Response to Referee #1

Manuscript: Air Stagnations for China (1985–2014): Climatological Mean Features and Trends (acp-2016-1072)

We are very grateful to the referees for their insightful comments. We carefully consider all the comments and suggestions, and carry out additional analysis on relevant problems. We hope that we have taken most of the referees' concerns into the revised manuscript. All the comments of Referee #1 are copied below in italics, and followed by our responses.

Referee #1:

General comments:
This manuscript presents very intriguing results with regard to the current status and positive trend of air stagnation in China during the previous 30 years. The analysis method is sounding and structure is well organized. This work certainly fit the scope of ACP. Overall, the results obtained here gain additional insight into how meteorology modulates the air pollution that is blanket across China. However, traditional, the atmospheric stability is characterized by thermodynamic metrics, such as PLAM developed by Yang et al. ACP 2016, which has been demonstrated to sufficiently reflect the real air pollution condition at most regions of China. The stagnation index (SI) was improved in this study by taking the terrain into account, which is composed of three components, but by nature it is quite different metric for characterize the atmospheric stability highly associated with air pollution. As such, more discussions are required, as detailed in the following comments. Therefore, I recommend this work be published in ACP after the following concerns have been adequately addressed.

Response:

We thank the referee for the positive evaluation to this article. As the referee mentioned, there are different metrics related to air pollution. Among them, the PLAM is of solid theoretic bases and is also successfully applied in China to analyze and forecast air pollution (Yang et al., 2016). The air stagnation index (SI) is a different metric and, to our knowledge, has not yet been systematically applied in China. So, in the revised manuscript, we try to add more discussions on relevant questions. The difference between SI and PLAM is also remarked.

References:

Yang, Y. Q., Wang, J. Z., Gong, S. L., Zhang, X. Y., Wang, H., Wang, Y. Q., Wang, J., Li, D., and Guo, J. P.: PLAM - a meteorological pollution index for air quality and its applications in fog-haze forecasts in North China, Atmos. Chem. Phys., 16, 1353-1364, doi:10.5194/acp-16-1353-2016, 2016.

Specific comments:

1. The seasonality of stagnation index (SI) with maximum in summer but minima in winter reported here seems contrary to the actual air pollution. For example, a large amount of previous studies (e.g., Cao et al., JGR 2007; Guo et al., AE 2009; He et al., AE 2011) have shown that seasonal variation of aerosol concentrations is significant in China, characterized by highest concentration in the winter and lowest in the summer. More interestingly, Guo et al. (2009) revealed more complicated seasonality of aerosol concentrations based on 11 PM observations sites. Therefore, the appropriate discussion concerning how the SI connects with aerosol pollution on the monthly scale is needed, given the easy availability nowadays. In other words, I would like to see the scatter plots of Stagnation days versus PM2.5 or PM10, similar to the plot convention in Fig. 8.

Response:

Air stagnation index (SI) has long been studied in North America continent (as introduced in the manuscript). This is a simple and meaningful metric to air pollution. However, this metric indicates adverse meteorological condition to air pollution, rather than the air pollution itself. Because air pollution level is determined by not only meteorological conditions, but also other complex factors such as emission sources and chemical reactions (Cao et al., 2007; Guo et al., 2009; He et al., 2011; Yang et al, 2016), etc. So, this kind of metric is only an indicator for air pollution potential—the potential for air pollution events. This is the reason that the metric may show bad correlation or even contrary to actual air pollution, when comparing them ***directly***.

For the fact that aerosol concentration in China is characterized by high value in winter and lower one in summer, it is obviously related to the seasonal variation of source emission, since there is more coal consumption in winter for heating, particularly in north China (Cao et al., 2007; He et al., 2011). Therefore, to make this kind of metric applicable for practical air pollution forecasting, Yang et al. (2016) incorporate source emission information into their PLAM index, and improve the forecasting skill successively. On the other hand, one can also investigate the sensitivity of air quality to stagnations by perturbing meteorological variables in regional chemical transport models (Liao et al., 2006). Jacob and Winner (2009) collected and compared results from different perturbation studies about the influence of meteorological variables on ozone and particulate matter concentrations, and summarized that air stagnation is the only metric that consistently shows a robust positive correlation.

The purpose of this paper is to provide a general distribution of air pollution potential over China, as well as its long-term trend, by the metric of air stagnation. This is also an effort to "isolate the meteorological factors that produce poor air quality" (Horton et al., 2012). The strength of this work is that, it provide an independent view to the meteorological background relevant to air pollution, without being interfered by the complexity of other factors, e.g. the variation of source emissions.

Since our purpose is not to apply directly to air pollution diagnosis or forecasting, like the work of Yang et al. (2016), and previous works have demonstrated good correlation between air stagnation and air pollution (Jacob and Winner, 2009), therefore at least at this stage, we do not try to compare the metric with concentrations of air pollutants.

This discussion has been added in the revised manuscript.

References:

Cao, J. J., Lee, S. C., Chow, J. C., Watson, J. G., Ho, K. F., Zhang, R. J., Jin, Z. D., Shen, Z. X., Chen, G. C., Kang, Y. M., Zou, S. C., Zhang, L. Z., Qi, S. H., Dai, M. H., Cheng, Y., and Hu, K.: Spatial and seasonal distributions of carbonaceous aerosols over China, J. Geophys. Res.-Atmos., 112, doi:10.1029/2006JD008205, 2007.

Guo, J. P., Zhang, X. Y., Che, H. Z., Gong, S. L., An, X. Q., Cao, C. X., Guang, J., Zhang, H., Wang, Y. Q., Zhang, X. C., Xue, M., and Li, X. W.: Correlation between PM concentrations and aerosol optical depth in eastern China, Atmos. Environ., 43, 5876–5886, doi:10.1016/j.atmosenv.2009.08.026, 2009.

He, K. B., Yang, F. M., Ma, Y. L., Zhang, Q., Yao, X. H., Chan, C. K., Cadle, S., Chan, T., and Mulawa, P.: The characteristics of PM2.5 in Beijing, China, Atmos. Environ., 35, 4959–4970, doi:10.1016/S1352-2310(01)00301-6, 2001.

Horton, D. E. and Diffenbaugh, N. S.: Response of air stagnation frequency to anthropogenically enhanced radiative forcing, Environ. Res. Lett., 7, 044034, doi:10.1088/1748-9326/7/4/044034, 2012.

Jacob, D. J., and Winner, D. A.: Effect of climate change on air quality, Atmos. Environ., 43, 51–63, doi:10.1016/j.atmosenv.2008.09.051, 2009.

Liao, H., Chen, W. T., and Seinfeld, J. H.: Role of climate change in global predictions of future tropospheric ozone and aerosols, J. Geophys. Res.-Atmos., 111(D12), doi:10.1029/2005JD006852, 2006.

Yang, Y. Q., Wang, J. Z., Gong, S. L., Zhang, X. Y., Wang, H., Wang, Y. Q., Wang, J., Li, D., and Guo, J. P.: PLAM - a meteorological pollution index for air quality and its applications in fog-haze forecasts in North China, Atmos. Chem. Phys., 16, 1353-1364, doi:10.5194/acp-16-1353-2016, 2016.

2. Page 3, line 13-17: For each of the other radiosonde stations: it is better to clarify how many station, for example 8 other radiosonde stations? According to Guo et al., ACP 2016, there are 120 radiosonde stations across China, and actually only part of the whole radiosonde netword was used in this study.

Response:

We obtained datasets of all the radiosonde stations across China (95 stations) and two stations (Blagovescensk and Vladivostok) outside but near the border of the country. Among them, 66 stations have corresponding surface datasets from CMA (See Appendix A). For each of the other 31 radiosonde stations without corresponding surface data, we considered the average of surface stations within 150 km as a substitute. In this way, we got additional 15 stations (See Appendix B). Air stagnations of these 81 stations are analyzed in this study. We have rewritten this part of sentences in the revised the manuscript to clarify.

There are 120 upper-air sounding stations in China, except for Hong Kong and Taiwan district (Li, 2006; Guo et al., 2016). The stations used in our study are those participate in global data exchange, which are available from the free-access Wyoming University soundings database (http://weather.uwyo.edu/upperair/sounding.html).

Reference:

Guo, J. P., Miao, Y. C., Zhang, Y., Liu, H., Li, Z. Q., Zhang, W. C., He, J., Lou, M. Y., Yan, Y., Bian, L. G., and Zhai, P.: The climatology of planetary boundary layer height in China derived from radiosonde and reanalysis data, Atmos. Chem. Phys., 16, 13309-13319, doi:10.5194/acp-16-13309-2016, 2016.

Li F. New Development with Upper Air Sounding in China. WMO TECO, 2, 2006.

3. Figure 1: The site outside of China like Blagovescensk, Vladivostok, and KingsPark should be plotted and marked.

Response:

Blagovescensk and Vladivostok have been marked on Fig. 1 in the revised manuscript. Kings Park is a site in Hong Kong, and has been treated as a normal site in China.

4. Page 4, line 25: What kind of spatial interpolation methods have the authors applied? More details should be given, like the size of grid point for the maps.

Response:

Results of stagnation days and cases were interpolated with cubic splines to $2^\circ \times 2^\circ$ grid. This detail has been added in the revised manuscript.

5. Section 3.2:" During summer a weaker pressure gradient lingers over China, which results in weaker atmospheric circulations and more frequent stagnations." I think at least one figure is needed to corroborate this argument, e.g., the pressure gradient difference between summer and annual mean.

Response:

Pressure patterns vary in strength and location seasonally. This is a fact known in climate studies in China (e.g. Ding et al., 2013). Figure R1 shows that in upper layer, the gradient of geopotential height is much weaker in summer than that in winter, so the pressure gradient varies in the same way. At surface (sea level), in winter, a very strong high-pressure center (i.e. the Siberian high) is generated over the frozen landscape of northern Asia. In summer, high surface temperatures over the land generate lows that replace wintertime highs. In general, pressure gradient at surface is also weaker in summer than in winter over most of China.

We are sorry that we had not properly cited reference about this fact. Now, we add the citation and the fact description in the revised manuscript.

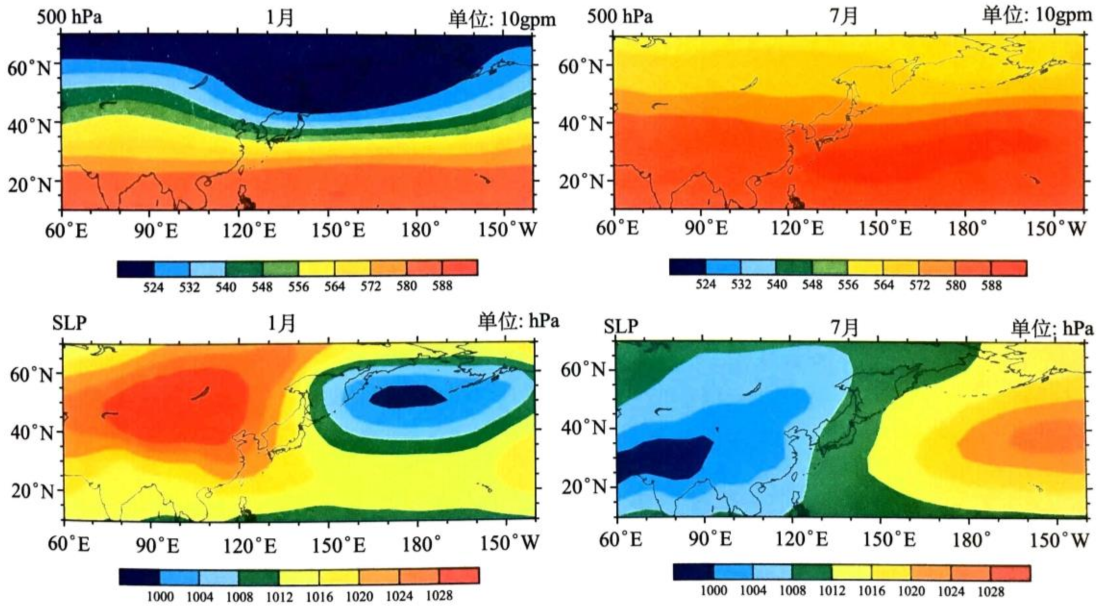

Figure R1. Atmospheric circulation in East Asia. Upper: geopotential height (unit: 10gpm) of 500 hPa in January (left) and July (right). Bottom: sea level pressure (unit: hPa) in January (left) and July (right). This figure is copied from Ding et al. (2013), their Fig. 1.1.

Reference:

Ding, Y. H., Wang, S. W., Zheng, J. Y., Wang, H. J., and Yang, X. Q.: Climate of China, Science Press, Beijing, 557pp, 2013 (in Chinese).