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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Munkhtsetseg, Shimizu. A, Matsuki. A, Batdorj. D, Matsui. H

To whom correspondence should be addressed:

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

- 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 clearly limits our understanding the climate system and shape the facing global issues of global warming.
- This is mainly caused by the lack of parameterization and recognition of iterative changes controlled by the natural forces and anthropogenic drivings.
- Mongolian dust brown color, seasonal characteristics, with coarse fractions.
- Mongolian dust has an attention of the its mass fraction in global dust, yet unlikely elaborated in the climate models due to its majority of coarse fraction for its a small contribution to the climate system through its radiative feedback.
- But, such recognized characterization might get no longer valid due to recent change in the driving of the emissions of air particulate matters. A large high concentrations of PM2.5 in the capital city of Mongolia has been observed as a result of the heavy consumptions of coal as a winter heating has rapidly spread as a mining industry taken off since 2000. Winter weather stagnant conditions governed by the Siberian magnifies the concentrations of the particulate matter emissions by trapping the polluted air below the boundary layer, so that results in a very large high concentrations of PM2.5, locally. Even recognized as one of the highly polluted capital cities in the world.
- Therefore, It is important to examine the emerging changes and shifting patterns of air particulate matters in Mongolia. More importantly, it is essential to reveal the significant changes in the the altered fraction particularly, in the dust seasons considering its high potential of intriuging in the free atmosphere to transported in the long-distance, so carrying

capacity of the role to shift the global climate system, and its side impacts on downwind regions.

- 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 μgm^{-3} per day or exceeding 6000 μgm^{-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.

–> 3.1.2

To investigate whether emerging PM patterns are associated with household winter heating activities, we demonstrated annual variations in PM10 and PM2.5 concentrations at the sites. Significant annual variations in PM10 and PM2.5 levels were observed at UB and DZ sites, with maximum concentrations exceeding 100 $\mu g/m^3$ during colder months (January, November, December) and lower levels consistently below 50 $\mu g/m^3$ during warmer months (May-September). These annual maximums coincided with the diurnal variations in PM10 and PM2.5 concentrations at sites DZ and UB, where PM concentrations reached their highest values during nighttime and early morning hours (approximately 8 PM to 4 AM UTC), with median values surpassing 50 $\mu g/m^3$. Conversely, both pollutants exhibited reduced concentrations during daytime hours (8AM to 4PM UTC), likely due to increased atmospheric dispersion. UB site exhibited similar daily fluctuations with extended periods (approximately 8 PM to 5 AM UTC) of elevated concentrations. Additionally, winter PM10 concentrations at both sites were primarily composed of PM2.5 (figure_5; mean values for PM10 with the color bar). The increase in PM10 and PM2.5 aligns with the heating active hours, suggesting that household coal consumption contributes to elevated PM levels at both DZ and UB sites. In contrast, ZU and SS sites displayed significantly lower annual PM10 and PM2.5 levels, with sudden frequent spikes in spring followed by occasional instances in autumn. These annual variations were more pronounced in PM10 compared to PM2.5, highlighting the impact of Gobi dust and sand storms. Similar occurrences were also noted at the DZ site, suggesting its exposure to both winter heating emissions and natural spring dust, reflecting its Gobi-region characteristics. The annual variability in PMs with higher concentrations during nighttime and colder months, indicating the influence of localized emission sources and reduced boundary layer mixing at UB and DZ sites. Additionally, the upward extended ranges without the bottom bottle of the violin plot, demonstrating greater variability during colder months. It implies instability in concentrations potentially reaching high levels above 400 $\mu g/m^3$ when Arctic oscillation/Siberian high intensifies with heating, and dropping below 50 $\mu g/m^3$ when it weakens or heating demand decreases. These findings confirm the

(DZ) emerging PM pattern is caused by household activities and influenced by meteorological conditions. Overall, meteorological factors appear to play a crucial role in governing PM levels.

–> 3.2.1

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)

[AND] To distinguish the emission driving variables, we demonstrated interrelations between(WS) and visibility (VIS) among particulate matters of PM10 and PM2.5 for study sites (figure_4). [AND] Higher PM concentrations tend to correspond to lower wind speeds (smaller circles) and reduced visibility (darker blue points) in UB. [AND] All Gobi sites show the largest variability in PM concentrations, with extreme outliers correlated with the WS primarily in the springs.

[AND] In comparison between PM10 increase with the PM2.5, as concentrations increase in PM10 concentration the ratio 1:1 is inscreased approximately 1.3 times for UB, and 2 times for all three Gobi sites. This increase in Gobi sites were further increased upto 5 times in ZU, and XXX times in SS sites showing the insufficient PM2.5 particulates in the those sites.

The Principal Component Analysis (PCA) biplot (Figure 7a) highlights the relationships among key variables, including PM10, PM2.5, wind speed (WS), wind direction (WD), visibility, relative humidity (r), and optical properties of aerosols (OPC). The first two principal components (Dim 1 and Dim 2) explain 66.52% of the total variance, with Dim 1 (44.36%) strongly associated with PM10 and PM2.5, indicating that these pollutants are major contributors to air quality variations. Visibility is inversely correlated with PM10 and PM2.5, suggesting that reduced visibility aligns with higher pollution levels. Wind speed and wind direction are positively aligned with Dim 2 (22.16%), reflecting their influence on pollutant dispersion.

The clustering of monitoring sites based on PM concentrations and geographic characteristics

(Figure 7b) reveals distinct patterns. UB (urban background) is characterized by high PM concentrations (positive Dim 1 scores), while SS (suburban site) demonstrates low PM levels, clustering tightly along the negative Dim 1 axis. DZ (industrial site) exhibits substantial variability, with clusters extending into higher Dim 1 and Dim 2 ranges, reflecting the complex interplay of emission sources and meteorological factors. ZU (rural site) overlaps with SS but shows greater spread, indicating moderate pollution levels influenced by seasonal and localized factors. These results underscore the significant spatial and meteorological influences on air quality across the studied locations.

[BUT]

[THEREFORE] 3 clusters, supply is different?

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

Figure 8 illustrates the trend analysis of PM10 and PM2.5 concentrations across four monitoring sites (UB, DZ, ZU, and SS) from 2009 to 2020. The time series demonstrates seasonal patterns and trends, with notable differences in particulate matter concentrations between the four seasons: Q1 (winter), Q2 (spring), Q3 (summer), and Q4 (autumn).

The p-values displayed on the figure indicate the statistical significance of trend changes in PM10 and PM2.5 levels for each season. At UB, significant negative trends are observed for Q1 and Q2 ($p < 0.001$). At DZ, a significant positive trend is observed for Q1 ($R = 0.17$, $p < 0.001$), indicating increasing particulate matter levels during this season.17, $p < 0.001$), while Q2 exhibits no significant trend ($R = 0$, $p = 0.915$)., highlighting a decreasing pattern in particulate concentrations during these periods over time. In contrast, Q3 and Q4 show weaker or nonsignificant trends (e.g., $R = -0.03$, $p > 0.2$), suggesting minimal changes in PM levels during the warmer months.

The industrial site (DZ) exhibits higher variability in PM levels, with periodic spikes indicative of localized emissions and industrial activities. Urban background (UB) consistently records elevated PM levels during Q1, driven by heating and combustion-related sources. Rural (ZU) and suburban

(SS) sites generally display lower particulate concentrations. However, at ZU, a significant negative trend is observed in both PM10 and PM2.5 for Q1, suggesting a consistent reduction in particulate matter during winter months (may reduced transboundary traffic). At SS, a negative trend is observed in PM2.5 for Q2, reflecting a seasonal decline potentially linked to reduced wind speed during spring.

The significant decreasing trends in PM concentrations in UB during colder months likely indicate improvements in emission control measures and a transition to more efficient heating practices. In contrast, a significant increasing trend is observed at DZ, particularly during Q1, suggesting rising emissions potentially associated with urbanized household practices and other local activities in Mongolia's regional towns.

- 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.

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.

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 in rural sites of SS and ZU is episodically dictated by dust events in spring or late autumn. 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

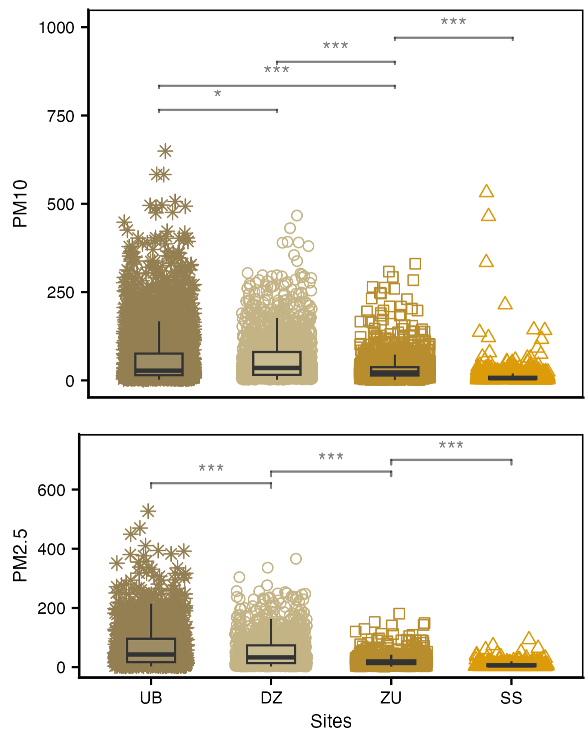

Figure 1: Distinct concentrations of coarse and fine particulates among sites

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

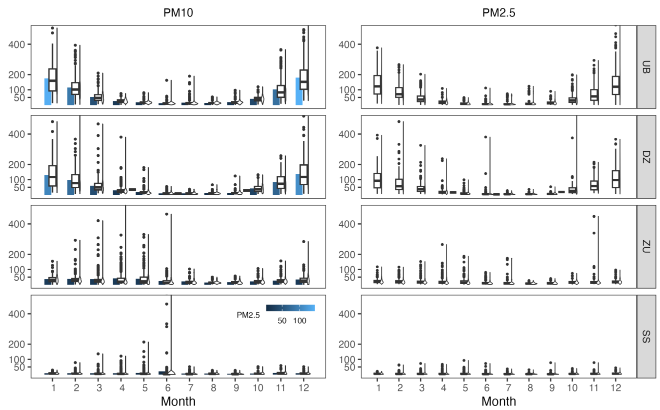

Figure 2: Annual variations of PM_{10} and $PM_{2.5}$

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

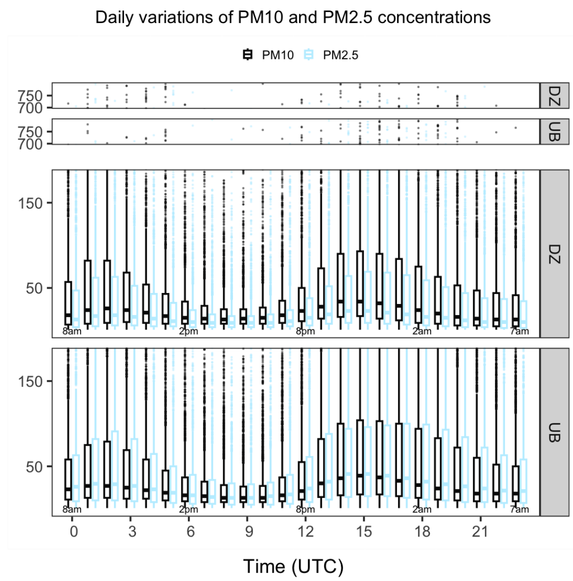

Figure 3: Daily variations of PM_{10} and $PM_{2.5}$ at UB and DZ sites

208 **Meteorological influence on PM_{10} and $PM_{2.5}$ variations**

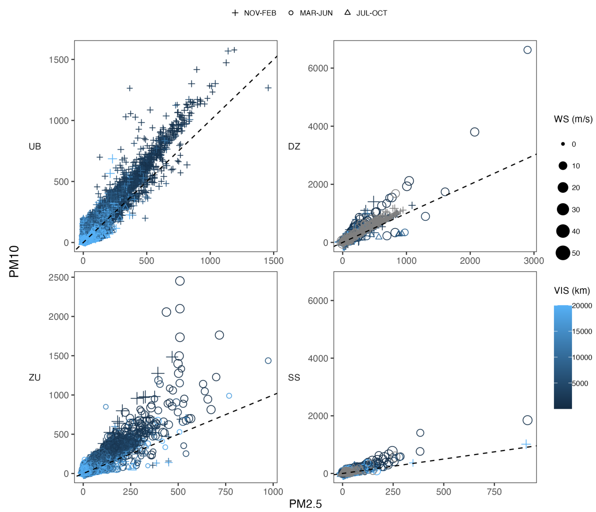

Figure 4: Relationships between meteorological major factors and variations of PM_{10} and $PM_{2.5}$

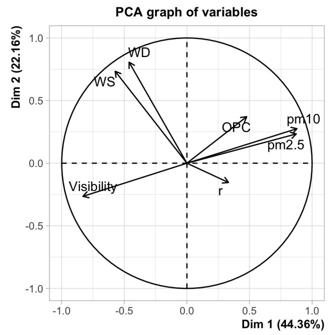

Figure 5: Spatio-temporal distinct feature of variations of PM_{10} and $PM_{2.5}$ with PCA analysis

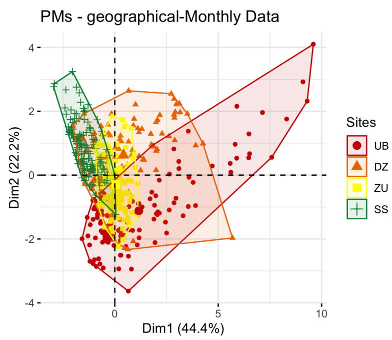

Figure 6: Patterns of meteorology and PMs at the 4 sites

Trends

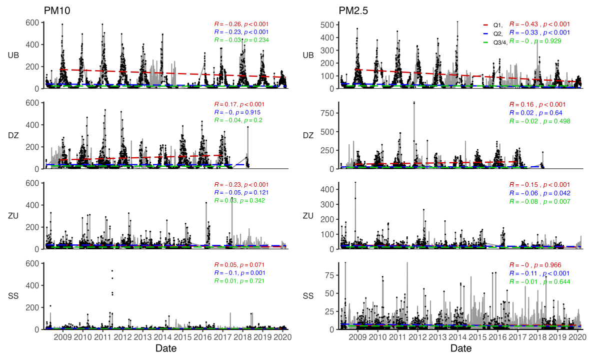

Figure 7: Interannual and seasonal trends of PM_{10} and $PM_{2.5}$ variations

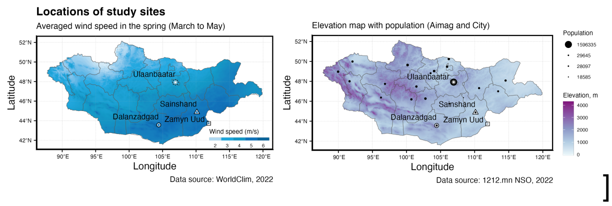

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Table 1. Measured data

	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

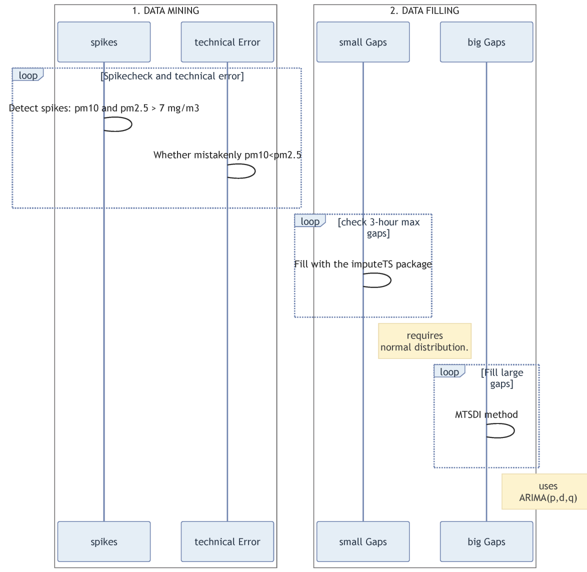

Figure 9: Scheme 1. Data handling procedure

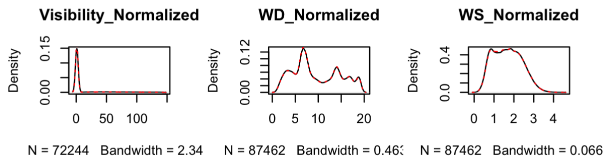

Figure 10: Figure 2. Data gap filling

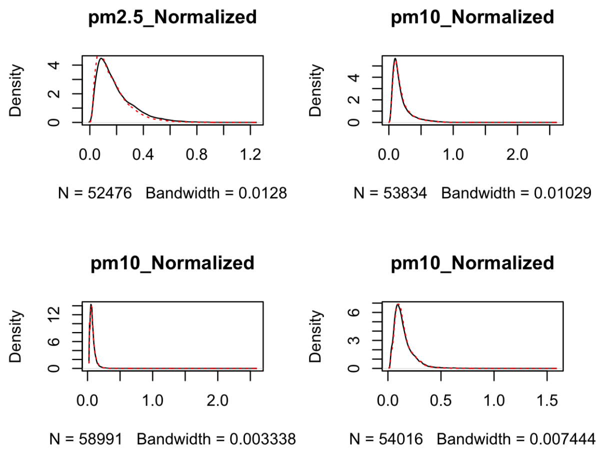

Figure 11: Figure 2b. Data gap filling

(1)

References

1. **Munkhtsetseg E**, **Shinoda M**, **Ishizuka M**, **Mikami M**, **Kimura R**, **Nikolich G**. 2017. Anthropogenic dust emissions due to livestock trampling in a mongolian temperate grassland. Atmospheric Chemistry and Physics **17**:11389–11401. doi:10.5194/acp-17-11389-2017.