Response to Referee and Editor on “Measurement Report: A Multi-Year Study on the Impacts of Chinese New Year Celebrations on Air Quality in Beijing, China.”

22 February 2022

Dear Editor and Referee:

Thank you for your time in re-reviewing our revised manuscript. We appreciate the helpful comments to make further improvements to our manuscript prior to publication. We have addressed the comments and have made minor modifications to the manuscript. Our replies to the comments are in blue below.

Editor Comments

Please note that your reference list has not been compiled according to our standards. Please consider adjusting your reference list with the next revision of your manuscript. The manuscript preparation guidelines can be seen at: https://www.atmospheric-chemistry-and-physics.net/for_authors/manuscript_preparation.html.

We have updated the format of references to reflect that of Copernicus publications.

1. Regarding your figure 10: With the next revision, please add the copyright symbol as follows: © Google Earth (either in the figure itself or in the caption). Please also add the corresponding author below the affiliations.

We have added the copyright statement to the figure caption. We have also noted the corresponding author.

2. The section "Correspondence to:" is missing from your *.pdf manuscript file. Please indicate it for the next revision.

We have added “Correspondence to: Pauli Paasonen (pauli.paasonen@helsinki.fi)” after the author list and affiliations.

Referee Comments

1. The language in the revised manuscript needs further improvement. Some low-level grammatical errors are easily found, such as the errors in line 46, 82, 182, 334, 487. I recommend to find a native English speaker to help correct this paper before next submission.

Thank you for pointing out these typos in the text. We have corrected them.

2. The authors stated that the study is the first using the CNY data covering several years. Actually, some previous studies have used more data to study this issue, such as Sun et al. (2020). The authors need to refer more papers in the introduction part.

Sun, Y., Lei, L., Zhou, W., Chen, C., He, Y., Sun, J., ... & Worsnop, D. R. (2020). A chemical cocktail during the COVID-19 outbreak in Beijing, China: Insights from six-year aerosol particle composition measurements during the Chinese New Year holiday. Science of the Total Environment, 742, 140739.

Thank you for pointing out that this statement was not entirely clear, and as a result, it could be misinterpreted. We would like to clarify that we haven't claimed that this is the first study, rather we stated (line 111), "it is one of the only studies to not only show measurements for a single CNY…". To address the referee's comment and make the statement clearer, we have rephrased this as, "it is one of only a few studies to not only show measurements for a single CNY…"

3. In section 3.1, the authors attributed high concentrations of SO2 and BC on CNY in 2018 to fireworks. However, during the 2018 CNY period fireworks were prohibited. The coal combustion can also emit a lot of SO2 and BC. Previous studies (e.g., Wang et al. 2018) suggested that massive emission of SO2 from coal-based power plants, steel and iron works, glassworks and cement mills in the southern Hebei province, the south of Beijing. Therefore, the high-level air pollutants on CNY in 2018 may be from long distance transportation.

Wang, Y., Li, Z., Zhang, Y., Du, W., Zhang, F., Tan, H., Xu, H., Fan, T., Jin, X., Fan, X., Dong, Z., Wang, Q., and Sun, Y.: Characterization of aerosol hygroscopicity, mixing state, and CCN activity at a suburban site in the central North China Plain, Atmos. Chem. Phys., 18, 11739-11752, 10.5194/acp-18-11739-2018, 2018.

Thank you for the description of emissions from fireworks versus other combustion sources. Although it is true that the pollutants could have been transported from southern Hebei province, this does clearly not explain the sudden increase followed by sudden decline that we see in Figures 2, 5, 8 and 11. We took note of the trajectory plots (Figure 4): Trajectories from 6 hours before CNY up to CNY are from southern/southwestern Hebei province, which means that if the high concentrations of observed SO_2 and BC were due to transport from this region, the high concentrations would have been seen during the whole overnight period, rather than a sudden peak around midnight. We can therefore infer that the observation is due to a sudden short-term emission source rather than long-term transport. Comparing this to our spatial analysis in Figures 10 and S2-S13, we see that the peaks occur in all parts of the metropolitan area at roughly the same time. This indicates that these short-term emissions are likely sourced within the metropolitan area because if the spike was transported from the south, there would be a delay between the observations in the south part of the city and the north part of the city.

We have made a minor revision to the paragraph starting at line 255 in the previous revision. In the new revision (now lines 268-276), this paragraph reads as follows:

> The measurements showed elevated nighttime concentration of H_2SO_4 on CNY in 2018 exceeding $3 \cdot 10^6$ cm^{-3} during the whole night, which was an order of magnitude higher than typical nighttime H_2SO_4 concentrations of $5 \cdot 10^5$ cm^{-3} (Dada et al., 2020). In 2019, there was no evident indication of anomalies in nighttime H_2SO_4 concentration during CNY. An unknown spike in H_2SO_4 was noticed at noon the day before CNY in 2018, and its association with celebratory activities is unclear. Like with $PM_{2.5}$ and SO_2, Figure 2 shows a distinctive spike in BC around midnight of the 2018 CNY. Although SO_2 and BC also originate from coal combustion and other emission sources (Wang et al., 2018), because of the shortness of the peak, and the fact that it occurs at exactly midnight, these simultaneous peaks of BC and SO2 during the nighttime of CNY most likely originate from firework burning.

We have added Wang et al., 2018 to the reference list.

4. Line 317-319. The authors said that the air masses transport conditions on CNY in 2018 and 2019 were rather similar. However, the trajectories in Fig.4 show that air mass transported from the south to Beijing in CNY 2018 but from the east to Beijing in CNY 2019. The authors need to know the pollution levels were distinct in the south and east regions of Beijing. Weaker diffusion conditions and more industrial emissions make that the pollution in the south of Beijing is much stronger than in the east (e.g., Wang et al. 2019). Therefore, the transportation from industrial pollutants should be stronger in CNY 2018.

Wang, Y., Dörner, S., Donner, S., Böhnke, S., De Smedt, I., Dickerson, R. R., Dong, Z., He, H., Li, Z., Li, Z., Li, D., Liu, D., Ren, X., Theys, N., Wang, Y., Wang, Y., Wang, Z., Xu, H., Xu, J., and Wagner, T.: Vertical profiles of NO2, SO2, HONO, HCHO, CHOCHO and aerosols derived from MAX-DOAS measurements at a rural site in the central western North China Plain and their relation to emission sources and effects of regional transport, Atmos. Chem. Phys., 19, 5417-5449, 10.5194/acp-19-5417-2019, 2019.

Thank you for the detailed explanation of sources from the south as opposed to the east. Thank you, also, for pointing out that we imply they are the same in 2018 and 2019, even though they are not. The referee is correct that in 2018, the airmass 6 hours through 2 hours prior to CNY midnight comes from southwest before arriving at the station, whereas in 2019, the airmass from 6 hours to 2 hours prior to CNY midnight arrive from the east.

The referee is also correct that the emissions from southwest and east are not the same, which we incorrectly stated were “rather similar.” The referee is further correct that we would expect air from the southwest to be more polluted than air to the east. However, what we see is different. Based on the Wang et al. (2019) paper, the air from 6 hours before CNY through 2 hours before CNY in 2019 (where airmass is from the east) should be cleaner than the air from 6 hours through 2 hours before CNY in 2018 (which is from the southwest). What is observed, on the other hand, shown in Figure 2, is that during this time frame – before the sudden peak is observed, which we could call the “background value” in this case – $PM_{2.5}$ concentrations in 2019 are higher than in 2018.

Nonetheless, the sudden peak around midnight with respect to the background concentrations is indicative of a short-term, probably nearby, emission source as opposed to long-range transport. From this, we can conclude that in both years, the sharp, short-term peak is from the short-term source, i.e. the firework burning.

To address the referee’s comment regarding our incorrect statement that the trajectories are rather similar, we have corrected the language in this paragraph to explain more clearly and correctly. We have removed the misleading statement that the trajectories are “rather similar.” The new language is now consistent with the figure.

This revised paragraph (lines 334-349 in the revised manuscript), which is now split into three paragraphs, reads as follows:

> The lower concentrations observed during the emission spike in 2019 can be either due to lower emission rates in the area with which the measured air mass is in contact, or due to a shorter exposure to roughly similar emissions during both years. Figure 4 shows 96 hour back-trajectories by Hysplit, during the night of CNY in 2018 and 2019, showing the sources of the airmasses. This provides further insights into the history of the

airmasses in Beijing, including how clean we can expect the airmasses to be before CNY, and whether the airmasses are stagnant around Beijing or whether clean air is being transported into the city.

These trajectories show the following: In 2018, the airmasses from six hours prior to CNY through CNY are from the southwest, and from two through six hours after CNY, the airmass is from the west. In 2019, airmasses from six hours prior to CNY through two hours prior to CNY the airmasses are from the east, and following the CNY the airmasses are primarily from the west.

Based on Wang et al. (2019), airmasses from the east are expected to be cleaner than from the southwest due to more diffusion and less emissions from industry. However, we observed the opposite: From six through two hours prior to midnight (i.e. the background value before the spike in pollution), the background pollutant concentrations are higher in 2019 than in 2018. This gives further indication that the emission sources are likely localized and short-term as opposed to long-range transport.

Wang et al. (2019) has been added to the reference list.

5. Figure 2i: Why the BLH was larger than 2 km in so much time, especially in 2018? In general, BLH was lower than 1 km in winter.

We have done an investigation and have verified that these measurements are correct. During the daytime, the BLH is greater than 2 km during times of clear or relatively clean air, which is in general the case during the daytime with clean conditions in this time period. Winter is the most polluted season in Beijing and therefore many studies are focusing on the highly polluted periods with low BLH. During periods of haze/air pollution episodes, BLH may remain less than 2 km during the daytime because of the radiative effects of aerosols, which is attenuating the incoming solar radiation, which decreases the energy reaching the surface and increases the atmospheric stability within the boundary layer, consequently keeping the BLH low. Since this is not the case at all times during the daytime in this time period, it is reasonable to have BLH >2km during the cleaner days.

Here are a couple of studies showing that 2 km is a reasonable value for daytime BLH in Beijing during times of clear air:

Liu, Q., Jia, X., Quan, J. *et al.* New positive feedback mechanism between boundary layer meteorology and secondary aerosol formation during severe haze events. *Sci Rep* **8,** 6095 (2018). https://doi.org/10.1038/s41598-018-24366-3

Jiang, Q.; Zhang, H.; Wang, F.; Wang, F. Research on the Growth Mechanism of $PM_{2.5}$ in Central and Eastern China during Autumn and Winter from 2013–2020. *Atmosphere* **2022**, *13*, 134. https://doi.org/10.3390/atmos13010134

6. Figure 10 was too vague. The full names of these measurement sites need to be annotated.

Thank you for pointing out that the figure could use some improvement for clarity.

The figure contains the abbreviations of each station next to the station. However, we realize that in grey font, it is somewhat difficult to see against the imagery. We have modified the annotations to be slightly brighter. Additionally, a table of the twelve MEP sites with their names in Chinese, abbreviations in English, and their latitude and longitude values is in the Supplementary material.

We have now added the site names translated to English in addition to the abbreviations to this table. We have added to the figure caption a reference to the table.

The figure and its caption are now as follows:

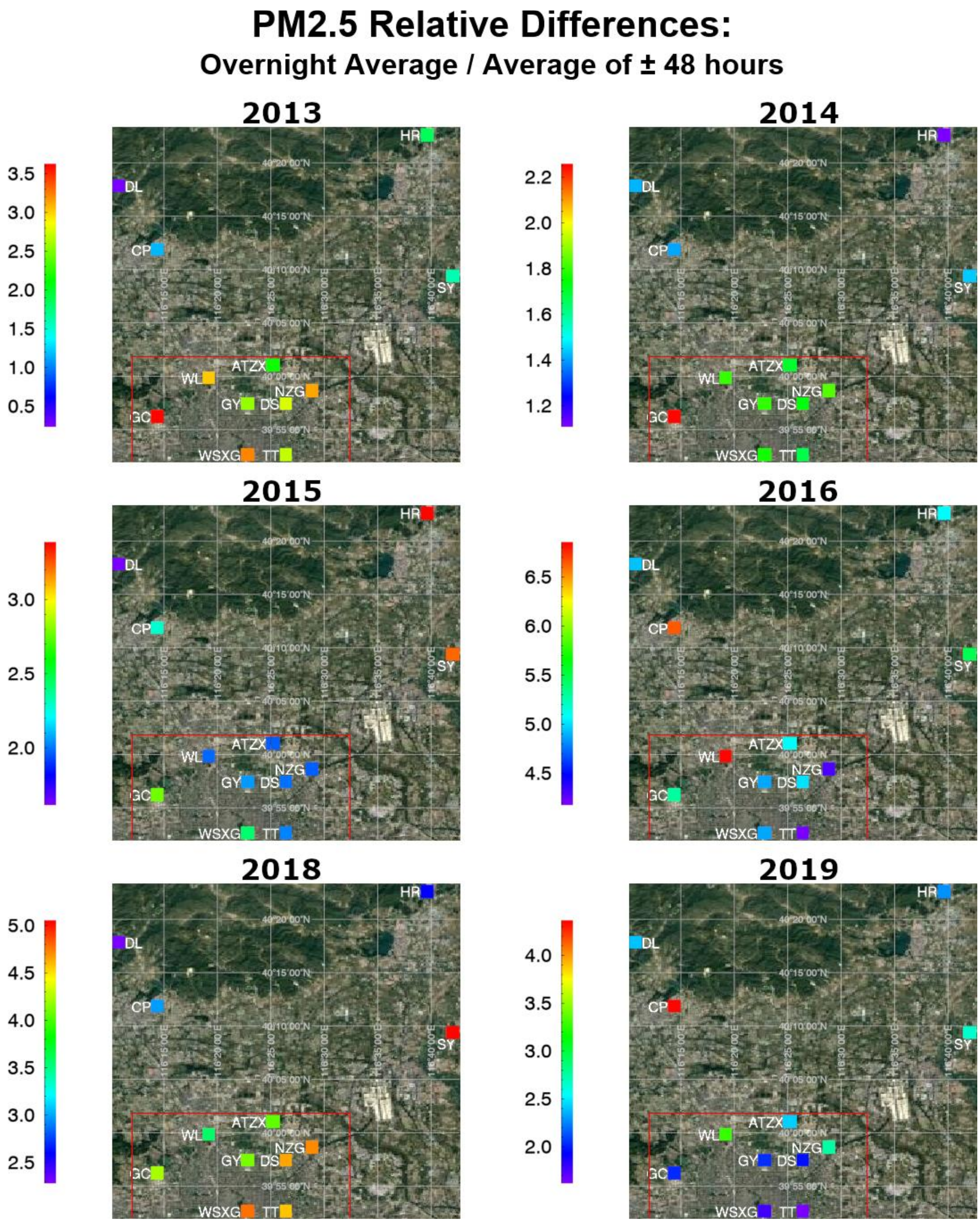

Figure 10: The 12 MEP sites mapped in the Beijing metropolitan area, showing the ratio of overnight $PM_{2.5}$ observations during the CNY (21:00-05:00) to all data during the period of 48 hours before through 48 hours after the CNY. The red line marks the approximate location of the 5th Ring Road. Note that the colorbars in each map are relative to only that year, and the colorbar range is not the same in different years. 2017 is omitted from this figure because data after 00:00 was not available. A list of the sites' full names in English and Chinese, along with their latitude and longitude coordinates can be found in Table S1 in Supplementary material. Imagery: © Google Earth.

Table S1 has been revised as follows:

Site name	Site name (eng)	Site abbreviation (eng)	Longitude	Latitude
东四	DongSi	DS	116.417	39.929
天坛	TianTan	TT	116.407	39.886
官园	GuanYuan	GY	116.339	39.929
万寿西宫	WanShouXiGong	WSXG	116.352	39.878
奥体中心	AoTiZhongXin	ATZX	116.397	39.982
农展馆	NongZhanGuan	NZG	116.461	39.937
万柳	WanLiu	WL	116.287	39.987
古城	GuCheng	GC	116.184	39.914
顺义	ShunYi	SY	116.655	40.127
昌平	ChangPing	CP	116.23	40.217
怀柔	HuaiRou	HR	116.628	40.328
定陵	DingLing	DL	116.22	40.292

Table S1: List of the 12 MEP (Ministry of Environmental Protection) sites in the Beijing metropolitan area, their translations and abbreviations in English, and their geographic locations.

Other:

The affiliation for one of the co-authors, Rosaria E. Pileci, has changed. The new version of this manuscript reflects her new affiliation.

We have moved the figures to be integrated into the text instead of appended at the end, per guidelines: “Figures and tables as well as their captions must be inserted in the main text near the location of the first mention (not appended to the end of the manuscript).”

When uploading our final revision, we will also upload the figures separately in pdf format.