

We thank the reviewers for the constructive comments. Below we present the comments of the reviewers (bold) and our replies with the proposed modification to the manuscript. In addition to the changes, we discovered a minor error in the calculations during the revision of the manuscript. While the scientific contents and our conclusions do not change, we now estimate a slightly lower number of mortality attributable to air pollution in Beijing (around 10%).

Reply to the comments made by Reviewer #3

1. As described in the paper, the yearly premature mortality (Fig. 6) is calculated from the yearly average of PM_{2.5} and yearly registered population (the latter is presented in Fig.5). Although day-on-day PM_{2.5} from 2001 to 2012 are shown in Fig. 2, the trend of PM_{2.5} cannot be seen clearly from the figure. I would suggest that the yearly averaged PM_{2.5} from 2001 to 2012 be presented and its variation on the estimated trend of premature mortality discussed.

We have followed the suggestions, and show the yearly averaged PM_{2.5} from 2001 to 2012 in a new figure. From the figure we can infer that there is a positive trend in the estimated AOD trend in Beijing between 2001-2012, although no clear increase is present after the year 2004.

2. As shown in Fig. 1, there could be large biases in daily PM_{2.5} estimated from AOD. How about the uncertainties in estimated yearly averaged PM_{2.5}? It might not be so large as for the daily averaged values, but a quantitative estimate is needed. For example, the yearly averaged PM_{2.5} estimated from AOD for the year 2012 can be compared with that calculated from the original PM_{2.5} measured at the embassy site.

We have compared the estimated PM_{2.5} to the ground-based PM_{2.5}, also we have compared the estimated PM_{2.5} to measured PM_{2.5} in Beijing from previous studies. In our study, the average estimated PM_{2.5} from May 10, 2010 to December 6, 2011 is 104 µg/m³. The average ground-based observed PM_{2.5} is 93 µg/m³, being rather close. Han et al. (2007) investigated PM_{2.5} concentrations in Beijing from 2001 to 2004 and found during summer of 2002, spring and autumn of 2003 that it was 79.6 µg/m³, 111.6 µg/m³ and 107.3 µg/m³, respectively. In this study, the estimated PM_{2.5} during summer of 2002, spring and autumn of 2003 was 73.7 µg/m³, 99.9 µg/m³, and 78 µg/m³. Wang et al. (2009) found in summer and winter during 2005-2007 in Beijing that the average PM_{2.5} was 102 µg/m³. During the same period, our estimated PM_{2.5} was 99 µg/m³. We can summarize that our calculations are well within 10% of the observed values present in the literature.

3. The authors state that ground-based PM_{2.5} is not available for the period 2001-2012 in Beijing (P28660, Line 24-25). This might be true for long-term CONTINUOUS measurements of PM_{2.5} over this period. In fact, there have been numerous measurements of PM_{2.5} as well as its chemical components in Beijing since the early 2000s, as reported in both domestic and international publications including some review pa-pers.

The authors may consider the possibility of using these observational data to validate their estimated PM_{2.5} for specific years or seasons.

We have revised that sentence. Also, we have compared the estimated PM_{2.5} to measured PM_{2.5} from previous studies in Beijing for specific seasons (see previous reply).

Reply to the comments made by R.P. Singh

1. The approach of Zheng et al. is interesting but it has uncertainties in estimating PM_{2.5} and yearly premature mortality. The sources of uncertainties must be discussed by the authors.

Uncertainties in the method applied here have been already partially discussed in Lelieveld et al. (2013). However, we added in the manuscript a discussion on uncertainties. It must however be stressed that we included only uncertainties from the Concentration-Response function. This, in fact, is associated with the highest uncertainties, typically much larger than from PM_{2.5} and AOD measurements. Finally, it is difficult (if not impossible) to quantify the uncertainties derived from the population database used, which is anyhow discussed in the manuscript.

2. The paper is interesting and important to bring out the attention of people about the poor air quality and its direct impact on human health and increasing mortality rate so that the sources of air pollution is reduced. Various sources of pollution in Beijing city may be added in the paper.

Sun et al. (2004), based on aerosol samples from 2002 to 2003 in Beijing, showed that coal burning and traffic exhausts, plus the dust through long-range transport, could be the major sources of the aerosol pollution in Beijing. The winter heavy fog in Beijing is not only correlated with local pollution emission, but also with long distance pollution transport from the surrounding areas of Beijing, such as Tianjin city, Hebei and Shandong provinces, etc. (Ma et al., 2010; Shi and Xu, 2012). Zhang et al. (2013), based on 121 daily PM_{2.5} samples collected in Beijing, showed that soil dust, coal combustion, biomass burning, traffic and waste incineration emission, industrial pollution, and secondary inorganic aerosol are the six main sources of PM_{2.5} aerosol speciation, and demonstrated that regional sources could be crucial contributors to PM pollution in Beijing.

3. The authors may consider to show a high resolution map of Beijing with Aeronet and US Embassy locations where air quality data was monitored. Air quality data (PM_{2.5}) considered in the recent study may be shown and its daily variations may also be discussed.

Following suggestions of the Referee, we show a map of Beijing with AERONET and U.S. Embassy locations, as well as administrative divisions including Beijing central area defined in the study in Fig. 1. We have discussed the seasonal variability in PM_{2.5} concentration, and compared it to previous studies in the part "4.2 Correlation analysis".

4. In Figure 2, authors may consider to show AOD variations.

Following suggestions of the Referee, we show AOD variations in Fig. 2.

5. The authors may discuss the importance of BLH and RH which are important parameters in the dynamics of atmospheric pollutants and also in weather conditions.

The correlation between AOD and $PM_{2.5}$ is strongly influenced by the vertical distribution of aerosols and the RH that impacts aerosol extinction coefficient. These two factors are related to atmospheric profiles, ambient conditions, as well as the size distributions and chemical compositions of aerosols, and they may have large spatial and temporal variations (Wang et al., 2010).

6. It will be interesting if the authors can show different age group of people who suffer with the increasing $PM_{2.5}$.

We have revised the figures, showing the yearly premature mortality by IHD, CEV, COPD and LC for people >30 yrs, and ALRI for infants <5 yrs from 2001 to 2012

Reply to the comments made by Reviewer #5

One major concern of this paper is the uncertainty. Instead of point estimate, it is more encouraged that the authors present the range the uncertainty (or confidential interval).

We understand the comments of the referee. To have a sound discussion of the uncertainties, we have compared the estimated $PM_{2.5}$ to the ground-based $PM_{2.5}$, also from previous studies for specific seasons. The mortality estimations have been estimated also for the upper-lower limit based on the Concentration-Response function confidence interval (95% confidence level) as these uncertainties are by far the largest in the calculations.

Specific comments:

1. Page 28660, Lines 12-13, authors need to add citation support to the statement “AOD and PM are related to atmospheric profiles, ambient conditions, as well as the chemical composition of aerosols”. Besides, there is no incorporation of these parameters in the development of AOD- $PM_{2.5}$ equation except BLH and RH. Are these parameters represented by BLH and RH? If then, the authors may need to reorganize the context to make this clear. The authors mentioned twice that the relationship between AOD and $PM_{2.5}$ is influenced by the chemical components of particles, both on Page 28660 Line 13 and on page 28664 line21. However, this parameter was not incorporated into the AOD- $PM_{2.5}$ equation; neither is discussed regarding its impact on the uncertainty of the results. Further elaboration on this statement is needed.

We have deleted this sentence, and correct the statement and cite one reference in the part “4.1 Influence of the BLH and ambient RH”. The correlation between AOD and $PM_{2.5}$ is strongly influenced by the vertical distribution of aerosols and the RH that impacts aerosol

extinction coefficient. These two factors are related to atmospheric profiles, ambient conditions, as well as the size distributions and chemical compositions of aerosols, and they may have large spatial and temporal variations (Wang et al., 2010). In order to reduce the uncertainties, the atmospheric BLH and ambient RH have been introduced into the correlation analysis.

2. Page 28660, lines 13-25, the time series method in the epidemiological studies and the study conducted in this paper are two different kinds of research. The former one is to develop the C-R function from known PM_{2.5} concentration and mortality data, while the latter uses the developed C-R function and PM concentration to estimate the mortality. It is confusing to use the comparison these two research as a motivation of this paper.

The time series method and the study conducted in this paper are two different kinds of research. The C-R function is based on epidemiological cohort studies. There is no relationship between the time series method and the method in this study, and we do not intend to compare these two researches. The sentence about the time series method is used to conclude previous studies regarding the relationship between PM concentrations and mortality in Beijing. Then we find the limitation of these studies, and introduce our method.

3. Page 28662, Line 9, why AOD at wavelength 550nm is selected to derive the ground-level PM_{2.5}?

Since most satellite AOD is derived at wavelength 550nm, and most atmospheric models also adopt this band, we select AOD at wavelength 550nm for the better comparison with the correlation coefficient between AOD (550nm) and PM_{2.5} from previous studies.

4. Page 28665, Line 3, it says “g is an empirical fit coefficient, and it equals 1 in this study.” What is the evidence for this value to be set to 1?

The coefficient g is an empirical fit coefficient. This value is set to 1 following previous studies in Beijing. Generally, RH influencing factor could be expressed as follows: $f(RH)=1/(1.0-RH/100)$. A more accurate correction could be obtained from experiments (Li et al., 2005).

5. Page 28662, the seasonal distribution and characteristics of AOD was presented. How does it affect the estimation of the ground-level PM_{2.5} concentration and mortality caused? The seasonal variability in PM concentration and mortality should also be discussed.

We have discussed the seasonal variability in PM_{2.5} concentration in the part “4.2 Correlation analysis”. For the monthly data, the highest mean of AOD and PM_{2.5} does not occur in the same month, since the relationship between AOD and ground-level PM_{2.5} is affected by Boundary Layer Height (BLH) and Relative Humidity (RH) in our model. Because long-term exposure to PM_{2.5} is associated with increased mortality, we discussed the yearly mortality due to PM_{2.5}, and no seasonal variability of mortality is discussed. Also the yearly mortality is affected by yearly PM_{2.5} concentration, population, and baseline mortality rate.

References

Han, L.H., Zhuang, G.S., Cheng, S.Y., and Li, J.: The mineral aerosol and its impact on urban pollution aerosols over Beijing, China, *Atmos. Environ.*, 41, 7533-7546, 2007.

Lelieveld, J., Barlas, C., Giannadaki, D., and Pozzer, A.: Model calculated global, regional and megacity premature mortality due to air pollution, *Atmos. Chem. Phys.*, 13, 7023-7037, doi:10.5194/acp-13-7023-2013, 2013.

Li, C.C., Mao, J.T., Lau, A.K.H., Yuan, Z.B., Wang, M.H., and Liu, X.Y.: Application of MODIS satellite products to the air pollution research in Beijing, *Sci. China Ser. D*, 48, Supp. II, 209-219, 2005

Ma, J.Z., Chen, Y., Wang, W., Yan, P., Liu, H.J., Yang, S.Y., Hu, Z.J., and Lelieveld, J.: Strong air pollution causes widespread haze-clouds over China, *J. Geophys. Res.*, 115, D18204, 2010.

Shi, X.H., and Xu, X.D.: Progress in the study of regional impact of aerosol and related features of heavy fog in Beijing City (In Chinese), *Chinese Journal of Geophysics*, 55, 3230-3239, 2012.

Sun, Y.L., Zhuang, G.S., Wang, Y., Han, L.H., Guo, J.H., Dan, M., Zhang, W.J., Wang, Z.F., and Hao, Z.P.: The air-borne particulate pollution in Beijing-concentration, composition, distribution and sources, *Atmos. Environ.*, 38, 5991-6004, 2004.

Wang, H.L., Zhou, Y.M., Zhuang, Y.H., Wang, X.K., and Hao, Z.P.: Characterization of $PM_{2.5}/PM_{2.5-10}$ and source tracking in the juncture belt between urban and rural areas of Beijing, *Chin. Sci. Bull.*, 54, 2506-2515. 2009.

Wang, Z.F., Chen, L.F., Tao, J.H., Zhang, Y., and Su, L.: Satellite-based estimation of regional particulate matter (PM) in Beijing using vertical-and-RH correcting method, *Remote Sens. Environ.*, 114, 50-63, 2010.

Zhang, R., Jing, J., Tao, J., Hsu, S.-C., Wang, G., Cao, J., Lee, C. S. L., Zhu, L., Chen, Z., Zhao, Y., and Shen, Z.: Chemical characterization and source apportionment of $PM_{2.5}$ in Beijing: seasonal perspective, *Atmos. Chem. Phys.*, 13, 7053-7074, doi:10.5194/acp-13-7053-2013, 2013.