Reply to Referee 2:

Dust weather in North China has been studied using PM_{10} concentration observation and ERA5 data. Quantitative contribution of the Mongolian cyclone and the cold high to the dust days were given. A common predictor of the two dust weather types was also identified. **The study will benefit the understanding the synoptic meteorological influence on dust weather in North China,** but still some points need to be further clarified.

Major comments:

1. It should be identified that if there are only two dust weather types of the Mongolian cyclone and the cold high which can influence the dust in North China?

Reply:

Thank you for your professional advice. The impact of the Mongolian cyclone on dust weather in North China has been widely revealed. **The composite original SLP for dust days without the Mongolian cyclone shows** the influence of a **cold high** (Fig. S1d). Therefore, the two types of Dust days were respectively **named Mongolian Cyclone (MC) type** and **Cold High (CH) type**. We apologize for any misleading in our previous manuscript. In the **revised version**, we describe the **dust days without Mongolian cyclones** as **influenced by other synoptic systems**, **primarily by cold high**.

Previous studies have shown that **there are more than two dust weather types** affecting North China. In addition to the Mongolian cyclone and cold high, synoptic systems such as a pure cold front can also lead to severe sandstorms in North China (Liu et al., 2004). This study **differs from traditional weather classification studies** by not further categorizing weather types beyond the Mongolian cyclone. The circulation anomalies related to the two types of dust weather are explored **to identify the common predictor**, which provides reference for dust weather forecasting and climate prediction. We have revised the relevant expressions and discussed in Section 6.

Related References:

Liu, J., Qian, Z., Jiang, X., and Zheng M.: A Study on Weather Types of Super

Severe Dust Storms in North China, Plateau Meteor, 23, 540–547, 2004 (in Chinese).

Revision:

p. 3, line 62–69: … more attention (Yin et al., 2023a). Research on subjective and objective classifications of dust weather has been conducted (Liu et al., 2004; Yun et al., 2013; Yi et al., 2021). These studies indicate that besides the Mongolian cyclone, **other synoptic systems such as the cold high** also played significant roles in causing dust weather in North China.

This study used PM_{10} concentrations as indicators to investigate the differences in the intensity of dust weather caused by the **Mongolian cyclone** and **other synoptic systems**…

p. 4, line 111–122: The primary surface synoptic system leading to dust weather in NC was the Mongolian cyclone (Li et al., 2022). Additionally, **other synoptic systems** could also contribute to dust weather affecting NC (Liu et al., 2004). By **objectively identifying the presence of the Mongolian cyclone**, Dust days were further classified into two categories. As depicted in the **original SLP fields** for the two types, the **main surface synoptic systems** for the two types of Dust days were the **Mongolian cyclone** and **cold high** respectively (Fig. S1c, d). Therefore, the two types of Dust days were respectively **named Mongolian Cyclone (MC) type** and **Cold High (CH) type**. Dust days caused by Mongolian cyclones (MC type) accounted for a significant portion during the spring seasons from 2015 to 2023, at 61.7%. **Other synoptic systems**, **mainly cold high systems** (CH type), accounted for 38.3% of the total Dust days…

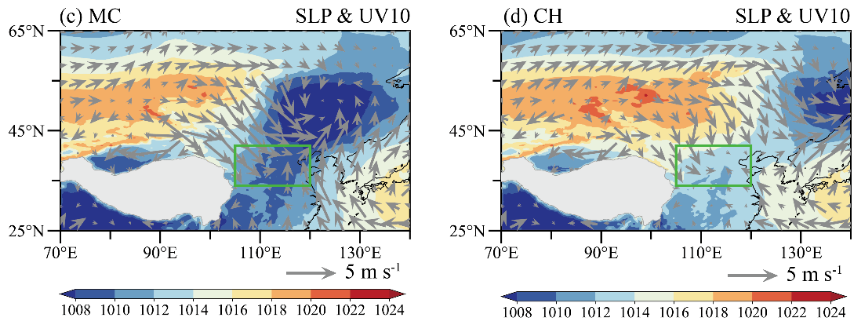

Figure S1. (c) **Composites** of **original SLP** (shading, units: hPa) and UV10 (vectors, units: m s^{-1}) during MC days. Panel (d) is the same as panel (c) but for CH days. The green boxes in panel (a)–(d) represent NC.

p. 13, line 291: This study **differs from traditional weather classification studies** by **not further categorizing weather types beyond the Mongolian cyclone.** The circulation anomalies related to the two types of dust weather were explored to identify the common predictor…

2. It's not so clear that how to get daily maximum PM_{10} concentration in North China from hourly observation data at the stations? If only maximum value in one station is considered, maybe the regional characteristics can not be represented due to local effect.

Reply:

(1) The method for selecting the daily maximum PM_{10} concentration in this study is as follows: First, **the daily maximum value for each station** in North China is selected from the hourly observed PM_{10} concentration data. Then, **the station with the highest PM_{10} concentration** in North China is chosen, and the maximum value at that station is used as a reference for selecting dust day.

(2) The **regional mean values of the daily maximum PM_{10} concentrations in North China** have been calculated. The daily regional average values indicate that the MC-type dust days still show relatively higher average PM_{10} concentrations, medians, and outliers compared to the CH-type dust days. **The results obtained do not show significant differences** compared to using the maximum PM_{10} concentration as the dust indicator in one station. The **actual hourly observed values of PM_{10} concentrations** are retained as the discriminant indicator. Using the actual PM_{10} concentration observations from the station with the highest value can **clearly demonstrate the drastic increase** in PM_{10} concentrations caused by dust weather, thereby **better identifying dust day**. **In previous studies**, the **thresholds for PM_{10} concentration** in dust weather were also defined **based on hourly actual values** (Wan et al., 2004; Wang et al., 2008). **Additionally**, through **composite analysis** of **maximum PM_{10} concentrations** during MC and CH days, the results show that **most parts of North China exhibit high PM_{10} concentrations** (**Fig. S3**). The composite results of dust days show that North China **still exhibits regional characteristics** of dust weather.

We **added the explanation** of the method used to obtain the daily maximum PM_{10} concentration in North China.

Related References:

Wan, B., Kang, X., Zhang, J., Tong, Y., Tang, G., and Li, X.: Research on classification of dust and sand storm basic on particular concentration, Environ. Monit. China, 20, 8–11, https://doi.org/10.3969/j.issn.1002-6002.2004.03.003, 2004 (in Chinese).

Wang, Y. Q., Zhang, X. Y., Gong, S. L., Zhou, C. H., Hu, X. Q., Liu, H. L., Niu, T., and Yang, Y. Q.: Surface observation of sand and dust storm in East Asia and its application in CUACE/Dust, Atmos. Chem. Phys., 8, 545–553, https://doi.org/10.5194/acp-8-545-2008, 2008.

Revision:

p. 3, line 90: During dust events, PM_{10} concentrations significantly increase, at least doubling or even increasing by tens of times (Dulam et al., 2014). In this study, **the maximum PM_{10} concentration** was utilized to **confirm the occurrence of dust weather in NC**. In order to better identify dust days, the daily maximum PM_{10} concentrations were selected from **the actual hourly observed values** for each station in NC. **The station with the highest PM_{10} concentration in NC** was chosen, and the **maximum value at that station** was used as a reference for selecting dust day…

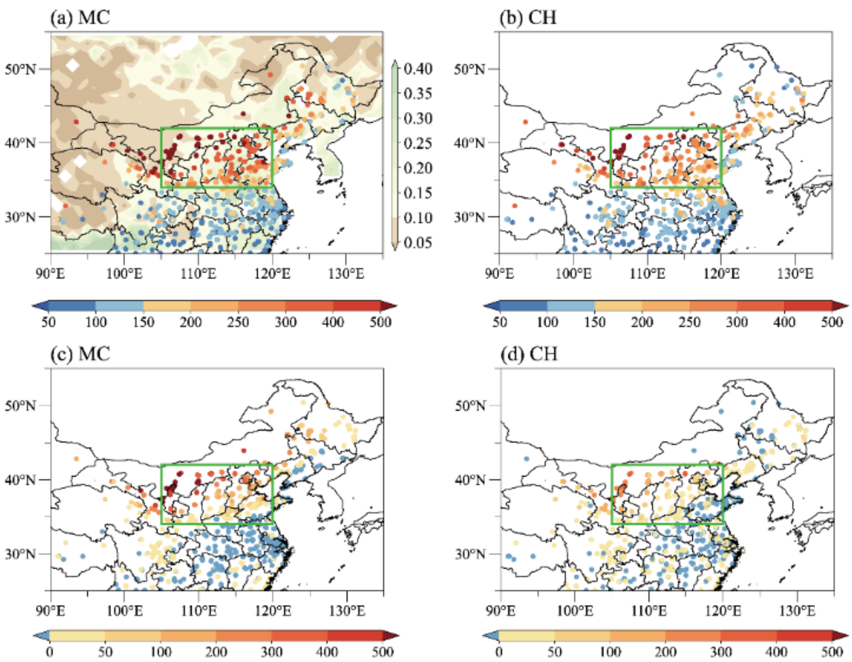

Figure S3. (a) Composite distribution of observed daily maximum PM_{10} concentrations (scatter, unit: μg m^{-3}) during MC days. Panel (b) is the same as (a) but for CH days. The shading in panel (a) indicates NDVI in March 2023. (c) Composite distribution of observed daily maximum PM_{10} concentrations anomalies (scatter, unit: μg m^{-3}) during MC days. Panel (d) is the same as (a) but for CH days. The green boxes in panel (a)–(d) represent NC.

3. In many previous studies, dust weather phenomenon and visibility observation were used to characterize the dust spatial-temporal distribution, which may lead different result with this study only using PM_{10} concentration. For example, April is the most frequent dust weather month in previous studies, but it's May in this manuscript. It should be pointed out and discussed.

Reply:

Thank you for your suggestion. The **definition of dust days using PM_{10} concentration** has been **applied in previous studies** (Krasnov et al., 2016; Jenkins et al., 2017). However, there is currently **no unified criteria** for this. Traditional dust weather defined by visibility and other weather phenomena **may differ** from dust weather identified solely by PM_{10} concentration. Additionally, PM_{10} concentration has been more widely observed since 2015, so the analysis in this paper covers the period from 2015 to 2023. The **increase in dust days in May** may be a result of **recent years**. These conclusions indeed require further research and discussion. **Figure 1** has been **revised**, and the differences in results have been **pointed out and discussed** in Section 6.

Related References:

Jenkins, G. S. and Diokhane, A. M.: WRF prediction of two winter season Saharan dust events using PM_{10} concentrations: Boundary versus initial conditions, Atmos. Environ., 167, 129-142, https://doi.org/10.1016/j.atmosenv.2017.08.010, 2017.

Krasnov, H., Katra, I., and Friger, M.: Increase in dust storm related PM10 concentrations: A time series analysis of 2001–2015, Environ. Pollut., 213, 36-42, https://doi.org/10.1016/j.envpol.2015.10.021, 2016.

Revision:

p. 13, line 291: … Furthermore, dust weather **identified by PM_{10} concentrations may differ from** traditional dust weather **defined based on visibility and other meteorological phenomena.** For example, in the years 2015–2023, Dust days defined by PM_{10} concentrations were **most frequent in May, rather than in April as seen in previous studies.** However, the increase in the number of dust days in May may be a recent trend that requires further study.

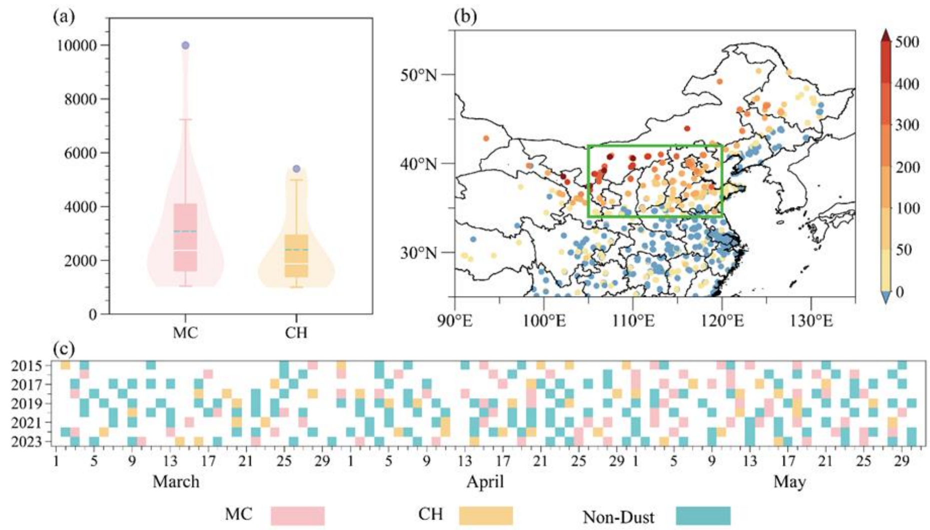

Figure 1. (a) Boxplots of daily maximum PM_{10} concentrations (units: μg m^{-3}) in NC during MC days (pink) and CH days (orange). The cyan dashed lines and blue dots in the boxplot represent average PM_{10} concentrations and outlier values. Density distributions of PM_{10} concentrations are shown by pink and orange shadings for MC days and CH days respectively. (b) The composite differences of observed daily maximum PM_{10} concentrations (scatter, units: μg m^{-3}) during MC days relative to CH days. The green box indicates NC. (c) The temporal distribution of MC days, CH days and Non-Dust days in spring from 2015 to 2023.

4. There is strict definition of dust weathers in meteorological society with several grads of floating dust, blowing dust, sand and dust storm, severe sand and dust storm. Its well know that high PM_{10} concentration is a major result from dust weather, but the threshold value need to be investigated further to match with the meteorological definition of dust weather. Also, $PM_{2.5}$ and PM_{10} ratio should considered to remove anthropogenic aerosol impact.

Reply:

(1) Previous studies have investigated the relationship between **PM_{10} concentration thresholds and traditional dust weather levels**, but a **unified standard has not yet been established**. For hourly PM_{10} concentrations, one set of criteria is as follows: Suspended dust: 200 μg $m^{-3} \leq PM_{10}$ (with very low wind speed); **Blowing dust**: **200 μg m^{-3}** $\leq PM_{10} <$ 5500 μg m^{-3}; Sand and dust storm: 5500 μg $m^{-3} \leq PM_{10} <$ 15000 μg m^{-3}; Severe sand and dust storm: 15000 μg $m^{-3} \leq PM_{10}$ (Wang et al., 2008). Another standard is as follows: Suspended dust: 600 μg $m^{-3} \leq PM_{10} <$ 1000 μg m^{-3}; **Blowing dust**: **1000 μg m^{-3}** $\leq PM_{10} <$ 2000 μg m^{-3}; Sand and dust storm: 2000 μg $m^{-3} \leq PM_{10} <$ 4000 μg m^{-3}; Severe sand and dust storm: 4000 μg $m^{-3} \leq PM_{10}$ (Wan et al., 2004).

In our study, we determined two PM_{10} concentration thresholds, 500 μg m^{-3} and 1000 μg m^{-3}, by calculating the first and third quartiles of the daily maximum PM_{10} concentrations from 2015 to 2023. According to the variation of daily maximum PM_{10} concentrations, days with peak PM_{10} concentrations exceeding 1000 μg m^{-3} were selected as representatives of dust days, while days with minimum PM_{10} concentrations below 500 μg m^{-3} were chosen as representatives of non-dust days. **Comparing our results with previous research**, **dust days** identified by the **1000 μg m^{-3} PM_{10}** concentration threshold **primarily correspond to** the traditional meteorological classifications of **blowing dust, sand and dust storm,** and **severe sand and dust storm**. Further studies are needed regarding the **matching** between the **PM_{10} concentration thresholds** and the **traditional dust weather levels**. This has been **discussed** in Section 6.

(2) Considering the potential **influence of anthropogenic factors**, we obtained the **$PM_{2.5}$ concentrations at the same site and time as the maximum PM_{10} concentrations** on the Dust days, and calculated the **$PM_{2.5}/PM_{10}$ ratio**. In North China, the average $PM_{2.5}/PM_{10}$ ratio typically ranges from 0.5 to 0.7 and exhibits distinct seasonal variations, being lower in spring (Wang et al., 2015). Among the dust days we examined, **only two days in 117 days had a $PM_{2.5}/PM_{10}$ ratio exceeding 0.5** (Fig. R1). **98.3%** of Dust days are consistent with the result in our study (Fig. R1). To eliminate the influence of anthropogenic aerosols, we have **excluded these two days**. Subsequently, we **updated all relevant figures and data**, with the **overall findings remaining largely consistent with the original results**. The method of using the $PM_{2.5}$ and PM_{10} ratio to remove anthropogenic aerosol impact has been **added to Section 2**.

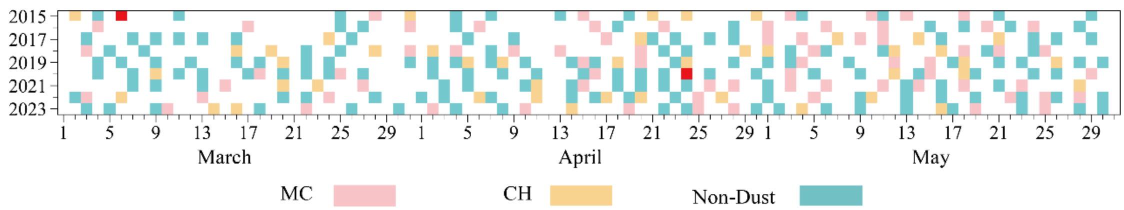

Figure R1. The temporal distribution of MC days, CH days and Non-Dust days in spring from 2015 to 2023. The **red square** indicates the Dust day with **$PM_{2.5}/PM_{10}$ ratio exceeding 0.5**, which is **excluded** from the analysis.

Related References:

Wan, B., Kang, X., Zhang, J., Tong, Y., Tang, G., and Li, X.: Research on classification of dust and sand storm basic on particular concentration, Environ. Monit. China, 20, 8–11, https://doi.org/10.3969/j.issn.1002-6002.2004.03.003, 2004 (in Chinese).

Wang, Y. Q., Zhang, X. Y., Gong, S. L., Zhou, C. H., Hu, X. Q., Liu, H. L., Niu, T., and Yang, Y. Q.: Surface observation of sand and dust storm in East Asia and its application in CUACE/Dust, Atmos. Chem. Phys., 8, 545–553, https://doi.org/10.5194/acp-8-545-2008, 2008.

Wang, Y. Q., Zhang, X. Y., Sun, J. Y., Zhang, X. C., Che, H. Z., and Li, Y.: Spatial and temporal variations of the concentrations of PM_{10}, $PM_{2.5}$ and PM_1 in China, Atmos. Chem. Phys., 15, 13585–13598, https://doi.org/10.5194/acp-15-13585-2015, 2015.

Revision:

p. 3, line 90: … Considering potential **anthropogenic influences**, the **$PM_{2.5}$ concentrations** were obtained **at the same site and time as the maximum PM_{10} concentrations** on the Dust days, and the **$PM_{2.5}/PM_{10}$ ratios** were calculated… In NC, the average $PM_{2.5}/PM_{10}$ ratio typically ranges from 0.5 to 0.7 and exhibits distinct seasonal variations, being lower in spring (Wang et al., 2015). To **eliminate the influence of anthropogenic aerosols**, **two days were excluded** from the selected Dust days as their **$PM_{2.5}/PM_{10}$ ratio exceeded 0.5**.

p. 13, line 291: … Previous studies have investigated the relationship between PM_{10} concentration thresholds and traditional dust weather levels, but a **unified standard has not yet been established**. According to the standards used in previous studies (Wan et al. 2004; Wang et al., 2008), Dust days identified by the **1000 μg m^{-3}** PM_{10} concentration threshold primarily **correspond to** the traditional meteorological classifications of **blowing dust**, **sand and dust storm**, and **severe sand and dust storm**…

5. How about the weather with the maximum PM_{10} concentration between 500 and 1000 μg/m^3?

Reply:

The maximum PM_{10} concentrations **between 500 and 1000 μg/m³** represents a **transitional phase** during the **development** and **cessation** of **dust weather**. In this study, we only focus on **extreme situations** of dust weather. The **dust days** selected based on the peak values of PM_{10} exceeding 1000 μg/m³ **represent the days most significantly impacted** by dust in North China **during typical dust events**. Aiming at **capture the most significant anomalous circulation patterns** and **extreme situations**, this study primarily analyzes the anomalous circulation features **during the peak impact** of dust weather. The circulation anomalies during the transitional phase of dust weather in NC are not included. Explanations regarding the weather associated with PM_{10} concentrations between 500 and 1000 μg/m³ have been **added in Section 6**.

Revision:

p. 13, line 291: … The study designates the **peak PM_{10} concentration** during periods when the daily maximum PM_{10} concentration exceeds 1000 μg m^{-3} as Dust days, **representing a typical dust event**. This aims to capture the most significant circulation anomalies and **extreme conditions** during dust events. The **transitional phase** during the **development** and **cessation** of **dust weather** in NC has **not been included** in this study…

6. The area of concern in this paper is limited at 34-42°N, 105-120°E, but the dust weather is a large-scale process that has an important impact on the entire northern region of China, and the two types of atmospheric circulation such as cold high and Mongolia cyclone will also affect Inner Mongolia and Northeast China. The introduction should also be supplemented by a statement of the rationale for the selection of the region, how it differs from other work, and the geographical importance of the selected area of analysis.

Reply:

Thank you for your suggestion. Dust weather significantly impacts the entire northern region of China. In this study, **unlike previous research** that **uniformly studied all dust weather events** in the **entire** northern region of China, we have selected the North China region (34-42°N, 105-120°E) for analysis. This region, **apart from the northwestern region** of China, experienced **the highest frequency and intensity** of dust weather events (Zhang et al., 2023). The **average PM_{10} concentrations** in this area during spring are relatively high, **surpassing those in the northeastern region** of China (Fig. R2). Furthermore, this region is **densely populated**, economically developed, and plays a vital role in China's **economy**, **politics**, **culture**, and **agriculture**. Therefore, enhancing the understanding and forecasting of dust weather in North China holds significant importance. The reasons for selecting this region, differences from other studies, and the geographical significance of the chosen analysis area have been **added in the introduction** section.

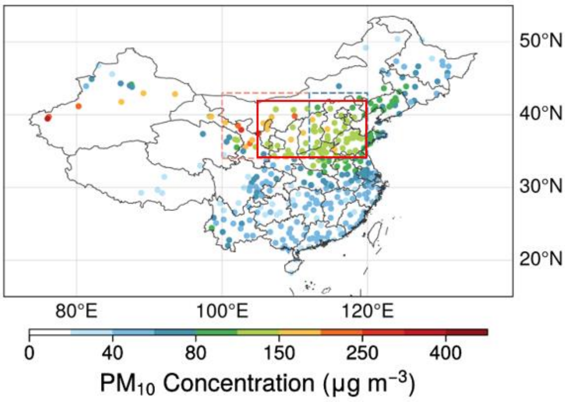

Figure R2. Spring mean PM_{10} concentrations in 2021 (cited from Li et al., 2022; Fig. 2e). The **red box** represent **NC** in our study.

Related References:

Li, J. D., Hao, X., Liao, H., Yue, X., Li, H., Long, X., and Li, N: Predominant type of dust storms that influences air quality over northern China and future projections, Earth's Future, 10, e2022EF002649, https://doi.org/10.1029/2022EF002649, 2022.

Zhang, X. X., Lei, J. Q., Wu, S. X., Li, S. Y., Liu, L. Y., Wang, Z. F., Huang, S. Y., Guo, Y. H., Wang, Y. D., Tang, X., and Zhou, J.: Spatiotemporal evolution of aeolian dust in China: An insight into the synoptic records of 1984–2020 and nationwide practices to combat desertification, Land. Degrad. Dev., 34, 2005–2023, https://doi.org/10.1002/ldr.4585, 2023.

Revision:

p. 1, line 29: … adversely affecting traffic safety.

North China (NC; 34–42°N, 105–120°E) is the region, apart from Northwest China, where spring dust weather **is most frequent**, **intense**, and has the **highest average PM_{10} concentration** (Li et al., 2022; Zhang et al., 2023). **In contrast to previous studies** that examined dust weather across the **entire** northern region of China, this study specifically focuses on NC. With a dense population, developed economy, and playing a vital role in China's **economy**, **politics**, **culture**, and **agriculture,** studying dust weather in NC is of great importance. In response to global warming …

Specific comments:

1. In the Data and method section, it is recommended to add a description of the study area and the number of PM_{10} stations used, as well as a distribution map.

Reply:

Thank you for your advice. The description of the study area and the number of PM_{10} stations used have been **added** in **Section 2**. The **distribution** of PM_{10} monitoring stations can be seen from **Fig. 1b**.

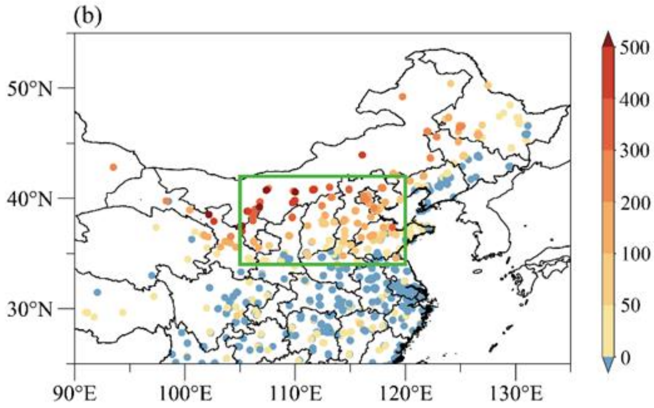

Figure 1. (b) The composite differences of observed daily maximum PM_{10} concentrations (scatter, units: μg m^{-3}) during MC days relative to CH days. The green box indicates NC.

Revision:

p. 3, line 80-81: … The **study area is located in NC**, specifically within the range of **34–42°N, 105–120°E**. PM_{10} and $PM_{2.5}$ concentration data from **556 stations in NC** have been utilized for selecting dust weather days, with negative and missing values excluded. The Normalized Difference Vegetation Index …

2. From table 2, it can be seen that the correlation between I_SAT and I_Gust10 and PM_{10} concentration is significantly higher than that of I_ACA-CA. There is no explanation in the text.

Reply:

We are sorry for not making it clear. It is **reasonable** that there is a **stronger correlation** between near-surface meteorological conditions and PM_{10} concentrations. Similar results have been observed in previous research related to atmospheric particulate matter pollution (Zhong et al., 2022). In this study, we **aim to identify a key**

anomalous circulation system that can predict both types of dust weather. **The circulation index I_ACA-CA most highly correlated with PM_{10} concentration** was selected as the common predictor (**R = 0.321)**. The absolute correlation coefficient is **higher than I_Z500c** (|R| = 0.205) and **I_Z500a** (|R| = 0.167). Additionally, cyclonic and anticyclonic circulation anomalies at 500 hPa during dust days also significantly correlated with anomalous strong surface winds and temperature. After organizing the logic, **Section 5** has been **rewritten** to avoid misunderstandings.

Related References:

Zhong, W. G., Yin, Z. C., and Wang, H. J.: The relationship between anticyclonic anomalies in northeastern Asia and severe haze in the Beijing–Tianjin–Hebei region, Atmos. Chem. Phys., 19, 5941–5957, https://doi.org/10.5194/acp-19-5941-2019, 2019.

Revision:

p. 10, line 217-240: … **In order to comprehensively predict dust weather of the MC and CH types**, we defined a series of meteorological indices **to explore the common anomalous circulation systems influencing these two dust weather types**… The 500 hPa cyclonic anomaly (**CA**) and anticyclonic anomaly (**ACA**) circulation systems were represented by the 500 hPa geopotential height indices **I_Z500c** and **I_Z500a** (Table 1) …

By **considering CA and ACA together**, calculating the difference in Z500 between them and normalizing it, the index I_ACA-CA was defined. **I_ACA-CA** is significantly correlated with the maximum PM_{10} concentration in NC (**R = 0.321**), with an absolute **correlation coefficient higher than I_Z500c (|R| = 0.205) and I_Z500a (|R| = 0.167)**. During MC days, CH days, and Non-Dust days, the composite values of I_ACA-CA also showed significant differences, corresponding to the composite PM_{10} concentration values during these days (Fig. 5a). Furthermore, **I_ACA-CA** exhibited **significant correlations with meteorological conditions** and horizontal circulation influencing dust weather in NC (Table 2), **consistent with the physical mechanisms** described in Section 4. Therefore, CA and ACA are closely related to dust weather in NC and are key anomalous circulation systems. I_ACA-CA is designated as a common predictor for the two types of Dust days in NC…

3. The lines of Figure 6 are light and similar in color, and there is no illustration of the lines in the figure.

Reply:

The colors of the lines in Figure 6 have been darkened, new colors have been applied to enhance differentiation, and relevant line illustrations have been added.

Revision:

p. 13, line 286-290:

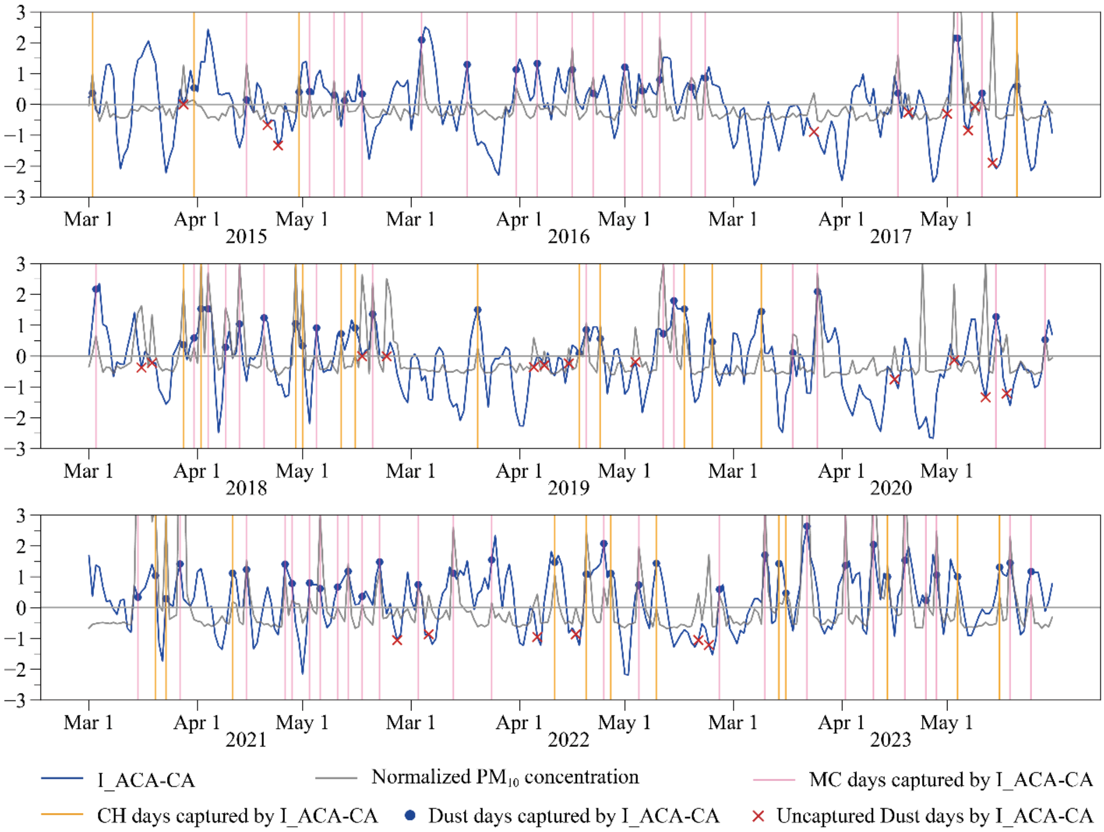

Figure 6. Daily I_ACA-CA (blue line) and normalized daily maximum PM_{10} concentrations observed in NC (grey line) in March (Mar), April (Apr) and May from 2015 to 2023. The blue dots indicate the Dust days captured when I_ACA-CA>0 and the corresponding I_ACA-CA value. The pink and yellow vertical lines indicate the MC days and CH days captured when I_ACA-CA>0, respectively. The red "x" marks represent the Dust days that I_ACA-CA failed to capture.