Response to reviewer's comments

Anonymous Referee #2:

This observational study describes the evolution of meteorological conditions and PM concentrations associated with a foehn event. As the warm, dry, and relatively clean foehn wind meets the cold, wet and polluted air mass in the Beijing area, a haze front formed. The large observational network captured the characteristics and evolution of this haze front as it moved through the network. The level of details captured by both the ground and the upper air observations (including wind profilers, Doppler Lidars and radiosounds) makes this study a useful contribution to the literature regarding foehn characteristics and its influence on air pollution.

The manuscript contains a large number of figures that are generally in good quality. The writing, however, could use substantial improvements, as described below.

We sincerely thank the reviewer for in-depth comments and helpful suggestions. We have responded to all the comments point-by-point and made corresponding changes in the manuscript. Following are detailed responses to all the comments.

Define the key terms. The central focus of the manuscript is on haze front, but there is no clear definition on what a haze front is and how to identify it from the observations. It is stated in the paper that "The HF line was identified by temperature and humidity contrasts between the warm and cold air masses and the convergence line of the surface wind field". How does this differ from foehn front? Is HF the same as foehn front? I would expect that a HZ should be identified by sharp contrast in PM values, instead of temperature and humidity. If HZ and foehn front are the same, then say it. In sum, it should be clearly stated near the beginning what you mean by haze front, foehn front, and what criteria are used to identify these fronts from your observational data.

Thank you for the comment. A haze front is not the same as a foehn front, but has some similarity to a foehn front in some cases, like in the case we studied here. "The haze front" is denoted mainly by its front-like structure and sharp contrast in polluted aerosol. This is why we didn't use the name "foehn front" in the manuscript. The foehn front is basically the foehn-induced "minifront" phenomena described in the literature by Vergeiner (2004) and Li et al. (2015). We identify a haze front by sharp contrast in PM values, instead of temperature and humidity. Thus, we have stated the meaning of the haze front in the introduction. The new added sentence reads:

"This HF was identified by a sharp contrast in $PM_{2.5}$ concentration and a convergence line in the surface wind field."

We also have revised the sentence you quoted above. The sentence now reads:

"The HF line was identified by a sharp contrast in $PM_{2.5}$ concentration, temperature and humidity between the warm and cold air masses and the convergence line of the surface wind field (Fig. 6-7, Fig. S1-S3), which was also consistent with the front edge of the hazy air mass seen in the satellite images (Fig. 4)."

The manuscript could benefit from reorganization. It is good to begin with describing background conditions for this episode. The sequence of the current description is: PM time series, sounding profiles, profiler winds, and finally synoptic patterns. I would reverse the order, starting from synoptic patterns and ending with surface observations including PM time series. More details are needed in the description of synoptic conditions. Right now, the synoptic patterns are shown, but there is very little discussion. In addition to describing the synoptic patterns for this case, there should be some discussion on how typical the pattern is and how often it occurs in order to put this particularly episode into historical context.

Thank you for the comment. We have adjusted the sequence of Section 3.1 as you suggested. Also, we have added more description of synoptic conditions in this section, and compared this synoptic pattern with the statistics of unfavorable synoptic conditions which exacerbate air pollution (Wang et al., 2020).

Further, I do not see the need to separate "The evolution of HF "and "Characteristics of the HF and foehn winds" into two sections.

Thank you for the comment. We have combined the section "3.2 The evolution of HF" and the section "3.3 Characteristics of the HF and foehn winds" into one section, named "3.2 The evolution and characteristics of the HF and foehn winds".

Some of the discussion could be improved. Some of the discussion is rather confusion. For example, "This HF occurred on 24 December 2015 concurrent with a severe air pollution episode." But according to the PM time series in Fig. 2a, PM is high on the 23rd, but dropped down to nearly 100 on the morning of the 24th, and gradually increased to nearly 500 in the afternoon of 25. So if HF occurred on the 24th, then it was not concurrent with severe air pollution episode. In fact, in the next paragraph, it is mentioned that "the Beijing area was clear with low pollution." It is unclear what the background pollution level was and what was associated by HF. Is the increase on the 24th due to the passage of HF? I would expect a sharp increase instead of a gradual increase.

Thank you for the comment. Because of using the mean $PM_{2.5}$ concentration of 35 sites in Beijing in Figure 2a, it is hard to distinguish the highly varied air pollution on 24th. So we have replaced Figure 2a with a new figure using hourly-mean $PM_{2.5}$ concentration of CP, AOT, YZ and 3-stations mean. According to the new Figure 2a, the Beijing area was clear with low pollution on the morning of the 24th, which was also verified from satellite images (Figure 4a, 4b). In brief, the background pollution level was low in Beijing before the passage of the HF on the 24th. The HF affected YZ causing a sharp increase in PM concentration at around noon. But meanwhile, $PM_{2.5}$ concentration decreased inversely at CP and kept a very low level at AOT. When the HZ arrived at AOT at 22:00 LST, it caused a sharp increase in PM (increased 268 μg m^{-3} in one hour). Consequently, the PM increase on the 24th was mainly due to the passage of HF. We have rewritten this whole paragraph. The sentences now read:

"This HF occurred on 24 December 2015 after a severe air pollution event. The mean $PM_{2.5}$ concentrations of CP, AOT and YZ varied between 300-400 μg m^{-3} on the morning of 23 December, which is a severe Air Quality Index (AQI) pollution level (Fig. 2a). Thereafter, two

significant $PM_{2.5}$ concentration decreases occurred around noon and midnight on that day. During the day on 24 December, the mean $PM_{2.5}$ concentration decreased to 73 $\mu g\ m^{-3}$ at 07:00 LST. At 11:00 LST, the $PM_{2.5}$ concentration at YZ sharply increased by 221 $\mu g\ m^{-3}$ in one hour. At 13:00 LST, the $PM_{2.5}$ concentration at CP decreased from 112 $\mu g\ m^{-3}$ to 32$\mu g\ m^{-3}$. The $PM_{2.5}$ concentration of AOT stayed below 80 $\mu g\ m^{-3}$ until 22:00 LST when it sharply increased by 268 $\mu g\ m^{-3}$ in one hour. The following day, the mean $PM_{2.5}$ concentration exceeded 500 $\mu g\ m^{-3}$ at 14:00 LST."

In the discussion of satellite images, it is unclear how you distinguish haze from fog or clouds in the satellite images?

Thank you for the comment. We have rewritten the first sentence in the first paragraph of section 3.2. The sentences now read:

"The visible channel true color images from the Himawari satellite clearly showed the movement and evolution of the HF. Normally, on the true color satellite images, clouds look white and gray and tend to have texture; haze is usually featureless and pale gray or a dingy white; fog looks similar to the color of clouds but without texture. However, clouds, fog, and haze are sometimes difficult to distinguish from satellite imagery. Hence, we referred to weather phenomena, visibility and $PM_{2.5}$ concentration observed by surface meteorological and air quality stations to distinguish them. A dense fog covered northeastern Tianjin and half of Xianghe county of Heibei Province at 08:00 LST (Fig. 4a)."

Some of the descriptions used present tense while others used past tense. Be consistent.

Thank you. We have revised present tense into past tense.

The discussion about the HF and foehn characteristics is exhaustion to read. Better rewriting is necessary to improve readability.

Thank you for the comment. We have rewritten the discussion about the HF and foehn characteristics.

Figures are generally in good quality, but figure captions could use more details. For example, the caption for Figure 1 should include a description of the different symbols, although they are described in the text. Also include AWS and PM stations in Figure 1.

Thank you for the comment. We have revised Figure 1 as you suggested.

The font size for the axis labels in the time series plots and some of text in the figures should be enlarged. They are currently too small to read unless the figures are enlarged by 200% (e.g., Fig. 10 c vertical axis, Fig. 10 b, the label for the color bar; Figure 2b).

Thank you for the comment. We have enlarged axis labels, color bar labels and some text in Figure 10 and Figure 2.

Clearly mark the time of HF passage on the time series plots.

Thank you for the comment. We have marked the time of HF passage on the time series plots.

References for review replies:

Li, X., Xia, X., Wang, L., Cai, R., Zhao, L., Feng, Z., Ren, Q., Zhao, K.: The role of foehn in the formation of heavy air pollution events in Urumqi, China. J. Geophys. Res. Atmos., 120, 5371–5384, https://doi.org/10.1002/2014jd022778, 2015.

Vergeiner, J. : South foehn studies and a new foehn classification scheme in theWipp and Inn Valley, PhD thesis, Univ. of Innsbruck, Austria, 2004.

Wang X, Zhang R: Effects of atmospheric circulations on the interannual variation in PM2.5 concentrations over the Beijing–Tianjin–Hebei region in 2013–2018. Atmos Chem Phys 2020, 20(13):7667-7682.