RESPONSE LETTER

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June 29th, 2018

We deeply appreciate the reviewer for his/her careful reviews of this paper.

Referee #3. *General Comments*

This paper presents a comparison between the surface PM2.5 mass concentration and upper-air visibility (i.e., visibility at 0.1, 0.3, and 0.5 km) during two winter haze episodes that occurred in the northwest part of downtown Beijing. While use of the term "visibility" for altitudes above the surface may be somewhat misleading, the essence of the study is concerned with a very important but rarely studied issue, namely, the vertical variation of aerosol loading, especially the consistency between ground-level and upper-level measurements monitored by a suite of instruments including the lidar, Cimel sunphotometers, PM2.5 particle samplers, etc. Such analyses are useful towards understanding the source of air pollution and its transport, as well as uncertainties in using ground-based measurements to represent column values or vice versa. The study is generally rigorous and sound. In light of these merits, I recommend publication if the following comments are properly addressed.

Specific comments:

1. Change the title to "Comparison of Air Quality at Different Altitudes from Multi-Platform Measurements in Beijing".

Reply:

Thanks for your valuable comment. We have changed the title "Multiplatform analysis of upper-air haze visibility in downtown Beijing" into "<u>Comparison of Air Quality at Different Altitudes from Multi-Platform Measurements in Beijing</u>" (see Lines 1-2 on **Page 1**).

2. In the abstract, please clarify the altitudes of the upper-air levels under study, the exact research period, and what the haze parameters refer to.

Reply:

We have added the periods of the haze episodes, the altitude of the upper-air visibility and the detailed haze parameters in the Abstract as shown the sentence of "<u>The features of upper-air visibility at altitudes of 0.1km, 0.3km and 0.5km and the two-dimensional haze characteristics in the northwest of downtown Beijing were studied by using a multiplatform analysis during haze episodes between December 17th, 2016 and January 6th, 2017.</u>" and the sentence of "<u>In addition, the two-dimensional haze characteristics could be studied by analyzing the correlation between vertical haze parameters (atmospheric boundary layer, haze thickness and aerosol optical thickness) and horizontal haze parameter (upper-air visibility).</u>" (see Lines 7-9 and Lines 12-14 on **Page 1**).

3. None of the AOD observation stations belong to the AERONET whose data is processed and quality-controlled by the NASA AERONET team. The instruments deployed at these stations are the same as AERONET, namely, French-made Cimel sunphotometers. However, the operational mode and retrieval algorithms are not the same as those from the AERONET because different institutions in China are involved.

Reply:

Thanks for your valuable comment. The AERONET data used in this paper are downloaded from the website of "https://aeronet.gsfc.nasa.gov" (Holben et al., 2001). Using the downloading data of Beijing site, Beijing_RADI site, Beijing_PKU site and Beijing_CAMS site, the aerosol optical thickness (AOT) value in the ground-based LiDAR site can be obtained directly through statistical calculation according to the distance information between the LiDAR site and the selected AERONET sites. Moreover, many researchers have analyzed the global or local AOT variation combining the AERONET data (Chen et al., 2016; Jiang et al., 2007; Kim et al., 2014; Lyapustin et al., 2011; Xiao et al., 2016; Yoon et al., 2016).

Figure R1 shows the AOT variation for the selected four AERONET sits and its statistical horal value for the ground-based LiDAR site in December 31, 2016.

Though the AOT value depends on the location of the AERONET site, the variation trend is basically consistent. Therefore, the calculated statistical horal AOT value for the LiDAR site would reflect sufficiently the actual AOT variation, which is used to demonstrate the feasibility of the retrieved AOT value with the ground-based LiDAR data through comparing each other.

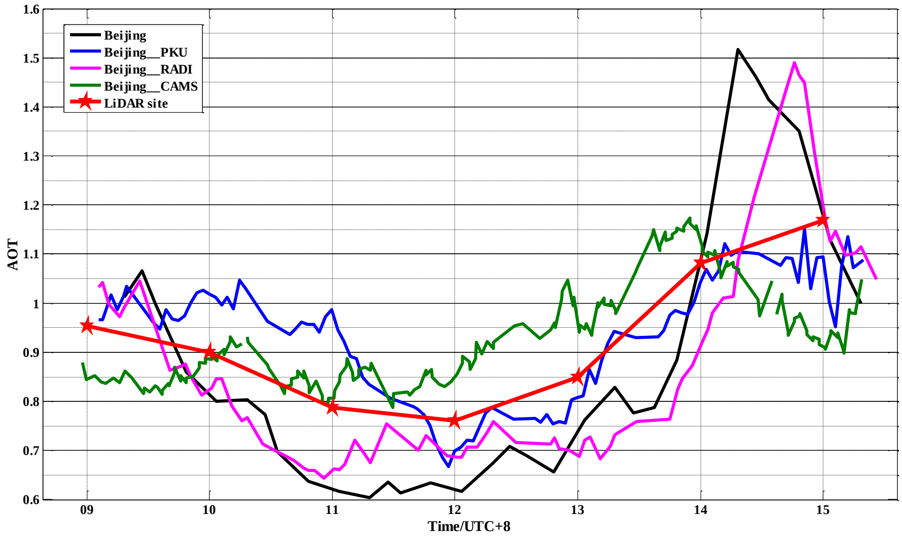

Figure R1: AOT variation for the selected AERONET sites and its statistical value for the ground-based LiDAR site in December 31, 2016.

4. Page 3: The term "data type" is incorrect. Use the term "variables" instead. State the periods of all datasets used here.

Reply:

We have changed the term "data type" into "variables" as shown the sentence of "The PM2.5 mass concentration is one of the variables to be monitored." (see Line 4 on **Page 3**). To state the periods of all datasets, we have added the sentence "Moreover, the periods of all the downloading PM2.5 mass concentration data and AOT data are the same as the detecting time, between December 13th, 2016 and January 11th, 2017, of ground-based LiDAR site." (see Lines 7-8 on **Page 3**).

5. Page 3: "AOT is classified as vertical haze parameter" is rather misleading because AOT is a column-integrated quantity, i.e., the total loading of aerosols.

Reply:

Thanks for your valuable comment. The aerosol optical thickness (AOT) is exactly the column-integrated quantity of aerosol extinction coefficient over a certain vertical distance (Dieudonné et al., 2017). It denotes the vertical total loading of aerosols. And because of its representative significance to pollutant concentration at a certain vertical distance, the AOT can be classified as vertical haze parameter.

6. A description of the algorithm used to retrieve AOD from Raman-Mie lidar signals is needed.

Reply:

Thanks for your valuable comment. Aerosol optical thickness (AOT) can be defined as the extinction of monochromatic light due to the presence of aerosols in the atmosphere. Based on the lidar equation, the aerosol extinction coefficient was retrieved by some robust inversion methods. Then the AOT can be obtained by the integration of aerosol extinction coefficient over a certain vertical distance (Dieudonné et al., 2017). To be more scientific, we have added the sentence "According to the definition of AOT, it can be obtained by the integration of aerosol extinction coefficient over a certain vertical distance with the expression of $\int_0^z \alpha_a(z)dz'$, where $\alpha_a(z)$ is the aerosol extinction coefficient (AEC) which is retrieved from ground-based Raman-Mie LiDAR data with some robust inversion methods (Ji et al., 2017)." to describe the method used to retrieve AOD from Raman-Mie lidar signals (see Lines 20-23 on **Page 3**).

7. The conclusion that "the spatial transport of pollutants has a significant effect on haze parameters" is made. It is unclear how this conclusion was reached based on the analysis presented.

Reply:

Thanks for your valuable comment. We have added the figure 8 to further describe the vertical transport of pollutants as shown in Fig. R2. Moreover, the descriptions about the vertical transport of pollutants have been added.

"As shown in Fig. 8, the vertical transport of particles could be obtained by comparing hourly variations of PM2.5 mass concentration and Up-Vis at different altitudes in certain period. In Fig. 8 (1), as the PM2.5 mass concentration near the ground decreased, the Up-Vis at the altitude of 0.5 km increased three hours later than that at the altitudes of 0.1 km and 03 km. This indicates pollutants might ascend and prevents the improvement of Up-Vis at the altitude of 0.5 km. In Fig. 8 (2), the Up-Vis at the altitude of 0.5 km increased rapidly, while the Up-Vis at the altitudes of 0.1 km and 0.3 km increased slowly four hours later. This demonstrates the delayed diffusion might result from the descent of pollutants. While the descent of pollutants cause that near-ground PM2.5 mass concentration decreased slowly in this period. Therefore, the delayed variations of Up-Vis between high altitude and low altitude indirectly reveal the influence of vertical transport of pollutants on variation of haze parameters." (see Lines 5-13 on **Page 9** and Figure 8 on **Page 10**).

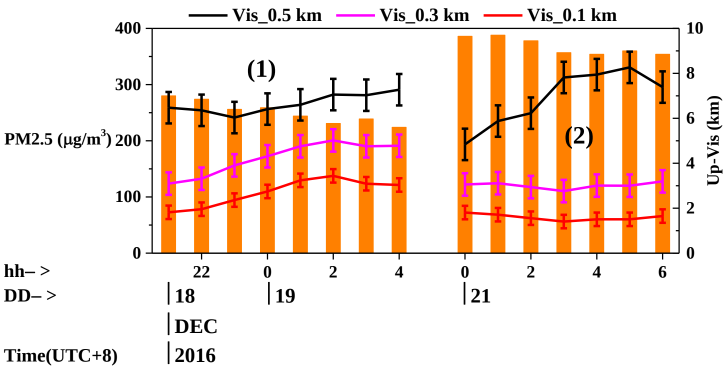

Figure R2: Hourly variation of Up-Vis and PM2.5 mass concentration in certain period.

Finally, the sentence "In addition, the delayed variations of Up-Vis between high altitude and low altitude reveal the vertical transport of pollutants." has been added to conclude the vertical transport of pollutants (see Lines 17-18 on **Page 12**).

8. Can you explain why the correlations between surface PM2.5 and visibilities at 0.3 km and 0.5 km are much stronger than the correlation between surface PM2.5 and visibility at 0.1 km?

Reply:

Thanks for your valuable comment.

The surface PM2.5 mass concentration in the ground-based LiDAR site is obtained directly through statistical calculation according to the distance information between the LiDAR site and the selected air quality monitoring sites, including Xizhimen north site, Wanliu site and Guanyuan site. So the statistical PM2.5 mass concentration is more representative for the ground-based LiDAR site.

Considering the location of the detecting sites and the influence of human activities on LiDAR signals at different altitudes, the LiDAR signal at high altitude (at 0.3km and 0.5km) is less affected by human activities, so more accurate and consistent Up-Vis at higher altitude can be obtained. And, Up-Vis at low altitude (0.1km) derived from the LiDAR signal depends on human activities obviously, and shows greater uncertainty.

As shown in Fig. R3, the correlations between surface PM2.5 and Up-Vis at altitudes of 0.3 km and 0.5 km are about 0.81 and 0.76, which are stronger than that at altitude of 0.1 km. To express more clearly, we have added the sentence "Moreover, owing to the location of detecting sites (located at the centre of Beijing) and the different influence of human activities on Up-Vis at individual altitudes, the correlations between surface PM2.5 and Up-Vis at altitudes of 0.3 km and 0.5 km (0.81 and 0.76 respectively) are much stronger than the correlation between surface PM2.5 and Up-Vis at altitude of 0.1 km (0.62)." (see Lines 8-11 on **Page 8**).

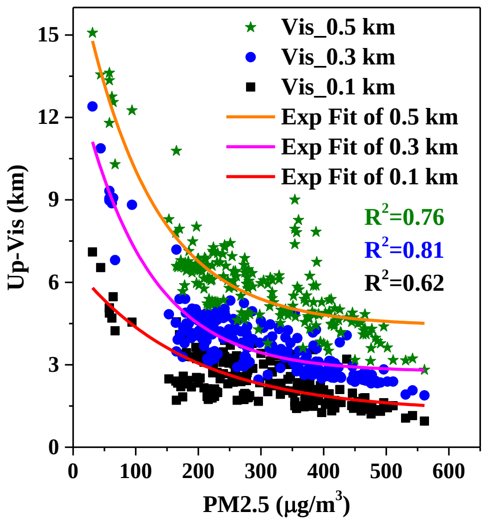

Figure R3: Scatter plot of PM2.5 mass concentration and Up-Vis in the northwest of downtown Beijing.

Referee #1. *The scientific meaning and academic value of this article is not described effectively. What is the contribution to the haze study due to this work? The conclusions and abstract are too simple and common, some conclusions are such specious arguments. A considerable part of the references listed is irrelevant to this paper. Authors need to study the relevant study results and articles carefully and refine more meaningful and detailed research goals. English expression need to be refined and modified.*

1. "The Up-Vis on non-haze days was about 3-5 times higher than that on haze days." There's a problem with this conclusion.

Reply:

Thanks for your valuable comment. The conclusion (The Up-Vis on non-haze days was about 3-5 times higher than that on haze days.) is obtained from the daily variation analysis of multiplatform data between December 13th, 2016 and January 11th, 2017 as shown in Fig. R4. To be more scientific, we have changed the sentence "The Up-Vis on non-haze days was about 3-5 times higher than that on haze days." into "The Up-Vis on non-haze days was about 3-5 times higher than that on haze days with the ground-based Raman-Mie LiDAR data between December 13th, 2016 and January 11th, 2017." (see Lines 11-13 on **Page 12**).

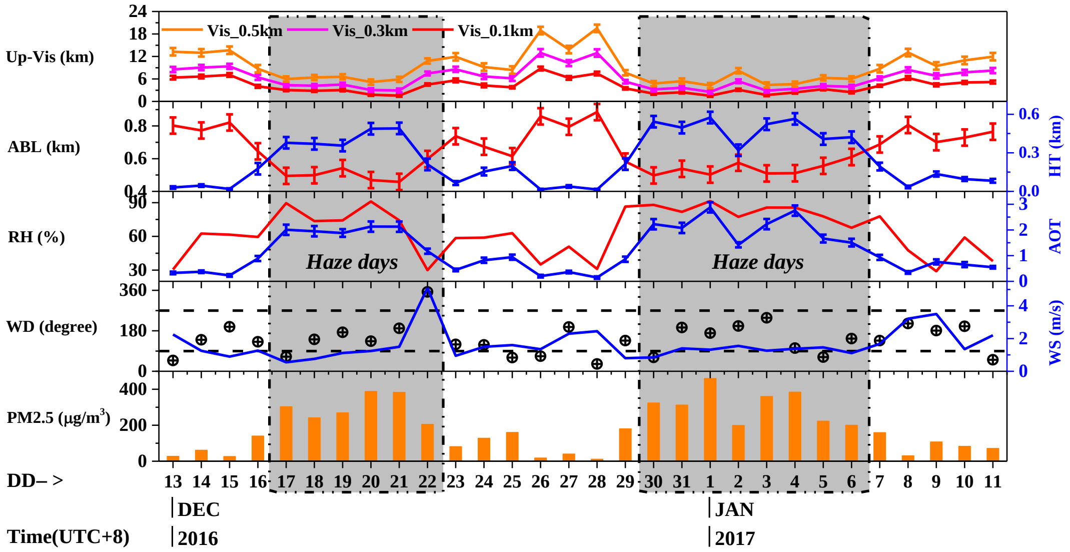

Figure R4: Daily variation of multiplatform data during successive haze episodes in the northwest of downtown Beijing.

2. "Moreover, a strong correlation between PM2.5 mass concentration and haze parameters shows an obvious influence of near-ground particle concentration on haze parameters, so the haze phenomenon could be alleviated by controlling pollutant concentrations near the ground". What is the definite scientific meaning if this conclusion?

Reply:

Thanks for your valuable comment. As shown in Fig. R5, with the increasing of near-ground PM2.5 mass concentration, the Up-Vis and atmospheric boundary layer (ABL) decrease exponentially, the haze thickness (HT) and aerosol optical thickness (AOT) increase linearly. Therefore, the excellent haze phenomenon can be realized by controlling the fine particle concentration near the ground.

To be more scientific, we have changed the sentence "Moreover, a strong correlation between PM2.5 mass concentration and haze parameters shows an obvious influence of near-ground particle concentration on haze parameters, so the haze phenomenon could be alleviated by controlling pollutant concentrations near the ground." into "Moreover, a strong correlation between PM2.5 mass concentration and haze parameters shows an obvious influence of near-ground fine particle concentration on haze parameters, so the haze phenomenon could be alleviated by controlling fine pollutant concentrations near the ground." (see Lines 15-17 on **Page 12**).

In addition, the essence of this study is concerned with the vertical variation of aerosol loading, especially the consistency between ground-level and upper-level measurements monitored by a suite of instruments including lidar, AERONET, PM2.5 particle samplers, etc. Such analyses not only help to understand the air pollution transport, but also benefit to understand the uncertainties in using ground-based measurements to represent column values. To be more scientific, we have added the sentence "Such analyses are useful to understanding the air pollution transport, as well as uncertainties in using ground-based measurements to represent column values." in the abstract (see Lines 15-16 on **Page 1**).

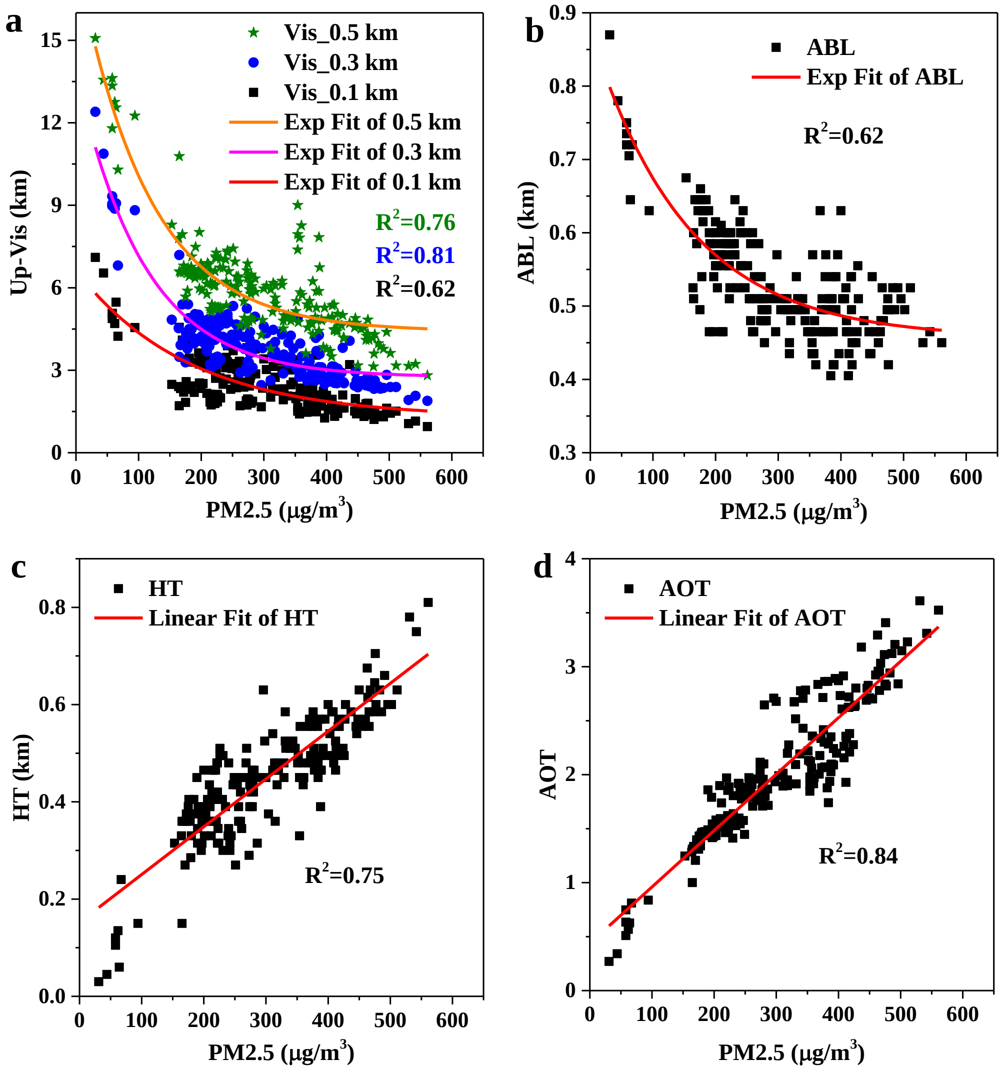

Figure R5: Scatter plot of PM2.5 mass concentration and haze parameters of Up-Vis, ABL, HT, and AOT in the northwest of downtown Beijing.

Reference:

Chen, H., Cheng, T., Gu, X., Li, Z., and Wu, Y.: Characteristics of aerosols over Beijing and Kanpur derived from the AERONET dataset, Atmospheric Pollution Research, 7, 162-169, 2016.

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