Spatio-temporal distinct patterns in variations of PM_{10} and $PM_{2.5}$ relative to the recent drivings of emission sources in Mongolia

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Abstract (150 words)

Storyline:

1. A new pattern is emerged
2. Air quality in urban sites is episodically dictated by dust events in spring or late autumn, yet seasonally governed by anthropogenic emissions in winter. [Air quality is governed by natural dust emission, and anthropogenic emissions]
3. With recent growing interest in urban life style, and combustion of coal/oyutolgoi for heating winter conditions results a highly increase in not only capital city but also towns
4. In a result, spring coarse dust, plus winter fine pollutants
5. spring coarse dust is immediately transported and deposited in the source area, whereas winter fine pollutants is permanently stayed in the source area due to stagnant atmosphere govern over entire country., perhaps floating in the near surface, deposits in the surface]
6. Alarms, the Mongolian dust in the spring, optical properties might be shifted; this gives ... Gobi dust and sand storms has become tuiren, from the shoroon shuurga. which clearly requires the attention.
7. r ratio shows ... emission source; dust might carry anthropogenic fine particulates as well.

Introduction

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* Advanced the knowledge of global dust, has reached to recognize the sources,.
  - Classification dust brown color, seasonal characteristics, with coarse fractions.
  - This knowledge further efficient to climate system when elaborating dust-aerosol effects.
  - But, a large uncertainties in the global dust model has existed so for climate models which
  - This is mainly caused by the lack of parameterization and recognition of iterative changes

* Mongolian dust brown color, seasonal characteristics, with coarse fractions.
  - Mongolian dust has an attention of the its mass fraction in global dust, yet unlikely elabo
  - But, such recognized characterization might get no longer valid due to recent change in the
  - Therefore, It is important to examine the emerging changes and shifting patterns of air pa
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- Study goal
  - We hypothesize ...
  - Our study will benefit not only to the global dust research but also climate, and further to the country itself for urban planning, and coal combustion.

Research Qs

Therefore, we aimed to demonstrate the distinct temporal and spatial variations of PM2.5 and PM10 across urban and rural Mongolia using extensive data from 2008 to 2020.

On spring, the dust storm from the Gobi Desert contribute significantly to increased aerosols in the atmosphere and ambient air pollution, leading to sporadic peaks in PM10 concentrations reaching as high as 64-234 $\mu g m^{-3}$ per day or exceeding 6000 $\mu g m^{-3}$ per hour (Jugder). concentrations of particulate matter is ephederemal, yet vary depending on whether the pollution cause is natural or industrial, local or transported, seasonal or non-seasonal, makes complex and challenging. 1. Do concentrations of particulate matters differ in between urban and rural sites, and even within Gobi sites? 2. Do distinct temporal variations has existed among the sites? 3. Do PM2.5 particulates has contributed to the PM10 annual variations?

- If yes, how much, and when and where?
- What is the sd, mean, and median
    - box plot
    - violin
    - scatter points, epidemic, sporadic
- Daily variations to examine it related to the heating
    - 2 peaks: smaller and bigger
    - compare the t-duration exceeds 50mug/m3/hour

4. Does it has distinct patterns among the sites regarding to the drivings

- How PMs varies with the wind speed and visibility
- Do they differently explained with variables and changes in drivings (with PCA analysis)

5. Is there any significant changes in time-series of PMs at 4 seasons
6. Is there any significant changes in ratio in the spring in respect to winter?

The present study will contribute significantly to the understanding of air particulate matter patterns in Mongolia and providing comprehensive data insights for policymakers and public health sectors. Our findings is useful not only for addressing national health impacts but also beneficial for understanding air particulate matter as ambient air pollution, and tackling atmospheric aerosol effects in the climate system, and revealing their transboundary effects to the downwind regions in South-east Asia.

Results

The spatio-temporal variations of the PMs at the study sites

To evaluate the spatial variations in particulate matter (PM) concentrations, we displayed hourly observed values of PM10 and PM2.5 for all study sites (figure_3). The mean p-values indicate that PM concentrations differ significantly at a 99% confidence level across all sites (figure_3), with the exception of a 95% confidence level between DZ and UB for PM10 (figure_3a), highlighting substantial concentration disparities among sites. While quantitative differences in PM concentration values exist across all sites, two key patterns emerge when examining median deviations from mean values and irregular observation fluctuations. For instance, PM10 demonstrates more erratic behavior than PM2.5 at each location, particularly evident at ZU and SS sites. Furthermore, the mean values calculated from hourly measurements surpass the median concentrations for both PM10 and PM2.5 across all sites, with notable prominence at UB and DZ locations. Consequently, significant spatial differences in PM concentrations exist among all sites, regardless of urban or rural classification. However, the sites can be categorized into two groups based on their characteristics: UB (urban) and DZ (rural town, Gobi); and SS (rural, Gobi) and ZU (rural, Gobi). These findings for DZ appear to support our hypothesis of emerging new emission patterns related to increased coal consumption during winter months.

[AND] To examine the PM emerging patterns whether it related to household heating fuel, we demonstrated annual variations in PM10 and PM2.5 concentrations at the sites. [AND] Significant annual variations in PM10 and PM2.5 levels demonstrating higher concentrations in colder months and lower concentrations in warmer months at UB and DZ sites.

[AND] During colder months (January, November, December), PM10 concentrations contributed by elevated levels in PM2.5 were exceed 100 $\mu g/m^3$, accompanied by PM10 and PM2.5 concentrations reached their lowest points during warmer months (May-September), with medians and ranges consistently below 50 $\mu g/m^3$. This distinct seasonal trend, peaking during the same cold months are supported by the diurnal variations in PM10 and PM2.5 concentrations at sites DZ and UB. A pronounced daily cycle is evident, at both DZ and UB sites, where PM concentrations peak during nighttime and early morning hours (approximately 8 PM to 4 AM UTC), with median values surpassing 50 $\mu g/m^3$. PM2.5 concentrations consistently follow a similar pattern but remain lower than PM10. In contrast, both pollutants exhibit reduced concentrations during daytime hours (8AM to 4PM UTC), likely due to increased atmospheric dispersion. At site UB, a comparable daily trend is observed, but with lower overall concentrations and less pronounced peaks. The variability, indicated by the interquartile range, is higher during nighttime, suggesting the influence of localized emission sources and reduced boundary layer mixing. These diurnal patterns underscore the temporal dynamics of air pollution, influenced by both anthropogenic activities and meteorological conditions.

nalysis of PM10 and PM2.5 concentrations revealed that ZU and SS maintained significantly lower levels through
high with violin meteorological effects

Annual maximum in the winter for DZ and UB are from PM2.5, which results an increase in PM10.

clearly states that .... DZ and UB are from the ... household ., that concentration can be as high as a arctic oscillation/Siberian high intensifies with the heating, as low as it loose or may combination of heating demand drops.

[BUT]

[THEREFORE] PM10 and PM2.5 concentrations are larger in the spring followed by the autumn for SS and ZU sites. Annual PM10 and PM2.5 concentrations peaks in the winter aligned with the daily variations happens at the heating time for SS and ZU sites. This points that the increase in PM2.5 and PM10 is from the coal combustion. It requires the cause the behind such the variations.

DZ site is polluted in the winter by the heating and in the spring by the natural dust.

3. Do PM2.5 particulates has contributed to the PM10 annual variations? Distinct temporal variations has existed among the sites. - PM2.5 particulates has contributed to the PM10 annual variations in UB and in DZ in winter. - If yes, how much, and when and where? - What is the sd, mean, and median - box plot - violin - scatter points, epidemic, sporadic - Daily variations to examine it related to the heating - 2 peaks: smaller and bigger - compare the t-duration exceeds 50mug/m3/hour

The emission patterns of interrelations among meteorological variables at the study sites

[AND] To distinguish the emission driving variables, at first we demonstrated interrelations between wind speed, visibility among particulate matters of PM10 and PM2.5 for each sites (figure_4).

Figure 6 illustrates the relationship between PM10 and PM2.5 concentrations across the four sites (UB, DZ, ZU, and SS) for different seasons, alongside variations in wind speed (WS) and visibility (VIS). At all sites, a strong positive correlation between PM10 and PM2.5 is evident, as highlighted by the linear trendlines. The slopes suggest proportionality, with PM2.5 typically contributing a significant fraction of PM10 concentrations.

Seasonal differences are prominent, with higher PM concentrations observed during November-February (marked as " + " symbols), particularly at UB and DZ, where values significantly exceed those from other periods. Wind speed and visibility also exhibit notable interactions; higher PM concentrations tend to correspond to lower wind speeds (smaller circles) and reduced visibility (darker blue points). Conversely, during March–June and July–October, marked by circles and triangles, respectively, the overall concentrations are lower, especially at ZU and SS, indicating better air quality conditions likely due to more favorable meteorological factors.

The site DZ shows the largest variability in PM concentrations, with extreme outliers during high-pollution periods. SS, on the other hand, exhibits relatively low PM levels across all seasons, aligning with its less polluted status. These results underscore the importance of local factors, including meteorological conditions and emission sources, in driving the observed PM dynamics.

DZ site is polluted in the winter by the heating and in the spring by the natural dust.

- PMs varies with the wind speed and visibility
- In general, three distinct patterns were resulted with PCA analysis, which is in consistent with temporal variation. explained with variables and changes in drivings (with PCA analysis)

The recent trends in concentrations of PMS and fine-coarse

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fractional changes at the sites
-   There are significant changes in time-series of PMs at 4
    seasons
-   There any significant changes in ratio in the spring in
    respect to winter in DZ.
-   Close relationships was found between PM2.5 in winter and r
    values in the spring.
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Conclusions

- The spatio-temporal variations of the PMs at the study sites - Concentrations of particulate matters differ in between urban and rural sites, and even within Gobi sites. - Distinct temporal variations has existed among the sites. - PM2.5 particulates has contributed to the PM10 annual variations in UB and in DZ in winter. - If yes, how much, and when and where? - What is the sd, mean, and median - box plot - violin - scatter points, epidemic, sporadic - Daily variations to examine it related to the heating - 2 peaks: smaller and bigger - compare the t-duration exceeds 50mug/m3/hour
    - The emission patterns of interrelations among meteorological variables at the study sites

    * PMs varies with the wind speed and visibility
    * In general, three distinct patterns were resulted with PCA analysis, which is in consistent with temporal variation. explained with variables and changes in drivings (with PCA analysis)

- The recent trends in concentrations of PMS and fine-coarse fractional changes at the sites

    * There are significant changes in time-series of PMs at 4 seasons
    * There any significant changes in ratio in the spring in respect to winter PM2.5 in DZ.

- Close relationships was found between PM2.5 in winter and r values in the spring. Thus, our research results clearly proves the distinct variations in PMs has emerged. The dust fine-coarse fractions was manifested at the town center for the Gobi sites, which reveals the that Mongolian dust composites not only coarse dust, but also fine particulate matters. The particulates likely consisted of the black carbon, which may give a substantial effect on climate systems. if this trend continues on as coal consumption with the population growth in the future.
- CO Carbon monoxide is obtained due to incomplete combustion of charcoal in a closed room.
- CO2

Results and Discussion

188 **Urban and rural distinct Spatio-temporal diverse variations of PM_{10} and $PM_{2.5}$**

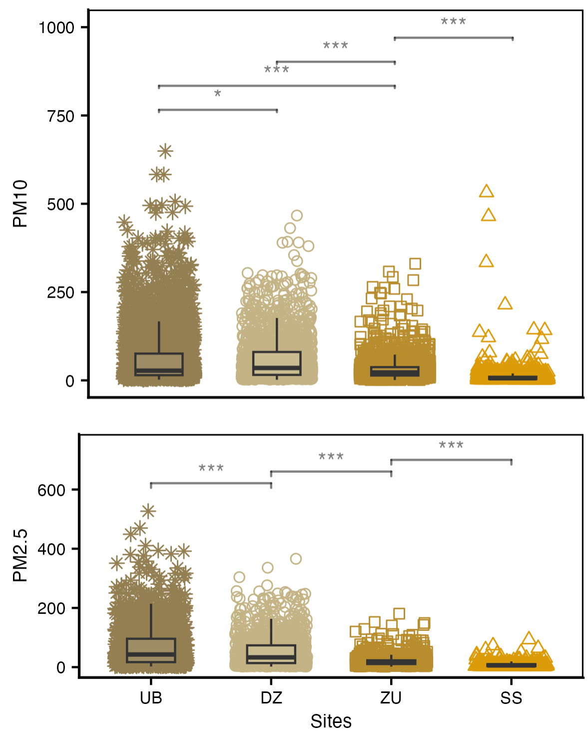

Figure 1: Distinct concentrations of coarse and fine particulates among sites

189 1. Compare the concentrations of PMs at UB is the 2. Significance level difference 3. Conclude

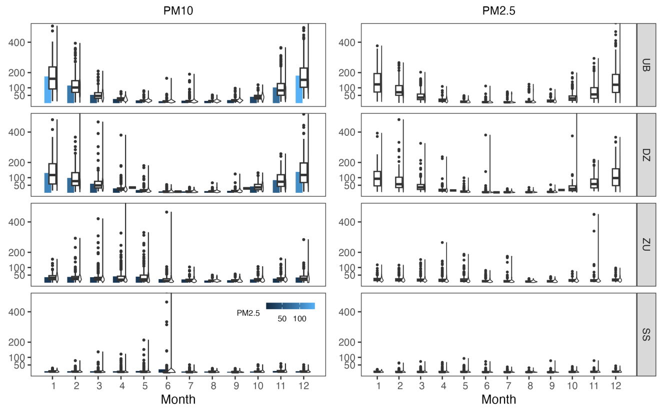

Figure 2: Annual variations of PM_{10} and $PM_{2.5}$

1. Clear annual variations at UB and DZ from pm2.5 pollutions 2. at ZU, and SS has a seasonally peaks episodic spring and late autumn from PM10

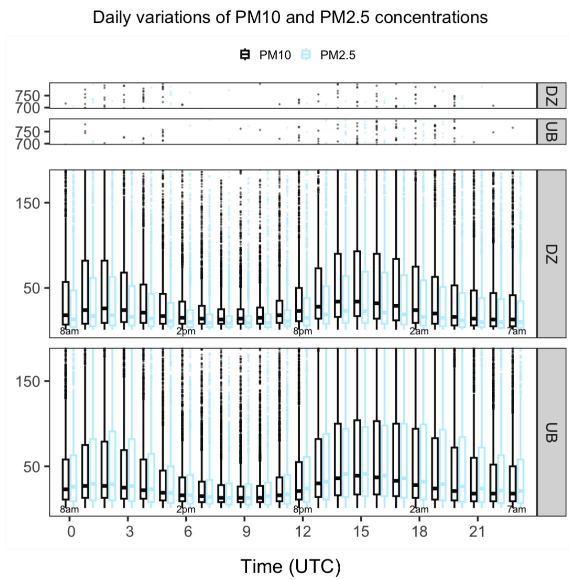

Figure 3: Daily variations of PM_{10} and $PM_{2.5}$ at UB and DZ sites

192 ## Meteorological influence on PM_{10} and $PM_{2.5}$ variations

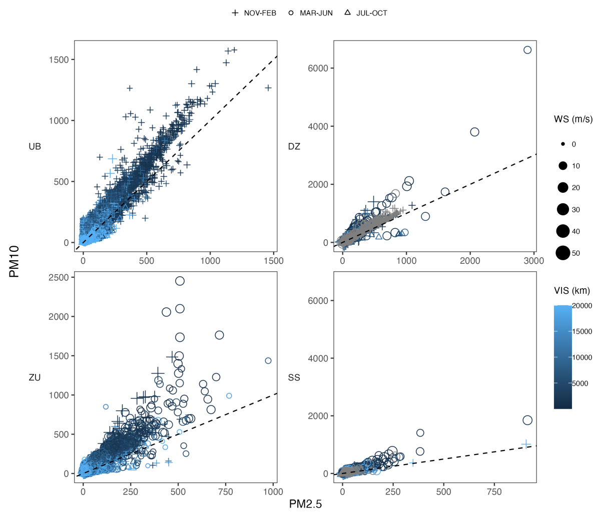

Figure 4: Relationships between meteorological major factors and variations of PM_{10} and $PM_{2.5}$

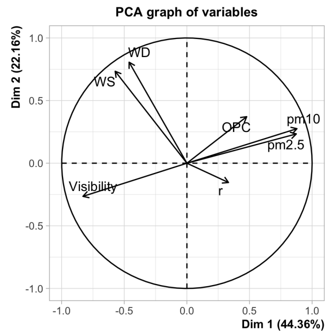

Figure 5: Spatio-temporal distinct feature of variations of PM_{10} and $PM_{2.5}$ with PCA analysis

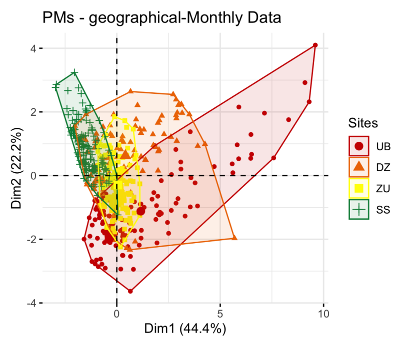

Figure 6: Patterns of meteorology and PMs at the 4 sites

Trends

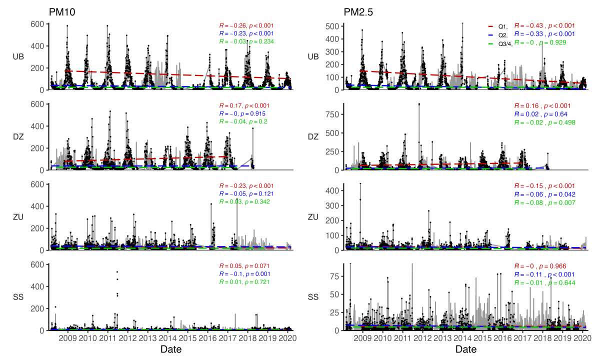

Figure 7: Interannual and seasonal trends of PM_{10} and $PM_{2.5}$ variations

Conclusions

In this study, we investigated the temporal variations of PM2.5 and PM10 concentrations at the 4 sites of rural and urban those located along the the wind corridor. Three distinct variations has been detected.

1. Air quality in urban sites is episodically dictated by dust events in spring or late autumn, yet seasonally governed by anthropogenic emissions in winter.
2. Air quality in rural sites of SS and ZU is episodically dictated by dust events in spring or late autumn.
3. Air quality in rural sites of SS and ZU is episodically dictated by dust events in spring or late autumn.

A clear seasonal variations in the sites of UB and DZ is [Air quality is governed by natural dust emission, and anthropogenic emissions] * Due to rapid increase in urban, and combustion of coal/oyutolgoi for heating winter conditions results a highly increase in not only capital city but also towns * In a result, spring coarse dust, plus winter fine pollutants [spring coarse dust is immediately transported and deposited in the source area, whereas winter fine pollutants is permanently stayed in the source area due to stagnant atmosphere govern over entire country., perhaps float- ing in the near surface, deposits in the surface] * Alarms, the Mongolian dust in the spring, optical properties will be shifted; this gives ... Gobi dust and sand storms has become tuiren, from the shoroon shuurga. which clearly requires the attention.

Following problems

- On downwind regions
- On national-level Demonstrating temporal and spatial variations of air particulate matter has become important for understanding characteristics of particulate matter in the climate system, providing valuable information for well-established air quality measures, and illustrating the good trace data for health studies. Because particulate pollutants have a

great impact on human health (Dockery and Pope,1994; Harrison and Yin, 2000; Hong et al., 2002), high atmospheric concentrations of these pollutants was a major concern particularly in urban areas, in the last 2-3 decades. Recent studies highlight that even low concentrations of these pollutants can lead to various health issues, and may associate with morbidity and mortality across the life span (Zigler et al., 2017). Children exposed to high levels of air pollution show increased rates of asthma, decreased lung function growth, and increased risk of early markers of cardiovascular disease (Bourdrel et al., 2017; Gauderman et al., 2015; Hehua et al., 2017). Short-term exposure with high level of PM10 resulted the chronic cardiovascular disease in Mongolia (Enkhjargal 2020). In addition to these health issues, (prenatal) neurodevelopmental impacts such as effects on intelligence, attention, autism, and mood, while aging populations experience accelerated cognitive decline when exposed to high levels of pollution is detected (Power et al., 2016). Long-term exposure to low levels of particulate matter, such as concentrations as low as 10 $\mu g m^{-3}$ (equilibrium to WHO Air Quality Guidelines), has been linked to increased lung cancer in the EU (Hvidtfeldt et al. 2021), with similar evidences reported in Canada (Bai et al., 2019), and significantly higher rates captured in China with concentrations up to 30 $\mu g m^{-3}$. Apparently, pollutants of particulate matters has effects to various health issues with the different thresholds and exposure durations. However, more in-depth and diversified research on air pollution and its health effects is essential, with the detailed information is necessary (Tan et al

2021) to have accuracy of assessing exposure to air pollution during developmentally relevant time periods, such as trimesters or months (Becerra et al., 2013; Gong et al., 2014; Kalkbrenner et al., 2014) or weeks (Chiu et al., 2016). Many research findings/Numerous research findings have advanced the field, and air quality indices is widely used for providing guidance, and public perception of air quality has been improved (Mirabelli et al., 2020).

Materials and Methods

Materials

Methods 3,000 words

Acknowledgements

Keep acknowledgements brief and do not include thanks to anonymous referees or editors, or effusive comments. Grant or contribution numbers may be acknowledged.

Figures (10)

Figure legends should be <350 words each. They should begin with a brief title sentence for the whole figure and continue with a short statement of what is depicted in the figure, not the results (or data) of the experiment or the methods used. Legends should be detailed enough so that each figure and caption can, as far as possible, be understood in isolation from the main text.

Tables. Each table should be prepared using the Table menu in Word or the table environment in TeX/LaTeX and accompanied by a short title sentence describing what the table shows. Further details can be included as footnotes to the table.

References (70)

Supplementary

Author contributions. You must include a statement that specifies the individual contributions of each co-author. For example: “A.P.M. ‘contributed’ Y and Z; B.T.R. ‘contributed’ Y,” etc. See our authorship policies for more details.

Competing interests. Submission of a competing interests statement is required for all content of the journal.

Materials & Correspondence. Indicate the author(s) to whom correspondence and material requests should be addressed.

Supplementary information Please submit supplementary figures, small tables and text as a single combined PDF document. Tables longer than one page should be provided as an Excel or similar file type. For optimal quality video files please use H.264 encoding, the standard aspect ratio of 16:9 (4:3 is second best) and do not compress the video. We encourage submission of step-by-step synthesis procedures for chemical compounds and data on compound characterization. Supplementary information is not copyedited, so please ensure that it is clearly and succinctly presented, and that the style and terminology conform to the rest of the manuscript.

Materials and Methods

A description of study sites

According to the spatial magnitude of wind stress in Mongolia (Figure 1), the largest magnitude of wind speed is on the Gobi sites, particularly those located in the southeast edge of the country.

- The impact of high winds on plant diversity varies across environmental gradients of precipitation and soil fertility (Milchunas et al., 1988).
- In the desert steppe zone, species richness was lower in the drier years but did not vary with grazing pressure.
- In the steppe zone, species richness varied significantly with grazing pressure but did not vary between years. Species richness is not impacted by grazing gradient in desert steppe, but it is in the steppe (Cheng et al., 2011).

In the last 2 decades, due to poverty and natural disasters there is population immigration has taken place from the rural to urban, especially to capital city of Mongolia. Due to tiny infrastructure to provide the mega city with the dense population, it introduces the urban pollution. Therefore, Ulaanbaatar air particulate matter mainly reflects the coal burning, and partly, natural dust.

Consequently, the atmospheric environment and climate for Mongolian Gobi has been impacted the most by frequent dust and and sand storm in the spring.

Our study was carried out in Dalanzadgad (town center) (Tbl. 1; 43.57°N, 104.42°E), Sainshand (Tbl. 1; 44.87°N, 110.12°E) and Zamyn-Uud (Tbl. 1; 43.72°N, 111.90°E) in the Gobi Desert, and at Ulaanbaatar (Tbl.??.??°N, 104.42°E) (city center) located in the temperate Mongolian steppe of Mongolia (Figure 2). Nomads and settlements of this sum have raised a large number of livestock, and they rank at number 30 out of 329 sums for the largest number of livestock raised per sum (Saizen et al., 2010). In the last decade, the number of dust events associated with wind erodibility increased by 30 % in Bayan-Önjüül (Kurosaki et al., 2011). This is an area where dust emissions activity has been monitored on a long-term basis (Shinoda et al., 2010a) at a dust observation site (DOS) adjacent to the study site (Fig. 1a). According to long-term meteorological observations made at the monitoring station of the Institute of Meteorology and Hydrology of Mongolia located near the site, the prevailing wind direction is northwest. Mean annual precipitation is 163 mm, and mean temperature is 0.1○C for the period 1995 to 2005 (Shinoda et al., 2010b). Soil texture is dominated by sand (98.1 %, with only 1.3 % clay and 0.6 % silt; Table 1; Shinoda et al., 2010a). Insert figure legends with the first sentence in bold, for example:

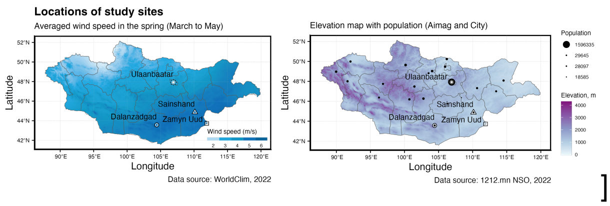

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Table 1. Measured data

	Location		Measured and collected data						Missing data	
SITE	COORDINATE	ELEVATION	TOTAL[1]	WS&WD[2]	VIS[3]	OPC[4]	PM2.5[5]	PM10[5]	PM2.5	PM10
Ulaanbaatar	47.92°N, 106.92°E	1350 m	76656	72603	72886	33241	67940	68777	11.4%	10.3%
Dalanzadgad	43.57°N, 104.42°E	1470 m	60336	46332	33812	-	46066	49172	23.6%	18.5%
Sainshand	44.87°N, 110.12°E	947 m	59040	50513	49720	-	47111	47313	20.2%	19.9%
Zamyn Uud	43.72°N, 111.90°E	967 m	67392	62432	63948	-	57317	58512	14.9%	13.2%

[1] Equipment height: 15 meter at urban site (Ulaanbaatar), 2 meter at Gobi sites (Dalanzadgad, Sainshand and Zamyn Uud); [2] Measurement range: 0–60 m/s; 0-365 degrees. Instrument model: Wind speed and direction PGWS-100, Gill, England; [3] Range: 10–20 000 m. Visibility meter PWD10, Vaisala, Finland; [4] Optical Particle Counter; [5] Range: 0.003–100 mg/m3, Flow rate: 20 L/m, Suction rate: 2 L/ m. Measured by Kosa monitor ES-640, TDK Co. LTD, Japan;

Figure 8: **Table 1.** A description of datasets obtained at the sites

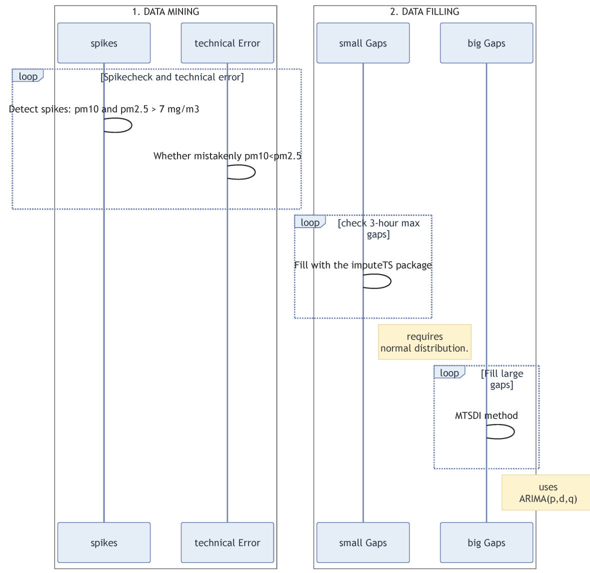

Figure 9: Scheme 1. Data handling procedure

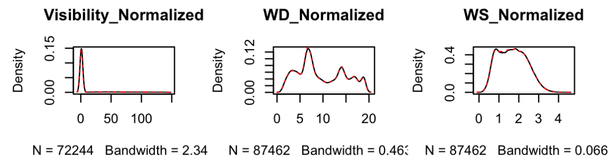

Figure 10: Figure 2. Data gap filling

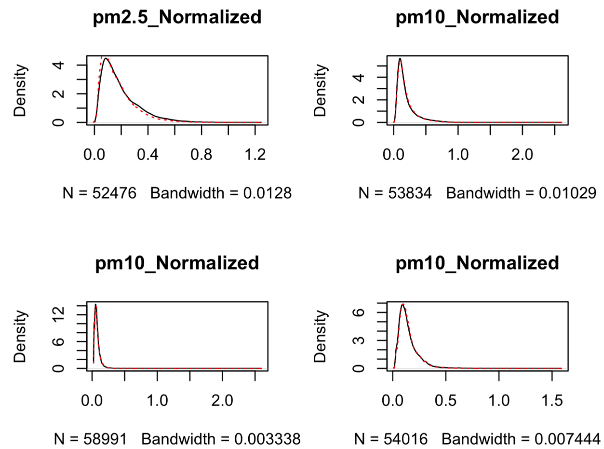

Figure 11: Figure 2b. Data gap filling

References