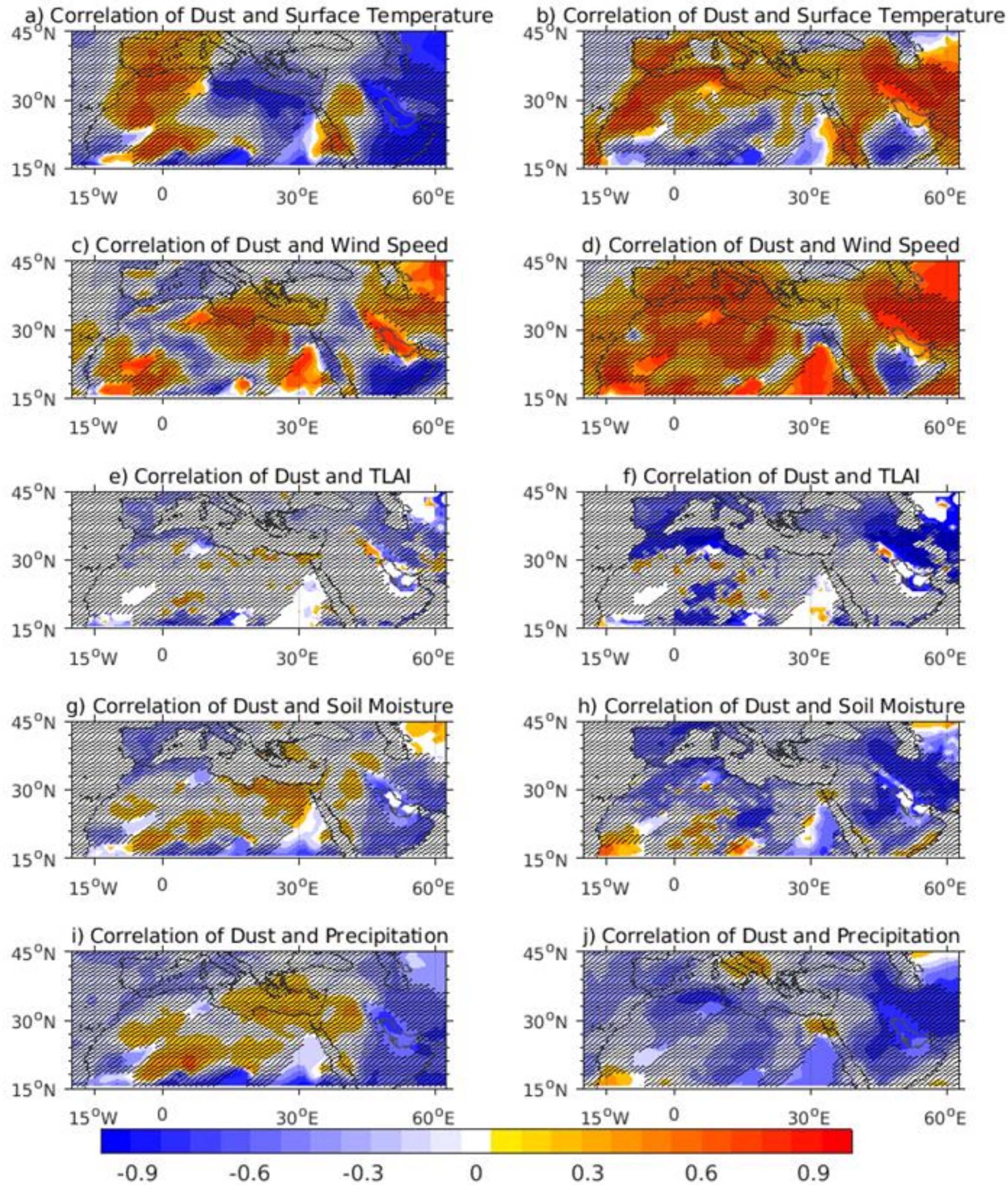

Figure 1: the correlation coefficient of dust with other considered parameters for all grids (i.e., cells with a horizontal resolution of 0.9° latitude by 1.25° longitude) over the MEAN region. The correlation is calculated using the annual mean time series of all grids. The climatology of dust concentration is used to specify dust hotspots (R1 to R5) regions. Regions with columnar dust concentration lower than 35 (µg/m3) are depicted with hatch-line in this figure.

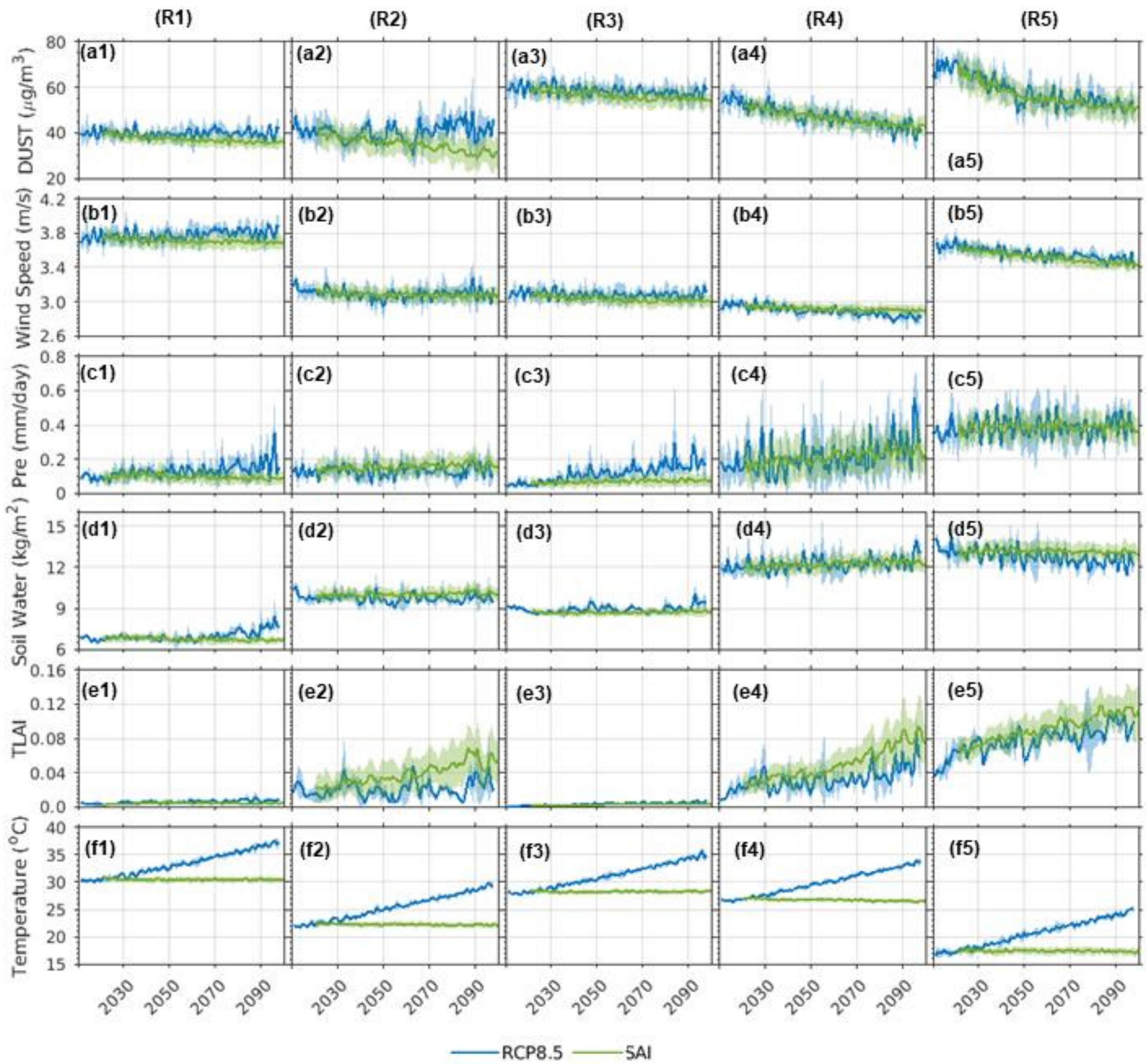

Figure 2: The annual mean values of the considered parameters for RCP8.5 and SAI scenarios. Different columns (i.e., columns 1 to 5) indicates the dust hotspots region R1 to R5, respectively, and different rows depicted the annual mean trends for different parameters with their standard deviation for all ensemble members.

b) The rest of the paper seems to me to be too much focusing on presenting the details about the changes in the different fields. I think many of the panels basically shows the same and that the number of plots and panels could be reduced. I really miss some solid analysis and results about what drives the changes in the dust. The dust generally decreases in the RCP8.5 scenario but it decreases further in the geoengineering scenario. Perhaps I am missing something but I could not find an explanation. The correlations in Table 3 could be a beginning, but the physical connection between the variables requires that the trends - which I guess determines most of the correlations here - are removed.

Reply: as you suggested, plots with the same content have been removed. Fig. 1 to 4 in the old version are combined and depicted as Fig. 1 to 3 in the new version. Fig 10, containing several same panels for with other figures for the monthly mean values, has been replaced by a new one for different hotspot regions (Fig. 11 for R4 and R5 dust hotspots and Fig. S1 for R1 to R3 dust hotspots in the new version).

As Fig. 2 and Fig. 3m (of the manuscript) depicted, the projected dust concentration has more reduction over dust hotspots for RCP8.5 scenario, compared with SAI scenario (Fig 3d, e, g and h, in new version), although, over the whole MENA region more reduction for SAI scenario has modelled (Fig. 2a-b).

As mentioned in the manuscript, because the dust emissions physically reduce with cooler temperatures, weaker winds, and wetter climate through increasing precipitation and soil moisture and, in turn, denser and broader vegetation coverage, all investigated parameters could affect dust concentration changes. Moreover, regarding the extent of the MENA region, different parts of this region have a special hydro-climate cycle, and subsequently, the different factors could be counted as a driving factor of the atmospheric dust change in different regions. By focusing on the dust hotspots, we find that, under both RCP8.5 and SAI scenarios the reduction of future dust is mainly controlled by the weaker surface wind, except for the R4 region and under the SAI scenario where an enhancement of the precipitation more than other parameters effects on the dust reduction. In the revised manuscript, Table 3 is replaced with new one with more detail about the correlation coefficient of each variable in the five dust hotspot regions. Moreover, the new figure of annual trends for parameters over the dust hotspots help the reader to understand the physical connections between the changes in dust concentrations and considered parameters (please see Fig. 10 in the new version).

Minor comments:
l54: reginal -> regional
Reply: done

l97: So this is an ensemble based on a single climate model? How are the different ensemble members generated?
Reply: the following sentences to the manuscript;
Line 97-100: For each ensemble member, the atmospheric state is initialized with 1 January conditions taken from different years between 2008 and 2012 of the reference simulation and a round-off (order of 10^{-14} K) air temperature perturbation, while the land, sea ice, and ocean start from the same initial conditions for each ensemble member.

l103: What is 'interhemispheric temperature gradient'?

Reply: the following sentences to the manuscript;

Line 104-107: The interhemispheric surface temperature gradient is defined in equation (1) of Kravitz et al (2017). It is simply the difference between the mean surface temperature in the Northern and Southern hemispheres. In the study of Tilmes et al (2018), the values for the interhemispheric differences for the different periods and scenarios are presented in Table 3 (T1).

l115-130: Is this a new method adopted for the present study? Is it described in the literature before? If it is new perhaps it should be described in more details and more background given. As it is now it is not transparent for me. For example, what is a transport bin?

Reply: this is not a new method, and the Dust Entrainment and Deposition model (DEAD) is used for the atmospheric dust mobilization scheme. Interested readers could find the detail about model in the lines 118-142 of the manuscript, and for more information could refer to the references mentioned in the manuscript.

l148: composite analysis? Is this the right word? You calculate the difference of temporal means.

Reply: the “composite analysis” phrase is replaced by “calculated the differences”.

l160, Table 3: Are the correlations averages over all the ensemble members? It should be mentioned in the caption that this is annual means.

Reply: as requested, we add the following sentences in the caption: “The correlation coefficients are calculated using annual mean time series resulting from the average of all ensemble members, and spatially averaged over the corresponding dust hotspot region”.

As mentioned I have problems with the presentation of the wavelet coherence. In line 171 why is [(n'-n)dt/s] the complex conjugate? Is omega_0 a constant? If it is how is it selected?

Reply: as mentioned above, to increase the understandability of correlation we replace Fig.2 with two new figures, and all sentences related to wavelet analysis have been removed.

l172: The sentence 'In this approach .. ' seems misplaced here and should be moved down near line 184.

Reply: as mentioned above the sentences related to wavelet coherence are removed.

More importantly in Fig. 2 the coherence is shown as function of time (x-axes) and period (y-axes). It is not clear from the text what these correspond to in the formulas.
Reply: as mentioned above the sentences related to wavelet coherence are removed.

Furthermore, the figure caption mention both the power and the phase which is not described in the text. The same goes for the cone of influence.
Reply: as mentioned above the sentences related to wavelet coherence are removed.

Eq. 6: Should there not be some smoothing here too?
Reply: as mentioned above the sentences related to wavelet coherence are removed.

The discussion of Fig. 2, page 7-8:
It should be pointed out more specifically in the text that Fig. 2 is for SAI. Does it look the same for the RCP8.5? Why focus on the SAI here?
Reply: as mentioned above the sentences related to wavelet coherence are removed.

The 22-years variability and variability larger than 16 years seems to be outside the cone of influence. Also, it is not significant in the GWTC. In general, the two regions in Fig. 2 look identical to me. I don't think you can say that there are significant differences.
Reply: as mentioned above the sentences related to wavelet coherence are removed.

And I don't really see any change after 2040. Perhaps just presenting the GWTC would be better.
Reply: as mentioned above the sentences related to wavelet coherence are removed.

l207: 'Out of phase'. Does this mean -180? Is it just difference in sign?
Reply: as mentioned above the sentences related to wavelet coherence are removed.

l246: How does this indicate that the model is consistent with observations? There are no observations used in the present study.
Reply: as mentioned above the sentences related to wavelet coherence are removed.

Table 3: Why the big difference between RCP8.5 and SAI for temperature correlations? Is this table only discussed in l258?

Reply: According to the time series, of surface temperature and dust concentration, these results for correlation are anticipated. Based on the model's output and as expected, the surface temperature has no considerable change under the SAI scenario. In contrast, the MENA region's surface temperature rises up to 6 degrees for the RCP8.5 scenario. In the meantime, a reduction is projected for dust concentration under both scenarios. It seems that the increasing trend of annual mean surface temperature alongside the decreasing trend of the annual mean dust concentration is the reason of the negative correlation under RCP8.5 scenarios. The results of Table. 3, are discussed in line 267-271.

Section 3 should be split in two or more subsections. Perhaps not start with the coherence?.

Reply: As you requested, the result section divided in three subsections as below (see lines: 170-290 of new version of the manuscript)

3. Results

3.1. Atmospheric Dust Concentration change under Different Scenarios

3.2. Candidate Variables change under Different Scenarios

3.3. Correlation of Atmospheric Dust Concentrations with Candidate Variables