Response to reviewers

Thanks for your great efforts and valuable comments, which helps to improve our manuscript. We have addressed the reviewers' comments on a point-to-point basis as below for consideration. Referee comments are in black. Author responses are in red. All the line numbers mentioned following are refer to the revised manuscript with no changes marked.

RC1: This manuscript is built on continuous aerosol measurements conducted during 4 springs in urban Beijing. The data and research topic are certainly of high interest. While the paper is well-organized and technically relatively well written, there are a few major issues that prevent me to recommend the publication of this paper in its present form. My main concerns in this regard are summarized below.

My first major comment is about the imbalance between the title of the paper and its contents. The title gives an impression that this paper is solely about association between new particle formation (NPF) and dust, but most of the results (sections 3.3-3.5 and a big fraction of section 3.2) have little/nothing to do with NPF. The same concerns the abstract.

Reply: Thanks for your helpful comments. In section 3.1-3.2, we generally described the dust days and NPF occurrence probability in spring from 2017 to 2021. The classification of two types of NPF events was conducted depending on whether the dust event occurred before NPF, to evaluate the influence of dust process on nucleation and growth process. In the section 3.3-3.5, we discussed almost the most severe dust storm case in recent twenty years and the following NPF case. For this case, we have relatively comprehensive measurements of particle size, chemical composition, hygroscopicity, which can help to reveal the variations of physical and chemical properties of nucleated particles, and even the ability to be activated as CCN. However, as reviewer mentioned, we should highlight the relationship with NPF in each section, to make the discussion more focused on how the dust particles modify the atmospheric conditions when NPF events occur.

One of the main results brought up by the authors is the contribution of anthropogenic emissions to particle formation and growth rates. Estimating such contributions is very difficult overall, and totally impossible when having no real-time measurements of low-volatile precursors causing NPF and growth. Simply comparing days with and without presence of dust cannot address this issue, so in this regard the conclusions made in this paper are not scientifically sound.

Reply: The influence of anthropogenic emissions on NPF event is difficult to be evaluated or quantified, especially in urban areas (Kulmala et al., 2022). In this work, we analyzed the long-term measurement of PNSD in spring in Beijing from 2017 to 2021, to characterize the NPF event influenced by dust process or not. However, as the

reviewer mentioned, there is no sufficient percussor measurement, especially the low-volatile organic vapor. Thus, we revised the discussion and abstract, to address the influence of dust event on NPF, instead of accessing the contribution from anthropogenic emissions. For example, in the abstract, the description about "contribution of anthropogenic emissions" has been revised to "By comparing the two types of NPF events, the observed formation (J_3) and growth rate (GR) of dust-related NPF events were approximately 50% and 30% lower than the values of normal NPF days, respectively, due to the extremely low condensation sink (~0.005 s^{-1}) caused by the strong wind during the dust process. The difference of NPF parameters got smaller when nucleated particles grew into the sizes above 10 nm, as the anthropogenic emissions accumulated fast during the few hours when dust ended and favored the growth process in the later stage." We also revised the discussions and conclusions.

As noted by the authors, condensation sink (CS) is an essential parameter determining whether NPF is possible in various conditions. It is a pity that the authors did not calculate CS for course mode particle, as it would have been possible from APS measurements. The total CS was very likely dominated by dust particles at least during the heaviest dust storms, and this might be one explanation why NPF was observed after the storms rather than during them.

Reply: The authors totally agree with the reviewer's comment that the coarse mode particles are major sink for precursor gases, which can result in high condensation sink (CS). Thus, NPF events do not occur during dust period. When dust particles fade, the CS is quite low (~0.005 s^{-1}) due to strong dilution by wind, which favored for the NPF event occurrence. That means when we talk about NPF, the dust period has ended and the concentration of pre-existing particles is quite low, and thus the contribution of coarse mode particle to CS can be ignored. Unfortunately, the APS measurement was not continuous and only available on March 2021. We discussed a typical and most severe dust case during 2017-2021. For this case study, the APS data was available and the influence on CS is discussed. It was found CS during dust storm was <0.02 s^{-1}, whereas it was much lower than the value during air polluted conditions (~0.04 s^{-1}) before dust and decreased to be lower than 0.01 s^{-1} when NPF occurred, as shown in Fig. 8 in the manuscript. In this study, we focused on how the dust event modified the atmospheric conditions when NPF occurred.

There are potentially valuable data on non-NPF-related chemistry associated with dust/non-dust in sections 3.3-3.5. Unfortunately, the current discussion on these data is rather qualitative, relying mainly on finding reported by earlier literature, and providing little new scientific insight. For example, the statement on lines 304-305 is self-evident. The authors did not explain how they combined direct hygroscopicity measurements to the hygroscopicity estimated from measured aerosol chemical composition.

Reply: In this study, we provided valuable information about how the dust processes modify the atmospheric conditions which facilitate the NPF event, which has been

rarely discussed in the open literature. However, due to the limited measurement data, some discussions are not thoroughly to give the scientific insight. We have supplemented discussions in the manuscript, to make the scientific conclusions more robust. For example, a profound discussion about how different dust types influenced NPF events was given and addressed the strength of dust processes determined the condensation sink before NPF event, which was a key parameter in determining the formation and growth rate of NPF.

The sentence of original line 304-305 has been removed. In this study, the hygroscopicity parameter (κ) is derived from H-TDMA directly, which was not estimated from chemical composition data from AMS. The variation of κ was consistent with the chemical component.

Minor issues:

lines 43-44: reduced compared to what?

Reply: the sentence has been corrected to "Model simulations were performed with and without dust, and the results predicted that total particle concentration and CCN were reduced by approximately 20% and 10%, respectively, as influenced by the dust pollution plume in East Asia (Manktelow et al., 2010)."

lines 54-55: 45% of aerosols. By what measure? AOD?

Reply: This sentence has been corrected to "However, based on the optical parameters, including particle linear depolarization ratio, volume linear depolarization ratio and lidar ratio derived from a Raman lidar, there were approximately 45% of aerosols below 1.8 km above the ground contributed by polluted dust (the mixture of anthropogenic aerosols and dust) in Northern China (Wang et al., 2021)."

line 305: this should be Fig. 10, not Fig. 8.

Reply: The hygroscopic parameters are given in Fig. 10, and the chemical composition are given in Fig. 8.

It is somewhat unclear what is the difference between positive and negative anomalies in Figure 3. Also, it not well explained what is subtracted from what in this figure.

Reply: We have supplemented the details of Fig. 3 in the text, to make it clear that how the anomalies are calculated. The anomaly plots were obtained by means of the PNSD of NPF occurring on non-dust days subtracting the mean PNSD of dust-related NPF in each spring from 2017 to 2021, and was shown in Fig. 3. The positive anomaly indicated how much the particle number concentration in each corresponding size bin on non-dust NPF days was higher than that on dust-related NPF days, whereas the negative anomaly indicated that PNSD was lower on non-dust NPF days.

Finally, it seems to me that not all references cited in the text can be found in the reference list.

Reply: The authors check through the manuscript and supplemented the missing references in the list.

Dupart, Y., King, S. M., Nekat, B., Nowak, A., Wiedensohler, A., Herrmann, H., David, G., Thomas, B., Miffre, A., Rairoux, P., D'Anna, B. and George, C.: Mineral dust photochemistry induces nucleation events in the presence of SO_2, Proc Natl Acad Sci USA, 109(51): 20842-20847, DOI: 10.1073/pnas.1212297109, 2012.

Hussein, T., Hameri, K., Aalto, P., Paatero, P. and Kulmala, M.: Modal structure and spatial temporal variations of urban and suburban aerosols in Helsinki Finland, Atmospheric Environment, 39: 1655–1668, DOI: 10.1016/j.atmosenv.2004.11.031, 2005.

Maring, H., Savoie, D. L., Izaguirre, M. A., Custals, L. and Reid, J. S.: Mineral dust aerosol size distribution change during atmospheric transport, J. Geophys. Res., 108(D19), 8592, doi:10.1029/2002JD002536, 2003.

Nie, W., Ding, A., Wang, T., Kerminen, V. M., George, C., Xue, L., Wang, W., Zhang, Q., Petaja, T., Qi, X., Gao, X., Wang, X., Yang, X., Fu, C. and Kulmala, M.: Polluted dust promotes new particle formation and growth, Sci Rep, 4: 6634, DOI: 10.1038/srep06634, 2014.

Peters, T. M.: Use of the aerodynamic particle sizer to measure ambient $PM_{10–2.5}$: The coarse fraction of PM_{10}, J. Air Waste Manage. Assoc., 56, 411–416, 2006.

- **RC2**: 'Comment on acp-2022-837', Anonymous Referee #2, 06 Feb 2023

This manuscript entitled 'Characterization of dust-related new particle formation events based on long-term measurement in North China Plain', describes the observation of new particle formation events following dust episodes observed in Beijing between 2017 and 2021, with a focus on one severe episode on March 15-16, 2021. Although the topic of the paper and the potential results regarding the interaction of dust with available precursors resulting in NPF could be an important addition to literature, the authors' claims that are not supported by scientific evidence prevent me from recommending this paper for publication in ACP.

General comments:

1. The authors evaluate the contribution of anthropogenic emissions to the nucleation processes.
The authors calculated the anthropogenic emissions as the difference in the size distribution, formation rates and growth rates during other NPF days and NPF following dust days. This approach is not justified, as it ignores available sinks, meteorology and atmospheric reactions.

Reply: The authors agree with the reviewer's comment that quantifying the contribution of anthropogenic emissions to NPF events based on the comparison of dust related NPF and non-dust NPF days was not robust and justified, due to the lack of direct measurement of precursors and model simulations. However, clear differences between dust related and non-dust related NPF events were found based on the long-term PNSD measurement, providing valuable information about how the dust storm process modified the atmosphere conditions when NPF event occurred. According to the reviewer's comments, we removed the conclusions about the quantifying of the influence of anthropogenic emissions on NPF and focused on how the dust process affecting NPF and highlight the intrinsic reasons.

2. Sections 2.3-2.5 discuss a case study in March 15-16, 2021. While the results are interesting, the conclusion cannot be extrapolated to other events as the case study described is one of a kind in the four years, as shown in Table 2. A comparison between NPF events following different types of dust episodes events could be helpful. In particular, a comparison between the episodes on March 15 and 28, with including interpretation of NPF and its related properties could give insight on the effect of different types of dust.

Reply: Thanks for your comments, we added the discussion of NPF events followed different types of dust days. We found the dust related NPF events are highly dependent on the strength and the end time of dust process. NPF event usually occurred around 8:00-12:00 when solar radiation increased, so if the dust processes prevailed during this time, it will prevent NPF occurrence. For some cases of blowing and floating dust days overlaid by the anthropogenic aerosols, for example, March 18, 2019, April 5, 2019 and May 15, 2019, the CS remains high during the dust (above 0.02 s^{-1}), which prevented NPF event. Under some cases (April 15-16, 2021, Fig. S1), the whole dust process was identified as blowing and floating dust episode depending on the strength how air masses containing dust particles influenced Beijing. NPF event can be observed when the whole dust process finished.

Blowing dust and floating dust was observed on May 6-7 and May 8, respectively, and both followed by the occurrence of NPF event, as shown in Fig. S2. It was also found the condensation sink (CS) before NPF started was approximately 0.0025-0.003 s^{-1} for both NPF events, indicating the extremely weak scavenging process by the pre-existing particles. The CS level were also similar during the NPF event indicating the concentration level of precursors and condensing vapor participating nucleation and growth were comparable for these two cases. The values of formation rate (J_3) and growth rate (GR) of NPF event on May 7th and 8th were quite close, with J_3 of 4.5 and 4.8 $cm^{-3}s^{-1}$, GR of 2.3 and 2.5 nm h^{-1}, respectively.

The discussions are supplemented in the manuscript and the figures are given in the supplementary materials.
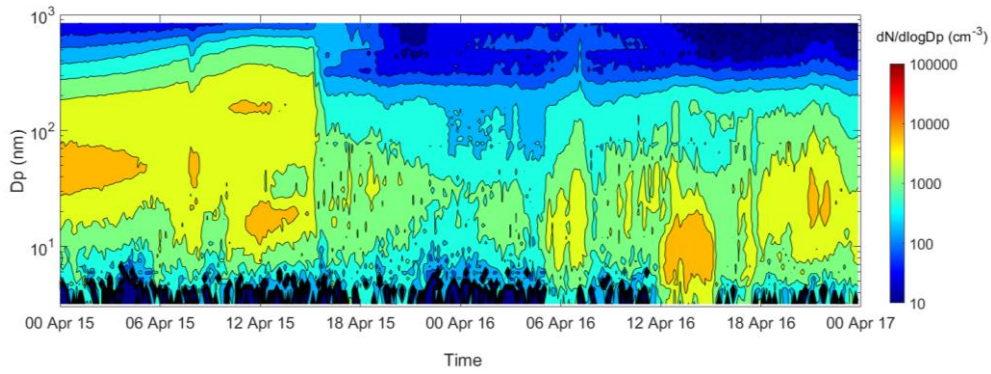
Fig. S1, NPF event occurred following blowing dust (April 15) and floating dust (April 16) in 2021
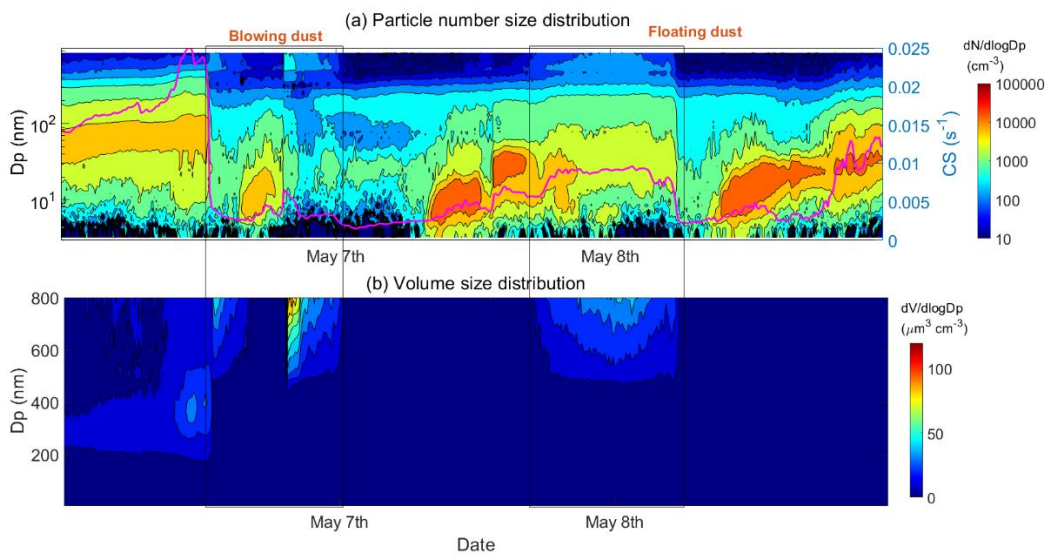

Fig. S2, NPF event occurred following blowing dust (May 6 and 7) and floating dust (May 8) in 2021. The particle number (a) and volume (b) size distribution are given and *CS* is given by pink line.
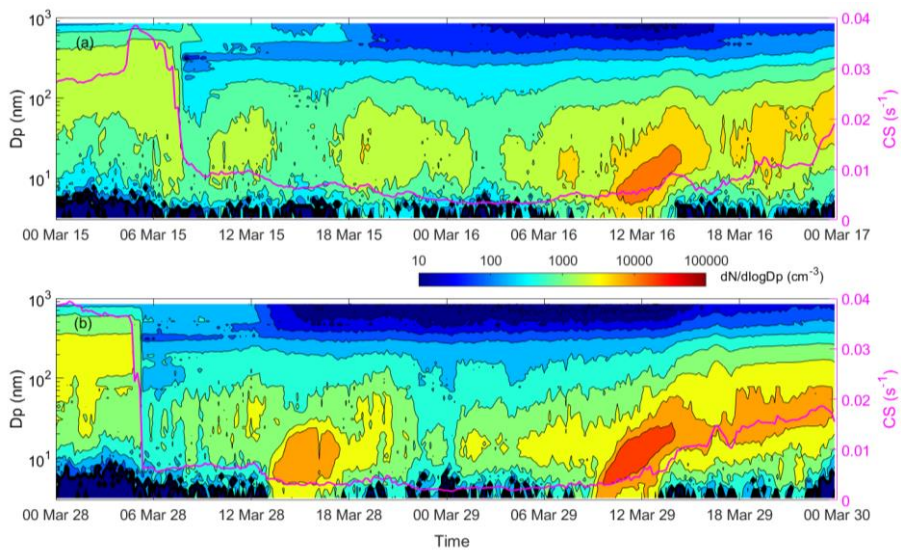
3. The authors report that an NPF event occurs after approximately 80% of dust episode, what was the limiting factor for the remaining 20%? Was the airmass direction different, the wind speed lower etc? Identifying the causes that inhibited the NPF during those 20% could improve the quality of the results.

Reply: Thanks for the constructive suggestion. We checked through all the dust days with NPF and without NPF days. It was found the air masses changed from northwest with the dust sources to other directions with anthropogenic emissions dominated. As given in Fig. S4-S5, floating dust occurred on May 15 2019 and April 1 2021, without NPF event when dust diminished. It showed the air mass originated from northwest during dust period on 00 UTC and switched to southwest since 06 UTC on May 15 and southeast since 06 UTC on April 1, respectively. The change of air masses resulted in the polluted dust case, which is the mixture of anthropogenic aerosols and dust and NPF event was prohibited due to the high level of condensation sink. Even the nucleation process was observed on April 1, the growth process was interrupted by the elevated background aerosol concentration, indicated by the increasing *CS*.

The 72 hours back trajectories arriving at CAMS station at four times a day (00, 06, 12, 18 UTC) on May 15 2019 and April 1 2021, respectively, with the terminal height of 500 m above ground level, derived by the TrajStat software, combined with HYSPLIT 4 model (Draxler and Hess, 1998; Wang et al., 2009). Trajstat, is a geographic information system-based software, which can view, query, and cluster the air mass trajectories and also conduct the potential source contribution analysis (Wang et al., 2009).

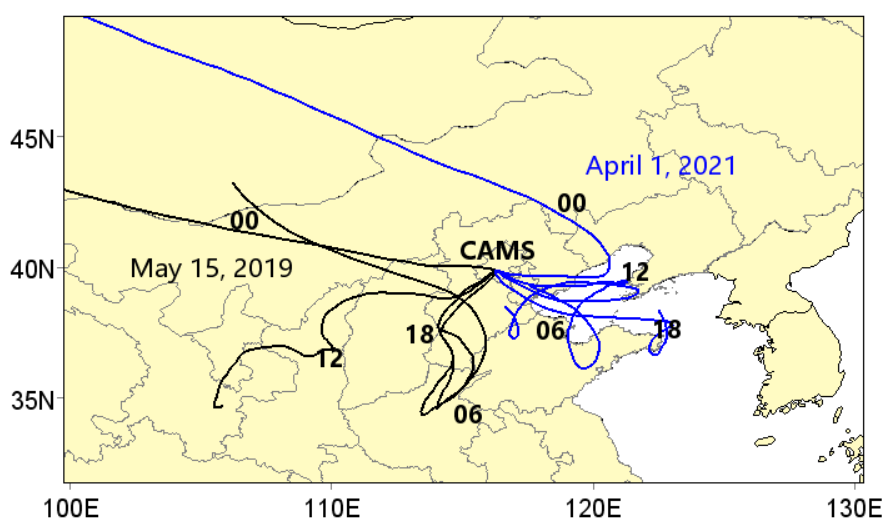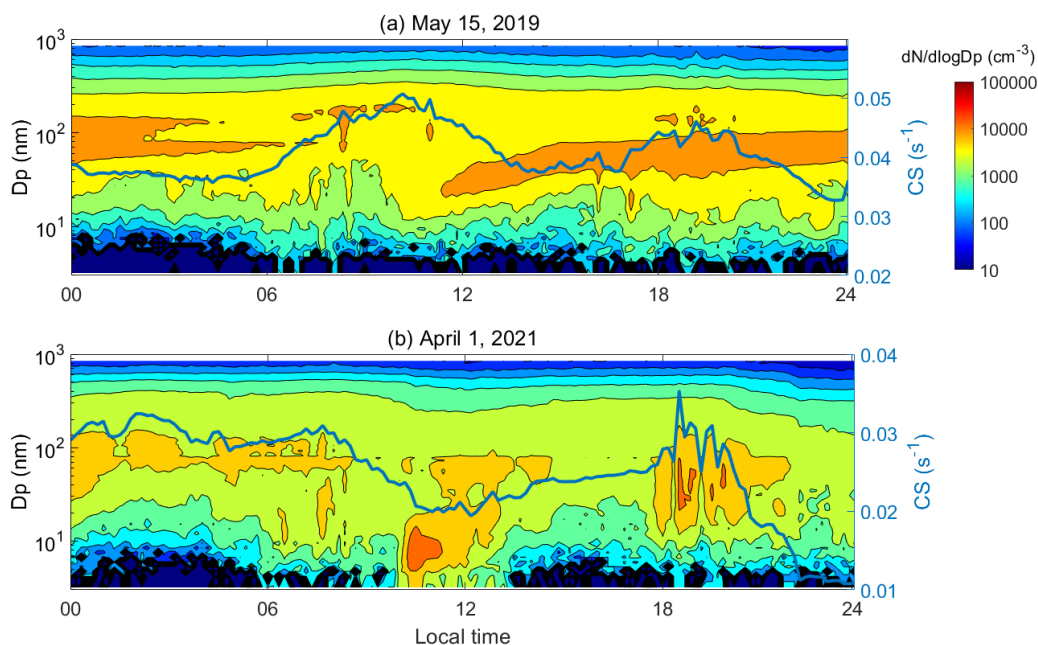The above information has been added in the manuscript and supplementary materials.

(a) May 15, 2019

(b) April 1, 2021

4. In section 3.3, the authors speak about primary and secondary organics, how did the authors derive this separation? Were there source apportionment techniques involved? Or was it based on previous literature? More details on the technique and results are needed.

Reply: The primary and secondary organic aerosols are identified based on the AMS data, by applying PMF method. The details are supplemented in the section 2.2 instrumentation.

Positive matrix factorization (PMF) (Ulbrich et al., 2009) and a multilinear engine (ME-2) (Canonaco et al., 2013) modelling of high time resolution organic mass spectrometric

data from HR-ToF-AMS have also been used to resolve organics into primary organic aerosols (POA) and oxygenated organic aerosols (OOA), which correspond to different sources and processes (Zhang et al., 2022).

Canonaco, F., Crippa, M., Slowik, J. G., Baltensperger, U. and Prévôt, A. S. H.: SoFi, an IGOR-based interface for the efficient use of the generalized multilinear engine (ME-2) for the source apportionment: ME-2 application to aerosol mass spectrometer data, Atmos. Meas. Tech., 6(12): 3649-3661, DOI: 10.5194/amt-6-3649-2013, 2013.

Ulbrich, I. M., Canagaratna, M. R., Zhang, Q., Worsnop, D. R. and Jimenez, J. L.: Interpretation of organic components from Positive Matrix Factorization of aerosol mass spectrometric data, Atmos. Chem. Phys., 9(9): 2891-2918, DOI: 10.5194/acp-9-2891-2009, 2009.

Zhang, Y., Zhang, X., Zhong, J., Sun, J., Shen, X., Zhang, Z., Xu, W., Wang, Y., Liang, L., Liu, Y., Hu, X., He, M., Pang, Y., Zhao, H., Ren, S. and Shi, Z.: On the fossil and non-fossil fuel sources of carbonaceous aerosol with radiocarbon and AMS-PMF methods during winter hazy days in a rural area of North China plain, Environ Res, 208: 112672, DOI: 10.1016/j.envres.2021.112672, 2022.

5. I suggest that the authors revise some of the interpretations in the paper which are either not consistent or not based on evidence from the observations. Examples:

Reply: we agree with the reviewer's comments that some conclusions in the manuscript were nor robust, and we have revised them based on the measurement data directly. Some sentences are not helpful to discussion, which are removed from the manuscript.

- Line 241: "When the dust particles arrived in Beijing at 8:00 LT on March 15, the volume mixing ratio of NO_2 and SO_2 decreased immediately, which was also influenced by the enhanced aerosol surface uptake process owing to elevated particle surface concentration" vs Line 247: "However, the concentrations of NO_2 and SO_2 were low during dust storms, indicating that anthropogenic emissions had less influence."

Reply: original L241: it has been revised to "When the dust particles arrived in Beijing at 8:00 LT on March 15, the volume mixing ratio of NO_2 and SO_2 decreased immediately due to the strong dilution by wind".

original L247: this sentence was removed.

- Line 284: During the dust storm period, transitional metal ions such as Fe and Mn can act as catalysts that favor sulfate formation via SO_2 oxidation (Usher et al 2003).

Reply: This sentence was removed.

- Line 262: The decrease in NO_2 and nitrate suggests that they probably shifted from fine to coarse particles during dust storms (Wang et al., 2013).

Reply: As we do not have direct chemical composition measurement, this sentence is removed.

- Line 269: This indicates different sinks for SO_2 and NO_2 during the dust storms. As discussed above, the uptake by mineral dust was a major sink for SO_2, whereas the uptake of NO_2 was minor, as the concentration remained low when the dust storm ended.

Reply: This paragraph has been revised to "The SO_2 volume mixing ratio increased quickly when the dust storm faded (22:00 LT on March 15), which was probably due to the weakened dilution process as the wind speed decreased from 5.8 m/s during dust episode to below 3.0 m/s at 20:00 LT on March 15. Another possibility was indicating that dust particles could be a major SO_2 sink (Usher et al., 2003). NO_2 also decreased when the dust storm started; however, it did not increase significantly when the dust storm ended, which differed from the variation in SO_2. However, heterogeneous reactions of mineral dust with SO_2, NO_2 can not be discussed further, due to the lack of direct measurement of chemical information of coarse mode particles."

6. The methods section lacks detailed explanation of most of the instrumentation and quality control.

- Were the aerosol measuring instruments cross checked for over-lapping sizes? Citations are missing.

Reply: The details of instrumentation, experimental setup and data quality control, as well as the citations, are supplemented in the text.

As the reviewer mentioned, there is an overlap size range of particle number size distributions (PNSDs) derived from TSMPS and APS, which is 500-850 nm. The resulting distributions of APS system were converted from aerodynamic to mobility diameters with assumed particle density of 2.5 g/cm^3 during the dust, as combined with TSMPS data. The PNSDs and calculated volume size distribution derived from TSMPS and APS, respectively, during March 15-17, 2021 was given in Fig. S6. The volume concentration was calculated based on PNSD, with the assumption of spherical shape. It showed the submicron particles (PM$_1$) was the dominant contributor to the particle number concentration (a), whereas the contribution to the volume can be ignored (b). It was found in the overlap size range between TSMPS and APS data (500-850 nm), the bias became smaller when particle size increased. At the last size bin of 850 nm, the number concentration derived from TSMPS was 50% higher than that from APS. The

information of the overlap size range was supplemented in the text and the figure was given in the supplementary materials.
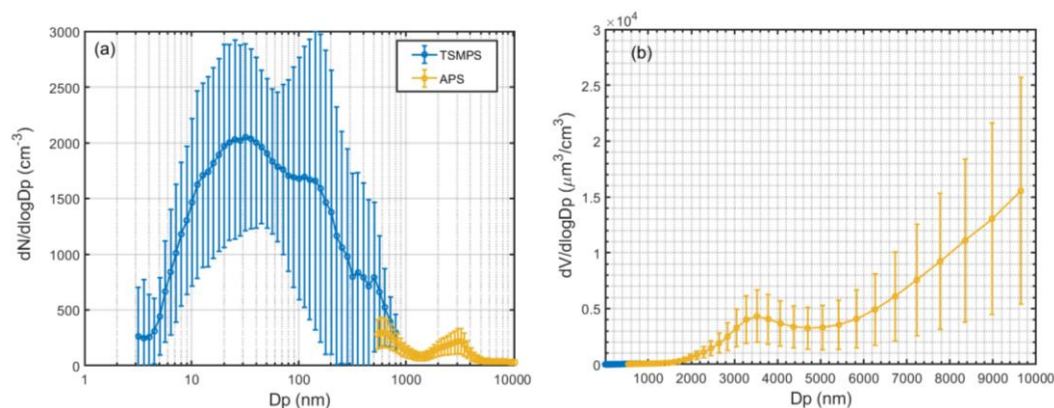

Fig. S6. The number size distribution (a) and volume size distribution (b) derived from TSMPS and APS.

The description of H-TDMA measurement and data inversion has been also added. The H-TDMA system is comprised of two DMAs, a CPC (Model 3772, TSI Inc., USA) and a humidifier system between the two DMAs. The first DMA selects the quasi-monodisperse particles at a diameter ($D_{p,dry}$ = 50, 100 nm) under the dry state with 30% RH (Maβling et al., 2003). Then, the size-selected particles pass through a humidity conditioner, which can be adjusted to the setting RH of 90%. The probability distribution function (PDF) of hygroscopic growth factor (HGF), HGF-PDF is inverted by the TDMAinv method developed by Gysel et al. (2009).

Maβling, A., Wiedensohler, A., Busch, B., Neusüß, C., Quinn, P., Bates, T., Covert, D.: Hygroscopic properties of different aerosol types over the Atlantic and Indian Oceans. Atmos. Chem. Phys. 3, 1377–1397, 2003.

Gysel, M., McFiggans, G.B., Coe, H.: Inversion of tandem differential mobility analyser (TDMA) measurements. J. Aero. Sci. 134–151, 2009.

- What are the detection limits and the time resolutions of the trace gas measuring instruments?

Reply: The TE 49C has a lower detection limit of 1 ppb and a precision of 1 ppb. The 42 CTL has a lower detection limit of 50 ppt and a precision of 0.4 ppb. The 43 CTL has a lower detection limit of 0.10 ppb and a precision of 1 ppb (Lin et al., 2009). Measurement signals of trace gases were recorded as 1 min averages (Lin et al., 2011), however, the hourly average data were used for discussion, in order to match with the PM mass concentration data. The above information and references have been added in the manuscript.

Lin, W., Xu, X., Ge, B. and Zhang, X.: Characteristics of gaseous pollutants at Gucheng, a rural site southwest of Beijing, Journal of Geophysical Research, 114, DOI: 10.1029/2008jd010339, 2009.

Lin, W., Xu, X., Ge, B. and Liu, X.: Gaseous pollutants in Beijing urban area during the heating period 2007–2008: variability, sources, meteorological, and chemical impacts, Atmospheric Chemistry and Physics, 11(15): 8157-8170, DOI: 10.5194/acp-11-8157-2011, 2011.

- The description of the HR-AMS-ToF is not sufficient, and citations are missing. For example what was the collection efficiency?

Reply: The description of HR-ToF-AMS with the citations has been supplemented in the manuscript. The chemical composition of non-refractory PM_1, including organic components, sulfate, nitrate, ammonium, and chloride, was derived using HR-ToF-AMS with a 5-min resolution (Drewnick et al., 2005). The calibrations of ionization efficiency were performed, using size-selected (300 nm) ammonium nitrate particles before and after the experiment. Default relative IE values were used for organics (1.4), nitrate (1.1), sulfate (1.2), ammonium (4.0), and chloride (1.3). The HR-ToF-AMS collection efficiency (CE) accounts for the incomplete detection of aerosol species owing to particle bounce at the vaporizer, and/or the partial transmission of particles by the lens (Canagaratna et al., 2007). In this study, a composition-dependent CE correction was used, following the methodology described by Middlebrook et al. (2012).

Canagaratna, M. R., Jayne, J. T., Jimenez, J. L., Allan, J. D., Alfarra, M. R., Zhang, Q., Onasch, T. B., Drewnick, F., Coe, H., Middlebrook, A., Delia, A., Williams, L. R., Trimborn, A. M., Northway, M. J., DeCarlo, P. F., Kolb, C. E., Davidovits, P., and Worsnop, D. R.: Chemical and microphysical characterization of ambient aerosols with the aerodyne aerosol mass spectrometer, Mass Spectrometry Reviews, 26, 185-222, 10.1002/mas.20115, 2007.

Drewnick, F., Hings, S. S., Decarlo, P., Jayne, J. T., Gonin, M., Fuhrer, K., Weimer, S., Jimenez, J. L., Demerjian, K. L., and Borrmann, S.: A New Time-of-Flight Aerosol Mass Spectrometer (TOF-AMS)—Instrument Description and First Field Deployment, Aerosol Science & Technology, 39, 637-658, 2005.

Middlebrook, A. M., Bahreini, R., Jimenez, J. L., and Canagaratna, M. R.: Evaluation of Composition-Dependent Collection Efficiencies for the Aerodyne Aerosol Mass Spectrometer using Field Data, Aerosol Science and Technology, 46, 258-271, 10.1080/02786826.2011.620041, 2012.

- Was there source apportionment performed?

Reply: The source apportionment has been conducted and the details are given in the supplementary materials.
The potential source contribution function (PSCF) analysis method has been widely

applied to study the potential source regions of pollutants (Ashbaugh et al., 1985; Wang, et al., 2009). The PSCF values for each grid cell (0.5°*0.5°) in the selected domain were calculated by counting the number of trajectories those terminated within each grid cell, as follows:

$$PSCF_{ij} = \frac{m_{ij}}{n_{ij}} \tag{1}$$

where n_{ij} is the number of endpoints that fall in the ij^{th} cell, and m_{ij} is the number of endpoints for the same cell with pollutant concentrations higher than the set criterion value. The PSCF values should be weighted according to n_{ij}. In this study, the weighting function (W_{ij}) was defined as follows:

$$W_{ij} = \begin{cases} 1.00 & 10 \times \overline{n_{ij}} < n_{ij} \\ 0.70 & 5 \times \overline{n_{ij}} < n_{ij} \leq 10 \times \overline{n_{ij}} \\ 0.40 & 2 \times \overline{n_{ij}} < n_{ij} \leq 5 \times \overline{n_{ij}} \\ 0.05 & n_{ij} \leq 2 \times \overline{n_{ij}} \end{cases} \tag{2}$$

where $\overline{n_{ij}}$ is the mean n_{ij} value. In this study, a potential source analysis was conducted for the nucleation and accumulation mode particles, which represented the air mass influence on the NPF event and the particles from long-range transport, respectively. The criterion values of $PM_{2.5}$ and PM_{10} mass concentration were 75 μg cm^{-3} and 100 μg cm^{-3}, which was the mean value in March, April and May in 2021.

The PSCF results (Fig. S7) showed that high $PM_{2.5}$ mass concentration at CAMS was dominated by two sources, the northwesterly and westerly originating air mass containing dust particles, and the southerly air mass with high mass loading of anthropogenic aerosols. However, for PM_{10} mass concentration, the high values only contributed by the air masses passing through Inner Mongolia and carrying dust particles.
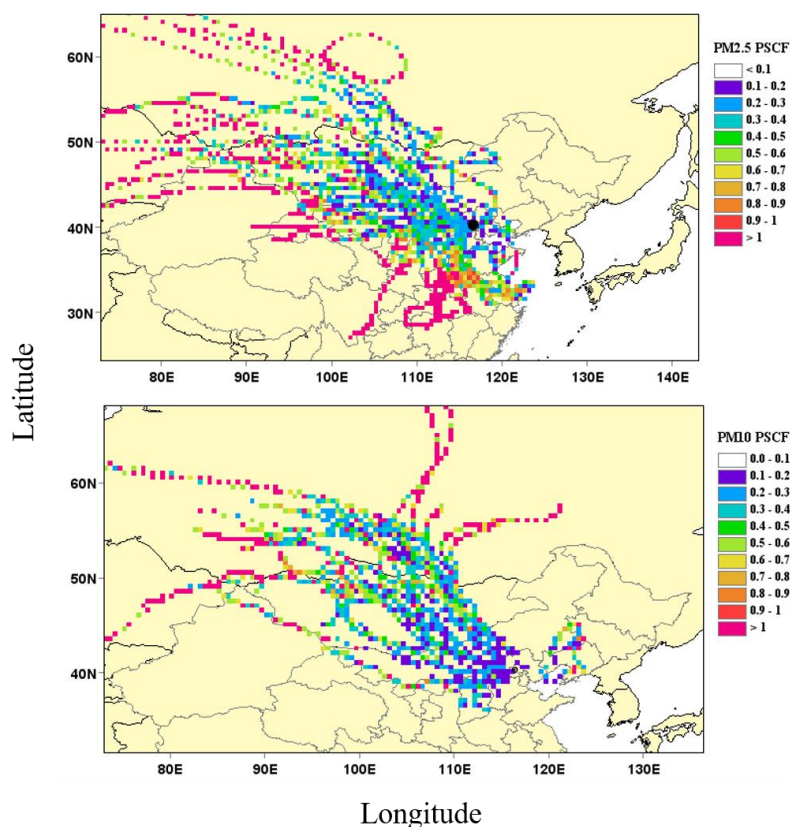
Fig. S7. Air mass classification of back trajectories arriving at the CAMS site in March, April and May, 2021. The color bar indicates the number concentration weighted potential source contribution function (PSCF) value of (upper panel) $PM_{2.5}$ and (lower panel) PM_{10} mass concentration.

Ashbaugh, L.L., Malm, W.C., Sadeh, W.Z., 1985. A residence time probability analysis of sulfur concentrations at Grand Canyon National Park. Atmospheric Environment 19 (8), 1263–1270.

- How were the dust events defined, not the distinction between the dust episodes, but the identification itself, was it based on airmass trajectories?

Reply: we give the definition in the section of 3.1 with original line 143-145. Three types of dust days are classified based on visibility (National Weather Bureau of China, 1979; Wang et al., 2005), including dust storm with visibility below 1.0 km; blowing dust with visibility of 1.0-10 km and floating dust with visibility below 10 km. The dust days we discussed in the manuscript were identified based on the above algorithm. In this study, the visibility data are from the national surface meteorological observation stations of China Meteorological Administration (CMA). Furthermore, the daily weather phenomena and visibility are issued by CMA (http://www.asdf-bj.net/publish/observation/5.html, last access on 23 March, 2023), which can also help to recognize the dust event. We conducted the identification of dust days during 2017-2021 spring based on the visibility data. We have supplemented the visibility data origins in the manuscript.

The 72 hours back trajectories on dust days March 15-17, 2021 were also calculated and given in the supplementary materials (Fig. S2). It showed the air mass passing through Mongolia, which is the source of dust storm.