



Particulate Matter and Number Concentrations of Particles Larger than 0.25 μm in the Urban Atmosphere of Jeddah, Saudi Arabia

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ABSTRACT

We investigated the temporal variation of PM and aerosol particle number concentration (TC, D_p 0.25–32 μm) during year 2012 in Jeddah city. We focused on the daily patterns, wind sector analysis, and the effect of ambient conditions. The daily median values of the PM_{10} rarely exceeded 200 $\mu\text{g}/\text{m}^3$. The $\text{PM}_{2.5}$ and PM_1 concentrations showed similar temporal variation with fraction of 39.5% and 19.3% of the PM_{10} , respectively. The daily median values of the TC were generally below 500 cm^{-3} but showed three distinguished peaks (as high as 950 cm^{-3}) occurred during late September–early November, which was during the time of the Hajj season. These peaks were also observable in the $\text{PM}_{2.5}$ and PM_1 . The PM_{10} daily pattern on workdays and Thursdays were similar with a pronounced peak as high as 90 $\mu\text{g}/\text{m}^3$ during the morning time. The $\text{PM}_{2.5}$ and PM_1 daily patterns were also similar to those of the PM_{10} , especially on Thursdays and workdays, but with lower concentrations. The TC daily pattern was almost the same on all days showing high concentrations (between 150 and 200 cm^{-3}) during the first half of the day. The daily patterns of the TC were similar to those of the PM_1 , especially on Workdays and Fridays. The emissions from the industrial city (located in the south of Jeddah) are the main source of PM in Jeddah. During the sea breeze that occurred in the afternoon accompanied low concentrations of PM and TC concentrations. The PM concentrations showed the famous U-shape with respect to the wind speed, whereas the TC was around 150 cm^{-3} when the wind speed was over 3 m/s. In general, the TC had a different behaviour with respect to the other ambient conditions than that of the PM concentrations, especially PM_{10} .

Keywords: Daily pattern; Meteorological dependence; Sector analysis.

INTRODUCTION

Particulate matter (PM) in the atmosphere originates from a variety of sources, which mainly include anthropogenic emissions and naturally forming aerosols. They are directly emitted, known as primary aerosols, into the atmosphere or formed via chemical reactions, known as secondary aerosols (e.g., Seinfeld and Pandis, 1998). Regional transport of PM over large distances is another reason for increased impacts and health effects due to exposure to high PM concentrations (e.g., Pope and Dockery, 1999; Pope *et al.*, 2002). The

impacts of aerosol particles on the Earth's climate can be direct or indirect: the direct effect is summarized affecting the radiation balance of the Earth whereas the indirect effect is a result of the role of aerosol particles as cloud condensation nuclei (CCN), which lead to clouds with larger number concentrations of droplets with smaller radii (e.g., Seinfeld and Pandis, 1998; Haywood and Boucher, 2000; Lohmann and Feichter, 2005).

There have been few studies that presented the current state of PM concentrations in Saudi Arabia (Khodeir *et al.*, 2012; Habeebullah, 2013; Munir *et al.*, 2013a, b; Rushdi *et al.*, 2013; Shaltout *et al.*, 2013). However, none of these previous studies presented a comprehensive analysis on the temporal variation of PM concentrations and only one of them was dedicated to Jeddah city (Khodeir *et al.*, 2012). For instance, Khodeir *et al.* (2012) investigated particulate matter ($\text{PM}_{2.5}$ and PM_{10}) composition at 7 sites in Jeddah

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for two weeks at each site during June and September, 2011. They also analysed the gravimetric samples with the X-ray fluorescence (XRF) to obtain the chemical composition of aerosols. Shaltout *et al.* (2013) focused on the chemical composition of PM_{2.5} during June–August 2011 at an industrial site and a residential site in Taif, which is a mountain city about 140 km east of Jeddah city. Rushdi *et al.* (2013) presented PM_{2.5} and PM₁₀ concentrations at ten locations within the capital city Riyadh during June and November 2006 and February and May 2007.

The longest data series on air quality parameters (NO_x, NO, NO₂, SO₂, CO, O₃ and PM₁₀) was published by the Hajj Research Institute, Umm Al-Qura University in Makkah (Munir *et al.*, 2013b), which is about 70 km to the east of Jeddah. This study presented the temporal variations over 12 valid years during 1997–2012. According to this study, the monthly average PM₁₀ (range 10–280 µg/m³) concentration showed an increasing trend. The same research group at the Hajj Research Institute utilized a part of that long-term data series and investigated the inter-correlation between the measured air quality parameters (Habeebullah (2013) during November 2011 and January–August 2012. A very similar study was also published by the same research group where they presented the same air quality parameters with a model simulation for the time period November 2011–July 2012 (Munir *et al.*, 2013a).

In this study we aim at evaluating the temporal variation of the particulate matter (PM₁₀, PM_{2.5}, and PM₁) and number concentration (TC) of particles in the diameter size range 0.25–32 µm during year 2012. We specifically focused on daily patterns, wind sector analysis, and the effect of ambient conditions on the PM's concentrations and TC. According to our knowledge, this has not been performed previously in Jeddah city or even in the Arabic Peninsula.

MATERIALS AND METHODS

Study Area and Potential Sources of Air Pollution

Jeddah is located in western Saudi Arabia by the Red Sea (Fig. 1). It is the most significant commercial center and the second largest city in the Saudi Arabia. The population of the city was more than 3.4 million inhabitants. The growth of the city over the last thirty years has been rapid and diverse, and continues to date (Saudi Network, 2008). However, due to lack of awareness and proper regulations, these development activities over the years have been accompanied by environmental degradation and air quality deterioration.

The city is surrounded by mountains in the north-east, east and south-east. The southern part is the old city, which is densely populated, whereas the northern part of the city is new, well organized, and less populated. Similar to urbanized regions, traffic is the main source of air pollution in Jeddah. More than 1.4 million vehicles are running in the streets of Jeddah city (Khodeir *et al.*, 2012). Vehicle fuels used in Jeddah are mainly unleaded gasoline and diesel. The international airport is located in the northern part of the city and the harbor located in the south-western part of the city; they are heavily used during certain seasons of the

Hijri calendar such as Omra and Hajj. South of Jeddah city is the industrial city and the Naval port. A part of the main road leading to Makkah emerges from south-eastern part of the city. The stationary sources within the city include an oil refinery, a desalinization plant, a power generation plant, and several manufacturing industries that are scattered mainly in the southern and eastern parts of the city.

Experimental Setup and Measurement Location

Particulate matter concentrations (PM₁₀, PM_{2.5}, and PM₁) and number concentration (TC) of particles in the diameter size range 0.25–32 µm were measured with one minute average by an optical scattering spectrometer (EDM-180D, Grimm Aerosol, Germany). The aerosol sampling was performed at 3.7 m height above the ground. A routine check on the instrument was performed every two weeks.

We also recorded meteorological parameters with half-hourly basis by using a compact weather station model WS600 – UMB (Lufft, Fellbach, Germany). The meteorological parameters included in this study were: ambient temperature, relative humidity, atmospheric pressure, and wind and speed. The meteorological sensor head was installed at 6.5 m height from the ground.

The aerosol and meteorological instruments were accommodated inside a carriage container (L × W × H 2.8 × 2.2 × 2.3 m³, GRIMM Aerosol Technik). We had three identical containers located beside each other on eastern parking lots of the King Abdulaziz University (KAU) campus, which was used by students during final examinations in late May and early June (Fig. 1). The surrounding area is mainly residential with minor roads. About 100 m to the south of the measurement site is one of the main roads (Abdullah Al-Sulaiman Road), which is a 6-lanes busy road linking the central parts of the old city with the Haramain Road at about 1.7 km to the east. About 100 m to the east and 200 m to the north are two main roads crossing with each other at round about. These roads are considered within the university campus and they are not as busy as the Abdullah Al-Sulaiman Road.

Data Handling and Processing

The measurements started in late 2011 and the data during the full year calendar 2012 is included in this study. There was a gap in May 2012 because of instrument maintenance. This period coincided with the final examinations when the parking lots were extensively used by students. Therefore, the effects of using the parking lots do not influence our result because that period is already missing from the data-base. The third container was relocated to another place after June 26th, 2012, after which the data from this container was not included in this study. Otherwise, the other two containers remained at the KAU campus and measured continuously until the end of year 2012.

Because we had data recorded from the either two or three stations, this allowed us to perform a quality check on the data and validate it with inter comparison. After all, we combined the valid data from all containers by filling gaps or calculating averages from the available data recorded from



Fig. 1. A map of Jeddah city showing the land use and main potential anthropogenic sources other than traffic. The measurement site location is indicated by a star on the small map showing King Abdulaziz University campus.

the instruments in the containers. Then we processed the half hourly statistics: mean, standard deviation, median, quartiles, 5%, and 95%.

RESULTS AND DISCUSSION

Review about the Ambient Conditions

The daily median value of the ambient temperature varied between 20 and 38°C with the minimum during January and the maximum during June–July (Fig. 2(c)). Based on

the half-hourly median daily pattern, the ambient temperature reached its maximum value (33.9°C) slightly before noon and it showed a minimum value (26.9°C) around 06:00 (Fig. 3(a)). The daily median value of the atmospheric pressure showed an inverse trend to that of the temperature (Fig. 2(d)); i.e., it was minimum during July (about 995 mbar) and maximum during January (about 1013 mbar). Regarding the daily pattern of the atmospheric pressure, it showed two peaks: one around 10:00 and another one around 21:00 (Fig. 3(b)). The daily mean relative humidity

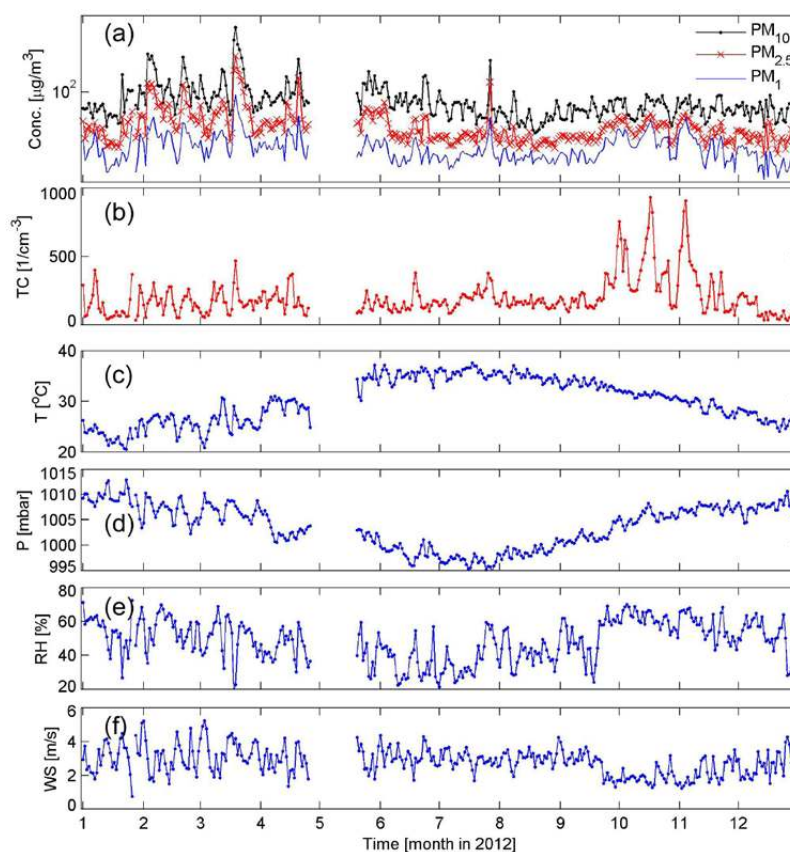


Fig. 2. Daily means during year 2012: (a) particulate matter concentrations, (b) number concentration of particles in the diameter range 0.25–32 μm , and (c–f) ambient conditions including temperature, pressure, relative humidity, and wind speed.

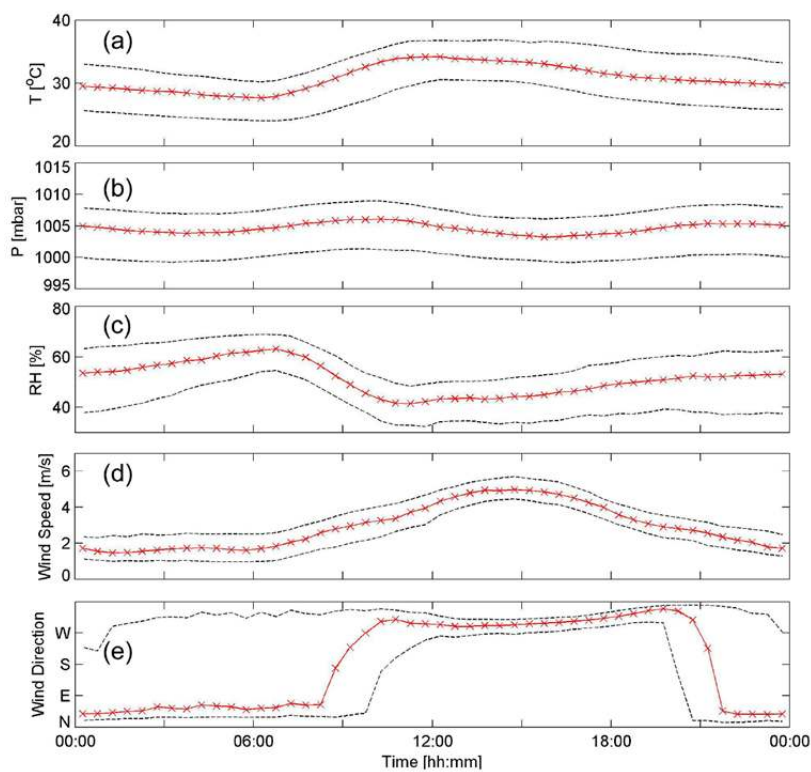


Fig. 3. Median diurnal variation of the ambient conditions: (a) temperature, (b) pressure, (c) relative humidity, (d) wind speed, and (e) wind direction. The dashed lines represent the quartiles.

varied between 20% and 70% throughout the year (Fig. 2(e)) whereas the daily pattern was opposite to that of the ambient temperature (Fig. 3(c)): it was maximum around 06:00 and minimum around noon.

The daily mean value of the wind speed varied between 1 m/s and 5 m/s (Fig. 2(f)) and it had a clear daily pattern with a maximum value around 15:00 (Fig. 3(d)). Similar to a coastal city, we observed the sea breeze in the daytime starting after 09:00 and ending by 21:00 (Fig. 3(e)). during the sea breeze, the atmospheric pressure dropped in the daytime, the relative humidity suddenly dropped in the morning and started to increase slowly throughout the day, and the wind speed increased steadily reaching its maximum (about 6 m/s around 15:00) and after that it decreased steadily (Figs. 3(b)–(d)).

PM Concentrations

Based on the daily median, the PM₁₀ was generally below 200 µg/m³ (Fig. 2(a)) with an overall mean value 104 ± 162 µg/m³. In February–April, the daily median values of the PM₁₀ showed several peaks with concentrations as high as 1400 µg/m³ (half-hour mean value as high as 2270 µg/m³), which accompanied a severe dust episode in late March. The PM_{2.5} daily median concentration closely followed the temporal variation of the PM₁₀ but with an overall mean value 34 ± 45 µg/m³ (Fig. S3(a)). The PM₁ daily median concentration also followed that of the PM₁₀ and PM_{2.5} with an overall mean value 13 ± 11 µg/m³ (Figs. S3(a)–(b)). The correlation coefficients between the PM daily mean concentrations was larger than 0.8 (Table 1).

Based on the half-hourly average the PM_{2.5} fraction was about 39.5% of the PM₁₀ concentration and that of the PM₁ fraction was about 19.2%. The monthly mean values of the PM₁₀ and PM_{2.5} reflects a seasonal variation with relatively higher concentrations during February–April (Table 2). This seasonal variation is mainly related to the dust episode season in Saudi Arabia when the concentration large particles is significantly higher than the annual average.

These mean values observed in Jeddah were lower than those previously reported for the capital city Riyadh as

Table 1. Correlation matrix between the PM's and TC based on the daily medians. See also Fig. S3 in the supplementary material.

	PM _{2.5}	PM ₁	TC
PM ₁₀	0.97	0.81	0.11
PM _{2.5}		0.88	0.20
PM ₁			0.61

76.3–189.4 µg/m³ and 146.0–312.2 µg/m³ respectively for PM_{2.5} and PM₁₀ during June and November 2006 and February and May 2007 (Rushdi et al., 2013). In another study performed for particulate matter (PM_{2.5} and PM₁₀) composition at 7 sites in Jeddah during two weeks at each site in June and September, 2011, the overall mean was 28.4 ± 25.4 µg/m³ and 87.3 ± 47.3 µg/m³ for PM_{2.5} and PM₁₀, respectively (Khodeir et al., 2012). The higher number reported in our study here are due to the fact that we included all possible events such as dust episodes in our calculations. Shaltout et al. (2013) focused on the chemical composition of PM_{2.5} during June–August 2011 at an industrial site and a residential site in Taif, which is a mountain city about 140 km east of Jeddah city. The overall PM_{2.5} concentration reported in there were 47 ± 15 µg/m³ and 46 ± 15 µg/m³ at the industrial and the residential sites, respectively. Compared to the PM concentrations reported in megacities such as Cairo and Beijing, the observed values in Jeddah are lower. But when compared to the EU cities, these concentrations exceed the allowed limiting value recommended by the EU regulations as 40 µg/m³ for 24-hour mean PM₁₀.

We calculated the Pollutant Standard Index (PSI) as a measure for the air quality in Jeddah based on the daily means PM₁₀ and PM_{2.5} (Fig. 4). The combined PSI showed that 36 days were Good, 262 days were Moderate, 21 days were Unhealthy for Sensitive Groups, 8 days were Unhealthy, 9 days were Very Unhealthy, and 5 days were Hazardous. The PM₁₀ was the responsible pollutant for the days falling within the worst four categories (Unhealthy for Sensitive Groups – Hazardous). On the other hand, the PM_{2.5} was the marker for the days classified as Good.

Table 2. Monthly means and standard deviations of the PM and number concentration (TC) of particles with $D_p = 0.25$ – 32 µm.

	PM ₁₀ [µg/m ³]		PM _{2.5} [µg/m ³]		PM ₁ [µg/m ³]		TC [m ⁻³]	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
January	96.3	237.4	29.7	54.2	11.9	12.2	146.0	137.6
February	190.3	195.4	65.4	49.4	18.9	10.7	176.9	115.2
March	222.2	319.7	75.3	95.8	20.9	19.0	182.2	119.8
April	129.1	124.6	46.7	45.7	15.5	9.6	206.1	142.9
May	158.4	233.5	45.2	33.2	13.5	6.5	179.8	122.8
June	97.3	81.2	27.1	16.9	10.0	5.8	184.1	148.8
July	76.7	89.4	24.2	30.5	10.0	6.4	218.9	131.4
August	49.4	41.7	16.6	7.8	7.9	2.7	170.4	67.4
September	60.9	38.1	21.1	9.4	10.7	5.7	224.5	145.1
October	70.1	67.3	29.7	18.8	17.4	8.9	424.1	253.9
November	70.7	59.6	25.9	15.6	15.0	9.9	320.4	265.8
December	62.9	53.5	19.6	11.4	8.4	4.5	122.6	89.5

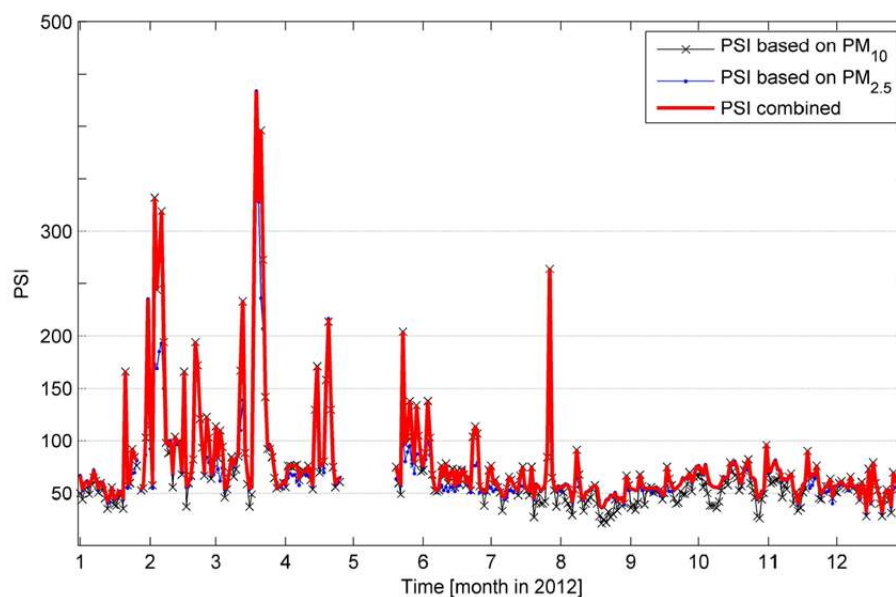


Fig. 4. The Pollutant Standard Index (PSI) calculated based on the daily means of PM_{10} and $PM_{2.5}$. The solid line represents the PSI calculated from a combination of PM_{10} and $PM_{2.5}$. The tick marks on the y-axis correspond to the PSI intervals defining the air quality level as Good, Moderate, Unhealthy for Sensitive Groups, Unhealthy, Very Unhealthy, and Hazardous.

Number Concentration (TC) of Particles between 0.25–32 μm in Diameter

The daily median values of the number concentration (TC) of particles with diameter between 0.25 μm and 32 μm also showed similar temporal variation as that of the PM's concentrations but some peaks resided for a slightly longer time (Fig. 2(b)). The overall mean value of the TC was $215 \pm 171 \text{ cm}^{-3}$ with daily median values were generally less than 500 cm^{-3} . In late September, October, and early November, the daily median value of the TC showed three distinguished peaks with concentrations as high as 950 cm^{-3} . All peaks observed in the PM_{10} daily medians were also observable in the both the PM_{10} and $PM_{2.5}$. On the other hand, the three peaks observed in the PM_{10} and TC daily median values during late September and early November were also observable in the $PM_{2.5}$ (Figs. 2(a)–(b)). This indicates that the events observed around October were from a different source and characteristics than those observed around February. The events observed around February were mainly dust episodes but those around October were most likely due to increased transportation and logistics activities during the Hajj season, when about five million persons reached Makkah; Jeddah as the closest port to Makkah became busy with logistics and exceptionally increased transport activities (sea port, airport, and land-transport). Besides that, the wind speed daily means (Fig. 2(f)) dropped down to $\sim 2 \text{ m/s}$. This drop is expected to increase the pollutant concentrations that are locally produced such as traffic emissions.

Comparison of the measured TC here to other locations can be a bit cumbersome because the reported values are usually either for the total particle number concentrations or size-specific fractions such as ultrafine (diameter $< 100 \text{ nm}$), accumulation mode (diameter between 0.1–1.0 μm), or

coarse mode (diameter $> 1 \mu\text{m}$). However, based on particle number concentration of the fine fraction, the accumulation mode does not usually exceed 20% of the total number concentrations in urban areas (e.g., Hussein *et al.*, 2004).

Daily Patterns of PM's and TC Concentrations

According to the urban activities in Jeddah, we considered Saturday–Wednesday as workdays. Friday is the weekend holiday and the some offices and companies did not have Thursday as a working day; therefore, Fridays and Thursdays were treated separately. The PM concentrations and the TC showed clear daily patterns (Fig. 5 and Figs. S1 and S2). The PM_{10} daily pattern on workdays and Thursdays was similar with a very well distinguished peak (between 06:00 and 12:00 with a maximum concentration as high as $90 \mu\text{g/m}^3$) during the morning time, which was not very pronounced in the Friday daily pattern (Fig. 5(a) and Figs. S1 and S2). The PM_{10} concentration was below $45 \mu\text{g/m}^3$ between 15:00 and 21:00; after that it increased again during the night time. Regardless to the absolute value, the daily patterns of the $PM_{2.5}$ and PM_{10} were similar and they both were slightly different than that of PM_{10} , especially on Thursdays and workdays (Fig. 5(a) and Figs. S1 and S2). These daily patterns are different than those observed in the EU or the USA. For example, the workdays daily pattern of the PM concentrations in the EU cities are characterized by a high concentration peak during the morning and afternoon hours, referred to that as traffic rush hours. Here in Jeddah, the sea breeze considerably reduced the PM concentrations during the afternoon.

The daily pattern of TC was similar to that of PM_{10} for workdays (Saturday–Wednesday) and Fridays (Fig. 5 and Figs. S1 and S2). On workdays, the daily pattern of TC showed a rather flat variation $150\text{--}200 \text{ cm}^{-3}$ during the

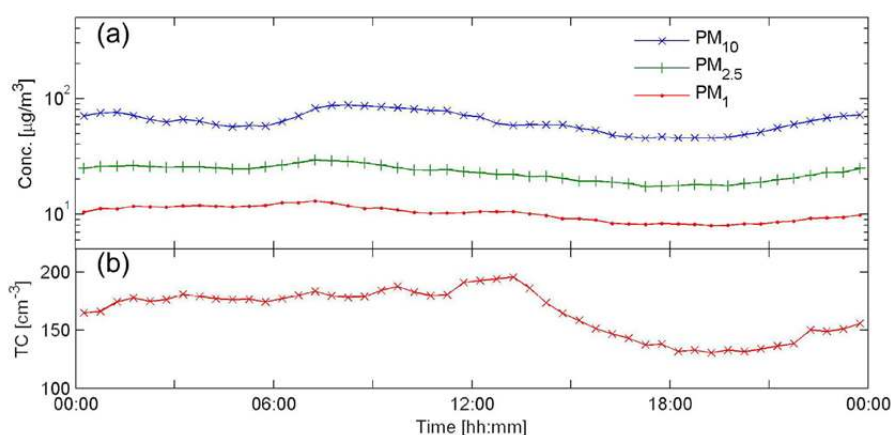


Fig. 5. Median diurnal pattern of (a) particulate matter and (b) total particle count in the diameter range 0.25–32 μm .

first half of the day (Fig. 5(b)). After the middle of the day, it suddenly decreased to about 135 cm^{-3} within six hours. The TC started to increase again in the late night. Although the decrease in the TC concentration occurred about three hours later, we believe it is related to the sea breeze, which brings a different type of aerosols than that emitted over the city.

Variation of Concentrations with Respect to the Ambient Conditions

The PM concentrations were the lowest during wind speed between 2 and 5 m/s (Fig. 7(e)). The high PM concentration during high wind speed is most likely due to dust loads transported to the city from the desert. This is clear in the surface plot of PM_{10} concentration with respect to the wind direction and wind speed that high concentrations coincided with wind directions between 0° and 225° degrees, which is the land wind sector (Fig. S4). Besides that, having such high concentrations during high wind speed suggests that it is not transported from nearby sources or simply because of enhanced dust re-suspension from the desert. In general, that wind sector represents desert (east), waste storage (north east), main road to Makkah (south east), industrial area (south), and the naval port (south west).

The emissions from the naval port and the main harbors are also very well pronounced in the TC and PM_1 for prevailing wind between 180° and 300° , and especially when the wind speed was below 2 m/s. The TC was rather constant during wind speed higher than 2 m/s and tends to increase with decreasing wind speed below 2 m/s (Fig. 7(f)). In general, the high concentration during low wind speed is an indication of local emissions not diluted or dispersed efficiently and that supports our conclusions for the source of the high TC concentrations during low wind speed and this wind sector.

Not surprising, during prevailing wind between 300° and 360° the TC, PM_1 , and $\text{PM}_{2.5}$ concentrations were as low as 100 cm^{-3} , $8\text{ }\mu\text{g}/\text{m}^3$, and $18\text{ }\mu\text{g}/\text{m}^3$, respectively. This represents clean air coming from the sea side and crossing over the northern parts of Jeddah.

The concentrations variations with respect to other ambient parameters (T, P, and RH) were connected to the dependence

on wind direction and wind sector. The sea breeze effect along with the local-versus-regional sources played a major role in modifying the PM and TC concentrations. However, we describe here briefly how the concentrations varied with temperature, pressure, and relative humidity. The PM_{10} concentrations were increasing with increasing ambient temperature above 40°C and below that they were rather constant (Fig. 7(a)). The $\text{PM}_{2.5}$ and PM_1 had their maximum values during ambient temperature between 25 and 30°C (Fig. 7(a)) whereas TC was maximum during ambient temperature between 30 and 35°C (Fig. 7(b)). The PM_{10} concentrations decreased with increasing relative humidity (Fig. 7(g)). On the other hand, the $\text{PM}_{2.5}$, PM_1 , and TC concentrations were increasing with the increasing the relative humidity (Figs. 6(g)–(h)). The effect of pressure on the PM concentrations and TC was not very clear to be described (Figs. 6(c)–(d)).

SUMMARY AND CONCLUSIONS

In this study investigated the temporal variation of PM_{10} , $\text{PM}_{2.5}$, PM_1 , and TC (number concentration of particles in the diameter size range 0.25–32 μm) during year 2012 in Jeddah city, which is a continuously developing city with a variety of anthropogenic sources. We focused on the daily patterns, wind sector analysis, and the effect of ambient conditions.

The daily median value of the PM_{10} concentration varied between 17.5 – $1400\text{ }\mu\text{g}/\text{m}^3$ during year 2012. Based on the daily means, the PM_{10} concentration exceeded $200\text{ }\mu\text{g}/\text{m}^3$ on 29 days in 2012 and they were observed during February–April. Similarly, the daily median value of $\text{PM}_{2.5}$ and PM_1 concentrations followed similar temporal variation but with lower concentrations; the $\text{PM}_{2.5}$ fraction was about 39.5% of the PM_{10} concentration whereas that of PM_1 was about 19.3%. The TC was generally below 500 cm^{-3} but showed three distinguished peaks (as high as 950 cm^{-3}) occurred during late September–early November, which was during the time of the Hajj season.

The TC and PM concentrations showed clear daily patterns. The PM_{10} daily pattern on workdays and Thursdays was similar with a pronounced peak as high as $90\text{ }\mu\text{g}/\text{m}^3$

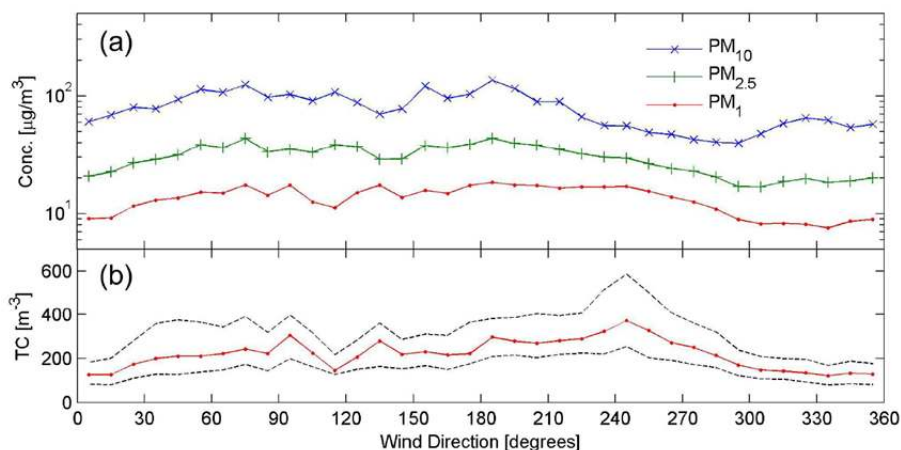


Fig. 6. Median trends of the (a) particulate matter concentrations and (b) total particle count in the diameter range 0.25–32 μm with respect to the wind direction. The dashed lines in the TC plot represent the quartiles.

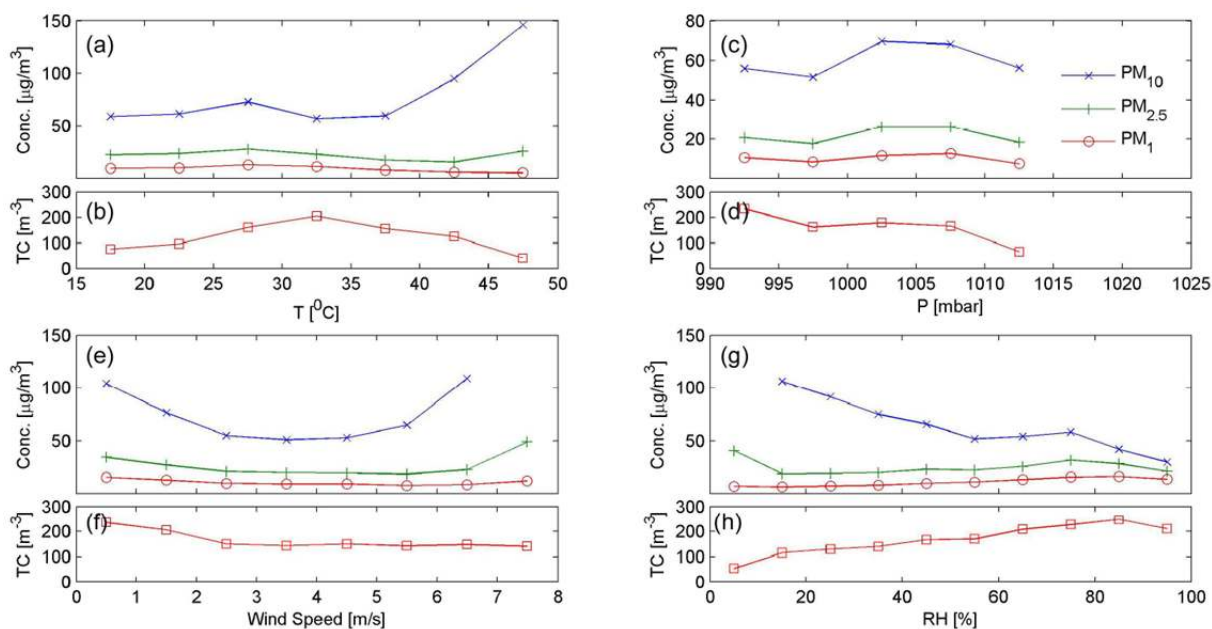


Fig. 7. Median trends of the particulate matter concentrations and total particle count in the diameter range 0.25–32 μm with respect to (a–b) ambient temperature, (c–d) atmospheric pressure, (e–f) wind speed, and (g–h) relative humidity.

during the morning time. This peak was not pronounced on Fridays. The daily patterns of the $\text{PM}_{2.5}$ and PM_1 were rather similar to those of the PM_{10} , especially on Thursdays and workdays, but with lower concentrations. The TC daily pattern was almost the same on all days with high concentrations during the first half of the day. The daily patterns of the TC were similar to those of the PM_1 , especially on Workdays and Fridays.

Based on the wind sector analysis, the industrial city (located in the south of Jeddah) can be considered as the source of PM. The sea breeze was well pronounced in the PM and TC concentrations, which all showed low concentrations. In general, the TC showed a different behavior with respect to the other ambient conditions (temperature, wind speed, relative humidity, and pressure) than that of the PM concentrations, especially PM_{10} . The PM concentrations

showed a clear U-shape with respect to the wind speed, whereas the TC was around 150 m^{-3} when the wind speed was over 3 m/s.

ACKNOWLEDGMENTS

This study was funded by the Deanship of Scientific Research (DSR), King Abdulaziz University (KAU), Jeddah, under Grant no. (1220/430). The authors, therefore, acknowledge with thanks DSR and KAU for technical and financial support.

SUPPLEMENTARY MATERIALS

Supplementary data associated with this article can be found in the online version at <http://www.aaqr.org>.

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Received for review, February 12, 2014
Accepted, March 19, 2014

Supplementary Material

Particulate Matter and Number Concentrations of Particles Larger than $0.25\ \mu\text{m}$ in the Urban Atmosphere of Jeddah, Saudi Arabia

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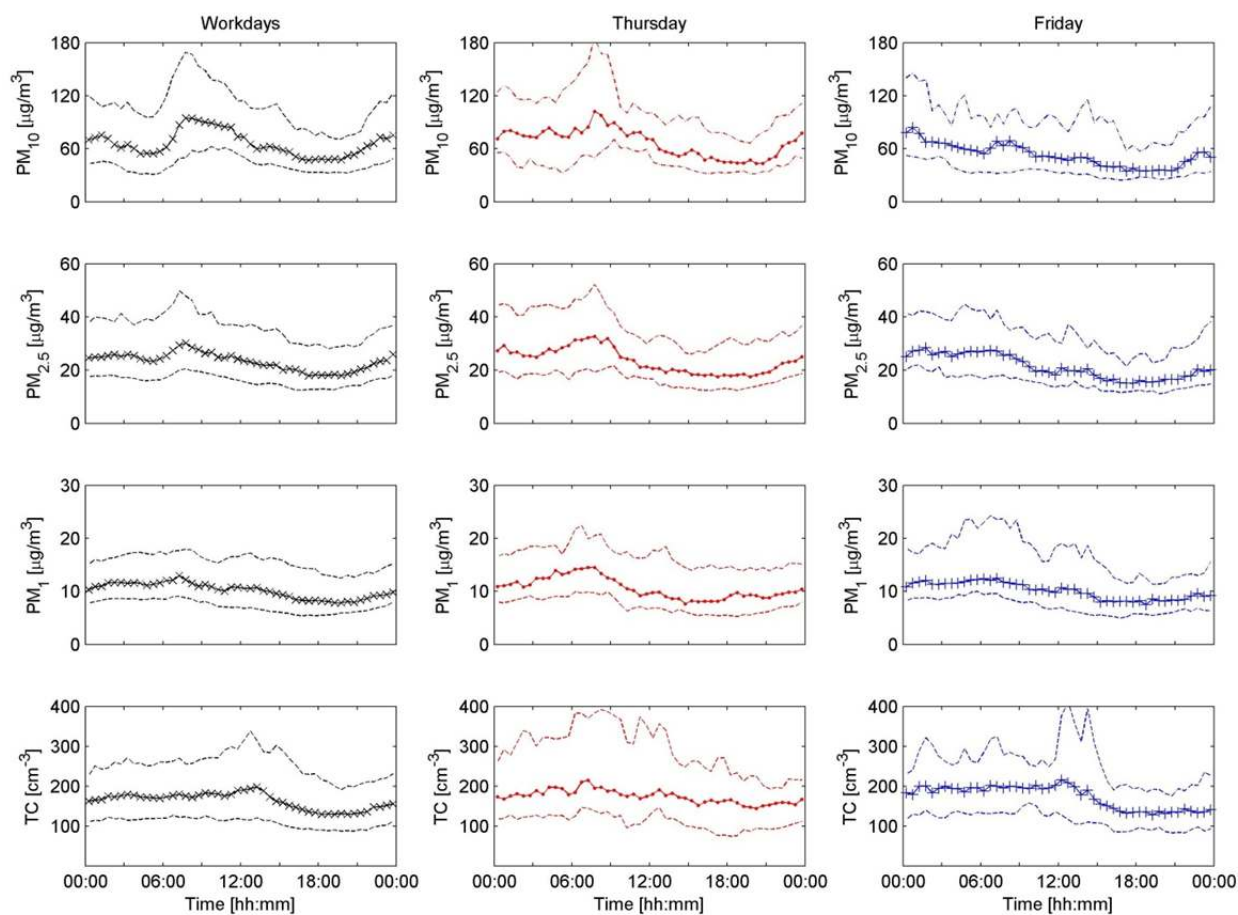


Fig. S1: Median daily patterns of the particulate matter concentrations and total particle count in the diameter range $0.25\text{--}10\ \mu\text{m}$ on workdays (Saturday–Wednesday), Thursdays, and Fridays. *Dashed lines represent quartiles.*

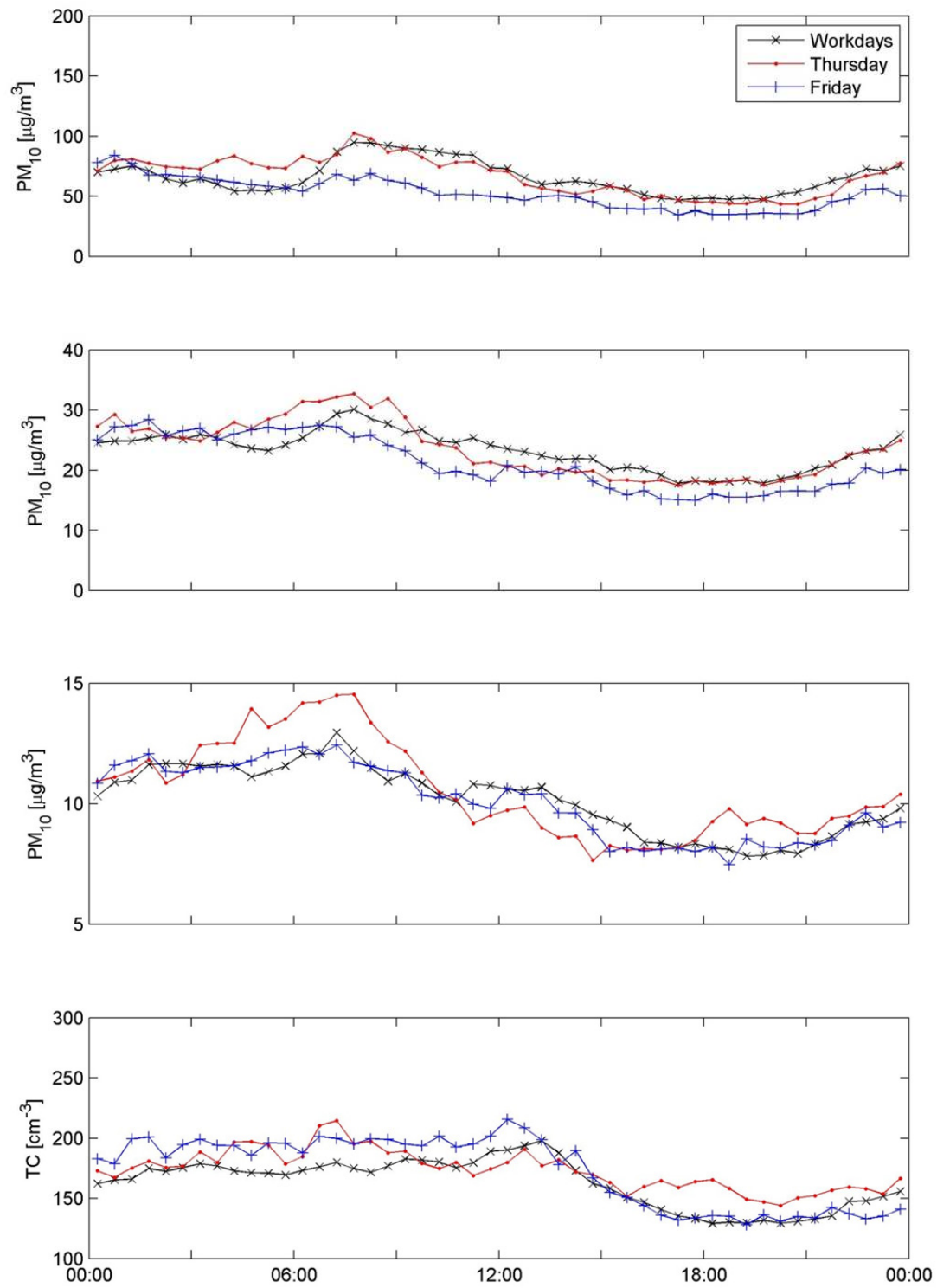


Fig. S2: Comparison between the median daily patterns of the particulate matter concentrations and total particle count in the diameter range 0.25–10 µm on workdays (Saturday–Wednesday), Thursdays, and Fridays.

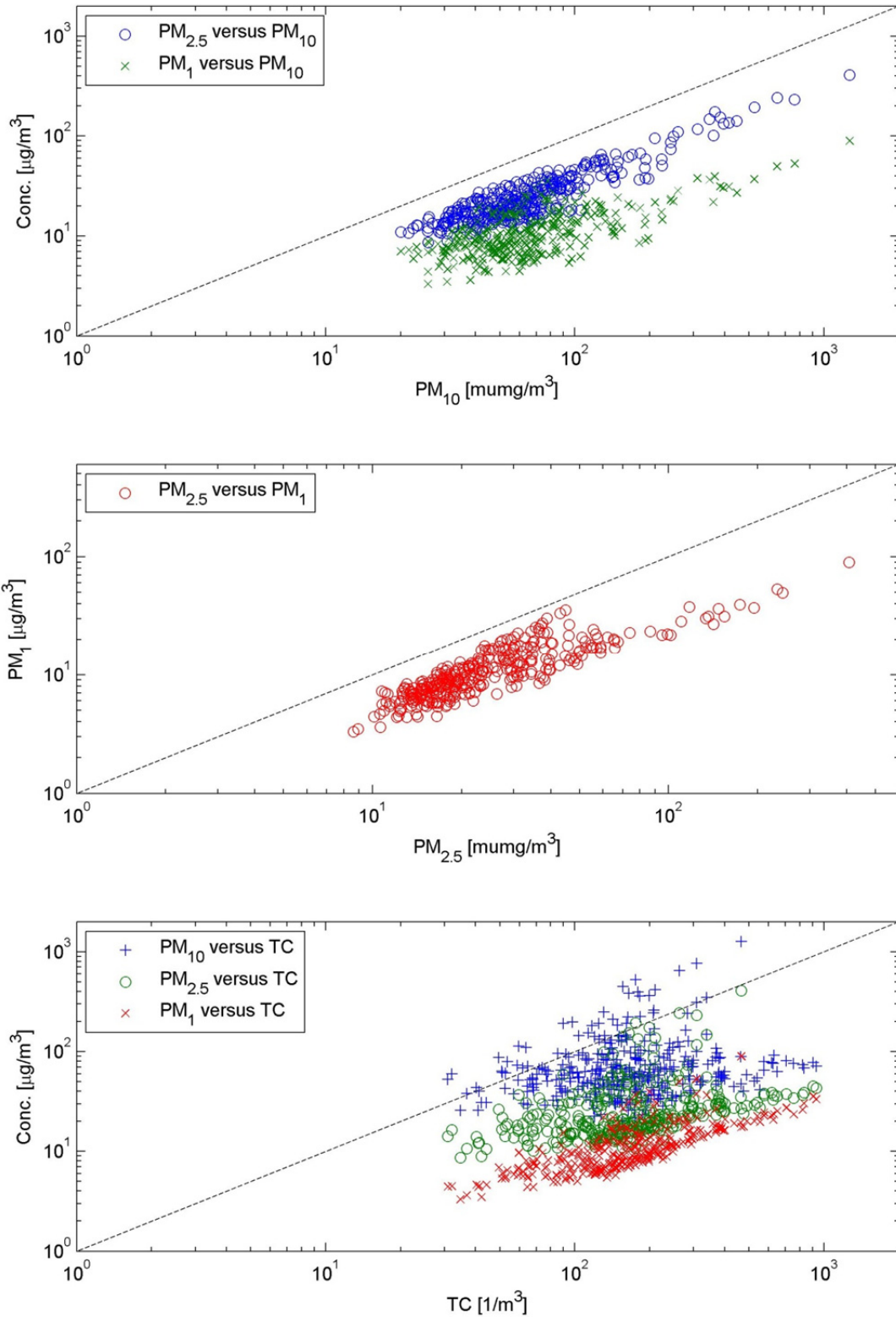


Fig. S3: Scatter plots of PM concentration versus each other as well as TC.

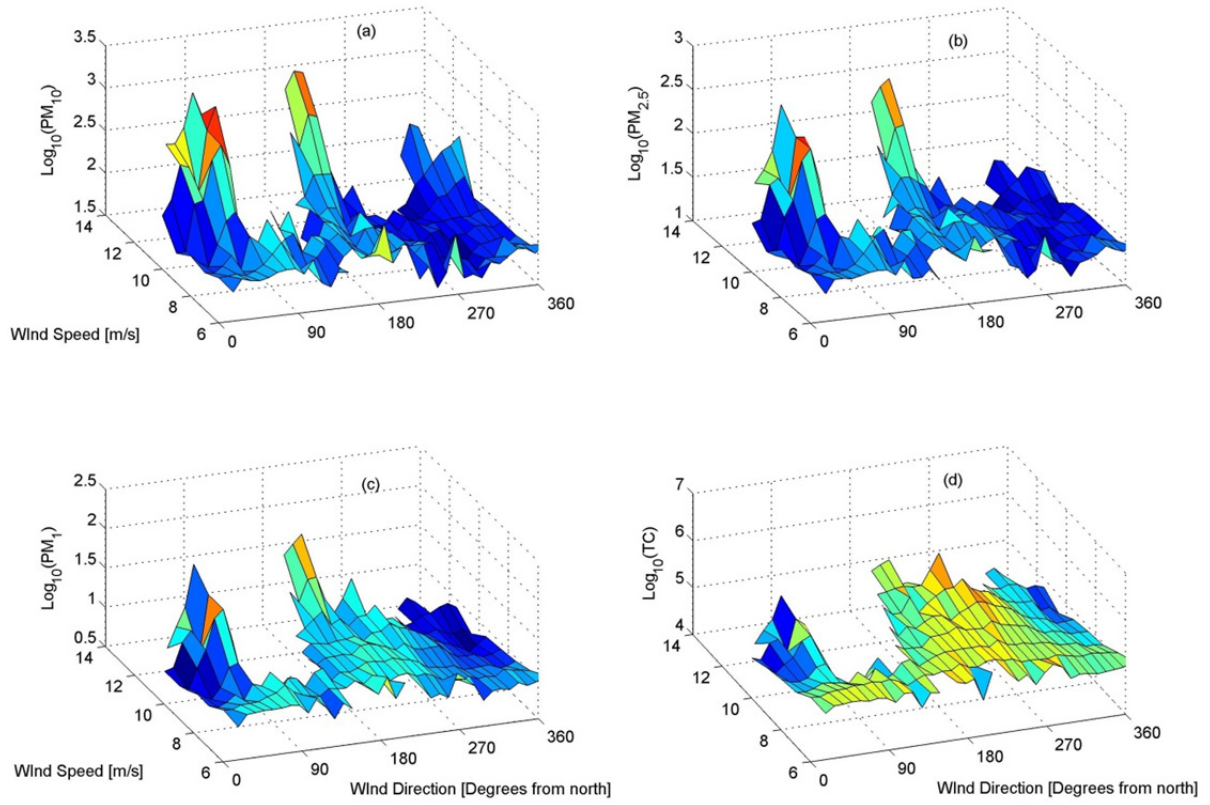


Fig. S4: Mean concentrations versus wind speed and wind direction: (a) PM_{10} , (b) $\text{PM}_{2.5}$, (c) PM_1 , and (d) TC.