Supplement of

The impact threshold of the aerosol radiative forcing on the boundary layer structure in the pollution region

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S1. Introduction to other datasets:

The virtual potential temperature ($\theta_v$) and pseudo-equivalent potential temperature ($\theta_{se}$) are calculated with Equations (1) and (2), respectively:

$$\theta_v = T \left(1 + 0.608q \right) \left(\frac{1000}{P} \right)^{0.286}$$

(1)

$$\theta_{se} = T \left(\frac{1000}{P} \right)^{0.286} \exp \left(\frac{r_sL_v}{c_{pd} T} \right)$$

(2)

where $T$ is the air temperature, $q$ is the specific humidity, $P$ is the air pressure, $r_s$ is the saturation mixing ratio, $L_v$ is the latent heat of vaporization at $2.5 \times 10^6$ J kg$^{-1}$, and $c_{pd}$ is the specific heat of air of 1005 J kg$^{-1}$ K$^{-1}$. All the relevant parameters can be calculated from the temperature and humidity profile data obtained with the MWR, and the values of $\theta_v$ and $\theta_{se}$ at different altitudes can be then further obtained.

The hourly TKE is calculated by instantaneous three wind components sampled by Doppler wind lidar every five seconds, shown as Equations (3)-(6). The calculated TKE profile has a spatial resolution ranging from 1-20 m up to 0.3 km and a spatial resolution of 25 m from 0.3 to 3 km, at a temporal resolution of one hour.

$$\text{TKE} = \sqrt{\overline{\delta_u^2} + \overline{\delta_v^2} + \overline{\delta_w^2}}$$

(3)

The one-hour vertical velocity standard deviation ($\overline{\delta_u^2}$) and one-hour horizontal wind standard deviation ($\overline{\delta_u^2}, \overline{\delta_v^2}$) are calculated with Equations (4)-(6), respectively

$$\overline{\delta_u^2} = \frac{1}{N-1} \sum_{i=1}^{N} (w_i - \overline{w})^2$$

(4)
\[
\delta_u^2 = \frac{1}{N-1} \sum_{i=1}^{N} (u_i - \bar{u})^2 \\
\delta_v^2 = \frac{1}{N-1} \sum_{i=1}^{N} (v_i - \bar{v})^2
\]  

(5)  
(6)

where \( N \) is the number of records per hour, \( w_i \) is the vertical wind velocity (m s\(^{-1}\)) at \( i_{th} \) level, \( u_i (v_i) \) is the horizontal wind speed (m s\(^{-1}\)) at \( i_{th} \) level, \( \bar{w} \) is the mean vertical wind speed (m s\(^{-1}\)), and \( \bar{u} (\bar{v}) \) is the mean horizontal wind speed (m s\(^{-1}\)) (Banta et al., 2006; Wang et al., 2019).
Figures S1-S4:

**Figure S1.** Left panel is the topographic distribution of most China with Beijing marked by a red star, the middle graph shows the Beijing-Tianjin-Hebei region with the Yanshan Mountains to the north, the Taihang Mountains to the west, and Bohai Bay to the east, and the right panel is the observation instruments with (a) microwave radiometer, (b) wind profile lidar, (c) ceilometer, and (d) sun-photometer used in this study.
Figure S2. (a) Temporal evolutions of the PM mass concentration (PM$_{2.5}$: solid red lines; PM$_{10}$: solid black lines) and aerosol optical depth (AOD; pink circles) from 27 November 2018 to 25 January 2019 in Beijing, with circled boxes represent typical haze pollution episodes named by ①-⑧. (b) Temporal evolutions of the PM$_{2.5}$ mass concentration during typical haze pollution episodes ①-⑦ in Beijing in winter.
**Figure S3.** Scatter plots of the absolute difference of aerosol radiative forcing at the surface and interior of the atmospheric column (|SFC-ATM|; x) versus turbulence kinetic energy (TKE; y) at different altitudes. The calculated hourly data used above were collected over a two-month period in Beijing from 27 November 2018 to 25 January 2019.
**Figure S4.** Scatter plots between the atmospheric boundary layer height (ABLH), water vapor density (AH), relative humidity (RH), and PM$_{2.5}$ concentration. (a) ABLH vs. AH; (b)… The calculated daily data used above were over a two-month period in Beijing from 27 November 2018 to 25 January 2019 (gray dots: daily data; other dots: mean data).
### Table S1-S2:

**Table S1.** Equations \((y = ax^b)\) and correlation coefficient \((R^2)\) of the fitted curves in Figure S5 and Figures 4-5.

| H (m) | a     | b     | R²  | a     | b     | R²  | a     | b     | R²  |
|-------|-------|-------|-----|-------|-------|-----|-------|-------|-----|
| 50    | 43.13 | -0.92 | 0.40| 46.90 | -0.97 | 0.91| 844.19| 0.18  | 0.13|
| 60    | 53.77 | -0.96 | 0.40| 60.47 | -1.02 | 0.92| 827.38| 0.19  | 0.14|
| 80    | 57.23 | -0.96 | 0.41| 66.45 | -1.02 | 0.93| 816.67| 0.18  | 0.13|
| 100   | 51.93 | -0.92 | 0.40| 61.69 | -0.99 | 0.93| 805.28| 0.19  | 0.14|
| 150   | 40.46 | -0.85 | 0.41| 46.10 | -0.91 | 0.92| 792.45| 0.22  | 0.15|
| 200   | 33.10 | -0.79 | 0.39| 35.78 | -0.84 | 0.91| 785.18| 0.24  | 0.15|
| 250   | 32.09 | -0.78 | 0.41| 35.64 | -0.84 | 0.92| 782.58| 0.23  | 0.14|
| 300   | 30.64 | -0.78 | 0.40| 33.68 | -0.82 | 0.92| 789.77| 0.21  | 0.13|
| 500   | 29.08 | -0.78 | 0.34| 41.96 | -0.92 | 0.88| 828.54| 0.19  | 0.17|
| 800   | 13.45 | -0.65 | 0.14| 26.54 | -0.89 | 0.82| 895.95| 0.15  | 0.18|
| 1000  | 1.96  | -0.30 | 0.01| 6.77  | -0.67 | 0.53| 944.42| 0.05  | 0.05|
| 1200  | 4.03  | -12.40| 0.02| 0.08  | -0.25 | 0.05| 801.90| -0.03 | 0.03|
| In    | 25.46 | -0.76 | 0.40| 29.72 | -0.83 | 0.91***|***|***|
| Above | 0.70  | -0.15 | 0.01| 1.01  | -0.28 | 0.29***|***|***|
### Table S2. Input parameters of SBDART model.

| MODULES                                      | OPTIONS                                                                 |
|----------------------------------------------|--------------------------------------------------------------------------|
| Wavelength limits, filter function specification | 1. WLINF: Lower wavelength limit                                          |
|                                               | 2. WLSUP: Upper wavelength limit                                         |
|                                               | 3. WLINC: Spectral resolution of the SBDART run                          |
| Solar geometry                               | 4. IDAY: Day number of the year                                          |
|                                               | 5. TIME: UTC time in decimal hours                                       |
|                                               | 6. ALAT: Latitude of point on earth's surface                           |
|                                               | 7. ALON: East longitude of point on earth's surface                      |
|                                               | 8. SZA: Solar zenith angle                                              |
| Surface reflectance properties                | 9. ISALB: Surface albedo feature                                        |
|                                               | 10. ALBCON: A spectrally uniform, surface albedo                        |
| Boundary layer aerosols                       | 11. IAER: Boundary layer aerosol type selector                           |
|                                               | 12. TBAER: Vertical optical depth of boundary layer aerosols nominally at 550 nm |
|                                               | 13. WBAER: Single scattering albedo used with IAER=5                    |
|                                               | 14. GBAER: Asymmetry factor used with IAER = 5                          |
|                                               | 15. ABAER: Angstrom exponents used with IAER = 5                        |
| Model atmospheres                            | 16. Atmospheric profile: Atmospheric profile                            |
|                                               | 17. ZPRES: Surface altitude                                             |

References:

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