Author's Response to 2nd Review of Anonymous Referee #2 (Report #1)

Second review of Manuscript egusphere-2025-880 entitled 'Evolution of aerosol optical depth over China in 2010-2024: increasing importance of meteorological influences' by Cheng Fan, Gerrit de Leeuw, Xiaoxi Yan, Jiantao Dong, Hanqing Kang, Chengwei Fang, Zhengqiang Li, Ying Zhang

On behalf of all co-authors, we thank Referee #2 for providing a second review of our Manuscript egusphere-2025-880 and the insightful comments which contribute to further improvement. Below we respond to each of the comments which are copied below (in black). After each comment we provide our response, in red, together with changes in the revised MS. Line numbers (indicated by L) refer to t the revised MS.

The reviewer acknowledge that the authors clarify that they replaced the MAIAC C6 dataset used in de Leeuw et al. (2023) with MAIAC C6.1 for this study and extended the study period to include data after 2021. In the revised manuscript, they emphasize the differences compared to de Leeuw et al. (2023). Based on my evaluation, most of my concerns have been addressed through clarifications or modifications. However, there are a few remaining issues that still need consideration.

Thank you for this kind comment and indicating remaining issues.

In the conclusion, it is commendable that the authors divided the study period into two parts, i.e., before and after 2018. Consequently, there is potential to reorganize the abstract to better highlight the main findings of this study. While acknowledging the diverse meteorological impacts on AOD variations across five study areas, the abstract only mentions results from three of them. Quantitatively comparing meteorological influences on AOD variation before and after 2018, as demonstrated in Lines 128-133, would enhance clarity. This approach aligns with the manuscript's focus on the increasing importance of meteorological influences, as highlighted in both the manuscript's title and Section 4.3.

Thank you for this comment. Lines 128-133 summarize results from de Leeuw et al. (2023) using a different data set (C6 instead of C6.1 used in the current paper) and different methods (KZ(12,3) instead of CMA12 and monthly means) to evaluate the total AOD reduction between 2010 and 2020 and the contribution of meteorological effects to the total reduction. The objectives of the current study (L 174- 181) are aimed at investigating the reasons for deviations from the long term trends in de Leeuw et al. (2023). Therefore, we did not do the analysis of meteorological and anthropogenic contributions. However, we did mention the overall reduction of the AOD between the beginning (2010) and the end (2024) of the time series studied (L654-657). In this revised version we have disentangled the meteorological and anthropogenic contributions for the whole period and those before and after 2018, following methods described in de Leeuw et al. (2023). The results are presented in Table 2 and described in the text in Section 4.1 (L600-642):

"Satellite measurements of AOD over China show that emission reduction policy has been successful in reducing the aerosol concentrations between 2010 and 2018, with an additional but smaller reduction toward the end of the study period, in 2024. Over the NCP, the AOD in 2024 had been reduced to 68% of its value in 2010, over the YRD to 62%, over the PRD to 70%, over the HNB to 55% and over the SCB to 57% (CMA12 values). These reductions are larger than reported by De Leeuw et al. (2023) for the period July 2011-February 2020. The current study covers the longer period, with the larger reductions indicating that AOD was further reduced after February 2020. However, it should be kept in mind that, in the current study, a new data set and different methods were used, which may have influenced the results.

The data further show that the AOD differences between the five regions have become smaller. In 2010 the AOD over the five regions ranged from 0.40 (PRD) to 0.53 (YRD and HNB), while in 2024 the AOD over the five regions ranged from 0.29 to 0.33 (see Figure 3). However, a closer look shows that the AOD did not vary monotonously and substantial variations occurred, as revealed after low-pass filtering (CMA12). The AOD not only varied between the five different regions, but the AOD variations within each region occurred at different times as illustrated in Fig. 3. Clearly, not only emission reduction policy and other anthropogenic factors (economic development, urbanization, etc.) influenced AOD but also meteorological factors. This is further illustrated by the analysis of anthropogenic and meteorological contributions to the AOD (cf. De Leeuw et al., 2023; Section 2.4.2) applied to the C6.1 data set. Because CESM data (available until July 2023) are used, the analysis was made for the period from January 2010 to July 2023, as well as the periods before and after 2018. Due to the CMA12 filtering, the period was reduced to July 2010 to January 2023. The results in Table 2 show that, over the whole period, meteorological contributions vary between 12% (NCP) and 33% (PRD), whereas over shorter periods they are overall larger, between 14% (SCB) and 31% (PRD) for the period until 2018 (Period 1) and 14% (YRD) to 52% (NCP) for the period after 2018 (Period 2). The data further show that during Period 2 the meteorological contributions were substantially larger than during Period 1: over the NCP (52% vs 16%), the PRD (43% vs 31%) and the SCB (38% vs 14%), whereas they are smaller over the YRD (14% vs 28%) and the HNB (21% vs 25%). In view of the large AOD increase between mid-2018 and January 2021 over the YRD and HNB (Fig. 3) the smaller meteorological contributions in Period 2 than in Period 1 may be surprising, However, the data in Fig. 3 also show the much higher AOD over these areas during extended periods in 2011 and 2014 with clear meteorological influences as shown in Fig. 7 for the YRD and Fig. 11 for the HNB, which may have resulted in relatively large meteorological contributions during Period 1.. When we isolate the period mid-2018 and January 2021, we find that the meteorological contributions were 33% over the YRD and 32% over the HNB.

The data in Table 2 show that the overall AOD reduction during the study period is mainly due to anthropogenic effects, most likely emission reduction policy. However, meteorological effects are substantial and their importance seems to increase as AOD becomes smaller. Their magnitude depends on the period analyzed and is connected with certain meteorological conditions. This will be further discussed in Sections 4.2 (before 2018) and 4.3 (after 2018).

Table 2. Anthropogenic and meteorological contributions to the AOD variation over each of the 5 study areas for the whole study period and periods before and after 2018.*

Period		7/2010-1/2023		7/2010-6/2018		7/2019-1/2023	
Type of contribution (%)	Total reduction 1/2010-9/2024	Anthrop.	Meteor	Anthrop.	Meteor	Anthrop.	Meteor
NCP	68	88	12	84	16	48	52
YRD	62	83	17	72	28	86	14
PRD	70	67	33	69	31	57	43
HNB	55	84	16	75	25	79	21
SCB	57	90	10	86	14	62	38

In addition to the differences between the periods before and after 2018, the monthly mean MAIAC and"

As regards the abstract, we note that the allowed word count is 250, which does not leave enough space to summarize many details. To follow your suggestion, we had to delete much of the original abstract and re-organize the text. We have now included results from the above analysis for the total study period and the period before and after 2018, for all 5 regions, as per your suggestion. The abstract now reads (L26-41):

"Time series of MODIS/MAIAC C6.1 aerosol optical depth (AOD) and model-simulated AOD were used to determine contributions of meteorological and anthropogenic effects to spatiotemporal AOD variations over five representative areas in China, during the period January 2010 - September 2024. The time series confirm the effective reduction of the AOD between 2010 and 2018, with an additional but smaller reduction thereafter. The overall AOD reduction is mainly attributable to emission reduction policy, but with substantial meteorological effects. The total reduction and meteorological contributions during the whole study period, and the meteorological contributions before and after

2018 over the five regions were for NCP (68, 12, 16, 52) (all in %), YRD (62, 17, 28, 14), PRD (70, 33, 31, 43), HNB (55, 16, 25, 21), SCB (57, 10, 14, 38). Meteorological effects for each of these periods and each region are discussed in detail. As an example, the above data show that the meteorological effects over the YRD and HNB after 2018 are smaller than before 2018 which can be explained by the occurrence of strong effects in the earlier period and the choice of the period over which effects were calculated. Monthly mean AOD patterns were distinctly different before and after 2016, suggesting that aerosol properties changed in response to emission reduction policy. In summary, this study highlights the complex interplay between meteorological and anthropogenic factors in shaping AOD variations across China and demonstrates the increasing significance of meteorological conditions in modulating China's AOD".

Regarding the introduction section, I suggest the authors consider simplifying Lines 1-93. A lengthy exposition may not be necessary, starting instead with a brief introduction to aerosols and emphasizing the significance of AOD in assessing the atmospheric environment. Given the manuscript's current length, streamlining this section could enhance readability. In authors' responses they insisted on retaining this content; thus, I would leave the final decision to the editor's discretion.

Thank you for this comment. Indeed, we did insist retaining the Introduction as it was. However, in this second revision we decided to follow your advice. We have re-organized the Introduction, in particular removed much of the more general aerosol descriptions, PM2.5 and trace gases. We thus shortened the text by 1.5-2 pp. We now start directly with AOD. Lines 48-114 have been replaced with (L46-64): "Satellite observations of aerosol optical depth (AOD) provide information on the spatiotemporal variation of aerosols in the atmosphere on local, regional and global scales with daily global coverage. Satellite data have been used to retrieve AOD since 50 years and long time series are available from individual sensors such as the MODerate resolution Imaging Spectroradiometer (MODIS) and combinations of sensors (Sogacheva et al., 2020). The use of satellites to monitor the evolution of AOD over China has been demonstrated by, e.g., Xu et al. (2015), Kang et al. (2016), Zhang et al. (2017a), Zhao et al. (2017), Proestakis et al. (2018), De Leeuw et al. (2018; 2022; 2023), Sogacheva et al. (2018a; 2018b). Time series of aerosols provide information on the evolution of their atmospheric concentrations which are influenced by anthropogenic and natural emissions, transformations in the atmosphere and removal processes. Anthropogenic emissions include those due to, e.g., industrialization, urbanization, traffic, domestic activities and associated increase in energy production, transportation, agricultural activities, land use, etc. Emissions, and thus concentrations, are reduced by the implementation of policies aimed at the reduction of air pollution and its adverse effects. Effects of changes in meteorological parameters on AOD and associated effects on AOD time series were explained in De Leeuw et al. (2023) (their Section 3.6). Meteorological effects on AOD can be determined using model simulations, which in turn can be used together with observations to determine anthropogenic effects (Kang et al., 2019; De Leeuw et al., 2023). These methods, explained in more detail in Sections 2 and 3, are used in the current study on the analysis of AOD time series over China." and continues at L116 in the first revision (L97 in the current 2nd revision: "Early in the 21st century, aerosol and trace gas concentrations over China"

Regarding Lines 448-449, the mention of Shanghai in this context, related to the analysis of the North China Plain (NCP), appears inappropriate.

Thank you for this comment. However, this seems to be a misunderstanding. In this sentence we cite an article by Liu et al. (2024), the title of which is "Assessment of national economic repercussions from Shanghai's COVID-19 lockdown". We have changed the sentence to (L392-393): "Liu et al. (2024b) reported that Shanghai's lockdown in 2022 resulted in a stagnating economy in parts of China"

We made a similar change on line 451.

Regarding the PRD, where long-range transported smoke aerosols from South Asia are common, it is essential to consider how such non-local aerosol emissions may influence the conclusions drawn in this study.

Thank you for this comment. However, it Is not clear which conclusions the referee refers to. We did mention in Section 3.3.3 (L765-770) “The peak values in the observational and simulated AOD data occur in about the same months, but the simulated maxima are much higher than those of the observations. A reason for this discrepancy may be the large influence of smoke on aerosols in the PRD (Zhang et al., 2010; Liu et al., 2021) which in the CESM model is treated as anthropogenic emissions and thus fixed at the 2010 level (Section 2.3). The data in Fig. 8 show that the simulated AOD in March 2010 was substantially higher than the observed AOD, suggesting that the initial anthropogenic emission estimates were high.”

and in Section 4.1 (L956-958): “ During these later years, elevated AOD peaks are observed over the PRD in the spring which are attributed to the transport of biomass burning plumes from Indochina during specific weather patterns (Xue et al., 2025)”.